Global Environment Facility

GEF/C.24/Inf.13
November 10, 2004

GEF Council
November 17-19, 2004

STRATEGIC OPTIONS AND PRIORITIES IN GROUNDWATER RESOURCES

(Prepared by the Scientific and Technical Advisory Panel)

Scientific and Technical Advisory Panel to the Global Environment Facility:

strategic options and priorities

in groundwater resources

November, 2004

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Preface

Groundwater represents a dominant, but often forgotten, freshwater resource: its wise use is essential to support sustainable development – more than 2 billion people rely on groundwater. The proper management and protection of groundwater are also very important elements in effective strategies to address desertification, adaptation to climate change, and maintaining ecosystems for biodiversity, especially in wetlands.

Groundwater is a vulnerable resource, which, if not adequately managed and controlled, is susceptible to degradation from over-use, contamination and other abuses, with consequential loss of water supplies and far-reaching long term, irreversible consequences for the environment, often with transboundary implications. The inherent social and economic characteristics of groundwater, and its close linkage and critical significance in relation to land and environmental issues, point towards the need for a precautionary, ecosystem approach to the management of groundwater.

The significance of groundwater is often insufficiently recognised in national economic development plans, and in the administration of water resources and environmental protection. The Scientific and Technical Advisory Panel (STAP) was therefore asked by the GEF to provide an assessment of the state of knowledge on groundwater, which would identify the principal threats, and strategic issues. To meet this request, STAP decided to convene a workshop on strategic priorities and options in groundwater resources, and to commission a review and synthesis document.

UNESCO's International Hydrological Programme (IHP) has made a significant contribution to the development of groundwater science and applied research. STAP therefore decided to organise both the workshop, and the review and synthesis, in collaboration with UNESCO (and also the International Association of Hydrogeologists (IAH)).

The purpose the workshop was to examine the following issues: the major global threats affecting groundwater resources; how to improve the protection of aquifers, and their sustainable use; strategic uses of groundwater in relation to land degradation, natural ecosystems and environmental sustainability; the management of groundwater resources; and the relationship between groundwater and the GEF's focal areas, i.e. climate change, biodiversity, international waters, land degradation and persistent organic pollutants (POPs).

STAP convened a technical workshop held in Paris, 5-7 April 2004, hosted by UNESCO, and co-organised by STAP and UNESCO. The workshop brought together a cross-section of experts from developed and developing countries, and was attended by STAP members Professor Leonard Nurse, and Dr. Alexei Maximov, representatives from UNESCO, IAH, the GEF Secretariat, the GEF Implementing Agencies (UNDP, UNEP and the World Bank), as well as representatives from the FAO, and STAP Secretariat.

I hope that the analysis, the workshop's conclusions, and STAP's recommendations will be of help to the GEF as it develops its work on groundwater.

Julia Carabias
STAP Chair

5 November 2004
Washington, DC

Executive summary

1. For millennia only a small fraction of the available groundwater resources was actively exploited for beneficial use by human beings. This changed dramatically in the mid-20th century when very significant exploitation of groundwater followed major advances in geological knowledge, well drilling and irrigation, pump technology and power development. Today the global rate of withdrawal is estimated to be 600-700 km^3 per annum. For example, in India groundwater provides about 80% of domestic water supplies in rural areas, with about 3 million hand-pumped boreholes having been constructed over the past 30 years. Some 244 km^3 per annum is currently estimated to be pumped from 15-17 million motor-driven dug wells and tube wells, with as much as 70% of national agricultural production being supported by groundwater.
2. The social and economic benefits of groundwater exploitation are enormous. Groundwater has become vital in many countries, with 2 billion people reliant on it for water supply. In arid and semi-arid regions of the world, it is often the only reliable source of water. Compared to surface water, groundwater has several advantages. It is normally well-protected from contaminants, requires minimal treatment, is less susceptible to extremes of climate, can be produced locally and incrementally to meet growing private, municipal, industrial and agricultural demand with minimal upfront capital expenditure.
3. But this accelerated development of groundwater over the past 25-50 years has not been without consequences. Global reserves are immense, but natural rates of replenishment are finite. The current (and growing) rate of use is not sustainable. And the problems are closely linked to ecological sustainability. Many global ecosystems are highly dependent on groundwater. For example, when groundwater is drawn from an aquifer there are inevitable effects on water bodies which receive that water, e.g. springs, rivers, wetlands, estuaries and seas, and on the biodiversity that these water bodies support.
4. In addition to over-abstraction of groundwater, i.e. quantity concerns, there are also significant issues about the maintenance of water quality. There are four main threats: contamination from natural geochemical sources, in particular from arsenic, e.g. in Bangladesh, and fluorine; salinisation of soil and groundwater due to inefficient irrigation and land use change; anthropogenic contamination, e.g. from use of nitrates (fertiliser) and POPs; and induced contamination, e.g. from seawater intrusion.

5. STAP commissioned a review and synthesis of these strategic groundwater issues (Annex 2): the review identifies a number of strategic directions and priorities relevant to the GEF's operational programmes. The broad conclusion is that appropriate management strategies need to be developed to deal with seven priority issues: managing the growth in demand for groundwater; sustainable management of transboundary aquifer systems; management of fossil, i.e. non-renewable, aquifers; protection of groundwater quality; soil and groundwater salinisation; protection of groundwater-dependent ecosystems; and dealing with the effects of climate change on groundwater, and its uses.
6. Hitherto the GEF's International Waters programme has dealt mainly with fresh water bodies, and large marine ecosystems, i.e. surface water. Recently the GEF has been an active leader in promoting transboundary aquifer issues, and has funded a small number of aquifer projects. (These are the Guarani aquifer project in Brazil (OAS/World Bank), two medium-sized projects in the Sahara/Sahel region (UNEP), and the Limpopo basin project in Southern African Development Community (World Bank)).
7. STAP believes that the GEF could make a larger contribution to global environmental benefits if more account were taken of the protection and management of groundwater in all the GEF's focal areas (apart from ozone depletion). This is especially so for: biodiversity, e.g. the contribution of groundwater to freshwater, brackish and coastal wetlands that host biodiversity; climate change, e.g. sea level rise, increased incidence of flooding and changes in precipitation patterns which increase the demand for drought-secure supplies and affect recharge; and sustainable land management, e.g. the recharge of aquifers, and poor management of irrigation and drainage. Groundwater should be mainstreamed in the design of GEF projects. In doing so, the GEF should have regard to STAP's report on the interlinkages[1] between the GEF's focal areas which provides advice on how to do this through use of a design tool.
8. The GEF should also review its current and pipeline projects to ensure that groundwater considerations have been adequately taken into account, and are an integral part of its international waters river and lake basin, and large marine ecosystem projects.
9. The GEF's existing groundwater portfolio has been developed as a series of standalone aquifer projects. The similar, but presently unrelated, projects in the Sahara/Sahel are an example: the GEF should consider how these might be linked together to provide a

[1] "A conceptual design tool for exploiting interlinkages between the focal areas of the GEF," to be published as a GEF working paper.

rationale for a coherent regional strategy, which could form a basis for other countries (or regions) in preparing future projects.

10. In the absence of a global convention on groundwater or on freshwater resources in general, there are no clear policy guidelines for groundwater projects. This provides an opportunity for the GEF to fulfill its catalytic role by considering a number of demonstration projects.
11. STAP suggests that the GEF's first priority should be a demonstration project to manage artificial aquifer recharge. Addressing the over-exploitation of groundwater is difficult, especially where controls on use are minimal, or difficult to enforce. There has been relatively little systematic evaluation of the effectiveness of artificial recharge, and the benefits are often anecdotal. Given the large number of variables involved, e.g. physical, socioeconomic, climate, a suite of projects would be useful to test a range of approaches. Groundwater recharge could also have beneficial effects on other focal areas, e.g. maintaining groundwater-dependent ecosystems, land-water management, and adaptation to climate change.
12. STAP also recommends that the GEF consider a number of other demonstration projects including: the interaction between saline and fresh international waters, both rivers and lakes; best practice in land and water management; groundwater management in small island developing states, which are often wholly reliant on groundwater; and land management practices and technology to contain land and groundwater salinity, especially in arid areas.
13. And finally, STAP recommends that the GEF and its Implementing Agencies, take concrete steps to encourage the integration of groundwater issues into the global dialogue on water which is being developed through the World Water Forum and other similar processes. Policies should be identified and promoted at the global level which incorporate groundwater elements into Integrated Water Resources Management and Integrated Coastal Management, into sustainable land management practices, and freshwater and coastal aquatic ecosystems conservation efforts.

SECTION 1: INTRODUCTION

1.1 Background

The Scientific and Technical Advisory Panel (STAP) was asked by the Global Environment Facility (GEF) for an assessment of the current state of knowledge on groundwater; this would identify the main threats and challenges to groundwater and provide an inventory of state-of-the-art approaches to the management and protection of groundwater, as a means to secure its environmental functions, and as a strategic resource for sustainable development.

In response to this request, STAP convened a technical review workshop on Strategic Options and Priorities in Groundwater Resources in Paris, 5-7 April 2004, co-organised with, and hosted by, UNESCO. In order to inform discussion at the workshop, a review and synthesis report of strategic issues in groundwater was commissioned (Annex 2).

UNESCO's International Hydrological Programme (IHP) has contributed significantly to the development of groundwater science, and has recently engaged in a scientific programme related to internationally shared aquifer resources management (ISARM). UNESCO/IHP, together with the International Association of Hydrogeologists (IAH) and other ISARM partners, including FAO, UN-ECE, OAS and other institutions, have a wealth of experience and offer a global network of national groundwater managers, hydrogeological, socio-economic, environmental and legal expertise.

1.2 Purpose of the workshop

The workshop reviewed the sustainability of groundwater resources, and approaches to the management of groundwater resources and environmental protection: in light of these, it suggested elements for a GEF strategy on groundwater.

The workshop looked at several related issues, including:

- the major global threats affecting groundwater resources, and the effects of projected climate change;
- groundwater and the increasing demand for water;
- ways to improve the protection of aquifer systems and their sustainable use;
- strategic uses of groundwater, in relation to land degradation, natural ecosystems and environmental sustainability;
- the management of groundwater resources; and
- the relationship between groundwater resources and GEF focal areas, i.e. biodiversity, climate change, international waters, land degradation, and persistent organic pollutants (POPs).

The workshop was also asked to address three specific issues and consider options for action on:

(a) over-exploitation and intensive use, e.g. saline water intrusion in coastal areas, and over-abstraction affecting ecosystems;
(b) demonstration projects and the development of priority technology options, in particular artificial recharge in water scarce, arid or semi-arid regions; and
(c) non-renewable groundwater resources, e.g. fossil aquifers, groundwater mining, and the concept of sustainable exploitation.

1.3 Workshop participants

The workshop brought together a group of experts from developed and developing countries, academia, research, international and government agencies, in addition to STAP members, Professor Leonard Nurse and Dr. Alexei Maximov, members of the UNESCO/IHP/ISARM and IAH networks, representatives from the GEF Secretariat, the GEF's Implementing Agencies (UNEP, UNDP and the World Bank), and the STAP Secretariat. (Details at Annex 1.)

1.4 Workshop organisation

The workshop was organised into three plenary sessions on: I. *Major Threats;* II. *Sustainability of Groundwater Resources*; and III. *Groundwater Management and Protection.* (Annex 3 lists the presentations made: further details can be found on the STAP website at www.unep.org/stapgef.) Three working group sessions were held to address: demonstration projects; regional strategies; and groundwater management and transboundary issues. The findings and conclusions of the working groups, and of the workshop, as a whole, were presented in a concluding plenary session.

SECTION 2: MAIN CONCLUSIONS

The workshop recognised that:

- Groundwater is a ubiquitous resource, found worldwide,
- Groundwater is important both for its development and environmental functions,
- Groundwater is important for the maintenance of river flows, water bodies and wetlands as habitats for biodiversity, and for protection from salinisation, especially in coastal areas,
- Groundwater is used by, and forms the basic necessity of life for, more than 2 billion people. Groundwater is therefore a priority in socio-economic development, and poverty reduction,
- Groundwater is used from scattered sources by millions of individual users, and, as a consequence, its use is generally not well-recognised by governments, and
- The significance of groundwater is not well-represented in national development plans, nor is it reflected in the institutional arrangements for the administration of water resources and the environment.

The workshop concluded that:

- If groundwater is not managed soundly, its critical environmental and socio-economic functions will continue to degrade, and
- This would jeopardise environmental sustainability, natural systems protection, human health and the scope for sustainable development.

In light of these observations, the workshop reached a number of conclusions on: the sustainability of groundwater resources (2.1); and groundwater resources management and environmental protection (2.2). These conclusions are reflected in some elements for a GEF strategy on groundwater (2.3).

2.1 Sustainability of groundwater resources

Uncontrolled groundwater development and abstraction by millions of farmers and other users is resulting in prospective groundwater crises on regional scales, e.g. in Southern Asia, North Africa and Mexico. If the current (reactive) crisis management approach is not changed into more proactive, long-term demand management to reduce groundwater depletion, then the outcome will be misery for groundwater-dependent societies, and deterioration of the environment. But with proper management groundwater development, and even over-abstraction, can offer an affordable and effective way to reduce poverty, which in itself is a major cause of environmental degradation.

The workshop concluded that the following measures were necessary to address the sustainability of groundwater resources:

(i) Strategies for sustainable groundwater development should be developed and implemented. These should accommodate and reconcile the need for environmental protection, and for social transition.

(ii) Renewable, as well as non-renewable, groundwaters should be managed for sustainable exploitation, preferably at the aquifer level. This should be based on orderly, planned depletion and stabilisation for renewable aquifers, and with long term exit strategies for non-renewable aquifers.

(iii) Governments should establish mechanisms to assess, plan and control the use and protection of groundwater resources, at both the national and local users' level.

(iv) The proper use of transboundary aquifers requires joint utilisation and protection strategies, with agreed frameworks and mechanisms to identify and share risks and uncertainties.

(v) Given the global nature of the task, clear priorities need to be set. These should focus on the management and protection of aquifers which are important for current and future socio-economic development, or which are subject to particular pressures and environmental threats. Priority should be given: to threats with irreversible or long-term impacts, such as aquifer degradation with salinisation and seawater intrusion in coastal zones; stabilisation of uses and rehabilitation of degraded aquifers; and sustainable use of non-renewable groundwater.

2.2 Groundwater resources management and environmental protection

The workshop concluded that the following measures were needed to improve the management and protection of groundwater resources:

Management

(i) Groundwater management and environmental protection should address a wide range of aspects, including:
  - control of groundwater depletion
  - land management for conservation of groundwater recharge including protection from surface-induced contamination
  - control of both human-induced, and natural groundwater problems
  - control of water and soil salinisation, and water logging, from rising groundwater levels and seawater intrusion
  - protection of groundwater-related ecosystems.

(ii) Management approaches need to be specific and geared to the particular characteristics of the aquifer system, including its socio-economic and institutional setting, and the actual and future demand for groundwater.

(iii) Awareness and education, of the general public and local users, are crucial to effective groundwater management. In developing and implementing domestic groundwater policy, countries should ensure that the support of local users is enlisted, and that they have a participatory role in groundwater management and protection.

Basin management

(iv) Aquifer systems often deviate from surface river basins, for example, large and deep multi-aquifer systems in arid regions are usually unrelated to surface water:
  - where relevant, especially in non-arid zones, groundwater management should be part of integrated river basin management
  - but basin management is not a pre-requisite for effective groundwater management. Where aquifers are essentially unconnected to surface water systems, e.g. in terms of exchanges as recharge or out-flows, and annual and long term variation in

groundwater storage, the groundwater basin should form an independent management unit

- in both cases the mandate of the river basin organisation should explicitly address groundwater.

Regional management

(v) In regions, with uniform hydrogeological and socio-economic conditions, especially in arid zones, e.g. in North Africa and the Sahara, regional strategies should be developed to address common issues and problems – as an alternative to a number of separate, individual aquifer projects. The advantages of regional strategies include:

- harmonised regional guidelines for groundwater policies, domestic and transboundary legal and institutional frameworks, and economic and other instruments for integrated groundwater management
- enhanced regional cooperation and support
- region-wide benefits from the demonstration and replication of successful management approaches and technologies
- common approaches to transboundary groundwater management, based on regional consensus and cooperation.

Water quality and pollution

(vi) Groundwater management should be integrated with land management to support groundwater availability and quality, and also to address land degradation, e.g. salinisation and drainage issues.

(vii) Natural geochemical sources, including arsenic and fluoride are a common cause of impaired drinking water quality, and a threat to human health; this should be addressed through planning, monitoring and the application of technology.

(viii) Quality limits for drinking water, as opposed to ecological water standards, need to be assessed, especially in arid and semiarid countries.

(ix) Emerging technologies for the re-use of water and nutrients, and returning marginal and polluted groundwaters and nutrient to the environment, offer considerable promise. Technologies and regulatory frameworks for waste disposal into aquifers, including the discharge of carbon oxide, and mineralised and toxic geothermal flows should be developed.

(x) The consequences of current, or previous polluting activities, e.g. mining, need to be addressed.

Demonstration projects

The workshop also concluded that the following issues would be suitable for demonstration projects (Table 1) to help identify and replicate successful management approaches:

- as a first priority, Managed (Artificial) Aquifer Recharge (MAR), integrated, where appropriate, with water re-use and the demineralisation of saline groundwaters.
- seawater intrusion, and the saline-fresh groundwater interaction, especially in coastal areas.
- groundwater management in small island developing states (SIDS).
- groundwater discharge to fresh and marine water bodies, i.e. rivers, lakes and seas.
- the use of economic instruments in developing cost-effective land and water management practices.
- management of the disposal of hazardous waste containing POPs, including improved and controlled agrochemical use.
- management of the impact of groundwater depletion from intensive use, large-scale extraction, and groundwater depletion on the environment (eco-hydrogeology).

Table 1: Summary of demonstration projects

Title	Issue	Objectives	Benefits	GEF linkages	Locations	Partners
Managed aquifer recharge (MAR)	MAR, as part of land and water management, needs to be better understood, if it is to be applied effectively, in particular in different physical and socio-economic contexts.	To demonstrate the effectiveness of MAR in providing seasonal storage of water to address water management issues in a range of hydrogeological and environmental settings.	Seasonal storage of water in aquifers for future use. Smoothing of supply/demand fluctuations. Stabilisation or raising of declining groundwater levels. Reduced loss of water to evaporation and runoff. Less storm runoff and soil erosion. Improvement of recharge and groundwater quality. Maintenance of environmental flows in streams/rivers. Reuse of urban storm and wastewater.	Biodiversity, e.g. groundwater-dependent ecosystems (GDEs). Land degradation, (as part of land and water management). Climate change. International waters (transboundary aquifers in arid areas).	Global.	UN agencies, NGOs, governments, private companies and individuals.
Seawater intrusion and saline-fresh groundwater interaction in coastal aquifers	Concentrated water demand from rapid development, irrigated agriculture and population density is resulting in saline intrusion, with loss of water resources, storage capacity and soil salinisation.	To demonstrate how a coastal aquifer can be used in a sustainable way to preserve its environmental functions.	Long-term environmental sustainability in coastal zones and small islands.	Biodiversity (GDEs). Climate change. Management of fossil groundwater; water and land salinisation.	Morocco (especially in the Atlantic part), Western Mexico (Sonora, Baja California), and North–Eastern Brasil (Pernambuco, Natal, Ceara), Cabo Verde archipelago islands, Easter Island (Chile), Galapagos islands (Equador).	UN agencies, NGOs, governments, municipalities, water agencies, water users' associations, private companies, and individuals.
Groundwater management in small island developing states (SIDS).	Groundwater resources of SIDS are limited and subject to over-exploitation and pollution. They are often closely linked to coastal ecosystems and sensitive to the impacts of economic development and climate change.	Integration of best groundwater management practices, e.g. aquifer storage management, groundwater protection, for sustaining groundwater resources and coastal GDEs.	A better understanding of the role of groundwater in maintaining coastal ecosystems in SIDS.	Biodiversity (GDEs, coral reefs), climate change.	Small island developing states in the Caribbean, Atlantic and Pacific.	UN agencies, governments, international agencies, and NGOs.

Table 1 (continued): Summary of demonstration projects

Title	Issue	Objectives	Benefits	GEF linkages	Locations	Partners
Groundwater discharge to international waters: the rehabilitation of Lake Victoria	Groundwater maintains river baseflow, and many lakes and wetlands also depend dominantly or seasonally on groundwater contributions. There is a trade-off between biodiversity preservation and aquifer development.	To demonstrate the importance of groundwater contributions to fresh, surface water systems.	Maintenance of water quality and quantity in receiving streams, lakes, wetlands.	Biodiversity (GDEs), climate change, international waters.	Rivers, lakes and seas; along international boundaries, e.g., Lake Victoria, Lake Baikal, Limpopo, Aral, Caspian, Mediterranean Sea.	UN agencies, NGOs, private sector companies, and government agencies.
Economic practices in land and ground water management	Groundwater management is often haphazard and does not consider the economic value of groundwater. Measures to protect groundwater are often not considered because the cost of "doing nothing" is not considered. The use of economic instruments could help to manage groundwater resources and help resolve potential or actual conflicts between users and uses.	To show how economic instruments can be cost-effective in protecting water resources, reducing land degradation and minimising impacts on GDEs. To demonstrate that economic instruments can be effective in changing land use practices for environmental/social benefit.	Reduced land degradation and impact on water resources and GDEs. A means to compare the costs of various land and water management options with socio-economic and environmental benefits. Reduced potential conflict between groundwater users. Prevention and reduction of land and water resource degradation, and drought and flood mitigation.	Land degradation. Biodiversity (GDEs). Climate change.	South and Eastern Asia, and South America.	UN agencies, NGOs, governments, water agencies, water users and associations, private companies, and individuals.
Disposal management of hazardous waste	POPs can be safely confined in favourable hydrogeological conditions, contributing natural hydrodynamic and chemical barriers, in addition to the engineered ones – making possible passive protection.	To provide environmentally sound practices (methodology, technological instruments, and site selection) for safe disposal of hazardous waste, including POPs.	Protection of groundwater quality, and human health.	POPs, land degradation.	Many developing countries with chemical, pharmaceutical, oil industries, and mining operations.	UN agencies, World Bank, local governments.
Eco-hydrogeology management practices	Large scale groundwater extraction can cause ecological problems: loss of wetland habitats, decrease in river flows, land subsidence, seawater intrusion, reduction in vegetation.	To assess, predict and protect groundwater resources from the negative ecological consequences of large-scale centralised groundwater withdrawal.	A methodology to manage rational groundwater extraction which minimises negative ecological consequences.	Ecosystem and biodiversity protection, sustainable development.	Large centralised well fields with high extraction rates for water supply and irrigation. Distributed over-exploitation for rural supply, e.g. in India.	UNEP, UNESCO, IUCN, RAMSAR Secretariat, World Bank.

2.3 Some elements for a GEF strategy on groundwater

The GEF's framework for international waters, mainly under operational programmes 8 and 9[2], addresses the services provided by basins and large water bodies: it is built on human-centred objectives and drivers of change, and implemented through the TDA-SAP[3] commitment-building process, and underpinned by the GEF's strategic priority on International Waters. This is an effective approach to environmentally sound management of groundwater, and the related management of land and ecological resources. There are opportunities in other focal areas to advance better management and protection of groundwater, which could provide a cost-effective means of achieving greater global environmental benefits. Groundwater affects, and is affected by, all the GEF's focal areas, with the exception of ozone depletion: table 2 identifies some of the significant groundwater linkages.

[2] Operational Programme 8 (Waterbody-based) and Operational Programme 9 (Integrated Land and Water Multiple Focal Area).

[3] The formulation of a science-based Transboundary Diagnostic Analysis (TDA) followed by a Strategic Action Programme (SAP) for projects under GEF-IW OPs 8 and 9.

Table 2: Examples of interlinkages between groundwater and the GEF's focal areas

Focal area	Significance and effects of groundwater	Effects on groundwater
BIODIVERSITY	Groundwater supports freshwater critical to ecosystems, Maintains dry-weather flows to freshwater, brackish and coastal wetlands, and oasis and dryland systems that host terrestrial and marine biodiversity. Support for low water flow levels and pollution free inflows into surface water bodies; and support for ecosystems in karst aquifers. Groundwater transport of land-based pollution into freshwater and marine water bodies. Groundwater prevents saline intrusion, important to the maintenance of biodiversity hotspots in coastal areas and SIDS. Polluted coastal groundwater discharges are a significant threat to coastal marine ecosystems, in particular coral reefs. Submarine groundwater discharges are important for marine biodiversity, e.g. fish reproduction and migration in large marine ecosystems.	Maintained surface vegetation protects groundwater in recharge zones. Regulates runoff and erosion, enhances, moderates and evens out groundwater recharge, reduces under-flooding and water level rise, with water-logging and salinisation – mainly from natural sources. Reduction of surface-based groundwater pollution.
CLIMATE CHANGE	Palaeo-groundwater records of earlier periods of climate change in recent geological history are useful in looking at forecasts. Opportunities for carbon sequestration in saline aquifers. Shallow aquifer seepage and evaporation for moderating the local rise in temperature, and reducing water stress. Groundwater and aquifer storage management to compensate for reduced availability, and higher variability of surface water. Artificial recharge to introduce surface water to the subsurface, and thereby reduce evaporation losses, often in excess of 1000 mm per annum in arid climates.	Increased demand groundwater, and reduced replenishment, changing recharge patterns, and increased pollution leakage because of declining groundwater levels. Changes in the temporal and spatial distribution of the groundwater recharge process. Changes in the configuration of aquifers in coastal areas, related to sea level rise.
INTERNATIONAL WATERS	Contribution of groundwater to maintaining transboundary riverine and lacustrine environments. Impact on riparian country resources. Impacts of water level rise (water-logging and under-flooding), or fall (land subsidence). Transboundary aquifer contamination. Movements of pollutants in transboundary aquifers and groundwater contaminant transport, in particular nutrient and high risk organic pollutant flows into transboundary water bodies and large marine ecosystems.	Transboundary threats from rapidly expanding well development, with over-abstraction and groundwater depletion. Transboundary threats of groundwater contamination and coastal aquifer salinisation.
OZONE DEPLETION	*Not applicable.*	

Table 2 (continued): Examples of interlinkages between groundwater and the GEF's focal areas

LAND DEGRADATION	Land improvement through improved groundwater management. Optimal water table management for support of surface vegetation cover, and mitigation of water-logging and salinisation. Groundwater irrigation to abate desertification with climate desiccation and dust formation.	Changes in groundwater recharge from poor irrigation-drainage management. Recharge and mobilisation of nutrients and minerals from the soil zone, and temporary or permanent saline or polluted depressions.
MULTIFOCAL AREA	The environmental functions of groundwater cut across focal areas: groundwater supports fresh and marine ecosystems; represents an important climate change mitigation strategy; is a principal transboundary water resource; land and groundwater management is an important land degradation strategy; and sound groundwater management is a valuable pollution-prevention strategy.	Groundwater depends on the environmental functions specific to the different focal areas. Wetlands and biodiversity protection provide for groundwater protection. Impacts of climate change on groundwater are profound, and include reduced replenishment and increased demands. Land degradation resulting from the degradation of groundwater resources. Surface-based pollution and inadequate pollution management and waste discharges result in groundwater quality degradation.
POPs	Regulated land use and controlled protection of groundwater recharge zones vulnerable to long-term or irreversible pollution (from non-point and unmanaged point contamination sources) is an important part of a pollution-prevention strategy. Established groundwater quality monitoring can act as an alarm system for land-based pollution. Improved agricultural practices including plant nutrition to reduce surface-based nutrient and chemical groundwater pollution.	Pesticide contamination in aquifers; and invasion of aquifers by leachates from industrial land disposal of waste, and inadequate storage and handling of pesticides, and other high risk persistent pollutants.

The workshop recommended that consideration be given to the following elements in developing a GEF strategy on groundwater.

(i) identify groundwater investment opportunities.

(ii) develop a balanced portfolio of groundwater projects which includes: (a) demonstration projects on promising technologies and management practices, e.g. managed artificial groundwater recharge and re-use, seawater intrusion and saline-fresh groundwater interactions, and groundwater management in SIDS; and (b) capacity building for harmonised management policies, regulatory and institutional frameworks in regional groundwater strategies.

(iii) identify and prioritise opportunities for integrating groundwater into current international waters basin projects and those in the pipeline: (a) introduce complementary groundwater activities into these projects, as well as projects in other GEF focal areas; (b) conduct a 'groundwater issues' review of selected GEF and non-GEF regional and focal area projects. (The objective of the review would be to deliver broad-based guidance and criteria for the preparation of GEF projects.)

(iv) adopt a more focused approach to the management and protection of groundwater resources by looking for opportunities to make use of the measures set out in section 2.2 above, in both international waters projects, and projects in other focal areas.

(v) conduct regional and country level stakeholder consultations, which balance the responsibility of users with the regulatory role of water administration, in order to secure local cooperation and build awareness of groundwater and its importance in different focal areas.

(vi) in the absence of a global framework convention on groundwater, the GEF's groundwater activities should refer to, and be based on, existing global environmental conventions, e.g. UNFCCC, CCD and CBD. The GEF should support the development of a global groundwater convention[4].

(vii) groundwater is a cross-cutting issue, with interlinkages to projects in other GEF focal areas (see Table 2). These interlinkages need to be reflected in the design of projects in the respective focal areas.

(viii) the effectiveness of an aquifer-by-aquifer approach to groundwater projects should be assessed in comparison with the development of broader, regional strategies. Groundwater projects

[4] UN-ILC has recently initiated the development and drafting of an International Groundwater Framework Convention.

should be developed to achieve regional gains, starting with the development of an inter-focal area regional groundwater strategy for the Sahara/Sahel arid and other semi-arid zones[5].

(ix) the GEF should undertake an assessment of the environmental services provided by groundwater; this would be helpful in communicating the advantages of better groundwater governance to decision-makers. The assessment should provide criteria for the valuation of ecological benefits (in economic terms) of groundwater management, and for the introduction of effective financial management mechanisms and instruments.

[5] "Draft Strategy For the Management Of Transboundary Aquifers in the African Region" UNESCO-ISARM, (forthcoming 2005).

Annex 1: list of participants

Experts

Walid A. Abderrahman,
King Fahd University of Petroleum and Minerals,
Dhahran, Saudi Arabia

Manzano Marisol,
Technical University of Cartagena,
Cartagena, Spain

Ian Gale,
British Geological Survey,
Wallingford, United Kingdom

Ramon Llamas,
Universidad Complutense,
Madrid, Spain

Igor Zekster,
Lakehead University,
Santa Barbara, California, USA

Emilio Custodio,
International Association of Hydrogeologists,
IGME, Madrid, Spain

Ken Howard,
University of Toronto,
Ontario, Canada

Jaroslav Vrba,
IAH –UNESCO,
Prague, Czech Republic

Shaminder Puri,
International Association of Hydrogeologists,
Abingdon, United Kingdom

Stephen S.D. Foster,
International Association of Hydrogeologists,
Wallingford, United Kingdom

Christian Leduc,
UMR HydroSciences,
Montpellier, France

Tushaar Shah,
International Water Management Institute,
New Dehli, India

Klaus Froehlich,
IAEA,
Vienna, Austria

Qingcheng He,
China Institute for Geo-Environmental Monitoring (CIGEM)
Beijing, People's Republic of China

Adrian Lawrence,
British Geological Survey,
Wallingford, United Kingdom

John Bwalya Mwansa,
Barbados Water Authority,
St. Michael, Barbados

Wilhem Struckmeier,
Federal Institute for Geosciences and Natural Resources
Hannover, Germany

Jac A. M. van der Gun,
Netherlands Institute of Applied Geoscience,
Utrecht, The Netherlands

Ricardo Hirata,
IAH,
São Paulo, Brazil

J. Margat,
BRGM- Service Eau,
Orléans, France

S. Ragone,
National Ground Water Association-NGWA,
Westerville, Ohio, USA

Jan Girman,
South Africa Mapping Project,
Pretoria, South Africa

Michela Miletto,
Organization of the American States,
Washington, DC, USA

STAP Members

Leonard Nurse,
Barbados

Alexei Maximov,
Russia

UNESCO

A Szöllosi-Nagy
A. Tejada-Guibert
Alice Aureli
Bo G. Appelgren
Raya Marina Stephan
Wilfried Gilbrich
Annukka Lipponen

UNEP

Takeiro Nakamura
Sheila Aggarwal-Khan

GEF Secretariat

Andrea Merla

UNDP

Andrew Hudson

World Bank

Rafik Hirji

FAO

Stefano Burchi
Jacob Burke

STAP Secretariat

Christopher Whaley
Guadalupe Duron

Annex 2: A review and synthesis of strategic issues in groundwater[1]

SECTION 1: HYDROGEOLOGY AND GROUNDWATER DEVELOPMENT

While not visible, like surface water, groundwater is ubiquitous in the global landmass, and is contained in the pore spaces of rock formations (aquifers). Its science (hydrogeology) has advanced rapidly over the last 35 years, contributing to the well-being and development of the human population in all parts of the globe. At the global scale, groundwater is the largest and most important source of fresh potable water, representing over 98% of accessible reserves, i.e. excluding fresh water locked up in the polar ice-caps. Volume estimates vary, but generally range from 7,000,000 km^3 to 23,400,000 km^3 – equivalent to a water depth of between 50 and 150m distributed across the earth's entire land surface, much of it in internationally-shared aquifer systems.

Groundwater discharge has always been critical for sustaining the baseflow in rivers and flow to springs. For millennia only a tiny fraction of the resource was actively exploited for beneficial use by humans. This changed dramatically in the mid-20th century when heavy development of groundwater followed major advances in geological knowledge, well drilling, pump technology and power development. Today, the global rate of withdrawal is 600-700 km^3 per annum. Groundwater provides, for example, 70% of piped water-supply in the European Union, and fuels Asia's 'green agricultural revolution'. In India groundwater provides about 80% of the domestic water-supplies in rural areas: some 2.8-3.0 million hand-pumped boreholes having been constructed over the past 30 years. Furthermore, some 244 km^3 pa are currently estimated to be pumped for irrigation from around 15-17 million motorised dugwells and tubewells, with as much as 70% of Indian agricultural production being supported by groundwater.

The social and economic benefits of groundwater exploitation are enormous. Groundwater has become vital to many countries, irrespective of their stage of economic development, with 2 billion people, countless farmers and a significant proportion of the world's industry relying on it for water supply. In arid and semi-arid regions of the world, it is often the only reliable source of water. Compared to surface water, groundwater exhibits unique advantages. It is normally well protected from contaminants, requires minimal treatment, is less susceptible to extremes of climate, and can be introduced locally and incrementally to meet growing private, municipal, industrial and agricultural demand, with minimal upfront capital expenditure.

Unfortunately, the accelerated development of groundwater in the past 25-50 years has not been without consequence; some impacts have been quite severe. To a large extent, this reflects a serious lack of investment in the scientific characterisation of aquifers and the development of appropriate and properly integrated groundwater resource management strategies. Simply put, the social, economic and environmental benefits associated with groundwater have gone largely unrecognised, and are seriously undervalued. Groundwater has been "out of the public sight", and thus "out of the political mind".

Global reserves may be immense, but natural rates of replenishment are relatively small, finite, and mainly limited to shallow aquifers in climatically wetter parts of the planet. Excessive groundwater extraction, notably in arid and semi-arid areas, can steadily deplete groundwater storage by lowering the water table, thus exacting a heavy toll on the future value and viability of the resource.

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[1] Discussion document prepared for the STAP Workshop on Strategic Options and Priorities in Groundwater Resources 5-7 April 2004, UNESCO, Paris. (A longer version of this document will be published by UNESCO in early 2005.)

The problem of sustainability is seriously exacerbated where groundwater quality is degraded by the release of urban, industrial and agricultural pollutants, or by the induction of saline groundwater from the sea or deep-seated brines. Problems are not limited to human needs. Groundwater is just one component of the natural hydrologic cycle. When groundwater is drawn from an aquifer by pumping and either used consumptively, or is chemically degraded, the water bodies destined to receive that water e.g. springs, rivers, wetlands, estuaries or seas will inevitably be affected. The natural environment, thus, stands to suffer in one of two ways: a depleted influx of fresh groundwater due to heavy up-gradient exploitation; or an influx of groundwater that has been degraded by salinisation, or the release of contaminants. Since groundwater flow velocities are normally very low (typically 10 – 100m pa), impacts are very slow to materialise. By the same token, impacts, once manifest, are very difficult to contain, and even more difficult to restore.

Over-Abstraction, Water-Level Decline and Sustainability

Global expansion in the development of groundwater resources has commonly led to over-abstraction (over-exploitation), and declining water-levels, and has raised concerns about long-term aquifer sustainability. In this context, over-abstraction is strictly defined as the pumping of groundwater that exceeds the average annual rate of aquifer recharge. While the term often carries a negative connotation, the practice can be appropriate since it takes advantage of an important property of the groundwater system, i.e. storage. In the long-term, in some cases, hundreds of years, over-exploitation is not a sustainable practice, and problems will eventually emerge (Table 1). The term groundwater “mining” also refers to the practice of over-abstraction and is often used synonymously. The term is best used, however, to describe the deliberate use of over-exploitation as a management plan strategically designed to dewater the aquifer indefinitely, to provide maximum socio-economic benefit. This type of management may facilitate economic growth and allow, for example, the postponement of investment in dams, long distance transfer of water, and desalination plants. The strategy is appropriate, if positively planned, realistically evaluated, and with close control over groundwater abstraction. There should also be a clear and feasible plan for alternative water supplies when the groundwater resources are exhausted. Examples of groundwater mining which include storage depletion include: some 10 km^3 pa on the North China Plain within the Hai He basin; and about 5 km^3 pa in the hundred or so recognised Mexican aquifers. In neither case is the rate of abstraction sustainable in the longer term.

Table 1: Benefits and problems of groundwater development

SOCIO-ECONOMIC BENEFITS	SUSTAINABILITY PROBLEMS
• economical provision of good quality, urban water-supply	• inefficient resource utilisation on a very widespread basis • growing social inequity in access to groundwater in some regions
• low cost development of drought-reliable rural water-supplies	• physically unsustainable abstraction rates in some more arid regions • reduction in dry-weather baseflow in some downstream watercourses
• accessible and reliable water-supply for irrigated crop cultivation	• irreversible aquifer damage locally due to saline intrusion and up-coning • localised land subsidence due to aquitard compaction
• improved drainage and salinity alleviation in some areas	• damage to some groundwater-dependent ecosystems

The issue of sustainability, and how much can be safely drawn from an aquifer, has been debated for almost a century. Early definitions focused on quantitative aspects, for example, invoking the term "safe yield" to describe the amount of water that could be pumped from an aquifer "regularly and permanently without dangerous depletion of the storage reserve". It is now well-established that water has value only by virtue of its economic use and that “protecting" or "sustaining" the viability of a groundwater resource for all time fails to recognise that regulated, long-term depletion, i.e. mining, can generate considerably greater net socio-economic benefits. It is no surprise that many of the world's most prosperous nations have profited enormously from over-exploitation of groundwater, although it must be said, mostly due to an ignorance of the hydrogeology and associated long-term risks, than through a carefully evaluated and planned strategy, examples, include the Ogallala aquifer of Texas in the U.S., the Great Artesian Basin of Australia, and the Lower Triassic Sandstone aquifer in France.

Impacts on Groundwater Quality

Compared to surface water, groundwater tends to be very resilient to chemical change. Consequently, most groundwater concerns have focused, historically at least, on the ability of aquifers to sustain supplies from a quantitative standpoint. In the past 30 years, this situation has changed significantly. Quantity remains a primary concern, but water quality problems, and in particular diffuse pollution from non-point sources, have moved centre stage. In effect, “aquifer sustainability” has taken on a new and urgent dimension. For example,

- where shallow aquifers underlie agricultural soils in Europe,
  >85% show nitrate concentrations in excess of the EU target value (25 mg/L),
  >20% show nitrate concentrations in excess of the drinking water standard (50 mg/L),
  >20% show pesticide concentrations in excess of the pesticide standard by a factor of 10 or more; and
- in a U.S. study, over 10% of community water-supply wells revealed detectable residues of one or more pesticides.

Issues concerning the maintenance of water quality are numerous and complex. They extend far beyond an understanding of hydrogeochemistry, contaminant sources and sub-surface chemical transport, and have become closely entwined with socio-economic considerations in a much broader environmental context. Legislative and regulatory measures aimed at maintaining and, in some cases, restoring groundwater quality, have mushroomed in many industrialised countries. Heightened awareness about groundwater contamination, prompted by increased expenditure on monitoring and site investigation, has largely fuelled the campaigns. Some of the most severe groundwater quality problems occur in less prosperous countries that are simply unable to provide adequate protection for their aquifers which, at the same time, are ill-equipped to monitor the degree to which groundwater quality has become impaired.

Natural geochemical sources of water quality impairment

While the quality of unpolluted groundwater is generally good, trace elements derived from the soils and rocks through which the groundwater passes will dissolve and, under some conditions, will reach concentrations detrimental to health. Most notable amongst these elements are fluorine (as fluoride) and arsenic. Others such as nickel, cadmium, chromium, cobalt and lead may also be problematic, though typically on a much smaller scale. Long-term consumption of water with excessive concentrations of fluoride gives rise to dental, and less commonly, skeletal fluorosis. Such problems affect arid and semi-arid areas in many parts of Africa, India and China in particular.

Drinking water containing arsenic has also been linked to numerous illnesses, including cardiovascular diseases and cancer. One of the largest recognised incidences of arsenic contamination is in groundwaters from the Bengal Basin, where groundwater is presently the main source of water supply. More than 90% of wells in some districts of south-east Bangladesh have unacceptably high concentrations of arsenic. Other regions of the world with high-arsenic groundwaters include parts of Argentina, Chile, China, Mexico, Nepal, Taiwan, Thailand, U.S.A. and Vietnam. In many of these regions, alternatives to groundwater are very limited.

Salinisation of soil and groundwater due to irrigation and land use change

In drier parts of the globe, many countries experience a serious loss of agricultural productivity due to soil and groundwater salinisation. In such cases the salinity is natural in origin, but the problem is manifest as a result of human activity. Typically, the problem is caused by:

- rising groundwater tables, associated with the introduction of inefficient irrigation using imported surface water in areas of inadequate natural drainage (wetland or irrigation salinity);
- natural salinity mobilised from the sub-soil due to land clearance which reduces evapotranspiration rates, increases aquifer recharge, and causes a significant rise in the shallow water table (dryland salinity); and
- excessive disturbance of natural groundwater salinity stratification in the ground through uncontrolled well construction and pumping.

Pakistan, India and Egypt contain some of the most extensively documented cases of irrigation-induced waterlogging and salinisation. However, it is difficult to evaluate the extent of these problems, based on the available figures. In the case of food security, estimates indicate that irrigation-induced salinity and waterlogging reduce crop yields in Pakistan and Egypt by 30 percent. In India, the problem is serious enough to threaten the growth of the agricultural economy.

The impact of waterlogging and salinisation on farmers and regional economies can be insidious. In the initial years, the introduction of irrigation often causes a dynamic transformation of regional and household economies. Farmers are able to grow valuable market crops and wealth is created. However, as the water table rises, the 'bubble economy' based on unsustainable water management practices deflates. Once salinised, both the land and the shallow vadose zone are difficult and expensive to reclaim.

Serious cases of dryland salinity are documented in more arid areas such as Australia and Central Asia. In Australia the Murray-Darling Basin is especially threatened, with 2.5 million hectares of agricultural land already affected. Losses from land degradation in the SyrDarya basin amount to $206 m pa.

Contaminants introduced from anthropogenic sources

Although groundwater tends to be less susceptible to contamination than surface water, water quality data now suggest that groundwater throughout the world is becoming increasingly contaminated by surface-sourced pollutants. Shallow groundwater in unconfined aquifers is at greatest risk. The subsoil and the underlying rock formations can eliminate or attenuate many water pollutants by natural physical, chemical and biological processes, but this natural capacity does not extend to all types of water pollutants, and varies widely in effectiveness under different hydrogeological conditions. The most common contaminants include nitrate, salinity, soluble organic compounds (including synthetic toxic species) and, under certain conditions, fecal pathogens. Industrial sites, landfills and agricultural lands receiving herbicides and pesticides can be an important source of persistent organic pollutants (POPs).

In general, the most severe cases of water quality degradation occur in the immediate vicinity of point source releases, such as industrial spills and leaks from underground storage tanks. But potentially far more serious are "distributed", "non-point" sources of contamination which have the ability to degrade water quality to levels that may be just marginally beyond drinking water quality standards, but extend over very large areas of the aquifer. Examples of distributed contaminant sources include the leaching of nutrients and pesticides from agricultural lands, and the release of septic tank effluent from densely populated urban areas.

Groundwater pollution is insidious and expensive: insidious because it takes many years to show its full effect on the quality of water pumped from deeper wells; and expensive because by the time it is recognised, the cost of remediating polluted aquifers tends to be prohibitive. Indeed, restoration to drinking water standards is rarely achievable.

Induced contamination, e.g. saline water up-coning, and seawater intrusion

When groundwater is pumped from a well, water can be drawn from a wide range of sources, some of which may be characterised by poor water quality. In some cases, the water may be induced from surface water bodies such as polluted lakes and rivers. In other cases, the water may be induced from adjacent aquifers, or aquitards, containing inferior quality water. This commonly occurs, for example, in urban areas where seriously polluted groundwater in shallow, abandoned aquifers is inadvertently drawn into a deep aquifer used for public water supply. From a management standpoint, the challenge is to sustain necessary pumping rates, while maintaining adequate quality.

The challenge is similar in coastal aquifers, where excessive lowering of well-water levels can lead to the encroachment of seawater. In coastal aquifers, fresh groundwater water is in contact with seawater, which naturally extends inland as a relatively deep, higher density wedge. The subtle hydrodynamic equilibrium between the fresh and saline water, established over long periods, is readily disrupted by human interference. Pump too little groundwater and potentially valuable fresh groundwater flows across the top of the seawater wedge and is lost to the sea; pump too much and seawater is drawn into the wells.

Although the phenomenon of sea water intrusion in aquifers is well known, the dynamic response of the fresh/saline water to pumping is very difficult to predict. Hydrogeological conditions can only be established by thorough field investigations, accompanied by extensive hydrochemical analysis and mathematical modelling. Such studies demonstrate quite clearly that individual wells can be affected by seawater intrusion, even when the aquifer as a whole is not over-exploited, i.e. it is being pumped at rates well below the natural aquifer recharge rate.

Wells located at remote distances from the coast can also be affected by saline water: the problem is caused by the presence of relatively dense, saline water bodies that inevitably occur beneath the freshwater aquifer, deep below surface. These saline water bodies may be connate in origin, or have evolved geochemically over geological time; others may represent the influx of seawater inflow from a past geological era. Irrespective of their origin, pumping of individual wells can draw such waters to a well through a process known as “up-coning”.

Effects of Climate Change on Aquifers

A very significant proportion of groundwater currently stored in aquifers, entered the aquifer as “recharge” under quite different climate regimes than exist today. Despite this, very little work has been done on the potential impacts of climate change on future groundwater resources. This is because, in the short-term, the large storage capacity of regional aquifers can mitigate against the types of impact that, in comparison, surface waters will sustain almost immediately. Over the medium to long-term, however, significant effects can be anticipated on groundwater as a result of climate change, some direct, others indirect.

The most important direct effect of climate change on groundwater is on the spatial-temporal distribution of precipitation and evapotranspiration, which dictate patterns of recharge. An understanding of the relationship between recharge and climate change is critical, because knowledge about recharge is essential for resource management. Even more important perhaps, are the indirect effects of climate change. These include: rising sea levels and the increased risk of seawater intrusion; retreating glaciers and the release of water that may indirectly recharge aquifers; more flood events, with implications for the design and utilisation of artificial recharge facilities; and changes in vegetation, soil and land use, which, in addition to their effects on natural recharge, will dramatically alter demand patterns for irrigation water.

Groundwater Dependent Ecosystems

Many global ecosystems are highly dependent on groundwater: changes in the quality, quantity, and temporal availability of groundwater can have a profound impact on species diversity and, in some cases ecosystem survival. The function and importance of groundwater-dependent wetlands and oases have long been established, and are protected in many jurisdictions. These broader ecological impacts, both real and postulated, are beginning to be taken into account in groundwater development in some countries, but much remains to be done. Most countries, for example, show little appreciation for: the ecological significance of, for example, shallow water tables that sustain deep rooted vegetation; groundwater discharge to estuaries that provide important refuge coastal lagoon habitat during extreme tidal salinity changes; and karst aquifers developed in limestones and dolomites that support biological communities which have evolved entirely underground.

Groundwater in Urban Areas and Coastal Zones

Over half the world’s population currently live in cities, and the number of urban dwellers is expected to increase by between 30 and 50% over the next 25 years, creating an unprecedented demand for water. One billion city dwellers, many living in slums, already lack access to safe drinking water, and two billion lack adequate sanitation. The use of groundwater has played a major role in the development of many of the world’s cities. But urban groundwater resources are becoming increasingly stressed by increased demand, and by contamination; this will increase water-supply costs and, if left unresolved, would compromise human health, leading to socio-economic and environmental decline.

There is an urgent need therefore, to identify and prioritise action. Healthy, sustainable cities need sustainable water supplies. Groundwater can continue to play an important role in the development of urban areas, but new technologies and judiciously planned management and protection strategies are required to increase water supply, reduce demand and make more efficient use of the available groundwater. A major challenge will be to meet the growing demand for safe water supplies in the face of competing political, societal and economic interests, and limited financial resources for technological innovation and essential infrastructure.

The megacities and urbanised zones are often located at major ports along the coastline. Urban areas within coastal strips often have high population inflows, for example up to 6% pa along the coast of the Gulf of Guinea in West Africa. The general problems of congestion are exacerbated by water scarcity and depletion, and by saline intrusion of (often) transboundary coastal aquifers, with a loss of coastal wetland eco-systems.

SECTION 2: PRIORITY ISSUES

During the past thirty years demand for groundwater has grown at an unprecedented rate. Groundwater quality has deteriorated, water levels have dropped, and many aquifers continue to be developed at rates that are unsustainable in the longer term. Potential problems, already manifest in many of the world's shared and domestic aquifers, commonly include a dwindling potable resource, damage to groundwater-dependent ecosystems and the encroachment of seawater – problems that may well be compounded by climate change. Much of this analysis also applies to transboundary aquifers, where the impacts are readily transferred across borders to neighbouring countries.

Prioritising issues for action is difficult because so many of the problems require prompt attention. Seven priority issues are discussed below, but ultimately it is the total threat to individual aquifer systems, from the cumulative effect of one, or more of these issues that is important. Most groundwater problems can be resolved through the development of comprehensive integrated management plans. This is not a simple task: the development of management strategies is as much a socio-economic question, as it is a technical one. A fundamental priority is meeting the growth in demand through demand management, more efficient management of the resource, and an ability to augment the resource through artificial recharge management. There are a number of complementary issues that: have a strong bearing on being able to meet demand sustainably, e.g. climate change and water quality protection; represent special resource management concerns, e.g. transboundary aquifers, fossil aquifer and coastal aquifers; and compete with global groundwater demand, e.g. groundwater-dependent ecosystems.

The sustainability of groundwater is closely linked with a range of micro- and macro-policy issues affecting land-use and surface water. Practical advances are urgently needed, but there is no simple blueprint for action, because of the inherent variability of groundwater systems, and of the related socio-economic backdrop. Incremental improvements are usually possible. Government agencies, including transboundary commissions, need to be established as 'guardians of groundwater'. They should work flexibly with local and international stakeholders, as partners in resource administration, protection and monitoring. They should also act on broader water resource planning and management strategy issues.

Both short- and long-term mechanisms to increase the productivity of groundwater use are important components of an overall strategy. Enhanced public awareness, appropriate legislative instruments, improved scientific understanding, and local capacity building, are also key elements for improving groundwater management.

Groundwater is undervalued and in urgent need of protection. There needs to be greater appreciation of the social and economic dependence on national and shared groundwaters. More investment is needed to strengthen institutional arrangements and to build capacity for improved management, before groundwater resources are irrevocably degraded. The international development agencies of donor countries and international development banks should place a higher priority on supporting efforts to strengthen the governance of groundwater resources and local aquifer management. Sustainable human livelihoods, food security and key ecological systems are dependent on the development of such initiatives.

Priority 1: Meeting demand growth

If global demand for groundwater is to be met on a sustainable basis, urgent, proactive measures are required. Solutions are complex and compounded by competing political, societal and economic demands, and limited financial resources for technological development and infrastructure. The framework for such solutions, however, is fairly simple. There are three options:

i. temper the demand for water;
ii. manage the resource more efficiently; and
iii. increase the supply of water.

Demand management

Demand for groundwater can be tempered through a wide variety of measures, including: limiting the number and depth of wells through controls on the issue of well construction permits; limiting accessibility to water to certain periods of the day; moving to a lower water use economy, e.g. away from irrigated agriculture; and fiscal measures.

For all measures, education is essential. An informed public can be an accepting public. Education in good water management practices, and the need for such practices need to be focused at all levels of government, in industry, and in the population at large.

Efficient management

Effective and responsible aquifer management begins with a sound database. Many governments, including some in high-income countries, often attach a low priority to collecting basic data on resource conditions. Long-term data, including key elements of the hydrological cycle, such as dry-weather stream flows, and groundwater-level trends, are essential as the basis for management, and for evaluating the implications of changes in use. Typically such data would be used to develop computer models and used to test and evaluate a wide range of alternative resource management scenarios for the aquifer. The following types of approach could be considered:

- Conjunctive use recognises the interdependency between the ground and surface water resources of a basin and optimises their combined development. Variations on this theme are many, examples include:
    a) the use of surface water for inefficient flood irrigation to enhance aquifer recharge in the wet season; and
    b) the use of groundwater in dry periods for irrigation to replace the normal surface water supply.
- Aquifer storage management, in which the available groundwater storage is managed through phased exploitation, for example, pumping at rates considerably in excess of annual recharge could be alternated with phases of reduced production. This would draw on the groundwater

reserve, but minimise the long-term impact on groundwater levels, creating temporary storage, which could be utilised by artificial recharge, or by natural recharge during storm events.

Groundwater flow models are a valuable aid for making decisions about resource management. Strategies for groundwater management are most effective when they are developed in close co-operation with stakeholders, and fully acknowledge economic, social and political conditions.

Decisions should be taken at the lowest appropriate level; this requires the direct involvement of local and regional agencies representing community interests. All stakeholders need be satisfied that their requirements are being met: workable solutions are unlikely to be reached without the full commitment, and co-operation of all levels of government, industry and the population at large.

Increasing water supply

There are limits to which demand can be reduced and resources managed more efficiently. When these are reached, the supply needs to be increased. Over-abstraction can be an effective means of providing additional water in the short-term: a more permanent solution is to augment the resource through artificial recharge or “managed aquifer recharge”.

Most aquifers could benefit considerably from artificial replenishment. Typically, this is achieved by: diverting excess precipitation into infiltration basins that recharge the aquifer under gravitation; injecting excess precipitation directly into the aquifer using appropriately designed wells; and using pumping wells to induce groundwater recharge from surface water bodies, such as rivers and lakes.

Storm water is the generally preferred source of recharge water, but considerable success has also been achieved with treated wastewater.

Priority 2: Sustainable management of transboundary aquifer systems

There are upwards of 30 transboundary aquifers systems in Africa, and in Latin America, with 90 in Europe. Many of the features of national groundwater issues apply equally to transboundary aquifer systems, though solutions are an order of magnitude more difficult. The reasons for these difficulties are well understood.

International donors are just beginning to support regional co-operation in water policy and management of transboundary waters. The GEF has been the only major funding source for transboundary waters projects, with a contribution of more than $1 billion over the last 10 years. Recently the GEF has been the leader in promoting transboundary aquifer issues, and as a result, there are now global and regional aquifer projects, and others under active formulation in the pipeline. The GEF Operational Programme 9[6] includes both surface and groundwater resources, and addresses the linkage with land degradation in dryland areas. The programme supports management of both surface and groundwater resources in transboundary drainage basins, addressing subsurface supplies with transboundary implications. It provides for commitment-building to secure sufficient quality and quantity of water to sustain the international waters environment, and its ecological diversity. With a broad and diverse approach, OP9 offers an effective instrument to address and support transboundary aquifer resources management, based on an integrated precautionary eco-system approach.

[6] Integrated Land and Water Multiple Focal Area.

Priority 3: Sustainable development of fossil groundwater

The management of fossil waters represents a special challenge because they are essentially non-renewable. A major priority is to develop a range of mechanisms (economic, legal, institutional and scientific) that will stabilise aquifers exhibiting serious hydraulic imbalance, and, where feasible, re-establish some discharge to the surface water environment. This can only be achieved by implementing a realistic balance of demand management measures, and supply or recharge enhancement. This variously requires:

- an institutional framework of appropriate style and scale
- a sound system of groundwater abstraction and use rights
- an economic analysis for sharing the benefits of shared resources
- adequate financial investment in infrastructure and water-saving technology
- active groundwater user and broader stakeholder participation, at the local, national and international level
- economic instruments to encourage reduced water consumption
- incentives to increase water harvesting and aquifer recharge.

Priority 4: Groundwater quality protection

Pollution is now widely recognised as a serious threat to the sustainable management of global groundwater resources. Prevention of contamination is much more cost-effective than remediation; this is especially true for many high risk persistent organic pollutants, because existing remediation technologies are incapable of restoring groundwater to drinking water quality standards.

Major progress is required on several fronts, including:

- Impact assessments of the effects of groundwater pollution on health, agriculture and the environment, including groundwater dependent ecosystems.
- Monitoring in high income countries. There is an urgent need to strengthen groundwater quality networks to provide an early warning of impending problems.
- Monitoring in low income countries. Groundwater quality monitoring programmes and laboratories capable of analysing groundwater need to be setup.
- Agricultural pollution. Chemicals used on agricultural land to improve crop production are a leading source of groundwater contamination. To reduce the threat of agriculture on global groundwater resources, there is an urgent need for: changes in agricultural management practices to reduce pollution risks; increased efficiency in the use of fertilisers and pesticides; introduction of alternative, environmentally-friendly agricultural practices; cost-benefit analysis of the economic consequences of water quality degradation due to agricultural activities; farmer education; soil and groundwater quality monitoring; and regulation and control of agricultural activities in vulnerable recharge areas of aquifers, and in protection zones of groundwater supplies.
- Development of methodologies for groundwater protection. Most approaches to groundwater protection invoke “standards of practice”, i.e. use prescribed formulae to zone land so that strict controls can be imposed on land use practices. Examples include the commonly used “wellhead protection”, and “aquifer vulnerability mapping techniques”. Neither method provides a reliable measure of the degree to which water quality will be degraded by a particular activity, or objective guidance on which practices may be permitted, and to what extent. Considerable work is required to resolve these issues and reduce subjectivity.

- Policy development. Policies for groundwater protection, quality conservation and management need to be developed.

Priority 5: Soil and groundwater salinisation

The degradation of groundwater because of elevated salinity is a common problem, but in most cases this is not related to surface contaminant sources (important exceptions being road de-icing salts and septic waste). The problem is not therefore, readily managed using conventional water quality protection measures. Most sources of salinity are entirely natural and in high abundance: they include seawater, deep formation waters, the soil zone (where salts in rainfall are concentrated by evapotranspiration), and the geological formations that host groundwater reservoirs. The problem of managing salinity is compounded by the high solubility of mineral salts and their extreme, virtually unimpeded mobility, in groundwater.

Given the magnitude of the global salinity problem, and the serious damage that can be caused to water resources, agricultural soils and groundwater-dependent ecosystems, the management of salinity is a high priority issue in many countries, especially those that border the sea. The management of salinity is normally a delicate task requiring a comprehensive database, and exceptionally good monitoring data. As a long-term solution, comprehensive integrated management plans need to be developed, generally supported by sophisticated three-dimensional groundwater flow models.

Priority 6: Protection of groundwater dependent ecosystems

A significant fraction of total aquifer replenishment is generally required to maintain dry-weather river flows and to sustain important aquatic and terrestrial environments. Resource development involving consumptive use of groundwater, or export from the sub-basin, reduces these natural aquifer discharges; this should be an important consideration in resource planning and environmental management, but has often been overlooked.

Governments need to recognise environmental requirements for groundwater, both aquatic and terrestrial ecosystems, and establish legislation, which ensure that: water managers consider the potential impacts on ecosystems when allocating groundwater resources; and catchment managers balance the benefits derived from the direct use of groundwater, with the environmental and socio-economic benefits provided by groundwater-dependent ecosystems.

Priority 7: Impacts of climate change on groundwater

The Third Assessment Report of the Intergovernmental Panel on Climate Change emphasises that while “groundwater is the major source of drinking water across much of the world … there has been very little research on the potential effects of climate change”. This omission requires redress because the potential impacts are profound and widespread. The potential impacts of climate change on groundwater are understood qualitatively, but there is a need to quantify the magnitude of these effects – in terms of loss or gain to the resource, and the socio-economic costs; and to develop technologies or management strategies than can reduce, or eliminate the risks. The IAH has established a Working Group on Hydrogeology and Climate Change that will work closely with the IAH Commissions on Managed Aquifer Recharge, Aquifer Dynamics and Coastal Zone Management, and Groundwater-Dependent Ecosystems, in an effort to co-ordinate research on the direct and indirect effects of climate change, and the consequences of mitigation and adaptation strategies, on global groundwater resources.

Annex 3: Workshop presentations

1. Major Threats to Groundwater, Ken Howard.
2. Global Threats on Quantity: Regional Groundwater Resources Assessment and Mapping, Igor Zektser.
3. Global Threat on Groundwater Quality, Ricardo Hirata.
4. Managing and developing groundwater resources: selected legal and institutional issues, Stefano Burchi.
5. Strategic Options and Priorities in Groundwater Resources, Draft Review and Synthesis Document, Bo Appelgren.
6. Over-exploitation, Intensive Use, and Salt Water Intrusion, Emilio Custodio.
7. Integrated Aquifer Resource Management Principles, Shaminder Puri.
8. Groundwater: Towards sustainable management of heavily exploited and non-renewable resources, Stephen Foster.
9. Sustainable Development of Groundwater under Climate Change in Extremely Arid Regions, Walid Abderrahman
10. Managed Aquifer Recharge in semi-arid environments, Ian Gale.
11. Groundwater Protection Policy and Management, Jaroslav Vrba.
12. Political Economy of Groundwater Irrigation in Asia, Tushaar Shah.
13. Land management in groundwater recharge zones: case study of the Iullemeden aquifer, Christian Leduc.
14. Hydrogeological Strategy for Humid Zone Conservation: case study of the Doñana Wetlands, Spain, Marisol Manzano.
15. World-wide Hydrogeological Mapping & Assessment Programme, Wilhem Struckmeier.
16. Persistent Organic Pollutants, Adrian Lawrence.

Annex 4: Demonstration projects

(This annex provides further details of 5 (out of 7) of the demonstration projects shown in Table 1.)

1. Managed aquifer recharge (MAR)

Issue

Over the last 20 years there has been an enormous increase in the use of groundwater across Asia, Africa and Latin America, particularly for irrigation. This has been of major benefit to domestic and agricultural users, supporting livelihoods and reducing vulnerabilities. The intensity of exploitation has, however, raised concerns that groundwater use – and the livelihoods and ecosystems it helps support – may not be sustainable. Over-exploitation of groundwater has become a problem in some areas (e.g. in Gujarat and Rajasthan, India) and is likely to become a problem in areas where groundwater development is being promoted as the primary engine for poverty alleviation and economic growth (e.g., the Nepal Terai, and adjacent areas in India). Addressing the problem is difficult, particularly where controls on groundwater use are minimal, or difficult to enforce. In this context, replenishing the stock of groundwater through MAR is an attractive idea. However, there has been little systematic evaluation of its effectiveness in different physical and socio-economic contexts, and the benefits quoted are often anecdotal. A balanced and informed perspective on the contribution MAR can make is therefore needed, in a range of different physical, climatic and socio-economic settings.

As competitive demands on water resources increase, combined with pressures from pollution, land degradation and climate change, the effective management of the available water resources becomes increasingly important. Managed aquifer recharge is one of the tools available for effective management; this should be used in conjunction with surface sources, rainwater harvesting, demand management, wastewater reuse and, where economic, desalination. MAR can be applied in a wide variety of ways, depending on the source of water available to be stored, the type of aquifer, as well as the financial, social and environmental constraints.

Objective

To demonstrate the effectiveness of Managed Aquifer Recharge in providing seasonal storage of water to address water management issues, in a range of hydrogeological and environmental settings.

MAR technologies should be applied as part of a water resource management strategy, in conjunction with other measures such as demand management. These technologies have been applied globally in a wide range of settings, with varying success: climatic (arid, semi-arid, humid and temperate), hydrogeological (fractured hard rock, consolidated sandstone and carbonate rocks, as well as unconsolidated alluvial sediments, the latter two types being both confined and unconfined), environmental (urban/rural, inland/coastal, GDEs and SIDS), and finance (government, NGO, external loan or grant, industrial or private). The lessons learnt need to be assessed, and guidance on best practice disseminated. This should be done through the establishment of a network of demonstration schemes, ranging from existing operational schemes, through additional support and monitoring of developing schemes, to the initiation of new schemes to transfer and develop the technology.

Benefits

The benefits of MAR are many and varied:

- seasonal storage of water in aquifers for future use
- smoothing of supply/demand fluctuations
- stabilisation or raising of declining groundwater levels
- reduction of loss of water due to evaporation and runoff
- impeding storm runoff and soil erosion
- improving recharge, and groundwater quality
- maintenance of environmental flows in streams and rivers
- reuse of urban storm and wastewater.

Link to GEF priorities

MAR can be applied to deal with issues in other GEF focal areas, particularly in arid and semi-arid environments, where water resources are being exploited near to, or beyond, their sustainable level:

- biodiversity (groundwater-dependent ecosystems, maintenance of environmental flows)
- land degradation (as part of land-water management)
- climate change (e.g. to address increased variability, as well as changing averages)
- international waters (transboundary aquifers in arid areas).

Locations

The technology has been applied globally using a number of techniques, ranging from rainwater harvesting and streambed modification, to the injection of tertiary treated wastewater into confined saline aquifers. The lessons learned need to be transferred, from developed to developing nations, as well as a south-south transfer of knowledge and experience.

Possible demonstration sites include:

- arid – the Middle-East, North Africa, the Gulf states, Namibia.
- semi-arid – parts of India and South Asia, southern Africa.
- small island developing states – Mediterranean, Caribbean, Pacific, as well as islands in the Atlantic and Indian Oceans.
- coastal aquifers – Mediterranean, Black Sea, Caspian Sea, as well as the Gulf of Guinea, in Guinea, other West African coasts, and other ocean coasts.
- humid – MAR has been applied in humid regions of Europe and the US, and elsewhere, to manage or reuse limited resources. (The application and development of these techniques to other environmental and economic settings needs to be assessed.)

Partners

The organisations which could be involved in the implementation of demonstration projects include: UN agencies, governments, NGOs, and the private sector and individuals.

2. Seawater intrusion and saline-fresh groundwater interactions in coastal aquifers

Issue

Population, and agricultural, industrial and tourist activities, tend to congregate along coastal areas, and in small islands. This creates a concentrated water demand, both continuous and seasonal, in areas often deprived of easy access to good quality water resources. Water schemes are developed which are costly to build and operate, often involving long transport and inter-basin linkages, or desalinisation of sea water and brackish groundwater. In many countries this represents a heavy burden, and may also bring serious environmental problems, as well as conflicts between communities. These problems can be more acute in arid and semiarid areas, because of irrigated agriculture.

In many of these coastal and island areas aquifers can supply high quality and cheap freshwater. Many of these aquifers have been already developed. But groundwater abstraction affects aquifer system hydrodynamics, and modifies the delicate natural balance between fresh and saline groundwater. The result may be a progressive loss of water quality by salinisation: as little as 2 to 4% of seawater may render freshwater unfit for most uses. Uncontrolled groundwater development in coastal areas is not only a serious risk for water resources, but may also affect soil salinity, wetlands and marine life. These issues need to be addressed through good management, to identify, avoid and correct the problems, and to increase social and environmental benefits. Good examples and successful cases need to be translated into guidelines and made known through field demonstrations.

Objective

To demonstrate how a coastal aquifer can be used in a sustainable way to preserve its environmental functions. This would require:

a) identifying the functioning of the system and its response to different stresses;
b) a monitoring network;
c) setting up a management institution, with the participation of stakeholders; and
d) establishing environmental protection and operational guidelines.

Benefits

Avoiding seawater intrusion and saline-fresh groundwater interaction are important in preventing land degradation. Coastal aquifers play a key environmental role in coastal areas and small islands, but these areas are also attractive for water resources development. These uses need to be reconciled to deliver environmental benefits.

Link to GEF priorities

This demonstration project would address: meeting the growth in demand for water; demand management; increasing water supply; the sustainable development of fossil groundwaters; the risk to water quality from seawater intrusion; groundwater discharge in coastal and submarine areas which support coastal and marine ecosystems; and the impact of climate change, with the delicate balance between freshwater and saltwater, and brackish water patterns, coastal areas and small islands, which are highly dependent on the recharge, directly related to climate.

Locations

Priority should be given to the demonstration projects located in:
a) a semi-arid coastal area, for example, in Morocco (especially on the Atlantic), Western Mexico (Sonora, Baja California) and North–Eastern Brasil (Pernambuco, Natal, Ceara); and
b) a small hydrogeologically permeable island, e.g. in the Cape Verde islands, Easter Island (Chile), the Caribbean, and in some of the Galapagos archipelago islands.

Partners

Demonstration projects might involve the following:
- UN agencies (UNESCO, FAO, UNDP, IAEA, and international and regional development banks)
- NGOs, e.g. World Geologists, OXFAM, FCIHS, EuroGeoSurveys, ASGMI, Organisation of American States
- Local organisations (local water authority, water users' association, local universities, local experts).

3. Groundwater management in small island developing states (SIDS)

Issues

Small island developing states (SIDS) display a microcosm of the water management issues usually found in larger land masses, with the additional constraints of being surrounded by saline water, and coastal ecosystems, together with associated economic activities. Importing water by pipeline is costly, although in some places there is the possibility of shipping water, and seawater desalination. Increasing pressure from tourism, agriculture and other economic development, needs to be balanced with sustainable management of groundwater, other water resources, and ecosystems. In these fragile environments, the coastal ecosystem often supports the economies of the island states through tourism and fisheries. The degradation of the groundwater-dependent ecosystem (GDE) will compound the degradation of local economic livelihoods.

Objectives

To integrate the best groundwater management practices, e.g. aquifer storage, and groundwater protection, for sustaining groundwater resources and coastal GDEs.
To demonstrate the effects of overexploitation, saline intrusion, groundwater pollution, conjunctive use and reuse, and how best practice management can be applied.

Benefits

A better understanding of the role of groundwater in the maintenance of coastal ecosystems in small island states, and the economic activities these ecosystems support, would enable best practice to be more widely applied. Good quality management and protection are needed to avoid degradation through over-development and pollution, particularly in view of climate change.

Link to GEF priorities

- Biodiversity (GDEs, maintenance of environmental flows)
- Climate change (addressing increased climate variability, as well as changing average temperatures and sea levels)

Locations

Small island developing states have common problems throughout the world. Demonstration sites should be distributed widely, e.g. in the Mediterranean, Caribbean, Pacific, as well as islands in the Atlantic and Indian Oceans.

Partners

Partner organisations may include: UN agencies, e.g.UNESCO; governments and intergovernmental agencies; and NGOs.

4. Groundwater discharge to international waters: the rehabilitation of Lake Victoria

Issue

Lake Victoria, with a surface area of 68,800 km^2, is the world's second largest expanse of fresh water, and the largest in the developing world. As a fishery, it provides an important source of food and income for 30 million near-shore residents in Uganda, Kenya and Tanzania. As a refuge for an unusually diverse range of biological species, Lake Victoria supports countless swamps and wetland ecosystems along its 3,500 km of convoluted coastline.

But Lake Victoria is in serious decline. Over fishing, the introduction of exotic species, deleterious land use practices, and pollution from a wide range of sources have all contributed to oxygen depletion, and the mass extinction of indigenous fishes. In 1988, the World Conservation Union's Red Book of Endangered Species listed hundreds of Lake Victoria endemic fish under a single heading "endangered". The haplochromine species, once prolific, is now in the midst of the first mass extinction of vertebrates that scientists have ever observed – already half the Lake's native fish are extinct.

Lake Victoria also faces an uncertain future: it is in danger of becoming the world's largest pool of dead water. Urgent action is required by scientists, policymakers, and development organisations, and a number of studies are well under way. The role of groundwater discharge to the lake has attracted only limited attention, but its importance to sustaining groundwater-dependent and lake ecosystems is becoming increasingly recognised. Effective groundwater management can have a significant role in saving Lake Victoria, which is contaminated by inadequate urban and agricultural land use practices in the catchment area.

Objectives

The objectives of this demonstration project are fourfold:

a) to determine the extent to which groundwater contributes to the overall Lake-water budget;
b) to identify subsurface contaminant pathways to the Lake;
c) to estimate contaminant loadings to the Lake, via groundwater pathways; and
d) to determine the extent to which climate change will influence groundwater discharge to the Lake.

Benefits

The study will demonstrate the importance of considering groundwater flow in lake-based studies, and provide data required to help bring Lake Victoria back from the brink of disaster.

Link to GEF priorities

The demonstration project would link to: groundwater-dependent ecosystems and biodiversity; climate change; and land degradation.

Location

In addition to the Lake Victoria catchment area in Uganda, Kenya and Tanzania, the demonstration project could be replicated in other parallel transboundary river, lake, inland sea basins, and large marine ecosystems/marine basin catchments, e.g. Volta Basin, Mediterranean, Caspian Sea and coastal areas along the Guinea Current.

Partners

A broad range of partner organisations may be interested, including: UN agencies, NGOs, private sector entities, government agencies, and environmental groups. (In Uganda, the Water Development Department, based in Entebbe, has a special interest.)

5. Economic practices in land and groundwater management - assessing the full economic value of groundwater

Issue

Aquifers are susceptible to degradation, both in terms of deteriorating water quality, and a reduction in water available to meet the needs of downstream users. Groundwater can play an important role in maintaining groundwater flow into rivers and wetlands, and sustaining ecosystems. But groundwater management is often haphazard, and does not consider the economic value of groundwater. As a consequence, measures to protect groundwater are often not considered because of the cost of "doing nothing" is not appreciated.

Intensive agriculture may result in widespread degradation of groundwater resources if it is practised over extensive areas of an aquifer's recharge zone. Intensive agriculture often relies upon a cheap source of water, and usually does not pay the economic price: it may degrade groundwater resources by leaching nutrients and pesticides from the soil to the water table, and by intercepting groundwater flow – to the detriment of high-value uses downstream.

The use of financial instruments to manage groundwater resources and help resolve conflicts between users and uses needs to be explored. The valuation of groundwater resources is not widely practised and methodologies to value groundwater and its functions are only beginning to be developed. For example, subsidising low intensity, low water use cropping to protect water resources for higher value water use may be cost-effective.

Objectives

The objectives are:

a) to develop an appropriate methodology for valuing groundwater, especially for sustaining wetland ecosystems, and social uses, including urban water supplies; and
b) to demonstrate that economic instruments can be useful and cost effective for changing land use practices, and thereby protect groundwater resources for environmental and social benefits.

Benefits

The main benefits are:

- a means to compare the costs of various land and water management options with socio-economic and environmental benefits
- the integration of best practices in land and water (surface and groundwater) management
- a reduction in local and transboundary potential conflicts between groundwater users
- the prevention or reduction of land and water resource degradation
- drought and flood mitigation.

Link to GEF priorities

The main linkages with GEF are:

- groundwater-dependent ecosystems and biodiversity. (The proposal would emphasise the role of groundwater in sustaining wetlands, and assess the value of groundwater's contribution, and the economic benefit derived from protective practices (for groundwater and soils), against the cost of remediation activities.)

- climate change. (Conflicts between users, and uses may increase, if rainfall patterns continue to be erratic, and water resources become more scarce, especially in semi-arid regions.)

Location

This project would be of widespread application to many regions including, South America, South and SE Asia, as well as Eastern Europe

Partners

A wide range of partner organisations may be interested, including: UN agencies, international and regional development banks, NGOs, government agencies, environmental groups, water-user and farmer associations, supply companies and individuals.