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# Groundwater Governance

## Synthesis of Thematic Papers/Case Studies

Preparing the ground for Regional Consultations and Global Diagnostic Report

Groundwater Governance
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Groundwater Governance
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**GROUNDWATER GOVERNANCE: A Global Framework for Country Action**
**GEF ID 3726**

**Groundwater Governance: Synthesis of Thematic Papers/Case Studies**
**(preparing the ground for Regional Consultations and Global Diagnostic Report)**

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**GLOSSARY OF ACRONYMS**

| | |
|---|---|
| APGP | Advisory Panel on Groundwater Policy (this project document) |
| APPR | Annual Project Progress Report |
| AWP | Annual Work Plan |
| BD | Biodiversity GEF Focal Area |
| BH | Budget Holder |
| BRGM | Bureau de Recherches Géologiques et Minières |
| CGIAR | Consultative Group on International Agricultural Research |
| CPR | Common Property Resource |
| ECA | Europe and Central Asia |
| EU WFD | European Union Water Framework Directive |
| FA | Framework for Action (this project document) |
| FAO | Food & Agricultural Organization of the United Nations (see Annex 7) |
| GEF | Global Environment Facility |
| GEO | Global Environmental Objective |
| GRAPHIC | Groundwater Resources Assessment under the Pressures of Humanity and Climate Change (UNESCO-IHP) |
| GWMATE | Groundwater Management Advisory Team (World Bank) |
| GWADI | Water and Development Information for Arid Lands (UNESCO-IHP) |
| GWES | Groundwater for Emergency Situations (UNESCO-IHP) |
| GWP | Global Water Partnership (see Annex 7) |
| IAEA | International Atomic Energy Agency (see Annex 7) |
| IAH | International Association of Hydrogeologists (see Annex 7) |
| IBNET | The International Benchmarking Network for Water and Sanitation Utilities |
| IGRAC | International Groundwater Resources Assessment Centre (see Annex 7) |
| IHP | International Hydrological Programme (UNESCO) |
| INBO | International Network of Basin Organizations |
| INWEB | International Network of Water-Environment Centres for the Balkans |
| IOC | International Oceanographic Commission (UNESCO) |
| IR | Inception Report |
| ISARM | International Shared Aquifer Resource Management (UNESCO-IHP) |
| IUCN | International Union for the Conservation of Nature and Natural Resources (see Annex 7) |
| IW | International Water (GEF Focal Area) |
| IWC | International Waters Conference |
| IW-LEARN | International Waters Learning Exchange and Resource Network |
| IWMI | International Water Management Institute (see Annex 7) |
| IWMR | Integrated Water Resources Management |
| LAC | Latin America and the Caribbean |
| LD | Land Degradation GEF Focal Area |
| MAB | Man and the Biosphere Programme (UNESCO) |
| MAR | Management of Aquifer Recharge (UNESCO - IHP) |
| MDGs | Millennium Development Goals |
| MENA | Middle East and North Africa |
| MODFLOW | U.S. Geological Survey modular finite-difference flow model |
| NEPAD | New Partnership for Africa's Development |
| NGO | Non-governmental Organization |
| OAS | Organization of American States |
| OECD | Organisation for Economic Co-operation and Development |
| PC | Project Coordinator |
| PCU | Project Coordinating Unit |
| PDO | Project Development Objective |
| PIR | Project Implementation Review |
| PSC | Project Steering Committee |
| POPs | Persistent Organic Products (GEF focal area) |
| PTS | Persistent Toxic Substance |

| | |
|---|---|
| SA | South Asia |
| SADC | Southern Africa Development Community |
| SEEAW | System of Environmental-Economic Accounting for Water |
| SIDA | Swedish Agency for International Development Cooperation |
| SC | Steering Committee (this project document) |
| SIDS | Sustainable Development of Small Island Developing States |
| SPPR | Semi Annual Project Progress Report |
| STAP | Scientific and Technical Advisory Panel (GEF) |
| TDA | Transboundary Diagnostic Analysis |
| ToR | Terms of Reference |
| TWAP | Transboundary Water Assessment Programme (GEF) |
| UNDP | United Nations Development Programme (see Annex 7) |
| UNEP | United Nations Environment Programme (see Annex 7) |
| UNESCO | United Nations Educational, Scientific and Cultural Organization (see Annex 7) |
| UNESCO-IHP | UNESCO International Hydrological Programme |
| UNICEF | United Nations Children's Fund (see Annex 7) |
| UN-ILC | (United Nations) International Law Commission |
| WB | The World Bank |
| WHO | World Health Organization (see Annex 7) |
| WHYMAP | World-wide Hydrogeological Mapping and Assessment Programme |
| WMO | World Meteorological Organization (see Annex 7) |
| WSSD | World Summit on Sustainable Development |
| WWAP | World Water Assessment Program |
| WWC | World Water Council (see Annex 7) |
| WWV | World Water Vision |

## 1. Introduction: why groundwater governance matters

The purpose of this 'global' project on groundwater governance presents something of a paradox – it is looking for a global solution to a set of essentially local problems. Patterns of groundwater use are necessarily determined by the aquifers that host the groundwater and the hydrogeological process that condition groundwater flow. Governance of that use is relatively straightforward – groundwater users and their pumps can usually be identified and appealed to as policy targets. But promoting improved governance of groundwater protection involves a more extended set of policy targets, from direct users of aquifer services, to land use mangers and all those who dispose solid and liquid waste to land and surface water. Overall, the main objective is the long term functionality of aquifer systems that furnish groundwater and other related economic and environmental services. In this sense, the terms aquifer and groundwater are not equivalent and care has to be taken when referring to the groundwater derived from aquifers, and the aquifer systems themselves (see Box 1).

**Box 1: Glossary of hydrogeological terms fundamental to groundwater governance**

**Groundwater:** Water present in the earth's crust in a saturated or non-saturated soil , weathered mantle or consolidated rock formation. Groundwater is moving in and out of these relatively 'static' geological layers – sometimes making clear cut distinctions between surface and groundwater impossible

**Aquifer:** An identifiable geological formation capable of storing and transmitting water in useable quantities. The hydraulic state of the aquifer (whether confined or unconfined) determines the response of the aquifer to development. An aquifer comprises the hosting matrix of rock and the groundwater held between the matrix.

**Aquifer Development:** The process of pumping or exploiting groundwater in an aquifer. This can be through pumping or through control of artesian flows or aquifer discharge in seepage zones. The level of development will incur a specific aquifer response which will tend to a new equilibrium level in the long run or result in aquifer exhaustion or the limits of lifting.

**Aquifer Depletion:** The reduction in aquifer storage (in unconfined aquifers) or pressure (in confined aquifers) as a result of development.

**Aquifer Degradation:** The change in groundwater quality brought about by introduction of pollutants into an aquifer or the replacement of groundwater by lower quality water

**Aquifer Recharge:** The rate at which an aquifer accepts water from meteoric sources (direct rainfall or transmission losses from stream beds) or leakage from adjacent aquifers.

**Aquifer Discharge**: The rate at which an aquifer drains to springs, seepage zones (including coastal sabkahs) under natural conditions

**Abstraction:** Withdrawals of groundwater from an aquifer against natural flow gradients – the human development of an aquifer. The development of a spring can also be counted as an abstraction for the incremental flow that is released.

**Sustainable use:** A socio-economic interpretation rather than a physical one that is criteria dependant. Continued access to acceptable quality groundwater in the long term. This has to be distinguished from 'sustainable yield' or 'safe yield'

First, the project needs to formulate working definition of 'groundwater governance'. From a review of existing definitions a possible wording is suggested here as a starting point for discussion in the Regional Consultations;

***Groundwater governance** is **the process** by which groundwater resources are managed through the application of responsibility, participation, information availability, transparency, custom, and rule of law. It is the art of **coordinating administrative actions and decision making** between and among different jurisdictional levels – one of which may be global.* (Adapted after Saunier and Meganck. 2007. Dictionary and Introduction to Global Environmental Governance)

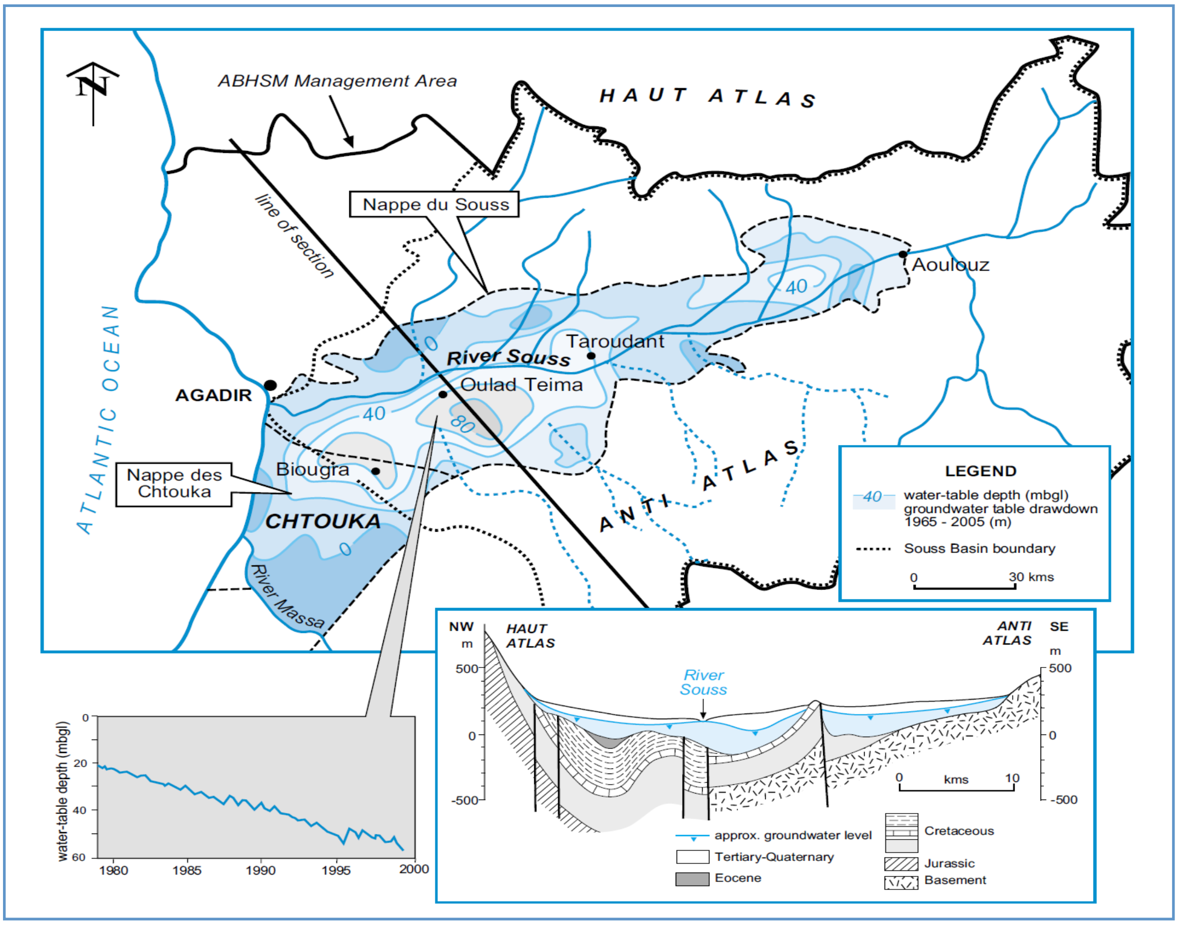
Second, the project is predicated on the assumption that the state of groundwater and groundwater governance is not 'good' and needs improvement. However, this presumes that we can distinguish 'good' governance from 'bad' or 'indifferent' groundwater governance. While criteria for making such a distinction may be available for water governance as a whole, the formulation of specific criteria for groundwater will need advice from the project's regional consultations and consultation mechanisms.

With this general provision on a working definition and criteria, 'groundwater governance' could be interpreted as the set of policies or decisions that impact groundwater use and groundwater protection. Governance can be distinguished from 'government' (who decides) and 'management' (what is done to implement decisions). In this sense groundwater governance is not 'fuzzy' but involves specific (and non-trivial) decisions about whether to turn on a pump, apply pesticides or manage waste etc. These are decisions that can be made day after day by water supply utilities and hundreds of millions of groundwater users and land use managers. But there may be many decisions, public and private, that appear to fall outside the immediate domain of 'groundwater governance' but which still impact groundwater use and groundwater protection. These can be in energy and land-use policy as much as trade and agriculture subsidies. A series of draft Thematic Papers (listed in Annex 1) on groundwater governance issues and prospects have been compiled to form a baseline for the project and illustrate the current scope of groundwater governance . At present these drafts will only be available in English.

Mankind has long interfered with the earth's crust and has build habits around geological patterns as a source of building materials, metals, minerals - and groundwater. These habits persist and can become entrenched through subsidies and expectations about access to groundwater (Shah et al. 2012). The imposition of hydraulic gradients on aquifers through enhanced drainage (development of springs and falaj systems) up to the installation of high capacity electro-submersible pumps imposes stresses on aquifer systems and raises questions on equitable access to groundwater and its protection as a public good. Figures 1 and 2 illustrate these impacts on groundwater levels – where they can be inferred from reliable measurements of groundwater levels.

The impacts of these stresses – the aquifer response to abstraction - are often invisible and unlike the monitoring of surface water systems there is no clear integrated measure of system state. Indeed the guess work is in the integration, the approximations that are made in time and space as individual geological and groundwater level observations are scaled up across an aquifer. Prior to any interference, groundwater heads determined by uplift, erosion and the shifting patterns of recharge and discharge. That configuration was not stable - as climatic zones shifted. With the advent of energised pumping in the 20th century, this dynamic equilibrium in the most accessible and mobile groundwater circulation was to change radically (Konikow, 2011). But changes in local recharge and discharge had already started to occur on a large scale as land-use patterns changed – urbanization, de-forestation. Subsequent agricultural intensification, notably the application of inorganic fertilizers, was already impacting groundwater quality before the widespread adoption of pumping technology. (Thematic Paper 1). Some aspects of governance relate to abstraction from very localised aquifers, but others relate to recharge processes and related land management over large areas and extensive aquifers. These present two distinct but not necessarily exclusive sets of governance.

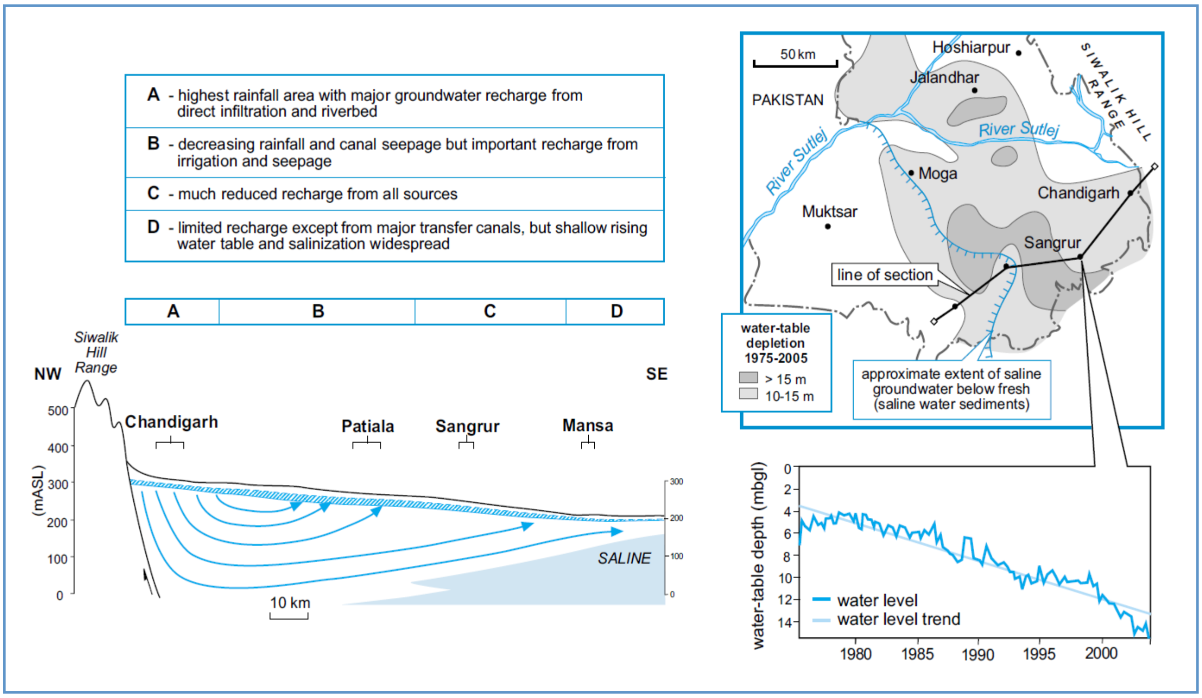
**Figure 1: Observed drawdown in the Souss basin, Morocco**




Source: GWMATE. Strategic Overview No. 4.

If we could all dip our hands into a readily accessible and inexhaustible pool or flow of unpolluted freshwater at any time, there would be no need for any water resource management - or literature. But access to resources has always been a struggle and a struggle that has defined civilizations and moulded landscapes. Even in humid environments, the security offered by access to groundwater has made all the difference – and it pays to look after the aquifers that furnish that groundwater. Under any mode and intensity of groundwater development, the point at which drawdown externalities become significant in terms of human health and livelihoods is important to recognize. Understanding how and when these externalities are felt physically and economically is therefore crucial to any discussion of governance.

**Figure 2: Observed drawdown 1980-2005 in the Punjab (Pakistan)**




Source: GWMATE. Strategic Overview No. 4.

In the 1950s and 60s, the case for well informed large scale development of groundwater for social and economic benefits (United Nations 1960) was made. Environmental impacts were factored in, but not seen as significant to the extent that the environmental costs of development would outweigh the benefits. 50 years on the lessons have been instructive. At a global level, groundwater is estimated to service 70% of potable and industrial water supply and 40% of agricultural demand. Data compiled for this programme indicate the rapid growth of groundwater use, particularly by agriculture (Box 2).

**Box 2: Mapping the state of global groundwater resource and use**

Groundwater resources have been mapped at global and regional scale (e.g. WHYMAP http://www.whymap.org/whymap/EN/Home/whymap_node.html; BRGM-Africa; SADC hydrogeological mapping) together with a wide range of national hydrogeological mapping initiatives ranging from 1: 1M to 1: 100: 000 scale. Individual development projects have mapped groundwater resources and piezometric data at much higher resolutions, sometimes including detailed GIS compilations have been made at country level (the Mali, )

This legacy of aquifer mapping, borehole inventories, drilling records is sometimes buried in the grey literature, but there are genuine attempts to put these reports in the public domain (http://www.bgs.ac.uk/sadc/index.cfm). The combined effort should not be forgotten and can be taken with global analysis of available statistical data for dominant agricultural use (Siebert et al. 2010 http://www.hydrol-earth-syst-sci.net/14/1863/2010/hess-14-1863-2010.html) which compiles the results of available detailed national reports such as the 4th Minor Irrigation Census for India. Urban/Industrial use as a fraction of total use may be relatively small (and will have declined in some post-industrial aquifers (The Chalk below London), but remain economically important. However, comprehensive estimates of all drinking water supply such as that carried out for the UNICEF and WHO Joint Monitoring Programme (http://www.wssinfo.org/data-estimates/table/) still give estimates that point to locally important sources of supply for urban areas and strong dependence in rural areas of developing countries (UNICEF/WHO Joint Monitoring Report December 2011)

The state of the earth's groundwater resources and the heath of the aquifers that supply human uses of groundwater are closely linked to the state of groundwater governance – the local arrangements that directly impact groundwater use and aquifer pollution. But the state of the shallow groundwater circulation in the Earth's crust, upon which we have now come to depend, is not 'good' by any measure. The sustained use of groundwater may simply not be a realistic prospect for many of our intensively exploited aquifers. Elsewhere, since the state of surface water bodies degradation may be even more severe, the interaction between surface water and groundwater will be transmitted. This begs a fundamental question of how we govern our use and abuse of groundwater, the aquifers that host it and the surface water systems that transmit essential recharge.

This reliance on groundwater is growing as alternative sources of surface water come under pressure. Indeed reliance upon groundwater can be taken as the first sign of water scarcity (Shah, 2006). But against this trend of growing dependency, the depletion of non-renewable groundwater resources and the irreversible degradation of aquifers have produced, in some cases, dislocation of people and livelihoods in some cases. The inevitable accumulation of demand for freshwater and the production of waste is modifying the circulation and quality of groundwater in the earth's crust to such a degree that once reliable access to high quality groundwater is no longer taken as a given. Ultimate source, ultimate sink – but we are now in a state where science can predict groundwater system responses – modelling and the management of large data sets has advanced considerably.

In broad definitions of natural resource governance, the principles of inclusive participation/representation, accountability, information flows, transparency and the respect for formal law and customary regulation count in the case of groundwater as much as any other natural resource. But in two crucial respects it is perhaps different, largely unseen and systems respond over time. The visibility of the annual hydrological cycle is not there and the occurrence and state of the resource is never clear to users – particularly how individual actions can impact a public resource.

As scarcity of high quality sources of water intensifies and treatment/alternative supply costs (energy principally) increase, water suppliers are having to look a the water risk in general. Many users of groundwater may realise that while the convenience of groundwater mobilisation offers many advantages, the issue of ultimate source and ultimate sink soon comes back to haunt them as reliance turns to dependency. In fossil aquifers de-coupled from contemporary recharge, the case for abstraction can be made on the basis of discharge that will happen anyway– the non-beneficial seepage to sabhkas or submarine springs. But as soon as a recharge component is recognised in aquifer response to rainfall events or development, the notion of 'sustainability' becomes much more difficult to track. In addition, across a rapidly changing world, the point at which groundwater abstractions can 'flip' from predominantly agricultural use to urban use is important to recognize this transition will unleash a new set of governance and management challenges.

The hydrogeological setting frames the sustainability problem and constrains the solutions. Marrying these settings to socio-economic patterns is essential to framework workable solutions. If patterns of abstraction, land use and population continue as projected, it may be impossible to relax some pressures, but it may be possible to be a little more imaginative with technical approaches (re-cycling and re-use) and waste minimization. For this, sustainable use of groundwater and aquifer services is perhaps a more realistic target than a broad notion of 'sustainability' which assumes that aquifer state remains unchanged. Depletion and degradation will continue to occur so that the it may make sense to think in terms of admissible or mutually acceptable criteria or indicators.

The spectrum of groundwater challenges from intensive use for agriculture to leachate from land-fill sites are common to most countries. As the utility of the earth's crust and groundwater circulation becomes apparent, new geological frontiers have opened up from hydrothermal production, hydro-fracturing (fracking) to gas storage to carbon sequestration. These relatively new uses of the underground space have direct implications for adjacent aquifers and the degree to which further protection of aquifers will be extended is being tested through environmental impacts assessments and public enquiries or judicial reviews.

The profession of groundwater developers and managers – the hydrogeologists – tend scare planners and economists with stories of end-games. What will happen if there is no action – case studies and scenarios for depleted and degraded aquifers. They scare because they care. But evidence of prescient action to avert groundwater crises is hard to find. Irrespective of the legal status of groundwater (generally classified as public water), the resource continues to be perceived as 'private'. There is still a gap to be bridged between the science and natural resource policy making in building the case for improved groundwater governance.

Are there solutions? Pasts attempts to regulate and manage groundwater as just another natural resource have informed us what not to do – and some indication of where to start. Some environmental reporting requirements are now prompting more inclusive assessments of groundwater status and risks to economic, social and environmental services derived from groundwater. But at the same time opportunities for conjunctive use and conjunctive management are being missed – as the necessary understanding of surface water- groundwater interactions has lagged and the structural role of groundwater in integrated water resource management has been ignored. In this sense, the explicit recognition of groundwater in water governance debates is hard to find. The emphasis remains centred on the surface water dominated 'hydraulic' administrations where investments are more supply driven, 'lumpy' and hence more visible (OECD, 2011)

To whom can a message for improved groundwater governance be addressed? This initiative is predicated on changing individual groundwater user and polluter behaviours in order to conserve the integrity of aquifers and sustain a set of socio-economic and environmental services. However, the appeal to modify specific behaviours will be mediated by institutions that can range from multi-national corporate interests through public agencies and community groups. It is therefore important to understand that although the potential targets to propagate such a message are wide, maintaining equitable, long term access to groundwater of acceptable quality will necessarily involve highly localised, tailored solutions. In this sense finding politically viable institutional arrangements will be more critical that simply fixing the broader institutional environment (through legislation or resource pricing) or relying on supply-driven technological fixes. The relative perspectives of users, natural resource managers, regulators and legislators are all relevant, but the point of groundwater use and the act of pollution are behavioural responses that have shown themselves resistant to change - even when the consequences of our groundwater 'habits' are terminal.

**Part 1: Groundwater Governance – status and trends**

## 2. Definitions of groundwater governance

What makes groundwater particular and its governance problematic? General definitions of water governance are held to apply to groundwater in most legal/jurisdictional domains (Thematic Paper 5 and 6) but the occurrence of groundwater in aquifers is distinguished by geological 'granularity' and much fuzzier boundary conditions. For instance, conventional riparian law related to clearly identified channels through which water flows cannot apply. In addition, groundwater may be distinguished from other mineral resources hosted in geological formations (including oil and gas) on the basis of its ubiquity, renewability and essential service to life. Added to this is the complication of third party effects. Not all land managers abstract groundwater from a specific aquifer for economic gain, but all land management will have an impact on aquifer recharge. This makes the application of community based management models or classical common property theory problematic for groundwater in particular (van de Schans, 2003).

Since the large scale and intensive use of groundwater has only occurred with the advent of the energised pump (Thematic Paper 8) it is perhaps understandable that water governance has not been able to catch up and that the long legacy of largely riparian based water law has been hard to adapt (Thematic Paper 6). Indeed, while systems of water allocation have historically concentrated on who gets what and how much of the renewable hydrological cycle that is apparent in river and stream flow, the formal inclusion of widespread customary use of groundwater has tended to lag behind.

### Water governance in general

In broad terms, effective water governance mechanisms should be accountable, transparent and participatory and should function in an integrated manner (FAO Water Tenure Guidelines, in press – see Box 3). Thematic Paper 5 provides an account of principles that have been applied in water governance models – socio-cultural, political, institutional, economic and ecological. In addition recent survey from OECD countries (OECD, 2011) has stressed the multi-level governance 'gaps' that compromise effective co-ordination and implementation of national water policies. However, such is the localised nature of groundwater access and use, it may help to distinguish between the general institutional environment in which policy, legal and administration norms are set at national level, and the much more detailed set of rules that govern water use and transactions (Shah 2005).

**Box 3. General Water Governance Principles**

Effective natural resource allocation and management decisions require accountability. Decision makers need to be held to account for the decisions that they make such that mistakes and poor decisions can be remedied and rectified. This is particularly important as regards water tenure which may be adversely affected by bad governance in terms of loss of livelihoods, investment and so on. Decisions made by technocrats in secret behind closed doors with no come back or chance of come-back are not likely to be good decisions.

Transparency is a key principle for ensuing better decision-making and accountability. Of course transparency is important in all walks of life but it is particularly important in the water resources sector where legislation is less about setting out legal rules and more about setting out a process for resource management, one that invariably impacts on water governance arrangements. Transparency implies: public access to information about water resources and water tenure arrangements including public access to water rights registers; decision making on the basis of publicly recognised and agreed criteria such as river basin management plans; an obligation to provide reasons when adverse decisions are made; cheap and rapid appeal procedures; and separating, as far as possible, politics from the decision making process.

Participation is necessary to ensure that better decisions are made. This is particularly important as regards water governance as such decisions may affect a range of different types of governance arrangement as well as different types of use. If decisions are not made on the basis of participation and 'buy in', not only are they likely to be substantively worse but they are also likely to be less easy to implement.

Integrated water resources management (IWRM) has become the dominant paradigm for water resources management. One of the most cited is that it is 'a process which promotes the coordinated development and management of water land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems' (Global Water Partnership). However, in terms of governance, the key integration requirement is that as far as possible all aspects of water tenure should be subject to a single basic water resources regime in terms of both legislation and institutional arrangements for the implementation of such legislation. Put another way, water is a single resources and should be managed as such. In practice this means is that all types of water use and thus water governance arrangements should be subject as far as practicable to the same basic legislative framework, with certain exceptions explored further below, irrespective of the type of activity. A key feature is that all water uses within a given basin and/or aquifer directly or indirectly impact upon each other.

**Distinguishing characteristics of aquifers and groundwater use**

Groundwater and the aquifers that host it can be distinguished from surface water resources in several key characteristics:

- unseen or unacknowledged even when exposed (groundwater in open-cast pits) but highly distributed (ubiquitous);
- aquifer responses to development generally occur over long periods of time – but can rapidly change when systems move from a confined to unconfined state;
- the responses and accessibility of shallow groundwater circulation need to be differentiated from deep circulation;
- aquifer degradation more difficult to address than aquifer depletion – varying impacts of contaminant loads depending on aquifer vulnerability ;
- some depletions and aquifer contamination/degradation (including saline intrusion) may be irreversible.
- levels not volumes count for most practical purposes;
- recharge: intensive abstraction influences recharge rates and replenishment of aquifers can be misinterpreted –
- no natural integrated measure and monitoring and assessment costs are high;
- recharge hard to get a handle on but global overviews becoming possible;
- aquifers are the ultimate source – and the ultimate sink ; and
- modes and intensity of exploitation are highly varied – and institutional responses equally so.

**Particular governance issues for groundwater use and aquifer protection**

This leads to a set of specific governance issues that while they relate to water governance as a whole, are particular to groundwater. These can be broadly stated as:

- the effective ownership of groundwater still perceived as intensely private in many parts of the world, a fact which interferes with modern notions of the State or local government as the guardian or trustee of what has become a resource of strategic importance;
- the allocation of groundwater for economic uses and its conservation to support groundwater dependent ecosystems and the baseflow of watercourses;
- protecting natural groundwater recharge processes from land-based interferences;
- protecting groundwater quality from land-based, 'diffuse' sources of pollution (e.g., the runoff of croplands, but also stormwater runoff in urban areas), and from the diffuse pollution originating from point sources like waste dumps, landfills, and the underground storages of substances;
- the interface between formal groundwater abstraction rights and customary rights and practices,
- the role of groundwater users and of relevant groupings in managing aquifers under stress; and
- the role of river basin agencies and organizations in integrating the groundwater variable in water resource. management.

**The governance challenges**

These characteristics of groundwater and aquifers present a special set of governance challenges, not least the applicability of general economic instruments to guide resource conservation and use. To some degree, the common pool resource analysis (Ostrom, 2001) provides method for recognizing a typology of challenges, but when considered alongside other common pool or 'public' resources, the principles that are derived may not be sufficient (Thematic Paper 5). Aquifers do not necessarily fall into neat typologies of common pool resources. There a wide diversity in terms of scale and three-dimensional character and response – from the short circulation in thin discontinuous alluvial aquifers to the long periods of deep, structurally controlled circulation. Adaptive management of such systems, including conjunctive management with surface water resources and protection of recharge areas will not necessarily involve neat, well bounded governance arrangements.

The defining feature in many ways is the mode of access, which (apart from publically constructed and maintained boreholes) tends to be private (Thematic Paper 8), and the susceptibility of groundwater circulation to all types of land use as part of the natural recharge cycle (Thematic Paper 4). While not everybody relies on groundwater source, all humans possess the ability to pollute and degrade groundwater. While this confers a special set of responsibilities on those who abstract groundwater, the consumptive behaviours of all can be expected to have some eventual impact on the quality of water contained in aquifers.

Generic definitions of governance and water governance provided above give some help, but the distinction between 'Institutional Environment' and 'Institutional Arrangements' is fundamental and important in terms of groundwater. An examination of groundwater governance needs a focus on institutional arrangements with respect to both points of abstraction (conditioned by land tenure/access) and the conservation and protection of aquifers through land management (spatial planning and management). However definitions of groundwater governance assume an inclusive definition of institutions in relation to environment and technology. The Common Property Resource (CPR) literature is instructive in some respects (Box 4) .

**Box 4: Common Property Resources**

In a summary paper prepared for (Ostrom, 2001) Notes that " considerable consensus exists that the following attributes of resources and of appropriators are conducive to an increased likelihood that self-governing associations will form" Ostrom (1990-2001) identifies four resource attributes and 6 appropriator attributes:

**Attributes of the Resource:**

R1. Feasible improvement: Resource conditions are not at a point of deterioration such that it is useless to organize or so underutilized that little advantage results from organizing.
R2. Indicators: Reliable and valid indicators of the condition of the resource system are frequently available at a relatively low cost.
R3. Predictability: The flow of resource units is relatively predictable.
R4. Spatial extent: The resource system is sufficiently small, given the transportation and communication technology in use, that appropriators can develop accurate knowledge of external boundaries and internal microenvironments.

**Attributes of the Appropriators:**

A1. Salience: Appropriators are dependent on the resource system for a major portion of their livelihood.
A2. Common understanding: Appropriators have a shared image of how the resource system operates (attributes RI, 2, 3, and 4 above) and how their actions affect each other and the resource system.
A3. Low Discount rate: Appropriators use a sufficiently low discount rate in relation to future benefits to be achieved from the resource.
A4. Trust and Reciprocity: Appropriators trust one another to keep promises and relate to one another with reciprocity.
A5. Autonomy: Appropriators are able to determine access and harvesting rules without external authorities countermanding them.
A6. Prior organizational experience and local leadership: Appropriators have learned at least minimal skills of organization and leadership through participation in other local associations or learning about ways that neighboring groups have organized.

Ostrom then goes on to set out a set of 8 design principles that can be assumed to apply to 'long –enduring common-pool resource institutions"

**Design Principles**

1. Clearly Defined Boundaries: Individuals or households with rights to withdraw resource units from the common pool resource and the boundaries of the common-pool resource itself are clearly defined
2. Congruence:
   a. The distribution of benefits from appropriation rules is roughly proportionate to the costs imposed by provision rules.
   b. Appropriation rules restricting time, place, technology, and/or quantity of resource units are related to local conditions.
3. Collective-Choice Arrangements: Most individuals affected by operational rules can participate in modifying operational rules.
4. Monitoring: Monitors, who actively audit common-pool resource conditions and appropriator behaviour, are accountable to the appropriators and/or are the appropriators themselves.
5. Graduated Sanctions: Appropriators who violate operational rules are likely to receive graduated sanctions (depending on the seriousness and context of the offense) from other appropriators, from officials accountable to these appropriators, or from both.
6. Conflict-Resolution Mechanisms: Appropriators and their officials have rapid access to low-cost, local arenas to resolve conflict among appropriators or between appropriators and officials.
7. Minimal Recognition of Rights to Organize: The rights of appropriators to devise their own institutions are not challenged by external governmental authorities.

For common-pool resources that are part of larger systems

8. Nested Enterprises: Appropriation, povision, monitoring, enforcement, conflict resolution. and governance activities are organized in multiple layers of nested enterprises.

In relation to the resource and appropriator attributes Ostrom (op. cit) goes on to note;

*"It is very important to stress that many of these variables are in turn affected by the type of larger regime in which users are embedded. Larger regimes can facilitate local self-organization by providing accurate information about natural resource systems, providing arenas in which participants can engage in discovery and conflict-resolution processes, and providing mechanisms to back up local monitoring and sanctioning efforts. The probability of participants adapting more effective rules in macro-regimes that facilitate their efforts over time is higher than in regimes that ignore resource problems entirely or, at the other extreme, presume that all decisions about governance and management need to be made by central authorities."*

The point about the institutional environment conditioning the eventual institutional arrangements is well understood, but perhaps because of groundwater's invisibility and perceived technical mystique, groundwater governance falls victim to an expectation that "*all decisions about governance and management need to be made by central authorities*". It is therefore interesting to note that in relation to specific groundwater institutions that have evolved in southern California, Blomquist (1992) stresses criteria for evaluating the performance of groundwater institutions which are applied to evaluate institutional responses to groundwater management in southern California are (in no particular order of priority);

1. Compliance
2. Effectiveness
3. Efficiency in administration (basin management costs)
4. Efficiency in resource use
5. Equity – fiscal equivalence
6. Equity – distributional considerations
7. Adaptability

This detailed evaluation illustrated the evolution and diversity of institutional responses across a set of aquifers in rich institutional environment with recourse to legal adjudication. If this range of responses is possible in a very small, but densely populated, area, how uniform or generic can we expect institutional responses elsewhere with possibly more varied hydrogeological conditions? As Blomquist (1992) argues in the case of California, there should be strong incentives to manage groundwater resources locally given the expense of importing water from other sources.

**A working definition of groundwater governance**

As indicated in the Introduction, the project needs to formulate working definition of 'groundwater governance' . From a review of existing definitions a possible wording is suggested below. This definition can serve as a starting point for discussion in the Regional Consultations.

*Groundwater governance is the process by which groundwater is managed through the application of responsibility, participation, information availability, transparency, custom, and rule of law. It is the art of coordinating administrative actions and decision making between and among different jurisdictional levels-–one of which may be global.* (Adapted after Saunier and Meganck. 2007. Dictionary and Introduction to Global Environmental Governance).

Accordingly, ' groundwater governance' could be interpreted as the set of policies or decisions that moderates groundwater use and promotes aquifer protection. Governance can be distinguished from 'government' (who decides) and 'management' (what is done to implement decisions). In this sense groundwater governance is not 'fuzzy' but has to frame specific (and non-trivial) decisions about whether to turn on a pump, apply pesticides or manage waste etc. These are decisions that can be made day after day by hundreds of millions of groundwater users and land use managers. But there may be many decisions, public and private, that fall outside 'groundwater governance' but which still impact groundwater use and groundwater protection. The distinction between management and governance is important. Broadly, groundwater management is the set actions to implement decisions that derive from the process of governance.

Assuming that a definition can be agreed, the project is predicated on the assumption that the state of groundwater and groundwater governance is not necessarily 'good' and needs improvement – i.e. that there is a governance gap. However, this presumes that we can distinguish 'good' governance from 'bad' or 'indifferent' groundwater governance. While criteria for making such a distinction may be available for water governance as a whole, the formulation of specific criteria for groundwater will need advice from the project's Regional Consultations.

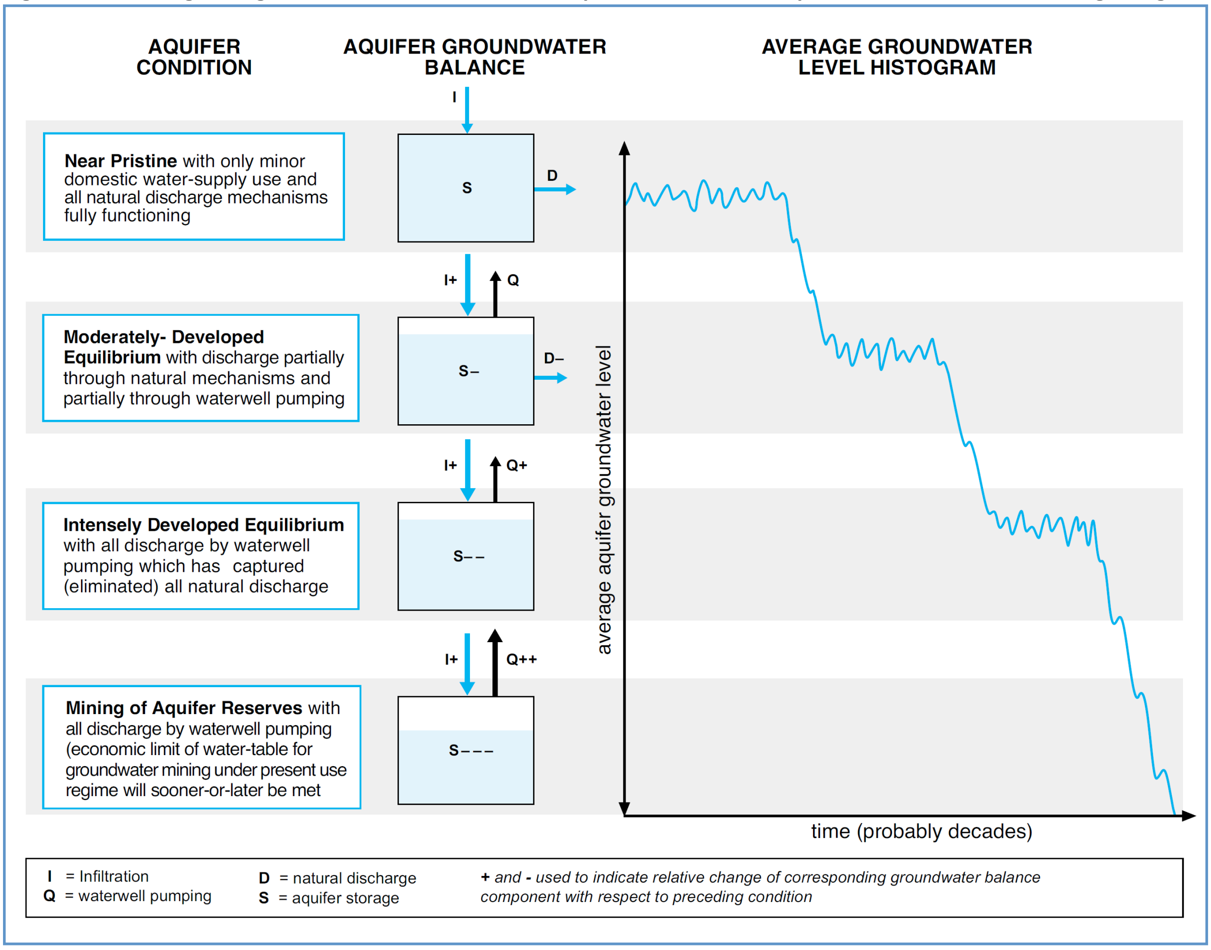
## 3. A context for groundwater governance

Thematic Paper 5 describes a set of institutional constraints and barriers to the implementation of effective governance. These have to be taken together with the physical hydrogeological realities set out in Thematic Papers 1-4. Starting from these hydrogeological 'realities', the issues of public versus private interests, scaling and time are briefly described.

**Hydrogeological realities - quantity**

Assessing the level of groundwater demand and state of aquifer depletion needs to be approached with care (Konkikow & Kendy, 2005; Konikow, 2011). The hydrogeological community have been at pains to educate public and policy makers in technically correct definitions and avoid casual use of such terms as 'over-exploitation' (Margat, 1992) or presumptions about using recharge as a criterion for development limits (Sophocleous, 1997, Custodio, 2002). The reason for this is that such misconceptions have fuelled attempts at governance which may prove misguided – or counterproductive (Ward, 2008). Therefore hydrogeologists have advocated abandoning the notion of 'sustainable yield' as a criterion for groundwater development (Broedehoft, 2007). Understanding recharge in relation to intensive pumping and the 'capture' of flow in aquifer systems is now a critical issue in groundwater resource planning (Thematic Paper 4). But in sub-humid climates (for instance Europe) groundwater management has come in and out of focus depending upon the point at which policy is made – in drought years or years of flood. This political reality notwithstanding, Figure 3 presents a generalised account of how aquifer development can progress and the impacts on groundwater levels.

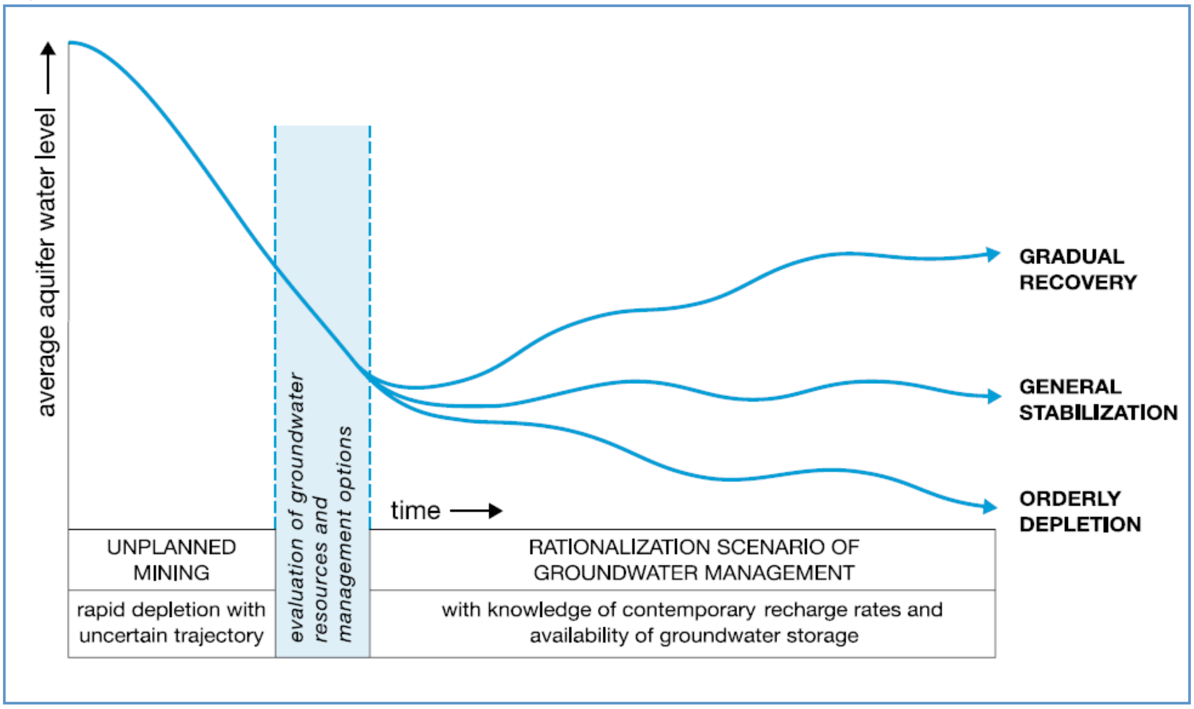
**Figure 3: The stages of groundwater resource development and their impact on the natural discharge of groundwater bodies**




Source: GWMATE Briefing Note 11

This pattern of development over time will be familiar to many groundwater managers and in trying to cope with observed depletion of aquifer storage (when unconfined) or aquifer flow (when confined). The technical response once groundwater resource and risk assessments have been made can be classified as illustrated in Figure 4 – assuming that technical management is possible and politically acceptable. Thematic Papers 2, 3 and 4 have focused on the technical scope for aquifer management.

**Figure 4: Targets for groundwater resource management in 'rationalization scenarios' following indiscriminate and excessive exploitation**




Source: GWMATE Briefing Note 11

But the  depletion concern is just one facet of sustainable use. Maintaining groundwater quality while also seeking to stabilise groundwater levels compounds the governance challenge, implicating not just groundwater abstractors but the whole array of actors involved in land-use and pollution management (Thematic Paper 1).

Actual institutional responses have tended to opt for technocratic regulation – some of which is necessary in the case of protecting aquifers for crucial water supply purposes. Other attempts to regulate demand have required clear incentives or direct and indirect resource and energy pricing policies. In addition, precisely where sustainable use of groundwater should matter ( e.g. Spain, Mexico, India, China) the scale of agricultural abstraction has proved impossible to regulate (e.g. Wester et al. 2011). Three basic questions arise

- Has the understanding  of pressures on the resource base and its inherent vulnerability been appreciated?
- Have national planning provisions/laws been adequate?
- Has localisation of resource management been effective? The scale of groundwater issues may be quite small and local solutions the obvious starting point anyway).

**Hydrogeological realties – quality**

The long-term accumulation of natural and man-made pollutants in aquifer systems and the two-way imprinting of groundwater and aquifer matrix may present a more intractable governance problem then groundwater quantity or levels (Thematic Paper 1). The role of drilling and pumping in mobilising naturally occurring pollutants such as arsenic or fluoride or inducing saline intrusion can be contrasted with the broader 'non-point' impact of land use management on groundwater quality. Improved governance of drilling and pumping involves engagement of clear-cut governance target – even if they can be counted in hundreds of millions. Engagement of groundwater polluters on the other hand presents a more universal governance issue and is as much an issue for urban water supply utility managers (Thematic Paper 3) as agricultural and environmental agencies seeking to regulate the application fertilizers and pesticides.

A much more sophisticated evaluation of the role of groundwater in furnishing sets of ecosystem functions has now become available (Morris et.al. 1993). Many of the environmental services maintained by groundwater levels are linked to amenity value and freshwater biodiversity (preference for wetlands as opposed to drained agricultural land, for example) but others such as continued functioning of oases in arid areas have direct impacts on livelihoods. Deciding how these ecosystem values are to be maintained (either  by active management of groundwater pumping regimes to augment surface flows or by relaxation of aquifer development to maintain groundwater levels) is not trivial particularly in densely populated areas where demand for ecosystem services is likely to be highest.

**Conjunctive use and conjunctive management**
It is argued that the full potential of conjunctive management of surface and groundwater has not been realised, in spite of the calls to commit integrated water resource management. Although it is possible to observe a lot of conjunctive use (groundwater scavenging in surface irrigation schemes), proactive conjunctive management to resolve scarcity and quality constraints has only seen partial application. In fact, the use of aquifers for managed storage of surplus surface water has broad application from small scale water supply and irrigation schemes to municipal supply where some form of aquifer-storage-recovery is possible. But beyond this, the regulation of recharge through land management also offers scope to improve groundwater quality and quantity. However, as observed above, the incentives to manage for quantity (in terms of reduced drawdown) will be more direct to groundwater users. Persuading individuals to reduce chemical inputs on land or change land management and waste disposal practices is more difficult since there may be no direct benefit them (as opposed to other direct users of the impacted aquifer). The governance challenge for full adoption of conjunctive management ( where it can make a difference) therefore extends across the technical management of water storage along a river basin and into the broader domain of recharge regulation through land management.

**Reconciling public and private interests in aquifer services**
Untangling the web of customary use of groundwater and more formal water allocation procedures still proves problematic. Free access to groundwater for *de minimus* use is taken as a given in most current water law (Thematic Paper 6). Some jurisdictions still give unfettered rights in use to land holders. If this private use did not impinge upon public interests in groundwater access and groundwater quality there would be no immediate governance problem. But it does – and in many complex and difficult to predict ways. Well interference, irreversible pollution of aquifer matrix all demand a level of responsible behaviour on the part of users of groundwater and the land through which it is recharged. The separation of land and water rights has generally occurred to avoid 'grabbing' of public resources (not to induce trading as some have interpreted).

**Taking groundwater governance to scale**
Scaling presents the major institutional challenge, particularly when taken with the scale of water administration generally (Thematic Paper 5). Many case studies point to the potential for innovative but local solutions to improve or prolong the state of a local resource (Thematic Paper 7). India stands out in terms of the scale and intensity of development – a but also in the USA where the arid west/SW has relied on development of deeper aquifers. Identifying the range of hydrogeological problems that need to be addressed needs careful analysis and presentation at the outset if the resort to governance is to have any legitimacy. Resource assessments and hydrogeological mapping at a scale that can be used by planners can prove vital in this regard. But it is significant that even in the United Kingdom hydrogeological mapping available at scales useful to planners (1:100,000) was only available in the 1980s and only then in the strategic southern Chalk and Limestone aquifers. The scale at which such groundwater problems as post-industrial groundwater rise and associated pollution. nitrate and pesticide application or use of geothermal energy need to be analysed and planned for may not be compatible.

**Governance and time – slow onset and rapid reversals**
Finally, anticipating governance requirements over time presents levels of risk and uncertainty not normally associated with conventional water resource management. The operation of a surface water reservoir, for example, is not beset by unforeseen evolution of water quality or incremental rises in pumping (slow onset problems) or rapid reversals once the hydraulic state of an aquifer system is altered or polluted (rapid reversals). The political responses to groundwater 'problems' may simply be too short-term to allow effective governance models to be applied (Thematic Paper 5).

## 4. Why groundwater governance will be important to sustain aquifer services into the future

Groundwater has had more a problem with sustainability. Hydrogeologists are keen to disabuse perceptions of 'safe-yield' or 'sustainable yield' for (Sophocleous, 2000; Custodio, 2002) as a technical criterion for development. This is simply because aquifer response to a pumping stress involves establishment of new system equilibrium which needs to be modelled accurately before being appraised. However, there are very good reasons for keeping groundwater levels and groundwater quality within locally acceptable limits. As Gleeson et al. (2012) note;

*"We believe that the solutions to both groundwater quantity and quality issues should be developed inclusively and locally. Aquifer-based communities can implement policy to achieve multigenerational goals that can later be modified using adaptive management. In the short-term, defining locally relevant goals and values and locally changing groundwater usage and protection will be critical. Hydrogeologists can play an active role by using groundwater models to simulate effects of management polices and measures in achieving the long-term sustainable goals and by monitoring the effectiveness of polices and measures. Information from modeling and monitoring provides scientific basis for adapting management measures. Water managers, local communities, and hydrogeologists should work together to set long-term goals, to device polices and measures by backcasting, and to adapt future measures in achieving the long-term sustainable goals. This is a feasible path towards sustainable groundwater use*."

It is to be expected that the regional priorities will reflect state of development and the hydrogeological opportunity as presented by the hydrogeological settings in that region - the physiographic character of the hydrogeology will mould the style and intensity of use. Four broad areas can be identified - in no particular order or priority

**Sustaining groundwater access and quality for water security and public health**

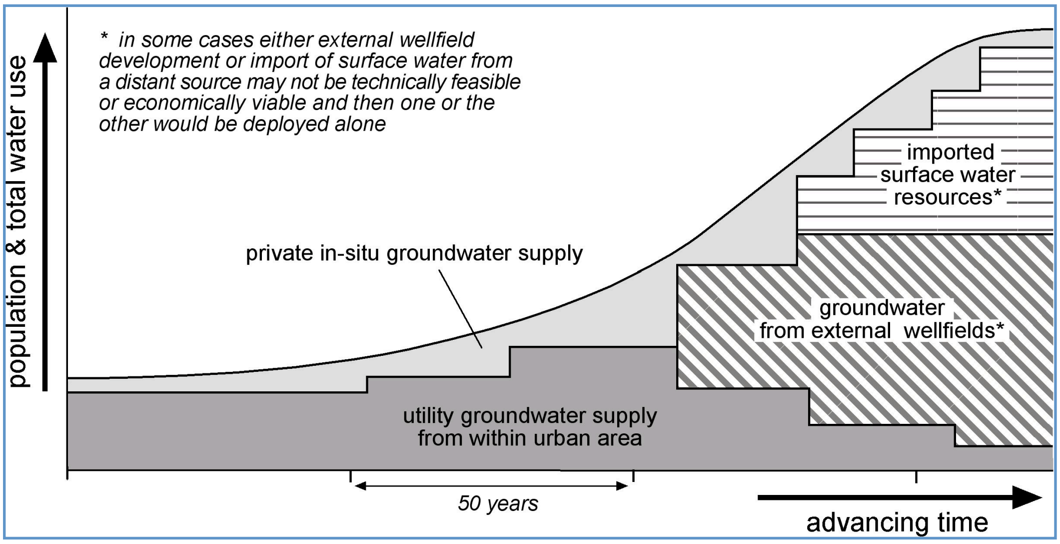
Access to clean safe drinking water from local aquifers will continue to be a priority concern. Current assessments of municipal supply indicate levels of dependency of 60% for the European Community. Producing bulk water volumes from sources used for potable and industrial supply is a key determinant of management and need overall maintenance of aquifer levels to continue to supply individual borehole abstractions and keep municipal systems pressurized. But the water quality priorities are equally important for both cases where no treatment is possible or affordable (rural water supplies and urban self-supply) and to keep down the costs of treatment for supply into reticulated systems for small towns and cities. In many cases it is public health legislation that help drive 'aquifer care' rather than water resource management per se. These considerations are not just for permanent settlement. The critical role of groundwater supplies in providing services for refugee camps, post-disaster reconstruction is never far from the public eye. Systems of water governance developed in times of peace might anticipate how access to groundwater can be governed in times of unrest or following natural disasters.

**Servicing an urbanizing world**

It is not just water supply to urban areas but the impact of urban land-use and industrial activity on local aquifers as repositories of waste (Thematic Paper 3). The concentrations of urban surfaces, waste and built space are combined with a set of geotechnical impacts resulting from both aquifer depletion and recovery. As urbanization proceeds, these impacts can be anticipated and planned for if the pace of urbanization is relatively orderly while remediation after the fact is likely to be much expensive (Figure 5).

The implications for municipal water supply have been highlighted in a subsidiary paper also commissioned for this project Foster et al. (2012). While is important to note that the precise proportion of groundwater for rural and urban water supply is not captured by such initiatives as the Joint Monitoring programme of WHO and UNICEF or the IB-NET, the reliance upon groundwater sources for specific cities can be as high as 100% even in relatively humid climates such as Brazil. For the European Community as a whole, groundwater is estimated to supply some 60% of urban inhabitants.

**Figure 5. Typical temporal evolution of water-supply sources with large-scale urban development**




Source: Foster et al. (2012)

The patterns of urbanization in relation to aquifers are significant. As Thematic Paper 3 points out, the urban groundwater governance issues within city limits can be contrasted with those issues occurring beyond the city limits. Defining precisely who is accountable, knowledgeable and responsible for groundwater management appears to become difficult in as the intensity of urbanization and demand for urban groundwater services increases.

**Sustaining trends in agricultural intensification**

Globally, almost 40% of equipped irrigated areas are now serviced with groundwater (Siebert et al. 2010). In the years ahead, the largest contribution to increased agricultural output is likely to come from intensification of production in existing irrigated areas (FAO, 2011b). This will require increased water productivity and higher cropping intensities, and will only be achieved through improved flexibility, reliability and timing of water service and more efficient water use, for which investments in both modernization of irrigation infrastructure and in institutional improvement will be necessary. Groundwater is the perfect delivery system for this anticipated intensification - and aquifers the perfect victim.

Because of the dependence of key food producers on groundwater, declining aquifer levels may create a risk to regional food production, with possible implications on food prices at global level. FAO has projected that the global area equipped for irrigation may increase at a relatively modest rate to reach 318 million ha. in 2050, compared to around 301 million ha. in 2009. Most of this increase in equipped areas is projected to take place in developing countries. This would represent an increase of around 11%, or 0.24% per year, much slower than in recent years, but with available surface water supplies severely limited, this increase can be expected to translate into yet more pressure on aquifers, not just from withdrawals. Increase application of agrochemicals can also be expected unless application efficiencies are substantially improved.

**Maintaining ecosystem functions and services**

Environmental values linked to groundwater may be a more explicit concern in post-industrial economies. This does not mean that they are not an issue in developing countries where ecosystem services maintained by groundwater can be significant – even if not recognized. Much of this value relates to the maintenance of wetlands and associated bio-diversity and environmental services (Sophocleous, 2002a, 2002b ). Maintaining naturally occurring and fluctuating groundwater levels that give the long-term pulse to such wetlands has proved difficult. Such wetlands are sensitive to small fluctuations in groundwater levels. In addition such wetlands are sensitive to the accumulation of pollutants transmitted through groundwater circulation. For many post-industrial economies, the amenity value placed upon such groundwater supported environments may be much higher than any direct livelihood value. But for countries addressing poverty and rapidly expanding urban populations, the priorities may the direct and indirect use values such as the provision of wastewater treatment services.

**Macro-economic rationale**

The macro-economic contribution of groundwater is most apparent in agriculture and urban water supply (where the bulk of the development investment and use occurs). For rural water supply, although the use is less intensive compared with agriculture, the investments are also highly distributed. The difficulties of estimating just the groundwater water resource contribution to agriculture have been explained in Siebert et al. (2010), and the difficulties in assessing the groundwater contribution to municipal services (Foster et al. 2012) and water supply and sanitation (UNICEF/WHO, 2011) at national level are well explained.

Broadly, the macro-economic contribution of groundwater can be related to a avoided treatment costs, just-in-time service, and higher agricultural productivities resulting from precision irrigation. The broader set of aquifer services are not captured

However, the macro-economic dependency on groundwater does not necessarily form the actual point of interest for people who depend on groundwater services. While the overall economic signals may be strong, the economic engagement that will determine governance outcomes is more likely to be centred on individual behaviour with regard to groundwater abstraction and the protection of the aquifer services that guarantee the supply. This will relate to livelihoods and the management of individual risk. In this sense it is not so much public control of natural resources that has necessitated governance, but private interests in maintaining a viable future for households. However the instrumental value of groundwater circulation is more long lived than surface systems since the time taken to emplace the resource and the long memory of pollution impacts......

## 5. What is driving the perceived need for groundwater governance?

If anything is to be concluded about the drivers of groundwater governance, then it is probably the latent appreciation of aquifer state; depletion and degradation has prompted most institutional responses. The facts about groundwater depletion and degradation have always apparent for some time (for instance cholera outbreaks in London in the 19th century ) and the scientific basis well established for some time (Thematic Paper 1 : Morris et al. 1993). Human induced aquifer depletion on the other hand has only become apparent since the second half of the 20th century . The sheer intensity and pace of growth of human demand and competition for groundwater quantity and quality in the late 20th century has no precedent. Rapid urbanization, widespread availability of drilling and pumping technology, and the associated land-use changes (Scanlon et al, 2007 ) have tended to overtake the capacity of natural resource institutions to plan and regulate an ordered progression of aquifer development. Regional and global policy in natural resource conservation has only shown a mixed response or awareness of the state of global groundwater resources and its use. In addition, it can be argued that much of the global discourse on water makes very little recognition of the particular character and vulnerability of aquifers and the room for manoeuvre.

Across Asia, the Americas, Africa, Europe and many regulatory systems show a trend to move from free appropriation of groundwater to regulatory, permit based systems (Thematic Paper 6). This has place new responsibilities on water resource agencies primarily concerned with surface water management. But since intensive development of groundwater is recent, institutional responses have lagged behind. However, it is not a given that aquifer systems can always buffer demand. Depletion and degradation can be fast and aquifer systems can 'flip' from confined to unconfined state or respond to a pollution event. With this experience in mind, some broad 'thematic' drivers can be identified – as described below.

**Human demand and competition for groundwater quantity and quality**

Attitude and culture shape approaches to every public issue, including groundwater. Often the incentives to use and profit from groundwater are high – but the externalities are largely unregulated. In some cases users refuse to act collectively and governments have had to amend water laws to allow government-forced constitution of water organizations. Irrigation subsidies can be introduced without social, economic and environmental impact assessment. The legal relationship to groundwater may be unclear under certain land tenure and riparian doctrines – or simply not conditioned by hydrogeological knowledge or local context. The governance arrangement that may work across a small aquifer developed for irrigation may not work in large aquifers supplying water to a range different activities in large urban, agricultural, industrial and mining areas. Indeed there are relatively few examples of self-organization in relation to the scale and intensity of the groundwater development (Thematic Paper 7) or indeed examples of how competition over groundwater can be resolved. However, there are general principles of water and regulatory law that are common to developed and developing countries and substantive and procedural rules are needed to ensure that conflict adjudication and administrative decision-making are not arbitrary (Thematic Paper 6).

**Latent appreciation of aquifer state; depletion and degradation**

The perception that human dependence on groundwater is in trouble has only be flagged in international fora in the last two decades. Prior to this, groundwater was mainly perceived as a development opportunity (United Nations, 1960). However, the state of aquifer depletion and degradation is not something that can be easily assessed with the required level of precision to effect governance in all places all at once. Accounts of long-term groundwater 'depletion' with high quality observation well data are not that common (examples for Chile, Morocco, and India can be found in the GWMATE case study series). However, much of the groundwater management 'action' has tended to be reactive rather than more pro-active approaches to prudent groundwater development advocated at the dawn of the groundwater boom in the 1960's. Today, dismantling public interest research may have long term impacts including the debilitation of the careers of water managers through various measures (low salaries, low social prestige, lack of tenure, uncertain career path, political-transitory appointments have a negative on resource management). At the same time knowledge and research are of no use if there are no organizations with resources (legal, financial, technical) to carry them to field implementation. The independence and competence of these organizations and their managers and personnel are important for groundwater governance. They are in many respects similar to regulators of public utilities. But as a general rule, it is not possible to protect what is not known. Even if known, it is not possible to protect without the necessary legal, logistical, tools to do so. The lack of financial resources to maintain public interest research in groundwater development and management will continue to constrain efforts to work toward improved groundwater governance

**Rates of change: rapid urbanization, technology uptake and land use changes**

The rate of change of human demand and pressure on aquifers since the mid 20th century cannot be underestimated. An analysis of land-use trends (FAO, 2011) indicates that the location of demand and technology (including groundwater pumping) will be concentrated on existing urban and rural land lands. There has been no net expansion of agricultural land since 1960 and feeding and housing a projected 9.3 billion people will occur on land that is already developed. This spatial concentration of productive and polluting activity has direct consequences for aquifers (Scanlon et al. 2006). It may prove impossible to relax aquifers in certain locations where groundwater use has high economic dependency. Equally, the costs of controlling, let alone mitigating, pollution from urban or agricultural sources may prove impossible to absorb.

**Regional and global policy in natural resource use and conservation**

What happens beyond national policy making and setting of regulations to conserve aquifer services also needs to be taken into account. Regional trade patterns and the national subsidies of agricultural production can have direct impacts on groundwater use. Irrigated staples such as corn, wheat and rice are highly responsive to global prices and levels of national subsidy (including biofuels) and much of this can translate into demand for groundwater where it has given producers the flexibility to get in and out of agricultural markets. Equally, it can be argued that the protection of international investments in land assets may transcend national codes. These signals on natural resource development may be at odds with regional conservation agreements or international conventions. For these reasons it is important that customary laws, uses, and organizations for conflict adjudication and water management be recognized by national formal legislation.  A real risk is that well intentioned national legislation can be overruled by international investment agreements.

## 6. Evidence of groundwater governance in practice (a sample of Case Studies) (6 pages)

The literature on groundwater governance in practice is extensive as indicated in the bibliography for Thematic Paper 5. However a key source of cases in relation to specific aquifers are now being published through the IAH Hydrogeology Journal (http://www.iah.org/publications_hydro_journal.asp) which tends to be where international experience in applying groundwater management is concentrated, as opposed to groundwater processes which are generally found in the hydrological science literature.

The range of country case studies produced for the project through the World Bank include;

- India (http://water.worldbank.org/water/node/83814)
- Kenya
- Morocco
- South Africa
- Tanzania
- Tunisia

To these can be added a set of individual aquifer case studies compiled under the World Bank GWMATE programme (http://water.worldbank.org/water/related-topics/groundwater-management-advisory-team ) together with briefing notes on thematic areas and strategic overviews. In addition case studies are being submitted through the PCM (see Box 4: for an example). Three broad types of aquifer governance 'problematique' can be identified.

**Aquifers as strategic reserves – ultimate sources**
From small island countries to the large stratiform continental aquifers with intensive development but limited or recharge and there is now a comprehensive set of aquifer studies and some examples of institutional responses that have tried to reverse trends. Issuing borehole permits combined with volume quotas or area quotas have been standard responses to reduce demand on stressed aquifers but have also met with limited or no success even when aquifers are the 'lenders of last resort' (FAO, 2006 - http://www.fao.org/docrep/009/a0994e/a0994e00.htm). Under such circumstances, a solution that is not politically viable is unlikely to change the behaviour of individual abstractors and polluters.

**Aquifers for economic development**
Many countries trying to grow rural economies through intensification have resorted to explicit subsidies to the rural sector in order to reduce groundwater pumping costs with the prime example being groundwater energy tariffs in peninsular India (World Bank, 2011 – India Case Study). The dependency on groundwater for rural water supply has also been recognized in rural water supply campaigns to extend coverage (UNICEF/WHO, 2011). Over the last 25 years economic water policy models have evolved in concept, theoretical and technical methods, scope and application to address a host of water demand, supply, and management policy questions. There have been a number of theoretical and empirical advances over this period, particularly related to the estimation of non-market, public good water- related values involving different valuation methods. Modelling advances include multiple, competing demands, types of incentives and technologies and behavioural responses, incorporation of groundwater and other supply alternatives, integration of institutional factors and increasing attention to system-wide impacts.

**Aquifers as part of river basin management plans**
With the advent of standardised finite difference codes (MODFLOW) running on relatively cheap personal computers. dedicated groundwater models for specific aquifers are now used widely since the early 1990s. However, the explicit inclusion of groundwater models in large scale river basin planning and magement is rare. Challenges lie in putting these models together and integrating of the individual demand and supply components, including of environmental impacts, across river basin and even inter-basin scales of analysis (Thematic Paper 2)

**Aquifers as environmental goods and services – and ultimate sinks**
The explicit appreciation of aquifers as suppliers of environmental goods and services has tended to occur in the OECD countries or arid countries with groundwater sustained wetlands or oases (Thematic Paper 9). While the susceptibility of aquifers to degradation is well established (Morris et. al. 2003), the economic appraisal of the positive contribution of 'in situ' goods and services is less certain. Valuation of existence values are locally contingent and in some cases the long term amenity value of maintained baseflows, for instance, can be difficult to compare with the immediate benefit of abstraction (FAO, 2004). The goods and services that derive from the indirect use of aquifers (e.g. as regulators of water quality) or their existence value in maintaining public amenity values cannot be de-coupled from the vulnerability of aquifers. Eventually, all poor quality wastewater generated on the land surface will find a pathway into an aquifer.

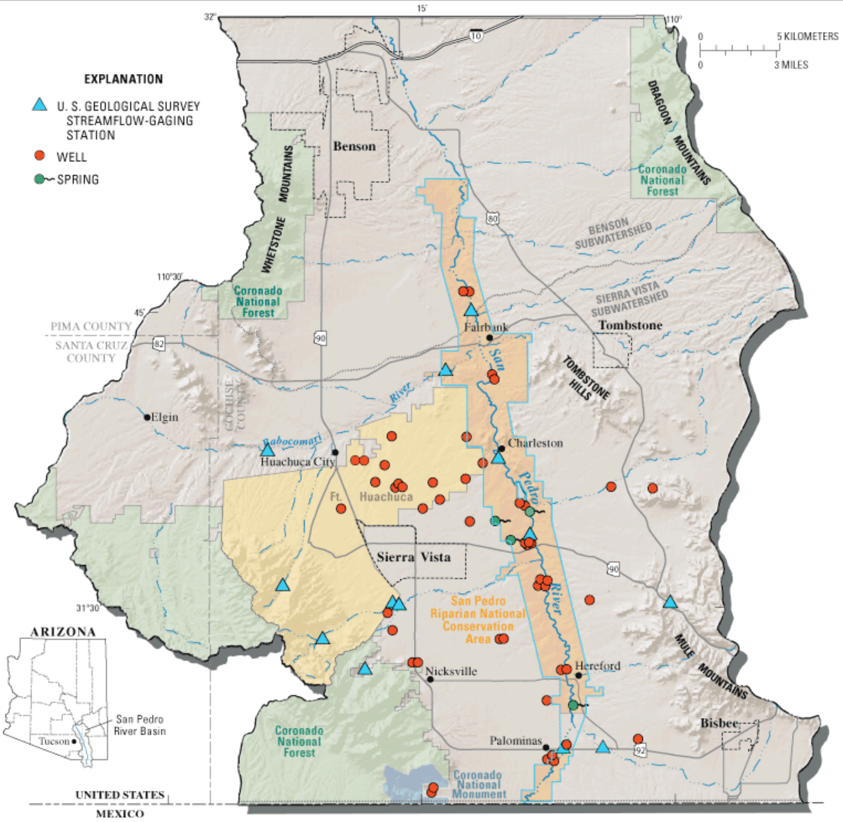
**Institutional adaptation – the evolution and implementation of groundwater policies, laws and regulations**

There appear to be few successful approaches to direct management of groundwater abstraction and pollution. Islands such as Malta have attempted such reforms to conserve its main strategic reserve. At the other end of the spectrum, the federal initiatives of India to encourage State governments to adopt a model Groundwater Bill and form State Groundwater Authorities are relatively recent and the evidence to assess the effectiveness is not available. At the same time, more informal attempts to regulate through information and self-monitoring (APFAMGS http://www.fao.org/nr/water/apfarms/index.htm ) have met with some success at local level. Perhaps the most notable advance is in the adoption of the Water Framework Directive by the European Community where protection of groundwater quality has become a key concern and target.

**Box 4: PCM submitted case study**

| | |
|---|---|
| **Institution U.S. Geological Survey** | |
| **Case Study Title** | **Efforts to achieve sustainable yield of groundwater in the San Pedro River Valley and Sierra Vista Subwatershed, Arizona, USA** |
| **Country** | United States |
| **Relevance to Groundwater Governance** | Like many parts of the American southwest, the population of the Sierra Vista subwatershed is rapidly expanding. Groundwater is the primary source of water for the residents of the Sierra Vista Subwatershed, Arizona, including Fort Huachuca, Bisbee, Sierra Vista, Huachuca City, Tombstone, and the rural residents of the Sierra Vista Subwatershed. Groundwater is also an essential component among the water sources that sustain the base flow of the San Pedro River and its associated riparian ecosystem. Water outflow from the Sierra Vista Subwatershed, including water withdrawn by pumping, exceeds natural inflow to the regional aquifer within the Sierra Vista Subwatershed. As a result, groundwater levels in parts of the Sierra Vista Subwatershed are declining and groundwater storage is being depleted. In the absence of effective management measures, continued decline of water levels and associated depletion of storage will eventually diminish groundwater flow to the San Pedro River.<br>In November 1988 the legal context of the upper San Pedro River (Southern Arizona, USA) and its attendant riparian system changed dramatically, as almost its entire length within the Subwatershed was protected by Public Law 100-696 that created the San Pedro Riparian National Conservation Area (SPRNCA). The Upper San Pedro Basin provides habitat for 389 avian species—almost half the bird species found in North America, 84 species of mammals, and 47 reptile and amphibian species. Per Public Law 100-696, the U.S. Bureau of Land Management has been charged to manage the SPRNCA "…in a manner that conserves, protects, and enhances the riparian area…" and the other resources found throughout the SPRNCA.<br>I n 2003, The United States Congress passed Public Law 108-136. Section 321 of this law recognized the Upper San Pedro Partnership, a consortium of 21 local jurisdictions, state and federal agencies, and non-government organizations, and directed the Partnership to restore and maintain the sustainable yield of the regional aquifer within the Sierra Vista Subwatershed by and after September 30, 2011. Some of the Partnership members are owners or managers of land and (or) are capable of implementing water-management measures. Other members include resource agencies with expertise in public policy, various scientific fields, and engineering. In pursuit of its goals, the Partnership has initiated and/or funded studies to better understand the regional hydrologic system, the riparian system, and recharge processes. The Partnership has also invested significant resources into systematically identifying, evaluating, and documenting water-management measures that will be used to attain sustainable yield of the regional aquifer. |
| **Geographical scope and aquifer linkage (physical area and aquifer systems implicated)** | The San Pedro River originates near Cananea, Sonora, Mexico and empties into the Gila River near Winkleman, Arizona, 275 km to the north. It is divided into an upper and lower basin, with the two separated near the center of the basin by a bedrock constriction. The Upper San Pedro Basin is subdivided into 3 subwatersheds. The Sonoran unit extends from the river's source in Mexico to the international boundary; the Sierra Vista Subwatershed begins at the international boundary and terminates at the USGS gaging station near Tombstone, AZ, about 45 km north of the international boundary; the Benson Subwatershed extends from the Tombstone gaging station to the Narrows. The case study would focus on the Sierra Vista Subwatershed because the SPRNCA, created by Public Law 100-696, is entirely contained in the Subwatershed and because Section 321 of Public Law directed the San Pedro Partnership to restore and maintain the sustainable yield of the regional aquifer within the Sierra Vista Subwatershed by and after September 30, 2011.<br>The 2,460 $km^2$ Sierra Vista Subwatershed is part of a broad alluvial valley 1,200 to 1,500 m above sea level. Located in the southern part of the basin and range physiographic province, it is bounded to the east and west by fault block mountains. The Huachuca Mountains (2,890 m) and Mustang Mountains (2,000 m) are to the west while the Mule Mountains (2,250 m) and Tombstone Hills (1,620 m) are to the east. The northern flank of the Sierra San Jose (2,500 m), just south of the international boundary, drains into Greenbush draw, a major ephemeral tributary that reaches the San Pedro River north of Palominas. Groundwater from the regional aquifer beneath the subwatershed is the primary source of water for the residents of the area. Groundwater is also an essential component among the water sources that sustain the base flow of the San Pedro River and its associated riparian ecosystem. |
| **Population implicated (number and structure)** | The 2010 census counted about 77,300 people in the Subwatershed. Sierra Vista is the largest city with an estimated population of 45,000 people including 7,200 people on Fort Huachuca. The incorporated cities of Bisbee, Tombstone, and Huachuca City add another 8,800 people. The remaining 23,500 people were living in unincorporated areas of the Subwatershed under jurisdiction of Cochise County. |
| **Date of compilation** | January 4, 2012 |
| **Website (if any)** | |

| **Material Groundwater Governance** |
|---|
| |
| **Photography/figures** |



## Part 2: How could groundwater governance be improved?

### 7. Enhanced principles for governance of groundwater

The foundations for any 'Global Framework' needs a set of guiding principles that can find common acceptance in all aquifer settings where groundwater development and protection is taking place.

The inherent character of groundwater presents a set of quite unique governance challenges and it can be argued that attempts at influencing the millions of individual decisions to use or abuse groundwater have failed to take hold because these challenges have not been adequately addressed. Pasts attempts to regulate and manage groundwater as just another natural resource have informed us what not to do – and some indication of where to start. For instance, some environmental reporting requirements are now prompting more inclusive assessments of groundwater status and risks to economic, social and environmental services derived from groundwater. But at the same time opportunities for conjunctive use and conjunctive management are being missed – as the necessary understanding of surface water- groundwater interactions has lagged and the structural role of groundwater in integrated water resource management has been largely ignored. In this sense, the explicit recognition of groundwater in water governance debates is hard to find. The emphasis remains centred on the surface water dominated 'hydraulic' administrations where investments are more supply driven, 'lumpy' and hence more visible.

Therefore, the basic or foundational water governance principles of accountability, transparency, user participation and the requirement to integrate assessments and management responses still apply but may need 'enhancing' to make them more applicable to groundwater use and address the 'governance gap'. In addition there may be a set specific principles of governance that relate to groundwater based on the presumption that that patterns and intensity of groundwater use will need to be sustained in the future. In summary, these groundwater governance principles are listed with brief comments below. All these principles are expected to apply at all levels of management – from local to global.

**Sustainability: incorporate aquifer response time and renewability**
A general notion of 'sustainability' in terms of simple recharge and withdrawal budgets is not sufficient. A more informed appreciation of how governance arrangements can be used to manage or relax aquifers under pressure is called for. These will necessarily involve quite subjective criteria as to what social, economic and environmental consequences are acceptable for a particular system of groundwater supply and use. In addition, the time over which aquifers respond to development or become imprinted with pollution presents a particular governance challenge when considering long terms sustainability of groundwater use. Finally, the development of non-renewable groundwater presents a specific governance challenge since decisions over planned depletion have to be made in purely socio-economic terms.

**Transparency: making groundwater and groundwater management visible**
Access to clearly presented information is therefore a fundamental pre-requisite for any water governance, but needs special effort in the case of groundwater. In addition, to making groundwater information accessible and visible, the highly localised process of governance also needs to be transparent – actors, communication channels and the means of negotiating decisions over groundwater use and aquifer protection.

**Participation: engage with groundwater stakeholders at aquifer scale**
Groundwater users and polluters also need to be visible. The engagement with users and polluters at aquifer scale is seen as essential in order to monitor and agree drawdown limits or acceptable limits to pollution. To be inclusive at every stage and level of the governance process in aquifer development and protection has proved a challenge for many water agencies. However, there is now evidence that the clear presentation of locally relevant groundwater information can be combined with participatory monitoring of aquifer state to agree acceptable levels of drawdown or groundwater quality.

**Accountability: stress economic benefits and consequences of groundwater use**
It has been stated that more could be done to stress the social and economic benefits of groundwater. However this realisation is only likely to have impact if accompanied by an account of the costs or consequences of use and a system of rules that effects compliance. This including the impacts of poor drilling and borehole construction and the adherence to commonly accepted norms and standards. Determining who benefits and who stands to lose as a result of use is fundamental – along with a system of allocating groundwater use in an equitable fashion. More problematic is the identification of those who cause groundwater pollution but do not use groundwater. For instance recognition of a polluter-pays principle may work well for all water users, but may prove difficult to extend to all those who change land-use or apply agro-chemicals. Tests or criteria for determining who is accountable for groundwater use and aquifer protection - and under what system of compliance standards - would seem to be fundamental principle of groundwater governance in particular.

**Clear <u>integration</u> with water policy: learn to play with groundwater – and groundwater players**

If groundwater governance is a neglected area of water policy, improved governance is only likely to occur if groundwater management can be integrated with water policy and management processes. An explicit shift from conjunctive use to conjunctive management is expected to yield benefits where the buffering and storage advantages of groundwater can be realised across landscapes and economic sectors. In this sense groundwater management needs to become more expert in playing with groundwater use in conjunction with surface water supplies and wastewater streams through imaginative use of economic and technical instruments (such as payment for environmental services, wastewater re-use) and imaginative collaboration with other water sector players.

**<u>Precautionary principle</u>**

The vulnerability of aquifer systems to surface processes and the human encroachment of the earth's crust has been well established – and further analysis of processes and impacts should not be an excuse for inaction. It makes sound economic and public health sense to identify and protect recharge areas - and recharge processes. For instance it is hard to improve upon natural processes of recharge for introducing groundwater and improving water quality and maintaining the integrity of the land-aquifer coupling will continue be a key concern in a crowded world. But it also makes sense to regulate the direct injection of pollutants and the disruption of aquifer fabric on the basis of a precautionary principle in the knowledge that such interference may proved to have impacts that are irreversible. This principle will be particularly important to the Small Islands Developing States (SIDS) in the Caribbean and Pacific regions where the options for obtaining alternative sources of water are extremely limited.

**<u>Knowledge management principle</u>**

A common plea made to hydrogeologists from non-hydrogeologists is that more could be done to popularise groundwater information and groundwater dynamics. While it is accepted that basic aquifer system behaviour in relation to supply (recharge) and demand (abstraction) still has to be modelled to fully appreciate storage depletion in particular, these sophisticated interpretations need get across to groundwater users to the point where groundwater use is moderated and aquifer protection advance can remain problematic. Therefore, beyond the basic dissemination of groundwater information, the use of groundwater information and knowledge to assess the risks to groundwater depletion and pollution will be key in assigning applying groundwater management criteria. In the case of groundwater (as opposed to surface water) it is essential to anticipate the evolution of groundwater quality and hydraulic state over time. The obligation to promote the use of groundwater knowledge is therefore seen as fundamental principle underpinning groundwater governance

## 8. Institutional Responses

From the outset, it is apparent that removing barriers between groundwater science and policy makers cannot be done without making the invisible somehow 'visible'. The scale and intensity of current and future impacts apparent. How such material is presented by the hydrogeological community together with range of multi-disciplinary science that is associated with its development and management (from epidemiology to power utility management) is important to give groundwater governance an institutional 'home' and demonstrate that there is an economic return for investing in groundwater governance. All this hinges on a working system of mutually acceptable arrangements between users and polluters to moderate behaviour and act in the local public interest. In the absence of any formal institutional response, such arrangements may occur spontaneously as local aquifer communities react to commonly felt threats or impacts. However, as discussed before, such is the invisible, transient nature of the resource, a realistic appreciation will need technical support when problems emerge – and preferably before. How should that support be structured? In addition, even when an institutional framework for natural resource governance is in place, the lack of any political viability in regulatory approaches may work against desired outcomes. In those cases, removal of constraints may need to be a first order response.

**Making groundwater information accessible**

The advanced hydrogeological knowledge that has been gained in studying aquifer responses to human demands will continue to be essential but piercing the consciousness of policy makers and water managers alike still remains a challenge. The absence or clear presentation of hydrogeological information can often mean that the essential information on the <u>scale</u> groundwater related risks to development or environmental services are simply not getting through. But for governance to work this groundwater information has to be accessible and useable by those who have a direct impact on groundwater quantity and quality. For instance, the APFAMGS project in Andhra Pradesh (http://www.fao.org/nr/water/apfarms/index.htm ) and had some success in helping both farmers and potable water users in village communities to manage inter-annual groundwater level fluctuations in local aquifers – largely by self-monitoring of pumped boreholes . While this is necessary, it is not likely to be sufficient to prompt self-regulation by users to the extent that aquifer levels can be stabilized, as in the case of the Guanajuato

State technical water councils (COTAS) reported by Wester et. al (2011) where more proactive mechanisms for enforcement of groundwater regulations and promotion of transparency and accountability are seen as necessary complements.

**Making an institutional home for groundwater**

Beyond the information hurdle, simply making an institutional 'home' for groundwater amongst related water and environmental institutions still appears to be difficult – particularly when dealing with urban groundwater governance (Thematic Paper 3). Traditionally, geological surveys or agencies have informed water resource and environmental regulators. Only a few countries have attempted to set up dedicated groundwater management agencies. India, for example, has had a Central Groundwater Board since 1970 and recently introduced a Central Groundwater Authority in an attempt to co-opt State Governments in promoting more active groundwater regulation. Clearly in a large country such as India, the scale and diversity of groundwater challenges is unprecedented. At the other end of the spectrum, many local initiatives related to groundwater management, such as recharge movements cited by Shah (2007) may arise in an information vacuum or without up to date scientific validation of their efforts.

**Removing constraints to groundwater governance**

While the points above have suggested areas where a positive approach can support groundwater governance, it is also reasonable to ask if there are nay institutional constraints to governance identified in Thematic Report 5 that could be removed? Many seemingly straightforward approaches to natural resource governance – including direct and indirect 'pricing' – may impose a rigid set of institutional instruments that are not politically viable and hence produce no governance solution. Adherence to abstraction licence quotas from a central agency or reform of electricity tariffs to rural areas may be things that just run into a political roadblock and do not obtain a political constituency for aquifer conservation or protection. More acceptable approaches, including amnesties on 'illegal' boreholes may have more positive impact if they bring the scale of the problem to light and set the basis for mutually acceptable solutions. Judging whether to regulate groundwater use at all, and if so, determining precisely where to start needs to be carefully thought through.

**Facilitating investment in groundwater management**

Identifying and facilitating investment in groundwater management has rarely become a priority or habit. Once a drought or groundwater pollution event has passed, interest tends to decline and institutions that were once considered vital in solving a groundwater resource problem are no longer fashionable, even if the risk persists. In many senses it is the lack of specific and persistent institutional responses to groundwater governance that has constrained efforts conserve and protect aquifers (Thematic Paper 5). The governance challenge tends to be lumped with those of water governance in general. This is certainly necessary , but not sufficient. The intensity of local demand for groundwater services is such that there is a lot of private interest which is occasionally mobilised into a public interest matter, by which time it may be too late to resolve. It could be argued that national and regional initiatives such as the specific groundwater pollution directives embedded in the EU Water Framework Directive – or the USA's CERCLA Superfund – are simply too late to remediate aquifer services even if they are successful in preventing further degradation. Hence it is probably necessary to establish the specific policy and investment 'space' for groundwater management at scales suited to the grouping of groundwater interests and the effectiveness of mitigation measures. But even here it can be realised that the interests of local livelihoods supported through access to groundwater may be incompatible with the need to protect an extensive aquifer to provide municipal supply . In this way, the governance and investment challenge is not as straightforward as financing river basin surface water resource development and management. Tailoring the investment space for groundwater governance is beset by the low-intensity but highly distributed nature of groundwater conservation and aquifer protection measures.

## 9. Stressing the benefits of governance

**Livelihoods outcomes and groundwater transactions**

The equity and welfare afforded by access to groundwater cannot be under-estimated, but is often overlooked in economic terms. The social and public health benefits deriving from what many water legislations recognize as 'de minimis' use are significant – but only as long as these use rights are protected and combined with aquifer protection measures. The complex micro-economic transactions surrounding groundwater use have been documented particularly well in India - from the seminal work of Shah (1993) onward. A formal groundwater market is an arrangement in which groundwater right holders trade their rights (either within the market itself or with outside parties). There is no single market model – and the experience is limited to just three countries (Australia, Chile and the USA, ), but the characteristics for market design will depend on (a) the prevailing hydrogeological regime, (b) the previous history of informal trading and/or rights, (c) the types and numbers of groundwater right holders and users and (d) the physical arrangements for moving water between users. Research into the water market initiatives we have found, in addition, is that there is no explicit connection between surface and groundwater right allocation, that no legal provisions tend to be ascertained to take account of external impacts and that transaction costs tend to be overlooked (Thematic Paper 10).

**Macro-economic outcomes**

The specific economic dependency on groundwater has not been systematically analysed or incorporated explicitly in national resources accounts (for example SEEAW). The economic literature on groundwater is predominantly of a partial equilibrium type (Thematic Paper 10) assuming the rest of the taking the rest of the economy can be treated as a set of parameters. Working toward general equilibrium solutions would not seem appropriate but there are some key considerations. Economic instruments can provide incentives to allocate and/or use groundwater more efficiently although such efficiency, tends to be analysed (if at all) from a static perspective and also de-linked from equity. There two main policy measures to reduce demand – direct pricing through resource abstraction fees and indirect pricing through increasing energy tariffs, These have to be set against - Positive economic incentives to change production patterns and subsidies for efficient use (such as irrigation systems – or water conservation. It is not certain that such attempts to management the demand for groundwater lead to actual water savings and relaxing of aquifers (Ward, 2007).

While the renewable nature of water resources is often assumed, this may not apply at all aquifer scales and over all time – aquifers can go through periods of non-replenishment. From a welfare perspective, there is an argument that the optimization of groundwater use should be linked to dynamic efficiency (and not just static), and intergenerational equity. This is linked to physical return flows, which are not always taken into account in some water legislations and management approaches. There is a need to distinguish and possibly reconcile two different economic interpretation of groundwater resources. Much emphasis has been placed from a management perspective on the "flow" dimension (income generated from groundwater development), but not so much on the "stock" dimension. Given that groundwater resources are generally recognized as "natural capital" assets, which amongst other things, generate income flows as an input for production but also can positively contribute to economic and social welfare and sustain biophysical flows of ecosystem services. Finally, from an economic viewpoint, it does not make sense at all to split quality and quantity dimensions. Actual groundwater demand occurs specific time, place, and with specific quality attributes.

**Environmental outcomes**

Environmental outcomes can be broadly interpreted, from maintenance of environmental quality standards in groundwater to the maintenance of low flows or wetlands and their associated biodiversity. Such is the array of environmental externalities associated with groundwater abstraction and pollution, that environmental impact assessments may not catch all of them, or if they attempt to do so (such as in the USA Superfund), the costs of remediation can be infinite (National Research Council, 1997). Capturing all the externalities and assigning a value to benefits foregone may be an exercise that can only be undertaken in specific (well financed) cases. However, the regional experience with the EU Water Framework Directive is also instructive in the regulation of chemicals and practices that cause aquifer degradation, together with reports on the environmental status of the basins in which groundwater circulation may play a key role in maintaining aquatic ecosystems. The key considerations in advancing such broad environmental regulation with respect to groundwater are;

- Capacity to assess and monitor and regulate
- Costs of environmental impact assessment and monitoring
- Costs of remediation

**10. Promoting viable Institutional strategies:**

It has already been noted that the governance of groundwater use can be promoted through a combination of initiatives appropriate to the hydrogeological setting and socio-economic conditions above an aquifer. Certain institutional 'conditions' as noted by Ostrom (2001) and the application of criteria Blomquist (1992) also appear to be necessary in some cases even if the institutional responses and eventual outcomes are diverse. So there appear to be no quick wins. What types of strategy have become apparent? Listed below is a sample of institutional strategies that can be identified from the available evidence . It is not exhaustive or inclusive of all the local hydrogeological and socio-economic conditions that exist, but suggests some starting points to improve the state of groundwater governance

- Engaging with users at aquifer scales and defining mutually acceptable levels of depletion and degradation
- Anticipating the evolution of groundwater quality and migration of natural pollutants (arsenic, fluoride etc…)
- Accounting for economic impacts and spreading production and environmental risks
- What to do when access to groundwater disappears
- Investing in governance take account of specific regional risks (conditioned by hydrogeology)

Groundwater development and regulation may be subject to 'unreasonable expectations' if policy is not well informed. This might apply to expectations that low yielding basement complex aquifers can furnish adequate supplies for irrigation or equally that curbs are put on development of highly productive karst aquifers if recharge processes are not well understood. There is a case for a balanced investment policy that recognizes the essential differences between shallow and deep groundwater circulation – and the political viability of changing user behaviour.

**Engaging with users at aquifer scales**
The flow of groundwater through aquifers may be complex, but development practice can be simple such as agreeing maximum acceptable drawdowns in pumped wells or simply banning the storage and application of pesticides across an aquifer that furnishes potable water supplies. These can be things that a well identified community of groundwater users can agree upon if basic information is made available and explained (Thematic Paper 7). How groundwater managers engage with user communities at the outset is important. If water resource agencies have failed to 'socialise' groundwater because of technical preferences for hydraulic management, then this might require a quiet revolution within the agency to establish a legitimate and respected platform to engage groundwater users. Equally, an initiative could be promoted as an autonomous, self-governing adaptation in which case it may make sense for water agency to simply get out of the way.

**Anticipating the evolution of groundwater quality**
Protecting aquifers from surface pollution, the migration of low quality water or the mobilization of natural pollutants such as arsenic is perhaps the most technically challenging strategy to put in place (Thematic Paper 1) . Not only is there a burden of proof (who caused the degradation) when a damaging level of pollution becomes apparent, but anticipating the aquifer vulnerability risk ahead of the damage to public health and reduction of economic output is something for which hydrogeologists many loose public trust of they they cry 'wolf' too often.

**Defining mutually acceptable levels of depletion and degradation**
Once a point of entry for improved groundwater governance is established, the promotion of specific groundwater objectives that address specific livelihood concerns - and are politically viable - becomes possible. With clearly bounded communities of users on small aquifers or aquifer blocks the task can be straightforward, but as the aquifer scale increases along with a e community of uses that encompass a diversity of economic and social interests, the task becomes complex. How it is approached in highly dispersed rural communities on thin discontinuous aquifers will be very different from the approach taken for a rapidly expanding urban area reliant upon a set of deep aquifers and aquicludes that gives a range of supply, disposal and geotechnical services.

**Spreading production and environmental risks**
In general more analytical effort could be made regarding the increases in groundwater development costs (i.e. as a result of prolonged and non-sustainable extraction), transfer of surface water from rural (irrigation) to urban (domestic) uses, and reductions of water availability due to severe drought and scarcity (Thematic Paper 9). This requires moving from a strict financial perspective (extraction costs, financial profitability in irrigation, financial cost of bulk water for water utilities, etc.), which is essential anyway, to a more comprehensive economic perspective that takes account of externalities and multiplier effects on macroeconomic variables – that is, a formal efficiency analysis) and a more complex analysis of social (i.e. equity) concerns. Economic analysis could also be able to shed some light on the economic cost of some management decisions within

an overexploitation context: inter-basin transfers compensation for potential (financial) losses to those farmers that have already contributed to overexploitation, public purchase of water rights etc.

**What to do when access to groundwater disappears**

At the limit of economic pumping or complete salinization of accessible groundwater, agricultural groundwater users may be able to move to other rural areas to practice farming or exit the rural rural economy altogether. Mixtures of this outmigration and partial return once aquifers have recovered have been observed in South Asia without a wholesale breakdown of rural economies. Options for urban communities who are reliant on local groundwater sources (Thematic Paper 2) are less flexible and imports of alternative water supplies have become standard solutions in post-industrial economies such as California as much as rapidly urbanizing developing countries in South Asia. At this stage it may also be important to look toward the frontiers of groundwater research and aquifer use (Thematic Paper 10) and consider provisions for the governance of these 'exotic' uses of aquifers before unintended environmental or public health impacts occur. For these reasons, it makes sense to always go back to the basics of aquifer recharge, storage and discharge (Thematic Paper 3) to evaluate the long-term impacts of development and judge where management of these processes, including conjunctive management (Thematic Paper 2), is viable in both technical and political terms.

**Structuring investment in groundwater governance**

The regional differentiation is important to stress. Groundwater governance targets will be conditioned as much by hydrogeological realties as expanding human demand for groundwater and related aquifer services. Being aware of the structural role of groundwater in economic development and how its use is shaping economic transitions may be higher priority for semi-arid countries seeking to stabilize rural economies (Thematic Paper 9). But even in humid settings where water scarcity does not appear to be a constraint for development, reliance upon a range of aquifer services for continued urban expansion can be locally intense. In either case, management of groundwater and aquifer services to sustain these uses will need a foundation in natural resource governance that recognizes the instrumental value of groundwater. For this reason, it makes sense to consider investment in 'soft' foundational steps. Among those steps that can be relevant;

- pull together aquifer and groundwater use information into a coherent, transparent baseline – patterns of groundwater dependency;
- make an institutional home for groundwater governance;
- establish user communities and their rights in groundwater use where management is required; and
- make transparency and accountability in groundwater supply and demand a requirement.

## Part 3: New horizons for governance - dealing with future uncertainties

### 11. Preparing for the anticipated impacts of climate change

Thematic Paper 12 has reviewed the range of groundwater related impacts that can be anticipated and the types of adaptation measures that are likely to be appropriate. The specific implications for groundwater are echoed in FAO (2010) as they relate to two main impacts;

- accelerated hydrological cycles and aquifer circulation; and
- shifts in land use and patterns of recharge and pollution.

The vulnerability of groundwater systems across different continents has recently been assessed (Thematic Paper 12) in relation to existing utilization, the effects of climate change on recharge and sea-level rise, and wealth; this is summarized in Table 4. As aquifers in humid and even semi-arid zones are intimately connected to streams and other water bodies, changes in aquifer level can lead to changes in network behaviour, such as the reversal from recharge from a river to discharge into it and vice versa.

**Table 4** Preliminary Assessment of Susceptibility of Groundwater in World Bank Regions to Climate Change (Thematic Paper 12)

| | Sensitivity | Exposure | | Adaptive capacity | |
|---|---|---|---|---|---|
| World Bank region | Utilization of groundwater | Climate change impact on recharge | SLR[1] & storm surge exposure | Per capita GNI[1] | Vulnerability[2] |
| **East Asia & Pacific** | Moderate | Increase | Medium | Moderate | Moderate |
| **Europe & Central Asia** | Low | Increase | Low | High | Low |
| **Latin America & Caribbean** | Moderate | Reduction | Medium | Moderate | Moderate |
| **Middle East & North Africa** | High | Uncertain | Low | Moderate | Moderate |
| **South Asia** | Moderate | Negligible | High | Low | High |
| **Africa** | Moderate | Reduction | Low | Low | High |

SLR – sea level rise; GNI – gross national income (in $US)
Vulnerability assessed from the sum of average of sensitivity and exposure ratings and adaptive capacity rating.
Groundwater utilization – low (2), moderate (4), high (6)
Impact on recharge – increase (2), uncertain/negligible (4), reduction (6)
SLR exposure – low (1), medium (2), high (3)
Per capita GNI – low (6), moderate (4), high (2) – relative to each other
Low vulnerability (<6), Moderate (6–9), High (>9)

**Accelerated hydrological cycles and groundwater circulation**

Aquifers have an important strategic value as accessible over-year stores of water in a relatively stable condition without evaporation losses. In addition, percolating water is naturally de-contaminated along diffuse recharge and circulation pathways. The development of groundwater has therefore been an important structural adaptation to drought and is likely to be more so in the future. Clearly this character of groundwater is of more strategic importance to potable water supply than agriculture since agriculture is generally indifferent to the quality of most freshwater stored in accessible aquifers. However, agriculture has been quick to exploit groundwater circulation and now accounts for over 80 percent of all groundwater withdrawals (Siebert *et al.*, 2010). Patterns of groundwater recharge drive groundwater circulation and are determined both by rainfall (direct recharge) and transmission losses along watercourses (indirect recharge). When localized alluvial aquifers are annually replenished, they have good connection to surface flows and are dependent on stream flow (duration and stage) and surface water bodies for recharge. Groundwater in such systems serves to buffer annual and seasonal variations in rainfall and runoff, and will require increasingly careful management for sustainable use.

How are arrangements for groundwater governance likely to change as a result of this?. First groundwater as a means of building resilience to reduced recharge and water scarcity will be a first order response, but there are other cases where climate change may present niches of enhanced aquifer recharge. The important point to recognise is that while levels of risk to existing hydrological regimes are broadly predictable, the uncertainty of cc on rainfall/runoff patterns is such that precise projects may be impossible. While temperature impacts and increased ET can be expected with a high degree of certainty, rainfall projections may simply add 'noise' with the result that no conclusive modelling of rainfall-runoff projections can be expected (Chiew et al, 2010).

**Changing patterns of land use and recharge**

The influence of land use on groundwater recharge is generally well documented in post-industrial economies where groundwater is an important component of potable supply (Thematic Paper 4). However, it will be important to understand the relative importance of base flow versus flood events in long-term recharge of alluvial aquifers. The role of forests in raising base flow, even while reducing overall runoff, needs more understanding. A good and clear understanding of the likely impacts of climate change on groundwater circulation is therefore very valuable, but is unfortunately bedevilled by the general uncertainty surrounding the prediction of rainfall and runoff under current conditions (Scanlon *et al.,* 2006) . The sustainability of groundwater use is determined by the rates of abstraction and recharge, and also quality of the recharge water. In broad terms, recharge is expected to be high where rainfall is high and vice versa. Recharge will also increase where permafrost thaws and may increase when runoff increases, particularly if over-bank flood events occur more frequently. Although there is a broad correlation between recharge rate and rainfall, replenishment in a specific aquifer is further governed by geology, topography and land use. Forested catchments tend to have lower rates of aquifer recharge than agricultural and cleared catchments, and afforestation, although desirable to sequester $CO_2$ , will probably reduce recharge; this would require compensation if groundwater resources are to be maintained.

## 12. Anticipating the impact of technologies and groundwater 'frontiers'

**Geophysical exploration**

The advances in earth science remote sensing and the application of petroleum exploration techniques to solve hydrogeological 'unknowns' (from rock characterization to geo-statistical appraisal of aquifer systems) can be expected to advance the precision and resolution of hydrogeological information. The degree to which this new information is interpreted to frame basic resource allocation questions remains to be seen. Generally, the application of high resolution geophysical surveys will remain expensive in relation to the budgets given for groundwater exploration and management. When public domain data such as the gravity anomaly data derived from the GRACE mission has become available, careful calibration and validation is required before the results can be applied at aquifer scale. (Doll et al. in press)

**Drilling and pumping technology**

The application of progressively advanced drilling technology is expected to make an impact in high value water well drilling at depth or in difficult (mixed matrix) geology while traditional methods of drilling (including manual methods, jetting, cable-tool, rotary, down-hole-hammer) will continue to be applicable. Costs of drilling (and hence access by private users) are only expected to come down where competitive markets in drilling can develop. Licensing of drilling contractors and obligations to file drilling reports with regulators are the corollary to open access to drilling technology – and the assurance of professional drilling and borehole construction standards. But in many cases the drilling industry is not regulated and opportunities for getting away with poor construction standards abound. In these cases, the adoption of national codes of practice for drilling and borehole construction makes sense. The limits of pumping depth and pump capacity are not expected to change significantly in the foreseeable future (Thematic Paper 8). What will change is the efficiency and reliability of groundwater pumping equipment – including the efficiency of solar panels and wind turbines. This will only intensify the pumping potential in both deep and shallow aquifers and extend areas of low intensity abstraction (though alternative energy sources). But apart from making the pumping technology more energy efficient and reliable, the access to technology and the responsible use of it in relation to aquifer properties that presents a specific governance challenge. In this respect, governance of groundwater pumping behaviour

**Further impacts on the built environment**

Subsidence as a result of aquifer drainage will continue to afflict urban and agricultural infrastructure and may be combined with groundwater rise in urban areas where industrial pumping has ceased and aquifer recovery has occurred (Thematic Paper 3). The institutional 'handle' on intensive agricultural use has been well explored, but the wholesale management of aquifers underlying urban areas may go beyond simple urban land use planning problem and involve management of aquifer zones in the urban hinterland as the risks to pollution of urban water supply and geotechnical stability become apparent. What happens to groundwater quantity and quality in these zones of 'transition' could be more significant in terms of economic and social impact. If there are options to import surface water and abandon groundwater sources then peri-urban aquifers may simply become accepted repositories of waste. But in many cases, particularly for the urban poor relying on self-supply, the depth at which groundwater can be obtained and its quality will remain critical livelihood issues.

**Implications of crustal encroachment**

Use of aquifers and adjacent geological structures for abstraction of shale gas (hydro-fracturing) or storage of gas (Evans and Chadwick, 2009) are now expanding the 'managed' underground space beyond the standard set of urban utilities and basement/bunker construction (Thematic Paper 10). At the same time, the use of groundwater circulation for geothermal energy and aquifers for carbon sequestration all involve decisions about who has the right to inject, withdraw and circulate groundwater.

**Evolution of environmental instruments and aquifer protection**

In addition to intervention of sovereign wealth funds in agricultural land acquisitions, the significance of global environmental agreements and treaties cannot be ignored. The 1992 UN Convention on Watercourses and the Draft Articles on Transboundary Groundwater may be explicit about groundwater as part of transboundary flow systems, the impact of other environmental treaties bears consideration. For instance the impact of Carbon Trading schemes under the Kyoto Protocol encouraging the sequestration of carbon in aquifers.

## 13. Conclusions and Recommendations

Overall, this Synthesis Report has highlighted the need to make a case for a global commitment to introducing and improving groundwater governance on the basis of a few principles or guidelines for implementation – but above all making the invisible visible. The regional contrasts and policy priorities will be significant, but overall this synthesis of groundwater perspectives on governance argues for a smarter, implementable approach to groundwater use and aquifer protection to sustain a set of critical aquifer services.

A general notion of 'sustainability' in terms of simple recharge and withdrawal budgets is not sufficient. Rather a more informed appreciation of how governance arrangements can be used to manage or relax aquifers under pressure is called for. Many solutions to conserve aquifer services in the long term may have sound technical and economic rationale but may not be politically viable.

The distinction between the governance of direct groundwater use and the governance of polluting behaviour that impacts the quality of groundwater in aquifers is important. Two, sometimes mutually exclusive, sets of actors are implicated and in many ways improving the governance of behaviour to maintain or improve groundwater quality may be more problematic than improving the governance of direct groundwater use.

Positive solutions – where they can be identified – have derived from direct engagement with groundwater users. This tends to confirm the overall observation that 'good' groundwater governance is likely to commence with 'socialisation' of users in ways that reveal their common interest in a particular aquifer. These interests may have nothing to do with long-term sustainability as such, but are more likely to be linked with health and livelihood concerns. Will our children be less ill in the future, will we be able to rely on this aquifer next year? Those whose livelihoods directly depend upon access to groundwater are making many complex but private decisions over their use of the resource and the technology to abstract it. Hydrogeology is also complex. For these reasons, the practice of management has to be straightforward if it is to change human behaviour.

There are more examples of experimentation with governance of groundwater in rural settings where agricultural use dominates and incentives to get aquifer management 'right' are high. Evidence from peri-urban and urban groundwater users in effecting collective approaches to aquifer are very few, even if the intensity of groundwater abstraction and dependency is more concentrated.

The set of Thematic Papers can sets the basis for investment in institutional arrangements that modify human behaviour in relation to aquifer use. The set of Thematic Papers that the project will continue to develop will serve as a basis for a Global Diagnostic and Framework for Action to influence human behaviour in relation to groundwater use and aquifer protectionThe need for improved groundwater governance to meet expanding human demands is emphasized. But it is also accepted that groundwater opportunities have already been foreclosed through neglect. Other groundwater development may expand if we can learn to 'play' with groundwater responsibly - in conjunction with surface water management and in tune with the political realities that overlie aquifers. Governance arrangements are fundamental in building this flexibility.

**Recommendations**

There are no hard dos or don't in promoting groundwater governance. The application of the enhanced governance principles outlined above will help. The physical and institutional diversity of the Latin American and Caribbean region alone will present specific challenges and opportunities. In order prompt discussion at regional level, four key recommendations emerge from the current 'stock taking' prepared by the project.

- ***Be imaginative in the presentation of groundwater messages.*** Groundwater theory may be complex, but effective practice has to be simple and straightforward if it is to be adopted at scales that will make a difference. Can more be done to first arrive at scientifically robust groundwater assessments and then get the essential technical messages across before it is too late?

- ***Determine who is really implicated in applying principles of 'good' groundwater governance.*** The overall institutional environment, including national legal frameworks for water management may or may not be sufficient, but the local institutional arrangements tend to determine governance outcomes. Before adjusting the former, has enough been understood about the latter?

- ***Account for the benefits and costs of groundwater development.*** If groundwater itself is 'invisible', then the groundwater economy is likely to be even more so. A clear account of how groundwater quantity and quality allow a national economy to function is a fundamental requirement in making a case for groundwater governance. Equally important is an account of the social and environmental impacts of development – the externalities associated with groundwater drawdown and pollution.

- ***Innovate in the application of technical groundwater management and the inclusion of the real groundwater players.*** The managers of groundwater could do more to innovate in the use of groundwater storage and aquifer services – from conjunctive use to maintain municipal water supplies to the safe use of natural remediation properties in aquifers. However, they also need to be equally innovative in collaborating with public and private institutions to obtain more leverage for groundwater governance. Industry, agriculture, municipalities and major manufacturing sectors can be guilty of aquifer depletion and degradation – but they can be key in reducing stresses. This should be a strong incentive for groundwater managers and policy makers to be more pro-active in their engagement with national integrated water resource management and with the preparation of forward looking investments related to strengthened groundwater governance.

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IAH lead:
1. Trends in groundwater pollution; trends in loss of groundwater quality and related aquifer services (inc. ecosystems);
2. Conjunctive use and management of groundwater and surface water.
3. Urban-rural tensions; opportunities for co-management.
4. Management of recharge/discharge processes and aquifer equilibrium states.

UNESCO lead:
5. Groundwater Policy and Governance
6. The legal frameworks for sustainable groundwater governance: at local, national, regional and international levels

FAO :
7. Local groundwater management institutions/user partnerships.
8. Social adoption of groundwater pumping technology and the development of groundwater cultures.
9. Macro-economic trends that influence demand for groundwater and related aquifer services.
10. Governance of the underground space and groundwater frontiers

World Bank
11. Political economy of groundwater governance
12. Water and Climate Change: Impacts on groundwater resources and adaptation options (http://water.worldbank.org/water/publications/water-and-climate-change-impacts-groundwater-resources-and-adaptation-options)

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