by Stephen Foster

Groundwater—sustainability issues and governance needs

IAH President, World Bank GW-MATE Director. E-mail: IAHFoster@aol.com

This paper provides a global overview of groundwater resource sustainability concerns and corresponding governance (management and protection) requirements, with special emphasis on the developing world and on Asia in particular. It is based on an opening plenary address to the International Association of Hydrogeologists (IAH) 34th Congress on the theme 'Groundwater — Present Status & Future Tasks', celebrated in Beijing, China in the year of the IAH 50th Anniversary on 9 October 2006.

Groundwater—present resource status

The boom in resource development

Groundwater is vital to very many nations, irrespective of their stage of economic development. Worldwide some 2.0 billion people and large numbers of industrial sites rely on continued access to groundwater for their water-supply, whilst irrigated agriculture is the major abstractor and accounts for by far the largest consumptive use. Today, with an estimated total global withdrawal of 600–700 km³/a, in one sense, groundwater is the 'world's most extracted raw material'.

The exploitation of groundwater resources for human use dates from the earliest civilizations. But massive resource development commenced in the industrialised nations from the 1950s and in the developing world from the 1970s — facilitated by improved hydrogeological knowledge and technological advances in waterwell drilling and in pump technology.

Comprehensive statistics on abstraction and use are not available (and figures vary widely from country to country and also across individual countries), but globally groundwater is estimated to provide at least 50% of current potable water supplies, 40% of the demand of those industries that do not use urban mains water, and 30% of water-use in irrigated agriculture.

Groundwater resource development has generated enormous socio-economic benefits by providing high-quality, low-cost, drought-resilient, water-supplies for urban areas, rural welfare and commercial agriculture (for example: supplying about 70% of EU drinking water, 80% of rural water-supply in Sub-Saharan Africa and 60% of Indian agricultural irrigation). As a result, many countries today have large 'groundwater-based economies' and aquifer storage plays a critical role in 'drought-proofing' economic development.

Concerns over degradation of the resource base

Whilst groundwater storage in aquifers is vast (representing over 99% of global freshwater reserves), replenishment is finite and its quality can be degraded. Inappropriate resource development for agricultural irrigation and urban water-supply (including depletion of reserves in some strategic aquifers) is widely leading to excessive groundwater level decline (Figure 1). This can frustrate poverty alleviation by reducing access to groundwater and mobilising naturally-occurring contaminants, and also sometimes results in aquifer salinisation (Figure 2), land subsidence and damage to wetland ecosystems.

Of equal concern is the widespread pollution of groundwater due to inadequate protection from urbanization processes, industrial discharges and agricultural intensification. Groundwater pollution consequent upon human activity at the land surface has been reported with increasing frequency over the past 20–30 years. Many more incidents are likely to be occurring as yet unobserved, as a result of the generally inadequate level of current groundwater quality monitoring. While aquifers are much less vulnerable to anthropogenic pollution than surface water bodies, *when aquifers become polluted, contamination is persistent and difficult to remediate* as a result of their large storage, long residence times and physical inaccessibility. The more spectacular groundwater pollution incidents (with large plumes of high concentration) are associated with industrial point sources from major accidental spillage or casual discharge. However, more insidious and persistent problems are associated with unsewered urban development and with diffuse pollution generated through intensification of agricultural cultivation.

Different aquifer types exhibit a wide variation in terms of their susceptibility to depletion side-effects and of vulnerability to pollution from the land surface. And, globally, data with which to assess the status of aquifer degradation are of questionable reliability, inadequate coverage and poor compilation. Recourse has to be made to 'type examples' and assumptions about the extension of comparable hydrogeological settings likely to be experiencing similar conditions of groundwater demand and subsurface contaminant load. But it can be concluded that aquifer degradation is much more than a localised problem and the sustainability of the resource base is threatened on quite a widespread geographical basis.

Groundwater also naturally plays an integral role in:

- sustaining certain ecosystems and landscapes in humid regions,
- supporting unique aquatic ecosystems in more arid regions and coastal belts,
- providing moisture to some extensive semi-arid and humid deep-rooted terrestrial ecosystems.

In some of the many intensively-developed aquifers of the more arid and/or densely populated regions, the 'environmental function' has already been largely lost as a result of extensive water-table lowering. Others are threatened both by indiscriminate groundwater development and equally by deterioration in groundwater quality, especially due to diffuse agricultural pollution (nitrate, phosphate, pesticides).

Root causes of resource unsustainability

In many countries, a substantial proportion of the large investment in groundwater development has been raised by private initiative or promoted by national or local government agencies with a purely 'groundwater development remit'. The widespread absence of effective groundwater management agencies, and frequent disinterest in local groundwater issues at river-basin agency level, has widely meant that adequate governance of the resource base has not occurred. Further development and conservation of groundwater will be vital for economical achievement of the UN-Millennium Development Goals (MDGs) and to sustain human livelihoods, food security and poverty alleviation already achieved from groundwater use.

All too often groundwater has remained a 'neglected resource', with funding for the improvement of resource understanding, management and protection coming at the bottom of the 'environmental

league table'. There remains a widespread lack of understanding of groundwater linkages and dependencies, including the critical link with land-use practices in aquifer recharge zones. Too many still regard groundwater as an unlimited and uncoupled resource, and this needs to be progressively corrected by political and public education. Beyond this there will be an enormous need for groundwater resource administration and management capacity building in gen-

eral and for strengthening appropriate institutional provisions, demand-side management and pollution control in particular.

Groundwater reservoirs are predictable and manageable given reasonable scientific diagnosis, adequate monitoring and effective institutional provision - and this in turn requires sustained political commitment and prudent investment via an appropriate management framework with stakeholder co-responsibility.

Figure 1 Stages of groundwater resource development in a major aquifer and their corresponding management needs.

If the condition of unstable development arises it is likely to result in a loss of potential yield even after balance is achieved, as a result of aquifer degradation; the illustration does not include consideration of downstream dependencies on aquifer discharge nor of temporal variations in aquifer recharge rates which can arise as a result of a range of independent causes.

Those marked * are a direct consequence of locally excessive groundwater abstraction but those associated with soil concentration + are widely distributed.

Figure 2 Principal processes causing aquifer salinisation.

There are significant areas of the globe where serious groundwater (and soil) salinisation have developed through: (a) excessive disturbance of natural groundwater salinity stratification through uncontrolled well pumping; (b) natural salinity having been mobilised from the landscape (consequent upon vegetation clearing for farming development with increased rates of groundwater recharge); and (c) rising groundwater table (associated with the introduction of inefficient irrigation with imported surface water in areas of inadequate natural drainage).

IDENTIFICATION OF KEY MANAGEMENT ISSUES BY WATER-USER SECTOR

Groundwater in Rural Water-Supply

Groundwater availability is critical to cost-effective rural water-supply provision. This is often managed on a 'community driven basis' (with NGOs and LGOs being the main providers of the capital works), but policy and practice needs to be better informed by hydrogeology. Procedures to secure the transfer and flow of knowledge (including website dissemination of operational success stories) and of benchmarking operational practices (choice of tools, equipment and personnel) are urgently required. In many cases hydrogeologically-difficult areas for low-cost water-supply coincide with current non-achievement of the MDGs — and such areas will require focused research to address problems of low yielding strata and natural groundwater quality hazards, which result in decreasing efficiency and escalating cost of rural water-supply provision but can be overcome with appropriate information and management.

Groundwater in Urban Water-Supply & Sanitation

Groundwater is of major importance in urban water-supply because of its use for public water-supply sources, growing numbers of small-scale service providers and a very high level of self-supply both in peri-urban areas to meet the basic MDG provision and by high-income families for luxury use.

In many ways urban groundwater resources are 'going backwards' — with problems of resource depletion and groundwater pollution growing faster than solutions. There is urgent need to take stock of, and evaluate risks to, all available water resources of developing cities, and not just the 'water utility component' which often does not reach 50 % of the total. Moreover, abandoning groundwater use may lead to very serious inundation, sanitary and infrastructure problems, due to water-table rebound.

The frequent absence of data on the status and trends of urban groundwater represents a significant long-term operational risk for water utilities, discouraging private-sector investment and increasing costs for municipal operators. Moreover, the 'integrating role' of groundwater systems (in terms of water-supply, wastewater disposal and drainage) and the threats posed by their interaction are not adequately recognised.

The loss of drinking water-supply capacity due to groundwater source pollution is significant and makes the task of meeting the water-supply MDG all the more onerous - with wastewater interactions being a key concern. Groundwater source protection can invariably be justified on straightforward economic criteria but often does not happen due to institutionally unclear and/or split responsibilities — and groundwater considerations need to become a primary factor in sanitation planning and land-use negotiations.

Groundwater for Irrigated Agriculture

Groundwater-based irrigation has reaped great benefits both to staple and cash-crop agriculture — this because of its farmer control, reliability during drought and sediment-free characteristics. It is generating more crops and jobs per drop (has higher water productivity) than most surface water irrigation. But for commercial growers groundwater pumping is usually only a small part of total production costs and thus, if access is unconstrained and land available, excessive exploitation will result. In some cases unplanned and uncontrolled depletion has led to severe competition — with escalating cost for basic rural water-supply provision and for subsistence farmers, which increases social inequity.

The key to confronting the resource management needs in areas of groundwater-irrigated agriculture is the development of locally-based government agencies to act as the 'guardians of groundwater', which catalyse full community participation in use management - backed by a simple enabling legal framework. In this context a number of important questions arise:

- how should technical understanding be made available to inform and constrain decision-making without making the process expert-dominated,
- how can the tendency of consensus decision-making to 'empower reactionaries' and 'disempower progressives' be counteracted, especially given the inevitable existence of hydrogeological uncertainty,
- which form should sanctions take in case of repeated non-compliance with community-agreed rules, and who should be responsible for their application.

There is a pressing need to optimise and/or to constrain agricultural use of groundwater in the interest of long-term resource sustainability in many areas. The main challenge is demand management to achieve physically-sustainable use, or (in some cases) planned depletion allowing time for a clear social exit strategy associated with economic transition.

It is important that groundwater resource availability is presented more clearly, so as to educate users to live within hydrogeological constraints. The ultimate target must be reducing consumptive use (especially non-beneficial evaporation) and not simply improving irrigation water efficiency. The approach of providing concessions on investment for improving irrigation water-use efficiency in exchange for a clear and measurable reduction in overall groundwater abstraction (and in reality evaporation) rights will be central to achieving hydraulic equilibrium in many over-committed aquifers.

Groundwater—future governance tasks

Nature of resource management and protection task

Groundwater is a major challenge in the field of natural resource management as a result of:

- it being a widely-distributed resource responding at basin scale but affected by a plethora of local users and polluters (farmers, small industry, communities, municipalities, etc),
- the behaviour of users and polluters being influenced by national policy decisions affecting land and water use (such as crop and energy pricing, etc).

Thus governance systems, resource policies and information provision need to relate to a wide range of scales and audiences. Moreover, different approaches to management are needed in the rural and urban environment.

Sustainable groundwater utilization requires actions to be taken at two different administrative levels (Figure 3):

- **macro-economic policy interventions** — because groundwater demand is strongly influenced by national subsidies (on water well drilling, electrical energy, food crops) which affects groundwater-based agriculture and the rate of transition to less water-dependent livelihoods
- **local-level management measures** — to create effective institutional arrangements (empowered government agency, adequate legal framework, user awareness/participation, groundwater abstraction charging, land-use constraints) to regulate and protect groundwater resources.

A key institutional requirement in many countries for improving groundwater management at field-level will be to transform the role of the government agencies responsible for groundwater from exclusively 'supply-development' to primarily 'resource-custodian' and 'information-provider', and to ensure that such agencies fully engage groundwater users and stakeholders in a participatory management process.

Proactive groundwater management

There is no simple blueprint for action, due to the intrinsic variability of both groundwater systems and socio-economic situations, which have to be reflected in the appropriate management strategies and priorities. It is always feasible to make incremental improvements in groundwater governance and the approach taken should

Figure 3 General institutional scheme for groundwater governance involving both 'top-down' and 'bottom-up' actions.

In most cases it will be most appropriate to consider 'economic measures' in the context of macro-level national pricing policies and 'demand management measures' will be, of necessity, amongst the possible micro-level local intervention.

depend to a considerable degree on information about (and interaction between) the following factors:

- the size and complexity of the groundwater resource,
- the degree of climatic aridity and the rate of aquifer recharge and resource renewal,
- the scale of groundwater abstraction and the number and types of groundwater users,
- the ecological role and environmental services dependent upon groundwater,
- the susceptibility and vulnerability of the aquifer system to degradation,
- natural groundwater quality concerns (trace element hazards and saline water presence).

A number of key technical and institutional lessons in relation to the governance of groundwater resources have been learnt (Figure 4).

In the context of the groundwater resource balance, the common paradigm of 'constant average rates of present-day aquifer recharge' is false and can lead to serious 'double resource accounting', especially in the more arid regions. In reality, the contemporary rate of aquifer recharge varies considerably with:

- changes in land use and vegetation cover, notably introduction of irrigated agriculture with imported surface water, but also with natural vegetation clearance and soil compaction,
- the urbanization process, and in particular the level of water-mains leakage, the proportion of unsewered (in-situ) sanitation and the degree of land-surface impermeabilisation,
- changes in surface water regime, especially diversion of riverflow,
- lowering of the water-table by groundwater abstraction and/or land drainage, leading to increased areas and/or rates of infiltration in some aquifer systems
- longer term climatic cycles, there remaining considerable uncertainty over the impacts on groundwater systems of the current global warming trend.

These variations mean that groundwater recharge (and thus resource potential) estimates have to be treated with caution.

Because groundwater is a 'highly decentralized resource', and one often developed by private initiative, its management and protection will not be effective without proactive social participation. But government agencies (as the 'guardians of groundwater' in the public interest) will have to make the 'first move' by taking the following steps:

- profiling groundwater users, and thereby understanding the socio-economic importance of the resource and assessing the risk of 'non-action' in respect of resource regulation and pollution control,
- prioritizing entry points to the governance process on a probable cost/potential outcome basis, taking into consideration the need to reconcile 'bottom-up' with 'top-down' actions,
- selecting 'pilot areas' to try out participatory groundwater resource management and quality protection — the boundaries of such areas (and subsequent aquifer management areas) should normally be defined on the basis of groundwater bodies with specific management needs.

Some key questions that often arise in relation to groundwater management and protection are:

- **Whether management interventions are always necessary?**

Although some low-storage aquifers are 'naturally regulating' (in extended periods of drought, well yields fall without damaging side effects or extensive third-party interference), abstraction control is usually needed to protect drinking water supplies and environmental flows—this can be achieved most directly through well-spacing rules or drilling constraints.

GENERIC LESSON 4	<i>although not capable of rigorous definition, the term 'aquifer overexploitation' should not be abandoned altogether because of its clear register at public and political level</i>
GENERIC LESSON 6	<i>groundwater management must critically assess the susceptibility of aquifer systems to adverse side-effects when subjected to temporary and long-term overdraft</i>
GENERIC LESSON 7	<i>if exploitation of non-renewable groundwater reserves is carefully-planned it can form part of a logical social development strategy</i>
GENERIC LESSON 9	<i>'demand-side interventions' will usually make a more significant long-term contribution to stabilising aquifer water balances than 'supply-side interventions'</i>
GENERIC LESSON 10	<i>a common fallacy is to assume that increasing 'irrigation water-use efficiency' invariably leads to 'ground water resource conservation', in practice the reverse is currently often the case</i>
GENERIC LESSON 13	<i>to mobilize effectively on groundwater management it is essential to have a systematic database of water-users or 'user groups', their use patterns and socioeconomic characteristics</i>
GENERIC LESSON 14	<i>regulating well construction — their numbers, depths and diameters -- is a key component in the control of groundwater abstraction</i>
GENERIC LESSON 15	<i>delineating aquifer management areas and promoting aquifer management organizations with balanced stakeholder participation are key management steps</i>
GENERIC LESSON 16	<i>establishment of groundwater abstraction rights is useful for mobilising user participation in resource management and eventually for resource reallocation</i>
GENERIC LESSON 17	<i>abstraction charging is an important demand management tool but a transparent and acceptable basis for determining use is an essential pre-requisite for effective implementation</i>

Figure 4 Some key generic lessons relating to developing a practical approach to the management of groundwater resources in intensively-developed aquifers.

These lessons are selected from a longer list identified by the World Bank's Groundwater Management Advisory Team (GW-MATE).

- **Can management actions be taken without adequate aquifer characterization?**

Here a 'parallel-track approach' is strongly advocated, making incremental improvements in management provisions while continuing to advance aquifer investigation and monitoring.

- **Can resource deficits be met by supply-side measures alone?**

In reality focused demand-management will also be essential in the longer run, since aquifer recharge enhancement is likely otherwise to stimulate increased groundwater abstraction.

- **Should conjunctive use of groundwater and surface water be practised?**

Where feasible planned conjunctive use will be advantageous, but for agricultural irrigation it is still often an incidental, sub-optimized, process and significant obstacles posed by existing land tenure and surface water rights have to be overcome.

- **How should the ecosystem and environmental function of groundwater be evaluated?**

In all situations the benefits of further development need to be carefully weighed against the costs of negative impact on groundwater environmental services, and understanding the groundwater flow regime and relative ecosystem dependence of shallow versus deep groundwater flow paths will be the key to identifying and balancing protection needs — but more research will normally be required to determine a reasonable 'groundwater resource allocation' for the environment and con-

siderable water resource administration skill will then be needed to introduce this as a constraint on the expectations of other users.

In relation to groundwater pollution threats, the major management task is one of protection. This requires sustained institutional action to identify 'hazardous activities' and 'vulnerable areas' (Figure 5) and thereby mobilising their participation in pollution control.

Figure 5 General technical basis for land-surface zoning in relation to groundwater pollution risk and protection measures.

Protocols for groundwater pollution vulnerability mapping and delineation of protection perimeters around supply sources are now well established and widely available.

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Stephen Foster has extensive experience in groundwater research, consulting and advisory work—with a wide variety of practical application both in his native Britain and worldwide. His more recent professional posts include WHO—Groundwater Advisor for Latin America & Caribbean (1986–89), BGS Chief Hydrogeologist (1989–91), BGS Divisional Director "Groundwater & Geotechnical Surveys (1991–99) and World Bank—Groundwater Management Team Director (2000–07). He is also a very active member of IAH, having been Vice President—Western Europe (2000–04) and elected President (2005–08). He is author of some 150 papers and reports.

Hutchison 'Young Scientist' Fund

William Watt Hutchison, "Hutch" to his many friends around the world, was a Scots-born Canadian geologist who served Canada and the IUGS in myriad dynamic and creative ways. Most notably, he served as the IUGS Secretary General (1976–1980) at a pivotal time in its history, and as IUGS President (1984–1987). The same boundless energy, enthusiasm, skill in communications, and ability to foster teamwork that characterized his work with the IUGS also carried him to preeminent scientific administrative positions in the Canadian Government, where he served as Director General of the Geological Survey of Canada and as Assistant Deputy Minister of Earth Sciences. His distinguished career was terminated in 1987 by his untimely death at the age of 52, following a painful struggle with cancer.

One of Hutch's last wishes was to establish under IUGS auspices a memorial foundation intended to promote the professional growth of deserving, meritorious young scientists from around the world by supporting their participation in important IUGS-sponsored conferences. The first 3 beneficiaries of the *Hutchison "Young Scientist" Foundation* attended the 28th International Geological Congress (IGC) in Washington, D.C., in 1989.

Initially, interest on the funds available to the Hutchison Foundation were insufficient to sustain comparable grants every four years without seriously eroding the principal. For that reason, the IUGS made no grants from the Foundation for the 30th IGC (1996), preferring instead to strengthen the fund by allowing it to earn interest for a longer period of time and by appealing for donations from the international geologic community. Grants from the Foundation again supported deserving young scientists beginning with the 31st IGC (2000), and should continue for future Congresses. The IUGS would like to expand the resources of the Foundation to make it possible also to offer support to deserving young scientists to attend other important IUGS-sponsored scientific meetings. The *Hutchison "Young Scientist" Foundation* is a worthy cause that honors a fine, caring man and a distinguished, public-spirited scientist and administrator. The foundation also celebrates and promotes those things that gave Hutch the most professional satisfaction: geology, international scientific collaboration, and stimulating young minds.

The IUGS welcomes contributions to the *Hutchison "Young Scientist" Foundation*. Please send donations to:

Dr. Antonio Brambati
IUGS Treasurer
Dept. of Geological, Environmental and Marine Sci. (DiSGAM),
University of Trieste, I-34127 Trieste, ITALY
Tel: +39 040 558 2046; Fax: +39 040 558 2048
E-mail: brambati@univ.trieste.it

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