EVOLUTION OF DEVELOPING CITY GROUNDWATER PROTECTION POLICIES: STAKEHOLDER CONSULTATION CASE STUDIES IN BANGLADESH AND KYRGHYZSTAN

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Abstract. The pressure of rapidly expanding urban populations in groundwater-dependent cities in the developing world is a major groundwater management issue. City planners in emergent economies realise that water resources are finite but wrestle with the need to introduce sustainability into their plans for infrastructural improvement without unnecessarily constricting economic expansion by overly restrictive policies. Realistic considerations of enforcement ability make it vital to involve urban groundwater stakeholders as early as possible in policy development if urban aquifer protection is to stand any chance of success. The experience of two such developing cities in Bangladesh and Kyrghyzstan is described where despite a limited resource and knowledge base attempts are being made to develop a locally appropriate and acceptable groundwater protection plan along sound hydrogeological principles. In both cities, the novel exercise of stakeholder consultation was considered by participants to be a welcome innovation.

Resumen. Un tema importante de la gestión de las aguas subterráneas es el crecimiento de poblaciones urbanas en ciudades del mundo en desarrollo cuyo suministro depende exclusivamente de aguas subterráneas. Los planificadores de ciudades en economías emergentes comprenden que los recursos de agua son finitos, pero se enfrentan con el dilema de introducir sostenibilidad en sus planes para mejorar la infraestructura sin restringir innecesariamente el desarrollo económico por aplicación de políticas excesivamente restrictivas. La protección de los acuíferos urbanos pude lograrse siempre que se logre incorporar a los interesados de recursos urbanos de aguas subterráneas lo más rápidamente posible en el desarrollo de políticas de protección. Se describe la experiencia de ciudades en Bangladesh y Kyrghyzstan donde, a pesar de poseer una base limitada de recursos y de conocimientos, se intenta desarrollar un plan de protección de las aguas subterráneas que se ajuste a las necesidades y expectativas locales, y que responda a sólidos principios hidrogeológicos. En ambas ciudades, el ejercicio de consultar a los interesados es una novedad, pero el grado de respuesta ha permitido esbozar las bases de políticas de gestión de los recursos hídricos.

Keywords: Groundwater, protection, developing countries, urban growth, stakeholder, water management

NEED FOR URBAN AQUIFERS TO BE MANAGED FOR CONSERVATION

Global trends in urbanisation mean that by 2010 it is estimated that half the world's predicted population of 6500 million will live in towns or cities, UNCHS (1987). 85% of urban population growth between 1980 and 2000 was concentrated in the developing world, such that by the year 2000, about twice as many people were living in cities in developing countries (1900 million) as in the developed world (950 million). Fair access to water supply and sanitation has always been a key issue in expanding cities but the sheer scale and extent of global urbanisation is placing unprecedented pressure on regional water resources around urban agglomerations UNEP, (1996).

The ability to replace a degraded urban aquifer by water tapped from the hinterland is a fast-receding luxury because increasingly such catchment resources may already be fully utilised for agricultural or ecological purposes Burke and Moench, (2000). Coupled with moves in the spirit of the 1992 Earth Summit manifesto (signed by more than 150 countries) demands are increasing to introduce sustainability principles into new water supply projects. In future, a city fortunate enough to possess a significant urban aquifer resource will no longer be able to assume that it is a discardable asset that can just be abandoned once depleted or heavily contaminated. Added to the issue of resource equity is the growing realisation that the water infrastructure of a city and an underlying aquifer system are interdependent. Mis-management, or more commonly absence of management, can result in the same city experiencing drastically falling water levels during early expansion followed by groundwater flooding at later development stages (Morris *et al.*, 1997), or incurring unforeseen and expensive future treatment costs to counteract the results of persistent contamination due to poorly planned/controlled activities at the land surface (Ahmed *et al.*, 1998; Seddique, 1998).

It is thus a major urban challenge to introduce not only aquifer protection principles into municipal planning but also to engender a greater ownership of such policies by all users of the urban subsurface in order to make them enforceable. This paper describes results from an ongoing collaborative research project[1] which seeks to demonstrate how such principles and a corresponding sense of ownership can be introduced into the dynamic but frequently impoverished world of small but fast expanding cities.

BACKGROUND TO PROJECT

The project commenced in late 1998 in the two developing cities of Narayanganj, Bangladesh and Bishkek, Kyrghyzstan with the following objectives:

- To employ available data to conduct aquifer vulnerability and subsurface contaminant load surveys to provide pollution risk assessments in each case study city,
- To use these assessments to engage groundwater stakeholders in the development of policy options for a city groundwater protection plan comprising a concise set of policy guidelines and a groundwater resource-planning map.
- To generalise the lessons learnt from the case studies for wider use by other groundwater-dependent developing cities.

The rationale of the project is to demonstrate whether practical aquifer protection policies can be developed using the urban groundwater management prescriptions espoused by the World Bank (Foster *et al.*, 1998), yet remaining within the limited financial/institutional resources typically available to managers and planners of the water infrastructure of an emerging-nation groundwater-dependent city.

The first objective of the project (pollution risk assessment) has been reported on in Morris *et al* (2001), and this paper describes the stakeholder consultation process.

URBAN PROTECTION POLICY CONSIDERATIONS

Why urban aquifer protection plans are uncommon

Globally, despite the widespread acceptance, in the abstract, of the benefits of groundwater protection, urban aquifer protection plans are, in practice, still unusual. This has been ascribed (Morris *et al.,* 1997) to:

– *Inability to see 'the big picture'*- wells may be drilled by a single utility or by any of hundreds of private users, fragmenting the knowledge base; problems such as overdraft or water quality deterioration are thus less easy to identify in their early stages; borehole construction is usually incremental and needs relatively low investment levels so it is less likely to be the subject of a city master water plan

– *Sustainability linkage unrecognised*- for the general public, reaction/residence times of water in observable features such as rivers are much easier to grasp than groundwater timescales; the strong sustainability focus of a resource whose pollution response and replenishment time-scales are typically measured in years→decades→centuries rather than hours→days→weeks is not so widely appreciated. The political outcome of this is 'out of sight, out of mind'.

– *Lack of data obscures 'the clear picture'*- Many urban water databases are not consciously linked to a management need, particularly early-warning surveillance. So when aquifer assessment is undertaken the results are often highly qualified because much laboriously collected information is found to be either inapplicable or inappropriate; such qualifications are necessary but hinder policymaking decisions

Therefore, despite the high dependence of both case-study cities on local groundwater, it was not at all surprising that neither had an aquifer protection strategy and that in effect, groundwater has been developed opportunistically in each case

Need for pragmatic design criteria

Any set of aquifer protection policies to be applied to an already-existing urban area will need to evolve strategies which, while they constrain land-use, accept trade-offs between competing interests and utilise the natural contaminant attenuation capacity of the strata overlying aquifers (Foster and Skinner, 1995). To implement such strategies hydrogeological understanding needs to inform land-use policies and provide simple robust matrices that indicate what activities are possible where, at an acceptable risk to groundwater. In turn, construction of such matrices requires pragmatic design criteria if planning is not to be so delayed as to irretrievably prejudice resource sustainability. Such criteria, which need to be targeted <u>from the outset</u> for a subsequent policy development and

[1] UK Dept for International Development KAR Project R7134, Groundwater Protection and Management for Developing Cities

aquifer management stage, include:

- *Uses available data:* The typical situation would be that projects of this type would be resourced only to use existing data *i.e.* either basic data arrays already collected for other purposes, or simple parameters easily collated from operational records. In Narayanganj, the standard of basic hydrogeological data was relatively poor, being limited to a handful of borehole logs in the centre of the city. In Bishkek, the standard of basic hydrogeological data was good, being comprehensive in parameters covered (geology, hydrogeology, water levels, location of wells etc), internally consistent and relatively up to date (mostly less than 20 years old). In both cities however routine monitoring information was poor or out of date, so that trends in aquifer usage and water quality were unknown.
- *Employs transparent tools:* To facilitate wide uptake, the tools used need to be simple and robust so they can be generalised to many different city situations with relatively little modification. The process needs to be relatively rapid, low cost and easy to undertake with limited human, technical and financial resources. For example, while digital GIS techniques were used in these case-studies to permit easy overlay of thematic material for map production, the number of stages was small enough and the ranking system simple enough for manual overlay techniques to have been employed if local resources had so dictated. A corollary is that the use of now widely available GIS software packages should not obscure the quality (or sparseness) of underlying data. Even more importantly, where it proves impossible to avoid using qualitative (but still objective and rational) techniques, these need to be openly but not deprecatingly described as such, in order to avoid loss of confidence in the policy development process if new data/new techniques become available and signal the need for future changes
- *Comprehensible to stakeholders:* In many cases important and influential stakeholders involved in urban water management decisions do not have a technical background either in engineering or in resource planning. Professional hydrogeological expertise in city water management is generally absent, and municipal water supply utilities may be more focussed on day-to-day operational needs of the present system, even where groundwater is a major urban resource. This was the case in both Narayanganj and Bishkek, where urban water management decisions do not appear to involve resource-knowledgeable institutions. Thus while the underlying rationale may be subtle, and the technical background complex, urban water management discussion documents need to be simple, clear and concise enough to engage municipal decision-makers with a minimum of technical jargon.

Precursor stages to the stakeholder consultation process

These three design criteria were employed not only at stakeholder consultation stage but also at the preceding pollution risk assessment stage, where the principal aim was to produce a single map that could be used by municipal planners and decision makers (the Groundwater Resource Planning Map or GRPM). Precursors to the GRPM were intended to inform and act as reference material for water resources specialists and included a succession of maps (Figure 1): groundwater vulnerability map or GVM, potentially hazardous activities map or PHAM, superimposed GVM and PHAM or 'hotspot' map (see Morris *et al*., 2001 for a fuller description of this process).

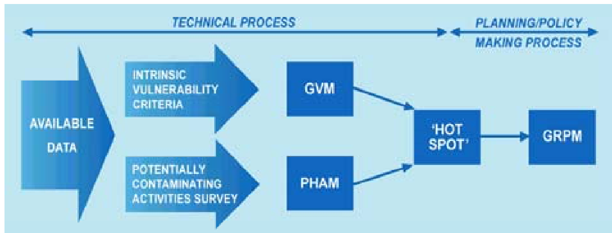

Figure 1. Evolution of component parts of a groundwater resource-planning map (GRPM)

The production of the maps served two purposes:

- Provision of much background hydrogeological and environmental information concisely, in a comprehensible format available for reference if required, to stakeholders who may be technically-oriented but would be unlikely to be drawn from hydrogeologically-related disciplines.
- Informing the project team's conceptualisation of how the aquifer system was likely to respond to urbanisation pressures, especially those likely to result in deterioration in raw water quality.

The maps were complemented by profiles of each city's groundwater setting and the corresponding water infrastructure using an urban questionnaire tool (Calow *et al.*, 1999). Extracts from these are provided in the next section. It was notable however that the Groundwater Resource Planning Map itself did not evolve until policy formulation and stakeholder consultation had been almost completed, because that exercise guided what each city's map would emphasise.

CASE-STUDY CITY PROFILES

Narayanganj, Bangladesh

Physical setting: (from Morris *et al.,* 2000) Narayanganj is a small city of about 1 million population, located 20 km south-east of Dhaka on the flat Ganges-Brahmaputra-Megna alluvial plain of central Bangladesh. A long-established industrial centre for the jute and hosiery industries, Narayanganj's proximity to Dhaka has favoured the recent development of light industry, and it is now a national textile manufacturing centre, with factories undertaking all stages of production from spinning, dyeing/bleaching and weaving through to the making of garments and other finished cloth products. Other industries include soap-making, metal re-rolling and metal and wood furniture manufacture. The rapid and unchecked growth of Dhaka into a megacity of 10 million inhabitants has seen inexorable encroachment on the rural hinterland west of Narayanganj, and the city is likely in the mid-term to become an industrial satellite suburb of Dhaka. It had itself a high estimated annual growth rate of 5.8% per annum during the 1990s.

Hydrogeological setting: Narayanganj is underlain by an unconsolidated alluvial aquifer system of Quaternary age which is many hundreds of metres thick across the entire project area but in which only the top 250 m (and principally the top 150 m) is utilised for groundwater supply purposes. Complex lateral interdigitation of medium to coarse sands occurs with finer-grained sands, silts and clays. As a first approximation the system is considered to comprise an upper aquitard covering a shallow aquifer which is separated from a deeper more productive aquifer by a lower much thicker aquitard (Figure 2).

Vertical connectivity is likely to be variable, depending on thickness and frequency of occurrence of fine-grained strata at any given location and it is probable that there is hydraulic connection with the Sitalakhya River whose channel is deep enough to incise into the upper aquifer sequence.

Bishkek, Kyrghyzstan

Physical setting: (from O'Dochartaigh *et al,* 2000) Bishkek has a population of approximately 800,000 and lies on the northern flanks of the Alatau range of the Tien Shan mountains in northern Kyrghyzstan. It is the country's capital and industrial centre and has witnessed changes since independence, notably the decline of the once-dominant Soviet military-industrial sector, and the increase in small private businesses, often with

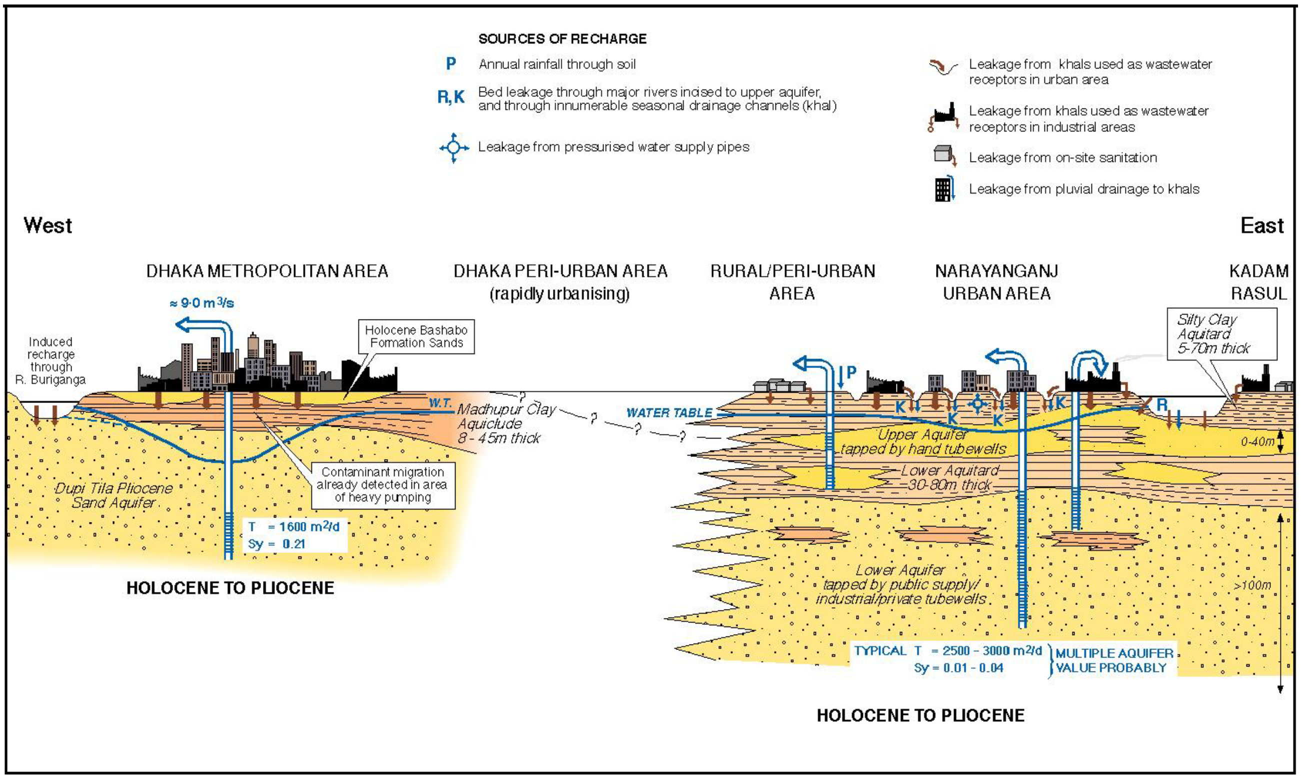

Figure 2: Groundwater setting of Narayanganj, Bangladesh

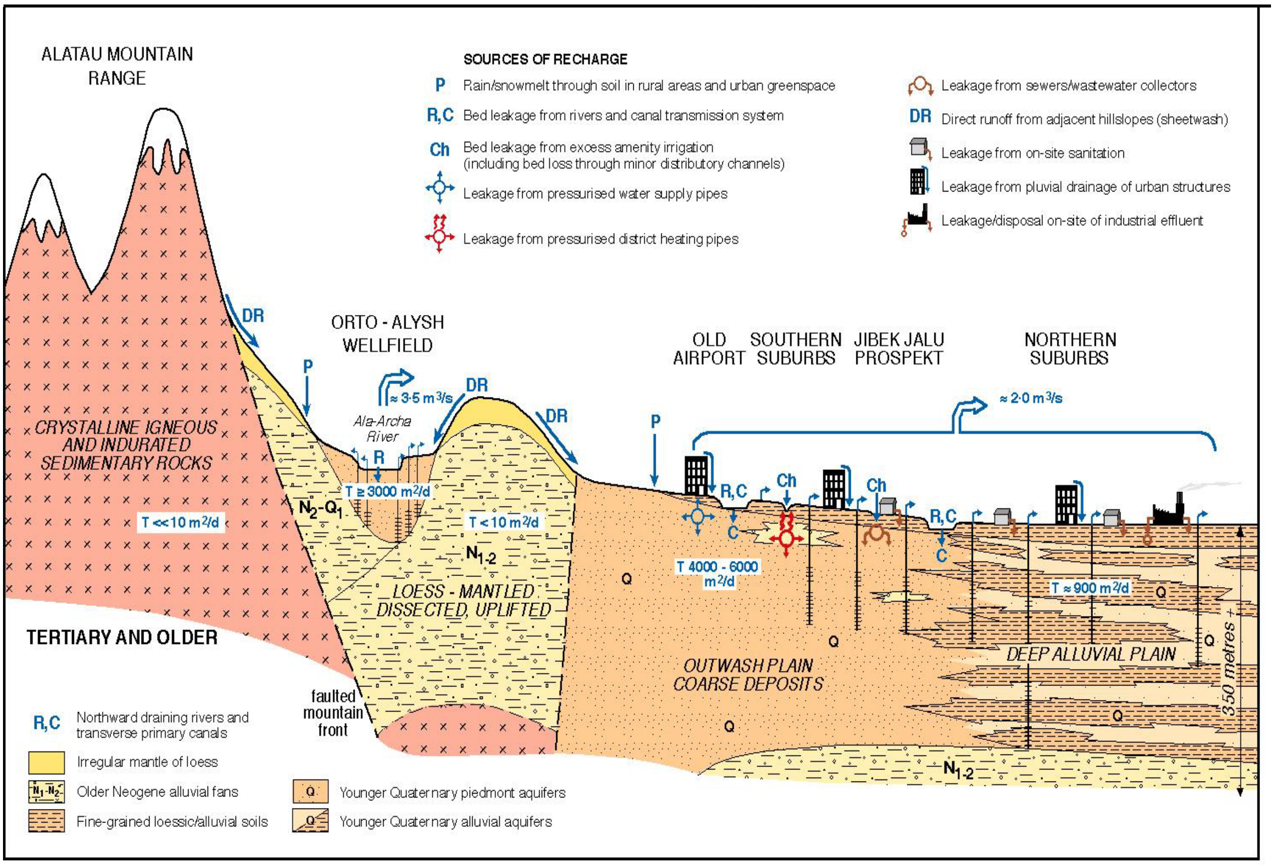

Figure 3 Groundwater setting of Bishkek, Kyrghyzstan

foreign investment. The city is 100% aquifer dependent for potable, domestic, commercial and industrial water supplies which are provided by both intraurban and periurban wellfields.

Hydrogeological setting: The city's groundwater setting is hydrogeologically complex, with a laterally heterogeneous fluvioglacial/alluvial multi-aquifer system of Quaternary age which is in excess of 350 m thick in northern districts of the city. There is strong lateral and vertical variability but as a first approximation the system fines laterally northwards away from coarse clastic piedmont deposits composed of coalesced alluvial fans fronting the foothills into more stratified deep alluvial plain sediments (Figure 3).

Despite the semi-arid climate there are extensive opportunities for recharge from snow-melt rivers and associated canal systems, draining the nearby Alatau range. Hydraulic connection with surface flow is thought to be strong across the southern piedmont area where the aquifer system is both unconfined and considered to possess strong vertical connectivity. More complex semi-confined conditions are present in the northern part of the city where three aquifer systems have been identified by a resource investigation project. Scope for significant pumping-induced vertical leakage exists, especially in the southern parts of Bishkek where low permeability horizons in the alluvial tract are thinner and less numerous. Unconsolidated sediments provide intergranular flow conditions, and the coarse alluvial and fluvio-glacial deposits comprising the aquifers have high transmissivities and significant vertical permeabilities, so urban boreholes abstract water at widely different depths.

IDENTIFICATION OF STAKEHOLDERS

Understanding development settings

Key to the identification of stakeholders in Bishkek and Narayanganj was a clear understanding of each city's groundwater development setting and urban water infrastructure. These were quite different in each city.

Groundwater development setting of Narayanganj: Groundwater provides more than 90% of drinking water supplies in the study area and there is a similar high dependence for industrial and commercial needs. Large-scale groundwater abstraction for public supply and industrial use is mainly from the lower aquifer, and located mainly within the urban area of Narayanganj. Broadly similar designs are employed for public supply and private industrial/commercial use wells alike, so the deeper aquifer horizons are not reserved for potable use. The piped water supply does not extend beyond central Narayanganj, and the per capita supply from the water utility to the urban part of the project area is estimated to average than 45 l p^{-1} d^{-1}. Actual per capita usage is therefore almost certain to be widely supplemented with private supplies from either the shallow or (less frequently) the deep aquifer.

While the groundwater productivity in the shallow aquifer is considered too low for large abstractions, it is tapped by numerous narrow diameter boreholes equipped with hand pumps for drinking water and domestic supply purposes. These are locally known as No.6 pumps. The operation of all such wells is the responsibility of local user(s) who could comprise just one family or a whole community. The total volume abstracted is unknown but there seems little doubt that the upper aquifer is the primary source of potable supply for the rural and periurban population of the project area as well as a supplement for urban households.

The resultant supply network is therefore diffuse, with piped water-supply coverage within much of urban Narayanganj but numerous handpump-equipped shallow boreholes in rural and periurban districts. A large number of private and industrial wells exist. There is a register but no published estimates exist of abstraction from the lower/main aquifer, and it is very likely that there exist many more unlicensed industrial wells.

There is no modern waste water and sewerage disposal system in the study area and dispersed on-site sanitation is widespread in urban, periurban and rural areas alike. Opportunistic use is made of the storm drainage system in central Narayanganj, mainly for sullage but illegal foul-water connections are said to be common. There is no wastewater treatment plant in the study area. Inadequate drainage result in frequent waterlogging of many parts of the town and this has become a problem.

Groundwater development setting, Bishkek: There is a very extensive piped water infrastructure (pressurised hot water as well as drinking water mains, plus piped sewerage), but widespread on-site sanitation is practised in single/two-story residential areas. Significant amenity irrigation of communal parts of residential areas occurs, using both canalised surface water and pumped groundwater. A highly productive but very localised periurban valley-fill well field located 8 km south of the urban area provides about two-thirds of the city's water demand, the balance coming from boreholes of various depths distributed throughout the city. These urban wells are screened extensively in the middle aquifer (typically >120 m intake depth), but the lower part of the upper aquifer (40 m-120 m) is also widely tapped.

The majority of abstraction boreholes are operated by the municipal water supply agency, who may provide water for both domestic and industrial processes, and there are also three separate reticulated systems for domestic water. One supplies cold water (domestic potable use), one supplies hot water taps (domestic non-potable use) and one supplies hot water for radiators (non-potable district heating use), the last of which appears to be a closed (non-consumptive) system which is operated only during the winter. All come under the description 'public water supply'. The private urban water use categories are less important both in number and volume of water pumped; a small number of factories have private wells, for potable or non-sensitive water supplies and there are also small numbers of private domestic and public municipal irrigation wells. Owner-operated supplies for commercial premises, hospitals and large state administrative buildings appear to be insignificant.

The wastewater disposal system comprises a piped sewerage element, to which industrial, commercial, apartment and public buildings together with some low-rise residential housing are connected, and a dispersed on-site sanitation element in many low-rise residential areas. The relative importance and geographical extent of the latter is not well documented, but may be significant. A wastewater treatment plant receiving domestic and industrial sewered effluent is located on the northern fringes of the city.

City stakeholder features

Thus in Narayanganj:

- Industrial users are important and influential stakeholders, meriting extra effort in consultation
- There is overlap between rural and urban water supply agencies, especially in the periurban area,
- Users of the shallow aquifer, which still serves as a resource as well as a receptor will be difficult to represent.
- No primary stakeholder groups were identified

While in Bishkek:

- State sector agencies remain the predominant stakeholder group members
- Only secondary stakeholders could be identified

- A post-independence depression in industrial activity offers opportunities for context-sensitive planning intervention to support a sound basic infrastructure
- Even though the upper aquifer is not widely used for potable supply, likely high vertical permeabilities, especially in the southern half of the city will favour rapid vertical movement of pollutants towards much deeper aquifers apparently remote from the land surface

In both cities it proved impossible to identify representative primary stakeholders (those with a direct resource interest, including groundwater users) who could participate in a consultation process. Although participation by primary stakeholders is looked-for, the degree of organisation (and thus representativeness) of such user groups may only occur in some urban contexts and may therefore be merely desirable rather than indispensable. In Narayanganj the absence of this stakeholder class was more than compensated for by the diversity of secondary stakeholders. (intermediaries in the delivering of policies, projects and services to primary stakeholders). These were drawn not only from public sector agencies/ministries but also local government and trade/industry associations. In Bishkek public sector organisations dominate the stakeholder spectrum but much underfunding and quite poor coordination post-independence has fostered a diversity of views by the agencies involved, ensuring active discussion of options.

THE STAKEHOLDER CONSULTATION PROCESS

Once identified, stakeholders were engaged through the medium of a periodic bilingual newsletter (Russian/English, Bangla/English), of which about half a dozen were issued in each city over an 18 month period leading up to a stakeholder workshop. The newsletters were kept short and focused, each edition communicating one aspect of the policy consultation process in a logical sequence leading through problem recognition, identification of future threats and consequences, setting of remedial/preventive objectives and targets and into policy formulation (Figure 4).

Thus different editions:

- Communicated a synopsis of results from the first part of the project, including the 'hot-spot' (potentially contaminating industries on vulnerable aquifer) map.
- Presented Strengths-Weaknesses-Opportunities-Threats (**SWOT**) analyses (Figure 5, Table 1) of different facets of the city water infrastructure

Figure 4 Evolution of groundwater protection policies for a groundwater dependent city

(public and private water supply, wastewater and solid waste disposal, management and regulatory control, planning). This analysis method was employed as it lends itself to brevity in presentation and is likely to be already familiar to some stakeholders from its wide use as a commercial business/market analysis tool.

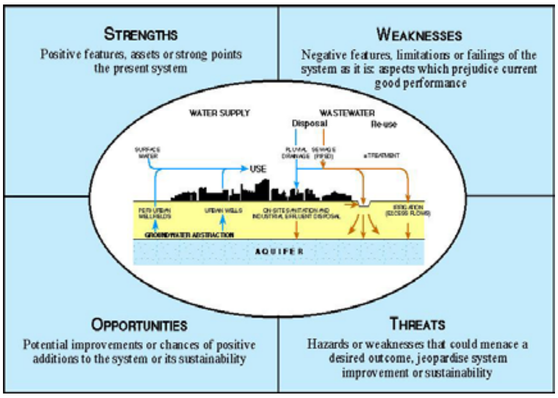

Figure 5: Strengths-Weaknesses-Opportunities-Threats (**SWOT**) analysis for groundwater-dependent city

- Provided Problems-Consequences-Targets-Requirements (**PCTR**) tables for water supply and wastewater/solid waste management. This analysis was intended to bring together public and private uses in such a way as to show the commonality of issues, the resolution of most of which would at some point require either the active participation (or at least the absence of opposition) of private sector users.
- Suggested a range of policy options based on broad strategic objectives (maintaining groundwater supply, safeguarding water quality, sanitary elimination of urban wastewater/solid waste). These were ranked in terms of degree of intervention needed to put the policy into effect (Weak to Moderate to Strong), with an implied link to relative efficacy (Table 2 as example)..
- Reported the results of the stakeholder workshop, at which each stage of the policy consultation process was revisited and reopened for modification by consensus and where the policy options were debated, revised and/or added to.

OBSERVATIONS ON THE STAKEHOLDER CONSULTATION PROCESS

1. The workshop comprised the penultimate stage of the consultation exercise in each city because the research project was coming to an end. However, in other programmes it would be expected that a successful workshop would lead to the establishment of a stakeholder forum, usually facilitated by sponsorship of an important stakeholder such as the city water utility, municipal planning department or public health agency. Unsolicited, participants at both workshops identified this as a recommendation. The direction such a forum might take would of course vary with the energy and influence of the participant individuals and the degree of autonomy enjoyed by the municipality in terms of planning regulation.
2. In a few cases there might be enough impetus generated to enact municipal ordinances, the enforcement of which will be much assisted by the prior consensus developed by a representative stakeholder forum. More typically it might become a lobby, seeking to influence central government or a particular ministry into the enforcement of existing environmental/water resource regulations or the enactment of new enabling legislation.
3. In Narayanganj participants identified a need for more involvement at local level in the planning process. Given the city's proximity to rapidly-expanding Dhaka, this reflected a general uneasiness over the remoteness and lack of transparency of the metropolitan planning authority which currently handles planning issues in the region around the capital city. In Bishkek it was felt that there was scope in the future for directing water supply and sanitation development assistance funds into urban infrastructure development/aquifer protection instead of concentrating exclusively on the rural sector, as at present.
4. It seems inescapable that if groundwater protection is to be brought into the municipal planning process, then stakeholder policy forums will have to enter the political arena if resultant planning regulations are to be enforceable and enforced.
5. Stakeholders liked the general approach of working openly through the policy development process, although this only became apparent during the workshops, since feedback from stakeholders receiving the newsletters beforehand had been very poor. Nevertheless, the newsletters provided a means to drip-feed quite complex information which could never be assimilated in the time available to a workshop audience, while the workshops provided the enabling forum for frank discussion of problems. Our view is that structured

newsletters and workshops complement each other and proved together to be an effective aid to stakeholder consultation.

6. There is nonetheless a paradox in the use of workshops for stakeholder consultation purposes. The meetings would be most influential and high profile if the decision makers within each stakeholder group attended them. Yet the time required for a workshop means that staff detailed to attend are rarely the most senior members of each stakeholder group. So secondary stakeholder consultations are burdened not only with ensuring that meeting deliberations are transmitted effectively to agency decision makers, (perhaps several levels higher in the organisational hierarchy) but also with the inability of participants to speak authoritatively on behalf of their respective agencies. This prolongs the consultation exercise with inevitably the risk of loss of credibility and interest in the process.

7. At both workshops comments by participants showed that although only those concerned with the city's water infrastructure attended, such cross-sectoral involvement was unknown. Even allowing for the novelty of the approach, it was clearly welcomed by attendees as a positive contribution to the urban water development process. There may be lessons to be learnt here on institutional involvement for international development agencies involved in urban water infrastructural improvements in small to medium-size cities

CONCLUSIONS

- Despite a limited resource and knowledge base, locally appropriate groundwater protection plans are being developed in the case study cities.
- Stakeholder consultation contributed significantly to the development of policy options for aquifer protection in both cities

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WATER-SUPPLY INFRASTRUCTURE-PERIURBAN (ORTO ALYSH) WELLFIELD	
STRENGTHS	**WEAKNESSES**
1. Located up groundwater gradient outside city and at topographically higher elevation. 2. High productivity in small area due to very high permeability, high specific yield and river-aquifer leakage. 3. Small interference effects between wells due to high permeability. Permits small, compact wellfield which simplifies distribution and treatment infrastructure 4. Wellhead protection/santary control area under control of utility. 5. Wellfield catchment areas still predominantly rural with few roads. 6. Aquifer baseline water quality likely to be high: significant quality derogation tolerable.	1. No control over catchment outside wellhead protection/sanitary control zones, despite existence of control directives. 2. Wellfield is susceptible to various pollution threats: aquifer is high vulnerability zone, adjacent to area of extreme vulnerability (losing reach of Ala Archa river). 3. Well catchments likely to include significant river leakage element; this could act as short-cut for pollutants in surface water to penetrate down to borehole intake levels. 4. Wellfield composite catchment not commonly known; time of travel zones not defined. 5. No coordination of either quantity or quality surveillance monitoring of piedmont recharge zone
OPPORTUNITIES	**THREATS**
1. Area of wellfield is compact and therefore easy to define for regulatory protection purposes. 2. Wellfield joint catchment would be relatively easy to define by existing groundwater modelling techniques. 3. Scope for progressively stricter control measures using time-of-travel zones defined by standard modelling techniques. 4. Proximity to National Park area could make regulation of potentially polluting activities easier for public to accept. 5. Stakeholder/public understanding of water supply protection issues could be improved by easier access to key urban water trends e.g. by means of a public information Website	1. Risk of microbial pollution from on-site sanitation of summer house co-operatives, either via river leakage or direct to aquifer: moderate probability hazard which could, however, be managed by treatment (raw water disinfection). 2. Susceptible to pollution incidents eg spillage from traffic accidents: low probability hazard but with potentially serious consequences. 3. Major pollution incident affecting wellfield would threaten 70% of city's water supply, only part of which could be offset by use of reserve wells in city. 4. Adjacent sensitive central government facilities may increase risk of terrorist attacks on infrastructure due to proximity. 5. Hazard of water quality deterioration due to use of agrochemicals for livestock pest control and in cultivated area, and increasing density of domestic properties in catchment 6. Risk of flood/mudflow damage to wellfield installations due to proximity of wellfield to axis of narrow valley.

Table 1: Example from Bishkek of SWOT analysis of one sector of city's water infrastructure

Objectives	Urban water management policies	Examples of policy measures to achieve targets	
		Degree of intervention Weak → Moderate	Moderate → Strong *Policies in left-hand column plus:*
Maintain groundwater supplies	1. Monitor groundwater levels and use results to manage urban aquifer	Install/maintain a water level monitoring system	Use results in directing/controlling abstraction
	2. Gain better understanding of groundwater resource so as to develop it in a sustainable way	Use model to update vulnerability assessment/provide source catchments	Undertake comprehensive 'Master Plan'-type water resource study, including improvement of groundwater flow model
	3. Value groundwater realistically to aid management of finite natural resource	Introduce pricing policies for public water supply to recover present supply costs	Extend pricing policies for public water supply to cover expansion to meet increasing demand ± future additional treatment requirement (i.e.long-run marginal costs)
	4. Mitigate effects of increasing abstraction on shallow aquifer users	Provide guidance to public on well interference effects	Provide substitution supplies where shallow aquifer likely to suffer early dewatering
	5. Constrain groundwater level decline in lower aquifer	Enforce well spacing criteria to minimise interference effects between neighbouring deep wells	Reserve good-quality water for potable/sensitive use and encourage use of shallow (poorer-quality) groundwater for non-sensitive uses (by abstraction licensing/quota system, licensing of drilling companies, amend building regulations to include water conservation technologies, subsidise water-efficient technologies/appliances
	6. Privatisation of specific functions	Privatise meter reading and bill collection to ensure recovery of cost of supply	Devise water charging system and implement collection sanctions that are both fair and transparent, and support measures that will enhance supply cost recovery
Safeguard water quality	7. Monitor groundwater quality and use results to manage urban aquifer	Install/maintain a water quality monitoring system	Use results in directing/controlling abstraction
	8. Eliminate shallow aquifer pollution due to poor well construction/ maintenance	Public awareness/schools education programme on wellhead maintenance Provide well construction guidelines and make compliance mandatory	Proactive wellhead maintenance teams Training/quality assurance of drilling teams
Improve Management	9. Encourage economic expansion consistent with conservation of urban groundwater resources	Classify industrial/municipal activities into hazard classes	Identify different hazard class suitabilities: encourage compliance by use of economic/regulatory instruments such as building controls.
	10. Support integrated pollution control for all existing industries	Use hazard + vulnerability classifications to identify industries of posing threat to groundwater	Prioritise industries posing main threat for integrated pollution control measures or relocation
	11. Enhance professional capacity	Employ professionals in utility to manage aquifer for its prime water supply function	Employ professionals in utility in key area of hydrogeology and groundwater resource development
	12. Implement existing laws and regulations to achieve national policy goals	No lesser-scale intervention effective, see right-hand column	Central government (executive and legislature) to explicitly support municipal and utility efforts to enforce existing pollution and abstraction control regulations
	13. Encourage people participation and public awareness	Educate press in groundwater issues to better inform public	Formalise stakeholder forum and act on consenus decisions recommended by them.

Table 2 Example from Narayanganj of policy options developed by stakeholder consultation for aquifer protection (water supply matrix)