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Groundwater: Quantity and Quality Issues
Affecting Water Supply

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Groundwater Quantity and Quality Issues Affecting Water Supply

Working Paper for the

Sector Development Programme (SDP) for water and sanitation in Bangladesh

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ABBREVIATIONS

BADC	Bangladesh Agricultural Development Corporation
DTW	deep tubewell (>150 m deep)
DPHE	Department of Public Health Engineering
EC	electrolytic conductivity
LGI	Local Government Institution
MPO	Master Plan Organization
NHS	National Hydrochemical Survey (conducted DPHE by BGS and MML in 1998-99)
NWP	National Water Plan
NWMP	National Water Management Plan
STW	shallow tubewell
TDS	total dissolved solids
WARPO	Water Resources Planning Organization
WHO-GV	World Health Organization guideline value (for drinking water)

1. INTRODUCTION

1.1 Purpose and Scope

The purpose of this report is to support the groundwater quantity and quality aspects of the revised Sector Development Programme (SDP) for water and sanitation in Bangladesh. The specific objectives of the work, as set out in the Terms of Reference (ToR) are:

1. Assess groundwater quality issues with particular focus on arsenic contamination.
2. Assess the potential of groundwater for urban and rural water supply, including the lowering of groundwater level;
3. Define strategies for arsenic mitigation, including inter-sectoral coordination;
4. Make recommendations for the management of groundwater including suggestion for inclusion in the Revised SDP and Water Act.

This report was prepared by Professor Kazi Matin Ahmed, Mr M A Samad and Mr Peter Ravenscroft under the guidance of SDP Team Leader Dr Tanveer Ahsan, based on the authors experience and knowledge of the literature, plus new data supplied by DPHE. No primary data were collected and no field visits made. Two of the authors (KMA and PR) had recently undertaken extensive consultation with relevant stakeholders in connection with the preparation of a revised Implementation Plan for Arsenic Mitigation (IPAM).

The report has seven sections. Sections 2 and 3 separately and critically review the respective constraints on groundwater quality and quantity on water supplies. Section 4 specifically addresses strategies for arsenic mitigation, and draws extensively the draft of the revised IPAM. In Section 6, we integrate groundwater quality and quantity constraints in a regional synthesis. Finally, in Section 7 we present recommendations for improved groundwater management in Bangladesh.

1.2 Groundwater in Bangladesh

Groundwater from Quaternary to Recent sediments is the principal source of domestic, industrial and irrigation supply in Bangladesh. The shallow alluvial aquifers are recharged through rainfall and flooding, and almost everywhere replenished each year, except in areas like Dhaka city where, due to continuously increasing abstraction, groundwater levels decline continuously. Recharge to deeper aquifers is more problematic to assess. The aquifer system can be divided into three parts:

i) an upper or main aquifer, extending to about 150 m[1]; the source of what is referred to in this report as shallow groundwater;

ii) a deep aquifer, extending from 150 m to about 350 m; and

iii) a very deep or lower aquifer, extending below 350 m to as much as 1600 m, about which very little is known.

The definitions of aquifers and tubewells have been a common source of confusion because of differing terminologies.

[1] The value of 150 m is a useful guide, but does not have precise significance, although it is approximately limit of aquifers deposited since the Last Glacial Maximum, and is an approximate limiting depth for the occurrence of arsenic pollution. However, older and arsenic free aquifers often occur at shallower depth.

Fig 1

2. GROUNDWATER QUALITY

2.1 Preamble

In the following sections, we evaluate the groundwater quality parameters relevant to planning and budgeting of water supply investments. Here we consider natural contaminants in full and anthropogenic contaminants in more generic form. We also differentiate between parameters that have systematic regional distributions and should be addressed in regional planning of investments (e.g. As, Fe, Mn, salinity) and those that can occur anywhere depending on local circumstances (e.g. microbes, industrial and agro- chemicals).

In the following sections, we identify the specific parameters that require attention in regional planning, and present the results in terms of shallow and deep groundwater separately (Figure 1). Although the chemistry of shallow aquifers is quite well defined from the National Hydrochemical Survey (NHS), it is noted (by comparing the NHS data coverage with the deep well installation area) that there are significant data gaps in the chemistry of deep groundwater.

We begin with a consideration of national drinking water standards, since these are the targets (performance criteria) by which Government will regulate the providers and ensurers of drinking water, and if these standards are not appropriate, then investments will be misguided or wrongly prioritised.

2.2 Water Quality Standards and Guidelines

Standards for drinking water quality for Bangladesh were published in 1997 under the provision of the Environment Protection Act 1995, based on the 1993 WHO Guidelines for Drinking Water Quality. There are 55 physical, chemical and microbiological parameters in the list of standards. For some, as noted in Table 1, the standards are different to the WHO guideline values.

The 1998-99 National Hydrochemical Survey (NHS) provides a baseline for evaluating groundwater quality over all the country except the Chittagong Hill Tracts. We supplement the NHS by considering a number of local and regional studies of natural water quality and anthropogenic pollution.

Among the natural parameters, As, Fe, Mn and salinity are matters of concern over large areas in deep and shallow aquifers, and in urban and rural areas. Natural parameters such as B, Ba and U are more localised problems. Microbiological, agrochemical and industrial pollutants need to be monitored to reduce the risk at areas of high risks.

The following chemicals were considered but rejected from regional planning because there are no or very few and low-level exceedances:

antimony	molybdenum
cadmium[2]	nickel
fluoride	selenium
chromium	zinc.
copper	

[2] Analysed in the NHS, but the detection limits mean that low level exceedances could have been missed. However, they are expected.

For some of these (Cd, Se,) the data sets are small, such as the three upazila subset of the NHS. For Aluminium, in the NHS, 1.7% of shallow wells and 6% of deep wells exceed the standard, although this is not health related.

The following chemicals were considered because they are listed as health-related parameters by WHO, but there are no or very few analyses, but are not expected to occur in Bangladesh. Nevertheless this should be established by analysing representative samples. These are:

mercury	tin
radon	radioactivity.
silver	

It is strongly recommended that Bangladesh's drinking water standards, or at least those that differ from current WHO guidelines and those that have guidelines but no standards, are reviewed giving particular consideration to the following:

- reducing the As standard to 10 µg/L on a phased time-scale;
- differentiating between health and aesthetic considerations, especially for Mn;
- differentiating between drinking water (health) and environmental quality standards (e.g. ammonia).

2.3 Issues Requiring Water Supply Mitigation Investment in SDP

2.3.1 Arsenic

Arsenic is the number one water quality problem, and occurs mostly in the southern and eastern parts of the country. Arsenic occurs (Figures 2 and 3) predominantly in shallow wells (<150m deep), while deeper wells (>150m deep) are mostly safe, except in some areas of Jessore. Arsenic needs special attention wherever rural water supply is based on shallow wells. Municipal piped water supplies, even in the arsenic affected regions, are relatively safe as they generally abstract from deeper aquifers.

In the NHS, 46% of shallow and about 5% of the deep wells exceeded the 10 µg/L WHO-GV, while 27% of shallow and about 1% of deep wells exceeded the Bangladesh standard (50 µg/L). Wells are most likely to exceed the limit in the southern half of the country. The most severely contaminated districts are Munshiganj, Lakshmipur, Noakhali, Chandpur, Gopalganj, Shariatpur, Faridpur, Rajbari, and Satkhira. The hill districts were not sampled under the NHS, however, subsequent testing has proved these areas to be mostly safe from arsenic contamination.

In the affected areas, concentrations range from below detection level to as high as 4730 µg/L. Because the health effects of arsenic are proven to be proportional to the concentration, in Figure 3 we show the proportions exceeding various thresholds (10, 50, 200 and 400 µg/L) to illustrate how the severity of the risk is distributed around the country. While arsenic at the 10 µg/L level is a national problem, the greatest risks, and therefore the highest priorities for water supply intervention, are concentrated in certain southern districts.

While the present standard (50 µg/L) should be a binding target for intervention, the WHO-GV (10 µg/L) should be seen as a high-priority non-binding target. It is likely to be adopted as a standard in the foreseeable future; it has been recognised to cause actual harm to concentrations of 10-50 µg/L (Ahsan et al., 2006); and is probably significantly more damaging to health than any other chemical parameter considered at the relevant guideline value (Smith et al., 20007). Indeed, there are additional reasons for giving top priority to arsenic mitigation. Research from Chile shows that the long-term effects of arsenic, through deaths from heart and lung disease and liver and bladder cancer can continue, and indeed increase, for several decades after exposure ends. Food, especially rice, can also make a major contribution to arsenic exposure, and when combined with exposure from drinking water, argues in favour of reducing the standard from 50 to 10 µg/L, and also reducing the As-content of irrigation water.

Detailed consideration of arsenic mitigation is presented in Chapter 4.

2.3.2 Iron

Iron, though not health related, is the most widespread water quality problem in urban and rural supply, and has been recognised as such since the introduction of groundwater for drinking purposes. The problem needs most attention in shallow aquifers as the deep aquifer has significantly lower concentrations (Figure 4). Shallow groundwater beneath the Madhupur and Barind Tracts are generally below the WHO-GV of 0.3 mg/L. Shallow aquifers over most of the SW, SE and NE regularly exceed 1.0 mg/L, as do wells along the Jamuna floodplain. The NHS reported a median of 1.1 mg/L and a maximum 6.1 mg/L for iron in shallow groundwater, with 23% of sample containing more than 5 mg/L.

2.3.3 Manganese

Large proportions of shallow and deep wells both in urban and rural areas exceed the Bangladesh standard (0.1 mg/L), which coincides with WHO's aesthetic guideline rather than the health-related guideline value of 0.4 mg/L (Figure 5). The health effects of Mn in humans are becoming more evident as a result of recent publications coming out of Bangladesh (e.g. Wasserman, 2006; Hafeman, 2007).

Manganese concentrations are particularly high in shallow aquifers and often, but not always, inversely correlated with arsenic. While Mn frequently coexists with high Fe, there are large areas of western and NC Bangladesh where Mn is >0.4 mg/L but both Fe and As are below the drinking water standards. Manganese concentrations are low in the deep wells in the south with few exceeding WHO guideline and few more exceeding the Bangladesh limit. Manganese concentration in groundwater is relatively high all over Bangladesh. In the NHS, 39% of shallow and 2% of deep wells exceeded the WHO-GV of 0.4 mg/L. On the other hand, 79% of the shallow and 22% of deep wells exceeded Bangladesh standard of 0.1 mg/L.

2.3.4 Salinity

Groundwater salinity may result from intrusion of modern seawater, but is more commonly water trapped at the time of deposition of the host sediments or emplaced during marine flooding events in the Pleistocene. Seawater salinity is dominated by chloride and to a lesser extent sodium, but because neither chloride, nor TDS or EC were measured in the NHS, hence Figure 6 shows 'Calculated EC[3]'. An EC value of a little over 2000 µS/cm is often approximately equal to a chloride concentration of 600 mg/L – the Bangladesh standard for the coastal area.

In shallow groundwater, EC increases to over 2000 µS/cm towards the south, up to the point where there are no data, presumably because shallow aquifers are thoroughly saline. Pockets of salinity occur inland, especially in Comilla and Chandpur districts.

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[3] This uses the procedure verified by Ravenscroft and McArthur (2004), [Calc. EC = 100 * Σ (Ca, Mg Na, K) - SO_4 (all in meq/L)], which is a useful guide to salinity, but not a substitute for proper measurement.

In deep groundwater, EC may also exceed 2000 µS/cm, but with three explanations. Randomly, older wells may be affected by leakage corroded or broken pipes. This is a well construction or ageing problem and has no general relevance for planning, other than it limits the useful life of wells. High-EC occurs systematically in a N-S band of high EC running N-S through Pirojpur, which coincides with high boron. This is high-Na but low-Cl water resulting from ion-exchange and not mixing with salt water (Ravenscroft and McArthur, 2004). Over time, this problem should gradually decline. The third reason is genuine intrusion of saline water, either residual or modern seawater. This is a real risk, but so far has not been documented in Bangladesh. For rural supply, this may be treated as semi-static constraint, but for urban supply, where pumping is intense, then detailed site-specific investigation is essential.

2.3.5 Others: Barium, Boron, Uranium, Nitrate and Ammonium

Boron occurs in shallow and deep groundwater, with a maximum concentration, in the NHS, of 2.1 mg/L, with just over 1% of samples exceeding 1.0 mg/L (BGD) but 4.7% exceeding 0.5 mg/L (WHO). Boron, is however, highly localised, and is most significant in the deep aquifer, where it constrains an area running through Barguna, Pirojpur and Jhalokati districts (Figure 7). It is unlikely that boron will migrate significantly, and can be treated as a static constraint that will gradually decline over time. The health effects of boron have been demonstrated in animals but not conclusively in humans (WHO, 2004), and considering the current WHO advice, an epidemiological study in the main affected area could be undertaken to assess whether the threats to health are real. On the other hand, the WHO is considering[4] raising the WHO-GV to as high a concentration as 2.4 mg/L, in which case the 'problem' would disappear (see section 2.5.1).

In the NHS, **barium** had a maximum concentration of 1.36 mg/L, with just 0.3% exceeding 0.7 mg/L (Figure 8). There is a small hot-spot in shallow groundwater in Satkhira and a few isolated elevated measurements in the deep aquifer. The health effects of barium are associated with nephropathy at high concentration and hypertension at the lower concentrations of concern here. A study of the main barium hot-spots may be undertaken.

In the NHS, **uranium** exceeded the WHO-GV (15 ppb) in 4% of samples[5] and had a maximum concentration of 47 ppb. The health effects of uranium in water are uncertain, but certainly this is a matter for concern. In India, Ghosh et al. (2007) reported evidence levels of enhanced alpha radioactivity in arsenic contaminated groundwater. Considering these results, a nationwide survey of uranium, radioactivity and radon could be undertaken, perhaps by BAEC with assistance from the IAEA.

Generally **nitrate** (and nitrite) concentrations in groundwater are extremely low due to the strongly reducing nature of the aquifers. However, in the far northwest (Panchgarh and Thakurgaon districts) there is evidence of rising nitrate concentrations (NMIDP, 1995?), although it is not known whether this results from fertiliser or sanitation or both. It is not yet clear whether this will require corrective action.

In most areas, elevated nitrate concentrations do not result from high N loading from pit latrines, presumably due to denitrification, although **ammonium** concentrations, positively correlated with

[4] See http://www.who.int/water_sanitation_health/dwq/chemicals/boron/en/. Accessed 14/10/09.

[5] A recent paper by Frisbie et al. (2009) on water quality in western Bangladesh erroneously reported that 48% of samples exceeded the guideline for uranium. This was due to reference to a 5 years out of date document and guideline (2 ppb). The correct number of exceedances in their survey was zero.

coliforms (Hoque, 1998) can be high due to incomplete oxidation of organic-N. However, ammonium concentrations of 1-8 mg/L are widespread in shallow groundwater throughout the arsenic affected areas, and lower but still elevated concentrations can be found in deep groundwater such as at Khulna (IWACO, 1981). Ammonium co-occurs with iron or arsenic, has a DWS of 1 ppm, and should be taken account of when addressing those parameters.

2.4 Issues Concerning Surveillance Monitoring and WSPs

2.4.1 Microbial contamination

Since the 1970s, waterborne disease has been the principal driver for action in water supply, since poor sanitation and high population density increase the risk of microbiological contamination of drinking water. Hoque (1998) found a median faecal coliform concentration in 2500 wells of 3 cfu/100 ml. Both this and the ARGOSS study (Ahmed et al., 1998) revealed that proximity of water wells to onsite sanitation was not directly correlated with microbiological contamination of groundwater. Rather, local hydrogeological conditions are key controls on the occurrence of faecal coliforms and streptococci in shallow groundwater. Also, the probability of bacterial contamination decreases with depth in the top 80m, but can increase again at greater depth, probably because microbes can be introduced during pump priming (Hoque, 1998).

Luby et al. (2008) found that out of 207 tubewells in three flood prone districts, 41% were contaminated by total coliforms, 29% by thermo-tolerant coliforms and 13% by faecal coliforms. The median concentrations in contaminated wells were 8 and 6 cfu per 100 ml of total and faecal coliforms. There was no significant association between contamination and poor sanitary inspection scores, though there was an association with a history of inundation.

Coliform bacteria indicate a pathway for more pathogenic bacteria, viruses and protozoans that can be introduced by anthropogenic activities. The microbial risk at shallow wells can be reduced by: (i) maximising the spacing between wells and latrines; (ii) increasing the depth of hand tubewells; (iii) better sanitary seals ad drainage at the wellhead; and (iv) avoiding the use dirty water for priming.

Cryptosporidium, though not tested currently for in Bangladesh, is a worldwide issue, is unlikely to be a major issue in groundwater except where wells are flooded, and could be a significant issue in surface water.

2.4.2 Synthetic Agrochemicals

Bangladesh is an agricultural country where all available land is utilized for growing crops, mainly high yielding varieties of rice. Many of the lands are used for three crops in a year. As a result, natural soil fertility is declining and farmers apply fertilisers to meet the nutrient deficits. Use of chemical fertilizers began in 1951 with import of ammonium sulphate, followed by urea and TSP in 1957, and potash in 1960 (Ahmed, 2008). Fertilizer demand sharply increased with the introduction of high yielding rice varieties, and also included phosphate, gypsum, zinc sulphate and micronutrients.

Matin et al (1994) reported that total pesticide use doubled over six years. Of the pesticides applied, insecticides comprised >95% of the total, with fungicides, herbicides and rodenticides making up the remainder. By chemical composition, organo-phosphorus compounds comprised 60.4%, carbamates 28.6%, organo-chlorines 7.6% and others 3.4%. Meizner (2004) reported that use of pesticides increased from 7,350 tons in 1992 to 16,200 tons in 2001. Many pesticides in use are banned or restricted under international agreements.

The risk of leaching agrochemicals residues into water supplies arises because groundwater occurs at shallow depths over most of the country and because farmers often overuse fertilizers and pesticides, even though average application rates of pesticides and herbicides are low by international standards. Results of analyses of pesticide residues for the FAP regional studies found only one site which gave cause for concern.

NMIDP (1995) tested 78 samples from high-risk areas, and found traces of contamination in 10 samples by organo-chlorines, but not organo-phosphates. Matin et al (1997) analysed water for organo-chlorine (OC) residues during 1992–1995, before and after the banning of OCs. They detected slight contamination of some surface and groundwater sources by DDT, heptachlor, lindane and dieldrin. However, the majority of the samples were free of residues. The presence of heptachlor in surface and ground water at levels well above WHO-GVs is a matter of serious concern.

In Bangladesh, the volume of agrichemicals and fertilisers used is continuously increasing. The risks to groundwater of continuous build up of pesticide residues and nitrate in also increasing, and is highest on the Teesta Fan, Barind and Madhupur Tracts where the aquifer conditions are less likely to promote natural attenuation.

2.4.3 Industrial Chemicals

Little is known about industrial pollution of groundwater in Bangladesh, but it would be surprising if the country does not experience the same type of problems as elsewhere in the world. The absence of reports of industrial pollution at present because of the general absence of appropriate monitoring (as noted above with pesticides) and investigations focused on high risk locations.

Certain industries are particularly likely to be associated with characteristic pollution. Tanneries and metal processing industries may both be sources of both chlorinated solvents (such as tetra- and tri-chloroethene) and heavy metals, especially chromium. Petroleum storage, including petrol filling stations, is another common source of pollution worldwide that is hardly, if ever, tested for in Bangladesh. Industrial waste water discharges are poorly regulated and may be a significant source of pollution. This said, the general procedure should be conducting a catchment risk assessment in the initial stage of water safety plan development in order to categorise risks to public water supplies. This, however, requires the existence of source protection zones (see 2.5.3).

The establishment of routine systematic monitoring for industrial and synthetic agro-chemicals should be a moderately high priority, albeit that the frequencies and analytical suites will need to be worked out in practice. The first priority would be a screening of large public supply wells in urban areas, especially the relatively shallow ones.

2.5 Critique of Water Quality Issues

2.5.1 Summary of Risks and Constraints

Arsenic. The health effects, at the concentrations experienced by millions, of arsenic are so great that it must be the highest priority for action in the sector. There are two distinct areas for action in the SDP:

(i) removing exposure at contaminated water sources; and (ii) protecting presently safe and new wells in at-risk areas.

The most common mitigation solution will be the use of deeper wells for water supply (but not for agriculture). Other solutions, such as surface water treatment, arsenic removal and (for rural supplies) rainwater harvesting may be considered; and where cost, acceptability, reliability, durability and overall water quality are comparable, preference may be given to surface water.

It is proven that some shallow wells change from safe to unsafe arsenic concentrations over periods of a few years. Predicting which wells will change and when is impractical for the foreseeable future. Further, most new wells are not tested. The essential requirement is to provide and ensure accessible and affordable testing at local level (see Section 4).

In the context of combined exposure from food and water, the health-based argument for lowering the standard from 50 to 10 µg/L is even stronger. The policy issue is when rather than whether the standard should change, and how its implementation should be phased. The change has different implications for each mitigation technology. For surface and rain water, it makes no difference; most deep groundwater sources will naturally comply with a lower standard; however, many dug wells and community arsenic removal systems[6] will struggle to comply with a lower standard.

Iron and Manganese (Low-Arsenic) Waters. This group of waters represents a second level of priority, driven by a combination of the aesthetic aspects of obtaining 'good' water and the health-based concern over (>0.4 mg/L) manganese. There will be a stronger demand for achieving these goals in urban and piped-rural supplies than at domestic tubewells, where the aesthetic aspects are more likely to be tolerated. Technologies for community and municipal iron removal are well-established, and both iron and manganese should be removed by aeration and sand filtration. It may also be practical to avoid high iron, as with As-avoidance, by sinking deeper wells, possibly even to the deep (>150m) aquifers, but in these cases the alternative aquifer horizons may contain high-Mn concentrations.

In cases where manganese is the only parameter to exceed the standard, which applies across a large swathe of western Bangladesh, it is assumed that concentrations can be reduced by aeration and sand filtration, but this should be demonstrated through pilot plants. In some case, however, high-Mn might also be avoided by drilling deeper. This points to the benefit of developing an upazila or union level database of all contaminants of concern.

Boron. Although there are significant exceedances of WHO guidelines and national standards, there is reason for caution in taking remedial measures. The evidential basis for health impacts at the reported concentrations is not very strong. On the one hand, an epidemiological study might be undertaken to establish whether health effects are evident in the exposed population, on the other hand, WHO is currently re-evaluating the guideline for boron, and is considering raising the guideline to as much as 2.4 mg/L. If this guideline should be adopted by WHO and then as a national standard, there might be no boron problem in Bangladesh. Hence, it may be prudent to delay action on boron until WHO concludes its review.

In assessing the size of the iron (and manganese) problem, it should be appreciated that many of the affected wells also contain >50 µg/L As. Figure 9 shows over much of the As-affected area, there will

[6] Achieving a lower target would require pre-oxidation of As(III) to As(V).

little separate need for Fe and/or Mn treatment. Mn removal or avoidance will be concentrated beneath Madhupur Tract, the northern part of the SW region, and the southern part of the NW region

2.5.2 Inherent Vulnerability of Deep and Shallow Groundwater

In almost all respects, shallow groundwater is inherently vulnerable to pollution than deep groundwater. In so far as deep groundwater may be impacted by surface pollutants, this will occur by leakage along the annulus of poorly grouted casings and where there is poor well-head drainage. Shallow groundwater may also be polluted by this route, but also by infiltration through soils, which will depend on the nature of surface horizons. Such factors should be incorporated into Water Safety Plans.

The principal exception to this pattern of risk is salinity, which may be drawn down from brackish aquitards at intermediate depth, or drawn in laterally from the coastal parts of confined. Shallow aquifers may, however, be affected by intrusion of modern seawater.

The risks of anthropogenic contamination is particularly high in parts of the NW (e.g. Thakurgaon, Panchgarh) where surface soils are highly permeable and the SE (e.g. Noakhali) where the water table is very close to the surface. Nitrate and pesticides would be more persistent in oxidising aquifers. Regarding industrial chemicals, petroleum hydrocarbons may be relatively persistent in reducing aquifers, whereas chlorinated solvents may be degraded in the highly reducing (As-contaminated and methanogenic) aquifers.

2.5.3 Groundwater Source Protection

Reduction of risks from anthropogenic sources of pollution can be achieved through spatial planning. However, there is normally a lack of public awareness about the areas from which water (and pollutants) entering the ground moves towards large water supply wells. Delineation of source protection zones (SPZs) will be an important activity in the future, and form the basis for protecting groundwater and responding to pollution incidents.

Two broad roles are foreseen: (i) for providers to protect areas close to sources; and (ii) for regulators to take the lead on more widespread aquifer protection, possibly as part of broader catchment management programmes. Procedures for SPZ delineation are well established in Europe and America but will require adapting for use in Bangladesh. SPZs are concentric zones, each based on the time of travel to the well, within which land use can be controlled through the planning process. Definition of Source Protection Zones should be integrated with water safety plans by forming the basis for catchment risk assessments.

Table 1. WHO Guidelines that Differ from Bangladesh Drinking Water Quality Standards

Chemical	Unit	WHO Guideline	Bangladesh Standard	Comment
Aluminium	µg/L	none	200	No WHO-GV (health). NHS records 1.7% of shallow wells and 6% of deep wells > 200 µg/L.
Ammonia / Ammonium[7]	mg/L	None None	0.5 1.0	No WHO-GV (health) for either, but WHO notes odour problems at ammonium >1.5 mg/L. Free ammonia is rare in groundwater, but ammonium of >1 mg/L if common in high-Fe and high-As waters.
Arsenic	µg/L	10	50	Lower standard likely to be adopted in foreseeable as high level exposure is eliminated. The change has major implications for the number of wells affected.
Barium	µg/L	700	10	Reason for standard unclear, and may warrant raising. Ba is found in the shallow aquifer in the extreme SW, and at various locations in deep GW.
Boron	mg/L	0.5	1.0	Reason for standard unclear, but WHO-GV changed from 0.3 to 0.5 mg/L in 1999.
Calcium	mg/L	None	75	WHO-GV not health-related.
Copper	mg/L	2.0	1.0	Reason for standard unclear, but makes little difference
Chloride	mg/L	None	150-600 inland 1000 coastal	Standards primarily aesthetic, but higher salinities are unacceptable to users. Salinity is a major issue near the coast and some inland areas.
Fluoride	mg/L	1.5	1.0	Reason for standard unclear, but makes little difference. In NHS, almost all wells were <1 mg/L and all were <1.5 mg/L.
Iron	mg/L	None	urban 0.3; rural 1.0	WHO notes 0.3 mg/L for aesthetic reasons. Concentration much higher than 1.0 mg/L are frequently objectionable to users.
Magnesium	mg/L	None	35	WHO-GV not health-related.
Manganese	mg/L	0.4	0.1	0.1 mg/L is for aesthetic reasons, 0.4 mg/L for health.
Nickel	µg/L	70	100	Reason for standard unclear, but makes little difference to exceedance levels.
Phosphate/ phosphorous	mg/L	None	6	No health basis for standard (important in surface water), but P stimulates microbial activity. If anthropogenic, may be associated with pesticides.
Potassium	mg/L	None	12	WHO-GV not health-related.
Sodium	mg/L	None	200	WHO-GV not health-related; higher values may be associated with unacceptable salinity.
Uranium	µg/L	15	none	Not specified in BGD standards.
Zinc	mg/L	3	5	Reason for standard unclear, but makes little difference

[7] The standards actually refer to Kjeldahl-N, which equates to the sum of ammonium and organic-N, but in practice is predominantly ammonium.

Fig2

Fig3

Fig4

Fg5

Fig6

Fig7

Fig8

Fig9

3. GROUNDWATER RESOURCE AND ABSTRACTION ISSUES

3.1 Preamble

The first systematic assessment of groundwater resources was done by the MPO (now WARPO) during the National Water Plan (NWP) Phase-I and updated in NWP Phase-II in 1990. The resources were reviewed and used by several projects such as the *"Declining Groundwater Levels Study'* and *"National Minor Irrigation Development Project"*. However, no attempt was made to re-assess the original MPO estimates. The groundwater resources were re-assessed under NWMP (WARPO (1998), calibrating groundwater levels response to irrigation development

A definition of the terms and procedures used in groundwater resources assessments in Bangladesh is given in Appendix A.

3.2 Resource availability

3.2.1 Shallow Groundwater

By shallow groundwater, we refer to the aquifers within no more than 150 metres of the surface, usually within the top 100m, and towards the coast may be within 20-30m. More particularly, what we refer to here as shallow groundwater is sustained by recharge from local rainfall and rivers, is fresh, and is definitely not overlain by saline or brackish groundwater. Its definition does not take account of dissolved contaminants such as arsenic.

The availability of shallow groundwater for abstraction can, in almost areas, be judged in terms of its chemical quality (see above) and the quantity of annual potential recharge summed over a convenient administrative area such as an upazila. Only in a few situations, such as around Dhaka City and parts of the Barind, is a more rigorous assessment of sustainability required. Groundwater resources assessments (for shallow aquifers) conducted by MPO (1990) are summarised by planning region in Table 2.

Table 2. Groundwater Recharge and Unconstrained Development Potential

			Maximum Usable Recharge to Technologies (e)			
Region	Gross Area (Mha)	Usable Recharge (Mm^3)	STW (a) (Mm^3)	DSSTW (b) (Mm^3)	DTW1 (c) (Mm^3)	DTW2 (d) (Mm^3)
Northwest	3,016	12,100	7,700	9,900	11,900	11,700
Northeast	3,569	23,100	2,900	5,000	14,500	10,500
Southeast	3,007	9,800	600	1,200	4,700	3,100
South-central	1,426	3,500	600	1,000	2,500	2,000
Southwest	2,562	5,600	2,000	3,200	4,906	4,200
Total (f)	13,580	54,100	13,800	20,300	38,500	31,500

Source: MPO (1990). Notes:

a) 14 l/s suction mode tubewells, 7 m pumping limit
b) 14 l/s deep-set suction mode tubewells, 9 m pumping limit.
c) One-cusec (28 l/s) deep tubewells, 20 m pumping limit.
d) Two-cusec (57 l/s) deep tubewells, 20 m pumping limit.
e) Maximum value of the medium range taken from each Upazila printed output.
f) Active Flood Plain (AFP) of 0.82 Mha not included.

The National Water Management Plan (WARPO, 1998; 2000) used the same models as the MPO (see Appendix A). During NWMP, two estimates of average potential recharge by upazila were prepared: first assuming that with extensive coverage of FCD projects recharge takes place only on F3 and F4 land; and second considering flooding on F2 land. However, the difference is not large and NWMP adopted the assumption of potential recharge with flooding on F3 –F4 land.

Domestic, Commercial and Industrial Demand for Groundwater

Under NWMP, the estimated demand of groundwater for the domestic, commercial and industrial sectors and are given in Table 3.

Table 3. Water Demand for Water Supply by Region in 2025

Region	**SMAs**	**Other Towns**	**Rural Areas**	**Total**	**GW**	**Area**	**GW**
	Population in million				**Mm^3/season**	**Km^2**	**mm/season**
SW	2.4	4.5	16.4	23.3	289	24,689	12
SC	-	3.4	10.6	14.0	179	13,034	14
NW	2.3	11.0	28.8	42.1	539	33,794	16
NC	26.8	6.0	17.6	50.5	566	17,199	33
NE	-	3.5	14.1	17.6	222	20,038	11
SE	-	4.0	14.2	18.2	232	11,240	21
EH	6.1	3.2	6.0	15.3	181	19,820	9
Total	**37.6**	**35.7**	**107.7**	**181.0**	**2209**	**139,813**	**16**
Source: NWMP							

Evaporative Demands for the Environment, Fisheries and Forests

Demands for groundwater arise from evaporation from the areas under environmental use, fisheries and forests. These are met from soil moisture, from irrigation returns and surface storage and that would return to groundwater reservoir. These estimates are shown in Table 4.

Table 4. Water Demand for Evaporation from Environment, Fisheries and Forests

Region		Environment		Fisheries		Forest		Total	
	GIU Area	Area	Demand	Area	Demand	Area	Demand	Area	Demand
	Km^2	Km^2	Mm^3	Km^2	Mm^3	Km^2	Mm^3	Km^2	Mm^3
SW	14,299	2350	35	633	287	1150	297	4132	620
SC	3527	788	6	146	43	191	39	1125	88
NW	32,358	5885	140	1459	628	1636	522	8979	1290
NC	15,860	3595	42	576	190	1792	406	5963	637
NE	6090	901	12	204	63	417	95	1522	170
SE	6495	1415	16	382	107	366	71	2162	194
Total	78,629	14,934	251	3399	1319	5551	1430	23,884	2999

Source: NWMP

Agricultural Demand

The maximum agricultural demand has been estimated by NWMP as the potential demands on groundwater i.e. maximum evaporation from agriculture in the Groundwater Irrigation Upazila (GIU) area and is given in Table 5.

Table 5: Maximum Evaporation from Agriculture in GIU Area

Sl No	Region	Irrigated		Rain fed		Total		
		Area	Demand	Area	Demand	Area	Demand	Depth
		Km^2	Mm^3	Km^2	Mm^3	Km^2	Mm^3	mm
1	SW	9335	4135	832	61	10,167	4196	413
2	SC	2149	639	253	12	2402	652	271
3	NW	21,072	9339	2306	245	23,378	9548	410
4	NC	9012	3023	884	59	9897	3082	311
5	NE	4283	1341	285	16	4558	1357	297
6	SE	4051	1145	283	13	4333	1158	267
Total		**49,903**	**19,622**	**4,842**	**406**	**54,745**	**20,028**	**366**

Source: NWMP

Groundwater resource assessment (for shallow aquifers) was done by MPO in 1987 and 1990 and for the NWMP in 2000. No systematic regional evaluation of deep aquifer studies has yet been undertaken. The Government has not accepted the groundwater resource assessment made by the NWMP (2000) and asked them to revise the assessment. Under these circumstances, the groundwater assessment made during NWP II (1990) is used here (Table 2).

Net water supply demands by region up to 2025 are shown in Table 3; the demand for environment, fisheries and forests has been shown in Table 4; and the maximum agricultural demand has been shown in Table 5. Table 6 summarises the demand for groundwater, the available recharge, and its balance.

Table 6. Usable Recharge and Groundwater Demand

<table>
<tr><th rowspan="2">Region</th><th rowspan="2">Gross Area (Mha)</th><th rowspan="2">Usable (1) Recharge (Mm^3)</th><th colspan="4">Groundwater Demands (Mm^3) (2)</th><th rowspan="2">Balance: UR – GD (Mm^3, %)</th></tr>
<tr><th>Water Supply</th><th>Environment</th><th>Agriculture</th><th>Total</th></tr>
<tr><td>Northwest</td><td>3,016</td><td>12,100</td><td>539</td><td>1290</td><td>9548</td><td>11,377</td><td>+ 723 (6%)</td></tr>
<tr><td>Northeast</td><td rowspan="2">3,569</td><td rowspan="2">23,100</td><td>222</td><td>170</td><td>1357</td><td>1,749</td><td rowspan="2">17,066 (74%)</td></tr>
<tr><td>North-central</td><td>566</td><td>637</td><td>3082</td><td>4,285</td></tr>
<tr><td>Southeast</td><td>3,007</td><td>9,800</td><td>232</td><td>149</td><td>1158</td><td>1,584</td><td>8,216 (84%)</td></tr>
<tr><td>South-central</td><td>1,426</td><td>3,500</td><td>179</td><td>88</td><td>652</td><td>919</td><td>2,581 (74%)</td></tr>
<tr><td>Southwest</td><td>2562</td><td>5,600</td><td>289</td><td>620</td><td>4196</td><td>5,105</td><td>495 (9%)</td></tr>
<tr><td>Eastern Hills</td><td>-</td><td></td><td>181</td><td>-</td><td>-</td><td>181</td><td></td></tr>
<tr><td>Total
(Mm^3, %)</td><td>13,580</td><td>54,100</td><td>2208
8.8%</td><td>2999
11.9%</td><td>19,993
79.3%</td><td>25,200
100%</td><td>28,900
(53%)</td></tr>
</table>

Notes:

1. Resource Assessment by NWP-II, see Table 2.
2. Groundwater demand estimated by NWMP.

Only 8.8% of groundwater is required for water supply; 11.9% for the environment; and 79.3% for agriculture. The resource availability indicates that, *without consideration of water quality issues*, there should be no serious regional problem of groundwater availability for water supply. However, at sub-regional level it is noted that recharge could be a constraint along the western border of Bangladesh, and especially beneath the High Barind. Difficulties may also arise due to the increasing depth to the water table (see Section 3.3).

Other Factors Affecting Quantitative Availability

Apart from water levels, abstraction is constrained by natural gas that prevents suction pumps from working and promotes corrosion of submersible pumps.

In certain areas, in parts of Pabna and Natore (Chalan Beel), parts of Sylhet and Jessore districts, and along the Jamuna (e.g. Manikganj), layers of boulders and gravel limit the drilling of deeper wells. The solution to this constraint will be the use of appropriate power rigs.

3.2.2 Deep Groundwater

Deep wells (150-350 m deep) were originally installed in the coastal area to avoid salinity, in the area shown by the data points in the NHS maps (Figures 2 to 6). That survey found that only 1% of deep wells exceeded 50 µg/L and none greatly exceeded that concentration. Since that time, deep wells have been installed at an increased rate both in that area and further north, over large areas of central Bangladesh.

Although the deep aquifers are part of the same regional alluvial aquifer system as the shallow aquifers, assessing their quantitative availability is fundamentally different. Not only are the deep aquifers generally overlain by low permeability aquitards and, more significantly, across most of southern Bangladesh, they are overlain by saline or brackish groundwater (Figure 10). The latter observation proves that these aquifers are not recharged by vertical infiltration of rainwater in the area where they are abstracted from. Water quality in the deep aquifers was discussed earlier, although it is repeated here that development is constrained by the threat of migrating arsenic and salinity, and locally constrained by boron, iron and manganese. Isotopic dating shows that deep groundwater is a few thousand to a few tens of thousands of years old (e.g. Aggarwal et al., 2000). To what extent deep groundwater is a renewable resource is a matter of serious debate, but it is certain that this resource can supply large quantities of good quality water for many years.

The clearest evidence of the potential of the deep aquifers as a source of long term supply is that without either planning or control, they supply good quality throughout most of the coastal zone (see Appendix B for a selected list of deep aquifer projects studies). This is best demonstrated by the deep municipal wellfield at Khulna which has sustained intensive pumping for more than 45 years with no evidence of either salinisation or arsenic pollution (BRGM, 2005). Key uncertainty, however, comes from the almost complete absence of water quality and quantity monitoring of deep groundwater (as opposed to production wells).

Although it has been repeatedly advocated since the 1970s (e.g. Morton and Khan, 1979), no regional quantitative assessment of the deep aquifers has been undertaken, although there have been local studies of limited scale and scope (e.g. Khulna). Recent basinal scale models (Michael and Voss, 2008; 2009) are major landmarks towards the need for a regional assessment, but are currently unable to provide more than a perspective on the rates of groundwater movement as they do not consider salinity or the attenuation of arsenic. These models require further development in parallel with the implementation of a greatly enhanced monitoring system, without which such models cannot be adequately calibrated for use as management tools.

The study by BRGM (2005) at Khulna is the most advanced modelling study of the deep aquifer in Bangladesh, and yet the uncertainties and complexities identified by that study highlight the difficulties of producing reliable assessments. Although three aquifers are identified but only one is modelled because of the apparently strong confinement. The deep aquifer ranges from 20 to 150 m thick, and abuts a 260 m clay layer in the west. Salinity is a greater threat than arsenic, but there is no evidence of a saline interface[8], rather large bodies of slightly brackish groundwater (≤ 6000 µS/cm) to the east and north, but not to the south. BRGM (2005) predict a major reduction in the volume of fresh water available at Khulna over a 25 year timescale. While the precise time-scale of change is debatable given the uncertainties over model parameters, the direction of change (deterioration) is inevitable, and this

[8] In fact, it is not certain whether a saline interface has been mapped in

principle must be built into water supply planning. To do this, it is essential to have a monitoring system that provides advance warning of change. A further general conclusion can be drawn from the Khulna studies. While basinal scale models[9] provide a useful perspective, they are gross generalisations that are not adequate for planning water supplies to individual towns, the prospects for which over a 30 year time-scale will be determined by local hydrogeological conditions. In the short term (say five years), priority should be given to developing sound conceptual models and implementing, progressively upgraded, monitoring networks based on these models. Without a sound conceptual model, numerical models will provide little benefit and inspire little confidence.

A final, but very important, point should be stressed. Distribution losses in urban centres tend to be very high. So, where apparently non-renewable sources of deep groundwater are used, much greater efforts than normal should be made to minimise these losses. Unlike situations like Dhaka, where leaking water returns to an exploited aquifer (i.e. an efficiency problem), in the coastal towns the leaking water is effectively lost forever.

While resources studies are in progress, a pragmatic approach to managing abstractions from deep municipal wellfields will be to install and monitor observation wells between the abstraction wells and the nearest saline or arsenic contaminated groundwater body.

3.3 Declining Water Levels and Rural Water Supply Technology

The deepest groundwater table data for Bangladesh in 2009 was collected from DPHE and was mapped. The depth to water table is classified into seven categories and, according to mode of abstraction technology, the country has been divided into five groups as shown in Figure 10.

In the first group the water table up to the depth of 6m from the land surface are suitable for No. 6 hand pump. This group covers the largest area of the country. The people of these areas have no problem to use tubewells except groundwater quality where the shallow aquifers are contaminated with arsenic. But in coastal areas most of the tube wells are in deep aquifers.

The second group is where the deepest water table ranges from 6m – 8m depth, here Tara pumps are are considered to be of marginal suitability for withdrawal of groundwater. The areal coverage by this mode of technology is shown in Figure 10.

The third group is where the deepest water table ranges from 8 – 15m depth. Here the Tara pumps are appropriated for rural domestic supply. The area seems to be second largest area of the country. To use this technology a large scale investment is required, and currently DPHE with the assistance of UNICEF is arranging to install Tara pumps in place of No. 6 hand pumps.

Due to gradual decline, where the groundwater table now ranges from 15m to more than 16m, the Super Tara pump is required to use for domestic purposes. This technology has a higher installation cost than normal Tara pumps and substantial investment will be necessary. The most problematic areas have been delineated from the deepest water levels map and are listed below:

[9] Both conceptual and numerical models.

District	Upazilas
Nawabganj	Gomostapur, Nachole, Nawabganj Sadar
Rajshahi	Tanore, Bagrnara, Paba, Mohanpur, Godagari, Durgapur
Naogaon	Niamatpur, Porsha, Shapahar
Tangail	Ghatail (Madhupur
Netrakona	Barhatta, Atpara
Mymensingh	Haluaghat, Ishwarganj, Muktagacha, Nandail, Gaffargaon, Fulbaria
Dhaka	Savar, Keraniganj
Narayanganj	Rupganj, Narayanganj Sadar, Bandar, Sonargaon
Gazipur	Gazipur, Kaliakoir, Kapasia, Sreepur, Sakhipur
Dinajpur	Dinajpur
Kishoreganj	Hossainpur
Habiganj	Chunarughat
Bandarban	Ramu
Rangamati	Barkal

Fig10

Fig11

Fig12

4. ARSENIC WATER SUPPLY MITIGATION[10]

A reconnaissance survey in 1998-99 estimated that 29% of wells exceeded 50 µg/L As. Screening of all wells in 272 most affected upazilas in 2000-03 found that 29% exceeded 50 µg/L. Subsequent surveys and data analysis indicate that 20% of all wells exceeded 50 µg/L. There has been no systematic update of these surveys, but it is noted that in affected areas the number of new wells, mostly untested, has increased by about 30%. In 2002, the GoB estimated that 29M people were exposed to >50 µg/L, although later surveys produced a revised estimate of 20.2M. BAMWSP surveys identified 38,118 suspected arsenicosis patients in 2000-03, but a DGHS survey in 2008 confirmed only 24,389 arsenicosis patients. These numbers refer only to skin manifestations and not other symptoms of arsenic poisoning, and considering the latency of health effects, this may be only the tip of the iceberg.

There are no reliable statistics on the proportion of the exposed population now served by safe water, although a 2007 Policy Advisory Note estimated that 14% of the exposed population had access to some kind of arsenic safe technology.

4.1 Responsibilities for Mitigation

- Providers: Providers (i.e. households, vendors, communities, government and NGOs) are accountable to citizens and LGIs to **deliver** safe water.
- Regulators: The Government of Bangladesh is accountable to **regulate** LGIs to eliminate exposure to unsafe water. This could commence by recognising LGIs that are successful in eradicating unprotected, uncoloured and unregistered drinking water sources.
- Ensurers: Local Government Institutions (LGIs) are accountable to **ensure** safe water for all through determining needs, mobilising demand and registration of providers.
- Supporters: Research agencies, donors and partners **offer** technical and capacity support to ensure the sustainability of mitigation.

4.2 Guiding Principles

(i) Mitigation technologies are substantially proven, and their strengths and weaknesses understood. They include deep tubewells, dug wells, pond/river sand filters, rainwater harvesting and some arsenic removal plants. There should be no *a priori* preference for the choice of technology.

(ii) Arsenic is only one obstacle preventing universal access to safe water.

(iii) Mitigation will be delivered through the combined efforts of government, NGOs, the private sector and individual citizens.

(iv) It is the duty of those who provide water to ensure its safety.

(v) The immediate, and obligatory, goal is to prevent exposure to arsenic concentrations of >50 µg/L, and it should be a target to prevent exposure to concentrations of >10 µg/L.

(vi) Mitigation must respect the rights of present and future generations.

(vii) LGIs will ensure access to arsenic mitigation and thereby to safe water.

(viii) Demand-led monitoring by LGIs will be complemented by risk-based targets for planning and prioritising interventions and budget allocations through DPHE.

(ix) Independent evaluations will ensure the quality and effectiveness of interventions, and also that the expected health-based outcomes are actually achieved.

[10] This chapter is based largely on the Draft recommendations for IPAM 2009.

(x) Transparent reporting and public accountability are fundamental to monitoring, coordinating and managing the activities of stakeholders across sectors.

4.3 Inter-sectoral coordination

4.3.1 Co-ordination

Implementation plan for each sectors should be elaborated by the respective ministry, but coordinated and monitored through the office of the Principal Secretary (PS), as shown in Figure 12, and described below:

- Arsenic Committees: There is scope to combine Arsenic Committees with Watsan Committees at local level. However, the National Committee should be retained to coordinate activities between ministries.
- Arsenic Implementation Monitoring Unit (AIMU): This will evaluate and coordinate activities in each sector.
- Local Government Institutions (LGIs) will play a central role in ensuring access to safe water by monitoring progress and soliciting action towards a series of non-exclusive goals by:

i. Maintaining a register of all water sources and their status (e.g. unpainted, red or green, last tested), and thus determining demand for safe water.

ii. Control local well drilling and use.

iii. Ensure that water providers test the safety of the water supplied, and conduct spot checks to confirm this.

iv. Exchange information on tubewell status and the location of patients through Arsenic Committees.

4.4 Technologies

Selection: Where two or more technologies appear technically feasible, preference shall be given to surface water sources. The determination of feasibility shall consider at least all the following factors: (i) the chemical and biological safety of the water; (ii) cost; (iii) social acceptability; and (iv) the temporal reliability of the water source.

Guidelines: DPHE will periodically revise guidelines for the selection, installation and operation of all safe-water technologies.

Water safety framework: All providers of arsenic mitigation should introduce DWSPs at the earliest practical date.

4.5 Planning, Monitoring and Evaluation

Tracking the ongoing demand for mitigation will be achieved by integrating bottom-up monitoring by LGIs and top-down monitoring by DPHE.

MLGRD&C will set targets for achieving access to safe water for all; and LGIs will be responsible for measuring and facilitating progress towards these goals. The monitoring of demand will be achieved through the Union and Upazila Arsenic Committees.

Third Party Evaluations

Audits will verify the provision, status and quality of particular technologies and/or agencies. The results will feed back to refine monitoring and improve planning and technology guidelines.

Random, annual monitoring surveys will quantify residual arsenic exposure in communities that have received mitigation, and will require assistance from public health specialists in measuring biomarkers.

4.6 Capacity Building

To make the IPAM-WS effective, institutional strengthening of DPHE, WASAs and LGIs is required, with greatest effort required at union level. LGIs will need thorough training, through formal courses, in how to carry out their enforcing role: roles and responsibilities; in maintenance of registers; reporting procedures; water quality testing; needs assessment; facilitation and advocacy.

A fundamental requirement for effective groundwater management is the creation of permanent posts for groundwater specialists.

4.7 Deep Groundwater Management

Deep aquifers are expected to the largest source of mitigation. However, the resource is poorly understood and a number of studies and supporting activities are required.

4.7.1 Delineation of Groundwater Management Units for Deep Aquifers

The response of the deep aquifers will vary between regions, and a sound spatial framework, geographic and vertical, is required to assess and control abstraction. Mapping units, which may be further subdivided in the future, should be defined, following hydrological principles and, as far as possible, administrative units.

4.7.2 Study to Predict Declining Water Levels in Deep Aquifers

A comparable approach to the DPHE/UNICEF 'Study of Declining Water Levels' is required for the deep aquifers to predict when hand tubewells will need to be converted from nr 6 to Tara pumps, which will require the complete replacement of a very expensive well unless previously equipped wit ha larger diameter casing.

4.7.3 Monitoring and Assessment

A monitoring network is urgently needed for the deep aquifer. Its' installation should be combined with investigation of aquifer properties and water quality, and refinement of conceptual models.

4.7.4 Mathematical Modelling of Deep Aquifers

Mathematical modelling should be progressively developed in parallel with investigations and monitoring.

4.7.5 Deep Aquifer Management Strategy

A short Deep Aquifer Management Strategy document should be prepared by, or through DPHE and WARPO.

4.7.6 Legislation and Regulation

To protect deep (and shallow) aquifers, legislation is required. This may be achieved by revising the Draft Water Act, but might require a separate Aquifer Protection Act, and will involve a system of abstraction licensing for mechanised wells.

4.8 Research and Development Activities

The following R&D activities are recommended:

4.8.1 Field testing and laboratories

There is a massive requirement for monitoring and provision of local testing facilities. Ideally, this should be at least two local manufacturers of validated field test kits in Bangladesh, and a predictable procurement pipeline.

4.8.2 Disposal of Arsenic-Rich Sludge

Despite research and the fact that arsenic removal plants are operating, there is no agreed protocol for disposing of As-rich wastes in Bangladesh.

4.8.3 In-situ (Subsurface) Arsenic Removal

In-situ treatment of groundwater, a long-proven process for public water supplies in Europe, which involves the cyclic injection of aerated water and withdrawal of water from which arsenic, iron and manganese are removed. It is the only mitigation technique that both permanently removes arsenic from water in the aquifer and does not generate an As-rich waste.

Also, as noted above:

- An epidemiological study of boron in deep groundwater in Barguna, Pirojpur and Jhalokati may be undertaken to determine whether there is evidence of health effects, and hence on what priority water supply interventions are required.
- A national survey of uranium, radon & radioactivity in groundwater may be undertaken by BAEC.

4.9 Reporting and Accountability

4.9.1 Principles

Transparent and reporting is central to public accountability, and requires: (i) physical and financial progress reporting by line ministries and NGOs; (ii) exchange of summarised data between ministries and sectors; (iii) skilled analysis of this information; and (iv) policies and rules to facilitate these actions.

4.9.2 Annual Reporting

An annual 'State of Arsenic in Bangladesh' report should be published to show the evolving status of contamination, disease and mitigation, and the activities and plans of major stakeholders. The report will inform government and civil society, with minimal technical language, about: (i) the number of contaminated and untested drinking water wells; (ii) the number of arsenicosis patients have been diagnosed; (iii) how many arsenicosis patients have had their symptoms improve or deteriorate; (iv) how many irrigations wells are contaminated; (v) what mitigation has bee installed or is planned; and (vi) how the health and economy of the nation is being affected.

The AIMU will be responsible to supply the necessary information, or provide a public statement of why it is not available, to produce the report. The production of the report, however, may be contracted out to an organisation skilled in explaining science to the general public. Apart from providing a public service, this report will be a self-regulating mechanism for all stakeholders in IPAM 2009.

4.9.3 Data Management

Data management is fundamental for designing, monitoring and evaluation of mitigation. NAMIC was created to store and distribute data, but closed at end of the BAMWSP project. The work was partly continued by APSU, but this too closed in June 2006.

5. REGIONAL SYNTHESIS

5.1 Northwest

Key issues. At regional level, groundwater recharge is just adequate to satisfy demands at full irrigation development, but there local shortfalls are expected, notably in the High Barind, where both wet and dry season water levels are declining.

The highest priority water issue is arsenic in the southern districts of Nawabganj and Pabna. Arsenic is also high at locations along the right bank of the Jamuna, where iron is also very high. There are large areas where Mn alone is a problem, both at the WHO and BGD levels, but both Fe and Mn co-occur at high concentrations in the northern half of the region.

Rural Water supply.

Most of the NW will require Tara pumps (or Super-Tara on the High Barind) except along the banks of the Jamuna and on the Tista floodplains, where Nr 6 pumps may continue to provide supplies. The area around Shibganj, Nachole and Niamatpur is predicted to have irrigation demand in excess of recharge, and may require regulation or other special measures to reduce impacts on domestic supply.

It is unclear whether deep tubewells will be successful in Nawabganj and Pabna districts, and so it is recommended that this area is prioritised for promoting community level treatment (both As-removal and surface water), but improved drilling methods should also be tested on an urgent basis. Along the Jamuna right bank, deep wells should be possible, but improved drilling methods may be needed to penetrate gravel layers. This may also be a solution for iron, otherwise treatment systems should be promoted.

It is noted that several hundred rural piped supplies have been installed on the Barind without an apparent requirement for Fe and/or Mn treatment; however, attempts to extend this to adjoining areas will face difficulty.

Urban Water Supply (exc. Rajshahi). Resource availability indicates that towns throughout can be supplied by tubewells but most will require Fe and/or Mn treatment.

Vulnerability. In almost areas, except the Barind and Chalan Beel areas, shallow groundwater will especially vulnerable to anthropogenic pollution from all sources, and is the only area where nitrate from both agriculture and on-site sanitation is likely to become a problem.

Other issues. There are pockets of brackish water around Manda upazila (Naogaon District).

5.2 North-Central

Key issues: At regional level, groundwater recharge is adequate. However, occurrences of thick clay layers restrict recharge locally on the Madhupur Tract. Water level is declining in and around Dhaka City and other parts of the region. Water level is deep over most part of the Madhupur Tract.

There is a severe arsenic problem in the southern part of the region in the districts of Munshiganj and Manikganj. Also there are some occurrences in the west and north, in the districts of Tangail and Jamalpur. Fe is generally low in the Madhupur Tract by very high along the peripheral rivers such as the Jamuna. Mn is high over most parts and a major problem, especially at BGD levels. There is a large area in the east, particularly in Manikganj district, where drilling to deeper levels are restricted.

Rural Water supply: As water levels are deep and declining over many areas, Tara pumps have to be used for rural water supply. A small number of rural piped water supply systems have been implemented in the area.

In Manikganj, Munshiganj and Narayanganj districts, arsenic and excessive iron can be avoided by drilling deep wells, but in places improved drilling methods may be needed to penetrate gravel layers.

Urban Water Supply (exc. Dhaka): Resource availability indicates that towns throughout can be supplied by tubewells but some will require Fe and/or Mn treatment. But impact of large scale abstractions in Dhaka city may reduce the water productivity in the wells in Narayanganj, Gazipur areas. Because of thick surface clay, shallow groundwater is better protected from anthropogenic pollution from all sources. However, concentration of industries in and around Dhaka and discharge of untreated wastes to the rivers pose great threat to groundwater, particularly in areas where the river cuts through the upper clay.

Other issues: There are chances of conflict among municipal, agricultural and industrial uses in the region.

5.3 Northeast

Key issues. At regional level, groundwater recharge is adequate; however, thick clay layers restrict recharge locally, such as in the Haor Basins, and in general the region, especially the Sylhet Basin is characterised by much greater hydrogeological complexity than other parts of Bangladesh. There is no evidence of water level decline in the region.

There is minor problem of arsenic in parts of Sunamganj, Habiganj, Netrakona and Kishoreganj districts. Deep aquifer has recently been exploited in these areas but is not an easy solution always. Also there are occasional gravel problems in small areas. Fe is generally very high over the entire region and Mn is also a problem, especially at the BGD standard.

Rural Water supply.

Most of the NE can be served by Nr 6 pumps as water level is very shallow. There are few pockets of deep water level in the hilly area where Tara may be required. Artesian wells are found in the hilly regions. Very few rural piped water supply system has been implemented in the area.

Urban Water Supply (exc. Sylhet). Resource availability indicates that towns throughout can be supplied by tubewells but most will require Fe/Mn treatment. Because of thick surface clays, shallow groundwater is better protected from anthropogenic pollution from all sources. Due to the hydrogeological complexity, greater flexibility and location-specific approaches will be required, and this in turn will require developing institutional skills in hydrogeology.

Other issues. There is a pocket of high B in the Haor Basin in the districts of Sunamganj, Habiganj, Kishoreganj and Netrakona.

Tea Garden Irrigation: As the area is major tea growing area, there is big demand for groundwater in the tea growing areas.

5.4 Southeast

Key issues: At regional level, groundwater recharge is adequate and water level is low over most of the region. Water level is relatively deep in parts of Comilla and Brahmanbaria districts.

This is one of the most severely arsenic affected regions of the country where large proportions of wells exceed safe levels of As in the districts of Brahmanbaria, Comilla, Chandpur, Noakhali and Lakshmipur. Fe is high over most of the area. Mn is also a minor problem in many parts of the region, especially at the BGD standard. High salinity has been reported from the Nabinagar - Muradnagar - Daudkandi – Chandina area.

Rural Water supply: Most of the plains of the region can be served with Nr. 6 pump. However, a small area in the plain may need Tara pumps, and the area around Damurhuda, Alamdanga, Chuadanga, Jibbanangar and Chowgacha is predicted to have groundwater irrigation demand in excess of recharge, and may require regulation or other special measures to reduce impacts on domestic supply.

Deep tubewells are feasible solution over most of the As-affected parts of the region, and will also provide low concentrations of Fe and Mn. As elsewhere, long term saline intrusion is a risk, especially closest to the coast.

A good number of rural piped water supply systems have been implemented in the area, a trend that will probably continue using deep groundwater.

Urban Water Supply (exc. Chittagong): Resource availability indicates that towns throughout can be supplied by tubewells. However, salinity will be a constraint for the groundwater where shallow groundwater use is restricted by arsenic. Iron removal may be needed, in some case even if water is abstracted from the deep aquifer. Very shallow groundwater in Noakhali region is vulnerable to pollution from onsite sanitation and other sources.

Other issues: Boron is generally high and there are few high concentrations.

Abstraction of either shallow or deep groundwater may cause land subsidence. This may be occurring already, but could be confused with regional tectonic subsidence.

5.5 South-Central

Key issues: At regional level, groundwater recharge is adequate. However, there is little groundwater irrigation in the area and shallow groundwater is relatively saline. Arsenic occurs in large number of shallow wells in the area and is a major problem in the districts of Shariatpur, Gopalganj and Faridpur. However, deep aquifer with As safe fresh water is available over most of the region.

Deep aquifer have been extensively used in the area as a mean of As safe fresh groundwater. Fe and/or Mn concentrations are generally low in the deep aquifer.

Rural Water Supply: Due to the problems of both arsenic and salinity in shallow groundwater, most of the SW will require deep wells fitted with Nr 6 pumps as water levels are within suction limits, nevertheless there may be a requirement for deep wells with Tara pumps in the medium term.

Urban Water Supply (exc. Barisal): Although resource availability indicates that recharge to shallow groundwater is not a constraint, this is largely irrelevant because most towns will be supplied by deep tubewells. However, in the long run, if abstracted without management and monitoring, there may be saline intrusion.

Vulnerability: Groundwater vulnerability is inherently low for the deep aquifer; however, rising sea level due to climate change may endanger shallow groundwater.

Other issues. Boron is high in the deep aquifer along a linear EW trending line through Barguna and Jhalokati districts.

5.6 Southwest

Key issues: At regional level, groundwater recharge is adequate except in the Sundarban mangrove forest. Arsenic is a severe problem in large proportion of shallow wells in the area and is a major problem. However, deep aquifers with As safe fresh water are present in the south, in the districts of Khulna, Bagerhat and Satkhira, although the deep aquifer contains As in parts of Jessore. Salinity is a problem in shallow groundwater in the Khulna, Bagerhat and Satkhira. Pockets of high salinity occur in deep aquifer in the region. Fe is high all over the region both in deep and shallow aquifers. Mn is high in the northern part of the region in the grater districts of Jessore and Kushtia. Fe and Mn concentrations are generally low in the deep aquifer.

Rural Water Supply: Most of the SW will require Nr 6 pumps as water levels are shallow in both the upper aquifer and the deep aquifer. However, there are larger fluctuations in water level in dry season and Nr 6 pumps may not work during the peak irrigation season. Modifications to well design may be necessary so that wells can be pumped by Tara pumps. There is a small pocket of relatively deep water levels along the border of Kushtia and Rajbari.

Arsenic, iron and manganese are spatially variable at small scales across most of the region, and deep wells will be used extensively. Shallow groundwater that is high in As is generally also high in Fe, and vice versa. In the northwest of the region, there is large areas (Jessore, Jhennaidah and Magura) where shallow groundwater is low in As and Fe, but high in Mn and will require avoidance through deep wells or treatment

Urban Water Supply (exc. Khulna): Resource availability indicates that towns throughout can be supplied by deep tubewells. In the long run, if abstracted without management and monitoring, there may be saline intrusion. Fe and Mn removal needed for the towns in the northern part of the region.

Vulnerability: As in the SW, groundwater vulnerability is inherently low for the deep aquifer, but rising sea level due to climate change may endanger shallow groundwater.

Other issues: Barium is relatively high background all over the region, and exceeds the BGD standard in parts of Satkhira.

Abstraction of either shallow or deep groundwater may cause land subsidence. This may be occurring already, but could be confused with regional tectonic subsidence.

5.7 Eastern Hills

Key issues: At regional level, most complicated groundwater conditions. Groundwater occurs in the coastal plain aquifers at shallow depths. Regional recharge estimates show enough resource to meet irrigation demands in the region. However, groundwater irrigation is very limited in the area. Arsenic occurs in a few wells in northern part of the region, i.e. in Mirsarai Upazila of Chittagong district. Saline water occurs along the coast.

Deep aquifer is used in the coastal plains as a means of fresh groundwater. Fe and Mn concentrations are generally high both in deep and shallow groundwater.

Rural Water Supply: Water level is low in the coastal plain in the shallow aquifers and occurs under piezometric pressure in the in the deep aquifer and hence can be abstracted using Nr 6 pumps. However, water levels are deep in the hilly region and Tara pump would be required. Also due to low yield in shallow aquifers in many parts of the hilly region, ring wells have to be used. Protected springs also can provide water supply in the hilly region.

Urban Water Supply (exc. Chittagong): Deep aquifers can provide water for municipal supplies in the coastal plains. Complex Geology makes it difficult to abstract large quantities of groundwater in the hilly regions. However, if abstracted without management and monitoring, there are potentials for saline water intrusions. Cox's Bazaar, because of a recent boom in tourism, needs special attention to ensure water supply for the coming years.

Vulnerability: Groundwater vulnerability is relatively low to the deep aquifer as there is relatively thick clay at the surface. However, shallow groundwater in the coastal islands such as St. Martin's is highly vulnerable to pollution from various surface sources. Changes in sea level due to climate change can affect shallow groundwater in the coastal plains.

6. WATER SUPPLY TO DIVISIONAL HEADQUARTERS

6.1 Introduction

The existing water supply activities, the groundwater and surface water resources of six Divisional Headquarters and the planning and development options are briefly discussed. A summary of demographic and key water supply statistics is given in Table 8. There is currently a massive shortfall in capacity. Only Dhaka (80%) and Rajshahi (73%) supply more than half of the population, with Sylhet and Barisal supplying only a quarter. All cities except Chittagong (55%) are predominantly dependent upon groundwater for their present supply.

Two demand projections[11] were considered: the NWMP estimates for 2025 and, as a check, a simple estimate based on supplying the projected 2025 population with 150 lpcd. In every case, huge increases in capacity are required to fully serve the projected populations. The smallest required increases are at Dhaka, and even these require a 1.8 to 4.0 times expansion, and at Rajshahi (2.0 to 3.5 times). At the other four cities, expansions of 5 to 15 times would be required. Such increases in supply will place heavy pressures on water resources, although the ability of present institutions to deliver these increases must be questioned.

The per capita water supply estimates should also be treated with caution, as these vary by a factor of more three between Khulna (71 lpcd) and Sylhet (236 lpcd). However, these uncertainties leave little doubt regarding future pressure on water resources. On the other hand, the demand projections may exaggerate the increased use of water resources because the 60-75% of people in Khulna, Barisal, Chittagong and Sylhet who are not presently served by the municipal supply presumably draw on some water resource in the area, albeit at a low per capita rate.

Options for surface water development are beyond the present scope of this chapter, which addresses only the potential of groundwater to provide continued and additional supplies for each of the six cities. The selection of the appropriate combination of surface water and groundwater requires specific feasibility and design studies.

6.2 Dhaka

Existing situation. The Dhaka City Corporation area has a population of about 13 million. Groundwater, the main source of water supply, is drawn from the Dupi Tila aquifer. Most wells >150m depth and a few PTWs have recently been sunk to >300m depth, into a deeper aquifer. The groundwater quality is naturally good, and does not require treatment for arsenic, iron or manganese, although there is legitimate concern about industrial pollution being drawn into the municipal wellfields. The groundwater level in the main aquifer has been declining continuously for more than forty years, with a significant portion of groundwater derived from mining of storage. The deep aquifer resource has yet to be estimated, and apparently water levels are falling more rapidly than in the upper aquifer. The wellfield area lies entirely within the urban area. Modelling studies have indicated that if abstraction were held constant, water levels would eventually stabilize due to capture of recharge from surrounding rivers and agricultural lands. However, because abstraction continues to grow, so does the cone of depression. Continued expansion of municipal pumping will potentially conflict with irrigation pumping in surrounding areas, although the latter is declining due to loss of agricultural land to urban expansion.

[11] It is noted that the NWMP forecasts are 1.7 to 2.3 times higher, however, the reasons are not explored here.

Up to 1990, declining groundwater levels had not caused land subsidence on the area of the Madhupur Tract (red soil areas), although impacts on the adjacent floodplains could not be determined[12]. The current status of subsidence is not known, and expansion of cone of depression beyond the Madhupur Tract will greatly increase the likelihood of land subsidence.

The groundwater resource at Dhaka could be enhanced by reduced and artificial recharge of rain water from roof tops, and perhaps also from retained floodwater after sedimentation.

Planning and operations of groundwater development at Dhaka WASA are constrained by the absence of groundwater specialists.

Development Options: To attempt to satisfy the ever increasing demand, Dhaka will need to develop additional surface water and groundwater resources. Options for surface water development[13] are beyond the present scope.

It is unlikely that the capacity of the long-established wellfields in the city area can be increased, except perhaps in the very short run, and in the long run their yields are more likely to decline as the piezometric surface continues to fall. Nevertheless, based on past inefficiencies, it is possible that interim benefits can be obtained by improving O&M at existing wells.

The recent performance of the deep aquifer appears to confirm earlier predictions that this resource will make a limited long-term contribution to Dhaka supply, however, existing data are limited and detailed assessments should be urgently undertaken. Special attention should be given to reducing distribution losses of water pumped from deep aquifers.

Lateral expansion of wellfields is a major for supply[14], although this will require careful assessment of (i) the impacts on irrigation; (ii) treatment of iron, manganese and arsenic; and (iii) the risks of land subsidence due to intensive pumping. Developing wellfields and large diameter transmission pipelines in the direction of long term sources of surface water, and along industrial-residential corridors, is likely to be a particularly valuable strategy.

A dedicated groundwater team should be established at DWASA to support planning and optimize operation of the present wellfields.

6.3 Chittagong

Existing situation. The Chittagong City Corporation area had a population is 3.75 million in 2008. About 55% of Chittagong WASA's water supply is supplied from groundwater. As a port, its position astride the Karnaphuli River and at the coast is important for its water supply.

Most of the CWASA tubewells withdraw water from an aquifer about 150 m deep. The aquifer consists of medium to coarse sand, but in some areas a hard siltstone layer makes drilling difficult. There are unconfirmed reports that groundwater development in the city is being affected by saline intrusion and lowering of groundwater table[15]. On the other hand, there are also reports that aquifers on the opposite

[12] DWASA. 1991. Dhaka Groundwater and Subsidence Study. EPC and MMP.

[13] Such as the 450 MLD plants suggested for Pagla/Keraniganj, Khilkhet and Saydabad.

[14] Development of a wellfield at Bhakurta-Hemayetpur in Savar to supply 150 MLD to Mirpur the area has been proposed.

[15] CWASA workplan 2009-15, presented on Feb 5, 2009 at the Local Government Division, Bangladesh Secretariat, Dhaka.

side of the river i.e. in Korean EPZ are good and the tubewells are supplying water to meet up the need of the industries[16].

Development Options: To meet growing demand, Chittagong WASA has plans to develop additional surface water treatment plants (SWTP) and groundwater sources, including; (1) a 136 MLD SWTP at Karnaphuli P-1; (2) a 45 MLD SWTP at Modunaghat P-1; and (3) 60 deep tubewells (30 MLD) within the existing water supply area.

In the longer term, CWASA has plans for additional surface water treatment plants at Modunaghat P-2 (45 MLD); Karnaphuli P-2 (136 MLD); and Karnaphuli left bank P-1 and P-2 (200 MLD capacity).

The status and availability of groundwater at Chittagong is unclear, although it is likely that it will continue to provide an important and long-term part of the city's water supply. Groundwater may be drawn not only from within the city area, but on both banks of the Karnaphuli and from further inland. To the east of Chittagong, groundwater is available from Holocene floodplain deposits as well as the Dupi Tila, but the possible requirements for treatment of iron, manganese and arsenic must be assessed, as should the possibility of land subsidence. The latter risk has apparently not been considered, but will apply mainly to the floodplain area, and not the Pleistocene sediments.

The risks of saline intrusion should be viewed as serious, and a monitoring network and a technical staff capable of interpreting the data, should be established. It has been suggested that for deep drilling within the city, down to say 500 m depth[17], may locate promising aquifers, however, no investigation has been carried out down to that depth.

It appears that a regional study on groundwater resources is required to be carried out for water supply purpose.

6.4 Rajshahi

Existing situation. The Rajshahi City Corporation had a population of 0.50 million in 2005. The River Ganges flows past the western part of the city, although groundwater is the principal water source, supplying 73% of the population from 45 PTWs that run for about 12 hr/day and about 6500 HTWs.

Presently, supply is drawn mainly from shallow aquifers that contain high iron[18] (from 0.5 to >5 mg/l) and manganese (around 1.5mg/l), but arsenic is relatively low, with a maximum is 30 ppb in one PTW. Deep aquifers (>150m) are free from iron (<0.3 ppm); arsenic is well below 50 ppb; and manganese exceeds 0.1 mg/L (Bangladesh standard) but is <0.4 mg/L (WHO guideline).

Development Options: While one option to meet projected demand is extraction and treatment of surface water from the Ganges, and potentially better solution is streambed infiltration from a line of wells adjacent to the river. Once established, such systems can supply highly reliable sources of water with minimal treatment needs[19].

Notwithstanding the prospects of streambed infiltration, conventional groundwater development should be a viable long-term option at Rajshahi, albeit there may be some water quality and quantity constraints and conflicts with irrigation abstractors.

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[16] Pers. Comm. (MAS). Discussions with BWDB personnel installing wells in the area.

[17] Depth indicated at the afore-mentioned CWASA meeting.

[18] An iron removal plant was established in 1937, courtesy of Rani Bhabani.

[19] Effectively, the shallow aquifer acts as a giant sand filter for river water. Such systems operate at Dhaka and Chapai Nawabganj.

Shallow groundwater requires Fe & Mn treatment, while the future decline in groundwater levels should be moderated by induced recharge[20] from the Ganges. During summer the river water level falls sharply and receives recharge from groundwater. Due to this behaviour the groundwater table decline substantially along with the withdrawal by the PTWs.

The declining water table in the Barind may affect groundwater at Rajshahi.

Deep groundwater does not require treatment, but future declines in water level are uncertain.

6.5 Khulna

Existing situation. The Khulna City Corporation area had a population of 1.55 million in 2008. The river Bhairab flowing through the City is a perennial river, but is situated in the tidal zone and is saline for several months each year. BRGM (2005) identified three aquifers, although only one was modelled because of the apparently strong confinement. The upper aquifer has been heavily exploited by private wells, but is severely contaminated by As, Fe and Mn, and locally affected by salinity. The second aquifer is free of arsenic but is saline (2-5,000 µS/cm). At present the municipal water supply and the rural drinking water are extracting groundwater from the deeper aquifer (<150-200m depth). The deep aquifer is at risk from either lateral saline intrusion or leakage from the upper saline aquifer, although to date[21] deep municipal wells have not been affected excepted where wells have been physically damaged.

The deep aquifer ranges from 20 m to 150 m in thickness, and abuts a 260 m clay layer in the west. Salinity is a greater threat than arsenic, but there is no evidence of a saline interface[22], rather large bodies of slightly brackish groundwater (≤ 6000 µS/cm) to the east and north, but not to the south. BRGM (2005) predict a reduction by up to half in the volume of fresh water available at Khulna by 2030. While the precise time-scale of change is uncertain, the direction of change (deterioration) is not. For water supply planning, it is essential to have a monitoring system that provides advance warning of change, and explore alternatives long-term alternatives such as imported surface water, conjunctive use, and in particular investigation of the large body of good quality deep fresh groundwater 5 km to the northwest of present conurbation. Further, major efforts should be made to minimise distribution losses of apparently non-renewable deep groundwater.

Development Options: Khulna could experience significant water stress over the next 30 years. Although the deep aquifer has performed well and is unlikely to deteriorate rapidly or simultaneously across the wellfield area, the BRGM study indicates that pumping from the present area probably cannot be increased on a sustainable basis, and that the present abstraction rate may not be sustainable in the very long run (>30 years). There is uncertainty in these predictions, but it would be imprudent not to begin evaluating alternative sources as a matter of urgency.

Deep groundwater should be used for the foreseeable future, but if the predicted reductions in fresh water volume are verified, then the balance of abstraction should be shifted to other sources while retaining the capacity to withdraw large volumes from this strategic reserve to cope with short-term loss of supply from distant sources.

If deep groundwater cannot sustain high abstraction rates, and surface water is constrained, shallow groundwater may be treated at a central plant to remove As and Fe.

[20] Currently the river receives baseflow from groundwater

[21] Deep well pumping in Khulna commenced in 1964.

[22] In fact, it is not certain whether a saline interface has been mapped in any area of Bangladesh.

Both surface water and groundwater alternatives exist, but both involve difficulties. The location and availability of a surface water source will depend partly on schemes being contemplated on the Ganges and Gorai rivers, and therefore provide an uncertain basis for water supply planning. For these reasons, it is important to proceed with exploring and assessing deep and shallow groundwater resources to the northwest of Khulna. Although inefficient in the short to medium term, surface water from the Bhairab could be abstracted and treated for part of the year, allowing the life of the deep aquifer resource to be extended.

Abstraction of either shallow or deep groundwater may cause land subsidence. Indeed, if this is an issue, the problem is probably already occurring, although care may be needed to separate the process from regional tectonic subsidence.

Further, leakage of deep groundwater from the distribution system should be minimised. Groundwater specialists should be recruited to oversee the management of the deep groundwater resource.

6.6 Barisal

Existing situation. Barisal City, with a present population of about 0.4 million, is situated by the river Kirtonkhola. Barisal is presently supplied by 23 deep PTWs that serve about 27% of the population, which is projected to double by 2025. BETS (2009) identified three aquifers at Barisal: an upper aquifer from 7 m – 120 m depth that is contaminated by arsenic. A second or lower aquifer exists between 150 and 240 m, and a third or deeper aquifer exists below 250 m, both of which are free from arsenic. The lower aquifer is commonly used for drinking water by the local people, but in places is brackish. The deeper aquifer system contains good quality water does not require treatment. At present in the upper aquifer the static water level is about 2m to 7m and groundwater level has been declining at a rate 0.50m per year, however, no equivalent data for the deeper aquifers could be obtained.

Development Options: Both groundwater and surface water options exist at Barisal: the Kirtonkhola river is apparently unpolluted in the dry season and is a potential source for surface water treatment. The existing conceptual model of groundwater flow at Barisal is insufficiently developed to provide confidence in any resulting numerical models. Groundwater abstraction from the deeper aquifer may be susceptible to saline intrusion. A detailed investigation, along the lines of the recent study at Khulna, is urgently required.

Groundwater abstraction may cause land subsidence, and should be monitored for, and differentiated from tectonic subsidence.

Irrespective of these options, major efforts should be made to minimise distribution losses of apparently non-renewable deep groundwater. Groundwater specialists should be recruited to oversee the management of the deep groundwater resource.

6.7 Sylhet

Existing situation. The City Corporation area had a population of 500,000 in 2008. The present water supply comes 98% from groundwater and 2% from surface water. There are 17 PTWs ranging from 91 m to 122 m in depth, and with discharge of 46 to 119 m^3/hr (BETS, 2009). Hydrogeological conditions at Sylhet are extremely complex and vary greatly over short distances. Within the top 100 m, there are three aquifers interbedded with three aquitards. This complexity is illustrated by continuously declining water levels at piezometer Sy-111, but not Sy-71 (both 24 m deep).

Development Options: The Surma river could potentially be developed, after treatment and possibly construction of a retention structure, as a source of supply to the city. The existing conceptual model at

Sylhet is insufficiently developed to provide confidence in any resulting numerical models. BETS (2009) suggest that the northern and northwestern parts of Sylhet city may be suitable for groundwater exploitation. Due to the complexity, more exploration effort will be required in Sylhet than elsewhere, with highly variable recharge, well yield and water quality.

Groundwater specialists should be recruited to oversee the exploration and management of groundwater supplies.

ummary of Demographic and Water Supply Statistics at Six Divisional Headquarters

Population 2001 (1)	Population 2008	Projected Population 2025 (2)	Current Supply (MLD)		Percent of Population Currently Covered	% GW in current supply	Current Supply (lpcd)	No. of PTWs	No of SWTPs	Dema
			GW	SW						NWMP
5.5M	13M	19.2M (5)	1390	229	80%	86%	156	484	4	6516
2.3M	3.75M	7.7M	110	90	41%	55%	130	73	1	2631
0.78M	1.55M	3.0M	43.78	0	40%	100%	71	50	0	815
0.54M	0.75M	1.4M	103	0	73%	100%	188	49	0	361
0.32M (3)	0.5M	0.94M (3)	29.5 (3)	0.06	25%	98%	236	17	1	253
0.22M	0.4M (3)	0.78M (3)	8.38	0	27%	100%	78	23	0	219

1) Population census 2001, Bangladesh Statistical Bureau.
2) Review of Water Supply and Sanitation Sector, NWMP, Draft working paper, November, 1998, WPNo.08-20.
3) Water supply sanitation and drainage project in Sylhet and Barisal city (BETS, 2009).
4) Including Narayanganj (14 PTWs and 2 SWTPs)
5) May be too low - other sources predict 17-18M by 2020 for Dhaka City.
6) From data in this table, assuming 150 lpcd for 100% of the population in 2025

7. Recommendations for Effective Groundwater Management

7.1 Preamble

The Terms of Reference for this assignment require "making recommendations for the management of groundwater including suggestions for inclusion in the Revised SDP and Water Act". The need for reform or reorganisation of water management is implicit in the statement, however, it is recognised that this is complex task, requiring extensive consultation, and one that cannot be entirely divorced from overall management of water resources. These recommendations can only be a start, and to this end we begin by reviewing the present status of the relevant agencies, their present performance and what is needed for them to carry out their present remits. We then address the structural gaps in the organisation of groundwater management. Subsequently we outline specific measures to be included in the Revised SDP and Water Act. The final part presents the scope for a national groundwater strategy to build the theoretical foundations for the proposed reforms.

7.2 Roles and Capacities of Agencies

Groundwater in Bangladesh is developed, used and managed by various agencies. Despite, the existence of national policies on both water (resources) and on safety water and sanitation, there is no integrated strategy to ensure the beneficial use, protection and sustainability of this vital natural resource. Current developments are mostly done on *ad hoc* basis driven by demand. There should be a national groundwater development/management policy or strategy to ensure sustainable development and management of groundwater to meet the demands of water supply, irrigation, industry and the environment.

The main organisations involved in groundwater management are listed in Table 8. To this list of stakeholders must be added the private sector who, as farmer and householders, are by far the largest abstractors of groundwater, but are not formally represented in water management other than through the general electoral process.

Table 8. Organisations Involved in Groundwater Management

Ministry	Department	
	Major role	Minor role
Water Resources	WARPO, BWDB	
Local Government	DPHE, WASAs	LGED, RDA
Agriculture	BADC, BMDA	DAE
Environment		DOE
?		BAEC
Industry?		EPZs
Energy & minerals?		GSB
Planning		Planning Commission
QUANGOs[23]		IWM, CEGIS

[23] Quasi-autonomous non governmental organisations

The functions involved in groundwater management can be classified into five groups: (i) monitoring; (ii) assessment; (iii) protection and regulation; (iv) development; and (v) research & development. The current roles of the main organisation are set out in Table 7.2, along with recommendations for their possible future roles, as discussed further below. The roles of some agencies has changed dramatically in the last two decades; notably BADC and to a lesser extent BWDB had a major role installing irrigation wells, but now have virtually none; and DPHE have had a more gradually shifting role form installing water supply wells to supply local government in this function. Beyond this, there has been a shift in planning away from top-down role in allocating government investments towards a more responsive role in coordinating and supporting state and private sector activities. It should also be noted that no agency[24] has meaningfully controlled the activities of the private sector in abstracting groundwater, and there has been only limited control and coordination between ministries.

Table 7.2 includes an assessment of the expertise in the different departments. No departments are assigned a 'strong' at present and most are classed as 'weak', however, 'strong' scores are considered necessary for WARPO, BWDB and DPHE. The principal reason for the low scores given to most agencies is staffing. None of the key agencies have sufficient qualified groundwater professionals, neither on permanent, contract nor consultant basis. This is perhaps the greatest constraint to achieving effective management of groundwater resources. There is a 'chicken and egg' argument here, but without appropriate skills in place, it is unlikely that the organisations will appreciate either the scope of technical works required or the organisational reforms required for effective resource management. It is stressed that the absence of groundwater professionals in the relevant government departments is not due to the absence of suitably qualified national scientists[25].

7.3 Groundwater Management Activities Not Currently Addressed

Currently a wide range of groundwater management tasks are either not being done or being done with seriously insufficient effort. These include:

- Investigation, assessment and monitoring of deep aquifers
- Arsenic investigation, assessment, monitoring and management
- Monitoring abstraction
- Protection of groundwater quality and remediation of polluted soil and groundwater
- Augmentation of surface water bodies and ecologically sensitive wetlands
- Control and licensing of abstraction and well drilling
- Artificial Recharge to reduce the impact of declining groundwater levels
- Assessing the sustainability of current and planned practices
- Creating the necessary legislative framework.

[24] With the possible, or partial exception of Dhaka WASA.

[25] Over the past decade, many well qualified young groundwater scientists have left the country because of the lack of appropriate employment opportunities. Meanwhile, many of the most experienced groundwater specialists in government have already, or are approaching, retirement. Many of the latter group gained their experience through groundwater development activities that are no longer conducted through government, and hence are not being replaced by new generations of suitably experienced staff.

7.4 Recommended Organisation of Groundwater Management Activities

For the reasons set out in sections 7.2 and 7.3, the present situation is not satisfactory, and a radical reform and upgrading groundwater management is urgently required. A basic principle of this proposal is that resource management should be separated from resource development, and should rest within the Ministry of Water Resources but should be separate from agencies that have executive responsibilities for water resources development. Currently, the organisation that comes closest to performing the management function is WARPO, but presently it is limited to planning and its staffing and resourcing are completely inadequate to carry out the proposed function. The Hydrology Wing and Groundwater Circle of the BWDB are better resourced, but their institutional location is incompatible with the separation of development and management responsibilities. The monitoring functions of the BWDB should be transferred to the agency responsible for groundwater management.

As illustrated by Figures 13 and 14, we see two alternatives for effective groundwater management: either to reorganise and greatly strengthen WARPO as a Water Resources Management or to create a dedicated groundwater management authority. Whichever of these alternatives is selected, the new organisation will require new staff, training, duties and responsibilities, and powers delegated through legislation.

To be effective in carrying out monitoring, investigations, and critically abstraction licensing, the new organisation must have a regional structure, which is why incorporating the BWDB field offices provides a base for both monitoring and regulation. Abstraction licensing, together with hydrological information, will provide a source of income. The establishment of the new organisation should be integrated with the proposed Water Act and possible Groundwater Act.

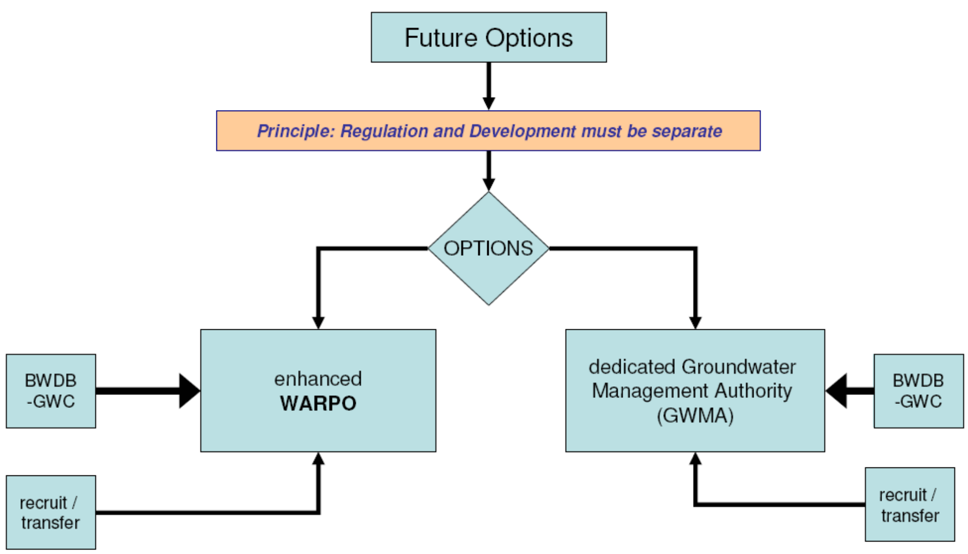

Fig. 13. Options for Organising Groundwater Management

Figure 14 develops this theme to show the management of groundwater could be divided into resource and supply functions.

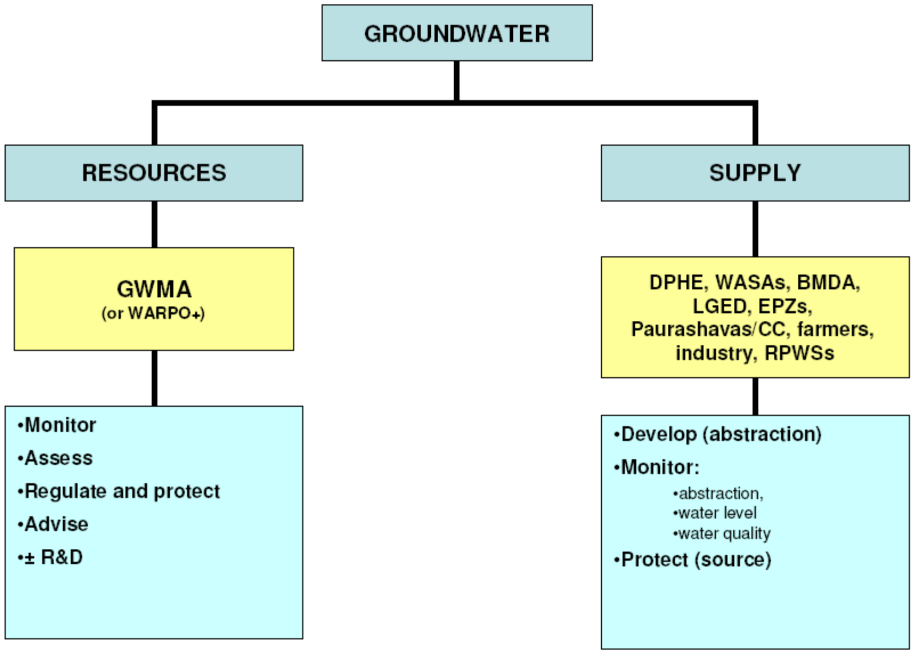

Fig. 14. Groundwater Management: Recommended Roles and Responsibilities

7.5 Recommendations for Inclusion in the Revised Sector Development Programme

Notwithstanding the financing of the physical measures and projects described earlier, from an institutional perspective, a number of institutional actions are required, as described below:

- Funding for a National Groundwater Strategy
- Creation of permanent and contract positions, and funding, for groundwater specialists in relevant departments. These should include, but not be limited to:
  - Each WASA or major City Corporation should establish, as a minimum, junior and senior posts for hydrogeologists.
  - WARPO should build up a team of groundwater professionals with not less one responsible for each of the seven planning units.
  - DPHE’s Groundwater Circle requires strengthening by employing hydrogeologists to provide support to paurashavas in developing and managing groundwater supplies, especially in the areas dependent on deep aquifers or continuing to rely on As-affected aquifers. In the longer run, some of these posts may be transferred to paurashavas
  - DPHE’s Groundwater Circle requires either dedicated staff or contract-based provision to compile and analyse monitoring data.
  - The BWDB will require additional resources to extend its groundwater monitoring functions to the coastal zone and deeper aquifers.
- In-service training for groundwater professionals, run through universities or other research institutions and delivered as inter-departmental short courses or research projects, and drawing on international expertise where appropriate.

- Support for R&D linking national executing agencies and executing research institutions plus, as appropriate, international research institutions. The focus of such research should be long-term issues that are recognised as important but do not require immediate resolution or it is recognised can only be resolved through long term data collection. Such actions should satisfy a number of criteria: (i) they entail significant scientific uncertainty; (ii) they contribute to professional development of both national agencies; and (iii) they do not replace what is properly and realistically the work of line agencies.
- Support for programmes to promote the scientific understanding of groundwater issues among stakeholders such as abstractors, NGOs active in the Watsan and water resources, and others.

7.6 Recommendations for Inclusion in the Water Act and Other Legislation

The present Draft Water Act is mainly focused on surface water issues, and needs to be extended to include more explicit consideration of groundwater management issues, including:

- Elaborate the 'water stressed area' concept to apply to both groundwater quantity and quality issues, which can be envisaged to include:
- declining groundwater levels resulting from either municipal or irrigation abstractions;
- saline intrusion or migration of arsenic; and
- industrial or agrochemical pollution.
- Establishment of abstraction licensing, that should allow for time-bound licences and time-bound exemptions for specific categories of abstraction (e.g. domestic hand tubewells).
- Establishment of licensing for well drilling, that should allow for time-bound licences exemptions for specific categories of drilling technology or well size.
- Establishment of Source Protection Zone as means of controlling future and present land-use to prevent or reduce pollution of water supplies.
- Establish legislation to require the clean-up of groundwater pollution based on the polluter-pays principle.

7.7 National Groundwater Strategy

7.7.1 Objectives

As noted above, a National Groundwater Strategy should be produced. The objectives[26] of the strategy should be to:

- Assess and describe the broad strategies shaping groundwater use, with an emphasis on integrated water resource management
- Appraise the ability of existing water resource management institutions to manage groundwater at local, regional and national levels.
- Bring about a fundamental change in mindset and attitudes towards groundwater at all levels.
- Make groundwater accessible to those who do not have ready access to water, particularly the very poor and resource poor farmers.
- Promote investment in groundwater so that sufficient funds are allocated to the development and use of groundwater; monitoring; research; and information dissemination.
- Improve understanding of the resource, the reliability of information, and access to that information.

[26] These objectives have been based on 'A Framework for a National Groundwater Strategy (NGS)'. Department of Water Affairs and Forestry, Republic of South Africa, 2007.

- o Ensure that regulation and other measures are in place to protect against over-exploitation and pollution
- o Ensure that programs are in place to adequately monitor the quantity and quality of the resource.
- o Create an enabling environment - through Strategies, Guidelines, and other communications
- o Ensure a sound institutional platform
- o Build hydrogeological capacity in the country

7.7.2 Scope of a National Groundwater Management Strategy

- Groundwater as a resource should be given an equal status alongside surface water, helping to meet the growing water demand, and recognising that SW and GW two aspects of the same resource.
- The knowledge and use of groundwater is increased along with the capacity to ensure sustainable management
- Pro-active groundwater management programmes are developed and implemented at required water resource management levels, focusing on both quantity and quality aspects

The strategy should focus on 10 key points:

i) Groundwater Management
ii) Groundwater Protection
iii) Monitoring
iv) Data and Information Management
v) Priority Use of Groundwater
vi) Institutional Arrangements
vii) Human Resources
viii) Education and Training
ix) Capacity Building
x) Promotion of Groundwater
xi) Research Needs

resent and Possible Future Activities of Government Agencies involved in Groundwater Management or Development

	WARPO		BWDB		DPHE		WASAs		BADC		BMDA		GSB		
	Current	Future	Current	Future	Current	Future	Current	Current	Current	Future	Current	Future	Current	Future	Curre
	X	X	X	X	X	X	?			X	X	X		X	
:	X	X	?	X	X	X	X	?	?	X	?H	X	?		X
nt			H	X	X	X	X				X	X			
&	?	X		X		X	X					?			
	?	X	?	X	X	X				X	X	X		X	X
er	*	***	**	***	*	***	0	*	*	**	*	**	*	**	*

 or future activity
activity
ossible activity

Groundwater Expertise (present / future):
'***' – strong; '**' – moderate; '*' – weak; '0' – no capacity
Note: all scorings are the consultants' subjective assessments or recommendations for dis
not approved by government or WSP.

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APPENDIX A.

GROUNDWATER RESOURCE ASSESSMENT PROCEDURES UNDER THE MPO AND NWMP PROJECTS.

The *Recharge Model* was used to simulate potential recharge on a Thana (upazila) basis using a twenty four-year series of rainfall excess and average flooding conditions.

The *Depth Storage Model* and the *Resource Potential Model* were used to estimate Usable Recharge using hydro-geological conditions averaged over the Upazila. The two parameters that most affect the estimates are deep percolation rate (for potential recharge) and specific yield (for stable recharge by technology). For these two, a range of values is therefore used in the assessment instead of a single value.

The *Single Cell Thana Model (SCTM)* was used to provide estimates of the development potential in an Upazila (formerly Thana), i.e. the proportion of the Net Cultivable Area (NCA) in each Upazila which can be irrigated from groundwater and residual soil moisture in the NCA Evaporation from other surfaces is assumed to be limited to the volume of soil moisture in the remaining area.

A total of 76 key Upazilas were selected by NWMP and subjected to detailed analysis of groundwater levels and historical irrigation development. The selection of key Upazilas was based on physiographic, aquifer geometry characteristics, the level of groundwater development and other possible parameters affecting resources availability and utilization, such as maximum depth to groundwater at the end of the dry season. The parameters defined in the key Upazilas were extrapolated to other Upazilas with similar physiographic, aquifer characteristics and development trends.

APPENDIX B

SELECTED DEEP AQUIFER STUDIES

A. Khulna City

A study was conducted by LGED & BRGM/ ANTEA/ ARMCO during 2005 under the project "Municipal Services Project Groundwater Resources and Hydro-Geological Investigation in and around Khulna City" and their findings are given below:

- The hydro-geological investigations highlighted the presence of an abnormal fresh water resource at the southern part of the project area, south of Khulna City Centre.
- This vital resource for Khulna City should be further investigated on priority basis.
- The actual depth of investigation is 350m. The geological information particularly data collected from petroleum companies, shows the possible presence of more potential aquifer below this depth but the hydro-geological information is not available .On this context they have recommended to install at least 5 very high depth tube well up to 600m depth in Khulna City.
- Since the fresh water resource of the deep aquifer is limited and can not sustain substantial increase in abstraction rates, an additional volume of drinking water may be derived from blending of water of different sources. The Electrical Conductivity of the deep aquifer near and south of the City Centre is very low. If this water is mixed with a small quantity of moderately mineralized water from the shallow aquifer. If this water is mixed with a small quantity of moderately mineralized water from the shallow aquifer the overall quality will be acceptable and the overall production can be increased by 25% or more. It is to be mentioned here that the ground water quality of shallow aquifer is good and Arsenic free except for high salt content.

In this context, the rural areas of Khulna, Satkhira and Bagerhat the deep aquifer might have potential for the purpose of supplying drinking water.

A study was conducted by N&R/ R&H Joint Venture, Aqua Consultants & Associates Ltd during 1992 under the project "DPHE-DANIDA Water Supply and Sanitation Project in Choumohani and Lakshmipur Pourashava" and their findings are given below

B. Choumohani (Noakhali)

- In Choumohani area there exists two deep fresh aquifers, one from approx. 175m - 250m, and a second below 275m. Above a clay layer between approx. 150m – 175m, a saline to brackish aquifer is present.
- The deep aquifer is high yielding and can easily supply the required quantity of water to the water supply system.
- Groundwater abstraction from deep aquifer in Choumohani is a mining process and ultimately may cause saline water intrusion which will cause increase chloride content.
- New sites may be located due to increasing demand of the drinking and domestic purposes.

C. Lakshmipur

- Deep aquifer is high yielding and can supply the required quantity of water. But unlike Choumohani the deep aquifer is protected against saline water intrusion.
- Two deep fresh water aquifers have been identified one at 150m-225m and the 2nd one from 250m-330m depth.

- Water quality of the two deep aquifers is good. Iron content ranges from 1.5mg/l to 2mg/l and chloride content is only 10mg/l.

D. Jessore, Choudanga and Jhenaidah (JICA Study)

JICA (2002) has conducted a "study on groundwater development of deep aquifers for safe drinking water supply to arsenic affected areas in western Bangladesh" and the findings of the study are given below:

- Study area covers three districts namely Jessore, Choudanga and Jhenaidah.
- Arsenic concentrations of more than 0.05 mg/l is found in the western section of the study area and less in the eastern section. The depth of these wells varies from 40m to 45m.
- There are seven Pourashavas in the study area with 40 Production Tube Wells (PTW) whose depths ranges from 100m to 120m show arsenic concentration are less than 0.01 mg/l. However, arsenic concentration is more than 0.05 mg/l but less than 0.1 mg/l were found in three wells (2wells in Moheshpur, Chuadanga and one well in (Krishna Chandrapur, Jhenaidah).
- Regionally groundwater flows towards the downward direction and this movement prevents where there is presence of aquiclude.
- At present there is no legal regulation of groundwater development and management in Bangladesh. The continuous utilization of deep groundwater in the future might cause an upward groundwater flow from deep aquifers
- Hydro geological conditions of the deep aquifers are not known and therefore, further study on deep aquifer is required.

E. Patuakhali, Barguna, Noakhali, Lakshmipur and Feni Districts (DWSG)

Introduction

The Five Districts Water Supply and Sanitation Group (DWSG) undertook a project (DPHE-DANIDA, 2001) to develop urban water supply and sanitation in five separate coastal districts of Bangladesh. The five districts covered by the project are Patuakhali, Barguna, Noakhali, Lakshmipur and Feni. The following Paurashavas are covered under the project.

District	Paurashavas
Patuakhali	Patuakhali, Galachipa, Kalapara
Barguna	Pathorghata (Kagchira), Amtali
Noakhali	Noakhali (Eklashpur)
Lakshmipur	Raipur, Ramganj
Feni	Feni

The geology of the project area consists of several hundred meters of sandy, silty and clayey formation of alluvial and marine origin. The layers are interbedded in irregular pattern and substantial lateral variations in lithology are also observed. This is the characteristics of deltaic sedimentation. The formations are mainly sandy with fine to medium sand.

The drilling programme has shown that the project areas content fresh groundwater in deep aquifers below a sequence of other aquifers containing saline and brackish groundwater. The density of fresh water is less than the saline water so deep fresh water would normally be rise above the saline water. But it is seen that the fresh water is entrapped between the saline aquifers. A hypothesis has been developed during the detailed hydro geological studies in Khulna region.

The hypothesis is that during the last glaciation the sea level was much lower than it is today. Due to large groundwater gradient and different climatic conditions the whole geological profile was flushed and saturated with fresh water. During the Holocene period, the sea level gradually uplifted, the gradient of the major rivers decreased and the river sediments were deposited. The sea started to penetrate the land through tidal rivers and the salt content in shallow groundwater started to increase and it rose to the present condition.

Due to density difference between fresh and saline water, the shallow aquifer could penetrate into deep aquifer contaminating the deep fresh aquifer, except where deep fresh water is protected by impervious thick clay layers (aquiclude). The deep fresh groundwater aquifers in the coastal belt of Bangladesh are remnants of a completely fresh system as discussed above. According to this hypothesis, the fresh water lenses can be considered as trapped by the sea level rise in the Holocene.

The hydrogeological conditions of nine pourashavas under five districts are briefly described below:

E.1 Eklashpur, Noakhali

Two deep fresh water aquifers exist in Eklashpur. The upper aquifer starts at 120m and extends down to 160m. The second fresh water aquifer extends from 200m depth to 270m depth. At present 7 production tubewells (PTW) are in operation and the present yield varies from 35 to 75m3/hr and the PTW can run for 16hr/day. The well spacing suggested a minimum of 200m. In lower aquifer chloride content is very low which is 20mg/l compared to 300mg/l in the upper aquifer. Iron content is higher than the allowable limit but lower than the upper aquifer. Arsenic is not detected in any of the aquifer.

E.2 Raipur, Lakshmipur

Five to six freshwater aquifers exist between 156m and 300m depth bounded by clay layers of varying thickness. A deep freshwater aquifer exists between 303 and 355m depth. This aquifer is confined to weakly leaky. Three production tubewells are in operation and the present yield varies from 15m^3/hr.to 50m3/hr and the operation time has been assumed as 19 h/day. Groundwater quality is good. Arsenic is also not detected.

E.3 Patuakhali, Patuakhali

In Patuakhali interbedded clays and freshwater aquifers extend from 250m to 375m depth. There are two fresh water aquifers, the upper one is thin and clay dominated in the east. A continuous clay layer separates the two aquifers. The deep fresh water aquifer is separated from the upper fresh water aquifer by a thick clay layer (aquitard).

Yield of five PTWs varies from 40 to 70m^3/h. It was suggested that in case of future requirement of PTW the deep aquifer below 300 m may be used and the well spacing should be at least 500 m. Groundwater quality is suitable for all purposes.

E.4 Amtali, Barguna.

Three freshwater deep aquifers exist in the area and the aquifers are interbedded with clay layers and these aquifers started from 270m depth and extend to the explored depth (375m). The aquifers are confined in nature. Groundwater quality is suitable and no arsenic was detected. The present production of two PTWs is 50m^3/h and 90m^3/h. If additional wells are required the deep aquifer is suitable for exploration. The spacing has been suggested as minimum of 150m.

E.5 Kalapara, Patuakhali.

Four freshwater deep aquifers exist in the area and the aquifers are interbedded with clay layers. The freshwater aquifer starts from 180m depth and extended down to 375m depth. The aquifers are confined in nature. Two PTWs are yielding 60m^3/hr and 85-90m^3/hr. and they run for about 19hr/day. Both the PTWs are withdrawing water from 350m deep aquifer. The same aquifer is suitable for further exploitation. The minimum spacing has been suggested as 150m. Groundwater quality is suitable for all purposes. Arsenic content is only 0.003 mg/l which is low.

E.6 Galachipa, Patuakhali.

There are three main freshwater aquifers, each separated by clay layer. The 1st aquifer started from 210m depth and is 22m thick, the 2nd started from 253m depth and is 36m thick and the 3rd aquifer started from 300m depth and is more than 50m thick. Present production of two PTWs is 90m^3/hr and it run for 14hrs/day. The minimum spacing of PTW has been suggested as 150m. Groundwater quality is suitable for all purposes. Arsenic contains < 0.01 mg/l.

E.7 Pathorghata, Barguna.

One deep freshwater aquifer exists at 250m and the thickness is more than 100m in the north and reduced in the south to about 50m. Three PTWs have been sunk at 310m depth and the production of the PTW ranges from 10 to 40m^3/hr. The main problem is the lateral migration of saline water. Groundwater quality is within tolerable limit.

E.8 Ramganj, Lakshmipur.

Two freshwater aquifers exist in Pamganj the upper freshwater aquifer is about 20m thick and it extends from 150m to 200m interbedded with clay layer. The main freshwater aquifer lies between 230 and 350m. The materials are consisting of sands with some clay. Three production tube wells are withdrawing water from the main deep aquifer and the yield varies from the main deep aquifer and the yield varies from 20 to 50m^3/hr. Iron content is high which ranges from 1.2 to 2.6mg/l whereas the tolerable limit is 0.3 to 1.0mg/l. Other constituents are within tolerable limit.

E.9 Feni

Two freshwater aquifers are identified in Feni area. The upper freshwater aquifer extends from 100m to 170m depth. The lower freshwater aquifer started from 180m to 250m depth. This lower aquifer is interbedded with clay layer. This lower freshwater aquifer is suitable for water supply because it is regionally extensive and continuous and content limited clay, mainly it is consisting of fine to medium sand. All the five tube wells are extracting fresh groundwater from this layer the depth of the wells ranges from 239 to 250m.The maximum safe yield of the PTWs range from 80 to >100m^3/hr. The tube wells operate for 16 hr/day with production capacity of 60m^3/hr. The ground water quality is within tolerable limit except iron which ranges from 1.1 to 2.7mg/l where as tolerable limit of iron is 0.3 mg/l to 1.0 mg/l. The well spacing suggested to be kept to a minimum of 200m.

From the study it can be inferred that the deep freshwater aquifers are suitable to supply he urban and rural water need of the above 5 districts till the planning period of 2020.