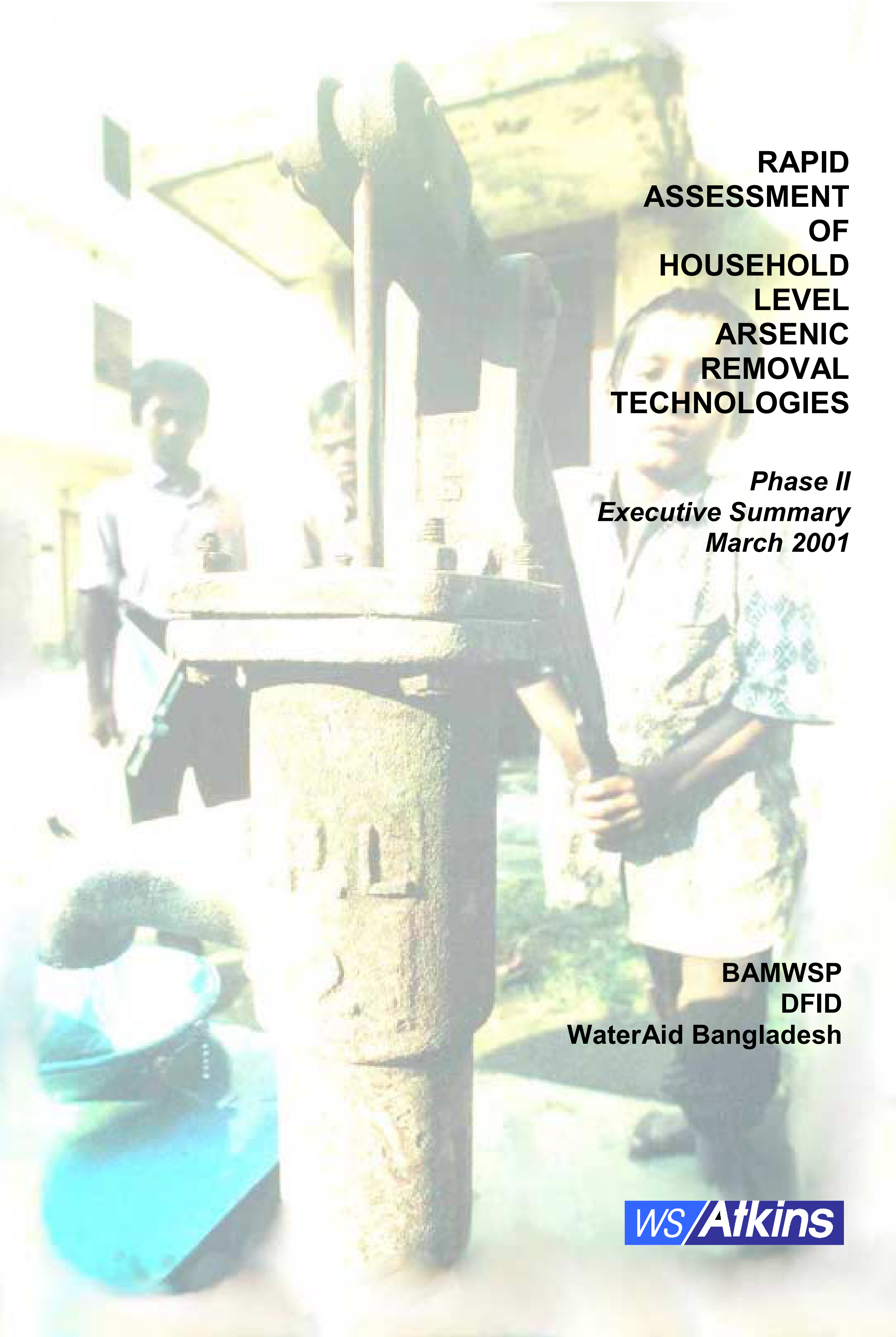

RAPID ASSESSMENT OF HOUSEHOLD LEVEL ARSENIC REMOVAL TECHNOLOGIES

Phase II
Executive Summary
March 2001

BAMWSP
DFID
WaterAid Bangladesh

WS Atkins

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EXECUTIVE SUMMARY

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INTRODUCTION

This report represents the conclusion of a two phase project, "Rapid Assessment of Household Level Arsenic Removal Technologies", which seeks to provide the first independent, comparative assessment of the performance and acceptability of a range of arsenic removal technologies at the household level. The project has been carried out in conjunction with the Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP), with the financial backing of the UK Department for International Development (DFID) and the management of WaterAid Bangladesh. The project was done by WS Atkins International with the assistance of Bangladesh Engineering and Technological Services (BETS), Intermediate Technology Development Group (ITDG) and Imperial College, London.

This project recognises that the development of technologies and assessment techniques is a dynamic and evolving process and is therefore providing inputs to two other environmental technology verification protocols. These are the BAMWSP/OCETA Environmental Technology Verification (ETV) Protocol and the World Health Organisation generic ETV for arsenic.

The technologies included in the project were selected on the basis of the following criteria after discussions between DFID, WaterAid, technology manufacturers, BAMWSP and other stakeholders: -

- Previous results were encouraging;
- Technology appeared relatively user-friendly;
- Technology readily available in country; and
- Promoting organisation was open and interested in participating in the study.

Technologies which fulfilled these criteria and have been included in this study were:-

- Alcan Enhanced Activated Alumina (Alcan)
- BUET Activated Alumina Filter (BUET)
- DPHE/Danida Two Bucket System (DPHE/Danida)
- GARNET Home-made Filter (GARNET)
- Sono 3-Kolshi Method (Sono)
- Steven's Institute Technology (Stevens)
- Tetrahedron Ion Exchange Resin Filter (Tetrahedron)

All technologies and processes, including those that have not been evaluated in the current study and which are designed to provide many types of arsenic mitigation (not just removal), may register with BAMWSP/OCETA for ongoing evaluation and verification.

A limited number of hard copies of the full report will be available at BAMWSP, DFID and WaterAid in Bangladesh and at WS Atkins in the UK. The full report will also be available on-line at the WaterAid web site (http://www.wateraid.co.uk) and the Arsenic Crisis Information Centre site (http://bicn.com/acic/). A web-site is also being created by WS Atkins which will incorporate the full report and raw data. Notification and links are being made through the IRC SOURCE Bulletin on http://www.wsscc.org/source/. Stakeholders will be informed when these are available on-line.

OBJECTIVES

The objectives of Phase II relate to both technical issues and to social acceptability and are as follows: -

- To assess the technical performance of the technologies, not only with regard to arsenic removal, but the addition/removal of other key elements, and whether the technologies contribute or not to bacteriological contamination;
- To try to identify arsenic 'break through' – the volume of water after which the technologies cease to remove arsenic;
- To evaluate the acceptability of the technologies to users;
- To identify key issues associated with management of waste from the filters, logistical sustainability in view of training requirements and support services.

OVERALL APPROACH

The assessment components in Phase II were carried out: -

(i) At 63 wells (21 in each of three villages) for field based technical performance and user acceptability assessment;
(ii) In Sonargaon for 'break through' testing and arsenic field test kit evaluation;
(i) In the Intronics laboratory, Dhaka, Bangladesh, for cross-checking of arsenic field-testing and for arsenic speciation; and
(ii) In the Imperial College Geochemistry laboratory, London, UK for crosschecking of Intronics laboratory results and for ICP analysis of feed and treated water for all wells and all technologies.

STUDY AREAS

The survey areas for field based performance and acceptability assessment in Phase II were Subidpur village (Hajiganj-5 union, Hajiganj upazila, Chandpur district, Chittagong division); Jalabad village, (Jalalabad union, Kalaroa upazila, Sathkira district, Khulna division), and Gargari/Autapara villages (Shahapur union, Iswardi upazila, Pabna district, Rajshahi division).

ARSENIC REMOVAL

Arsenic removal by technologies was evaluated by the following testing programme: -

PHASE I: -

- Four paired samples (feed and treated waters) for every replicate of a technology at a well
- Three replicates of each technology at every well
- Nine technologies at every well (27 replicates in total)
- Five tubewells per area
- Four areas
- Technologies operated by project team

PHASE II: -

- Eight paired samples (feed and treated waters) for every replicate of a technology in an area
- Three replicates of each technology in each area
- Seven technologies in each area
- Twenty one tubewells in each of three areas
- Technologies operated by well owners

The overall performance of the technologies in terms of arsenic removal is shown in Table 1 for both phases of the project. Performance of individual technologies on an area by area basis in Phase II is illustrated in Figure 1.

Table 1 – Number of arsenic samples and percentage of samples below 0.05mg/L for technologies in Phase I and Phase II

TECHNOLOGY	Number of treated water samples		Percentage of treated water samples below 0.05mg/L arsenic	
	Phase I	Phase II	Phase I	Phase II
Alcan	240	72	100	100
BUET	240	72	99	100
DPHE/Danida	240	72	34	25
GARNET	240	72	75	43
Sono	240	72	98	100
Stevens	240	72	96	85
Tetrahedron	240	72	81	81

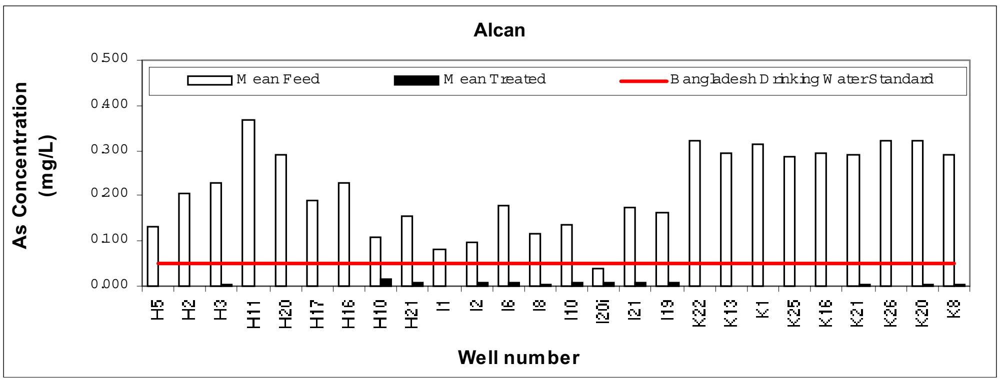
It is clear from both Table 1 and Figure 1 that three of the technologies tested during this project consistently reduced arsenic concentrations to well below the Bangladesh Drinking Water Standard of 0.05mg/L in all areas tested. These technologies were Alcan, BUET and Sono.

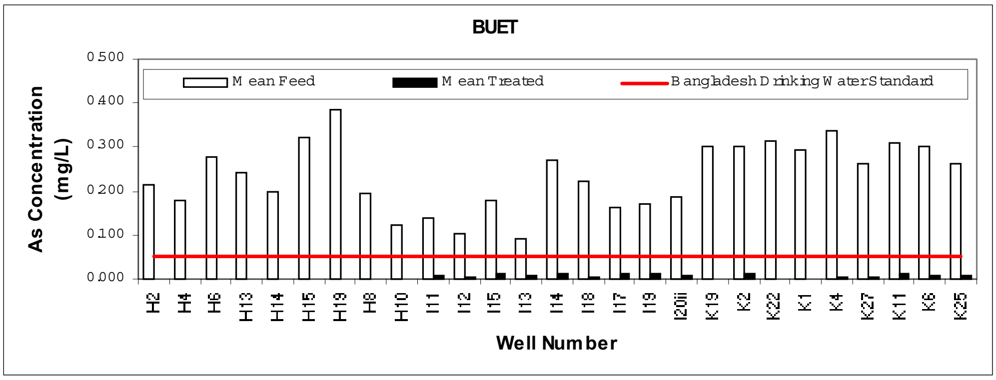
Two of the remaining technologies, Stevens and Tetrahedron, performed well at many tubewells but in some instances failed to reduce arsenic to below 0.05mg/L.

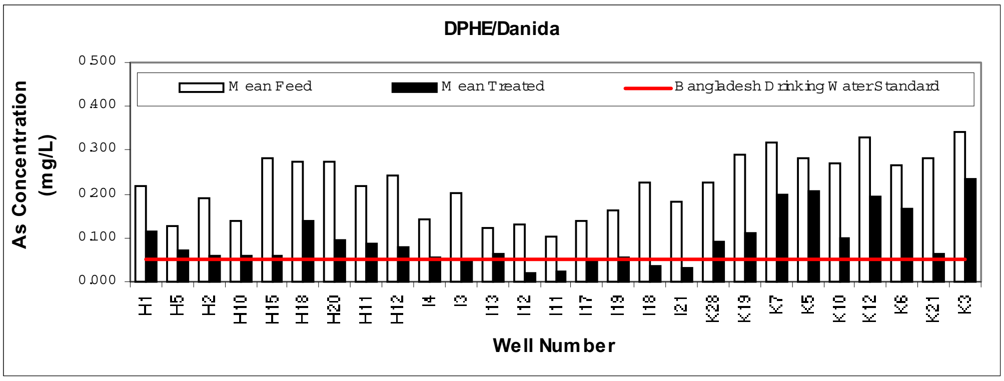
The discrepancy in performance of the Stevens technology between Phase I and Phase II was due entirely to a worse performance in Kalaroa in Phase II. Field observations suggest that the change in performance may be attributable to incorrect use/maintenance by the householders in Phase II.

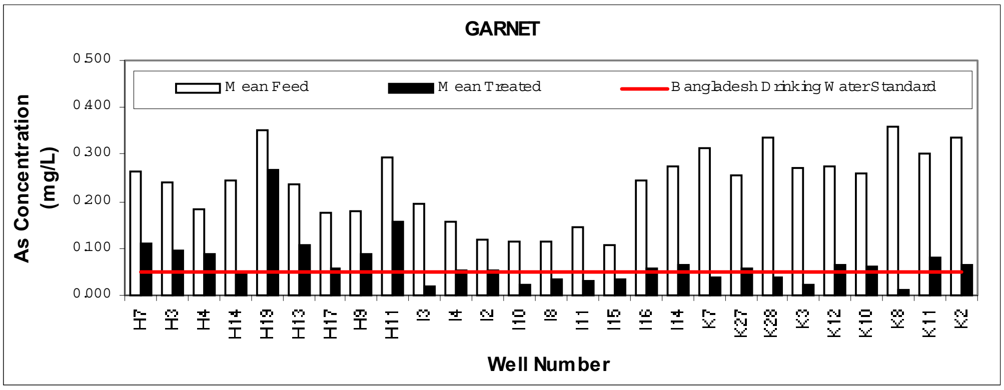
The performance of the Tetrahedron technology was quite variable at some tubewells. Where treated water concentrations were initially high, performance generally improved with time and can most likely be attributed to re-equilibration within the resin column following movement of the technology.

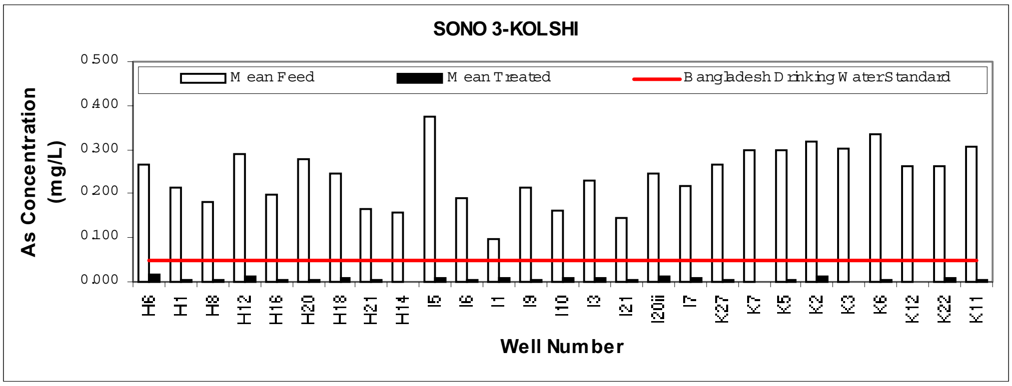
Figure 1 - Arsenic Removal by Technologies

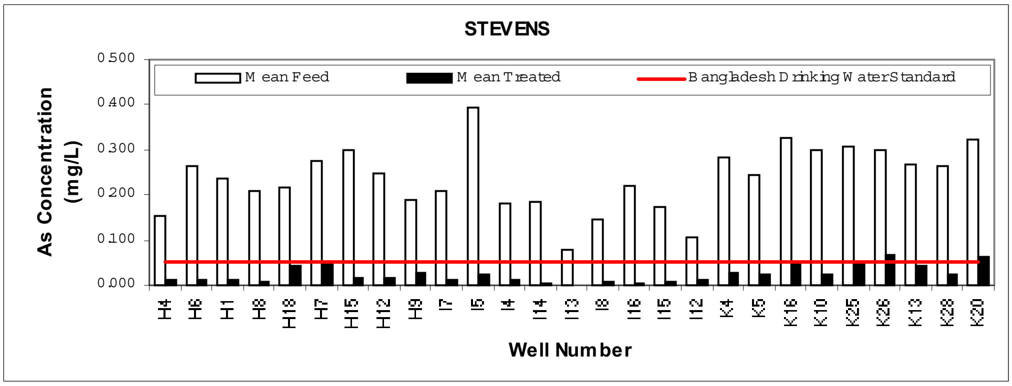


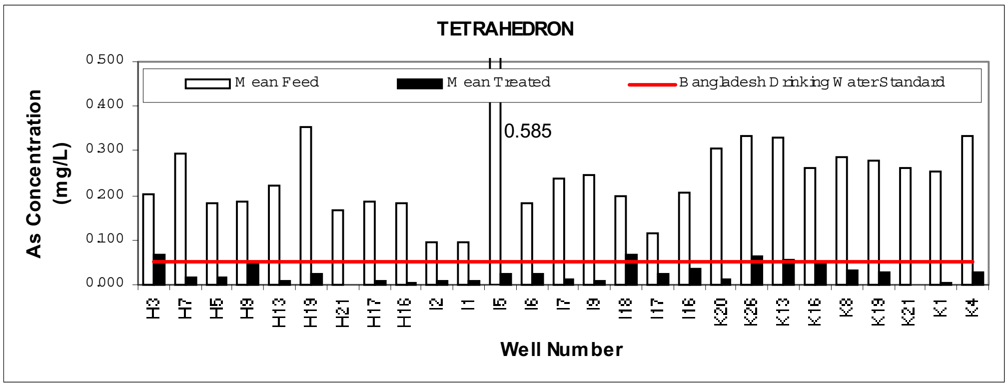

BUET
Mean Feed
Mean Treated
Bangladesh Drinking Water Standard
As Concentration (mg/L)
0.500
0.400
0.300
0.200
0.100
0.000
H2 H4 H6 H13 H14 H15 H19 H8 H10 I11 I12 I15 I13 I14 I18 I17 I19 I20ii K19 K2 K22 K1 K4 K27 K11 K6 K25
Well Number


DPHE/Danida
Mean Feed
Mean Treated
Bangladesh Drinking Water Standard
As Concentration (mg/L)
0.500
0.400
0.300
0.200
0.100
0.000
H1 H5 H2 H10 H15 H18 H20 H11 H12 I4 I3 I13 I12 I11 I17 I19 I18 I21 K28 K19 K7 K5 K10 K12 K6 K21 K3
Well Number


GARNET
Mean Feed
Mean Treated
Bangladesh Drinking Water Standard
As Concentration (mg/L)
0.500
0.400
0.300
0.200
0.100
0.000
H7 H3 H4 H14 H19 H13 H17 H9 H11 I3 I4 I2 I10 I8 I11 I15 I16 I14 K7 K27 K28 K3 K12 K10 K8 K11 K2
Well Number


SONO 3-KOLSHI
Mean Feed
Mean Treated
Bangladesh Drinking Water Standard
As Concentration (mg/L)
0.500
0.400
0.300
0.200
0.100
0.000
H6 H1 H8 H12 H16 H20 H18 H21 H14 I5 I6 I1 I9 I10 I3 I21 I20ii I7 K27 K7 K5 K2 K3 K6 K12 K22 K11
Well Number





The two remaining technologies, GARNET and DPHE/Danida performed less well in Phase II. In neither phase did either technology consistently reduce arsenic concentrations below 0.05mg/L in any area. Both technologies performed best in Iswardi where feed concentrations are, on average, lower than the other areas.

Reasons for the poor performance of the GARNET technology in Phase II compared with Phase I are not fully understood. In all areas, it seems likely that a reluctance of householders to maintain the required low flow rate accounted in part for the less efficient arsenic removal. However, this is unlikely to fully explain the particularly poor performance in Hajiganj. Here, alkalinity was much lower and redox potential much higher than in the other two areas but the impact of this is not clear at this stage.

The strongest limiting factor on the performance of the DPHE/Danida technology appears to be the concentration of arsenic in the tubewell water. It would appear that the technology does not have the capacity to reduce arsenic below 0.05mg/L when feed water concentrations exceed approximately 0.12mg/L. This theory is supported by results from an NGO Forum study of 60 DPHE/Danida units in Putiajani, which has shown that when raw water concentrations rose to above 0.13mg/L the incidence of failure increased.

Data inspection suggests that there is no clear relationship between non-arsenic chemistry of feed waters and arsenic removal by any of the technologies.

TECHNOLOGY IMPACTS ON OTHER WATER CHEMISTRY PARAMETERS

One of the objectives of the study was to assess the technical performance of the technologies with regard to the addition/removal of key elements other than arsenic,

Chemical parameters were investigated at 63 selected wells as part of the village based technical survey. One paired sample (feed and treated) for each of the 21 technology units in each area was tested in the field for each of the following parameters:

- Total Iron
- Ferrous Iron
- Total Manganese
- Total Aluminium
- Dissolved Oxygen
- Turbidity
- Fluoride
- Chloride
- Phosphate (reactive)
- Nitrate
- Redox potential
- Sulphate
- Sulphide
- Alkalinity
- pH
- Conductivity

In addition, ICP analysis was carried out on 126 samples (63 feed and 63 treated), to identify the concentrations of a standard suite of metals and the impact of the technologies upon this standard suite. Data from the feed waters demonstrate the broad differences in groundwater chemistry between the three test areas:

- At Hajiganj, silicon, boron and potassium concentrations are high and calcium, barium and strontium levels are low compared to the other areas;
- In Iswardi, phosphorus and iron concentrations are low, while manganese and sulphur are high compared to Hajiganj and Kalaroa waters.

A summary of the impact of treatment on water chemistry for each of the technologies is given in Table 2 below.

Table 2 – Summary of the impact on water chemistry by the technologies

Parameter	Alcan	BUET	DPHE/ Danida	GARNET	Sono	Stevens	Tetrahedron
pH		↑		↑↑	↑↑		↓
Alkalinity	↓	↓	↓	↓	↓↓	↓	↓
Redox		↓		↓↓	↓↓		↑↑
Total Iron	↓	↓	↓	↓	↓	↓	↓
Ferrous iron	↓	↓	↓	↓	↓	↓	↓
Manganese	↓	↓↓	↑↑	↓↓	↓↓		
Aluminium	↓↓		↑↑	↓↓	↓		↓
Chloride							↑↑
Phosphate	↓↓	↓			↓↓	↓	↓
Sulphate	↑		↑↑			↑↑	
Conductivity	↓						↑

↑ = increased in treated waters compared to feed waters
↓ = decreased in treated waters compared to feed waters
Double arrows indicate a relatively large change in parameter.
No arrow indicates little or no consistent change in parameter.

The observed changes in pH are likely to be caused by a combination of the following processes: -

- The loss of carbon dioxide from the bicarbonate buffered system, lowering the concentration of both bicarbonate and hydrogen ions (i.e. increasing the pH);
- Metal hydrolysis, decreasing pH;
- The interaction of water with metallic iron in the Sono, increasing pH;
- The interaction of water with alkaline brick chips, increasing pH.

Raised pH helps increase the kinetics of iron precipitation. The presence of dissolved iron contributes to arsenic removal processes by co-precipitating and adsorbing arsenic from solution. In theory, more complete aeration and high iron concentrations will favour more efficient removal of arsenic. However, data do not appear to support this with arsenic removal by GARNET and DPHE/Danida most efficient in Iswardi, where iron concentrations were generally the lowest of the three survey areas.

Alkalinity appeared to reduce in most of the technologies, presumably due to the introduction of hydrogen ions, resulting from either surface chemical action (activated alumina and resin) or by metal hydrolysis.

All seven of the technologies removed both the total and ferrous iron (Fe(II)) from the water during treatment. However, there is some indication that the DPHE/Danida and Tetrahedron technologies were not as effective as the others at removing total iron.

The Sono technology showed a dramatic decrease in redox potential between feed and treated waters, probably caused by the action of the metallic iron. The GARNET shows a similar trend to the Sono which may be a result of Fe(II) in some of the brick chips. The chlorine tablet used with the Tetrahedron, increases the redox mV and helps oxidise iron and arsenic to their more stable trivalent and pentavalent forms respectively.

Oxidation and hydrolysis of the reduced form of manganese, Mn(II), is a slower process than that of ferrous iron and three of the technologies (DPHE/Danida, Stevens and Tetrahedron) do not significantly reduce manganese concentrations. Indeed, in the case of DPHE/Danida manganese concentrations are significantly increased by the addition of potassium permanganate, at times to levels exceeding Bangladesh Drinking Water Standards.

Alcan, GARNET, Sono and Tetrahedron consistently removed aluminium from feed waters. The BUET and Stevens technologies also removed aluminium in Hajiganj and Iswardi but added it in Kalaroa in some cases. The reason for this is not clear. Data indicate that the DPHE/Danida adds aluminium to the water, occasionally to above the Bangladesh Drinking Water Standards. The source of the aluminium is the coagulant used in the arsenic removal process.

Chloride concentrations were not affected dramatically by any of the technologies, although Tetrahedron, as expected, introduced some chloride ions into solution, which also accounts for the increased conductivity for Tetrahedron treated waters. Phosphate concentrations were reduced by the Alcan, Sono, Tetrahedron and Stevens. Sulphate concentrations show a general increase in most of the technologies and a pronounced increase where sulphate coagulants are used (DPHE/Danida and Stevens).

BREAK THROUGH

None of the technologies have achieved break through during the Phase II testing to date. This was largely to be expected within a rapid assessment. The volumes of water put through the technologies each day were close to the maximum possible in a 12 hour period. (Table 3). This is with the exception of the Stevens, where there was a delay during the period in getting hold of reagents, and the Tetrahedron and Alcan which would have needed constant filling over 12 hours.

The break through testing will continue for at least another month and the results presented as an addendum to this report.

Table 3 - Flow Rates and Volumes put through Technologies during Break Through Testing

Technology	Mean Flow Rate (L/hr)	Maximum Volume in 12 hour period (L)	Mean Daily Volume Achieved in Break Through Testing (L)
Alcan	240	2875	1692
BUET	4.1	50	42
DPHE/Danida	3.6	43	42
GARNET	1.1	13	11
Sono	3.3	40	34
Stevens	14.1	169	74
Tetrahedron	52	624	201

BACTERIOLOGICAL ISSUES

A rapid assessment of microbiological performance of the arsenic removal technologies has been included in Phase II to provide an initial indication of:

- The increased health risk from human or animal faecal contamination associated with use of the seven technologies compared with existing drinking water quality;
- The possibility that technologies may harbour bacteria within the filter material and provide a potential breeding ground for pathogens.
- A concern that bacteria may be added to water from bio-films, which develop in the technologies and are sloughed off under certain conditions.

Counts of total and faecal coliforms in feed water from all wells were obtained at the beginning of the field-testing period.

The bacterial levels found in untreated water from the selected wells are within the low risk category of WHO guidelines for untreated rural water supplies. This baseline assessment confirms that contamination detected subsequently in treated waters cannot be attributed to sources from faulty or unprotected wells, which villagers would already be exposed to in their drinking water.

Over the following 30 days of the assessment, treated water from each replicate of all technologies was sampled between one and three times. In Iswardi and Hajiganj, both total and faecal coliforms were analysed in all cases, in Kalaroa the initial assessment was restricted to total coliforms. In cases where treated water was consistently found to contain high levels of contamination, an attempt was made to identify how the water had become contaminated, by sampling direct feeds and water from different stages of the treatment process for a single technology replicate.

With the exception of Tetrahedron and Stevens (which have a chlorination step), faecal contamination was found in at least two of the 9 replicates for all technologies tested, at levels that represent significant risk on the basis of WHO guidelines (>100 cells per 100mL – Figure 2). This highlights the increased risk from human or animal faecal contamination associated with operating any technology when compared with drinking water directly from a tubewell.

The Sono-3-Kolshi and Alcan technologies are of greatest concern since heavy contamination, with counts over 100 faecal coliforms per 100mL, was found in two Iswardi replicates and one Hajiganj replicate of both technologies, one week from the start of field testing. High counts were subsequently obtained in another replicate of the Sono and Alcan in Iswardi (over 50 faecal coliforms per 100mL) and a Sono in Kalaroa (over 200 faecal coliforms per 100mL). High levels of contamination were also associated with GARNET and DPHE/Danida in Hajiganj and Kalaroa. BUET presented a particular issue in Kalaroa and the reason for this is unclear.

In the case of the Alcan, the cause of contamination was readily observable, with the unsealed units known to have been used as a surface for washing and laundry. In addition, the plugs used to close the filter when non-treated water is required are not watertight. These issues are relatively straightforward to resolve. Preliminary results also suggest that flushing with uncontaminated feed water is effective in reducing contamination and this implies that as long as contamination is occasional, bacteria and pathogens should not build up or breed in the technology.

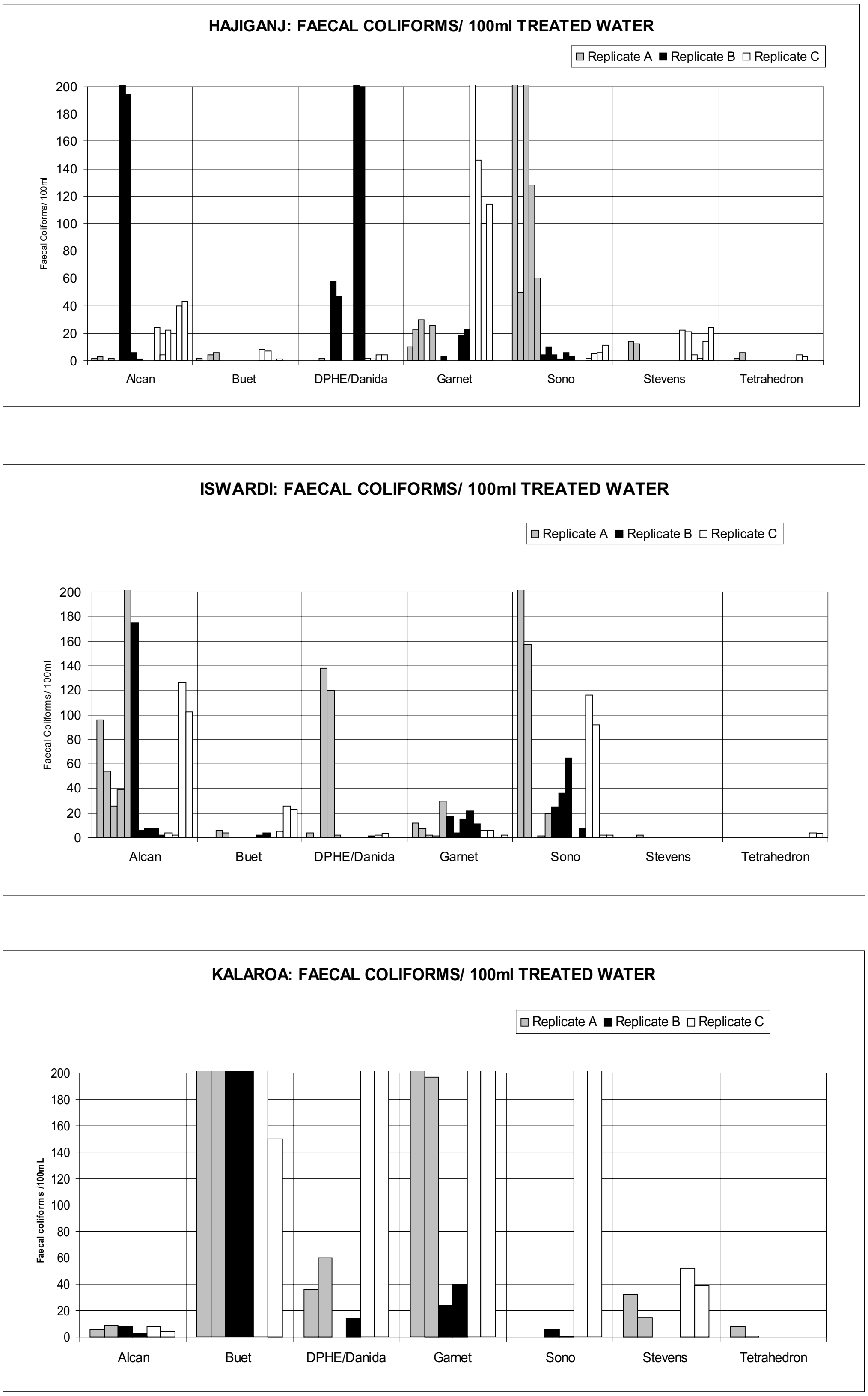


Figure 2: Faecal coliform counts in treated waters for the three survey areas

The source and manner of contamination for the other technologies were less obvious and observations of the basic sanitary conditions suggest that contamination routes and processes are likely to vary. Awareness of basic hygiene issues and measures that would help to avoid faecal contamination was found to be extremely limited. In the cases of Sono, Alcan, BUET, DPHE/Danida and GARNET, heavily contaminated treated water samples were obtained when low or zero faecal coliforms were present in the water going into the technology and, since most treated water samples were collected direct from the technology, it would seem that neither feed or collecting vessels are the primary cause of contamination.

In contrast with the Alcan, it appears that once contaminated, the sand filters harbour bacteria and are not readily flushed by further clean batches of water. Regular bleaching (more than once a week in some cases) is required to maintain acceptable levels of bacteria. This is clearly a severe limitation, since even relatively simple maintenance procedures were often not followed and bleaching, in particular, was unpopular due the unpleasant taste that persists for several batches of treated water. In addition, while bleaching is effective in eliminating or at least significantly reducing bacteria, the process will not necessarily kill all potential pathogens. It is noted that weekly bleaching is stated as a requirement in recent instructions for the operation of GARNET.

The discovery of potentially harmful levels of contamination in the initial samples presented an ethical dilemma and the decision was made to bleach technologies regularly to ensure that householders were not put at unnecessary risk. This however interfered significantly with the results of the bacteriological assessment and it was not possible to assess the development of contamination over the 30 day field work period.

Comparisons of total coliforms and non-coliform bacteria counts in feed and treated water suggest that additional numbers of non-harmful bacteria result from the use of the technologies. It is not clear if these are derived from biofilms within the filters or result from natural growth during the increased time involved in processing the water.

ACCEPTABILITY TO POTENTIAL USERS

The specific objectives of the social investigation were: -

- To build rapport among the local inhabitants and tell them about the risks from arsenic contamination so that the technology testing was carried out with people's active support and co-operation;

- To elicit and measure the perception of the household heads/members about arsenic poisoning as well as their interest in using arsenic-free tube-well water;
- To assess the relative acceptability of the arsenic removal technologies among the concerned households;
- To examine the willingness and ability of the households belonging to different economic categories to buy the technologies for subsequent household use.

The attitudes of the householders to the above issues were collected through informal discussion and formal questionnaire based discussions on five occasions during the survey period.

There is a regional variation in respect to the socio-economic condition of the households. While the households in Iswardi are mostly poor and more conservative in attitude, those in Kalaroa and Hajiganj are relatively better off. While the Iswardi households in general showed a sense of satisfaction over the opportunity to use the treated water, it was apparent from discussion that they are yet to treat this activity as one of the essential household chores. For Iswardi households, tubewells are the primary source of water supply, and almost all families, poor or otherwise, have tubewells of their own. Dependence on this sole source of water should lead to them viewing arsenic removal as an urgent household activity.

In Kalaroa and Hajiganj the households are relatively well-off and, in contrast to Iswardi, are not exclusively dependent on tube-wells as a source of water, since there are many ponds around. The households showed a greater sense of awareness and urgency for drinking arsenic-free water.

Poverty was a determining factor as to whether a household would prefer to buy a technology or not. Most of the households in all three regions were initially attracted to the more expensive technologies like Alcan and Tetrahedron but once they were informed about the cost, their preference shifted to the cheaper, but less rapid technologies. Initial costs and ongoing operational costs are shown in Table 4.

Table 4 –Technology Costs

Technology	AL	BUET	DPHE/ DANIDA	GA	SONO	ST	TE
Average Initial Cost (Tk)	25,000	1000	325	400	325	500	12,000
Annual Operational Cost (Tk)	15,000	Unknown	Unknown	Unknown	Unknown	Unknown	6000

However, costs per litre of water are not known and this should be given as soon as breakthrough is identified for all technologies.

Once the households had used three different technologies, they were asked to rank them according to overall preference. Three points were given for favourite, two for second favourite and one for least favourite. The total scores from all 63 households are set out in Table 5.

Table 5 – User preference scores for technologies

Area	Technology						
	AL	**BUET**	**DPHE/ DANIDA**	**GA**	**SONO**	**ST**	**TE**
Kalaroa	23	14	18	10	23	15	23
Iswardi	27	12	22	19	19	13	13
Hajiganj	21	16	20	14	18	22	13
Total Score	71	42	60	43	60	50	49

(highest score possible, if all ranked technology first, is 3 x 9 x 3 = 81)

Scores (from 1 'extremely poor' to 7 'excellent') were also given for each technology for fifteen different features including flow rate, taste, smell, ease of use, cost, ease of movement, ease of maintenance and waiting times. The scores for each feature are averaged and then averages summed to give a total score for each technology, which are shown in Table 6.

Table 6 – Total user scores for technology features

Area	Technology						
	AL	**BUET**	**DPHE/ DANIDA**	**GA**	**SONO**	**ST**	**TE**
Kalaroa	77	34	71	53	65	44	66
Iswardi	83	20	65	38	61	46	52
Hajiganj	75	42	64	58	77	48	56
Total Score	235	96	200	149	203	138	174

(highest score possible is 7 x 15 x 3 = 315)

Alcan came first in both comparative assessments overall, though there were some regional variations (2^{nd} in Hajiganj for example). It is favoured mostly because of high flow rate and low operation and maintenance requirements. The Sono came second on both counts because of its cheaper price, water taste and smell, and low maintenance. The DPHE/Danida came closely behind for similar reasons. This is indicative of the fact that the households would prefer a lower specification technology if it is affordable to them. The lower specification technologies also score well because of the household psychology that most prefer to use technologies on an individual basis, since collective management creates problems.

The households indicated their willingness to pay up to Tk1000 for any of the technologies. The majority, however, were willing to pay between Tk300 and Tk500. The householders were willing to pay approximately Tk30-50 a month for maintenance. Some households living in close proximity, as in the case of Iswardi, even talked about their willingness to procure high-performing but more costly technologies on an instalment basis, although they were worried about collective management. Almost all the households irrespective of their economic condition stressed the need for government subsidy or some kind of assistance from other sources to enable them to procure the technologies for their household use.

In all cases, it was the female members, mostly the housewives, who were associated with managing and running the technologies. At the same time, these women had little or no say in family decisions involving financial matters. More pro-active involvement of the male heads or members should be encouraged, to allow them to develop and understanding and make appropriate decisions in respect purchasing the technologies for their family use.

Tentativeness in expressing opinions and even perceptions was quite evident among the housewives associated with testing of the technologies. This might have been due to the short time span of the three phases of testing when they were not fully aware of all the technical issues. The housewives' position in the households, especially in respect to decision-making, might also explain this. As such, any effort pertaining to introduction of a complex set of activities in a rural setting should allow enough time for education to enable participants to understand the process fully. The necessity of a holistic approach to include all household members cannot be over-emphasised.

The problems associated with arsenic may be well understood by the national level policy-makers, but it will require intensive motivation campaigns to bring home in the minds of rural people the perils of arsenic contamination. The task is challenging especially in view of the time lag between contamination and long-term visible effects of it. In any case, any effort to popularise the arsenic-mitigation technologies would first require convincing the grassroots level potential users about the dangers of the contamination.

PROPONENTS QUESTIONNAIRE

Questionnaires asking for plans regarding production, marketing, distribution, training, long term support and waste management strategies were sent to manufacturers of all technologies tested. Responses have been received from all proponents.

Responses indicated that all proponents are proposing to produce in Bangladesh if demand for their product makes it worthwhile. Some of the more sophisticated filter material, such as Enhanced Activated Alumina for the Alcan, would still be imported but from India rather than Canada.

All proponents claim that they can significantly increase production capacity if demand for their products increases. Marketing for the technologies follows a largely predictable route (NGOs, BAMWSP, workshops and print media). Most also anticipate using NGOs and/or government institutions to support their distribution plans, along with their own disseminating networks. The Stevens Institute technology is likely to have its own 'Star Technology Centre', which will co-ordinate its distribution, training and support service activities.

Most proponents plan to use their own training bodies to train field staff and a mixture of their own staff and NGO staff to train the householders. Sono plan to carry out all their own training through 'disseminating agents' and Alcan hope to be able to use the services of thana level government staff in addition to their own resources. With the exception of DPHE/Danida, the proponents seem to feel that training is a short term, one-off event with none expressly stating that they have plans to provide on-going training for users.

Most proponents have given thought to how they will support users after 'hand over' (for replacing breakages, spare parts, reagents) but none yet have a full support infrastructure in place. It remains to be seen how easy some of the ideas will be to put into place. All proponents have different approaches and demands of NGOs and local government.

Alcan, Stevens Institute and Tetrahedron have clearly done a considerable amount of research into the composition and implications of the waste from their technologies. All suggest that there is not a great problem with the waste, so long as the waste is treated carefully. The clear message appears to be to avoid disposal to areas where high acid concentrations could be present and anoxic areas (such as the bottom of ponds).

WASTE MANAGEMENT

The waste management issues are covered very briefly here. More detail is given in the Main Report. All technologies that remove arsenic from groundwater will at some time produce arsenic waste either as a solid or a liquid waste sludge. It is apparent from simple calculations that the yearly household production of arsenic contained in residues is likely to be very small (2-5g maximum). Arsenic-rich wastes produced from the majority of household level removal technologies will be in one of two forms and originate from dissolved Fe, Mn and Al in the water, as well from the addition of coagulants. These are oxyhydroxide flocs (i) in relatively large volumes of water (e.g. in wash waters) or (ii) trapped in the matrices of the filters.

The solubility of such arsenic containing residues in the environment is likely to be very low and this is not considered to be a major environmental issue for Bangladesh.

CONCLUSIONS

These conclusions and recommendations are made, based only on the results of a 'rapid' assessment. A rapid assessment by definition is unable to make conclusions about longer term performance and impact.

Arsenic Removal

The three most consistently effective technologies for removing arsenic to below 0.05mg/L are the Alcan, BUET and Sono technologies. The Stevens and Tetrahedron are also effective at reducing arsenic levels to below 0.05mg/L most of the time.(between 80% and 95% of samples). This appears valid for all arsenic concentrations and is independent of other water quality factors. It is likely that the performance of Stevens would be improved with strict adherence to operation and maintenance instructions.

The DPHE/Danida is generally not effective at reducing arsenic to below 0.05mg/L if the well water arsenic concentration is above approximately 0.12mg/L. At feed water concentrations below this the DPHE/Danida is generally effective. The GARNET is unpredictable and it is not yet clear why this should be.

Impact on Other Water Chemistry Parameters

In general, the technologies do not appear to increase any of the significant water parameters tested to beyond the Bangladesh Drinking Water Standards, with the exception of the DPHE/Danida, which on occasion takes both manganese and aluminium above Bangladesh Drinking Water Standards and WHO recommended health levels.

Bacteriological Performance

While the bacteria results represent a worst-case scenario, given the limited training, education and support that was possible for such a rapid assessment, they do highlight the potential for dangerous levels of faecal contamination with many these technologies.

Tetrahedron and Stevens technologies, which include a chlorination step, perform well in terms of microbiology, although minor modifications would be recommended for Stevens to reduce the limited contamination observed occasionally. It is also likely that straightforward design modifications to the Alcan would reduce the microbiological problem associated with this technology.

Household hygiene is clearly important, but high faecal coliform counts were not consistently associated with particular households and it appears that contamination is relatively easy under the rural conditions in which the technologies are required. The impact of even basic instruction in hygiene was however noticeable in reducing faecal coliform counts over the course of this assessment, suggesting that with proper training, acceptable performance may be achievable.

The results for the Alcan and Sono-3-Kolshi are largely in line with previous findings of BRAC (BRAC, 2000). The levels of contamination in the BRAC report were similar to the findings here. The findings here are higher for Sono than in the BRAC study.

The level of faecal contamination that is acceptable for untreated drinking water in rural situations is a matter for debate both within Bangladesh and at a global level. While it is unlikely that the WHO standards of zero faecal coliforms per 100mL are realistic in this context, it is probable that counts of over 100 cells per 100mL will remain of concern in any classification. Unless performance can be significantly improved, some of the technologies may remain inappropriate as options.

Acceptability

Study areas differed in terms of socio-economic status, understanding of the arsenic issues and reliance on tubewell water. Poverty was a determining factor as to what price householders were prepared to pay. Although most households expressed a preference for the features of the most expensive technology (Alcan), very few could realistically afford this on an individual basis, and low cost benefits of other technologies are reflected in the scores of the user preference survey.

It is not appropriate at this stage to judge technologies on cost. This should be done as a cost per litre when breakthrough has been achieved for all technologies.

Proponents

Proponents are ready and able to increase production upon demand. However, the distribution, training and support service infrastructure plans have not been developed and plans for these often place a great deal of emphasis on support from NGOs and local government. Waste management issues have been considered by the larger organisations (Alcan and Stevens) but the practical support of villagers for disposal of major amounts of waste is lacking at present.

SUMMARY OF CONCLUSIONS FOR EACH TECHNOLOGY

FEATURE	ALCAN ENHANCED ACTIVATED ALUMINA	BUET ACTIVATED ALUMINA	DPHE/DANIDA 2BTU	GARNET	SONO 3 KOLSHI	STEVENS INSTITUTE	TETRAHEDRON
Arsenic removal	Almost all As removed	Almost all As removed	Not recommended with feed water As >0.12mg/L	Unpredictable – not clear why yet. Control of flow rates important.	Consistently below 0.02mg/L in all areas	Variable but generally well below 0.05mg/L. Correct operation – particularly use of reagents – important.	Variable but generally well below 0.05mg/L. Performance seems better when proportion of As(III) is high.
Other water chemistry	OK	OK	Manganese and aluminium above Bangladesh Drinking Water Standards and WHO recommended health levels	OK	OK	OK	OK
Bacteriological issues	Temporary contamination a times. Flushed out. Seal unit. Do not wash over unit.	Contamination in sand filter. Further research required.	Some contamination in sand filter. Further research required.	Some contamination in sand filter. Further research required.	Contamination in sand filter. Further research required.	Low level contamination. Mainly from outlet pipe.	Low level contamination.
Break through	Not achieved after 52,500 litres	Not achieved after 1,302 litres	Not achieved after 1,302 litres	Not achieved after 341 litres	Not achieved after 1,054 litres	Not achieved after 2,294 litres	Not achieved after 6,231 litres
Flow rate	>3600 litres in 12 hours (> 100 families' need)	50 litres in 12 hours (>= family need)	43 litres in 12 hours (>= family need)	13 litres in 12 hours (< daily family need)	40 litres in 12 hours (>= daily family need)	169 litres in 12 hours (> 5 families' need)	624 litres in 12 hours (> 20 families' need)
User acceptability	1st Favourite	7th Favourite	3rd Favourite	6th Favourite	2nd Favourite	5th Favourite	4th Favourite

RECOMMENDATIONS

Proponents

There are many recommendations concerning mainly minor modifications to the design and operation of the technologies. These are being sent direct to the proponents but are also available in Appendix 5 of the Main Report. The main recommendations are that: -

- The feasibility of a lower priced, smaller capacity, enhanced activated alumina unit should be investigated;
- The design of the BUET needs considerable attention in terms of height and flow control devices, to improve acceptability;
- DPHE/Danida should consider using different coagulants (maybe iron-based) and a larger candle for the sand, to improve efficiency of arsenic removal;
- A fixed flow control device for the GARNET should be designed so that the correct flow is always maintained.
- Stevens should use a tap rather than a tube and should have a lid to minimise contamination. Instructions should include disposing the first batch to waste following sand washing, to avoid potential peaks in treated water arsenic concentrations;
- More detailed laboratory based testing of the GARNET should be carried out to examine in detail the processes at work, and identify potential ways in which performance might be improved.

In light of the microbiological findings from the rapid assessment, it is recommended that a review of requirements for operation and maintenance of the technologies should be made, for example suggesting a suitable frequency of bleaching, and providing instructions for this process. Until this review has been completed, it is recommended that any technologies supplied (whether free or purchased) should contain a specific warning that water should be boiled prior to drinking.

Implementing Agencies

The performance of the technologies in terms of arsenic removal and social acceptability suggests that despite the relatively alarming nature of microbiological results the programme should not be delayed at this stage. It is suggested that more detailed phase of microbiological testing should be associated with the introduction of the selected arsenic removal technologies on a larger scale.

In light of the findings from the rapid assessment, a review of requirements for operation and maintenance of the technologies is required. Simple modifications that may reduce some of the problems have been identified and are included in the final report. These will also be provided to the manufacturers. Implementation of these, and/or modification of the operation instructions should be considered prior to wider distribution.

The manufacturers will need to consider implications of the findings of this assessment and any future phase of testing, in regard to the requirement for a local support infrastructure and longer training requirements. It is likely that this will have to involve BAMWSP working with other government and non-governmental bodies at a local level. Collaboration should be enlisted at the earliest possible stage.

A more detailed cost-benefit analysis of arsenic removal technologies and alternative arsenic free sources of drinking water should continue alongside the programme.

Consideration should be given to the financing of, and financial support for, these technologies, particularly the more expensive, but effective and robust technologies.

Further research

The break through testing is continuing for one further month at present. This should be continued until break through is achieved for all technologies. Further breakthrough testing should be undertaken on waters of a range of chemistries, in parallel with a wider distribution programme.

When breakthrough is achieved, costs per litre of water for each of the technologies should be determined and the results made widely available.

It is recommended that attention should be given to:

- Identifying the level of microbiological contamination in existing drinking water supplies – at the point of consumption;

- The sources and persistence of microbiological contamination within the technologies;
- Abundance of specific pathogens and the potential for the sand filter technologies to provide a breeding ground for these and other bacteria;
- The effectiveness of education and increased training in operation of technologies on reduction of bacterial contamination and the level of support required to maintain acceptable bacterial levels.

Laboratory testing of technology performance with simulated well waters should be done, to better understand the processes and capabilities of the different technologies. This is scheduled for inclusion in the BAMWSP/OCETA ETV project.

A more detailed assessment of the users' attitudes to the technologies and their use, operation and maintenance should be carried out, once recommendations to the proponents have been taken on board.