



**RAPID  
ASSESSMENT  
OF  
HOUSEHOLD  
LEVEL  
ARSENIC  
REMOVAL  
TECHNOLOGIES**





*Phase II Report  
March 2001*

**BAMWSP  
DFID  
WaterAid Bangladesh**

**WS/Atkins**

# Rapid Assessment of Household Level Arsenic Removal Technologies Phase II Report

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## 1. INTRODUCTION

### CONTEXT

- 1.1 There is now a strong desire in Bangladesh to move to an effective and co-ordinated response to the arsenic problem. This response needs to take the form of both a short-term emergency response and long-term strategic planning. Bangladesh has many potential mitigation options for the arsenic problem, including surface water sources, rainwater harvesting, hand dug wells, deeper tubewells, community supplies and filtration. Many of these will, however, take several years to be fully implemented. In the short term, treatment of groundwater from existing household tubewells is potentially the most effective solution.
- 1.2 This report represents the conclusion of a two phase project, “Rapid Assessment of Household Level Arsenic Removal Technologies”, which seeks to provide the first scientifically based 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). The output from this project is a comprehensive source of information on technologies for future use by BAMWSP and by any agencies, government or non-government, in recommending the use of some of the technologies currently available in Bangladesh.
- 1.3 This project is not designed to be a stand-alone exercise. Whilst this project has sought to address the urgent and specific focus of technology assessment, it recognises that the development of technologies and assessment techniques is a dynamic, evolving process. Therefore, this project is 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.
- 1.4 This project was commissioned to look at nine promising technologies that were available in mid-2000. The technologies included in the project were selected on the basis of the following criteria after discussions between DFID, WaterAid, contractors, the Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP) and other stakeholders: -
  - Previous results were encouraging;
  - Technology appeared relatively user-friendly;

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- Technology readily available in country (21 units of each technology were required for this project);
- Promoting organisation was open and interested in participating in the study.

It is acknowledged that a few other household level arsenic removal units existed. However, they did not, at the outset of this project, fulfil all of the above criteria. All household technologies and processes, including those which have become available since mid-2000, which are designed to provide many types of mitigation (not just removal) may register with BAMWSP/OCETA for evaluation and verification.

**PHASE I OUTCOMES**

- 1.5 The results from Phase I are presented in a Phase I Draft Final Report (January 2001) which can be accessed on the WaterAid web site (<http://www.wateraid.co.uk>) and the Arsenic Crisis Information Centre site (<http://bicn.com/acic/>). Notification and links are being made through the IRC SOURCE Bulletin on <http://www.wsscc.org/source/>.
- 1.6 Phase I of this project was designed to assess which technologies reduced arsenic to below 0.05mg/L for specific water chemistry or all water chemistries tested. From the original list of nine technologies, seven were assessed as removing arsenic under specific or all water chemistry conditions tested. These were put forward to Phase II for further evaluation, and included:

	<b>Future reference in report</b>
• Alcan enhanced activated alumina filter	Alcan
• BUET activated alumina filter	BUET
• DPHE/Danida two bucket system	DPHE/Danida
• GARNET home-made filter	GARNET
• Sono 3-kolshi method	Sono
• Stevens Institute technology	Stevens
• Tetrahedron ion exchange resin filter	Tetrahedron

- 1.7 The two technologies which were not taken forward to Phase II, because they did not, on average, reduce arsenic concentrations to below 0.05mg/L at any of the 20 wells tested, were passive sedimentation and the Ardasha filter.

## PHASE II OBJECTIVES

- 1.8 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 (such as iron, manganese and aluminium), and whether the technologies contribute or not to bacteriological contamination.
  - To try to identify ‘break through’ – the volume of water after which the technologies cease to remove arsenic to the required level.
  - To evaluate the acceptability of the technologies to the users, with regard to convenience, affordability, reliability, treated water quality and waste disposal.
  - To identify key issues associated with management of waste from the filters, logistical sustainability and training requirements and other support services.

## PHASE II APPROACH

- 1.9 The aim of this project was to carry out as much of the research as possible in the field, to demonstrate that results can be provided rapidly without the need for transportation of large numbers of samples and laboratory analysis. Bangladesh and UK laboratory analysis was kept to a minimum, saved only for cross-checking of field samples, for inductively coupled plasma (ICP) analysis of a standard suite of elements, and for speciation of arsenic.

## SURVEY AREAS

- 1.10 Of the four different geographical regions included in the Phase I study, three were selected for survey in Phase II. Sitakunda was the area omitted because it was the area that would be potentially most affected by any political disruption of field work during the Phase II programme. Surveys were carried out in each of the three areas simultaneously. The three areas included in the Phase II survey were: -
- Subidpur village in Hajiganj upazila, Chandpur District;
  - Gargari and Autapara villages in Iswardi upazila, Pabna District;
  - Jalalabad village in Kalaroa upazila, Satkhira District.

## PHASE II PROGRAMME

1.11 Preparations for Phase II began before the conclusion of Phase I to speed up the overall programme. The full programme was as follows:

- 15<sup>th</sup>-19<sup>th</sup> December 2000 Technical training for social survey staff
- 1<sup>st</sup>-13<sup>th</sup> January 2001 PRA refresher training for social survey staff
- 14<sup>th</sup>-19<sup>th</sup> January 2001 Well and household selection
- 25<sup>th</sup> January 2001 Mobilisation to the field
- 27<sup>th</sup> January 2001 Village Introductory Workshops
- 31<sup>st</sup> January 2001 Stakeholders' Phase II Introductory Workshop Dhaka
- 28<sup>th</sup> February 2001 Completion of Fieldwork
- 11<sup>th</sup> March 2001 Village Closing Workshop

1.12 The Phase II programme and content was presented at a stakeholders workshop in Dhaka on 31<sup>st</sup> January 2001. No requests were made for any changes to the programme or content and, therefore, the Phase II assessment has been carried out as proposed at the workshop.

1.13 A final workshop was held with stakeholders in Dhaka on 13<sup>th</sup> March 2001.

## REPORT STRUCTURE

1.14 This report comprises:

- Introduction;
- Detailed methodology describing logistical and analytical methods for technical and social surveys;
- Results from the field survey of the wells, technologies and households;
- Results from the proponents' questionnaire and waste management strategies;
- Conclusions on the technical performance and acceptability of the technologies;
- Recommendations for further areas of research and for implementation.

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- 1.15 As with Phase I, this report seeks to keep the presentation of the results to a clear and coherent minimum. Therefore, only the summary data and interpretation are presented within the main body of the report. Much of the additional information is presented in a series of supporting Appendices. The raw data will be made available on the BAMWSP, WaterAid, ACIC and WS Atkins web-sites. All who receive this report will be informed of the web-site addresses when the data has been set up on them and encouraged to disseminate this information to other interested parties.
- 1.16 The Appendices provide a detailed explanation of field procedures, quality control measures and technology results.
- 1.17 An extended, stand alone, Executive Summary has also been produced, giving a summary of the results, for wider circulation.
- 1.18 An additional set of short documents is proposed for each technology, one set in English and another set in Bengali, giving a summary of the results and the key strengths and weaknesses of each technology.

## **2. METHODOLOGY**

### **INTRODUCTION**

- 2.1 This section provides a brief description of the methodologies used in Phase II. This includes the overall approach to the surveys, the technical methods employed in the field and laboratory and the methods for assessing user acceptability. A more detailed presentation of the sampling methods and associated quality control procedures is given in supporting Appendices.

### **OVERALL APPROACH**

- 2.2 The assessment components in Phase II were essentially carried out in four different survey bases:
- (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;
  - (iii) In the Intronics laboratory, Dhaka, Bangladesh, for cross-checking of arsenic field-testing and for arsenic speciation; and
  - (iv) In the Imperial College Geochemistry laboratory, London, UK for cross-checking of Intronics laboratory results and for ICP analysis of feed and treated water for all wells and all technologies.

### **Household and Well Selection and Technology Distribution**

- 2.3 In three of the villages visited in Phase I, households were selected using the following criteria: -
- Arsenic concentration in the raw tubewell water of at least 0.10mg/L;
  - Representative cross-section of household social status and wealth;
  - Ideally, at least seven individuals using the well;
  - Close proximity to one another for practical field testing.

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- 2.4 Three replicates of each of the seven technologies were provided for assessment in each of the three survey areas. Selected households were provided with only one technology replicate at any one time and consequently a final selection of 21 household wells was made for inclusion in the survey in each area of the three study areas.

**VILLAGE BASED TECHNICAL AND SOCIAL SURVEYS****Village Based Survey Programme**

- 2.5 The Phase II rapid assessment programme was set at 32 days. On the first day of the programme an opening workshop was held in the village to explain the project, the proposed programme and to give a first explanation of the operation of the technologies. Eleven days after completion of the field surveying, a closing workshop was held to enable discussion between the users of the technologies and with all residents of the village and to disseminate further information regarding the technologies.
- 2.6 Between the opening and closing workshops, households at each of the 21 tubewells were supplied with three different technologies over the course of the 32 day assessment period. The households used each of the three technologies at the well for between seven and ten days at a time before being supplied with a different technology.
- 2.7 The technical survey team carried out testing for six days during each 10 day session. They then returned to Dhaka to bring back the data for analysis and to meet to ensure consistent approaches to analysis between the three areas. This also meant that the householders were left alone to operate the technologies for three days before the technologies were moved. The householders, therefore, had six days of day-to-day technical support in the operation and maintenance of the technologies and were then left to operate the technologies by themselves. However, the social survey teams remained in the areas and were on hand for support.

**Survey Teams**

- 2.8 In each of the three areas, a technical and a social survey team carried out the assessments. The total team size in each area was seven members, with both technical and social survey teams comprising three members and one overall team leader. The technical and social survey teams worked closely together to address issues raised by the villagers and to deal with any problems which arose from the use of the technologies and their transfer after ten and 20 days.



### **Staff Training**

- 2.9 The technical teams comprised staff from Bangladesh Engineering and Technological Services (BETS) Limited, who had carried out the Phase I assessment. They underwent additional training in field microbiological testing prior to departure to the survey areas.
- 2.10 The social survey teams from the Intermediate Technology Development Group (ITDG) received technical training from the technical staff. This covered technology description, operation and maintenance and the possible implications for users. This training was carried out in December 2000.
- 2.11 During January 2001, all the nine members of the social survey teams were given five days of PRA refresher training conducted by PromPT. During the training, which involved both classroom teaching and simulated practical application and exercises, the team members were exposed to different Participatory Rapid Appraisal (PRA) tools and techniques, including those especially relevant to the study objectives, such as Social Mapping and Wealth Ranking. Exposure to the PRA tools and techniques enabled the investigators to reacquaint themselves with the art of rapport building with the rural people.

### **Technical Assessment**

- 2.12 The assessment of the technologies' technical performance covered three main issues relating to water quality in feed and treated waters. These were arsenic, non-arsenic water chemistry and bacteriological analyses. For each of these analyses, the detailed testing methodology and Quality Control Procedures are set out in Appendices 1 and 2 respectively.

#### *Continued assessment of technology arsenic removal*

- 2.13 Water samples were taken for each of the 21 technologies (three replicates of seven technology types) in each of the three areas. Feed and treated paired samples were taken on as many occasions as testing capability allowed. This resulted in approximately three paired samples for each technology per week, nine in total. Each of the feed and treated waters were tested for arsenic concentrations. The paired values enable an evaluation of percentage arsenic removal and reduction in arsenic concentration to be made, in addition to confirming whether or not the technologies remove arsenic to below 0.05mg/L.
- 2.14 In addition to the testing relating to the technologies, at three wells in each area, water was tested for arsenic concentrations throughout one day. Samples were taken and tested every 90 minutes to see if arsenic concentrations varied dramatically during the day. Each individual sample was divided into four aliquots, three for arsenic analysis in the field and one for laboratory analysis, in order to assess the influence of equipment analytical error on the results.

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- 2.15 In all cases for arsenic testing the PeCo 75 field-testing kit was used. One paired sample (feed and treated) for each technology was sent to the Intronic laboratory in Dhaka for cross-checking. Analysis was supervised by Dr Peter Swash at all times. This provided a total of 126 samples, approximately 15% of total field samples.

*Analysis of other water chemistry parameters in feed and treated waters*

- 2.16 The non-arsenic parameters tested in the field comprised the same list as in Phase I with the addition of Faecal and Total Coliforms. However, in Phase I, the samples for testing non-arsenic parameters were filtered, using a 0.2µm syringe filter, to assess the concentration of each parameter in solution and able to pass freely through the technologies. In Phase II, the samples were not filtered, so that the total concentrations of each parameter in the water before and after treatment could be assessed. The exception to this was sulphate, where high turbidity may interfere with the analysis. Turbid feed waters were therefore filtered before analysis. The physical parameters tested for were:

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

- 2.17 One paired sample (feed and treated) for each of the 21 technology units in each area was tested for each of the above, to assess:

- (i) what impact the technologies have on each of the parameters; and
- (ii) what possible impact the water chemistry parameters may be having on the efficiency of arsenic removal by each technology.

- 2.18 In addition, the 126 samples that were sent back to the Intronic laboratory for arsenic field test cross-checking, were then sent to the Imperial College laboratory in London for ICP analysis. The ICP analysis was carried out on the paired 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.

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- 2.19 The testing programme set out above also enabled the treated waters to be tested for chemicals used in the technologies, either as reagents or within the filter material. Additional tests for this were also done in the field.
- 2.20 The equipment used for field testing of the above parameters was as follows:
- Hach Spectrophotometer (DREL-2010) for total iron, ferrous iron, manganese, aluminium, fluoride, chloride, phosphate, nitrate, sulphate, sulphide;
  - Hach Portable Turbidimeter for turbidity;
  - Lutron pH/Redox meter
  - Lutron Dissolved Oxygen and Temperature meter
  - Lutron Conductivity meter
  - Hach alkalinity test kit

*Assessment of bacteriological contamination*

- 2.21 The objective of a rapid assessment of the microbiological implications of each of the arsenic removal technologies was to provide an initial consideration of:
- The increased risk of human or animal contamination, inevitable as a consequence of a switch to a process of water treatment (with more opportunities for contamination between source and mouth) from direct use of tubewell water.
  - The possibility that technologies themselves may harbour bacteria within the filter material and provide a potential breeding ground for pathogens.
  - A concern expressed that there may be non-human bacteria added to water from bio-films that develop in the technologies and then are sloughed off under certain conditions.
- 2.22 The microbiological assessment was carried out using the OXFAM-DelAgua Portable Water Testing Kit. This equipment has been designed to conform to parameters specified in *World Health Organisation Guidelines for Drinking Water Quality Volume III*.
- 2.23 Analysis was done for total coliform bacteria (TC) and thermotolerant (faecal) coliforms (FC). These are standard microbiological indicators usually selected because of their abundance and survival in the freshwater environment and the relative ease with which they can be grown to allow rapid enumeration.
- 2.24 Total coliforms include some organisms that are naturally present in the environment (soil or water for example) and are not necessarily of sanitary importance. They have been included in this survey as the first step in a rapid

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assessment to determine whether bacterial contamination is indeed an issue meriting further consideration. This also provides a general indication of the total bacterial levels and a simple handle with which to assess the issue relating to addition of bacteria from loss of any bio-film developed within the technologies.

- 2.25 Faecal coliforms, in contrast, are of direct relevance to health because they demonstrate that contamination with human or animal faecal material has occurred. They are used to form the basis of a risk assessment and microbiological classification schemes for drinking water quality.
- 2.26 The level of risk associated with presence of faecal coliforms can be further clarified by analysis for specific organisms such as faecal streptococci or clostridium. This type of analysis requires laboratory facilities and is considerably less straightforward, particularly in remote, rural locations. Therefore, the decision was taken that at this stage that it was neither vital nor feasible to carry out such further analysis. This is in keeping with the principle of field based testing and the identification of potentially key issues, rather than detailed consideration of specifics.
- 2.27 Feed waters from all wells were sampled initially to assess the baseline contamination prior to arsenic removal (50mL and 100mL samples in each case). In Iswardi and Hajiganj, both total and faecal coliforms were analysed in all cases, while in Kalaroa only total coliforms were included for the initial assessment. Bacterial contamination in treated waters from all replicates of each technology was then assessed after at least 10 days (during the second session) and after 20 days (during the third session), with additional surveys carried out where the programme allowed. In Kalaroa, faecal coliforms in all treated waters were assessed during the final session only.
- 2.28 In cases where analysis of the treated water initially revealed what was considered to be a potentially significant health risk (that is a high level of faecal contamination), users were asked either to boil their water or to stop using the water while the technology was thoroughly cleaned with dilute bleaching solution and a clear or very low result was obtained on re-testing.
- 2.29 For technologies where treated water was consistently found to contain high levels of contamination, more detailed surveys were carried out in an attempt to identify the stage at which the water had become contaminated. This included an assessment of the ‘true’ feed water as the householders use the technology in practice. In some cases, for example, the technology is filled from a bucket of water that may have been standing open for some time.
- 2.30 The microbiological assessment was supported with a basic sanitary inspection, to assess potential sources or risks of contamination and feasible mitigation measures. The importance of hygiene was stressed to the householders during the instruction on technology operation.

- 2.31 The issue of what levels of contamination are acceptable in a Bangladesh context is considered in the light of WHO recommendations and the microbiological counts obtained.

### **Social Assessment**

- 2.32 The social survey was carried out alongside the technical survey. The social survey team arranged the opening village workshops at which they presented the programme for the social survey. Both teams informed the householders about the adverse effects of drinking arsenic-contaminated tube-well water, objectives of the testing of the technologies, types of technologies to be tested, and the objectives of the social investigation. They explained the role that was required of the village inhabitants in carrying out the whole range of activities relating to the testing of the technologies.
- 2.33 Once the technologies had been installed, the social survey teams spent time with the householders on an informal basis (seven households per surveyor) discussing water use and arsenic in general and answering questions about the technologies. If the surveyors were unable to answer technical questions, they referred to the technical survey team.
- 2.34 Each household was asked to use three different technologies over the survey period, using each for seven to ten days. After day seven, a formal, questionnaire based survey was carried out with the householders (see Appendix 3 for questionnaire). The questionnaire was developed by both WSAI and ITDG and was designed for use as a basis for more extensive discussion. After ten days, the householders were asked specific questions about operation of the technologies, since the householders had been left alone three days to operate the technologies by themselves.
- 2.35 Once the householders 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.
- 2.36 Scores (from 1 'extremely poor' to 7 'excellent') were also given for each technology for fifteen different criteria including flow rate, taste, smell, ease of use, cost, ease of movement, ease of maintenance and waiting times. The scores for each criterion were averaged to give a score for each criterion in each area.
- 2.37 Quality Control was done by senior ITDG staff undertaking frequent field visits to all the three study areas to oversee the activities of the field investigators. On all occasions, they reviewed the filled-in questionnaires along with the field investigators and provided the required feedback to them. During such visits, they also contacted local government officials, elites and the household members to discuss matters related to the study

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- 2.38 At the closing workshop in each of the villages, the householders were encouraged to share their experiences of the technologies and to say what features they liked and did not like.

**BREAK THROUGH TESTING**

- 2.39 The break through testing was carried out at Sonargaon, close to Dhaka. Break through is the point at which the technology's arsenic removal efficiency has declined to the point that arsenic concentrations in the treated waters approach those in feed water due to a progressive deterioration in technology performance.
- 2.40 If a technology is going to be sustainable, then achieving break through in a rapid assessment under normal operating conditions should not be achievable. Therefore, the technologies were kept in continuous operation each day to try and achieve break through. Volumes of water passing through the technologies were recorded in terms of the number of 20 litre batches.
- 2.41 Three replicates of each of the seven technologies were set up at a well in Sonargaon. Feed water concentrations were measured on a weekly basis. Treated water concentrations for each replicate of each technology was measured every two to three days.
- 2.42 The equipment used to measure the arsenic concentrations was the PeCo 75. Other water chemistry parameters were tested using the Hach Spectrophotometer (DREL-2010).

**ARSENIC FIELD TEST KIT EVALUATION**

- 2.43 Arsenic field test kit evaluation was also carried out at Sonargaon. The kits which were included in the survey included:
- PeCo 75;
  - Merck field test kit;
  - Hach Arsenic field test kit; and
  - General Pharmaceutical Limited (GPL) field test kit.
- 2.44 Three copies of each type of field test kit were used to measure arsenic concentrations in common sample waters. The sample waters in common comprised:
- Two different feed water samples;
  - One treated water from each technology;

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- A 0.05 mg/L arsenic standard;
  - A 0.10 mg/L arsenic standard; and
  - A 0.25 mg/L arsenic standard.
- 2.45 In addition to the precision and accuracy testing, the kits were also evaluated in terms of the ease of use, time for testing and cost and safety.

**LABORATORY ANALYSIS BANGLADESH****Cross-checking of Field Samples**

- 2.46 Approximately 15% of field samples were stabilised with 1mL 1:1 nitric acid and sent to the laboratory in Dhaka for analysis using an atomic adsorption spectrophotometer with hydride generator (AAS-HG). Analysis was supervised by Dr Peter Swash of the project team. This provided a cross-check of field sample results. This included one paired sample from each well from the first session (feed and treated waters from all 63 wells). Twenty one samples from the second and third sessions in the field were taken at random to observe whether there was any change in the performance of the PeCo 75 over time.

**Arsenic Speciation**

- 2.47 Samples for well feed waters from all 63 wells included in the survey were speciated for arsenic. The method uses ion exchange resin columns which selectively remove As(V) from water samples. As(III) in the water passes through the column and is analysed by conventional AAS-HG. Total arsenic concentration in the samples is also analysed by AAS-HG. As(V) is total less As(III).

**LABORATORY ANALYSIS UK**

- 2.48 All of the samples from the first of the three testing periods, which were sent to the Dhaka laboratory (feed and treated results from all 63 wells), were then sent to the Imperial College Geochemistry laboratory for analysis using ICP. This enabled:
- a direct comparison of Bangladesh and UK laboratory results for arsenic to be made, and
  - the creation of a standard element suite of results for feed and treated waters at all wells and for all technologies. The Hach field results could then be cross-checked and further information provided on the presence/absence (in well water) and removal/non-removal (by technologies) of other elements not tested in the field.

## **PROPONENTS QUESTIONNAIRE**

2.49 A questionnaire was sent out to the proponents asking them to supply information about:

- production, marketing and distribution strategies for their technologies;
- plans for provision of support services to users; and
- waste management strategies.

2.50 The proponents questionnaire is shown in Appendix 3.

## **PRESENTATION OF RESULTS**

### **Technical Results**

2.51 Wherever possible, the technical results in Phase II are presented in graphs rather than tables for ease of reading and interpretation. The data used in generating the graphs and, indeed, the raw data, will be available alongside the final report when it is placed on the internet.

2.52 Many graphs show the results on a well by well basis. In each area, wells were given a unique identification number. This number is used in the graphs and is preceded by:

- ‘H’ for Hajiganj;
- ‘I’ for Iswardi; and
- ‘K’ for Kalaroa.



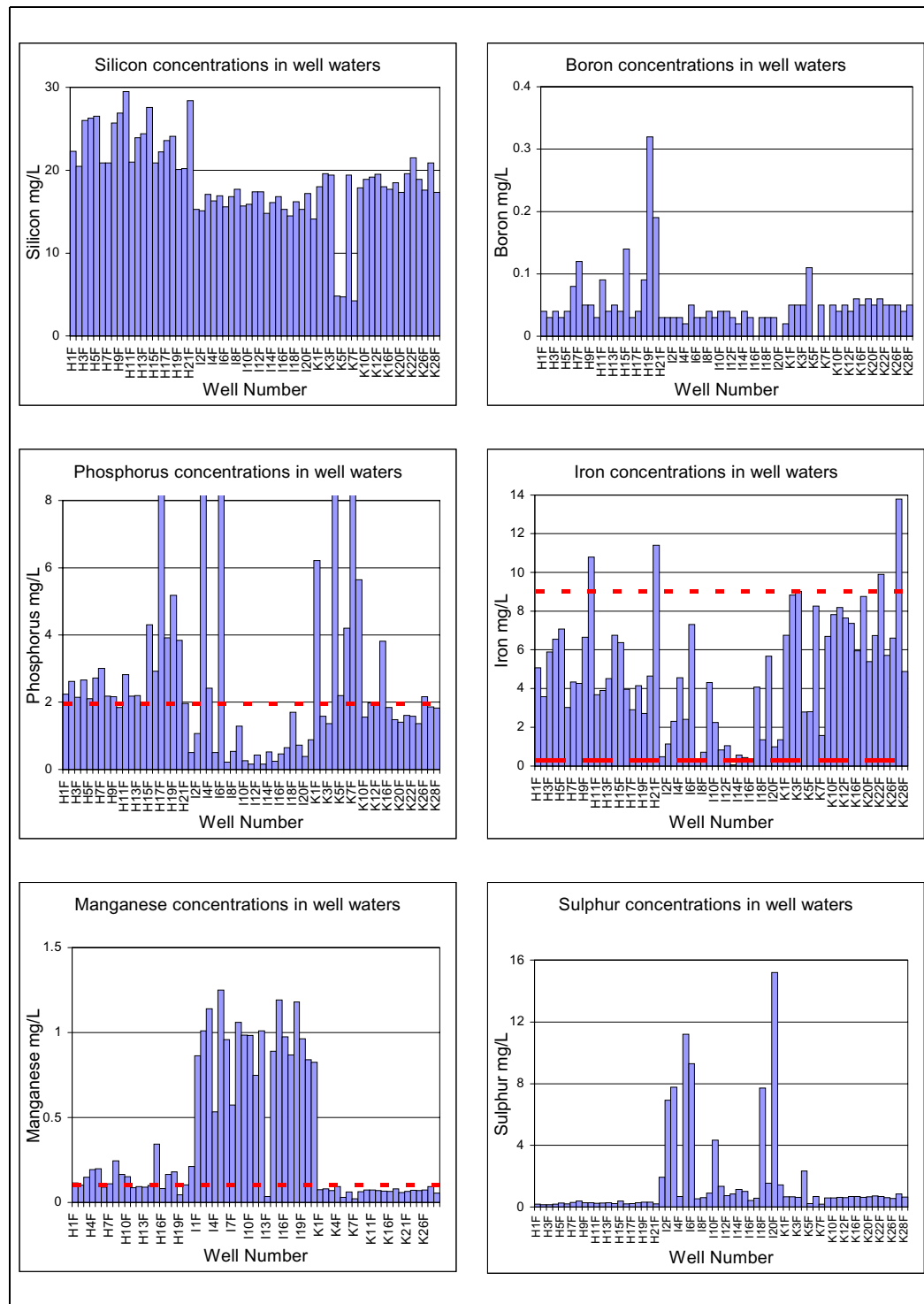
### **3. TECHNICAL PERFORMANCE RESULTS**

#### **WATER CHEMISTRY**

##### **Evaluation of ICP data**

- 3.1 The ICP data on the 63 feed waters from the three selected areas were reviewed and key differences between the samples are illustrated in Figures 3.1 and 3.2. Figure 3.1 shows high concentrations of silicon and boron in Hajiganj waters as compared to Iswardi and Kalaroa. In Iswardi phosphorus and iron concentrations are low, while manganese and sulphur are high as compared to Hajiganj and Kalaroa waters. Waters in Hajiganj are low in calcium, barium and strontium and high in potassium compared to the other two regions (Figure 3.2). Aluminium concentrations show no distinct regional differences.
- 3.2 The ICP results are presented in full in Appendix 4.

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**Figure 3.1 - Concentrations of Silicon, Boron, Phosphorous, Iron, Manganese and Sulphur in well waters**

Dashed line shows Environmental Quality Standards for Bangladesh:

--- Max. acceptable concentration

— Min. acceptable concentration

Well Number codes: H=Hajiganj; I=Iswardi; K=Kalaroa

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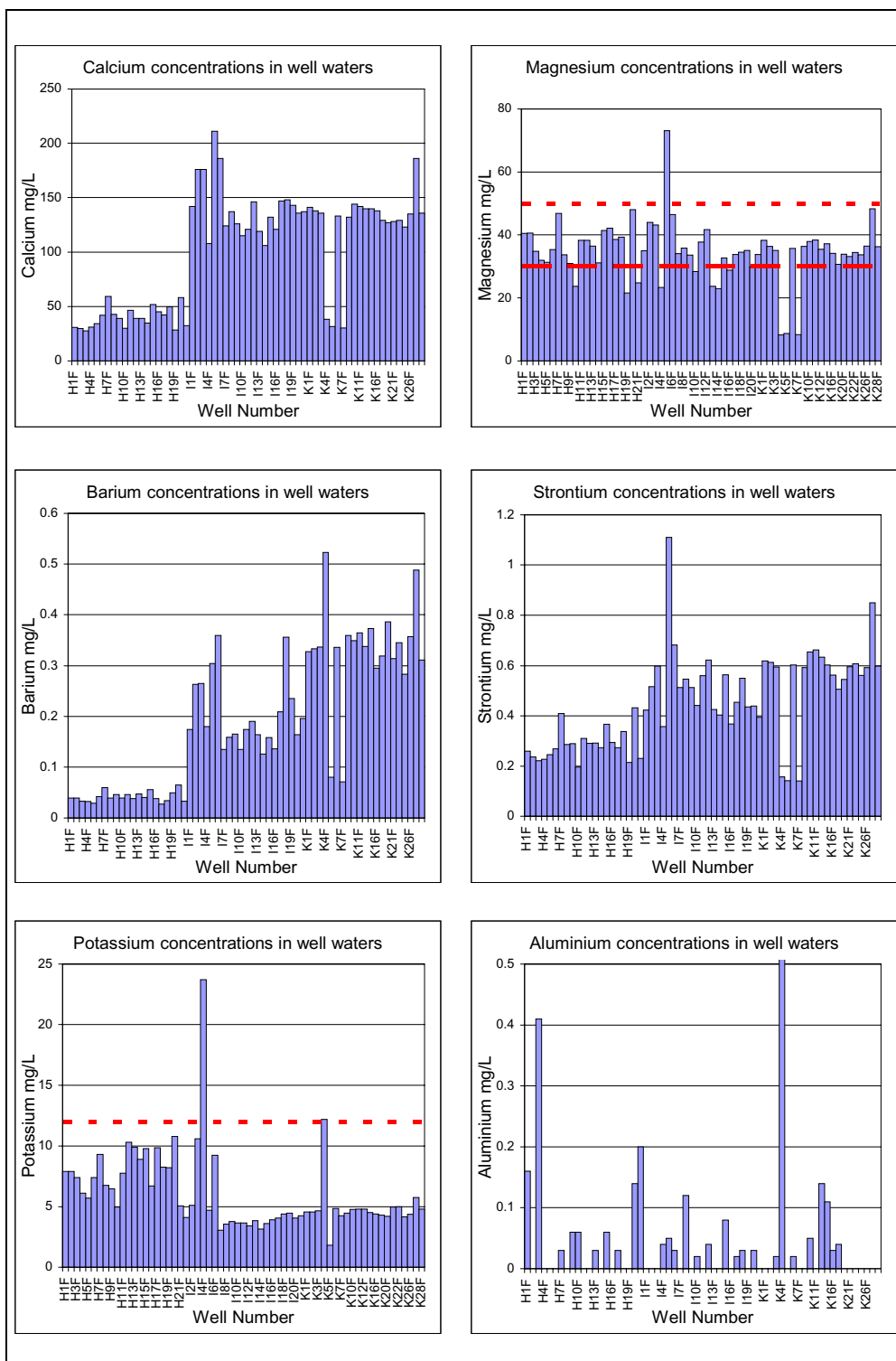


Figure 3.2 - Concentrations of Calcium, Magnesium, Barium, Strontium, Potassium and Aluminium in well waters

Dashed line shows Environmental Quality Standards for Bangladesh:

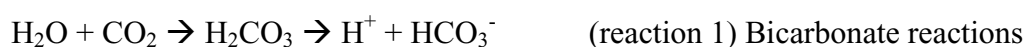
--- Max. acceptable concentration

--- Min. acceptable concentration

Well Number codes: H=Hajiganj; I=Iswardi; K=Kalaroa

### Decarbonation in Tubewell Waters

- 3.3 It was observed that the pH of well water often increases on standing. This is explained by decarbonation of the water and influences of the bicarbonate buffer (see reaction 1 below). Dissolved carbon dioxide concentrations in the groundwater are elevated under the reducing environment below the water table. Decarbonation (CO<sub>2</sub> removal) pushes the equilibrium to the left, lowering the concentration of both bicarbonate and H<sup>+</sup> (i.e. increasing pH). The other reaction simultaneously taking place is the oxidation and hydrolysis of dissolved iron (reactions 2 and 3) which tends to increase H<sup>+</sup> concentration (i.e. decreases pH).



- 3.4 The raised pH increases the kinetics of iron precipitation and removal from solution. This is the reason why aeration is an important part of water treatment and removal: if inadequate time is allowed for aeration, pH does not increase and complete hydrolysis of the dissolved iron does not take place. The presence of dissolved iron contributes to arsenic removal processes by coprecipitating and adsorbing arsenic from solution. The more complete the aeration and the higher the iron concentration in solution, the more efficient the removal of arsenic by attachment to flocs of iron oxyhydroxide would be expected to be. When extra iron is added through coagulants or in filter matrices this should also promote the arsenic removal process.
- 3.5 Most of the technologies reduce the alkalinity of the waters by simple aeration and the introduction of H<sup>+</sup> through either surface chemical action (activated alumina and resin) or through hydrolysis of coagulants (iron or aluminium sulphate). The reduction in alkalinity in waters from the Sono are thought to be due to the reaction of water with metallic iron in the top kolshi.

### ARSENIC CONCENTRATIONS

- 3.6 The arsenic results are presented in four forms:
- the comparison between PeCo 75 field results, Dhaka laboratory results and UK laboratory results;
  - arsenic concentrations in seven wells over one day;
  - the arsenic removal results for each technology; and
  - the speciation results for each well.

### PeCo 75 versus AAS Hydride Generator

3.7 The correlations between PeCo 75 and AAS-HG in Phase II are better than they were in Phase I, particularly in the case of Hajiganj (0.93) and Iswardi (0.94). The comparisons are shown in Figure 3.3. There is a tendency for the PeCo 75 to read higher than AAS-HG at all levels. On average, PeCo 75 reads approximately 25% higher than AAS-HG. The field survey results have been left in their original form with no change because:

- (i) the field results are not always higher than the laboratory results; and
- (ii) this builds in a ‘safety margin’ for the results presented.

### Bangladesh Laboratory versus UK Laboratory

3.8 The relationship between the Intronic laboratory in Dhaka (AAS-HG) and the Imperial College Geochemistry Laboratory in London (ICP) is shown in Figure 3.4 (correlation of 0.94). The ICP results are, on average, approximately 8% higher than AAS-HG. Overall, however, the results show that the AAS-HG in Dhaka is producing results of a high standard, suitable to act as a cross-check for the field survey results.

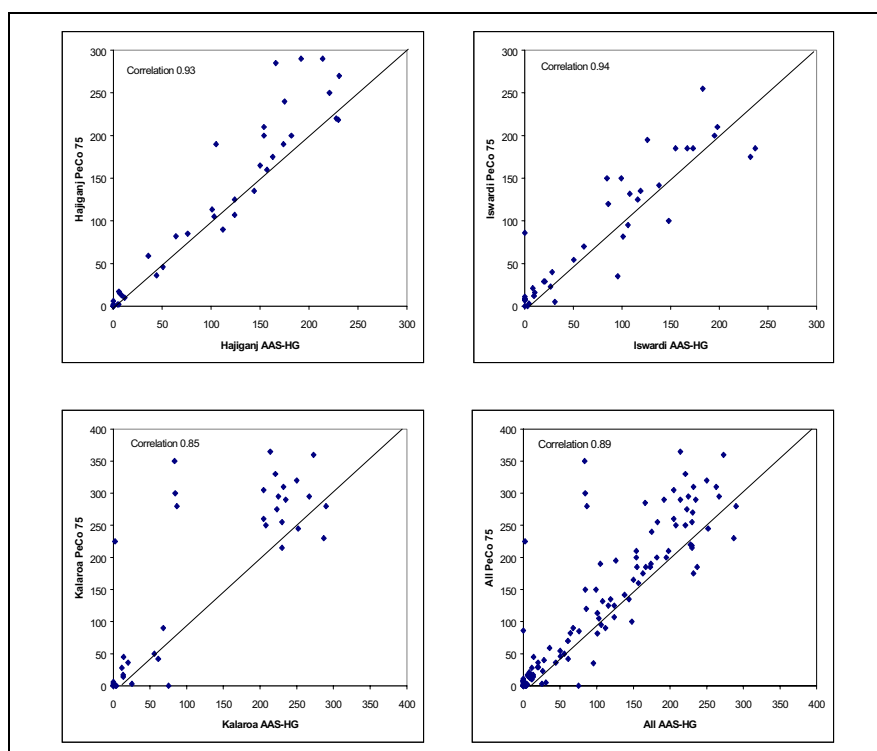


Figure 3.3 - Comparison of PeCo 75 (Field) and AAS-HG (Laboratory) Results

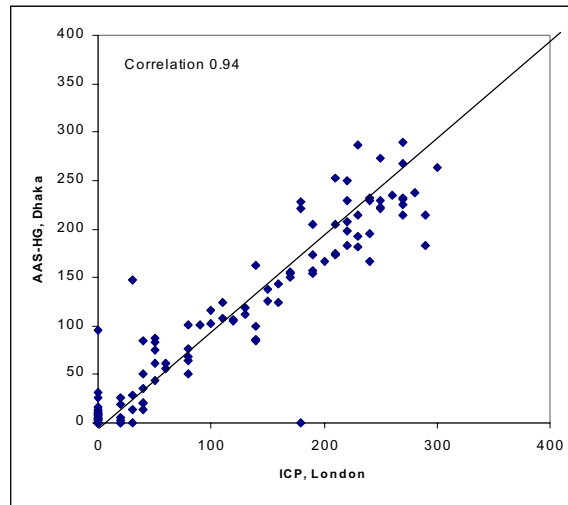


Figure 3.4 - Comparison between Bangladesh and UK Laboratory Results

**Changes in Arsenic Concentrations in Wells over One Day**

3.9 The analysis of feed water arsenic concentrations, every ninety minutes on one day, for seven wells, shows that there are some minor fluctuations in arsenic concentration. However, they are, on the whole, not dramatic. One well in Hajiganj (H16) and one in Iswardi (I05) did show marked variation, but not enough to reduce arsenic concentrations to safe levels. On the whole, the minor variation suggested that arsenic levels were slightly lower at the beginning of the day, but not significantly.

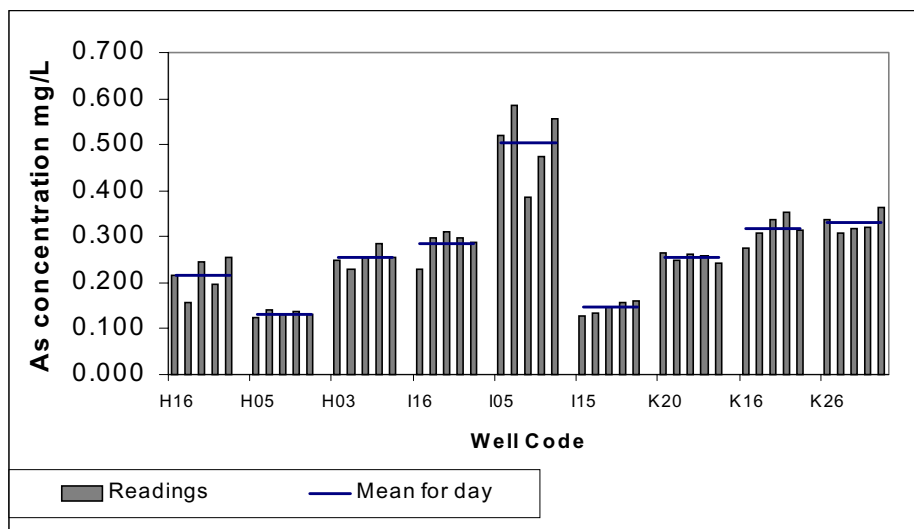
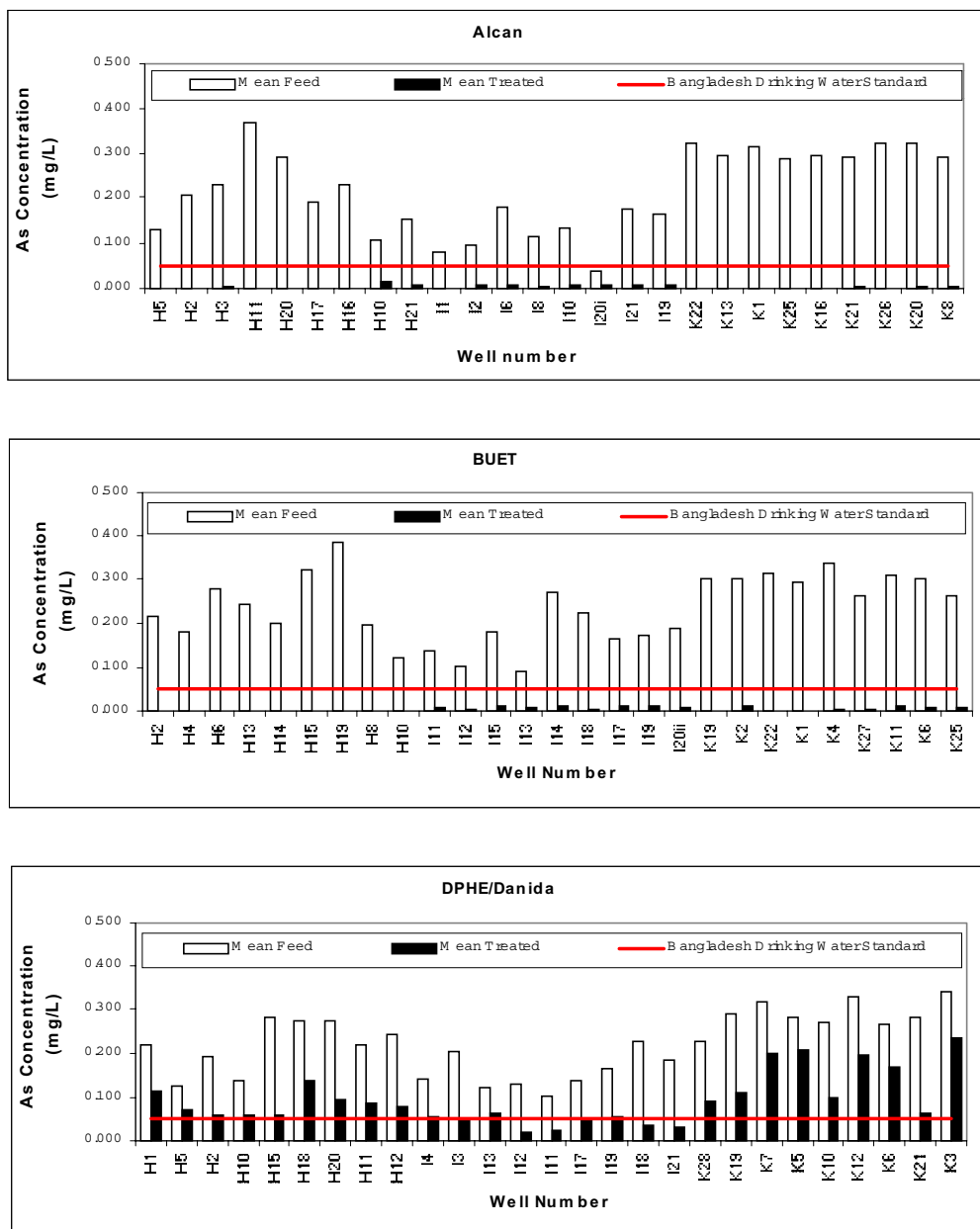


Figure 3.5 - Changes in As Concentrations in Tubewell Water Over One Day measured by PeCo 75

### Arsenic Removal by Technologies

3.10 The performance of the technologies in terms of arsenic removal is shown in Figure 3.6. The results support the conclusions drawn in Phase I. The Alcan Enhanced Activated Alumina, the BUET Activated Alumina and the Sono 3-kolshi technologies all performed consistently well at all sites reducing arsenic concentrations to below 0.05mg/L in every treated water sample. In Phase I, 99.5%, 98.8% and 98.3% respectively of treated water samples for these technologies were below 0.05mg/L in all four areas.



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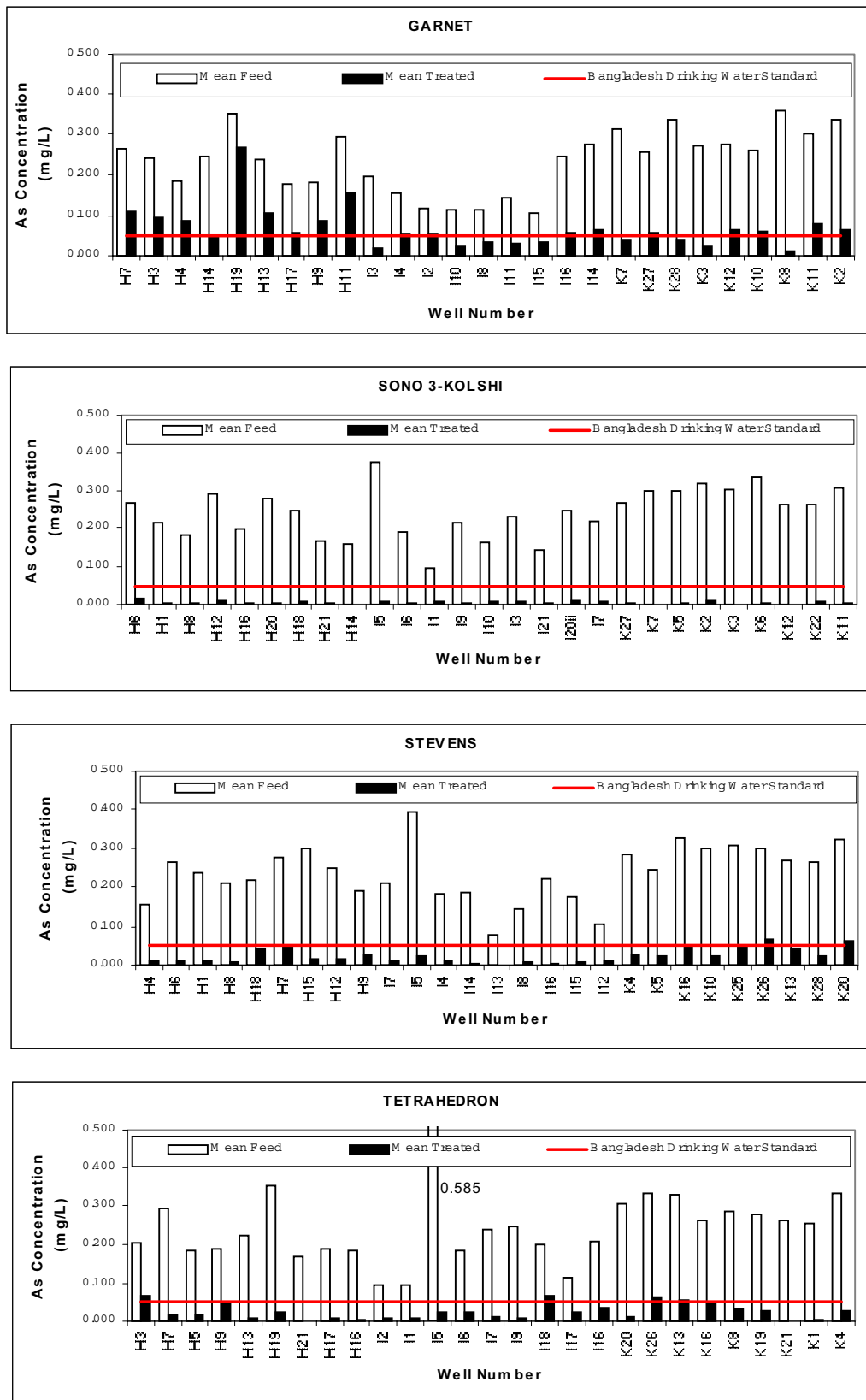


Figure 3.6 - Arsenic Removal by Technologies



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- 3.11 The Stevens Institute technology performed well in Iswardi reducing arsenic concentrations to below 0.05mg/L in all treated water samples as it did in Phase I. However, it performed less well in Hajiganj where 8% of treated water samples exceeded 0.05mg/L and particularly in Kalaroa where 38% of treated water samples exceeded 0.05mg/L. In both of these areas all exceedences were below 0.08mg/L. In contrast to the performance of the Stevens Institute technology in Phase II, 100% of treated water samples were below 0.05mg/L in Kalaroa in Phase I. The performance of the technology in Hajiganj was similar in both phases of the project (13% of treated water samples exceeded 0.05mg/L in Phase I).
- 3.12 Possible causes for the slightly worse performance in Phase II than Phase I are a change in reagents supplied and inadequate stirring by the householders. In Phase I all technology preparation was carried out by the field survey team.
- 3.13 It was noted in Hajiganj that one of the treated water samples which exceeded 0.05mg/L was quite discoloured, having been taken immediately after sand washing. This suggests that arsenic concentrations exceeding 0.05mg/L may be a function of the thoroughness of sand washing rather than arsenic removal performance of the filter.
- 3.14 As in Phase I, the Tetrahedron performed best in Iswardi with only 8% of treated water samples exceeding 0.05mg/L arsenic (in Phase I, 100% samples were below 0.05mg/L). In Phase II, 21% of treated water samples in Hajiganj and 29% in Kalaroa exceeded 0.05mg/L arsenic. Where initial treated water concentrations at a tubewell exceeded 0.05mg/L, the performance of the Tetrahedron generally (but not always) improved with time at the well.
- 3.15 The GARNET performed poorly in Hajiganj with only 8% of treated water samples below 0.05mg/L. It faired better in Kalaroa and Iswardi where 54% and 66% respectively of treated water samples were below 0.05mg/L.
- 3.16 The DPHE/Danida again did not perform very well in the survey areas. About 96% of treated water samples in Kalaroa and 88% in Hajiganj exceeded 0.05mg/L arsenic. In Iswardi, where feed arsenic concentrations were lower, the technology performed slightly better with 42% of treated water samples exceeding 0.05mg/L arsenic.

**Speciation**

- 3.17 Arsenic speciation is an important factor as a number of the technologies will be dependent on the nature of the anionic complex and its ability to chemically combine with coagulants (Stevens and DPHE/Danida) and surface active materials (resins and activated alumina). The oxidation, hydrolysis and removal of iron allow arsenic in solution to be readily removed and this is more efficiently removed when present in the pentavalent state (Figure 3.7).

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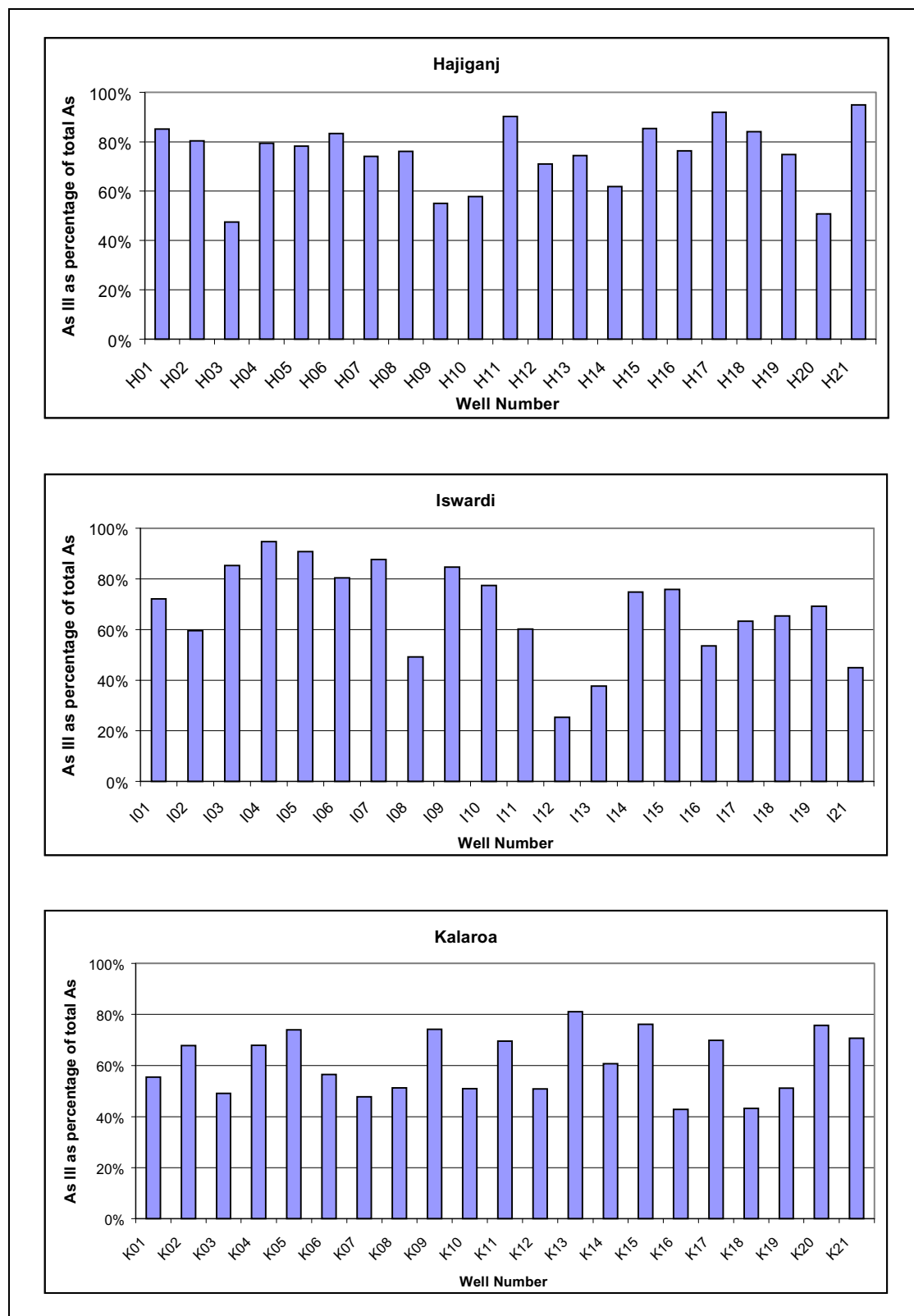


Figure 3.7 - Proportion of As(III) of Total Arsenic at the 63 Survey Wells

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3.18 The proportion of As (III) in the groundwater does not seem to have any influence upon the performance of the DPHE/Danida (Figure 3.8). There is some negative influence on the GARNET (i.e. greater the proportion of As (III), the less the percentage As removal). The Tetrahedron is influenced more significantly by the proportion of As(III) (the greater the proportion of As(III) the greater the percentage arsenic removal).

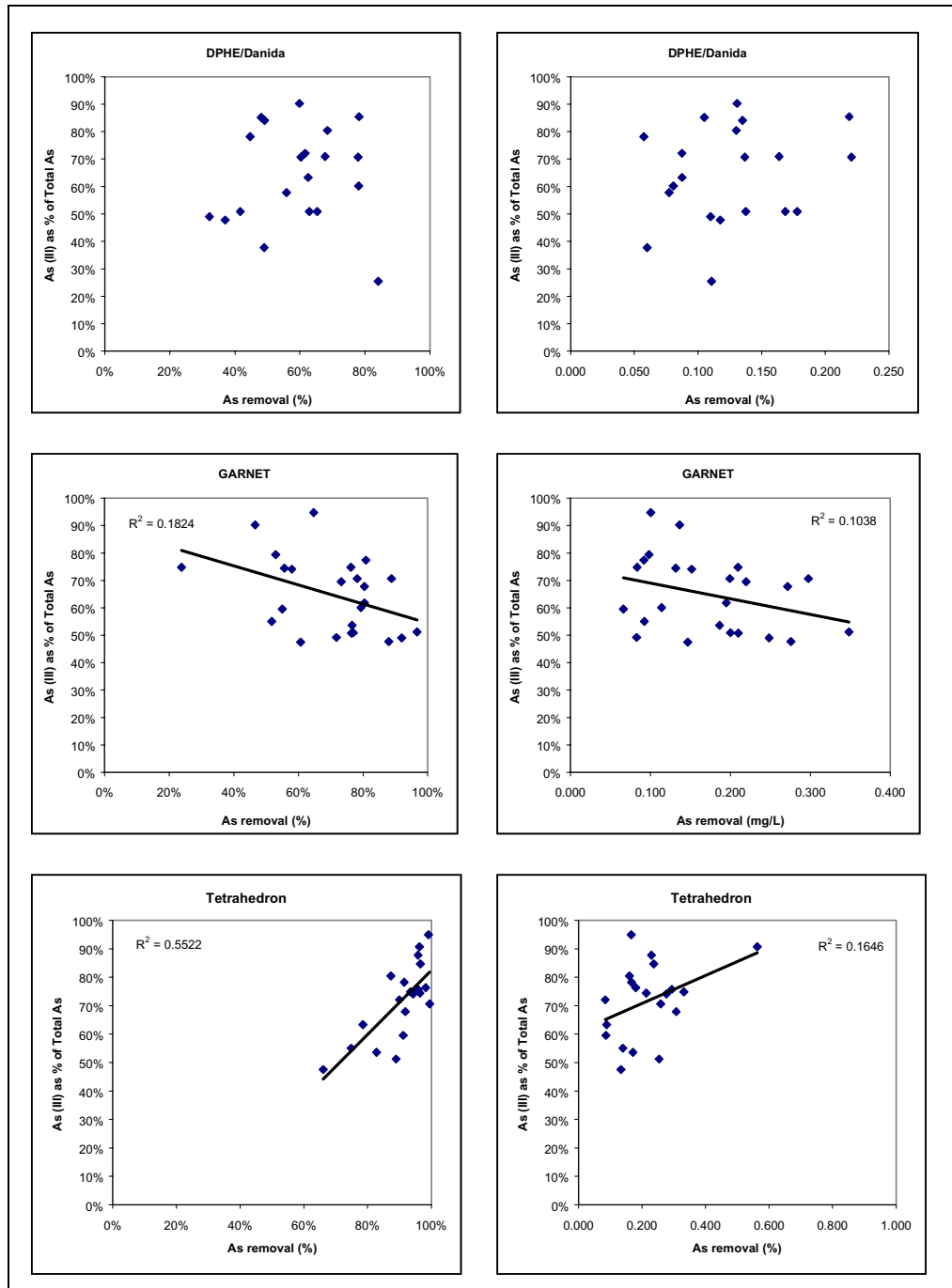


Figure 3.8 - Influence of the proportion of As (III) in groundwater on the performance of DPHE/Danida, GARNET and Tetrahedron

## TREATMENT OF NON-ARSENIC PARAMETERS BY TECHNOLOGIES

### Introduction

- 3.19 From Phase I of the project it was clear that the technologies performed differently in the different areas. No clear correlation could be identified with one individual water quality parameter and it is more likely that arsenic removal is a function of more than one parameter.
- 3.20 Water quality parameters in the feed waters and treated waters have been compared to provide a preliminary insight into the chemical processes occurring within each of the seven technologies.
- 3.21 The results for non-arsenic parameters are presented and discussed by parameter rather than by technology, to enable comparisons between processes to be made where relevant.
- 3.22 Graphs of the feed/treated water quality data are presented in Figure 3.11 to Figure 3.20.

### Iron and Redox

- 3.23 As indicated on Figure 3.9 and Figure 3.10, all seven of the technologies remove the both total and ferrous iron (Fe(II)) from the water during treatment. Indeed, most of the technologies remove iron to levels below the range of acceptable concentration identified in the Bangladeshi Drinking Water Standards. There is some indication from the ICP data that the DPHE/Danida and Tetrahedron technologies are not as effective as the others at removing total iron. The increase in total iron at one well by the Stevens technology may possibly be the result of iron passing through the filter after insufficient sand washing. Iron discoloration of the treated water was observed at a different site in Hajiganj immediately after washing.
- 3.24 The mechanisms for iron removal vary between oxidation, adsorption, coagulation, settlement and filtration depending on the technology.
- 3.25 Comparing redox mV measurements between feed and treated water samples (Figure 3.11) the most apparent difference is for the Sono technology, which shows a dramatic decrease in redox potential. This is believed to be caused by the action of the metallic iron on the water. The GARNET shows a similar trend to the Sono which may be a result of Fe(II) in the some of the brick chips. The function of the chlorine tablets in the Tetrahedron is as a strong oxidising agent which increases the redox mV and helps oxidise iron and arsenic to their more stable trivalent and pentavalent forms respectively.

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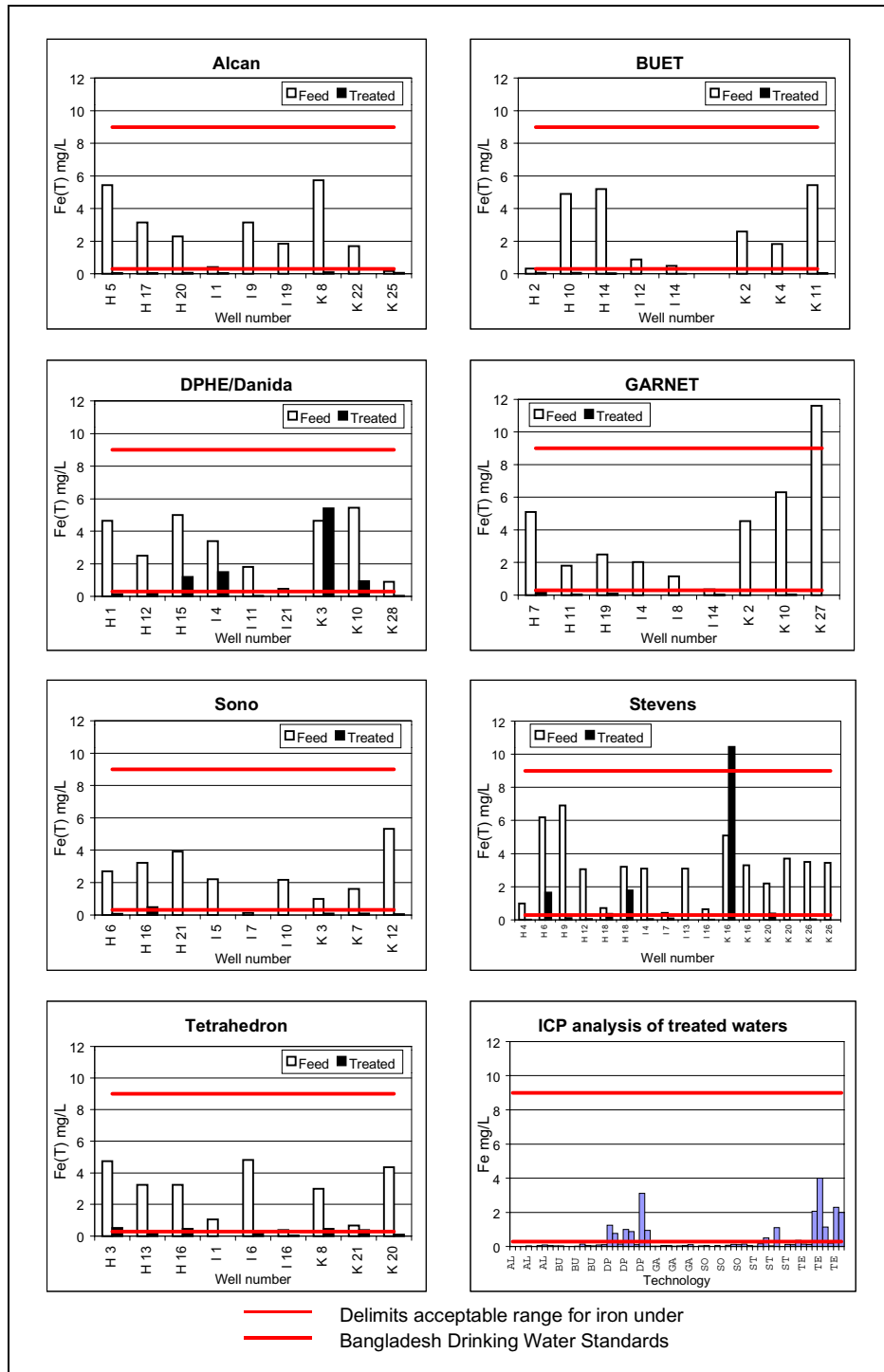


Figure 3.9 - Total iron concentrations in feed and treated waters

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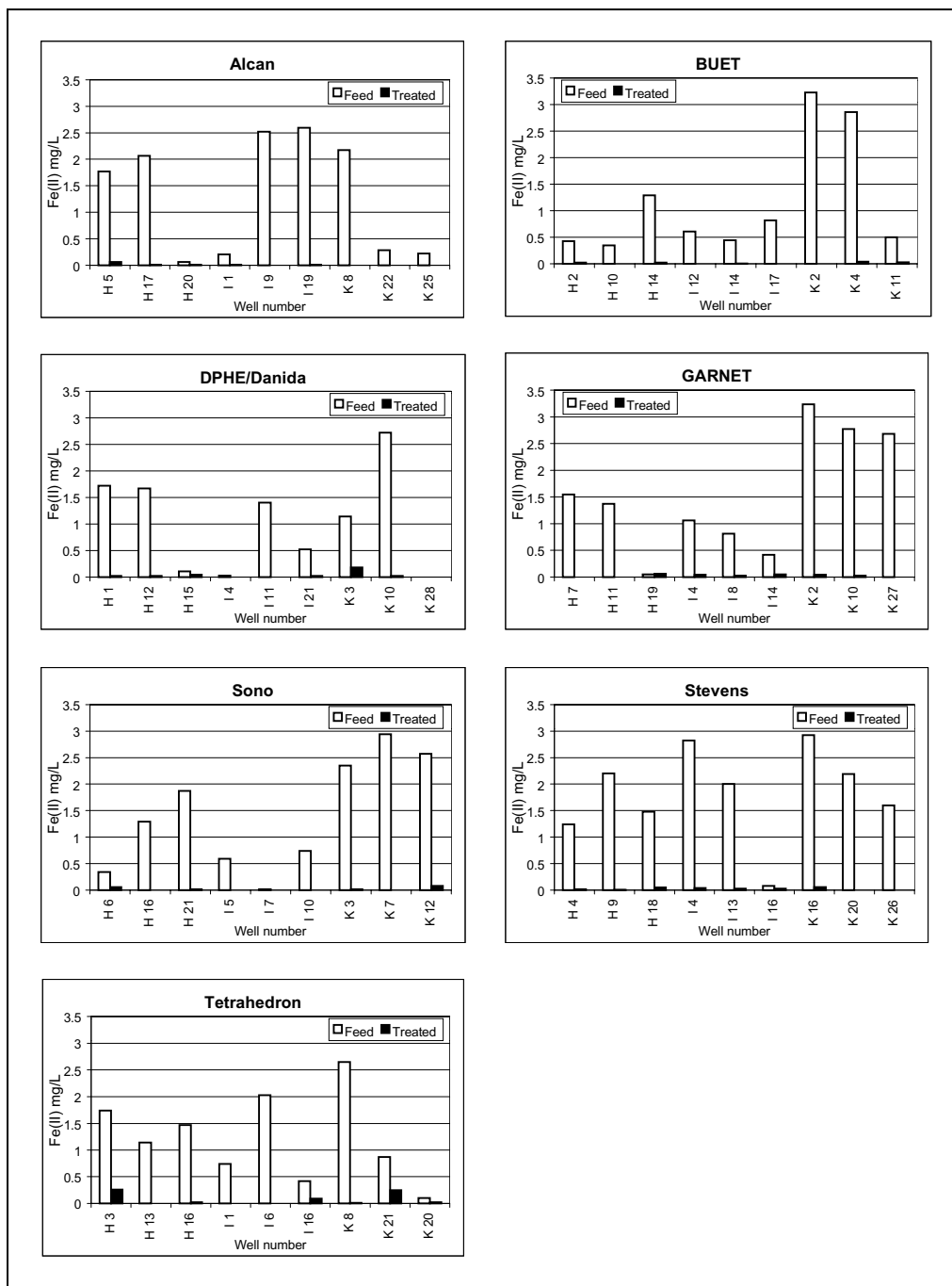


Figure 3.10 - Iron (II) concentrations in feed and treated waters

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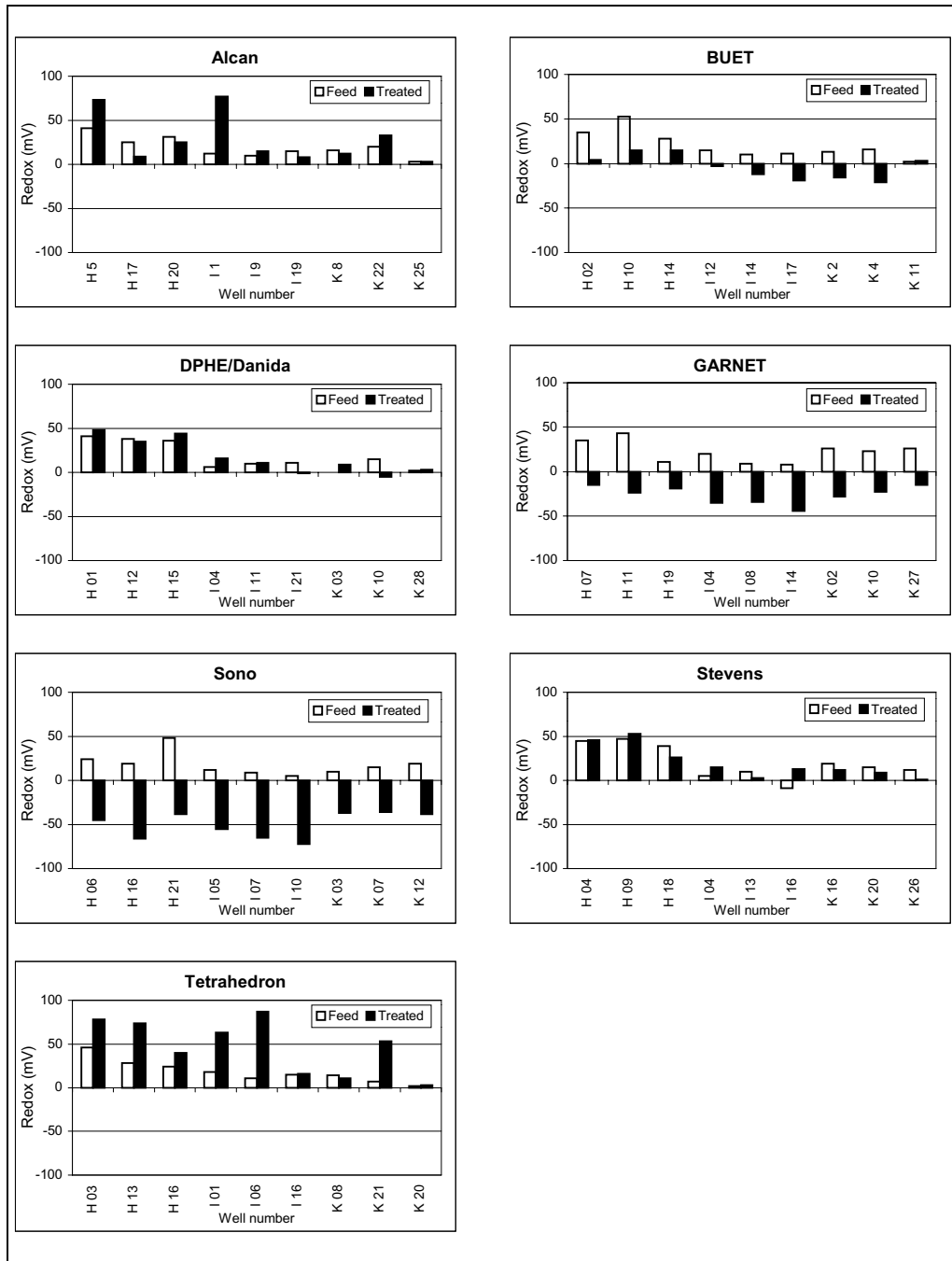


Figure 3.11 - Redox in feed and treated waters

### Manganese

3.26 Oxidation of the reduced form of manganese, Mn(II), is a much slower process than that of ferrous iron and it is evident from Figure 3.12 that three of the technologies, DPHE/Danida, Stevens and Tetrahedron do not significantly reduce manganese concentrations. This is somewhat surprising for the DPHE/Danida which utilises a strong oxidant to speed the process of metal oxidation. The removal achieved by both the Sono and GARNET technologies may be partly due to the increase in alkalinity caused by their component brick chips.

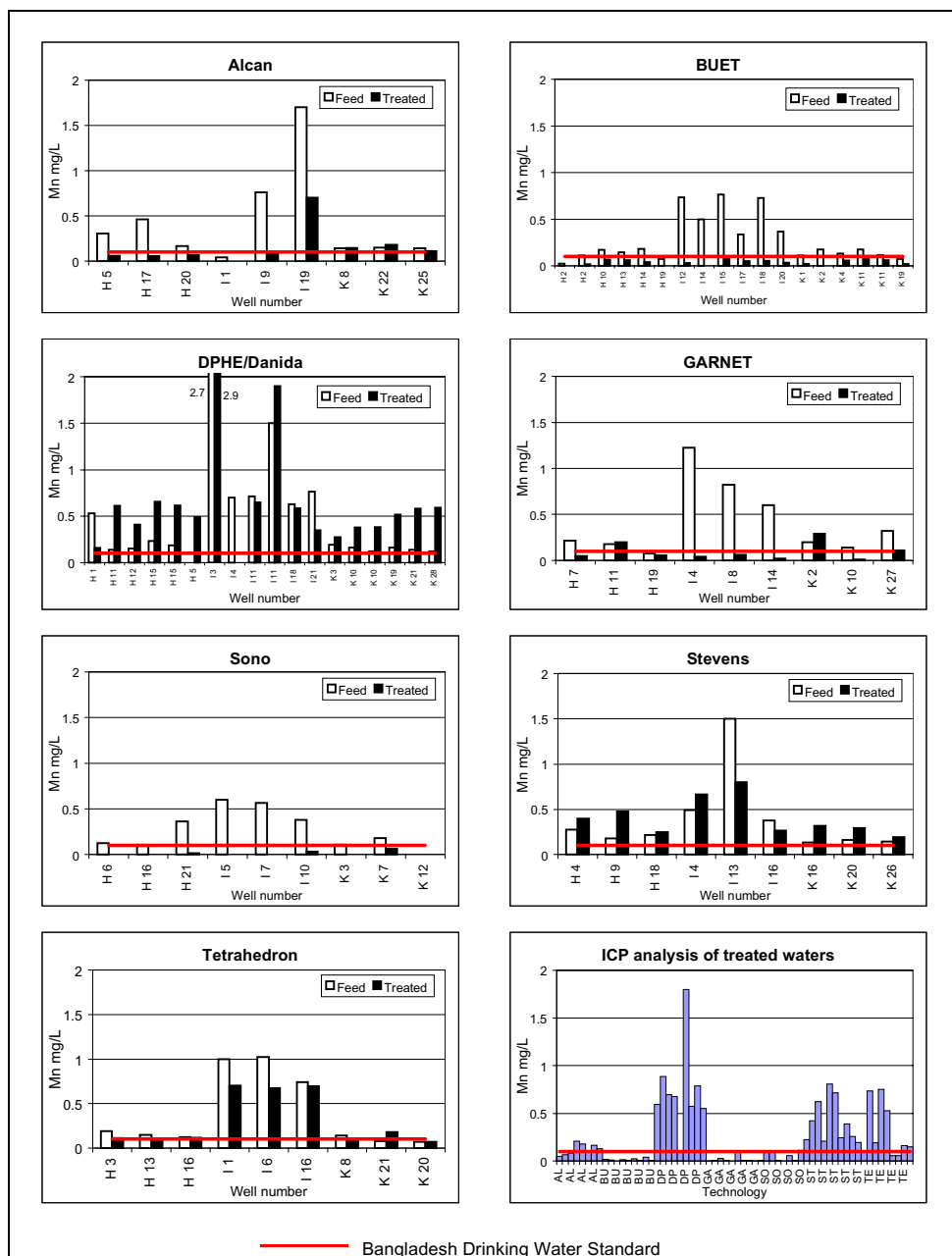


Figure 3.12 - Manganese concentrations in feed and treated waters



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Aluminium

3.27 Alcan, GARNET, Sono and Tetrahedron technologies appear to consistently remove aluminium from feed waters (Figure 3.13). BUET and Stevens technologies also remove aluminium in Hajiganj and Iswardi but appear to add it in Kalaroa in some cases. The reason for this is not clear. Both the Hach and ICP data indicate that the DPHE/Danida technology adds aluminium to the water although the ICP data suggest that treated water concentrations are much greater than those indicated by Hach testing and that they are frequently in exceedence of the Bangladesh drinking water standard of 0.2mg/L. The source of the aluminium is the coagulant used in the arsenic removal process.

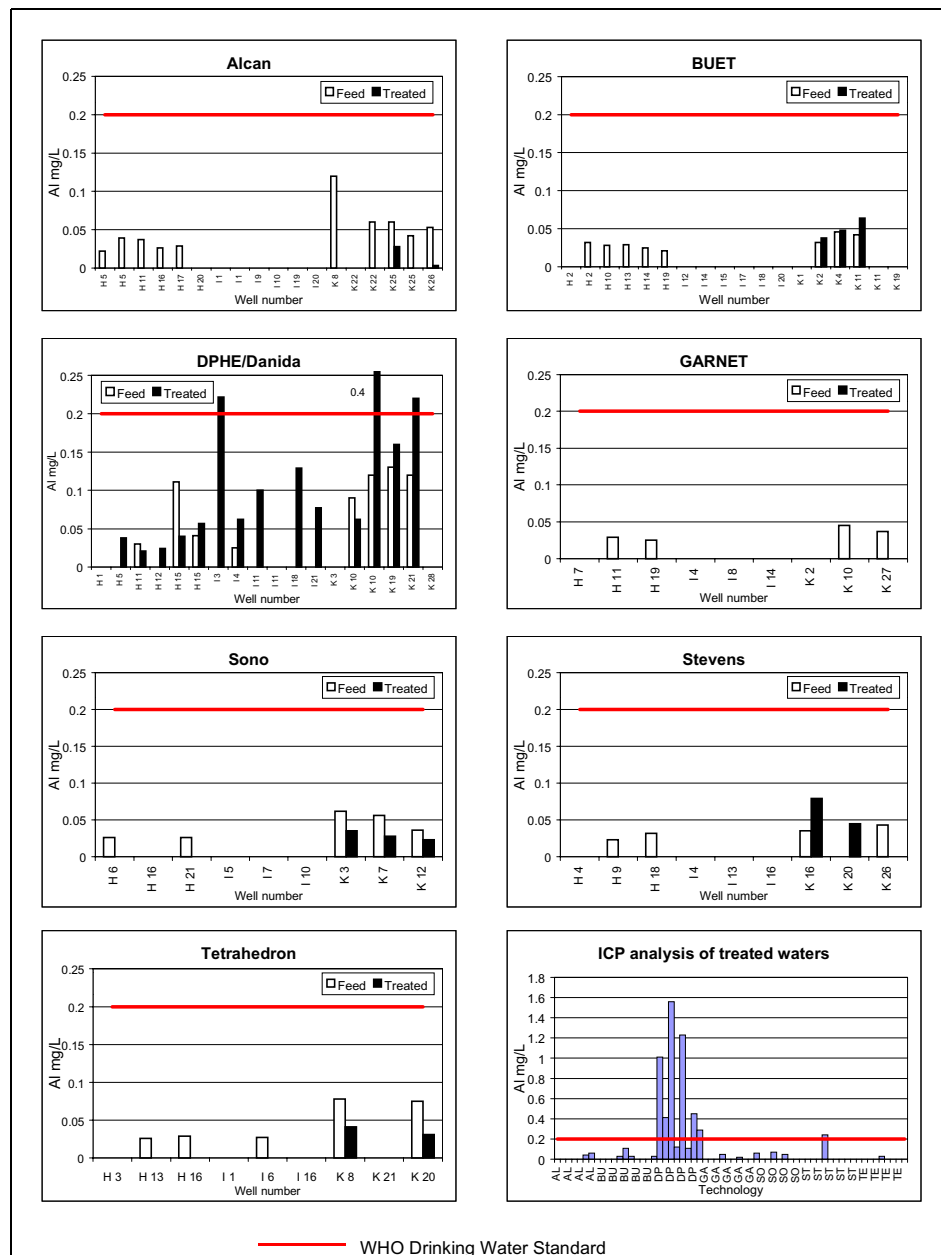


Figure 3.13 - Aluminium concentrations in feed and treated waters

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**Chloride**

3.28 Chloride concentrations are not affected dramatically by any of the technologies, although Tetrahedron does appear to introduce some chloride ions into solutions, which also accounts for the increased conductivity for Tetrahedron treated waters.

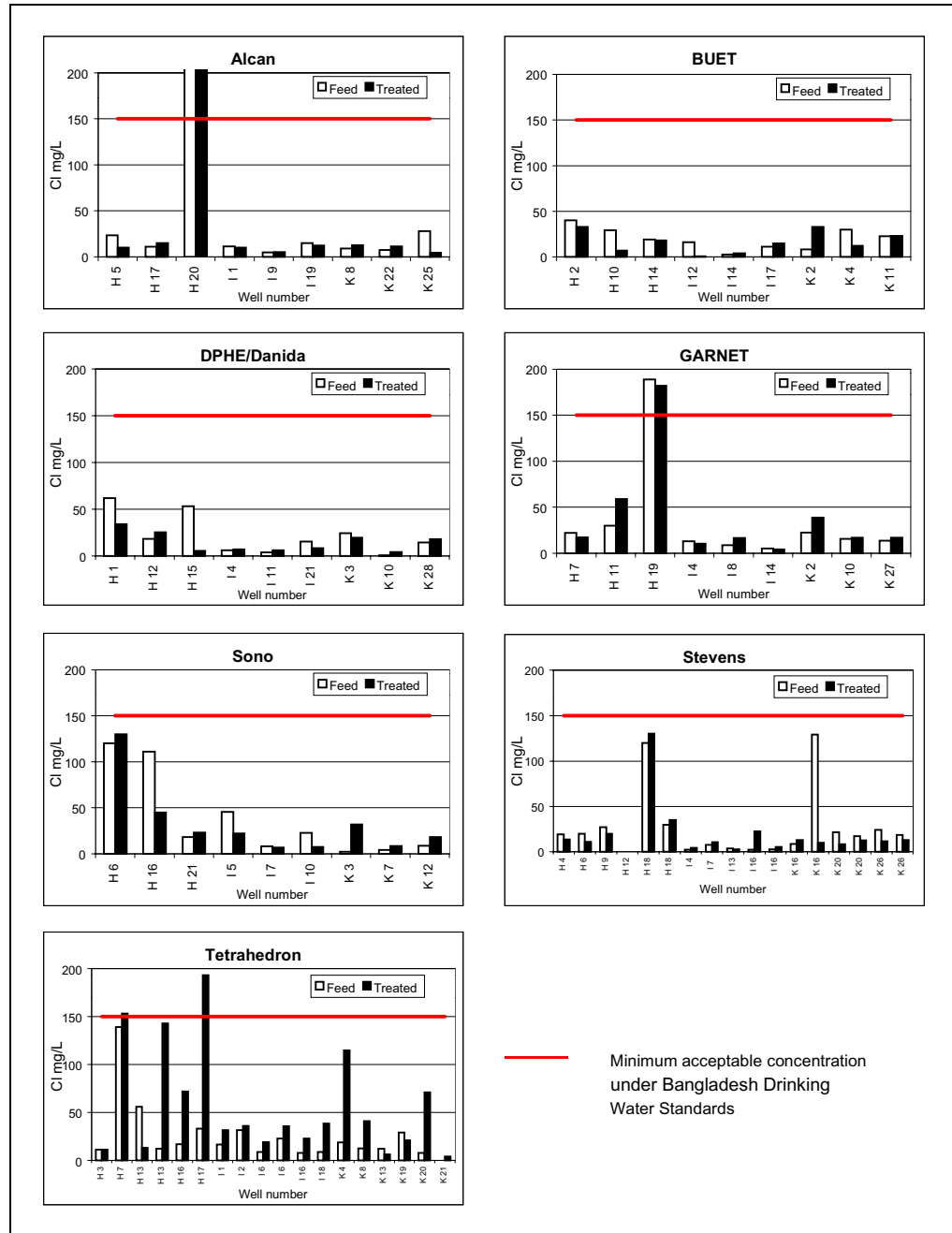


Figure 3.14 - Chloride concentrations in feed and treated waters

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Phosphate

3.29 Phosphate concentrations appear to be only consistently reduced by Alcan and Sono 3-kolshi technologies. Despite phosphate’s affinity for ion exchange in the Tetrahedron technology there appears to be little change in concentration between feed and treated waters for this technology.

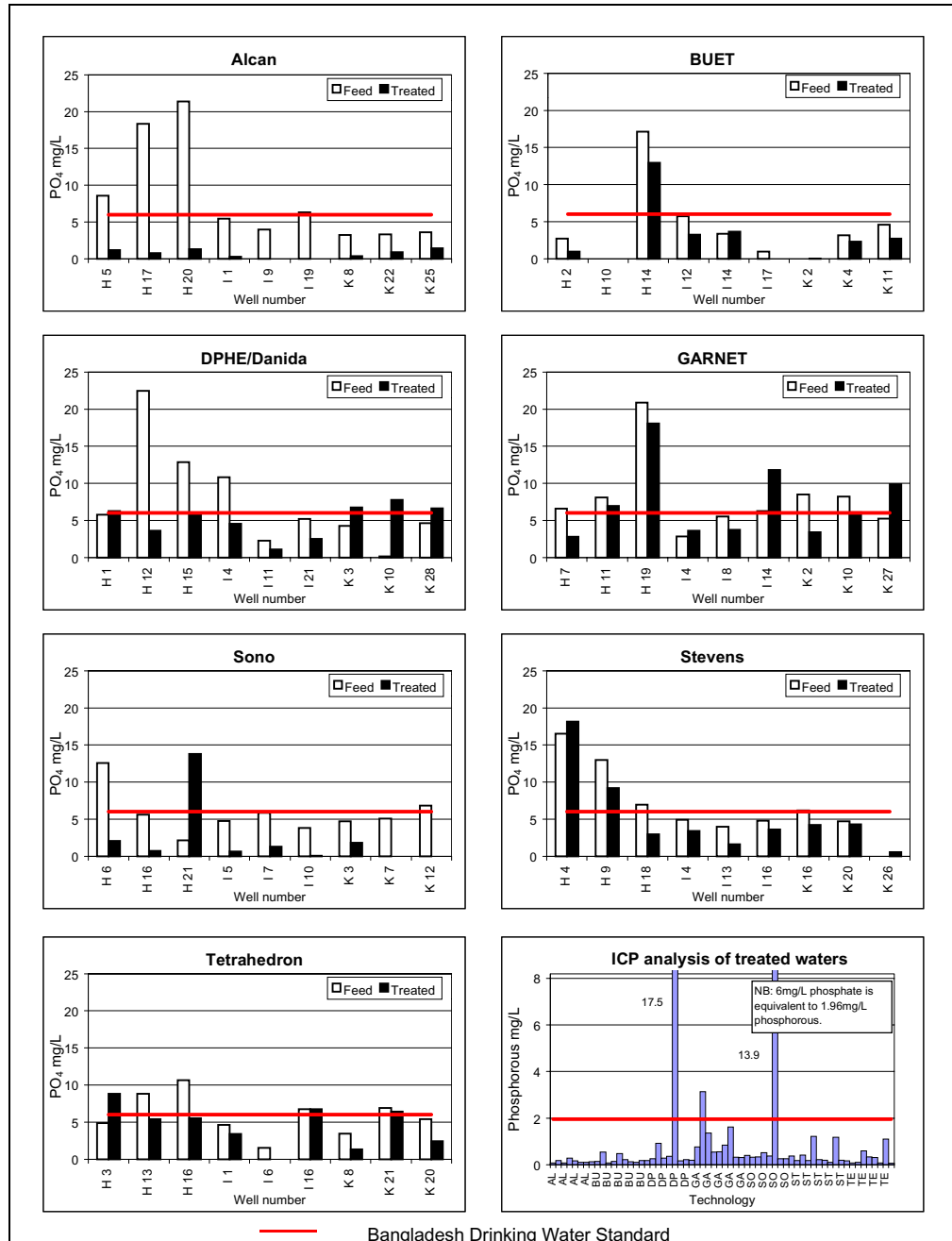


Figure 3.15 - Phosphate concentrations in feed and treated waters

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Sulphate

3.30 Sulphate concentrations show a general increase in most of the technologies (Figure 3.16) and a pronounced increase where sulphate coagulants are added to the waters (DPHE/Danida and Stevens). Raised concentrations for other technologies are not as easily explained; with Alcan the increased levels imply that sulphate may be coming from the enhanced activated alumina filter material.

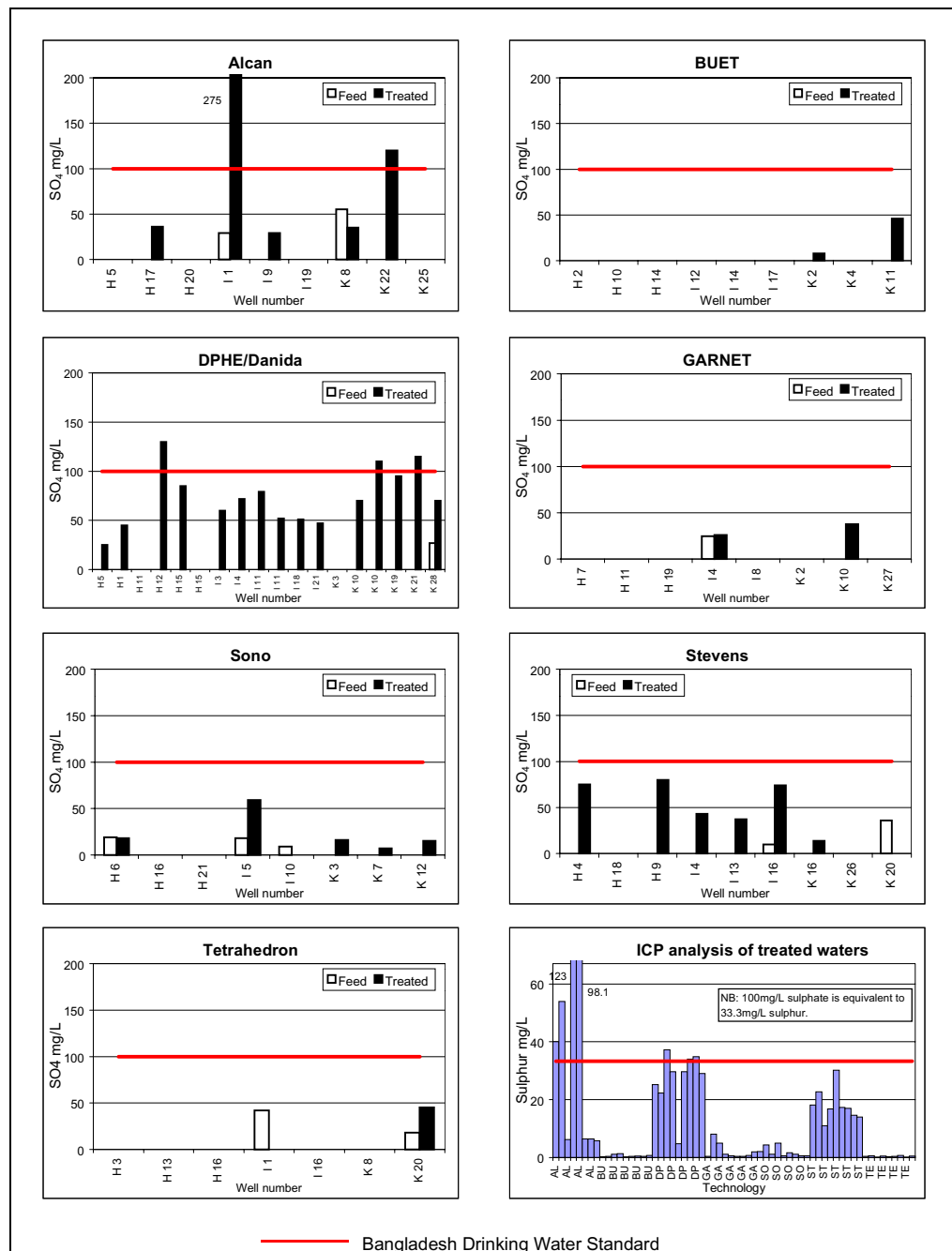
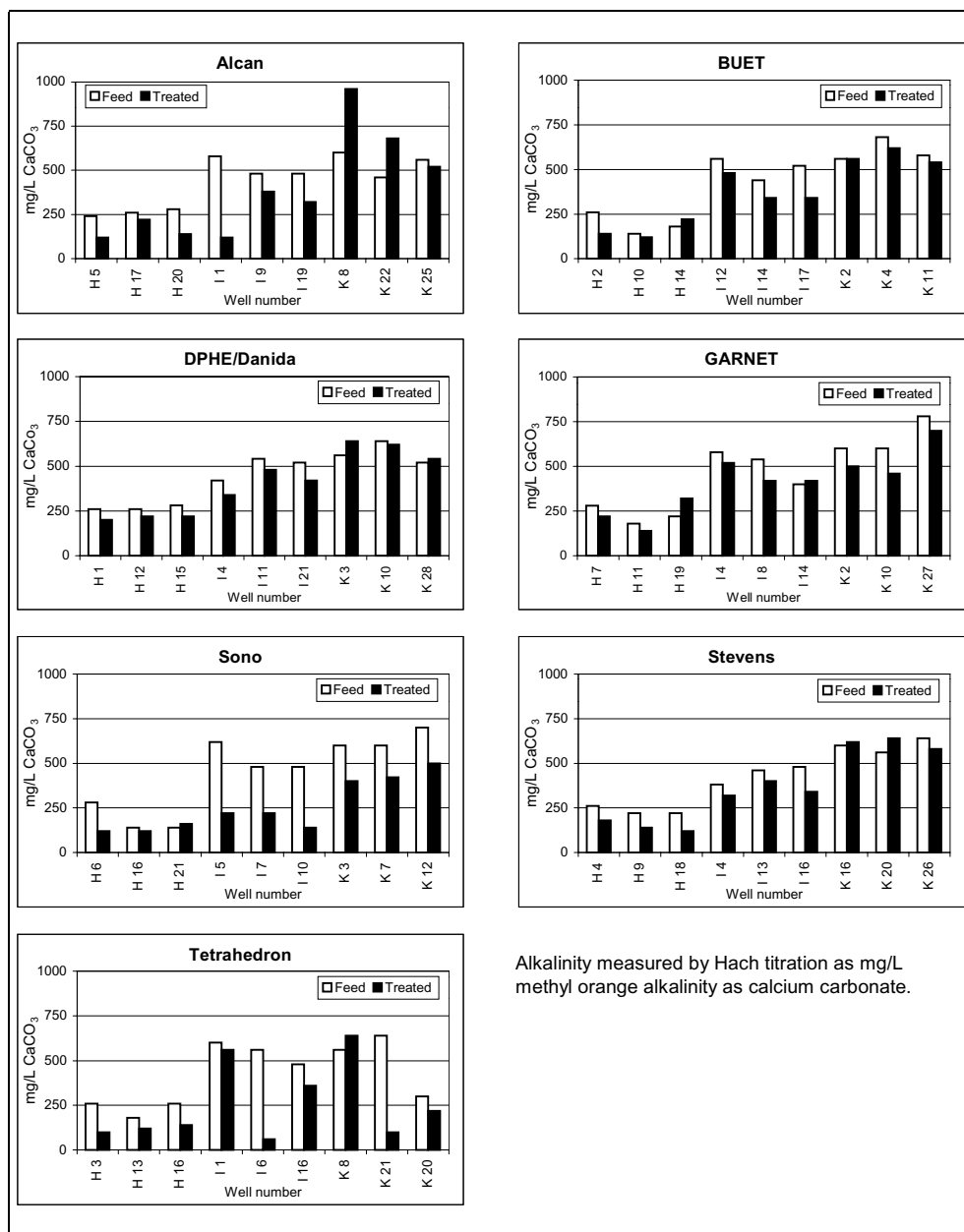


Figure 3.16 - Sulphate concentrations in feed and treated waters

**Alkalinity**

3.31 The pH of well waters rises and the alkalinity decreases when they are pumped to the surface. The water undergoes decarbonation and this has an impact on the  $H_2O + CO_2$  equilibrium. Most of the technologies appear also to reduce the alkalinity of the waters by the introduction of  $H^+$  ions, through either surface chemical action (activated alumina and resin) or through hydrolysis of coagulants (iron or aluminium sulphate). The mechanism for the significant reduction in alkalinity of waters from the Sono technology is not clear particularly in light of the increase in pH (see Section 3.32).

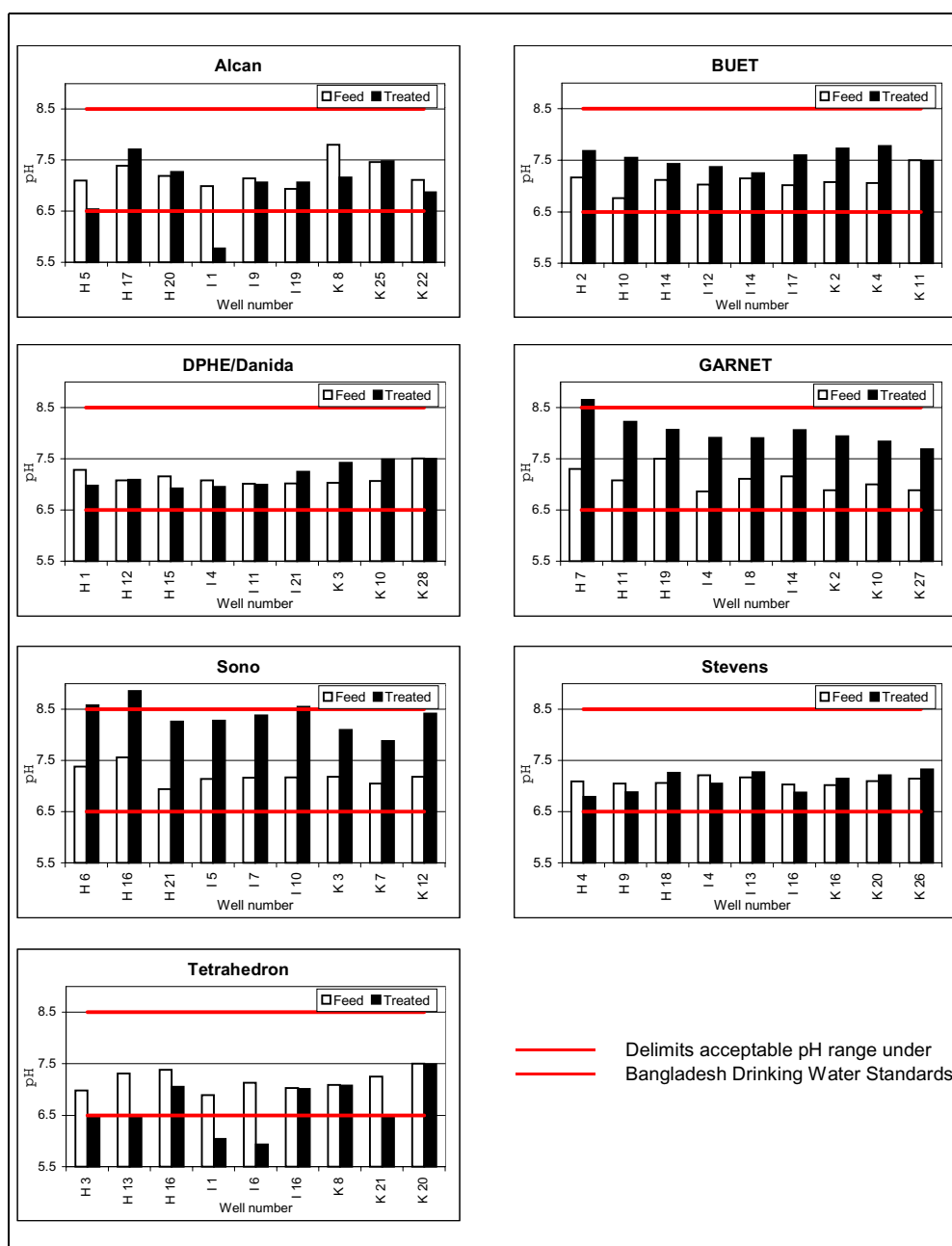


Alkalinity measured by Hach titration as mg/L methyl orange alkalinity as calcium carbonate.

**Figure 3.17 - Alkalinity in feed and treated waters**

**pH**

3.32 The pH changes between the feed and treated waters give an indication of the chemical processes taking place when using the different technologies. The addition of coagulants reduces the pH marginally due to hydrolysis reactions (Figure 3.18). The pH of waters passing through GARNET and BUET tends to increase and this relates to the nature of the brick and alumina respectively. The significant increase in pH of the water passing through the Sono is likely to relate to the interaction of water with metallic iron in the first kolshi.



**Figure 3.18 - pH in feed and treated waters**

### Conductivity

3.33 With the exception of the Sono 3-kolshi (decrease) and the Tetrahedron (increase), there were no significant changes in the conductivity of the treated waters compared to the feed waters. The increase in conductivity in the treated waters from the Tetrahedron may be attributed to the addition of chloride and sodium ions from the bleaching tablet used in the process. The Sono 3-kolshi appears to remove calcium and magnesium ions, reducing conductivity of the waters.

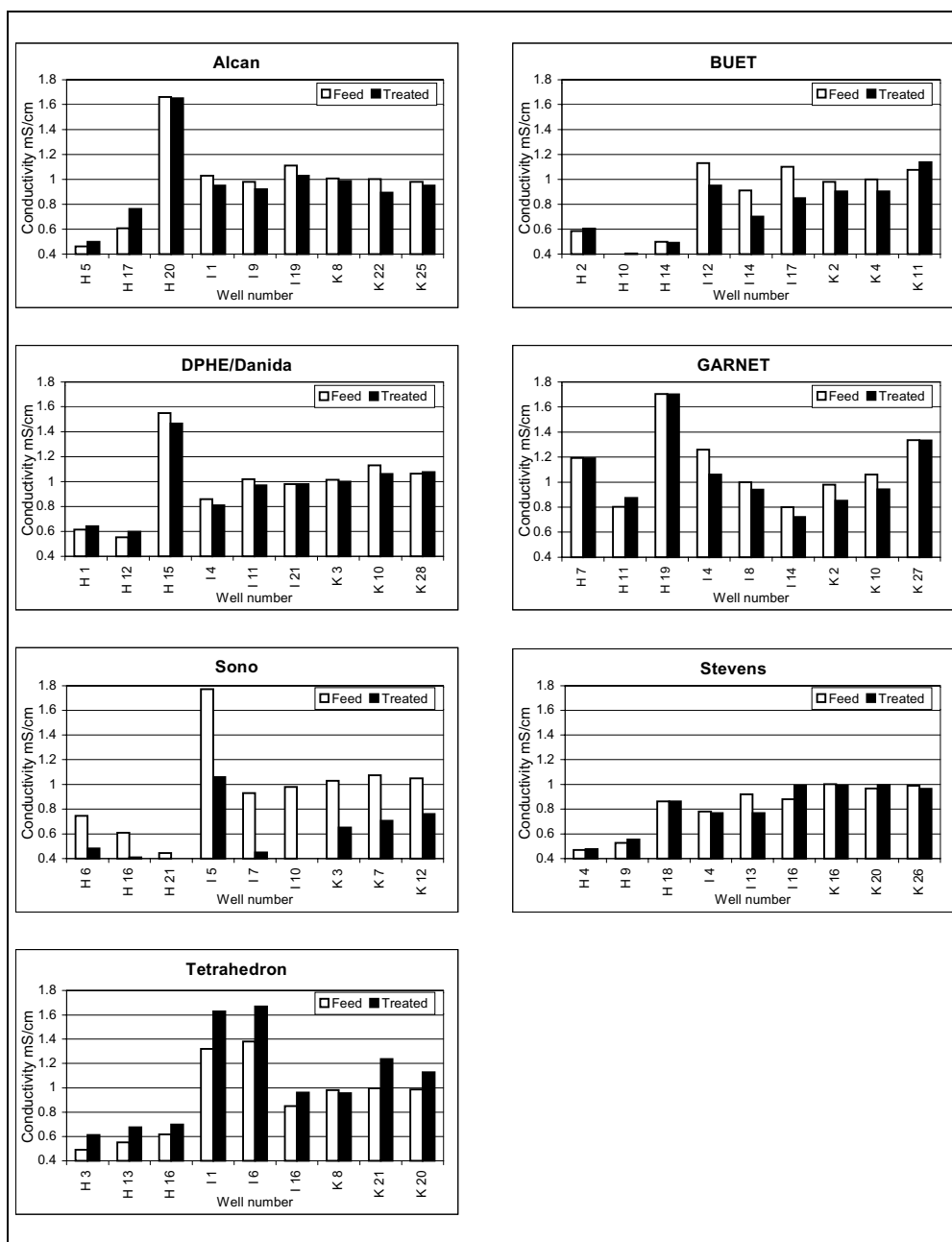


Figure 3.19 - Conductivity of feed and treated waters

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## Other Elements

- 3.34 ICP data for treated waters identify some further trends (Figure 3.20). Water from the BUET technology has elevated copper and zinc concentrations which may arise from impurities in the provided chemical coagulant/oxidant. Elevated zinc concentrations arising from the Tetrahedron potentially originate in the resin column.
- 3.35 The Sono 3-kolshi waters have reduced concentrations of magnesium, calcium, strontium and barium but elevated levels of potassium compared to feed waters. The Alcan, and to some extent BUET, also appear to remove calcium, strontium and barium. Alcan, BUET and Sono also remove silicon from solution. Boron concentrations are raised in waters treated by Tetrahedron.

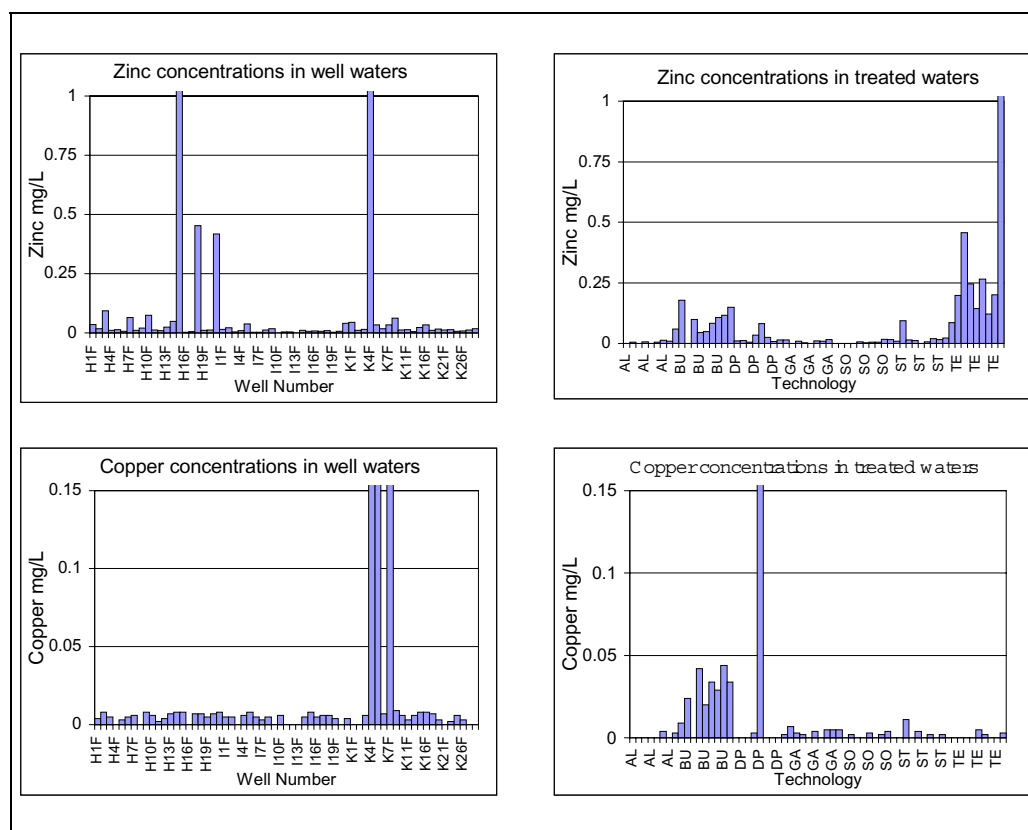
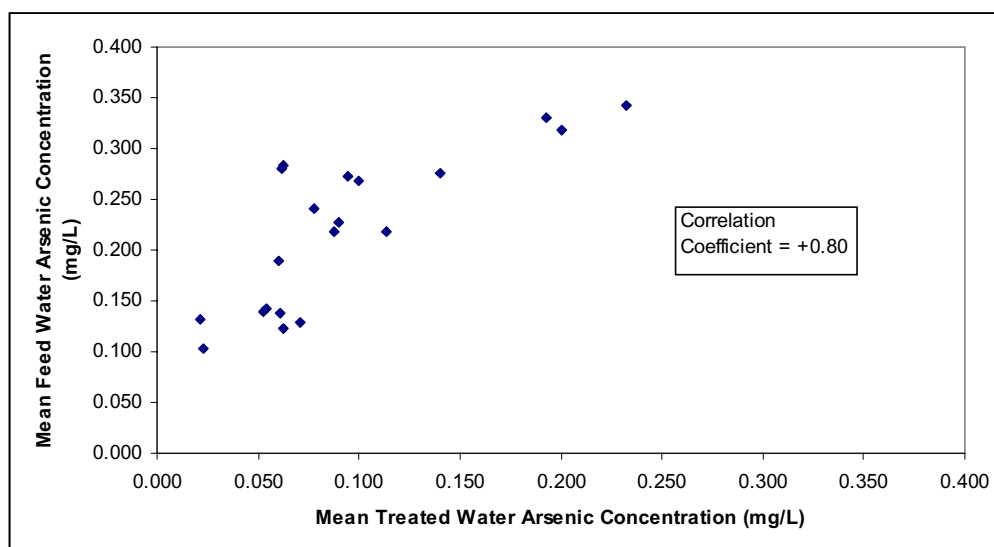


Figure 3.20 - Copper and Zinc concentrations in feed and treated waters (ICP analysis)



## INFLUENCES ON ARSENIC REMOVAL BY TECHNOLOGIES

- 3.36 The influence of both arsenic and non-arsenic water quality on arsenic removal has been assessed by inspection of the Hach, ICP and PeCo 75 data. For each technology, a correlation coefficient has been evaluated for the following variables: -
- Mean feed water arsenic concentration and mean treated water arsenic concentration at a well;
  - feed water parameter concentration and technology arsenic concentration reduction;.
  - feed water parameter concentration and technology percentage arsenic removal.
- 3.37 A table of the correlation coefficients is provided in Appendix 4. For six of the seven technologies, the strongest correlation is between mean feed water arsenic concentration and arsenic concentration reduction i.e. the higher the concentration of arsenic in the feed water the greater the arsenic concentration reduction for these technologies. This correlation is strongest for Alcan, BUET, Sono, Stevens and Tetrahedron technologies (with correlation coefficients of 1.00, 1.00, 100, 0.98, 0.99 respectively). GARNET has a weaker correlation at 0.76.
- 3.38 The strongest influence on the performance of the DPHE/Danida technology appears to be feed water arsenic concentration (the correlation coefficient between mean feed water arsenic concentration and mean treated water arsenic concentration is +0.80). This is illustrated in Figure 3.21. It is clear that the higher the feed arsenic concentration, the higher the treated water arsenic concentration. Arsenic concentrations are rarely reduced below 0.05mg/L when feed arsenic concentrations exceed approximately 0.120mg/L. For the DPHE/Danida technology, the correlation between feed concentration and arsenic concentration reduction is lower at +0.67.
- 3.39 This theory is supported by results from a study which NGO Forum undertook of 60 DPHE/Danida units in Putiajani. Approximately 80% of the units reduced arsenic to below 0.03mg/L. The arsenic feed concentrations were in the region of 70mg/L to 140mg/L. Those that did not reduce arsenic to below 0.05mg/L had feed concentrations in excess of 0.12mg/L.

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**Figure 3.21 - Relationship between mean feed water and mean treated water arsenic concentrations for the DPHE/Danida technology**

- 3.40 There is no strong evidence of other water chemistry parameters affecting arsenic removal. However, correlations between all parameters can be inspected in Appendix 4.

## BACTERIOLOGICAL PERFORMANCE

### Feed Waters

- 3.41 Bacteriological quality of feed water, direct from the wells was, as expected, good in all areas (Figure 3.22). Counts obtained for total coliforms were low, generally less than 30 total coliforms per 100mL and faecal coliforms were rare in most samples. Occasional wells contained up to 10 faecal coliforms per 100mL. These higher results almost always corresponded to wells with no concrete apron and/or located immediately adjacent to a toilet. Only one well was found to have higher levels of faecal coliforms (HA-15), but subsequent results suggested that this was an atypical result, caused by abnormal contamination. In general, bacterial levels in the well feed-waters were marginally higher in Kalaroa, although the reason for this is unclear.
- 3.42 In untreated waters it must be stressed that only faecal coliforms are of direct relevance in the consideration of health risks. Other members of the coliform group may occur naturally in water and do not necessarily indicate faecal contamination (*Cairncross & Feachem (1993) Environmental Health Engineering in the Tropics: an Introductory Text 2nd edition. London: John*

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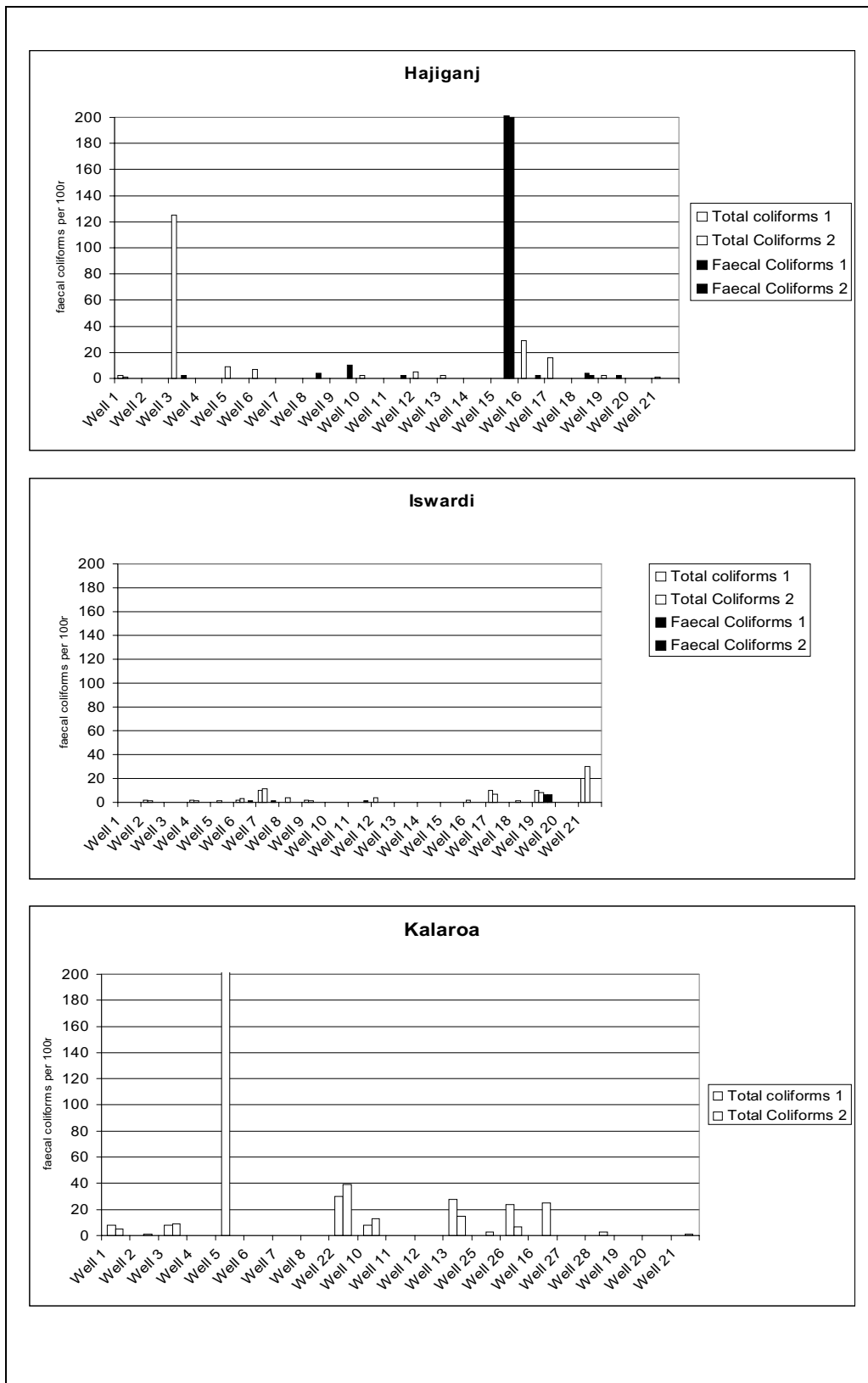


Figure 3.22 - Bacteria concentrations in feed waters sampled directly from selected wells between 28<sup>th</sup> and 31<sup>st</sup> January 2001.

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- 3.43 *Wiley & Sons*). Total coliform counts, however, give an initial indication of bacterial load and potential contamination for an initial assessment.
- 3.44 The bacterial levels found in the selected wells are within the low risk category of WHO guidelines for untreated rural water supplies (Table 3.1).

**Table 3.1 - WHO Guidelines for Untreated Rural Water Supplies**

Thermotolerant (faecal) Coliforms Count per 100ml	Risk Category
0	In conformity with WHO guidelines
1-10	Low risk
10-100	Intermediate risk
100-1000	High risk
>1000	Very high risk

from: World Health Organization *Guidelines for Drinking Water Quality Volume III*

- 3.45 Although well water does not represent the direct feed corresponding to the treated waters sampled subsequently, this assessment provides an initial assessment of baseline feed quality and would have allowed major problems with source water currently used for drinking to be identified. It suggests 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. A more detailed assessment of contamination source and direct feed quality was carried out where potential issues were identified.

**Faecal Contamination in Treated Waters**

- 3.46 Treated water samples from all replicates of all technologies were tested between one and three times over a 20 day period and the results, as number of faecal coliforms per 100ml, are shown in Figure 3.23. For each sample, duplicate counts based on 50 ml and 100ml volumes were done and the results are shown in Appendix 4.
- 3.47 With the exception of Tetrahedron and Stevens, faecal contamination at levels representing significant risk (>100 cells per 100 ml) occurred with at least two of the 9 technology replicates for all technologies tested. This highlights the increased opportunity for human or animal faecal contamination associated with operating any technology when compared with drinking water directly from a tubewell.

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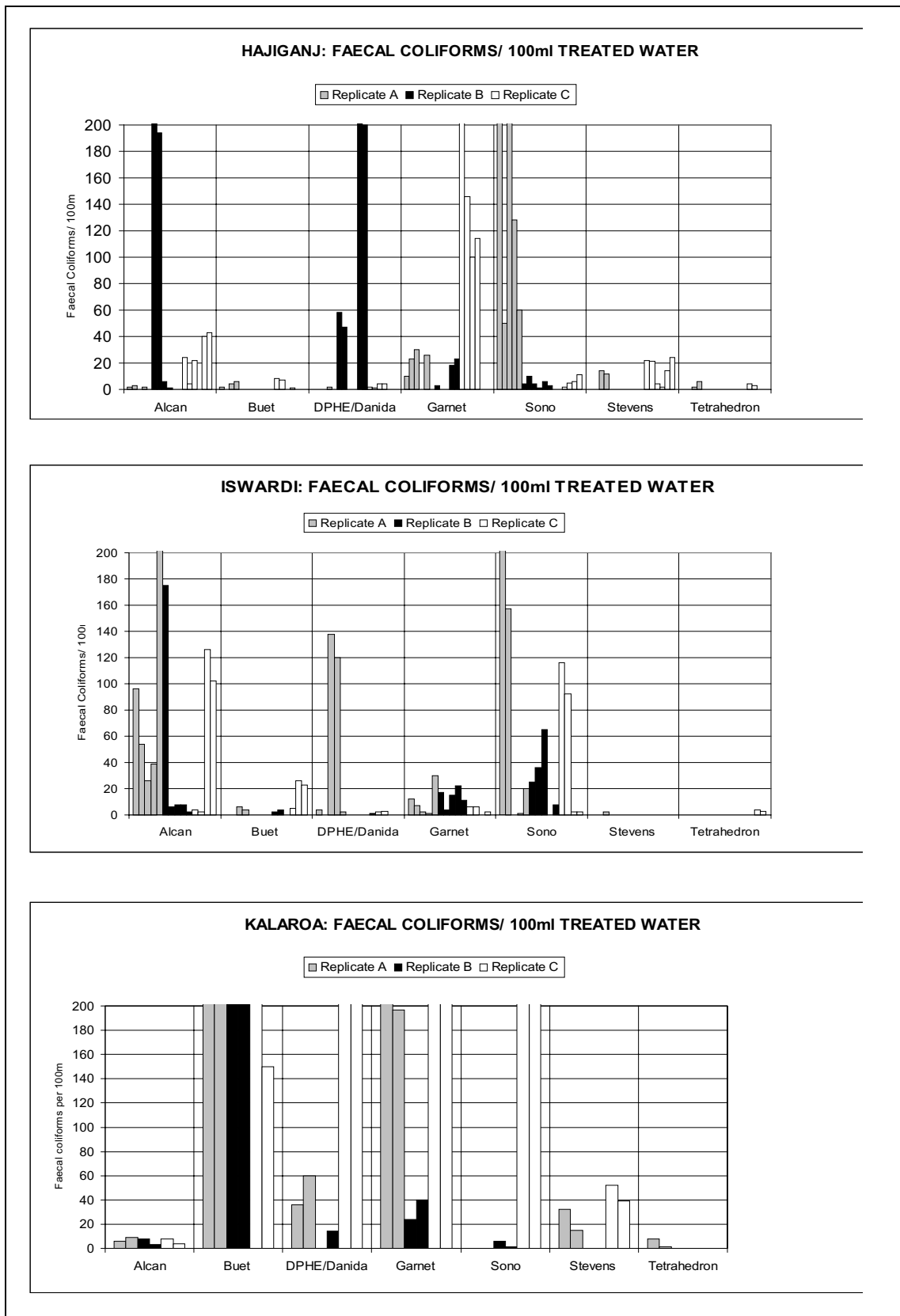


Figure 3.23 - Bacteriological quality of treated water from all replicates of all technologies between 2<sup>nd</sup> and 24<sup>th</sup> February 2001.

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- 3.48 The low counts obtained for Tetrahedron and Stevens can be explained by the chlorination step that these technologies involve. In the Stevens, ferric hypochlorite is added to the feed-water, while with Tetrahedron the feed-water is poured over a sodium hypochlorite tablet. This process must effectively retain sufficient residual chlorine in the treated water to kill bacteria present since counts were generally zero even when samples were taken from water that had been standing in a collecting bucket for some time. Residual chlorine concentrations were however below that detectable by the Del Agua kit (<0.1mg/l) and so the process cannot be guaranteed to eliminate all bacteria or pathogens.
- 3.49 On rare occasions when faecal contamination was found in samples from the Stevens technologies, this was associated with samples taken from a collecting bucket in which the delivery tube has been lying. It is most likely that contamination comes from this tube, which is long and easily contaminated by trailing on the ground, particularly during the daily sand washing process.
- 3.50 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.
- 3.51 The results for Alcan, in particular, and Sono are largely in line with the findings of BRAC (BRAC, 2000), where they found contamination in these technologies. 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.
- 3.52 In the case of the Alcan, the cause of contamination was readily observable. In most cases, Alcan units were set up under the wells so that water could be pumped directly into the technology. The Alcan thus provided a useful flat surface, and on various occasions villagers were found washing or doing laundry on top of them. The units are not sealed and this must account for bacterial contamination, since no feed vessel is used and no collecting bucket is required. In addition, the plugs used to close the filter and divert water down the chute, when non-treated water is required are not watertight and it is possible that faecal pollution may also occur in this way. These issues are relatively straightforward to resolve and newer Alcans are reported to have a top cover with a flange, which should reduce contamination from this source. Basic education would also be predicted to be effective, since pointing out the problem to villagers proved effective in this assessment.

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- 3.53 The source and manner of contamination for the other technologies was less obvious and observations of the basic sanitary conditions suggest that contamination routes and processes are likely to vary from house to house and between areas. Many technologies were sited outside, in yards, together with various animals and within the reach of children. Awareness of basic hygiene issues and measures that would help to avoid faecal contamination was found to be extremely limited. It was not unusual to observe women involved with hand-shaping dung into fuel bricks, fill technologies without washing their hands first. Most of these technologies have tubes or nozzles that can be removed or fall off and become easily contaminated. For many technologies, there is a need for a feed-water vessel, a collecting bucket and in some cases a stirrer, all of which can potentially harbour bacteria.
- 3.54 In general, bacteriological samples were taken directly as the water drained from the technology, suggesting that the collecting bucket is not the primary source. Evidence suggested, however, that samples taken from the collecting buckets (when a direct sample was not possible) contained higher levels of bacteria, particularly if the bucket had been standing around, uncovered, for some time. This was particularly true for the GARNET and Sono, since with the BUET and DPHE/Danida, villagers were generally found to leave the water in the top bucket of the technology until required.
- 3.55 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, since bleaching normally eliminates bacterial contamination relatively successfully. This accounts for much of the variation in results that can be seen between samples in Figure 3.23 and it was not possible to assess the development of contamination over the 30 day field work period.
- 3.56 Repeat sampling did suggest that once contaminated, the sand filters harbour bacteria and are not readily flushed by further clean batches of water. It is likely that if technologies had been left without bleaching bacterial levels would increase as further contaminated batches were fed through. 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. It is not possible to determine from these results whether the sand filters provide a breeding ground for bacteria and pathogens, and further work is clearly required on this issue.
- 3.57 While these results are likely to 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 the majority of these technologies. Although household

hygiene is clearly one of the main factors determining contamination levels, presentation of the faecal coliform results by household

- 3.58 Figure 3.24 also shows that poor bacteriological performance is not entirely an issue relating to a few households with poor hygiene or particular habits. The study suggests that contamination is relatively easy under the rural conditions in which the technologies are required. The impact of just basic instruction in hygiene was, however, noticeable in reducing faecal coliform counts over the course of this assessment and suggests that with proper training, acceptable performance may be achievable.
- 3.59 The level of faecal contamination that is acceptable for untreated 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/100mL will remain of concern in any classification. Unless performance can be significantly improved, some of the technologies may remain inappropriate as options. In any case it is clear that further work on the effectiveness of training is required and that there are important implications for proponents when considering levels of field support that they must provide.
- 3.60 A more detailed assessment of contamination source and the impact of bleaching was carried out on some replicates of each technology but was limited by time and testing equipment available. This is discussed below but was extremely limited and the above assessment points to the need for considerably more detailed surveys.

### **Contamination Sources and Persistence**

- 3.61 It must be stressed that these surveys were restricted to one or two replicates only and do not provide definitive answers. Key findings were as follows and merely provide further indications:
- 3.62 In all cases (Sono, Alcan, BUET, DPHE/Danida and GARNET) heavily contaminated treated water samples were obtained when low or zero faecal coliforms were present in the directly corresponding feed water.
- 3.63 In the case of Sono and BUET the bacterial contamination was found to be associated with the sand filter. It is not possible to isolate treated water for different stages in DPHE/Danida or GARNET but it seems likely that it is the sand filters that retain and potentially allow further breeding of bacteria.



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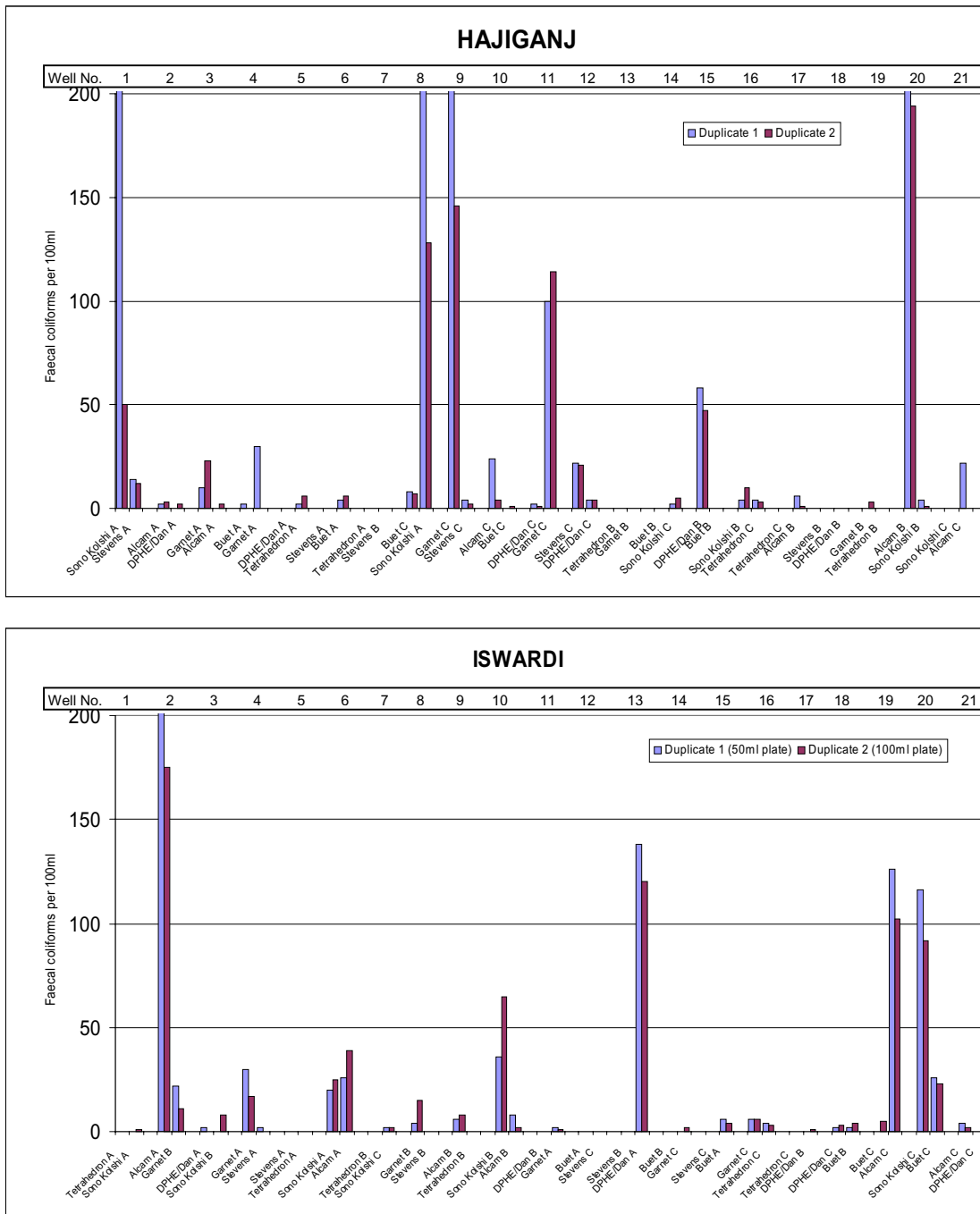


Figure 3.24 - Faecal Coliforms /100ml of Treated Water by Household for Hajiganj and Iswardi

3.64 In some cases contaminated feed water vessels may account for pollution of treated water but this is clearly not always the case. It seems likely that once a contaminated feed has been poured into the technology the sand filters harbour the bacteria and subsequent batches may be contaminated.

- 3.65 In the case of Alcan, further flushing with one complete volume of clean feed water reduced the faecal coliform counts in the treated water by over 50 % suggesting that further use of non-contaminated feed would flush the technology relatively rapidly and that there is therefore little chance of pathogens multiplying within the Alcan. It is not clear whether the same applies for slower technologies with sand filters, in which there is perhaps more potential for longer periods of microbiological retention.
- 3.66 The other primary finding from these surveys is that passing a dilute bleaching solution (1 teaspoon bleaching powder in 20 litres of water) through the technologies is effective in eliminating or at least significantly reducing bacteria. It is important to consider that this process would not necessarily kill all potential pathogens. Bleaching was found to be required around once a week. This is in fact stated as a requirement in recent instructions for the operation of GARNET, but it is clear that in practice this is often not carried out. All technologies were however bleached at the beginning of each new session, with the exception of Sono-3-Kolshis, which were provided new at the start of the assessment and were therefore not bleached until the second session after high counts had been obtained. Activated Alumina components were also not bleached although in Hajiganj this did prove effective in reducing counts from one Alcan and did not appear to affect arsenic removal.

### **Other Bacteria**

- 3.67 The Del Agua kit allows some non-coliform organisms to grow and it was anticipated that this together with total coliform counts would allow an evaluation of the potential introduction of non-human bacteria from biofilms that develop in the technologies. In practice, however the growth of large numbers of coliforms suppresses the growth of other bacteria and it is impossible to draw firm conclusions regarding other organisms. The numbers of total coliforms and other bacteria were high in treated water, often uncountable for 50 and 100mL sample plates. Not all of these were faecal coliforms and since levels in feed waters were generally very low it does seem 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 just result from natural growth during the increased time the time involved in processing the water.

### **BREAK THROUGH**

- 3.68 Only four processes can be realistically used for arsenic removal from drinking water: co-precipitation, adsorptive filtration, ion exchange and membrane processes. The high concentration of iron in waters is a potential interference to many of these techniques which rely mostly on the surface characteristics of the filter media (resin, activated alumina, metallic iron and

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brick chips). The highly ion specific coatings can clog and become coated, reducing treatment rates and causing a slow progressive reduction in the efficiency of the process. The filter material and media must therefore be regularly changed or cleaned, hence the continual need to monitor feed rate for “breakthrough”. Breakthrough is the point after which the performance starts to deteriorate significantly due to clogging or other mechanisms and is dependent on individual water chemistry. Coagulation-coprecipitation based technologies, such as Stevens, are not influenced by these factors and should be able to treat a whole range of water qualities and meet Bangladesh drinking water standards.

- 3.69 The arsenic concentrations in the feed and treated waters for each of the technologies at the start of the break through testing period (5<sup>th</sup> February 2001) are shown in Table 3.2.

**Table 3.2 - Feed and Treated As Concentrations at the Start of Break Through Testing**

TEST	As CONCENTRATION (for technologies, mean of 3 replicates)
<b>Feed water (mean of three samples)</b>	<b>0.332mg/L</b>
Alcan Enhanced Activated Alumina	0.001mg/L
BUET Activated Alumina	0.001mg/L
DPHE/Danida 2BTU (*)	0.064mg/L
GARNET	0.046mg/L
Sono 3-kolshi	0.002mg/L
Steven’s Institute (*)	0.060mg/L
Tetrahedron	0.007mg/L

(\*) even though figures are in excess of 0.05mg/L, tests are continuing because the DPHE/Danida and Stevens Institute are removing significant levels of arsenic and break through will be when this level of removal no longer occurs.

- 3.70 None of the technologies achieved break through during the Phase II testing (see Figure 3.25). This was largely to be expected within a rapid assessment. If break through had been achieved, then it is likely the technology would not be a sustainable option. The volumes of water put through the technologies each day are close to the maximum possible in a 12 hour period, given the flow rates achieved for each technology (Table 3.3). 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.

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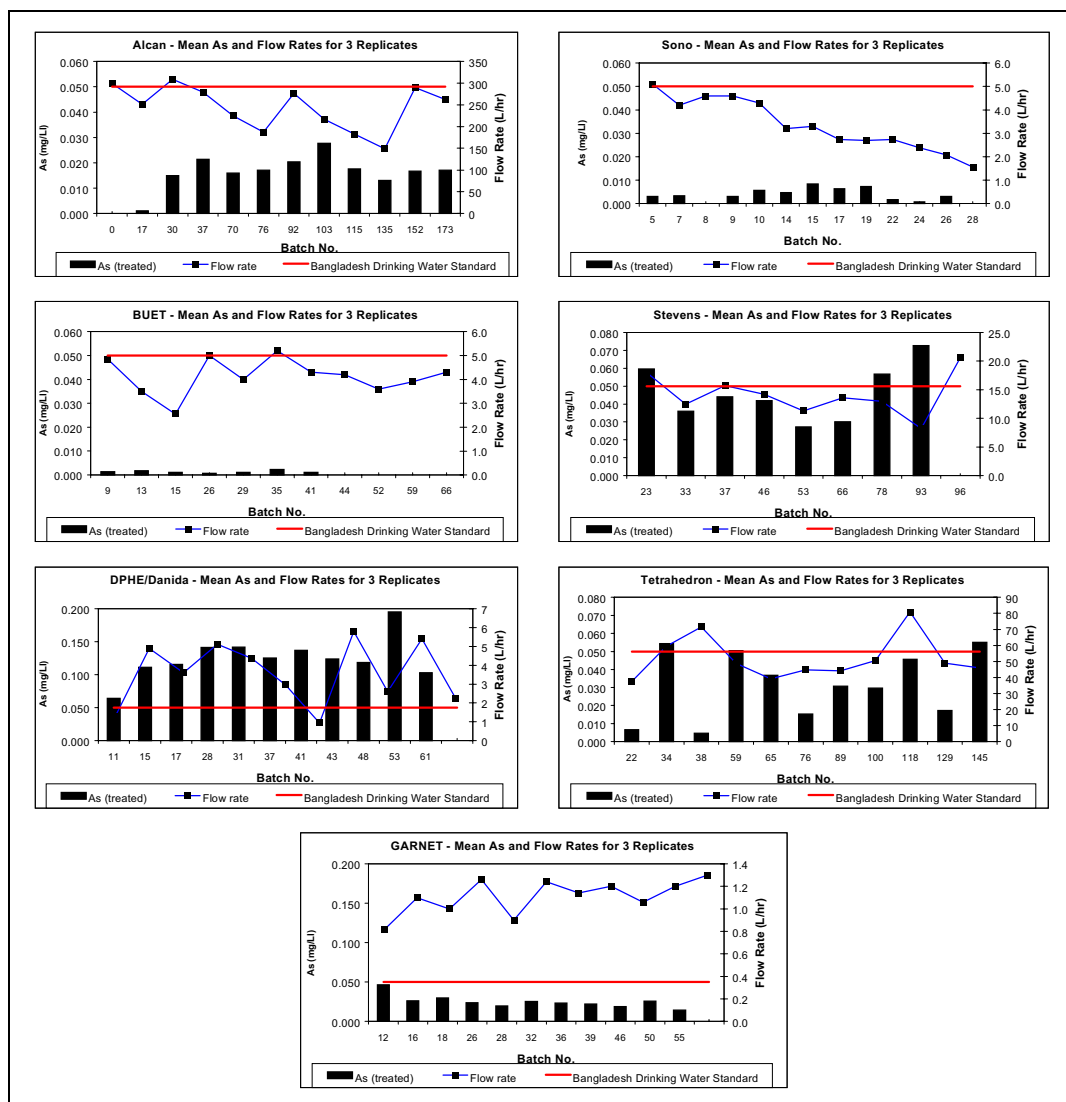


Figure 3.25 - Break Through Testing and Flow Rate Results

Table 3.3 - 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

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- 3.71 The break through testing will continue for at least another month and the results presented as an addendum to this report.
- 3.72 Flow rates for the technologies in the field differed from those presented in Phase I, tested under laboratory conditions, with the exception of BUET which stayed the same. The GARNET flow rate was quicker than in the laboratory and the other five were all slower than in the laboratory. The water at Sonargaon is turbid.
- 3.73 For the flow rates presented above, for Sonargaon, only the Alcan, Stevens and Tetrahedron would comfortably provide sufficient drinking water for a household (based on 5 litres/person/day). The BUET, DPHE/Danida and Sono are close to providing enough water for a household (average of 6.5 people per household) with one unit, whilst the GARNET would provide enough for approximately 1.5 litres/ householder /day. However, it should be noted that the flow rates quoted are a mean rate. The flow rates over time, as shown in Table 3.3, do vary considerably. The impact and importance of maintenance is illustrated by the increase in flow rates following maintenance. The Sono develops a ‘crust’ in the top kolshi and this just needs to be broken. This has been done since the last reading shown in Figure 3.25.
- 3.74 In none of the cases shown in Figure 3.25 does the change in flow rate appear to affect the ability of the technologies to remove arsenic.

**FIELD TEST KIT EVALUATION****Technical Performance**

- 3.75 The field test kit evaluation was carried out at Sonargaon, where feed water arsenic concentrations are approximately 0.33mg/L. Samples were also stabilised and brought back to the laboratory to see if acidification had any impact on field test kit performance.
- 3.76 The results of the comparative survey for technical performance indicate that there is considerable variation between each test kit. This variation is more evident when testing for lower concentrations of arsenic.
- 3.77 One of the field test kits, the PeCo75, uses a photometer to read the coloured stain on the filter paper, whilst the other three rely upon visual inspection of the filter paper and comparison with a pre-prepared scale, with darker colours representing increased arsenic concentration. The PeCo75 also has a coloured scale for visual reference as backup.

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3.78 The scales for field test kits which rely upon visual assessment are as follows:

- Merck kit: 0 0.1 0.5 1.0 1.7 3.0 mg/L
- Hach kit: 0 0.01 0.03 0.05 0.07 0.3 0.5 mg/L
- GPL: 0.03 0.05 0.07 0.1 0.2 0.3 0.5 mg/L

3.79 It is believed that the Merck kit and Hach kits are being improved in terms of the sensitivity (i.e. distribution of points on the scale). Merck are increasing sensitivity at the low range (below 0.1mg/L) and Hach are increasing the sensitivity between 0.07mg/L and 0.3mg/L

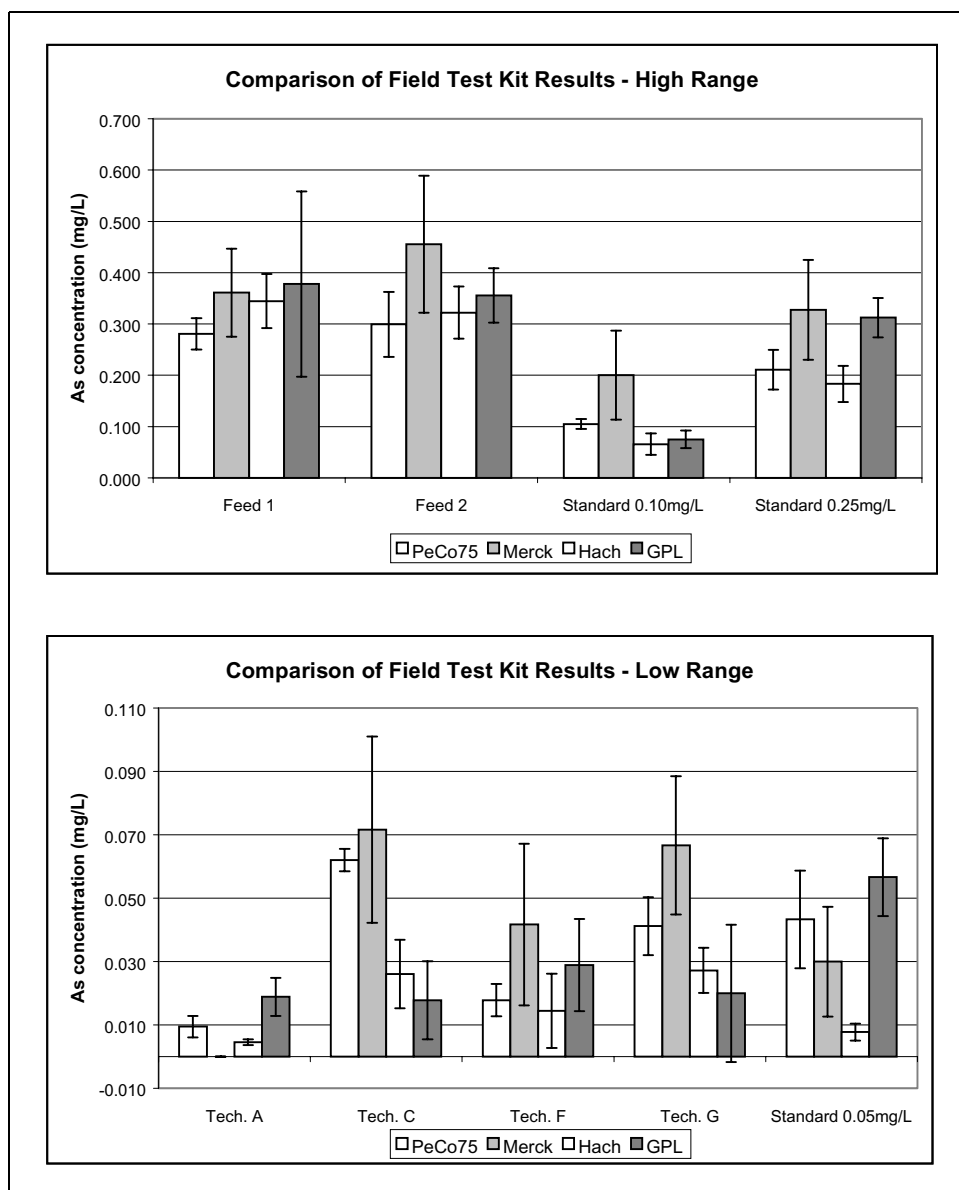


Figure 3.26 - Comparative Performance of Field Test Kits for High and Low Arsenic Concentrations

- 3.80 At high arsenic concentrations, the Merck tended to give slightly high results, whilst the other three kits were fairly similar. The Merck also had the largest standard deviation (see Figure 3.26) at the high range, indicating a wider variation in the colour of the filter paper and the reading of the results.
- 3.81 In the low range, Merck tended again to give slightly higher results than the other kits, except for samples below 0.01mg/L where it failed to detect arsenic. The Hach and the GPL tended to read slightly lower. The Merck and the GPL had the highest standard deviations, again illustrating the wider variation in the colour of the filter paper and in the interpretation of the results.
- 3.82 In both the high and low ranges, the PeCo75 had the smallest standard deviation, showing greater consistency in its results. Visual confirmation of the results for the PeCo75 suggest that the photometer reads well. It is the performance of the filters that causes any variation in results.

#### **Non-performance Related Comparisons**

- 3.83 In addition to the technical performance, the field test kits were also evaluated in terms of ease of operation, time for test, performance with acidified samples, cost and safety. The results of the evaluation are set out in Table 3.4 below. Strengths and weaknesses are presented for each, along with recommendations for improvement.

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Table 3.4 - Evaluation of Field Test Kits

Criteria	PeCo75	Merck	Hach	GPL
<b>Ease of operation</b>				
<b>- Procedure</b>	50 mL sample. Dilution if anticipated concentration >0.1mg/L. Addition of two reagents. Leave until reagents stopped fizzing. Place filter paper in photometer. Fairly straight forward.	5 mL sample (planned kit will double this). Place mercury (II) bromide strip in test-tube lid. Add zinc and 10 drops of HCl acid. Wait for 30 minutes. Remove strip and read against chart. Simple process. No dilution required below 3mg/L.	50 mL sample. Five stages with 5 different reagents. Several waiting periods (2 minutes, 3 minutes and 30-35 minutes). No dilution required below 0.5mg/L.	Approx. 15 mL sample (first line on test tube). Place mercury (II) bromide filter paper in filter. Add approx. 5mL HCl acid to test tube. Then three reagents – ten minutes between reagents 2 and 3. Ten minutes after final reagent. No dilution required below 0.5mg/L.
<b>- Time for test</b>	Approx. 20 minutes, including preparation of filter and cleaning of flask and filter.	40 minutes, including cleaning, preparation and reading.	About 50 minutes for testing, 1 hour including washing and preparation.	35 minutes for preparation, testing and cleaning.
<b>- Instructions</b>	In English, detailed and quite complex. Room for improvement.	Simple instructions in one paragraph in several European languages.	In English and Spanish. Clear diagrams for each stage.	In Bengali, clear but incomplete and no diagrams.
<b>Number of tests which can be carried out simultaneously</b>	Number only restricted by number of flasks and filters. Photometer then used to test each sample in quick succession. In practice, a maximum of six samples for one sampler.	Restricted by number of test tubes. In practice, six would be the maximum at any one time for surveyor.	Restricted by number of jars with rubber caps. Multiple stages means about 3 is the maximum any surveyor could do at any one time.	Restricted by number of test tubes (two per set but only one filter). Maximum possible at one time for a surveyor would be three because of the multiple stages.



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Criteria (cont)	PeCo75	Merck	Hach	GPL
<b>Safety</b>	Original reagents in tablet form in sealed containers. Reagents are toxic (one is sulphamic acid, the other sodium borohydride). Dust from disintegrating tablets could be a hazard. In Bangladesh, 1 mL of 1:1 nitric acid was needed with each sample in addition to reagents to counter high alkalinity concentrations. Safe with careful use.	HCl acid drops sometimes hard to get out of bottle. Shaking can cause sudden release. Mercury (II) bromide strip is toxic. Safety instructions given for use. No instructions for disposal.	Skin contact with three of five reagents should be avoided. No liquid acid. Sealable plastic pouch provided for used mercury (II) bromide strips. No safety instructions with kit for use or disposal of reagents.	Skin contact with all reagents should be avoided. HCl acid in a difficult to handle container and an imperfect plastic pipette to pour into narrow test tube – plenty of scope for spillage or acid on hands.
<b>Cost</b>	US\$770. Reagents US\$1.80 per test. Capital cost for photometer a one-off cost.	US\$70 for 100 tests (US\$0.70 per test). Needs replacing after every 100 tests.	US\$85 per kit (100 tests). Needs replacing every 100 tests. Unit cost = US\$0.85	US\$50 for 100 tests (US\$0.50 per test). Needs replacing after every 100 tests.
<b>Field to laboratory testing</b>	Able to measure arsenic in samples even when acidified and taken away from site.	Does not detect arsenic in water which has been acidified for storage and later analysis.	Does not detect arsenic in water which has been acidified for storage and later analysis.	Does not detect arsenic in water which has been acidified for storage and later analysis.
<b>Recommendations</b>	PeCo75 has tried to get away from using liquid acid. However, it seems that liquid acid improves performance. It must be ensured that the components of the plastic filter fit very tightly.	Colour scale needs more detail at lower range. This is being addressed. A spare test tube and top will double number of tests that can be done at any one time.	Extra bottles and rubber tops for larger number of simultaneous tests. Timer would be helpful as many stages timed – last stage 30-35 minute margin crucial. Safety instructions. Brush required for cleaning bottle to remove accumulated precipitates stuck to test bottle.	More robust container for acid. Use dropper rather than pipette. Instructions need more detail – particularly ensuring reagents are dissolved before next step. Improve quality of chemicals and the mercury (II) bromide discs. Some improvements seem to have been made already.

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<b>Criteria (cont)</b>	<b>PeCo75</b>	<b>Merck</b>	<b>Hach</b>	<b>GPL</b>
<b>Strengths</b>	Simple chemistry. Simple construction. Easy to use for non-experts. Objective answers given.	Simple. Cheap. High quality chemicals. Readily available. Proven test kit with results which have been accepted by scientific community.	Well presented instructions. High quality reagents. Manufacturer a recognised world leader in field test kits.	Low range testing covered in detail. Cheap. Locally produced. Spare parts readily available.
<b>Weaknesses</b>	Expensive at present. Costs should come down as production is increased. Kits, spare parts and consumables not readily available at present.	Low concentrations hard to measure. Longish test time at 30 minutes.	Time for testing. Number of stages. Long waits with narrow time margin for final stage. Colour range.	Fiddly and quite complex procedure. Need to be quite well qualified to use properly.

## 4. HOUSEHOLDER SURVEY RESULTS

- 4.1 In all there were 63 households were consulted in Kalaroa, Hajiganj and Iswardi upazilas (names of 63 household heads are provided in Appendix 4). The households are from different economic groups defined in terms of the size and types of dwellings, land ownership and approximate monthly income. The distribution of households between income groups is shown in Table 4.1.

**Table 4.1 - Distribution of households between income groups**

<b>Economic Group</b>	<b>Hajiganj</b>	<b>Iswardi</b>	<b>Kalaroa</b>	<b>Total</b>
High Income (>Tk. 10,000/month)	4(19%)	5(24%)	7(33.3%)	16(25%)
Middle Income (Tk. 5-10,000/month)	11(52%)	5(24%)	7(33.3%)	23(37%)
Low Income (<Tk. 5,000/month)	6(29%)	11(52%)	7(33.3%)	24(38%)
<b>Total</b>	<b>21(100%)</b>	<b>21(100%)</b>	<b>21(100%)</b>	<b>63(100%)</b>

- 4.2 As can be seen in Table 4.1, the 21 households in Kalaroa are evenly distributed among the three income groups. The middle income households make up the majority of households in Hajiganj and the low income group dominates in Iswardi. Most of the householders in Iswardi appear to be a bit traditional in their outlook, compared to the ones in other two upazilas.
- 4.3 The existing sources of water for the 63 selected households were also investigated. In Kalaroa, all 21 households use tube-well water for drinking purpose, although they depend on pond water for washing purpose. In Iswardi, the households have no other sources of water other than tube-well and they use this water for drinking, cooking and washing purpose. The situation in Hajiganj is a bit different, where dependence on tube-well water for drinking purpose is a bit lower. However, it appears that use of tube-well water for drinking is universal in all the three locations.

### SUMMARY OF HOUSEHOLDERS' SURVEY RESULTS

- 4.4 The results from each of the areas are presented in three tables and in summary text. The three tables for each area cover:
- ranking of the three technologies used (3 points for most liked to 1 point for least liked of the three);
  - an average score for each of the technologies for fifteen criteria; and
  - an indication of willingness-to-pay, and payment and management terms for each of the technologies.

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- 4.5 The detailed resume of responses from the householders in given in Appendix 5.

**Results - Hajiganj**

- 4.6 The Stevens was the preferred technology based on the ranking exercise, closely followed by the Alcan (Table 4.2). The preference scores for all technologies were quite similar, illustrating that there was no one technology preferred by all householders who used it.

**Table 4.2 - Ranking of each technology used - Hajiganj**

Household No.	Alcan	BUET	DPHE/Danida	GARNET	Sono	Stevens	Tetra-hedron
01			xxx		x	xx	
02	xxx	x	xx				
03	xxx			x			xx
04		x		xx		xxx	
05	xxx		xx				x
06		xxx			xx	x	
07				x		xx	xx
08		x			xxx	xx	
09				xx		xxx	x
10	xx	x	xxx				
11	x		xxx	xx			
12			x		xx	xxx	
13		xx		xx			x
14		xxx		x	xx		
15		x	xx			xxx	
16	xxx				xx		x
17	xxx			xx			x
18			x		xx	xxx	
19		xxx		x			xx
20	xx		xxx		x		
21	x				xxx		xx
<b>Total</b>	<b>21</b>	<b>16</b>	<b>20</b>	<b>14</b>	<b>18</b>	<b>22</b>	<b>13</b>

- 4.7 The Alcan and the Stevens also came top of the scoring exercise, with Sono a close third (Table 4.3). The only weaknesses for Alcan were cost and difficulty in moving, whilst for Stevens they were replacement of reagents and cleaning frequency. Flow rates, waiting times and physical structure were the main reservations with the Sono. This was similar for the DPHE/Danida although reagents were more of a concern than physical structure.
- 4.8 Tetrahedron performed well except on cost, smell and the fact that materials were not available locally. The BUET performed slightly below average for all criteria. Flow rates, waiting times and ease of maintenance were the main low scoring criteria for the GARNET.

*Rapid Assessment of Household Level Arsenic Removal Technologies – Phase II Report***Table 4.3 - Scoring for each technology for fifteen criteria - Hajiganj**

Criteria	Alcan	BUET	DPHE/ Danida	GARN ET	Sono	Stevens	Tetra- hedron
1. Enough arsenic-free water	••••••	••••	••••	•	••	•••••	••••••
2. Water available quickly	••••••	••••	•••	•	••	•••••	••••••
3. Water tastes good	••••	•••••	•••••	••••••	••••••	•••••	•
4. No bad smell in water	••••	••••	•••••	••••••	••••••	••••••	••
5. Less bothersome in use	••••••	••••	•••	•	•••	••••••	••••
6. Cost - within ability?	•	•••	••••••	••••	••••••	••••••	•
7. Ease of moving	••	•••	••••••	••	•	••••••	•••
8. Ease of maintenance	•••••	••	•••••	••	•••	••••••	••••••
9. Physical structure is good	•••	•	•••••	••	••	••••••	•••••
10. Materials locally available	-	•••	•••••	••••••	••••••	•••••	-
11. Need for additional materials	••••••	-	-	••••••	••••••	-	-
12. Cleaning frequency	••••••	••	•••	•••	••••••	••	••••
13. Waiting time	••••••	•••	•	•	••	••••••	•••••
14. Need to keep to strict schedule	••••••	•••	•	•••	••••	•••••	••••••
15. Ease of operation	••••••	•	••••••	••	••••	••••••	••••••
<b>Total Score</b>	<b>75</b>	<b>42</b>	<b>58</b>	<b>48</b>	<b>64</b>	<b>77</b>	<b>56</b>

4.9 The wealthier status of many of the households, compared to the other two areas, is reflected in the higher prices that the householders say they would be prepared (Table 4.4). The amounts they are willing to pay, however, suggest that the higher specification, higher cost technologies would only be affordable with multiple household use or with high levels of subsidy. For most of the lower technologies the amount the householders are willing to pay would cover capital and recurrent costs.

**Table 4.4 - Willingness-to-pay and management basis - Hajiganj**

Technology	Willingness-to-pay		Preferred payment basis	Preferred management basis
	Capital costs (Tk.)	Monthly costs (Tk.)		
Alcan	700/- to 1,000/-	100/- to 200/-	None	Share
BUET	200/- to 500/-	-	Lump sum	Individual
DPHE/Danida	100/- to 600/-	20/- to 100/-	Lump sum	Individual but ready to share with neighbours
GARNET	200/- to 300/-	15/- to 20/-	Instalment	Individual
Sono	100/- to 500/-	15/- to 50/-	Lump sum	Individual
Stevens	300/- to 400/-	15/- to 50/-	Instalment but could do lump sum	Individual
Tetrahedron	700/- to 3,000/-	-	Lump sum	Share

**Surveyors' Observations - Iswardi**

- 4.10 The households represent a variety of families from different economic groups, a few are quite rich with male members working abroad. Some families are very poor. However, most of them are aware of the possible dangers of arsenic poisoning. It does not preclude the need for more intensive awareness-building campaign.
- 4.11 In the locality, almost every household has access to pond water and they use this water for washing and cooking purposes. When the arsenic scare swept the country, they even drank pond water after boiling. As such, in the absence of being convinced fully about the necessity of using the technologies, which of course represent an additional burden for the housewives, it would take quite some time for them to adopt the technologies.
- 4.12 Poverty coupled with absence of in-depth understanding about the perils of arsenic contamination will continue to affect the decision-making process in respect to procuring the technologies for continuous household use.
- 4.13 Before placing the technologies for household use, it would have been appropriate to inform the housewives in detail about the maintenance requirements of different technologies. Even after the training they did get and using them, the persons handling the technologies were not exactly sure about the proper operation and maintenance techniques.

**Results - Iswardi**

- 4.14 In Iswardi, the ranking exercise revealed a preference for the Alcan, followed by the DPHE/Danida (Table 4.5). This was followed by Sono and the GARNET jointly and then the Stevens, BUET and Tetrahedron.
- 4.15 For the scoring exercise, the Alcan again came first (Table 4.6), scoring low only on cost, ease of movement and availability of materials locally. The Sono came second, based mainly on taste of treated water, cost and ease of maintenance. The Stevens again scored consistently well, save for smell, bothersome use and the need for additional reagents. Tetrahedron did poorly on cost, smell of water (chlorine) and not being able to get materials locally. The DPHE/Danida scored best on ease of movement and the physical structure and less well on the operational and time criteria.
- 4.16 The householders in Iswardi were very reluctant to pay the full price for any of the technologies (Table 4.7). The largest contribution offered was Tk. 3000/- for the Alcan. In many cases, householders were reluctant to pay anything. It should be remembered that this is the poorest and least educated of the three areas and there is still a need for education on this issue. There was a strong call for subsidy support for technologies.

**Rapid Assessment of Household Level Arsenic Removal Technologies – Phase II Report****Table 4.5 - Ranking of each technology used - Iswardi**

Household No.	Alcan	BUET	DPHE/ Danida	GARNET	Sono	Stevens	Tetra- hedron
01	xxx	-	-	-	xx	-	x
02	xxx	-	-	x	-	-	x
03	-	-	xxx	xx	x	-	-
04	-	-	xxx	xx	-	x	-
05	-	-	-	-	xxx	xx	x
06	xxx	-	-	-	xx	-	x
07	-	-	-	-	xxx	x	xx
08	xxx	-	-	xx	-	x	-
09	xxx	-	-	-	xx	-	x
10	xxx	-	-	x	xx	-	-
11	-	x	xxx	xx	-	-	-
12	-	xx	xxx	-	-	x	-
13	-	x	xxx	-	-	xx	-
14	-	x	-	xxx	-	xx	-
15	-	x	-	xxx	-	xx	-
16	-	-	-	xxx	-	x	xx
17	-	xx	xxx	-	-	-	x
18	-	xx	x	-	-	-	xxx
19	xxx	x	xx	-	-	-	-
20	xxx	x	-	-	xx	-	-
21	xxx	-	x	-	xx	-	-
<b>Total</b>	<b>27</b>	<b>12</b>	<b>22</b>	<b>19</b>	<b>19</b>	<b>13</b>	<b>13</b>

**Table 4.6 - Scoring for each technology for fifteen criteria - Iswardi**

Criteria	Alcan	BUET	DPHE/ Danida	GARN ET	Sono	Stevens	Tetra- hedron
1. Enough arsenic-free water	•••••	•	••••	••	•••	•••••	•••••
2. Water available quickly	•••••	•	••	••••	•••	•••••	•••••
3. Water tastes good	•••••	••••	••	•••••	••••••	••••	•
4. No bad smell in water	•••••	•••••	••	••••	••••••	-	-
5. Less bothersome in use	•••••	-	••••	••••••	•••••	-	-
6. Cost - within ability?	-	-	-	•••••	••••••	••••••	-
7. Ease of moving	-	-	••••••	-	-	••••••	•••••
8. Ease of maintenance	•••••	•	••••	••	••••••	•••••	•••
9. Physical structure is good	•••••	-	••••••	-	-	••••••	•••••
10. Materials locally available	-	••••••	•••••	-	-	••••••	-
11. Need for additional materials	•••••	-	-	•••••	••••••	-	••••
12. Cleaning frequency	•••••	•	••	••••	••••••	•••	•••••
13. Waiting time	•••••	-	-	••••	•••	•••••	••••••
14. Need to keep to strict schedule	•••••	-	-	••••	••••••	•••••	•••
15. Ease of operation	•••••	•	••	•••	••••	•••••	••••••
<b>Total Score</b>	<b>83</b>	<b>20</b>	<b>38</b>	<b>46</b>	<b>65</b>	<b>61</b>	<b>52</b>

**Rapid Assessment of Household Level Arsenic Removal Technologies – Phase II Report****Table 4.7 - Willingness-to-pay and management basis - Iswardi**

Technology	Willingness-to-pay		Preferred payment basis	Preferred management basis
	Capital costs (Tk.)	Monthly costs (Tk.)		
Alcan	2,000/- to 3,000/-	15/- to 20/-	None	Share
BUET	100/- to 300/-	20/- to 30/-	Lump sum	Individual
DPHE/Danida	100/- to 200/-	30/- to 50/-	Lump sum (need subsidy)	Individual
GARNET	100/-	3 HH – none 6 HH – 15/-	Lump sum	Individual
Sono	5 HH 200 to 300/- 4 HH can't afford even Tk.50/-	None	Lump sum	Individual
Stevens	100/- to 300/-	10/- to 15/-	Lump sum	Individual
Tetrahedron	None – too much	50/- to 100/-	Some said lump sum if subsidy	Share (if subsidy)

**Surveyors' Observations - Iswardi**

- 4.17 The social survey team made the following observations after the conclusion of all of their discussions.
- 4.18 Most of the 21 households have been found to be relatively poor both in economic and socio-cultural aspects. Being illiterate and unaware, they are less motivated to understand the dangers of arsenic poisoning.
- 4.19 The households are dependent on tube-well water for most of their daily chores. Dependence on other water sources like ponds and wells are not much pronounced.
- 4.20 As indicated by the households themselves, there is a great need for motivation campaign among the people in respect to the dangers of drinking arsenic-contaminated water.
- 4.21 Poverty factor has a great bearing on the preference of the households in respect to procurement of the technologies. Although the households using technologies like Alcan and Tetra Hedron demonstrated a good deal of liking for these two as sources of good and enough water, they could never think of buying these because of high price.



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- 4.22 But majority households opted for cheap but less efficient technologies for their individual tube-wells owing to their lack of buying capacity.
- 4.23 Housewives and in some cases daughters have been exclusively associated with test-running of the technologies at their household level. There was no involvement of the male members at all. Lack of involvement of the male heads or husbands affected the decision-making process (in respect to purchase of the technologies), as the housewives were reluctant to decide about it before consulting with their husbands.
- 4.24 The women felt that they had not received sufficient training on the operation and maintenance of the technologies.

**Results Kalaroa**

- 4.25 In both the ranking and scoring exercises, the Alcan came top (sharing first place with Terahedron and Sono in the ranking exercise see Table 4.8 and Table 4.9). The Alcan scored high for all criteria except cost and ease of movement. The Tetrahedron scored well for all except cost and the taste and smell of the water (due to the chlorine). Once the householders were informed of the merits of chlorine, they said that they would try and get used to the taste and smell. Sono was well received on all counts except for flow rates and the inconvenience of frequent topping up.

**Table 4.8 - Ranking of each technology used - Kalaroa**

Household No.	Alcan	BUET	DPHE/ Danida	GARNET	Sono	Stevens	Tetra- hedron
01	xx	x	-	-	-	-	xxx
02	-	x	-	xx	xxx	-	-
03	-	-	xx	x	xxx	-	-
04	-	x	-	-	-	xx	xxx
05	-	-	xxx	-	xx	x	-
06	-	x	xx	-	xxx	-	-
07	-	-	xx	x	xxx	-	-
08	xxx	-	-	x	-	-	xx
09	-	-	xx	x	-	xxx	-
10	-	xx	-	x	xx	-	-
11	-	-	xx	x	xxx	-	-
12	xxx	-	-	-	-	xx	x
13	xx	-	-	-	-	x	xxx
14	-	xx	x	-	-	-	xxx
15	xx	-	-	-	-	x	xxx
16	xx	-	x	-	-	-	xxx
17	xxx	xx	-	-	x	-	-
18	xxx	x	-	-	-	xx	-
19	xxx	-	-	-	-	x	xx
20	-	xx	-	x	xxx	-	-
21	-	-	xxx	x	-	xx	-
<b>Total</b>	<b>23</b>	<b>14</b>	<b>18</b>	<b>10</b>	<b>23</b>	<b>15</b>	<b>23</b>

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4.26 The GARNET scored low on all of the operational, water volume and waiting time criteria but high on taste/smell, cost, locally available materials and ease of use. Likewise, the DPHE/Danida scored low on the time and inconvenience associated with preparation of water before filtration but the design, ease of use, cost and water quality were liked. The Stevens scored consistently well, only losing out on smell and frequency of cleaning. The BUET was not particularly liked for any of the criteria.

**Table 4.9 - Scoring for each technology for fifteen criteria - Kalaroa**

Criteria	Alcan	BUET	DPHE/ Danida	GARN ET	Sono	Stevens	Tetra- hedron
1. Enough arsenic-free water	●●●●●●	●●●●	●●●	●	●●	●●●●	●●●●●●
2. Water available quickly	●●●●●●	●●●●	●●●	●	●●	●●●●	●●●●●●
3. Water tastes good	●●●●	●●	●●●●●	●●●	●●●●●●	●●●●●●	●
4. No bad smell in water	●●●●	●	●●●●	●●●●●	●●●●●●	●●●	●●
5. Less bothersome in use	●●●●●●	●●●●	●●	●	●●●	●●●●	●●●●●●
6. Cost - within ability?	●	●●●	●●●●●	●●●●	●●●●●●	●●●●	●●
7. Ease of moving	●	●●●●	●●●●●●	●●	●●●	●●●●●●	●●●●
8. Ease of maintenance	●●●●●●	●●	●●●●	●	●●●●	●●●●	●●●●●●
9. Physical structure is good	●●●●	●	●●●●●	●●	●●●	●●●●	●●●●●●
10. Materials locally available	-	●●	●●●	●●●●●	●●●●●●	●●●	-
11. Need for additional materials	●●●●●●	-	-	●●●●●●	●●●●●●	-	-
12. Cleaning frequency	●●●●●●	●●●	●●●	●●●●	●●●●	●●●	●●●●●●
13. Waiting time	●●●●●●	●●	●	●●●	●●●●	●●●●	●●●●●●
14. Need to keep to strict schedule	●●●●●●	●●	●	●●●	●●●●	●●●●	●●●●●●
15. Ease of operation	●●●●●●	-	●●●●●	-	●●●●●	●●●●●	●●●●●●
<b>Total Score</b>	<b>77</b>	<b>34</b>	<b>53</b>	<b>44</b>	<b>71</b>	<b>65</b>	<b>66</b>

**Table 4.10 - Willingness-to-pay and management basis - Kalaroa**

Technology	Willingness-to-pay		Preferred payment basis	Preferred management basis
	Capital costs (Tk.)	Monthly costs (Tk.)		
Alcan	1,000/- to 3,000/-	30/- to 50/-	3 HH – instalment 6 HH – lump sum	Share
BUET	500/- to 700/-	20/- to 50/-	Lump sum	Individual
DPHE/Danida	200/- to 300/-	10/- to 50/-	Lump sum	Individual
GARNET	200/- to 1500/-	10/- to 50/-	8 HH – lump sum 1 HH – not pay	Individual
Sono	200/- to 300/-	10/- to 50/-	Lump sum	Individual
Stevens	500/-	20/- to 100/-	Lump sum	Individual
Tetrahedron	300/- to 2000/-	30/- to 100/-	3 HH – instalment 6 HH – lump sum	Share

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- 4.27 The willingness-to-pay was higher for the Alcan and the Tetrahedron technologies but the maximum that any household was prepared to pay was Tk. 3,000/- (Table 4.10). Most of the other technologies were almost affordable according to the willingness-to-pay analysis, both for capital and for monthly costs.

**Surveyors' Observations - Kalaroa**

- 4.28 During interactions with housewives and other community members over a period of a month or so, the investigating team members had occasions to hold in-depth discussions relating to the arsenic problem and the arsenic-treating technologies. Their main observations are set out in the following paragraphs.
- 4.29 Being residents of an arsenic-contaminated region, they are aware of the arsenic problem and its implication in their life. However, most of the households were in favour of a strong motivation campaign so that the relatively poor and illiterate people can also be motivated to use arsenic-free tubewell water.
- 4.30 All the 21 households have the opportunity to use some kind of arsenic-treated water during the past one month and they got used to drinking such water. As such, they developed a new awareness and taste for such water. Exposed to the motivation programme and a new taste of water, the households are now eager to have such facilities on a continual basis.
- 4.31 It was apparent from the discussions that the households would prefer some kind of subsidy from government or other sources to enable them to procure the technologies, especially the costly ones, for their family use.
- 4.32 In all cases, it was the housewives who were associated with the treatment of water through different sets of technologies. The male members of the households had little or no involvement in the process. Although the housewives were involved in the operation, they were hesitant to decide about buying the same prior to consultation with their household heads or husbands.
- 4.33 The women felt that they had not received sufficient training on the operation and maintenance of the technologies. Such knowledge and experience could increase their confidence and help them in deciding about procurement of the technologies for their household use at a future date.
- 4.34 Most of the households preferred individual procurement and exclusive use, although some of them indicated their willingness to share these with their relatives or neighbours. One reason is that their preferred technologies in terms of cost do not provide enough water. Another reason has been their lack of encouraging experience of joint ownership in a facility in a rural setting.

**General observations**

- 4.35 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.
- 4.36 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.
- 4.37 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 4.11.
- 4.38 Alcan came first in both comparative assessments overall (see Table 4.12 and Table 4.13), though there were some regional variations (2<sup>nd</sup> 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.
- 4.39 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.

**Rapid Assessment of Household Level Arsenic Removal Technologies – Phase II Report****Table 4.11 - 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

**Table 4.12 - 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  $3 \times 9 \times 3 = 81$ )

**Table 4.13 - 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  $7 \times 15 \times 3 = 315$ )

4.40 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.

4.41 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

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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.

- 4.42 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.

## 5. PROPONENTS QUESTIONNAIRE

- 5.1 The responses from the proponents to questions asked about plans for manufacture, marketing and distribution; support for users; and for management of waste are summarised in Table 5.1 below.
- 5.2 Regarding manufacture, 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.
- 5.3 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.
- 5.4 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.
- 5.5 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.
- 5.6 Most proponents have given considerable thought to how they will support users after ‘hand over’ (for replacement of 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 different demands of NGOs and local government. This perhaps is one area where BAMWSP can be of considerable assistance in the near future.
- 5.7 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 correctly. 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).

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Table 5.1 - Answers to the Proponents Questionnaire

QUESTION	ALCAN ENHANCED ACTIVATED ALUMINA	BUET ACTIVATED ALUMINA	DPHE/DANIDA 2BTU	GARNET	SONO 3 KOLSHI	STEVENS INSTITUTE	TETRAHEDRON
<b>Where are you proposing to manufacture the technology?</b>	Dhaka.	Initially at Environmental Engineering Laboratory of BUET. If it successful, then mass production could be arranged.	In the working areas of Noakhali, Feni, Lakshimpur, Barisal and Pirojpur, both at thana and district levels through private entrepreneurs.	At project or household site, whether urban or rural. It requires only components which are available in the local market.	Kushitia. It may be extended to field level if required.	Bangladesh	Dhaka, Bangladesh
<b>Where are you planning to get your filter materials from?</b>	Enhanced activated alumina will initially be produced at Alcan Chemicals Brockville, Ontario, Canada. When demand is high enough, Alcan will consider producing the media in the region.	West Bengal, India	Locally.	From local markets.	Local to users.	Sand & bucket filters are from Bangladesh. Chemicals are for now imported from the USA. A plant can be set up in Bangladesh when the demand for chemicals allows. Bangladesh has the raw materials for the reagents.	The ion exchange resin will be obtained abroad. All other supplies will be from Bangladesh.
<b>How many units are you planning to manufacture in the next year?</b>	Current planned capacity is up to 2000 units per month. This can be easily increased. Alcan can manufacture several tens of thousands of tonnes of enhanced activated alumina and will scale up the production as necessary. Alcan has the financial strength to do this without external financing.	As per demand	10,000	GARNET will encourage and train local promoters and users to manufacture it.	Existing capacity is 200 units per day. If demand increases capacity can be increased.	Two engineers can make approximately 100 filters manually per day. We can supply as many filters as needed.	It will depend on the demand. We can manufacture up to 10,000 individual well units in the first year.



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**MARKETING**

QUESTION	ALCAN ENHANCED ACTIVATED ALUMINA	BUET ACTIVATED ALUMINA	DPHE/DANIDA 2BTU	GARNET	SONO 3 KOLSHI	STEVENS INSTITUTE	TETRAHEDRON
<b>How are you planning to publicise your technology?</b>	Through advertising in the local press and media, as well as contacts through BAMWSP and NGO'S like BRAC, NGO Forum, Rotary.	Through BAMWSP, UNICEF, Danida, NGOs and others	Workshops, focus group discussion, meetings, developing IEC materials and mass campaigning.	Through GARNET SA members, BAMWSP, Rotary and other Civil Society Groups and Government organisations. Promoted as short term measure.	Advertisements in various electronic and print media; NGOs; government at union, thana and district levels; BAMWSP.	We will publicise through advertising, workshops, scientific & public presentation, field demonstration, and participation in validation programs.	Through NGOs, BAMWSP and also newspaper advertisement and seminars.
<b>What marketing have you done so far?</b>	Technology offered to BAMWSP and UNICEF for their projects. Outside Bangladesh the system is being promoted in India for both arsenic and fluoride removal.	Little. Three units have been distributed in Sonargaon, Narayangonj.	As above. Established 8 entrepreneurs and two chemical processing plants.	None so far. Carrying out field-testing among selected GARNET members.	International and national seminars; dissemination of technologies in arsenic affected areas and local medical practitioners and health workers.	N/A	Seminars, since 1998, and marketing to BAMWSP and NGOs. We have also talked to business, govt. departments, NGOs, the World Bank, the Asian Development Bank and US AID.

**DISTRIBUTION**

<b>How will you distribute your technologies to householders?</b>	As BRAC has > 1 office per thana, we plan to set up an agreement with them to distribute our product. We may also appoint an agent/distributor in each thana.	Except filter sand and iron frame, all will be supplied to the householder from BUET's laboratory. As filter and frame are difficult to transport, these will be collected and manufactured locally.	Through Project staff, NGOs and private entrepreneurs.	Will train interested local institutions, civil societies and others to manufacture locally.	Own disseminating agents; government institutions; NGOs and private business.	The Star Tech Centre is to be set up in Bangladesh by the Earth Identity Project and Stevens Institute of Technology. It will manufacture and distribute the filters, train users, and monitor treated water quality. Distribution will be by the Star Tech Centre; NGOs & other organisations.	1. Through NGOs 2. Through local Government (union offices) 3. Through potential businesses that have extensive networks in the rural areas.
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## TRAINING

QUESTION	ALCAN ENHANCED ACTIVATED ALUMINA	BUET ACTIVATED ALUMINA	DPHE/DANIDA 2BTU	GARNET	SONO 3 KOLSHI	STEVENS INSTITUTE	TETRAHEDRON
<b>How will you train the householders to use your technology?</b>	Every household that buys our technology will get adequate "hands on" training so that they can easily use it.	The householders will be trained at BUET laboratory. The Engineers of DPHE at Thana level can be trained as trainer at BUET laboratory and they can train householders.	House to house visit and court yard meetings.	Through local institutions based on local communication channels, lectures and practical sessions. Pictorial aids and videos may also be used.	At household level, using Sono's own disseminating agents.	Householders will be trained by NGOs, local representatives, and distributors.	Distributors will be trained and given instructions (SOPs) on how to train the users. All qualified trainers will be given a trainer's certificate renewable yearly after re-test. We will randomly evaluate training quality and remedy, if needed.  Any changes made will be immediately made known to all trainers.
<b>Who will you use to do the training?</b>	Our own trained staff will train the thana level personnel of BAMWSP, BRAC or agent/distributor, who in turn will train the householders.	Research students and thana level Engineers of DPHE.	Hygiene promoters from field NGOs, Project staff and WATSAN committee members.	GARNET SA staff will conduct training of trainers from various organisations and communities.	Large scale training to the disseminating agents will be organised in-house at the Human Resource Development Centre using experts.	Engineers at the Star Tech Centre and NGOs will train the representatives in the villages. The local representatives will then train the householders under the supervision of the engineers.	Distributors of the technology will be used for providing the training. The trainers will be local people that will always be available to users.
<b>How much time do you think it takes to train the users properly?</b>	Training should take less than two hours.	1 day	3 separate days (basic, follow up and refresher training).	Introduction, disinfecting, placement of components and demonstration of O&M – 2 hours.	In a neighbourhood cluster, a trainer will be able to train 20 householders in a week.	It takes approximately 30 minutes to train the householders.	It will take approx. 45 minutes to train the householders on how to use the technology.

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**SUPPORT SERVICES FOR USERS**

QUESTION	ALCAN ENHANCED ACTIVATED ALUMINA	BUET ACTIVATED ALUMINA	DPHE/DANIDA 2BTU	GARNET	SONO 3 KOLSHI	STEVENS INSTITUTE	TETRAHEDRON
<b>What are plans for providing users with replacements when technologies break or have achieved 'break through'?</b>	The units are simple in design and robust. We shall have complete after sales service available to our customers through BRAC or agents/distributors who will have stocks in hand.	Except for activated alumina, the users can procure or replace all items locally. With a little skill, a user can manufacture components. Spent alumina can be regenerated using the facilities of science laboratories of local schools or virgin alumina can be supplied through DPHE.	Through field NGOs and private entrepreneurs.	Local promoters or users will replace filters when broken or achieve 'break through'. Promoters will be informed of impact of local water quality on likely life cycle and O&M requirements. A written guide will be given on when and how to replace.	In each user's locality a woman having 6-8 grade schooling will be trained as a depot holder, who will be first point provider of relevant services.	Star Tech Centre will provide filter sand & buckets, reagents, and pipe fitting for buckets. No arsenic break though occurs in this filtration process.	Tetrahedron will have central regeneration points for the units for whenever it becomes necessary, to allow the user to use the unit for another cycle. Regeneration, using salt, should be at the thama level. Govt. agencies (e.g. DPHE) or NGOs will be trained to do this. Pay arrangements will be made with them to perform the service. These people will mainly be the same people that provide the training. Replacements will be given at a nominal cost if the unit breaks (unlikely event).
<b>How do you propose to supply users with replacement materials and spare parts?</b>	We plan to have stock of enhanced activated alumina and spare parts in Bangladesh to be available to users through BRAC or agents/ distributors.	As above or direct from BUET laboratory.	Materials are locally available. Users have to purchase at actual cost from the market or entrepreneurs.	As above.	As above.	We intend on giving the first filter units as a package and thereafter a nominal fee will be required for replacement of broken parts.	Spare parts will be kept in distribution centres. Number of distribution centres and locations will depend on users. Need for spare parts should be small.

## Rapid Assessment of Household Level Arsenic Removal Technologies – Phase II Report

**SUPPORT SERVICES FOR USERS (continued)**

QUESTION	ALCAN ENHANCED ACTIVATED ALUMINA	BUET ACTIVATED ALUMINA	DPHE/DANIDA 2BTU	GARNET	SONO 3 KOLSHI	STEVENS INSTITUTE	TETRAHEDRON
<b>If your technology uses reagents, how will you provide users with a constant supply of reagents?</b>	Alcan's enhanced activated alumina was designed as a single use media and can be disposed of at the end of its useful life. No reagents are required for its use.	Reagents is locally available.	Chemicals are also made locally, available through established chemical processing plants. Local entrepreneurs are selling it in the program area.	Only reagent is bleaching powder for maintenance and that is easily available throughout Bangladesh.	Not applicable	Star Tech Centre will package & distribute the chemicals used for water treatment directly and through other NGOs.	The Tetrahedron units use a chlorine tablet as the only reagent. The tablets will be kept in sealed desiccated bags in the distribution centres for regular supply to the users.  Common salt, used for the regeneration of the resin column, will also be stored at the distribution centres.
<b>If users have a problems with operating or maintaining the technology, how will you help them with their problems?</b>	Complete after sales service will be available for our customers through BRAC or agents/ distributors.	Trained DPHE Engineers and technicians at thana level will be used to solve problems.	Among the technology users, caretakers are selected and provided with additional training for supporting the users who have problems with O&M.	GARNET SA staff will provide refresher training to users to help them solve their own problems.	Trouble shooting training will be provided through technology disseminating agents.	We intend to monitor the use of the filters for 1 year to ensure the householders use the filters properly and that the filtered water meets the Bangladesh drinking water standards.	If up front training does not suffice, then users will be helped with problems by Tetrahedron's service group.  Users will always be able to obtain information, training or service at the regeneration point, located at thana level.

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**PROPONENTS' WASTE MANAGEMENT PLANS**

QUESTION	ALCAN	BUET ACTIVATED ALUMINA	DPHE/DANIDA 2BTU	GARNET	SONO 3 KOLSHI	STEVENS INSTITUTE	TETRAHEDRON
<b>What elements, if any, do you think need special treatment in your waste liquid, sludge or filter material?</b>	When the media is spent it can be replaced with fresh material. Regeneration of the spent media is not required, so there will be no waste liquid sludge and only non-hazardous solid waste to be disposed of.	Elements needing treatment: 1. iron sludge accumulated in the feed bowl and on the cloth screen. 2. iron sludge trapped in the sand filter 3. spent alumina	Washing/regeneration effluents and spent brick chips will need special treatment.	Waste sludge is rich in arsenic and there is the possibility of leaching of arsenic. So any treatment to make arsenic more stable in the sludge would be beneficial.	For our technology, no special treatment is required for waste management.	Sludge containing iron oxyhydroxide and As will be generated when the sand filters are washed. Analysis shows that the sludge contains approx. 1194 mg-As/kg of wet sludge (62% water). A soil sample from near a well had 18 mg-As/kg. Extraction results from US EPA TCLP showed that only 0.005mg/L of As was leached from the sludge compared with 0.014mg/L As from the soil sample. The results showed that the leachability of As from the sludge was so low due to high adsorption capacity of the iron oxyhydroxide for As. Under oxic conditions such as topsoil, very little As will be released from the sludge. However, if the sludge is placed in anoxic conditions, such as bottom of ponds, iron oxy-hydroxide may be reduced to soluble ferrous iron, resulting in the release of As. So, the sludge should be collected and disposed of properly or treated & used as construction material.	This system can be regenerated, giving the unit a new life by treating it just with common salt. The waste brine produced after regeneration will contain As salts that will be concentrated at the thana level by trained staff. High As wastewater will be collected in big drums at the regeneration centres and neutralised with chemicals. The upper supernatant part can be disposed anywhere since it will have no As content. The precipitate or the lower solid waste part will be stored, collected and disposed of properly.  In addition to "neutralising As" we are currently testing other waste treatment ideas (e.g. extracting As in pure form). We didn't use strong acid-base regeneration or discarding options because these options produce waste that can be more hazardous than the As. Leachability tests on some of the materials recommended for discarding, even in lined landfills, are questioned in several studies.

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**PROPONENTS' WASTE MANAGEMENT PLANS (continued)**

QUESTION	ALCAN ENHANCED ACTIVATED ALUMINA	BUET ACTIVATED ALUMINA	DPHE/DANIDA 2BTU	GARNET	SONO 3 KOLSHI	STEVENS INSTITUTE	TETRAHEDRON
<p><b>How do you propose that the users should dispose of the waste from your technologies?</b></p>	<p>The spent media meet the TCLP guideline set by the US Environmental Protection Agency (US EPA). The leachability of the material from Alcan, tested to the US EPA TCLP protocol is &lt;5mg/l and is classified as non-hazardous. However, care should still be taken to ensure that it is not disposed of with strong acids. The spent media can also be used in concrete, glass making and other industries.</p>	<p>For 1. and 2. above, the waste should be disposed to a bed of cowdung. For 3. in mortar and concrete manufacturing.</p>	<p>The users dispose of the waste from the unit to cow dung pits.</p>	<p>Users will recycle the washing/regeneration effluent through the filter. The spent brick chips and sand should be disposed of in cow dung pits or latrines.  Research and development is still being carried out, particularly in relation to the disposal of solid waste.</p>	<p>Surface dispersion.</p>	<p>The users should collect the sludge in the sludge containers provided with the filters. The NGOs or distributors will collect the sludge for proper disposal or treatment.</p>	<p>Users will not be burdened with waste disposal.  The regeneration will be conducted at the central station at thana level and the waste will be handled by trained persons as described above. Before bringing the units for regeneration, the users will be advised to store a few pitchers of treated water for using during the regeneration period. The process of regeneration should take no longer than 30 minutes, but it may take as long as a day if there is a backlog.  Users will be provided with a timetable when they will need to bring the units for regeneration. The timetable will be developed by us, based on the number of users and the quality of untreated water. We are currently conducting a 150 site pilot study to fine-tune the calculation for determining time required between regenerations.</p>



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**PROPONENTS' WASTE MANAGEMENT PLANS (continued)**

QUESTION	ALCAN ENHANCED ACTIVATED ALUMINA	BUET ACTIVATED ALUMINA	DPHE/DANIDA 2BTU	GARNET	SONO 3 KOLSHI	STEVENS INSTITUTE	TETRAHEDRON
<b>Are you going to provide any support to the users in terms of managing or collecting the waste material?</b>	Spent media would be collected when the fresh media is added, and disposed of in nominated acceptable landfill areas. A procedure will be set to ensure that no cross contamination can occur.	No.	Waste disposal is monitored randomly and feed back is communicated to the users.	If the users are unable to manage disposal (say because of limited space), GARNET SA will collect and dispose of the solid waste in sanitary landfills, community managed pits or brick fields.	Relevant training will be imparted as part of the users' training on the technology. If necessary, refresher training will be organised at a later stage.	So far, we have given 40-litre containers for the families. Sludge is collected and settled at the bottom of the containers. We have also developed fabric bags for the collection and de-watering of sludge. The bags can be hung between two trees or poles. The sludge is poured into the bags. The bags allow water pass through and retain the solids. Our staff and/or NGOs should collect the sludge 1 or 2 times a year. The sludge can be buried at designated and elevated areas to prevent it from being washed away by rainwater. The NGOs can also mix the sludge with coal fly ash, lime, or cement and used the treated material as construction fill or road base. The treated material has low hydraulic permeability and relatively high compressive strength, preventing the release of arsenic.	Neither management nor collection of waste materials will be required from the users. The only waste (as explained above) is a dry salt mixture containing the extracted arsenic and other compounds removed from the water. This waste salt will be generated at the regeneration station by trained personnel.
<b>If so, how are you going to collect the waste?</b>	We will discuss disposal options with each user. The favourite option, at least initially, is likely to be landfilling. Options such as use of spent media in concrete, glass making and other industries, will depend on ease of accessibility to each. Training required for landfilling is small, but we will tell relevant parties to avoid mixing the spent media with strong acids. We will require users to specify the means of disposal and accept responsibility for ensuring that the disposal is done according to our guidelines and stipulations, which are quite simple. We will also periodically monitor the disposal process and procedures.				Waste collection not applicable.		The waste will then be neutralised chemically for disposal or the arsenic will be removed as a pure commercial product by our trained staff. In some cases the As high salt from regeneration could be immobilized. We have recently conducted a study on this process.
<b>If you are going to collect the waste what are you going to do with it?</b>							

## **6. WASTE DISPOSAL OPTIONS FOR RESIDUES FROM TECHNOLOGIES**

### **INTRODUCTION**

- 6.1 All technologies that remove arsenic from groundwater will at some time produce arsenic waste either as a solid or a liquid waste sludge. The volume of waste and the chemical stability of the arsenical material produced will depend upon the type of compound precipitated and the technology and additives used for treatment. 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). 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.
- 6.2 The technical term “oxyhydroxide” is used throughout this discussion and refers to the iron sludge: a brown jelly like material containing only a very minor percentage of arsenic on the dried solid residues (<1%). This material is not significantly toxic owing to a low solubility but should be disposed of in a sensible and responsible fashion.
- 6.3 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 as well from the addition of coagulants:
- (i) Oxyhydroxide flocs in relatively large volumes of water such as in the settlement buckets from multi-stage systems or backwash waters;
  - (ii) Oxyhydroxide flocs trapped in the matrices (e.g. sand and bricks) of filter systems.
- 6.4 Emphasis is placed in this discussion on practical and achievable methods of disposal.

### **ALCAN**

- 6.5 No chemical additions are made during the use of this treatment technology. The process relies wholly on the active surface area of enhanced activated alumina to remove arsenic from drinking water. Other compounds can also compete for the active sites on the alumina and for this reason other elements such as iron and phosphate may accumulate on the surface. Arsenic-bearing



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iron oxyhydroxide will eventually build up within the enhanced activated alumina and will need to be backwashed out of the system and disposed of.

- 6.6 Deterioration in the performance of the enhanced activated alumina renders the material obsolete and regeneration or disposal of a large quantity of activated alumina (aluminium oxide) (40Kg per unit) will be required. The frequency of changing the alumina will depend on the nature of the water being treated.

**Disposal Option for Backwashed Water**

- 6.7 Disposal to latrine likely to be feasible for most households, especially if to a sealed septic tank.

**Disposal Option for Spent Activated Alumina**

- 6.8 Collection of the enhanced activated alumina will be carried out for incorporation into bricks or to designated landfill. Such a process would stabilise the arsenic and fix the residual amounts of arsenic in the alumina.
- 6.9 Users need to be informed of this.

**BUET**

- 6.10 Initially 1mL of potassium permanganate ( $\text{KMnO}_4$ ) solution is added to the water as an oxidant to convert trivalent arsenic into the pentavalent form, which is more easily removed from solution. Dissolved iron present in solution undergoes oxidation and is hydrolysed into colloidal sized particles. Such particles adsorb arsenate and remove a component of the arsenic. The amount of arsenic removed in the filter should be dependent on the iron concentration in the water (though no correlation with data from this project). Arsenic-bearing iron oxyhydroxide will accumulate in the sand filter materials and will periodically require cleaning or disposal. For the arsenic that is not removed in the sand filter the highly efficient activated alumina removes the remaining arsenic from solution. The adsorption of arsenic, aluminium, iron and other species onto the surface of the material will cause the small quantity of alumina in the column to degenerate eventually and the media will require disposal and replacement.

**Important Reactions in the Filter Bucket: -**

- $\text{Fe(II)} \rightarrow \text{oxidant} \rightarrow \text{Fe(III)} \rightarrow \text{Fe(OH)}_3$
- $\text{Fe(OH)}_3$  removed in sand filter
- $\text{Fe(OH)}_3 + \text{AsO}_4^{3-} \rightarrow \text{solid arsenical residue for eventual disposal}$

### Disposal Option for Backwashed Water

- 6.11 Disposal to latrine likely to be feasible for most households, especially if to a sealed septic tank.

### Disposal Option for Spent Activated Alumina and Sand Filter Materials

- 6.12 Disposal to shallow pit:
- Likely to be feasible for most households.
  - Disposal in a dedicated, clearly identified pit away from the household. This may need to be specially constructed.
  - Materials should be covered with fresh soil after placing into pit.
- 6.13 Awareness/training required.

### DPHE/DANIDA

- 6.14 Aluminium sulphate ( $\text{Al}_2(\text{SO}_4)_3$ ) with minor amounts of potassium permanganate ( $\text{KMnO}_4$ ), as an oxidant, are added to the tube well water. The aluminium compound undergoes a process called hydrolysis and is converted into a jelly like compound of aluminium hydroxide. The sulphate stays in solution as does the potassium and permanganate. Arsenic present in the water is adsorbed onto the colloidal sized floccules and as these aggregate they start to settle, the larger the floc size the more rapid the settling rate. The process therefore gives rise to an amorphous arsenic-aluminium bearing sludge that will accumulate i) at the bottom of the pre-filtration bucket, and ii) within the sand filter. The majority of the sludge will settle in the bucket while the remainder will be removed in the sand filter. Additional elements such as iron and phosphate concentrations within the water will also be removed and will be present in the coagulant sludge.

#### *Important Reactions in the Top Bucket: -*

- $\text{As(III)} \rightarrow \text{oxidant} \rightarrow \text{As(V)}$
  - $\text{Al}_2(\text{SO}_4)_3 \rightarrow 2\text{Al}^{3+} + 3\text{SO}_4^{2-}$
  - $\text{Al}^{3+} + 3\text{H}_2\text{O} \rightarrow \text{Al(OH)}_3 + 3\text{H}^+$
  - $\text{Al(OH)}_3 + \text{AsO}_4^{3-} \rightarrow \text{solid arsenical residue for eventual disposal (hydrated aluminium hydroxide-type compound onto which arsenic is adsorbed)}$
- 6.15 While the process may appear to produce large volumes of wet arsenic-rich sludge this material has a high liquid:solid ratio and is actually mostly water (>90%). The main type of arsenical sludge will be an aluminium

oxyhydroxide onto which arsenic is adsorbed. The arsenic solubility of this compound is not known but is expected to be higher than the iron equivalent.

#### **Disposal Option for Backwashed Water**

- 6.16 Disposal to latrine likely to be feasible for most households, especially if to a sealed septic tank.

#### **Disposal Option for Degenerated Sand**

- 6.17 Disposal to shallow pit:
- Likely to be feasible for most households.
  - Disposal in a dedicated, clearly identified pit away from the household. This may need to be specially constructed.
  - Materials should be covered with fresh soil after placing into pit.
- 6.18 Awareness/training required.

#### **GARNET**

- 6.19 No chemicals are added during use of this technology, which is essentially a brick and sand filter. The iron rich brick chips must contain some free lime and reduced iron compounds (Fe(II)) within the porous solids, originating from the baking of clay, iron compounds and calcium carbonate at high temperature under reducing conditions. The pH of the arsenic containing water is raised by the alkaline nature of the brick chips as well as from the decarbonation of the water. Together with the oxygenation of the water in the filter this will promote the oxidation and hydrolysis of the iron held in solution. Arsenic is simultaneously coprecipitated and removed with the iron to form an arsenical iron oxyhydroxide. The high concentrations of iron in the red brick chips also play a role in arsenic removal and arsenic-bearing iron oxyhydroxides will accumulate on the surface of the filter particles in both the top and bottom buckets. The arsenical sludge of iron oxyhydroxide, onto which arsenic is strongly adsorbed, will need to be periodically washed out to prevent clogging.

#### **Disposal Option for Filter Washings**

- 6.20 Disposal to latrine likely to be feasible for most households, especially if to a sealed septic tank.

### Disposal Option for Degenerated Brick Particles and Sand Filter Materials

#### 6.21 Disposal to shallow pit:

- Likely to be feasible for most households.
- Disposal in a dedicated, clearly identified pit away from the household. This may need to be specially constructed.
- Materials should be covered with fresh soil after placing into pit.
- Awareness/training likely to be relatively straightforward.

#### 6.22 Awareness/training required.

### SONO

6.23 No chemical additions are made to the water; the main chemical reactions occur within the top kolshi where the majority of the arsenic is removed (>95%). Here the presence of a layer of metallic iron induces low Eh conditions causing arsenic to be precipitated from solution onto iron oxyhydroxide and possibly as other arsenic bearing compounds that form under reducing conditions. Relatively rapid oxidation and “rusting” of the metal takes place. This reduces the effectiveness of the iron layer in the kolshi and eventually it no longer functions as designed. The iron material cements together and the top kolshi must be totally discarded. As most of the arsenic is contained in this kolshi, its treatment needs consideration.

#### *Important Reactions in the Top Kolshi: -*

- $\text{Fe}^0 + 1.5\text{H}_2\text{O} + 0.75\text{O}_2 \rightarrow \text{Fe}(\text{OH})_3$
- $\text{Fe}(\text{OH})_3 + \text{AsO}_4^{3-}$  (iron oxyhydroxide onto which arsenic is adsorbed - arsenical ferrihydride)

6.24 An arsenical iron oxyhydroxide compound will also accumulate in the second kolshi containing the sand-charcoal filter material (minor coarse brick particles), allowing any arsenic not removed in the top kolshi to be recovered. The arsenical iron oxyhydroxide will accumulate within the matrix of the filter material causing clogging and eventually reducing the passage of water through the technology. The second kolshi must then be discarded.

#### *Important Reactions in the Second Kolshi*

- $\text{Fe}(\text{II}) \rightarrow \text{Fe}(\text{III}) \rightarrow \text{Fe}(\text{OH})_3$
- $\text{Fe}(\text{OH})_3 + \text{AsO}_4^{3-} \rightarrow$  solid arsenical residue for eventual disposal (Iron oxyhydroxide onto which arsenic is adsorbed - arsenical ferrihydride)

**Disposal Option for Kolshis Containing the Degenerated Iron-sand and Sand-charcoal Mixtures**

6.25 Disposal to shallow pit:

- Likely to be feasible for most households.
- Disposal in a dedicated, clearly identified pit away from the household. This may need to be specially constructed.
- Materials should be covered with fresh soil after placing into pit.

6.26 Awareness/training required.

**STEVENS INSTITUTE**

6.27 3.8g of iron sulphate mixture containing a minor quantity of calcium hypochlorite (an oxidant) are added to 20L of well water. Following rapid stirring of the solid mixture into the water the iron compound dissolves and the iron undergoes rapid hydrolysis and the formation of colloidal flocs. The conversion of As(III) to As(V) takes place through the action of the added oxidant as well as being catalysed by the oxidation of Fe(II) to Fe(III). The dissolved arsenic within the water is coprecipitated and adsorbed onto the iron floccules, which settle to the bottom of the bucket. Coagulation will therefore give rise to an amorphous arsenic-iron bearing sludge that will accumulate i) at the bottom of the pre-filtration buckets, and ii) in the matrix of the sand filter. Additional elements originating in the well water may also coagulate and be removed in the sludge. These elements are benign and occur only in trace quantities. The use of the coagulant introduces iron into the water and produces a large volume of co-precipitated arsenic-rich sludge; this material has a high liquid:solid ratio and is actually mostly water (>95%).

***Important Reactions in the Primary Mixing Bucket***

- $\text{Fe}_2(\text{SO}_4)_3 \rightarrow 2\text{Fe}^{3+} + 3\text{SO}_4^{2-}$
- $\text{Fe}^{3+} + 3\text{H}_2\text{O} \rightarrow \text{Fe}(\text{OH})_3 + 3\text{H}^+$

**Disposal Option for Sand Filter Washings**

6.28 Disposal to latrine likely to be feasible for most households but preferably to soak-away or drainage.

6.29 No need to dispose of sand filter material.

**TETRAHEDRON**

- 6.30 Contact of the well water with sodium hypochlorite (“Chlorine tablets” NaOCl), an oxidising agent, results in the oxidation of arsenic from its trivalent to its pentavalent form. It also adds significant chlorine taste to the water but helps minimise bacterial growth. The ion exchange resins are highly selective: they remove arsenic and other compounds with a similar valency. It is the surface of the resin beads that makes the material function and arsenic removal relies on the availability of an adequate number of active sites on the material. Iron or other compounds, inorganic and organic, may eventually coat the resin beads, rendering them less effective. The resins would then need to be regenerated. When treating some water compositions extensive maintenance of the resins may be required.
- 6.31 Iron oxyhydroxide will eventually build up within the resins and the system requires routine back-washing. Backwashed waters should not contain significant concentrations of arsenic and can be discarded to a drain.
- 6.32 Ion exchange processes do not, under normal use, produce a solid waste stream because the media are regenerated. Regeneration of the resin may be carried out periodically by flushing with salt (NaCl) solution. Ideally this should be done at a centralised facility. The frequency of regeneration will depend on the nature of the water being treated.

**Disposal Option for Degenerated Resin**

- 6.33 Resin beads need to be regenerated
- Regeneration typically involves flushing with salt solution; the resultant liquid wastes will be saline and rich in arsenic and require special treatment. Regeneration should be carried out at a centralised facility.
- 6.34 Awareness/training required.

## 7. CONCLUSIONS AND RECOMMENDATIONS

### CONCLUSIONS

- 7.1 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**

- 7.2 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.
- 7.3 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.
- 7.4 The GARNET is unpredictable and it is not yet clear why this should be.

#### **Impact on Other Water Chemistry Parameters**

- 7.5 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**

- 7.6 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.
- 7.7 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.

- 7.8 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.
- 7.9 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.
- 7.10 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**

- 7.11 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.
- 7.12 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.



**Rapid Assessment of Household Level Arsenic Removal Technologies – Phase II Report****SUMMARY OF CONCLUSIONS FOR EACH TECHNOLOGY**

FEATURE	ALCAN ENHANCED ACTIVATED ALUMINA	BUET ACTIVATED ALUMINA	DPHE/DANIDA 2BTU	GARNET	SONO 3 KOLSHI	STEVENS INSTITUTE	TETRAHEDRON
<b>Arsenic removal</b>	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.
<b>Other water chemistry</b>	OK	OK	Manganese and aluminium above Bangladesh Drinking Water Standards and WHO recommended health levels	OK	OK	OK	OK
<b>Bacteriological issues</b>	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.
<b>Break through</b>	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
<b>Flow rate</b>	>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)
<b>User acceptability</b>	1 <sup>st</sup> Favourite	7 <sup>th</sup> Favourite	3 <sup>rd</sup> Favourite	6 <sup>th</sup> Favourite	2 <sup>nd</sup> Favourite	5 <sup>th</sup> Favourite	4 <sup>th</sup> Favourite

### **Proponents**

- 7.13 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.

## **RECOMMENDATIONS**

### **Proponents**

- 7.14 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.
- 7.15 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**

- 7.16 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.
- 7.17 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.
- 7.18 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.
- 7.19 A more detailed cost-benefit analysis of arsenic removal technologies and alternative arsenic free sources of drinking water should continue alongside the programme.
- 7.20 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**

- 7.21 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.
- 7.22 When breakthrough is achieved, costs per litre of water for each of the technologies should be determined and the results made widely available.
- 7.23 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;

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- 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.

7.24 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.

7.25 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.