Bangladesh Environmental Technology Verification
-Support to Arsenic Mitigation
(BETV-SAM)

PERFORMANCE MONITORING AND EVALUATION

OF

READ-F Arsenic Removal Technology for Household

Final Performance Verification Report

Draft Version-1
September 2009

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ACRONYMS

ART	Arsenic removal technology
BCSIR	Bangladesh Council of Scientific and Industrial Research
BDW Std	Bangladesh Drinking Water Standard
BETV-SAM	Bangladesh Environmental Technology Verification – Support to Arsenic Mitigation
BGS	British Geological Survey
ETV-AM	Environmental Technology Verification – Arsenic Mitigation
GoB	Government of Bangladesh
MA	TPM Monitoring Agency
NAMIC	National Arsenic Mitigation Information Centre
TEC	Technical Expert Committee
TPM	Technology Performance Monitoring
TTC	Thermotolerant Coliform
WHO	World Health Organization

EXECUTIVE SUMMARY

The Bangladesh Environmental Technology Verification-Support to Arsenic Mitigation (BETV-SAM) project is a bilateral project between the Governments of Bangladesh and Canada. The project, among other activities, field tests arsenic removal technologies (ARTs) in order to either verify or deny a technology performance claim. The Environmental Technology Verification-Arsenic Mitigation (ETV-AM) project, predecessor to the BETV-SAM project, had selected and field tested five ARTs; four technologies, including the Read-F household ART, have been provisionally verified and are allowed to be marketed for normal household use, under the Conditions of Deployment specified in the provisional certificate document. Full certification of these technologies depends on their long-term performance during the Technology Performance Monitoring (TPM) Program.

The TPM Program was designed to assess the performance of provisionally verified ARTs under "real world" conditions, over a period of one year. The Program deployed thirty one (31) units of Read-F household ARTs over twenty five (25) wells with 25 different water matrices in Manikganj, Balagonj, Jhikorgacha, Ishwardi and Chapainawabgonj. These areas were chosen on the basis of their groundwater quality parameters, e.g. arsenic, iron and phosphate concentrations that meet or exceed the deployment conditions set in the provisional verification for the Read-F ART. Wells were selected following site selection criteria and the deployment conditions including suitability of water matrix, ease of access, proximity to possible point sources of pollution, and availability of space for installing ART, storing equipment, and performing water analysis on site.

Read-F ART units were operated and maintained by end-users, who were trained by the technology proponent and the MA field crews and supervised by the MA field crews. They recorded the volume of water treated in a day, assisted MA field crews in their routine work, and participated in other housekeeping activities. .

The technology performance was closely monitored by the MA field crews; they analyzed treated water for arsenic on a weekly basis using an Arsenator and following a strict QA/QC protocol; and collected samples of raw and treated water at regular intervals and delivered them to designated laboratories to be analyzed for arsenic, other chemicals, and microbiological contamination. The program lasted for about twelve (12) to fourteen (14) months to collect adequate data to be able to assess the performance of the Read-F ART.

The data collected during the TPM program shows that the technology performance appears a bit better than that found during the ETV-AM program. Nine Read-F units have reached breakthrough point after generating between 11,000 L and 46,000 L of arsenic safe-water; two more units were on the verge of breakthrough after producing more than about 40,000 L of treated water; and the rest were producing arsenic-safe water when the field monitoring was terminated.

Analysis of data presented in this report lead to the following conclusions.

1. Read-F ART can produce arsenic safe-water[1]water that meets Bangladesh drinking water standard guidelines from well water contaminated with ≤800 µg/L of As, ≤8.0 mg/L of phosphate, ≤0.4 mg/L of manganese, 0 – 20 mg/L of iron, and pH≈ 7 ± 1, provided that operating instructions given in this report are followed.
2. A Read-F unit should be able to provide Arsenic safe water to single family; 45 L to 50 L per day, for at least two (2) years and generate ≥32,000L of arsenic-safe water.
3. The technology is unable to remove manganese from well water and should not under any circumstances be used to treat groundwater containing >0.4 mg/L of manganese.
4. The technology performance should be monitored regularly to make sure that treated water meets the Bangladesh drinking water standards.
5. Read-F ART can and should be certified, with revised deployment conditions presented in **Section 5.2,** for marketing and sales in Bangladesh.

[1] "Arsenic-safe" is a terminology used to indicate that total As < 50 µg/L, i.e. below the permissible value for drinking water standard in Bangladesh (Government of Bangladesh: Ministry of Environment and Forest (1997) Environment Conservation Rules: Schedule 3.)

1. INTRODUCTION

The Bangladesh Environmental Technology Verification-Support to Arsenic Mitigation (BETV-SAM) project is a bilateral project between the Governments of Bangladesh and Canada. The project, among other activities, field tests arsenic removal technologies (ARTs) in order to either verify or deny a technology performance claim. The Environmental Technology Verification-Arsenic Mitigation (ETV-AM) project, predecessor to the BETV-SAM project, had selected and field tested five ARTs. BCSIR, on the basis of the field test results and recommendations from the Technical Expert Committee (TEC)[2], has issued Provisional Verification Certificates to four (4) technologies, Alcan, Read-F, Sidko, and SONO ARTs. These technologies are allowed to be marketed in Bangladesh to treat arsenic-contaminated groundwater under conditions stipulated in the Legal Agreement that the proponents signed. In addition, the ETV-AM program recommended an expanded field monitoring program, which examines the performance of these technologies in other regions and with different water quality parameters with the aim and/or hope of constructing a more complete picture of the capabilities and limitations of these technologies in Bangladesh.

The BETV-SAM Field Technical Performance Monitoring (TPM) Program was designed to assess the long term performance of these four ARTs under "real world" conditions and to generate data that will show the true capabilities of these technologies. Each technology that performs satisfactorily under this program will receive a final verification certificate from BCSIR**.** If on the basis of the TPM results, it is deemed necessary that the existing deployment conditions for the technology should be modified, the modifications will be documented in the deployment conditions provided with the final Verification Certificate.

This program deployed thirty (31) units of Read-F ART - a photograph of Read-F is shown in **Figure 1.** Twenty five (25) wells were used – triplicate units were deployed on three of the wells – with 25 water matrices in Manikgonj, Balagonj, Jhikargacha, Ishwardi and Chapainawabgonj regions of Bangladesh. The program closely monitored the performance of these Read-F units for about one year. The results of the year long TPM program on the Read-F ART are presented and discussed briefly in this report.

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[2] The TEC is composed of a select group of scientists and technology experts, assembled to advise BETV-SAM on technical aspects of the project.

FIGURE 1: A photograph of Read-F ART

2. OBJECTIVE

The primary objective of the TPM program was to field test the Read-F ART in different regions of Bangladesh under "real world" conditions and:

A. Assess its performance by collecting raw and treated water samples and analyze them for arsenic (As), other chemicals, and microbial contamination,

B. Improve the technology's performance/and output, if possible, through modification of Operation and Maintenance procedures,

C. Determine well water quality parameters, i.e. concentrations of arsenic, iron, phosphate, manganese, pH, etc. that the technology can treat , and produce potable/safe water

D. Make sure that treated water meets Bangladesh drinking water standard or WHO drinking water guidelines.

The project would, based on the TPM observations, either accept or reject the Read-F proponent's performance claim[3]. If the proponent's claim is verified at the end of the TPM project, the technology would be recommended for certification by the Government of Bangladesh (GoB) and be allowed to be marketed in Bangladesh under the set conditions that would be specified in the technology verification certificate.

[3] Limitations of Performance Verification Statements and Range of Applicability – Verification applies only to the operating conditions stated in the performance verification statement. In the monitoring program, the verification applies to the individual technology operated under the conditions of the verification test at the individual well.

3. PERFORMANCE MONITORING PROCEDURES

A detailed description of the technology performance claim, working and deployment conditions, and performance monitoring procedures have been described in detail in the Field Monitoring Instructions and Handouts and will only be described briefly in the following sections.

3.1 TECHNOLOGY DESCRIPTION

Read-F ART is designed to remove arsenic from arsenic contaminated tube well water using cerium oxide impregnated ethylene-vinyl alcohol (EVOH) resin. A schematic diagram of Read-F is shown in **Figure 2**. It consists of a plastic bucket (140mm diameter × 320 mm in height) with a lid, three plastic scoop-nets, cloth filters, arsenic removal media and sand filter. The arsenic removal media sits on a scoop-net that is placed about 20mm above the bottom of the bucket. At a distance of approximately 53mm above it is placed another scoop-net covered with two layers of cloth filters. The sand filter that sits on top of the second scoop-net and is in turn covered with a third scoop-net. The gross weight of the unit is approximately 7 kg. Arsenic contaminated well water is poured into the unit, allowed to filter through sand and arsenic removal media, and leave through the outlet port. Well water does not need pre-treatment and the unit operates in flow through mode. The Read-F technology is designed to serve one to three families.

3.2 PROPONENT'S PERFORMANCE CLAIM

The proponent originally claimed that a Read-F household unit is capable of processing 40,000L of groundwater with an influent arsenic concentration of ≤500 µg/L and generate arsenic-safe water at a minimum flow rate of about 1.1 L/min. No limitations were placed on other water quality parameters, such as pH and concentrations of dissolved Fe, PO_4^{3-}, Mn, etc. The ETV-AM program, on the other hand, specified that the technology could treat 40,000 L of groundwater contaminated with ≤500 µg/L of arsenic and other water quality parameters presented in Table 3.1 and produce arsenic-safe water.

Table 3.1: Groundwater quality treatable by Read-F ART as specified by the Proponent and ETV-AM

Source\Water Quality	[As]/µg/L	pH	Fe(II)/mg/L	PO_4^{3-}/mg/L
Proponent	≤500			
ETV-AM	≤500	≤ 7.5	≤ 10	≤ 4.0

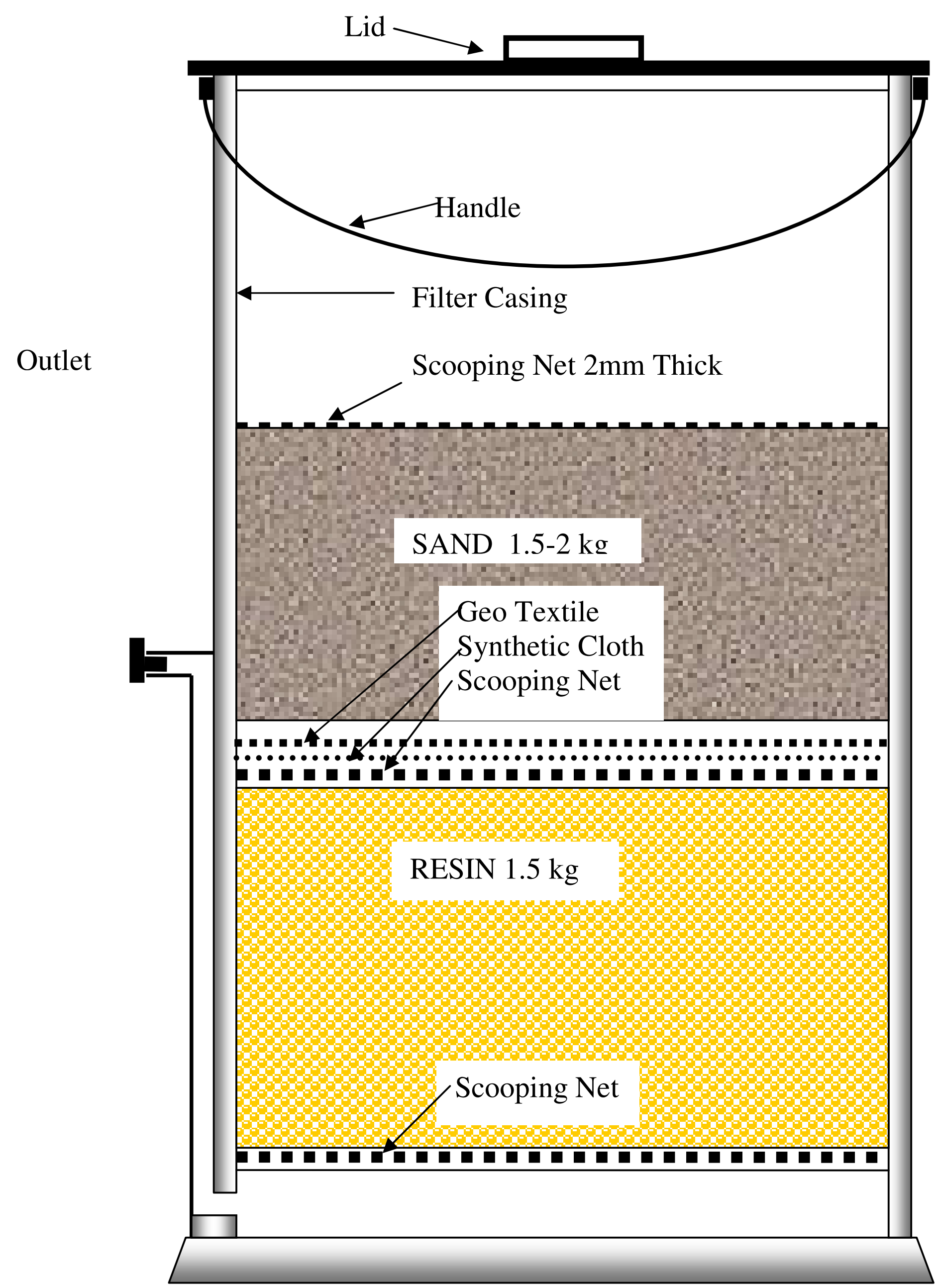

Figure 2: Schematic diagram of READ-F Household Arsenic Removal unit

3.3 SITE AND WELL SELECTION

The BETV-SAM project in consultation with BCSIR and the TEC selected Manikgonj, Balagonj, Jhikorgacha, Ishwardi and Chapainawabgonj sites for Read-F performance monitoring on the basis of their groundwater quality parameters. Twenty five wells were selected - four (4) in Manikgonj, two (2) in Balagonj, seven (7) in Jhikorgacha, six (6) in Ishwardi, and six (6) in Chapainawabgonj - after screening of wells in each region. Screening involved analyzing well waters for arsenic, iron, and phosphate using field test kits and selecting suitable wells; followed by a detailed analysis of the latter wells in an internationally accredited analytical laboratory. The selection was based on deployment conditions contained in the provisional verification certificates (**Table 3.1**), and other criteria discussed in section 1.0 above.

The concentrations of arsenic, iron, manganese, and phosphate in wells selected to monitor Read-F's performance varied between 100 µg/L and 800 µg/L, 0.3 mg/L and 20.1 mg/L, 21 µg/L and 2245 µg/L, and 0.2 mg/L and 8.0 mg/L, respectively, and all well water pH was around 7.0 ± 0.6. Nine wells - four in Manikganj, two in Balagonj, one in Ishwardi and two in Chapai - do not meet deployment conditions specified in the provisional verification certificate for arsenic, iron or phosphate. These wells were chosen deliberately in the hope of obtaining and/or identifying the true capabilities of the Read-F ART and finding deployment conditions that are realistic, appropriate, and based on field observations. A summary of the well water quality parameters are presented in **Table 3.2.**

Table 3.2: Summary of the well water quality parameters: Mean values ± CI (confidence interval at 95% confidence level) where the Read-F ARTs were deployed

Location	Well/ Unit ID	[As(T)] µg/L	As(III)/ As(T)	[Fe] mg/L	$[PO_4^{3-}]$ mg/L	[Mn] µg/L	pH
Manikgonj	W94/U1	213±17	0.96	18.74±1.71	5.9±0.8	768	7.1±1
	W36/U32	427±93	0.94	13.82±1.64	7.5±0.8	1,300	7.5±0.7
	W100/U3	120±8	0.93	12.97±1.33	4.4±0.6	505	7.1±0.5
	W145/U4	107±8	0.96	8.62±0.86	6.2±0.9	593	7.3±0.4
Balagonj	W60/U5	116±9	1.30	20.15±1.35	7.0±3.0	281	6.8±0.2
	W29/U6	152±16	0.75	3.30±0.07	7.8±3.6	39	7.1±0.1
	W29/U26	152±16	0.75	3.30±0.07	7.8±3.6	39	7.1±0.1
	W29/U27	152±16	0.75	3.30±0.07	7.8±3.6	39	7.1±0.1
Jhikorgacha	W14/U7	107±7	0.97	5.24±0.49	1.2±0.3	21	7.2±0.4
	W20/U8	108±10	0.92	3.99±0.50	2.5±0.7	63	7.3±0.4
	W34/U9	109±11	0.88	5.28±1.30	1.2±0.6	24	7.6±0.4
	W77/U10	100±14	0.91	5.78±1.0	1.8±0.6	36	7.2±0.4
	W15/U11	121±13	0.92	6.66±0.66	1.4±0.2	26	7.2±0.4
	W117/U12	395±32	0.98	7.74±1.03	1.9±0.2	44	7.2±0.4
	W118/U13	337±49	0.99	6.27±0.54	2.1±0.2	33	7.2±0.5
Ishwardi	W35/U14	456±147	1.00	6.15±1.07	2.0±1.2	777	6.7±0.6
	W36/U15	264±36	0.86	0.35±0.08	0.3±0.1	881	7.0±0.3
	W45/U16	191±19	0.87	0.57±0.77	0.3±0.1	1,100	7.1±0.2
	W53/U17	106±23	0.91	2.40±0.67	0.7±0.2	1,067	7.6±0.5
	W131/U18	392±15	0.85	1.40±0.50	0.2±0.0	1,200	7.2±0.3
	W101/U19	799±108	0.86	2.72±0.86	0.5±0.2	2,245	7.4±0.3
	W101/U28	799±108	0.86	2.72±0.86	0.5±0.2	2,245	7.4±0.3
	W101/U29	799±108	0.86	2.72±0.86	0.5±0.2	2,245	7.4±0.3
Chapai	W37/U20	203±28	0.95	2.55±1.73	0.4±0.6	1,404	7.0±0.5
	W44/U21	357±73	0.90	6.04±1.92	1.2±0.6	995	6.9±0.5
	W47/U22	475±36	1.07	12.00±2.43	3.2±1.2	605	6.8±0.6
	W51/U23	205±78	1.00	9.35±2.34	2.4±0.7	1,200	6.7±0.5
	W56/U24	532±77	0.94	7.44±1.87	1.8±0.6	910	6.8±0.5
	W05/U25	106±13	0.92	2.78±0.76	0.9±0.3	870	6.9±0.3
	W05/U30	106±13	0.92	2.78±0.76	0.9±0.3	870	6.9±0.3
	W05/U31	106±13	0.92	2.78±0.76	0.9±0.3	870	6.9±0.3

3.3 TECHNOLOGY INSTALLATION, OPERATION AND MAINTENANCE

All Read-F units have been installed by the MA field crews and operated and maintained by end-users under the supervision and guidance of the MA field crews. Both the MA field crews and the end-users have been trained by the proponent in technology installation, operation and maintenance (O&M) procedures. The end-users also recorded the daily production volume of arsenic-safe water and engaged in other housekeeping activities. In addition, the MA field crews also convened meetings in the local community from time-to-time, to ensure that the technology is operated and maintained properly and the villagers used treated water for drinking and cooking purposes.

The BETV-SAM and BCSIR engineers and scientists trained the MA field crews in taking, preserving, and delivering samples to the designated analytical laboratories, analyzing samples in the field, and data recording and record keeping procedures. They prepared and delivered weekly and monthly sampling schedules; took regular field trips to make sure that TPM activities proceeded as designed and expected; provided on the job training to the MA field crews, answered their questions and responded to their inquiries, and were on hand to deal with any and all issues pertaining to the TPM program.

The Read-F ART is designed to provide potable water to one to three households. It is a stand alone unit and operates like a conventional filter with water flowing downward and arsenic dissolved in water is adsorbed onto the media. The technology O&M specified that:

1. Backwash the filter media when water flow rate reduces significantly, which is a vague instruction
2. Backwashing frequency depends on concentration of Fe in well water, which is again a vague instruction, and
3. Other housekeeping instructions, such as covering the unit and cleaning water handling jugs, buckets, etc.

The technology as designed was inconvenient to operate because there were no provisions to store well water and feed it to the unit without an attendant being present. In order to improve its performance and ease of operation the following changes to the technology assembly and its O&M were implemented.

1. The unit was mounted on a stand with a raw water reservoir that could hold about 20L of well water. The well water was added to the reservoir, mixed well with air, and then fed into the Read-F unit.

2. Media was backwashed twice a week when treating water with ≥ 2mg/L of Fe and reduced backwashing to once a week when well water Fe is less than 2 mg/L
3. The daily production of treated water was restricted to about 120 L or alternatively increased backwashing frequency in proportion to daily production rate if higher volume of treated water was produced.

3.4 SAMPLING AND SAMPLE ANALYSIS

The Monitoring Agency (MA) conducted all field work in consultation with BCSIR and BETV-SAM engineers and scientists. They collected water samples (raw and treated), preserved and delivered them to the designated analytical laboratories or analysed them on-site for arsenic, iron, and other water quality parameters; measured flow rates, recorded daily production rate from caretakers' water consumption sheets, etc. Details on sampling, preservation, labeling, quality assurance and quality control (QA/QC), data recording and record keeping, and other related activities, are given in the Field Monitoring Instructions and Handouts and will not be repeated here. ***However, it was necessary to reschedule sampling frequency of treated water because of the technology was not operated as planned. Under the new schedule, the program collected samples at least once a month when the effluent As concentration was ≤20µg/L, two samples a month when the effluent As was between 20 and 29µg/L, and once a week when effluent As concentration reached to ≥ 30µg/L. In addition to As, water samples were also analyzed for Fe and*** PO_4^{3-} ***and Mn.***

4. EVALUATION OF TECHNOLOGY PERFORMANCE

Most Read-F units performed well and did not reach breakthrough during the field monitoring period, while a few had failed prematurely and/or reached breakthrough. Those that failed within the first six months of the monitoring period were recharged with fresh arsenic removal media and operated again. This section presents a summary of the field observation data and assesses Read-F's performance for the removal of arsenic, manganese, and other regulated chemicals that are found in groundwater as well as its propensity to harbour and grow bacteriological contamination.

4.1 ARSENIC REMOVAL ABILITY

Read-F's ability to remove arsenic from arsenic contaminated groundwater and produce arsenic-safe water was evaluated by collecting and analyzing raw and treated water samples, from each unit, for arsenic and other water quality parameters. A summary of the raw water quality data is presented in the previous section. The following sections will discuss treated water quality parameters.

As mentioned before, a number of effluent water samples were collected from each unit and analyzed for arsenic and other water quality parameters. The effluent arsenic concentrations prior to breakthrough from each unit were analyzed statistically (t-statistic)[4] using MINITAB®14 software. The results along with the volume of arsenic-safe water produced by each unit are presented in **Table 4.1** and shown graphically in **Figure 4.1**. Also presented in this Table are the p-values, which indicates the probability of effluent arsenic concentrations exceeding 50µg/L during the useful life of the arsenic removal media. **Figure 4.2** shows a normal probability plot showing expected standard deviations between measured and mean effluent As concentrations vs. effluent As concentration. The salient features of the data presented in **Table 4.1** are as follows:

1. All Read-F units performed well; eighteen (18) units generated ≥40,000L of arsenic-safe water, nine (9) units produced between 30,000L and 40,000L of arsenic-safe water, and the rest did not perform as well. The end-users operating these latter units - U26, U27, U19 and U28 –did not strictly adhere to the revised O&M procedures.
2. The improved performance of the Read-F ART is attributed to the changes made to the technology O&M procedures, which was discussed in the previous section. However, it is important to note that all end-users may not have adhered to the new O&M procedures.

[4] The ***t-statistic***, discovered by W. G. Gosset in 1908, is employed when the number of samples to be analysed is small, the normal distribution of the sample mean may not be applicable and the sample standard deviation is different from the true population standard deviation (obtained for a large number of samples).

3. The concentrations of As and PO_4^{3-} dissolved in groundwater – over the range of concentrations examined in this program – do not seem to affect Read-F's performance as demonstrated by the data presented in **Figures 4.3 and 4.4.** However, drawing a definite conclusion at this point is premature because majority of the units did reach to their breakthrough points and there are no indications that they will do so any time soon.
4. In most cases, effluent arsenic concentrations prior to breakthrough appears, as demonstrated in **Figure 4.1**, to be independent of the cumulative volume of treated water and fluctuates around a mean value of less than 50 µg/L. This is supported by the near linearity of the probability plots – for units that do not show arsenic breakthrough – presented in **Figure 4.2**. However, the effluent arsenic concentration appears to increase linearly with increasing volume of treated water in units #2 to #3 cases.

There are no reasons to believe that effluent arsenic concentrations should increase linearly with increasing volume of treated, similar to those seen for units U26, U19, and U15. It is very likely that these units have not been operated properly and iron dissolved in groundwater has not been oxidized and removed adequately through air oxidation and by the filter in these units.

The arsenic removal media have a nominal capacity for arsenic; as long as that capacity is not saturated or very close to being saturated, it should be able adsorb arsenic dissolved and in groundwater and reduce its concentration to a level that is controlled by the residence time or by the arsenic adsorption-desorption kinetics. However, the effluent arsenic concentration is expected to rise when the media capacity limit is approached.

The data presented in **Table 4.1** shows that almost all Read-F units (27 out of 31) were able to produce more than 34,000 L of arsenic-safe water and about nineteen (19) units producing more than 40,000 L of arsenic-safe water. Three (3) units produced less than 23,000 L of arsenic-safe water and these were units that were installed on wells 29 and 101 in Balagonj and Ishwardi, respectively. These observations cannot be attributed to water quality parameter because triplicate units installed on wells in Balagonj and Ishwardi produced widely varying quantity of arsenic-safe water. It cannot be attributed to variation among different units either, because triplicate units installed on a third well in Chapai produced comparable results and all other units performed very well. Therefore, it is assumed that those units were not operated properly by the end-users.

The data and the above discussion leads to the conclusion that Read-F could play an important role in the provision of arsenic-safe water to people in arsenic affected areas of Bangladesh provided that it is installed on appropriate wells and operated and maintained following instructions provided in this document.

Table 4.1: Total effluent arsenic concentrations, associated significance level (p-values), and the cumulative volumes of treated water generated by different Read-F units

Location / Unit	No. of Data Points	$[As(T)]_{Eff}$/ µg/L Mean ± CI[5]	P-value[6]	Cumulative Volume/L
Ma/U1	14	3±1	0	≥40,150
Ma/U32	32	44±6	0.08	=35,400
Ma/U3	17	3±1	0	≥37,980
Ma/U4	17	3±1	0	≥38,910
Ba/U5	16	5±1	0	≥34,100
Ba/U6	45	37±4	0	≥35,140
Ba/U26	23	37±11	0.02	23,160
Ba/U27	9	23±13	0.0	=12,780
Jh/U7	16	3±1	0	≥43,580
Jh/U8	16	4±1	0	≥43,650
Jh/U9	16	2±1	0	≥43,340
Jh/U10	16	2±1	0	≥40,710
Jh/U11	16	4±1	0	≥45,900
Jh/U12	15	10±4	0	≥43,540
Jh/U13	16	19±9	0	=46,920
Is/U14	15	10±4	0	≥43,460
Is/U15	22	38±11	0.03	=37,890
Is/U16	14	5±2	0	≥40,900
Is/U17	15	4±2	0	≥43,280
Is/U18	33	43±7	0.05	=43,090
Is/U19	19	56±16	0.44	=21,670
Is/U28	6	40	0.61	=10,740
Is/U29	28	39±11	0.05	=39,310
Ch/U20	14	4±1	0	≥41,120
Ch/U21	16	11±3	0	≥39,170
Ch/U22	16	23±10	0	≥41,480
Ch/U23	14	8±4	0	≥42,180
Ch/U24	14	7±2	0	≥40,880
Ch/U25	15	5±2	0	≥42,170
Ch/U30	14	1±0	0	≥40,310
Ch/U31	14	2±1	0	≥39,910

[5] CI stands for confidence interval

[6] P-values less than 0.05 (i.e. at 95% confidence level) indicate the probability of effluent arsenic concentration exceeding 50µg/L

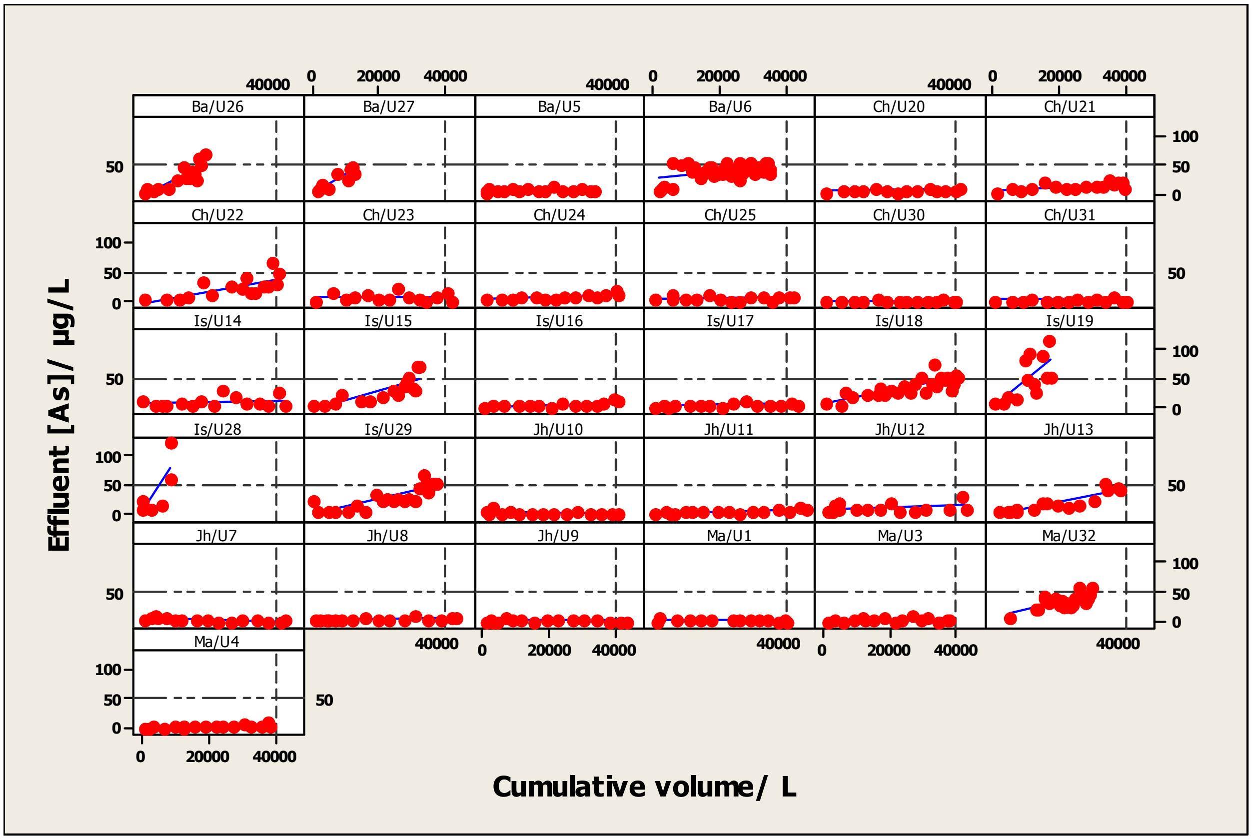

Figure 4.1: Plots showing effluent arsenic concentrations from different Read-F units as a function of volume of treated water

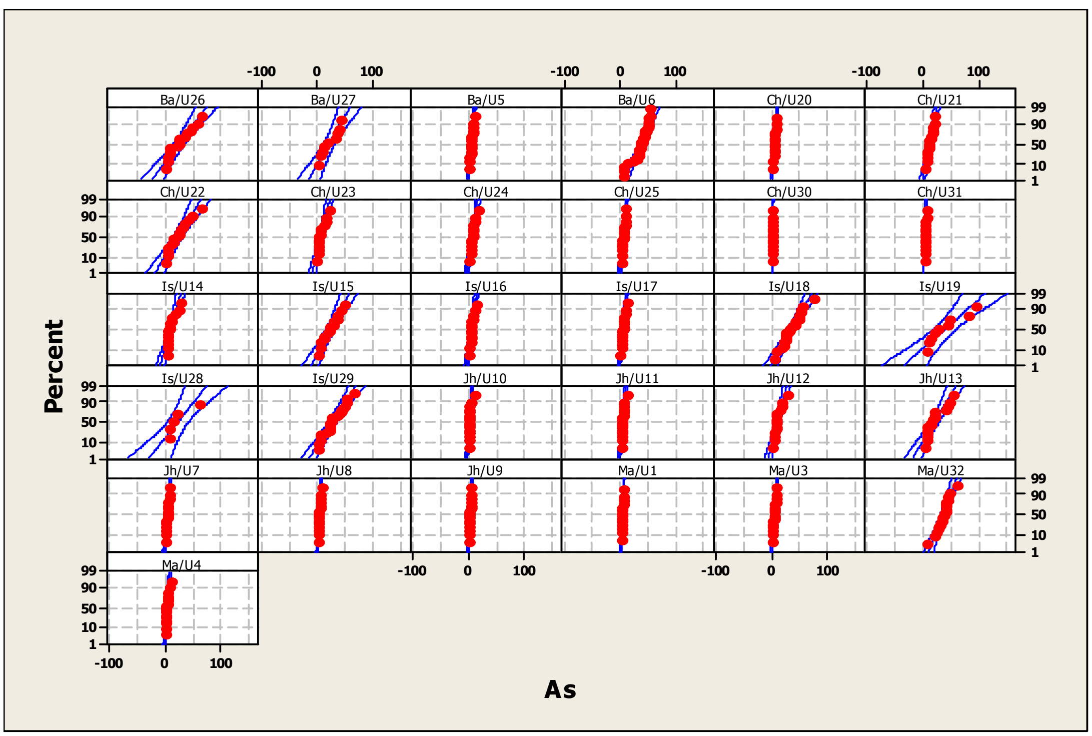

Figure 4.2: Normal probability plots showing expected standard deviations between measured and mean effluent As concentrations vs. Effluent As concentration

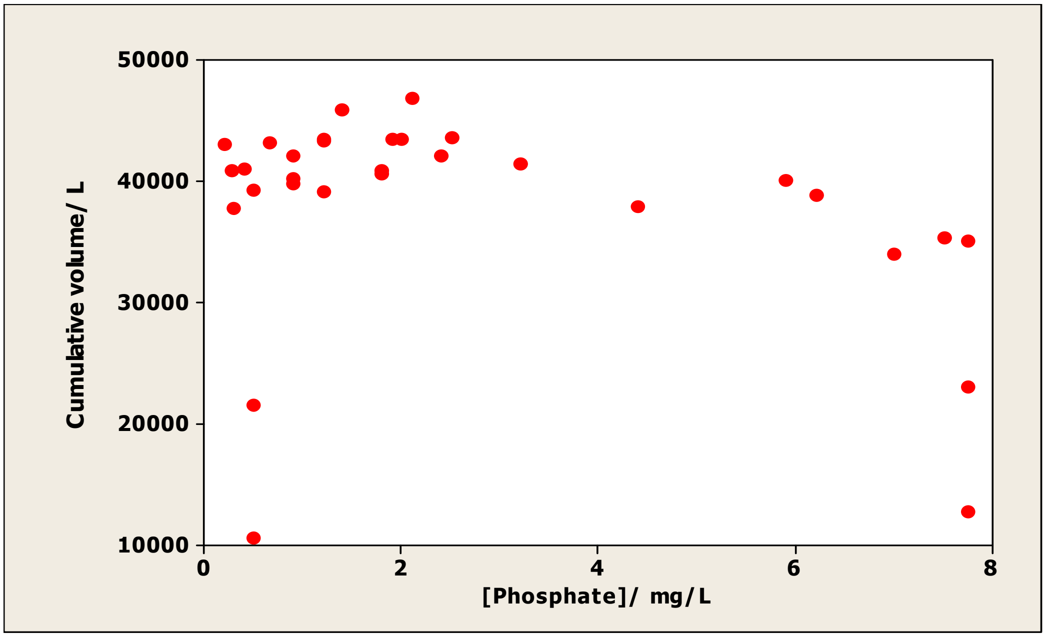

Figure 4.3: Plot showing volume of water treated by different Read-F units vs. concentration of phosphate in water

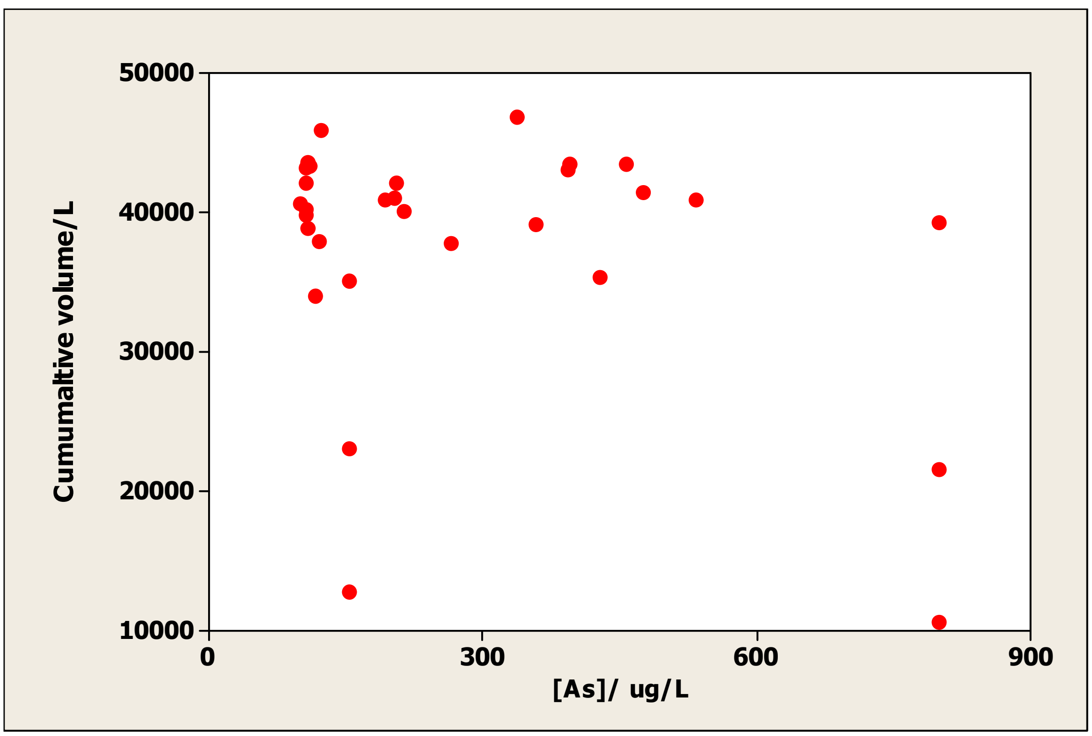

Figure 4.4: Plot showing volume of water treated by different Read-F units vs. concentration of arsenic in water

4.2 REMOVAL OF OTHER CHEMICALS

In addition to arsenic, raw and treated water samples were also analyzed for a host of other natural as well as technology-specific chemicals and bacteriological contamination. These findings have implications for the technology performance, the quality of water it generates and the handling and disposal of the wastes it generates.

For example, groundwater in Bangladesh is also known to contain manganese (Mn) at levels that exceeds the WHO guideline of 0.4 mg/L. Thus, raw and treated water were analyzed for Mn and sixteen (16) out of twenty five (25) wells selected to monitor Read-F performance monitoring were contaminated with ≥0.4mg/L of Mn. The average concentrations of Mn in raw and treated well water from different Read-F units are presented in **Table 4.2.** The data show that Read-F ART has limited capability for the removal of manganese and the fraction of Mn removed varies from unit to unit. Furthermore, the fraction of Mn removed by different Read-F units was insignificant for the most part. This makes the technology unsuitable to treat groundwater containing ≥0.4 mg/L of Mn.

Other chemicals that are found in groundwater in Bangladesh are barium (Ba), chromium, lead, nickel, and fluoride. Of these chemicals, only barium was found to be present at concentrations that exceed the Bangladesh drinking water standard of 10µg/L in all wells, but not the WHO guideline of 1 mg/L. The concentrations of Ba in the raw and treated water are presented in **Table 4.3**. As can be seen, Ba concentrations in groundwater varied between 77µg/L and 470µg/L and the fraction of Ba removed through treatment processes was small.

Table 4.2: Mean influent and effluent concentrations of manganese for different Read-F units

Location	Well/unit ID	No. of Data Points	$[Mn]_{Inf}$/µg/L	No. of Data Points	$[Mn]_{Eff}$/ µg/L
Manikgonj	W94/U1	3	768	4	545
	W36/U32	1	1300	3	1,078
	W100/U3	2	505	5	410
	W145/U4	3	593	5	242
Balagonj	W60/U5	2	281	4	149
	W29/U6	3	39	3	6
	W29/U26	3	39	2	4
	W29/U27	3	39	2	7
Jhikorgacha	W14/U7	2	21	3	7
	W20/U8	2	63	2	37
	W34/U9	2	24	2	5
	W77/U10	2	36	2	7
	W15/U11	2	26	2	13
	W117/U12	2	44	2	19
	W118/U13	2	33	3	26
Ishwardi	W35/U14	3	777	5	51
	W36/U15	3	881	2	7
	W45/U16	3	1100	6	155
	W53/U17	3	1067	6	202
	W131/U18	3	1200	12	236
	W101/U19	4	2245	8	153
	W101/U28	4	2245	2	1,055
Chapai	W37/U20	2	1404	3	1,263
	W44/U21	2	995	3	813
	W47/U22	2	605	2	495
	W51/U23	2	1200	2	1,150
	W56/U24	2	910	2	765
	W05/U25	2	870	2	700
	W05/U30	2	870	2	330
	W05/U31	2	870	2	530

Table 4.3: Mean influent and effluent concentrations of Barium for different Read-F units

Location	Well/unit ID	No. of Data Points	$[Ba]_{Inf}$ /µg/L	No. of Data Points	$[Ba]_{Eff}$ µg/L
Manikgonj	W94/U1	1	311	2	112
	W36/U32	-	-	2	115
	W100/U3	1	190	2	115
	W145/U4	2	185	2	52
Balagonj	W60/U5	1	77	3	29
	W29/U6	3	93	3	26
	W29/U26	3	93	2	18
	W29/U27	3	93	2	20
Jhikorgacha	W14/U7	1	380	1	260
	W20/U8	1	280	2	186
	W34/U9	1	340	2	235
	W77/U10	1	370	2	180
	W15/U11	1	460	2	355
	W117/U12	1	380	1	16
	W118/U13	1	330	3	257
Ishwardi	W35/U14	2	230	2	86
	W36/U15	2	160	3	110
	W45/U16	2	150	3	58
	W53/U17	2	180	3	103
	W131/U18	2	145	2	110
	W101/U19	2	125	2	45
	W101/U28	2	125	1	59
	W101/U29	2	125	3	27
Chapai	W37/U20	1	197	2	180
	W44/U21	1	240	2	190
	W47/U22	1	230	2	140
	W51/U23	1	470	2	345
	W56/U24	1	230	2	185
	W05/U25	1	220	2	170
	W05/U30	1	220	2	120
	W05/U31	1	220	2	155

4.3 PROPENSITY FOR BACTERIAL CONTAMINATION

The MA field crews, sample handlers and analyzers, and caretakers were given adequate personal hygiene instructions and were reminded on the importance of hygiene in order to prevent bacterial contamination in raw water, treated water and the technology. This, however, does not totally eliminate the possibility of contamination of water or the equipment. It was for this reason that raw and treated water in Manikganj, Balagonj and Ishwardi were analyzed for ThermotolerantColiform (TTC) and *E-coli*. These sites were selected because samples taken in these sites could be delivered to the designated laboratory within 6 hrs of sampling. The bacteriological test results presented in **Table 4.4a, 4.4b and 4.4c** show that:

1. The well waters are generally free from microbial contamination and any contamination found in raw water is most likely introduced at one point or another through the chain of events from sampling to sample analysis.
2. Most treated water samples were also found to be contaminated with TTC and *E.coli* and in a few cases, the contamination was found to be very high. Bacterial population in the treated water did not increase with time and did not exhibit a particular pattern. This could be due the fact individual units are flashed regularly with hot water, which could essentially destroy bacterial colonies formed in a unit.
3. Since well water is generally free from bacterial contamination, the observed contamination is believed to be introduced by the end-users, sampler and sample handlers, analysts, and others.
4. Closer of the data show that bacterial contaminations are possibly introduced by the end-user because treated water from some units, such as units #3 and #4 show occasional contaminations.
5. The data presented here does not allow a conclusion as to whether the Read-F ART does or does not harbor, foster, or grow bacteria.

Table 4.4a: The concentrations (counts/100 mL) of TTC and *E. coli* in raw and treated water samples taken from Read-F units in Balagonj

Well/Unit ID	Sampling Date	Influent		Effluent	
		TTC	E. Coli	TTC	E. Coli
W60/U5	16-Jan-08	0	-	39	4
W60/U5	30-Jan-08	0	-	15	4
W29/U6	16-Jan-08	0	-	20	11
W29/U6	30-Jan-08	0	-	3	3
W29/U6	13-Mar-08	0		152	83
W29/U26	13-Mar-08			8	0
W29/U26	16-Jan-08			14	5
W29/U26	30-Jan-08			5000	784
W29/U27	13-Mar-08			87	1
W29/U27	16-Jan-08			240	176

Table 4.4b: The concentrations (counts/100 mL) of TTC and *E. coli* in raw and treated water samples taken from Read-F units in Manikgonj

Well/Unit ID	Sampling Date	Influent		Effluent	
		TTC	E. Coli	TTC	E. Coli
W94/U1	7-Feb-08	0		23	0
W94/U1	7-Feb-08			0	
W94/U1	1-Apr-08	0		189	15
W94/U1	28-Apr-08	0		340	0
W94/U1	24-Jun-08	0		122	5
W94/U1	28-Aug-08	36	22	103	95
W94/U1	16-Sep-08	0		3	1
W94/U1	17-Dec-08	0		58	4
W36/U32	25-May-08			11	1
W36/U32	25-May-08			42	4
W36/U32	23-Jun-08			216	40
W36/U32	22-Jul-08	0		222	19
W36/U32	13-Aug-08	0		35	0
W36/U32	27-Aug-08	2	1	4	0
W36/U32	9-Sep-08	0		14	0
W36/U32	6-Oct-08	0		10	0
W100/U3	7-Feb-08	0		0	
W100/U3	7-Feb-08	0		0	
W100/U3	1-Apr-08	0		0	
W100/U3	28-Apr-08	0		0	
W100/U3	24-Jun-08	0		10	1

W100/U3	28-Aug-08	0		133	12
W100/U3	16-Sep-08	7	0	0	
W100/U3	17-Dec-08	0		0	
W145/U4	27-Feb-08	0		114	42
W145/U4	27-Feb-08	0		224	112
W145/U4	1-Apr-08	0		0	
W145/U4	28-Apr-08	0		184	17
W145/U4	24-Jun-08	1	1	58	53
W145/U4	27-Aug-08	0		0	
W145/U4	17-Sep-08	0		1	1
W145/U4	21-Dec-08	0		2	0

Table 4.4c: The concentrations (counts/100 mL) of TTC and *E. coli* in raw and treated water samples taken from Read-F units in Ishwardi

Well/Unit ID	**Sampling Date**	**Influent**		**Effluent**	
		TTC	**E. Coli**	**TTC**	**E. Coli**
W35/U14	23-Mar-08	5	0	59	47
W35/U14	23-Apr-08	26	0	2	0
W35/U14	25-May-08	0		1000	392
W35/U14	13-Jul-08	1	1	72	16
W35/U14	13-Jul-08	2	0	79	27
W35/U14	10-Sep-08	4	3	210	19
W35/U14	13-Oct-08	63	28	11	10
W35/U14	12-Jan-09	0		13	0
W36/U15	23-Mar-08	50	26	296	10
W36/U15	23-Apr-08	0		18000	0
W36/U15	25-May-08	0		19	3
W36/U15	13-Jul-08	1	0	17	9
W36/U15	13-Jul-08	0		12	7
W36/U15	4-Sep-08			35	11
W36/U15	10-Sep-08	8	4		
W36/U15	23-Sep-08	0		60	14
W36/U15	28-Oct-08	0		24	7
W36/U15	16-Nov-08	0		198	3
W36/U15	30-Nov-08	0		208	3
W45/U16	23-Mar-08	0		3	0
W45/U16	23-Apr-08	0		78	38

Well/Unit ID	Sampling Date	Influent		Effluent	
		TTC	E. Coli	TTC	E. Coli
W45/U16	25-May-08	0		8	0
W45/U16	13-Jul-08	1	0	5000	568
W45/U16	13-Jul-08	1	0	980	53
W45/U16	10-Sep-08	0		15	5
W45/U16	13-Oct-08	0		200	3
W45/U16	12-Jan-09	0		50	6
W53/U17	23-Mar-08	0		94	0
W53/U17	23-Apr-08	1	1	53	45
W53/U17	25-May-08	2	0	4	4
W53/U17	13-Jul-08	0		32	11
W53/U17	13-Jul-08	0		36	5
W53/U17	10-Sep-08	0		320	15
W53/U17	4-Oct-08			13	9
W53/U17	13-Oct-08	120	28		
W131/U18	23-Mar-08	0		1	0
W131/U18	23-Apr-08	0		75	5
W131/U18	25-May-08	2	1	8000	220
W131/U18	26-Jun-08	0		46	6
W131/U18	26-Jun-08	0		31	8
W131/U18	23-Jul-08	2	2	4	1
W131/U18	14-Aug-08	65	40	55	27
W131/U18	16-Sep-08	0		32	2
W131/U18	16-Sep-08	3	0	27	2
W131/U18	16-Nov-08			25	1
W131/U18	4-Dec-08	2	0	14	0
W131/U18	12-Jan-09	74	0	19	3
W101/U19	23-Mar-08	0		0	
W101/U19	20-Apr-08	0		159	4
W101/U19	18-May-08	0		5	0
W101/U19	28-May-08	32	0	11	0
W101/U19	28-May-08	14	0	22	0
W101/U19	25-Jun-08	0		36	1
W101/U19	26-Jun-08	0		25	0
W101/U19	16-Jul-08	0		138	15

Well/Unit ID	Sampling Date	Influent		Effluent	
		TTC	E. Coli	TTC	E. Coli
W101/U28	23-Mar-08			0	
W101/U28	20-Apr-08			7	0
W101/U28	18-May-08			25	8
W101/U29	6-Apr-08			9	
W101/U29	20-Apr-08			49	0
W101/U29	18-May-08			1000	4
W101/U29	16-Jul-08			7	2
W101/U29	25-Aug-08			11	0
W101/U29	16-Sep-08			8	0
W101/U29	4-Dec-08	0		2	0
W101/U29	19-Jan-09	5	0	3	0

5 RECOMMENDATION AND DEPLOYMENT CONDITIONS FOR READ-F

5.1 RECOMMENDATION

Thirty one (31) units of Read-F ART have been deployed and installed on twenty five (25) wells – triplicates were installed on three (3) wells - in five different regions of Bangladesh and operated by the end-users under the supervision of the MA field crews under "real world" conditions. The data presented in the previous section show that:

1. Almost all units (27) generated ≥ 34,000L of arsenic-safe water and units installed on 80% of the wells generated more than 40,000 L of arsenic-safe water.
2. Twenty (20) units – that is 80% of wells with water treated by Read-F ART – do not show any indications of imminent arsenic breakthrough (see **Figure 4.1**) after generating 34,000 L to 46,000L of arsenic-safe water.
3. The performance of the Read-F ART on 80% of the wells meets or exceeds the proponent's performance claim. On the remaining wells, the technology meets or exceeds ≥85% of the proponent's performance claim (40,000) apart from 4 Read-F replicate units which do not meet or exceed >85% of the proponent's performance claim.
4. Poor hygiene practices could easily contaminate treated with bacterial contaminations because arsenic removal has to be washed by hands once or twice a week.

It is safe to conclude that the technology can provide arsenic-safe water to people in arsenic affected areas of Bangladesh by following the deployment conditions specified below. BETV-SAM, on the basis of performance monitoring and evaluation presented in this report, recommends that Read-F ART be certified for marketing and sale in Bangladesh.

5.2 READ-F DEPLOYMNET CONDITIONS

The performance monitoring data presented and analyzed in previous sections indicate that Read-F ART can produce arsenic-safe water if it is deployed on wells that meet the deployment conditions specified below. The performance monitoring data also show that the technology is prone to biological contamination. The adverse health effect of bacterial contamination treated water could overwhelm the gains made from removing arsenic. It is for these reasons that BETV-SAM recommends that the technology should be deployed under the following terms and conditions.

5.2.1 Deployment Condition

1. Read-F can produce arsenic-safe water that meets Bangladesh drinking water standard from well water contaminated with ≤800 µg/L of As, ≤8.0 mg/L of phosphate, ≤0.4 mg/L of manganese, 0 – 20 mg/L of iron, and pH 7.0 ± 0.8
2. The well water should be analyzed before the deployment and installation of a Read-F unit to make sure that well water meets conditions specified in Condition **#1** above.
3. The proponent must supply an *Installation, Operation and Maintenance Manual* that contains the **RECOMMENDATION AND DEPLOYMENT CONDITIONS FOR READ F.**
4. A Read-F unit should be able to provide Arsenic safe water to single family; 45 L to 50 L per day, for at least two (2) years and a Read-F ART should be able to generate ≥40,000L of arsenic safe water.
5. The technology is unable to remove manganese and should not under any circumstances be used to treat groundwater containing >0.4 mg/L[7] of manganese.
6. The sand and arsenic removal filter media must be washed regularly and frequently. When Fe concentration is ≥2 mg/L in the well water, the sand and arsenic removal media have to be washed at least twice in a week. The washing frequency can be reduced to once a week when Fe concentration is less than 2 mg/L.
7. The unit should be sterilized with about 5 L of boiling water after washing media.
8. The technology should not be used to produce more than about 120 L of arsenic-safe water in a day, unless the washing frequency is adjusted proportionately.
9. The technology performance should be monitored after deployment to make sure that treated water is safe for human consumption. Therefore, treated water should be tested for arsenic: a) immediately after technology installation.
10. The technology proponent must comply with the Government of Bangladesh approved National Waste Management Protocol for safe disposal of arsenic wastes generated by Read-F ARTs.

5.2.2 Hygiene Practice

1. The end-users should wash their hands with soap and plenty of water and make sure that they are absolutely clean before adding water to the unit, removing and washing sand and arsenic removal media (**Section 5.2.1; point #5**), or servicing Read-F any other way.

[7] This limit is recommended by the World Health Organization

2. The pots or pans to be used to wash arsenic removal media should be cleaned thoroughly. To do this, add about 2 L of water to the pot, add one tea-spoon of either Chlotech solution or bleach powder to the water, mix it well, swirl it around a number of times and then throw it away, rinse it with clean water.
3. Remove arsenic removal media and sand, pour it in the above clean pot, wash it with clean water to remove iron oxide, and then put cleaned media and sand back into the unit.
4. Sterilize media with boiling water after cleaning.

5.2.3 Media Replacement

1. The technology performance should be monitored periodically to ensure that treated water is arsenic-safe. Hence, the treated water should be analyzed after six (6) months of technology installation and once every two months (or bimonthly) thereafter that.
2. The arsenic removal media should be replaced when arsenic concentration in the treated water is greater than 40 µg/L.
3. A Read-F unit that is deployed following the above conditions to serve a single family should be able to produce arsenic-safe water for at least two years at a rate of 45L/day. Therefore, the unit's arsenic removal media have to be replaced with fresh media after two years if treated water cannot be analyzed in an approved testing facility to ensure that its arsenic content is below 50 µg/L and conforms to the Bangladesh drinking water standard for arsenic. This is a costly option; however, it is the only option that would lower the villager's risk of consuming water contaminated with unacceptable level of arsenic, due to the fact that the Read-F unit's filtration media has possibly reached the end of its useful life.

The technology proponent must supply an Installation, Operation and Maintenance manual to the users that incorporates the above directives and must train at least one person to be responsible for technology operation and maintenance.

5.2.4 Technology Users Support Systems

This section deals with the support system for the technology user. Read-F ART certification is not predicated upon the realization of the recommendations made here. The

BETV-SAM, however, feels that efforts should be made to fulfil the following recommendations and that they are essential to the sustainable use of Read-F ART.

1. ***Analysis of treated Water for Arsenic***: As suggested above, Read-F technology users should replace the Read F unit's media after two years, unless they can have water treated by their Read-F unit and know that after two years, the unit is still producing arsenic-safe water. Ideally, however, a mechanism should exist that would allow testing the treated water affordably at regular intervals before the two year time line is over, to ensure that the unit is still functioning properly and producing arsenic-safe water for the household that acquired the unit. This would provide the most reliable indicator of when the Read-F unit in a possession stop producing arsenic-safe water and needs to be replaced with a new unit. This test would consist of an analysis, using a reliable laboratory or a reliable field test kit used by a trained technician, of the arsenic concentration in the treated water. Presently, there are very few facilities in the arsenic affected areas of Bangladesh that have the ability to analyse water samples for arsenic with acceptable and consistent level of accuracy. Such facilities are required if ARTs are to be used in an optimal manner, from the standpoint of producing arsenic-safe water. There are DPHE and NGO regional laboratories/offices that should be able to provide such a service. In addition, there are trained community healthcare professionals and possibly young university graduate entrepreneurs, who would be able to provide this service with training and assistance from DPHE, BCSIR, and other governmental organizations. It is the role of DPHE to promote and over see the development of a testing capability in arsenic-affected areas.

2. ***Technology Distribution System***: Any technology is likely bound to break down at some point in its life. Repairs and spare parts will be needed. This and other investigations have found that taps, buckets, and other pieces of a Read-F break down often enough and have to be replaced. For most households, reaching the Read-F vendor and acquiring replacement would be very, very difficult if not impossible altogether. A distribution office in the vicinity, a store acting as an agent for the vendor, or any such facilities located in the town shopping centre or within a convenient distance would be very useful. If these facilities were

available in the immediate vicinity, then Read-F ART users could readily obtain parts required for repairing a broken unit, ask questions about technology operation and maintenance, and obtain guidance if and when needed. Furthermore, Read-F ought and should stock-up spare parts and supply them to distribution offices, vendors, etc.

ANNEX A: COST ANALYSIS

The following Table provides the cost of production of arsenic-water (per Litre and per day) to Read F ART users. The calculation does not take into account the cost of replacement of broken taps and other repair costs since we do not have their prices.

Table A1: Household arsenic-safe water production coasts

Considerations and Description	Quantity	Basic Cost	Costs (Basic + Maintenance & Depreciation)
Read F ART Cost		Tk5,500[8]	
Daily Production Volume	45 L		
Media longevity[9]	2 years		
Volume of Arsenic-Safe Water Produced in two years	33,000 L		
Depreciation Costs	20%/Year		
Arsenic Removal Media	1 set	Tk5,000[8]	
Read F Media Housing Longevity	5 years		
The Cost of Treating One Liter of Water		**Tk0.17**	**Tk0.19**
Daily Water Consumption Const		**Tk7.50**	**Tk7.64**
Monthly Water Consumption Cost [10]		**Tk225.50**	**Tk229.1**

NOTES:

The cost estimates presented in the above Table is based on the assumption that:

1. A household consumes 45 L of arsenic-safe water in a day.
2. Only arsenic removal media has to be replaced for five years or as long as the Read F unit lasts.

[8] These price could change with time

[9] Based on TPM Data

[10] 30 days per month