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

PERFORMANCE MONITORING AND EVALUATION

OF

SIDKO AdsorpAs® Granular Ferric Hydroxide Technology

Final Performance Verification Report

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 Sidko, have been provisionally verified and are allowed to be marketed for normal household and community 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 fifteen (15) units of Sidko community ARTs over as many wells with varying water matrices in Manikganj, Jhikargacha, Bera and Chapai. 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 these particular ARTs. 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.

Sidko ART units were operated and maintained by caretakers under the supervision of the monitoring agency's (MA) field crews and after being trained by the technology proponent and the MA field crews. The caretakers also recorded volume of water treated in a day, assisted MA field crews in their routine work, and engaged 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 field test kits following strict QA/QC protocols or in independent analytical laboratories following Standard Methods; and collected samples of raw and treated water at regular intervals and delivered 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 Sidko ART.

The data collected during the TPM program shows that the technology performance appears to be much better than that found during the ETV-AM program. Three Sidko units have reached breakthrough point after generating between 220,000 L and 387,000 L of arsenic safe-water; three more units were on the verge of breakthrough after producing more than about 383,000 L of treated water; and the rest were producing arsenic-safe water when the field monitoring were terminated.

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

1. The technology can produce arsenic-safe[1] water from well water contaminated with $\leq$750 µg/L of As $\leq$7 mg/L of phosphate, $\leq$0.4 mg/L of manganese, 0.0 to 23.0 mg/L of iron, and pH 7.0 ± 1.0
2. The technology cannot remove manganese from groundwater and should not under any circumstances be used to treat groundwater containing $\geq$0.4 mg/L of manganese.
3. A Sidko unit installed and operated following the instructions given in this report, should be able to provide arsenic-safe water to about 20 families, 45 L to 50 L per family per day, for at least one (1) year; i.e. a Sidko should be able to generate $\geq$360,000 L of potable water.
4. The Sidko 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 different 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 report is dealing with the performance of Sidko ART.

The program deployed fifteen (15) units of Sidko ART - a photograph of Sidko ART is shown in **Figure 1** - over as many wells and as many water matrices in Manikgonj, Jhikargacha, Bera and Chapainawabgonj regions of Bangladesh and closely monitored their performances for about one year. The results of the year long TPM program on the Sidko 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 Sidko ART

2. OBJECTIVE

The primary objective of the TPM program was to field test the Sidko 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 Sidko proponent's performance claim[3]. If the technology's performance is verified at the end of the TPM project, it 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

Sidko ART – a flow diagram of which is shown in Figure 2 – is a flow-through arsenic removal filter. It consists of two 500 L tanks, one for the raw water and the other to store treated water; an iron removal (sand) filter to remove iron flocs generated from oxidation of iron dissolved in well water; and an arsenic removal filter filled with AdsorpAs® media to remove dissolved arsenic. Well water is aerated while being pumped into the raw water tank in order to oxidize and flocculate iron dissolved in groundwater. Flocculated iron is removed by an iron removal filter and arsenic dissolved in water is removed by adsorption on the AdsorpAs® media. The Sidko technology is designed to serve fifty families; to supply a minimum of 2250 liters – 45 L per family per day - of potable water per day; and to generate about 600,000 L of arsenic-safe water.

3.2 PROPONENT'S PERFORMANCE CLAIM

The proponent originally claimed that the Sidko community unit ART is able to treat groundwater contaminated with ≤500 µg/L arsenic, < 0.5 mg/L of phosphate, <0.2 mg/L of dissolved iron, and other contaminants specified in Table 3.1 and produce 600,000L of arsenic-safe water. The ETV-AM program, on the basis of its field testing, specified that the technology could treat groundwater contaminated with ≤500 µg/L of arsenic, ≤4.0 mg/L of phosphate, ≤10 mg/L of dissolved iron, and pH ≤7.5 and produce 121,500 L of arsenic-safe water.

Table 3.1: Groundwater quality treatable by Sidko ART as specified by the Proponent and ETV AM

	[As]/ µg/L	pH	O_2/mg/L	Fe(II)/mg/L	Mn^{2+}/ mg/L	PO_4^{3-}/mg/L
Proponent	≤500	5.5 – 9.0	>0.5	<0.2	<0.05	≤ 0.5
ETV AM	≤500	<7.5	---	≤10	---	≤4.0

Open V_1 & V_4 and close V_2, V_3 and V_5 for Normal Operation
Open V_2 & V_3 and close V_1, V_4 and V_5 for backwashing

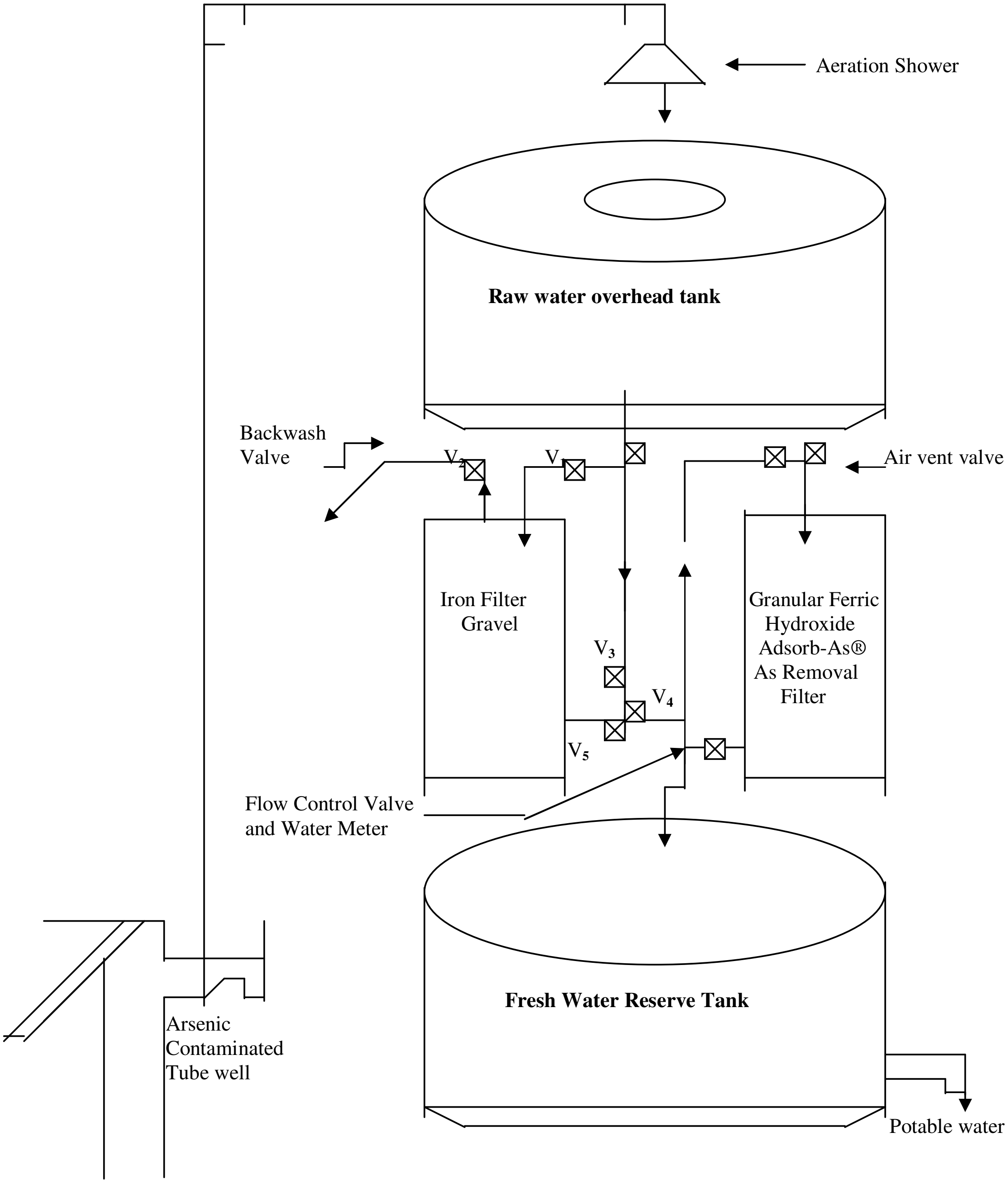

Figure 2: A schematic flow diagram of a SIDKO arsenic removal system

3.3 SITE AND WELL SELECTION

The BETV-SAM program in consultation with BCSIR and the TEC selected Manikgonj, Bera, Jhikorgacha and Chapainawabgonj for Sidko performance monitoring. The selection was made on the basis of groundwater quality parameters. Four wells were selected in each of Bera, Chapai, and Manikgonj and three in Jhikorgacha after screening wells in each region, analyzing well waters for arsenic, iron, and phosphate using field test kits and selecting suitable wells, and a detailed analysis of well water samples from wells that met well selection criteria in an internationally accredited analytical laboratory. These wells were selected on the basis of deployment conditions contained in the provisional verification certificates (**Table 3.1**), ease of access, proximity to possible point sources of pollution, and availability of space to install the Sidko ART, store equipment and for analysis of water samples on site.

Table 3.2: Summary of the well water quality parameters: Mean values ± CI (confidence interval at 95% confidence level) where the Sidko ART 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	W06/U1	292±26	0.91	16.01±0.95	6.88±1.38	1240	7.1±0.22
	W86/U2	167±30	1.01	4.67±3.27	3.96±2.77	430	7.4±0.35
	W107/U3	147±9	1.00	16.84±1.27	6.18±1.68	465	7.1±0.69
	W125/U4	101±9	0.83	7.04±0.87	4.80±1.74	185	7.2±0.09
Jhikorgacha	W30/U5	106±13	0.09	5.85±0.66	1.3±0.29	27	7.1±0.12
	W68/U6	94±5	0.87	5.75±0.65	2.28±0.35	88	7.2±0.26
	W76/U7	101±9	0.92	5.62±0.93	2.43±0.20	92	7.4±0.31
Bera	W02/U8	188±47	0.66	9.02±1.21	1.87±0.85	1133	7.3±0.23
	W85/U9	439±85	0.33	10.07±3.48	1.43±0.20	1356	7.3±0.14
	W86/U10	91±9	0.56	1.07±0.20	0.63±0.17	777	7. 0±0.29
	W87/U11	78±7	1.19	23.83±1.13	0.9±0.63	623	6.9±0.25
Chapai	W70/U12	541±58	0.77	5.31±1.10	1.08±0.72	1333	7.3±0.20
	W71/U13	188±23	0.97	2.01±1.01	0.8±0.45	987	7.2±0.33
	W57/U14	725±23	0.90	9.74±0.76	1.6±1.72	1333	7.2±0.1
	W74/U15	345±19	1.23	1.13±0.15	1.37±1.90	1733	7.3±0

The concentrations of arsenic, iron, manganese, and phosphate in wells selected for Sidko's performance varied between 78 µg/L and 725 µg/L, 1.07 mg/L and 23.83 mg/L, 27 µg/L and 1733 µg/L, and 0.63 mg/L and 6.88 mg/L, respectively and well water pH was around 7.0. A summary of the well water quality parameters are presented in **Table 3.2.** The data presented in **this Table** show that five wells; three in Manikganj and two in Chapai, do not meet deployment conditions set in the provisional verification certificate for arsenic, iron or phosphate. These wells were chosen deliberately in the hope of obtaining the true capabilities of Sidko ART and finding deployment conditions that are realistic, appropriate, and are based on field observations.

3.4 TECHNOLOGY INSTALLATION, OPERATION AND MAINTENANCE

All Sidko units have been installed by the Sidko proponent and operated and maintained by caretakers under the supervision and guidance of the MA field crews. Both the MA field crews and the caretakers have been trained by the proponent in technology installation, operation and maintenance (O&M) procedures. The caretakers also recorded the daily production volume of arsenic-safe water, engaged in other housekeeping activities, and assisted the MA field crews in their daily work. The MA field crews supervised the day-to-day operation of the technology, trained caretakers in data recording and record keeping, and participated in the media backwashing media and repair work. 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 purpose.

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 trip 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 Sidko ART is designed to operate semi-automatically in that the pump starts automatically pumping well water into the raw water tank when it is empty. All units were not operated uniformly for the first four months of the program and the daily production rate varied from 200L to 2000L. The production rate would have a strong influence on technology performance. Units producing around 1500 to 2000 L/day of arsenic-safe water failed prematurely and after being operated for about three to four months and treating about 120,000 L of groundwater. While those treating ≤1000L well water in a day did not show any sign of imminent arsenic breakthrough. In order to operate all Sidko units the same way, the following changes to the Sidko O&M were put in place: a) restrict daily production rate to about 1000 L and b) backwash iron filter two to there times in a day preferably after treating about 500 L (or a tank) of groundwater. These changes are expected to: a) allow iron dissolved in groundwater to be fully oxidized, flocculate, and hopefully precipitate in the raw water tank, b) reduce the amount of iron flocs reaching the iron filter, and c) eliminate iron flocs reaching the arsenic removal filter. Attempts have been made to implement the above changes to the technology O&M between May 2008 and March 2009; however, the changes have been applied uniformly. The MA field crews or the proponent backwashed the arsenic removal filter when the flow rate was considerably reduced.

3.5 SAMPLING AND SAMPLE ANALYSIS

The MA field crews 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 analyzed them on-site for arsenic, iron, and other water quality parameters; measured flow rates, recorded daily production rate from caretakers' log book, 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,*** PO_4^{3-} ***and Mn.***

4. EVALUATION OF TECHNOLOGY PERFORMANCE

Most Sidko 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 iron and arsenic removal media and operated again. This section presents a summary of the field observation data and assesses Sidko's performance for the removal of arsenic, manganese, and other regulated chemicals that are found in groundwater and evaluates Sidko's propensity to harbour and grow bacteriological contaminations.

4.1 ARSENIC REMOVAL ABILITY

Sidko'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 (see **Table 3.1**) and the treated water quality parameters will be presented and discussed in the following sections.

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 was 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, the probability - within 95% confidence limit - of effluent arsenic concentrations exceeding 50μg/L during the useful life of the arsenic removal media.

Please note that **Figure 4.1** does not show data collected for the Sidko unit #15. This is because this unit failed prematurely soon after installation and again after being recharged with fresh arsenic and iron removal media. Hence, the number of samples of treated water collected and analyzed from this unit is small and inadequate for statistical analysis.

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[4] The ***t-statistic***, discovered by W. G. Gosset in 1908, is employed when number of samples to be analyzed 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).

The salient features of the data presented in Table 4.1 are as follows:

1. All Sidko units performed well and thirteen units out of the fifteen generated ≥290,000L of arsenic-safe water, which is at least nearly three times that produced during the ETV-AM field testing program. The lower production capacity of the other units (U1, U9 and U15) - still higher than those generated during ETV AM - is perhaps due to the way these three units were operated.
2. The improved performance of the Sidko ART is attributed to the changes made to the technology Operation and Maintenance procedures, which was discussed in the previous section. However, it is important to note that caretakers may not adhered to the new O&M procedures because of operational difficulties, such as time limitations, etc.
3. The volume of treated water (**Figures 3 and 4**) does not show any correlation with concentrations of arsenic and phosphate in well water over the range of concentrations examined in this project. These observations along with the fact at least 50% of the units did reach breakthrough point make it difficult to draw a definite conclusion on the effect of arsenic and phosphate on Sidko's performance.
4. Iron dissolved in groundwater, however, appears to help technology performance. Most units installed on wells containing ≥5 mg/L of dissolved iron performed very well and did not reach breakthrough point by the time this program was ended with a few exceptions; such the ones installed on wells #9 and #10. However, high dissolved iron could also lead to premature arsenic breakthrough if the technology is not operated properly and instructions given in this report are not followed.
5. Effluent arsenic concentration 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 except for units U1, U5, U6, and U7. This is supported by the near linearity of the probability plots – for units that do not show arsenic breakthrough – presented in **Figure 4.4**. For these units, however, effluent arsenic concentration appears to increase linearly with increasing volume of treated water. This is perhaps due to the way that these units have been operated.

There are no reasons to believe that effluent arsenic concentrations should increase linearly as the volume of treated water increases, similar to those seen for units U1, U5, U6, and U7. 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 the iron removal filter in these units. Consequently, some of the iron leaked through the arsenic removal filter and ended-up in the effluent. Generally, treated water containing ≥35 µg/L of As was found to contain 0.2 – 5.0 mg/L of iron and high As in the effluent is generally found to be associated with high iron.

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

Location / Unit	No. of Data Points	$[As(T)]_{Eff}$/ µg/L Mean ± CI[5]	P-value[6]	Cumulative Volume/L
Ma/U1	27	19±5	0.00	>293,000
Ma/U2	20	2±1	0.00	>343,000
Ma/U3	20	10±3	0.00	>363,000
Ma/U4	17	6±2	0.00	>395,000
Jh/U5	29	38±5	0.00	≥383,000
Jh/U6	40	34±4	0.00	≥403,000
Jh/U7	31	41±4	0.00	≥387,000
Be/U8	14	10±5	0.00	>323,000
Be/U9	30	31±5	0.00	≥254,000
Be/U10	25	16±4	0.00	>319,000
Be/U11	17	3±1	0.00	>398,000
Ch/U12	26	28±6	0.00	≥422,000
Ch/U13	26	23±6	0.00	≥356,000
Ch/U14A[7]	9	24±13	0.00	>309,000
Ch/ U15A[6]	5	39±31	0.38	>221,000

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. The effluent arsenic concentration is

[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

[7] The letter **A** indicates that media were replaced after arsenic breakthrough

expected to decrease with increasing residence time and reach a limiting value irrespective of the volume of water processes as long as is not saturated or is not close to being saturated. However, effluent arsenic concentration is expected to rise when media capacity limit is approached.

The data presented in **Table 4.1** shows that Sidko ART may not be able to produce 600,000 L of arsenic-safe water as claimed by its proponent. However, thirteen units out of fifteen were able to produce ≥290,000 L of arsenic-safe water, which is at least about three times as much that produced during ETV AM field testing. Furthermore, the water quality parameter of some wells exceeded the deployment conditions specified by the ETV-AM program. Therefore, the technology could play an important role in providing 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.

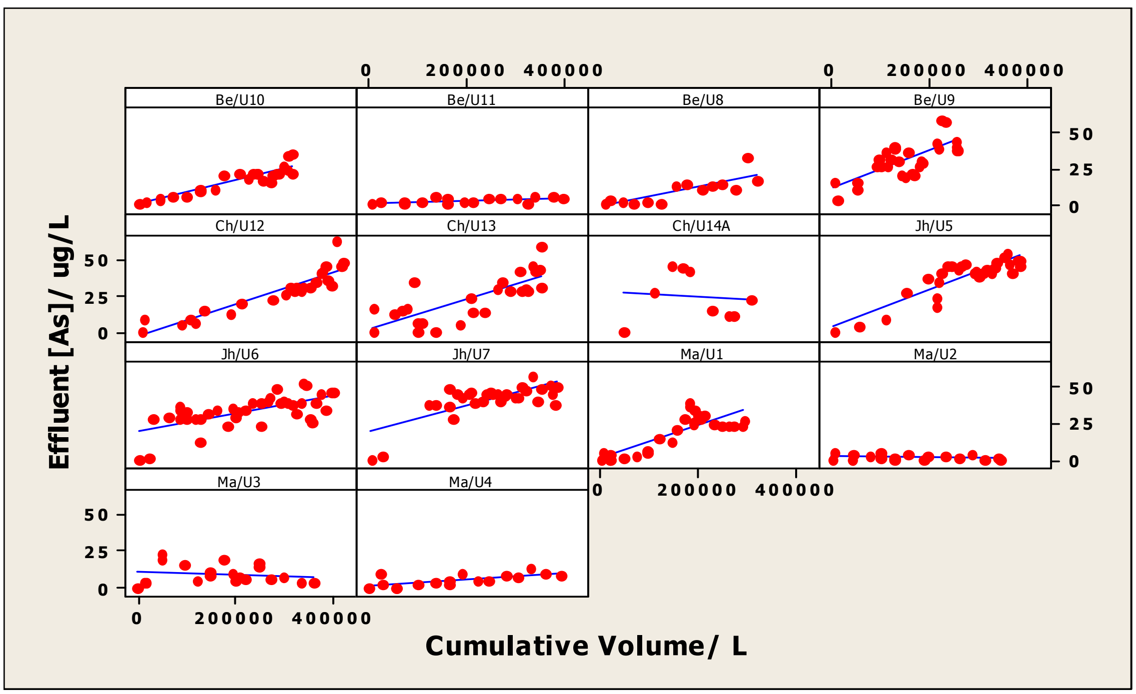

Figure 4.1: Plots showing effluent arsenic concentrations from different Sidko units as a function of volume of treated water

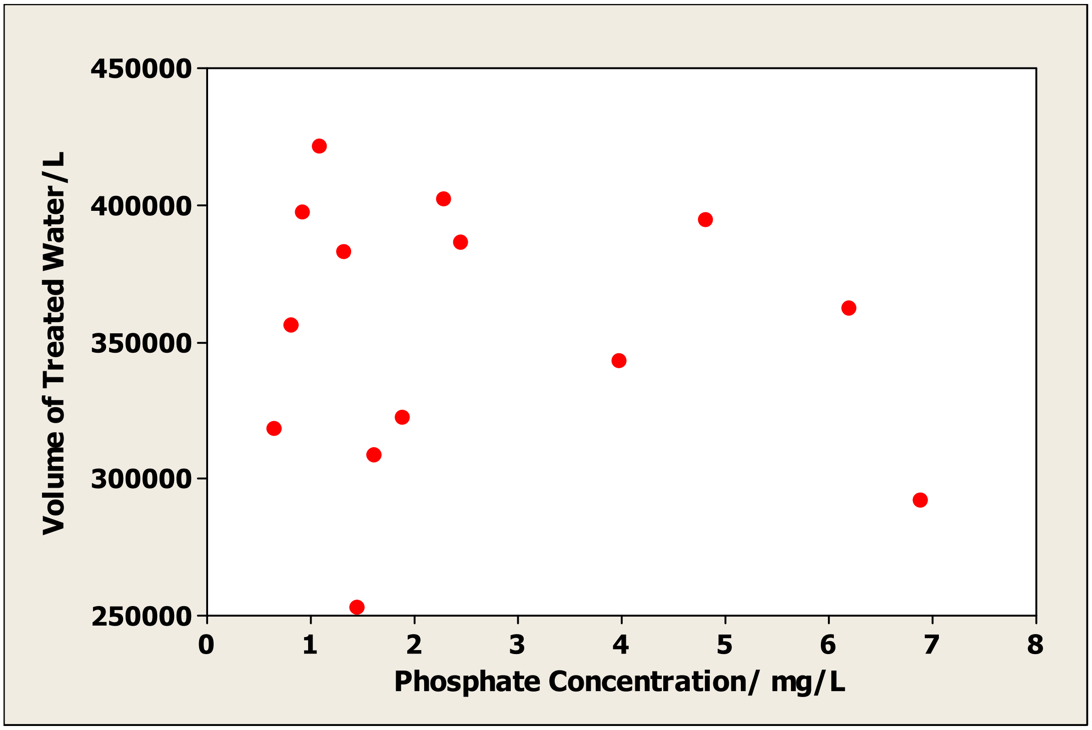

Figure 4.2: Plot showing volume of water treated by different Sidko units vs. concentration of phosphate in water

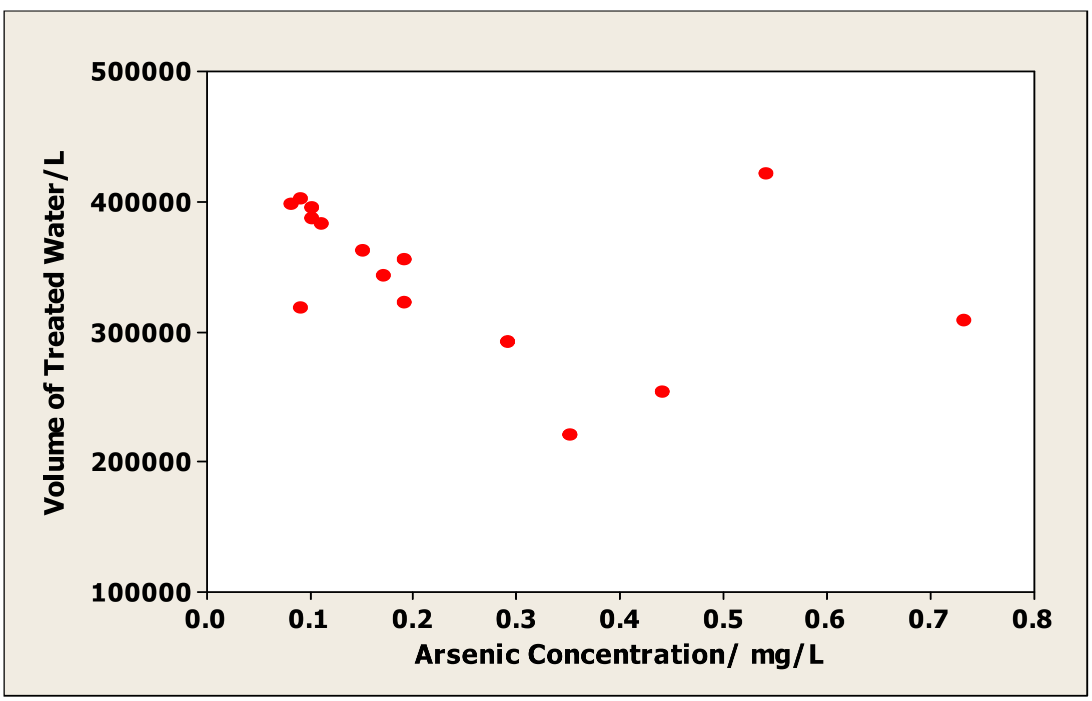

Figure 4.3: Plot showing volume of water treated by different Sidko units vs. concentration of arsenic in water

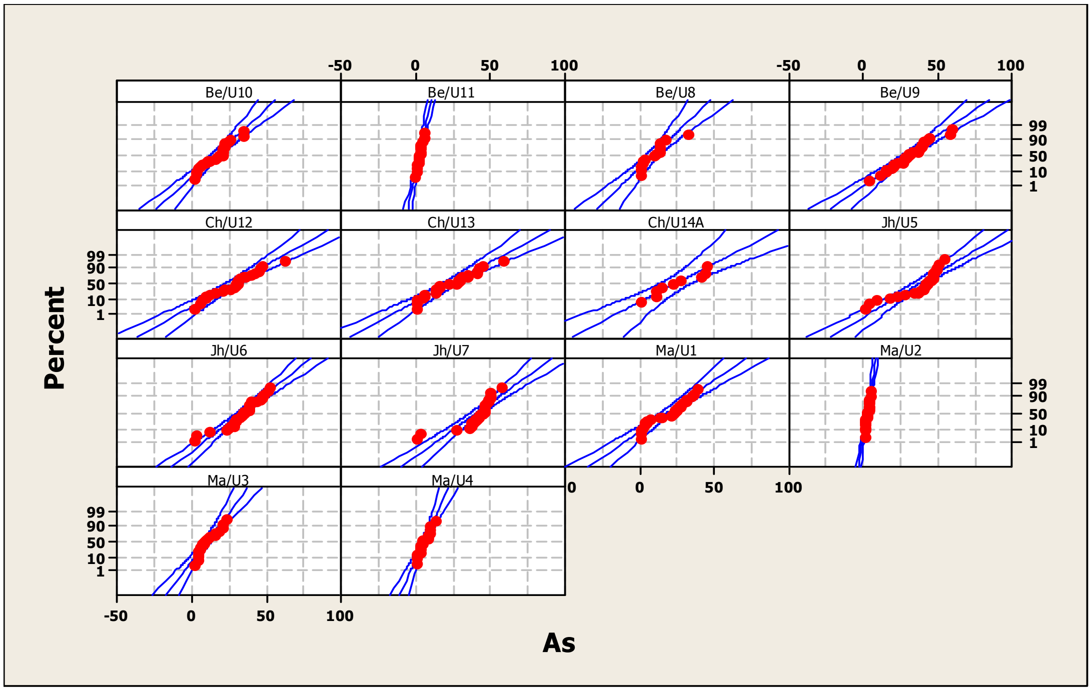

Figure 4.4: Normal probability plots showing expected standard deviations between measured and mean effluent As concentrations vs. Effluent As concentration.

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 many places of 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 eleven (11) out of fifteen (15) wells selected to monitor Sidko performance monitoring were contaminated with >0.4 mg/L of Mn. The average concentrations of Mn in raw and treated well water from different Sidko units are presented in **Table 4.2.** The data show that Sidko 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 Sidko units was insignificant for the most part. This makes the technology unsuitable to treat groundwater containing ≥0.4mg/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 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 68µg/L and 420µg/L and the fraction of Ba removed through treatment processes was small.

Table 4.2: Mean influent and effluent concentrations of manganese for different Sidko units

Location	Well/unit ID	No. of Data Points	$[Mn]_{Inf}$/µg/L	No. of Data Points	$[Mn]_{Eff}$/ µg/L
Manikgonj	W06/U1	3	1240	7	1227
	W86/U2	2	430	4	400
	W107/U3	2	465	6	379
	W125/U4	2	185	2	180
Jhikorgacha	W30/U5	3	27	2	26
	W68/U6	3	88	2	81
	W76/U7	3	92	2	80
Bera	W02/U8	3	1133	2	560
	W85/U9	3	1356	9	1178
	W86/U10	3	777	6	34
	W87/U11	4	623	6	561
Chapai	W70/U12	3	1333	3	1133
	W71/U13	3	987	2	700
	W57/U14	3	1333	2	815
	W74/U15	3	1733	2	1700

Table 4.3: Mean influent and effluent concentrations of Barium for different Sidko units

Location	Well/unit ID	No. of Data Points	$[Ba]_{Inf}$ /µg/L	No. of Data Points	$[Ba]_{Eff}$ µg/L
Manikgonj	W06/U1	2	183	4	78
	W86/U2	1	130	3	69
	W107/U3	1	130	3	160
	W125/U4	1	68	2	66
Jhikorgacha	W30/U5	2	360	2	330
	W68/U6	2	420	1	350
	W76/U7	2	420	2	350
Bera	W02/U8	2	180	2	125
	W85/U9	3	210	3	151
	W86/U10	2	115	3	85
	W87/U11	3	300	3	166
Chapai	W70/U12	2	230	3	197
	W71/U13	2	215	2	155
	W57/U14	2	205	2	170
	W74/U15	2	165	2	145

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, 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 and Bera were analyzed for thermo-tolerant coliform (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 and 4.4b** 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 samples analysis.

2. The treated water samples were also found to be free from bacterial contamination for the most part and the occasional contaminations found in treated water is believed to be introduced by caretaker, sampler, sample handler, analyst, and others.
3. Sidko ART 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 Sidko units in Manikgonj

Site/Unit ID	Sampling Date	Influent		Effluent	
		TTC	E. Coli	TTC	E. Coli
Ma/U1	7-Feb-08	0		5	2
Ma/U1	1-Apr-08	0		0	
Ma/U1	29-Apr-08	7	1	0	
Ma/U1	23-Jun-08	1		0	
Ma/U1	27-Aug-08	18	0	99	0
Ma/U1	16-Sep-08	0		0	
Ma/U1	5-Nov-08	0		0	
Ma/U1	26-Nov-08	0			
Ma/U1	1-Apr-08			0	
Ma/U2	29-Apr-08	0		0	
Ma/U2	24-Jun-08	2	0	0	
Ma/U2	24-Jun-08	15			
Ma/U2	28-Aug-08			0	
Ma/U2	16-Sep-08	0		3	3
Ma/U2	17-Dec-08	0		0	
Ma/U3	27-Feb-08	0		0	
Ma/U3	1-Apr-08	0		0	
Ma/U3	29-Apr-08	35	0	0	
Ma/U3	24-Jun-08	1		0	
Ma/U3	13-Aug-08	0	0	0	0
Ma/U3	27-Aug-08	1	0	0	
Ma/U3	30-Oct-08	0		0	
Ma/U3	29-Jan-08	0		3	0

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

Site/Unit ID	Sampling Date	Influent		Effluent	
		TTC	*E. Coli*	TTC	*E. Coli*
Be/U8	6-Mar-08	74	0	0	
Be/U8	8-Apr-08	1	0	0	
Be/U8	11-May-08	0		0	
Be/U8	10-Jul-08	0		1	
Be/U8	11-Sep-08	0		0	
Be/U8	21-Oct-08	0		0	
Be/U8	12-Jan-09	0		0	
Be/U9	6-Mar-08	0		0	
Be/U9	6-Apr-08	0		0	
Be/U9	6-May-08	0		0	
Be/U9	21-May-08	0		2	0
Be/U9	8-Jun-08			36	16
Be/U9	12-Jun-08	0	0	0	0
Be/U9	3-Jul-08			0	
Be/U9	24-Jul-08	0	0	0	
Be/U10	6-Mar-08	0		0	
Be/U10	6-Apr-08	0		1	1
Be/U10	6-May-08	0		0	
Be/U10	7-Jul-08	0		0	
Be/U10	23-Sep-08	0			
Be/U10	16-Oct-08	0		1	0
Be/U10	4-Dec-08	0		0	
Be/U10	12-Jan-08	0			
Be/U11	6-Mar-08	0		0	
Be/U11	6-Apr-08	0		0	
Be/U11	6-May-08	22		0	
Be/U11	7-Jul-08	0	0	0	
Be/U11	7-Jul-08	0			
Be/U11	23-Sep-08			0	
Be/U11	16-Oct-08	0		0	
Be/U11	4-Dec-08	0		0	

5 RECOMMENDATION AND DEPLOYMENT CONDITIONS FOR SIDKO

5.1 RECOMMENDATION

Fifteen units of Sidko ART have been deployed and installed in four 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. Twelve units produced ≥300,000 L of arsenic-safe water, while the other three units generated between 221,000 L and 293,000 L of arsenic-safe water.
2. There are no indications of imminent arsenic breakthrough (see **Figure 4.1**) in units 1-4, 8, 10, 11, and 14 after generating 300,000L to 400,000L of arsenic-safe water.
3. The performance of at least 40% of the units reached about 65%-70% of the proponent performance claim (600,000L).

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 Sidko ART be certified for marketing and sales in Bangladesh.

5.2 CONDITIONS FOR DEPLOYMENT OF SIDKO ART

The performance monitoring data presented and analyzed in previous sections indicate that Sidko 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 treated water can occasionally be contaminated with biological contaminations if not handled properly. 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. The Sidko technology can produce arsenic-safe water that meets Bangladesh drinking water standard from well water contaminated with ≤725 µg/L of As, ≤7 mg/L of phosphate, ≤0.4 mg/L of manganese, 0.0 – 23 mg/L of iron, and pH 7.0 ± 1.0.

2. A Sidko unit installed and operated following the above instructions, should be able to provide arsenic-safe water to about 20 families, 45 L to 50 L per family per day, for at least one (1) year; i.e. a Sidko ART should be able to generate ≥360,000L of potable water.
3. The well water should be analyzed before the deployment and installation of a Sidko unit to make sure that well water meets conditions specified in **Condition #1** above.
4. The proponent must supply an *Installation, Operation and Maintenance Manual* that contains the **RECOMMENDATION AND DEPLOYMENT CONDITIONS FOR SISKO.**
5. The well water should be allowed to stand in the raw water tank for at least two (2) hours if the concentration iron dissolved in groundwater is ≥3.0 mg/L to allow iron dissolved in groundwater to oxidize, coagulate and flocculate before passing it through the iron and arsenic removal media.
6. The iron removal media ***must be backwashed 2 to 3 times a day***, i.e. after treating a tank of raw water, to remove iron flocs and the arsenic removal filter should be backwashed once a month.
7. The technology should not be used to produce more than about 1,000 L of arsenic-safe water in a day unless conditions stated in **4 & 5** above can be met and satisfied.
8. The technology is unable to remove manganese from well water and should not under any circumstances be used to treat groundwater containing >0.4[8] mg/L of manganese.
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 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 Sidko ARTs.

5.2.2 Hygiene Practice

1. The technology operators should make sure that their hand are clean before operating the unit, repairing it, or doing any other work on it. They should wash

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

their hands with soap and plenty of water and make sure that they are absolutely clean before operating, repairing, or doing any other work on the unit.

2. The end-users should wash their hands with soap and plenty of water and make sure that they are absolutely clean before collecting treated water.
3. Kolshi's and other containers used to collect water must be cleaned and disinfected thoroughly. To do this, add about 2 L of water to the Kolshi, 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, and finally rinse Kolshi with clean water.

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 tested for arsenic after six month and once a month 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 Sidko unit that is deployed following the above conditions (**section 5.2.1**) and to serve twenty (20) families should be able to produce arsenic-safe water for at least a year at a rate of 1000L/day. Therefore, arsenic removal media have to be replaced with fresh media after a year, if treated water cannot be analyzed in an approved testing facility to ensure that its arsenic content is below 50 µg/L, 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 Sidko unit's arsenic removal 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 two persons 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. Sidko ART certification is not based on 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 Sidko ART.

1. ***Analysis of treated Water for Arsenic***: As suggested above, Sidko technology users should replace the arsenic removal media after ten months, unless they can have water treated by their Sidko unit and know that after ten months, 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 ten months timeline is over, to ensure that the unit is still functioning properly and producing arsenic-safe water for the community that acquired the unit. This would provide the most reliable indicator of when the Sidko unit in the possession of a community stop producing arsenic-safe water and arsenic removal media needs to be replaced with fresh ones. 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 and other pieces of a Sidko break down often enough and have to be replaced. For most communities, reaching the Sidko 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 Sidko 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, Sidko 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 Sidko ART users. The calculation does not take into account the cost of replacement of broken taps and other repair costs due lack of information on the pricing, frequency these breakdowns, etc.

Considerations and Description	**Quantity**	**Basic Unit Price (BUP)**	**BUP Plus Technology Depreciation Cost**
Sidko ART Unit Cost	1	Tk62,000[9]	
Daily Production Volume	1000 L		
Media lifespan [10]	1 Year		
Sidko Production Capacity	365,000 L		
Hardware Depreciation	5%/Year		
Arsenic Removal Media Cost	Per Unit	Tk27,000[9]	
Hardware Longevity	20 Years		
Cost to Treat A Liter of Water		**Tk0.17/L**	**Tk0.18/L**
Daily Water Consumption Cost per Family		**Tk7.86/Day**	**Tk8.07/Day**
Monthly Water Consumption Cost per Family [11]		**Tk235.77/Month**	**Tk242.26**

NOTES:

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

[9] These price could increase with time

[10] Based on TPM data

[11] 30 days in a month

1. Twenty household share one unit and each household consume 45 L of arsenic-safe water in a day.
2. The media needs to be replace annually and that media costs Tk27,000.
3. The cost for analysis of Sidko treated water is not included.