

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

**PERFORMANCE MONITORING AND
EVALUATION**

OF

**MAGC/Alcan Household Arsenic Removal
Technology**

Final Performance Verification Report

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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 Alcan 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 MAGC/Alcan (Alcan) household ARTs over twenty five wells – triplicate units were installed on three wells- with twenty five 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 Alcan 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.

Alcan ART units were operated and maintained by end-users, who were trained by the proponent and the Monitoring Agency (MA) field crews and supervised by the latter. The end-users recorded volume of water treated in a day, assisted MA field crews in their routine work, and participated in other housekeeping activities.

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The technology performance was closely monitored by the MA field crews; they analyzed treated water for arsenic on a weekly basis using Arsenators and following strict QA/QC protocols; and collected samples of raw and treated water at regular intervals and delivered samples 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 Alcan ART.

The data collected during the TPM program shows that the technology performance appears much better than that found during the ETV-AM field testing and performance verification program. Six Alcan units have reached breakthrough after generating between 11,000 L and 17,000 L of arsenic safe-water¹; two more units were on the verge of breakthrough after producing 17,000L to 24,000L of treated water; and the rest were producing arsenic-safe water till the field monitoring were terminated and produced over 17,000L.

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

1. Alcan ART can produce arsenic-safe water from well water contaminated with $\leq 900 \mu\text{g/L}$ of arsenic, $\leq 6.5\text{mg/L}$ of phosphate, $\leq 0.4 \text{ mg/L}$ of manganese, 0 – 23 mg/L of iron, and pH 7.0 ± 1.0 .
2. The technology is unable to remove manganese and should not under any circumstances be used to treat groundwater containing $>0.4 \text{ mg/L}$ of manganese.
3. An Alcan unit installed and operated following the above instructions, should be able to provide arsenic-safe water to a single family, 45 L per family per day, for at least fifteen (15) months; i.e. an Alcan ART should be able to generate $\geq 20,000\text{L}$ of potable water.
4. Alcan ART can and should be certified, with revised deployment conditions presented in **Section 5.2**, for marketing and sale in Bangladesh.

¹ “Arsenic-safe” is a terminology used to indicate that total As $< 50 \mu\text{g/L}$, 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, MAGC/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 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 on the MAGC/Alcan arsenic removal technology (Alcan ART).

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

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 Alcan ART

2. OBJECTIVE

The primary objective of the TPM program was to field test the Alcan ART in five hydrologically 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 contaminations,
- 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 tolerate , and produce arsenic-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 Alcan proponent’s performance claim³. 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 the Field Monitoring Instructions and Handouts and will only be described briefly in the following sections.

3.1 TECHNOLOGY DESCRIPTION

The Alcan ART is designed to remove arsenic from arsenic contaminated tube well water using Acti Guard AAFS-50. A household unit consists of a covered plastic bucket and fitted with a valve near the bottom and two perforated plates to support media separated from each other and from the bottom of the bucket by about 25 cm. A third perforated plate is placed at the top and covered with a cotton filter to remove suspended solids from the raw water. A photograph of the MAGC/ALCAN household unit is shown in **Figure 1**.

To operate the technology, well water is poured into the bucket, filtered through arsenic removal media, and treated water is collected in a suitable clean container from the tap that is attached to the bucket. According to the proponent instructions, the unit can operate continuously, if desirable, with a maximum flow rate of 120 L/hr and should be able to deliver approximately 960 liters of potable water over an eight-hour period of operation in a day. However, it was found that the technology cannot produce a reasonable volume of potable water if operated continuously and arsenic will breakthrough prematurely. Therefore, it was operated in batch mode. Each unit was filled with well water, allowed to stand for about 15 – 20 minutes, and then the tap was opened and treated water was collected in a suitable container, making sure that adequate water remains in the unit to cover the media. If arsenic removal media is not covered with water the air was found to be trapped between the two plates supporting the media and between the lower plate and the bottom of the bucket, rendering difficulties in the filtration process. It is important to note that the production of arsenic-safe water was limited to between 45 L and 50 L per day per unit during the TPM program.

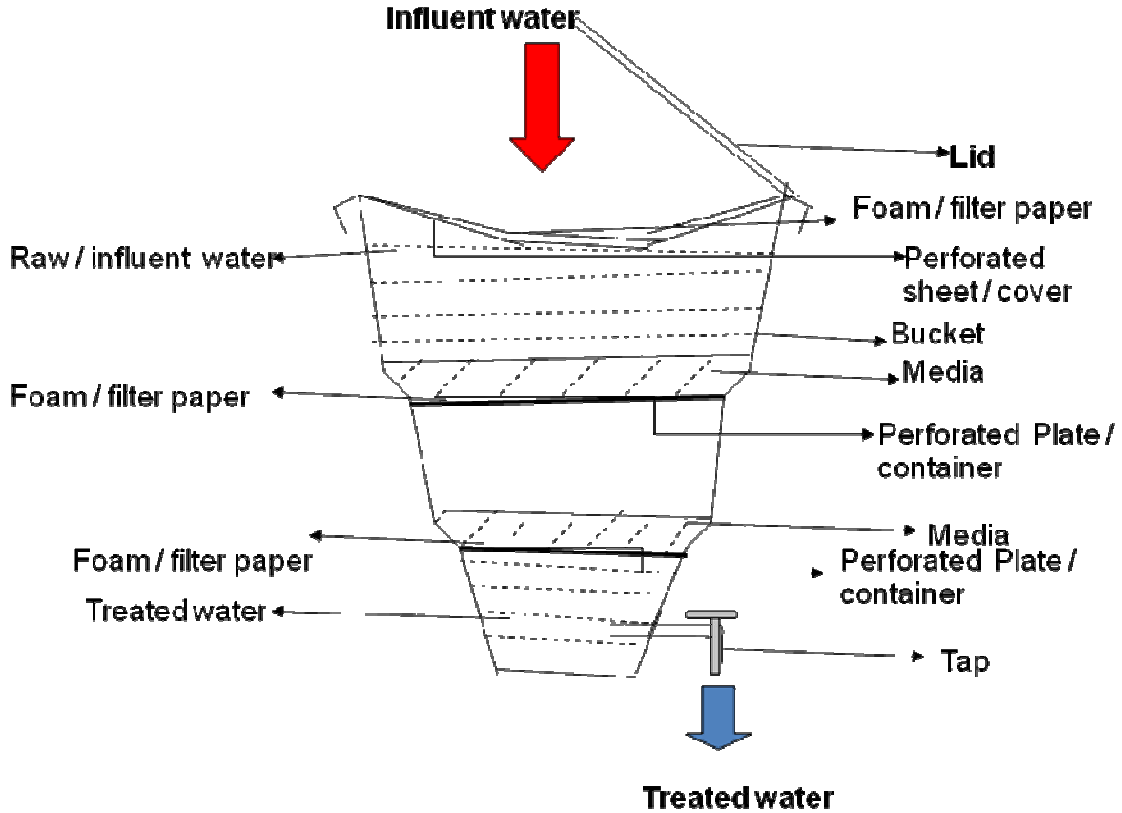


Figure 2: schematic representation of Alcan ART

3.2 PROPONENT’S PERFORMANCE CLAIM

The proponent claims that an Alcan household unit is capable of processing 10,950 liters of groundwater with an influent arsenic concentration of 330 µg/L and generate arsenic-safe water at a minimum flow rate of 60 L/hr. The ETV-AM program, on the other hand, specified that the technology could treat groundwater contaminated with ≤330 µg/L of arsenic, ≤10 mg/L of iron, ≤4.0 mg/L of phosphate, and pH ≤7.5 and produce 8,100 L of arsenic-safe water.

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

	[As]/ µg/L	pH	Fe(II)/mg/L	PO ₄ ³⁻ /mg/L
Proponent	≤330			≤0.5
ETV-AM	≤330	≤7.5	≤10	≤4.0

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 Alcan performance monitoring on the basis of their groundwater quality parameters. Twenty five wells were selected - 4 in Manikgonj, 2 in Balagonj, 7 in Jhikorgacha, 6 in Ishwardi and 6 in Chapainawabgonj based on preliminary 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 well selection was guided by the 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 Alcan's performance varied between 60 µg/L and 860 µg/L, 2.78 mg/L and 23.54 mg/L, 41 µg/L and 1500 µg/L, and 0.1 mg/L and 9.5 mg/L, respectively, and well water pH was around 7.0 ± 1.0 . Ten wells - four in Manikganj, two in Balagonj, one in Jhikorgacha and three in Chapai - do not meet the deployment conditions set 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 Alcan 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**.

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Table 3.2: Summary of the well water quality parameters: Mean values \pm CI (confidence interval at 95% confidence level) where the Alcan ART were deployed

Location	Well/Unit ID	[As(T)] $\mu\text{g/L}$	As(III)/ As(T)	[Fe] mg/L	[PO ₄ ³⁻] mg/L	[Mn]/ $\mu\text{g/L}$	pH
Manikgonj	W95/U1	186 \pm 11	0.32	10.00 \pm 0.64	4.5 \pm 0.6	388	7.0 \pm 0.4
	W102/U2	171 \pm 13	1.07	15.86 \pm 1.28	5.7 \pm 1.6	307	7.0 \pm 0.7
	W117/U3	83 \pm 6	1.78	5.83 \pm 1.53	4.4 \pm 0.9	357	7.0 \pm 0.6
	W123/U4	66 \pm 10	1.07	8.32 \pm 2.01	4.6 \pm 1.2	250	7.0 \pm 0.7
Balagonj	W21/U5	135 \pm 29	1.17	23.54 \pm 3.82	6.5 \pm 3.2	427	6.0 \pm 1.1
	W73/U6	111 \pm 13	0.86	3.27 \pm 0.47	9.5 \pm 2.1	41	7.0 \pm 0.4
	W73/U26	111 \pm 13	0.86	3.27 \pm 0.47	9.5 \pm 2.1	41	7.0 \pm 0.4
	W73/U27	111 \pm 13	0.86	3.27 \pm 0.47	9.5 \pm 2.1	41	7.0 \pm 0.4
Jhikorgacha	W33/U7	102 \pm 26	1.30	6.15 \pm 0.75	1.9 \pm 0.5	80	7.0 \pm 0.2
	W99/U8	105 \pm 7	1.97	6.00 \pm 0.64	2.3 \pm 0.6	53	7.0 \pm 0.3
	W111/U9	240 \pm 50	0.43	6.88 \pm 0.29	1.6 \pm 0.3	61	7.0 \pm 0.2
	W112/U10	215 \pm 17	0.48	7.30 \pm 0.48	1.8 \pm 0.4	57	7.0 \pm 0.3
	W113/U11	150 \pm 20	1.69	6.09 \pm 0.82	1.4 \pm 0.1	48	7.0 \pm 0.4
	W116/U12	442 \pm 52	0.87	6.32 \pm 0.80	1.6 \pm 0.3	69	7.0 \pm 0.3
	W115/U13	209 \pm 17	0.98	7.03 \pm 0.86	1.5 \pm 0.0	57	7.0 \pm 0.8
Ishwardi	W38/U14	324 \pm 26	0.79	4.12 \pm 0.17	0.9 \pm 0.4	867	7.0 \pm 0.7
	W68/U15	207 \pm 42	0.73	2.78 \pm 0.31	0.1 \pm 0.1	1,500	7.0 \pm 0.8
	W91/U16	289 \pm 36	0.80	3.06 \pm 0.30	0.7 \pm 0.2	1,300	7.0 \pm 0.5
	W108/U17	325 \pm 52	0.80	5.56 \pm 0.14	0.8 \pm 0.3	1,200	7.0 \pm 0.8
	W109/U18	171 \pm 41	1.02	2.88 \pm 0.56	0.7 \pm 0.3	887	7.0 \pm 0.6
	W110/U19	290 \pm 64	0.80	4.11 \pm 0.21	0.6 \pm 0.2	1,500	7.0 \pm 0.7
	W91/U28	289 \pm 36	0.80	3.06 \pm 0.30	0.7 \pm 0.2	1,300	7.0 \pm 0.5
	W91/U29	289 \pm 36	0.80	3.06 \pm 0.30	0.7 \pm 0.2	1,300	7.0 \pm 0.5
Chapai	W15/U20	860 \pm 15	0.76	10.88 \pm 0.69	3.6 \pm 2.0	392	7.0 \pm 0.3
	W23/U21	94 \pm 17	0.80	4.22 \pm 1.13	0.7 \pm 0.5	665	7.0 \pm 0.5
	W25/U22	622 \pm 80	0.46	10.53 \pm 4.41	2.8 \pm 1.1	375	7.0 \pm 0.3
	W59/U23	163 \pm 42	1.80	6.23 \pm 7.67	1.0 \pm 1.1	520	7.0 \pm 0.2
	W50/U24	326 \pm 99	1.80	13.89 \pm 5.84	3.0 \pm 2.0	400	7.0 \pm 0.2
	W61/U25	189 \pm 73	0.97	8.42 \pm 4.05	1.5 \pm 0.2	735	7.0 \pm 0.4
	W59/U30	163 \pm 42	1.80	6.23 \pm 7.67	1.0 \pm 1.1	520	7.0 \pm 0.2
	W59/U31	163 \pm 42	1.80	6.23 \pm 7.67	1.0 \pm 1.1	520	7.0 \pm 0.2

3.4 TECHNOLOGY INSTALLATION, OPERATION AND MAINTENANCE

All Alcan units have been installed by the MA field crews and operated and maintained by the 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). 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 use treated water for drinking and cooking purposes.

The BETV-SAM and BCSIR engineers and scientists trained the MA field crews for water sampling, sample preservation and transportation, sample analysis in the field, data recording and record keeping, etc. 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 Alcan ART was designed to produce at least 50 L of treated water in hour; however, as discussed before, this could not be realized in practice. It operates like a conventional filter with water flowing downward and arsenic dissolved in water is adsorbed onto the media. The technology O&M specifies:

1. The media and the cotton filter should be washed by hand using clean water to remove iron oxide, sands and silt regularly.
2. If the unit is used for the first time or after sitting idle for a few days, then the first batch of treated water should be discarded and the unit should be rinsed with 20L of hot water.
3. The technology could be used, if desired, to produce more than 50L of arsenic-safe water in a day.
4. Other housekeeping instructions, such as covering the unit if not in use, cleaning water handling jugs and buckets and keeping them in sanitary conditions.

However, the above instructions are general and are not useful for “real world” situations, for which specific instructions are needed. Therefore, the following changes to the technology O&M were implemented in order to use it reliably and improve its performance.

1. The technology is operated in batch mode and the arsenic removal media is not allowed to run dry.

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2. A brand new Alcan ART unit is filled with well water, allowed to stand for about 15 – 20 minutes, and treated water is collected in a clean bucket or in a kolshi, making sure that adequate water is left behind to cover arsenic removal. Afterwards, the unit is topped-up with well water, allowed to stand in the unit for about 15 – 20 minutes, and then the same amount of water is collected for consumption.
3. The arsenic removal media should be removed, washed and reloaded into the unit once every two weeks.
4. The unit should be disinfected once a week with about 15 L of boiling water. The unit is emptied of water, boiling water is added to the unit, allowed to stand for half an hour, and then letting it to pass through.
5. The technology was used to produce about 50 L of arsenic-safe water in a day; however, more water could be treated as long as instructions #3 and #4 above are followed and media washing frequency is adjusted accordingly. For example, the arsenic removal media should be washed once or twice a week if the unit is used to generate ≥ 100 L of treated water in a day.
6. The units were covered if not in use and all water handling jugs, buckets and kolshis were kept clean and in sanitary conditions.

3.5 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, labeled 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 $\leq 20\mu\text{g/L}$, two samples a month when the effluent As was between 20 and $29\mu\text{g/L}$, and once a week when effluent As concentration reached to $\geq 30\mu\text{g/L}$. In addition to As, water samples were also analyzed for Fe, PO_4^{3-} and Mn.*

4. EVALUATION OF TECHNOLOGY PERFORMANCE

Most Alcan units performed well and did not reach breakthrough during the field monitoring period. A few units 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 Alcan'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

Alcan'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 (**Table 3.2**). The following sections will discuss treated water quality parameters.

Eleven to twenty six effluent water samples were collected from various 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. **Figure 4.1** shows variation of effluent arsenic concentration as a function of cumulative volume of treated water and **Table 4.1** presents the volume of arsenic-safe water produced by each unit and the results of statistical analysis.

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

1. All Alcan units performed well; 23 units produced $\geq 17,000$ L arsenic-safe water, and the rest of the units generated between 11,000 L and 17, 000 L of potable water and of which only five produced less than 15,000 L arsenic-safe water. It is suspected that these latter units were not operated and maintained properly. Still, the above figures show that Alcan's performance met and exceeded the proponent's performance claim.
2. Twenty three (23) units did not show any sign of imminent arsenic breakthrough and it is very likely that they would have been able to produce a much higher quantity of arsenic-safe water had the program continued.

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).

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3. The improved performance of the Alcan ART is attributed to the changes made to the technology O&M procedures, as was discussed in the previous section.
4. The concentrations of arsenic and phosphate dissolved in groundwater – over the range of concentrations examined in this program - do not appear to affect Alcan’s performance as demonstrated by the data presented in **Figures 4.2 and 4.3**. The concentration of iron, on the other hand, appears – as shown in **Figure 4.4** – to be positively related to the Alcan performance. However, drawing a definite conclusion – on the effect of water quality parameters on Alcan performance – at this point is premature because of the fact that nearly 70% of the units did reach to their breakthrough points and there are no indications that they will do so any time soon.
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 50µg/L. This is supported by the near linearity of the probability plots – for units that do not show arsenic breakthrough – presented in **Figure 4.5**.

The data presented in **Table 4.1** shows that all Alcan ART units were able to produce more than 11,000 L of arsenic-safe water and 22 units produced >17,000 L of arsenic safe water, which is \geq twice that of the proponent’s performance claim. This is despite the fact that the water quality of ten wells exceeded the deployment conditions specified by the ETV-AM program. Therefore, it is concluded that the technology can play an important role in provision of arsenic-safe water to people in arsenic affected areas of Bangladesh provided that the Alcan ART is installed on appropriate wells and operated and maintained following instructions provided in this document.

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

Location / Unit	No. of Data Points	[As(T)] _{Eff} / µg/L Mean ± CI ⁵	P-value ⁶	Cumulative Volume/L
Ma/U1	27	20±4	0	≥25,700
Ma/U2	16	4±2	0	≥21,600
Ma/U3	15	4±1	0	≥27,500
Ma/U4	15	4±1	0	≥21,100
Ba/U5	17	4±3	0	≥33,100
Ba/U6	19	26±9	0	13,500
Ba/U26	10	25±13	0.002	11,700
Ba/U27	14	20±10	0	13,600
Jh/U7	14	2±1	0	≥20,700
Jh/U8	16	4±2	0	≥21,900
Jh/U9	9	20±14	0.001	11,600
Jh/U10	15	4±2	0	≥19,300
Jh/U11	16	2±1	0	≥20,500
Jh/U12	21	39±6	0	12,300
Jh/U13	15	5±2	0	≥25,300
Ish/U14	13	11±7	0	≥17,300
Ish/U15	13	11±6	0	≥17,400
Ish/U16	13	11±6	0	≥17,300
Ish/U17	18	26±10	0	16,400
Ish/U18	14	10±5	0	≥17,400
Ish/U19	12	11±14	0	13,400
Ish/U28	19	14±4	0	≥17,400
Ish/U29	17	12±4	0	≥17,300
Ch/U20	20	14±7	0	≥20,000
Ch/U21	14	1±0.5	0	≥21,100
Ch/U22	15	5±2	0	≥21,700
Ch/U23	14	4±2	0	≥18,300
Ch/U24	15	8±6	0	≥20,200
Ch/U25	14	4±4	0	≥17,700
Ch/U30	14	3±1	0	≥18,400
Ch/U31	14	4±1	0	≥18,700

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

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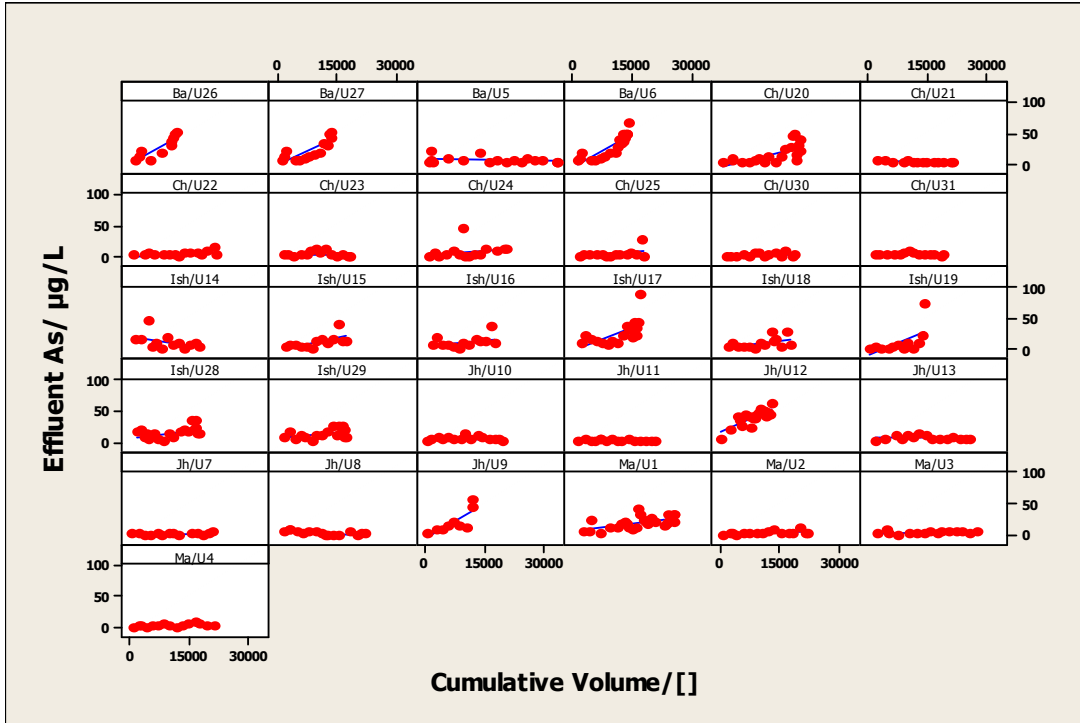


Figure 4.1: Plots showing effluent arsenic concentrations from different Alcan units as a function of volume of treated water

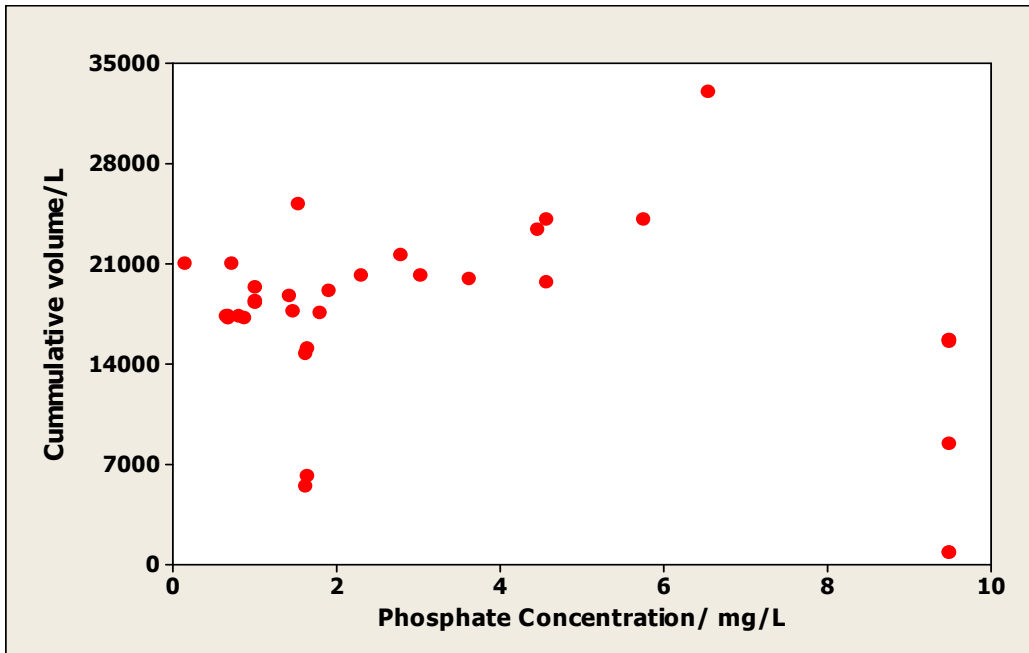


Figure 4.2: Plot showing volume of water treated by different Alcan units vs. concentration of phosphate in water

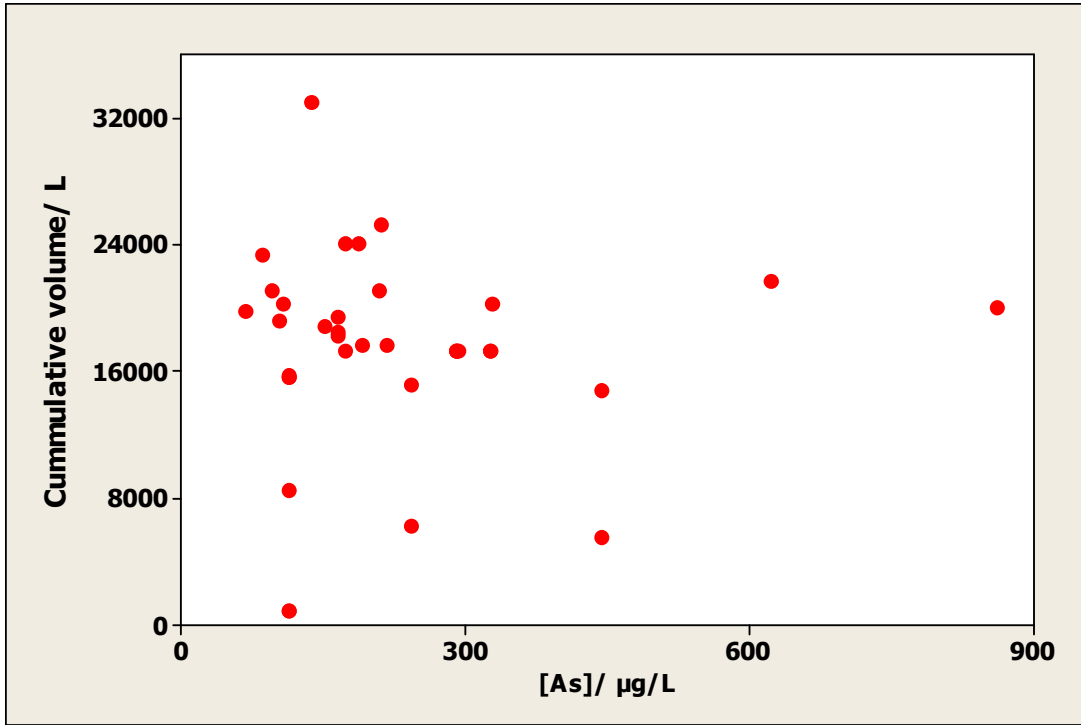


Figure 4.3: Plot showing volume of water treated by different Alcan units vs. concentration of arsenic in water

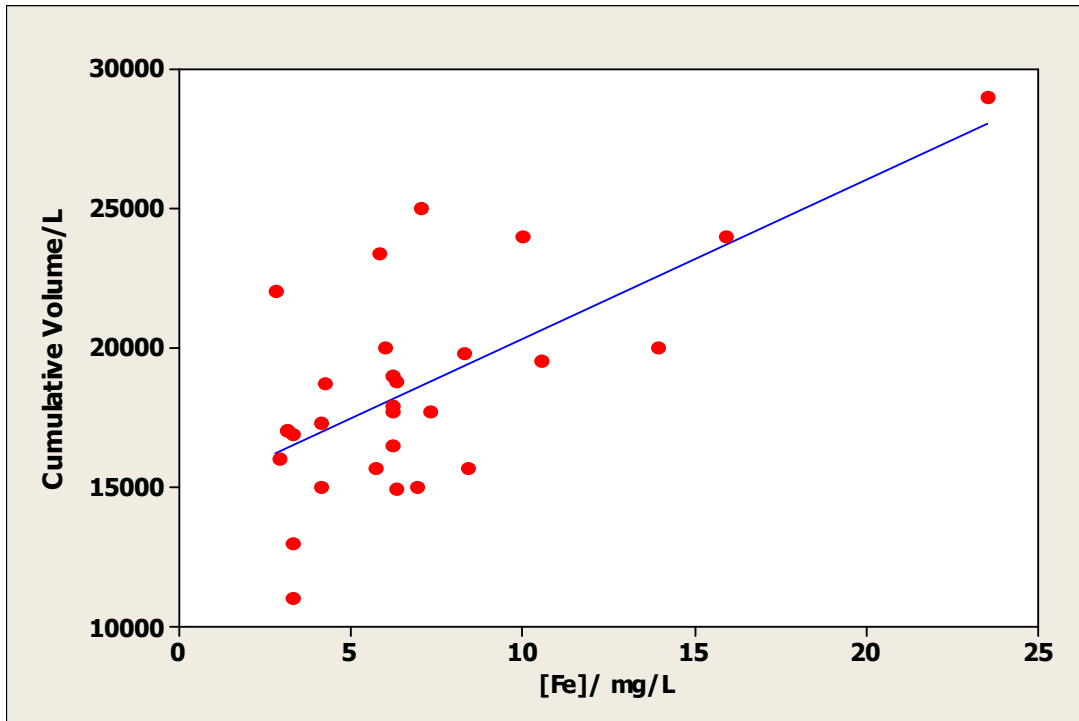


Figure 4.4: Plot showing cumulative volume of treated water vs. concentrations of iron in well water

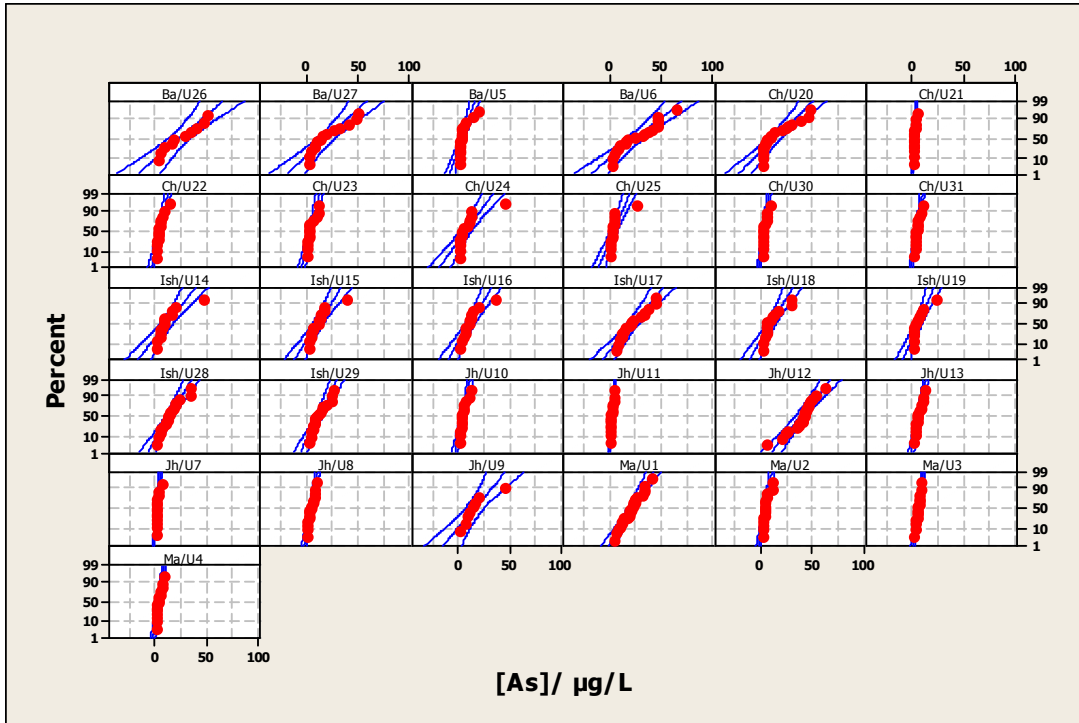


Figure 4.5: Normal probability plots showing expected standard deviations between measured and mean effluent As concentrations vs. effluent As concentration

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 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 ten out of 25 wells selected to monitor Alcan performance monitoring were contaminated with ≥ 0.4 mg/L of Mn. The average concentrations of Mn in raw and treated well water from different Alcan units are presented in **Table 4.2**. The data show that Alcan 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 Alcan units was insignificant for the most part. This makes the technology unsuitable to treat groundwater containing ≥ 0.4 mg/L of Mn. Two to three data points show that Mn concentrations in treated water are higher than that of raw water; however, this may be attributed to analytical errors because the technology does not employ manganese products and cannot add Mn to the treated water.

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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 10 μ g/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 78 μ g/L and 540 μ g/L and the fraction of Ba removed through treatment processes was between negligible to over 50%.

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

Location	Well/unit ID	No. of Data Points	[Mn] _{Infl} / μ g/L	No. of Data Points	[Mn] _{Eff} / μ g/L
Manikgonj	W95/U1	4	388	4	319
	W102/U2	3	307	4	222
	W117/U3	3	357	2	270
	W123/U4	3	250	2	175
Balagonj	W21/U5	3	427	4	579
	W73/U6	2	41	3	41
	W73/U26	2	41	2	51
	W73/U27	2	41	3	36
Jhikorgacha	W33/U7	2	80	4	91
	W99/U8	2	53	4	86
	W111/U9	3	61	6	69
	W112/U10	2	57	2	118
	W113/U11	2	48	1	38
	W116/U12	2	69	3	64
	W115/U13	2	57	2	70
Ishwardi	W38/U14	3	867	6	365
	W68/U15	3	1500	6	594
	W91/U16	2	1200	6	703
	W108/U17	3	1200	5	686
	W109/U18	3	887	5	415
	W110/U19	3	1500	5	597
	W91/U28	2	1200	5	597
	W91/U29	2	1200	6	609
Chapai	W15/U20	3	392	3	212
	W23/U21	2	665	4	267
	W25/U22	2	375	2	310
	W59/U23	2	520	2	325

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Location	Well/unit ID	No. of Data Points	[Mn] _{Inf} /μg/L	No. of Data Points	[Mn] _{Eff} / μg/L
	W50/U24	2	400	2	355
	W61U25	2	735	2	545
	W59/U30	2	520	2	405
	W59/U31	2	520	2	430

Table 4.3: Mean influent and effluent concentrations of barium for different Alcan units

Location	Well/unit ID	No. of Data Points	[Ba] _{Inf} /μg/L	No. of Data Points	[Ba] _{Eff} μg/L
Manikgonj	W95/U1	3	221	8	93
	W102/U2	2	175	4	48
	W117/U3	2	160	2	84
	W123/U4	2	80	2	38
Balagonj	W21/U5	3	272	6	36
	W73/U6	1	92	3	21
	W73/U26	1	92	2	42
	W73/U27	1	92	3	22
Jhikorgacha	W33/U7	1	410	4	149
	W99/U8	1	310	5	165
	W111/U9	1	340	3	210
	W112/U10	1	370	2	160
	W113/U11	1	350	1	160
	W116/U12	1	540	3	333
	W115/U13	1	460	2	310
Ishwardi	W38/U14	2	205	4	39
	W68/U15	2	78	4	6
	W91/U16	2	135	2	16
	W108/U17	2	125	2	16
	W109/U18	2	155	2	18
	W110/U19	2	100	2	10
	W91/U28	2	135	2	20
	W91/U29	2	135	2	19
Chapai	W15/U20	2	276	4	29
	W23/U21	1	240	4	96

Location	Well/unit ID	No. of Data Points	[Ba] _{inf} /µg/L	No. of Data Points	[Ba] _{eff} µg/L
	W25/U22	1	220	2	130
	W59/U23	1	300	2	141
	W50/U24	1	320	2	195
	W61/U25	1	220	2	127
	W59/U30	1	300	2	170
	W59/U31	1	300	2	170

4.3 PROPENSITY FOR BACTERIAL CONTAMINATION

The MA field crews, sample handlers and analyzers, and end-users were given adequate personal hygiene instructions and were reminded on the importance of hygiene in order to prevent bacterial contamination of 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 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, 4.4b and 4.4c** show that:

1. The well waters are generally free from microbial contaminations 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 found to be contaminated with TTC and *E.coli* and in a few cases, the contamination was found to be very high. Bacterial populations in the treated water did not increase with time and did not exhibit a particular pattern. This could be due to the fact that individual units are washed regularly with boiling water, which sterilizes the unit and essentially destroys bacterial colonies formed in a unit.
3. Since well water is generally free from bacterial contamination, the observed contaminations are most likely introduced at one point or another through the chain of events from sampling to sample analysis.
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 #4, #16, #18, and #19 show very little contaminations if any. While effluent from other units that have been tested either show occasional or frequent contaminations.
5. The data presented here does not allow a conclusion as to whether the Alcan ART does or does not harbor, foster, or grow bacteria.

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

Well /Unit ID	Influent		Effluent	
	TTC	E. Coli	TTC	E. Coli
W21/U5	4	1	14	10
W21/U5	3	1	4	1
W73/U6	8	0	232	14
W73/U6	0		48	27
W73/U26	8	0	59	7
W73/U26	0		72	10
W73/U26			5	3
W73/U27	8	0	192	12
W73/U27	0		240	14
W73/U27			24	15

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

Well /Unit ID	Influent		Effluent	
	TTC	E. Coli	TTC	E. Coli
W95/U1	0		34	21
W95/U1	2	0	2	1
W95/U1	0	0	0	
W95/U1	0	0	21	3
W95/U1	30	11	37	5
W95/U1	0		1	1
W95/U1	0		1320	0
W95/U1			120	2
W102/U2	1	0	1	0
W102/U2	149	6	110	2
W102/U2	385	70	14	3
W102/U2	212	0	11	1
W102/U2	85	0	9	1
W102/U2	3	1	14	3
W102/U2	0		2	2
W102/U2	0		0	
W117/U3	13	0	3	0
W117/U3	37	0	6	0
W117/U3	0		0	
W117/U3	0		2	0
W117/U3	0		2	0

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Well /Unit ID	Influent		Effluent	
	TTC	E. Coli	TTC	E. Coli
W117/U3	0		4	3
W117/U3	0		91	0
W117/U3			14	0
W117/U3			15	0
W117/U3			0	
W123/U4	0		0	
W123/U4	0		0	
W123/U4	0		0	
W123/U4	0		6	0
W123/U4	0		3	1
W123/U4	0		6	3
W123/U4	0		1	0
W123/U4	0		11	0

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

Well /Unit ID	Influent		Effluent	
	TTC	E. Coli	TTC	E. Coli
W38/U14	0		512	1
W38/U14	1	0	168	87
W38/U14	0		1	0
W38/U14	0		0	
W38/U14	150	13	138	9
W38/U14	0		7	3
W38/U14	0		0	
W68/U15	0		22	0
W68/U15	2000	40	2000	18
W68/U15	7	2	3	1
W68/U15	128	78	6	3
W68/U15	120	5	62	51
W68/U15	8	0	11	10
W68/U15	0		50	0
W68/U15	0		0	
W91/U16	0		2	0
W91/U16	0		1	0
W91/U16	2	2	3	1
W91/U16	1	0	1	0
W91/U16	0		1	0
W91/U16	2		0	

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Well /Unit ID	Influent		Effluent	
	TTC	E. Coli	TTC	E. Coli
W91/U16	0		8	0
W91/U16	0		0	
W108/U17	0		0	
W108/U17	0		20	0
W108/U17	0		5	0
W108/U17	5	0	28	0
W108/U17	37	36	1217	47
W108/U17	0		7	0
W108/U17	0		0	
W108/U17	6	0	3	0
W108/U17	0		0	
W108/U17	0		17	7
W108/U17	7	3	0	
W109/U18	0		0	
W109/U18	0		8	0
W109/U18	3	0	1	0
W109/U18	400	86	0	
W109/U18	43	40	0	
W109/U18	0		0	
W109/U18			0	
W109/U18			0	
W109/U18			3	0
W110/U19	0		0	
W110/U19	6	1	35	3
W110/U19	0		1	1
W110/U19	10	0	1	0
W110/U19	134	40	0	
W110/U19	1	1	1	0
W110/U19	60	40	1	0
W110/U19	28	0	28	3
W110/U19	5	2	1	0
W110/U19	0		132	14
W110/U19	7	0	3	0
W91/U28	0		72	0
W91/U28	0		232	0
W91/U28	1		14	0
W91/U28			10	0
W91/U28			820000	5100

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Well /Unit ID	Influent		Effluent	
	TTC	E. Coli	TTC	E. Coli
W91/U28			12	0
W91/U28			1	0
W91/U28			0	
W91/U28			0	
W91/U29	0		0	
W91/U29	5	2	0	
W91/U29			5000	46
W91/U29			2	0
W91/U29			0	
W91/U29			3	0
W91/U29			3	3
W91/U29			0	

5 RECOMMENDATION AND DEPLOYMENT CONDITIONS FOR ALCAN

5.1 RECOMMENDATION

Thirty one units of Alcan ART have been deployed and installed on twenty five wells in five hydrogeologically different regions of Bangladesh, operated by the end-users under “real world” condition, and supervised by the MA field crews. The data presented in the previous section show that:

1. All Alcan units performed well, generated $\geq 11,000$ L, and 21 units generated $\geq 17,000$ L of arsenic safe water.
2. Twenty two (22) units – that is more than 80% of wells whose water were treated by Alcan ART – do not show any indications of imminent arsenic breakthrough (see **Figure 4.1**) and generated between 17,000L to 33,000L of arsenic-safe water.
3. Poor O&M procedures could have been a factor for units that produced between 11,000 L and 15, 000 L of arsenic safe water.
4. The performance of 100% of the units exceeds the proponent’s performance claim as well as that specified by the ETV-AM deployment conditions.
5. Poor hygiene practices could easily contaminate treated with bacterial contaminations because arsenic removal has to be washed by hand once every two weeks.

It is, therefore, 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 Alcan ART be certified for marketing and sale in Bangladesh.

5.2 CONDITIONS FOR DEPLOYMENT OF ALCAN ART

The performance monitoring data presented and analyzed in previous sections indicate that Alcan 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. The technology can produce arsenic-safe water that meets Bangladesh drinking water standard from well water contaminated with $\leq 860 \mu\text{g/L}$ of As, $\leq 6.5\text{mg/L}$ of phosphate, $\leq 0.4 \text{mg/L}$ of manganese, $0.0 - 23 \text{mg/L}$ of iron, and $\text{pH } 7.0 \pm 1.0$.
2. An Alcan unit installed and operated following the above instructions, should be able to provide arsenic-safe water to a single family, 45 L to 50 L per family per day, for at least fifteen (15) months; i.e. an Alcan ART should be able to generate $\geq 21,000\text{L}$ of arsenic-safe water.
3. The well water should be analyzed before the deployment and installation of an Alcan 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 ALCAN**.
5. The technology is unable to remove manganese and should not under any circumstances be used to treat groundwater containing $>0.4 \text{mg/L}$ ⁷ of manganese.
6. The filter media must be washed once every two weeks to remove iron flocs, sands and silt that accumulate over time.
7. The media should preferably be always covered with water following initial filling of the unit with well water. It is then topped-up with fresh well water, allowed to stand for about 15 min. to 20 min., and treated water is collected in a clean bucket or Kolshi.
8. The technology should not be used to produce more than about 50 L of arsenic-safe water in a day unless condition **#3** above is met and the media washing frequency is adjusted appropriately. For example, if the unit is used to generate 100 L of arsenic-safe water in a day, then the media should be washed at least once a week.
9. The media should be washed with about 15 L of boiling water once a week and after washing media. The boiling water is added to unit, allowed to stand in the unit for about 20 minutes, and then taken out.
10. 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.
11. The technology proponent must comply with the Government of Bangladesh approved National Waste Management Protocol for safe disposal of arsenic wastes generated by Alcan ARTs.

⁷ This limit is recommended by the World Health Organization

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 arsenic removal media (**Section 5.2.1; point #5**), or servicing Alcan any other way.
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, and rinsed with clean water.
3. Remove arsenic removal media, pour it in the above clean pot, wash it with clean water to remove iron oxide, and then put it back into the unit.

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. An Alcan unit that is deployed following the above conditions (Section 5.2.1) to serve a single family should be able to produce arsenic-safe water for at least fifteen (15) months at a rate of 45L/day. Therefore, Alcan's arsenic removal media should be replaced after fifteen (15) months if treated water cannot be analyzed in an approved testing facility to ensure that arsenic concentration in the treated water 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 Alcan unit's filtration media has possibly reached the end of its useful life.
4. If testing facilities are available and the unit operation is continuing, however, arsenic removal media should be replaced when analysis of a treated water sample – either taken after fifteen months or the test result as specified in **Section 5.2.1, point #9** – indicates that arsenic concentration in the treated water is greater than 40 µg/L.

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. Alcan 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 Alcan ART.

- 1. Analysis of treated Water for Arsenic:* As suggested above, Alcan technology users should replace arsenic removal media after fifteen months, unless they can have water treated by their Alcan unit analyzed to ensure that after fifteen 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 fifteen months 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 Alcan unit in a possession stop producing arsenic-safe water and its media needs to be replaced with fresh media. 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 a few 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 particularly the cotton/foam filter of an Alcan break down often enough and have to be replaced. For most households, reaching the Alcan 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 Alcan 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, Alcan 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 Alcan 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 costs

Considerations and Description	Quantity	Basic Cost	Costs (Basic + Maintenance & Depreciation)
Alcan Unit Cost	1	Tk3500 ⁸	
Daily Production Volume	45		
Media lifetime ⁹	1.25 Years		
Volume of Arsenic-Safe Water Produced in 15 Months	20,500 L		
Depreciation Costs	20%/Year		
Arsenic Removal Media	1 unit	Tk3,000 ⁸	
Alcan's Bucket Assembly Longevity	5 Year		
The Cost of Treating One Liter of Water		Tk0.17	TK.0.18
Daily Water Consumption Const		Tk7.68	Tk7.95
Monthly Water Consumption Cost¹⁰		Tk230.48	Tk238.39

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 an Alcan unit lasts.

⁸ These prices could change with time

⁹ Based on TPM data

¹⁰ 30 days per month