Kanchan Arsenic Filter
Evaluation of Applicability to Cambodia

Phase I Technical Report

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The information provided in this report is part of an ongoing technology evaluation project. The reader is advised that the results should be considered preliminary and will be supplemented by the more extensive Phase II portion of the project at a later date.

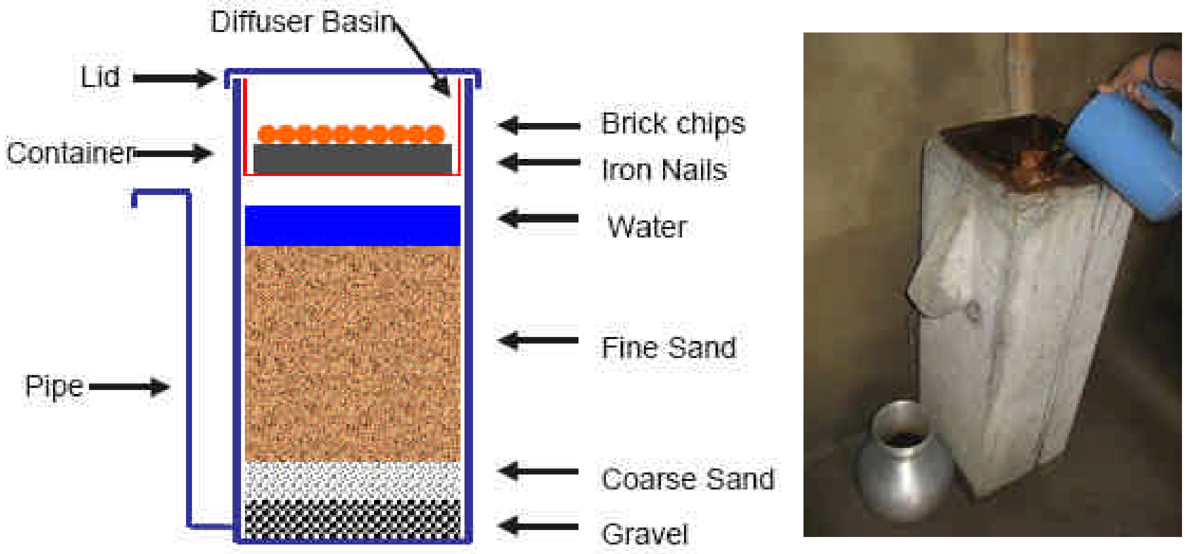
Introduction

Arsenic contamination is a significant threat to the drinking water safety in Cambodia, especially in the rural regions where hundreds of thousands of peoples rely primarily on groundwater for their drinking water needs. A recent study commissioned by the Ministry of Rural Development (MRD) and UNICEF to test the water from 16,000+ tube wells for arsenic in 7 central provinces bordering the Mekong and the Bassac rivers (including Kandal, Kampong Cham, Kratie, Kampong Chhnang, Kampong Thom, Prey Veng and peri-urban Phnom Penh provinces) found that an estimated 320,000 people in 1,600 villages are at risk. A study by the Swiss Federal Institute of Aquatic Science and Technology (EAWAG) reported arsenic concentration as high as 1,300 μg/L, which is 26 times higher than the Cambodian standard of 50 μg/L (MIME, 2004) in the Mekong delta south of Phnom Penh (Buschmann et al., 2007). In late 2006, a knowledge, attitude, and practices (KAP) survey jointly conducted by the MRD, UNICEF and the Institute of Technology of Cambodia (ITC) found several suspected arsenicosis cases in the Kandal province. These cases of skin diseases and cancers were analyzed and confirmed by the Ministry of Health (MoH) to be arsenicosis (MRD and MoH, 2007).

There is strong demand among various stakeholders on Cambodia to find effective solutions. A grant was awarded by the Asian Development Bank (ADB) to evaluate the applicability and limitations of the Kanchan Arsenic Filter (KAF) as a potential arsenic mitigation option for Cambodia.

The KAF was developed by the Massachusetts Institute of Technology (MIT) and a Nepali NGO, Environment and Public Health Organization (ENPHO) based on 7 years of extensive inter-disciplinary laboratory and field studies in rural villages of Nepal (Ngai et al, 2006). This awards-winning filter is an open-content technology and requires no external energy/material input for operation and requires no replacement parts except nails. Refer to Figure 1 for a diagram of the filter.

Figure 1 - Components of the Kanchan Arsenic Filter (KAF)



Project Schedule, Participating Organizations & Funding Sources

<u>Overall Study Duration (Phase I & II)</u>

- 1st of February 2008 to 31st of December 2008

<u>Phase I Study Duration</u>

- 1st of February 2008 to 25th of August 2008

<u>Lead organizations:</u>

- Institute of Technology of Cambodia (ITC)
- Ministry of Rural Development (MRD)

<u>Support organizations:</u>

- Centre for Affordable Water and Sanitation Technology (CAWST)
- Massachusetts Institute of Technology (MIT)

<u>Funding sources:</u>

- Asian Development Bank Pilot Demonstration Activity – US $50,000
- Mondialogo Engineering Competition – US $6,500

Selecting a Site for Phase I Testing

We wanted to find a research site representative of the general condition of arsenic contaminated area of Cambodia so we identified published studies and summarized the water quality data in them (see Table I below):

Table 1 - Arsenic-Related Data for Tubewells in Cambodia (Previous Studies)

	Buschmann et al 2007	***Berg et al 2007***	***Feldman et al 2007***	***Sthiannopkao et al 2008***
Number of samples	90	204	19	15
Arsenic (ug/L)	233	212	148	269
Iron (mg/L)	2.8	2.8	6.2	2.57
pH	7.03	6.94	6.99	6.1
PO4 (mg/L)	1.8	0.59	-	-

We randomly tested 13 tubewells in Kien Svay and talked to households regarding their interest in participating in this research. One household has high arsenic and was very cooperative, so we selected that tubewell as our research site. As noted below, our research site has worse conditions than average, yet not too extreme, making it a good research location.

Table 2 - Comparison of Phase I Site to Data from Previous Studies

	Buschmann et al 2007	***Berg et al 2007***	***Feldman et al 2007***	***Sthiannopkao et al 2008***	***Our site***
Arsenic (ug/L)	233	212	148	269	**637**
Iron (mg/L)	2.8	2.8	6.2	2.57	**6.43**
pH	7.03	6.94	6.99	6.1	**7.02**
PO4 (mg/L)	1.8	0.59	-	-	**5.09**

Filter Configurations Used During Phase I Testing

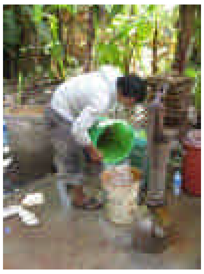
Because of the very high arsenic levels, 5 different configurations were tested to see if any particularly configuration improved performance. The five configurations were:

1. **Original filter design** (Filters F1 and F2). 5 kg of nails were placed in the diffuser basin of an otherwise traditional biosand filter.

2. **Pre-rusted nails configuration** (Filters F3 & F4) - to evaluate whether pre-rusting can give better iron loading, resulting in increased arsenic removal.

3. **Submerged nails configuration** (Filters F5 & F6) - to evaluate whether submerging nails under water at all times will lead to more rusting, increasing arsenic removal.

4. **Manual aeration configuration** (Filters F7 & F8) - to evaluate whether pouring water between 2 buckets for 20 times prior to pouring water into the filter can increase arsenic removal.



5. **Mechanical aeration configuration** (Filters F9 & 10) - to evaluate whether aeration by air bubbler, prior to pouring water into the KAF, can improve arsenic removal.

Volume & Frequency of Water Added During Phase I

Research was started on the 3rd of February, 2008. Every day, household owner poured 20L of water into each filter in the morning, and another 20L of water in the evening. ITC and/or MRD staff visited the filters 3 times per week for inspection. Every week, water samples (raw and filtered) were collected and tested on site and at ITC's laboratory.

Phase I Analyses & Testing Equipment Used

During the Phase I study a digital Wagtech Arsenator was used because the results can be read digitally. While UNICEF does not endorse any particular product, the 2008 UNICEF Handbook on Water Quality states that the Arsenator "… uses an optical photometer to digitally measure the colour change on mercuric bromide filter paper, however, it is much more portable. It detects arsenic within a reported range of 2-100 µg/L (ppb). The Arsenator is significantly more expensive than manual colour comparison kits, but is more accurate and precise. A recent UNICEF-commissioned study from India comparing the Arsenator with laboratory AAS-HG showed a very high correlation of 0.998 (Shriram Institute, 2006)". During the Phase I study samples of raw water were generally diluted by a factor of 10 to say within the digital readout range. Filtered water samples were not diluted. Verification of the results will be described in the "Confirmation of Arsenic Results" section of this report.

Table 3 - Water Quality Testing Methods

Parameter	***Instrument/ Method***
Arsenic	Wagtech digital arsenator
Iron	Jenway spectrophotometer
Phosphate	Wagtech photometer 7100
pH	Hanna HI 8424 microcomputer pH meter
Turbidity	Wagtech digital turbidimeter
Total coliform	Membrane filtration, Bio-rad media
E. Coli	Membrane filtration, Bio-rad media

Arsenic Removal Results

- Excellent arsenic removals were observed during both the dry and wet seasons, at 95-97% depending on the configuration. Figures 2 and 3 shows the results for F1, F2, F3, and F4
- Removal effectiveness in Cambodia is consistent with data from Nepal, which showed an average of 85-90% arsenic removal from over 1000 filters tested after 1 year in operation (Ngai et al, 2007).
- After the 1st week start-up period, only 1 out of 224 filtered water samples (0.5%) exceeded the Cambodian standard of 50 ppb (MIME, 2004), from a raw water average of 637 ppb of arsenic.
- No observed trend of increasing arsenic concentration over 30 week period (8400 liters of water filtered).
- Manual and mechanical aeration and submerged nails processes seemed to not improve arsenic removal compared to the original design under our study conditions. There was a slight improvement in the initial week of arsenic results by using the pre-rusting configuration.

Figure 2 - Excellent Arsenic Removal in the Original Design

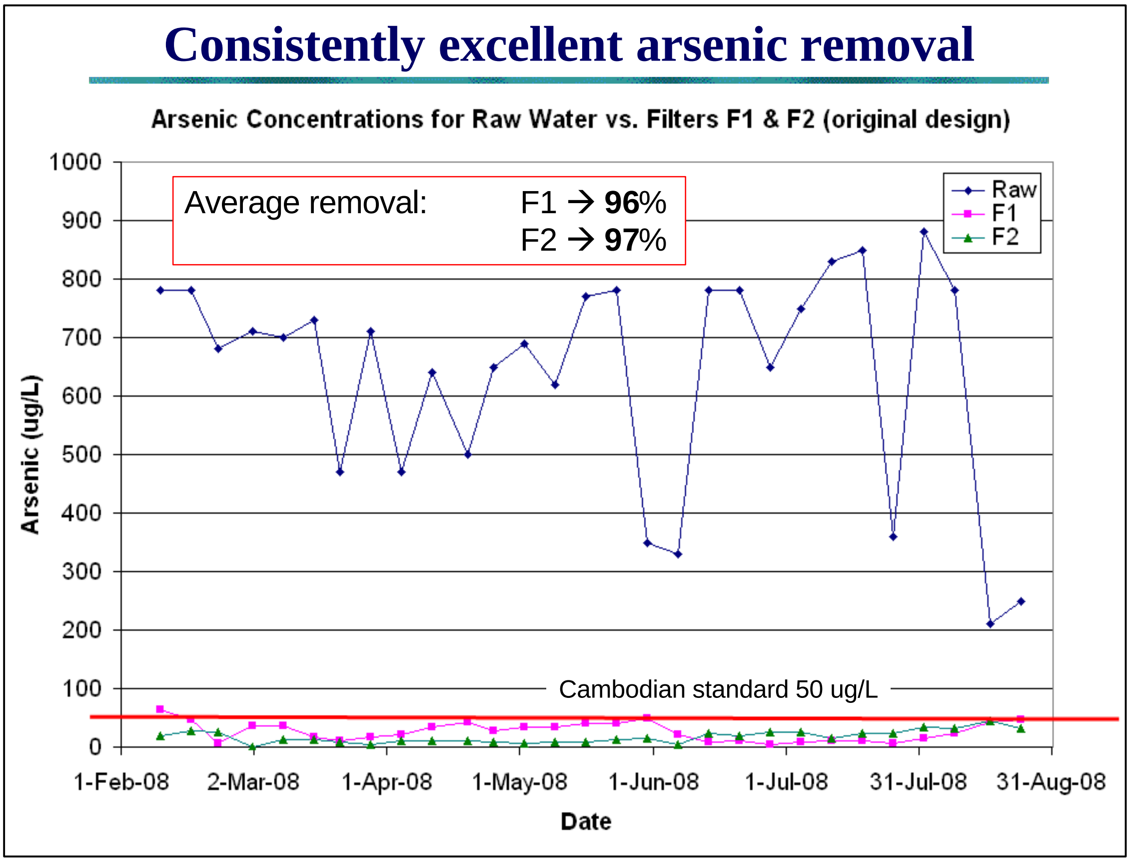
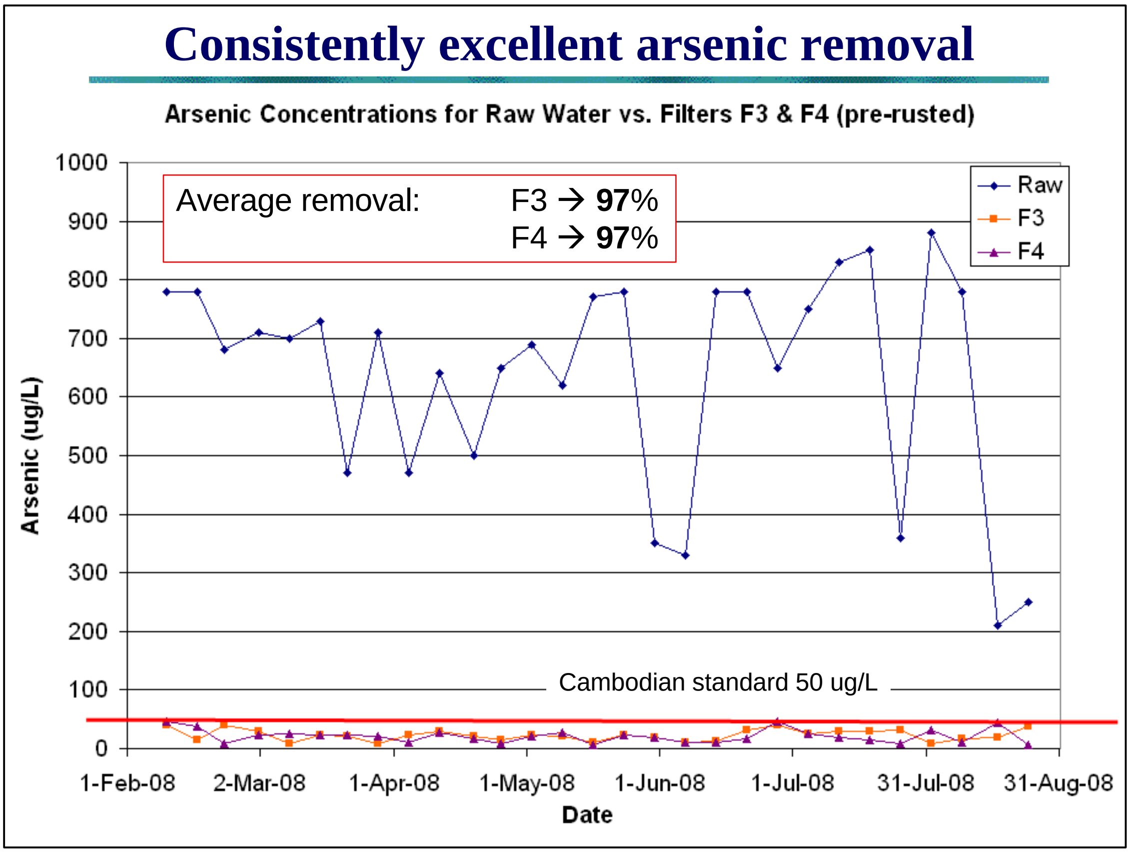


Figure 3 - Excellent Arsenic Removal in for Pre-Rusted Iron Nails Design



Confirmation of Arsenic Results

Confirmation of arsenic results was done in part by shipping preserved samples to laboratories in France and the USA as noted in Table 4.

Table 4 - Confirmation of Arsenic Results

Split sample on 3rd May 2008 sent to CIRAD lab, France by ICP

	Raw water		Filter 2	
	France	Our study	France	Our study
Arsenic (ppb)	820	780	23	28

Split sample on 12th July 08 sent to a government lab in Boston, USA by ICP/ICP-MS

	Raw water		Filter 2	
	USA	Our study	USA	Our study
Arsenic (ppb)	590	830	13	15

These laboratory analyses of preserved samples (pH < 2) confirm that the raw water arsenic levels are very high and confirmed the filters are producing arsenic levels significantly below the Cambodian standard.

Impact of Flow Rate and Filter Cleanings on Arsenic Removal

- Arsenic removal appeared to be not significantly affected by the flow rate nor the frequency of cleaning.
- Flow rate appears to be adequate for household use.
- Flow rate can be effectively restored through simple cleaning, which takes 15-20 minutes. Filter cleaning involves swirling approximately the top 2 cm of sand, removing the turbid water, and repeating 2 to 3 times.
- The time between filter cleanings was typically 2 to 2.5 months. However manual aeration (F7 & F8) and mechanical aeration (F9 & F10) clogged more quickly than other configurations resulting in a need for more frequent cleanings.

Figure 4 - Flow Rate vs. Arsenic Removal

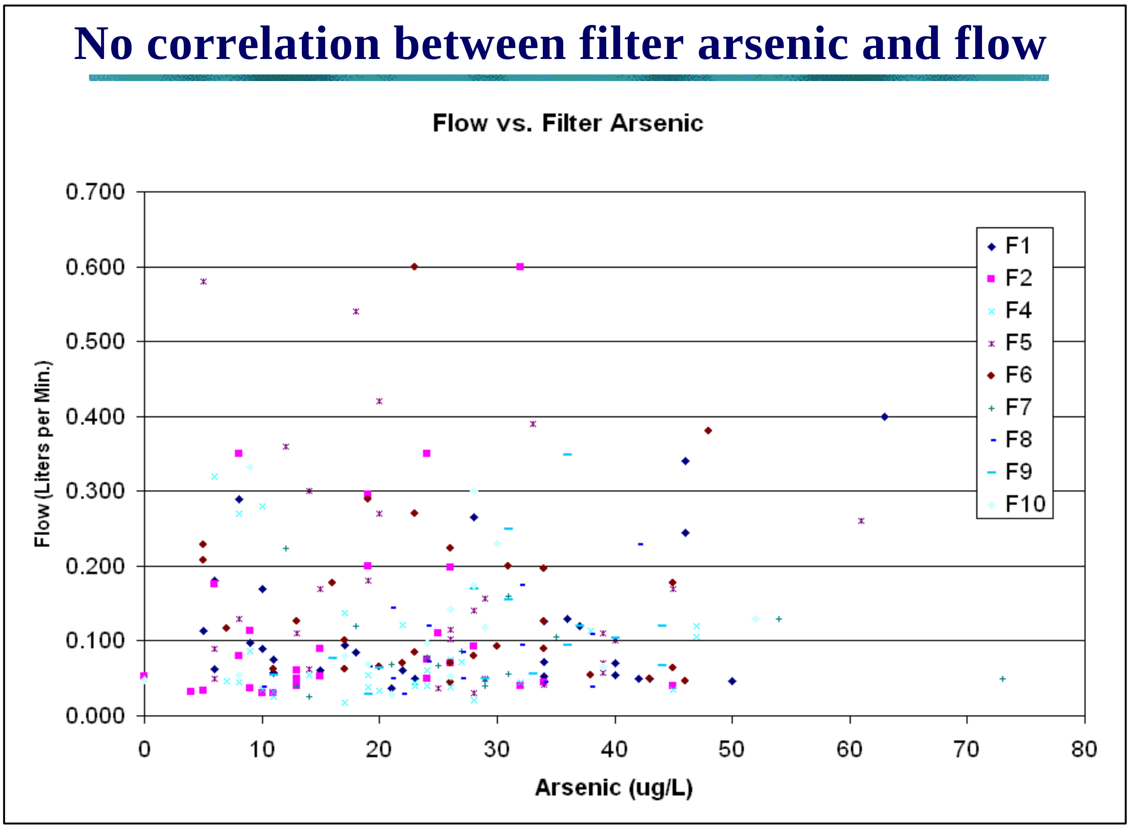
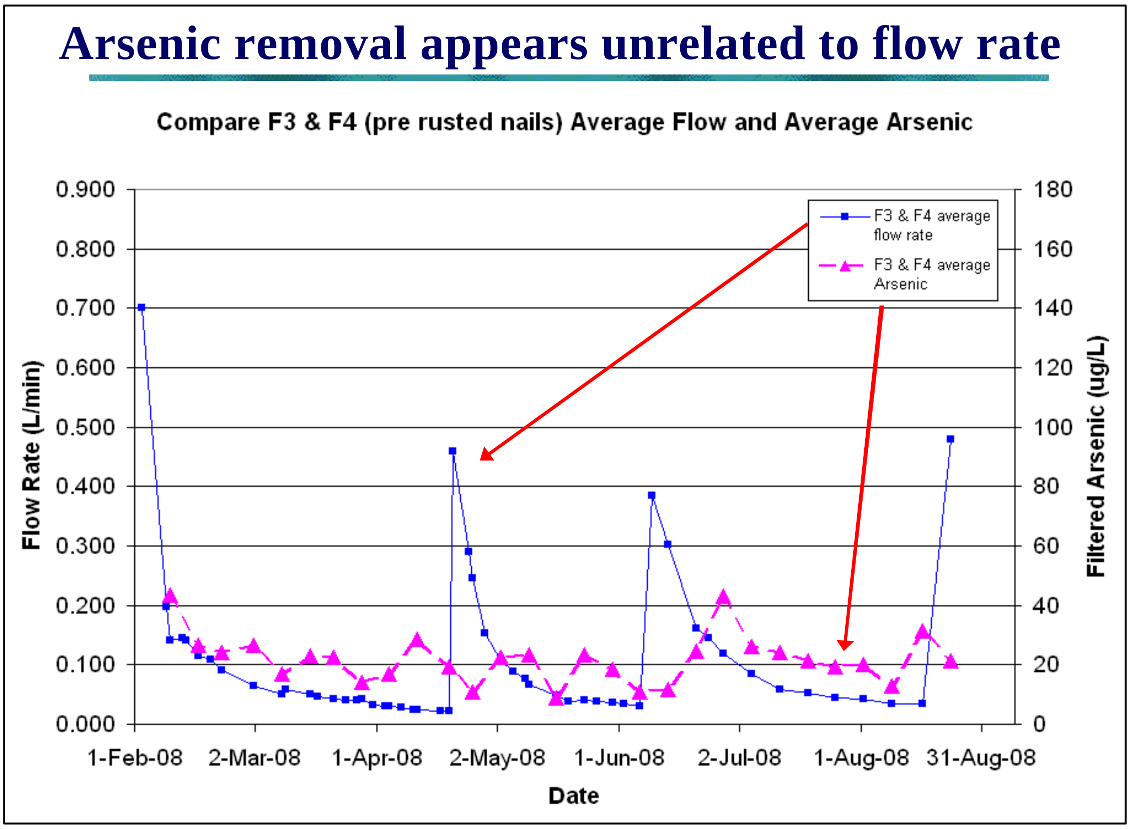


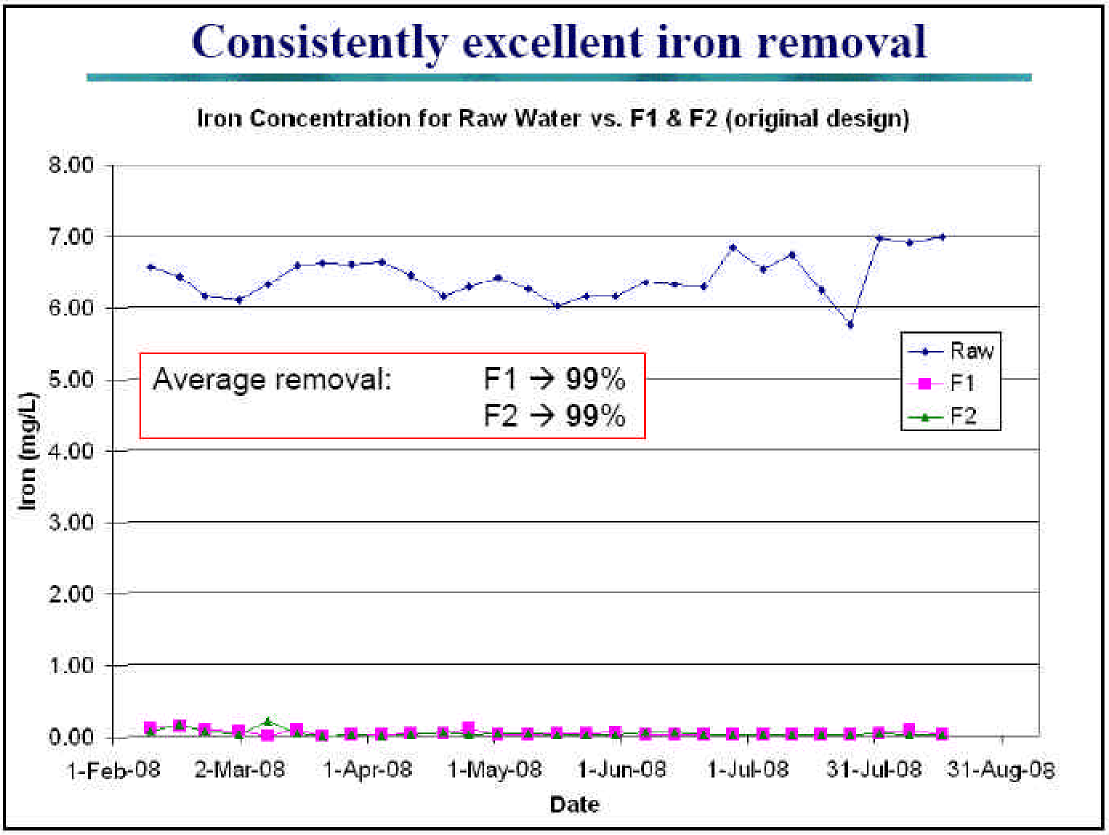
Figure 5 - Arsenic Results vs. Filter Cleaning



Iron Removal Results

- During Phase I excellent and consistent iron removals were observed for all the configurations regardless of whether wet or dry season (99% for all configurations).
- Removal effectiveness in Cambodia is consistent with data from Nepal, which showed an average of 90-95+% iron removal from over 1000 filters tested after 1 year in operation (Ngai et al., 2007).
- In many parts of the world, high iron removal is often associated with high user acceptance and sustainability of the technology.

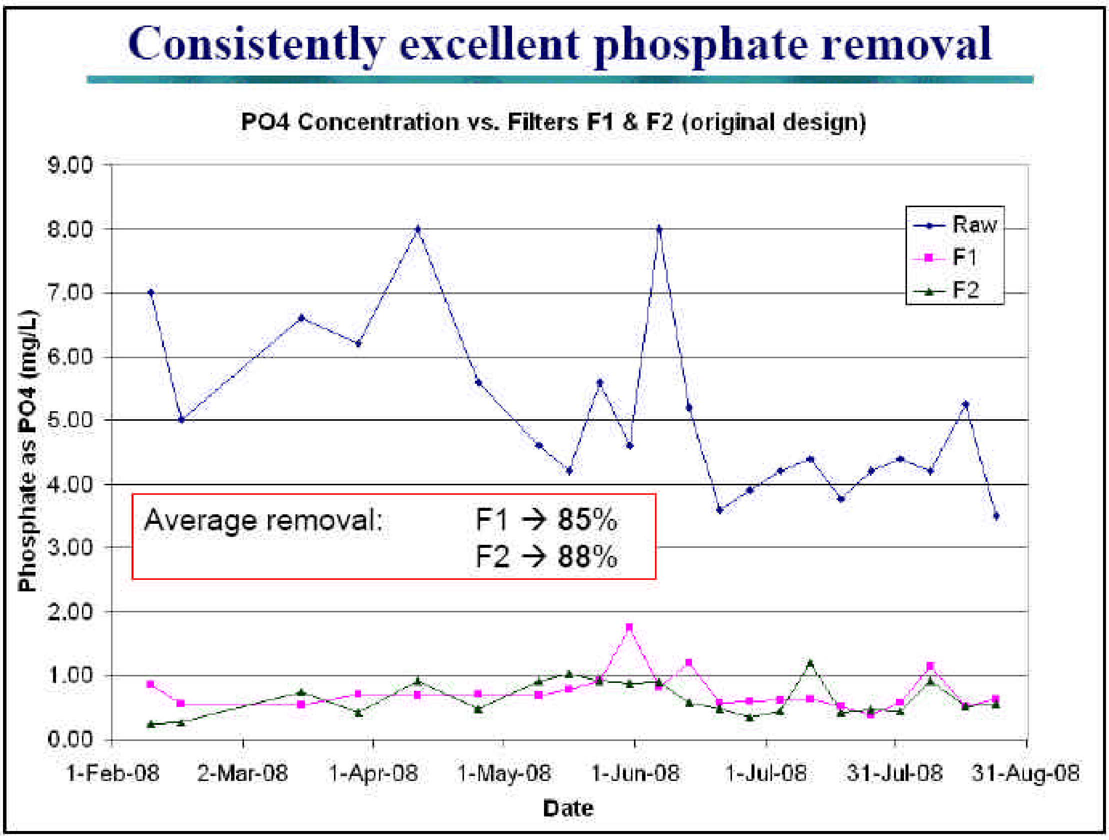
Figure 6 - Excellent Iron Removal in the Original Design



Phosphate Removal Results

- Consistent phosphate removals (85%, 88%, 83%, 86%, 89%, 86%, 88%, 88%, 88%, 85% for the different filters) were observed during both dry and wet seasons
- Removal effectiveness in Cambodia is consistent with data from Nepal, which showed an average of 80-85% phosphate removal from over 1000 filters tested after 1 year in operation (Ngai et al., 2007).
- Despite the high raw water phosphate levels (average of 5.09 mg/L as PO4), which is known to interfere with arsenic adsorption (Mahin et al., 2008), the filters were able to achieve consistently very high arsenic removals.

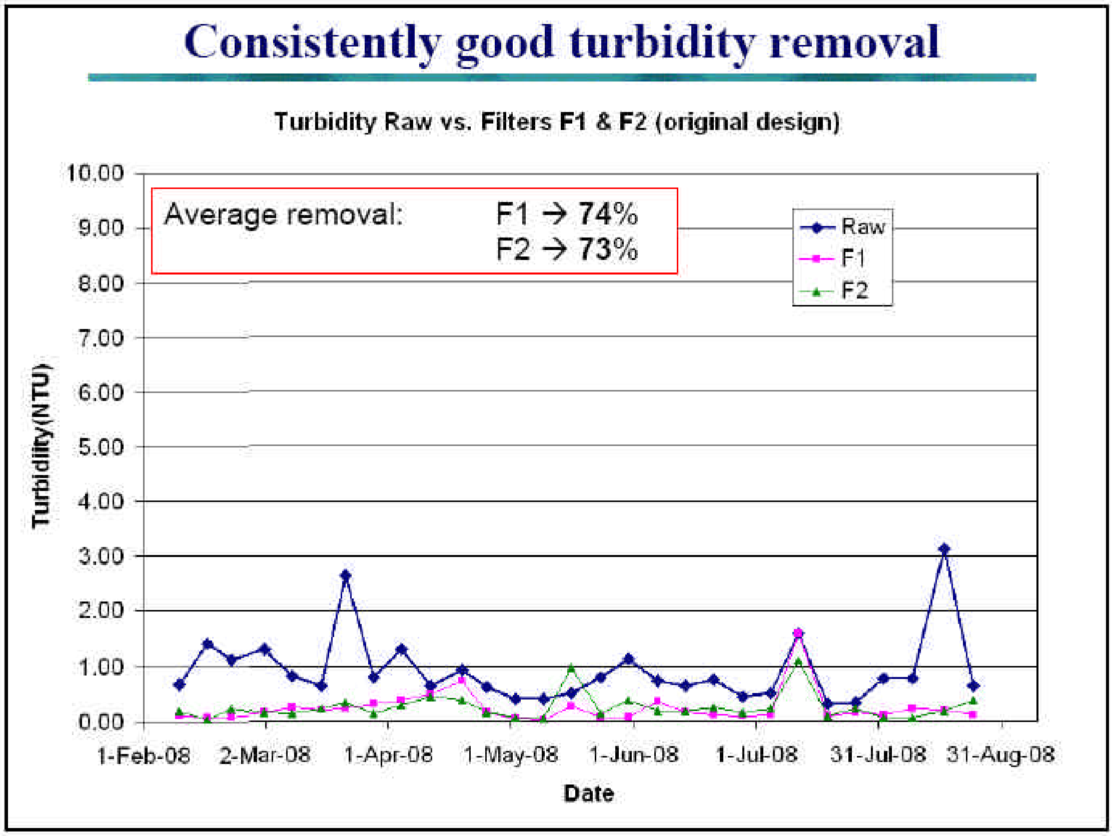
Figure 7 - Excellent Phosphate Removal for the Original Design



Turbidity Removal Results

- Consistent good turbidity removal for all filters. The % removal is a function of the low raw water turbidities typically found in groundwater.
- Removal effectiveness in Cambodia is consistent with data from Nepal, which showed an average of 80-95% turbidity removal from over 1000 filters tested after 1 year in operation (Ngai et al., 2007).
- In many parts of the world, high turbidity removal is often associated with high user acceptance and sustainability of the technology.

Figure 8 - Good Turbidity Removal for the Original Design



E. coli Removal Results

For most filter configurations raw water *E. coli* levels were very low. The Phase I study confirmed that for these filters *E. coli* levels were not increasing through the filter.

For the pre-rusted configuration the filtered water has higher *E. coli* in the initially 2-3 weeks after installation. It is believed that bacterial contamination may have been introduced to the water during pre-rusting. This can presumably be avoided in the future by covering the pre-rusting container.

After the start-up period of 2-3 weeks, all filters have zero *E. coli* in the filtered water.

Figure 9 - *E. coli* Removal for the Original Design

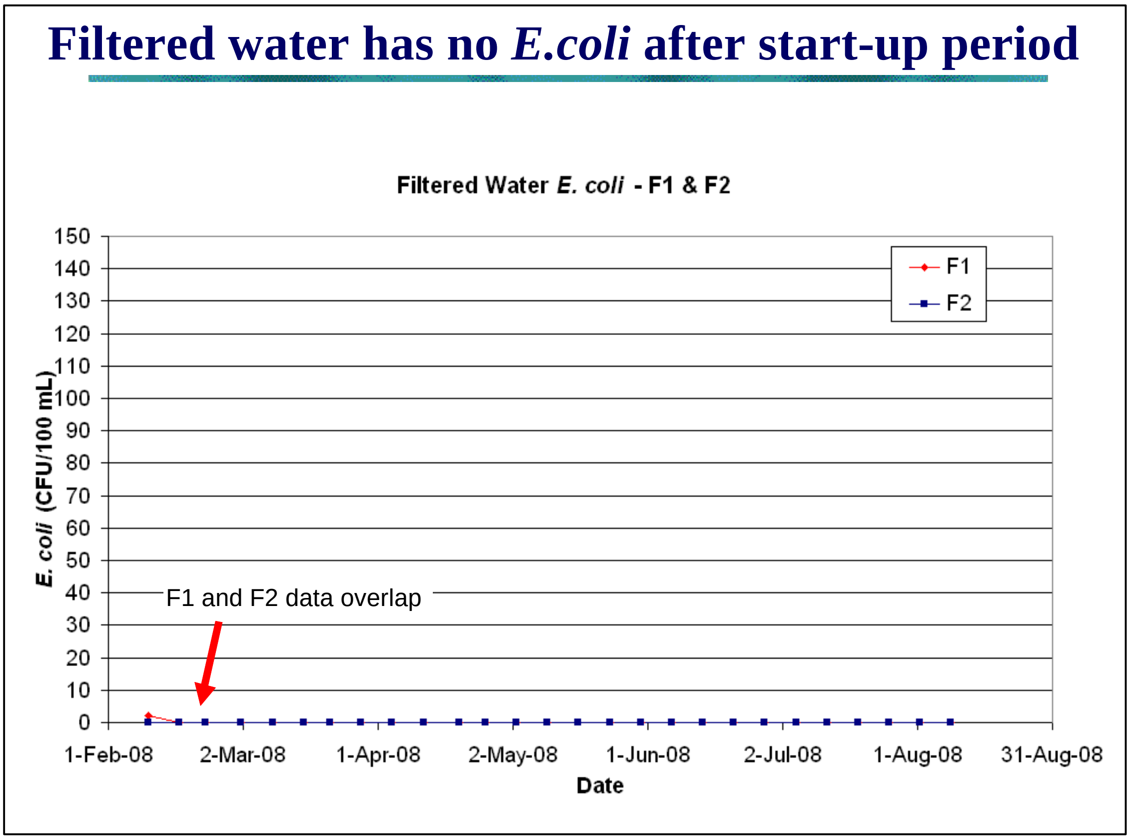
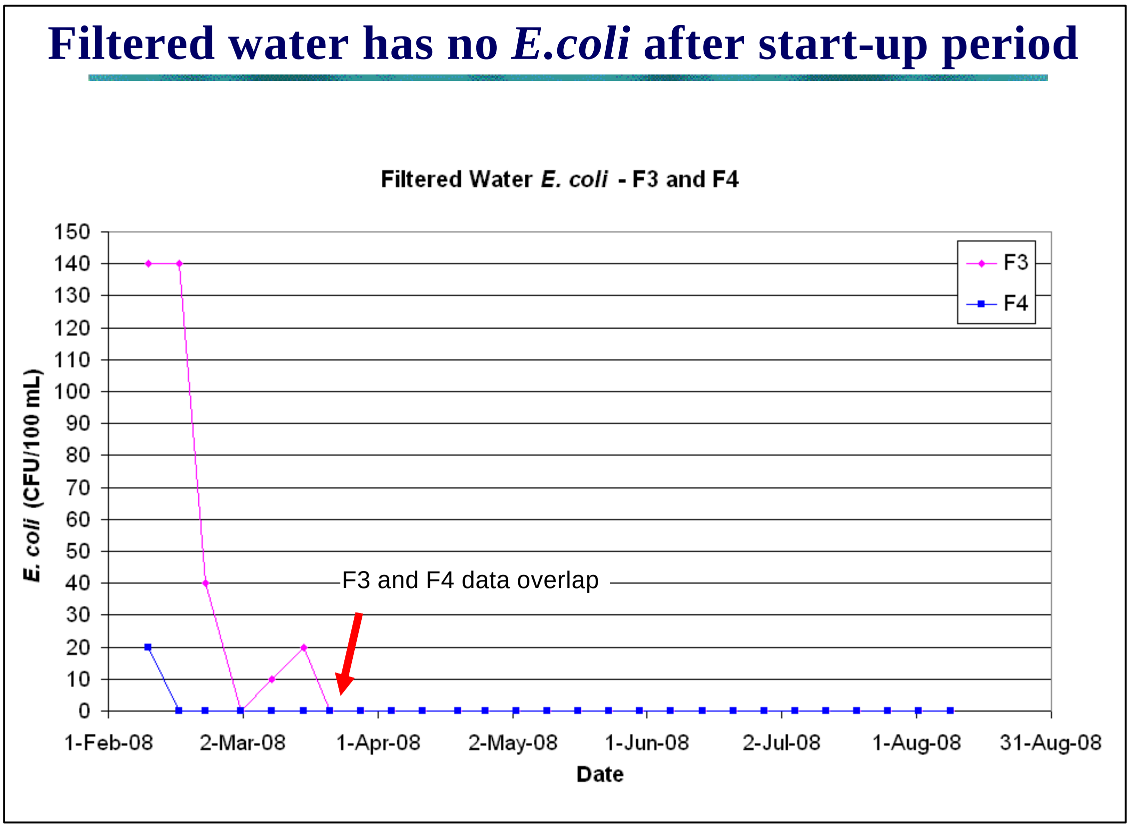


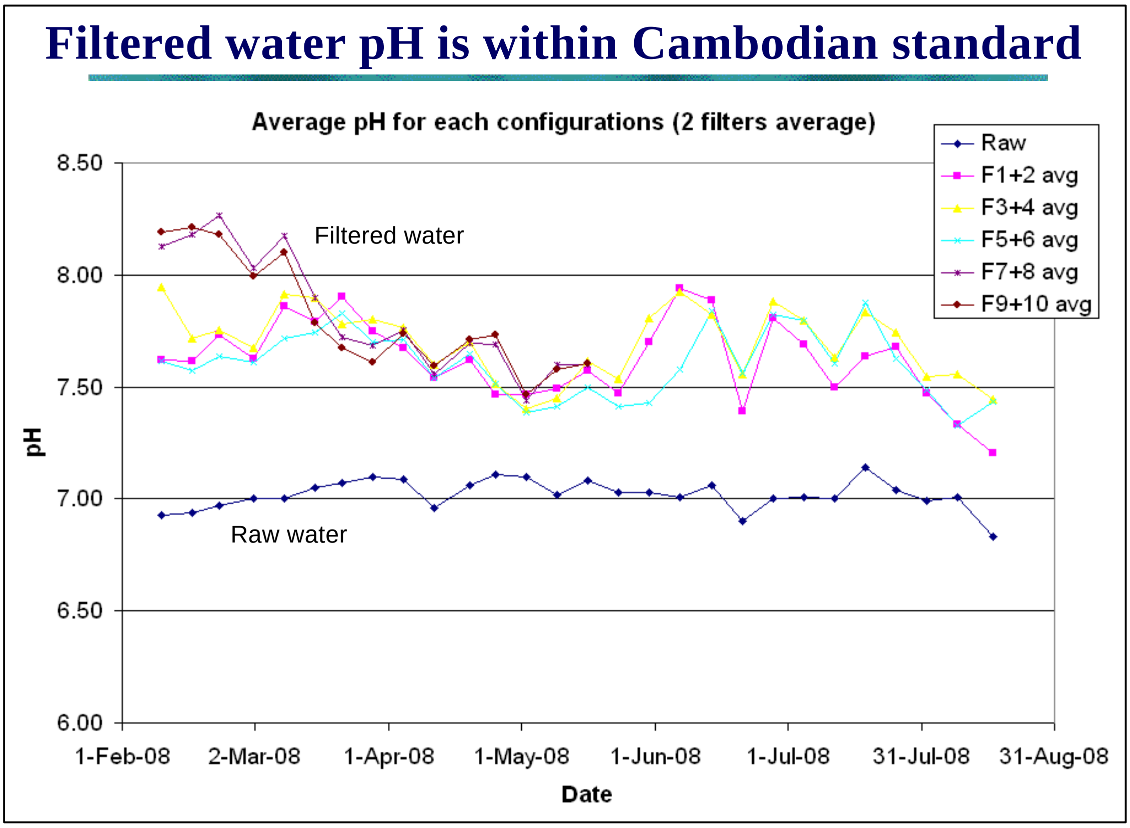
Figure 10 - *E. coli* Removal for the Pre-Rusted Nails Filters



pH Results

- The pH of the water from all 10 filters is within the Cambodian standard of between 6.5 and 8.5 (MIME, 2004). Refer to Figure 11.
- The filtered water pH increases by about 0.5 to 1.0 pH unit, which is consistent with data from Nepal, which showed an average of 0.35 to 0.4 pH unit increase from over 1000 filters tested after 1 year in operation (Ngai et al, 2007).
- The increase in pH is believed to be related to decarbonation (e.g. carbon dioxide equilibrium) and possibly from contact with alkaline concrete materials.

Figure 11 - pH of the Raw Water and Filtered Water



Comparison of Phase I Results with Other Studies

We compared our results with two other studies of iron-amended biosand type filters and the results are summarized in Table 5 below:

Table 5 - Comparison of Results from 3 Different Iron-Amended Biosand Type Filters

	Peang et al 2006	*Chiew et al 2008*	*Our study*
Location	RDI	RDI	Kiensvay
Number of filters	4	3	10
Arsenic removal	**92%**	**40-75%**	**97%**

Possible reasons for the differences noted above could be:

1. Differences in rusting?
2. Differences in raw water characteristics/chemistry of raw water?
3. Differences in design and setup of experiments such as amount of water used?

Discussion of Potential Important Differences Between the Results of This Study and the Chiew et al. 2008 Study

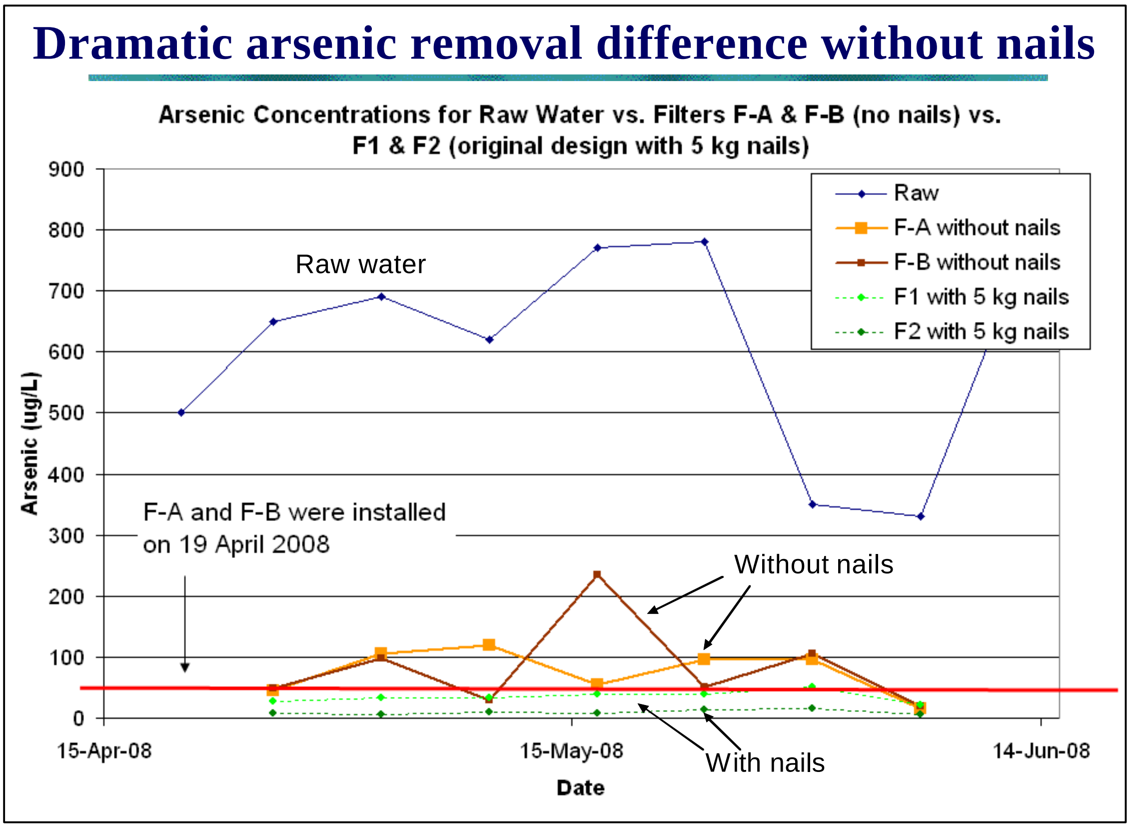
1. Rusting

Chiew et al. 2008 states that "Some preliminary work was done to check the impact of the rusted nails on arsenic removal. A few samples were extracted from the standing water (between the nails and sand bed) and analyzed,…, nor was there substantial increase of dissolved iron. A control filter with the nails removed was operated to compare the arsenic removal and found that arsenic removal is similar to those with nails. This suggests the nails do not play a major role in removing arsenic…"

It appears from the above that the nails in the Chiew et al. study were not adding any significant amounts of iron to incoming water. But according to the works at MIT and ENPHO (Ngai & Walewjik, 2003; Ngai et al., 2006), iron added from the nails is a critical part of the KAF's arsenic removal effectiveness.

To test whether the nails (rusting) were critical to the % removals of arsenic achieved we used the same raw water and ran it through the filters without any nails. As can be seen below the results indicate the importance of the rust that is generated from the supplemental nails.

Figure 12 - Comparison of the Effluent Arsenic Levels for Filters with Nails (in dotted green) & Filters without Nails (orange & brown)



2. Differences in Raw Water Quality

As noted below in Table 6 below the most significant differences in the raw water between the two studies appear to be the pH and the hardness levels.

Table 6 - Comparison of Phase I Raw Water Quality from this Study to Chiew et al. Study

	Chiew et al 2008			*Our study*
	Filter 1 input	Filter 2 input	Filter 3 input	Raw water
Arsenic (ppb)	344	98	258	651
Iron (mg/L)	1.9	4.82	2.0	6.43
Phosphate (mg/L)	0.93	2.69	1.04	5.58
pH	7.44	7.19	7.50	7.02
Turbidity	11	45.7	10.5	0.93
Hardness (mg/L)	175	157	192	120

As noted previously in this report Table 2 below compares the raw water pH of our study versus 4 other published studies that we found on high arsenic areas of Cambodia. It appears that our raw water pH is consistent with the other published studies. Elevated pH is known to potentially impact iron based arsenic treatment systems. We will look at the hardness issue closely during Phase II of this study.

Table 2 - Comparison of Phase I Site to Data from Previous Studies

	Buschmann et al 2007	***Berg et al 2007***	***Feldman et al 2007***	***Sthiannopkao et al 2008***	***Our site***
Arsenic (ug/L)	233	212	148	269	**637**
Iron (mg/L)	2.8	2.8	6.2	2.57	**6.43**
pH	7.03	6.94	6.99	6.1	**7.02**
PO4 (mg/L)	1.8	0.59	-	-	**5.09**

3. Differences in Design and Setup of Experiments

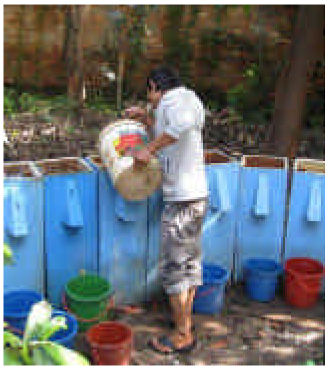
Chiew et al. 2008	Our study
	
Feed water to filters piped from tubewell from far away	Filters right next to tubewell
18 liters water fed into each filter on Monday to Friday only	40 liters water (20L morning and evening), every day
About 1500L of water filtered	About 8400L of water filtered
(Photo from Chiew et al. report)	

It is possible that the pouring water into the filters only once from Monday to Friday (and only 18 L) may have contributed to the lack of any significant rust in the Chiew et al. study. We believe the use of the filter in the morning and evening and the volume we used is consistent with likely village water use patterns.

Next Steps

There are two key activities in the next phase of this research project. First, we will continue the on-going field research at Kien Svay to observe long term trends to see if arsenic removal capacity exhaustion will occur. Second, we will test the filter in more challenging locations to determine the limitation of the filter, with close consideration on rusting characteristics and water chemistry.

1. Field Testing Component for Existing Filters



- Household will continue to pour 40L of water per day into each of the 6 filters.
- MRD and ITC staff visit the filters weekly to assess the condition of the filters.
- Collect and test water samples (raw and filtered) on site and at ITC laboratory monthly.
- Send some split samples to France and USA for additional cross-checking and data verification.

2. Demonstration study of 30 filters in Kampong Cham and Kandal Provinces

- Evaluate the applicability of the filter under different water chemistry conditions.
- Include challenging water chemistry conditions of which we think the filter will fail, allowing us to determine filter performance limitations.
- Households will pour 40L of water per day into each of the filters. The filtered water can be used for washing and cleaning, but not for drinking yet.
- MRD and ITC staff will visit the filters monthly to inspect filters and test water. Parameters to be tested include: arsenic, iron, pH, *E. coli*, turbidity, phosphates, and hardness.
- Send samples overseas for crosschecking
- Conduct a social evaluation to investigate user acceptance and sustainability.

Conclusions

The phase 1 field testing results have been very encouraging. The raw water from the tubewell in the field testing site contains high arsenic and phosphate levels, which represents a challenging treatment condition. Nevertheless, the Kanchan Arsenic Filters were found highly effective.

All of the 10 filters are consistently reducing arsenic levels from an average of 637 ppb to less than 50 ppb. The average removal percentage is in the 95-97% range. In addition, there is no observed trend of increasing arsenic concentration over 30 week period (8400 liters of water filtered).

In Phase 2 of this research project (September to December 2008), we will continue the on-going testing to determine whether arsenic capacity may be exhausted. In addition, we will explore the limitations of the filter by installing them at more challenging locations. We will also look into the issue of hardness and water usage patterns.

It is expected that this research project can fill an important gap in the delivery of safe drinking water for Cambodia. Although arsenic has been found, there is currently no suitable removal technology for Cambodia. A successful verification of the performance of the Kanchan Arsenic Filter can provide policy-makers and implementers a reliable mitigation option to arsenic affected households.

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