HMG's
Ministry of Physical Planning and Works
Department of Water Supply and Sewerage
Water Supply and Sanitation Division Office
Nawalparasi

Report on a Four-month Performance Evaluation of the Cement Arsenic Biosand Filter (ABF) for Mitigation of Arsenic Contamination

Arsenic Biosand Filter

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Table of Contents

List of Acronyms:

ABF	Arsenic Biosand Filter technology
AAS	Atomic Absorption Spectrophotometry
ENPHO	Environmental and Public Health Organization, Nepal
HACH	American company that produces field test kits for water
UNICEF	United Nations' International Children's Fund
WHO	World Health Organization
WSSDO	Water Supply and Sanitation Division Office, Nawalparasi
L/hr	Liters per hour
ppb	parts per billion (a.k.a. micrograms per liter)

Acknowledgements

There are a few people I would like to thank, without whom this project would not have been the success it is. I am very grateful to them for their help and support through the course of the five months:

I would like to thank Mr. Gajendra Kumar Thakur, Senior Division Engineer for WSSDO for suggesting and supporting this project through the office. I also extend thanks to Mr. D.B. Jha, Overseer of the Arsenic Testing and Mitigation Section of WSSDO, for his encouragement, advice, and assistance.

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Lastly, but perhaps most importantly, I give my heartfelt gratitude to Bel Kumari Karki, Woman Worker of WSSDO Nawalparasi and assistant in this project. Without her selfless dedication and tireless effort there would have been no data, no report, and no project.

Warmly,

Naomi V. Odell
Peace Corps Volunteer

I. Background

In the past two years, HMG's Water Supply and Sanitation Division Office in Nawalparasi with the help of UNICEF has done considerable investigative research into the presence of arsenic in this district's tube wells. This research has shown that arsenic contamination in the shallow aquifer tube wells is indeed present at severe levels in parts of the district. These findings indicate a serious threat to the health of the resident population. For this reason, WSSDO Nawalparasi wishes to investigate and implement arsenic mitigation methods in the field. Several small-scale mitigation measures have already been developed in South Asia and Nepal, such as the 3-Gagri filter, Arsenic Biosand Filter (ABF), modified dug wells, collection of rain water, and other types of arsenic removal plants. All of these mitigation techniques show limited success in the areas where they have been implemented. Therefore, it is important for WSSDO to take into consideration the specific advantages and disadvantages of each technology it considers using in order to best meet the needs of the communities suffering from arsenic poisoning in Nawalparasi.

II. Project Description and Objectives

This project focused on investigating the ABF as an effective mitigation technology for arsenic contamination removal. In anticipation of future mitigation efforts for arsenic, WSSDO Nawalparasi tested the ABF with two main goals in mind. Our first goal was to test the capability, efficacy, and lifetime of the filter components. By "capability" we refer to the reduction of high concentrations of dissolved arsenic to acceptable or negligible amounts that are safe to drink. The arsenic-removal capacity of the filter has already been tested and proven by the ABF filter designer, Tommy Ngai and his team, in 2003[1] through a series of experiments in the lab and field. For this part of the investigation, our experiment worked to confirm Tommy Ngai's findings. By "efficacy" we refer to how many months the filter will successfully remove arsenic; in other words, we want to find if the ABF has a "saturation point" over time. Hypothetically, since there is a finite amount of arsenic removing media, there should also be a finite amount of arsenic this media is able to absorb. It is expected that over a period of time the media will become more laden with arsenic, and therefore will absorb it less effectively. At some point, the amount the media can absorb will fall to a value less than is safe to drink. In other words, over time the effluent filter water will have

[1] Ngai, Tommy; Walewijk, Sophie. "The Arsenic Biosand Filter Project: Design of an Appropriate Household Drinking Water Filter for Rural Nepal," July, 2003.

increasing arsenic content, eventually reaching above 50 ppb. This is the saturation point. Our data, taken over a suitable period of time, should reveal the saturation point and therefore the approximate lifetime of the arsenic-removal media.

Our second objective was to observe and assess the ease with which the filter can be operated and maintained, identifying what advantages or disadvantages exist. These observations will be instructive to us while preparing training, implementation methods, and activities. It will also help WSSDO give better support to users if this office decides to use the ABF technology for mitigation measures in the future.

The general set up of our experiment was as follows. We tested two filters for a total of four months. This testing period was split into two Phases lasting two months each, from November to January (Phase I), and again from February to March (Phase II). Between the two phases we briefly paused and assessed the progress of the experiment, making necessary changes. For the duration of each of the two-month phases, we charted the arsenic concentration of the tube well water (influent) against the filtered water (effluent.) The two filters differed in characteristics: one filter had 2.5 kilograms of arsenic-removing material (rusted iron nails), and the other had 5 kilograms of nails. Also, the source of the water differed for each filter, although the arsenic concentrations of the wells were approximately the same and were intended to be similar for each filter. From this data we hope to be able to estimate the "removal proficiency lifetime" of the active ingredients. There was no "control" filter set up in this experiment.

III. Methods

In order to obtain good results that reflect the conditions in the field while taking into consideration the limitations of time, staff, and transportation, certain requirements for filter placement and design were made. First, the filters were placed in locations where the influent tube well water at a concentration more than 250 ppb. This minimum limit represents an approximate average of filter contamination in villages of Nawalparasi without being too low for good observation of arsenic removal potential. Furthermore, a higher concentration of arsenic in the experimental wells would theoretically show the efficacy and lifetime of the filter in a shorter period of time. As our experiment was limited by time restraints, this was an important consideration if we wished to obtain data that showed evidence of saturation. Second, the location was limited to the immediate Ramgram Municipality area (i.e. wards

2,3,5) due to our transportation, time, and staffing restraints. These households had reliable alternative sources of arsenic-free water (such as a connection to the WSSDO piped water) so that the families would not form a dependency on the filters that would prove difficult at the end of the research period, and when the filters would be removed. Lastly, different quantities of arsenic removing media (iron nails) were added to each of the two filters. This requirement would give good comparative data on how the quantity of nails affected the removal capacity of the filters. Therefore, one filter contained 2.5 kilograms of nails while the other contained 5 kilograms.

Testing the wells and the filtered water for fecal coliform content was also considered during this project, but dismissed due to lack of testing materials and time. Furthermore, a bacterial count test performed by Tommy Ngai during Phase II of testing showed that there were no bacteria in Tube Well A. Tube Well B was not tested. This led us to conclude that, for at least one well, bacterial tests would be unnecessary.

3.1 Tube Well Selection and Filter Locations

The two tube wells used for filling the filters were initially selected based on the arsenic concentration measured in the wells with the ENPHO Arsenic Field Test Kit[2]. This level was required to be above 250ppb in order to reflect the condition of most contaminated wells in Nawalparasi and to represent a reasonable average. Therefore, first referring to arsenic concentration data collected by WSSDO in 2002[3], several wells within Ramgram Municipality that had showed concentrations at or above 250 parts per billion (ppb) were selected. Upon visiting and testing the wells again with the ENPHO Kit, two wells exhibited arsenic concentrations of 300 ppb. This level was satisfactory for further testing of the ABF, and these two households were requested to cooperate with our experiment by placing the two ABFs in their homes. The two houses and their wells were located within 50 meters of one another, and were the homes of medium to large-sized families. Neither family actively used the water from the filters as they already were connected to the arsenic-free piped water supplied by WSSDO. This was deliberate, as we wanted to discourage dependence on the filter. During the testing, the two wells generally exhibited similar arsenic concentrations, although those concentrations varied both over time and according to which arsenic testing kit was used *(See Graphs in Discussion section)*.

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[2] Designed by the Environmental and Public Health Organization (ENPHO) of Kathmandu, Nepal.
[3] "Report of Arsenic Test Results". WSSDO/UNICEF, Nawalparasi, December 2002

Table 1: Filter Location Data

Filter	Well S.N.*	Household Name	Ward No.	Nails added	Latitude	Longitude	Initial well arsenic conc.	HH size
A	1655	Mayanath Dhungana	5	5 kg	N27°31.82	E83°39.67	300 ppb** (ENPHO)	8 persons
B	1661	Muna Lal Shrestha	5	2.5 kg	N27°31.82	E83°39.65	300 ppb** (ENPHO)	15 persons

* This Serial Number refers to the 2002 arsenic testing done by WSSDO. ** From the previous testing, well 1655 had a concentration of 400ppb and well 1661 had a concentration of 350 ppb.

Two cement ABFs were constructed at each home in a partially protected location (i.e. protected from sun, rain, being knocked over, or in the way of daily activities.) They were not placed inside the homes, as the families were not actively using them for drinking water. The filters were labeled, and two fifteen-liter buckets were measured and marked to deliver 10 liters of water per bucketful used in the filter. A form was created to help the families keep track of the amount of water they added to the filter daily. During Phase I, a minimum of 30 liters per day was set in order to reflect the average drinking water usage by a medium-sized family (6-8 members) per day. During Phase II, this minimum was raised to 40 liters per day according to our observations. The families were instructed how to use the filter, bucket, form, and asked to fill the filter with 2-3 buckets of water (20-40 liters) daily. The testers added another 20-30 liters each day to meet the goal of 40 liters per day.

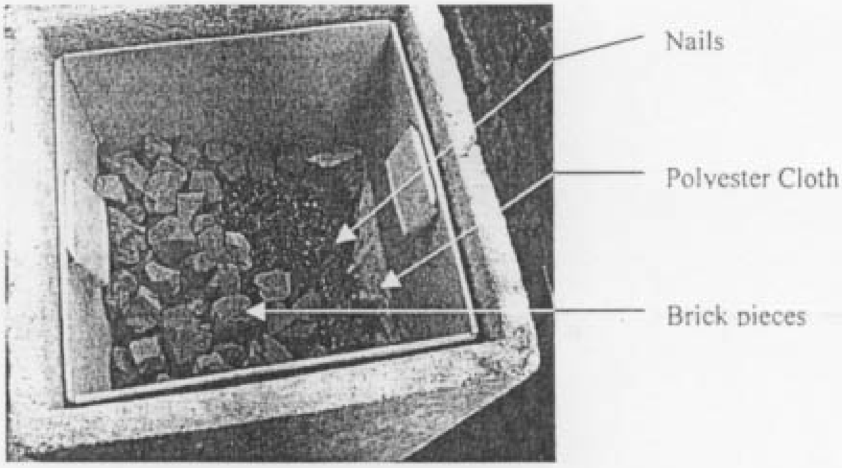
3.2 Filter construction

Two ready-made cement filter moulds were purchased in the Parasi bazaar area and transported by cycle rickshaw to Driver Tol, about half a kilometer to the west. These moulds had already been cleaned and sterilized using a chlorinated wash, as could be verified by the smell of chlorine in the cement. The moulds were positioned within the compound at each house, cleaned out with a solution of detergent, and then rinsed thoroughly with water. After washing hands, the internal filter materials, pre-washed and pre-packed by the distributor (Nepal Red Cross Society), were added in the following order:

1- **Small gravel** – up to 5 cm thick (no water added at this point)
2- **Medium-grain sand** – up to 5 cm from the ledges where the diffuser box sits. As sand was added, water was also poured in so that the sand was effectively added to water. This allowed the sand to fall evenly and prevent air holes from forming.
3- **Iron shoe tacks**, 13mm "blue" - in a metal diffuser box suspended 5 cm above the level of fine sand. No polyester cloth was added between the nails and the bottom of the box at the time, although recommended by the designer of the filter. It was added later, for the second two-month testing period.

4- **Brick pieces** – 20-30 pieces placed on top of nails to buffer the force of the water as it entered the filter. This would keep the nails from being scattered when water was added.

Figure 1: Diffuser Box Set-up (shown in layers)



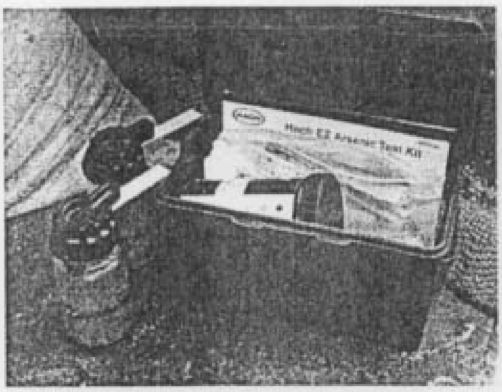
Note: during use, each layer was evenly spread over the bottom of the diffuser box.

3.3 Filter Testing and Test Kits

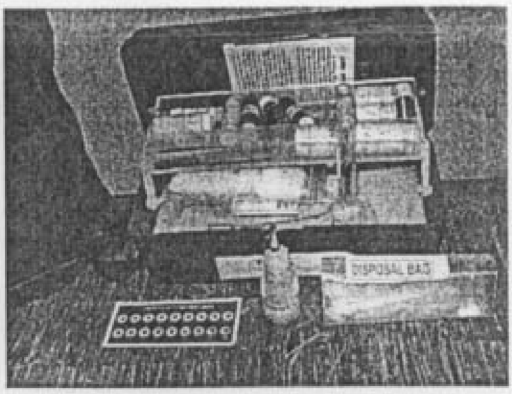
The filtered water (effluent) was tested every other day (once every two days), and the wells (influent) were tested once every week. Two types of arsenic field test kits were used: the American HACH Arsenic Test Kit and the Nepali ENPHO Arsenic Field Test Kit (See Figure 2). The HACH kit has the highest accuracy for arsenic concentrations between 0-50 parts per billion (ppb). The accuracy range for the ENPHO Kit is either unknown or has not yet been established. In the first week of Phase I (Nov-Dec) the wells and filters were tested with the Nepali ENPHO kit. After that, the American HACH Kit was used to test both the wells and filters for three and a half months through Phase I and Phase II, after which our supplies had exhausted. After this point we reverted back to the ENPHO kit for the remainder of the testing.

Once during Phase II, the Wagtech digital Arsenator was used to test the arsenic concentrations of the wells as the accuracy of the HACH and ENPHO field kits were coming into question due to the divergent results gotten from them. The Arsenator has best accuracy for concentrations between 0-100ppb, which register digitally. For values greater than 100ppb, a dilution is required, and the result compared against a colorimeter chart as with the other two field kits. Since we could not test the tube well water using the Atomic Absorption Spectrophotometer (AAS), the Arsenator was felt to be more accurate than both the HACH and ENPHO field kits and would help verify our results from those kits.

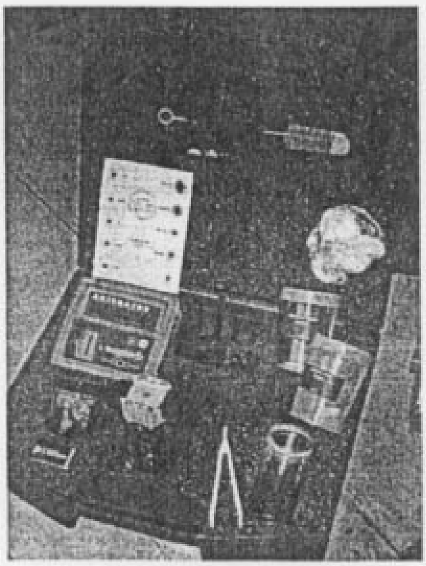
Figure 2: Test kits used



HACH Kit (American)



ENPHO Kit (Nepal)



Wagtech "Arsenator" Test Kit

3.4 Flow Rate Measurements

During Phase I, the flow rate of the wells was not measured consistently. A few measurements were taken, although without much accuracy. This measurement was added to the data collection process during Phase II and after the filters had been cleaned. The flow rate was gauged using a simple, measured one-liter container and a watch with a second hand. After adding at least 20 liters of water to the filter, the water was captured in the measuring container for exactly 60 seconds. This measurement was then converted into Liters per hour (L/hr) in order to make accurate comparisons. Previous observations made by Tommy Ngai, et al suggested that a minimum flow rate of 10 L/hr should be allowed. This minimum appeared to be satisfactory among the users he surveyed. If the rate drops below this, the filter is less than efficient and needs to be cleaned.

Figure 3: Measurement of Flow Rate

3.5 Filter Cleaning

The filters were cleaned after Phase I was completed, At this point it was felt the flow rate had slowed below an efficient level. This was an intuitive judgment as we were not taking direct measurement of the flow rate at the time, and very similar to what villagers would do while operating and maintaining their filters. The method of cleaning was as follows:

1- Make sure the filter is not full of water and has stopped draining.

2- Remove the diffuser box holding the nails and set aside.

3- With your hand, gently disturb the top layer of sand until the sitting water is murky with dirt, sand, organic matter, and iron dust.

4- With a small cup or jug remove the murky water from the filter. Ideally, dump this waste into a pit that contains cow dung, as recommended by Tommy Ngai, et al[4]. This precaution, however, not followed here, the waste being dumped in a roadside ditch outside the house compound.

5- Carefully add water to the filter again, and repeat steps 3-4 two more times.

6- Pour nails into a bucket or other large bowl and rinse with clean water. Drain and rinse three more times to remove any dirt and particulates.

[4] Ngai, Tommy; Walewijk, Sophie. "The Arsenic Biosand Filter Project: Design of an Appropriate Household Drinking Water Filter for Rural Nepal." July, 2003. Confirmed by observations with Tommy in the field.

7- Replace the polyester cloth and return the nails to the diffuser box, spreading them evenly. *Note: there was no polyester cloth before the cleaning, but we placed one in each filter after the cleaning process, as recommended by the designer.*

8- Replace the diffuser box in the cement frame and flush the filter twice with about 20 to 30 liters of well water each.

IV. Discussion and Results

NOTE: Please refer to Appendix A for complete data tables.

4.1 Recommended Changes made after Phase I

Testing during Phase I (November to December) proved to be useful in observing filter construction and transport problems, allowed time for the recommended one month necessary to prime the filters[5], and later helped us to improve the experiment. It was clear after Phase I that a much longer experimental period was necessary if we wished to see the results we hypothesized, namely a saturation of the filters and a decrease in their ability to remove arsenic. For this reason, we decided to carry on the project for another two months, or Phase II, in the same location. Ideally, for more accurate testing purposes, it would have been best if the filters could have been moved to another location that shows higher arsenic concentrations in the influent tube well water. Moving the filters again, however, was too difficult as moving the empty cement moulds alone was backbreaking work in the first trial: to move them while at the same time trying to preserve the internal layering of sand would have disrupted the experiment unnecessarily Therefore, testing was continued in same location. We also increased and stabilized the amount of water added to the filter each day to 40 L, which we felt reflected the drinking water use of a 6 to 10 member family in the village.

In Phase II, measurement of the flow rate was also added to our experimental objectives. From this data, we hoped to determine how often users would need to clean their filter systems. We also had a bacterial count performed by Tommy Ngai's team for one well and filter, Tube Well and Filter A, to gauge whether we should add this measurement into our experimental objectives. It was found that both Well and Filter A were without fecal coliform contamination, and therefore the idea of also testing for bacteria was dropped. It would still be a very valuable to test bacteria removal in future experiments, however, particularly to see

[5] Tommy Ngai, et al.

if the collection of iron dust on the sand layer disrupts the filter's long term ability to remove microorganisms.

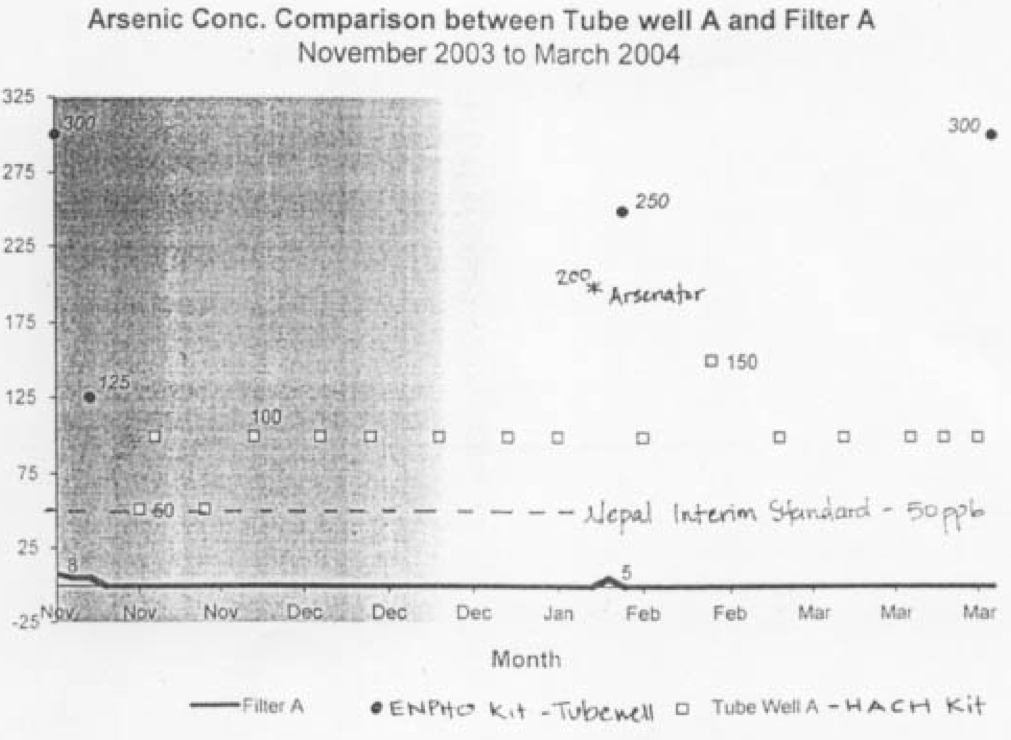
4.2 Affect of Filter Cleaning

The filters were cleaned after the completion of Phase I. By this time the flow rate had visibly and significantly decreased. At the time of cleaning, the rate was only 3.5 L/hr (the minimum acceptable is 10 L/hr) and a layer of fine, particulate iron had collected on top of the sand layer. This clay-like layer probably accounted for most of the slowing in the flow rate. As we were not performing tests on the bacterial removal capability of the filter there is no data on how cleaning affected the bacteria removing capacity of the filter.

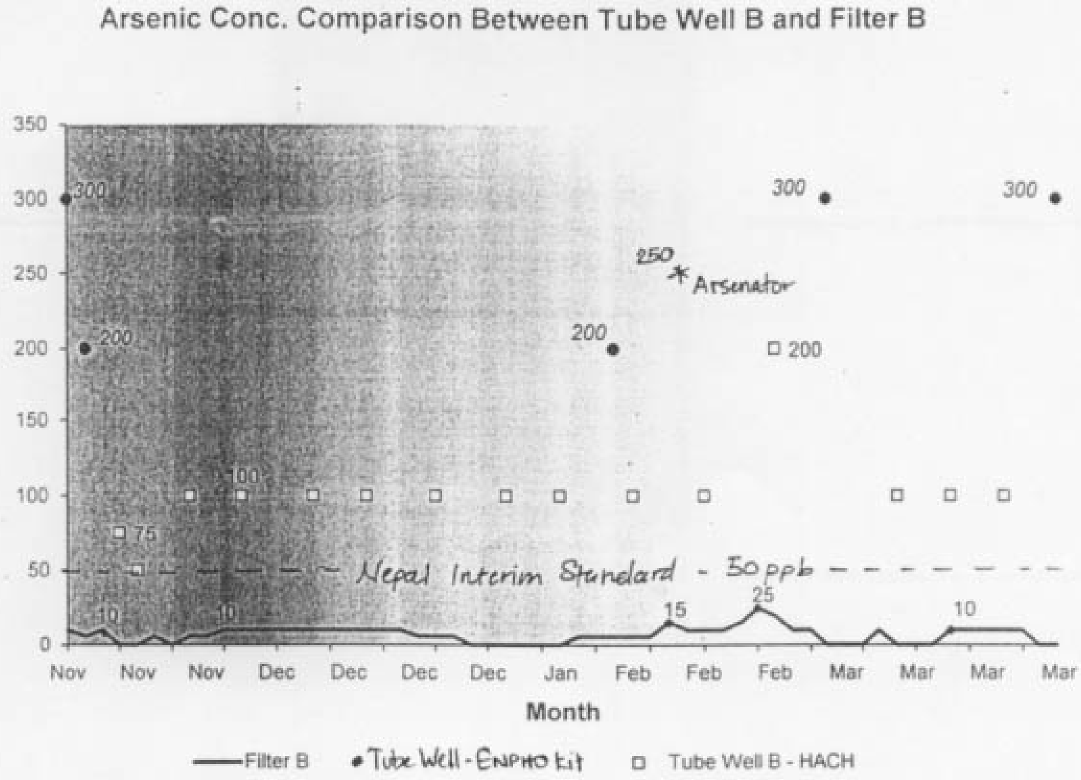
4.3 Filter Efficacy Performance

Graphs *1* and *2* show that the arsenic removal capacity of the two filters was very reliable. For the duration of four months (Phase I and II) both filters removed arsenic to below the Nepal Interim Standard value of 50 parts per billion (ppb). Filter A with 5 kg of nails showed close to 100% removal proficiency, consistently removing all the arsenic from the water. Filter B with 2.5 kg nails performed at around 95% removal proficiency, leaving an average arsenic concentration of 10ppb in the water daily. This value is below the Nepal Standard, and just meets the WHO standard of 10 μg/L (or 10 ppb).

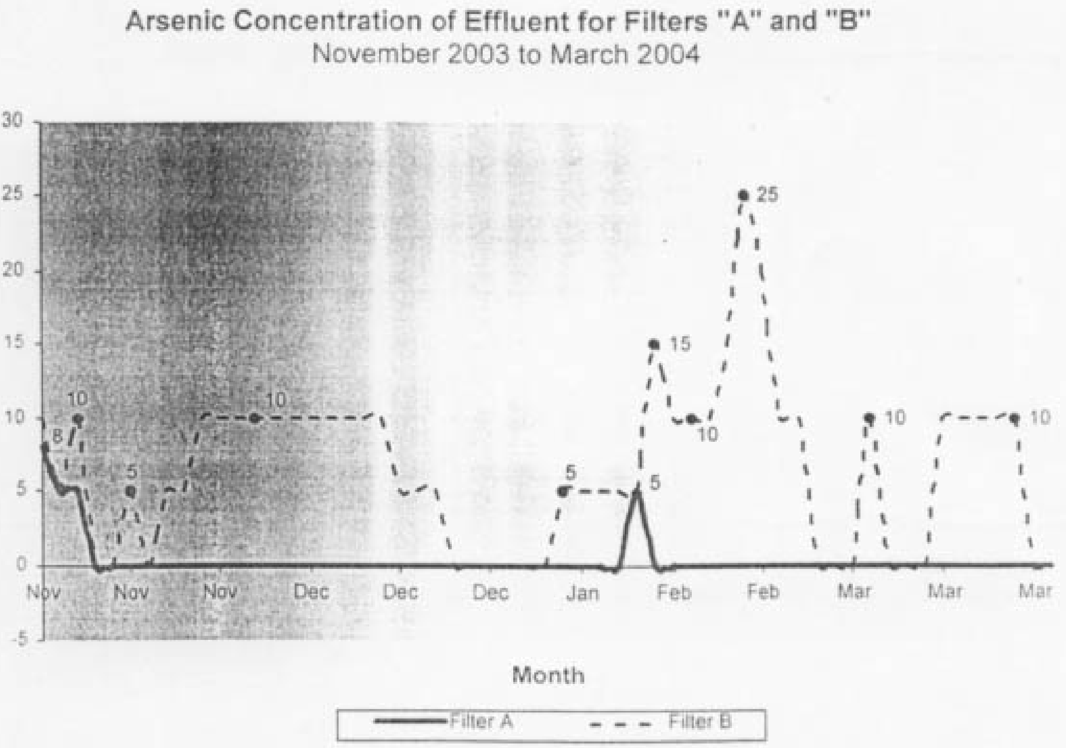
Graph 1:



Graph 2:



Graph 3:



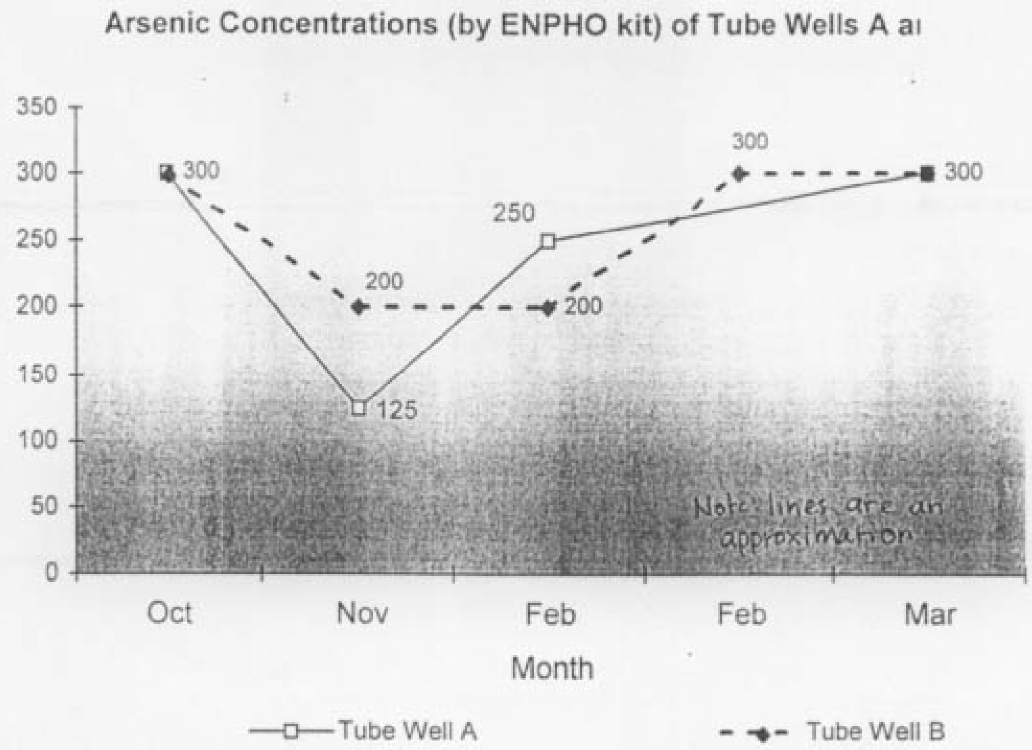
The amount of water added daily was different for Phase I and Phase II. Filter A had a mean average of 30.7 L added daily for Phase I, and 37.3 L daily in Phase II. Filter B had a mean average of 35.2 L added daily for Phase I, and 41.6 L daily in Phase II. Filter B generally had higher levels of water added because the family of the house where it was placed was large and had many daughters-in-law. The home where Filter A was place only had one daughter-in-law and half the members, therefore making it more difficult for them to keep up with the volume of water needing to be added.

Unlike the tube well concentration data, both kits reported very similarly for the arsenic concentration of the effluent from the filters. This is most likely due to the fact that the effluent arsenic concentration fell within prime accuracy ranges of both kits. In the data below, arsenic concentration values tested by both the ENPHO and HACH kits are arranged without discrimination as they fall very close to one another. The mean average arsenic concentration of the effluent of Filter A was 0.6ppb for Phase I and 0.2ppb for Phase II. Filter B had a mean average concentration of 5.6ppb for Phase I and 7.7 for Phase II. The two filters show slightly opposing trends between the two Phases. The concentration trends for Filter B are more significant as less arsenic was removed from this water. The marginal increase in arsenic concentration from Phase I to Phase II may be due to the increase in water added daily to the wells (from approximately 30 L/day to 40 L/day.)

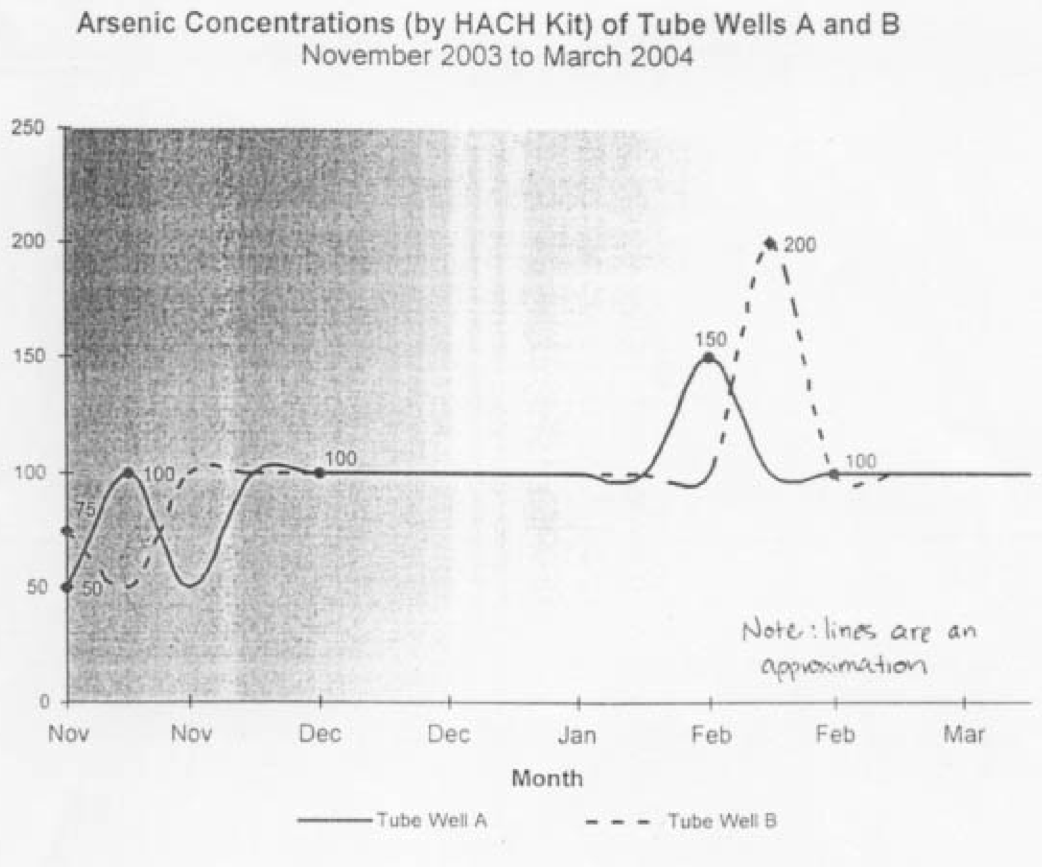
4.4 Well Concentration Fluctuations

During the course of the four months the tube wells were tested once a week. We found that the arsenic concentration of the wells varied over time, as shown in graphs *4* and *5*. Some fluctuations seemed to be linked to the time (or season) when the well was tested, while other fluctuations seemed to depend on the test kit used. The data points from the first three weeks of Phase I, for example, are tested with the ENPHO kit for both well A and B. The initial test shows a concentration of 300 ppb for both wells, but the subsequent test, two weeks later, exhibits a significant drop. The concentration of Well A decreased by 33% down to 200ppb, and that of Well B down by 58% to a low of 125ppb. Three to four months later in Phase II, in the middle of the driest season of the year, the concentrations reported by the ENPHO kit shot back up to 300ppb. This observation makes it appear that there are serious fluctuations in the aquifer arsenic concentration with time.

Graph 4:



Graph 5:



Looking at the HACH kit results, however, one sees fluctuations but not as extreme as those reported by the ENPHO kit. They also do not occur at corresponding times. Instead, there seems to be a general average at a concentration of 100ppb for the results produced by the HACH kit. The most noticeable fluctuation for all test kits occurs in early February (Phase II), when there is a general increase in the arsenic concentration of the wells. This sudden increase is unexplained, and the concentrations for both wells quickly stabilize and return to 100ppb afterward.

It is felt that the ergonomics of the HACH kit can cause errors in the testing when using lead acetate. Generally, we did not use the lead acetate, a reagent meant for removing sulfur contamination, because of the difficulty and because after adding Reagent 1 and then smelling the mixture for a "rotten egg" odor (the procedure recommended for detecting sulfur contamination) usually produced negative results. The difficulty is this: the lead acetate must sit suspended in a cotton ball just underneath the mercury bromide test paper. If this cotton touches the paper, it can cause discoloration and a misreading of the results. Yet, there is no barrier between the cotton and the paper, and no good way to secure it. It is very easy to accidentally place the cotton too close to the paper and disrupt the results of the test. Also, there were times when testing the water showed there was no sulfur present, and other times when it did. All of these difficulties may have decreased the accuracy of the HACH kit results.

The variation over time of the arsenic concentration in the tube wells takes away from the consistency of the data. The dramatic drop in the first few weeks of Phase I (in the ENPHO results) and subsequent stabilization cannot be explained with clarity. Further testing using a more reliable technology, such as AAS, was unavailable, leaving conclusions open. We did attempt to verify the results of the two kits using the Wagtech "Arsenator" Field Test kit during Phase II. The Arsenator technology is similar to that of the ENPHO and HACH kit, but with slightly more reliability as it reads values between 0-100 ppb digitally. Above that limit, the Arsenator uses a colorimetric scale just as the other kits. The Arsenator confirmed that the wells were above the Nepal Interim Standard of 50 ppb, and also above 100ppb. It did not, however, confirm that both wells registered above 250ppb. For Tube Well A, the arsenic concentration registered at 200ppb. For Tube Well B, the concentration registered at 250ppb.

In the end, all three test kits produced results in the same range (greater than 100ppb,) but rarely the same result came from all three at once. This error may have been due to the accuracy of the field kits, as related to their relative ranges of accuracy, as well as human error in reading the colorimeter scale. The quality of the errors were not tracked, however, as the kits were not always used to test the wells simultaneously. It is not clear what circumstances may have caused these changes, although there may be some connection to the level of the water table at the time of testing. As the season became drier, the concentration of the well appears to have increased. However, it is difficult to make any conclusions on this point without consistency in the testing process and without a more reliable test, such as with AAS, to compare against.

The fluctuating values of arsenic concentrations in the tube wells affect this experiment directly. First, it brings the reliability of the test kits into question, at least for arsenic ranges above 100ppb. Second, it makes our testing less reliable for predicting the efficacy and lifetime of arsenic removal of the filter for high-level contamination in villages. Our aim was to test wells that had arsenic concentrations greater than 250ppb. It was felt that this level would be high enough to reflect the condition of most contaminated wells in Nawalparasi. Furthermore, if the concentration of the experimental wells are too low, the efficacy and lifetime of the filter should theoretically increase, making it imperative to test for a much longer period of time before seeing the expected hypothetical results of saturation. However, the differing trends in the tube well concentrations degrade the overall data. The well concentration is too low for the purpose of our study. Both kits reported concentrations less than 250ppb for the majority of the four-month testing period. A low well concentration is not inductive to finding a saturation point or lifetime of the arsenic removal media, especially for removal capacities at higher concentrations.

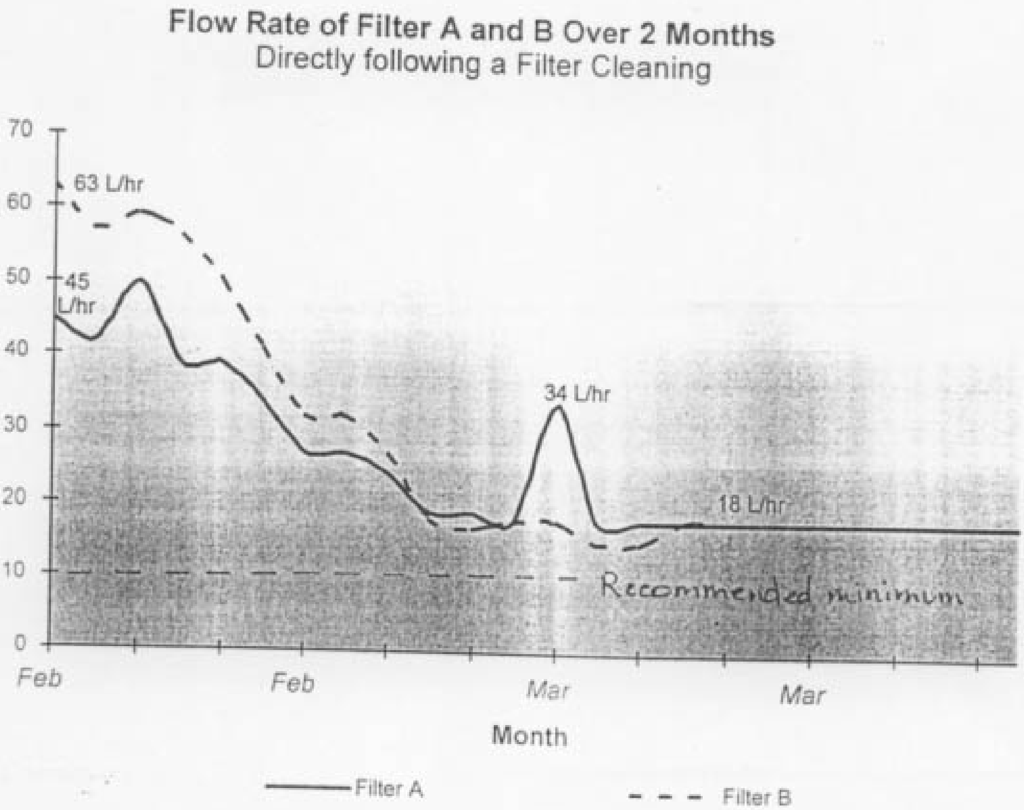
4.5 Filter Saturation Point and Lifetime –

This experiment produced no data indicating that the arsenic removing media (iron nails) had reached a saturation point in removal ability. Throughout the four months of testing, the filters removed 95-100% of the arsenic content of the water, depending on how much media was in the filter. This could mean two things: first, the hypothesis is false, and no saturation point exists for the iron nails in the filter. Second, not enough time was available to get the results. In order to make a conclusion, this experiment must be extended for as long as necessary, probably not less than a year of continual testing to find whether there is evidence of saturation. In this case, it would be best to transfer the filters to wells that have an arsenic concentration higher than 250 ppb for timely results. The inaccuracy and relatively low value of the arsenic concentration in the wells may have also contributed to a lack of saturation point results.

4.6 Flow Rate Observations–

The only instances where the filters were measured at flow rates less than 10 L/hr was during Phase I and just before filter cleaning. The flow rate seemed especially slow directly before cleaning, at a rate of 3.5 L/hr. The following *Graph 6* shows the trends in flow rate for the two filters over the Phase II, from February to March. Filter B, with only 2.5 kg nails, showed almost consistently a higher flow rate than Filter A, the only deviation being in early March when the filmy dust layer that had formed from the nail dust and biofilm above the fine sand layer of Filter A was significantly disturbed by the testers. As the graph shows, once the dust settled again the flow rate dropped back to normal.

Graph 6:



According to the data from Phase II (*See Appendix A*), it appears that the flow rate also may have a direct affect on the removal efficiency of the filter. When the water was moving through the filter at rates greater than 30 L/hr, it seems that the removal was less efficient. This trend is particularly evident in the results from Filter B (2.5 kg nails), which consistently showed higher effluent arsenic concentrations that Filter A. This observation would correspond with those made by Tommy Ngai, et al, and the assertion that the water must have some prolonged contact with the nails and with air to remove arsenic effectively.

It is notable that the few flow rate measurements taken during Phase I exhibited a very low rate, less than 10 L/hr in general. It is suggested that the placement of the polyester cloth in the diffuser box during Phase II of testing may have prevented excessive clogging of the filter by iron dust particles.

4.7 Operation and Maintenance Observations

Several observations were made concerning O&M of the filters. The first thing noticed was that the filters are heavy, cumbersome, and hard to transport. Even if they are built or molded close to the final location, moving them into position takes effort. Once the filter is set up in a location, it cannot safely be moved. Therefore, one must choose the location carefully, preferably near the well and in the house. An alternative to cement, the plastic model of the ABF, is more transportable, but less sustainable in the village than the cement filter as they must be ordered from Kathmandu.

During set-up, there were no written instructions to follow in the proper way for construction. Correct installation is very important, however, since the method by which sand is added can drastically affect the flow rate and bacterial removal capacity of the filter. Instructions for setting up and cleaning should be available and carefully followed.

While using the filter daily, it was noticed that the force of the water poured into the filter disturbs the nails and leaves holes in the nail cover. This is not good for proper removal of arsenic, as the nails should cover the bottom of the diffuser box evenly. We added more small brick pieces on top of the nails as a buffer to remedy this. There was much less disturbance of the nails after adding another 1 kg of brick pieces to each of the filters. The brick pieces covered the nails entirely in a layer about 5-6 cm thick. Still, it was necessary to occasionally rearrange nails before adding water, especially in Filter B with only 2.5 kg nails.

The polyester cloth, added before Phase II of testing, seemed to decrease the amount of iron dust, filaments, and nails that fell through the diffuser box and onto the surface of the sand. This seemed to keep the flow rate higher for a longer period of time. It is possible, however, that over time the water could be slowed while going through a clogged cloth rather than a clogged sand layer. This might depend on the quantity and size of the iron particles.

The filter flow rate ran at an acceptable rate (greater than 10 L/hr) for at least two months (the duration of Phase II) without needing cleaning. It seems that the filter, when running properly, may need cleaning only once every two months at the most. Cleaning the filter once a month is unnecessary, especially as cleaning temporarily disrupts the bacteriological removal capacity of the filter[6].

V. Conclusions and Recommendations

5.1 Conclusions

The Arsenic Biosand Filter has proven to be a successful temporary technology for removing arsenic from tube well water in the village. From our tests we see that it very effectively removes arsenic from the water, reducing it to safe levels for an extended period of time. Our studies show that with 5 kg of nails added, the filter can remove up to 100% of arsenic in influent ranges of 100-200ppb for a period up to four months. After construction, the maintenance of the filter was easy and sustainable, and cleaning was only necessary after 1.5 to 2 months. Cleaning the filter too frequently, in fact, can inhibit its arsenic removing capabilities by causing the water to flow through the filter too fast.

The ABFs reported ability to also remove bacteriological contamination makes it doubly useful in the village, where it has been reported that up to 50% of all tube wells are contaminated with fecal coliform[7]. Once the ABF is installed and primed, it runs smoothly and predictably, providing drinking water at an acceptably fast rate, unlike the 3-Gagri filter technology. The heaviness of the filter also ensures that it will not be easily damaged, and its presence in the home is significant enough to encourage continued use.

The second objective of this study, namely to find if the arsenic-removing media had a saturation point, was not met. However, we would strongly encourage further studies on this subject in order to better serve the people who will be using this mitigation technology for an extended period of time.

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[6] Tommy, et al.

[7] Tommy, et al, pg. 14 (citing studies from another group.)

5.2 Recommendations for Future Training in Operation and Maintenance

During implementation of this technology in the village, I would strongly recommend that a thorough training program be developed. In this program, construction, operation, and maintenance materials (booklets, posters, cards, etc.) should be developed for distribution along with the filters. This way, users could refer to these materials before applying to WSSDO or another support agency for help if problems arise. Ideally, it would be best to also develop a monitoring schedule, either through WSSDO or some other agency, to check the performance of the filters periodically, as it is not known if they decrease in efficiency over time.

5.3 Recommendations for Further Testing of ABF Mitigation Technology

We encourage further testing of the ABF in order to find if it has a saturation point, and how long it takes to reach that point. For better, more accurate results, we have a few recommendations. Testing should continue for up to a full year. This testing would be ideal if it included tests for bacteriological removal, iron removal, and phosphate interference. Prior to testing, do more research on the test kit specifications and limitations. Be familiar with the ideal testing range of the kit, and confirm data collected periodically using the AAS technology. Have enough chemicals provided in the chosen kit to last the entire duration of the testing period, and test the experimental tube wells several times before beginning testing to verify that the arsenic concentration falls within the desired range.

Concerning space limitations, place the filters in locations that will more accurately reflect the lifestyle and space of those who will be using it in the villages. In this trial, the families were not actively using filters, so did not always add water consistently in the interim days. Also, they could not make comments on the advantages and disadvantages of the filtered water (flow rate, taste of the water, ease of use, etc.) In the future, set up this experiment in the home of a family that would actively use the filter and place it in a central location of their home. The more interaction the family has with the filter, the better we can learn its operation and maintenance requirements. Also, to reduce labor and lifting, place the filters closer to the well, if possible, and inside the home where it is protected from weather, dirt, and traffic.

If WSSDO continues to work with the ABF in testing or implementation, I would also recommend that it pay those WSSDO workers who are assigned to the job, as is naturally expected and should go without saying in any office-related work.

Appendix A

Complete Data Tables

Phase I - FILTER A: S.N.1655 -- 5 Kgs Nails-- Mayanath Dhungana, Driver Tol, Parasi (N27* 31.82 : E83*

Day	Tester	Date	As Conc. Filtered (ppb)	As Conc. Tube well (ppb)	pH	Flow Rate (L/hr)	Liters of water added since last test	Test Kit used	Observations and comments
0	BKK/NVO	29-Oct-03		300				ENPHO	
1	BKK/NVO	10-Nov-03	8		7.5		20	ENPHO	rearranged nails to cover gaps, pikes brickettes in the middle
2	NVO	11-Nov-03		125	6.5		30	ENPHO	rearranged nails again
4	NVO	12-Nov-03	5				15	ENPHO	
5	BKK/NVO	14-Nov-03	5				37	HACH	no lead acetate used
7	BKK/NVO	16-Nov-03	0	50			29	HACH	put lead acetate in tube well test only... maybe too much cotton, contact between cotton and HgBr paper?
9	BKK	18-Nov-03	0	100			40	HACH	no lead acetate used
11	BKK	20-Nov-03	0				50	HACH	rearrange the nails
13	BKK	22-Nov-03	0				60	HACH	
15	BKK	24-Nov-03	0	50			70	HACH	
17	BKK	26-Nov-03	0				80	HACH	
19	BKK	28-Nov-03	0				60	HACH	
21	BKK	30-Nov-03	0	100			70	HACH	
23	BKK	2-Dec-03	0			2	80	HACH	3 mc-100m (??)
25	BKK	4-Dec-03	0			3	70	HACH	4 min 200 m.L
27	BKK	6-Dec-03	0				60	HACH	
29	BKK	8-Dec-03	0	100		4.8	70	HACH	5 minu 400ML
31	BKK	10-Dec-03	0				80	HACH	
33	BKK	12-Dec-03	0				60	HACH	
35	BKK	14-Dec-03	0	100			50	HACH	
37	BKK	16-Dec-03	0			2	90	HACH	3 minut 100m.L, rearranged nails
39	BKK	18-Dec-03	0				60	HACH	
41	BKK	20-Dec-03	0				50	HACH	
43	BKK	22-Dec-03	0	100			80	HACH	
45	BKK	24-Dec-03	0				60	HACH	
47	BKK	26-Dec-03	0				50	HACH	
49	BKK	28-Dec-03	0				60	HACH	
51	BKK	30-Dec-03	0	100			80	HACH	
53	BKK	1-Jan-04	0				60	HACH	
55	BKK	3-Jan-04	0				60	HACH	
57	BKK	5-Jan-04	0	100			80	HACH	
59	BKK	7-Jan-04	0				70	HACH	
61	BKK/NVO	9-Jan-04	0				40	HACH	flow rate has slowed noticeably
Average liters of water added per day							30.7		

Phase II - FILTER A: S.N.1655 -- 5 Kgs Nails-- Mayanath Dhungana, Driver Tol, Parasi (N27* 31.82 : E83* 39

Day	Tester	Date	As Conc. Filtered (ppb)	As Conc. Tube well (ppb)	pH	Flow Rate (L/hr)	Liters of water added since last test	Test Kit used	Observations and comments
62	NVO	2-Feb-04	0	250	6.5	3.5 L/hr *	20	***ENPHO***	*First tested flow rate, then cleaned filter. Flow rate tested only after adding 20 L of water to the filter.
62	NVO	2-Feb-04	0	100	--		20	HACH	Rearranged nails
65	NVO	5-Feb-04	5	--	--	45 L/hr	60	HACH	Maya says she'd drink the water if it were indoors where the dogs could not drink it and more convenient to fill.
68	NVO	8-Feb-04	0	--	--	42 L/hr	90	HACH	filter needs more brickettes to prevent nails from moving.
70	NVO/BKK	10-Feb-04	0	--	--	50 L/hr	82	HACH	
72	NVO/Raj	12-Feb-04	0	150	--	39 L/hr	80	HACH	Next time need to use lead acetate in testing well concentration.
75	NVO	15-Feb-04	0	--	--	39 L/hr	80	HACH	Did not need to rearrange nails too much.
77	NVO	17-Feb-04	0	--	--	34 L/hr	80	HACH	Added more brickettes yesterday, nails are now not so affected when pouring water in the filter.
79	NVO	19-Feb-04	0		--		80	HACH	nails are level
80	NVO	20-Feb-04		100	--	27 L/hr		HACH	used lead acetate in well test
82	NVO	22-Feb-04	0		--	27 L/hr	130	HACH	
84	NVO	24-Feb-04	0		--	24 L/hr	80	HACH	nails were disturbed, maybe by kids? Rearranged
86	NVO	26-Feb-04	0		--	19 L/hr	80	HACH	Top of the sand layer is a layer of fine rust particles from box, on top a light tan color,underneath a rusty red. About 2mm thick.
89	NVO	29-Feb-04		100	--			HACH	nails were disturbed and needed rearranging. Used lead acetate in testing well
89	NVO	29-Feb-04	0		--	18.5 L/hr	120	***ENPHO***	
91	NVO	2-Mar-04	0		--	18 L/hr	80	***ENPHO***	
93	NVO	4-Mar-04	0		--	33.5 L/hr	80	***ENPHO***	Disturbed fine dust layer, 3-3-04, while showing filter to Tommy. Could feel biosand film on top of sand/dust layer.
94	BKK	5-Mar-04		100	--			HACH	
96	BKK	7-Mar-04	0		--	18 L/hr	80	HACH	
98	BKK	9-Mar-04	0		--	18 L/hr	80	HACH	
100	BKK	11-Mar-04	0		--	18 L/hr	80	***ENPHO***	
102	BKK	13-Mar-04	0	100	--	18 L/hr	90	HACH	
104	BKK	15-Mar-04	0		--	18 L/hr	80	HACH	
106	BKK	17-Mar-04	0		--	18 L/hr	80	HACH	
108	BKK	19-Mar-04	0	100	--	18 L/hr	80	HACH	
110	BKK	21-Mar-04	0		--	18 L/hr	80	***ENPHO***	
112	BKK	23-Mar-04	0		--	18 L/hr	80	***ENPHO***	
114	BKK	25-Mar-04	0		--	18 L/hr	90	***ENPHO***	
116	BKK	27-Mar-04	0	300	--	18 L/hr	90	***ENPHO***	
	Rajesh	9-Feb-04	--	100+/200	--			Arsenator	Before and after dilution. WagTech product.

Average liters of water added per day 37.3

Phase I - FILTER B: S.N.1661 -- 2.5 Kgs Nails-- Muna Lal Shrestha, Driver Tol, Parasi (N27* 31.82 : E83* 3

Day	Tester	Date	As Conc. Filtered (ppb)	As Conc. Tube well (ppb)	pH	Flow Rate (L/hr)	Liters of water added since last test	Test Kit used	Observations and comments
0	BKK/NVO	29-Oct-03		300				ENPHO	
1	BKK/NVO	10-Nov-03	10		7.5		25	ENPHO	rearranged nails to fill gaps, piled brickettes in middle
2	NVO	11-Nov-03		200	6.5		40	ENPHO	
4	NVO	13-Nov-03	5				25	ENPHO	Iron nails from "Rama Industries, India', original purpose as shoe tacks, 13mm "blue"
5	BKK/NVO	14-Nov-03	10				25	HACH	did not use lead acetate
7	BKK/NVO	16-Nov-03	0	75			22	HACH	put lead acetate in well test ONLY. Maybe the cotton touched the HgBr paper? Low result
9	BKK	18-Nov-03	0	50			70	HACH	did not use lead acetate
11	BKK	20-Nov-03	5				60	HACH	
13	BKK	22-Nov-03	0				80	HACH	
15	BKK	24-Nov-03	5	100			80	HACH	
17	BKK	26-Nov-03	5				90	HACH	
19	BKK	28-Nov-03	10				80	HACH	
21	BKK	30-Nov-03	10	100			100	HACH	
23	BKK	2-Dec-03	10			3	110	HACH	2 minut 100m.L, rearranged nails
25	BKK	4-Dec-03	10			4	60	HACH	3m 200m.L
27	BKK	6-Dec-03	10				70	HACH	
29	BKK	8-Dec-03	10	100		12	90	HACH	5 minut 1 Lit
31	BKK	10-Dec-03	10			3	80	HACH	2 minut 100M.L
33	BKK	12-Dec-03	10				60	HACH	
35	BKK	14-Dec-03	10	100		3	60	HACH	2 minut, 100m.L, rearranged nails
37	BKK	16-Dec-03	10			3	90	HACH	2 minut, 100m.L, rearranged nails
39	BKK	18-Dec-03	10				60	HACH	
41	BKK	20-Dec-03	5				70	HACH	
43	BKK	22-Dec-03	5	100			80	HACH	rearranged nails
45	BKK	24-Dec-03	5				90	HACH	
47	BKK	26-Dec-03	0				60	HACH	rearranged nails
49	BKK	28-Dec-03	0				50	HACH	
51	BKK	30-Dec-03	0	100			80	HACH	
53	BKK	1-Jan-04	0				70	HACH	
55	BKK	3-Jan-04	0				80	HACH	
57	BKK	5-Jan-04	0	100			70	HACH	
59	BKK	7-Jan-04	5				60	HACH	
61	BKK/NVO	9-Jan-04	5				60	HACH	flow rate has slowed noticeably
Average Liters of water added per day							35.2		

Phase II - FILTER B: S.N.1661 -- 2.5 Kgs Nails-- Muna Lal Shrestha, Driver Tol, Parasi (N27* 31.82 : E83* 3

Day	Tester	Date	As Conc. Filtered (ppb)	As Conc. Tube well (ppb)	pH	Flow Rate (L/hr)	Liters of water added since last test	Test Kit used	Observations and comments
62	NVO	2-Feb-04	5	200	6.5		20	ENPHO	Cleaned filter after testing flow rate. Tested the arsenic conc. Of "old water sitting in filter over the past week, perhaps. Rearranged nails. NOTE: flow rate tested only after adding 20 L of water
62	NVO	2-Feb-04	5	100			20	HACH	
65	NVO	5-Feb-04	5			63 L/hr	40	HACH	
68	NVO	8-Feb-04	15			57 L/hr	80	HACH	Needs more brickettes
70	NVO/BKK	10-Feb-04	10			59 L/hr	80	HACH	
72	NVO/Raj	12-Feb-04	10	100		56 L/hr	120	HACH	Checked smell of tube well sample water after adding reagent 1: rotten eggs, need to use lead acetate next time.
75	NVO	15-Feb-04	10			50 L/hr	100	HACH	Rearranged disturbed nails.
77	NVO	17-Feb-04	15			41 L/hr	180	HACH	Added more brickettes, no more disturbing the nails when pouring water
79	NVO	19-Feb-04	25				100	HACH	Nails a little out of place, rearranged
80	NVO	20-Feb-04		200		32 L/hr	--	HACH	Used lead acetate for well test
82	NVO	22-Feb-04	20			32 L/hr	200	HACH	which is why so much water is being put in. They don't drink it.
84	NVO	24-Feb-04	10			27 L/hr	110	HACH	Will need fresh supplies for HACH kit soon. Currently not available, office says after 8-10 days.
86	NVO	26-Feb-04	10				80	HACH	Top of the sand layer is a layer of fine rust particles from box, on top a light tan color,underneath a rusty red. About 2mm thick.
89	NVO	29-Feb-04		300	6.5		--	ENPHO	Nails are fine, not disturbed.
89	NVO	29-Feb-04	0		6.5	18 L/hr	120	ENPHO	
91	NVO	2-Mar-04	0			17 L/hr	80	ENPHO	
93	NVO	4-Mar-04	0			18 L/hr	80	ENPHO	seems a little less prominent than the film perceived in filter A.
94	BKK	5-Mar-04		100			--	HACH	
96	BKK	7-Mar-04	10			18 L/hr	80	HACH	
98	BKK	9-Mar-04	0			15 L/hr	90	HACH	
100	BKK	11-Mar-04	0			15 L/hr	80	ENPHO	
102	BKK	13-Mar-04	0	100		18 L/hr	80	HACH	
104	BKK	15-Mar-04	10			18 L/hr	90	HACH	
106	BKK	17-Mar-04	10			18 L/hr	80	HACH	
108	BKK	19-Mar-04	10	100		18 L/hr	80	HACH	
110	BKK	21-Mar-04	10			18 L/hr	60	ENPHO	
112	BKK	23-Mar-04	10			18 L/hr	80	ENPHO	
114	BKK	25-Mar-04	0			18 L/hr	90	ENPHO	
116	BKK	27-Mar-04	0	300		18 L/hr	90	ENPHO	
	Rajesh	9-Feb-04		100+/250				Arsenator	Readings before and after dilution. Kit is a WagTech product.

Average Liters of water added per day. 41.6