1.782 Environmental Engineering Masters of Engineering Project
Fall 2007 - Spring 2008

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MIT Clean Water 4 All, Inc.
Final Master of Engineering Group Presentation – Ghana Team
May 30th, 2008

Cash Fitzpatrick
Izumi Kikkawa
Andrew Swanton

Vanessa Green
Tamar Losleben
Presentation Outline

- Ghana: Background and Logistics
  - Horizontal Roughing Filtration: Tamar Losleben
  - Household Filtration (Biosand Filter): Izumi Kikkawa
  - Chlorine Products: Cash Fitzpatrick
  - HWTS Consumer Choice Study: Vanessa Green
  - Ceramic Pot (Kosim) filter + Chlorine Disinfection with Aquatabs: Andrew Swanton
Background

Types of water sources used by households

- Pipe inside the home
- Pipe outside the home
- Tanker
- Well
- Borehole
- Spring or Rain water
- Dugout
- Stream
- Other

Percentage of Households by region (Drinking water as biggest problem)

(National Statistical Services Survey - CWIQ 2003)

Local Perception: Lack of Clean Drinking Water is a Major Problem

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Large Percentage of Water Source is Dugouts
E-Coli, Total Coliform, and Turbidity of Raw Water Samples from Selected Dugouts During the Rainy Season in Tamale and Savelugu Districts

<table>
<thead>
<tr>
<th>Location</th>
<th>Date (2006)</th>
<th>E. coli (CFU per 100 mL)</th>
<th>Total Coliforms (CFU per 100 mL)</th>
<th>Turbidity (TU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ghanasco Muali Dam, TD</td>
<td>20-Jun</td>
<td>169</td>
<td>6,621</td>
<td>~1,600</td>
</tr>
<tr>
<td>Kalerga Dam, TD</td>
<td>22-Jun</td>
<td>754</td>
<td>13,475</td>
<td>&gt;2,000</td>
</tr>
<tr>
<td>Bipelar Dam, TD</td>
<td>27-Jun</td>
<td>100</td>
<td>21,667</td>
<td>38</td>
</tr>
<tr>
<td>St. Mary's Dam, TD</td>
<td>29-Jun</td>
<td>1,650</td>
<td>52,110</td>
<td>&gt;2,000</td>
</tr>
<tr>
<td>Dungu Dam, TD</td>
<td>4-Jul</td>
<td>133</td>
<td>4,540</td>
<td>400</td>
</tr>
<tr>
<td>Libga Dam, SD</td>
<td>6-Jul</td>
<td>0</td>
<td>500</td>
<td>75</td>
</tr>
<tr>
<td>Bunglung Dam, SD</td>
<td>11-Jul</td>
<td>200</td>
<td>5117</td>
<td>300</td>
</tr>
<tr>
<td>Diarc Dam, SD</td>
<td>13-Jul</td>
<td>0</td>
<td>3,417</td>
<td>23</td>
</tr>
<tr>
<td>Libga Dam, SD</td>
<td>17-Jul</td>
<td>50</td>
<td>1,408</td>
<td>50</td>
</tr>
<tr>
<td>Gbanyami Dam, TD</td>
<td>19-Jul</td>
<td>367</td>
<td>19,150</td>
<td>~1,000</td>
</tr>
<tr>
<td>Vitting Dam, TD</td>
<td>25-Jul</td>
<td>1,400</td>
<td>12,767</td>
<td>~125</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td><strong>438</strong></td>
<td><strong>12,797</strong></td>
<td><strong>690</strong></td>
</tr>
</tbody>
</table>

Source: Foran, 2007
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Pilot Study of Horizontal Roughing Filtration in Northern Ghana as a Pretreatment Method for Highly Turbid Water

Tamar Rachelle Losleben
Objectives

• Characterize dugout particle sizes and distribution
  – Turbidity, settling stability, filtrability, sequential filtration, solids settleability

• Pilot test horizontal roughing filter (HRF)
  – Particle size characterization, turbidity, flow rate, microbial contamination
Ghanasco Dam

Photo Credit:
Murcott 08
Kunyevilla Dam
Settling Test of 4 Dam Waters

- 17-Jan 6:10 PM Ghanasco Dam
- 21-Jan 12:25 PM Kunyevilla Dam
- 17-Jan 10:30 AM Kpanvo Dam
- 21-Jan 12:25 PM Gbrumani Dam
- 21-Jan 12:25 PM Gbrumani Dam Hand Pump
Dugout → Pretreatment → Slow sand filtration (SSF)

**Maximum raw water turbidity:**
(Wegelin, 1996; Galvis 1993)

- 99-99.99% removal of microorganisms
  (Wegelin, 1996)
- 20-50 NTU

**Raw Dugout Samples in Tamale and Savelugu Districts** (Foran, 2007)

<table>
<thead>
<tr>
<th></th>
<th>Dry Season</th>
<th>Rainy Season</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average <em>E.Coli</em> (CFU/100 mL)</td>
<td>779</td>
<td>438</td>
</tr>
<tr>
<td>Average Total Coliform (CFU/100 mL)</td>
<td>26,357</td>
<td>12,797</td>
</tr>
<tr>
<td>Average Turbidity</td>
<td>248 NTU</td>
<td>931 NTU</td>
</tr>
</tbody>
</table>
Horizontal Roughing Filters (HRF)

Courtesy of SANDEC. Used with permission.
Ghanasco Dam Pilot HRF

- 700 L Polytank
- 1 inch PVC pipe
- 1 inch valve (brass gate or PVC ball)
- 1 inch PVC elbow
- 4 inch to 1 inch PVC reducer
- 4 inch PVC pipe
- 4 inch PVC elbow
- Cinderblocks and adobe bricks
- Effluent flows to soak-away drainage
# Comparison of the Turbidity Reduction Performance of HRF Media

<table>
<thead>
<tr>
<th></th>
<th>Average HRF effluent turbidity</th>
<th>Average filtration rates (ml/min)</th>
<th>Average additional turbidity removed by HRF after settling</th>
<th>Average % additional turbidity removed by HRF after</th>
<th>Average % total HRF turbidity reduction</th>
<th>Filtration coefficient, $\lambda$ (min$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G granite gravel</td>
<td>51 NTU</td>
<td>220 (1.6 m/hr)</td>
<td>46 TU</td>
<td>61 %</td>
<td>84 %</td>
<td>0.002</td>
</tr>
<tr>
<td>D local gravel</td>
<td>72 NTU</td>
<td>170 (1.3 m/hr)</td>
<td>30 TU</td>
<td>47 %</td>
<td>76 %</td>
<td>0.0007</td>
</tr>
<tr>
<td>P broken pottery</td>
<td>61 NTU</td>
<td>200 (1.5 m/hr)</td>
<td>18 TU</td>
<td>55 %</td>
<td>80 %</td>
<td>0.0006</td>
</tr>
<tr>
<td>Goal:</td>
<td>&lt; 50 NTU</td>
<td>41-270 (0.3-2.0 m/h)</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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MIT Clean Water 4 All, Inc.
Ouagadougou Pilot HRF
International Institute for Water and Environmental Engineering
Burkina Faso

- June 5 - July 28, 2006
- Loumbila Dam
  (Sylvain, 2006)
## Comparison of Pilot HRF Performance

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Media</td>
<td>broken burnt bricks</td>
<td>granite gravel G</td>
<td>local gravel D</td>
</tr>
<tr>
<td>Average filtration rate (m/h)</td>
<td>0.30</td>
<td>1.6</td>
<td>1.3</td>
</tr>
<tr>
<td>Filter length and media size (mm)</td>
<td>270 cm, 30-50&lt;br&gt;85 cm, 15-20&lt;br&gt;85 cm, 5-10</td>
<td>350 cm, 12-18&lt;br&gt;250 cm, 8-12&lt;br&gt;100 cm, 4-8</td>
<td>400 cm, 15-25&lt;br&gt;150 cm, 5-15</td>
</tr>
<tr>
<td>Raw water turbidity</td>
<td>40-500 NTU</td>
<td>313 NTU</td>
<td>301 NTU</td>
</tr>
<tr>
<td>Prefiltered water turbidity</td>
<td>5-50 NTU</td>
<td>51 NTU</td>
<td>72 NTU</td>
</tr>
<tr>
<td>Faecal coliforms* (/100ml)</td>
<td>&gt; 300</td>
<td>---</td>
<td>8400</td>
</tr>
<tr>
<td>Raw water</td>
<td>&lt; 25</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Mean turbidity reduction</td>
<td>77 %</td>
<td>87 %</td>
<td><strong>84 %</strong></td>
</tr>
</tbody>
</table>

* as *E.coli*
HRF Channel Design

Channel at Kunyevilla Dam

Kunyevilla Channel

Total channel length 45 m

Raw dugout water

700 NTU

$\lambda = 0.13 \text{ hr}^{-1}$

$Q = 75,000 \text{ L/day}$

Granite Gravel

Slow sand filter

700 NTU

22.5 m

16.1 m

6.4 m

20 NTU

Figure by MIT OpenCourseWare.
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Background ~Biosand Filter (BSF)~

- Household treatment
- Intermittent slow sand filtration
- Removes:
  - >90 % of *E.coli* bacteria
  - 100 % of protozoa and helminthes (worms)
  - 50-90 % of organic and inorganic toxicants
  - <67 % of iron and manganese
  - most suspended solids
- 270,000 BSFs installed in 25 countries
  - Disadvantages:
    - does not suite treatment of high turbid water
      » Decline in treatment efficiency, frequent clogging and maintenance requirement

Turbidity Limit ~50 NTU
Local Plastic Design BSF

Biolayer: *schumutzdecke*, biofilm
- most purification proceeds here
- estimated to be 5-10 cm in depth\(^1\)

Modification: Create additional biolayer

doxygen diffusion is essential

\(\rightarrow\) standing water layer should be 5-10 cm

### Results & Discussion - Flow Rate -

**BSF A** (without modification) 32.0 (4.1)

**BSF A’** (without modification) 25.9 (4.9)

**BSF B** (additional 5 cm sand layer) 21.8 (6.0)

**BSF C** (additional 10 cm sand layer) 21.1 (4.3)

#### Design flow rate
- ~ 20 L/hr
- Upper limit 30 L/hr
- Lower limit 5 L/hr

**Flow Rate**

- No decline in flow rate

**MIT Clean Water 4 All, Inc.**

**Lower flow rates for BSF B & C**

**No clogging**
Results & Discussion - Turbidity -

MIT Clean Water 4 All, Inc.

Variation in operation? Need for cleaning?

After day 13

<table>
<thead>
<tr>
<th>Dugout and BSF</th>
<th>Average turbidity [NTU] (standard deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dugout</td>
<td>306 (97)</td>
</tr>
<tr>
<td>A (without modification)</td>
<td>22 (17)</td>
</tr>
<tr>
<td>A’ (without modification)</td>
<td>20 (14)</td>
</tr>
<tr>
<td>B (additional 5 cm sand layer)</td>
<td>15 (6.8)</td>
</tr>
<tr>
<td>C (additional 10 cm sand layer)</td>
<td>14 (1.4)</td>
</tr>
</tbody>
</table>
### Results & Discussion - Turbidity -

#### After day 13

<table>
<thead>
<tr>
<th>BSF</th>
<th>average turbidity removal (standard deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (without modification)</td>
<td>92 % (7 %)</td>
</tr>
<tr>
<td>A' (without modification)</td>
<td>93 % (6 %)</td>
</tr>
<tr>
<td>B (additional 5 cm sand layer)</td>
<td>95 % (2 %)</td>
</tr>
<tr>
<td>C (additional 10 cm sand layer)</td>
<td>95 % (1 %)</td>
</tr>
</tbody>
</table>

- **BSF average turbidity removal**: A and A' show similar results with 92% and 93% respectively, indicating that without modification, turbidity removal is consistent. BSF B and C, with additional sand layers, show improved results at 95% removal despite day 13 ripening.

- **Need for cleaning?**
  - The graph suggests that BSF A and A' may need cleaning due to a slight dip in turbidity removal after day 13.
  - BSFs B and C show more stable performance, likely due to the additional sand layers.

- **Variation in operation?**
  - The data does not clearly indicate significant variation in operation between days, with results generally consistent across all BSFs.

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Results & Discussion -Microbial-

**Total Coliform**

<table>
<thead>
<tr>
<th>Day</th>
<th>30</th>
<th>38</th>
<th>43</th>
<th>46</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dugout</td>
<td>30000</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>BSF A</td>
<td>0</td>
<td>Present</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>BSF A'</td>
<td>300</td>
<td>Absent</td>
<td>Absent</td>
<td>Present</td>
</tr>
<tr>
<td>BSF B</td>
<td>200</td>
<td>Absent</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>BSF C</td>
<td>0</td>
<td>Present</td>
<td>Absent</td>
<td></td>
</tr>
</tbody>
</table>

**Hydrogen Sulfide Bacteria; Presence/Absence**

- BSF A
- BSF A'
- BSF B
- BSF C

- **average 86 % removal**

- **average influent:** 12,000 cfu/100ml

- *E. Coli* mostly not detected in influent/effluent
Discussion -LPD BSF-

Flow Rate
• Modified BSFs had slower flow rates
  Due to additional basin with sand
• All BSFs had not clogged after 46 days of operation

Turbidity
• Dugout: wide variation
• Filter ripening: after 13 days
• Modified BSFs showed slightly higher turbidity removal
  – Decline in BSF A & A’: operation conditions? cleaning?
  – No decline in BSF B & C: could be benefit of modification
    Able to withstand more operational variation, or less frequent cleaning

Total Coliform Removal
• No quantitative data after filter ripening (Day 13)
• 86 % removal with average effluent of 430 cfu/100 ml (on Day 11)

E. Coli
• Mostly was not detected in influent/effluent
HydrAid™ BioSand Filter

- Approximately 200 HydrAid BSFs installed (December, 2007) in Kpanvo Village
- By International Aid
- Additional layer of superfine sand

Tests conducted at 30 households:
- Turbidity
- E.Coli
- Total Coliform
- Flow rate

**Average turbidity not high**
- Dugout ~85 NTU
- Influent ~32 NTU
Design Flow Rate 47 L/hr

- measurements not taken at maximum head thus slower than design flow rate
- cleaning every 3 days
- clogging was not problematic

average flow rate: 17 L/hr
Results & Discussion - Turbidity -

**Average**

Influent: 32 NTU  
Effluent: 2.9 NTU  
Removal: 87%
Results - Microbial -

Total Coliform

![Graph showing log_{10} Total Coliform vs Household]

- **log_{10} Total Coliform (log_{10} cfu/100ml)**
  - Influent
  - Effluent

- **Number of Households**
- **log_{10} Removal of Total Coliform**

- **Average Removal**: 1.9Log_{10}

- **Average Effluent**: 710 cfu/100 ml

- **E. coli**: detected in 9/22 samples (influent)
  - Average influent: 960 cfu/100 ml (9 samples)
  - 55% removal
Discussion -HydrAid BSF-

Flow Rate
• Slower than design flow rate, but not problematic

Turbidity
• Influent: relatively low turbidity
• Effective in turbidity removal
  average removal 87 %, average effluent 2.9 NTU

Total Coliform
• Effective in total coliform removal
  average removal:1.9 log10 units, 95 %
• Effluent concentration is high: 710 cfu/100ml

E. Coli
• Only detected in limited # of samples
## Summary

<table>
<thead>
<tr>
<th></th>
<th>Locally Plastic Design BSFs</th>
<th>HydrAid BSFs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Flow Rate</td>
<td>15-20 L/hr; modified</td>
<td>47 L/hr</td>
</tr>
<tr>
<td>Measured Flow Rate</td>
<td>29 L/hr; 21 L/hr</td>
<td>17 L/hr *</td>
</tr>
<tr>
<td>Turbidity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>influent</td>
<td>227 TU</td>
<td>32 NTU</td>
</tr>
<tr>
<td>effluent</td>
<td>16 TU; 11 TU</td>
<td>2.9 NTU</td>
</tr>
<tr>
<td>removal</td>
<td>93 %; 95 %</td>
<td>87%</td>
</tr>
<tr>
<td>Total Coliform</td>
<td></td>
<td></td>
</tr>
<tr>
<td>influent</td>
<td>15,000 cfu/100ml</td>
<td>20,000 cfu/100ml</td>
</tr>
<tr>
<td>effluent</td>
<td>430 cfu/100 ml **</td>
<td>710 cfu/100ml</td>
</tr>
<tr>
<td>removal</td>
<td>87 % **</td>
<td>95%</td>
</tr>
<tr>
<td>Cost</td>
<td>$ 16 - $ 25</td>
<td>$ 50 - $ 65</td>
</tr>
</tbody>
</table>

* Not measured at maximum head
** Average values on Day 11
*** Average value after 30+ days of operation

Local Plastic Design Biosand Filter Summary:
- Slower design flow rate
- Higher influent turbidity, higher percent removal
- Lower percent total coliform removal, lower effluent concentration
- Much less expensive
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Overall Goal: To Compare HTH Chlorine Dosing System with Aquatabs

• Thesis Title: “Efficacy of Gravity-Fed Chlorination System for Community-Scale Water Disinfection in Northern Ghana”

• Specific Objectives
  – To take Pulsar 1 System* and convert it for drinking water usage for community scale chlorination
  – Based on current capacity, need to significantly lower output residual chlorine concentrations
    • CDC: <2mg/L after 30 mins and >0.2mg/L after 24 hours
  – Compare different chlorine options (community scale versus household scale)

Pulsar 1 system is unique in being a highly accurate chlorine dosing system that does not require electricity (gravity feed). It was designed for large-scale swimming pools, but we hypothesized that it might be appropriate to adapt for developing country contexts such as schools, hospitals, and rural communities.
How the Pulsar Works

- Operates in parallel with water line (diverts some flow and re-injects downstream)
Field Work Site

Water Source: Elevated Tank

Pulsar 1 Unit
Modifications Made in Ghana

Modifications

• Added ¼” Spiked Grid
• Enlarged “Emergency Shutoff Valve”
• Added a dilution nozzle
• Reduced the inlet/outlet flows

Results

• Less contact with chlorine tablets in dissolving cup
• Divert more influent water away from the chlorine tablets
• Decreased total flow in and out of Pulsar unit
Field Work Results

- Successfully lowered concentrations to drinking water levels in Ghana

0.6-1.6 mg/L chlorine residual
But There’s a Problem…

• This final modification causes frequent O&M problems
  – Low internal flow rates leads to chlorine buildup of tubes & parts
  – Is therefore *unsustainable*
Further Research at MIT Lab

- Installed new parts to increase Pulsar’s internal dilution capacity

- Emergency Shutoff Valve – Pulls more water into the Pulsar unit

- Dilution Nozzle Assembly – Diverts more of this water away from the dissolving cup
Cambridge Lab Work Results

- Partially successful in lowering chlorine concentrations to drinking water levels
Results: HTH vs. Aquatabs on Supplies Cost

HTH is \textit{48X} Times Cheaper!

\begin{itemize}
  \item HTH: \textbf{\$0.03/m^3}
  \item Aquatabs: \textbf{\$1.5/m^3}
\end{itemize}
Results: HTH vs. Aquatabs on Treatment Cost (cont)

Includes: Price of chlorine, Pulsar 1 & Kosim filter, and operational cost of Pulsar

Pulsar 1 + HTH is much more economic on a volumetric ($/m3) basis!
# Overall HTH vs. Aquatabs Comparison

<table>
<thead>
<tr>
<th></th>
<th>Kosim Filter with Aquatabs</th>
<th>Pulsar 1 Unit with HTH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum Flow Rate</strong></td>
<td>Low (1-7 L/day)</td>
<td>High (&gt;100,000 L/day)</td>
</tr>
<tr>
<td><strong>Can Serve Many People</strong></td>
<td>🌟 🌟</td>
<td>🌟 🌟 🌟 🌟</td>
</tr>
<tr>
<td><strong>Cost of Treatment ($/m³)</strong></td>
<td>🌟 🌟 🌟</td>
<td>🌟 🌟 🌟 🌟</td>
</tr>
<tr>
<td><strong>System Lifetime</strong></td>
<td>~2 years*</td>
<td>~10 years*</td>
</tr>
<tr>
<td><strong>Low Initial Cost ($)</strong></td>
<td>🌟 🌟</td>
<td>🌟</td>
</tr>
<tr>
<td><strong>Low Running Cost ($/yr)</strong></td>
<td>🌟 🌟 🌟</td>
<td>🌟 🌟 🌟 🌟</td>
</tr>
<tr>
<td><strong>Simple O&amp;M</strong></td>
<td>🌟 🌟 🌟</td>
<td>🌟 🌟 🌟 🌟</td>
</tr>
<tr>
<td><strong>Materials Availability</strong></td>
<td>🌟 🌟</td>
<td>🌟 🌟 🌟 🌟</td>
</tr>
</tbody>
</table>

*Value Assumed by Author  🌟 = Poor  🌟 🌟 = Moderate  🌟 🌟 🌟 = Good

There is no “single best option”, so site-specific circumstances will dictate the appropriate technology.
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Consumer Choice Research

Objectives

• Assess the relative value and cost of HWTS options in Northern Region, Ghana

• Make recommendations about which products are likely to have the greatest impact on local drinking water quality based on product effectiveness, adoption and sustained use

Team included: Vanessa Green, Gaetan Bonhomme, Avani Kadakia, Gabriel Shapiro, Matt Thomson, Musah Abdul-Wahab, Jaafar Pelpo, Ibrahim Mohammed Ali, Alhassan Tahiru Senini & Susan Murcott
Field Research: Study Design

Final survey instrument included three elements:

1. Baseline survey: water management and ability to pay
2. Water quality testing (microbial and turbidity)
3. Conjoint (choice task) to assess product feature preference
## Results: Household Demographics

<table>
<thead>
<tr>
<th>Type</th>
<th>Gender (% Female)</th>
<th>Religion (% Muslim)</th>
<th>House Type (Roof)</th>
<th>Education</th>
<th>Average Household Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>% Tin</td>
<td>% Thatch</td>
<td>Primary</td>
</tr>
<tr>
<td>Urban (n=118)</td>
<td>77%</td>
<td>94%</td>
<td>100%</td>
<td>5%</td>
<td>51%</td>
</tr>
<tr>
<td>Rural (n=119)</td>
<td>70%</td>
<td>86%</td>
<td>15%</td>
<td>97%</td>
<td>19%</td>
</tr>
</tbody>
</table>

**Low rural education**

- **Significant difference in house type** between rural and rural communities
- **Similar household size**, urban result different from previous work in middle income areas
### Results: Water Source Access & Challenges

#### Primary Urban Water Sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Urban Respondents (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainwater Collection</td>
<td>58%</td>
</tr>
<tr>
<td>Private Household Tap</td>
<td>54%</td>
</tr>
<tr>
<td>Other (Improved)*</td>
<td>27%</td>
</tr>
<tr>
<td>Dugout/Dam</td>
<td>23%</td>
</tr>
<tr>
<td>Public Standpipe</td>
<td>19%</td>
</tr>
<tr>
<td>Tanker Truck Water</td>
<td>14%</td>
</tr>
</tbody>
</table>

*Typically a neighbor’s household tap (infrequent flow, taps open 2-4x/mo)*

#### Primary Rural Water Sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Rural Respondents (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dugout/Dam</td>
<td>93%</td>
</tr>
<tr>
<td>Borehole</td>
<td>63%</td>
</tr>
<tr>
<td>Rainwater Collection</td>
<td>50%</td>
</tr>
<tr>
<td>Public Standpipe</td>
<td>20%</td>
</tr>
<tr>
<td>Protected Dug Well</td>
<td>4%</td>
</tr>
<tr>
<td>Protected Spring</td>
<td>4%</td>
</tr>
</tbody>
</table>

#### Key Challenges:

**Urban:** Water Quantity & Recontamination

**Rural:** Source Distance & Water Quality

- Majority of urban and rural respondents **collect rainwater**
- Urban respondents get water from a **private tap or a neighbor** (infrequent flow, taps open 2-4x/month)
- Rural respondents **use a dugout**, some access boreholes/standpipes
Results: Needs Assessment

Health: Diarrheal Incidence

High diarrheal incidence among both urban and rural respondents, especially among children under five.

<table>
<thead>
<tr>
<th>Type</th>
<th>Turbidity</th>
<th>Total Coliform (TC)</th>
<th>E. Coli</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ave. (TU)</td>
<td>Max. (TU)</td>
<td>% with CFU</td>
</tr>
<tr>
<td>Urban (n=118)</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>59%</td>
</tr>
<tr>
<td>Rural (n=119)</td>
<td>238</td>
<td>1000</td>
<td>89%</td>
</tr>
</tbody>
</table>

Household Drinking Water Quality

Recontamination remains a challenge

Highly turbid source water, and significant contamination
Results: Current Water Management Practice

Urban and Rural Water Treatment Methods

```
% Utilization

Urban     Rural
GWC Municipal Water  96%  8%
Cloth Filter       93%  20%
Settling in Vessel  47%  26%
Alum              42%  8%
Boiling           3%   3%
Chemicals         0%   0%
Ceramic Filter    1%   0%
Candle Filter     0%   0%
```

“We use alum only when the water becomes very muddy at the end of the dry season”
–Rural resident, Lahagu.

Significant adoption of cloth filter in rural areas where distributed

Limited use of other treatment products, with the notable exception of alum in rural areas
Results: Ability to Pay

**Urban Households:**
- Average income of GHS 1,530 / yr
- Ability to pay for water GHS \textbf{0.21 / day}*

**Rural Households:**
- Average income of $619 / yr
- Ability to pay for water GHS \textbf{0.08 / day}*

“*If you are going to bring an expensive filter to this village you need to bring it at the time of year that we have just finished farming*”  – Rural respondent, Golinga.

**Urban and Rural Ownership of Household Goods**

<table>
<thead>
<tr>
<th>Cooking Fuel</th>
<th>Transportation</th>
<th>Electronics</th>
<th>Utilities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Firewood</strong></td>
<td><strong>Charcoal</strong></td>
<td><strong>Motorcycle</strong></td>
<td><strong>Mobile phone</strong></td>
</tr>
<tr>
<td>72%</td>
<td>98%</td>
<td>93%</td>
<td>91%</td>
</tr>
<tr>
<td>73%</td>
<td>47%</td>
<td>41%</td>
<td>38%</td>
</tr>
<tr>
<td>81%</td>
<td></td>
<td>32%</td>
<td></td>
</tr>
<tr>
<td>46%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Ability to pay calculation assumes that 5% of daily income allocated to water
Results: Purchasing Location

**Urban Purchase Location**

- Door-to-Door
- General Store
- Roadside Stand
- Specialty Store
- Street Vendors
- Market Day

**Rural Purchase Location**

- Door-to-Door
- General Store
- Roadside Stand
- Specialty Store
- Street Vendors
- Market Day

---

“**For items that I buy often I would like door-to-door or a store in the community.**” – Rural respondent, Golinga.

“I always buy at the market because I assume that is where I can get the best price” – Rural respondent, Golinga.
Results: Conjoint Attribute Importance

- Attribute importance quantifies the effect that each of the HWTS product attributes selected had on a respondent’s overall product preferences; Urban and rural communities had similar attribute importance rankings.

Source: G-lab Final Report, February 2008
Results: Consumer Preference

- Health impact was most important to both urban and rural respondents

- Durable products favored (respondents want something that will last)

- Short treatment time more important in urban

- Slight preference for clear/crisp (urban) and clear/chlorine (rural)

- Higher prices preferred in urban areas, limited price sensitivity in rural
# HWTS Product Options Assessment

<table>
<thead>
<tr>
<th>Type</th>
<th>Household Water Product</th>
<th>Turbidity Efficacy</th>
<th>Microbial Efficacy</th>
<th>Local Availability</th>
<th>Annual cost (GHC) / family*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Particle Removal</strong></td>
<td>Cloth Filter</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Alum</td>
<td>High</td>
<td>Low-Moderate</td>
<td>High</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>BioSand Filter</td>
<td>Local LDP</td>
<td>High</td>
<td>Moderate</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Int. Aid</td>
<td>High</td>
<td>Moderate</td>
<td>Low-Moderate</td>
<td>22</td>
</tr>
<tr>
<td><strong>Particle Removal &amp; Safe Storage</strong></td>
<td>Pot Filter (Kosim)</td>
<td>High</td>
<td>Moderate</td>
<td>High</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Candle Filter</td>
<td>OK</td>
<td>High</td>
<td>Moderate</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Mission</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Berkefeld</td>
<td>High</td>
<td>Moderate</td>
<td>Low-Moderate</td>
<td>136</td>
</tr>
<tr>
<td><strong>Disinfection</strong></td>
<td>SODIS (UV)</td>
<td>Low</td>
<td>Low-Moderate</td>
<td>Moderate</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>HTH Chlorine</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Liquid Chlorine</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>2 – 5</td>
</tr>
<tr>
<td></td>
<td>Aquatabs (20l)</td>
<td>Low</td>
<td>High</td>
<td>Low-Moderate</td>
<td>13</td>
</tr>
<tr>
<td><strong>Coagulation &amp; Disinfection</strong></td>
<td>PuR™ (P&amp;G)</td>
<td>High</td>
<td>High</td>
<td>N / A</td>
<td>45 - 80</td>
</tr>
<tr>
<td><strong>Safe Storage</strong></td>
<td>Locally Manufactured</td>
<td>N / A</td>
<td>N / A</td>
<td>Low</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>CDC (SWS)</td>
<td>N / A</td>
<td>N / A</td>
<td>Low</td>
<td>2.4</td>
</tr>
<tr>
<td><strong>Sachet Water</strong></td>
<td>Hand-tied (single)</td>
<td>N / A</td>
<td>N / A</td>
<td>High</td>
<td>275</td>
</tr>
<tr>
<td></td>
<td>Factory (wholesale)</td>
<td>N / A</td>
<td>N / A</td>
<td>High</td>
<td>657</td>
</tr>
</tbody>
</table>

Note: Annual cost per family was estimated by calculating using an anticipated average household size of 12 individuals and 2 liters of drinking water per individual per day.
HWTS Product Assessment Description

- **Particle removal:** Alum and the *Kosim* ceramic pot filter have the most potential in the short term as they are low-cost, they effectively reduce turbidity (and microbial contamination), and are available in northern Ghana.
  - The OK candle filter and biosand filters (locally manufactured and International Aid) have longer term potential

- **Disinfection:** UV has not been shown to be highly effective given high atmospheric dust seen in northern Ghana, and thus chlorine disinfection emerges as the priority option.
  - Chlorine disinfection is less effective in water with turbidities >30 NTU, thus in rural areas with turbid source water chlorination should be used in conjunction with particle removal
  - PuR™ offers a simple solution as it combines both particle removal and disinfection in a single sachet; however, the relatively high-cost and lack of availability in the region reduces the attractiveness of this option

- **Safe storage:** Low-cost safe storage options have the potential to enhance protection from recontamination, particularly if used in conjunction with chlorine disinfection.

- **High end products:** The more expensive Mission and Berkefeld candle filters as well as sachet water product should be targeted to upper and middle class...
Market Segmentation

- **Objective:** Describe the household water treatment landscape in terms of observable differences between sample populations
  - To facilitate the development of targeted HWTS interventions
  - To promote product adoption and sustained use

- **Market Landscape:**
  - The vertical axis is source water, defined by community location and water quality
  - The horizontal axis is profession which serves as proxy for both income and daily activity

- **Segmentation:** Based on observed HWTS preference the eighteen respondent types were combined into five segments, and priority HWTS products were matched to each segment
### HWTS Market Landscape, N. Ghana

<table>
<thead>
<tr>
<th>SOURCE WATER</th>
<th>RESPONDENT</th>
<th>Housewife</th>
<th>Agriculture</th>
<th>Production</th>
<th>Sales &amp; Other</th>
<th>Trader</th>
<th>Professional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>2b</td>
<td>Agricultural / Clear Water (&lt;10 TU)</td>
<td>Chlorine &amp; safe storage</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Rural</td>
<td>3b</td>
<td>Agricultural / Turbid Water (&gt;10 TU)</td>
<td>Alum, chlorine &amp; safe storage</td>
<td>Ceramic pot (or biosand) with chlorine &amp; safe storage</td>
<td></td>
<td></td>
<td>3a</td>
</tr>
</tbody>
</table>

Priority HWTS products were matched with each segment based on observed differences in: 1) source water quality, 2) ability to pay and 3) consumer preferences.
HWTS Recommendations by Target Segment

Priority Options: Product Effectiveness, Adoption and Sustained Use

- Develop a **safe storage product** – strong preference for traditional durable, significant recontamination challenge

- Consider **local manufacturing of a low-cost HWTS chlorine product** (e.g., HTH or Liquid Chlorine)

- Develop a **chlorine treatment protocol** for communities with non-turbid water – specifically dosing within 24h of consumption to combat recontamination due to long storage

- Opportunity for a **targeted sachet water business** that focuses on the urban upper and middle class

- Opportunity for **low-cost combined treatment products** in communities with turbid source water (e.g., Alum / Biosand / Kosim + Chlorine Disinfection (Aquatabs))

- **Focus Kosim sales / distribution** on rural areas with turbid water, and continue to develop the biosand for this market
Presentation Outline

- Ghana: Background and Logistics
- Horizontal Roughing Filtration: Tamar Losleben
- Household Filtration (Biosand Filter): Izumi Kikkawa
- Chlorine Products: Cash Fitzpatrick
- HWTS Consumer Choice Study: Vanessa Green
- Ceramic Pot (Kosim) filter + Chlorine Disinfection with Aquatabs: Andrew Swanton
Overview

3-Week Pilot Study: Combined Kosim Filter and Aquatabs System

• 59 Households: 24 lower-class, 35 lower middle-class

• Baseline: Survey, WQ Testing, Distribution of Jerry Cans, Aquatabs

• Follow-up (1 Week Later): Survey, WQ Testing
Baseline Survey Results

16 Questions to Gauge User Acceptability, Appropriate Cleaning, Perception

Key Questions and Results:

• From where do you collect your water? 95% dugout

• How many times per week do you add water to the Kosim filter? 2.9

• Can you act out for me how to clean the filter? 100% yes

• Do you like the taste of the filtered water? 100% yes
Follow-Up Survey Results

8 Questions to Gauge User Acceptability, Perception with Addition of Aquatabs

Key Questions and Results:

• Do the Aquatabs improve the taste of the water? 100% yes
• Would you recommend the use of Aquatabs to others? 100% yes
• Have you had any problems using Aquatabs? 100% no
• Specific Problems: “not comfortable”, hernia/urine more yellow, stomach aches
Cost Results

Aquatabs cost 3 pesaws (=3 cents) per tablet, 3 GHC (= $3 US dollars) for 100

• Question: “Would you spend 3 GHC for 100 Aquatabs?”
• If no: “What do you think a fair price is for 100 Aquatabs?”
• Kalariga (lower-class): 25% willing to pay 3 GHC, 1.8 GHC average
• Kakpagyili (lower middle-class): 94% willing to pay 3 GHC, others 1.2 GHC
# Water Quality Data

## Dugout

<table>
<thead>
<tr>
<th>n</th>
<th>Turbidity (NU)</th>
<th>TC (CFU/100mL)</th>
<th>EC (CFU/100mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kalariga</td>
<td>1</td>
<td>400</td>
<td>6,200</td>
</tr>
<tr>
<td>KakDam1</td>
<td>1</td>
<td>400</td>
<td>&lt;100</td>
</tr>
<tr>
<td>KakDam2</td>
<td>1</td>
<td>1200</td>
<td>23,000</td>
</tr>
</tbody>
</table>

## Pre-Treatment, Stored Water

<table>
<thead>
<tr>
<th>n</th>
<th>Turbidity (NU)</th>
<th>TC (CFU/100mL)</th>
<th>EC (CFU/100mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kalariga</td>
<td>1</td>
<td>150</td>
<td>5,000</td>
</tr>
<tr>
<td>Kakpagyili</td>
<td>2</td>
<td>200</td>
<td>6,000</td>
</tr>
<tr>
<td>Total</td>
<td>3</td>
<td>180</td>
<td>5700</td>
</tr>
</tbody>
</table>

## Post-Filtered

<table>
<thead>
<tr>
<th>n</th>
<th>Turbidity (NU)</th>
<th>TC (CFU/100mL)</th>
<th>EC (CFU/100mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kalariga</td>
<td>24</td>
<td>16</td>
<td>2,200</td>
</tr>
<tr>
<td>Kakpagyili</td>
<td>35</td>
<td>17</td>
<td>2,300</td>
</tr>
<tr>
<td>Total</td>
<td>59</td>
<td>16</td>
<td>2,800</td>
</tr>
</tbody>
</table>

## Post-Aquatabs

<table>
<thead>
<tr>
<th>n</th>
<th>Turbidity (NU)</th>
<th>TC (CFU/100mL)</th>
<th>EC (CFU/100mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kalariga</td>
<td>24</td>
<td>11</td>
<td>2,000</td>
</tr>
<tr>
<td>Kakpagyili</td>
<td>35</td>
<td>38</td>
<td>900</td>
</tr>
<tr>
<td>Total</td>
<td>59</td>
<td>27</td>
<td>1,300</td>
</tr>
</tbody>
</table>
% Reductions

(-)ve % reductions, indicate % increase

Stages of Water Treatment, Kalariga

<table>
<thead>
<tr>
<th>Water Quality Values</th>
<th>Dugout</th>
<th>Pre-Treatment Stored Water</th>
<th>After Filtering</th>
<th>After Aquatabs</th>
</tr>
</thead>
<tbody>
<tr>
<td>%Red, LRV:</td>
<td>%Red, LRV:</td>
<td>%Red, LRV:</td>
<td>%Red, LRV:</td>
<td></td>
</tr>
<tr>
<td>Turb.: 63, 0.43</td>
<td>Turb.: 89, 0.95</td>
<td>Turb.: 35, 0.19</td>
<td>Turb.: 89, 0.95</td>
<td></td>
</tr>
<tr>
<td>TC: 19, 0.09</td>
<td>TC: 56, 0.36</td>
<td>TC: 7, 0.03</td>
<td>TC: 56, 0.36</td>
<td></td>
</tr>
<tr>
<td>EC: -49, -0.17</td>
<td>EC: 39, 0.21</td>
<td>EC: 18, 0.09</td>
<td>EC: 39, 0.21</td>
<td></td>
</tr>
</tbody>
</table>

Stages of Water Treatment, Kakpagyili

<table>
<thead>
<tr>
<th>Water Quality Values</th>
<th>Dugout</th>
<th>Pre-Treatment Stored Water</th>
<th>After Filtering</th>
<th>After Aquatabs</th>
</tr>
</thead>
<tbody>
<tr>
<td>%Red, LRV:</td>
<td>%Red, LRV:</td>
<td>%Red, LRV:</td>
<td>%Red, LRV:</td>
<td></td>
</tr>
<tr>
<td>Turb.: 92, 1.10</td>
<td>Turb.: 52, 0.32</td>
<td>Turb.: -138, -0.38</td>
<td>Turb.: 92, 1.10</td>
<td></td>
</tr>
<tr>
<td>TC: 52, 0.32</td>
<td>TC: 70, 0.52</td>
<td>TC: 70, 0.52</td>
<td>TC: 70, 0.52</td>
<td></td>
</tr>
<tr>
<td>EC: -20, -0.08</td>
<td>EC: -83, -0.26</td>
<td>EC: -83, -0.26</td>
<td>EC: -83, -0.26</td>
<td></td>
</tr>
</tbody>
</table>

MIT Clean Water 4 All, Inc.
Limit of Detection: <5 TU, Displayed as 2.5 TU

Turbidity Detected, Baseline: 3/24, Post-intervention: 2/24
Turbidity Test Results-Kakpagyili

Limit of Detection: <5 TU, Displayed as 2.5 TU

Turbidity Detected, Baseline: 2/35, Post-intervention: 8/35
Total Coliform Test Results

3M Petrifilm Test

<table>
<thead>
<tr>
<th>Community</th>
<th>Households with No TC Detected</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
</tr>
<tr>
<td>Kalariga</td>
<td>5/24=21%</td>
</tr>
<tr>
<td>Kakpagyili</td>
<td>21/35=60%</td>
</tr>
<tr>
<td>Both</td>
<td>26/59=44%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Community</th>
<th>TC Count Decreased</th>
<th>TC Count Increased</th>
<th>TC Count Remained the Same</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kalariga</td>
<td>15/24=63%</td>
<td>3/24=13%</td>
<td>6/24=25%</td>
</tr>
<tr>
<td>Kakpagyili</td>
<td>12/35=34%</td>
<td>7/35=20%</td>
<td>16/35=46%</td>
</tr>
<tr>
<td>Both</td>
<td>27/59=46%</td>
<td>10/59=17%</td>
<td>22/59=37%</td>
</tr>
</tbody>
</table>

Image of a petri dish removed due to copyright restrictions.
**E. Coli Test Results**

<table>
<thead>
<tr>
<th>Community</th>
<th>Baseline</th>
<th>Post-Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kalariga</td>
<td>21/24=88%</td>
<td>24/24=100%</td>
</tr>
<tr>
<td>Kakpagyili</td>
<td>31/35=89%</td>
<td>34/35=97%</td>
</tr>
<tr>
<td>Both</td>
<td>52/59=88%</td>
<td>58/59=98%</td>
</tr>
</tbody>
</table>

Average EC concentrations higher in follow-up?

- 1 household during follow-up with *E. Coli*: 2,200 CFU/100mL
- 7 households during baseline with *E. Coli*: 50-200 CFU/100mL
Free Available Chlorine Test Results

% of Households with FAC level > 0.1 mg/L at follow-up

Kalariga: 63%, Kakpagyili: 66%
Flow Rate Test Results

Flow Rates Comparison

<table>
<thead>
<tr>
<th>Description</th>
<th>Age</th>
<th>Turbidity (TU)</th>
<th>TC (CFU/100mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New, Filters, Clear Water</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>New Filters, Dirty Water</td>
<td>0</td>
<td>200-300</td>
<td>2,150-100,000</td>
</tr>
<tr>
<td>Old Filter, Dirty Water</td>
<td>1 year</td>
<td>400</td>
<td>6,200</td>
</tr>
</tbody>
</table>
Summary

• Average TC Conc. Reduced by 50%
• TC: 46% reduced, 37% same, 17% increased from baseline to post-intervention
• No TC: 44% to 64%, No EC: 88% to 98%
• 64% Households had FAC > 0.1 mg/L at follow-up
• FAC b/t 0-0.25 mg/L: 32% increased, 32% decreased (TC conc)
• FAC b/t 1.01-2.00 mg/L: 67% increased, 8% decreased (TC conc)
• All survey respondents: “improved taste of water” “would recommend to others”