Safe water provision for Northern Ghana

David Barnes ~ Clair Collin ~ Sara Ziff

MIT M.Eng. Thesis Final Presentations
April 24, 2009

Project Aim

- Work with Pure Home Water (PHW), a Northern Ghana-based social enterprise marketing safe water technologies
- Work towards PHW goal:

  Safe water for 1 million people in Northern Ghana over next 5 years

- Research additional safe water technologies for Northern Ghana, where 50% lack access to improved water source

Water Challenges in Northern Ghana

- Poverty
  - Low cost options required
- High turbidity water (>50 NTU)
  - Difficult to treat
- Lack of water-infrastructure
  - Household scale technologies
- Water-based disease prevalence
  - Guinea worm
  - Diarrhea

Addressing drinking water needs in Northern Ghana

- Technologies to improve water quality
  - Biosand filter – Clair Collin
  - Siphon filter – Sara Ziff

- Mitigating water scarcity
  - Rainwater harvesting – David Barnes

Clair Collin

Biosand filtration of high turbidity water:

Modifications to standard filter design and safe storage of filtrate

Presentation Overview

- Aims of research

Part I

- Biosand filter (BSF)
  - Overview of BSF technology
  - Design modification options research
  - Selected design optimization
  - Recommended BSF design

Part II

- Safe filtrate storage
  - Necessity for safe filtrate storage
  - Safe storage options
  - Recommended safe storage system

- Integrated BSF and safe filtrate storage system

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Aims of research

- Design a modified biosand filter for treating high turbidity water
- Recommend method for safe storage of filtrate
- Low cost system using locally sourced materials

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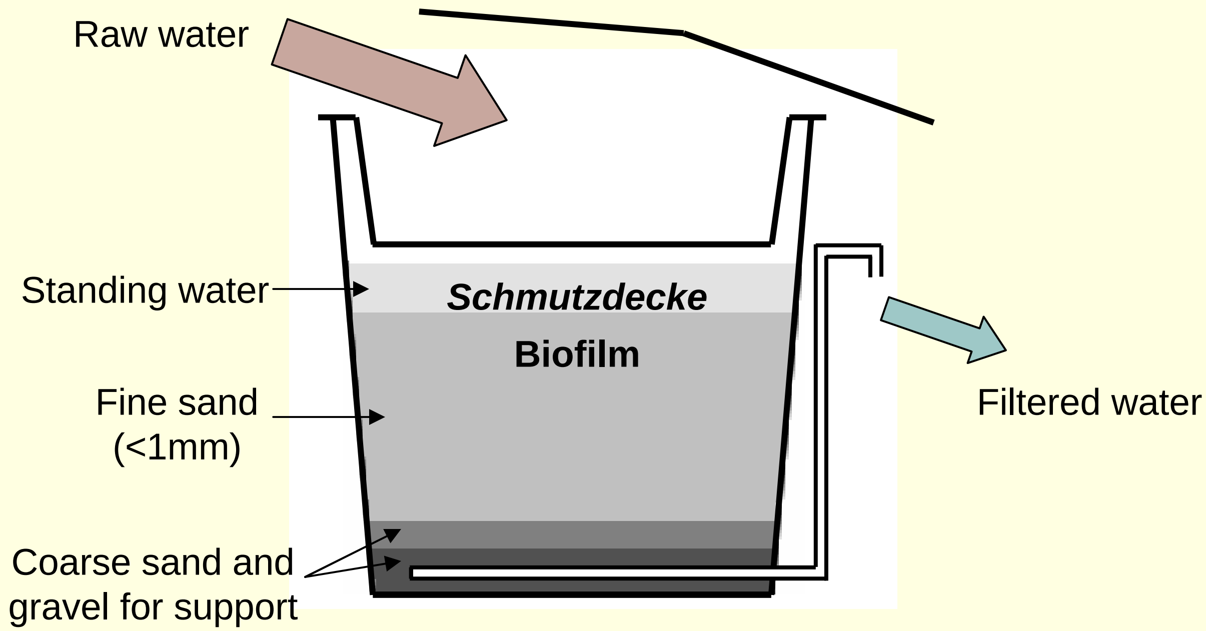
Biosand filter technology

- Intermittent slow sand filtration
  - Mechanical filtration of particles
  - Chemical/biological oxidation of organic matter



Biosand Filter Technology

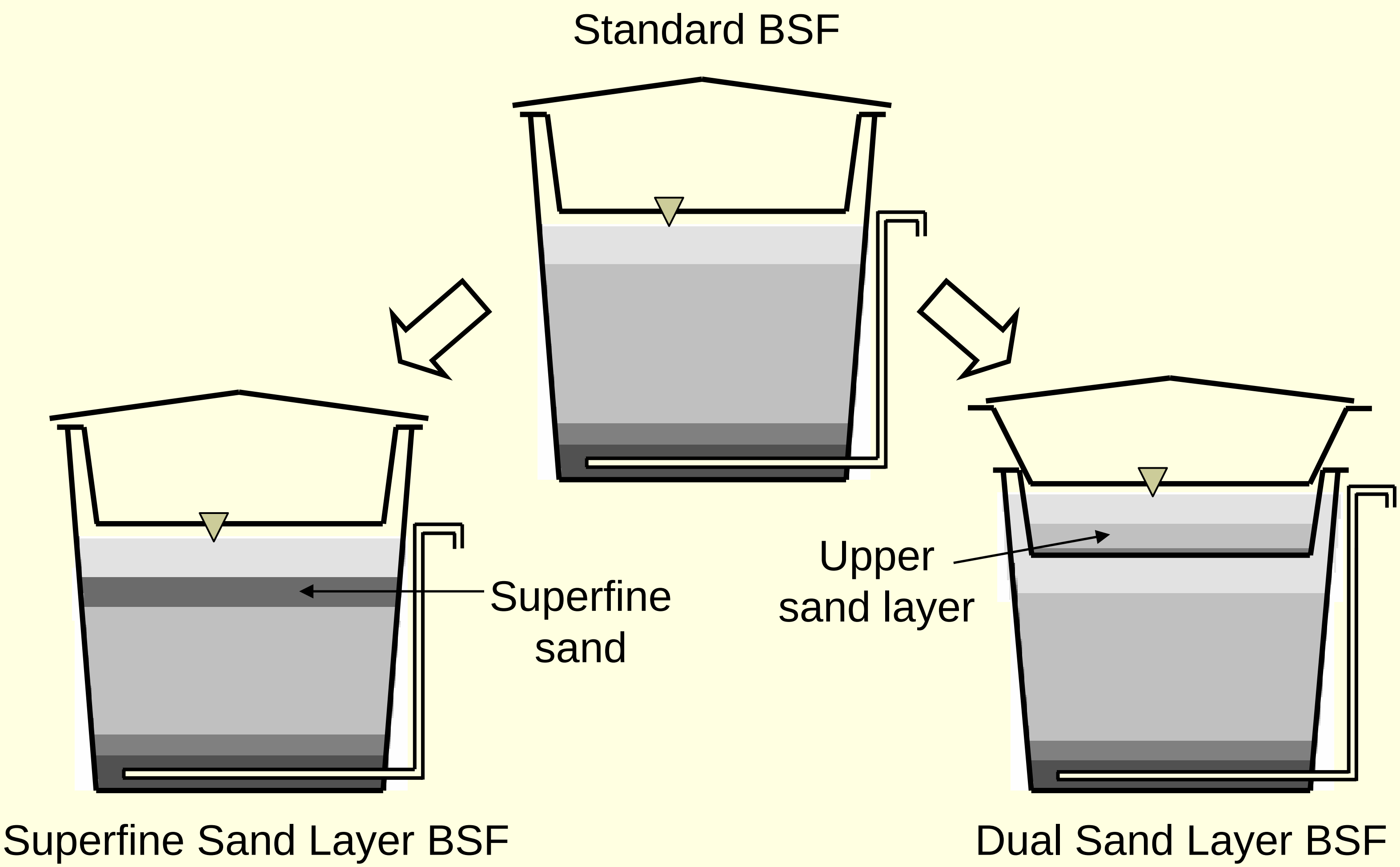
- Low turbidity source water, <50 NTU
  - Pathogen reduction
    - Bacteria: 1-log – 3-log
    - Viruses: 0.5-log – 3-log
    - Protozoa: 2-log – 4-log
  - Turbidity reduction
    - 85% - 95%

- High turbidity source water, >50 NTU
  - Not known

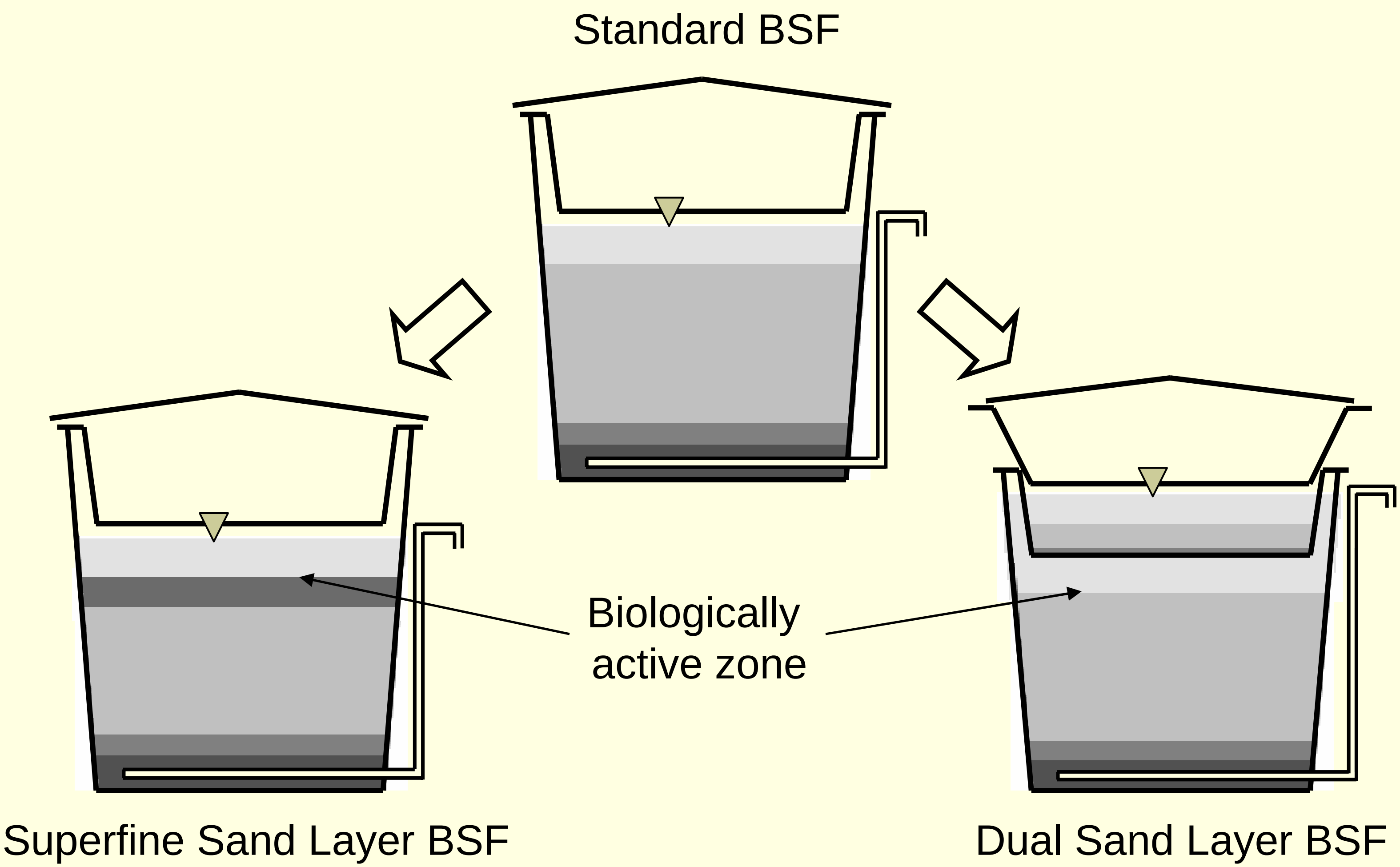
BSF Design Options

- Goal: reduce turbidity, thereby pathogen contamination
  - Sedimentation – too slow
  - Coagulation & flocculation – too expensive
  - Additional filtration
    - Roughing filtration – too big/complicated
    - <u>Finer sand (0.7 mm) – worth investigating</u>
    - <u>Additional sand (second layer)– worth investigating</u>

BSF Design Options



BSF Design Options



BSF Design Options

- Superfine Sand Layer BSF
  - Increased turbidity removal **16%**
  - Microbial removal:

    Total coliform **> 85%**

    (E. coli > 83%)
  - Frequent cleaning disturbs biology

- Dual Sand Layer BSF
  - Increased turbidity removal **38%**
  - Microbial removal:

    Total coliform **> 95%**

    (E. coli > 85%)
  - Frequent cleaning has minimal disturbance on biology

BSF Design Options

- Superfine Sand Layer BSF
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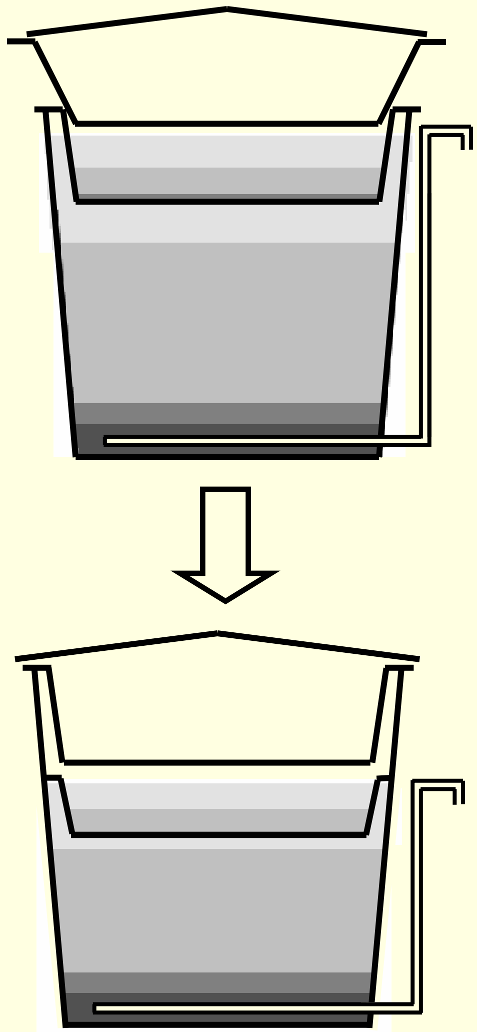
- **Dual Sand Layer BSF**
  - **Increased turbidity removal 38%**
  - **Microbial removal:**

    Total coliform > 95%

    (*E. coli* > 85%)
  - **Frequent cleaning minimal disturbance to biology**

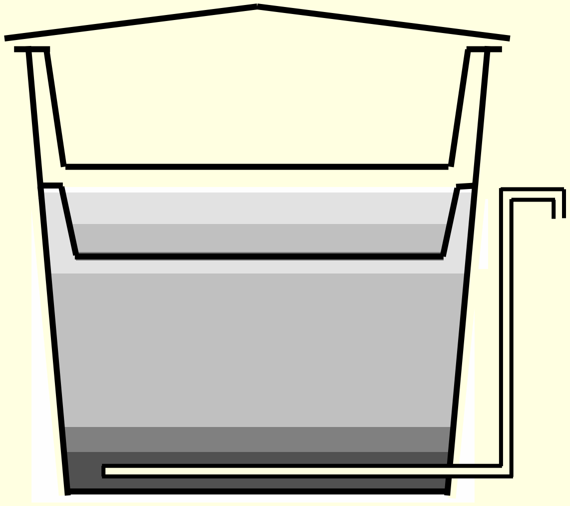
Dual Sand Layer BSF

- Design optimization - tests
  - Sand layer depth
    - Upper sand layer 3 cm
    - Lower sand layer
  - 3-day cleaning program
  - Filling frequency
    - Twice per day
  - Filling volume
    - Double filter pore volume
  - Dissolved oxygen concentration profile
- Cost of filter
  - Unmodified ~$17
  - Modified ~$18



Dual Sand Layer BSF

- Design optimization - results
  - Dual sand layer higher indicator bacteria removal than control filter
    - Turbidity >93%
    - *E. coli* >97%
    - Total coliform >71%
  - 3-day cleaning program
    - No effect on performance
  - Increased filling frequency
    - Decreased performance
  - Increased filling volume
    - Decreased performance
  - Dissolved oxygen
    - Oxygen reached lower sand layer for biological activity



Recommendations

- Dual Sand Layer BSF
  - High turbidity reduction
  - Efficient microbial reductions
  - Frequently cleaning has minimal disturbance on biologically active zone
  - Achieved with low-cost modifications
- Dual sand layer BSF recommended for further testing

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  - Recommended safe storage system

- Integrated BSF and safe filtrate storage system

Necessity for Safe Filtrate Storage

- Protect filtrate from recontamination from dirty hands, cups and utensils
- Prevent access to animals and children
- Critical to success and sustainability of biosand filter

Safe Storage Options

- Safe storage vessel
  - Jerry can
  - Plastic bucket with lid
  - Dispenser tap
  - Low cost
  - Durable

- Jerry can
  - Difficult to fit tap
  - Bought recycled - plastic impregnated with palm oil
- Plastic bucket with lid
  - Easy to fit tap
  - Bought clean

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- **Plastic bucket with lid**
  - **Easy to fit tap**
  - **Bought clean**

Safe Filtrate Storage Recommendations

- High BSF flow rate – villagers did not store filtrate
  - Teach filtering water only as required
- Collect filtrate in safe storage bucket with lid and tap

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- **Integrated BSF and safe filtrate storage system**

Integrated Biosand Filter and Safe Filtrate Storage System

- In areas with high turbidity water, the following system is proposed for further research:

Dual Sand Layer Biosand Filter

+

Safe collection of BSF filtrate

+

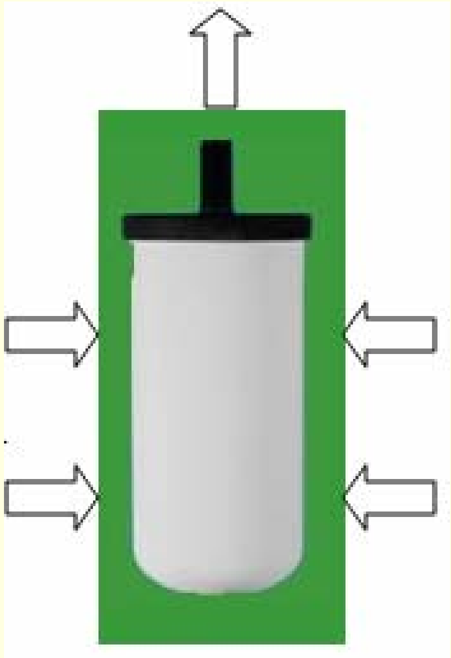
Teach use of filter <u>only</u> when water is required

Sara Ziff

Siphon Filter Assessment for Northern Ghana

Siphon Filter

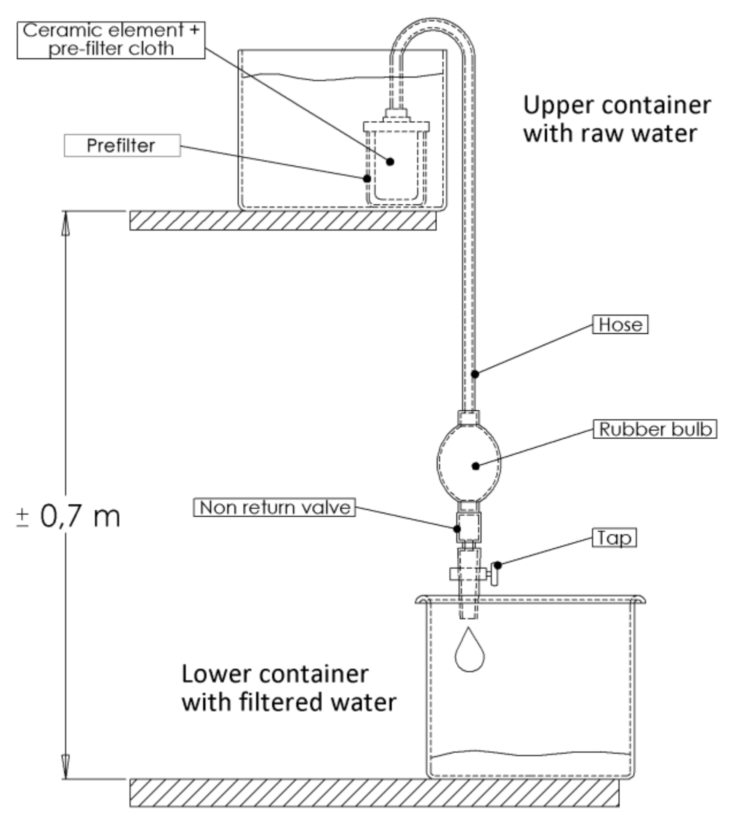
- Household ceramic water filter
- Based on ceramic candle filter design
- Fast flow rate (3-5 L/hour)
- Low cost (Current ~ US$10; Future ~ US$5)
- Effective: 99.999% removal found by independent lab



Siphon Filter Use

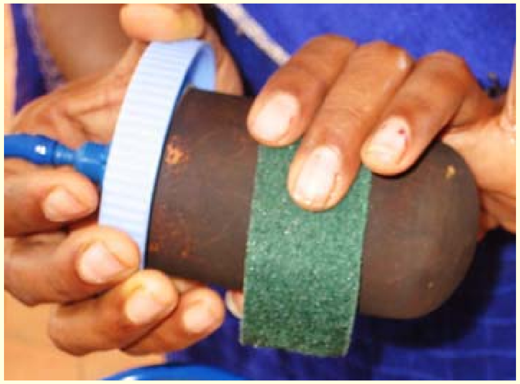
- To Use:
  - Place ceramic element in elevated upper container
  - Place tap in lower container
  - Press bulb to start flow, using siphon effect

Conventional Set-up



Siphon Filter
Maintenance

- Filter clogs periodically due to particles
- Backwashing restores flow
- Cloth pre-filter
- At a certain point, scrubbing needed



- End-of-life gauge tells when element too thin

Objective:

To which types of households should PHW market the siphon filter?

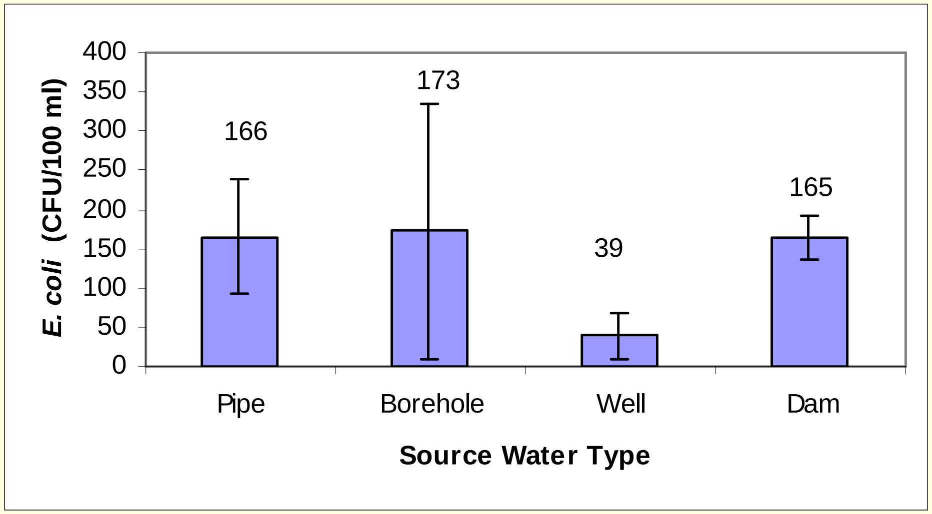
Method:

Ghana Field Study

- 24 siphon filters distributed to households
- Household types:
  - lower and upper class
  - turbid and low turbidity water sources
- Water quality testing
- Effective Use survey

Water Quality Findings
Source water characterization

- 48 total source water samples
  - Pipe, borehole, well, dam
- 58% “improved” sources, 42% “unimproved” sources
- Overall high levels of *E. coli*
- Intermediate to high risk level[1]



1 World Health Organization, (1997) Guidelines for Drinking Water Quality, Vol. III, Surveillance and Control of Community Supplies. 2nd Ed. Geneva: WHO.

Water Quality Findings
Filter Performance

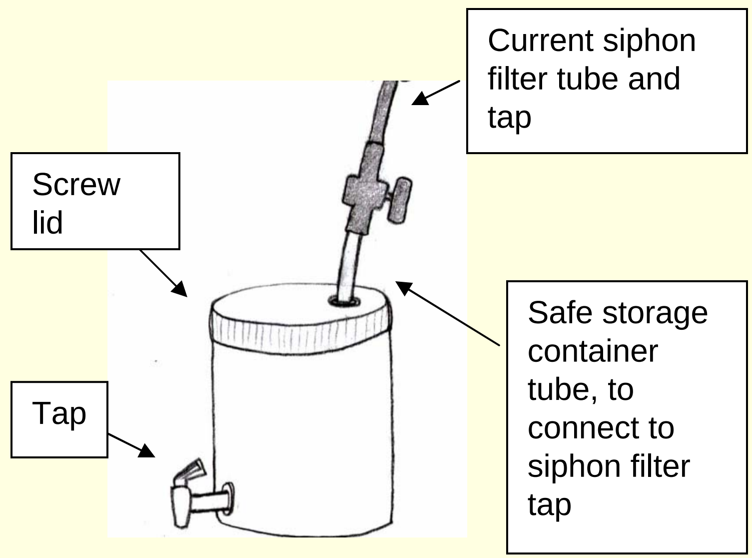
- Reported values do not include 6 samples suspected of recontamination
- 90.7% avg. removal of total coliform
- 94.1% avg. removal of *E. coli*
- Turbidity removal influenced by ceramic particle leaching
  - Occurs during first use of filter
  - Aesthetic effect

Water Quality Findings Recontamination

- Initially, thought could avoid possible recontamination:
  filtered water samples taken from tap
- However, filtered water sometimes had higher levels of coliform than household stored water
- Two possible causes:
  (1) bacterial regrowth
  (2) taps resting in dirty lower water containers
- Thought to be latter cause, but more research needed

Recommendation
Safe Storage Container

- Now: lower containers usually buckets or jerry cans →
  - Difficult to keep clean
- Siphon filter needs safe storage container
  - Maintain microbial quality of filtered water
- Recommended design →
- Could be marketed with siphon filter



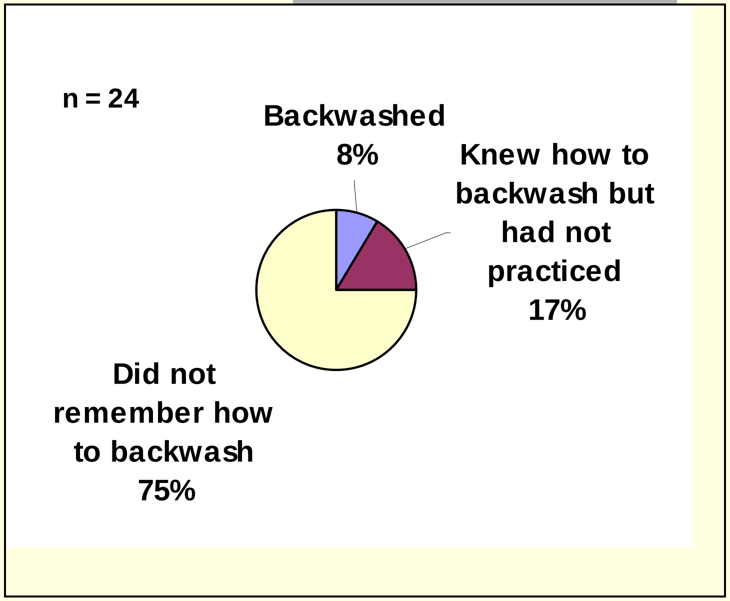
Effective Use Findings

Large Clay Pots as Upper Containers

- Large clay pots often used as water storage containers
- Not easily elevated
- However, distance between upper water level and tap sufficient if clay pot full
- Recommendation: Pictorial instructions for large clay pot users

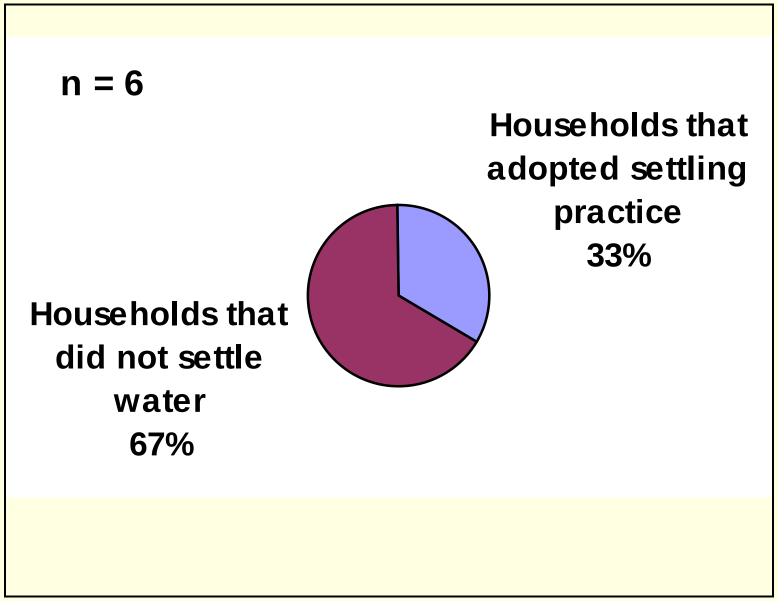
Effective Use Findings
Backwashing/Scrubbing

- Backwashing and scrubbing process not well understood
- 75% of households did not understand backwashing →
- Scrubbing better understood
  - More intuitive?
- 33% scrubbed the filter during study
  - Source water for all was turbid
  - Backwashing not performed
- Over-reliance on scrubbing will shorten life of ceramic element
  - Esp. for turbid water



Effective Use Findings
Settling

- Reduces turbidity
- Decreases necessary frequency of scrubbing
- Only 33% of users drinking dam water throughout study settled water
- Indicates settling not readily adopted



Overall Findings
Middle vs. Lower Class

- Lower class households often drank highly turbid water
- However, class not found to influence how effectively filters were used

Overall Findings
High vs. Low Turbidity Water

- High turbidity water:

  Filters clogged frequently
  - Study participants did not consistently maintain filter (backwashing, settling)
- Low turbidity water:

  Filter maintenance less crucial
  - Filter clogged infrequently even with little maintenance

Comparison of Siphon Filter to Other Options

- Established treatment options considered for marketing by PHW:
  - Siphon filter
  - Chlorine
  - Alum (coagulant)
  - *Kosim* ceramic pot filter

Comparison of Siphon Filter to Other Options
Low Turbidity

<table>
<tr><th>Treatment Option</th><th>Pros</th><th>Cons</th></tr>
<tr><td rowspan="3">Siphon Filter</td><td>Low cost</td><td rowspan="3">Safe storage not included</td></tr>
<tr><td>Small</td></tr>
<tr><td>Fast flow rate</td></tr>
<tr><td rowspan="3">Kosim Pot Filter</td><td rowspan="3">Integrated safe storage</td><td>Higher cost</td></tr>
<tr><td>Large</td></tr>
<tr><td>Slow flow rate</td></tr>
</table>

<table>
<tr><td rowspan="3">Siphon Filter</td><td>Infrequent purchase</td><td rowspan="3">Recontamination issue</td></tr>
<tr><td>No wait</td></tr>
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<tr><td rowspan="3">Chlorine</td><td rowspan="3">Effective disinfection</td><td>Consumable</td></tr>
<tr><td>Wait required</td></tr>
<tr><td>Disinfection byproducts</td></tr>
</table>

Comparison of Siphon Filter to Other Options

High Turbidity

Treatment Option	Pros	Cons
Siphon Filter	Infrequent purchase	**Extensive maintenance**
	Low cost	
		Recontamination issue
Alum plus Chlorine	**Simple**	Consumable
	Effective disinfection	Relatively expensive
		Disinfection byproducts

Siphon Filter	**Cleaning options other than scrubbing**	**Extensive maintenance required**
	Fast flow rate	
***Kosim* Pot Filter**	Less maintenance required	**Scrubbing only cleaning option**
		Slow flow rate

Recommendations to PHW

- More research needed with safe storage container to resolve recontamination
- Siphon filter education:
  - Detailed literature
    - Pictorial and technical English/translated versions
  - Specialized training
- Turbid water users:
  - Advise settling
    - Simple, free
  - Suggest alum
    - < US$4.50/year
    - However, may be too much of a hassle/cost

Recommendations

- Choice of treatment option is not clear-cut, especially for users of highly turbid water
- PHW should discuss options with potential buyers

Assessment of Rainwater Harvesting in Northern Ghana

David Barnes

Overview

- Introduction
- Objectives
- Current Status
- Economic
  - Cost/m^3
- Technical
  - Reliability
- Water Quality Analysis
  - Tank/Cistern Water Quality
- Conclusions/ Recommendations

Introduction

- Objective
  - Assess the current state of rainwater harvesting
  - Assess performance and potential for scaling up

Methods

- RWH Technical Surveys
- Household surveys for Presbyterian Tank Program household RWH systems
- Water quality sampling
  - 3M Petrifilm and Colilert
- Pricing of system components
- Interviews with contractors, NGO's, local government

Current Status of Rainwater Harvesting in Northern Ghana

- Three NGO’s
  - Schools, Hospitals/Health Clinics
    - World Vision
    - New Energy
  - Households
    - Presbyterian Church and Pure Home Water
- Government program at school’s
- Do-it-yourself informal rainwater harvesting
- Two rainwater harvesting systems >50 yrs old
  - Savelugu Hospital
  - Veterinary College

System Designs

Three Design's

- $10m^3$ Ferrocement Tank
  - $708 US
- $30m^3$ Cement Block Tank
  - $2750 US
- $75m^3$ Cement Block Tank-Octagonal
  - $3500 US

Ability to Pay for Household RWH

- Estimated as 5% of annual income[1]
  - Urban= $64 USD/yr
  - Rural= $26 USD/yr
- Presbyterian Tank Program with no interest
  - $35 USD/yr ($708 USD/20 years)
- Rural unaffordable, urban affordable

1 McPhail, A.A. (1993) The Five Percent Rule for Improved Water Supply: Can Households Afford More? World Dev., 21 (6), 963–973.

Presbyterian Tank Program

	# of Users	Roof Area (ft^2)	Demand Scenario 1 Reliability (5 L/day/capita)	Demand Scenario 2 Reliability (20 L/day/capita)	Scenario 1 Unit Cost (USD/m^3)	Scenario 2 Unit Cost (USD/m^3)
High	7	772	99.9%	78%	$2.77	$0.89
Average	14	369	96%	26%	$1.48	$1.38
Low	20	200	43%	5%	$4.13	$8.62

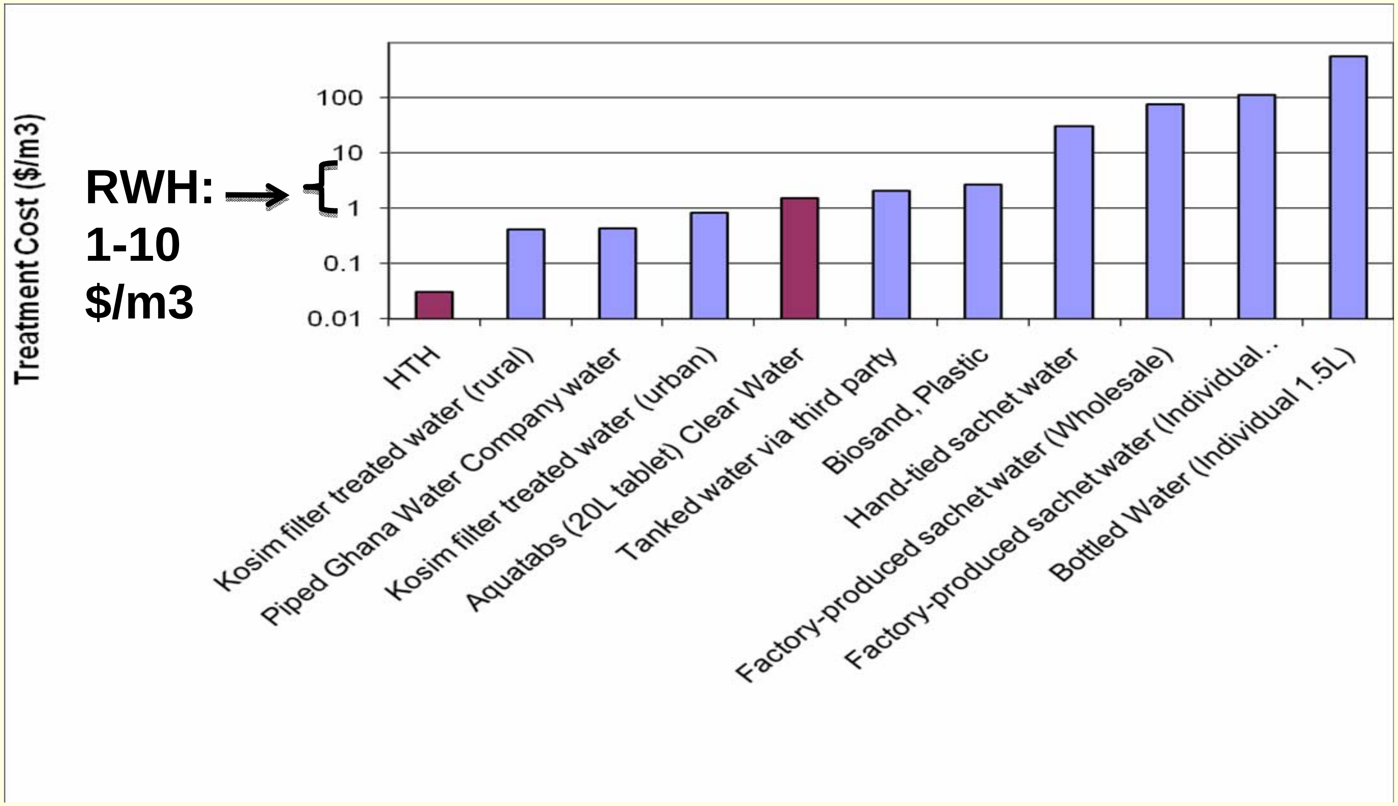
- Various reliability and demand scenarios and their resulting unit costs per cubic meter
- No discounting

Community RWH sites

Tank Name	Rooftop Area (ft^2)	Storage Capacity (ft^3)	Demand (gal/day)	Reliability %	Cost (USD)	Unit Cost (USD/m^3)
World Vision	12149	1766	433	68	8333	$1.02
Pong Tamale Health Clinic	500	18	4.2	75	*300**	$3.45
Pong Tamale Vocational School (1)	612	35	262	5	*500**	$1.38
Pong Tamale Vocational School (2)	748	35	262	6	*500**	$1.12
Pong Tamale Health Center	753	2649	50	91	3500	$2.78
Savelugu Hospital	819	2649	262	11	3500	$4.40

*** Cost estimated, tank cost unknown**

Alternative Technologies



Adapted from Murcott et al., 2008

Design Issues

- Dead Storage
- Leaky taps/tanks
- Guttering!
- Expense and Subsidy
  - Tank Cost
- Maintenance

Cost Competitiveness

- If capital is available, RWH systems are cost competitive with alternative technologies with no discounting
- Ability to Pay indicates that average rural residents would be unable to afford Presbyterian $10m^3$ tank, even without interest.
- Currently almost entirely subsidized
  - Sustainability and upscale?

Water Quality

- Presbyterian Tank Program
  - 42% (6 out of 14) positive for total coliform contamination greater than 10 CFU/100 ml
  - 14% (2 out of 14) positive for *E.coli* contamination greater than 10 CFU/100 ml
  - 100% of fetched water samples contaminated
- Recommend use of filter
  - *Kosim*
- Could be used with rainwater and for filtration of supplementary source (i.e. dugout)
- Further water quality investigations should be conducted

Recommendations

- Low-hanging fruit
  - Fully gutter existing systems to improve reliability
  - Suggest water filtration with RWH programs
    - Can also use with supplementary source
  - Install guttering where water tanks are installed
    - Schools, hospitals, community centers
  - Address design issues to improve efficiency
    - Recommended where no improved water source available (bore, piped)

Recommendations for PHW, Northern Ghana

- Further Research on New Household Water Treatment Options
  - Dual Sand Layer Biosand Filter + safe filtrate storage
    - Effective microbial reductions in high turbidity water
    - Low-cost modification to standard BSF
  - Siphon Filter
    - Resolve recontamination issue, then,
    - Recommended for treating low turbidity water
    - Compares favorably to other PHW products
- Water Scarcity
  - Rainwater harvesting
    - Expensive, supplemental technology
    - Recommended where no improved water source available and where water storage tanks required anyway
    - Competitive with other technologies on a unit cost basis
    - Capital investment required

Thank you

- Questions are welcome!