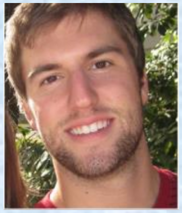
Water Treatment Process Design for Rural Regions of Developing Nations

This presentation highlights water treatment process design systems based on the field research performed in Rwanda.

Jay Todd C. Max



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Swan

SAFE WATER FOR ALL NATIONS

S.W.A.N is an initiative started by Dr. Massoud Pirbazari of the University of Southern California focusing on the improvement of drinking water quality for citizens of developing countries. SWAN's goal is to provide comprehensive and visually based information so that people, at the household level, can treat their water, and in turn, improve their health and well-being.

THIS SITE IS UNDER CONSTRUCTION. All material included in this presentation has been adapted from sources* outlined on the final slide.

** We would like to thank those whose work has been pivotal in the creation of this site.*

(See Reference Page for Sources)

To the Visitor,

Your comments and suggestions would be appreciated. Please direct your thoughts to Jay Todd Max at jmax@usc.edu

-Thank you.

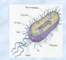
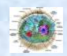
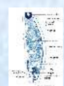
To the Sponsors,

Financial support of the following organizations is gratefully acknowledged

Viterbi School of Engineering Merit Research Program: *encouraging USC undergraduate students to perform innovative research*

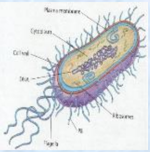
Marshall School of Business' ThinkImpact Scholarship: *funding a major portion of co-author Jay Todd Max's Rwanda field research*

Presentation Outline

- **Emerging Waterborne Disease Lists**
  - **Bacteria** 
  - **Viruses** 
  - **Protozoa** 
  - **Helminths** 
- **Rural Treatment Design Methods**
  - **Pre-filtration Process (Roughing Filtration)**
  - **Bio-sand Filtration Process**

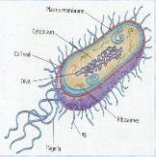
- **Rwanda Case Study**
  - **Implementation of Design Systems**
    - **Bio-sand Filter Unit**
    - **Full Treatment Process**

Bacteria



Pathogen	Disease	Treatment	Efficacy
Campylobacter jejuni	Campylobacterosis	Chlorine, UV	Effective
E. Coli verocytotoxin-producing (VTEC)	Diarrhea (bloody)	Irradiation, stanitation	Effective
E. Coli (STEC)	Enterotoxins	Irradiation, stanitation	Effective
E. Coli (EHEC)	Disease, HUS	Irradiation, stanitation	Effective
Helicobatero pylori	Ulcers, gastritis	Hygene, clean consumables	Somewhat Effective
Legionella	Legionnaire's disease	Chlorine Dioxide, monitor	Effective
Shigella	Shigellosis	Hygene, careful food preparation	Effective
Yersinia interocolitica	Aches, fever	Culinary sanitation and waste control	Effective
Yersinia pestis	Plague	Antiobiotics, avoid infected rotents	Somewhat Effective
Vibrio cholerae	Cholera	Chlorine, UV	Effective

Bacteria (continued)

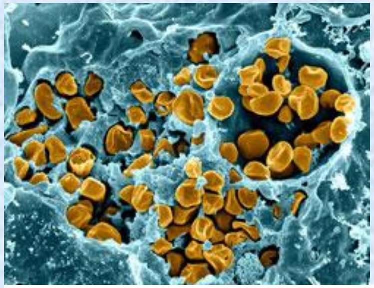


Pathogen	Disease	Treatment	Efficacy
Francisella tularensis	Flu-like symptoms, systemic failure	Use insect repellant	Effective
Mycobacterium tuberculosis (resistant)	Weakness, fever, cough	Obey drug regimen	Effective
Mycobacterium avium	M. avium complex (MAC)	Multiple Antibiotics	N/A
Salmonella	Salmonellosis	Antibiotics	N/A
Salmonella enterica serovar Typhimurium	Gastroenteritis	Prevent fecal cross-contamination with water sources	Effective
Klebsiella	Pneumonia	Antibiotics	Effectve
Leptospira	Fever, aches	Avoid contacting contaminated water	Effective
Mycobacterium paratuberculosis	Crohn’s Disease	UV and Gamma Irradiation	N/A
Burkholderia anthracis	Pulmonary Infection	UV	Effective

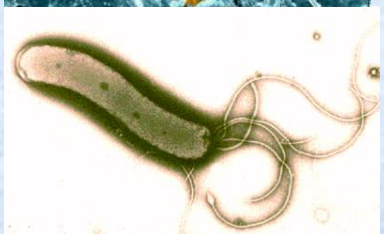
N/A= Information is currently unknown

Bacteria

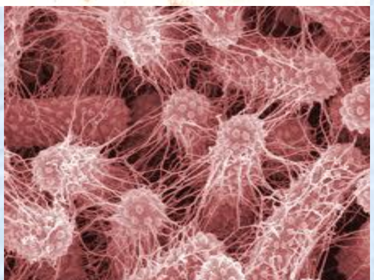
Disease Symptoms



Francisella tularensis



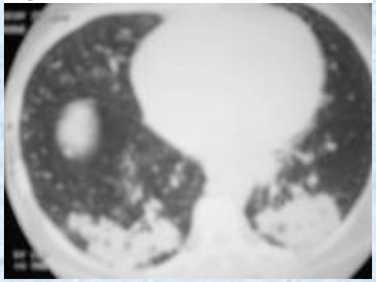
Helicobacter pylori



Klebsiella pneumoniae

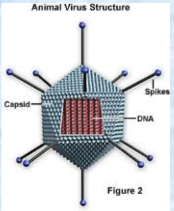
Fig 4.

Legionella pneumonia



Mycobacterium avium

Viruses

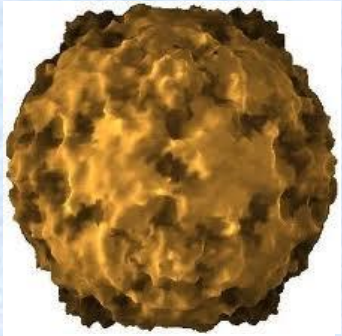


Technical Name	Disease	Treatment*	Efficacy
Norovirus	Gastro-Intestinal Inflammation	Flocculation and ozone	Effective
Polio-myelitis	Polio	Filtration and Flocculation	Very Effective
Coxsackie	Fever, oral blisters	Flocculation and ozone	Effective
Reovirus	Diarrhea	Flocculation and ozone	Effective
Rotavirus	Diarrhea	Flocculation and ozone	Effective
Hepatitis-A	Jaundice, fever	Flocculation and ozone	Effective
Hepatitis-E	Jaundice, fever	Flocculation and ozone	Effective
Echovirus	Pneumonia, rash, encephalitis	Flocculation and ozone	Effective

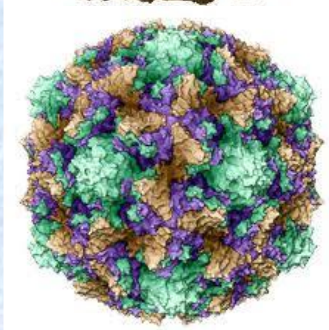
*Flocculation and Filtration are highly recommended (and effective) whenever possible

Viruses

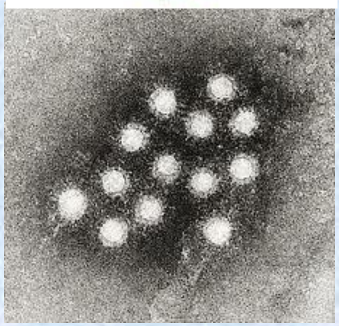
Disease Symptoms



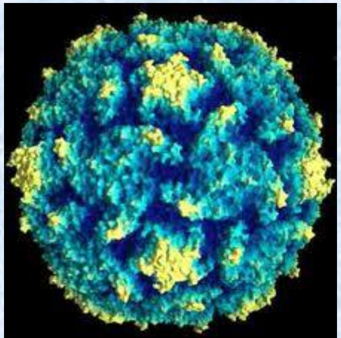
Echovirus



Coxsackie



Hepatitis A, E



Polio

Protozoa

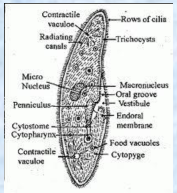


Fig. 11.6 Paramoecium

Pathogen	Disease	Treatment	Efficacy
Cryptosporidium parvum	Diarrhea	UV, Ozone, Microfiltration (RO)	Effective
Giardia lamblia	Diarrhea	Filtration stages	Somewhat
Entamoeba histolytica	Amoebiasis	Multi-step filters	Somewhat effective
Cyclospora cayetanensis	Watery Diarrhea	UV, Ozone, Microfiltration	Effective
Giardia intestinalis	Diarrhea, cramps	Multi-step filters	Somewhat Effective
Vittaforma cornea	Ocular infection, Urinary tract infection	Antibiotics	Effective
Microsporidium africanus	Corneal ulcer	N/A	N/A
Naegleria fowleri	PAM-Primary Amebic Meningeoncephilitis	No tested strategies	N/A
Trachipleistophora anthropothera	Myosis, sinusitis	N/A	N/A
Toxoplasma gondii	“Flu-like” symptoms	UV, Ozone, Microfiltration	Effective

N/A= Information is currently unknown

Protozoa (continued)

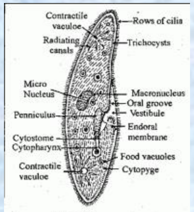


Fig. 11.6 Paramoecium

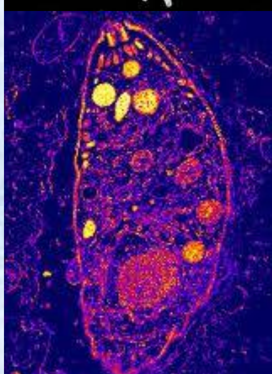
Pathogen	Disease	Treatment	Efficacy
Encephalitozoon intestinalis	Microsporidiosis	Albendazole regimen	Very Effective
Enterocytozoon bieneusi	Diarrhea	Nitazoxanide regimen	Effective
Encephalitozoon hellem & E. cuniculi	Microsporidiosis	Hygene, handle bodily fluids carefully	Somewhat Effective
Trachipleistophora hominis	Myosis, sinusitis	Albendazole regimen	Effective
Giardia duodenalis	Diarrhea	Treatment plant	Somewhat
Nosema oncularum	Microsporidiosis	Albendazole, Fumgillin bicyclohexalammonium regimen	Effective
Brachiola vesicularum	Eye inflammation, skin infection	Abendazole, Itraconazole regimen	Somewhat Effective
Brachiola algerae	Fever, fatugue	Abendazole, Itraconazole regimen	Somewhat Effective
Brachiola connori	Microsporidiosis	Abendazole, Itraconazole regimen	Somewhat Effective

Protozoa

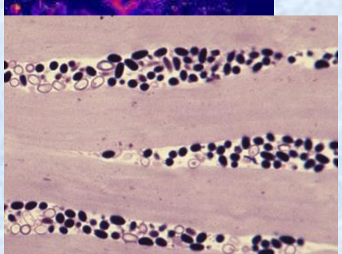
Disease Symptoms

Entamoeba histolytica

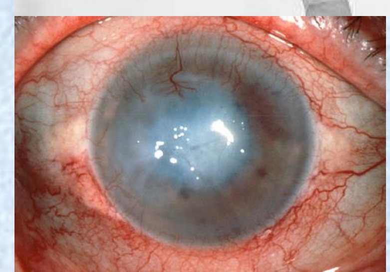
Giardia lamblia



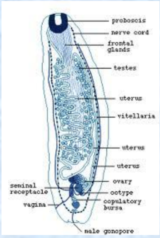
Toxoplasma gondii (prenatal)



Vittaforma corneae



Helminths



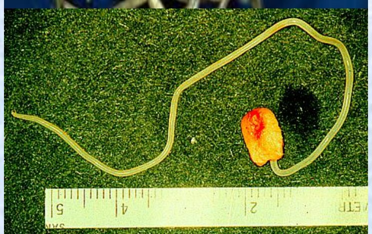
Pathogen	Disease	Treatment	Efficacy
Ascarids	Abdominal discomfort	Filtration	N/A
Pinworms	Itchy anal region	Filtration	N/A
Hookworms	Anemia, protein deficiency	Baffled filter	Somewhat Effective
Strongylids	Abdominal pain, diarrhea	Filtration, hygene	Effective
Angiostrongylids	Abdominal pain, fever	Filtration	N/A
Capillarids	Anemia, fever	Microscreening	Very Effective
Guinea worms	Fever, local blister	Microscreening	Very Effective
Liver flukes	Liver pain, fever	Microscreening	Very Effective
Cystic tapeworms	Diarrhea, abdominal pain, weakness	Microscreening	Very Effective
Fascioliasis	Fever, malaise	Control snail population	Effective
Schistosomes	Rash, fever	Control snail population	Somewhat Effective

N/A= Information is currently unknown

Helminths

Disease Symptoms

Ascarid



Guinea Worm

Helmith

Hookworm

Liver Fluke

Water Treatment for Rural Areas of Developing Countries

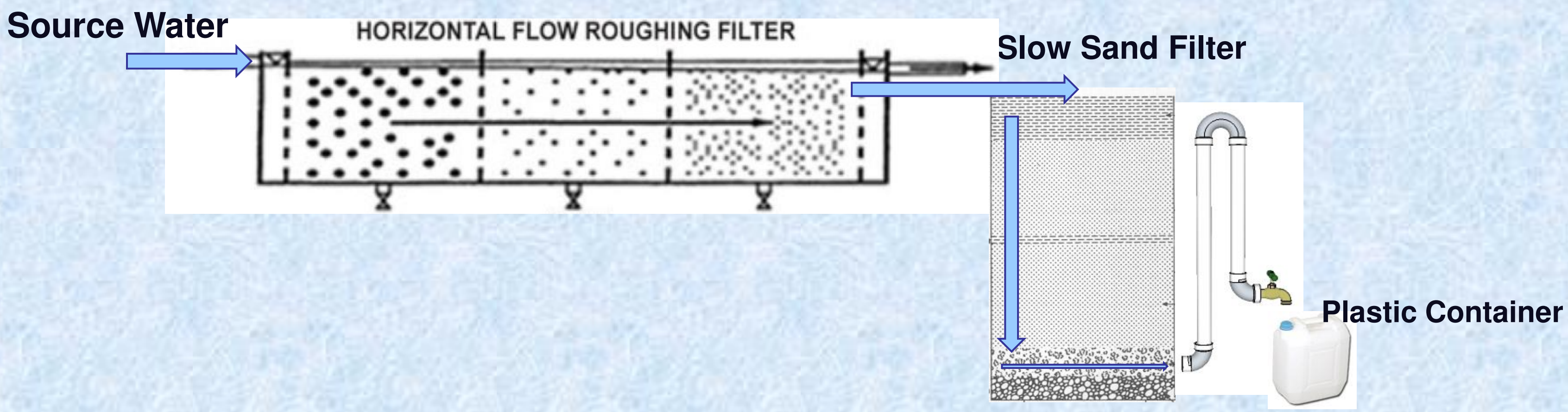
- More than one billion of the worlds poor lack access to safe water
- Currently, water in these areas goes untreated or the treatment process does not effectively remove harmful contaminants
- The following slides present methods of treating unsafe water in the rural areas of developing countries

Children in Uganda collecting unsafe river water

2007

Components for Complete Treatment

- 1) Horizontal Roughing Filter (HRF) for Pretreatment
  - Necessary for highly turbid source water, such as murky ponds and rivers
  - Removes most of suspended particles
- 2) Bio-sand Filter for Treatment
  - If the source water has low turbidity (<50NTU), bio-sand filter can be used without HRF
  - This bio-physicochemically removes most soil particles and microbes
- 3) Chlorine Contact for Disinfection (inside plastic storage container)
  - After adequate contact time with chlorine, any remaining microbes are killed
  - Water is then ready for drinking and household use



Schematic of Main Components of Treatment Process
(please see the following slides for details)

Horizontal Roughing Filter (HRF): Pretreatment for highly turbid water

Description

- This is a large filter basin made for cleaning raw dugout water that is visibly turbid
- It uses natural filter materials such as pebbles and gravel to slowly filter turbid water
- The output water is clean enough for bio-sand filtration
- There are three stages of filtration with filter materials decreasing in size from one stage to the next
- HRF is not necessary for water that is already mostly clean. It is only to be used for pretreatment of particularly dirty water
- HRFs have been used effectively in the developing world (like Ghana) for decades

HRF at Mafi Kumase Dam, Ghana, 1985

Instructions for HRF units for small Communities

- Construct a water-tight basin with a slight slope from one end to the other

- Divide the basin into three sections so that water will pass through all three sections while moving from one end to the other

- Fill the sections with gravel of the following size
  - First Section: about 15mm
  - Second Section: about 10mm
  - Third Section: about 5mm

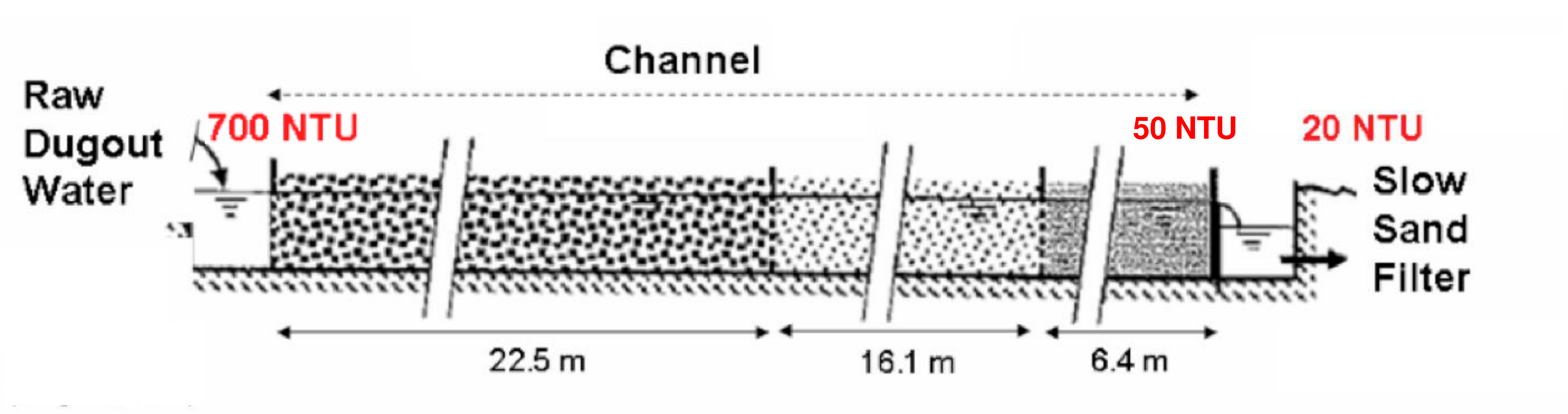
- Direct the raw water into the first section and once it has been filtered, treat it for household use
  - Use a slow-sand filter for final treatment

- Occasionally clean the filter pebbles to maintain the filter's effectiveness
  - This can be done by either backwashing or by removing the pebbles and washing them

HRF Basin at Chirifoyili Dam, Ghana

Filter media options: granite, broken pottery, gravel

Horizontal Roughing Filtration (HRF): Wegelin Case Study



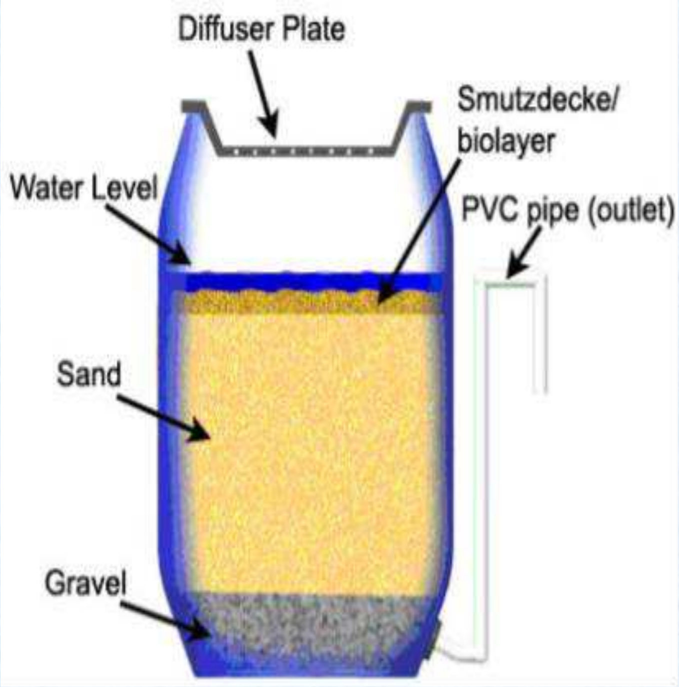
Typical HRF used in Northern Ghana communities for pretreating raw dugout water

Results:

- **Percentage removal of microbes and suspended particles (requires biofilm ripening):**
  - **50% removal for raw dugout water**
  - **95% removal for low-turbidity water**
- **Flow velocity**
  - **0.5 – 2 m/hr range**
  - **0.3 m/hr maximum for 680 NTU**
- **Granular media: gravel or pottery**

HRF at Mafi Kumase Dam, Ghana, 1985

Bio-sand Filtration Process

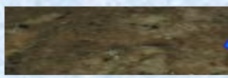


- This inexpensive process produces water **clean enough for disinfection** and household use
- If the input water is highly turbid (>50NTU), an HRF is recommended for pre-treatment (before bio-sand filter)
- Water should be distributed evenly over the sand using a diffuser plate
- Water is passed through **Fine Sand, then Coarse Sand, and then Gravel**
- Outlet pipe height determines the water level and should be 20cm above the granular media
- A biolayer "**Smutzdecke**" that grows naturally on top of filter is mainly responsible for treating water

Bio-sand filter Components

Filter Media

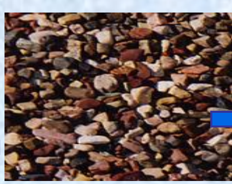
Smutzdecke
-biolayer
forms naturally

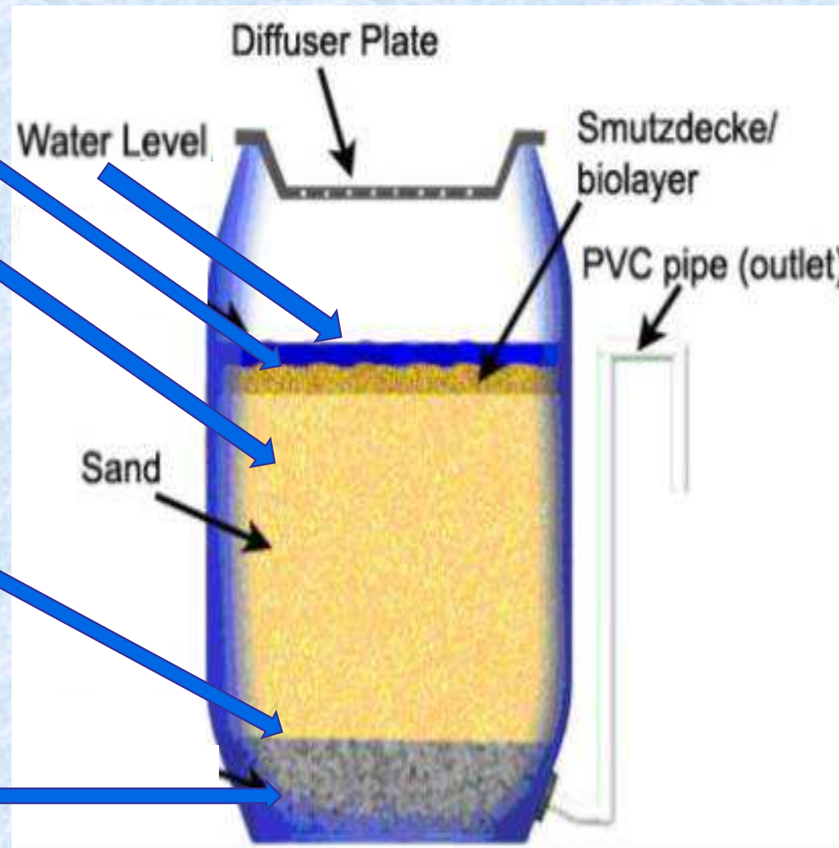


First Stage
Fine Sand
Particles ~2-8mm

Middle Stage
Coarse Sand
Particles ~8-16mm

Final Stage
Gravel
Particles ~18-32mm





- Biolayer removes contaminants
- Outlet pipe is placed approximately 0.2m below the biolayer to provide adequate water pressure

After Filtration: Disinfect

- Once water has been treated, it may need to be disinfected before it can be used as drinking water
- The purpose of disinfection is to kill all the harmful microorganisms remaining in the water
- Disinfectants require a certain amount of time in the water (contact time) to effectively kill microbes
- Disinfection requires precise doses
  - Too little disinfection means ineffective disinfection
  - Too much disinfection results in toxic water for the consumer
- Disinfected water must be stored in an uncontaminated container

Suggested Disinfection: Chlorination

- In developing regions, chlorine is a common disinfectant, though it requires consistent access to a replenishing supply
- Chlorine, Cl2, destroys the bacterial cell walls and can damage the enzymes, nucleic acids and membrane lipids vital for microbe survival
- Chlorine can come in solid, liquid and gas forms– the solid form is usually the most accessible and cheapest
- Correct chlorine doses and mixing time
  - 220mg of chlorine must be mixed in each liter of water for 30 min
    - This can come in many forms
      - Sodium Hypochlorite: 460 mg NaOCl per liter
      - Halazone: 4mg tablet per liter
      - Calcium Hypochlorite: 1 drop of 100% solution per 10liter or 210 mg per 100 liters

High-Test Hypoclorite (pills)

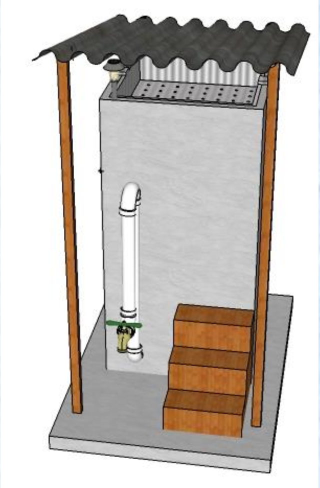
Aquatabs (tablets)

Piyush (drops)

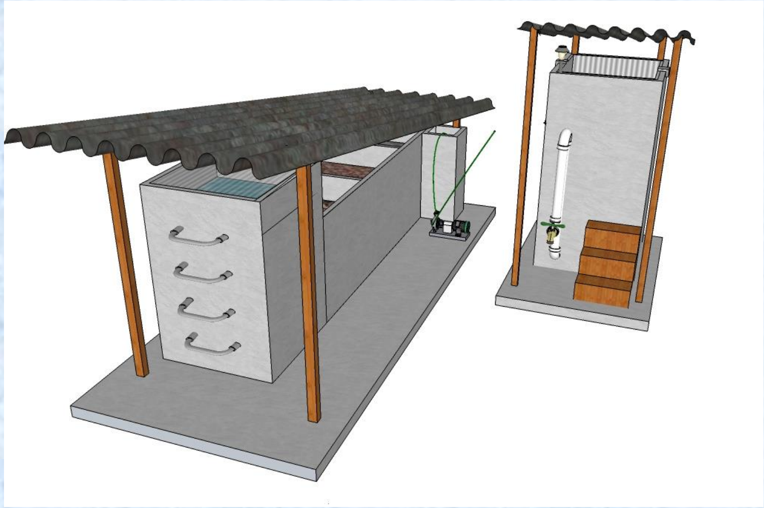
Proposed Water Treatment Process Design for Rural Communities

Introduction:

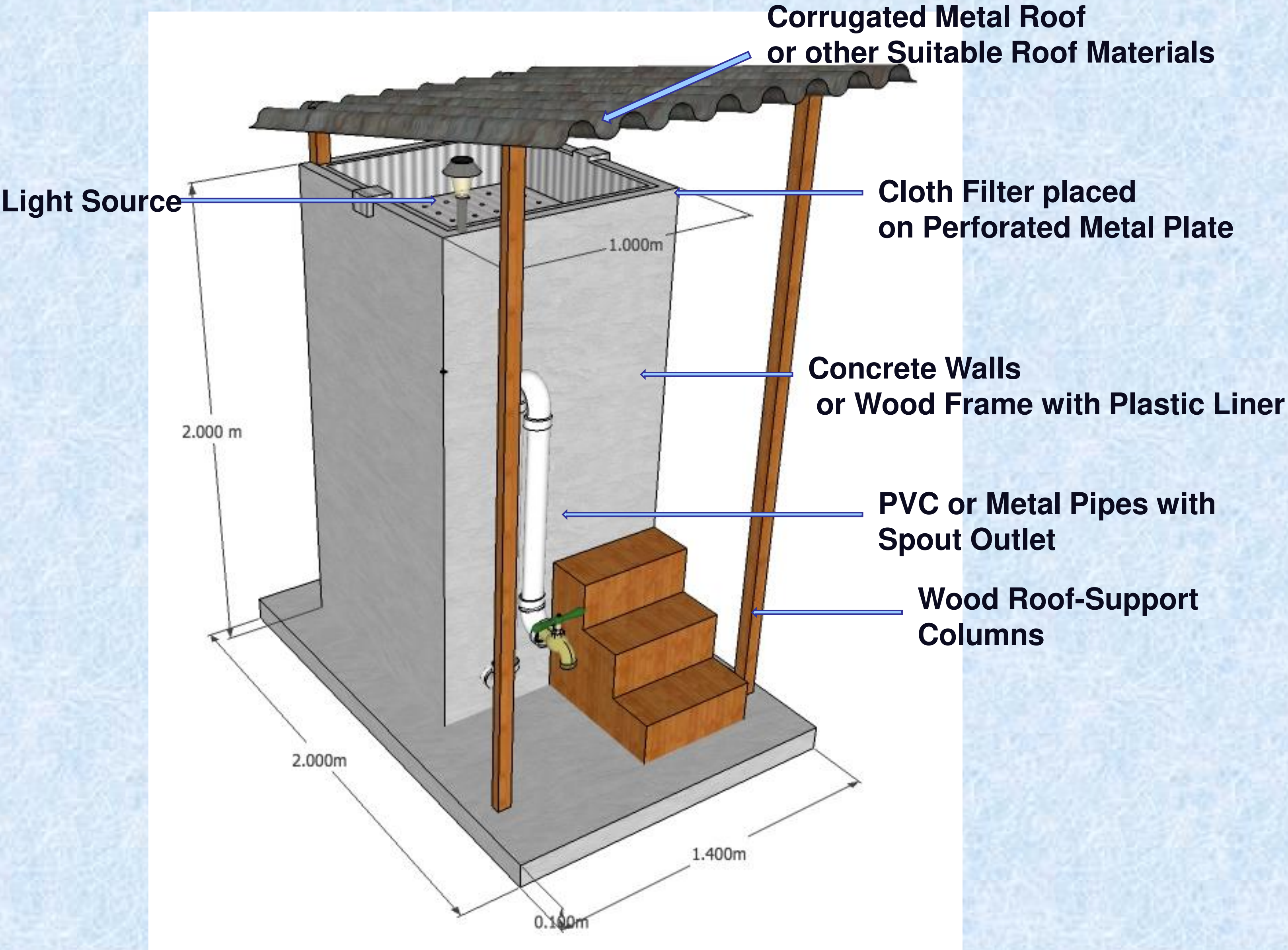
- Bio-sand Filter Process
  - For Visibly Clear water (<50NTU)
  - Treats 60 liter/hr
  - Provides for 10 families



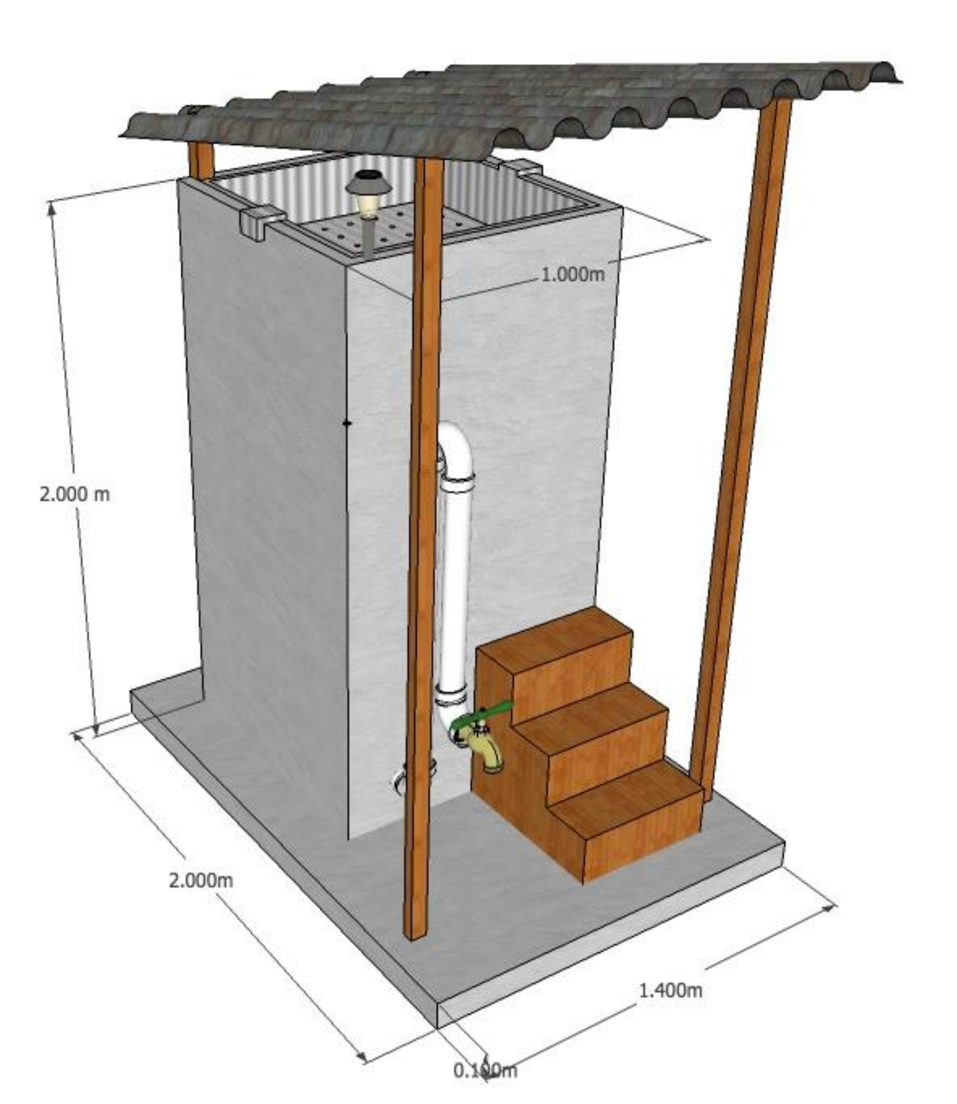
- Full Treatment Process (Bio-sand filter plus pre-treatment)
  - For Visibly High-Turbidity water
  - Provides purified water for 90 families (5400 liters/day)
    - Based on assumption of 3 Bio-sand Filters operating 24hr/day, requires water storage following HRF



Bio-sand Filter Process



Bio-sand Filter Design for Different Community Sizes



- **Community Size: 50 people**

Dimensions: 0.75m x 0.75m x 1.75m
Max. Flow Rate: 50L/hr

- **Community Size: 100 people**

Dimensions: 1m x 1m x 2m
Max. Flow Rate: 100L/hr

- **Community Size: 200 people**

Dimensions: 1.5m x 1.5m x 2m
Max. Flow Rate: 225L/hr

Components of Bio-sand Filter Process

- Biofilter Unit
  - The main component of Biofilter, where all of the treatment occurs and treated water is stored

- Filter Cloth Frame
  - Perforated metal holds the cloth/fabric for initial filtration

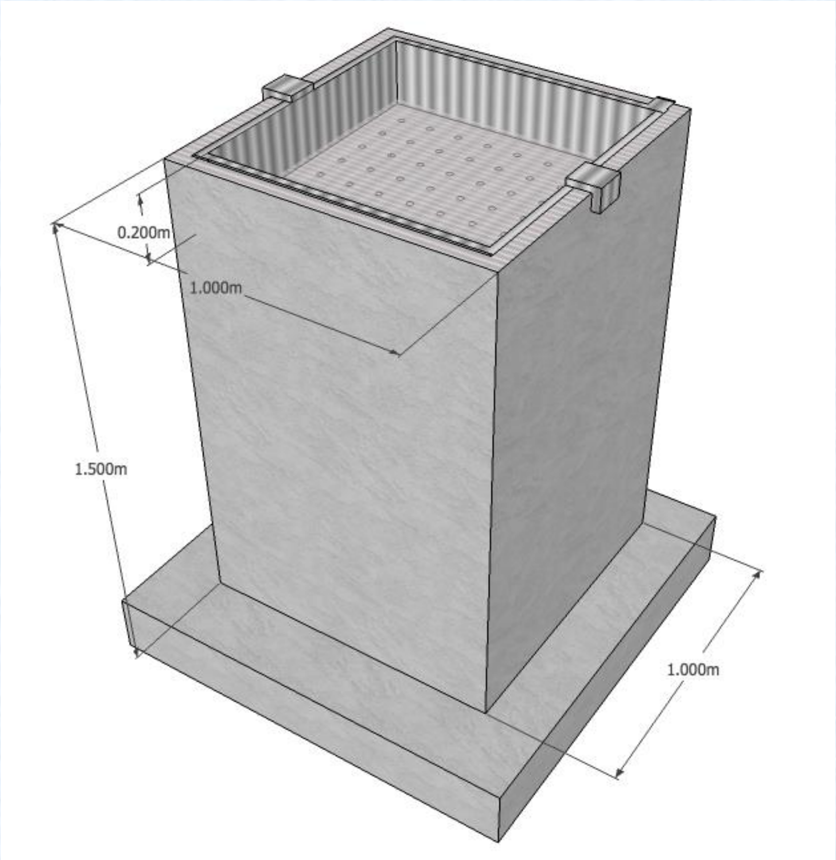
- Roof
  - Protects from overheating and evaporation of filtering water
  - Allows for rainwater capture when possible

- Steps
  - Facilitate easy access to biofilter

- Light
  - Provides visibility for people needing water during sundown

- Out-spout
  - Easily dispenses desired amounts of water
  - Maintains desired water-level inside of tank to avoid tank from drying out

Cloth-Filter and Perforated Metal Plate Holder



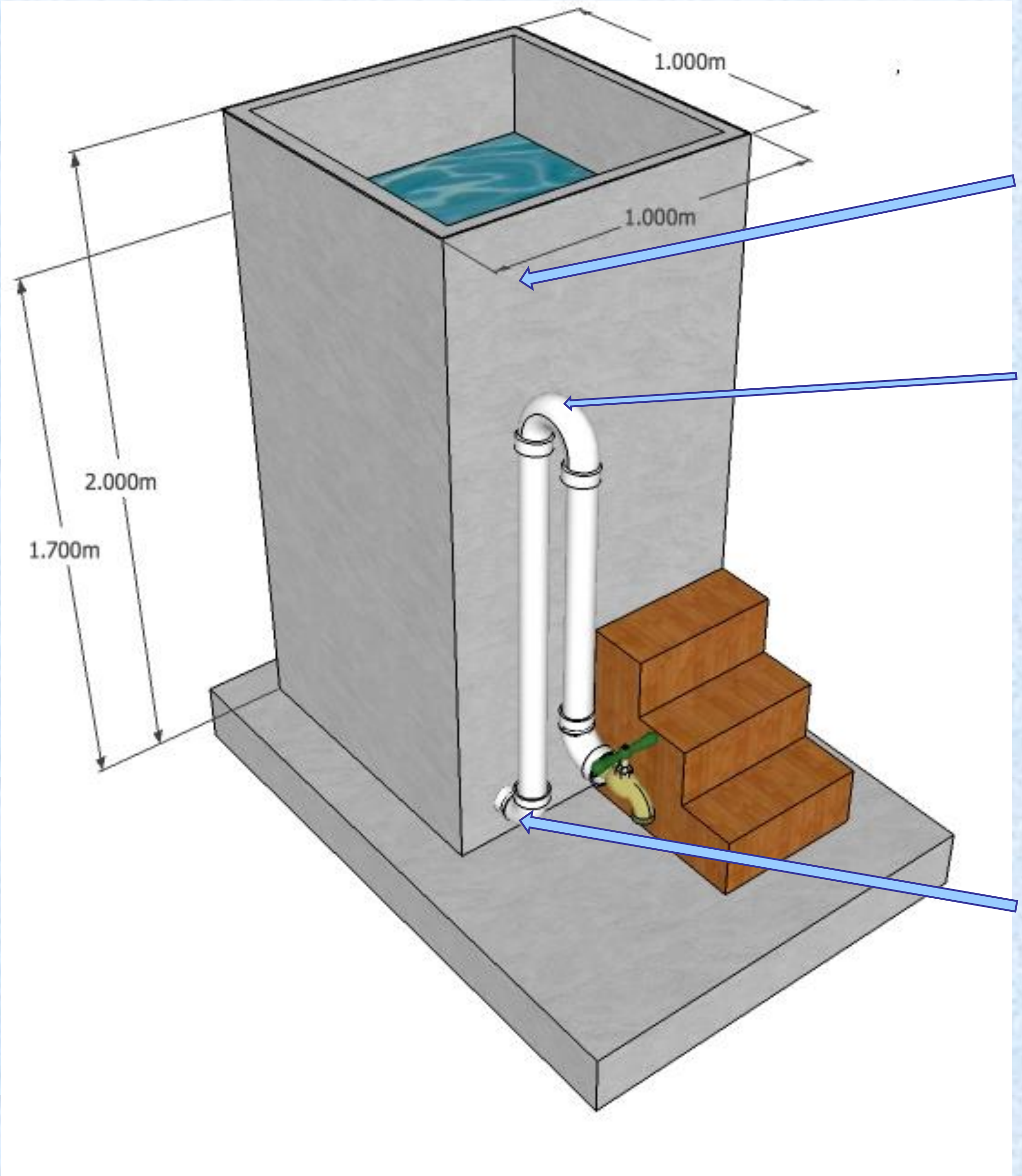
•Cloth Filter (cotton/fabric) is placed on the perforated metal plate holder

•The cloth filter provides initial filtration, removing

•Water should be poured onto cloth filter rather than directly into biofilter

•The cloth filter should be cleaned when necessary

Out-Spout Component



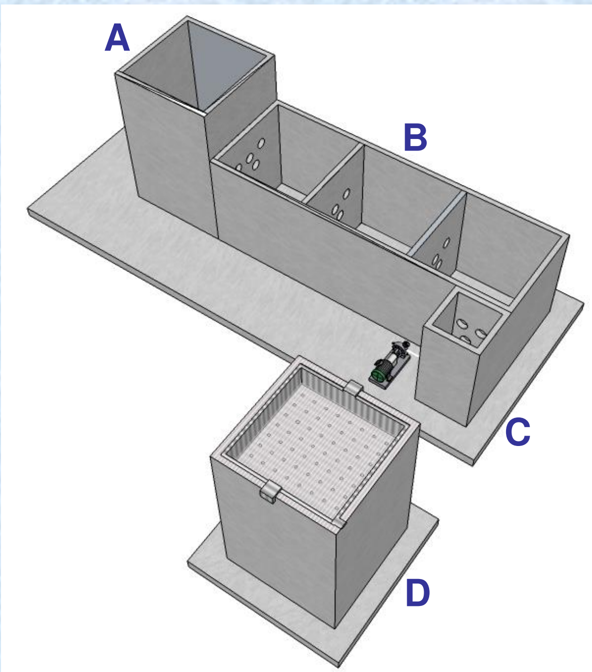
Water Level is about 1.70 m above the bottom of tank

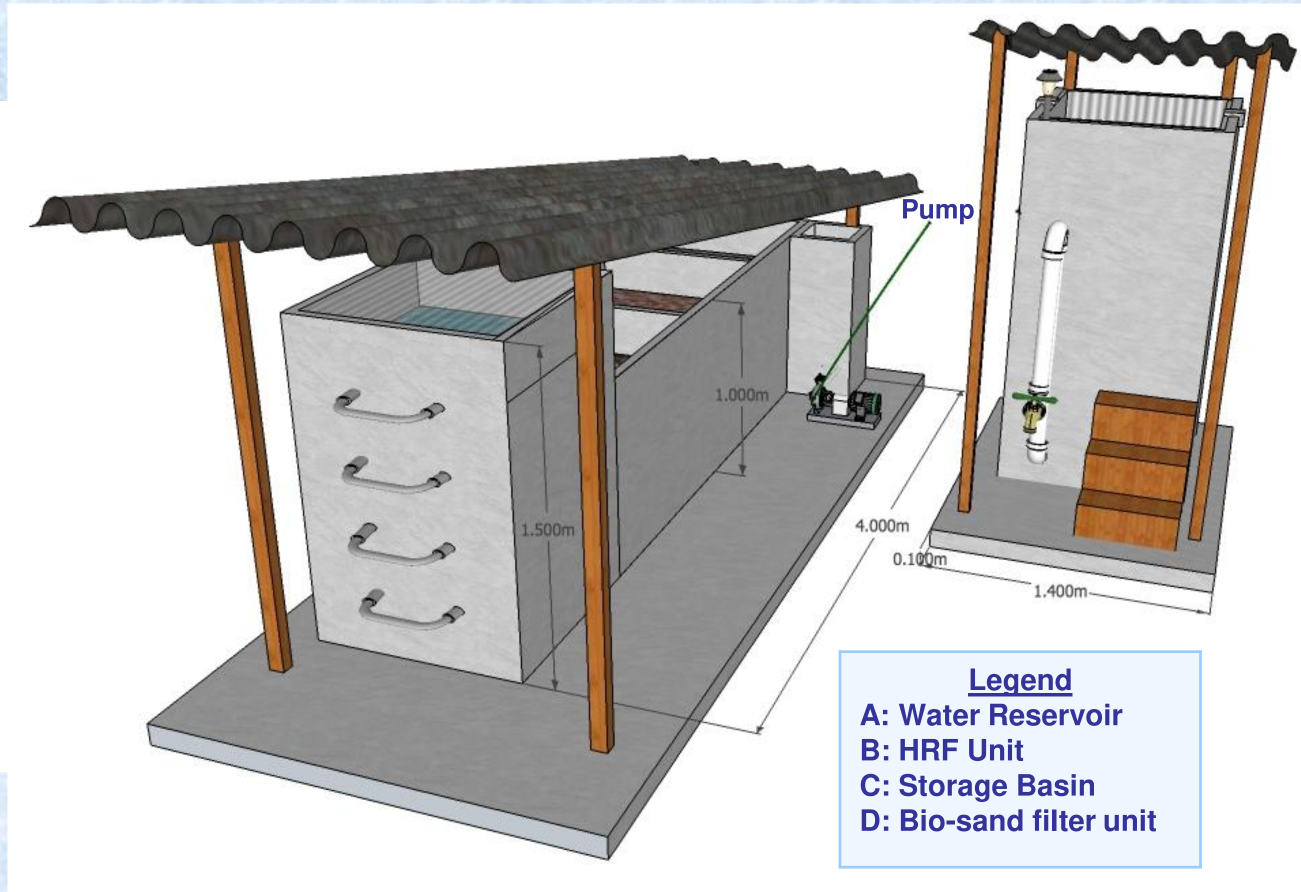
Top of pipe is about 0.25m below the water level

Bottom of pipe is about 10 cm above the bottom of tank

Full Treatment Process

Schematics of Horizontal Roughing Filter (HRF)





Treatment Sequence:

1. Water is transported or pumped into water reservoir (A)
2. Water passes through HRF (B) and enters storage basin (C)
3. Water is pumped from storage basin (C) into bio-sand filter unit (D)

Note: water with low turbidity can be delivered directly to the Bio-sand filter, if desired

Presentation Summary

>1 billion people without safe water

↓

Emerging waterborne diseases plague these vulnerable people

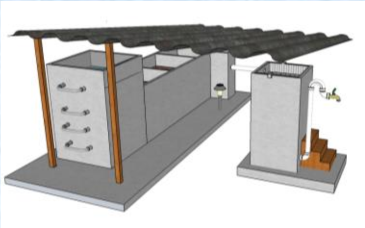
↓

Most solutions are too expensive and/or too technical

↓

Bio-sand Filter Process provides safe water when surface water is visibly clear, < 50NTU

Full Treatment Process (HRF + Biosand Filter + Chlorination) provides safe water direct from highly turbid source water



Community Forum

Briefing Translator

Field Research: Rwanda

By Jay Todd Max

2013

Bucket-bath Room

Local Contacts

Motivation for Rwanda Field Research

- I was always interested in real-world observation of water supply systems in developing countries

- I lived with my host-family in rural Rwanda in a mud-brick house for 7 weeks, learning their way of life

- Rural communities in Rwanda have water supply situations typical of the developing world

- I made quantitative and qualitative records of the water system in the community, and of all input that the community members gave

- The following slides show the information I garnered and the analysis I was able to perform using that information

My host-family in our house
Mama (in the blue/yellow conga) with two daughters and three sons

Field Research: Rwanda

- Location: Bwana, Rwanda
  - Eastern Province
  - Rwamagana District
  - Rural Community (pop. ~200 people)
- Spoken Language: Kinyarwanda
- Economy: Agriculture

Case Study: Rwanda

- Water Sources
  - Climate
    - Rainy Seasons March-April-May and Sept.-Oct.-Nov.-Dec., otherwise DRY
  - Environment
    - Nearly 900-1200mm/yr rain
  - Surface water area 430,000 ha of the total area of 2,630,000 ha (~14.6%)

- Transport/Distribution
  - Surface water is pumped to communities and towns
  - Pipe system carries water to local taps
  - Jerry Can(s) transport water from taps to homes

Case Study: Rwanda (continued)

- Typical water treatment
  - Cities treat water using conventional methods
  - Towns filter (but do not purify) surface water and pump it to some nearby communities
  - Some rural communities have groundwater pumps
  - Rural communities sterilize water by adding drops of chlorine solution to plastic containers full of water

- Cost Structure
  - Currency: RWF-Rwandan Franc
    - Conversion Rate
    - About 600 RWF = 1 USD
  - Costs 100,000 RWF (about $170 USD) to install a water tap with access to filtered water pumped from a nearby town
  - Water costs 10 RWF per plastic container (20L) when pumped from a nearby town

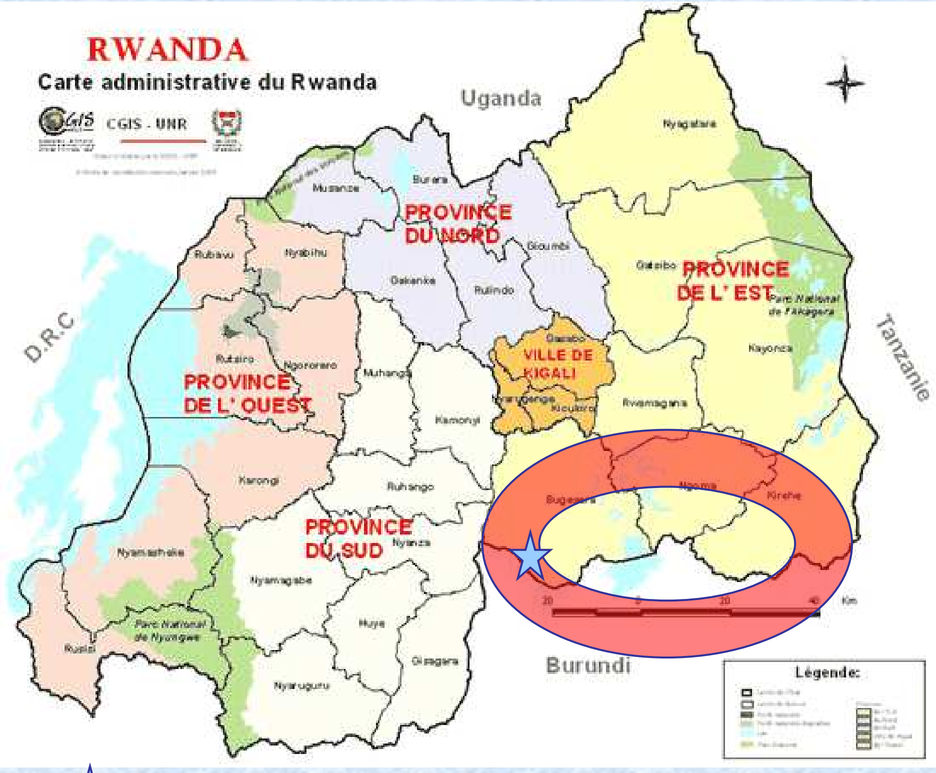
Families filing their plastic containers with water from a hand-pumped groundwater well

Rwandan Franc coins (both sides)
Community members purchase water pumped from nearby towns using these coins

Recommended Use of Bio-Sand Filter Process

- Criteria of an appropriate location for Bio-sand Filter
  - Surface water is nearby
    - Wetland, Lake or River
  - Community lacks distribution of filtered water
    - It is rural, far from a city or town
    - EWSA (Energy, Water and Sanitation Authority) piping does not reach this community

      and/or
  - Can be particularly helpful in regions with frequent droughts
    - East and Southeast Lowlands



Location of Munazi

- Recommended Locations for Bio-Sand Filter use
  - Districts: Bugesera, Ngoma and Kirehe
    - Mostly regions in the southeast
    - These areas satisfy all of the above criteria
  - Bio-sand Filter will easily clean nearby surface water for safe use
  - The communities 6mi. south of the town of Munazi are good examples of where the Bio-sand Filter would be situated best

Implementation of Bio-sand Filter Unit

- Location
  - Select a site according to recommendations on the previous slide
  - Choose a central location within a village near surface water
- Construction
  - Bio-sand Filter should be constructed according to the instructions given in the "Bio-sand Filter Design" slides
  - Bio-sand Filter design incorporates the following components: concrete support slab, access steps and filter cloth holder
  - The Bio-sand Filter should be covered with a sloped, corrugated-metal roof
- Dispensing
  - The Bio-sand Filter requires one unit of water to be added to it for each unit of water dispensed; this keeps the filter from running dry
- Maintenance
  - Cloth filter needs periodic cleaning
  - Efforts should be made to establish a healthy biofilm layer on top of the bio-sand filter

Recommended Use of HRF Treatment Process

- HRF treatment process may be appropriate for the following communities:
  - Community is near a river or other surface water (this requires a pump to convey water to the HRF)
  - Community lacks distribution of filtered water such as from EWSA
  - Community is in a region with frequent droughts (such as East and Southeast Lowlands)
- Recommended locations for HRF treatment units
  - Along the southern stretch of the Nyabarongo River
  - In the southern lowlands of the Eastern Province

Implementation of HRF Water Treatment Process

- Location
  - Site-selection according to prior slide
  - Central location within village
  - Near surface water

- Construction
  - HRF should be constructed according to instructions presented in the previous slides
  - If desired, pump HRF-treated water to a Bio-sand filter for further treatment
  - HRF should be covered with a sloped, corrugated-metal roof

- Dispensing
  - Maintain a supply of inflow water by pumping water into the first chamber of the HRF
  - The amount of water that the pump supplies is how much water may be dispensed from the treated end

- Maintenance (when HRF treatment quality decreases)
  - Replace the filter media with new materials

  or

  - Remove the filter media, clean it, and then return it to the chambers

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