Pilot Study of Horizontal Roughing Filtration in Northern Ghana as Pretreatment for Highly Turbid Dugout Water

by

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Pilot Study of Horizontal Roughing Filtration in Northern Ghana as Pretreatment for Highly Turbid Dugout Water

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Abstract
In Northern Region Ghana (NRG), earthen dams called dugouts collect highly turbid rainwater runoff and intermittent stream flow. These dams serve as many communities’ main source of drinking and domestic water despite their physical and microbial contamination. Slow sand filtration (SSF), a low-cost technology for treating microbial contaminated drinking water is only recommended for water < 50 NTU. Two research objectives were established to address this issue: to characterize dugout particle sizes and distribution and to test a pilot horizontal roughing filter’s (HRF) effectiveness at removing turbidity from highly turbid dugout water. Among the four dugouts tested in NRG, they typically have high concentrations of non-settleeable colloidal (< 1µm) and small supracolloidal particles (< 10µm). In addition, a pilot HRF at Ghanasco Dam in Tamale, NRG was conducted using three 7m tubes filled with three sizes of granite gravel, local gravel, and broken pieces of ceramic filters arranged by decreasing size. The pilot study was run for 52 days to test if HRF could reduce the high turbidity (305 NTU) to < 50 NTU to make SSF a viable option. There were a number of promising outcomes: the best performing media, the granite gravel, by removing an average 46% of the influent turbidity, produced an average effluent turbidity of 51 NTU which almost achieved the goal of < 50 NTU. The granite gravel HRF removed twice as much turbidity (46%) as plain settling (25%). Overall, the granite gravel removed 76% and 84% of the influent turbidity according to the settling test and pilot HRF data respectively. Three recommendations derived from this pilot HRF study are (1) to monitor dugout water quality, (2) to investigate media and particle properties to enhance colloidal particle removal (3) to modify the HRF to effectively remove very high dry season turbidities and likely even higher rainy-season turbidities from dugout water.

Keywords: Roughing filtration, horizontal roughing filtration, slow sand filtration, turbidity, Northern Region Ghana, dugouts, drinking water sources, physical water quality

Introduction
Approximately 50% of the population in Northern Region Ghana (NRG) collects drinking water from unimproved sources such as dugouts1, rivers, unimproved dugwells, and tankers (GSS, 2006). Dugouts are manmade rain harvesting ponds that are an unreliable source and of poor microbial quality averaging 779 E. coli CFU2/100 ml in the dry season (Johnson, 2007) and 438 E. coli CFU/100 ml in the rainy season (Foran, 2007). The average dugout turbidity in NRG is extremely high ranging from 248 NTU (Johnson,

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1 Dugouts will be used synonymously with dams or rain harvesting ponds that catch and store runoff and water from intermittent streams.
2 CFU stands for colony forming unit and refers to viable cells.
2007) in the dry season to 931 NTU\(^3\) in the rainy season (Foran, 2007). Many waterborne diseases such as diarrhea, typhoid, cholera, and infectious hepatitis come from fecal pollution from human and animal sources that wash into this surface water. Other water-related diseases such as Guinea worm and bilharzias are also prevalent. The incidence of these diseases is very high in communities that collect and drink untreated dugout water. The morbidity of such diseases can have serious economic implications for people who are infected and find themselves unable to work or take care of their family.

Difficulties arise in the microbial treatment of highly turbid water because particulate matter can enhance microbial growth, inhibit clear detection of microorganisms, and interfere with SSF and disinfection processes, making them less effective and more expensive (Health Canada, 2001). The World Health Organization (WHO) suggests that more turbid water creates greater risks of acquiring a gastrointestinal illness (WHO, 2004). Water of 5 NTU or lower is acceptable in taste and appearance to most consumers (WHO, 2004).

Although rainwater usually carries few particles, rain runoff carries suspended particles into the dugouts worsening the water’s physical water quality. Other sources of turbidity include algal growth, erosion of loose soil, deposition of dust from the air, wind advective mixing of lake sediments, water collection, fishing, and humans and animals entering the dam. Characterization of particle size and distribution greatly vary depending on the climate, soil type, the slope of the area, and land use practices.

High turbidity negatively impacts the effectiveness and durability of low-cost community and household scale drinking water treatments such as slow sand filtration (SSF), ceramic pot filtration (Kosim filters\(^4\), and chlorination. While dugouts can and should also be improved as storage basins, effective and appropriate technologies that do not rely on chemical treatment to treat and reduces raw dugout water to < 50 NTU are needed at the community level.

This problem was approached with two objectives:
1. To improve dugouts as a surface water source to decrease the cost of treatment.
2. To reduce the turbidity of dugout water to make slow sand filtration a possibility.

The first objective was approached by testing four dam’s physical water quality in order to better understand the suspended particles’ sizes and settling behavior. The second objective was targeted by constructing and testing a pilot horizontal roughing filter (HRF)

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\(^3\) The dry season turbidity values were originally measured with the DelAgua® turbidity tube’s turbidity units (TU) but were converted to the Hach® 2100 P portable digital turbidimeter’s nephelometric turbidity units (NTU) using a correlation determined from data analysis: NTU = 0.7408*(TU); R\(^2\) = 0.9234. TU and NTU units were compared using the student’s t-test and linear regression. The t-test gave a p-value of 0.04 which is less than 0.05 so the null hypothesis is rejected and it is likely that there is significant difference between the outcomes of the TU and NTU.

\(^4\) Kosim filters are household ceramic filters fabricated the local NGO Pure Home Water according to the NGO Potters for Peace’s design.
at Ghanasco Dam in the semi-urban area of Tamale, NRG, to determine its effectiveness at reducing the dugout turbidity to a level adequate for SSF.

**Removal and disinfection of waterborne pathogens in highly turbid water**

SSF and chlorination are two of the most common, low-cost and easily maintained water treatment systems for surface waters in developing countries. To extend the runtimes of SSF, literature guides suggest SSF influent be less than 50 NTU (Galvis, Visscher, Fernández, & Berón, 1993). Not only does highly turbid water require longer chlorine contact times and the addition of more chlorine compounds, but disinfection may not be effective enough against pathogens within flocs or particles for turbidities > 0.1 NTU (WHO, 2004). The presence of particles can create a habitat for bacteria that stimulates their growth. Organic matter and chlorine could react to form disinfection byproducts; however the WHO prioritizes the provision of pathogen-free drinking water and reduction of the incidence of waterborne illness above the control of disinfection byproducts (WHO, 2004).

**Horizontal roughing filtration pretreatment**

A horizontal roughing filter (HRF) basically acts as a large sedimentation tank where the settling distance is reduced by the presence of a coarse media such as gravel allowing colloidal particles to settle. HRF can effectively remove colloidal-size particulates without the addition of coagulant chemicals and also provide a large solids storage capacity at low head loss. Sedimentation and adhesion to media particles are the main particle removal mechanisms (Schulz & Okun, 1984).

Figure 1 Solids removal in HRF (Wegelin, 1996)
Allowing a granular media filter to ripen and form a biofilm strongly influences the quality of water produced because fine particles adhere to and accumulate on the media (Amirtharajah, 1988). With time, as the HRF stores more particles, the filter efficiency increases until the filter flow is inhibited by the accumulated particles and the filter media must be cleaned.

In the 1980s, Water and Sanitation in Developing Countries (SANDEC) and the Centro Inter-Regional de Abastecimiento y Remoción de Agua (CINARA) received funding to promote HRF and standardize its design, operation, and maintenance practices (Wegelin, 1996) (Galvis, Latorre, Sánchez, & Sánchez, 2006). Since then, roughing filters have been implemented in more than 25 countries5 (Wegelin, 1996). The first HRF in Ghana was built in the Volta Region in Mafi Kumase in the mid-1990s as part of SANDEC’s surface water treatment program for roughing filter (RF) pilot projects in rural areas headed by Martin Wegelin and supported by a team of local Ghanaian engineers including Afrowood Consulting Ltd. led by Dorcoo Kolly from Mafi Kumase (Figure 2).

![Figure 2 Mafi Kumase HRF: dirty gravel media (left) and view of HRF from the inlet (right)](image)

To maximize the particles collected, HRF requires a low filtration rate of 0.5-2 m/h (Boller, 1993, Wegelin, 1993). For maximum and average turbidities of 650 and 84 NTU respectively, CINARA suggests a filtration rate of 0.3 m/h (Galvis et al., 1993). Because maximum turbidity values in NRG are over 1000 NTU during the rainy season, the filtration rate may have to be as low as 0.3 m/h to achieve an effluent of 50 NTU.

When properly operated and maintained, HRFs have performed well. According to the WHO Drinking Water Quality Guidelines (2004), RF can remove 50% of bacteria from raw water and up to 95% if the system is protected from turbidity spikes by a dynamic filter or if it is only utilized when ripened. In Sudan’s Blue Nile Health Project (BNHP), the gravel and brunt brick media in the HRFs respectively removed 87% and 77% of the influent turbidity that ranged from 40-500 NTU (as cited by Wegelin, 1996). In contrast, a pilot HRF system at the International Institute for Water and Environmental Engineering (2iE) in Ouagadougou, Burkina Faso produced a HRF 4-19 NTU effluent with only a 32% mean turbidity reduction (Figure 3)(Sylvain, 2006). The difference

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5 In 1995, HRFs were in use in Costa Rica, Colombia, Peru, Bolivia, Argentina, Burkina Faso, Ghana, Cameroon, Sudan, Ethiopia, Kenya, Tanzania, Malawi, Zimbabwe, Swaziland, Madagascar, South Africa, Pakistan, India, Sri Lanka, Burma, China, Thailand, Malaysia, and Indonesia, and Australia.
between the BNHP and 2iE HRF is the raw water quality; the later turbidity was ten times higher than the former allowing for a greater percentage of the turbidity to be removed. Given the turbidity range in NRG, a HRF needs to reduce the influent turbidity by 80-90% to produce a 50 NTU effluent.

![Figure 3 2iE HRF pilot study, Ouagadougou, Burkina Faso (Sylvain, 2006)](image)

**Materials and methods**

**Sampling techniques**

Water samples were collected from the shore of four dams near Tamale from customary collection points. Daily samples from the pilot HRF were taken to monitor it for 52 days from January 13, 2008 to February 28, 2008. If a filter valve clogged, the valve was readjusted and water was allowed to flow for 3-5 minutes before sampling.

Microbial samples from the dam and the tanks were collected by dipping the 100 ml Whirlpack® bag below the water surface. Pilot HRF system microbial sample were collected from the effluent tubes in Whirlpack® bags. The microbial samples were stored in a cooler with ice packs and processed within six hours of their collection. One surface soil sample was taken from the periphery of Ghanasco Dam.

**Physical water quality tests**

The Simple Methods for Water Quality Analysis from SANDEC’s *Surface Water Treatment by Rouging Filters: A Design, Construction, and Operation Manual* was used (Wegelin, 1996). These water quality tests use durable, inexpensive equipment to make water quality monitoring and filter performance possible in low-income communities. They were used to characterize the physical particle properties of four dams in the Tamale area and monitor the performance of the Ghanasco Dam pilot HRF.

**Turbidity**

In the field turbidity was measured with a DelAqua® turbidity tube in turbidity units (TU). For all other lab procedures, turbidity was measured in nephelometric turbidity units (NTU) using a Hach® 2100 P portable digital turbidimeter.

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6 Suspended solids are not to be confused with turbidity. While turbidity is a measurement of the cloudiness or haziness of water due to particles blocking light as it tries to pass through the sample, suspended solids are the measure of the actual particle mass per mass of water.

7 The DelAqua® turbidity tube measures: 25.5cm long, outer diameter of 2.8cm, and inner diameter 2.3cm.
**Fitrability**
The filterability test is a low-cost substitution for suspended solids, but it only yields relative values of solid matter removal. One-hundred milliliters of water was added to a 250ml cylinder of a filter set\(^8\) with a 1.5µm polycarbonate capillarpore membrane filter (Hach® FT-3-1101-047). The filtrate volume was recorded at 1, 2, and 3 minutes.

**Solids Settleability**
One liter of water was added to an Imhoff cone. The amount of settled solids (ml) was recorded after 15 minutes, 30 minutes, 1, 2, 4, 8, and 24 hours.

**Suspension Stability**
One liter of water settled for two days. The settled water turbidity was measured at 0, 15, 20, 60, 90, and 120 minutes and 4, 8, 24, 32, and 50 hours with a turbidimeter.

**Sequential Filtration**
The influent and effluent turbidity of separate water samples that filtered through 1µm, 8-12µm, and 20-30µm filter papers\(^9\) on a filter set was measured using a turbidimeter.

**Physical water quality of dams**
The physical water quality of four dams close to Tamale in NRG was tested: Ghanasco Dam (also the site of the pilot HRF), Gbrumani Dam, Kpanvo Dam and Kunyevilla Dam (Figure 4). These dams differed in the way water is accessed and their level of watershed protection.

![Figure 4 Map of Tamale and locations of dugouts](image)

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\(^8\) The filter set includes a 250ml cylinder, 250ml filter support, and filter disk.

\(^9\) Polycarbonate capillarpore membrane, 47mm filter papers were used (ZB921, Schleicher & Scull)
Description of dam sites

Ghanasco Dam is a large dugout that does currently not dry up. Water is collected directly from the muddy shores of the dam. It does not have a fence, reeds, or grasses around its periphery (Figure 5).

Gbrumani Dam is surrounded by a natural barrier of tall grasses and a fence. It has five hand pumps with gravel infiltration galleries\(^\text{10}\). One sample was taken from the hand pump water and one directly from the dugout (Figure 5).

Kpanvo Dam\(^\text{11}\) surface area is smaller than Ghanasco Dam and its periphery is also denuded of reeds and grasses. We were informed that it would dry up with the next 1-2 months at which point the community would need to purchase water (Figure 6).

Kunyevilla Dam has a large surface area, no periphery fence, and very little grass along its clay-packed periphery. It was drying up very quickly at the time of the visit on January 21, 2008. Women purchase water from Tamale once the dam dries up (Figure 6).

\(^{10}\) These improvements were built by Rotary International and the Carter Foundation.

\(^{11}\) Kpanvo Dam received five treadle pumps from the Guinea Worm Eradication Campaign (GWEC) so individuals would no longer wade into the dam to collect water. The treadle pump spouts were covered by Guinea worm cloth filters to ensure that any water collected was free from copepods. After three days of use, two of the five treadle pumps were already in need of repair. Beneficiaries were using the remaining three pumps. All individuals also received free pipe filters from the GWEP while free biosand filters were disseminated by International Aid.
Ghanasco Dam pilot HRF system details

Ghanasco Dam’s average turbidity during the test was 374 NTU. The dugout’s proximity to the Peace Corps Tamale Sub Office (TSO) and to the Tamale market made purchasing and transporting materials, taking water samples back to the TSO (where the laboratory was located), and monitoring the system convenient.

![Figure 7 Ghanasco Dam, Tamale, Northern Region Ghana](image)

Design and construction

The construction of the HRF was completed with locally available PVC pipe and two 700L polytanks according to the design in Figure 8. Four tubes were assembled with different media inside (Figure 9). The ends of the 7 meter 4” PVC pipe were capped with a 90° elbow angled upward to keep the tubes full of water.

![Figure 8 Detailed design of the Ghanasco Dam pilot HRF](image)

The granite gravel (G), local gravel (D), and broken pottery (P) media were cleaned and sorted by size. A small amount was placed in a plastic sieve and plunged in clean water three times. The sieve basket was then passed to the next water bucket and plunged into the water three times. Finally, this was repeated a third time or until further plunging did not dirty the water. Once washed, mesh screens with 5 mm openings were used to separate the 4-8 mm pieces. Mesh sieves with 13 mm openings were used to separate the 8-12 mm media. The largest media came from what remained on the 13 mm screens.
Operation and maintenance
The HRF system flow rate, tank levels, and turbidity were monitored daily. The two storage tanks were filled daily and stirred four times a day. Turbidity measurements were taken before and after mixing the tanks. Mixing helped re-suspend the particulate matter that had settled and accumulated. Filter performance is affected by turbidity and particle size. The relative particle size characterization shows how each process alters the particle sizes present.

Results and discussion

Physical water quality of dams
Knowledge about the type, size, and behavior of suspended particulate matter in the dams is pivotal to determining the main source of particles, how to prevent them from entering the dam water, and how to remove them from dugout water.
A water sample’s relative particle size and concentration can be determined from the dam settling test shown in Figure 10. The Gbrumani Dam and hand pump samples had the fewest particles. Kpanvo Dam and Kunyevilla Dam followed a similar settling trend that shows they have larger sized particles than Gbrumani Dam because, respectively, 77% and 92% of their turbidity settles out. In comparison with Kpanvo Dam and Kunyevilla Dam, Ghanasco Dam started at the highest turbidity, but only half of its turbidity settled, leaving its settled turbidity at 125 NTU, 75 NTU higher than the maximum recommended for SSF. Water with very low turbidity reduction through settling could require a turbidity removal step such as HRF prior to SSF.

**Pilot study – HRF performance evaluation**

Turbidity removal was the main indicator of the pilot HRF’s efficacy and overall, the pilot HRF at Ghanasco Dam performed well. Through gravity sedimentation in the tank, the average turbidity percent removal was 59% in the G tank and 55% in the P tank. The average effluent turbidity\(^\text{12}\) from all of the tubes was between 51 NTU and 72 NTU (Table 1). This range of average effluent turbidities from the HRF tubes nearly satisfies the 20-50 NTU requirement for water being treated by SSF. However, unfortunately, the best performing coarse media, the granite gravel, that removed an average of 84% of the turbidity was also the most expensive at $79.67 per cubic meter (Table 1).

\(^{12}\) This turbidity data was initially measured in TU with a turbidity tube and was converted to NTU according to the correlation found between TU and NTU.
Table 1 Comparison of HRF media average turbidity removal effectiveness

<table>
<thead>
<tr>
<th>Media</th>
<th>Average HRF effluent turbidity</th>
<th>Average filtration rates (ml/min)</th>
<th>Media cost ($ per m³)</th>
<th>Average total % turbidity reduction by HRF system</th>
<th>Filtration coefficient λ (min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G granite gravel</td>
<td>51 NTU</td>
<td>220 (1.6 m/hr)</td>
<td>$79.67</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>$8.16</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>Free except for transport</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>
</tr>
</tbody>
</table>

Figure 11 illustrates the turbidity settling trends of two parts of the pilot HRF: the upper portion of the figure shows the settling behavior of tank water (A – maximum turbidity in fully mixed tank; B – most settled turbidity in tank) and lower portion shows the settling behavior of the HRF effluents (C – maximum turbidity of pilot HRF effluent; E – most settled turbidity of pilot HRF effluent). The settling tests showed that about 30% of the turbidity settled out of mixed tanks in 24 hours.

After two days, the mixed tanks’ turbidity (A) leveled out at the settled tanks’ turbidity values (B) (Figure 11). Allowing the settled tank samples to settle further showed very little reduction in turbidity. Similarly, allowing the G, D, and P effluents (C) to settle longer barely improved their turbidity (E). The amount of unsettleable particles...
represents the turbidity introduced by very small, colloidal particles such as clay. Therefore, the improvement that the roughing media makes on turbidity percent removal is the difference between B and C and is 46%, 30%, and 19% for the G, D, and P tubes respectively (Table 2). Including the effects of settling and the pilot HRF led to 71%, 58%, and 47% average total turbidity removals respectively for the three tubes (Table 2). Subtracting the HRF percent turbidity removal from the total percent turbidity removals yields the percent turbidity removals from plain settling: 25%, 28%, and 28% for G, D, and P respectively.

Table 2 Turbidity Removal Results from Ghanasco Dam Pilot HRF Settling Tests

<table>
<thead>
<tr>
<th>Settling test</th>
<th>Average settled HRF effluent turbidity (E)</th>
<th>Average % turbidity removal by HRF after settling in tank based on...</th>
<th>Average total % turbidity removal by HRF system according to the settling test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial*</td>
<td>Settling records</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G granite gravel</td>
<td>219 NTU</td>
<td>52 NTU</td>
<td>46%</td>
</tr>
<tr>
<td>D local gravel</td>
<td>193 NTU</td>
<td>77 NTU</td>
<td>30%</td>
</tr>
<tr>
<td>P broken pottery</td>
<td>193 NTU</td>
<td>96 NTU</td>
<td>19%</td>
</tr>
<tr>
<td>Goal:</td>
<td>---</td>
<td>&lt; 50 NTU</td>
<td>---</td>
</tr>
</tbody>
</table>

* Initial turbidity is the averaged settled and mixed tank turbidities from the settling test.

**HRF Channel Design**

In 2002, the local NGO Village Water built a 28-meter long covered concrete-lined channel and cistern with two rope and washer hand pumps at the Kunyevilla Dam near Tamale, NRG (Figure 12). The dugout water flows through three 4-inch diameter pipes, a 28-meter long, concrete-lined channel partially filled with large gravel, a covered 16-meter concrete channel filled with sand, and finally reaches the sunken cistern. The channel was in a state of disuse and many of the channel coverings have been removed. It was unclear whether the channel was designed to be a HRF.

Using the filter coefficient calculated for the granite gravel (G), the best performing but most costly Ghanasco Dam pilot HRF media, a theoretical HRF was designed to be built...
in a concrete-lined or plastic tarp-lined channel that transported the raw water through the HRF and SSF by gravitational flow, eliminating the need for mechanical pumping. At the end of the channel, the water enters a partially underground cistern equipped with rope and washer pumps. Not only would this design simplify the system by reducing the cost of mechanical pumping, but it would also limit the amount of mechanical parts that could break and need to be repaired and improve easy access to the media for cleaning.

A number of assumptions were made:

- Beneficiary population: 10,000 people
- Water demand: 7.5 L/pp/day, \( Q = 75,000 \text{ L/d or 3.12 m}^3/\text{h} \)
- Rainy season dugout mean turbidity: \( T = 700 \text{ NTU} \)
- Flow rate: \( q = 1.6 \text{ m/h} \)
- Cross-sectional area: \( A = 1.95 \text{ m}^2 \)
- Depth: \( z = 1 \text{ m} \)
- Width: \( y = 2.\text{ m} \)

The length of the channel HRF was determined by varying the length (x) of the channel until the effluent turbidity, \( T_0 \), reached 20 NTU, a turbidity adequate for SSF. The channel has the same proportions of large (50%), medium (36%), and small media (14%) as in the Ghanasco Dam pilot test. The depth is only 1 m for easy removal and cleaning of the filter media. The design length of the HRF channel, 45 m, is about double the length of the 28 m Kunyevilla Dam channel. From the dam settling test, it was evident that the Ghanasco Dam particles are not as settleable as those in Kunyevilla Dam. Thus, the Ghanasco Dam HRF channel must be longer than Kunyevilla’s. This suggests the Kunyevilla Dam may have been initially built to be a HRF.

**Conclusions**

With poor groundwater accessibility, water quantity, quality, and accessibility will become a growing problem and potentially also a source of social tension, conflict, and economic burden in Northern Region Ghana and other water scarce regions of Sub-Saharan Africa. While millions of donor dollars fund interventions provide boreholes, one complimentary long-term solution also lies in improving and protecting dugouts. Solutions that grant communities improved access to potable water must be multi-dimensional and focused on developing community ownership and leadership of the project and creating financially sustainable O&M systems.
The first step is to better understanding dugout water quality and their physical and chemical properties as water sources. Until this occurs, problems with treating highly turbid water will persist. In turn, as more is learned about the physical water quality of dugouts, HRF and other technologies can be modified to more effectively remove suspended particles from highly turbid waters. For the extremely turbid water in NRG, using design parameters from Wegelin (1996), the best performing media, the granite gravel (G) barely met the target turbidity of < 50 NTU with its average effluent of 51 NTU. The filtrability and sequential filtration results confirmed that the majority of turbidity remaining in the HRF tube effluents was from colloidal (< 1µm) and small supracolloidal particles (< 10µm). Given that this pilot study was run during the dry season when NRG dugout turbidities are typically lower (250 NTU), the results suggest the HRF design needs to be modified further to remove colloidal particles such as clay and to be effective treating more turbid rainy season NRG dugout water (931 NTU) (Foran, 2007).

In this pilot HRF study at Ghanasco Dam, plain settling in the HRF tanks removed an average of 57% of the turbidity, while a laboratory settling test showed about 30% reduction of turbidity through settling. The coarse media in the pilot HRF enhanced turbidity reduction by removing an average of 55% of the turbidity of raw dugout water (average 350 NTU) entering the HRF tubes from the HRF tanks. Out of the three coarse media, granite gravel (G), local gravel (D), and broken pottery (P), the granite gravel media on average removed the most turbidity at 84% turbidity removal and a filter coefficient of 0.002 min⁻¹. The results from the settling test emphasize the importance of HRF in particle removal because, on average, the granite gravel (G) media removed 46% of the initial turbidity, twice as much as plain settling, which removed an average of 25% the turbidity.

Overall, with average 80% turbidity removal and an average effluent turbidity of 61 NTU, HRF has potential as a pretreatment option for the dugouts in Northern Region Ghana. Therefore, with more investigation of the HRF effectiveness at removing turbidity from even more turbid, rainy seasons dugout water, using SSF could be a viable, low-cost treatment option in a multi-stage filtration system that first treats the raw water with HRF.

Summary of Key Results

- During this pilot HRF study, Ghanasco Dam dry season turbidities were between 176 and 540 NTU.

- The pilot HRF system removed between 76-84% of the total influent turbidity while its average flow rate stayed within the SANDEC guidelines (54 – 270 mL/min).

- The granite gravel (G) media performed the best and met the target of reducing the turbidity to < 50 NTU by removing 84% of the influent turbidity (128 - 313 NTU ) and producing an average effluent turbidity of 51 NTU.
• The average effluent value for the granite gravel (G), local gravel (D), and broken pottery (P) was 61 NTU, which nearly reached the target of < 50 NTU for SSF.

• Laboratory settling tests showed about 30% of the turbidity in the tanks settled while data from the pilot HRF showed approximately 57% of the turbidity settled.

• Settling tests showed that the particle removal mechanisms in HRF were responsible for 46% of the turbidity removal in the granite gravel (G) tube and 30% and 19% turbidity removal for the local gravel and broken pottery respectively.

• The filtrability and sequential filtration tests showed that the majority of particles left in the HRF effluent are colloidal and small supracolloidal particles that do not easily settle.

Recommendations
The structure of community-based management and operations of centralized water systems will greatly vary. However, the following guidelines are applicable to many situations when choosing a community and project site for a community-scale water system:

• **Develop Local Watershed Protection Plans** - Inexpensive improvements can be made to the periphery and catchment area of the dugout to improve its water quality. For example, one could plant natural barriers to catch particulate matter in runoff before it enters the dam, improve sanitation, or dig deeper dams to conserve water by reducing the surface area exposed to evaporation.

• **Dugout Water Quality Monitoring** – Long-term monitoring of not just the improved water supplies, but the surface water and other unimproved sources including all the rural dugouts in NRG will create a much clearer picture of their physical water quality, seasonal changes, and long-term trend in water quantity, quality, accessibility, and reliability and how climate change, deforestation, desertification, and changing weather patterns are impacting the poor rural populations who rely on these sources in Northern Ghana.

• **Setting up a Dugout Monitoring Campaign after the Model of the Guinea Worm Eradication Accolades** - Partner with trained Guinea Worm Volunteers (GWV), universities and schools, and Peace Corps Volunteers (PCVs) to monitor dugout water quality. If provided with some basic, inexpensive lab equipment, the monitors could train the Guinea worm volunteers and team up with students to perform simple monthly or bimonthly physical water quality tests similar to those performed in this study such as turbidity, solids settleability, and suspension stability plus simple microbial testing. The results could be compiled, analyzed, and shared with a central office. Follow-up support must be available to communities whose results show positive microbial contamination and/or
especially high turbidity to plan for and implement a source protection and/or treatment intervention.

- **Rehabilitate and Upgrade Existing HRFs** - Rather than constructing more new HRFs in Ghana, it would be more cost-effective to repair the existing HRF systems, like the channel at Kunyevilla Dam, and work closely with the community to develop better operations and maintenance practices. Preliminary work should focus on community participation together with a local leaders and a technically trained person to identify challenges and solutions. Completion of a baseline health survey before implementing the project and some time after the intervention would allow conclusions to be drawn on the HRF-SSF system’s impact on reducing the disease burden of diarrheal disease. This information could be used to do a cost-benefit analysis and comparison between the Disability Adjusted Life Years (DALYs) prevented by a borehole, HRF-SFF system, and coagulation-chlorination system.

- **Investigate Media and Particle Properties to Enhance Colloidal Particle Removal** - Investigation of the chemical and physical properties of coarse roughing media available in NRG and colloidal particles in the dugout water could lead to improvements in the HRF design to favor biofilm formation and/or use particles charges and chemical properties to improve turbidity removal.
References


Ghana Statistical Services. (2006). Data on unimproved water sources was obtained from the GSS office by Massachusetts Institute of Technology Senior Lecturer Susan Murcott.


Millipore. *Water microbiology: Laboratory and field procedures*.


