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Field and Laboratory Comparison of the Hydraulic Performance of Two Ceramic Pot Water Filters

by

Duncan Peabody

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Engineering Science
Department of Civil and Environmental Engineering
College of Engineering
University of South Florida

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Keywords: point-of-use treatment, household water treatment and safe storage,
Dominican Republic, flow rate, hydraulic conductivity

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TABLE OF CONTENTS

LIST OF TABLES iii

LIST OF FIGURES iv

ABSTRACT vi

CHAPTER 1 INTRODUCTION 1
- 1.1 Background 1
  - 1.1.1 Access to Drinking Water 1
  - 1.1.2 Household Water Treatment and Safe Storage (HWTS) 2
  - 1.1.3 Ceramic Water Filters 3
- 1.2 Motivation 7
- 1.3 Research Objectives 7

CHAPTER 2 LITERATURE REVIEW 9
- 2.1 Household Water Consumption 9
- 2.2 Effect of Flow Rate Variation on Water Quality Improvement 10
- 2.3 User Acceptability of Flow Rate 12
- 2.4 Flow Rate Measurements 13
- 2.5 Hydraulic Conductivity 14

CHAPTER 3 METHODS 18
- 3.1 Dominican Republic Field Site 18
  - 3.1.1 Initial Site Assessment 19
  - 3.1.2 Filter Distribution and Education 22
- 3.2 Laboratory Study 24
- 3.3 Water Quality Testing 24
- 3.4 First Hour Flow Rate 25
- 3.5 Falling Head Test 27
- 3.6 Modeling Flow Rate to Estimate Hydraulic Conductivity 29
  - 3.6.1 Model for Potters for Peace Filter 30
  - 3.6.2 Model for FilterPure Filter 32

CHAPTER 4 RESULTS AND DISCUSSION 35
4.1 Field First Hour Flow Rates 35
4.1.1 Individual Filter First Hour Flow Rates 37
4.1.2 Comparison of FilterPure and Potters for Peace First Hour Flow Rates 39
4.1.3 Change in First Hour Flow Rate Over Time 41
4.1.4 Discussion of Field First Hour Flow Rate 44
4.2 Laboratory First Hour Flow Rate 47
4.3 Falling Head Test 48
4.3.1 Modeling Flow Rate with Hydraulic Conductivity: Potters for Peace Model 50
4.3.2 Modeling Flow Rate with Hydraulic Conductivity: FilterPure Model 53
4.3.3 Discussion of Hydraulic Conductivity 55

Chapter 5 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH 57
5.1 Conclusions for the Field and Laboratory Studies 57
5.2 Recommendations for Future Research 58

REFERENCES CITED 60

APPENDICES 63
Appendix A Pre-Implementation Field Survey 64
Appendix B Institutional Review Board Approval Letter 68
Appendix C Water Sources of La Tinajita 69
Appendix D Regular Field Survey 70
Appendix E Calculation of Volume/Month Laboratory Equivalent 71
Appendix F Excel Spreadsheet for PFP Hydraulic Conductivity 72
Appendix G Excel Spreadsheet for FP Hydraulic Conductivity 73

LIST OF TABLES

Table 1. Improved and Unimproved Drinking Water Sources as Defined by the World Health Organization (WHO) 2

Table 2. Evaluation of Household Water Treatment and Safe Storage (HWTS) Options 4

Table 3. First-Hour Flow Rate Range Requirements for Filter Factory Quality Control. 11

Table 4. Results and Applicability of Previous Hydraulic Models 14

Table 5. House Numbers Organized According to Water Source. 21

Table 6. Field Test Schedule 35

Table 7. Filters Removed from Study Listed by Cause for Removal. 36

Table 8. First Hour Flow Rate Averages for Individual Filters. 38

Table 9. First Hour Flow Rate Averages with Confidence Intervals Over Entire Study 39

Table 10. Average First Hour Flow Rates Observed in the Field for FilterPure and Potters for Peace Ceramic Filters During Months 7-13. 42

Table 11. PFP Filters with First Hour Flow Rates Above Median and Standard Deviations Above 70. 43

Table 12. Laboratory Falling Head Test Data 50

Table 13. First Hour Flow Rate and Hydraulic Conductivity for Four Laboratory Filters 55

Table 14. Comparison of Hydraulic Conductivity Results with Previous Research 56

LIST OF FIGURES

Figure 1. The Potters for Peace (PFP) Ceramic Pot Filter. 5

Figure 2. The FilterPure Filter Model. 6

Figure 3. Location of Field Site in the Dominican Republic. 18

Figure 4. GPS Map of La Tinajita Showing Water Sources and House Locations. 19

Figure 5. The T Device. 26

Figure 6. Assumed Geometry and Parameters Needed to Model Flow Through the Potters for Peace Filter 30

Figure 7. Assumed Geometry and Parameters Needed to Model Flow Through the FilterPure Filter 33

Figure 8. Distribution of First Hour Flow Rate Averages of Individual Filters. 40

Figure 9. Average Monthly First Hour Flow Rates Observed in the Field for FilterPure and Potters for Peace Ceramic Filters During Months 7-13. 41

Figure 10. Box Plot of First Hour Flow Rate for FP and PFP Filters During Months 7-13 42

Figure 11. Laboratory First Hour Flow Rate. 47

Figure 12. Cumulative Volume Processed by Filters in Laboratory in 24 Hours. 49

Figure 13. Water Height versus Time for Filter PFP1 51

Figure 14. Water Height versus Time for Filter PFP2 51

Figure 15. Cumulative Volume Processed vs. Time for Actual and Estimated Flow Rates for Filters PFP1 and PFP2. 52

Figure 16. Graphical Representation of FP Filter Geometry 53

Figure 17. Water Height versus Time for Filter FP1 54

Figure 18. Water Height versus Time for Filter FP2 54

ABSTRACT

Currently 884 million people worldwide are living without access to an improved source of drinking water (WHO/UNICEF, 2011). Piped-water on premises is the ultimate goal of World Health Organization (WHO) due to the ability to treat all of the water and distribute it safely in pressurized pipes. However, Household Water Treatment and Safe Storage (HWTS) is an option for improving the quality of drinking water where that infrastructure is not yet developed, especially where there is a risk of recontamination between point of collection and point of use (Clasen, 2006). This study analyzed one such HWTS, the ceramic pot water filter. The study compared the hydraulic properties of the FilterPure (FP) and Potters for Peace (PFP) ceramic pot filters through a thirteen-month field study in the Dominican Republic and laboratory studies at the University of South Florida.

In the field study 55 filters were tested for first hour flow rate and hydraulic conductivity. Eight first hour flow rate tests were conducted in the field on one month intervals during months 7- 13. FP filters had an average first hour flow rate of 553 ml/hr and PFP Filters had a first hour flow rate of 395 ml/hr. No significant change in first hour flow rate was observed over time in FP filters. PFP experienced an average increase of 31 ml/hr per month during the seven-month testing period.

Falling head tests were conducted on four filters in the laboratory and the flow rate was modeled to determine hydraulic conductivity. Hydraulic conductivity values for

FP filters ranged from k = 0.0534 - 0.0950 cm/hr and for PFP filters ranged from k = 0.0094 – 0.0390 cm/hr.

Eight out of 29 (26%) Potters for Peace filters in the field had first hour flow rates of less than 250 ml/hr by month nine of the study and had to be replaced and removed from the study. In total 24 of 55 (44%) filters (8 FP and 16 PFP) had to be removed from the study due to several reasons discussed in this thesis.

CHAPTER 1 INTRODUCTION

1.1 Background

1.1.1 Access to Drinking Water

Target 7C of Millennium Development Goal Number 7 aims to "halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation (United Nations, 2010)." Currently 884 million people worldwide are living without access to an improved source of drinking water (WHO/UNICEF, 2011). A list of what constitutes an improved drinking water sources is provided in Table 1. However, the global community defines "safe drinking water" only by the water source and not by the water quality. Therefore, the number of people without access to clean drinking water is likely to be much higher (WHO/UNICEF, 2011). Piped water on premises is the ultimate goal of World Health Organization (WHO) due to the ability to treat all of the water and distribute it safely in pressurized pipes. However, Household Water Treatment and Safe Storage (HWTS), also known as Point of Use (POU) Treatment, is an option for improving the quality of drinking water where infrastructure is not yet developed, especially where there is a risk of recontamination between point of collection and point of use (Clasen, 2006).

1.1.2 Household Water Treatment and Safe Storage (HWTS)

According to 2007 estimates, 18.8 million people are using POU treatments technologies worldwide. These treatments include chlorination with liquid or tablet, solar disinfection (SODIS), flocculation/chlorination, biosand filtration, and ceramic filtration (Lantagne, 2010). Compared to the 884 million people without access to an improved drinking water sources there is thus a small number of people using POU treatments.

Table 1. Improved and Unimproved Drinking Water Sources as Defined by the World Health Organization (WHO). Improved sources are defined by the type of water source, not by the water quality.

Improved Source	Unimproved Source
Household connections	Unprotected wells
Public standpipes	Unprotected springs
Boreholes	Vendor-provided water
Protected dug wells	Bottled water
Protected springs	Tanker-truck provided water
Rainwater collections	

Source: WHO/UNICEF 2011

Each type of POU treatment method has several pros and cons. Lantagne et al. (2006) developed three criteria for evaluating different HWTS methods:

1. Does the HWTS option remove or inactivate viral, bacterial, and parasitic pathogens in water in a laboratory setting?

2. In the field, is the HWTS option acceptable, can it be used correctly, and does it reduce disease among users?

3. Is the HWTS option feasible at a large scale?

Using these criteria the authors developed visual methods to show the pros and cons of each HWTS option (Table 2). Table 2 shows that SODIS and flocculation/chlorination are the most effective POU treatments in laboratory studies. Ceramic filters are effective in removing bacteria and protozoa but their effects on viruses are, as of yet, unknown.

1.1.3 Ceramic Water Filters

Ceramic water filters (CWF) are manufactured using clay, water, and some burnable material such as sawdust or rice hulls. The burnable material creates porosity in the fired ceramic which allows water to flow through. The basic materials for manufacturing ceramic filters are readily available in most countries and many areas of the world have a history of making artisan goods from clay. Therefore it is considered an appropriate technology for many developing countries. However, the characteristics of the clay (particle size, plasticity, purity, shrinkage, etc.) and burnable materials (type, size, shape, etc.) vary significantly among manufacturers and regions.

There are several types of ceramic filters, including discs, the "candle" type, and the pot filter. The ceramic pot filter is the most commonly produced ceramic filter. From this point forward the acronym CWF will refer specifically to the ceramic pot water filter. CWF are produced in over 18 countries (Rayner, 2009). This research will focus on two different ceramic pot filters produced in the Dominican Republic. Both filters use colloidal silver as a bactericide to enhance biological removal, though they apply the silver with different methods.

Table 2. Evaluation of Household Water Treatment and Safe Storage (HWTS) Options. The evaluation was based on three criteria: lab studies, field studies, and the scalability.

Criterion	Lab Studies (Removal)			Field Studies		Scalable
HWTS Option	**Virus**	**Bacteria**	**Protozoa**	**Accept-able to users?**	**Positive Health Impact**	
Chlorination	Medium	High	Low	Yes	Yes	Yes (operates at village and national scale)
SODIS	High	High	High	Yes	Yes	Unknown (operates at village and regional scale)
Biosand Filtration	Unknown	Medium-High	High	Yes	Yes	Unknown (operates at village and regional scale)
Ceramic Filtration	Unknown	Medium-High	High	Yes	Yes	Unknown (operates at village and regional scale)
Flocculation/ Chlorination	High	High	High	Yes	Yes	Yes (operates at village and national scale)

Adapted from Lantagne et al. (2006)

The first model is the Potters for Peace (PFP) model. Potters for Peace (http://www.pottersforpeace.org/) is a US-based Non-Governmental Organization (NGO) that designed the Potters for Peace ceramic pot filter in the 1990s and now promotes it in over 18 countries (Lantagne, 2010). Following the devastation of Hurricane Georges in 1998 in the Dominican Republic, Instituto de Desarrollo de la Economía Asociativa (IDEAC) formed a partnership with a local artisan group. The artisan group was trained by representatives from Potters for Peace in the manufacturing of CWF. Intermon Oxfam and a Spanish savings and loan bank (Caja de Ahorros Mediterraneo) provided financing to establish a filter factory in Yamasa where the artisan group is based.

(a) (b)

Figure 1. The Potters for Peace (PFP) Ceramic Pot Filter. (a) A PFP filter in its bucket at a household in the field. (b) A cross-sectional view of the PFP filter.

The PFP model is produced by mixing clay and sawdust with water and shaping the ceramic pots with a mechanical press. The PFP filter is coated with colloidal silver after it is fired. The filter is shaped like a flower pot with a flat bottom and tapered sides. It holds 8 L of raw water. The filter is placed inside of a 5-gallon bucket and water is passed through the filter and stored in the bucket (Figure 1). The plastic lid prevents further contamination of the water and acts as vector control for mosquitoes.

The second filter model is a new model developed by the US-based NGO FilterPure (FP). FilterPure (http://www.filterpurefilters.org/) has filter manufacturing facilities in the Dominican Republic and Haiti, with their main factory located in Moca, Dominican Republic.

The FP filter differs from the PFP design in two main aspects: the shape and the method of silver impregnation. The FP filter that was investigated in this study has a rounded bottom and clover-shaped cross-sectional area. It holds 7 L of raw water (Figure 2). The colloidal silver is incorporated into the water that is used to mix the clay and sawdust. When the filters are fired the colloidal silver melts and covers the surface of the micro-pores. As water passes through the micro-pores of the filter it is forced to come in contact with the colloidal silver.

Figure 2. The FilterPure Filter Model. The FP model has a "lemon-juicer" shape to increase the surface area and a rounded bottom. The plastic lid covers the filter when it is in the bucket.

1.2 Motivation

User acceptance is one of the most important factors in the success of any type of health intervention. Regardless of a filter's ability to remove pathogens, it is unable to serve its intended purpose if it is not being used. The Ceramic Manufacturing Working Group released a report in 2010 recommending best practices for ceramic water filter production and further research goals (CMWG, 2010). In the report the Working Group cites low flow rates as one of the two main barriers to user acceptance, along with filter breakage. While short-term flow rate monitoring has been performed in the laboratory (Lantagne, 2010; Oyanedel, 2008) there is a lack of research on hydraulic performance of ceramic filters in the field.

One of the areas lacking in knowledge of CWFs is their long-term performance in the field. Many studies have evaluated individual filter performance after years in service (Brown et al., 2008; Westphal, 2008) and others have followed filter performace during a period of a few months (Al-Moyed, 2008; Dundon, 2009) but monitoring over a long period is limited.

1.3 Research Objectives

This research aims to evaluate the short and long-term hydraulic performance, in the field and in the laboratory, of two different types of ceramic water filters, specifically in terms of hydraulic conductivity and first-hour flow rate. The following two research questions will be used for evaluation.

1. Do the hydraulic properties of the two filter types change over time, as determined by the first-hour flow rate and hydraulic conductivity?

2. Does one filter model (FP or PFP) perform better than the other as determined by first hour flow rate and hydraulic conductivity?

These two questions are addressed using laboratory and field measurements to determine the first-hour flow rate and the hydraulic conductivity of the filters. The field tests took place in 55 households in the community of La Tinajita in Puerto Plata province in the north of the Dominican Republic. The laboratory tests took place at the University of South Florida or at the non-governmental organization, A Mother's Wish Foundation, which is located near the field test site.

CHAPTER 2 LITERATURE REVIEW

The majority of peer reviewed journal articles on the topic of ceramic water filters has had a primary focus on water quality and health impacts (Clasen, 2004; du Preez, 2008; Bielefeldt, 2009). This study intends to take a different approach to determine the effectiveness of ceramic pot water filters, by examining their hydraulic properties. Much of the previous literature on this topic exists in unpublished theses or technical reports for international development agencies. Therefore many of the references cited in this research are not peer reviewed journal articles.

2.1 Household Water Consumption

Although the ultimate goal of CWF is to remove contamination from water, it is not an effective POU treatment if it does not provide sufficient quantity of clean drinking water to meet the needs of a household. A review of past studies on drinking water requirements for humans produced an estimate of 3.3 L/person/day of drinking water (Howard and Bartram, 2003). When cooking and hygiene are considered the required quantity increases to more than 10 L/person/day (Howard and Bartram, 2003).

The Institute of Medicine released a 2004 report on dietary reference intakes, which recommended water consumption of 3.7 L/day for males and 2.7 L/day for females. Approximately 20% of the water is derived from food (IOM, 2004). However a

USDA study of drinking water ingestion in the United States reports the average male water consumption, not including water from food sources, at approximately 1.4 L/day and the average female water consumption at approximately 1.2 L/day (EPA, 2011). Thus the recommended daily intake does not necessarily reflect the actual household water demand. Furthermore water intake needs can vary significantly based on climate, physical activity, and many other factors.

2.2 Effect of Flow Rate Variation on Water Quality Improvement

Flow rate has been proposed as a quality control parameter for filter manufacturers. Manufacturers must produce pore sizes that optimize the relationship between flow rate and improvement of water quality, as measured by reduction in turbidity and pathogens. Several studies have been conducted to determine the optimal flow rate. In a survey conducted of 18 filter manufacturers throughout the world, all but two of the manufacturers used first-hour flow rate testing as one of their quality control methods. The other two factories reported different methods for flow rate testing. The average minimum flow rate reported ranged from 1.0 – 3.0 L/hr in the first hour while the average maximum flow rate ranged from 2.0 – 5.0 L/hr in the first hour (Rayner, 2009). Table 3 below shows the established first-hour flow rate range, as reported by each factory. None of the factories in the survey reported acceptable flow rates below 1.0 L/hr.

A study was conducted with PFP filters in Nicaragua to assess the change in microbial water quality when the flow rate was increased to 2-8 L/hr by adding more burnable material to the pre-fired mix. Fourteen filters were tested during 6 months and no considerable difference in *E.* Coli removal was found between the augmented filters and the normal PFP filters during the six months (Bloem, 2009).

Table 3. First-Hour Flow Rate Range Requirements for Filter Factory Quality Control. Each of the 18 factories listed below reported their first-hour flow rate ranges which are used as part of their quality control process to sort out bad filters.

Factory	Organization	Filter Capacity (L)	Acceptable Flow Rate Range (L/hr)
Benin	Potters Without Borders	8	2.0 - 2.5
Cambodia (1)	Potters For Peace	10	2.0 - 3.0
Cambodia (2)	RDI-C	11	1.5 - 3.0
Colombia	Potters for Peace	n/a	2.0 - 3.0
DR	Filter Pure	6	1.0 - 3.0
Guatemala (1)	AFA Guatemala	7.1	1.0 - 2.0
Guatemala (2)	Potters for Peace	11	1.0 - 2.5
Indonesia (1)	Potters for Peace	9	1.5 - 3.5
Indonesia (2)	RDIC & Potters for Peace	8	1.75 - 3.0
Myanmar	Thirst-Aid	10	1.5 - 4.5
Nicaragua (1)	Potters for Peace	8	1.0 - 3.0
Nicaragua (2)	Potters for Peace	7	1.0 - 2.5
Nigeria	Potters for Peace	n/a	2.0 - 3.0
Sri Lanka (1)	Potters for Peace	10	2.0 - 3.0
Sri Lanka (2)	American Red Cross	8	1.0 - 2.5
Tanzania (1)	Filter Pure	8	1.5 - 3.0
Tanzania (2)	Potters For Peace	7	3.0 - 5.0
Yemen	Potters Without Borders	7.1	1.5 - 3.0

Adapted from Rayner (2009)

A similar 5-week study was performed with FP filters, testing various clay:sawdust ratios. Flow rate was increased from 0.518 L/hr to 1.168 L/hr by reducing the clay content from 53% to 50% without any observation of decrease in total coliform removal (Klarman, 2009). Lantagne et al. (2010) found that, in FilterPure filters, the maximum first-hour flow rate below which filters achieved greater than 99% reduction in total coliforms was 1.7 L/hr. This is below the maximum first-hour flow rate standards set by all of the factories listed in Table 3, including the two FilterPure factories.

2.3 User Acceptability of Flow Rate

The users' perceptions of the flow rate is equally as important as the actual measured filtered water. In a study done in Southern Africa approximately 10% of the 43 filter users questioned reported that the filter was too slow (du Preez, 2008). In a larger study done in Cambodia on filters distributed by Resources Development International (RDI) and International Development Enterprises (IDE) 324 of 600 households were no longer using their filters regularly. Five percent of those not using their filters said it was due to the filter not producing sufficient water (Brown, 2007). A Tulane University study of PFP filters in Nicaragua concluded that one of the three main barriers to filter use was slow filtration rates (Lantagne, 2001). The other two were "malfunctioning" and "fragileness." In all three studies the actual flow rates and desired flow rates were not reported.

2.4 Flow Rate Measurements

Lantagne et al (2010) performed a laboratory study to compare the flow rates of PFP filters to those of the FP filters during a six week period. Eight L per day were filtered through the filters and first-hour flow rate measurements were taken twice a week. The initial flow rates for PFP and FP respectively were 0.84 – 1.22 L/hr and 0.46 – 0.53 L/hr. After the six week period the PFP maintained a similar flow rate of 0.78 – 1.28 L/hr while the FP filters showed an increase in flow rate to 0.57 – 0.64 L/hr.

A 12-week laboratory study of 24 filters from Nicaragua, Ghana, and Cambodia, in which the filters had a constant water height of 20cm, showed that filters from Cambodia and Nicaragua had an initial mean flow rate of 0.73 L/hr and 0.85 L/hr respectively, while the Ghana filters had an initial mean flow rate of 2.41 L/hr. However, after 12 weeks none of the 24 filters produced more than 0.5 L/hr (van Halem, 2006).

The flow rates from the studies above show a significant disconnect between the first-hour flow rates that the factories in Table 3 reportedly use and the actual first-hour flow rates being measured in laboratory experiments. Furthermore, the findings from the van Halem study raise concerns that although a filter may meet quality standards before being distributed, the flow rate can quickly reduce to unacceptable levels, regardless of its initial flow rate.

2.5 Hydraulic Conductivity

Several studies have investigated the hydraulic conductivity of ceramic filters in the laboratory (Lee, 2001; Fahlin, 2003; van Halem, 2006; Miller, 2010). Each study developed a different equation to model the flow of water through the ceramic filters. Table 4 gives a summary of the results and their applicability to this study.

Table 4. Results and Applicability of Previous Hydraulic Models

Study	Model Summary	Hydraulic Conductivity (k) Study Results	Applicability
Lee(2001)	Disk with 50 mm diameter and 5mm thickness	0.162 cm/hr	Applicable to bottom of filter.
Fahlin (2003)	PFP Flower Pot - Assumed filter to be truncated cone with flat bottom; Accounted for change in hydraulic head.	0.171 – 0.325 cm/hr	Applicable to PFP filter.
van Halem (2006)	PFP Flower Pot - Truncated cone geometry; Assumed same k for bottom and sides. Confirmed with Mercury porosimetry.	0.0152 – 0.0433 cm/hr	Applicable to PFP filter. Model agreed with results.
Miller (2009)	Parabaloid Filter - Assumed same hydraulic conductivity and thickness throughout filter.	0.227 – 0.272 cm/hr	Applicable to FP filter.

Lee (2001) measured the hydraulic conductivity of a 50 mm diameter ceramic disk with a 5mm thickness, manufactured with a 50:50 clay to burnable ratio. Using a simple rearrangement of Darcy's law (Equation 1) and a constant head test which provided measured flow rate data, the hydraulic conductivity of the ceramic disk was calculated to be 0.162 cm/hr.

$$Q = \frac{kAh}{d} \quad (1)$$

where:
Q = flow rate (ml/hr)
k = hydraulic conductivity (cm/hr)
h = hydraulic head (cm)
d = thickness of ceramic (cm)
A = area of ceramic (cm^2)

Fahlin (2003) developed a model for the PFP filter by using a truncated cone with a flat bottom as the geometrical basis for his model (Equation 2). He also accounted for the change in hydraulic head on the sides of the filter as the water level changed and assumed that the hydraulic conductivity would be different in the sides and bottom of the filter.

$$Q = \frac{k_B A_B h}{t_B} + \frac{k_S A_S h_S}{t_S} \quad (2)$$

where:
Q= flow rate (ml/hr)
k_B = hydraulic conductivity of bottom (cm/hr)
k_s = hydraulic conductivity of sides (cm/hr)
A_B = area of bottom (cm^2)
A_S = area of sides (cm^2)
h = hydraulic head on bottom (cm)
h_s= hydraulic head on sides (cm)
t_s = thickness of sides (cm)
t_B = thickness of bottom (cm)

Van Halem (2006) used the same truncated cone geometry as Fahlin (2003) to produce a different model (Equation 3). In that study, the author assumed that the hydraulic conductivity of the side and bottom could be considered to be the same. The model was compared to empirical data obtained in laboratory experiments and was shown to be accurate for modeling flow rate.

$$Q = 2\pi \frac{k}{t_S}\left(\frac{r_T - r_B}{6L} h^3 + \frac{r_B h^2}{2}\right) + \frac{k}{t_B}\pi r_B^2 h \qquad (3)$$

where:
Q= flow rate (ml/hr)
k = hydraulic conductivity (cm/hr)
r_T = radius at top of filter (cm)
r_B = radius at bottom of filter (cm)
t_s = thickness of sides (cm)
t_b = thickness of bottom (cm)
h = hydraulic head (cm)
L = length of exterior side wall (cm)

Miller (2010) studied a new form of paraboloid filter being produced in Ghana. He modeled the hydraulic conductivity (Equation 4) and found that it remained fairly constant between 10 to 20 cm of hydraulic head but increased below those levels. He determined that this was likely due to stored water in the upper parts of the filter walls which skewed the flow rate measurements.

$$Q = \frac{4\pi ck}{3t}\left[-h\left(\frac{c^2}{4}\right)^{\frac{3}{2}} + \frac{2}{5}\left(\frac{c^2}{4} + h\right)^{\frac{5}{2}} - \left(\frac{c^2}{4}\right)^{\frac{5}{2}}\right] \qquad (4)$$

where:
Q = flow rate
k = hydraulic conductivity
h = hydraulic head

and c is given by

$$c = \sqrt{\frac{1}{b}} \qquad (5)$$

where:
b = coefficient relating height and radius of filter.

The hydraulic conductivity is important for assessing filter performance because it describes the ease with which water flows through the filter material. Therefore different production variables can be tested to see which provides the best hydraulic characteristics. It can be used as a tool for the standardization of production variables to ensure that the most optimal and consistent flow rates are achieved by filter manufacturers.

CHAPTER 3 METHODS

3.1 Dominican Republic Field Site

The field study was performed in the rural community of La Tinajita in the province of Puerto Plata, Dominican Republic (Figure 3). The main source of income in the community is agriculture. The site was suggested by the directors of A Mother's Wish Foundation (http://www.amotherswish.org/), a rural clinic located in a neighboring village. This foundation, run by James Pickard and Rita Rizek, provides medication, vaccination, prenatal care, and other medical attention free of charge to rural communities in the vicinity of their clinic located in the municipality of Pedro Garcia. James Pickard and Rita Rizek also assisted in the initial pre-implementation surveys and provided logistical support and storage for testing equipment and extra filter supplies.

Figure 3. Location of Field Site in the Dominican Republic. La Tinajita is located in the northern province of Puerto Plata, 40 miles north of the large city of Santiago.

3.1.1 Initial Site Assessment

An initial site assessment took place during June 2010. A pre-implementation survey (Appendix A) was carried out prior to the distribution of the filters. The survey included a health assessment and water usage and knowledge questionnaire. GPS coordinates were also collected to map the community (Figure 4). A community meeting was also held, facilitated by the directors of A Mother's Wish, to explain the study to the community and let them know what was expected of them if they were to participate. The study protocol was approved by the Institutional Review Board (IRB) of the University of South Florida (see Appendix B).

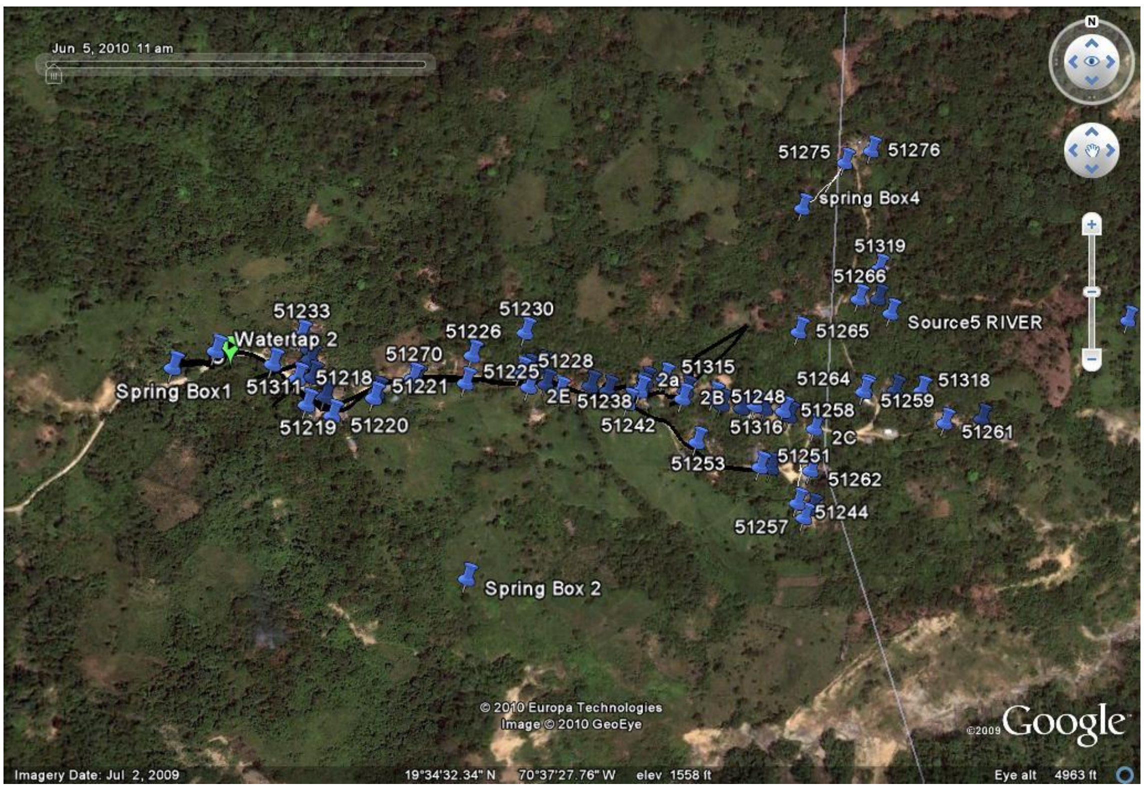


Figure 4. GPS Map of La Tinajita Showing Water Sources and House Locations. House numbers were assigned by A Mother's Wish Clinic in a census.

The majority of the 55 houses receive water from one of three spring sources. The first spring source (Spring Box 1 in Figure 4) has a springbox which is not functioning correctly and offers little contamination protection. The second and third water sources (both located near Spring Box 2 in Figure 4) are unprotected spring sources. All three sources feed separate distribution systems consisting of 1,000 gallon storage tanks which run to individual taps in homes. Most homes have their taps either outside the house or in their outdoor kitchens. There are four houses at the end of the community which have private unprotected water sources (Spring Box 4 and Source5 in Figure 4). These sources have no distribution system so water is collected at the source. (Table 5 provides a list of house numbers with the study identification number that is organized by water source. Appendix C provides more in depth discussion of each water source.) Water from these five sources is generally not apt for drinking because it comes from unprotected surface water sources which are located in the same general vicinity as livestock and agriculture. However, five surface water sources listed in Appendix C, along with rain water, are the primary sources of drinking water for the community. Large five-gallon bottles (botellones) of purified drinking water are not available in the community so very few households drink purified water. Because of the lack of access to purified water and the poor quality of drinking water in the community, Tinajitas was determined to be an appropriate candidate for the field study.

La Tinajita has a population of 267 with an average household size of 4.6 people. Of the household members interviewed in the baseline survey 66% had a primary school education or below. Of the remaining population 22.5% had some high school education or higher. The majority of the houses (83%) had pit latrines. One house had a flushing toilet and eight houses (15%) had no latrine or shared a latrine with a neighbor.

Table 5. House Numbers Organized According to Water Source. An equal number of filters of each type were assigned to households at each source. The bottom line gives the number of house on each source as well as the total number of households receiving filters.

Springbox	Unprotected Spring Intake #1	Unprotected Spring Intake #2	Point of Source Spring	River	
51221	51245	51253	51275	51266	
51270	51227	51251	51276	51267	
51218	51228	51257			
51211	51229	51244			
51272	51314	51262			
51226	51280	51230			
51225	51243	51317			
51313	51315	51263			
51220	51259	51318			
51223	51278	51265			
51231	51258	51264			
51233	51316	51261			
51271	51246	51320			
51224	51249	51260			
51269	51248	51256			
	51240				
	51268				
	51339				
	51238				
	51239				
	51277				
	51242				Total
15	**21**	**15**	**2**	**2**	55

3.1.2 Filter Distribution and Education

During the week of August 23-29, 2010 100 ceramic water filters (CWF) were purchased from two different CWF manufacturers in the Dominican Republic; 50 from Potters for Peace (PFP) located in Yamasa, Monte Plata and 50 from Filter Pure (FP) located in Moca.

Meetings were held beforehand with each of the filter manufacturers to explain the study and express the importance that all of the filters must come from the same batch. Each manufacturer acknowledged this requirement. Nevertheless, upon receiving the filters from the Yamasa PFP factory they appeared to have come from several different batches, as their serial numbers did not coincide and there was different coloration in the clay. The filters were stored in their original boxes in a storage container at A Mother's Wish Foundation's rural clinic until they were distributed.

Distribution took place on August 30 and September 1, 2010. Filters were provided free of charge so as to obtain the largest sample size population. Fifty-five households were provided with a filter and each of the 55 households was assigned a number based on the census performed by A Mother's Wish Clinic prior to the study. House numbers were sorted by the water source from which they received water (previously shown in Table 5). Filters were distributed such that each group of homes connected to a source had an equal number of PFP and FP filters. The remaining filters were stored at A Mother's Wish to replace broken or non-functioning filters.

Prior to receiving the filter, the head of each household was required to attend an education session. Female heads of households were encouraged to attend because they are generally in charge of water and maintenance of the filter. Therefore it was most desirable that they were the individual to receive the initial use and maintenance education. However, some male heads of household did attend. The author of this thesis does not believe that there is a bias in households where males attended the initial education session because follow-up education was provided during the monthly visits to individual homes. In these visits the author of this thesis dealt almost exclusively with female heads of household and proper use and maintenance was emphasized.

The initial education session consisted of three parts: The purpose of the study, the purpose of the filter, and the proper maintenance and use of the filter. In the first part participants were reminded of the reason for the study and their role in the study, mainly allowing the investigators access to their filter for monthly testing and answering surveys to complement the data. The second part of the session explained the function of the filter and the importance of clean drinking water. Finally, the third part of the session taught participants how to properly use and maintain the filters. The same set of guidelines, a hybrid based on both the PFP and FP guidelines for cleaning the filters, were given for both filters in order to prevent any bias. The guidelines were:

1. Clean the filter every one to two weeks with hot water and the filter brush provided with the filter.

2. Wash the bucket using cold water with bleach every month.

3. Every two to three months submerge the pot filter in boiling water for two minutes.

Along with each filter a scrub brush was provided to each household with the stipulation that the scrub brushes be used solely for cleaning the CWF.

As the study progressed it became necessary to replace many filters due to malfunction and breakage. 24 of 55 (25%) filters had to be replaced over the duration of the study. Seven of the replaced filters were FP and 17 were PFP.

3.2 Laboratory Study

Three PFP filters and three FP filters were selected and transported back to the University of South Florida campus. Two of each type of filter was set up for laboratory testing, while the remaining two filters were reserved for future testing, if needed. The experiments were carried out, in the laboratories of the Civil and Environmental Engineering at the University of South Florida, but not by the author of this thesis.

3.3 Water Quality Testing

Contacts were made with a laboratory at the Superior Institute for Agriculture (Santiago, Dominican Republic), located approximately 1 hour from the field site. This laboratory was established with the help of Dr. Christine Stauber (Georgia State University). Thus the laboratory staff had previous experience performing water quality analysis, according to US-EPA standard methods, for biosand filtration studies conducted by the University of North Carolina and Rotary International. The laboratory was contracted for this study to test for total coliforms, *E. coli*, and turbidity. The microbial water quality data acquired in this study is the focus of another research project and the results will not be presented in this thesis.

3.4 First Hour Flow Rate

The majority of factories that test for flow rate do so by measuring the volume of water that flows through the filter in one hour (Rayner, 2009). This is referred to as the first hour flow rate. There are two methods for performing this measurement. The first test consists of filling the filter and measuring the effluent produced after one hour. The second test uses a calibrated “T” device to measure the change in the water height, which then corresponds to a volume of water filtered. Both methods were found to achieve similar results as is discussed in detail below.

In the first method the bucket receiving the water is first emptied by opening the spigot until no water flows out. The filter is filled to its maximum volume (8 L for PFP filters and 7 L for FP filters). After 55 minutes the spigot on the receptacle bucket is opened for five minutes and drained into a beaker as the filter continues to process water. After one hour the water has finished draining. The spigot on the bucket is closed and the volume of the water in the beaker is measured using a graduated cylinder.

In the second method a “T” device was constructed to measure the change in water height in the filter during one hour of filtration. The “T” consists of a vertical ruler which is attached to a horizontal crosspiece that sits on the rim of the filter, in order to keep the height of the ruler constant (Figure 5). The T is calibrated by placing it in an empty filter. Water is added to the filter in 250 ml increments and the corresponding height on the ruler is recorded. The addition of 250 ml is repeated and the height on the ruler is recorded each time until the filter is at its maximum capacity (8 L for PFP filters and 7 L for FP filters).

Figure 5. The T Device. The horizontal wood piece fixes the height of the ruler in the filter. The drop in water height after one hour corresponds to the amount of water filtered.

Using the 250 ml marks and the millimeter marks in between we were able to accurately measure the volume of water filtered to within 50 ml. The accuracy of the "T" method was compared to the first method at the beginning in six filters of the study and again mid-way through the study (June 2010) on greater than 40 of the first hour flow measurements performed in the field during the second week of June. The volume measurements obtained in these comparisons corresponded in every case to within 50 ml.

Because the two first hour flow rate methods provided similar results to within 50 ml, the second method was selected for measurements in the field and laboratory studies because it was faster, so, more measurements could be taken in one day. First hour flow rates were measured by filling the filter to the maximum fill line marked on the ruler of the T. Separate T's were constructed for use for PFP and FP due to their different size and shape. The maximum fill line indicated 8L for the PFP filter and 7 L for the FP filter.

In the field study the water for testing was provided by a member of the household and was either rainwater or water from one of the five surface water sources in the community. As soon as the filter was filled the time was recorded and the observer continued to the next house and filled that filter to the maximum volume. After an hour had passed the surveyor returned to the first house and measured the change in height on the T. The height was recorded and later converted to its corresponding volume. Using this method the surveyor could measure first hour flow rates in approximately 8-10 houses in two hours.

Along with the volume of water filtered, the initial saturation level (wet or dry) of the filter was recorded by visual observation. This is because the initial saturation of the filter could potentially affect the flow rate of the filter and generally was an indicator of whether the family was using their filter or not. Therefore measurements taken from dry filters were not analyzed with the rest of the data.

3.5 Falling Head Test

The first hour flow rate is a good measurement for comparing filter types and testing quality control of the manufacturing process. However, it may be a misleading parameter because the flow rate decreases as the water level (i.e. the head) drops in the filter. Therefore a filter with a first hour flow rate of 1 liter/hr will filter less than 2 L in two hours. In order to provide an idea of the rate by which the flow rate changes with the change in head, a falling head test is performed. The falling head data were also used to calculate the hydraulic conductivity of specific filters.

There are two ways to perform the falling head test. The first method is referred to as the “volume-interval method.” In this method fixed effluent volume-intervals are selected (e.g. 1, 2, 3 L). When the effluent volume reaches each interval the time is recorded. In the second method, the “time-interval method,” there are fixed time intervals (e.g. 1, 2, 3 hr, etc.) and the change in water height is recorded at each time interval. This method uses the same “T” device as the first hour flow rate but repeats the measurement several times without refilling the filter. In this case the filter is filled to its maximum capacity and the time is noted. After one hour the water level is measured using the ruler attached to the T. However, no water is added to the filter. After the second hour the water height is recorded and again no water is added to the filter. This process continues for four hours. The height of the water at each hour interval is then converted to its corresponding volume and the volume filtered during each hour can be determined.

The volume-interval method was initially used in the field, recording the time it took for the filter to discharge 1, 2 and 3 L. After the first two trials it was realized that the filters were filtering at a much slower rate than anticipated and the falling head test took too long using the chosen volume interval of 1L. Therefore, for the rest of the trials the time-interval method was used in which the change in water height is recorded at one hour intervals for a total of four hours. Water was provided by a member of the household and was either from rainwater or one of the five water sources in the community.

For the laboratory falling head tests the filter was first soaked for two hours. Then the T element was placed in the center of each filter and adjusted in order for the ruler to be perpendicular to the surface of the water. The depth in cm of the water level was recorded at hour intervals, for at least four consecutive hours. The time lapse, effluent volume, and water depth were recorded at each hour interval in the same manner as the first-hour flow test.

3.6 Modeling Flow Rate to Estimate Hydraulic Conductivity

Darcy's Law can be used to model the flow of water through a porous medium as follows:

$$Q = kA\frac{\Delta h}{L} \tag{6}$$

where:
Q = flow rate (ml/hr)
k = hydraulic conductivity constant (cm/hr)
A = surface area of porous medium (cm^2)
Δh = the change in hydraulic head (cm)
L = length (or thickness) of water path through the porous medium (cm)

Darcy's Law can be adjusted to conform to the geometry of different filter shapes and sizes. The following modeling equations, and the spreadsheets used to compare them to the actual data, were developed by Dr. Jeff Cunningham at the University of South Florida.

3.6.1 Model for Potters for Peace Filter

The Potters for Peace model used in this study is based on the truncated cone geometry developed by Fahlin (2003). It was also assumed that the thickness (d) and the hydraulic conductivity (k) are constant throughout the filter. Figure 6 shows the shape of the PFP filter with certain parameters that were measured in the laboratory.

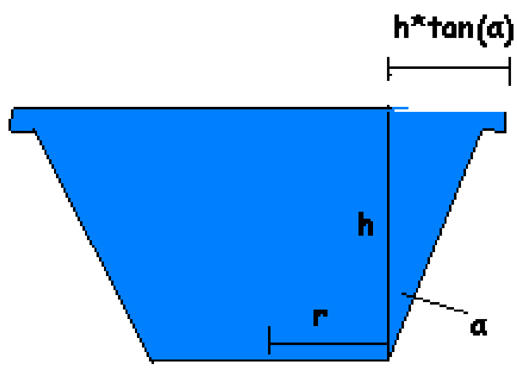


Figure 6. Assumed Geometry and Parameters Needed to Model Flow Through the Potters for Peace Filter

The sides and bottom were considered separately. Darcy's law can be applied to the bottom of the filter.

$$Q_b = \frac{k\pi r^2 h}{d} \tag{7}$$

where:
Q_b = flow rate of filter bottom (ml/hr)
k = hydraulic conductivity (cm/hr)
r = radius of bottom of filter (cm)
h = height of water (cm)
d = thickness of filter (cm)

For the sides of the filter, the slope of the walls, angle α, was determined (Figure 6). Using angle α the radius with respect to height could then be determined:

$$r(h) = r_b + h * \tan(\alpha) \tag{8}$$

where:
r_b = radius of filter bottom (cm)
α = angle of wall slope (radians)
r(h) = radius at height h (cm)

Darcy's Law (Equation 7) can be modified to accommodate for the sides of the filter by substituting Equation 8 as follows:

$$Q_s = \frac{k\pi h^2}{d}\left[r_b + \frac{1}{3} h tan(\alpha)\right] \tag{9}$$

where:
Q_s = flow rate of filter sides (cm)

Finally Q_b and Q_s can be combined to create Equation 11 which provides the flow rate for the entire filter:

$$Q = Q_S + Q_B \tag{10}$$

$$Q = \frac{k\pi}{d}\left[r_b^2 h + h^2 (r_b + \frac{1}{3} h\, tan\alpha)\right] \tag{11}$$

In order to calculate the hydraulic conductivity (k) Equation 11 is written in terms of $\frac{dh}{dt}$ using Equations 12 and 13 to produce Equation 14:

$$\frac{dV}{dt} = \frac{dh}{dt}\left[\pi (r_b + \frac{1}{3} h\, tan\alpha)^2\right] \tag{12}$$

$$-Q = \frac{dV}{dt} \tag{13}$$

$$\frac{dh}{dt} = \frac{-k}{d}\left[\frac{\frac{1}{3}h^3 \tan\alpha + h^2 r_b + r_b^2 h}{(r_b + h\tan\alpha)^2}\right] \tag{14}$$

Then dh/dt can be written in a different form (Equation 15) and then rearranged to give the height of the water at time t + Δt (Equation 16).

$$\frac{dh}{dt} = \frac{h(t+\Delta t) - h(t)}{\Delta t} \tag{15}$$

$$h(t+\Delta t) = h(t) - \frac{k\Delta t}{d}\left[\frac{\frac{1}{3}h^3 \tan\alpha + h^2 r_b + r_b^2 h}{(r_b + h\tan\alpha)^2}\right] \tag{16}$$

3.6.2 Model for FilterPure Filter

The FilterPure model assumes a bowl shape (Figure 7) with a geometry described using Equation 17.

$$r = ah^n \tag{17}$$

where:
r = radius at height h (cm)
h = height of filter (cm)
n = constant <1
a = constant

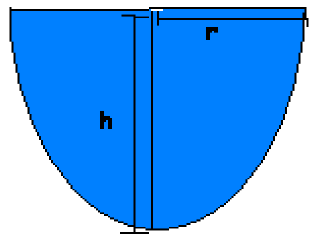


Figure 7. Assumed Geometry and Parameters Needed to Model Flow Through the FilterPure Filter

Using Equation 17 the values for the constants a and n can be determined graphically, based on the measured values of height (h) and radius (r). Once the geometry of the filter is determined it can be used to adapt Darcy's law (Equation 7) to the FP filter. The flow rate Q for the FP filter can be written as follows:

$$Q = \int_0^{2\pi} \int_0^{h} k \nabla h \, r \, dz \, d\theta \tag{18}$$

where:

$$\nabla h = \frac{h - z}{d} \tag{19}$$

z = height of the water

When equations 17 and 19 are substituted into Equation 18 and the integrals are taken Equation 20 is obtained:

$$Q = \frac{2\pi a k}{d(n+1)(n+2)} h^{n+2} \tag{20}$$

As with the Potters for Peace model, Equation 20 can be written in terms of $\frac{dh}{dt}$ by relating the flow rate to the change in volume within the filter using Equation 13. In this case:

$$-Q = \frac{dV}{dt} = \frac{dh}{dt}(\pi a^2 h^{2n}) \tag{21}$$

and therefore,

$$\frac{dh}{dt} = \frac{-2k}{ad(n+1)(n+2)} h^{2-n} \tag{22}$$

Equation 22 can be solved to provide the height of the water after time Δt (Equation 23):

$$h = \left(h_0{}^{(n-1)} + \frac{2k(1-n)\Delta t}{ad(n+1)(n+2)}\right)^{\frac{1}{n-1}} \tag{23}$$

where:
h_0 = initial water height (cm)

Using Equation 16 for PFP filters and Equation 23 for FP filters a spreadsheet can be developed which compares the estimated values of water height to the actual values. The hydraulic conductivity variable k is adjusted until the best fit is achieved. This is presented in section 4.3.3.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Field First Hour Flow Rates

The first hour flow rate was measured monthly in the field study, during months 7 – 13 (March 2011 – September 2011) after the initial filter distribution. Because of time constraints and in an effort to achieve consistent results, the first hour flow rate test was performed during one day each month. As such only households that had somebody home on that particular day were sampled. This resulted in approximately 30 - 40 filters being measured each month.

Up until June 2011 first-hour flow tests were performed during the second week of the month in order to keep equal spacing between measurements. In June, measurements were taken twice, in the second and fourth weeks of the month. All measurements from July 2011 forward were taken during the fourth week of the month. See Table 6 for an overview of all of the field tests completed in each month.

Table 6. Field Test Schedule. Two first hour flow rate tests were performed in June. The usage month is the number of months that have passed since the initial filter distribution in September 2010.

Field First Hour Flow Rate Calendar										
2011 Month		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
(Month of Use)		5	6	7	8	9	10	11	12	13
Test Performed (X)				X	X	X	XX	X	X	X

Out of the 55 (26 FP and 29 PFP) filters that were originally distributed in the community, only 31 (19 FP and 12 PFP) of the original filters were still in use at the end of study. The other 24 households either had their filter replaced at some point during the study or never used their filter regularly enough to be part of the study. Table 7 provides the reasons for filter removal. Because the overall objective of this study was to monitor filter performance over time, these 24 households were removed from the main study, as their replacement or unused filters were no longer on the same timeline as the original filters. Unless otherwise noted, all figures and tables in this section refer only to the 31 filters that were in use for the entire thirteen-month study.

Table 7. Filters Removed from Study Listed by Cause for Removal. The 24 households that were removed from the study were separated into four categories. (1) Filters which had unacceptably slow flow rates. (2) Filters which broke. (3) Households that moved from the community. (4) The filter was never or rarely used.

	Number Removed		
	Overall	FP	PFP
Reason for Removal	initial n=55	initial n=26	initial n=29
Slow	8(15%)	0	8
Broke	7(13%)	4	3
User Moved	2(4%)	1	1
Never Used	7(13%)	2	5
HH Removed	24(44%)	7	17
HH Remaining	31(56%)	19	12

Eight of the 29 (29%) PFP filters originally distributed had to be removed because their first hour flow rates were found to decrease to unacceptably low levels over time. Therefore, a standard for filter replacement was developed. Filter owners with filters that had first hour flow rates of 250 ml/hr or less were instructed to scrub the inside of the filter vigorously to try to increase the flow rate. If in the following month the flow rate had not increased then the filter was replaced with a new filter. It is possible that the flow rates of the filters increased initially after the scrubbing. However, as van Halem (2006) showed, the flow rate quickly decreases back to its previous state within a short time period. Because this study tested on a monthly interval, an increase in flow rate of the scrubbed filters was never observed. Households with filters that filtered 250 ml/hr or less for two consecutive months were also provided a new filter if they requested it. The threshold for replacement was established at 250 ml/hr because in surveys and conversations in the field, there was very little discontent among filters with filters that had first hour flow rates above 250 ml/hr. Below 250 ml/hr users generally expressed concern to the researchers over a lack of water quantity. Although these eight PFP filters with inadequate flow rates were removed from the study early on, they do have relevance to the research objectives as they show a very rapid decrease in first hour flow rate over time. Therefore certain sections of the Results and Discussion chapter will refer to this subset of eight filters. The remaining 16 filters that were removed from the study are not considered in the discussion of the first hour flow results.

4.1.1 Individual Filter First Hour Flow Rates

The individual filter first hour flow rate averages for the study are presented in Table 8 along with the standard deviation and sample size. The filters listed in the table are the 31 filters which lasted through the entire study and thus will be the basis for most of the analysis and discussion. Notice that there are eight more FP filters than PFP filters.

This difference is mainly due to the removal of eight PFP filters for inadequate flow rates.

Table 8. First Hour Flow Rate Averages for Individual Filters. The overall study average is shown for each filter along with the standard deviation and sample size.

Individual First Hour Flow Rate Averages (ml/hr)							
FilterPure	(n=19)			Potters for Peace (n=12)			
Filter #	Study Average	Std Dev	Sample size (n)	Filter #	Study Average	Std. Dev.	Sample Size (n)
272	740	230	6	233	950	210	5
221	430	250	6	244	290	40	8
225	440	190	6	246	290	110	8
227	590	190	6	248	330	130	8
228	530	160	7	249	220	80	6
241	790	300	7	252	760	350	8
242	290	140	7	259	500	70	8
243	440	80	8	261	850	330	8
251	510	90	8	267	180	50	7
253	530	180	7	276	460	60	7
257	540	40	7	278	370	30	5
263	910	120	8	280	325	276	5
264	300	70	7				
265	540	50	7				
266	300	70	7				
270	550	100	4				
275	530	80	6				
277	790	50	7				
245	670	370	5				

The average first hour flow rates for FilterPure filters ranged from 290 ml/hr to 910 ml/hr. Standard deviations ranged from 40 ml/hr in filter 257 up to 370 ml/hr in filter 245. PFP first hour flow rates ranged from 180 ml/hr to 950 ml/hr with standard deviations from 30 ml/hr up to 350 ml/hr. No filter, FP or PFP, had an average first hour flow rate at, or above, the minimum requirement of 1 liter per hour set by filter manufacturers (see information presented previously in Table 3).

4.1.2 Comparison of FilterPure and Potters for Peace First Hour Flow Rates

The first goal of the first hour flow rates was to compare the hydraulic performance of the FP and PFP filters. During the seven months of the first hour flow rate testing the FilterPure filters produced an overall average (n=123) first hour flow rate of 550 ml/hr with a standard deviation of 250 ml/hr while the Potters for Peace filters produced a first hour flow rate average (n=86) of 450 ml/hr with a standard deviation of 290 ml/hr (see Table 9). The Potters for Peace average would have been lower had the subset of eight unacceptably slow filters not been changed out. The lower 95% confidence interval of the FP first hour flow rate average is equal to the upper 95% confidence bound of the PFP average.

Table 9. First Hour Flow Rate Averages with Confidence Intervals Over Entire Study

Field First Hour Flow Rate (ml/hr)		
	FP	PFP
Average	550	450
Std. Dev.	250	290
Sample Size	123	86
Upper 95% Conf. Interval	590	510
Lower 95% Conf. Interval	510	390

Figure 8 provides a histogram of the average first hour flow rates of FP and PFP filters over the eight trials. By looking at the distribution of first hour flow rate averages of each filter a better sense of the overall performance of each type of filter is obtained. Notice that the highest frequency (42%) of first hour flow rate average for FP is in the 500 to 599 ml/hr interval. This agrees with the overall average for FP filters which was 550 ml/hr. However the highest frequency (27%) of PFP first hour flow rates is in the 200 to 299 ml/hr interval and the second most frequent (18%) first hour flow rate is in the 300 to 399 ml/hr interval. Meanwhile the overall average is 450 ml/hr. However, the PFP distribution also shows several occurrences (27%) of filters in the upper ranges from 700 ml/hr to 999 ml/hr. This wide distribution of first hour flow rates accounts for PFP's higher standard deviation and larger 95% confidence intervals.

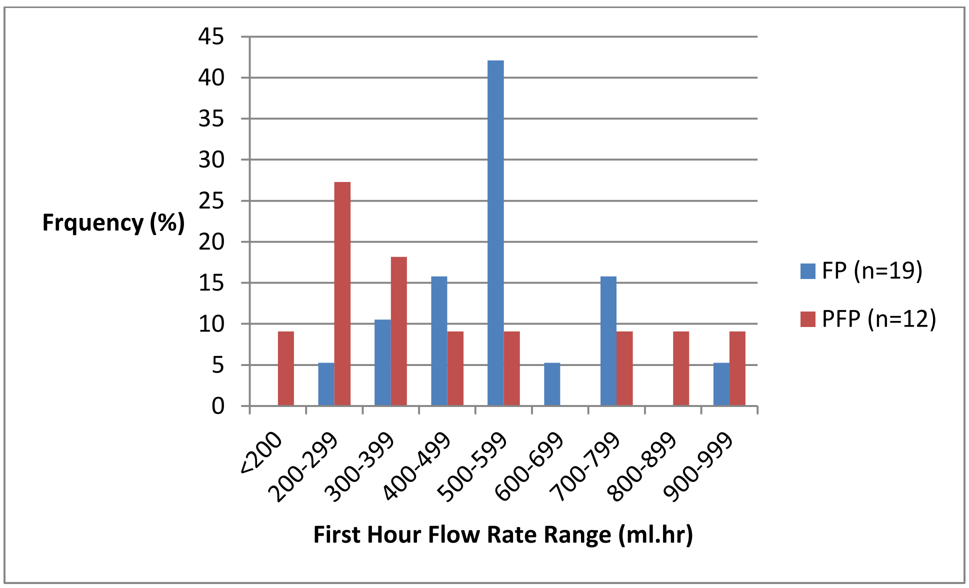


Figure 8. Distribution of First Hour Flow Rate Averages of Individual Filters. The frequency is given as a percentage of total sample size.

4.1.3 Change in First Hour Flow Rate Over Time

The second goal of the first hour flow rate tests was to determine whether there was a trend over time in the hydraulic properties of the FP and PFP filters. First hour flow rate data were only collected from months 7-13 of the study so all discussion and conclusions will refer to flow rate trends within this time period. Figure 9 provides the average monthly first hour flow rate for the filters sampled each month. Table 10 provides the averages for each first hour flow rate trial as well as the sample size and standard deviation.

The linear trend line fitted to the monthly FP averages in Figure 9 shows a slight -7 ml/hr per month decrease during the seven months of testing. The linear trend line fitted to PFP monthly averages shows a +31 ml/hr per month increase during the seven months.

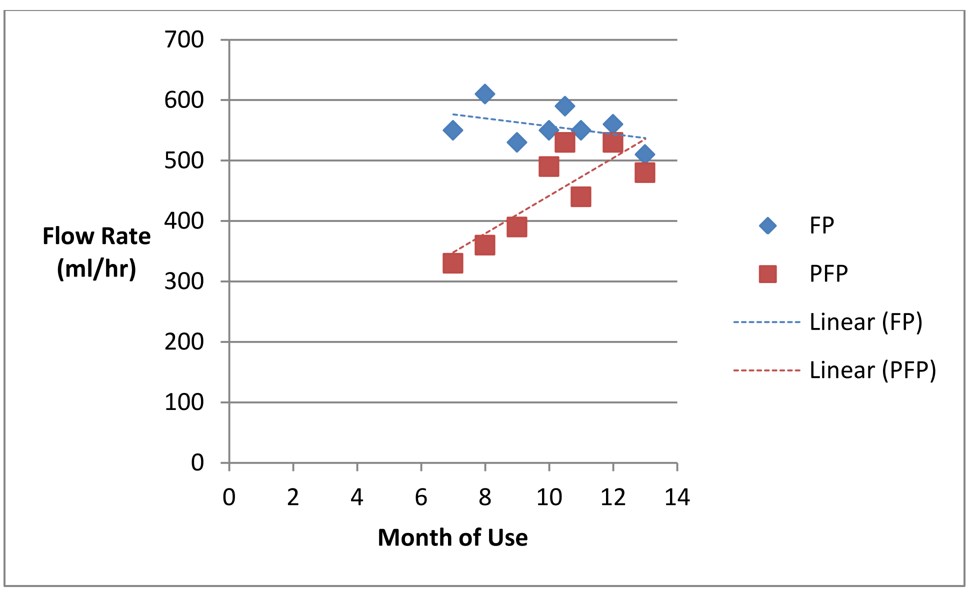


Figure 9. Average Monthly First Hour Flow Rates Observed in the Field for FilterPure and Potters for Peace Ceramic Filters During Months 7-13.

Table 10 shows the standard deviations for the monthly averages for both filter types. FP standard deviations are fairly consistent, remaining between 200 – 290 ml/hr except for month 10(4) where the standard deviation is 360 ml/hr. Standard deviations for PFP show a large increase from month 9 to month 10(2) from 100 to 420 ml/hr. This occurs at the same point in the study where PFP shows the largest increase in first hour flow rate, jumping from 390 ml/hr to 490 ml/hr. Figure 10 provides a different visual representation of overall changes in first hour flow rate for each filter type.

Table 10. Average First Hour Flow Rates Observed in the Field for FilterPure and Potters for Peace Ceramic Filters During Months 7-13. The standard deviation and number of households (n) are listed below each month's average.

	Month(Wk)	7	8	9	10(2)	10(4)	11	12	13
FP	Avg.	550	610	530	550	590	550	560	510
	Std. Dev.	230	200	220	210	360	230	250	290
	n	13	14	16	15	15	18	16	15
PFP	Avg.	330	360	390	490	530	440	530	480
	Std. Dev.	180	140	100	420	380	260	300	350
	n	9	11	9	12	12	11	11	11

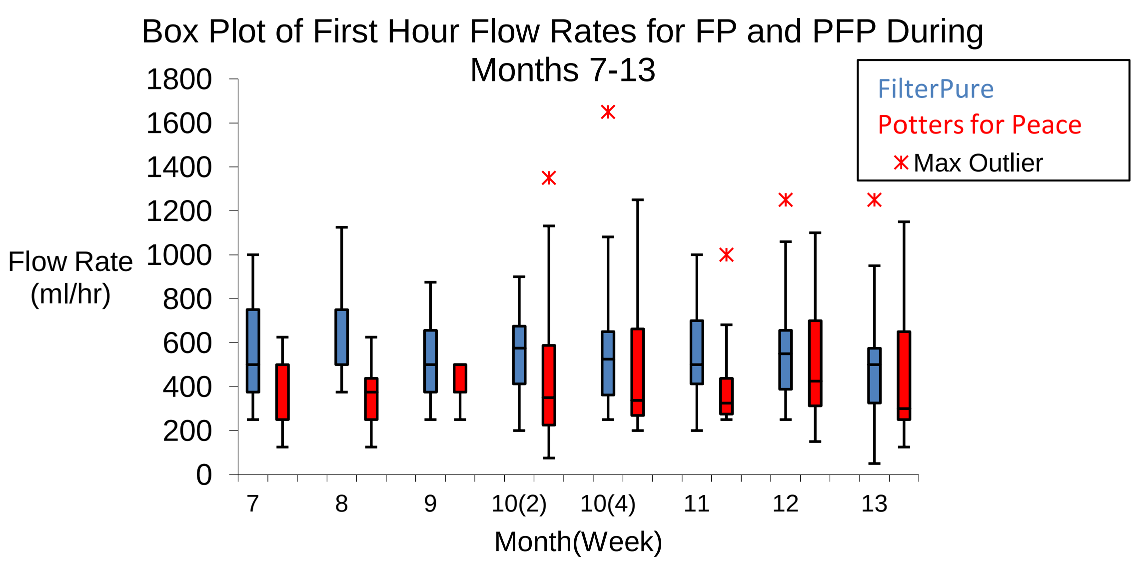


Figure 10. Box Plot of First Hour Flow Rate for FP and PFP Filters During Months 7-13. FP is represented by blue boxes and PFP is represented by red boxes.

The red boxes, which represent PFP filters, show a smaller range between months 7 – 9 when the standard deviation is smaller. When the standard deviation increases between months 9 and 10 the boxes become much larger, owing to a greater range of first hour flow rates. However, the median first hour flow rate for PFP stays within the range of 200 – 400 ml/hr though all seven months of testing. In month 8 the first hour flow rate average is 360 ml/hr and the median first hour flow rate is 375 ml/hr. In month 10(4) when the average first hour flow rate reaches its highest value (530 ml/hr) the median first hour flow rate is 340 ml/hr. It appears that the increase in first hour flow rate did not occur in all of the filters but rather in the filters that had first hour flow rates above the average median first hour flow rate of 340 ml/hr. Table 11 provides closer examination of the PFP filters that had first hour flow rates above the average median and with standard deviations greater than 70. These filters experienced the largest variation in first hour flow rate, and thus had the greatest influence of change in overall first hour flow rate.

Table 11. PFP Filters with First Hour Flow Rates Above Median and Standard Deviations Above 70.

PFP filters in Upper Flow Rate Range with High Standard Deviations										
Filter #	Avg.	Std. Dev.	7	8	9	10(2)	10(4)	11	12	13
233	950	210	n/a	1000	1000	1000	n/a	n/a	650	1150
252	760	350	250	375	375	1100	1000	1000	950	1000
261	850	330	500	500	500	1350	1150	900	1100	800
		Avg.	375	625	625	1150	1075	950	900	983

Table 11 also shows where the increase in overall first hour flow rate average occurs. PFP filters 252 and 261 experience very large increases between months 9 and 10(2) and then continue to maintain higher flow rates for the rest of the first hour flow rate tests. Because the sample size of PFP filters is 12, these changes have a very large influence, both on the average first hour flow rate and the standard deviation of the PFP filters.

It is possible that filters 252 and 261 were slightly cracked, which increased their flow rate. Other PFP filters during the study had to be removed due to large cracks appearing in the filter membrane. However, visual observation by the author did not reveal any noticeable cracks. Furthermore, water quality data taken in a different study performed on the same filters continued to show removal of total coliforms similar to the removal shown before the first hour flow rate increase. Therefore the filters were not removed from the study.

4.1.4 Discussion of Field First Hour Flow Rate

The two main findings of the field first hour flow rate testing were that (1) the first hour flow rate of FP filters is, on average, 100 ml/hr greater than that of PFP filters, and that (2) FP filters were more consistent in their hydraulic performance with regard to first hour flow rate while PFP experience an overall average increase of 31 ml/hr per month. A secondary finding of the first hour flow rate tests is that FP has less of a problem with inadequate flow rates than PFP filters within the time period of this field study. Eight out of the 29 (26%) PFP filters had to be replaced within the first nine months of use due to unacceptably slow or zero flow rates. None of the FP filters had to be replaced due to slow flow rates. The reason for the difference is likely because of different production variables related to quality control at the point of manufacturing.

There did not appear to be any major fouling of filters in this study. Van Halem (2009) performed an in depth study of fouling mechanisms in PFP filters and found that the slowing of the flow rate is due mainly to inert particles and natural organic matter (NOM) clogging the internal pore structure. The removal of larger particles on the surface of the filter by scrubbing only temporarily increased the flow rate but due to inert particles and NOM inside the filter membrane there is an overall decrease in the flow rate over time, approaching zero ml/hr. One reason for not experiencing major fouling during this study could be the relatively low turbidity of the raw water used in the community.

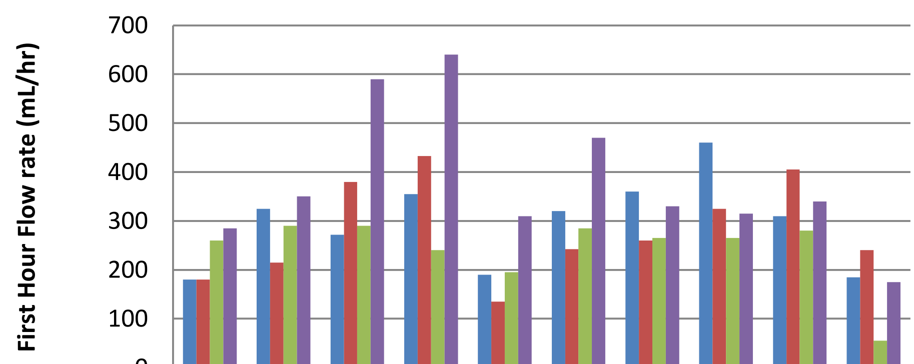
The two manufacturing variables most likely to affect this issue of inadequate flow are the different raw materials mixes and the silver application of the filters. FP pulverizes their sawdust and passes it through a 0.30 μm sieve in an attempt to obtain a consistent pore diameter of 1.3 μm after firing (Lantagne, 2010). The PFP Nicaragua manual instructs the use of a basic wire mosquito screen to sieve the sawdust, which has holes of approximately 2.4 mm (Rayner, 2009). This allows a larger distribution of sizes of sawdust particles to into the mix and should result in a less uniform pore size with some very large pores and some very small pores. This can be confirmed by visual observation of the two filters by the author. It is possible that larger pore openings on the surface of the PFP filter allow larger inert particles to enter the internal pore structure of the filter where they become stuck in smaller internal pores. FP filters' smaller pores may be able to resist penetration by larger particles.

It is also possible that the distinct silver application methods of the two filter manufacturers have a different influence on the accumulation of biological material in the filter pores. For example, Van Halem (2009) found that rinsing the filters with a chlorine solution, and thus oxidizing the NOM inside of the filter membrane, increased the flow rate by almost three fold. The painted-on application of silver for PFP filters has been shown not to penetrate deep into the filter (van Halem, 2006). This would allow biological material to accumulate in the interior of the filter where they don't come into contact with silver. FP claims to add significantly more silver to their mix than PFP. They also add the silver into the wet mix so that it is believed to disperse evenly throughout the filter membrane. This could result in more consistent oxidation of NOM in the filter membrane, preventing clogging of the internal pores. This could be tested by producing several FP filters without silver and comparing the flow rate over time to the silver impregnated filter.

Although the FP filters performed better than the PFP filters with regard to the first hour flow rate, neither of the filters achieved the minimum flow rate expectations of 1,000 ml/hr reported by the filter manufacturers, (provided previously in Table 3). This agrees with Van Halem's (2006) findings for PFP filters from Nicaragua and Cambodia in which the flow rate of PFP filters, after 12 weeks of testing, had all decreased to below 0.5 L/hr. Lantagne (2010) also found similar findings for FP filters, in which the flow rate ranged from 0.46 L/hr to 0.64/L/hr over a six week study. There were zero filters evaluated in this study, from either manufacturer, that averaged 1,000 ml/hr or greater over the seven month first hour flow rate test period.

4.2 Laboratory First Hour Flow Rate

Because first hour flow rate data were not obtained during the first few months of operation in the field, laboratory experiments were conducted to understand better how the filters may have performed during the first 2-3 months of the study. Using surveys (Appendix D) and observations made by the author in the field it was determined that, on average, filter users in the field tests in the Dominican Republic were filtering approximately 80 L per month. (See Appendix E for explanation of this estimation.) This value of 80 L per month was used to determine the lab equivalency of one month of filter use in the field site based on total volume of water processed by each filter. Figure 11 provides a graph of the first hour flow rate measurements taken for each of the four filters measured in the laboratory.



	0	1(1)	1(2)	1(4)	1(5)	2	3	5	9	10
	25-Feb	4-Mar	8-Mar	10-Mar	8-Apr	15-Apr	22-Apr	6-May	2-Jun	9-Jun
FP 1 (mL)	180	325	272	355	190	320	360	460	310	185
FP 2 (mL)	180	215	380	433	135	242	260	325	405	240
PFP 1 (mL)	260	290	290	240	195	285	265	265	280	55
PFP 2 (mL)	285	350	590	640	310	470	330	315	340	175

Figure 11. Laboratory First Hour Flow Rate. The horizontal axis gives the field study week equivalent for each trial with the actual date below it. Week 0 represents the first ddition of water. Four trials were done during Week 1 so the day equivalent is listed in parentheses next to the week.

During the first week equivalent the first hour flow rate increased in all of the filters until day 5 when the first hour flow rate dropped for all four filters. After day 5 the first hour flow rates of FP filters began to increase once again. The PFP filters increased again initially and then began to level off. However, in week 10 there is another large observable decrease in the first hour flow rates of all four filters. After the first decrease in first hour flow rate in week 1 filter PFP2 never returned to perform as it had in days 0 to 4. All hydraulic tests that were performed in the laboratory were performed with tap water which has turbidity <1 NTU. However the filters were spiked intermittently with pond water obtained from the USF Botanical Gardens for a separate study evaluating the change in water quality of the filters over time (data not provided here). The pond water had a turbidity that ranged from 10 to 60 NTU for these tests. This water was added on April 12 (i.e. between weeks 1 and 2) and continued to be added in between each first hour flow rate test on 4/20, 4/25, 5/12, 5/24, and 6/2 (before first hour flow test). No strong conclusions can be drawn correlating the spikes of pond water to the flow rate trends.

4.3 Falling Head Test

In the field three FP filters and three PFP filters were initially selected for the falling head tests. However, because of the slow filtration rates of the filters, and the difficulty of performing multi-day falling head tests in the field, no falling head data were obtained that are usable for determining the hydraulic conductivity.

In the laboratory falling head tests were performed to include data points after 24 hours to see the volume of water filtered in one full day. This is important, as it was rare to observe filter users in the field who filled their filter more than once per day. These data were used to calculate the hydraulic conductivity, as well to better understand the change in cumulative volume based on first hour flow rate. Figure 12 shows the cumulative volume produced during the March 8 laboratory falling head tests.

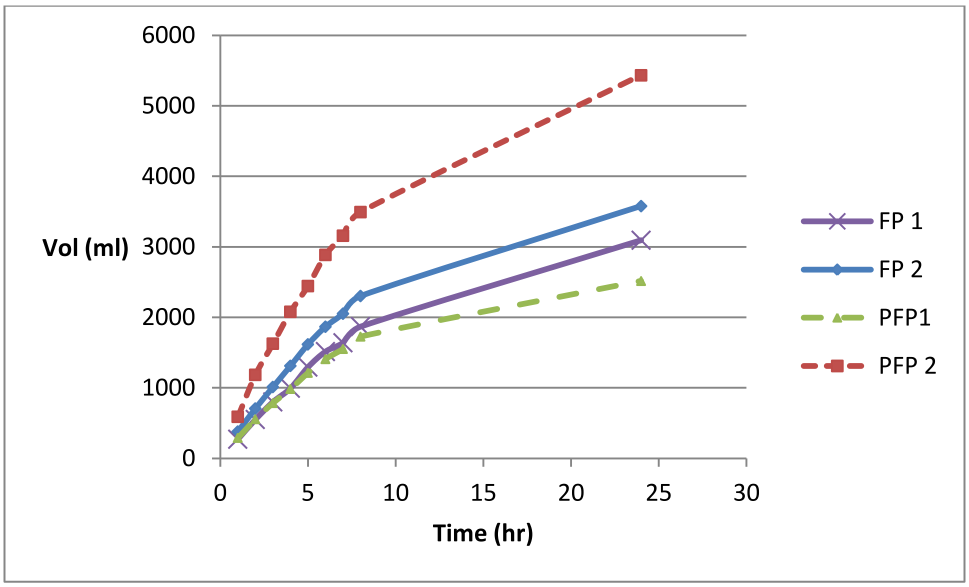


Figure 12. Cumulative Volume Processed by Filters in Laboratory in 24 Hours.

As shown in Figure 12 a 300 ml/hr difference in the first hour flow rates of PFP1 and PFP 2 results in a 2,918 ml difference in the total effluent volume after 24 hours. PFP1, which has a first hour flow rate of 290 ml/hr, produces 2,515 ml of water in 24 hours. This equates to approximately 0.5 L/person/day for a household of five. PFP2, which has a first hour flow rate of 590 ml/hr, produces approximately 5,433 ml of water in 24 hours. This equates to approximately 1.1 L/person/day for a household of five. This means that a filter that has an initial first hour flow rate of 590 ml/hr could potentially produce sufficient water for a household. However if, over time, the first hour flow rate of the filter decreases by 300 ml/hr it will no longer produce a sufficient quantity of water for a household of five.

4.3.1 Modeling Flow Rate with Hydraulic Conductivity: Potters for Peace Model

In the laboratory falling head tests the water height was measured over eight hours. The water height and change in time were compared with the models that were described previously in the Methods section. The models were then compared to the actual data and adjusted to provide the best fit. Table 12 provides the measured data used in the following analysis.

Table 12. Laboratory Falling Head Test Data.

Δt	Water Height (cm)			
(hrs)	FP1	FP2	PFP1	PFP2
0	24	23.9	21.7	21.4
1	23.3	23	21	20.5
2	22.9	22.4	20.6	19.3
3	22.4	21.8	20.1	18.3
4	21.6	20.9	19.8	17.5
5	21.4	20.4	19.4	16.5
6	20.5	19.3	18.6	15.6
7	20	18.4	18.5	15
8	19.3	17.7	18.1	14.1

For the PFP filters Equation 16 is used to estimate a predicted change in water level. The equation is used in an Excel spreadsheet (see Appendix F for spreadsheet) which predicts the water change for intervals of 0.1 hours over eight hours. The spreadsheet also shows the measured values for the variables α and r_b, which in this case are α = 0.152 radians and r_b = 9.5 cm. The variable k is used as the fitting parameter. The value for k is modified until the error between the actual data points and the predicted line is as low as possible. The estimated and actual height versus time data are graphed (Figure 13 and Figure 14).

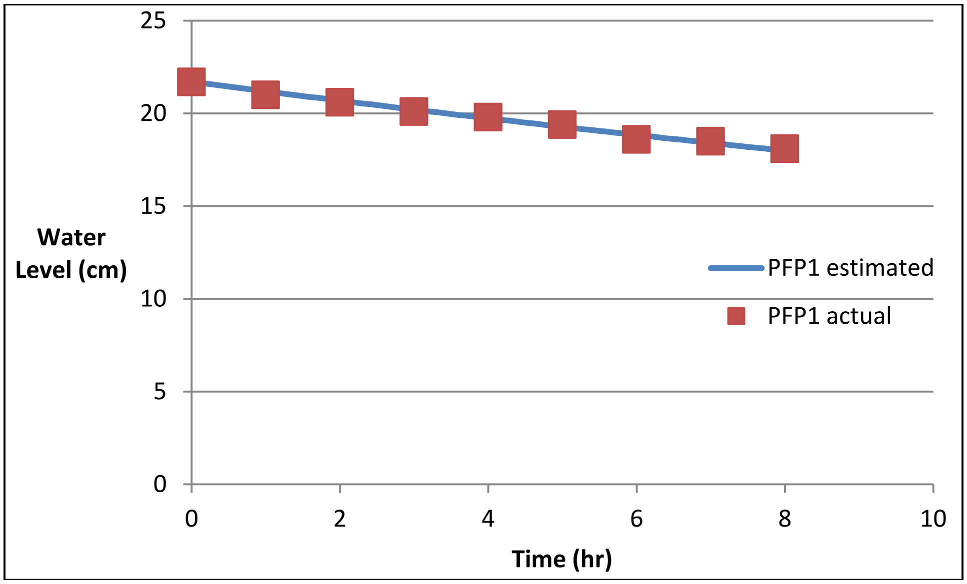


Figure 13. Water Height versus Time for Filter PFP1. The best fit was achieved with a hydraulic conductivity of k = 0.0161 cm/hr.

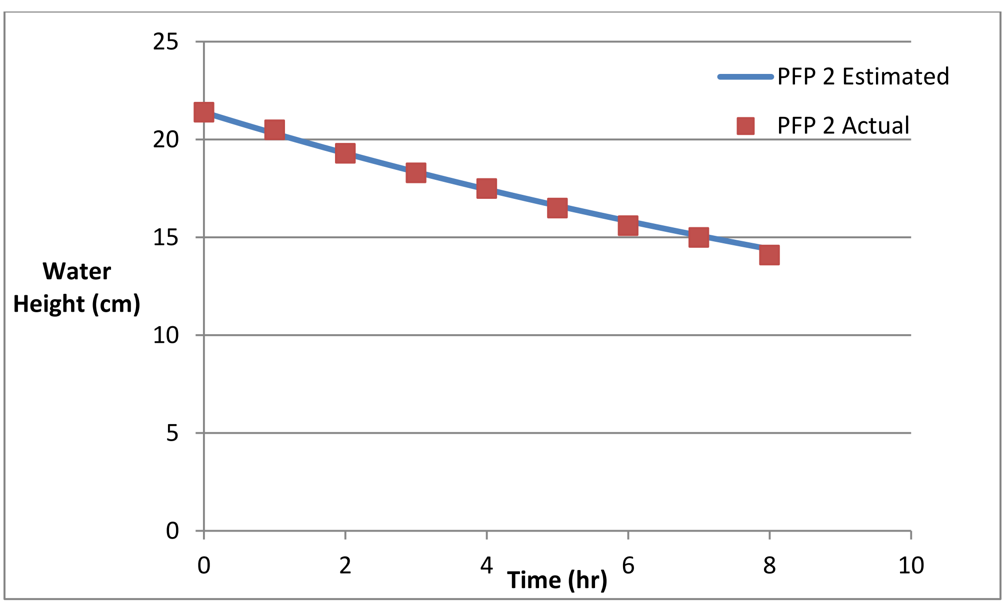


Figure 14. Water Height versus Time for Filter PFP2. The best fit was achieved with a hydraulic conductivity of k = 0.0351 cm/hr.

The modeled line and actual data fit very well for PFP1 and PFP2. Filter PFP1 achieves the best fit when a hydraulic conductivity k = 0.0161 cm/hr is used, while PFP2 achieves the best fit with a hydraulic conductivity k = 0.0351 cm/hr. It was expected that filter PFP1 would have a lower hydraulic conductivity than filter PFP2 because the hydraulic conductivity is proportional to the flow rate (Q) and filter PFP2 has a higher flow rate than filter PFP1.

The k values were used to calculate an estimated flow rate (Q_e) value for each interval using Equation 10. The estimated cumulative volume processed is then compared to the actual cumulative volume processed (Figure 15). The actual cumulative volume for Filter PFP 1 agrees very well with the model. However, the model slightly underestimates the cumulative volume of PFP2.

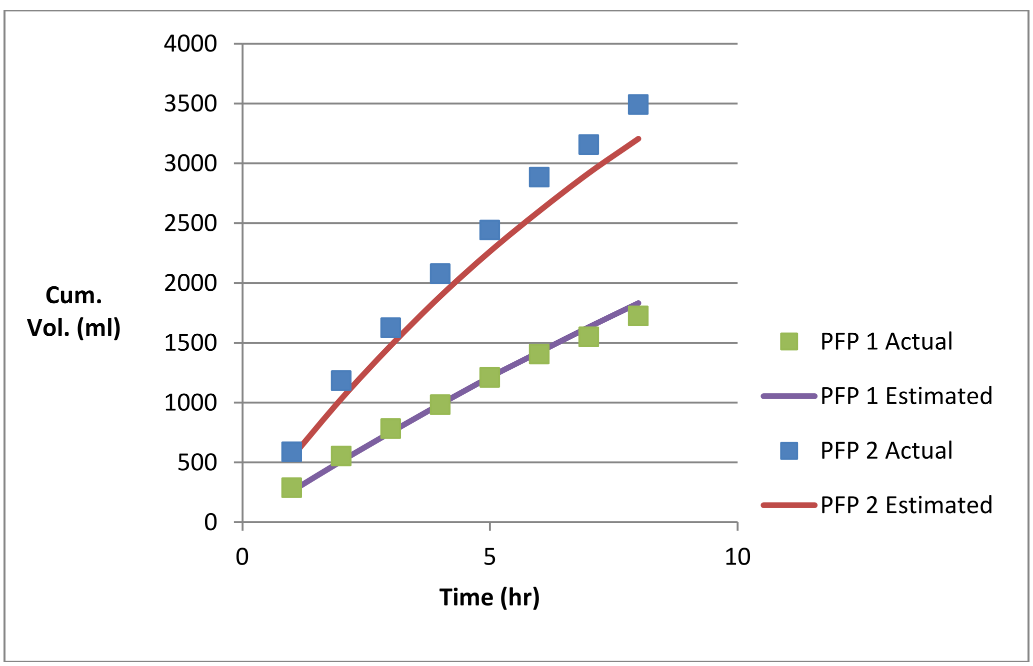


Figure 15. Cumulative Volume Processed vs. Time for Actual and Estimated Flow Rates for Filters PFP1 and PFP2.

4.3.2 Modeling Flow Rate with Hydraulic Conductivity: FilterPure Model

In order to estimate the value for coefficients "a" and "n", which describe the geometry of the FP filter, four measurements were taken of the radius of the filter at different heights. The four data points were plotted and a polynomial equation was fit to provide an equation in the form of Equation 17 (Figure 16). In this case the values obtained were a = 13.2 and n = 0.187.

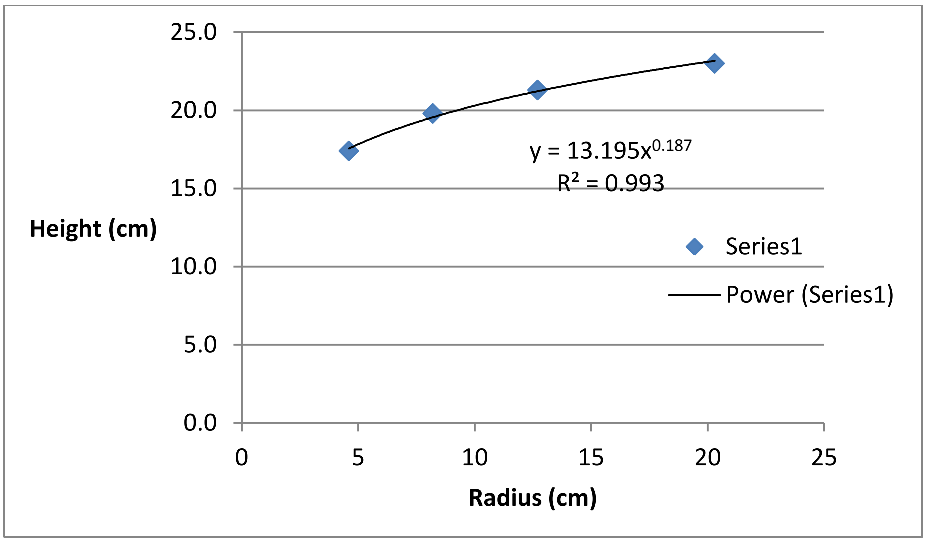


Figure 16. Graphical Representation of FP Filter Geometry.

The FP filter falling head data was evaluated using Equation 23 to estimate the water height at $\Delta t = 0.1$ hr from 0 to 8 hours. As with the PFP falling head data, a spreadsheet was created (Appendix G) which allowed the hydraulic conductivity, k, to be modified until the sum of the errors between the model and the actual data points was minimized. The model was graphed with the actual data points (Figure 17 and Figure 18).

The data in Figure 17 provides the best fit when filter FP1 has a hydraulic conductivity of k = 0.0534 cm/hr. The data in Figure 18 provides the best fit when filter

FP2 has a hydraulic conductivity of k = 0.0752 cm/hr. As expected, filter FP2 has a higher k value than FP1 because it has a higher first hour flow rate.

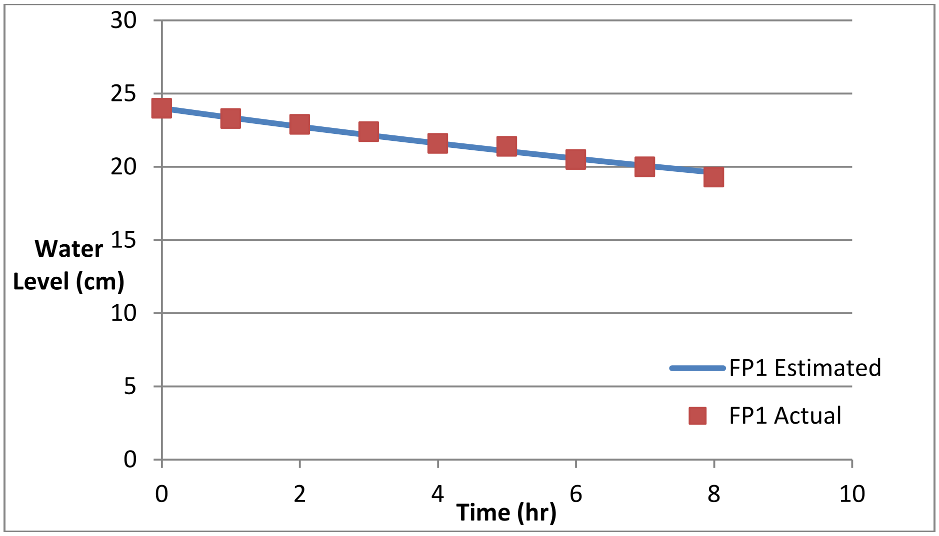


Figure 17. Water Height versus Time for Filter FP1. The best fit was achieved with a hydraulic conductivity of k = 0.0534 cm/hr.

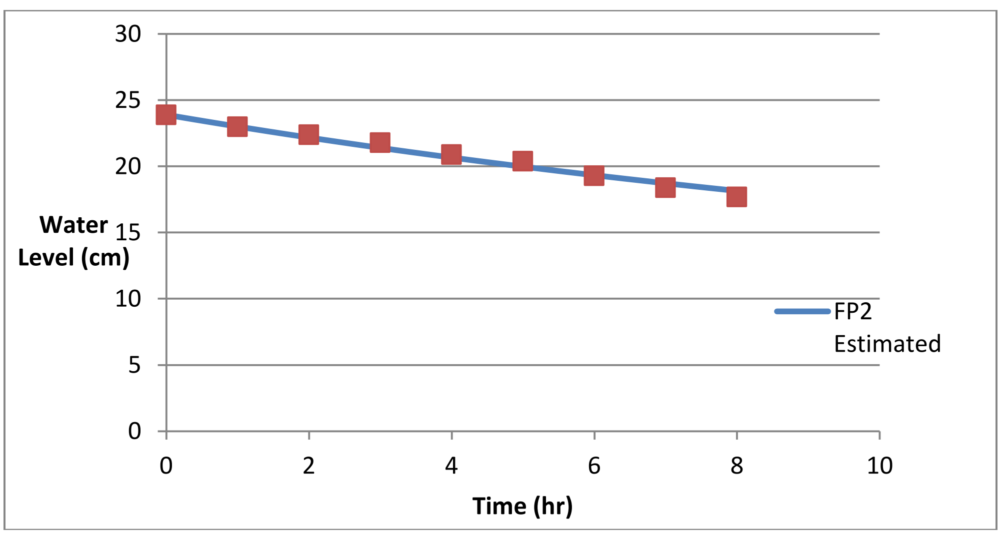


Figure 18. Water Height versus Time for Filter FP2. The best fit was achieved with a hydraulic conductivity of k = 0.0752 cm/hr.

4.3.3 Discussion of Hydraulic Conductivity

The same process as in Sections 4.3.1 and 4.3.2 were performed for a second set of data from falling head tests done on the same four filters in the laboratory. Table 13 summarizes the results for the first hour flow rates and hydraulic conductivities obtained for the four laboratory filters for the March 8 and March 10 falling head tests. For each model the hydraulic conductivity is proportional to the first hour flow rate. Filter FP1 has a lower flow rate than FP2 and therefore it also has a lower hydraulic conductivity. Also, when first hour flow rates increase for the same filter (e.g. FP1 on March 8 versus FP1 on March 10) the hydraulic conductivity also increases. The same holds true for the PFP filters.

Table 13. First Hour Flow Rate and Hydraulic Conductivity for Four Laboratory Filters

Date		PFP1	PFP2	FP1	FP2
8-Mar	1st Hour Flow Rate (ml/hr)	290	590	272	380
	k (cm/hr)	0.0161	0.0351	0.0534	0.0752
10-Mar	1st Hour Flow Rate (ml/hr)	240	640	355	433
	k (cm/hr)	0.0094	0.0390	0.0720	0.0950

The hydraulic conductivity for PFP filters was lower than that of the FP filters even when the flow rate of the PFP filter was higher (Table 13). Filter PFP2 had a first hour flow rate of 590 ml/hr but hydraulic conductivity k = 0.0351 cm/hr. Filter FP2 had a smaller first hour flow rate of 380 ml/hr but a greater hydraulic conductivity k = .0752 cm/hr. However, as was shown in Figure 12 filter PFP2 produced a greater volume of water than filter FP2. Therefore, it is determined that the first hour flow rate is a better indicator of long term effluent production than hydraulic conductivity by itself. Without its corresponding modeling equation the hydraulic conductivity (k) cannot predict whether one filter will produce a greater volume of water over time.

The higher hydraulic conductivity of FP filters might be due to the production variables influencing pore size and consistency as was discussed in Section 4.1.5 concerning the first hour flow rate. This is the most likely explanation for both the higher hydraulic conductivity of the FP filters and their higher overall first hour flow rate.

The range of k values for the PFP filters is similar to the hydraulic conductivity values obtained by the van Halem model (2006) which estimated a range of 0.0157 – 0.0433 cm/hr. The hydraulic conductivity values for Lee (2001), Fahlin (2003), and Miller (2010) were all an order of magnitude higher (Table 14). However Miller and Lee were observing different types of filters and the filters in the Fahlin (2003) study had higher flow rates (1,400 to 2,700 ml/hr) than in the van Halem study and this study.

Table 14. Comparison of Hydraulic Conductivity Results with Previous Research.

Study	Model	Hydraulic Conductivity (k) (cm/hr)	Flow Rate (ml/hr)
Lee(2001)	disk	0.162	n/a
Fahlin (2003)	PFP	0.171 – 0.325	1,400- 2,700 *
van Halem (2006)	PFP	0.0152 – 0.0433	600-1,500 *
Miller (2009)	Parabaloid Filter	0.227 – 0.272	1,000 (avg. n=6)
Peabody (2012)	PFP	.0094 - .0390	240 – 640
Peabody (2012)	FilterPure	.0534 - .0950	270 - 430

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

5.1 Conclusions for the Field and Laboratory Studies

The research objectives of this study were to determine (1) if the hydraulic properties of the FilterPure and Potters for Peace filter models changed over time and (2) if there was a difference in hydraulic performance between the two different filter models. One finding in the field study is that during months 7 – 13 of use the FP filters did not see a noticeable change in first hour flow rate, whereas the PFP filters showed an overall increase of 31 ml/hr per month. It is believed that the increase in the overall first hour flow rate of PFP filters was mainly due to a large increase in the individual first hour flow rates of two specific filters.

During the field study 26% of the PFP filters decreased to unacceptable or zero flow rates within nine months of use showing that PFP filters have a significant problem with slowing flow rates. FP filters performed better than PFP overall in terms of first hour flow rate. FP overall first hour flow rate averaged 550 ml/hr while the PFP filters averaged 450 ml/hr. The difference in production variables, especially burnable material and silver application, along with quality control at the manufacturing facilities, are likely reasons for this. However, neither the FP nor PFP filters met the recommended water production standards set by Howard and Bartram (2003) or the Institute of Medicine (2004) of approximately 3.3 L/person/day. The filters also did not meet the minimum flow rate expectations of 1.0 L/hr suggested by the filter manufacturers. First hour flow rate measurements obtained in the laboratory during the first 10 week equivalent of filter use, when fitted with a linear trend line showed a slight overall increase in first hour flow rate for both FP filters and an overall decrease for both PFP filters.

The hydraulic conductivity was determined for the four filters in the laboratory using two different hydraulic models for the two types of filters. FP filters had a measured hydraulic conductivity range of k = 0.0534 - 0.0950 cm/hr while PFP filters had a hydraulic conductivity range of k = 0.0151 – 0.0390 cm/hr. The hydraulic conductivity was greater for the FP than for the PFP filters, even when the first hour flow rate and 24 hour total effluent volume were less.

5.2 Recommendations for Future Research

More research is recommended to determine the mechanisms of flow rate decrease in the filters. Different mixes and pore sizes should be tested for hydraulic properties over the long term to determine which experiences the smallest decrease in flow rate. The FP filters experienced less of a problem with inadequate flow rate and one possible explanation is the smaller pore size. Research could be done on the variations in pore size and consistency and their effects on long-term flow rate.

It is also recommended that the effect of various types and particles sizes of solids loading be investigated. The flow rate of PFP filters in van Halem's (2006) study decreased to as low as 210 ml/hr from 710 ml/hr within a few weeks due to being loaded with canal water with turbidity up to 31 NTU. The field study represented in this thesis rarely experienced turbidity levels greater than 3 NTU and observed a time period of 5-9 months for the flow rates of PFP filters to decrease to comparable levels.

As mentioned previously in Section 4.1.4, the difference in long term flow rate decrease should be analyzed in filters with and without silver impregnation to determine if the silver has an influence on flow rate decrease. Due to the large variation in overall performance seen between filters of the same manufacturer, it is recommended that researchers obtain a large enough sample size to ensure that the results are representative of the majority of filters.

More research on the user influence on the performance of filters should be conducted. The proper maintenance and use of filters should be monitored in field studies as it is important in the long-term performance of the filters. It is possible that much of the variability in filter performance in the field has to do with variability in the degree to which the filter is properly cared for. The effect of the gender of the member of the household that cares for the filter should be considered. Women are generally in charge of the household chores. The amount of drinking water consumed in sites where ceramic filters are used should also be analyzed, both before implementation and after. Although flow rates are often below manufacturers' claims, very little discontent with flow rates was observed in this field study, among users with filters that had first hour flow rates above 250ml/hr. This suggests that households in the field study do not drink as much water as is suggested in previous studies (Howard and Bartram, 2003). Thus the discrepancy between suggested water ingestion and the actual demand should be examined. It should be determined if an increase in water production will result in an increase in water consumption.

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APPENDICES

Appendix A Pre–Implementation Field Survey

DATE: ________ **Baseline Survey (Pre-intervention/education)**

House Number:

A. Person who obtained consent			B. Interviewer	
C. Date			D. Time	
E. Country/Region/Village			F. GPS	
G. Gender	1 Male	0 Female		
H. Age				
I. Level of Education	1 Primary	2 Junior High	3 High School	4 Other (higher)
J. Years of School				
K. Number living in household				
L. List Age and Gender	Age	Gender	Sick or Ill? Diarrhea?	With what?
1.			1 Yes 2 No	
2.			1 Yes 2 No	
3.			1 Yes 2 No	
4.			1 Yes 2 No	
5.			1 Yes 2 No	
6.			1 Yes 2 No	
7.			1 Yes 2 No	

NOTES:

1.Where do you usually collect the water for the house?

1 Dam	*2 River*	*3 Well*	*4 Canal*	*5 Spring*	*6 Rainwater*
7 Water Tap Inside	*8 Water Tap Outside (attached to house, on plot, off plot)*	*9 Bottled water (brand?)*	*10 Other*	*11 Don't Know/ No Response*	

Appendix A (Continued)

2. Who is the primary person who collects drinking water?

1 Mother	2 Father	3 Young girl	4 Young boy	5 Other

3. a. How many times per day do you collect water?

b. How many times per week do you collect water?

4. How long does it take you to travel to your drinking water source?

1- <30 min	2- 30 min	3- 30- 60 min	4- > 60 min

5. Approximately how much water do you use per day for:

Drinking:	Cooking:	Cleaning:	Washing:	Bathing:	Farming:

6. What do you think are the biggest health problems currently facing your family (or village)?

7. Do you think your current water is safe to drink?

1 yes	2 No	3 DK

8. How do you know your water is safe to drink?

1 water is clear	2 water comes from tap	3 no bacteria	4 water is cold/warm	4 Other :

9. How do you know your water is not safe to drink?

1 water is dirty	2 from bad source	3 has bacteria	4 water is cold/warm	5 Other :

10. What are the different methods for treating water at household level? Have you used any of the following before and if yes, how often?

Type	Knew	Used			
Boiling	1	1 Never	2 Rarely	3 weekly	4 Daily
Chlorine	2	1 Never	2 Rarely	3 weekly	4 Daily
Filter	3	1 Never	2 Rarely	3 weekly	4 Daily
Other	4	1 Never	2 Rarely	3 weekly	4 Daily
Other	5	1 Never	2 Rarely	3 weekly	4 Daily
Other	6	1 Never	2 Rarely	3 weekly	4 Daily

Appendix A (Continued)

11. May I see your current	1 Yes	2 No	drinking water?

12. What source is this water from?	13. Source of Primary drinking water?	15. What container do you store it in?	16. Do you cover it?	17. Is the water treated?	18. What is it treated with?	19. How long ago was it treated? (hrs)
1 Dam	*1 Dam*	1 Bucket	1 Yes 2 No	1 Yes 2 No	1 Chlorine 2 filter 3 Other	
2 River	*2 River*	2 Jerry Can	1 Yes 2 No	1 Yes 2 No	1 Chlorine 2 filter 3 Other	
3 Well	*3 Well*	3 Barrel/Drum	1 Yes 2 No	1 Yes 2 No	1 Chlorine Appendix E Continued2 filter 3 Other	
4 Canal	*4 Canal*	4 Clay pot	1 Yes 2 No	1 Yes 2 No	1 Chlorine 2 filter 3 Other	
5 Spring	*5 Spring*	5 Saucepan	1 Yes 2 No	1 Yes 2 No	1 Chlorine 2 filter 3 Other	
6 Rainwater	*6 Rainwater*	6 Jug	1 Yes 2 No	1 Yes 2 No	1 Chlorine 2 filter 3 Other	
7 Water tap inside	*7 Water tap inside*	7 Kettle	1 Yes 2 No	1 Yes 2 No	1 Chlorine 2 filter 3 Other	
8 Water tap outside	*8 Water tap outside*	8 Bottles (materials:___)	1 Yes 2 No	1 Yes 2 No	1 Chlorine 2 filter 3 Other	
9 Bottled water-brand	*9 Bottled water-brand*	9 No container, water not stored	1 Yes 2 No	1 Yes 2 No	1 Chlorine 2 filter 3 Other	
10 Other	*10 Other*	10 DK	1 Yes 2 No	1 Yes 2 No	1 Chlorine 2 filter 3 Other	
11 DK/NR	*11 DK/NR*	11 NR	1 Yes 2 No	1 Yes 2 No	1 Chlorine 2 filter 3 Other	

20. What do you use the treated water for?

1 drinking	2 cooking	3 washing fruits/veggies	4 washing hands	5 bathing	6 washing dishes	7 washing clothes	8 other

Appendix A (Continued)

21. Who drinks the treated water?

1 Everyone	2 Only elders	3 Only children	4 Only sick people	5 No one	6 Other

22. Can you give me some of the treated water?

1 yes (collect)	2 No	99 Don't have

23. Can you give me some of the water you use for drinking now?

1 yes (collect)	2 No	99 Don't have

24. Can you collect water from the drinking water source now?

1 yes (collect)	2 No

Time at end of Interview:___________________

Length of interview:______________________

Appendix B Institutional Review Board Approval Letter

UNIVERSITY OF SOUTH FLORIDA

DIVISION OF RESEARCH INTEGRITY AND COMPLIANCE
Institutional Review Boards, FWA No. 00001669
12901 Bruce B. Downs Blvd., MDC035 • Tampa, FL 33612-4799
(813) 974-5638 • FAX (813) 974-5618

May 12, 2011

James Mihelcic, PhD
Civil and Environmental Engineering
ENB118

RE: **Expedited Approval for Continuing Review**
IRB#: Pro00001074
Title: Dominican Republic Ceramic Filter Study

Study Approval Period: 6/10/2011 to 6/10/2012

Dear Dr. Mihelcic,

On 5/11/2011 the Institutional Review Board (IRB) reviewed and **APPROVED the above protocol for the period indicated above.** It was the determination of the IRB that your study qualified for expedited review based on the federal expedited category number:

(6) Collection of data from voice, video, digital, or image recordings made for research purposes.

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

Also approved was the waiver of documentation of informed consent.

Please reference the above IRB protocol number in all correspondence regarding this protocol with the IRB or the Division of Research Integrity and Compliance. It is your responsibility to conduct this study in accordance with IRB policies and procedures and as approved by the IRB.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

[redacted]

John Schinka, PhD, Chairperson
USF Institutional Review Board

Appendix C Water Sources of La Tinajita

Source	Spring	Spring	Spring	Spring	River
Picture					N/A
Details	EWB-U of Kentucky constructed a tank and rebuilt a crude spring box in 2009. Aqueduct built by the community in the 90s.	No springbox or intake structure. Spring is fenced in but in the middle of a cow pasture. Aqueduct constructed by community.	No springbox or intake structure. Aqueduct constructed by community.	No springbox or intake structure.	Agricultural lands and other communities upriver.
Households Served	18	19	14	2	3
Service Level	Household taps	Household taps	Household taps	Point Source	Point Source
System Storage Capacity	1,800 gallons	600 gallons	600 gallons	None	None
Contamination Risk	Intermediate to High	High	High	High	High

Table provided courtesy of Ryan Schweitzer, University of South Florida

Appendix D Regular Field Survey

Fecha: _________ Hora: _________

Cuestionario (Regular)

Numero de Casa			
A. Numero de Filtro		B. Edad	
C. Entrevistador		D. Tipo de Filtro (1-FP or 2-PFP)	
E. # Personas/Casa		F. Género (1-Hombre, 0-Mujer)	
G. Educación (1-Primaria, 2-Colegio, 3-Secundaria, 4-Otra)			
Edad	Género	¿Enfermo? (1-Sí, 2-No)	¿De que? (1-Diarrea, 2- Otra enfermedad)

1. A. ¿Para que usa el agua tratada/limpia? *Estimar Cantidad/Actividad.*

1-Tomar	2-Cocinar	3-Lavar comida	4-Lavar las Manos

Preguntas	
3. Esta usando el filtro?	
4. Da suficiente agua?	
5. Con que frecuencia lo llena?	
6. Todos los miembros de la casa beben este agua?	
7. Le gusta el sabor del agua?	
8. Problemas o comentarios?	

2. Observaciónes sobre el filtro *(Describe)*			
a. El filtro esta seco?			(Si esta seco, porque?)
b. La cubeta tiene agua?			
c. La cubeta esta sucia?			
d. Otras observaciones			

Agua No Filtrada

Muestra	Turbidez	Coliformes Totales	E. *coli*

Appendix E Calculation of Volume/Month Laboratory Equivalent

The following explains how the monthly field equivalent volume was arrived at for use in the laboratory experiments:

In household surveys conducted on January 27, 2012 (n=14hh) the question was asked, "How often do you fill up your filter?"

The average response was every 2.8 days PFP and 2.4 days FP. With volumes of 8.5 L and 7 L respectively that corresponds to 91 L for PFP and 87.5 L for FP per month. That is assuming that the filter was empty when they added more water. We found that this was often not the case as many of the filters still had water in the filter remaining after three days. Thus, an estimate of 80 L per month was calculated for the average water processed per filter per month in the field.

Appendix F   Excel Spreadsheet for PFP Hydraulic Conductivity

Experimental data

time (hr)	h (cm)
====	====
0	21.4
1	20.5
2	19.3
3	18.3
4	17.5
5	16.5
6	15.6
7	15
8	14.1

Mathematical model

d =	1.3	Cm	
R_b =	9.65	Cm	
alpha =	30	degrees = 0.152	radians
k =	0.0351	cm/hr	
error =	0.214	cm^2	
dt =	0.1	Hr	

time (hr)	h (cm)		error^2 (cm^2)
====	====		====
0	21.4	← known	
0.1	21.29		
0.2	21.18		
0.3	21.07		
0.4	20.96		
0.5	20.85		
0.6	20.74		
0.7	20.63		
0.8	20.53		
0.9	20.42		
1	20.32		0.033825
1.1	20.21		
1.2	20.11		
1.3	20.00		
1.4	19.90		
1.5	19.80		
1.6	19.70		
1.7	19.60		
1.8	19.50		
1.9	19.40		
2	19.30		2.24E-06
2.1	19.20		
2.2	19.11		
2.3	19.01		
…	…		
8.0	14.41		

Appendix G Excel Spreadsheet for FP Hydraulic Conductivity

Experimental data

Time (hr)	h (cm)
====	====
0	23.9
1	23
2	22.4
3	21.8
4	20.9
5	20.4
6	19.3
7	18.4
8	17.7

Mathematical model

d =	1.5	Cm
k =	0.0752	cm/hr
error =	0.7486	cm^2

time (hr)	Height (cm)	error	
=====	=====	=====	
0	23.9		<--- this one will be known
0.1	23.81		
0.2	23.72		
0.3	23.63		
0.4	23.54		
0.5	23.45		
0.6	23.36		
0.7	23.27		
0.8	23.18		
0.9	23.09		
1	23.01	0.00	
1.1	22.92		
1.2	22.84		
1.3	22.75		
1.4	22.67		
1.5	22.58		
1.6	22.50		
1.7	22.42		
1.8	22.34		
1.9	22.26		
2	22.17	0.050795	
2.1	22.09		
2.2	22.01		
2.3	21.94		
2.4	21.86		
2.5	21.78		
2.6	21.70		
…	…		
8.0	19.60		