DEVELOPMENT OF A PROTOTYPE OF AN INDIVIDUAL SLOW SAND FILTER FOR INTERMITTENT USE IN THE PHILIPPINES

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GLOSSARY OF TERMS

Coliforms	A large group of bacteria whose presence indicate the presence of disease causing pathogens.
Effective size	The effective size is the d_{10} size. Ten percent of the sample, by weight, is smaller than the d_{10} size.
Pathogens	Infectious organisms transported in natural water systems from one animal host to another. The species include bacteria, viruses and parasitic worms.
Schmutzdecke	Thin layer of biologically active microorganisms on a filter bed which break down organic matter.
Turbidity	A quantitative measurement of suspended particles by the extent to which light is absorbed or scattered by suspended material.
Uniformity coefficient	The uniformity coefficient = d_{60} divided by d_{10}

ABSTRACT

Water supplies on the island of Mindanao in the Philippines are frequently contaminated. Because of sparse population and low disposable income, sophisticated treatment facilities are quite often not feasible. Slow sand filtration is an inexpensive means of obtaining potable water without altering the aesthetic quality or addition of chemicals, both of which are important to locals. However, no designs exist for small intermittently used systems so a prototype was designed based on municipal specifications where possible. Preliminary investigations of the quality of the water produced showed bacterial count reductions up to 99.8% The effluent was also colourless and odourless but several vital quality parameters were not evaluated due to experimental constraints. The individual slow sand filter for intermittent use can be considered a possible solution at affordable cost but a more comprehensive pilot study is needed to fully determine how appropriate the filter is for use on Mindanao.

1. INTRODUCTION

Water resources projects on the island of Mindanao in the Philippines are plagued with the problem of contamination of supplies. Most of the northern plains of the island have slow running rivers or shallow wells as their water supply. Figure 1 is a typical example of how wells are often contaminated by activities at the well head such as laundry and animal husbandry (Manz, 1991). Even some wells with flowing aquifers have shown high levels of contamination,

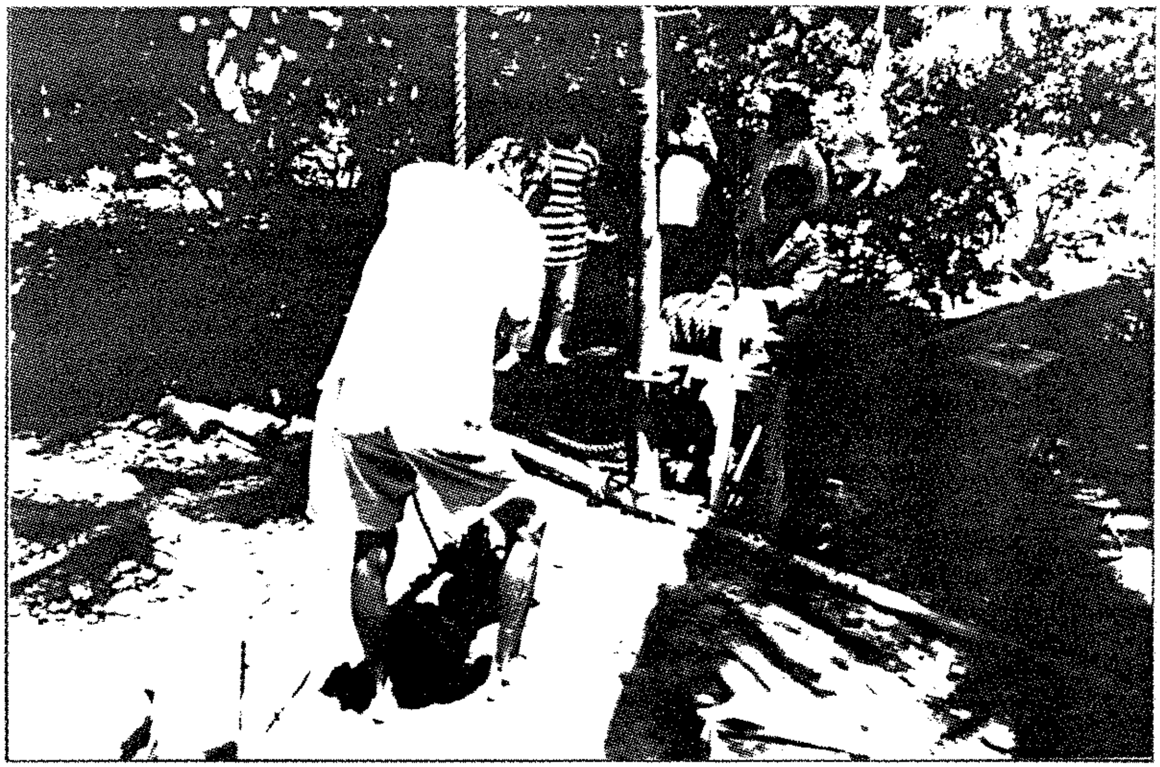


Figure 1.1 Constructing typical water source (Manz, 1991)

meaning that the ground water is contaminated upstream of the well site.

1.1 Background Information

The practice of communal washing of clothing, children and animals at a water source is a cultural phenomenon which has been hard to discourage. The outlet of any source or distribution system becomes a social gathering spot and the inevitable result is the fouling of the water supply.

Figure 1.2 Typical well head site (Manz, 1991)

Frequently, the consequence of consuming the water has been multiple bouts of dysentery. Although there have been no recent deaths caused by dysentery, the immune system is severely weakened by repeated attacks and many die of unrelated diseases which can be traced to the unsafe water supply (Viacrucis, 1991). Characteristics of the area do not allow for the development of sophisticated treatment plants and distribution systems. The communities are very sparse making systems development expensive. The land use is almost exclusively agricultural and large rice paddies cover the landscape for miles. Disposable income for any development is low and it is unlikely that any development would receive local support. Locals are also fond of fresh tasting water. Extensively treated water is not likely to be readily accepted and locals have consumed known contaminated fresh water rather than chemically treated supplies in the past. It is therefore necessary to develop appropriate technology to meet the objective of supplying potable water at minimal cost, while satisfying indigenous preferences.

1.2 Previous Solutions

Local authorities have proposed several methods for decontamination in the past. Each had its own merits but disadvantages associated with the methods prevented their full implementation:

Table 1.1 Previous Solutions for Decontaminating Supplies (Veracruza, 1991)

Option	Method	Benefits	Disadvantages
Cheese Cloth	Running water through fine pored cloth	Takes out fine particles in water supply	Pathogens are not eliminated
Boiling	Boiling water for extended period	Kills pathogens	Fines remain. Oxygen effervesces and leaves flat taste. Expense of fuel.
Chlorine	Addition of chlorine tablets to water	Kills pathogens and clears water	Odour and taste do not comply with local preferences

Development of an appropriate system for water purification will therefore have to meet the following criteria:

• Affordable	20¢ per month is the suggested maximum willingly paid by locals for water supply.
• Simple	Costs could be reduced if individuals within the community could construct and manage their own systems.
• Low Maintenance	Elimination of expensive replacement parts and technicians would make the system more acceptable.
• Aesthetically Pleasing	The water produced must conform to local preferences in potable water: - Colourless - Odourless - Not flat (oxygen not effervesced)
• Safe	World Health Organization (WHO) standards must be met.

Because of the remote locations of most of the people who the devised system would have to service, it was thought best to employ a system specifically designed for use by individual households. This would ensure that:

- The system would have a reduced chance of recontamination after purification. Distribution systems over large distances between adjacent farms increase the possibility of infection.
- People would be encouraged to take better care of personalised systems as they would be solely responsible for maintenance.
- The system would allow for the intermittent use of water when needed and therefore keep usage at necessity levels.

The idea of an individual slow sand filter thus evolved to meet these needs. There are no specifications for individual occasional use so it was decided to design a prototype for initial investigations.

1.3 Research Objectives

The nature of the investigation was to be very preliminary. Standard parameters were to be monitored and evaluated. Because of the unknown behaviour of such a system, it was seen as advantageous to conduct an investigation to determine the possible chance of success. Also observations would be carried out in order to design improved pilot studies.

The research was divided into three principal tasks:

(i) Design a preliminary prototype for an inexpensive individual slow sand filter for intermittent use based on existing specifications for municipal systems.

(ii) Evaluate pertinent quantitative water quality parameters to determine if water produced by such a system for occasional use meets WHO standards for potable water.

(iii) Observe qualitative water quality and operational parameters for suitability to the preferences of the regions in which such a filter would be used.

2. LITERATURE REVIEW

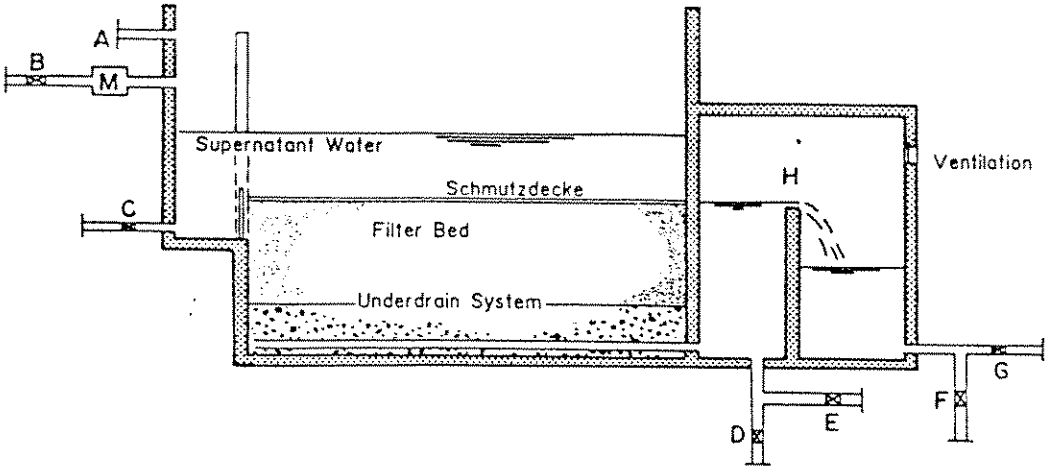
" Under appropriate circumstances, slow sand filtration not only may be the cheapest and simplest, but also the most efficient method of water treatment"

(Huisman and Wood, 1974)

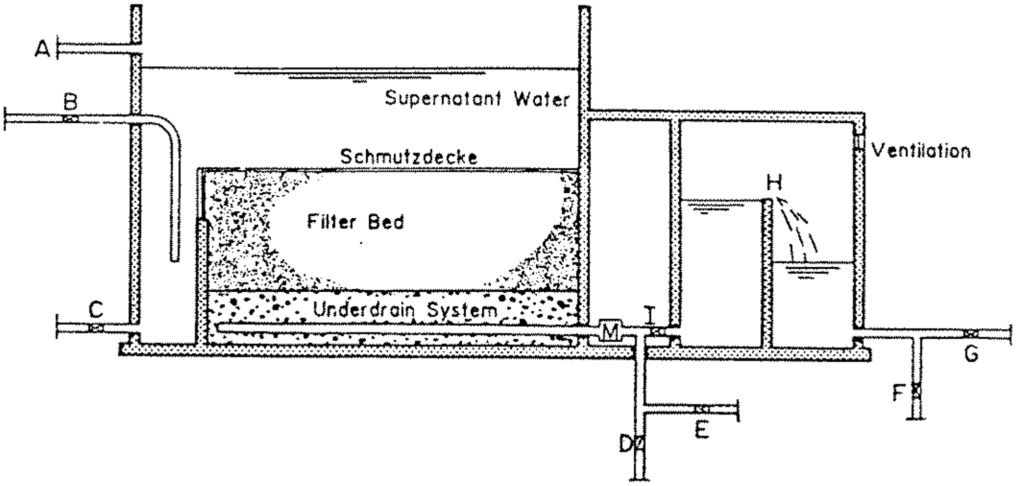
Slow sand filtration as illustrated in Figure 2.1 has been used in Europe for hundreds of years and is still the method of choice in many major cities in the world (Collins et al., 1989). The process involves the filtering of water through a bed of sand and into a drain of gravel. There the water passes into an underdrain system and can then be distributed. The purification takes place in the top 0.2 to 2 cm of the sand bed by a collection of biologically active organisms. The "schmutzdecke" breaks down all organic matter in the water and also fill the interstices of the sand so that solid matter is retained quite effectively. The filter slowly clogs and must be eventually cleaned by replacing the top 5 cm of dirty sand. Time is then required to allow for the redevelopment of the schmutzdecke.

2.1 Credibility of Slow Sand Filters

"Slow sand filters have consistently demonstrated their effectiveness in removing suspended particles with effluent turbidities below 1.0 NTU and in achieving 98 - 99% reductions in bacteria." (Cleasby et al. 1984)



A. Filter Overflow Drain
B. Influent Flow Control Valve
C. Supernatant Water Drain Valve
D. Filter Bed Drain and Filter-to-Waste Valve
E. Valve For Backfilling Filter With Treated Water.
F. Treated Water Waste Valve
G. Valve To Clearwell
H. Overflow Weir
M. Flow Meter



A. Filter Overflow Drain
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D. Filter Bed Drain and Filter-to-Waste Valve
E. Valve For Backfilling Filter With Treated Water
F. Treated Water Waste Valve
G. Valve To Clearwell
H. Overflow Weir
I. Effluent Flow Control Valve
M. Flow Meter

Figure 2.1 Slow Sand Filters With Effluent Control

The lack of slow sand filters in North America is mostly due to their larger site requirements compared to rapid sand filters (Montgomery, 1985). Typical hydraulic loading rates for slow sand filters range from 0.13 to 0.26 m/h requiring a filter area of 37 to 75 hectares respectively, to service a city of only 500 000 at current levels (Collins et al, 1989). There is a definite disadvantage in highly populated areas for the use of slow sand filtration. Rapid sand filters, which require at least 40 times less land area, have taken preference in areas where land is expensive.

Another reason for the low profile of slow sand filters in the North America is the lack of pretreatment of the water. This results in the frequent clogging of the sand layer reducing the hydraulic loading rate to the point where the filter becomes inoperable. Without preliminary clarification, slow sand filters cannot cope with the highly turbid waters of many water sources (Steel and McGhee, 1979: Montgomery 1985). In many third world countries, the filter is cleaned periodically by manual removal of the top 5 cm of sand, an option not often feasible in the North America due to high labour costs. This would not pose a problem in Mindanao because of relatively low labour costs and the fact that individual ownership of systems would be an incentive to keep the filter in operational condition.

Systems have been in operation in other third world countries such as India and Zimbabwe for years with excellent results (Schulz and Okun, 1984). The modification of the process to an individual unit should be as successful as the municipal systems since the effectiveness of the filter lies in its biological and adsorptive properties, which will not be altered by individual design. Overall, slow sand filters provide a number of distinct advantages for developing countries which are summarized here (Feachem, McGarry, and Mara, 1977):

1. The cost of construction is low.
2. Simplicity of design and operation means that filters can be built and used with limited technical supervision. Little special pipework, equipment, or instrumentation is needed.
3. The labour required for maintenance can be unskilled because the major job is cleaning the beds, which can be done by hand.
4. Imports of material and equipment can be negligible and no chemicals are required.
5. Power is not required if gravity head is available, and there are no moving parts or requirements for compressed air or high-pressure water.
6. Variations in raw water quality and temperature can be accommodated provided turbidity does not become excessive: overloading for short periods does no harm.
7. Water is saved - an important matter in any area - because large quantities of washwater are not required.

2.2 Slow Sand Filter Hydraulics and Microbiology

Removal mechanisms of slow sand filters may be considered a combination of physical straining, biological action, and adsorption (Viessman and Hammer, 1985; Huisman and Wood, 1984). Gelatinous bacterial assemblages form on the surface and in the upper layer. Initially, particles larger than the pore openings in the schmutzdecke are strained at the interface (Edwards and Amirtharajah, 1985). As water enters the schmutzdecke, biological action breaks down some organic matter and additional straining may occur. The water then enters the top layer of sand where more biological action and physical straining occurs, as well as some attachment/adsorption of materials onto the coated sand grain surfaces (Fox et al., 1984). There is reported to be little treatment after the top few centimetres of a slow sand filter (Cleasby et al., 1984, Cleasby, 1983).

Filtration rates for slow sand filters are comparatively low when compared to other filtration systems. The sand is not stratified and the hydraulic characteristics are governed by the finer portions of the sand. Normal operation is at about 0.1 m/h although safe water has been produced as high as 0.4 m/h. The normal range of head loss from clean to clogged conditions in the sand bed and filter appurtenances is 0.6 to 1.2 m (Schulz and Okun, 1984).

2.3 Existing Design Criteria

Typical design criteria for slow sand filters are listed in Table 2.1 along with treatment performance. These criteria are specified for large communal systems operating continuously. No information is available in the literature that specifies the criteria for a system that is small enough for individual use or is to operated intermittently instead of continuously. It was decided that the prototype design would adhere to general design criteria wherever possible with the remaining parameters selected by intuition.

Table 2.1 Characteristics of Slow Sand Filters in Rural Water Supplies - (a) General design criteria, and (b) Treatment performance (From IRC, 1987)

(a) General Design Criteria	Design Parameter
Design period	10 - 15 years
Period of operation	24 h/d
Filtration rate in filters	0.1 - 0.2 m/h
Filter bed area	10 - 200 m^2 per filter, minimum of two units
Initial height of filter bed	0.1 - 1.0 m
Specification of sand	Effective size 0.15 - 0.30 mm
Height of underdrains including gravel layer	Uniformity coefficient <5 preferably <3
Height of supernatant water	0.3 - 0.5 m
(b) Water Quality Parameter	**Treatment Performance**
Colour	30 - 100% reduction
Turbidity	Generally reduced to less than 1 NTU
<u>E. coli</u>	Between 95 and 100% and often 99 and 100% reduction in the level of <u>E. coli</u>
Cercaria	Virtual removal of cercariae of Schistosoma, cysts, and ova
Viruses	99 - 100% removal
Organic matter	60 - 75% reduction in chemical oxygen demand
Iron and manganese	Largely removed

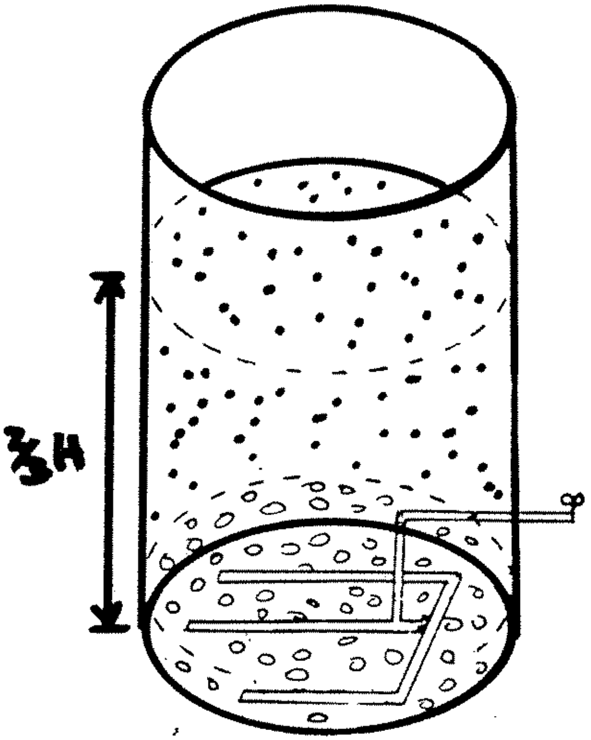
3. MATERIALS AND EXPERIMENTAL METHODS

The major objective of the project is to develop a preliminary design for a prototype of an affordable individual slow sand filter. Consequently, many design decisions were made with this reality in mind making the modification of some design criteria necessary. Also, the new parameter of intermittent use was a topic on which there are no guidelines, leading to several intuitive decisions. The experimentation also reflects the preliminary nature of the project.

3.1 Prototype Design

Figure 3.1 shows a sketch of the design. The first decision regarding design was the size and shape of the filter container. For very small daily water production, prebuilt circular, square or rectangular tank shapes may be an economical approach (Bellamy et al., 1991). A plastic 17 gallon garbage bin was chosen as the basic container for the filter. This was based on the simplicity of the container, size, relative ease of acquisition, and cost. It was envisaged that similar containers could be obtained in the areas in which the filter would be used or containers of similar structure could be easily constructed. The cover of the bin was later used to reduce velocity head of the water being poured into the filter. This was done arbitrarily with 1/8 inch holes punched in the cover in a concentric pattern approximately 5 cm apart.

DESIGN



17 GALLON DRUM

25 mm GRAVEL

CONSTRUCTION SAND

½" PVC PIPES

Figure 3.1 Prototype Design

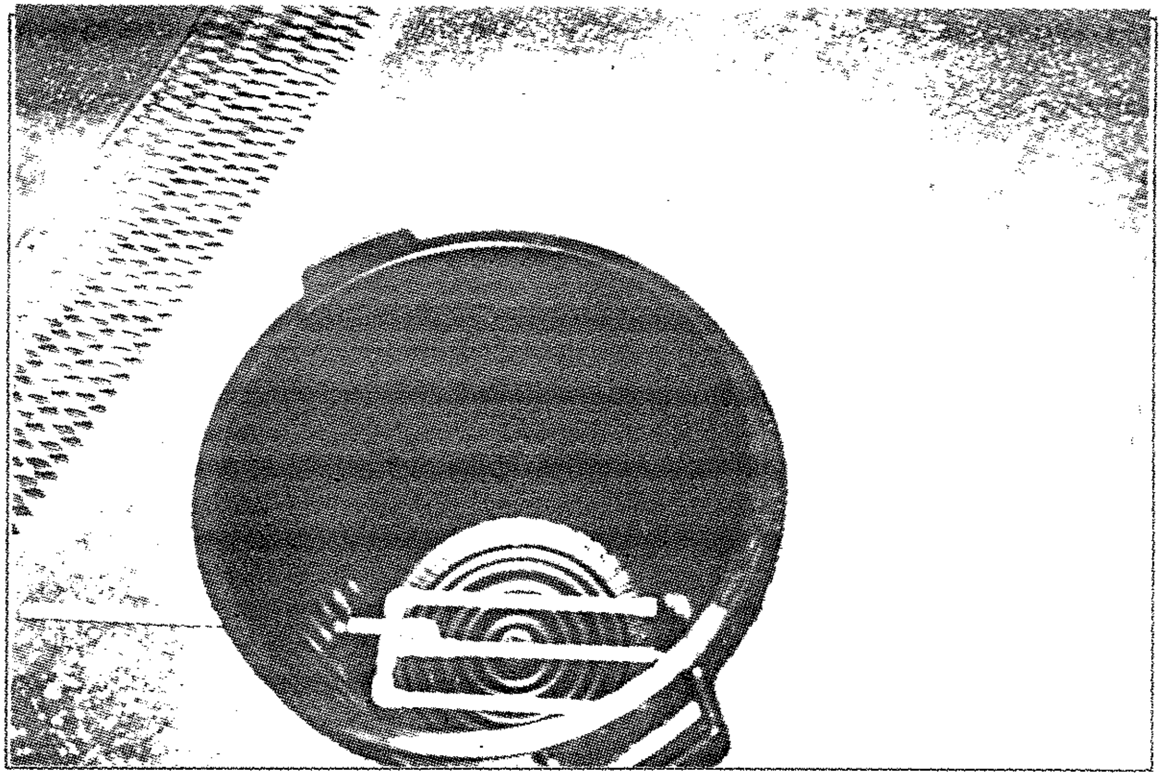


Figure 3.2 Underdrain system in filter conatiner

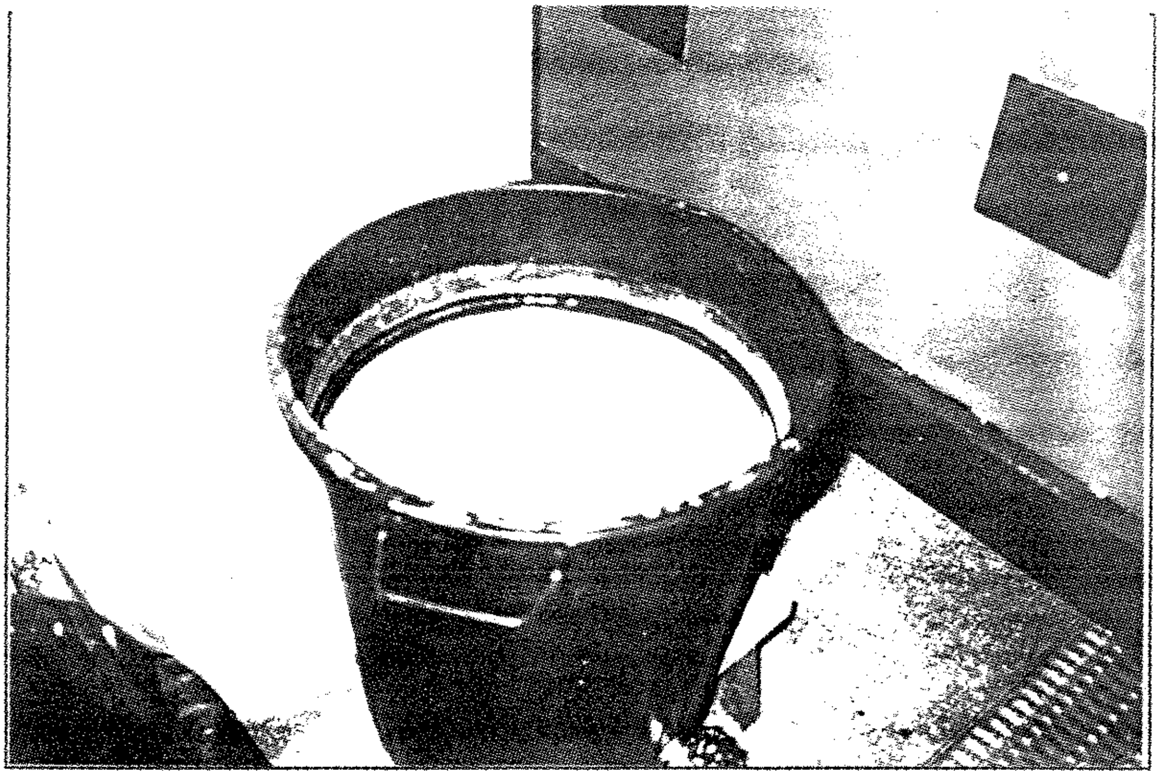


Figure 3.3 Complete Prototype

The underdrain piping for smaller systems is frequently split, open-joint farm tile or perforated plastic pipe (Bellamy et al., 1991). Half inch pvc pipes were chosen because of cost, ease of construction and familiarity in Mindanao. The arrangement of the pipes used corresponds with conventional underdrain design with 1/8" holes made for perforations. Holes were drilled in the bottom of the assemblage to minimize the entrance of sand into the effluent system. The effluent pipe was raised to achieve the same effect as well as allow for the practical placement of a hole in the bin. The underdrain system was installed in the bin and the hole sealed with silicon to prevent leakage.

The underdrain system is to provide a low velocity, low headloss means of draining the filtered water from the filter container. A 5 cm bed of 20 mm gravel was placed on the underdrain pipe network to achieve this. Because of the limited depth available, it was decided not to use different layers of gravel to economise on space. Another layer of say 14 mm gravel would have used at least another 5 cm of sand bed height, reducing the adsorptive capacity of the filter.

Visscher et al (1987) recommend a range in effective size of 0.15 to 0.30 mm for the filter sand. Construction sand from the civil engineering concrete lab was thoroughly washed and placed to a depth of 2/3 the total height of the bin. This resulted in a sand bed of 0.35 m, leaving a further 0.2 m for the supernatant water. The effective size of the sand was 0.25 mm but a significant amount of clay was washed from the sand possibly increasing the effective size.

These designs may not eventually be of paramount importance though, since there will most likely be no facilities for determining gradations of filter media on Mindanao. Media will likely vary at different locations also, so it is necessary to allow flexibility in bed composition. Table 3.1 summarizes the prototype dimensions in comparison with existing design standards:

Table 3.1 Comparison of Existing Standards and Prototype Design

Parameter	Existing Standard	Prototype
Depth of filter bed (m)	1.0 to 1.4	0.4
Area of filter bed (m^2)	10 to 100	0.17
Height of supernatant water (m)	1.0 to 1.5	n/a
Depth of underdrains (m)	0.3 to 0.5	0.05
Specifications of filter bed		
Effective size sand (mm)	.15 to .35	0.225
Uniformity coefficient	< 5	1.46

3.2 Water Sampling and Analysis

The first problem involved obtaining untreated water for filtering. The scheme used involved leaving a drum of water overnight to allow for the dissipation of its chlorine content. A smaller nine litre pail was filled with water and soil from a dog's litter area. It was speculated that this would contain a substantial amount of pathogens and the colonies were expected to multiply in the warm dechlorinated water. Some water from the pail was then added to the larger barrel of water and left for a further 24 hours to multiply. The samples of water run through the filter would then have been out of the local distribution system for 48 hours.

It was necessary for the filter to be subject to usage as similar as possible to daily use by a Filipino household. Officials of the Health Ministry in the Philippines gave 20 litres per day as the potable water requirement for the average household. It was decided that 27 litres of water would be run through the filter daily (to allow for excesses and the fact that the pails held nine litres of water). The water was run all at once to simulate the fetching of water in the early morning by children.

The next consideration was the testing of the influent and effluent. Since a natural water source was not available, it was decided that percentage reduction of water quality parameters was the best measure of performance. This would compensate for the variations of contaminants in the spiked raw water samples. Ideally, the samples would be tested daily for all quality parameters. However, the lack of equipment on campus and unavailability of testing facilities elsewhere resulted in tests being done only to determine total coliform count. This is representative of the pathogen population of the water and it can give a good indication of overall quality in investigations this preliminary. Sample bottles obtained from the Provincial Laboratories were used for collecting samples. The bottles were tightly sealed and isolated after collection and then taken to the laboratory at the Foothills Hospital complex for testing.

The head loss and the hydraulic loading were monitored in a very preliminary way by recording the flow rate of the water through the filter. This is also a measure of schmutzdecke development and clogging of the sand bed. The total time for the 27 litres of water to flow through the filter was recorded and converted to a hydraulic loading for that particular run through the filter.

3.3 Quality Control

Several methods were instituted to ensure quality testing of the water samples:

(i) Two pails of water were poured first, because all 27 litres could not be held in the volume above the sand bed. The third was poured when nine litres had filtered through.

(ii) Filtering was done all at once to simulate the Mindanaon custom of fetching potable water once (or twice) daily.

(iii) The effluent sample was not taken at the beginning of the test. Test samples of 100 ml were taken after about 23 litres had filtered through the filter. This allowed for the outflow of any bacteria that may have accumulated in the faucet.

(iv) A daily log of the aesthetic appearance of the water was kept. This was subjective but the only available measure of turbidity.

(v) A check was made at the run of every nine litres for sand particles in the effluent. A qualitative comment was then made on any amount of sand present.

4. RESULTS AND DISCUSSION

The discussion of experimental results is divided into three sections relating to the objectives. The first section deals with the design of the filter and the modifications for individual use. The second deals with the quality parameters tested and the third deals with the parameters qualitatively observed.

The daily log of the performance of the prototype is shown in Appendix A. The log gives the daily hydraulic loading, the reduction in total coliforms when tested and the qualitative observation of colour and other comments. Sand content of the effluent was noted when observed.

4.1 Design for Individual Use

The prototype met the preliminary objectives of design:

(i) The cost of the unit was approximately \$30 which would be affordable to most locals. A bill of materials is given in Appendix B.

(ii) The unit is small enough to be used by individual households.

(iii) The system can be used intermittently for water supply. There is no need for continuous flow as is in the existing design criteria.

4.2 Evaluation of Water Quality Parameters

Total coliform reduction was as high as 99.8% and the effluent produced was aesthetically pleasing with no colour or odour. The plot of total coliform reduction shows that the filter meets WHO specifications for percentage reductions of acceptable water supplies. The plot also verifies results claimed by other researchers. Other parameters were not tested because of experimental constraints.

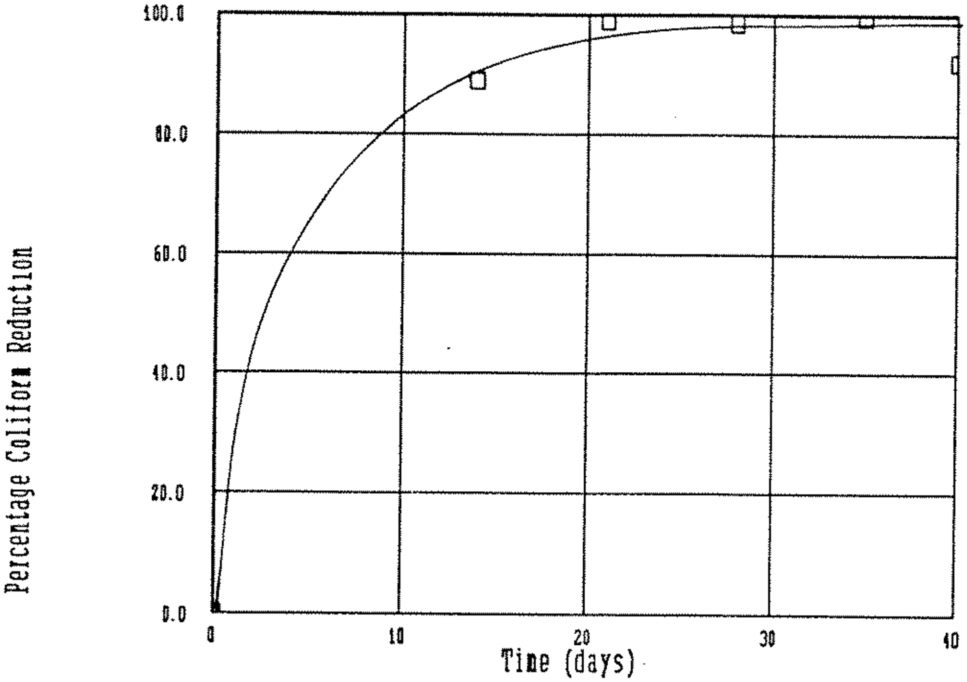


Figure 4.1 Reduction in Total Coliforms

4.3 Hydraulic Considerations

The hydraulic loading of the filter remained relatively constant, but showed signs of very slow decrease. The development of the schmutzdecke did not significantly curtail the flow in the six weeks that the filter was operated.

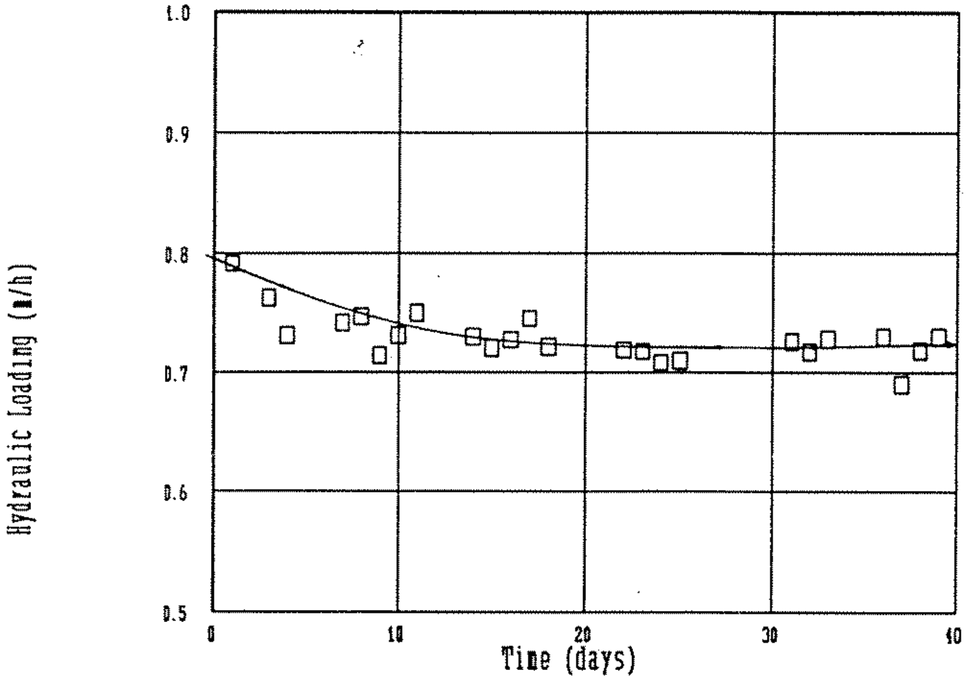


Figure 4.2 Variation of Hydraulic Loading

The mean hydraulic loading of 0.73 is well above the design specifications (0.1 to 0.2 m/h) for slow sand filters. This did not prevent the filter from attaining 99.8% reductions in total coliform count and it can be derived that hydraulic loading up to 0.7 m/h can still produce water of potable quality.

4.4 Evaluation of Qualitative Parameters

The daily journal in Appendix A shows the reduction in the qualitative parameters. Colour and turbidity were observed and note was also taken of the odour of the effluent. There are no established procedures to test taste of the effluent. Some sand was present in the effluent in the operation of the filter when hydraulic loading was highest. This was not corrected as the design of the filter does not allow alterations to the underdrain system once installed.

5. CONCLUSIONS

It can be concluded from the experimental data that:

(i) The concept of an individual slow sand filter for occasional use is a viable potential solution to the contaminated water supply problem on Mindanao. The preliminary investigations of the prototype design clearly establish the ability of such a filter to produce potable water on demand.

(ii) Treatment performance of the filter shows that it has the capability to reduce total coliforms up to 99.8% being used on demand only, with hydraulic loadings up to 0.7 m/h.

(iii) Qualitative parameters such as colour and odour were observed to be acceptable while the clarity of the effluent implies very low turbidity.

6. RECOMMENDATIONS

The procedure was limited by the preliminary nature of the experiment, and the non availability of testing opportunities to provide a more comprehensive analysis of the prototype. From the difficulties experienced in obtaining data, and both quantitative and qualitative observations, many options are available for further development of the prototype. These recommendations are divided into:

- Modifications to the design of the prototype
- Additional parameters that should be tested
- Improvements in the testing of previous and additional parameters
- Cultural adaptations for regional usage

6.1 Modifications

1. Raw water should be introduced to a slow sand filter in a way that does not disrupt the sand bed (Bellamy et al., 1991). Dissipation of velocity head in pouring the raw water onto the filter bed was one of the factors believed to delay the development of the schmutzdecke layer. Although adequate reductions of coliforms were obtained, this occurred after approximately two weeks and it is suspected that this could have been accelerated if the dispersion of the top layer of sand with each filter run was lessened. Each of the following should be investigated to determine if greater dissipation of velocity head accelerates development:

a. The drilling of smaller holes in the lid of the bin.

b. The insertion of a inlet tube closer to the sand bed to lessen elevation head.

c. The insertion of a splash plate along the side of the filter wall to further dissipate velocity head.

Any combination of these or other methods could be used to ensure the inlet of raw water with minimum effect on the sand bed. Continuous flow systems are not as severely affected by this problem because a constant height of supernatant water is maintained. These are the only modifications considered which would not seriously affect the total cost of the unit.

It is however worth noting that the reductions still meet specifications despite the regular disruptions to the sand bed surface. This suggests initially that the disruption of the sand bed may not be as critical as previously stipulated. No conclusion has been made on this aspect of performance as a control with a non disturbed sand bed was not simultaneously tested. This would have to be investigated thoroughly in further development of the prototype.

2. The sand in the effluent is most likely a result of the uniformity coefficient of the support layer. Reducing the gravel size to 14 mm aggregate would decrease the amount of filter runs before the sand in the effluent is not noticeable. On the other hand, it must not be overlooked that locals manufacturing and using the filters will not have access to equipment to determine the gradation of gravel samples. High hydraulic loadings should

be decreased before specifications for sand and gravel sizes are considered.

3. The hydraulic loading could be decreased to allow even more complete breakdown of pathogens and suspended fines as they pass through the schmutzdecke. Performance of slow sand filters tend to be more effective as filtration rates are lowered (Bellamy et al., 1991). The decreased flow rate will mean increased residence time in the biologically active layer, causing even higher percentage reductions at earlier in the design period. These methods are proposed to achieve this decreased loading:

    a. Reduction of the underdrain pipe size which increases both the frictional head losses in the underdrain system and exit head losses.

    b. Reduction in the size of pipe perforation which would increase entrance losses.

    c. Decrease in the effective size of the sand layer. This again would be a last resort as the locals will be forced to use what sand is available to them.

    d. Controlling the effluent flow rate by adjusting tap.

Any or all of these modifications should only be adopted if the performance of the filter can be shown to be adversely affected by the high hydraulic loading. In fact, 10% of the facilities in the United States operate at loading rates greater than 0.5 m/h (Bellamy et al., 1991). Therefore, unless further study indicates that high hydraulic loadings in intermittently used filters reduces filter performance, the modifications should be considered of secondary concern.

Also to be noted is the fact that the specified hydraulic loadings are for continuously run systems which are under constant head. The loading in the prototype varies with time as the water filters through the sand bed and no specifications exist for systems with changing head. Overall, desirable rates for municipal systems are based on several parameters that are very different from those present in the prototype individual system and as such no exhaustive recommendations can be made.

6.2 Additional Parameter Testing

1. Water temperature has been shown to be a critical parameter in the removal efficiency of slow sand filters, and all types of particulates are affected (Bellamy et al., 1991). In hot climates, such as the Philippines, the most important concern will be the intense primary production by algae. Maturation is reached much quicker and filter scraping may be necessary at shorter intervals. Temperature testing would aid in a more effective prototype.

3. Age of the schmutzdecke, or time for bacterial generation within a schmutzdecke may be more important than filtration rate (Collins et al., 1989). Therefore, the development of the schmutzdecke should be monitored by taking coring samples of the top 10 cm of the sand bed. By monitoring schmutzdecke development, the removal of source water bacteria may be better predicted.

2. Other water quality parameters should be quantitatively tested on a daily basis to determine the overall treatment performance of the filter. Total coliforms was the only parameter tested in this procedure but parameters to be tested should include:

   - Colour - percent reduction
   - Turbidity - absolute NTU values
   - E coli - absolute concentration
   - Cercariae - absolute concentration of Schistosoma, cysts, and ova
   - Viruses - percent reduction
   - Organic matter - percent reduction
   - Iron and manganese - absolute concentration

   If the WHO standards for these parameters are met, the filter will then undoubtedly be safe for operation.

4. The rational for filter shading is that it will diminish primary productivity by reducing or eliminating solar radiation (Bellamy et al., 1991). In climates where seasonal algal blooms are prevalent, shading will prolong filter cycles. Allegedly though, this decreases activity in the schmutzdecke (Huisman and Wood, 1974). Yet, a pilot study in India (Sundaresan and Parmesian, 1982 and Joshi et al., 1982) studied three parallel filters; one completely covered, a second protected from direct sunlight and a third uncovered. Schmutzdecke development was curtailed in the covered filters but coliform reduction was 98% compared to 69% in the open filter. Tests investigating filter shading should be designed to determine the effect on the individual slow sand filter.

6.3 Pilot Prototype Testing Procedures

Prior to beginning a pilot study of the prototype, a study of existing raw water quality should be done on the source supplies to make preliminary assessments of the suitability of the treatment method. Tests should be performed on the sources on Mindanao to determine turbidity, colour and algae count. Water of high quality gets best performance from slow sand filters, but relevant modifications can be made based on results to give equally satisfactory performance. Once preliminary sampling has been conducted, a pilot study can then be designed to investigate options for a particular set of raw water quality parameters. An exhaustive list is given in Table 6.1 (from Bellamy et al., 1991).

Some variables will obviously be of greater importance than others depending on raw water characteristics. For example, high clay content water would need extensive investigations into hydraulic loading rate, sand size, frequency of scraping etc., while high algae content will be preoccupied with the age and type of schmutzdecke and length of time to maturity. Availability of local media may also restrict design modifications. Once the invariables have been fixed, other parameters can then be investigated for optimum performance.

Table 6.1 Process variables affecting removal efficiencies

Category	Variable
Design	• Hydraulic loading rate • Sand size: d_{10}; Uniformity coefficient, UC • Headloss allowed • Sand bed depth (maximum and minimum) • Treated water storage (to maintain steady flow)
Operating	• Frequency of scraping • Length of time filter is out of operation after scraping • Minimum bed depth permitted • Length of time to "maturity" • Flow variation (alleviated by treated water storage) • Age and type of schmutzdecke • Space between ice cake and sand depth
Ambient	• Water temperature • Raw water quality (particle size, colour, turbidity) • Kinds of micro-organisms present • Concentrations of micro-organisms • Algae kinds and concentrations • Turbidity character and magnitude • Organic compounds and concentrations • Nutrients and concentrations

Some improvements to the existing testing procedure would give extra credibility to these studies:

1. The effluent should be tested at several times within the flow through the filter. The results obtained were all taken in the last five litres of water to be filtered and as such may be biased by the longer residence time in the filter. This could be eliminated by:

    (i) Taking a sample of water at the beginning of the run to represent the water remaining in the filter between runs.

(ii) Taking a sample at the calculated time for fresh water to filter through the sand bed, based on the hydraulic loading. For the mean loading of 0.7 m/h this would be at 30 secs after the commencement of the run.

(iii) Taking a sample at the middle of the run, that is when half the water to being filtered is through the sand bed.

(iv) Taking a sample at the end of the run, during the filtering of the last five litres of water.

This process would give a better representation of the degree of biological action at each stage of the filtration process. The suitability of water left stagnant in the filter between filtration runs will also be determined.

2. The testing period should not be limited to six weeks but should continue until the hydraulic loading is reduced to the level of rendering the filter inoperable. The filter would then be cleaned and the time for recovery to acceptable water quality determined. A system of two filters run alternately would indicate the timing of utilising and cleaning filters to ensure continuous availability of potable water.

The design life of the filter would first have to be determined. As the prototype was only run for 15 minutes daily, the equivalent design life of the prototype would be over 15 years. Once the time for clogging is determined, the need for additional filters can be assessed.

6.4 Cultural Adaptations

Several observations were made by a visiting group of Filipino health workers as to the assimilation of the proposed filter into Mindanaon water culture. In an effort to make the technology appropriate to the existing water culture, several recommendations are made to deal with some of the anticipated problems:

Collection

Water collection is traditionally the function of children. It was felt that children may not be as sensitive as necessary to the need for as little disturbance as possible to the sand bed. The recommendations already made to increase dissipation of velocity head will help to alleviate this problem. Additional measures may be needed to further protect the sand bed. One such measure could be the introduction of a spout system into which children would pour water, through which the water would gently flow down to the filter cover. The effect of this and any other methods would have to be determined in a study involving placement of prototypes in households.

Storage

Potable water is usually stored in earthen jars. The change to drawing from a tap might be resisted by some. Also, areas given distribution systems in the past have had the problem of children drinking directly from the tap with their lips directly on the tap orifice. This only promotes recontamination of the effluent and further exposes the children to possible infection. A modification suggested by one of the health workers holds promise for correction of both problems. The filter would be directly connected to an earthen jar and the tap be replaced by a valve. That way, children would not have access to the filter orifice and the tradition of earthen jar storage of potable water can be continued.

Construction

The recycling of old vehicle tires into household articles such as furniture has been one of the success stories of the island. There is every reason to expect that containers for the filter could easily be made in the same manner sighting that some locals have already replaced earthen jars with recycled tire containers. This would further reduce the cost of the filter, eliminating one of the major component expenditures, the plastic bin.

7. REFERENCES

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APPENDIX A

Daily Log

Date	Flow Time (s)	Hydraulic loading (m/h)	% Coliform Reduction	Comments
OCT 22	738.74	0.79		clear, odourless, some sand
23	857.48	0.68		"
24	766.49	0.76	undef	"
25	799.29	0.73		"
28	788.88	0.74		"
29	782.89	0.75		"
30	819.10	0.71		"
31	779.98	0.73	88.9	"
NOV 01	780.00	0.75		clear, odourless, little sand
04	800.69	0.73		"
05	811.02	0.72		"
06	803.78	0.73		"
07	784.72	0.75	99.0	"
08	810.95	0.72		"
12	813.22	0.72		clear, odourless, no sand visible
13	814.60	0.72		"
14	825.41	0.71	98.5	"
15	823.71	0.71		"
18	827.06	0.71		"
20	805.87	0.73		"
21	815.50	0.72	99.7	"
22	803.27	0.73		"

Daily Log Continued

Date	Flow Time (s)	Hydraulic loading (m/h)	% Coliform reduction	Comments
Nov 25	800.52	0.73		clear, odourless, no sand visible
26	847.15	0.69		"
27	814.21	0.72		"
28	800.75	0.73	91.7	"

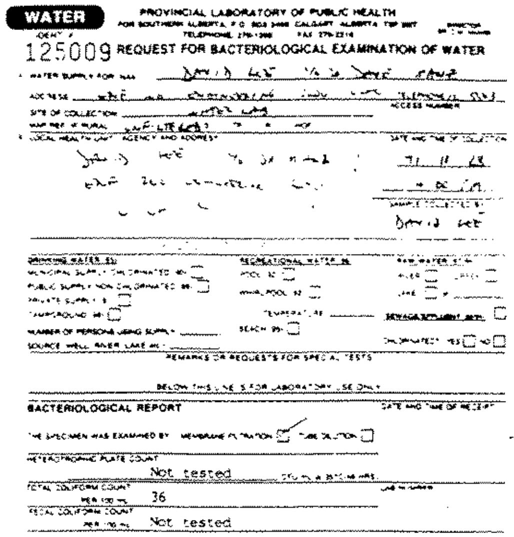
APPENDIX B

Bill of Materials

Item	Cost	Tax	Total
Garbage bin	11.98	0.84	12.82
5 ft. 1/2" CPVC pipe	2.69	0.19	2.88
1 1/2" Stop/W Adapt	7.29	0.51	7.80
1 PVC pipe cement	3.49	0.24	3.73
4 1/2" CPVC Elbow 90	2.36	0.17	2.53
2 1/2" CPVC Cap	.78	0.05	0.83
2 1/2" CPVC Tee	.98	0.07	1.05
Fibreglass screen	1.04	0.07	1.11
Totals	30.61	2.14	32.75

APPENDIX C

Sample Water Test Reports



WATER PROVINCIAL LABORATORY OF PUBLIC HEALTH

125009 REQUEST FOR BACTERIOLOGICAL EXAMINATION OF WATER

WATER SUPPLY FOR NAME

ADDRESS

SITE OF COLLECTION

LOCAL HEALTH UNIT AGENCY AND ADDRESS

DATE AND TIME OF COLLECTION

SAMPLE COLLECTED BY

DRINKING WATER

RECREATIONAL WATER

RAW WATER

REMARKS OR REQUESTS FOR SPECIAL TESTS

BELOW THIS LINE IS FOR LABORATORY USE ONLY

BACTERIOLOGICAL REPORT

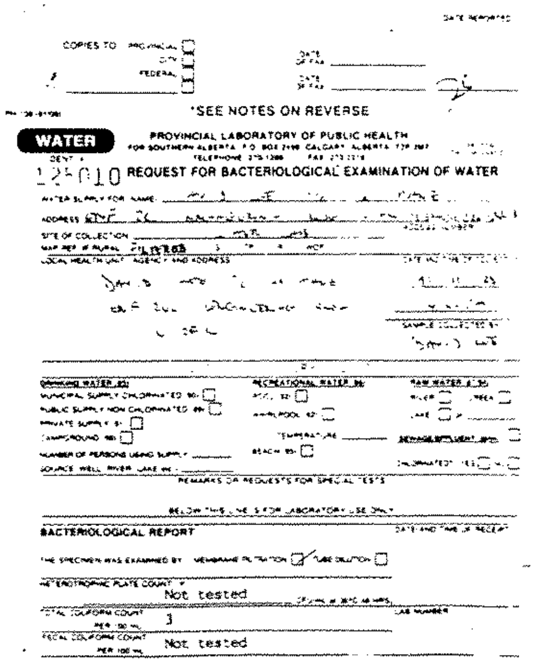
DATE AND TIME OF RECEIPT

THE SPECIMEN WAS EXAMINED BY MEMBRANE FILTRATION ☑ TUBE DILUTION ☐

HETEROTROPHIC PLATE COUNT Not tested

TOTAL COLIFORM COUNT PER 100 mL 36

FECAL COLIFORM COUNT PER 100 mL Not tested



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*SEE NOTES ON REVERSE

WATER PROVINCIAL LABORATORY OF PUBLIC HEALTH

125010 REQUEST FOR BACTERIOLOGICAL EXAMINATION OF WATER

WATER SUPPLY FOR NAME

ADDRESS

SITE OF COLLECTION

LOCAL HEALTH UNIT AGENCY AND ADDRESS

DATE AND TIME OF COLLECTION

SAMPLE COLLECTED BY

DRINKING WATER

RECREATIONAL WATER

RAW WATER

REMARKS OR REQUESTS FOR SPECIAL TESTS

BELOW THIS LINE IS FOR LABORATORY USE ONLY

BACTERIOLOGICAL REPORT

DATE AND TIME OF RECEIPT

THE SPECIMEN WAS EXAMINED BY MEMBRANE FILTRATION ☑ TUBE DILUTION ☐

HETEROTROPHIC PLATE COUNT Not tested

TOTAL COLIFORM COUNT PER 100 mL 3

FECAL COLIFORM COUNT PER 100 mL Not tested