SLOW SAND FILTER CONCEPTUAL DESIGN FOR THE FEDERATED STATES OF MICRONESIA (FSM)

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ABSTRACT

Cholera outbreaks have occurred repeatedly throughout the islands of the Federated States of Micronesia (FSM). Outbreaks occurred in Chuuk in 1983 and in Pohnpei State in April 2000. The Pohnpei outbreak resulted in 20 deaths, and over 3,000 people were infected with the disease. The rapid spread of this disease was attributed to lack of proper water and food sanitation especially in villages that are being served by small community water supply systems. There are 24 municipal water supply systems around Pohnpei that provide untreated and non-potable water to the rural communities. These small systems provide water to more than 50% of Pohnpei's population. The other islands, Yap, Chuuk, and Kosrae, have very similar situations. Since 1999 the principal investigators of this project have been exploring the use of slow sand filtration technology as a means of improving the water provided by the small community system throughout the FSM. Results indicate that it is feasible to use local materials for filters media. These studies have also determined optimum filter loading rates for the local filter media. What was needed next was to pull together the results of the pilot studies and to develop design plans, cost estimates, and operational manuals for slow sand filtration systems designed appropriately for the rural water systems of the FSM.

Site visitations were made to community water supply systems in Pohnpei and Kosrae States. Information was collected on: daily water demand, the turbidity level of the source water, and possible location for installing slow sand filters. From this information, complete facility drawings for three different sizes of slow sand filters with capacities of 20, 60, and 150 gallons per minute (gpm) of flow were developed. The three sizes reflected the demands of the smallest, largest, and medium sized community water supply systems. The drawings that were developed show inflow and outflow pipes to the plant, the under drain systems beneath the filter media, and the required flow controls. The estimated cost of each plant has been included in this study. The total project costs varies from $148,525 to $307,630 for a filter with a capacity of 150 gpm depending on the types of filter media that are used. Recommendations on Filter operation and maintenance also have been made.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The lack of clean drinking water is significant problem for residents of the high, volcanic island of the Federated States of Micronesia (US EPA, 1986). The island of Pohnpei in the Federated States of Micronesia (FSM) suffered severe outbreaks of cholera in April 2000, which resulted in 20 deaths, and over 3,000 infected people. The epidemic started at Enipein, a remote village of the island where there is no potable water supply and no proper sanitation facilities (PUC, 2001). At the conclusion of a three-day symposium that was held in Pohnpei on the cholera epidemic, lack of proper water and food sanitation were defined as the sources of spread of the disease (Cholera Symposium, Pohnpei 2001). A similar outbreak occurred in Chuuk in 1983. Again, contaminated water supply systems were suspected as a source of spreading the disease. In both states the water systems suspected of spreading the disease are supplying raw untreated surface water to the consumers. Simple filtration and chlorination could do much to improve the sanitation of these systems.

In 1990, David Sasaki, the State of Hawaii's Veterinary Medical Officer, published a travel report following his November 8-15 1990 visit to Kosrae. He estimated an annual incidence rate of leptospirosis on Kosrae of 400 cases per 100,000 individuals. According to Sasaki, this estimate for incidences of leptospirosis was 61 times higher than Hawaii's highest annual incidence rate estimate of 6.5 cases per 100,000 individuals and 8000 times greater than the United States estimated incidence rate of 0.05 cases per 100,000 nationwide (Sasaki, 1990). Between January 1990 and October 1990, eight patients were airlifted to Hawaii at a cost of $25,000 per person (Sasaki, 1990). In his report, Sasaki recommended that Kosrae chlorinate the stream fed fresh water systems, as most cases of leptospirosis involved exposure to these waters.

In order to reduce the incidence rate of leptospirosis and other water borne illnesses, water treatment is necessary. Recommended treatment includes both filtration and chlorination (US EPA, 1986). Furthermore, the treatment technology must be economical to build, and simple to operate and maintain given the adverse economic and environmental conditions of this remote island. For these reasons, slow sand filtration has been selected as a potential water treatment technology.

2. PROJECT OBJECTIVES

The objective of this project was to put together the findings of earlier Kosrae slow sand filter pilot studies and to develop detailed conceptual construction drawings, operation recommendations, and construction costs for small slow sand filtration plants. The resulting recommendations and drawings are planned around and sized appropriately for use by the many small community water supply system throughout the FSM.

The specific objectives were to:

1) Collect information on several potential sites for use of slow sand filtration technology in Kosrae and Pohnpei. This information includes the location, water demand, source of inflow, and the turbidity levels of the source water.

2) Develop detailed conceptual structural drawings of a slow sand filter plant for typical sites in FSM. These drawings include details of structural requirements, and complete descriptions of required inflow and outflow piping systems, filter and underdrain systems, and filter controls. The design packages cover various potential sites in FSM with construction cost estimates for each site.

3) Develop an operation manual on how to operate the recommended slow sand filter system. This manual will include information on, when the filters need to be scrapped, how to backfill the filters, and how to control the inflow and out flow from the filter.

3. BACKGROUND

Originating in Europe, slow sand filtration is classified as the first, modern water-treatment technology (Ellis, 1985). This filtration process removes particles and microorganisms by the slow percolation of water through a porous sand media. Unlike other water treatment technology (i.e. rapid sand filtration), conventional slow sand technology does not involve chemical or physical pre-treatment applications (Collins et al, 1992).

The origin of slow sand filtration technology dates back to 1790, in Lancashire England (Weber-Shirk and Dick, 1997a). It was there that rudimentary sand filters were first constructed to purify water used in the bleaching process. In 1804, John Gibb of Paisley Scotland constructed a sand filter used primarily for his bleachery, however, he also sold excess filtered water to the public (Ellis, 1985). In 1827 Robert Thom improved upon Gibb's design (Ellis, 1985). Two years later, James Simpson used this modified design in his plans for a one-acre sand filter for the Chelsea Water Company of London (Ellis, 1985). The health benefits attributed to London's first sand filter led to the construction of additional filters. By 1852, the city of London required filtration of all drinking water sold to the public. To ensure fulfillment of this requirement, the Thames Conservancy Board was established to regulate drinking water quality (Hendricks, 1991).

Adoption of slow sand filter technology spread throughout Europe in the mid- to late 1800's and by 1872, the technology had reached the United States. Poughkeepsie, New York was the first American town to build a slow sand filter (Hendricks, 1991). Additional installations followed, and by 1899, twenty such filters were in use in the United States (Hendricks, 1991).

America's preference for this technology, however, was not forthcoming. By 1940, the United States had approximately 100 slow sand filters with an aggregate capacity of

52.6 million gallons per day (mgd), in contrast to roughly 2, 275 rapid sand filters with a production capacity of 237 mgd (Hendricks, 1991). Problems associated with highly turbid waters made conventional slow sand treatment impractical for communities plagued with such source water. Conventional slow sand filters clogged under such conditions, and the technology of choice became rapid sand filtration, due to its ability to produce large quantities of acceptable finished water from highly turbid source water (Ellis, 1985). An additional factor influencing the move to rapid sand filtration was public support for the newest technology available, regardless of community size (Logsdon, 1991).

Recently, however, slow sand filtration technology has received a resurgence of interest in the United States (Logsdon, 1991). Increased concerns regarding the persistence of *Giardia* cysts in many municipal water systems has led to a greater interest in slow sand technology (Lange, Bellamy, Hendricks and Logsdon, 1986; Fogel, Isaac-Renton, Guasparini, Moorehead and Ongerth, 1993). With the 1989 passage of the Surface Water Treatment Rule (SWTR) in the United States, many previously unfiltered surface water sources now require filtration (Logsdon, 1991; Brink and Parks 1996). The United States Environmental Protection Agency (EPA) has set a turbidity standard $\leq$ 1 nephelometric turbidity unit (NTU) 95 percent of the time, never to exceed 5 NTU's. Furthermore, the removal or inactivation of *Giardia* cysts is to be $\geq$ 3-logarithmic (log) and virus removals are to be $\geq$ 4-log removal. Removals of microorganisms in slow sand filters have proven to be 2 – log to 4 – log in effluent of slow sand filters (Hendricks and Bellamy, 1991). The effectiveness of slow sand filtration in removing *Giardia* cysts is well documented (Fogel et al., 1993; Bellamy, Hendricks and Logsdon, 1985; Ellis, 1985). Research in the United States and Great Britain has shown the effectiveness of slow sand filtration in removing viruses and bacteria (Wheeler and Lloyd, 1988; Poynter and Slade 1977 as cited by Hendricks and Bellamy, 1991).

The effectiveness, affordability and ease of operation available with slow sand filtration systems is appealing to small communities (those under 10,000 people) that lack significant capital for constructing, operating and maintaining rapid sand filtration facilities (Riesenberg, Walters, Steele, and Ryder, 1995; Li, Ma and Du, 1996). As of 1984, a survey by Simms and Slezak identified 71 slow sand filtration facilities in operation in the United States. Brink and Parks (1996) stated that a preliminary report compiled for the American Slow Sand Association indicated that 225 such facilities were in use in the United States. It is anticipated that additional facilities will be built by small communities needing affordable, effective water treatment technology to comply with the surface water requirements established in 1989 (Logsdon, 1991; Brink and Parks, 1996).

4. GENERAL DESCRIPTION OF SLOW SAND FILTRATION TECHNOLOGY

4.1 Mechanisms of Filtration

Particulate (microbial, viral and sediment) removal in slow sand filtration is considered a passive process, differing from rapid sand filtration in that chemical pre-treatment of inflow is generally not performed and backflushing (pressurized flow reversal) is not used for cleaning the filter media (Haarhoff and Cleasby, 1991). In rapid sand systems, filtration requires flocculation to coagulate particles contained in the inflow, coupled with backflushing every 1-2 days to dislodge coagulated particles trapped in the media (Haarrhoff and Cleasby, 1991). In contrast, slow sand water purification depends upon two passive removal mechanisms: 1) biological and 2) physical-chemical; neither of which is well understood (Weber-Shirk and Dick, 1997a; Weber-Shirk, 1997b). Removals attributed to biological activity within the filter media are absent in rapid sand filters, due to the aforementioned processes that prevent establishment of biological communities within the filtration media (Haarhoff and Cleasby, 1991).

In slow sand filters, biological processes are considered to dominate the uppermost region of the filter bed (Haarhoff and Cleasby, 1991; Ellis 1995). A layer termed the *schmutzdecke*, literally translated as "dirty skin" (as cited in Hendricks, 1991), forms on the surface of the sand bed and is believed to contribute to the removal of water impurities. Considerable disagreement exists in the literature, however, as to how and to what extent this is accomplished (Weber-Shirk and Dick, 1997a).

It has been hypothesized that within the *schmutzdecke*, algae, plankton, diatoms, and bacteria break down introduced organic matter through biological activity (Weber-Shirk and Dick, 1997a).

Collins et al. (1992) showed that bacterial concentrations in the *schmutzdecke* were a function of elapsed time and potential for cell growth, rather than the filtration of free-living bacteria from source water. This suggests that biological communities grow and develop within this layer.

In addition to the *schmutzdecke*, the sand grains of the filter bed provide additional biological and physical mechanisms that contribute to removal efficiency (McMeen and Benjamin, 1997; Ellis 1985). A biofilm develops around the sand grains and it has been hypothesized that such films create sticky surfaces, causing the attachment of organic and inorganic particles (Weber-Shirk, 1997b). This surface is thought to be biologically active (consisting of bacteria, protozoa and bacteriophages) and a site for the decomposition of organic matter (Weber-Shirk, 1997b). Hendricks (1991) presents a thorough review of the potential pathways that particles (organic and inorganic) follow through the filter media and the theoretical collisions such particles experience within the media.

Physical mechanisms such as straining and adsorption are also considered to contribute to the removal effectiveness of slow sand filters Adsorption of suspended material is influenced by zeta potentials (Hendricks, 1991). According to O'Brien (1996), a zeta potential may be described as follows:

> A charged particle suspended in an electrolytic solution attracts ions of the opposite charge to those at its surface, where they form the Stern layer. To maintain the electrical balance of the suspending fluid, ions of opposite charge are attracted to the Stern layer. The potential at the surface of that part of this diffuse double-layer of ions that can move with the particle when subjected to a voltage gradient is the zeta potential. This potential is very dependent upon the ionic concentration, pH, viscosity, and dielectric constant of the solution being analyzed.

The biological and physical factors associated with slow sand filtration make factors affecting filter biogeochemistry (pH, dissolved oxygen, and temperature) useful variables to measure in pilot studies designed to determine: 1) the suitability of a particular water source considered for filtration and, 2) the performance of a particular filtration media for slow sand filtration (Ellis, 1985).

Temperature measurements are used in determining physical characteristics of the media such as the intrinsic hydraulic conductivity, k' which is a function of the viscosity of the water moving through a filter and the filter media itself (sand size, distribution and the aggregation of the sand grains) (Hendricks, 1991). Temperature adjustment for viscosity allows for determination of the porous characteristics of the media (Hendricks, 1991), which is useful for determining: 1) if a particular sand meets the porosity specifications for slow sand filtration applications, and 2) what amount of head loss can be expected due to this porosity when the filter bed is clean (Hendricks, 1991).

4.2 Design Elements

A slow sand filter consists of essentially three components: 1) sand, 2) gravel and 3) an under drainage (Ellis, 1985). A container (circular, square or rectangular) is used to hold a column of water (the supernatant or headwater) on a bed of sand (filtration media) supported by a gravel medium (Pyper and Logsdon, 1988). The column of water provides a pressure head for driving the flow of raw water through the filter media. The gravel supports the sand bed in addition to the under drains, a network of perforated pipes that collect filtered water and channel it out of the filter container (Ellis, 1985), which it covers. The gravel is arranged with the finest grade directly beneath the sand bed and successively coarser grades leading to and surrounding the under drain pipes (Pyper and Logsdon, 1991). Haarhoff and Cleasby (1991) cite recommendations made by Visscher regarding design criteria for slow sand filters. These are presented in Table 1 with a modification on bed depth (*) as shown in Hendricks (1991).

Table 1. Design Criteria and Recommendations for Slow Sand Filters

DESIGN PARAMETER	RECOMMENDATION
Depth of filter bed:	
Initial Bed Depth	0.8 m-0.9 m (2.63 ft-2.95 ft) *modified 1.0-1.3 m (3.28 ft-4.27 ft)
Minimum Bed Depth (requires re-sanding at this depth)	0.5 m-0.6 m (1.64 ft-1.97 ft)
Maximum Bed Area	200 m^2 (2153 ft^2) minimum of 2 beds
Sand size:	
Effective size (d_{10})	0.15 mm-0.30 mm (0.006 in-0.012 in)
Uniformity Coefficient (UC)	< 5 (preferably <3)
Depth of gravel support	0.3 m-0.5 m (0.984 ft-1.64 ft
Depth of supernatant (headwater)	1 m (3.28 ft)
Filtration Rate	0.2 m/hr

5. PREVIOUS STUDIES

The principal investigators of this project completed two studies using a slow sand filter pilot plant that was constructed on the island of Kosrae. In the first study that was completed on March 2001, a pilot plant consisting of four test cylinders was constructed near the Tofol stream in Kosrae (Khosrowpanah, et al., 2001). Each plant included four PVC pipe test cylinders each 13 feet long and 12-inch diameter with 5.5 feet of sand media sitting on 2 feet of gravel bed. A weir, regulating the inflow to the each cylinder at approximately 230 ml/min, was located at the top of the plant. Each cylinder was equipped with three piezometers, sampling taps, and an outflow weir that prevented the creation of negative pressure across the filter media. Two of the filters contained locally available sand material that was prepared according to typical SSF specifications. The other two contained commercially prepared sand media that was imported from off island. The pilot plant was operated for a period of six months. Testing included: 1) two coliform spiking tests for each of the four filters to determine the filter bed maturity, 2) daily inflow/outflow turbidity measurement to determine the filter turbidity removal's rate, 3) daily head loss measurement across the filter bed to determine the scrapping time for the filters, and 4) weekly monitoring of influent and effluent total coliform and dissolved oxygen to monitor the biological health of the filter.

The first set of experiments involved comparison of two local-sand and two imported-sand test cylinders. The imported sand size distribution was specifically designed for the slow sand filtration process. It behaved very closely to what would be expected from examining the literature of previous studies of the slow sand filtration system. Coliform removal rates in the range of 90.3 to 99.8 were obtained. Turbidity removal rates were at acceptable levels. Filter cycle time ranged from 30 to 60 days indicating that slow sand filtration using commercially available sand would be a viable option.

The tests runs made on the locally available sand sources were not as conclusive. Coliform removal rates of from 94 to 99.5 percent were obtained. Turbidity removals similar to the commercial sand were obtained, although it seemed to take much longer for the filter to expel the fines existing in the filter media at start up. This could indicate a deficiency in the washing of the local filter media prior to installing it in the filters. These removal rates even with the minimal head losses through the filter indicate that it might be possible to use higher loading rates and thus create a filter design of significantly less volume and therefore less cost.

The principal investigators of this project undertook a second study. This study involved further investigation on the use of local basalt media. The study included determining the optimum inflow to the filters (hydraulic loading rates) and also the particle size distributions within the bed media (uniformity coefficient). The goal was to: 1) modify the existing pilot plant to gain better flow control to the test cylinders, 2) measure the level of turbidity and coliform removal, under four different hydraulic loading rates, and 3) evaluate two different local sand size distributions in the four test cylinders. A constant flow was pumped to the filters by using small electrical pumps (Masterflez L/S). The results indicated that using local basalt, as media requires extensive washing in order to remove the dirt. The scraping time that is the time that filter has to shutdown and the 1-3 cm of the top layer be removed could increase to 45 days if the inflow to the filters has turbidity below 5 NTU.

6. METHODOLOGY AND PROJECT'S RESULTS

The project objectives were accomplished by site visitation, development of conceptual construction-drawings with the cost estimate for three different sizes of SSF for the FSM, and providing recommendations on filter operation and maintenance.

6.1 Phase I. Site Visitation

Pohnpei state has approximately 24 small community water supply systems that deliver untreated water to each community. The location of Pohnpei's community water supply systems is shown in Figure 1. Kosrae State has seven village water supply systems (Figure 2) delivering untreated water to village residents. The same situation exists in the other community water supply system in the FSM. Most of these small systems include a pipe that brings water from a small diversion structure at the sources to a large storage tank followed by a gravity feed distribution system to the village houses.

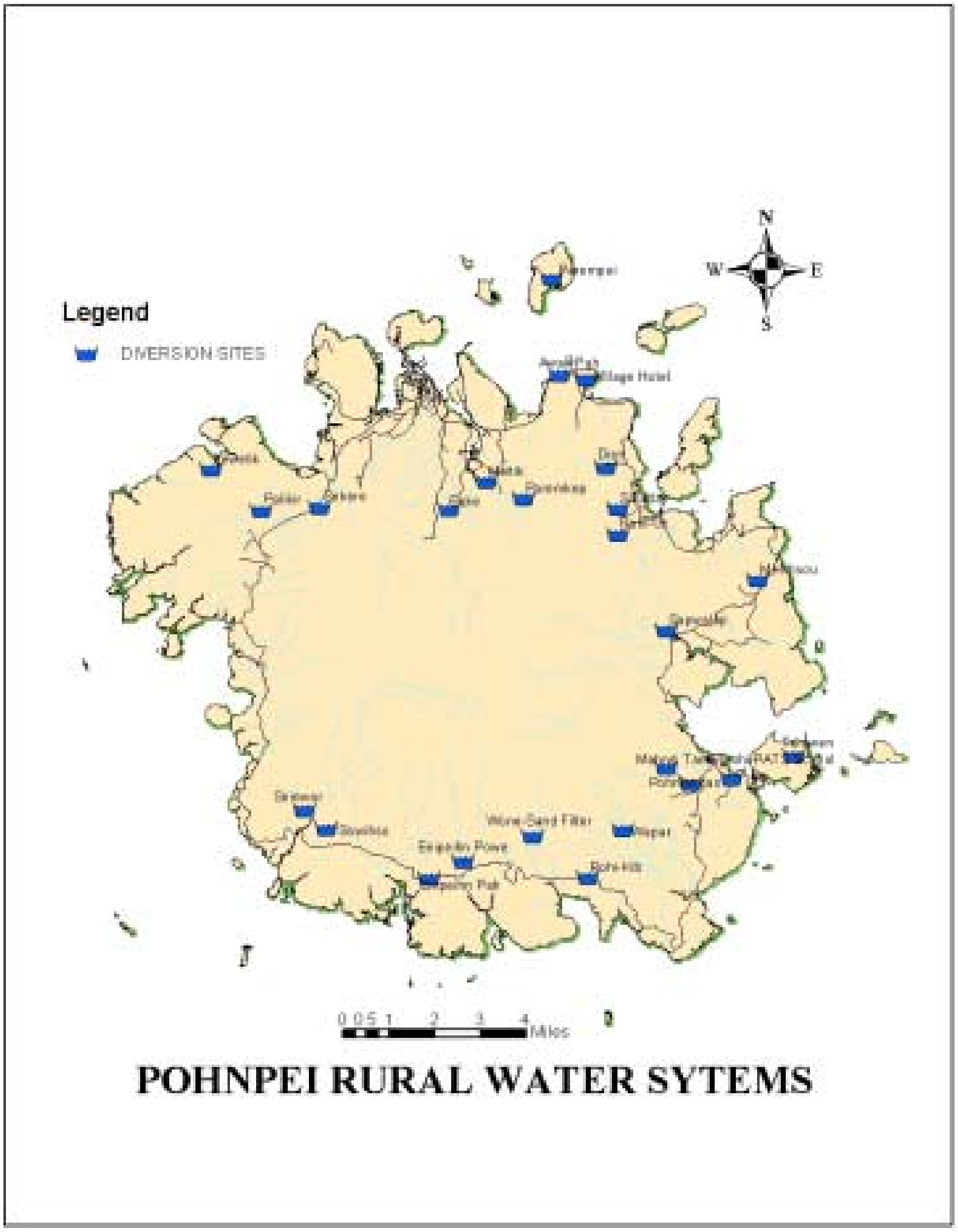

Figure 1. Location of untreated rural water supply systems on Pohnpei Island

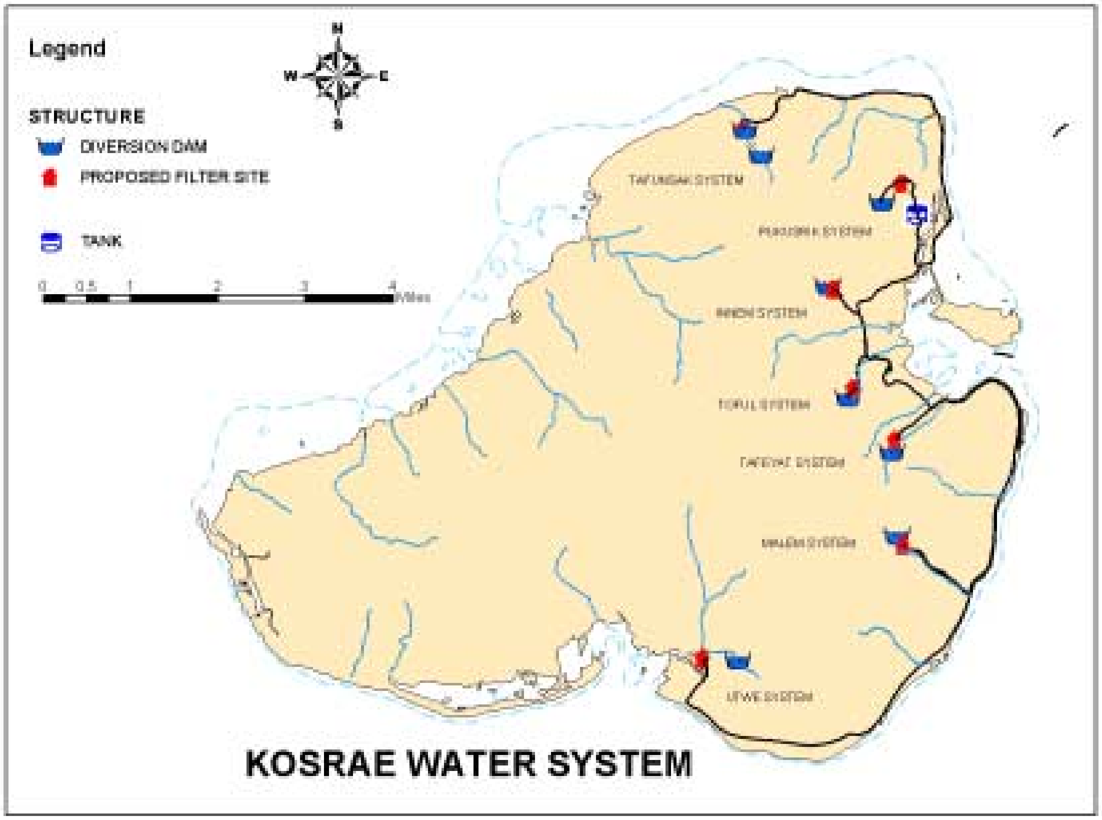

Figure 2. Location of Untreated Rural Water Supply Systems on Kosrae Island

A site visitation was made to all Kosrae and some of the Pohnpei community water supply systems. Some of these sites are shown in Figure 3 through 6. Two sets of data were collected. The first set of data was the estimation of the needed flow for user consumption. The needed flow for sites in Pohnpei and Kosrae States are shown in Table 2 and 3. The second set of data (for Kosrae only) that was gathered dealt with the physical characteristics of potential locations for a slow sand filter plant. As mentioned earlier the size of the slow sand filters depends upon the water demand. For example, to provide 1.6 million gallons a day for the Toful municipality in Kosrae requires a filter bed area of approximately one third of an acre. So, it was important to have a site that can physically accommodate the filters. In addition, topographic considerations were evaluated in order to determine the need for excavation that could increase the cost of construction.

Based on the needed flows (table 1 and 2) three flow rates; 20, 60, and 150 gpm were selected for the slow sand filter designs.

Figure 3. Pukusrik Dam, Kosrae Island

Figure 4. Toful Dam, Kosrae Island

Figure 5. Malem Diversion Dam, Kosrae Island

Figure 6. Mahnd Storage Tank, Pohnpei Island

6.2 Phase II. Design, Construction, and Cost Estimates

From information in phase 1, we developed a conceptual construction-drawing package for a typical slow sand filter that can be applied to water systems in the FSM. This package includes a complete set of structural drawings of the facilities for producing 20, 60, and 150 gpm filtered water. These drawings, which are shown in Appendix A and B show inflow and outflow pipes to the plant, the under drain system that lies beneath the filter bed media, and the required flow control systems. Basic structural details are also provided. The design drawings are also provided in AutoCAD format on the CD contained in the envelope attached to the inside back cover of this report. These AutoCAD files can also be obtained directly from the Water and Environmental Research Institute of the Western Pacific at the University of Guam.

While these plans are not final construction drawings, they will be useful to those seeking to secure funding to construct an actual facility. These plans will also greatly reduce the workload and thus the expense of producing final construction drawings for each project.

A completed construction cost estimate has been provided for the conceptual filter designs. These estimates, which show the unit cost of each of the components of the slow sand filters, are shown in Appendix C, D, and E.

A typical slow sand filter facility normally consists of two identical filter tanks that supply the community with treated water. During the time when filter scraping is required, one filter will be shut down and scraped while the other remains in service. However, to reduce the operational manpower, and project cost we developed a conceptual construction-drawing package with only one filter. The extra water from this filters will be stored in a storage tank for the time that filter needs to be scraped thus eliminating any discontinuity in providing drinking water for the community. The cost of storage tank is not included in the cost estimate that listed in Appendix C, D, and E.

To increase the length of the time between when the filter needs to be scraped, the inflow water should be relatively low in turbidity. This may require the need for a settling basin before the water inflows to the filters. Flow controls and water distribution to the filter beds has been kept as simple as possible to avoid problems with long-term maintenance of the facility. There are two valves that controls the flow, one located at the inflow, and one located at the outflow of the filters. The function of the inflow valve will be to control inflow and also for shutdown of the filter during scraping times. The outflow valve will be used to control the flow rate through the filter. As shown in Appendix A and B the filter has two Piezometers. The Piezometer will indicate the head loss through the filter's media and thus will serve to warn those operating the filter when scrapping will be required. The filter media will be of local crushed basalt or imported sand. The imported sand will be more expensive but it will eliminate the washing requirements. According to the Kosrae pilot study, the performances of local and imported sand are the same; with the exception that local sand requires extensive washing. This washing is for the removal of fine particles that will clog the filters.

Table 2. Location of Community Water Systems on Pohnpei Island

Water System Name	Latitude Coordinates of Diversion Sites*	Longitude Coordinates of Diversion Sites*	Required Flow (gpm)
Lewetik	158.141200	6.937554	15
Sekere	158.175600	6.925591	
Eirke	158.216400	6.924862	65
Meitik	158.228500	6.934017	45
Paremkep	158.240200	6.928399	25
Village Hotel	158.259900	6.966474	
Parempei	158.249100	6.998098	25
Dien	158.266300	6.938282	25
Saladak	158.270000	6.925383	
Rohi-Uh	158.270100	6.917164	90
Mesihsou	158.314200	6.902600	45
Sapwalap	158.285300	6.886788	
Temwen	158.325700	6.847049	65
Tamworohi-PATS School	158.306100	6.839767	
Pohnlangas	158.292900	6.837998	
Mahnd	158.285200	6.843096	65
Wapar	158.271600	6.823538	
Rohi-Kiti	158.260500	6.808350	90
Wone-Sand Filter	158.242800	6.821562	
Enipeihn Powe	158.221100	6.813551	35
Enipeihn Pah	158.210200	6.808246	
Sowihso	158.177800	6.823746	
Seinwar	158.170700	6.829676	120
Awak Pah	158.251500	6.967514	15

*These Latitude and Longitude Coordinates were determined from digitized USGS Quadrangle Sheets for Pohnpei which were developed using the Clark 1866 Spheroid

Table 3. Location of Community Water Systems on Kosrae Island

Water System Name	Latitude and Longitude Coordinates of Diversion Sites*	Required Flow (gpm)	Latitude and Longitude Coordinates of Possible Filter Sites*
Pukusrik	5.35073, 163.01120	250	5.35402, 163.014747
Innem	5.33690, 163.00222	110	5.33651, 163.00329
Toful	5.31846, 163.00569	166	5.32002, 163.00674
Tafeyat	5.30948, 163.01282	100	5.31160, 163.01341
Malem	5.30163, 163.03049	350	5.329416, 163.01475
Palesrik	5.27509, 162.98730	125	5.27550, 162.98168
Tafunsak	5.36064, 162.99010	400	5.36311, 162.98850

*These Coordinates are provided in the WGS-84 Coordinate System

6.3 Phase III. Filter Operation and Maintenance

Operation of the slow sand filter requires that relatively few tasks be performed. The initial task after filter construction is plant start-up. The routine tasks include scraping the filter media, sand handling, monitoring, and maintenance.

6.3.1 Plant Start-Up

Following construction, the plant requires a break-in period before the production of potable water can begin. The first step is to fill the sand bed from the bottom with raw water, and the second step is to be sure the water production is of acceptable quality.

To displace the air pockets within the sand bed media, the bed should be saturated by slowly backfilling the sand media from the bottom of the filter. The rate of backfilling should be in the range of 0.1-0.2 meter of bed depth per hour or 0.3-0.6 ft/hr, (Hendricks, 1991). The filters shown in appendix A will take about 6 hours to backfill with four feet of bed media. As shown in Appendix A, the backfilling will take a place by closing the gate valves at the inflow and outflow to the filter, then letting the flow goes to the filter by opening the gate valve 6" under drain pipe. When the backfilling is compete, the flow should rise to three feet above the bed material before opening the gate valve at the outflow to the distribution system.

Following the start-up of a new filter or a filter in which the sand media has been displaced completely, a "ripening" process will occur within the sand media. As mentioned earlier in this report, ripening refers primarily to the development of a biofilm surrounding the particles of filtration media but also includes the Schmutzdeske layer. The ripening period will range from about one week to several months. Warm temperatures and high nutrients will decrease the ripening time (Hendricks, 1991).

According the Kosrae pilot study (Khosrowpanah et al, 2001) the maturation period for local and imported sand media was 24 hours.

6.3.2 Routine Operating Tasks

Scraping and backfilling the filters will be requires to insure that the filter is operates effectively.

Scraping and Backfilling

Slow sand filter should be scraped when the headwater rises to the overflow level. Our recent pilot study indicated that if a settling tank is used before flow enters the filter the period between the filters be required scrape would be approximately 45 days.

The following steps is recommended for scraping the filters:

1. Remove any floating material
2. Slowly drain the water level to just below the level of sand media
3. Scrape the top 1-3 cm of sand
4. Remove the scraped sand from the filter box
5. Wash the filter walls if they are dirty

As shown in Appendix A, by closing the inflow to the filter and opening the outflow valve you can reduce the level of water in the filter box. The time required for scraping largely depends on the depth of sand removed and the method used to transport sand from the filter.

6.3.3 Headloss Versus Time

As shown in Appendix A, there is a Piezometer connected to the filter’s outflow pipe. The function of this Piezometer is determining when a filter will need scraping. It should be measure daily, beginning at plant start-up. A plot of headloss versus time should be made. This will help to determine the time for scraping.

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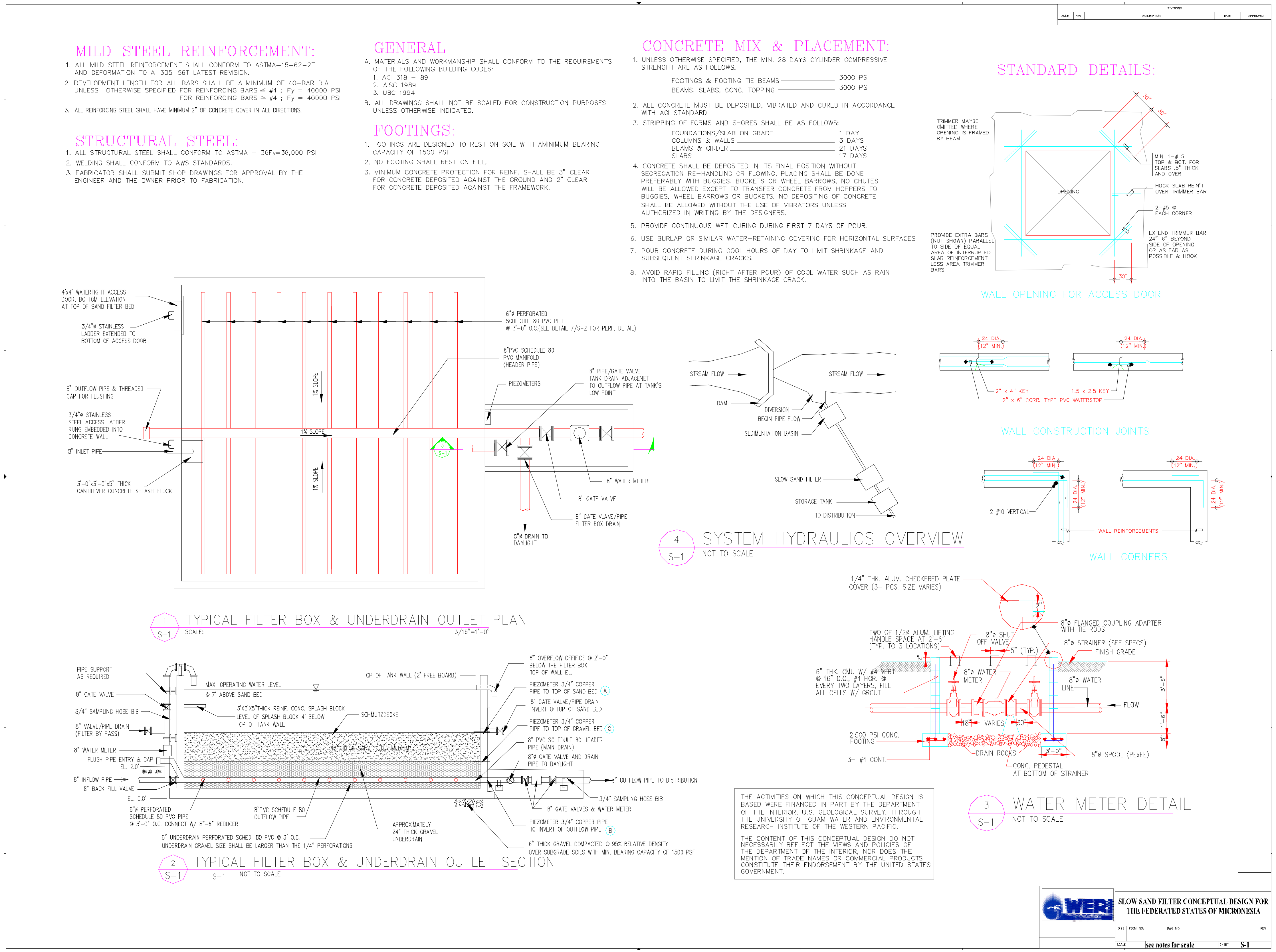
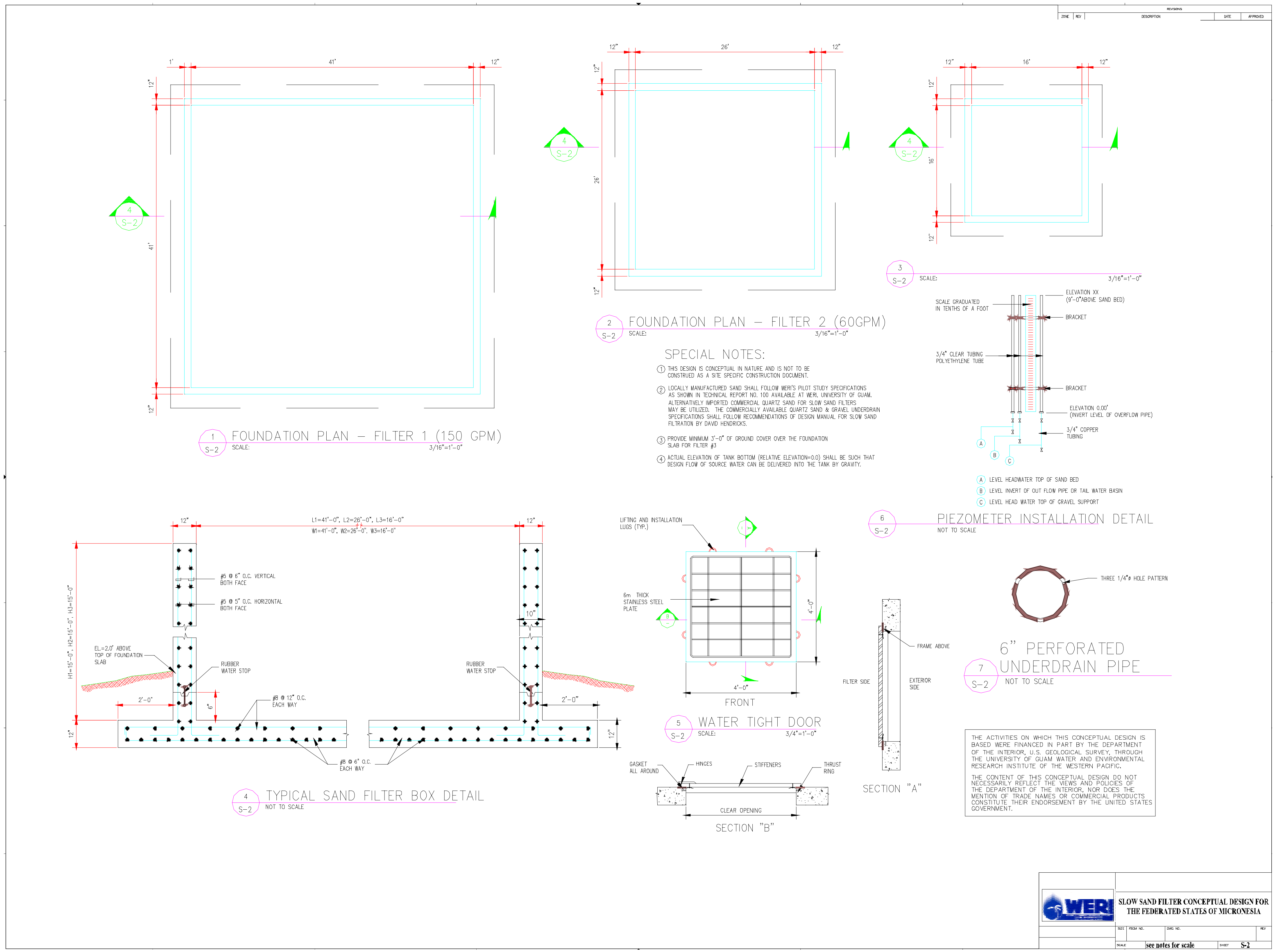
APPENDIX A. Slow Sand Filter Conceptual Drawing



APPENDIX B. Slow Sand Filter Structural Drawing



APPENDIX C

Table 1. Cost Estimate for Slow Sand Filter with 150 gpm Capacity

SLOW SAND FILTER BUDGETARY CONSTRUCTION COST ESTIMATE (150 GPM CAPACITY)					
COST ESTIMATE PROVIDED BY MASOUD & COMPANY (JANUARY 2003)					
NO.	ITEM	QUANTITY	UNIT	UNIT COST	TOTAL COST
1	8" SCHEDULE 80 PVC PIPE	80	FT	$19.94	$1,595.00
2	8" PVC SCHED. 80 COUPLING	8	EA	$56.25	$450.00
3	8" PVC SCHED. 80 ELBOW 90 DEGREE	3	EA	$65.00	$195.00
4	6" SCHEDULE 80 PVC PIPE PERFORATED	600	LF	$25.00	$15,000.00
5	6" PVC SCHED. 80 COUPLING	20	EA	$31.25	$625.00
6	6" PVC SCHED. 80 ELBOW 90 DEGREE	5	EA	$40.00	$200.00
7	6" TO 8" PVC SCHED 80 REDUCER	15	EA	$62.50	$937.50
8	8" GATE VALVE BRASS	6	EA	$687.50	$4,125.00
9	8" SCHEDULE 40 GALVANIZED PIPE	80	LF	$29.11	$2,328.57
10	8" MJ 90 DEGREE ELBOW	4	EA	$225.00	$900.00
11	8" SOLID SLEEVE JOINT	8	EA	$225.00	$1,800.00
12	4'X4' SS WATER-TIGHT DOOR & FRAME	1	EA	$3,562.50	$3,562.50
13	MAGNETIC TAPE	1	LS	$250.00	$250.00
14	STRUCT. STEEL REINFORCED CONC. (3000 PSI, GRADE 40 STEEL)	174	CY	$312.50	$54,386.57
15	TRENCH BEDDING SAND	1	LS	$1,500.00	$1,500.00
16	GRAVEL BASE COURSE	46	CY	$45.00	$2,083.33
17	COMPACTION	1	LS	$1,250.00	$1,250.00
18	TRENCHING/BACKHOE/EXCAVATOR	1	LS	$22,400.00	$22,400.00
19	3/4" HOSE BIB	2	EA	$6.25	$12.50
20	LOCALLY MANUFACTURED SAND FILTER (commercial sand quartz @ $462/cy	249	CY	$150.00	$37,355.56
21	LOCALLY MANUFACTURED GRAVEL FOR UNDERDRAIN	125	CY	$120.00	$14,942.22
22	PIZOMETERS	3	EA	$435.00	$1,305.00
23	WATER METERS 8"	2	EA	$1,250.00	$2,500.00
24	PIPE ADHESIVE, PLUGS, MISC. FITTINGS	1	LS	$500.00	$500.00
25	FENCE & GATE	400	LF	$56.25	$22,500.00
26	STAINLESS STEEL LADDER	2	EA	$1,800.00	$3,600.00
27	MISC. CONCRETE STRUCTURES, OPEN CHANNEL, WIER, ETC.	1	LS	$4,500.00	$4,500.00
28	SMALL TOOLS & MISC. EQUIPMENT	1	HR	$1,400.00	$1,400.00
29	LABOR	1920	HR	$15.00	$28,800.00
30	SUPERVISION	240	HR	$30.00	$7,200.00
31	LAND SURVEYING DURING DESIGN AND CONSTRUCTION PHASES	1	LS	$2,500.00	$2,500.00
32	SITE SPECIFIC DESIGN AND CERTIFICATION	1	LS	$4,500.00	$4,500.00
33	CONSTRUCTION PERMITTING, FEES	1	LS	$900.00	$900.00
	SUBTOTAL				$246,103.76
	OVERHEAD, TAX, & CONTINGENCIES @ 25%				$61,525.94
	GRAND TOTAL				$307,630

APPENDIX D

Table 2. Cost Estimate for Slow Sand Filter with 60 gpm Capacity

SLOW SAND FILTER BUDGETARY CONSTRUCTION COST ESTIMATE (60 GPM CAPACITY)					
COST ESTIMATE PROVIDED BY MASOUD & COMPANY (JANUARY 2003)					
NO.	ITEM	QUANTITY	UNIT	UNIT COST	TOTAL COST
1	8" SCHEDULE 80 PVC PIPE	80	FT	$19.94	$1,595.00
2	8" PVC SCHED. 80 COUPLING	8	EA	$56.25	$450.00
3	8" PVC SCHED. 80 ELBOW 90 DEGREE	3	EA	$65.00	$195.00
4	6" SCHEDULE 80 PVC PIPE PERFORATED	380	LF	$25.00	$9,500.00
5	6" PVC SCHED. 80 COUPLING	14	EA	$31.25	$437.50
6	6" PVC SCHED. 80 ELBOW 90 DEGREE	5	EA	$40.00	$200.00
7	6" TO 8" PVC SCHED 80 REDUCER	10	EA	$62.50	$625.00
8	8" GATE VALVE BRASS	6	EA	$687.50	$4,125.00
9	8" SCHEDULE 40 GALVANIZED PIPE	80	LF	$29.11	$2,328.57
10	8" MJ 90 DEGREE ELBOW	4	EA	$225.00	$900.00
11	8" SOLID SLEEVE JOINT	8	EA	$225.00	$1,800.00
12	4'X4' SS WATER-TIGHT DOOR & FRAME	1	EA	$3,562.50	$3,562.50
13	MAGNETIC TAPE	1	LS	$250.00	$250.00
14	STRUCT. STEEL REINFORCED CONC. (3000 PSI, GRADE 40 STEEL)	110	CY	$312.50	$34,259.26
15	TRENCH BEDDING SAND	1	LS	$1,500.00	$1,500.00
16	GRAVEL BASE COURSE	29	CY	$45.00	$1,316.67
17	COMPACTION	1	LS	$1,050.00	$1,050.00
18	TRENCHING/BACKHOE/EXCAVATOR	1	LS	$14,140.00	$14,140.00
19	3/4" HOSE BIB	2	EA	$6.25	$12.50
20	LOCALLY MANUFACTURED SAND FILTER (commercial sand quartz @ $462/cy	100	CY	$150.00	$15,022.22
21	LOCALLY MANUFACTURED GRAVEL FOR UNDERDRAIN	50	CY	$120.00	$6,008.89
22	PIZOMETERS	3	EA	$435.00	$1,305.00
23	WATER METERS 8"	2	EA	$1,250.00	$2,500.00
24	PIPE ADHESIVE, PLUGS, MISC. FITTINGS	1	LS	$500.00	$500.00
25	FENCE & GATE	400	LF	$56.25	$22,500.00
26	STAINLESS STEEL LADDER	2	EA	$1,800.00	$3,600.00
27	MISC. CONCRETE STRUCTURES, OPEN CHANNEL, WIER, ETC.	1	LS	$4,500.00	$4,500.00
28	SMALL TOOLS & MISC. EQUIPMENT	1	HR	$1,400.00	$1,400.00
29	LABOR	1210	HR	$15.00	$18,150.00
30	SUPERVISION	150	HR	$30.00	$4,500.00
31	LAND SURVEYING DURING DESIGN AND CONSTRUCTION PHASES	1	LS	$2,500.00	$2,500.00
32	SITE SPECIFIC DESIGN AND CERTIFICATION	1	LS	$4,500.00	$4,500.00
33	CONSTRUCTION PERMITTING, FEES	1	LS	$600.00	$600.00
	SUBTOTAL				$165,833.11
	OVERHEAD, TAX, & CONTINGENCIES @ 25%				$41,458.28
	GRAND TOTAL				$207,291

APPENDIX E

Table 3. Cost Estimate for Slow Sand Filter with 20 gpm Capacity

SLOW SAND FILTER BUDGETARY CONSTRUCTION COST ESTIMATE (20 GPM CAPACITY)					
COST ESTIMATE PROVIDED BY MASOUD & COMPANY (JANUARY 2003)					
NO.	ITEM	QUANTITY	UNIT	UNIT COST	TOTAL COST
1	8" SCHEDULE 80 PVC PIPE	80	FT	$19.94	$1,595.00
2	8" PVC SCHED. 80 COUPLING	10	EA	$56.25	$562.50
3	8" PVC SCHED. 80 ELBOW 90 DEGREE	5	EA	$65.00	$325.00
4	6" SCHEDULE 80 PVC PIPE PERFORATED	240	LF	$25.00	$6,000.00
5	6" PVC SCHED. 80 COUPLING	8	EA	$31.25	$250.00
6	6" PVC SCHED. 80 ELBOW 90 DEGREE	5	EA	$40.00	$200.00
7	6" TO 8" PVC SCHED 80 REDUCER	8	EA	$62.50	$500.00
8	8" GATE VALVE BRASS	6	EA	$687.50	$4,125.00
9	8" SCHEDULE 40 GALVANIZED PIPE	80	LF	$29.11	$2,328.57
10	8" MJ 90 DEGREE ELBOW	4	EA	$225.00	$900.00
11	8" SOLID SLEEVE JOINT	8	EA	$225.00	$1,800.00
12	4'X4' SS WATER-TIGHT DOOR & FRAME	1	EA	$3,562.50	$3,562.50
13	MAGNETIC TAPE	1	LS	$250.00	$250.00
14	STRUCT. STEEL REINFORCED CONC. (3000 PSI, GRADE 40 STEEL)	70	CY	$312.50	$21,759.26
15	TRENCH BEDDING SAND	1	LS	$1,500.00	$1,500.00
16	GRAVEL BASE COURSE	18	CY	$45.00	$830.00
17	COMPACTION	1	LS	$1,050.00	$1,050.00
18	TRENCHING/BACKHOE/EXCAVATOR	1	LS	$6,300.00	$6,300.00
19	3/4" HOSE BIB	2	EA	$6.25	$12.50
20	LOCALLY MANUFACTURED SAND FILTER (commercial sand quartz @ $462/cy)	38	CY	$150.00	$5,688.89
21	LOCALLY MANUFACTURED GRAVEL FOR UNDERDRAIN	19	CY	$120.00	$2,275.56
22	PIZOMETERS	3	EA	$435.00	$1,305.00
23	WATER METERS 8"	2	EA	$1,250.00	$2,500.00
24	PIPE ADHESIVE, PLUGS, MISC. FITTINGS	1	LS	$500.00	$500.00
25	FENCE & GATE	400	LF	$56.25	$22,500.00
26	STAINLESS STEEL LADDER	2	EA	$1,800.00	$3,600.00
27	MISC. CONCRETE STRUCTURES, OPEN CHANNEL, WIER, ETC.	1	LS	$4,500.00	$4,500.00
28	SMALL TOOLS & MISC. EQUIPMENT	1	HR	$1,400.00	$1,400.00
29	LABOR	760	HR	$15.00	$11,400.00
30	SUPERVISION	95	HR	$30.00	$2,850.00
31	LAND SURVEYING DURING DESIGN AND CONSTRUCTION PHASES	1	LS	$2,500.00	$2,500.00
32	SITE SPECIFIC DESIGN AND CERTIFICATION	1	LS	$3,500.00	$3,500.00
33	CONSTRUCTION PERMITTING, FEES	1	LS	$450.00	$450.00
	SUBTOTAL				$118,819.78
	OVERHEAD, TAX, & CONTINGENCIES @ 25%				$29,704.94
	GRAND TOTAL				$148,525