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Development of Environmentally Sustainable Methods for Treatment of Domestic Wastewater and Handling of Sewage Sludge on Yap Island

Joseph D. Rouse

Water and Environmental Research Institute of the Western Pacific, University of Guam, UOG Station, Mangilao 96923, Guam

E-Mail: jdrouse@uguam.uog.edu

Tel.: +1-671-735-2691; Fax: +1-671-734-8890

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Abstract: A survey was conducted of the wastewater treatment systems and related sludge handling practices on the island of Yap, in the Federated States of Micronesia, to assist in identifying areas where further work would be merited to improve on effectiveness and sustainability. A detailed inventory was made of communal septic tanks as found at health centers and schools. The precise location of each unit was determined and functionality was documented. Though most of these septic tanks appeared to be functional, there were concerns due to some units being positioned within the tidal zone, covered over with vegetation, or out of reach of the pump truck. The centralized wastewater treatment plant on Yap provides only primary treatment consisting of a limited removal of suspended solids. Thus nearly raw sewage is being discharged to the bay. Excess sludge is drawn from the treatment plant on a quarterly basis, which following drying is supposed to be transferred to the landfill; however, local farmers regularly make use of it as fertilizer for crop application without adequate treatment. As an immediate target for further study and pilot testing, exploring the use of an attached-growth process as an inexpensive retrofit to enhance the effectiveness of the treatment plant is proposed. In addition, the benefits of implementing a composting program for recycle of waste sludge in a safe manner and developing a framework for management of septic tanks are discussed.

Keywords: wastewater; sewage sludge; treatment; sustainable infrastructure; tropical islands; Yap; Micronesia.

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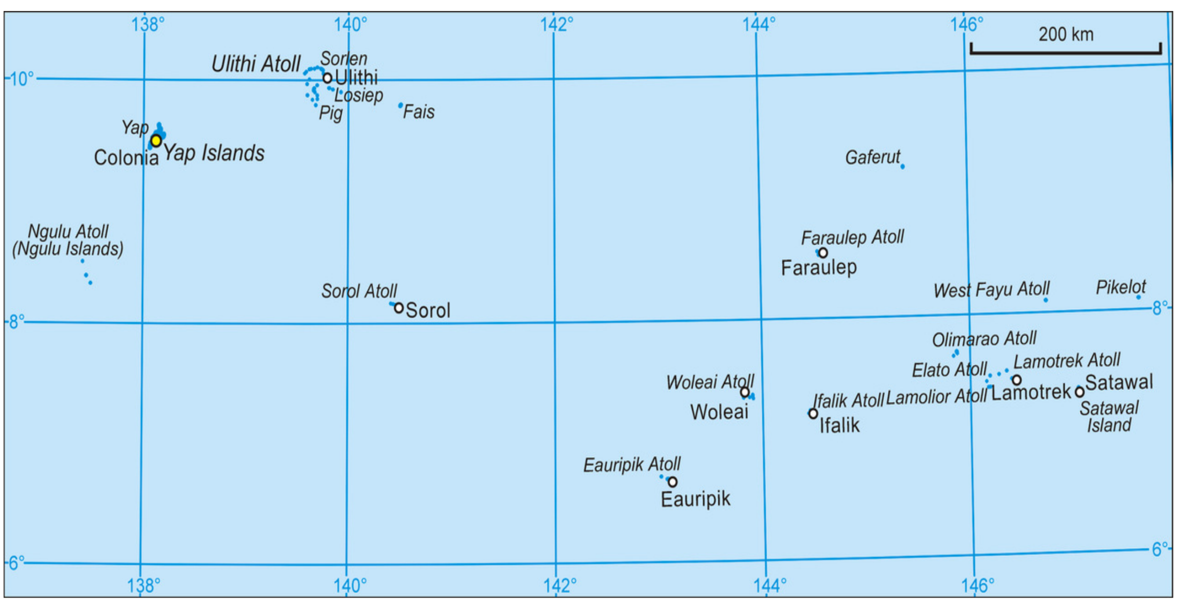
1. Introduction

Inadequate treatment of domestic wastewater (or sewage) in the islands of the Western Pacific has been responsible for serious human and environmental health problems due to contamination of water supplies and damage to natural resources [1]. The reason for this has often been attributed to the lack of functional technologies, which are difficult to obtain and maintain due to the vast geographical distances among the island communities and the high costs for providing services.

Yap State (Figure 1), the western-most state of the Federated States of Micronesia (FSM), covers approximately 500,000 square miles (1,300,000 square kilometers) of ocean yet has only 45.8 square miles (119 square kilometers) of land surface, consisting of numerous small islands. Only about 20 of these are inhabited. The main island of Yap, traditionally called "Wa'ab," which is actually four closely interconnected continental islands, has a population of approximately 7700 people, or 65% of the state population (11,863 – 2015 estimate [2]) [3]. The only centralized wastewater treatment plant (WWTP) in the state is on the island of Yap in the town of Colonia. Unfortunately, the treatment currently being provided is clearly insufficient with nearly raw wastewater being discharged to the ocean near the population center. In addition, the numbers and locations of pit latrines and septic tanks on the island are not adequately inventoried and the degree of treatment and extent of upkeep being provided are largely unknown. Furthermore, excess sludge produced at the WWTP is used for agricultural purposes without prior treatment to meet appropriate standards for human safety. Thus, improved management of this potentially useful resource is urgently needed.

Figure 1. Map showing the island of Yap (upper-left corner) among the islands of Yap State of the Federated States of Micronesia. Image source: Aotearoa – Wikimedia Commons [4].



The objective of this project is to contribute to the development of an inventory of up-to-date information on the existing wastewater-related infrastructure on the island of Yap. Such an inventory would be of use in identifying existing problems and prioritizing areas where corrective action would be best directed, in order to improve the overall functionality and sustainability of wastewater treatment and related practices on the island. This objective was met by conducting field surveys to document and characterize the existing wastewater treatment systems and related sludge handling practices on Yap. As practicable, these items include:

(a) Identification of locations of individual treatment units (i.e., pit latrines and septic tanks), and evaluation of treatment efficiency.
(b) Description of the centralized wastewater treatment plant, including design capacity and degree of treatment being achieved.
(c) Description of excess sludge handling and disposal practices, including the quantity generated and degree of treatment being achieved.
(d) Documentation of disposal practices for treated wastewater and sludge and evaluation of environmental and public health impacts.

2. Methodolgy

The methods employed over the course of this project incorporated civil and environmental engineering fieldwork. All work was carried out by the principal investigator with assistance of a student from the University of Guam. Prior to commencing fieldwork, points of contact in the Yap Environmental Protection Agency (Yap EPA) and utilities offices were established to clarify the intent of the investigation to the local authorities.

Fieldwork commenced by conducting meetings with pertinent local officials on utility boards and other government agencies to obtain guidance concerning locations and details of septic tanks and other wastewater treatment facilities. Subsequently, as practicable, the locations of septic tanks and other known treatment facilities were confirmed and documented by use of global positioning system (GPS) technology (Colorado 300, Garmin). Furthermore, the sole wastewater treatment plant and related disposal practices were inspected and documented.

3. Principal Findings and Discussion

3.1. Septic tanks

Septic tanks are reportedly being used as a first line of treatment for domestic wastewater at 31% of the 2311 households in Yap State [5], where a household on average consists of six persons. Almost all of these septic tanks – as concrete box structures – are located on the main island of Yap.

It was not practicable, nor considered advisable, to attempt to locate and inspect all the household septic tanks, which amounts to an estimated 700 household units – all located on private property. The Yap EPA does not have a full accounting of the numbers and locations of septic tanks because to date there have been no enforceable regulations concerning their construction and placement. Registration of septic tanks only occurs when a loan or grant is involved, as with the construction or purchase of a house. Accordingly, over a recent four-year period, only 18 units have been formally noted in the agency's Septic Tank System Log. However, the Loan & Grant Division of the Yap Community Action Program does have design drawings for use in new construction of single compartment septic tanks. The design consists of a 4- X 5-foot (6-foot depth) reinforced concrete tank with an outlet to two parallel 20-foot leaching lines (8-foot separation). It is doubtful, though, that many of the existing residential units employ a leaching field, versus a leaching pit.

The Yap State Public Service Corporation responds to about three service calls per month to pump out septic tanks, which they provide for a fee of $90 per tank. About once every year they encounter difficulties such as a septic tank being in an inaccessible location or not having an access port (manhole) built into the concrete structure. Overall, there are no outstanding problems with the use of septic tanks on the island that would demand immediate widespread corrective action. However, the impact of septic tank discharges on the quality of groundwater, and possibly even coastal ocean water, could be difficult to discern apart from a well-directed sampling program.

With the assistance of the Yap EPA, it was considered reasonable to conduct a thorough inventory of communal septic tanks (Figure 2), such as those found at Community Health Centers (Table 1), Early Childhood Education Centers (Table 2), Elementary Schools (Table 3), and other miscellaneous facilities (Table 4). The general condition and functionality of each unit was documented and their precise locations determined by GPS. The GPS data, however, are not repeated in this report, but are made available separately for use by appropriate authorities.

Figure 2. Large communal septic tank used for a remotely located village on Yap.
Image source: author.

As noted in the Tables 1 through 4, many of the communal septic tanks appeared to be fully functional and a resident manager with knowledge of the system was often present who could attest to periodic servicing. There were some concerns, though, such as the septic tank at Rumuu Early Childhood Education Center (Table 2), which is positioned in the tidal zone and encroached by seawater. In addition, there were a couple of tanks covered with vegetation (Tables 2 and 3) and one case were the location of the tank could not be visually confirmed (Gilman Elementary School, Table 3), In these cases it is doubtful whether the tanks were being properly maintained. Furthermore, at Maap/Tamilaeng Elementary School (Table 3) the septic tank was located down a steep slope in a forest growth and was out of reach of the pump truck. This septic tank was overloaded and extremely foul and no doubt will have to be abandoned in favor of a more suitable location in due time.

Table 1. Septic Tanks (STs) at Community Health Centers.

	Village/area	Comments
1	Maap/Rumuung	ST appears functional
2	Gagil	ST appears functional
3	Tomil	ST appears functional
4	Malaav	ST appears functional
5	Gilman	ST appears functional

Table 2. Septic Tanks (STs) at Early Childhood Education Centers.

	Village/area	Comments
1	Maap	ST appears functional
2	Rumuu	ST in ocean tidal zone
3	Gagil	ST appears functional
4	Tomil	ST appears functional
5	Dalipeebinaew	ST covered by vegetation
6	Kanifay	ST appears functional
7	Gilman	ST appears functional

Table 3. Septic Tanks (STs) at Elementary Schools.

	Village/area	Comments
1	Maap/Tamilaeng	Out of reach of pump truck
2	North Fanif	ST appears functional
3	SDA Campus	Seven functional STs
4	Rumuu	ST under outhouse
5	Bael	ST appears functional
6	Gagil	Holding tank only, no drainage
7	Tomil (B)	ST appears functional
8	Tomil (A)	ST appears functional
9	Dalipeedinaew	"Never been serviced"
10	Kanifay	ST covered by vegetation
11	Gilman	ST exact location not confirmable

Table 4. Septic Tanks (STs) at other Communal Facilities.

	Village/area	Comments
1	Ablul Village	Two STs for village outhouses
2	Maritime Academy	STs not confirmed (out of scope)
3	Daabach Village	Large septic tank for village
4	Catholic High School	Large retrofitted ST

At the time of this report, an environmental lawyer was on a two-year assignment with the Yap EPA to develop environmental regulations that will, in part, cover the construction, placement, and operation of septic tanks and leaching fields. These regulations should start having positive environmental impacts in the not too distant future. Though not binding in the FSM, the Guam EPA has requirements for placing septic tanks and leaching fields that vary according to the geological features in different parts of the island. Yap likewise needs to determine the proper management of septic tanks with respect to the local environmental conditions. In the Philippines a National Sewerage and Septage Management Program was recently established to improve sanitation through a combined approach to fecal sludge management and septic tank cleaning [6]. The program employs a holistic approach offering advice on such issues as tariffs and fees, cleaning frequency of tanks, and methods to gain public participation. Early results show that there is no single right way to implement such a program and adaptation to local circumstances is critical. Nonetheless, lessons are being learned and best management practices are being developed, which may also be applicable on Yap and in other tropical regions.

3.2. Landfill leachate

Following in suit with the Fukuoka-type landfill installed in Kosrae, FSM, a few years ago, Yap State has also elected to construct the same type of landfill (nearly completed at the time of this study; Figure 3). While a landfill leachate collection and treatment system would more appropriately classified as an industrial operation, due to this landfill being predominately for domestic solid waste, it will be briefly discussed in this report concerned with domestic wastewater. The uniqueness of the Fukuoka-type landfill is that ventilation is employed to promote aerated conditions throughout the landfill with the intent of preventing methane production. Considering that methane gas production at landfills is generally not rich enough to be put to use as an energy source, it is deemed more suitable to avoid anaerobic conditions with the potential of methane escaping to the atmosphere where its reported effects would be much greater than that of carbon dioxide [7], as produced under aerobic conditions.

Figure 3. Newly constructed Fukuoka-type landfill on Yap prior to first use. Image source: author.

The leachate pond shown in Figure 4 was holding only rainwater at the time of this report (prior to commencement of trash collection). Overflow from this pond passes through a sand filter (Figure 5) prior to being discharged to a forest gully. Effluent discharged from this new facility on Yap will be analyzed for chemical oxidation demand (COD) and pH. (Standards employed in Kosrae call for COD levels to be maintained below 100 mg/L and pH below 10, which have not been exceeded to date.) In the future a more aggressive form of leachate treatment may have to be considered if acceptable discharge levels for nutrients, heavy metals, or organic compounds are not maintained.

Figure 4. Leachate collection pond at the new landfill. White box on far side of pond is for sand filtration. Image source: author.

Figure 5. Detailed view of the sand filtration unit process at the new landfill. Image source: author.

3.3. Wastewater treatment

In Colonia, the main residential area and business center on Yap, the municipal WWTP consists of an Imhoff tank system (Figure 6), which was commissioned around 1974. The plant has two lines designed to operate in parallel (Figure 7); however, only one line is used at a time due to the relatively low intermittent flow entering the plant from only about 300 household connections. The unmetered inflow is thought to be somewhat less than the design flow of 170,000 gallons per day (640 cubic meters per day). Imhoff tanks are very user friendly and have low operational costs due to the absence of mechanical aeration and internal recycle. However, they provide only a primary level of treatment consisting of a limited removal of suspended solids. The solids that settle in a compartment below the flow channel are periodically expelled under the natural hydraulic head in the system, thus eliminating the need for mechanical pumping. No chemical or biological treatment is employed in the plant, hence the effluent, which is being discharged to the ocean, is not much different from raw sewage. Furthermore, the 1000-foot (300-meter) outfall is known to be broken open at approximately 500 feet (150 meters) from the shore. As a consequence, it is discharging sewage at a depth of 10 to 20 feet (3 to 6 meters) near the industrial district of Colonia about a half mile (one kilometer) from the main business district. Testing by the Yap EPA for Enterococci in the coastal zone has, surprisingly, yet to yield a count of greater than 30 per 100 millimeters, which would require posting warning signs.

Figure 6. Imhoff tank sewage treatment plant in Colonia, Yap. Image source: author.

To upgrade the process to a conventional secondary level of treatment, a completely new plant would have to be constructed with a much larger footprint. Such a facility would require substantial capital and O&M costs. Another method worthy of consideration that could harness biological treatment power with a relatively simple addition to the existing facility would be to use an attached-growth (or biofilm) process [8, 9]. Using this method, effective biomass would be retained in the unit process by use of a biocarrier support matrix. Potentially, as a relatively simple retrofit, biocarrier material could be attached to a frame and positioned in the existing tank so as to intercept the flow path of the wastewater. Figure 8 shows the interior of one of the Imhoff tanks drained for inspection, where such a frame could be inserted. Evaluation of such an attached-growth process would be a avenue for future research and development.

Figure 7. One flow line in the Imhoff tank sewage treatment plant. Image source: author.

Figure 8. Imhoff tank emptied for inspection showing compartment where biocarrier matrix could be inserted. Image source: author.

3.4. Sludge handling

Excess sludge is drawn from the bottom of the Imhoff tanks on approximately a quarterly basis (Figures 9 and 10). It is intended that following drying (Figure 11), the sludge should be transferred to the solid waste landfill; however, local farmers take it for use as fertilizer for food crops. Currently, there is no regulatory guidance in Yap State concerning treatment requirements for sewage sludge prior to use. Though not binding in the FSM, the United States EPA offers widely accepted definitions for different classes of biosolids that could serve as a guideline [10]. Exceptional quality (Class A) biosolids, which have no crop harvesting restrictions, consist of treated residuals that contain no detectible levels of pathogens and low levels of heavy metals. Technologies that can meet Class A standards must process the biosolids for a sufficient length of time at a temperature high enough to yield a product in keeping with the required pathogen cut. Composting is one such option that can be considered as an environmentally friendly method to recycle the nutrients and organic matter found in municipal wastewater solids. Depending on the level of treatment achieved, the cured compost could be used for production of food crops (if Class A), or for environmental reparation of badlands, which are abundant on Yap.

Figure 9. Sewage sludge from Imhoff tank being discharged to drying bed. Image source: author.

Figure 10. Fresh wet sewage sludge in drying bed at beginning of drying period. Image source: author.

Figure 11. Air dried sludge with an estimated 50% solids content. Image source: author.

Rigorous bacteriological testing should be used to evaluate the compost product prior to use. Where this is not possible, if standardized procedures are followed with respect to time and temperature of treatment (i.e., 30 days active composting with internal temperatures 55^{o}C or higher for 15 days [11]), the quality of the final product can be assumed to meet Class A standards with a reasonable degree of certainty. If questions concerning safety should emerge due to a lack of testing, applications avoiding contact with food crops, in keeping with more lenient standards, could readily be employed.

As the subject of a subsequent study, a pilot test could be conducted to evaluate the feasibility of developing a suitable composting practice at the WWTP. A rough estimate of the quantity of air dried excess sludge (ca. 50% solids) per sludge drawing event (about four times per year) comes to only 100 cubic feet, which should be a workable volume, not requiring the aid of special equipment. Notwithstanding, if a greatly expanded septic-tank sludge collection program were to be implemented (as discussed above), then further study would be necessary to scale the facility and equipment accordingly. The potential benefits of composting would include:

(a) reducing solid waste input to the new landfill,
(b) protecting the public from health hazards,
(c) repairing badlands, and
(d) generating revenue.

4. Conclusions

It is evident from this study that considerable progress has been made on Yap to bring the status of domestic wastewater treatment and sludge handling practices to a reasonable level of development. However, conclusions drawn here would also suggest that further work is merited to achieve a higher degree of treatment practices in a sustainable manner. More specifically, developing a framework for the management of septic tanks and implementing a composting program for recycle of waste sludge would do much to enhance public safety and environmental sustainability. In addition, exploring the use of an attached-growth process as an inexpensive means of improving the efficiency of the WWTP is proposed.

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Conflict of Interest

The author declares no conflict of interest.

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