Engineering Internship 2006: Final Report

Shoals Marine Laboratory

Prepared for Ross Hansen, Project Manager
by Leslie Campbell, Nicole Ceci, Lisa Damiano, Clara Yuan

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Introduction

In the summer of 2006, four engineering interns from Cornell University and the University of New Hampshire took part in the inaugural Sustainable Engineering Internship at Shoals Marine Laboratory (SML). SML offers an ideal setting for engineering students to apply theory learned in class to the field. All systems can be analyzed from beginning to end, the island-wide consequences of modifications to individual systems are easily anticipated, and the impact of every load or change can be immediately realized.

The initial goals of the program were to gather data to determine system level improvements, provide recommendations based on those data, and to provide a framework for future internships.

The interns monitored and evaluated the freshwater, saltwater, wastewater and electrical systems by running tests and collecting data. With the help of various experts, the interns gathered a variety of data more detailed than had previously been recorded. These data allowed the interns to analyze the island's general efficiency and make appropriate recommendations for future changes. Furthermore, these inaugural intern's suggestions will be crucial in shaping this program for future summers.

The following report details the data collected, the research completed, and the recommendations made by the engineering interns. This internship program yielded many important discoveries about the workings of the island, including those outside the initial scope. Overall, this inaugural summer has produced a wealth of information, however, there is still much more to be discovered by future interns.

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System Overview

SML uses a primary wastewater treatment facility. During mid-summer when SML populations are at their peak, the average wastewater flow ranges between 3,500-4,000 gal/day. Wastewater from all buildings on campus is piped to the facility where it enters a 1000 gallon primary settling tank. From this tank, it travels to two more 1000 gal tanks in series where further settling of solids occurs. A filter located in the second settling tank helps remove solids from the wastewater. Total retention time in the facility including all three tanks can varies between 1 -1.7 days.

Pumps located on both sides of the third tank alternate discharge between two chlorination batch tanks. The pumps are designed to move approximately 500 gallons of wastewater at a time. The chlorination batch tanks are designed to discharge the disinfected wastewater after a contact time of 30 minutes. The chlorinated discharge is instantly dechlorinated by the injection of sodium metabisulfite.

Problem Overview

System Monitoring

SML island engineers collect daily data on wastewater discharge, but there exists the desire for smaller sample intervals, in order to gauge wastewater discharge patterns over the period of a day rather than on a daily basis. This finer resolution of data will provide baseline data for the system as well as alerting island staff to any irregularities.

Leak Possibility

The wastewater treatment facility has been working reliably, with the island meeting the requirements of their overboard discharge permit every summer since the most recent revision of operating procedure. However, irregularities in historical data for the 2006 season raise the possibility of leaks from one or more of the tank.

An investigation by the engineering interns into historical data uncovered irregularities in the sewage log, which includes daily records of the number of times the pumps on the third tank and the batch tanks run. This season, approximately 575 gallons (see appendix for calculation details) of wastewater are moved by the pumps each time they run. Although the count varies, the number of daily movements typically falls between 2-8

However, the count fell well outside that typical range on a few occasions. On May 13 2006 the counter registered 19 movements, indicating almost 11,000 gallons of wastewater had been treated and discharged by the system. This discrepancy suggests that either an unusually high flow came through the treatment plant that day or that the counter was not operating correctly.

The first possibility was discounted due to the extremely low population of the island (only a handful of staff were present at this time), many times less than peak island populations which result in flows around 4000 mgd. The remaining explanations involve infiltration.

It was noted that around May 13, severe flooding was occurring in the states of New Hampshire and Massachusetts due to continuous rainfall for over a week. On May 12, 2006, the governor of New Hampshire declared a State of Emergency due to this abnormal series of rain events and subsequent flooding. The simultaneity of this extreme weather phenomenon suggested that excess rain was likely the cause of tank flooding; either through overflow over the tops of the tanks, and/or infiltration into the pipes, holding tanks at the Grass Lab and Bartels and/or the settling tanks in the wastewater treatment facility itself. A discussion with the island engineer present during this time concluded that flood levels never reached the grade of the wastewater treatment facility, eliminating the possibility of inflow through the top of the tanks, but a significant amount of rain did fall on the island.

The two remaining possibilities were infiltration into the piping or into the settling tanks. Infiltration into the piping was doubtful because of high flow rate The engineering interns thus hypothesized that the hydrostatic pressure from groundwater level elevated above the tanks' invert (due to rain, particularly continuous, heavy rainfall over an extended period of time) had either created cracks in the tank or exacerbated existing leaks. This suspicion was a serious one, for if groundwater was seeping into the tanks, wastewater could be seeping out of them through those same cracks.

Treatment Alternatives

SML's overboard discharge permit expires in 2009, and this permit may or may not be renewed. Furthermore, even if it is renewed, there is the distinct possibility that it will have stricter requirements. In addition, the current wastewater system on the island requires intense chemical usage both posing as a health risk to the operators as well as costing materials and transportation. Currently, the wastewater discharge is treated for total suspended solids (TSS), although there are no standards for this amount. Biological oxygen demand (BOD) is not reduced at all and thus the high BOD concentrations in the discharge could be causing adverse impacts on the discharge locale. The current sludge disposal method is also antiquated and unsustainable.

Data Collection

System Monitoring

From July 19, 2006 to August 10, 2006 data was collected from the wastewater treatment facility at two hour intervals from 6:00 am to 10:00 pm. Counters in the wastewater treatment facility display the number of times each pump has run since island start-up. This information can be used to calculate the daily wastewater discharge.

Leak Possibility

With the help of Prof. Nancy Kinner and Jennifer Jencks of the University of New Hampshire, the engineering interns performed a rhodamine dye test to ascertain the presence of a leak from the first settling tank. In essence, the first tank was dyed with a high concentration of rhodamine, and samples were taken every two hours from the tank and the adjacent body of water (known as the “swale”). Any rhodamine found in the swale would have to come from the wastewater tank.

Only the first tank was chosen for testing because it is closest to the adjacent body of water. Leaks in it would thus likely have the most serious consequences and cracks in it would likely be larger than in the other tanks.

In order to prevent premature dilution of the rhodamine concentration in the wastewater tank, the test began at 11:00 pm, when wastewater flow is minimal. In order to guarantee detectable concentrations of rhodamine and to maintain a closed system, a boom was constructed in the swale to contain a small test area.

Background samples of both the tank and the swale were taken to determine the background concentration of rhodamine in both bodies of water. A calibration curve was determined with the following standards: 0.5 ppb, 10 ppb, 50 ppb, and 100 ppb.

The test was initiated at 11:00 pm on July 26, 2006 by stirring in a concentrated bottle of rhodamine dye. Once uniform color was achieved on either sides of the tank, sampling began. Two samples from each sampling site were taken. The sampling sites were both sides of the contained swale area, both sides of the top and bottom of the tank, for a total of two sampling sites in the contained swale area and four sampling sites in the tank.

Measurement of the samples by a fluorometer began the next afternoon on July 27, 2006, and was completed by that evening.

Treatment Alternatives

On July 21, 2006 each of the basements/foundations was measured, evaluated, photographed and sketched for Clivus New England representative Joseph Ducharme. Clivus New England is a distributor for Clivus Multrum composting toilet units. Ducharme later performed a site visit.

Other treatment alternatives were researched primarily on the World Wide Web.

Results

System Monitoring

Although the discharge cycles are programmed to alternate between the two batch reactor tanks, the data show that Batch Reactor 1 took on a disproportionate number of discharge cycles during the data collection period. In Figure 1, note how Batch Rector 2 increases in discharge cycles more slowly than Batch Reactor 1. From the evening of July 29th to the morning of August 7th, Batch Reactor 2 discharged only once. This lack of alternation may be due to environmental interruptions (i.e., on July 20th, Ross Hansen, Island Project Manager, found and removed a vertebra in the check valve between Batch Reactors 1 and 2) or programming error.

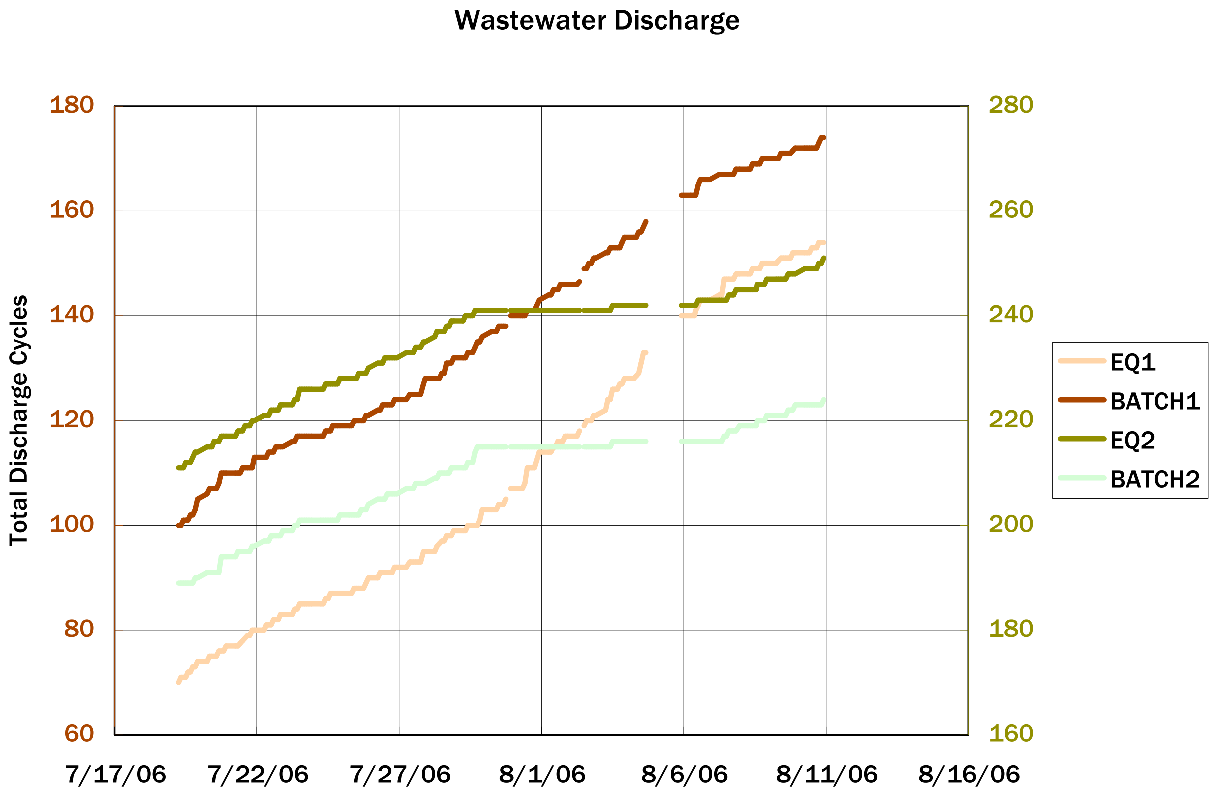

Figure 1: Wastewater discharge over collection period

Note also the cycle count disparity between Batch Reactors 1 and 2 – Batch Reactor 1 experienced approximately 100 cycles less than Batch Reactor 2 at all times. This disparity may be due operating only one of the batch reactors during the beginning of the season, when the population is low, or other operational reasons.

Another discrepancy lies between the pump cycles of the third tank and the discharge cycles of the batch reactors. As detailed in "System Overview" above, for every pump cycle experienced by the third settling tank, a discharge cycle should be experienced the matching batch reactor not more than 30 minutes later. However, the data show this pairing not to be the case. Frequently it seems, the pumps on the third tank will run without corresponding discharge cycles from the batch reactors. Figure 2 clearly demonstrates how batch reactor discharge cycles don't follow along with settling tank pump cycles.

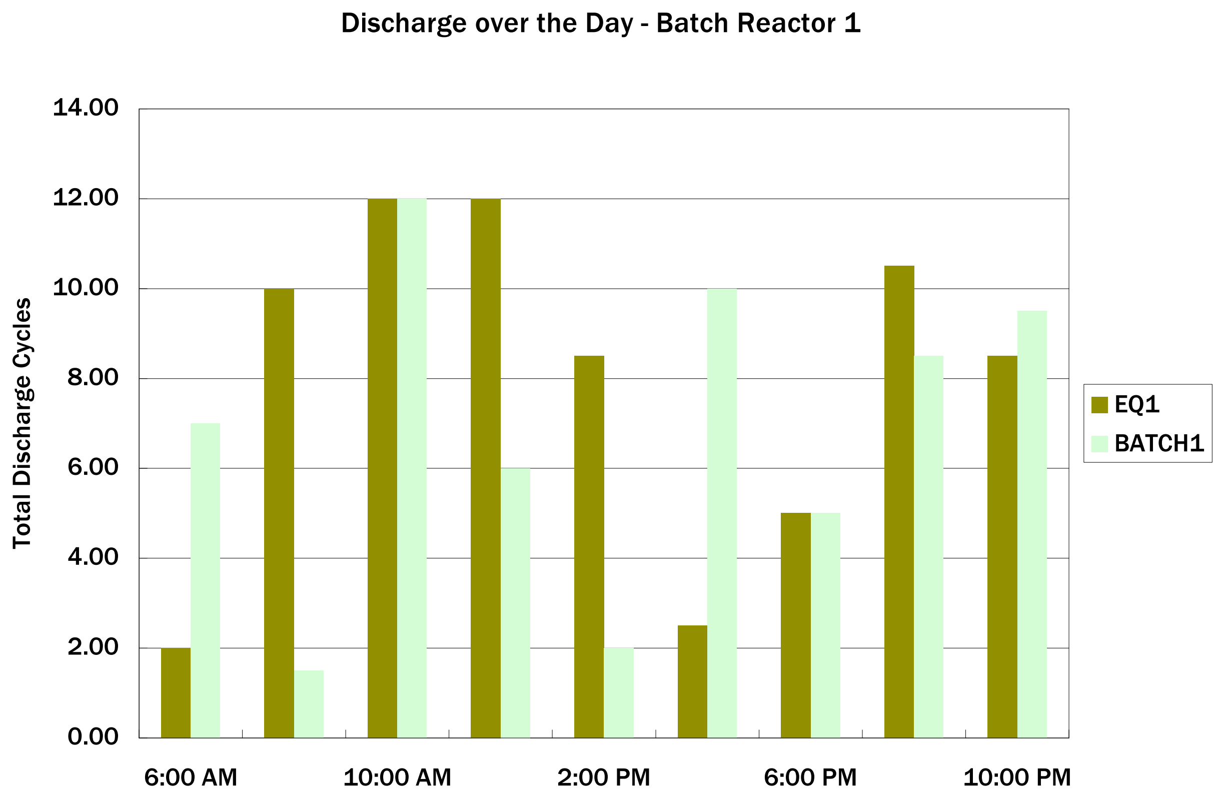

Figure 2: Total discharge cycles over the day for Batch Reactor 1

By the end of the collection period, the equalizer pumps had run approximately 15 times more than the batch pumps had. This difference is certainly significant, since it should be no greater than 2 (the case that both batch reactors are in the 30-minute contact period). This discrepancy may be due to differences from the design operation.

There did not appear to be strong patterns in wastewater discharge over the day. Figure 3 shows peaks at 6;00 am, 10:00 am, 4:00 pm, and 10:00 pm. The peak at 10:00 am may due to kitchen wastewater generation after breakfast, but based on the results of the freshwater system analysis (see "Freshwater System - Results" on page 39), that peak is more likely due to morning ablutions. The increased discharge in the evening hours are likely also due to evening ablutions, including showers. The peak at 4:00 pm, however, cannot be explained by ablutions, since there is no corresponding peak in freshwater consumption. This peak cannot be explained by the salt water consumption, either, since there is no corresponding peak in toilet flushes or salt water inflow. The explanation, might lie in operational irregularities, as noted above. Note the high variability in the average discharge cycles of Batch Reactor 1 over the day, which seems to support the possibility of operational irregularities in more aspects than just the ones noted above.

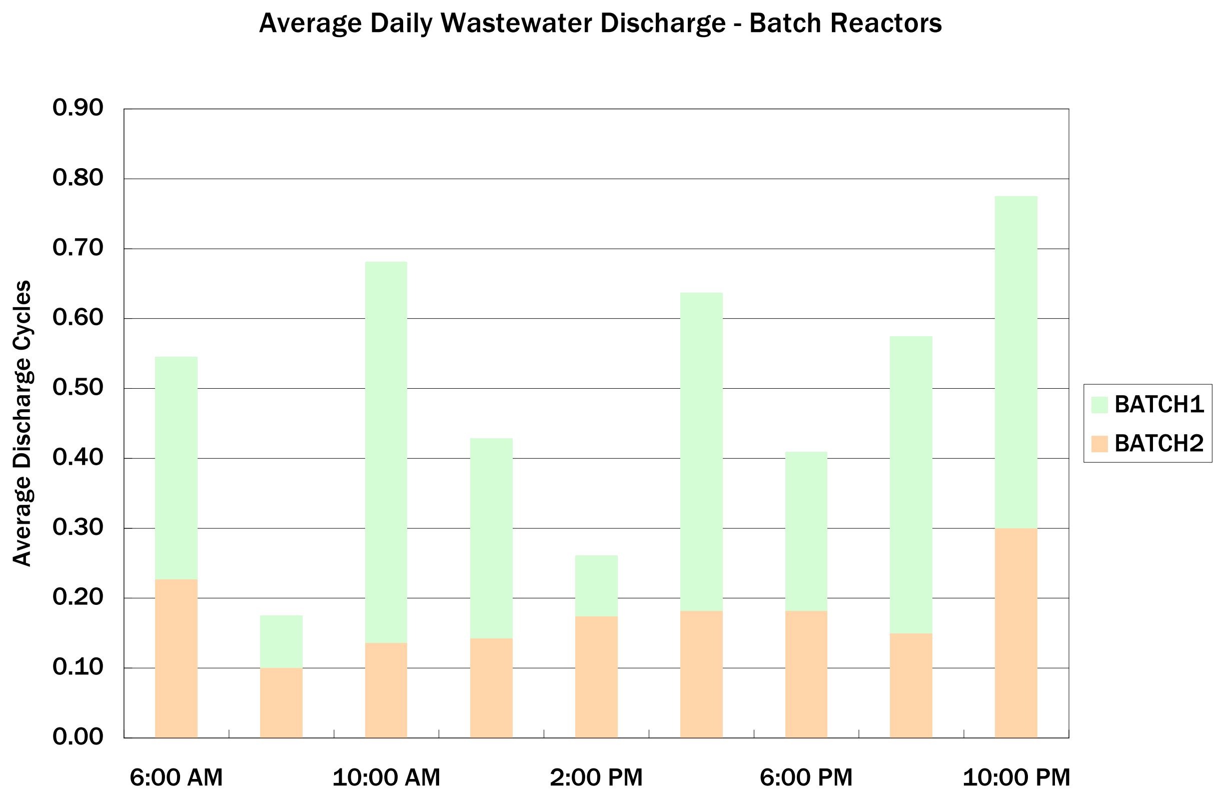

Figure 3: Average daily wastewater discharge cycles over the collection period

Treatment Alternatives

Please see "Recommendations" below for the results of the research into treatment alternatives.

Leak Test

Although sampling was only intended to be carried out for 24 hours, it was observed that dye appeared at significant concentrations only at the 11th reading, 22 hours after the dye had first been mixed into the first tank. Thus sampling resumed on the afternoon of July 27th to map the progress of rhodamine concentration. Samples were taken at 12:00 pm, 2:00 pm and 4:00 pm. As seen in Figure 4, the concentration of rhodamine dye began decreasing after 2:00 pm, so sampling was stopped at 4:00 pm.

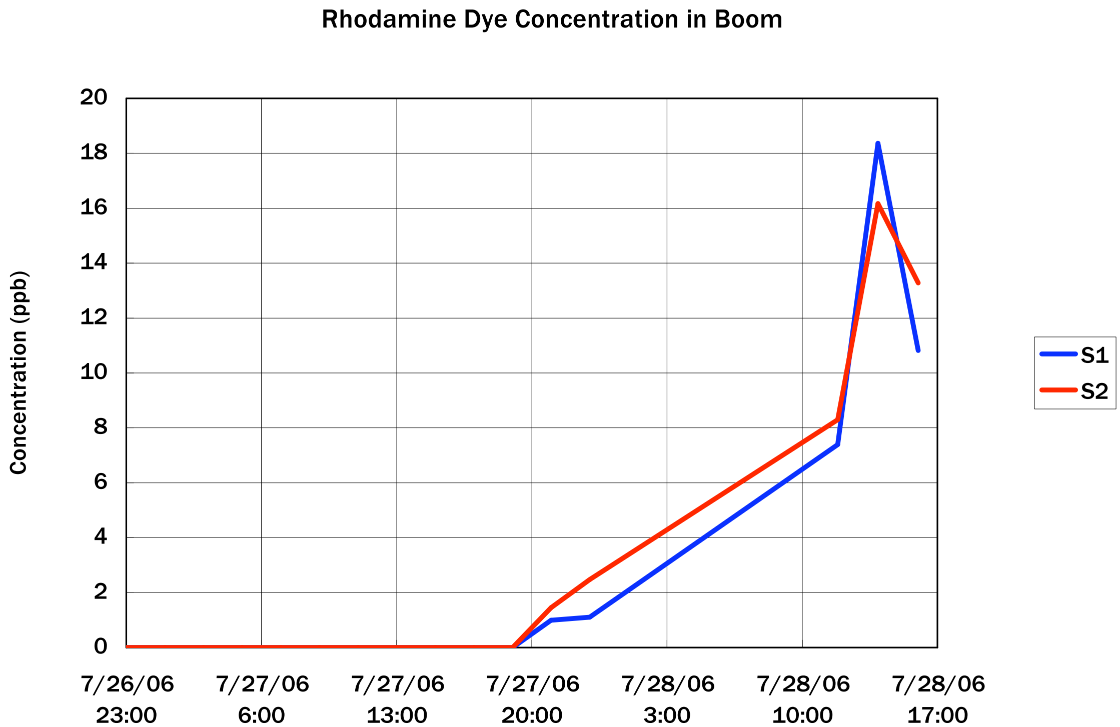

Figure 4: Graph of rhodamine concentration in boom over time

The results of the dye test imply a leak in the first settling tank, although the leak does not seem to be very fast since 20-22 hours elapsed before a significant amount of dye traveled the 3 feet to the swale. In addition, the highest concentration of rhodamine measured in the swale was 18.3 ppb, several magnitudes less than the initial tank concentration of roughly 20,000 ppb.

The presence of a leak in the first tank suggests the possibility of leaks in the other tanks as well, since the other tanks are of the same age and in roughly the same location, subject to the same hydrostatic pressures.

Recommendations

System Monitoring

Due to the numerous operational irregularities discovered during system monitoring, the programming, the float switches, the pipe fittings, and the pipes themselves in the wastewater treatment facility should be checked to ensure correct operation. Monitoring the system non-stop for a day may be beneficial in determining specific problems and their causes.

Leak Test

Now that the presence of a leak in the first tank has been confirmed, the public health consequences are of primary and immediate concern. In particular, the island's groundwater source of freshwater may be contaminated, and the possibility of such contamination should be ascertained as soon as possible. More rigorous testing to determine the exact speed and extent of the leak may be performed. Most importantly, the wastewater treatment system should be repaired, upgraded, or replaced as soon as possible; ideally by the start of the next season.

Treatment Alternatives

Regulations

All alternative wastewater treatment options such as composting toilets and greywater systems are regulated under Maine State Regulations, CMR 241. It is recommended that an in depth look into these regulations be made by the appropriate persons at Shoals Marine Laboratory. Below is a brief summary of the important findings that were made during the engineering intern's evaluation of the code.

It was noticed that Maine has relatively few regulations regarding alternative technologies such as composting toilets and greywater treatment systems. For the installation of composting toilets, a site evaluation is not needed, however permits are required. Clivus New England is a pre-approved manufacturer of composting toilets in the state of Maine. In terms of greywater disposal, a plumbing inspector has to approve any system with subsurface disposal of the water. A septic tank is also required for any greywater system. The controlling factor of 126 gallons per day flow or 70% of the base design flow, should be used for the minimum design flow when sizing.

If a leach field system is installed to treat greywater, a large number of disposal field regulations must be followed. It must be noted however, that sizing regulations are based upon disposal fields for blackwater. Treatment and sizing will be different for greywater only systems. All sizing information can be found in Tables 600.1-600.3 of CMR 241. Essentially, the size of a disposal field is dependent on the soil profile of the area. If more than one soil type is present, the type that is the limiting factor should be used in the sizing process. Sizing is also dependent on wastewater volume, quality of the wastewater and the depth of the limiting soil factor. Rain, surface, and groundwater cannot drain into any component of a disposal field system. Appledore Island might be subject to septic system setbacks due to its marine location. These regulations can be found in Table 700.2-700.4.

Regardless of the system Appledore chooses to implement, permitting and acceptance will be determined by the state of Maine on an individual basis.

Financing

There are multiple sources of financing for the projects researched and suggested by the engineering interns of Shoals Marine Laboratory. Below is a list and description of the most prominent financial opportunities that could be utilized.

Overboard Discharge Elimination Program Grants

Because composting toilets and an accompanying greywater treatment system would remove the need for SML's Overboard Discharge Permit, specific funding is available. This zero OBD grant provides financing for the removal of overboard discharge systems that have been legally licensed by the Department of Environmental Protection. This grant is available for municipalities, quasi-municipalities, county commissioners on behalf of unorganized territory, or directly to the owner of an overboard discharge permit. If SML is considered an individual land owner, funding is based upon the average annual income; however, if SML is considered a municipality or quasi-municipality, funding is decided on a case by case basis.

If the funding is granted, reimbursement will be given after the work is completed.

The contact information for this program, copied below, is available on the state of Maine website as given below. A full application packet for the grant can be found in the appendix to this report.

Contact: Tim Macmillan, P.E., Administrator

Address: Overboard Discharge Grant Program
17 State House Station
Augusta, ME 04333-0017

Email: Tim.a.Macmillan@maine.gov

Phone: 207.287.7765

Website: http://www.maine.gov/dep/blwq/docgrant/obdpara.htm

National Science Foundation

The National Science Foundation (NSF) funding is the resource for about 20% of the research done by American universities and colleges. SML has already had multiple projects funded by NSF and is thus accustomed to the application and funding process. Applications for funding of both the solar panel project as well as the composting toilet installation could be submitted as NSF projects. Further information about applying for funding by the NSF is available on NSF's website.

Website: http://www.nsf.gov/funding/

Maine State Revolving Loan Fund (SRF)

Financial assistance from the Maine State Revolving Loan Fund is available to municipalities and quasi-municipalities. SML could be considered a quasi-municipality in that it is the sole provider of island utilities; however, the likelihood of successfully categorizing SML as such is unknown. The Maine Municipal Bond Bank is the financial manager of this particular program. The interest rates of loans offered through the SRF are 2% below the market rate. Contact information for this loan program can be found below.

Contact: Steve McLaughlin

Address: Division of Engineering & Technical Assistance
17 State House Station
Augusta, ME 04333-0017

Phone: 207.287.7768

Website: http://www.maine.gov/dep/blwq/docgrant/srfparag.htm

First Principles

In order to evaluate the treatment alternatives presented above, governing first principles were developed. These first principles embody the priorities, conditions, and requirements which were identified as important considerations. The first principles and their categories are outlined below.

- Givens: First principles over which SML has little or no control; these must be of primary consideration
  - Regulatory standards: All evaluations must meet or exceed regulatory standards
  - Wastewater characteristics: All evaluations must effectively treat SML's wastewater in particular, taking into consideration time, volume, and frequency of flows; salinity; strength; etc. of the wastewater
  - Geography and geology: All evaluations must practicable in the face of Appledore's climate, space, and subsurface conditions
- Constraints: First principles must be considered but are more flexible
  - Costs: Evaluations will be based on the costs of the different options, including capital investments and grant funding opportunities
  - Operation and maintenance: Evaluations will be based on the extent of operation and maintenance required, including reliability of the proposed system, start-up time, need for trained personnel, etc.

  - Safety: Evaluations will be based on the system's safety for public health as well as the operators of the system
- Other: First principles which should be considered, but are very flexible in implementation and interpretation
  - Sustainability: Evaluations will take into account the sustainability of any proposed systems.
  - Adaptability and extensibility: Evaluations will take into account the ability of the proposed system to tie into other systems on the Island and to accommodate future needs.

Blackwater Treatment Alternatives

The research as well as the recommendations that have been made for the wastewater system can be found in the following subsections. It is the interns' recommendation that composting toilets be used to help remove the need for the SML's overboard discharge permit. Unfortunately, these toilets would require building auxiliary structures. Once blackwater has been removed from the wastewater system, greywater would still require onsite treatment (see "Greywater Treatment Alternatives" below).

Clivus Multrum Composting Toilets[1,2]

System Overview

The Clivus Multrum composting toilet consists of a large composting unit or battery of composting units located below and up to ten horizontal feet from the toilet stools. Multiple stools can feed into each composting unit, and a number of composting unit sizes are available. Clivus New England offers two types of toilets: a waterless toilet and a low-flow, foam flush toilet. Clivus New England also has available a waterless urinal model.

The waterless toilet is a dry toilet that sits directly above the composting unit, so waste is moved purely by gravity. In waterless designs, some water is added by a sprayer built into the composting unit in order to keep the compost moist, ensuring effective decomposition.

The low-flow, foam flush toilets are supplied by a Japanese company under the name of Nepon toilets (note that Clivus New England has exclusive distribution rights for Nepon toilets). Nepon toilets use three ounces of water and Neponol, a biodegradable alcohol-like soap, with each flush. The toilet tank holds fresh water and a small bottle of Neponol soap, which automatically drips into the water reservoir. Each bottle of Neponol lasts one month and a 10-month refill costs $150 from Clivus New England. A 4-watt air pump foams the Neponol soap and water mixture so it can completely lubricate the toilet bowl and plumbing with only three ounces of water. When the toilet is flushed, the air pump uses 8 watts of energy for 30 to 60 seconds. Nepon toilets must be hooked up to a 120 V AC power source to run the pump. The Neponol foam keeps the toilet clean and aids composting by keeping the waste slightly moist. Nepon toilets are also preferred by many customers because they are more similar to conventional flush toilets than the waterless "black hole" toilets. In buildings where both types are installed, the Nepon toilets are used far more than the waterless toilets.

Waterless urinals can be installed to empty directly into the composting unit. Urine from the urinals and the toilets filters down through waste and shavings until it reaches the bottom of the unit. The final product is a high-salt content leachate. There is a leachate discharge pump at the bottom of the composting unit, and the leachate is safe to combine with greywater.

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[1] Ducharme, Joseph, sales representative for Clivus New England. Site visit to Shoals Marine Laboratory. 4 August 2006.

[2] Clivus Multrum. Specification sheets and installation manuals. Obtained from Joseph Ducharme, sales representative for Clivus New England on August 4, 2006.

Both types of toilets and the urinals are connected to the same composting units, so none limits the choice of which composting unit to install. Nepon toilets require 4-inch PVC plumbing and pipe slopes no steeper than 45º to ensure effective waste transport. Waterless toilets need a 14-inch straight, vertical outflow; thus, they must be located directly above the composting unit. Waterless urinals also need a straight, vertical pipe to the composting unit, limiting the number of urinals that can fit directly over a given composting unit.

Process Overview

The composting units themselves contain no moving parts. Waste flows into the back of the composting unit and slowly slides down a sloped inner surface. The slope allows waste to stay aerated by maintaining continuous movement, keeping the unit odor-free. A small vent fan running on 0.5 to 70 watts, depending on the chosen model, also keeps the composting unit aerated. The fan creates a negative pressure that draws air down the toilet—keeping odor down—and out the vent exhaust.

Waste accumulates towards the bottom of the composting unit, where it continues to be broken down by microbes and worms. Planer shavings (approximately $4.00 per bale) must be added to the composting unit occasionally to create space for oxygen circulation between layers of waste. Once or twice a month the waste must be leveled out with a long-handled rake. There is a maintenance door near the top of the composting unit to provide access, and the operation should take no more than 30 seconds per unit.

Nothing should be removed from unit for the first two to five years it is in operation, and it should be emptied no more than once per year thereafter. Since some volume is removed approximately once a year, an air pocket is created at the bottom of the unit, enhancing aeration as well. Emptying the composting unit consists of removing approximately one bushel of compost, and the unit is never to be completely emptied. Final digested material is 5-10% the volume of the initial waste, and it is safe to dispose on-site with no further treatment. The final material may have to be buried up to 6 inches below ground, depending on state regulations.

At the beginning and end of each season, the composting unit must be started and winterized, respectively. Winterization involves shutting off power, disconnecting the liquid (leachate) outflow pipe, and adding an extra layer of wood shavings. The composting unit may freeze over the winter, in which case it will thaw by the beginning of the next season. In fact, the freeze-thaw cycle helps break down the waste to a smaller size. To start the composting unit, the waste must be aerated and infused with new bacteria and worms. Although worms can migrate to the center of the compost and thus survive the winter, their survival is not guaranteed. The units can be used several times over the winter without needing to be started, but any unit that is used continuously over the winter should be kept warm enough to prevent freezing.

In comparison with units primarily designed for small residences, Clivus Multrum composting units are far superior. Residential units do not process the waste to a polished final product that is easily disposed on-site. Many of these smaller units, including Sun-Mar, Biolet, and Envirolet brand models, simply dehydrate waste and therefore require frequent emptying. SML has experience numerous operational and maintenance issues with both of its Sun-Mar brand composting toilets.

Applications

The current wastewater treatment plant on Appledore is apparently failing. A rhodamine dye test conclusively showed an active leak from at least the first settling tank (see “Leak Test” on page 11). Malfunctioning float switches and pumps in the wastewater treatment process may also be leading to over/under disinfection by incorrectly regulating contact time in the batch reactors (see

"System Monitoring" on page 8). Composting toilets can be installed to replace all the traditional toilets on the island, which would eliminate the need for repairing the central plant. Composting toilets fully treat all blackwater produced on the island, but a greywater treatment system is needed to complete the treatment process.

The composting units are relatively large compared with the space available underneath most of the island's buildings, so the structure of the island's bathroom facilities may need to be changed. Instead of having decentralized facilities located in most buildings, SML may have to either erect centralized free-standing outbuildings, or build extensions to existing structures. The most feasible plan may be to erect several outbuildings around the island, each serving two or three neighboring buildings. Photovoltaic panels can also be used to power the vent fans on each unit if available (see "Solar panel feasibility - Applications" on page 59).

Recommendations from Clivus:

- Founders: two M-12s; may fit underneath building, but must remove debris or change bathroom locations
- Kiggins: two M-35s; outbuilding should be built
- Bartels: convert porch or staff lounge to restrooms or build outbuilding
- Dorms: erect one or two outbuildings in between dorms
- PK: enough space underneath to convert porch to bathroom
- K House: 1 M-10 or M-12 will fit easily under current bathrooms
- Hamilton: erect outbuilding or share with Kiggins or Laighton
- Laighton: erect outbuilding

Total cost: approximately $175,000 plus cost of outbuilding construction.

The Clivus recommendations did not appear to be the most efficient configuration for SML's load, so a new configuration was estimated based on toilet flush data and cost efficiency.

Recommendations from SML engineering interns:

- Founders/Laighton/Hamilton: one M-35, 6 toilets, erect outbuilding
- Kiggins: one M-35, 6 toilets, erect outbuilding
- Bartels: one M-10, 4 toilets, erect outbuilding at the back of the staff lounge
- Dorms 1 and 2: one M-12, 4 toilets, erect outbuilding
- Palmer-Kinne Lab/Laighton/Dorm 3: one M-10, 4 toilets, erect outbuilding
- Grass Lab: one M-10, 2 toilets, either erect outbuilding or convert 2nd storey private bathroom into public restroom
- Kingsbury House: two M-10, 3 toilets, place in same locations as current composting units

Total cost: approximately $160,000 plus cost of outbuilding construction.

First Principles

- Regulatory standards: permit required, but permitting process is not intensive, since the units are widely used in Maine and New Hampshire
- Wastewater characteristics: since the composting units treat only blackwater, SML is not unique in this regard
- Geography and geology: composting units need to be located below toilet units, at most 10 horizontal feet away, requiring two storey outbuildings or plumbing retrofits
- Costly:
  - High, at approximately $160,000 plus cost of outbuilding construction
  - Save money by dramatically reducing or eliminating chlorine and sodium metabisulfite consumption
- Operation and maintenance:
  - Easy start-up and close-down procedures,

    - Maintenance procedure only a few minutes every month during the season
    - Electricity consumption by vent fan only
    - Clivus New England provides 24/7 technical support,
    - All replacement parts stocked in Clivus New England distribution center and available by next-day UPS to the Portsmouth harbour
    - SML staff can be trained to perform all routine maintenance
    - Low likelihood of breaking: no moving parts, all metal parts are stainless steel, simple, low-tech operation
- Safe: contained units are sealed to the public
- Sustainable: removes BOD, end-of-season sludge, recovers soil resource from waste product
- Adaptable and extensible: a limited number of new toilets can be added to each composting units; additional composting units can be added to almost anywhere on the island

Other Advantages

- Decentralized wastewater treatment provides redundancy, so that even when one system becomes non-operational, others are still available
- Replacing indoor toilets with outbuildings frees up space in the existing buildings

Other Disadvantages

- Plumbing between composting units and toilets must be completely indoors—pipes cannot handle weathering
- Decentralized treatment increases the time it takes to check up on the system by spreading it across the island instead of keeping it in one spot
- Concrete pads must be poured for all composting units to sit on
- Foundations that can fit composting toilets should be repaired so they do not flood and are level
- Composting toilets do not address greywater

Incinerating Toilets

System Overview

Incinerating toilets dispose of blackwater by burning it. They are self-contained units with a traditional commode-type seat connected to a holding tank which contains a gas-fired or electric heating system. The incinerated product is a fine, sterile ash, which can be disposed of easily and without hazard of infection. The ash is usually 1-3% the volume of the pre-incineration waste and can be spread outside or disposed along with other trash. Incinerating toilets are a waterless alternative to traditional toilets.

In this evaluation, only Storburn International Inc. incinerating toilets are being considered. The only other incinerating toilet manufacturer's units are an electrical version requiring the unpleasant maintenance operation of scraping half-burned feces from the walls of the holding chamber.

Process Overview

The incinerating toilet is used in the same way as other waterless toilets. After 40-50 uses, the burn cycle is initiated. A propane-fired heating system incinerates the waste in the holding tank. The incinerating process reduces the waste to an ash.

Applications

Since the incinerating toilets are stand-alone units designed to fit in a conventional bathroom, they would be installed in existing bathrooms and stalls. No extensive structural modifications need take place.

First Principles

Regulatory standards

Incinerating toilets are allowed under section 1005.0 of 144 CMR 241 Maine's Subsurface Wastewater Disposal Rules as alternative toilets. A permit from the local plumbing inspector is required before installation.

Incinerating toilets must satisfy applicable fire and building codes, incinerate only when the toilet lid is tightly closed and a blower is blowing makeup air, and combust at a temperature of at least 1400°F. Vents servicing the unit shall terminate at least 24 inches above the roof.

Wastewater characteristics

SML's wastewater characteristics do not need to be considered as unique in the case of incinerating toilets, because of the decentralized nature of the units. The units will experience the same kind of use in SML as in any conventional household.

Geography and geology

The high bedrock on Appledore Island will not pose a problem for incinerating toilets. Incinerating toilets are located aboveground and are self-contained. No fixtures are needed below the unit, nor does plumbing need to be installed. The ash product from the toilets is sterile and can be disposed of virtually anywhere, although it is too nutrient-poor to be used as fertilizer. The toilets do not require large amounts of space because they are designed to fit into a standard bathroom.

Costs

One unit from Storburn costs approximately $3000, and includes ventilation equipment.

Installation and transportation costs are unknown at this point, but an inquiry has been submitted.

With a storage chamber of 3 gallons, Storburn literature recommends incinerating after 40-50 uses. One packet of anti-foam reagent needs to be added before each incineration cycle. The cost of this reagent is yet unknown.

The largest operations cost will undoubtedly be the fuel used to heat the chamber for each incineration cycle. Storburn literature claims that 100 lbs of propane will burn 600 uses. If all the toilets on the island were to be replaced with incinerating toilets, at peak population, 100 lbs of propane would last approximately three days. Although SML currently uses donated propane, the future of that supply is uncertain. At any time, the donations may stop, and SML would suddenly face an enormous cost.

Operation and maintenance

The combustion chamber is self-cleaning; however, the ventilation system will probably require cleaning.

Ash will need to be emptied out of the combustion chamber regularly, but the task should not be onerous, as the chamber should be relatively odourless, the ash will be sterile, and there will be approximately a half cup.

Information still unknown includes start-up and shut-down times, reliability, need for trained personnel, and tolerance of winter disuse.

Safety

One of the biggest advantages of incinerating toilets is the sterility of the ash product. The ash can be disposed of easily and safely. After each burn cycle, the chamber is also disinfected.

The unit is designed to undergo the burn cycle only when locked. The combustion chamber is made of cast nickel alloy.

Sustainability

Propane fuel burning produces some air pollutants. The incineration process removes most nutrients from the ash, so that it cannot be used to replenish soil. The system, as a mechanism for processing waste, lacks sustainability in that it produces no useful energy or matter (only waste heat and nutrient-poor ash) to replenish what was required to operate it.

Adaptability and extensibility

Due to the self-contained nature of the units, the use of incinerating toilets will remove blackwater management from the current wastewater treatment process. It will not rely on any other system on the island, besides propane or natural gas supply.

Due to the self-contained nature of the units, use of them can be expanded indefinitely along with the expansion of a propane or natural gas supply.

Greywater Treatment Alternatives

Shoals Marine Laboratory currently treats all of the island's wastewater at a treatment plant where primary settling and disinfection occurs. If the recommended composting toilets are installed on the island, a new system for greywater management will need to be employed. Greywater is any wastewater from sinks, baths, and kitchen appliances which requires less intensive treatment than full wastewater. A simple option for treatment would be to create a modern variation on a leach field.

Due to the unique geological characteristics that are found on the island, testing to determine the hydrology of the island is recommended first. Andrew Neal, a hydrology graduate student at the University of Arizona, was consulted by the engineering interns as to his opinions of the hydrology tests required for this island. He recommends that a series of monitoring wells be established in order to develop a groundwater profile and establish a baseline hydraulic head gradient for any groundwater. These wells could also be used to run time domain reflectrometry to track unsaturated conditions in the shallow soil. In addition, two large wells should be constructed to perform a pump test, allowing determination of the saturated hydraulic conductivity of the groundwater. A chemical analysis of the current groundwater conditions is necessary in order to establish a background signal for later testing.

Rather than using intensive testing, however, the island's hydrology could also be modeled to generate approximate values for the hydraulic and chemical parameters. However, this less accurate method may or may not be an appropriate plan of action. An environmental engineering firm could be hired to perform the necessary tests. However, professors from Cornell, UNH, or graduate students looking to gain field experience, such as Andrew Neal, might be willing or convinced to donate their services.

Presby Environmental Alternative Leach Field[3]

System Overview

Presby Environmental, Inc. produces a piping leach field system brand-named Enviro-Septic. The piping is made of high-density corrugated and perforated plastic and a special mat of coarse plastic fibers surrounding the pipe. The mat creates an ideal growth environment for bacteria, the

[3] Presby Environmental Informational Packet. 2004.

major mechanism for treatment of the wastewater. A non-woven geotextile plastic fabric stitched into the mat contains the system. The piping is 12 inches in diameter and comes in 10-foot sections.

Applications

There are multiple distributors of this product in the state of Maine and it satisfies the requirements of the Maine Subsurface Wastewater Disposal Rules. Any estimate of how much piping would be necessary would require a soil and hydrology report. The sizing of leach fields depends on the type of soil, bedrock, and resulting characteristics of the area. No definitive conclusion on whether this system would be suitable for the island can be made until the island hydrology is characterized. The installation of the system would require some heavy equipment as well as a large amount of fill, substantially increasing the cost of the project.

From a contractor's experiences with the product, it requires constant maintenance due to clogging in the pipes and other operational problems. The contractor instead recommended Eljen Corporation's In-Drain GSF, which he has successfully used at many of his building sites.

First Principles

- Regulatory standards: approved by the state of Maine
- Wastewater characteristics: SML's greywater characteristics should not be any different from conventional characteristics, even if leachate from the composting units were to be pumped into the greywater system, as the leachate is of a naturally high salt concentration; the use of saltwater toilets would not add substantially to that concentration
- Geography and geology: the system adapts readily to irregular and/or sloping sites with the possibility of a multi-level installation if needed
- Costs: unknown without characterization of geology and hydrology of the island; however, installation will incur high costs due to transportation and use of heavy equipment as well as substantial amounts of fill
- Operation and maintenance: user reviews of frequent clogging
- Safety: unknown
- Sustainability: unknown
- Adaptability and extensibility: unknown

Other Advantages

- Reduced leach field area
- Uses no stone fill

Eljen Corporation Alternative Leach Field[4]

System Overview

Eljen Corporation, based out of Connecticut, offers a product called an In-Drain Geotextile Sand Filter (GSF). It is a non-aggregate leach field system that utilizes a 2-stage biomat made from recycled materials to pre-treat wastewater before it enters the soil and groundwater. These biomats reduce the size of a leach field anywhere from 50-70%; claiming an effective biomat area 3 times that of any piping or chamber system. The installation of the system is very simple with minimal machinery. The biomats require a 6-inch layer of approved sand below the biomat. Separation between the layers of fabric increases oxygen transfer. A perforated pipe above the mat distributes the wastewater evenly across the surface while an anti-siltation fabric sits on top

[4] Eljen Corporation. Online resource accessed on August 5, 2006 at http://www.eljen.com.

of this pipe to reduce fine particles from entering the system. A porous top layer is placed upon this system to allow oxygen exchange and evapotranspiration.

Applications

The reduced bed depth allowed by this system is ideal for the rocky nature of Appledore Island. As with the Presby Environmental system; no definite decision can be made to the applicability of this system to the island. Groundwater depths as well as the soil profile and other such soil characteristics would need to be studied to determine the plausibility and specifics of the system.

The state of Maine highly recommends Eljen's system, citing the impressive performance of the alternative media. The state also comments on the low number of problems reported. It is the recommendation of the interns at Shoals Marine Laboratory that the Eljen system be researched further by SML for installation on Appledore Island as a greywater treatment system.

First Principles

- Regulatory standards: legal but not widespread; may need extra inspection for permit
- Wastewater characteristics: sand will rarely clog or need replacing when used as a greywater-only system
- Geography and geology: sand filter used with leach field reduces field size, requiring relatively little depth and space
- Costs: $3,000 to $8,000
- Operation and maintenance: sand must be changed occasionally
- Safety: contained underground, reducing chance of groundwater contamination
- Sustainability: sand is not damaging to the environment; final product is cleaner than without sand filter in place
- Adaptability and extensibility: greywater can be recycled through the filter; more filters can always be added

Other Advantages

- No stone required and minimal fill
- Easy installation with no assembly required
- Made from lightweight recycled materials
- Highly recommended by users and the state of Maine

Other Disadvantages

- Cost dependent on hydrology and geology evaluation
- Must ship in fill and excavate a trench for the product

Infiltrator Systems, Inc. Alternative Leach Fields[5][6]

System Overview

Infiltrator Systems, Inc. manufactures plastic leach field drainage chambers which can reduce the size of a traditional field by up to 50%. The chamber protects the soil from oversaturation by rainfall and eliminates the need for gravel. Soil or sand, with a greater infiltrative capacity than gravel, is used as the sole medium of filtration. The chamber, a plastic half cylinder installed either above or below ground, shields the soil from rain and runoff. Piping along the top of this chamber transports the wastewater effluent to be sprayed onto the soil. The bottom of the

[5] Infiltrator Systems, Inc. Design and Installation Manual for Infiltrator Chambers in Maine. 6 August 2006.
[6] Infiltrator Systems, Inc. Online resource accessed on August 6, 2006 at http://www.infiltratorsystems.com.

chamber is completely open for maximum infiltration and the sides are louvered to allow for evapotranspiration. The infiltrator chambers are able to handle heavy peak flows and can be designed to fit any size system.

The chambers come in various sizes in order to serve best the daily volume of wastewater as well as the size of the leach field. The infiltrator chambers are durable and easy to install. They can be installed above or below ground and are lightweight and flexible, requiring no extra machinery for installation and few man-hours. The lower number of man-hours needed for installation and the inexpensive cost of the chambers makes the Infiltrator chamber design more economical than traditional gravel and pipe leach fields, often reducing the price by 30-50%. Infiltrator Systems' chambers have been used all over the country for greywater disposal, especially in places where more traditional systems have failed. It has even been successfully used in conjunction with Clivus Multrum composting toilets.

Applications

Maine state regulations require a septic tank to prevent foods, soaps, and other small solids from entering the drain field and clogging the pipes. Since wastewater will be entering the ground and nourishing vegetation, harmful chemicals such as excessive amounts of chlorine, should not be discharged into the system. Due to the shallow bedrock on Appledore Island, It is likely that fill would need to be brought to the island.

Before any further designs can be made or a specific quote given, Appledore Island needs to perform a thorough characterization of Appledore Island's hydrology and geology. Necessary information includes the percolation rate and type of soil, slope of the ground, depth of the groundwater, and depth of the bedrock.

First Principles

- Regulatory standards: specific installation instructions approved by the state of Maine
- Wastewater characteristics: greywater is spread out in field almost immediately so it will not spoil
- Geography and geology: flexible chambers fit topography, but fill will likely still be needed
- Costs: depends entirely on system chosen and soil characteristics
- Operation and maintenance: no moving parts, quick and easy installation
- Safety: unit is underground but may contaminate, hence the need for thorough characterization of island's hydrology
- Sustainability: eliminates overboard discharge, puts untreated water into ground, requires small leach field, requires no chemicals for treatment
- Adaptability and extensibility: new chambers can be added, leach field must be dug out to be expanded

Other Advantages

- Reduces size of a traditional leach field
- On-site disposal method

Greywater Planters Evapotranspiration System[7]

System Overview

Greywater is settled in a septic tank before being evenly distributed into an underground leach field. The leach field is lined and this prevents the wastewater from contaminating groundwater. Specially chosen "water hungry" plants (grasses, alfalfa, broad-leaf trees, evergreens) are planted above the field. The field is lined and filled with fine sand and gravel. A clear greenhouse-like roof is often constructed over the plant bed to keep out excess precipitation while allowing maximum sunlight in.

Greywater contains few suspended solids, and those that are present are settled out in the septic tank. The settled greywater is then pumped out to the leach field where it is evenly distributed by pipes throughout the sand. The fine sand holds greywater in the root zone and transports filtered water upward by capillary action. Plants transpire additional water into the atmosphere and microbes on their roots break down any pathogens that may be present in the greywater. Urine can also be diverted with special toilet bowls and added to the greywater stream. Urine is almost always sterile and it is full of nitrogen, which plants can easily utilize. Some composting toilet units have leachate drains that can also be linked to the greywater system for similar reasons.

Applications

Although evapotranspiration systems are generally used for wastewater treatment, they can easily be converted to treat greywater only. The exact structure of the bed depends on the rate of evaporation on Appledore Island, but the bed would be filled with gravel and soil. This limits the possible locations of the bed to an area with deeper bedrock.

First Principles

- Regulatory standards: legal, but not widespread; building permit may be necessary to construct roof
- Wastewater characteristics: greywater is spread out in field almost immediately so it won't spoil; can be used seasonally, some plants may need to be replaced in spring depending on choice of annuals and perennials
- Geography and geology: requires less depth than conventional leach fields, but still requires some digging; may not be suitable given Appledore's climate
- Costs: depends entirely on system chosen and soil characteristics; low-energy system, with only one pump needed to distribute greywater; fill must be transported from the mainland
- Operation and maintenance: pipes cannot be allowed to clog, but no other regular maintenance is necessary; plants may need to be harvested occasionally
- Safety: contained underground, but can overflow if overloaded; lined to prevent groundwater contamination
- Sustainability: greywater recycled back into ecosystem, providing plants with nutrients; low energy system, requiring only one pump to distribute greywater; on overboard discharge needed
- Adaptability and extensibility: leach field must be dug out to be expanded, new piping and mats must be installed

Other Disadvantages

- Limited storage capacity

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[7] Solomon, Clement, Peter Casey, Colleen Mackne, and Andrew Lake. Evapotranspiration Systems. Online: National Small Flows Clearinghouse, 1998 <http://www.nsfc.wvu.edu>

- Less harsh soaps and detergents should be used
- Seasonal evaporation should exceed transpiration by 24 inches during use. However, note that this figure is for treatment of all wastewater, not just greywater.

Clivus Multrum Soil Absorption System (SAS)[1,2]

System Overview

Clivus Multrum greywater systems bring greywater to one central location where it is pumped through a holding tank that contains a series of particulate filters. After the filtering process, the greywater is pumped out to the Soil Absorption System, a specialized leach field, where it feeds into the root zone of the plants. The size of the entire greywater system is dependent on the load applied to it. Biodegradable soaps should be used; bleach and other harsh chemicals should be avoided and well diluted when necessary. The particulate filters should be scraped with a putty knife once per year to removed build-up. This can be done at the beginning or end of the season.

Applications

The location of a Clivus Multrum greywater system would be determined by a hydrologist. The surface and ground water on Appledore Island must be tested for flow patterns to minimize the risk of contamination. The size of the unit is dependent on peak load, and the size of the unit will dictate where it can be safely built.

First Principles

- Regulatory standards: although leach fields are common, the Clivus Multrum SAS is a modified leach field system
- Wastewater characteristics: holding tanks in greywater systems run the risk of allowing greywater to stand for too long and become blackwater, which requires more treatment and can cause drain pipe clogging
- Geography and geology: suitability for Appledore Island can only be determined after a comprehensive assessment of the island's hydrology and geology; some digging will be required
- Costs: approximately $4,500 per system, an additional $4,500 flat design fee
- Operation and maintenance: filters must be scraped once per season
- Safety: unit is underground and hence may contaminate groundwater, hence the need for a thorough hydrology evaluation
- Sustainability: eliminates overboard discharge, eliminates strong chemicals used to disinfect greywater, puts untreated water into the ground
- Adaptability and extensibility: to expand capacity, new leach fields must be dug out

Other Advantages

- System is completely designed and sized by professionals
- Single manufacturer for composting toilets and greywater system streamlines maintenance

Other Disadvantages

- Single manufacturer for composting toilets and greywater system allows SML to have just one contact for all wastewater treatment system support

Overboard Discharge

System Overview

An overboard discharge system would entail pumping treated greywater into the ocean. Treatment included chlorination and dechlorination. The island must be granted a permit by the state of Maine and satisfy regulation dictating effluent characteristics.

Applications

Since SML already has an overboard discharge license, the wastewater treatment system already in effect may be used for this option. Thus, this option would be the simplest and most cost effective means of disposing greywater. However, there exists the distinct possibility that the island's overboard discharge license will not be renewed in 2009, and so considering alternatives is critical.

First Principles

- Regulatory standards: permit may or may not be renewed; if permit is renewed, the renewed permit may or may not have far stricter requirements
- Wastewater characteristics: greywater should not sit in tanks for extended periods of time, or it will become blackwater
- Geography and geology: uses existing system
- Costs: since the current system leaks, repairs or replacement tanks are needed
- Operation and maintenance: chlorine and sodium metabisulfite are still needed to chlorinate and dechlorinate the greywater; pumps need service occasionally
- Safety: system is fully enclosed, but still discharge into the open ocean
- Sustainability: involves overboard discharge and intense chemical use; long-term consequences to marine life unknown
- Adaptability and extensibility: overboard discharge permit caps discharge volume; new tanks must be added to increase system capability

Traditional Leach Fields

System Overview

In a leach field, wastewater effluent is piped into a subsurface are lined with stones, gravel and soil. The soil traps wastewater so that it can be used to nourish the plants above. The stones, gravel and soil acts as a natural filter for the greywater. The effluent can be gravity-fed or pumped into a leach field. Using a pump increases the cost and complexity of the system, but reduces the chance of clogging in the pipes and distributes the greywater more evenly. Per Maine regulations, a septic tank would be needed to prevent food, soap and other small solids from entering the field.

Applications

A leach field in combination with composting toilets is a possibility on Appledore Island. Due to the shallow bedrock, it is likely that gravel and soil would need to be shipped to the island to create the necessary soil conditions. Groundwater contamination is a concern since Appledore uses a well to obtain fresh drinking water. It is likely that a secondary treatment option, in addition to a septic/holding tank, would be necessary even if the leach field treats only greywater. Although the exact size of the necessary leach field is determined by numerous factors including slope of the land, daily flow rate, type of soil, etc, a minimum of three feet of dry soil would be necessary. Wrapping pipes in a fabric filter or using an array of pipes as a trickling filter for the effluent can reduce the size of a leach field. Similarly, alternating between two leach fields allows the soil in one to recover its percolation rate while the other is in use and limits the chance of overflow. Finally, pressurized pipes can be utilized to limit the chance of clogging.

First Principles

- Regulatory standards: leach fields are common and legal
- Wastewater characteristics: greywater is spread out in field almost immediately so it will not spoil
- Geography and geology: leach fields extensive amounts of fill and much deeper bedrock than is typically found on Appledore
- Costs: depends entire on system chosen and soil characteristics; however, whichever system is chosen will likely involve transporting large amounts of fill and gravel
- Operation and maintenance: pipes cannot be allowed to clog
- Safety: contained underground, and could possibly contaminate groundwater, the source for most of SML's drinking water
- Sustainability; eliminates overboard discharge, puts untreated wastewater into the ground
- Adaptability and extensibility: leach field must be dug out to be expanded

Other Disadvantages

- Might not be possible on the island due to shallow bedrock and large amount of rain
- Must be careful about what kinds of shampoos, laundry detergents, dish soaps, etc. are used.

Drip Irrigation[8]

System Overview

Greywater can be used for irrigation purposes. The wastewater can be distributed by a subsurface drip irrigation system, saturating the soil and nourishing plants. The effluent can be gravity-fed or pumped into the soil bed. Using a pump increases the cost and complexity of the system, but reduces the chance of clogging in the pipes and distributes the greywater more evenly. Per Maine regulations, a septic tank would be needed to prevent food, soap and other small solids from entering.

Applications

This process requires approximately 1 foot of unsaturated soils, thus making it feasible on Appledore Island where the bedrock is shallow. The nutrients in the discharge would provide nourishment for non-edible plants. Due to the concern over groundwater contamination, the lined soilbeds may be a better candidate for wastewater irrigation. Lined soilbeds are filled with gravel, soil, rocks, and screening.

First Principles

- Regulatory standards: although a permit is probably required, a drip irrigation system should be legal so long as only non-edible plants are receiving the irrigation
- Wastewater characteristics: a drip irrigation system may or may not be able to withstand the high salt content of urine additions from composting unit leachate; this capability most likely depends on the overall volume of other greywater, which would dilute the salt concentration of urine; SML could switch to readily available biodegradable soaps and detergents and other less harsh chemicals

[8] GeoFlow. 29 July 2006 < http://www.geoflow.com/index.html >

- Geography and geology: since only a 1-foot depth is required, many places on Appledore could be found to be suitable
- Costs: high installation and purchase costs
- Operation and maintenance: must ensure that pipes do not clog; otherwise overflow or uneven distribution may occur, especially if the system is not sized appropriately; relatively long start-up time in each season, the plants must grow to a certain degree of maturity before robust uptake will occur
- Safety: should pose no harm to humans unless the plants are eaten
- Sustainability: "closes the loop" in a sense, since the drip irrigation system performs resource recovery
- Adaptability and extensibility: in order to expand capacity, more land would have to be landscaped, more drip lines would have to be installed and laid; if a pumped system is used, there exists a limit to how far one pump can deliver the greywater

Sand Filter[9]

System Overview

Sand filtration is most effective when used in combination with some other treatment option. A sand filter is a small piece of machinery placed in a box of sand through which the water runs before being re-collected and circulated through another system, such as a leach field. A pump would be needed to move the water through the sand, and a septic tank would be needed to prevent food, soap and other small solids from entering the filter.

Applications

A sand filter can be used in conjunction with a leach field to limit the chance of groundwater contamination. The sand filter consists of 2 feet of sand in a box beneath the surface. Wastewater is continuously circulated through the filter with about ¼ of the water being diverted to the secondary treatment site (e.g. leach field) on each pass. Since the water has been filtered once, the size of the leach field can be reduced. Also, since the sand is all contained within the box bed, the sand can be changed easily to avoid clogging.

First Principles

- Regulatory standards: when used in conjunction with a conventional greywater treatment system, such as a leach field, considered a relatively common method
- Wastewater characteristics: SML could switch to readily available biodegradable soaps and detergents and other less harsh chemicals, aiding in the system's viability
- Geography and geology: sand filter itself sits in a box aboveground, not hindered by Appledore's high bedrock, as well as reducing the size of the primary treatment system (e.g., leach field), which may make it cheaper or feasible for implementation on Appledore
- Costs: $3,000 to $8,000
- Operation and maintenance: sand must be changed occasionally; however, unless sized incorrectly, sand will rarely clog and need replacing when used as a greywater-only treatment system; requires electric power to pump greywater through the filter
- Safety: contained underground, reducing chance of groundwater contamination
- Sustainability: sand is not damaging to the environment, and final product is cleaner than without sand filter in place; however, the used sand that must be replaced with fresh sand needs to be disposed

[9] Aqua Point. 29 July 2006 < http://www.aquapoint.com/html/sand_filters.html >

- Adaptability and extensibility: greywater can be recycling through the filter, and more filters can be added

Other Disadvantages

- Not sufficient for wastewater treatment on its own.

Stabilization Pond

System Overview

In a stabilization pond, wastewater is first filtered through soil and then used to nourish appropriate vegetation (duckweed, elephant ears, and cattails), plankton, and even fish. The effluent can be gravity-fed or pumped into the stabilization pond. Using a pump increases the cost and complexity of the system, but reduces the chance of clogging in the pipes and distributes the greywater more evenly. Per Maine regulations, a septic tank would be needed to prevent food, soap and other small solids from entering.

Applications

A stabilization pond as shallow as 1.5 meters with a surface area of 1 acre will serve approximately 200 people. A stabilization pond is traditionally used to treat both black and greywater; however, the system could be modified to treat greywater only. An aerated stabilization pond requires less space but more pumps and machinery. Also, using several lagoons in series allows for such aeration and each pond can have a different sort of plant/animal life. Each pond will be slightly cleaner than the previous and requires different plants/animals in each. However, the freezing winter conditions on Appoledore Island render a lagoon relatively impractical. Another type of stabilization pond is the constructed wetland. In wetlands, the water is kept subsurface but can still be used to nourish vegetation. Approximately 1 cubic foot of wetland is needed for every gallon of wastewater produced per day. The treated effluent may have to be discharged or piped out to prevent overflow if it is not reused.

First Principles

- Regulatory: not directly addressed in current regulations, so permit process will probably be intensive
- Wastewater characteristics: a stabilization pond may or may not be able to withstand the high salt content of urine additions from composting unit leachate; this capability most likely depends on the overall volume of other greywater, which would dilute the salt concentration of urine; SML could switch to readily available biodegradable soaps and detergents and other less harsh chemicals
- Geography and geology: requires at least a depth of 1.5 meters and a surface area of 1 acre, which may or may not exist in a practical location on the island
- Costs: depends on cost of labor and cost of plants, but relatively expensive to build
- Operation and maintenance: relatively large start-up time at the beginning of the season (must wait for plants to mature to a certain degree); but in-season maintenance is minimal, since treatment relies on robust natural processes
- Safety: pond is open and uncovered; groundwater contamination possible
- Sustainability: greywater drains toward ocean; groundwater is not fully treated
- Adaptability and extensibility: must be dug out to expand system, but no fill is necessary

Trickling Filter[10,11,12]

System Overview

Bacteria living on rocks or a plastic medium located inside a tank are used to filter the greywater. The effluent can be gravity-fed or pumped into a tank. Using a pump increases the cost and complexity of the system, but reduces the chance of clogging in the pipes and distributes the greywater more evenly. Per Maine regulations, a septic tank would be needed to prevent food, soap and other small solids from entering.

Applications

The rocks offer a surface on which the bacteria can attach. Rotating or fixed distributors are used to deliver the effluent evenly to the top of the cylindrical rank. An additional settling tank is needed after the filter for any slime debris accumulated from the rocks to settle out.

First Principles

- Regulatory: a permit is almost certainly required; however, the permitting process may not be too difficult since trickle filters are relatively well-known if not widespread
- Wastewater characteristics: greywater is spread out in field almost immediately so it will not spoil
- Geography and geology: can be installed aboveground, but will require a certain amount of surface area
- Costs: requires capital investment in pumps, filter media, and settling tanks; disinfection chemicals are a recurring cost
- Operation and maintenance: similar to current/traditional system – pump maintenance and monitoring; rocks may need to be rotated or changed on an infrequent basis
- Safety: closed system, only treated wastewater is discharged
- Sustainability: low-energy system; uses natural processes to treat greywater; disinfection required before discharge; removes nitrogen and organic matter from the wastewater
- Adaptability and extensibility: additional capital investments required in order to significantly expand capacity

Other Advantages

- Can reduce the size of a traditional leach field

Other Disadvantages

- Water would still need to be disposed of (ie leach field or overboard discharge)
- Filters might be needed to prevent bacterial mats from polluting water

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[10] AMWELL. 29 July 2006 < http://www.amwell-inc.com >.
[11] NSW Environmental. 29 July 2006 < http://www.nswplastics.com/environmental >.
[12] Septic Tank to Anaerobic filter to Trickling Filter with Recirculation to Anaerobic Filter. Austin City Connection. 29 July 2006 < http://www.ci.austin.tx.us/wri/treat12.htm >.

Solar Aquatics System[13]

System Overview

The Solar Aquatics System (SAS) uses a series of batch reactors housed in a greenhouse to treat wastewater to an exceptionally high standard. Untreated wastewater enters a settling tank where solids are removed through primary treatment. The clarified wastewater is then gravity-fed into subsequent tanks housing the appropriate flora and fauna necessary to degrade different components of the wastewater. This system can be tailored to treat most types of wastewater by pre-selecting the number of tanks and types of species to be utilized in each tank. The effluent from a well-designed SAS is clean enough to be recycled in toilets or irrigation.

Soaps are broken down by microbes and bacteria in the first tanks of a solar aquatics greywater system. Algae, microbes, and plants are introduced in the next few tanks to begin denitrification. Snails, fish, and plants aid in removal of organics in subsequent tanks. The final step is often a marsh tank that houses plants such as cattails, bulrush, and water irises, which destroy pathogenic bacteria in the wastewater.

Applications

SAS was developed to treat full-strength wastewater. However, using SAS as a greywater-only treatment system in conjunction with another blackwater management system, such as composting toilets, would be more appropriate for SML. Otherwise, the island's toilets would have to be converted to fresh water and a system for disposing of sludge from the settling tanks in an environmentally sound way would have to be devised. The first several tanks in a traditional solar aquatics system are settling tanks, which would not be necessary in a greywater system.

First Principles

- Regulatory: due to the extremely innovative nature of this technology, a permit would certainly be required and moreover, the permit may be relatively difficult to obtain
- Wastewater characteristics: if used as a greywater-only treatment system (as recommended), then SML's wastewater characteristics will not be a limiting factor; however, if SAS is used as a completely wastewater treatment solution, then the toilets would have to run on freshwater rather than salt water
- Geography and geology: aboveground units; probably do not need completely level surfaces throughout entire greenhouse
- Costs: cost depends on flow, but due to the complexity and rarity of the system, likely to be extremely expensive
- Operation and maintenance: plants must be harvested occasionally but in general natural processes maintain the treatment with little operational or maintenance needs; low-energy system; start-up times are likely to be long, as plants which fail to survive the winter (a distinct possibility) need to be replanted and bacteria need to be regrown
- Safety: reactors are open, but covered in plants
- Sustainability: effluent is suitable for recycling; sludge produced by bacteria could be treated in a small composting unit
- Adaptability and extensibility: increased flows may be accommodated only with difficulty, as new batches or replacement batches would have to be built and installed, complete with the appropriate ecology, which may be costly and/or difficult to establish

[13] "Cluster, Multi-Unit & Village Systems." Ecological Engineering Group. July 2006. http://www.ecological-engineering.com/cluster.html .

Other Advantages

- New courses could be offered at Shoals to study the treatment plant
  - Applied biology, sustainability, various engineering
- Similar systems in Weston, MA and other towns have drawn significant money from eco-tourists visiting the facility
- NSF grants funds more readily for innovative and sustainable technologies
- The lab relies so heavily on surface water for fresh water needs that it is risky to discharge any greywater into the ground via leach field

Summary

Table 1: Summary of blackwater treatment alternative evaluations

	Clivus Multrum Composting Toilets	Incinerating Toilets
Regulatory standards	Easy	Medium
Wastewater characteristics	Suitable	Suitable
Geography and geology	Somewhat suitable	Extremely suitable
Costs	Expensive	Medium
Operation and maintenance	Low	Medium
Safety	High	High
Sustainability	High	Medium
Adaptability and extensibility	Medium	Very high