Engineering Internship 2006: Final Report

Shoals Marine Laboratory

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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.

WASTEWATER SYSTEM

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.

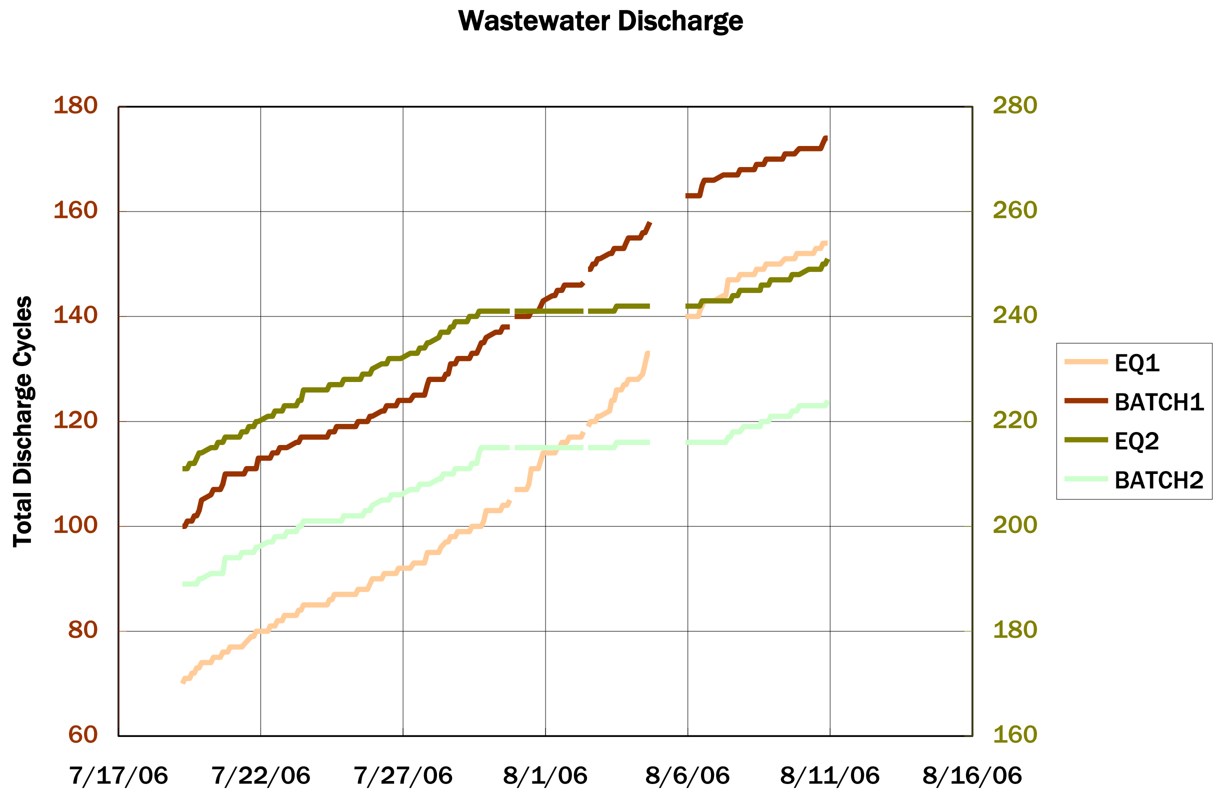

Figure 1: Wastewater discharge over collection period

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.

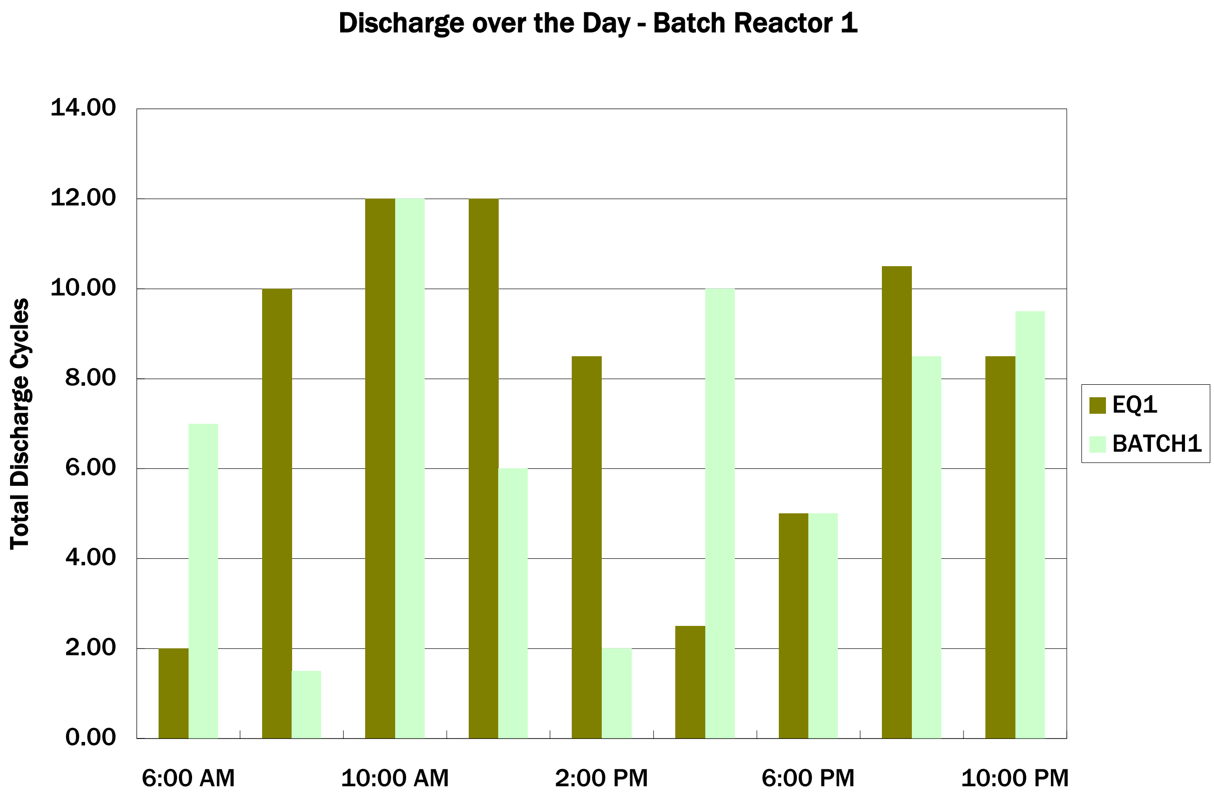

Figure 2: Total discharge cycles over the day for Batch Reactor 1

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 40), 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.

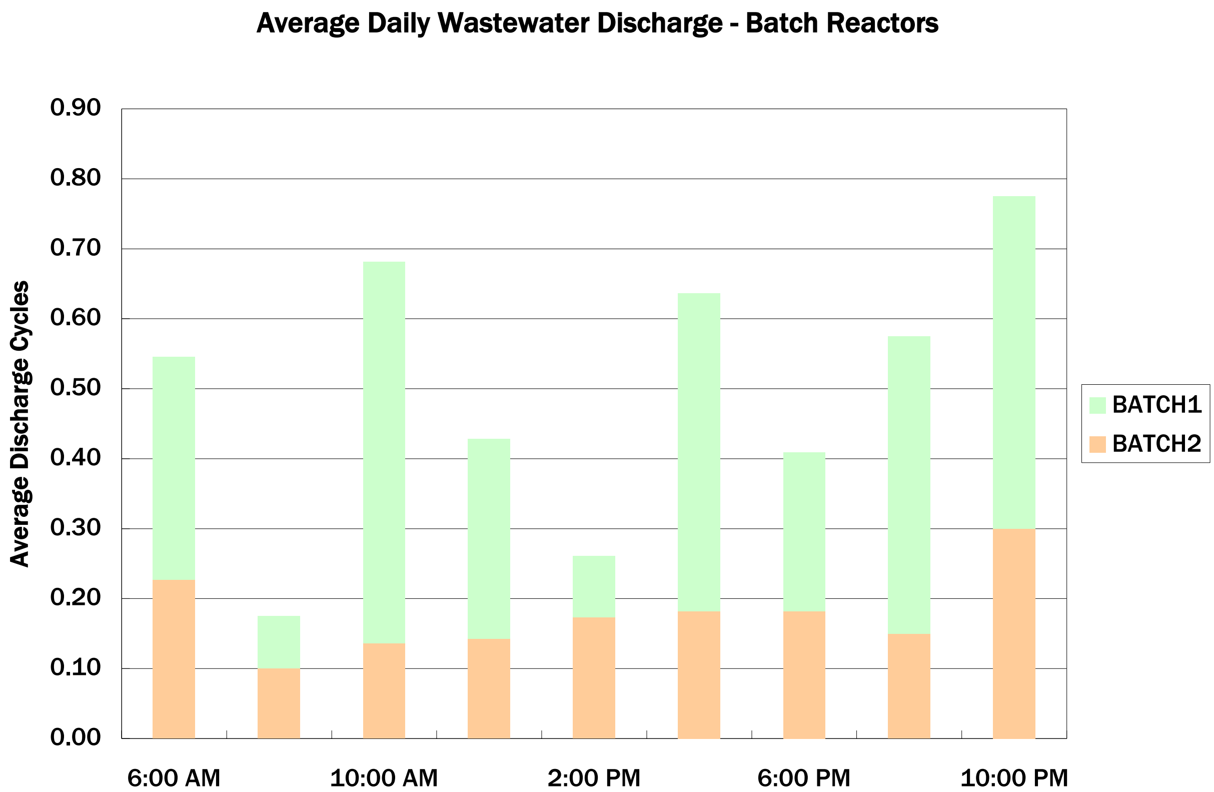

Figure 3: Average daily wastewater discharge cycles over the collection period

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.

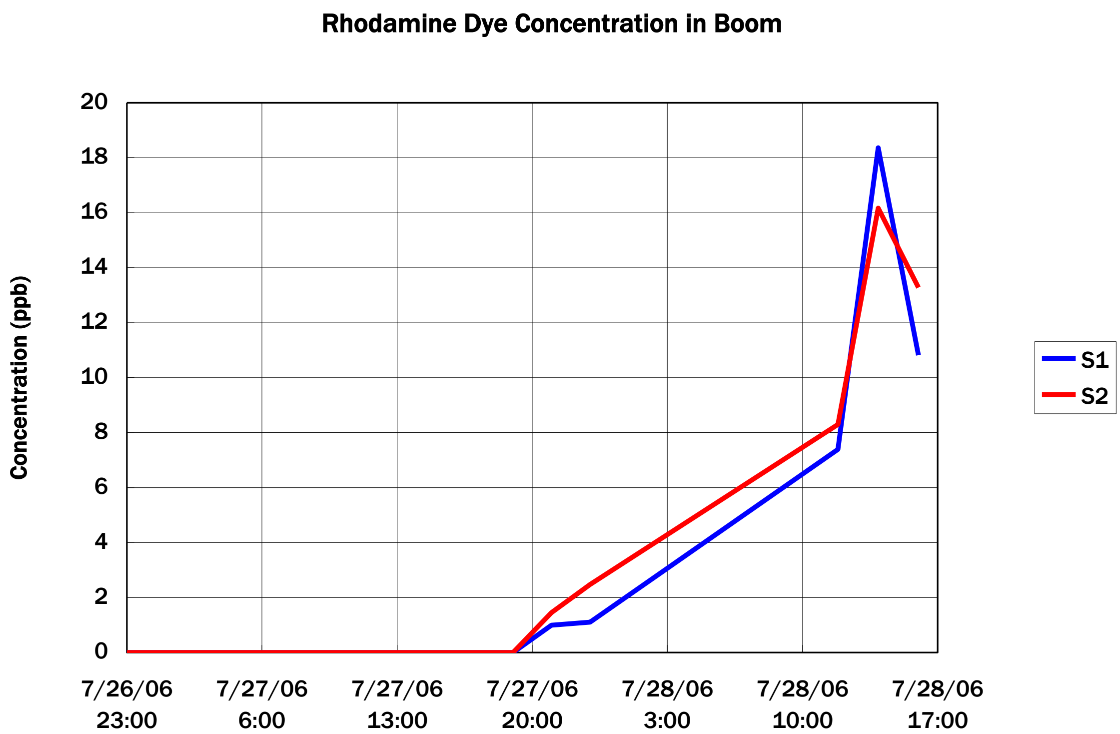

Figure 4: Graph of rhodamine concentration in boom over time

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 60).

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

[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

[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

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[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

Table 2: Summary of greywater treatment alternative evaluations

	Presby Environmental Alternative Leach Field	Eljen Corporation Alternative Leach Field	Infiltrator Systems, Alternative Leach Field	Greywater Planters Evapotranspiration
Regulatory standards	Easy	Medium	Easy	Medium
Wastewater characteristics	Suitable	Suitable	Suitable	Suitable
Geography and geology	Suitable	Somewhat suitable	Somewhat suitable	Somewhat suitable
Costs	Expensive	Expensive	Unknown	Unknown
Operation and maintenance	Very high	Low	Low	Low
Safety	Unknown	Medium	Medium	Medium
Sustainability	Unknown	High	Medium	High
Adaptability and extensibility	Unknown	Low	Low	Low

	Clivus Multrum SAS	Overboard Discharge	Traditional Leach Field	Drip Irrigation
Regulatory standards	Medium	Unknown	Easy	Medium
Wastewater characteristics	Suitable	Suitable	Suitable	Somewhat suitable
Geography and geology	Somewhat suitable	Extremely suitable	Unsuitable	Suitable
Costs	Expensive	Medium	Unknown	Expensive
Operation and maintenance	Low	Low	Low	Medium
Safety	Medium	Medium	Medium	High
Sustainability	Medium	Low	High	High
Adaptability and extensibility	Low	Medium	Low	Medium

	Sand Filter	Stabilization Pond	Trickling Filter	Solar Aquatics
Regulatory standards	Easy	Difficult	Medium	Medium
Wastewater characteristics	Suitable	Suitable	Suitable	Somewhat suitable
Geography and geology	Suitable	Somewhat suitable	Suitable	Suitable
Costs	Expensive	Unknown	Expensive	Expensive
Operation and maintenance	Low	Medium	Medium	Low
Safety	High	Low	High	High
Sustainability	High	Medium	Medium	Very high
Adaptability and extensibility	High	Medium	Low	High

Salt Water System

System Overview

SML uses salt water to operate nine sea tables and 22 five-gallon flush toilets all season, as well as a reverse osmosis (RO) machine for partial seasons. The main salt water pump supplies the sea tables, the toilets, a few spigots, and the fire hoses. Another salt water pump is dedicated to the RO machine and only operates while that machine is in use.

Problem Overview

Currently the island's toilets are operating properly, but there are complaints that the sea tables lose pressure and sometimes completely lose all water flow. The pump was either sized incorrectly or the system is failing. System failure might be due to a variety of factors, including leaks in the system, increased demand for which the pump was not sized, build-up on the inside of the pipes, corrosion of the pump's bronze impeller from the salt water, or failure of the pump itself.

Data Collection

System Flow Monitoring

From July 18, 2006 to August 10, 2006 data was collected every two hours from 6:00am to 10:00pm on the main salt water pump. Intake and discharge pressure as well as flow rate through the pump were recorded. The collected data can be found in the appendix.

On July 22, 2006 discharge from the sea tables was measured every two hours from 8:00am to 8:00pm. Flow rate was calculated by measuring the time necessary to fill a four-gallon bucket. Three replicates were taken per reading at each of the three different salt water discharge pipes. The discharge pipes discharged salt water from the Grass Laboratory sea tables, Palmer-Kinne Laboratory and Laighton sea tables, and the Kiggins Commons sea tables, respectively.

From July 19, 2006 to July 22, 2006 data was collected on salt water used by the toilets. Charts posted in each salt water toilet stall on the island requested that users mark the chart when they flushed. The chart was divided into two-hour segments so data could be analyzed on the same intervals as system intake monitoring data. The toilet discharge data is broken down by number of flushes per stall per building per two hours between 6:00am and 10:00pm over four days. The toilets were assumed to discharge five gallons per flush.

Salt Water Pump Testing

At high tide (6:21pm) on August 3, 2006 the T-valve directly outside of the salt water pump shed was opened. This cut the salt water supply to the entire island and therefore significantly reduced the total dynamic head on the pump. The flow meter read 45gpm during the test, however this was deemed to be unrepresentative of the pump's capacity due to excessive friction head loss at the small opening of the T-valve.

During high tide (10:35am) on August 8, 2006 the same T-valve was opened above the narrow fixture to eliminate the potential error from the small discharge spigot on the valve. During high tide (12:08pm) on August 10, 2006 a valve on the salt water line was opened at the top of the hill outside of Palmer-Kinne Laboratory, the highest point in the salt water system.

Results

System Flow Monitoring

The daily data show significant trends in flow, intake pressure and discharge pressure. Figure 5 uses intake pressure as an example. All three parameters showed similar extrema with respect to time. See the appendix for a complete collection of charts and data analysis.

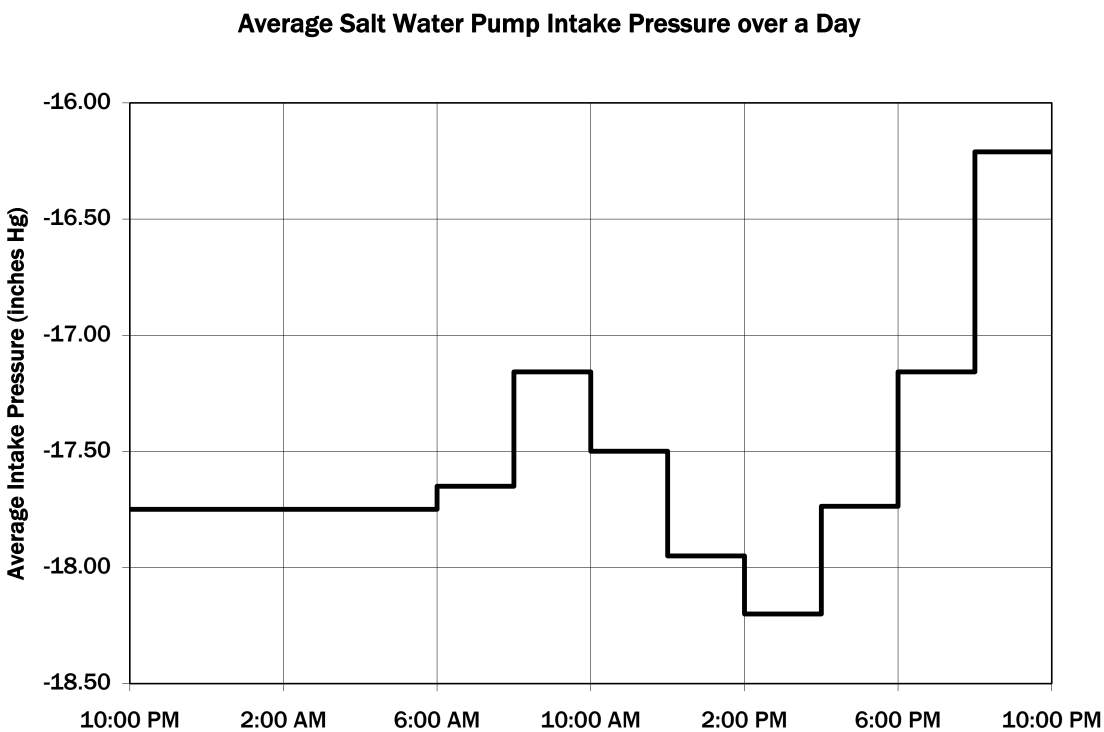

Figure 5: Average salt water intake pressure shown as a function of time over the day. Average intake pressure between 10:00pm and 6:00am is an estimation using 10:00pm and 6:00am data values.

Salt water discharge from toilets and sea tables for July 22, 2006 were combined to yield total salt water discharge for that day. These figures were then compared for inconsistencies with the salt water pump intake data for July 22, 2006. Any possible leaks in the salt water piping system would appear as inequalities between the inflow and outflow. Although the inflow and outflow do not exactly equal one another throughout the whole day, they are close enough to rule out leaking salt water pipes as a major cause of water loss, as seen in Figure 6. This conclusion is further supported by the exclusion of salt water spigot use, since those data were not collected, the inclusion of which would increase outflow.

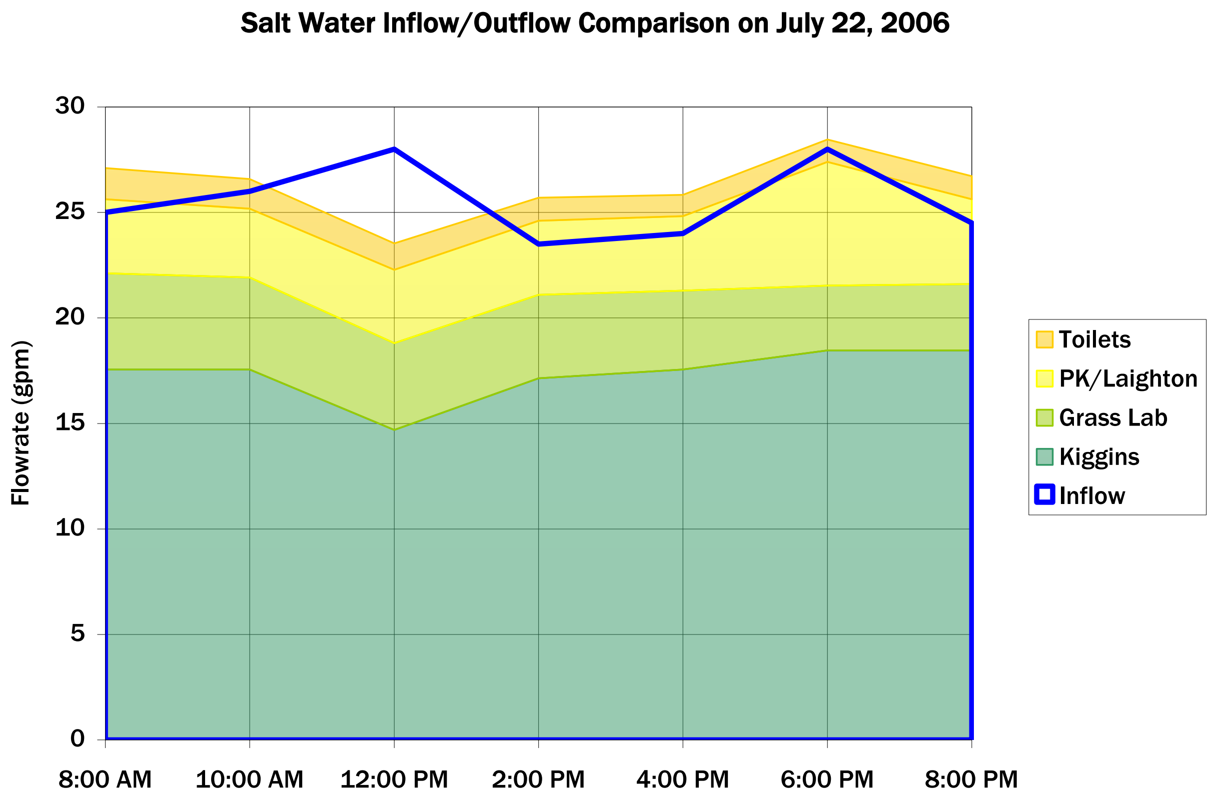

Figure 6: Comparison of salt water system inflow and outflow on Saturday, July 22nd, 2006

Salt Water Pump Testing

System flow monitoring data were used to evaluate the main salt water pump's performance. Comparing the actual performance of the pump with a theoretical performance based on manufacturer-provided specifications shows that there is a serious discrepancy. The theoretical performance assumed a calculated total dynamic head (TDH) of 95 ft (see Appendix A for calculation), which corresponds to flow rate of 188 gpm, an order of a magnitude away from the actual flow rate of 23-35 gpm. This extremely large difference suggests that either the TDH calculation is wrong or the pump specifications are faulty. Those suspicions are further supported by the fact that the pump was originally chosen for a flow rate of 60 gpm in the system.

In the salt water pump test at the salt water pump shed, the flow meter indicated an increase in flow rate from 25 gpm to above 60 gpm, the end of the meter's range. Intake pressure increased from -13 in Hg to -30 in Hg, the end of the gauge's range. The discharge pressure dropped from 55 psi to 15 psi. In the test at Palmer-Kinne Laboratory, the flow rate increased to 54 gpm, the intake suction increased to -20 in Hg, and the discharge pressure decreased to 55 psi.

The pump's performance of 54 gpm to the highest point in the system (approximately the T-valve at Palmer-Kinne Laboratory) is close to the design performance of 60 gpm, undermining the large difference found between actual and theoretical performance. In this case, the decrease in flow of approximately 6 gpm may be the result of impeller wear and/or algal growth, which slowly decreases pipe diameter while increasing the friction in the system.

The data from the second test at the salt water pump shed were used to back-calculate a TDH of 150 ft (see Appendix A for calculation), which corresponds to a capacity of approximately 60 gpm in the manufacturer-provided specifications. This actual capacity is the same as the design capacity, further undermining the previous TDH calculation. The original TDH calculations had many sources of error, such as pipe length measurement error, since the pipe was not always visible. Thus, the back-calculation of 150 ft is probably more accurate than the original estimate of 95 ft.

Note that the suction head as calculated from the intake pressure is –22.7ft (see Appendix A for calculation), while the change in elevation from water line to the pump is only about 15 feet, depending on the tide cycle. This larger suction head value indicates a problem with intake, such as clogging the intake pipe, since the difference means that the pump is working harder to pull water in than it theoretically should.

While the pump is currently capable of delivering 54gpm to the top of the system, it is only delivering 23-35gpm to the entire system. The TDH for the system must then be substantially greater than the TDH from the intake to Palmer-Kinne Laboratory. With less than 5 ft of static head after it, Palmer-Kinne is approximately the highest point in the salt water system. Therefore, the additional TDH after Palmer-Kinne must be due to friction head, which is influenced by both the size of piping and the types and numbers of pipe fixtures (valves, elbows, toilets, etc.) attached. The flow through the system would theoretically be improved by reducing the number of fixtures on the line, increasing pipe diameter, and changing the piping materials.

The possibility that the pump itself is failing through wear or some other factor is supported by an incident that occurred during the interns' last days on the island. On August 11, 2006 the salt water pump lost its prime and the system went down for an unknown number of hours. The salt water intake and check valve were replaced by divers.

Recommendations

The current intake pipe should be cleaned to remove algal growth or any other build-up, such as mussels, which may have rooted in the pipes. Cleaning off build-up will increase the pipe diameter and decrease friction head in the piping.

SML's next pump should have a plastic or stainless steel impeller, since the current model is prone to corrosion in the salt water environment.

The current piping has many elbows and other fixtures, which increase the TDH of the system. Some of these joints do not appear to be necessary, such as the pipes diverting salt water in a square around the tower. In this situation a pipe straight into Palmer-Kinne could probably be used instead of four elbows. Decreasing the number of fixtures would increase flow rate throughout the system.

Installing larger pipes would also decrease TDH and therefore increase flow. We recommend replacing the current 2 in line from the pump to the Tower with a larger line, reducing friction head considerably.

The sea tables can be better utilized. Many classes only use the organisms for a few days, after which they sit in the table and die. The organisms can be used and released and then the sea table's water supply can be turned off, which would conserve salt water for use in the toilets and remaining sea tables. A minimum flow to the sea tables can also be determined by the marine biologists, so that the sea tables are not taking more salt water than they strictly need. Some salt water recycling may be able to be utilized in the sea tables. A small pump can be installed to pull a portion of the outflow back up to the top of the tables. Kiggins is a good candidate location because several neighboring tables can use recycled water while only purchasing one pump.

A timer can be placed on the pump to match the power it uses to the loads applied. This will both save energy and prolong the life of the pump. The pump can be switched to a lower power to bring in less water at night when the toilets are not being used heavily. If cleaning the pipes appears to increase the flow, or if a new pump is purchased, the timer could be used to decrease power use at high tide as well.

SML can purchase a more powerful pump, but increasing pump capacity should not be necessary with proper plumbing and maintenance. A less powerful 5 hp pump with a 6 ½ in impeller, for example, also provides the design capacity of 60 gpm for SML's system, according to manufacturer-provided specifications. Note that this less power pump would incur a lower energy cost. In addition, the current plumbing may not be able to withstand a large increase in pressure.

Composting toilets will decrease the amount of salt water used on the island. Installing composting toilets will lower the salt water demand up to 2.5 gpm during peak use.

Freshwater System

System overview

Shoals Marine Laboratory derives its fresh water from two sources: a well and a reverse osmosis unit. The well is a 20 foot dug well supplied by groundwater under the influence of surface water. The reverse osmosis unit is used only when the water in the well drops to a low level. Fresh water from both sources is pumped into an underground cistern where the water is chlorinated. From the cistern, the water is pumped to a steel tank partially filled with air. From the steel tank, the water flows through a flow meter and into a manifold located in Kiggins Commons. The manifold distributes the water to other buildings on the campus.

Problem

There is currently a lack of information about freshwater use throughout the day. Currently, data is collected only in the morning and evening. Collecting data at more frequent intervals throughout the day might provide insights into the system that will aid in management.

Data Collection

From July 19, 2006 to August 10, 2006, the reading from the flow meter located between the steel tank and the manifold was recorded every two hours from 6:00 am to 10:00 pm. The flow meter was read to the nearest 10 cubic feet.

Results

From Figure 7, one can see that there was a slight downward trend in freshwater consumption over the collection period. The average freshwater consumption rate was 1.296 gpm with a standard deviation of 0.012 gpm. There were three outliers in the data: from 8:00 pm August 3rd to 8:00 am August 4th, freshwater consumption was extraordinarily high. Freshwater consumption during that 12-hour period was 3 to 5 times higher than the prevailing average.

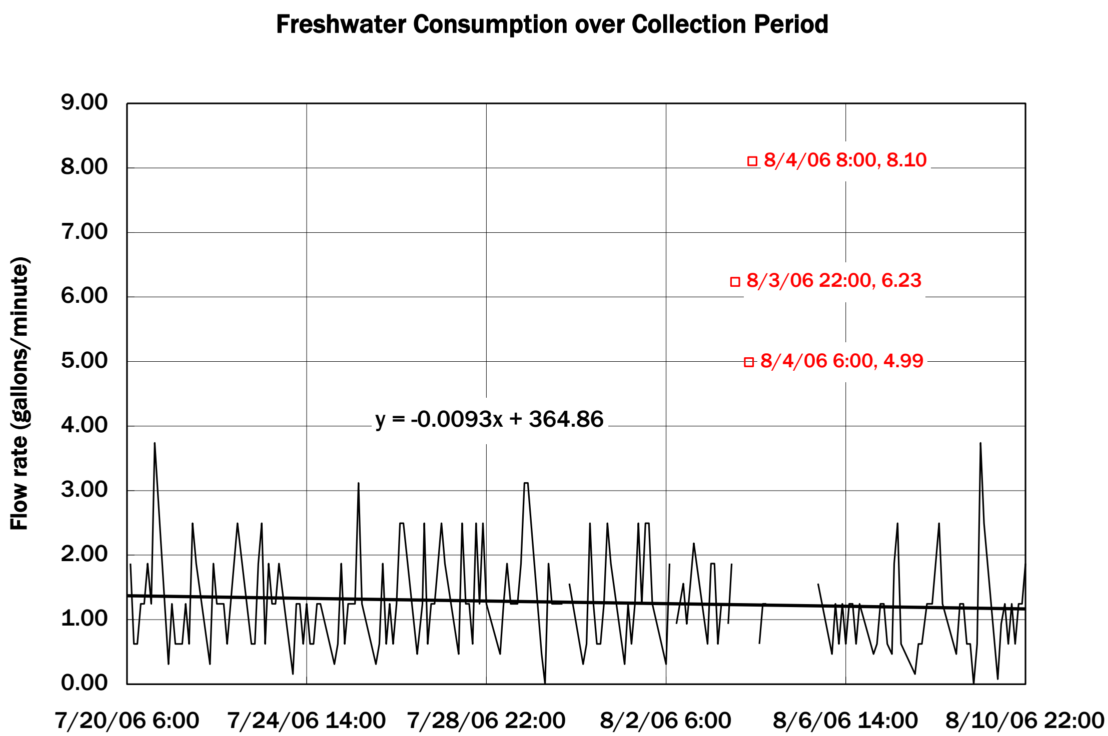

Figure 7: Freshwater consumption rate over entire collection period
The downward trend was likely a result of the declining island population, since per capita freshwater consumption can be seen in Figure 8 to have remained relatively steady across the collection period, at an average of 0.012 gpm/person with a standard deviation of 0.008 gpm/person, excepting the three outliers mentioned above. Possible explanations for these outliers include recording error and equipment malfunction.

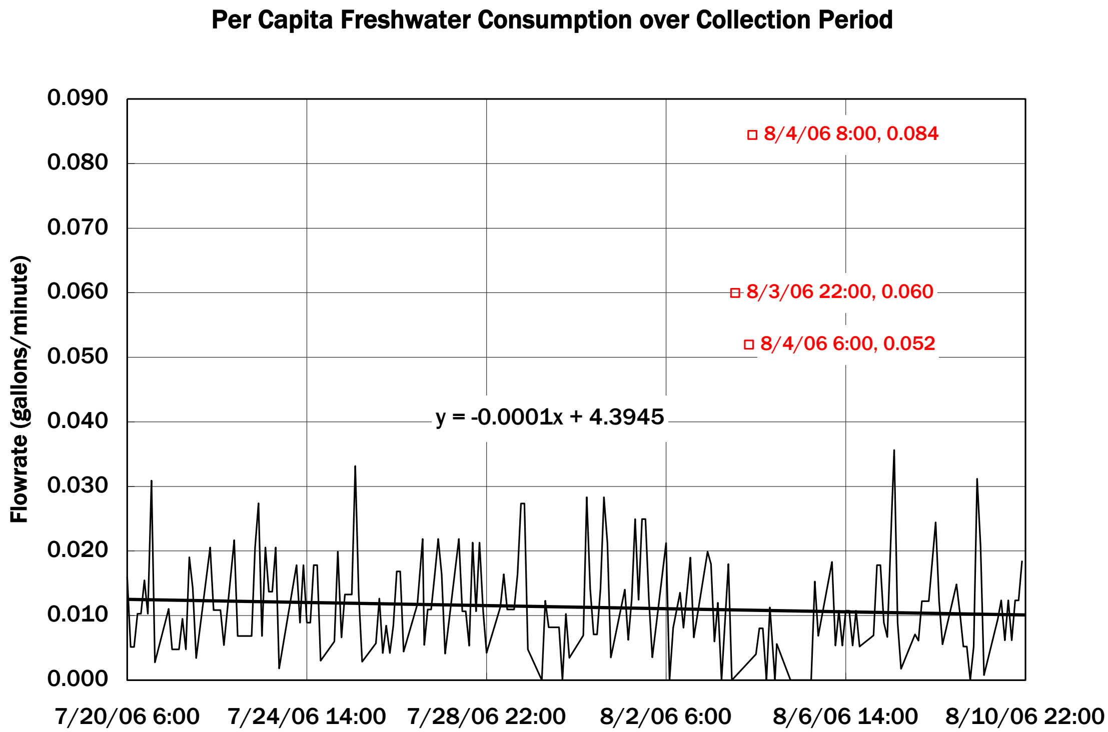

Figure 8: Per capita freshwater consumption over the entire collection period

In Figure 9 there are two noticeable peaks in freshwater consumption: from 6:00 am to 10:00 am and from 6:00 pm to 10:00 pm. These peaks coincide with breakfast and lunch; however, lunch at 12:30 pm evinces no such peak. Hence, the peaks are probably a result of morning and evening hand/face washings, and not freshwater consumption by the kitchen. On the other hand, note that shower restrictions to protect the kitchen's supply of fresh water are in effect from 7:00 am to 9:00 am and from 5:30 pm to 7:30 pm. Thus, one can conclude that washing (including showers) is a larger contributor to freshwater consumption than kitchen usage.

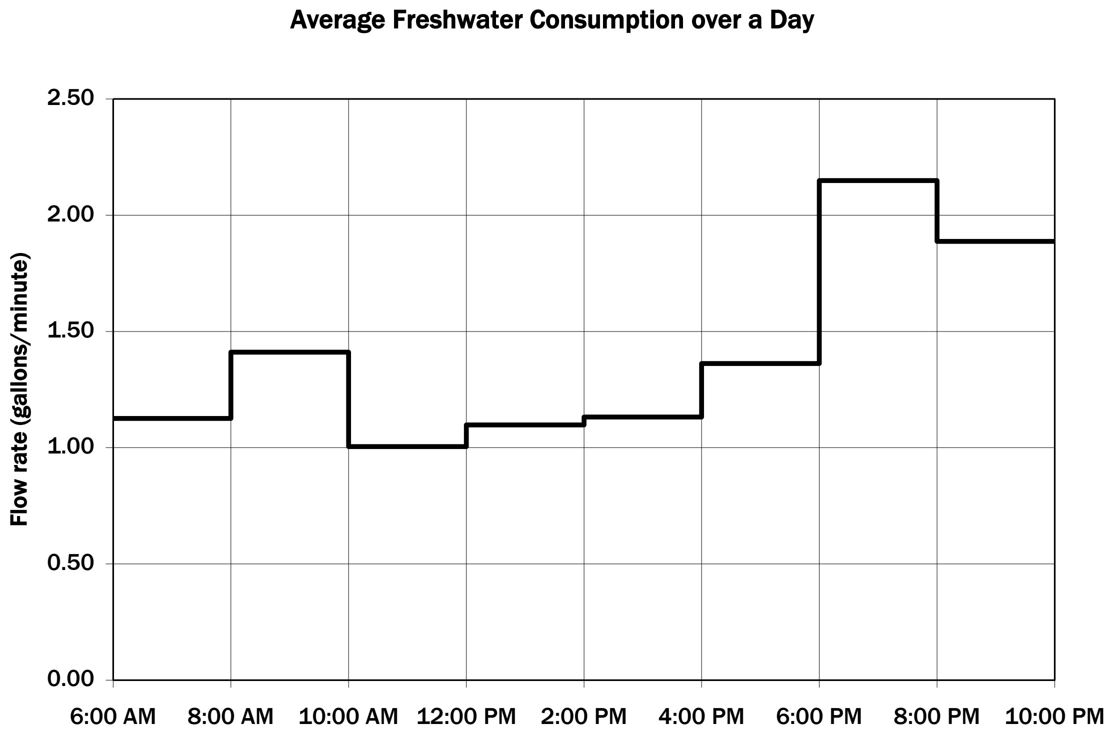

Figure 9: Average freshwater consumption rates over a day

Average per capita freshwater consumption followed the same pattern as total freshwater consumption. See the appendix for supporting data and charts.

Table 3 shows that the average rate of freshwater consumption is the highest in the last five years. This increase in consumption is most likely due to an increase in island population, however, since the average per capita freshwater consumption in 2006 is the lowest in the last five years. Averages in past years were taken over the same period as data collection this year: July 20th to August 10th; however, in some cases, historical data was incomplete and comparable statistics could not be calculated.

Table 3: Yearly average of freshwater consumption historical summary

	Freshwater Consumption	
Year	Average (gpm)	Average per capita (gpm)
2001	1.19	
2002	1.13	0.014
2003		
2004	1.06	
2005	1.19	0.015
2006	1.27	0.012

Recommendations

Although SML currently meets its freshwater needs with the well and the reverse osmosis unit when necessary, the reverse osmosis unit is costly to run and time-consuming to set up and shut down at the beginning and end of each season. Running the reverse osmosis unit fewer days in the season saves the cost of the additional energy required to power the machine. Furthermore, not running the unit during the season removes the cost of cleaning the membrane professionally. Thus, maintaining a low rate of freshwater consumption so as to use the well as long as possible is in the island's best interest.

SML has already implemented extensive freshwater conservation measures[14] that make it a role model for water efficiency. There are few additional measures that SML could implement, but some do exist.

SML staff should thoroughly check pipes and plumbing fixtures for leaks in the spring and fall, when vegetation is sparse. Repairing these leaks present a cost effective method for preventing unnecessary water use.

Low flow showerheads should also replace the current showerheads. 2.5 gpm showerheads can aerate the water such that the flow still feels like that from a conventional 4.5 gpm showerhead. These devices are fairly common; they should be inexpensive and easy to install.

Many appliances are available in low-flow or water-efficient models. In particular, front-loading washing machines use less water than their top-loading counterparts. There are three washing machines on the island, one of which is top-loading. When the top-loading machine reaches the end of its useful life, it should be replaced with a front-loading water-efficient model. Similarly, other appliances should be replaced with water-efficient models at the end of their useful lives. Note, however, that such candidates are limited because many of SML's appliances are already water-efficient.

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

Electrical System

System overview

Shoals Marine Laboratory is serviced by a simple electrical system distributing power throughout the island. Three diesel generators supply power at 480 V for the island: two 68 kW Caterpillar generators and one 30 kW Detroit generator, all located in the utility building. At the beginning and end of SML's operating season, the Detroit generator is in operation. In the middle of the season, one of the Caterpillar generators is used to support the greater population, while the other serves as a backup. An Enercon paralleling control system automatically switches between the Caterpillar generators. A manual switchover and shutdown is required to switch between the Caterpillar and Detroit generators.

480 V power is sent "up the hill" from the utility building to Kiggins Commons, where it is distributed to the southern half of the island. From Kiggins, 480 V power is distributed to the Tower and Bartels Hall. The Tower delivers 480 V power to the main salt water pump, Palmer-Kinne Laboratory, and the Kingsbury House. Transformers inside Kiggins, the Tower, Palmer-Kinne, and the Kingsbury House step down the power to 208/120 V for local building loads and for distribution to other buildings.

The utility building also sends 480 V power to the reverse osmosis unit, the only other 480 V load on the system besides the main salt water pump. A transformer inside the utility building steps down the power to 208/120 V, for building loads on the northern half of the island.

A schematic of the island's electrical system is attached.

Justin Eisfeller and Paul Krell, distribution engineers at Unitil Corporation, provided basic training on power systems.

Projects

Documentation

One-line drawings of the electrical system provided by Unitil Corporation were field-verified and corrected. Panels were labelled as on the one-line drawings to ease identification.

Background

Unitil Corporation possesses one-line drawings documenting Appledore Island's electrical system.

Problem overview

The one-line drawings were out of date and inaccurate. Up to date and accurate drawings are necessary for documentation of the electrical system.

Data collection

Field tours of the site were conducted during the internship period, during which panel and transformer nameplate ratings, connections between panels and transformers, and breaker ratings and labels were noted.

Results

Panel and transformer nameplate ratings, connections between panels and transformers, breaker ratings and labels were verified updated on the one-line drawings. Updates to the one-line drawings have been completed. The updates will be submitted to Unitil, allowing Unitil to update their CAD drawings.

Panels and transformers were named on the updated one-line drawings with the following information: Cornell University building code, building name, nameplate rating, and type of equipment. Panels and transformers were labelled with these same names to aid in identification.

An overview schematic of the electrical system was completed. It is attached to this report.

Recommendations

Although panel and transformer nameplate ratings, connections between panels and transformers, breaker ratings and labels were field-verified, wiring size and grounding state were not. Wiring sizes should be field-verified as well and checked to ensure that they are appropriately sized for the load they are carrying to minimize voltage drops. Much of the equipment was not grounded at the time of the field inspection, and, for safety reasons, should be grounded in the near future.

Energy consumption

Energy consumption was monitored to identify usage patterns across time and buildings. An energy audit of electrical devices was conducted.

Problem overview

SML's energy efficiency was unknown. Increasing energy efficiency decreases per unit energy costs.

Fluctuations in energy consumption over the course of a day were unknown. Data on daily loading cycles and peak consumption periods aid in loading management.

Data collection

Energy audit

Ed Mailloux from Unitil Corporation conducted an energy audit of SML on July 19 and 20. A comprehensive survey of lighting fixtures, water heaters, refrigerators and other appliances was conducted. In addition to nominal power consumption, actual lighting loads were measured in Dormitories 1, 2 and 3.

Usage patterns

From July 20, 2006 to August 10, 2006, the level of diesel in the day fuel tank was recorded every two hours from 6:00 am to 10:00 pm, tracking generator fuel consumption over time.

A power meter was installed on the Kiggins 480 V distribution panel to track building loads up the hill. Power entering that panel was recorded July 19-20. Power distributed to Kiggins building loads was recorded July 20-26. Power distributed to the Tower was recorded July 26-August 1. Power distributed to Bartels was recorded August 1-10.

A power meter was installed on the utility building 480 V main distribution panel to track overall island loads. The main breaker was monitored July 19-August 2.

Results

Energy audit

Mailloux's energy audit revealed that some of the existing lighting fixtures are not as energy efficient as newer models. Mailloux recommended replacing existing T-12 fluorescent lamps with T-8 lamps and replacing incandescent lamps with compact fluorescent. Based on these simple changes, he calculated an annual energy savings of 6,464 kWh, assuming that all lights are on 12 hours a day, 5 days a week, 12.5 weeks a year. At a cost of 19.6 ¢/kWh, the new fixtures would cost $1,266.99 less to run per year. The total cost of replacement would be $4,279.15, resulting in a simple payback period of 3.38 years.

Mailloux also analyzed non-lighting energy use, which includes an ice machine, refrigerators, a walk-in cooler and freezer, a dishwasher, a steam table, electric water heaters, an air compressor, and the salt water pump. Mailloux's analysis shows that there are no cost-effective replacements to install due to the limited length of operating hours. Most systems that increase energy efficiency through intelligent control save energy during non-summer months, when the island is not in operation. The baseline for energy savings begins at 2000 operating hours, but most of the island equipment operates less than 1000 hours a season.

Usage patterns

The average fuel consumption rate was 2.83 gallons/hour. Over the collection period July 20-August 10, fuel consumption steadily decreased (Figure 10). The downward trend is most likely due to the declining island population, since the per capita fuel consumption rate over the collection period remains relatively stable (Figure 11). Note that the two outliers in Figure 10 are not outliers in Figure 11; thus, they are probably the result of high island populations.

The average per capita fuel consumption rate was 0.028 gallons/hour/person.

Figure 10: Generator fuel consumption July 20-August 10

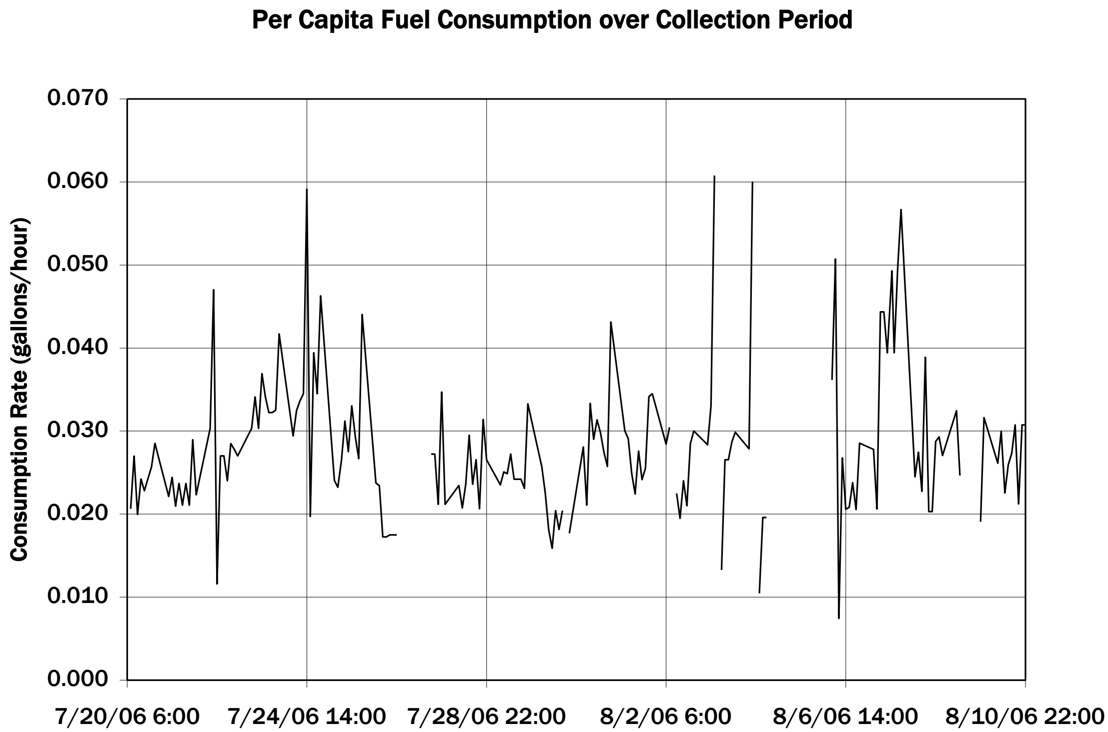

Figure 11: Per capita generator fuel consumption July 20-August 10

On average, fuel consumption rates increased sharply after 6:00 pm (Figure 12). This escalation is probably due to the increased used of lights close to and after sunset, since lighting comprises a significant portion of SML's electrical load.

Two additional maxima occur 6-8 am and 10 am-12 pm. These peaks correspond to meal times when the kitchen is preparing food and cleaning up, as well as break times when staff and students might be using electronic devices, such as laptops.

Minima 8-10 am and 2-6 pm correspond to class times when many students and faculty are in the field. Fuel consumption was lowest 10 pm-6 am (at an average of 2.58 gallons/hour), probably because of the lack of activity during that time.

These patterns are substantiated by the average electrical loads over the day on the Kiggins 480 V distribution panel (Figure 13). Note that the Tower and Bartels loads are relatively flat in Figure 13, whereas the Main power output is much more erratic, accounting for much of the extrema mentioned above. The difference between Main power output and the sum of the Tower and Bartels loads is the Kiggins 120 V distribution panel. This panel distributes power to Kiggins, the residence halls, Laighton, and Hamilton, further supporting the speculation that the maxima are due to mealtime and break time activities.

As would be expected based on generator fuel consumption, generator power output follows the same patterns (Figure 14).

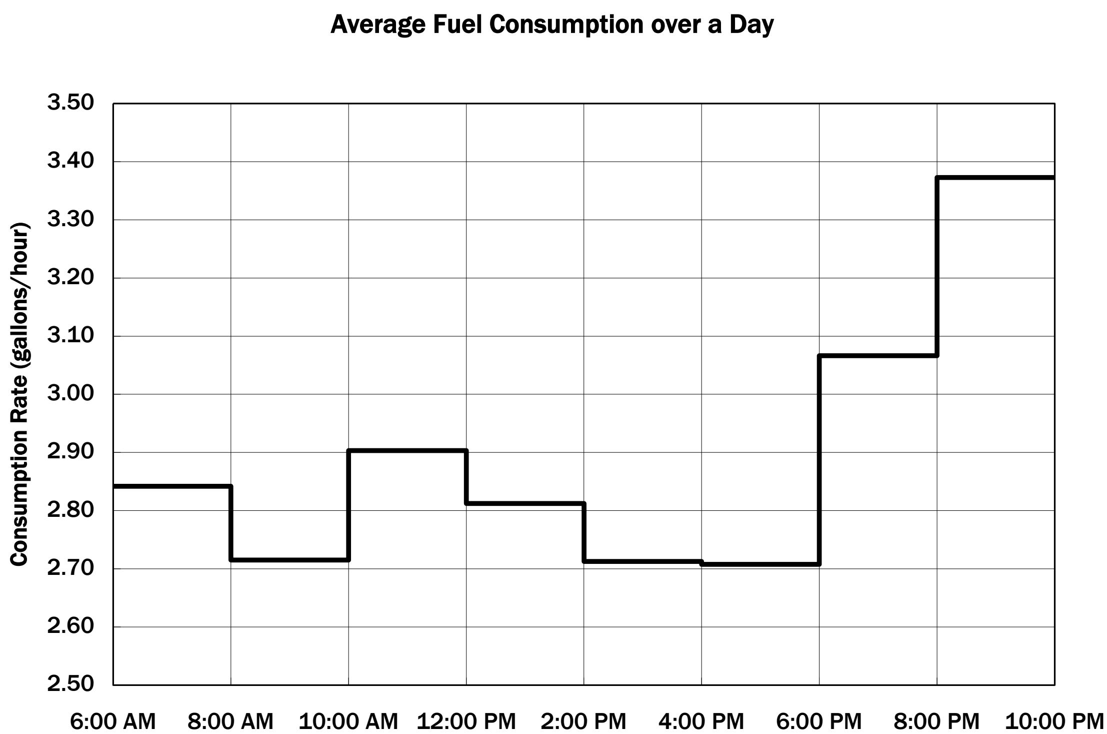

Figure 12: Average fuel consumption over a day

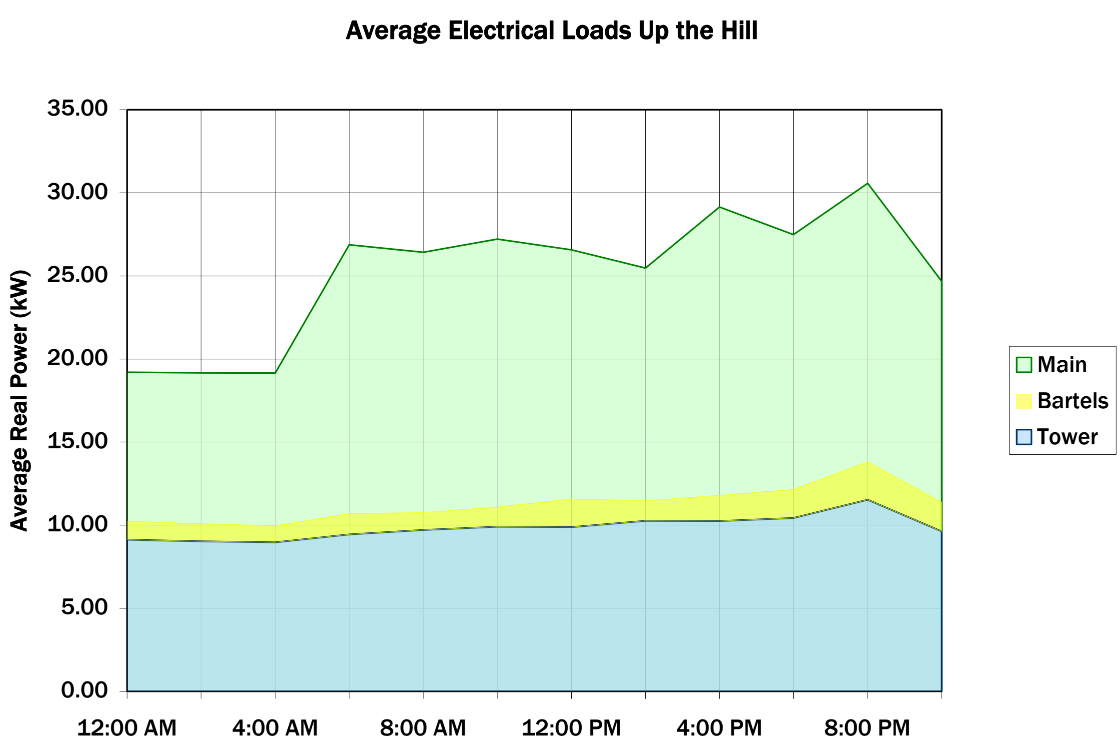

Figure 13: Average electrical loads on the Kiggins 480 V distribution panel.
Note that Bartels and Tower averages are stacked, while Main averages are not.

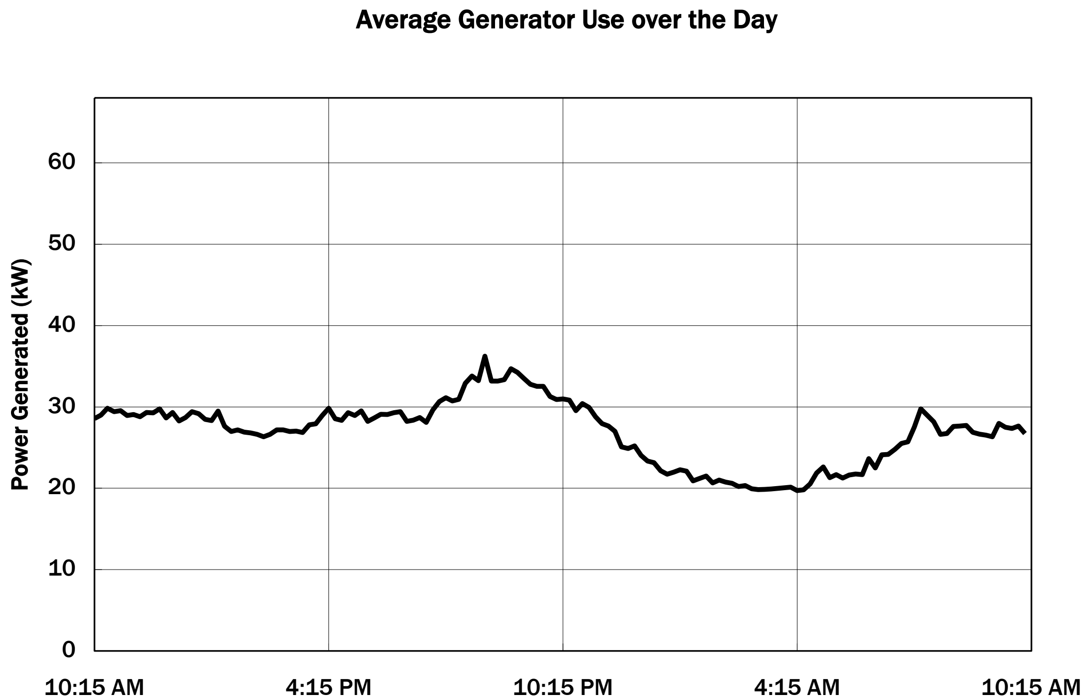

Figure 14: Average generator use over the day July 19-August 2

Average fuel consumption over the collection period this year is comparable to average fuel consumption over the same period in past years with a marked decrease in per capita fuel consumption this year (Table 4). This decrease may be a reflection of more energy efficient equipment (especially lighting), since many loads are fixed relative to population. However, incomplete historical data renders conclusions tentative.

Table 4: Yearly average fuel consumption historical summary

	Fuel Consumption	
Year	Average (gph)	Average per capita (gph)
2001	3.12	
2002	2.86	0.037
2003		
2004	2.83	
2005	3.11	0.041
2006	2.83	0.027

Recommendations

Energy audit

The shortest payback period, by far, is for replacing the incandescent lamps with compact fluorescent lamps. As a result of this favourable cost-benefit ratio, we recommend that incandescent lamps be replaced first, if capital time for lighting fixture is replacement is limited.

Usage patterns

Since the peak periods are not dramatic and are due to relatively inflexible causes, such as sunset and meals, we do not recommend any action to flatten demand. However, the usage patterns presented should be taken into consideration when adding significant loads to the system.

Power system quality

The electrical system was monitored at the utility building to determine the quality of the power supplied. Generator utilization was evaluated to determine power generation efficiency. Voltage readings were analyzed for voltage drops to examine the quality of the distribution system.

Background

Supply quality[15]

Many factors affect a power system's quality. Some common indicating measures include frequency regulation, voltage balance, current balance, harmonic current distortion, and voltage drops. Frequency regulation refers to how well the frequency of the power remains within 60 ±0.2 Hz. Fluctuation outside of those bounds may damage or decrease the useful lifespan of sensitive equipment, such as motors.

Voltage balance is the percent difference in voltage magnitudes between the three phases. A deviation greater than 2% is considered significant, especially close to the power source. Voltage imbalance is a result of uneven loads on the three phases, and therefore increases further downstream in the distribution system.

Current balance, likewise, is the percent difference in current magnitudes between the three phases. Although no acceptable range of values exists for current imbalance, it is useful to compare it with voltage balance, as the two should increase and decrease together.

Harmonic current distortion is a result of square wave loads on the sine wave power supply, thus distorting power supply waveforms. Excessive harmonic distortions can harm sensitive equipment. A common benchmark for public utility power systems is a total harmonic distortion (THD) of 5%.

Voltage drops are the voltage lost in the wiring distributing the power. They are a direct consequence of Ohm's Law, V=IR. Thus, the greater the resistance of the conductor or the current being forced through it, the greater the voltage drop. Note that the resistance of a wire is directly proportional to its length and inversely proportional to its diameter.[16] Significant voltage drops result in undervoltage at the power delivery point, potentially damaging sensitive equipment designed for a specific voltage.[17] Voltage drops are considered significant when they exceed 5% of the nameplate voltage.

Generator efficiency

Generator power output is composed of four measurements: real power, reactive power, apparent power, and the power factor.Real power is a function of resistance. Reactive power is a function of reactance. Apparent power is a function of impedance, and is thus the sum of real and reactive powers. The power factor is the ratio of real power to apparent power, and is thus a measure of the relative

[15] Krell, Paul, P.E. Personal interview. 10 August 2006.
[16] Eisfeller, Justin; Krell, Paul, P.E. 18 July 2006.
[17] Wikipedia contributors. "Voltage drop". Wikipedia, The Free Encyclopedia. 3 Jun 2006, 17:01 UTC. Wikimedia Foundation, Inc. Accessed on August 13, 2006 at http://en.wikipedia.org/w/index.php?title=Voltage_drop&oldid=56682609.

effect of inductors and capacitors which dissipate no energy but drop voltage and draw current.[18] The higher the power factor, the less voltage and current is lost to non-load bearing components.

The operating efficiency of a generator depends mainly on its design, age and capacity utilization. The Caterpillar generators run most efficiently at 70%-80% loads[19].

Wet-stacking is the accumulation of unburned fuel in the exhaust system, reducing fuel efficiency and shortening the useful lifespan of the generator. Wet-stacking occurs when the generator is run on low loads and therefore at operating temperatures too low to completely burn all the fuel. The accumulation of unburned fuel has the potential to foul fuel injectors, engine valves, and the exhaust system. Wet-stacking typically when the generator is run at 30%-40% of its capacity for extended periods of time.[20]

Problem overview

Supply quality

The quality of the power supply, as measured by frequency regulation, voltage and current imbalance, harmonic current distortion and voltage drops, was unknown. Low quality supply could damage sensitive equipment and shorten their lifespans.

Generator efficiency

Generator efficiency and the probability of wet-stacking in the generator were unknown. Operating the generators at suboptimal conditions is less fuel- and cost-effective than operating them at optimal conditions.

Data collection

Supply quality

A power meter was installed on the utility building 480 V main distribution panel to measure power quality in terms of frequency regulation, voltage and current imbalance, and harmonic current distortion. The main breaker was monitored July 19-August 2.

Ed Mailloux of Unitil Corporation conducted an energy audit of SML on July 19 and 20. While he conducted the energy audit, Mailloux also measured voltages at each of the panels.

Generator efficiency

The same power meter mentioned above tracked island-wide loads on the generator.

Results

Supply quality

Frequency regulation is a concern because the frequency often lower than the benchmark range. Table 5 shows that the average frequency is well within the benchmark range, but the extrema fall outside

[18] All About Electric Circuits. "True, Reactive, and Apparent power". All About Circuits. Vol. II, Ch. 11. Accessed on August 12, 2006 at http://www.allaboutcircuits.com/vol_2/chpt_11/2.html.
[19] Caterpillar, Inc. "Gen Set Performance Data [83Z05911]". 13 July 2006. Accessed on July 13, 2006 at http://tmiweb.cat.com/tmi/servlet/cat.edis.tmiweb.gui.TMIDirector?Action=buildtab&ref...
[20] Avtron Manufacturing, Inc. "Load Banks for Prevention of Wet-Stacking in Diesel Generator Sets". 15February 2003. Accessed on August 12, 2006 at http://www.avtron.com/pdf/wp-WetStacking.PDF

of that range. In particular, the minimum frequency exceeds the lower bound of the benchmark range significantly.

Note that frequency data is reported in terms of the minimum, average, and maximum frequency in each sample interval.

Table 5: Generator room 480 V main distribution panel Phase A frequency statistics July 19-August 2

	Date & time	Frequency (Hz)	Deviation from benchmark range (Hz)
Minimum	7/26/06 19:15	57.362	-2.638
Average		59.980	-0.020
Maximum	7/29/06 12:15	60.930	0.930

A closer analysis of the data shows that a significant proportion of the frequency samples falls below the benchmark range of 60 ±0.2 Hz (Table 6). Almost every minimum in the sample interval is low, and almost half the sample average are low.

Table 6: Proportion of generator room 480 V main distribution panel Phase A frequency samples exceeding acceptable bounds from July 19, 2006 to August 2, 2006

	Sample Proportion
Minima below	99.80%
Averages below	47.05%
Averages above	0.00%
Maxima above	4.17%

Voltage imbalance, on the other hand, does not affect SML to a significant extent (Table 7). The maximum voltage imbalance exceeded the benchmark value of 2%, but not significantly, and further analysis reveals that the benchmark threshold was only exceeded in 1.74% of the samples.

Table 7: Voltage imbalance across three phases of generator room 480 V main distribution panel from July 19, 2006 to August 2, 2006

	Date & time	Voltage imbalance	Deviation from benchmark range
Maximum	7/23/06 10:55	2.620%	0.620%
Average		0.962%	0.000%

For the most part, current imbalance follows voltage imbalance, as expected (Figure 15).

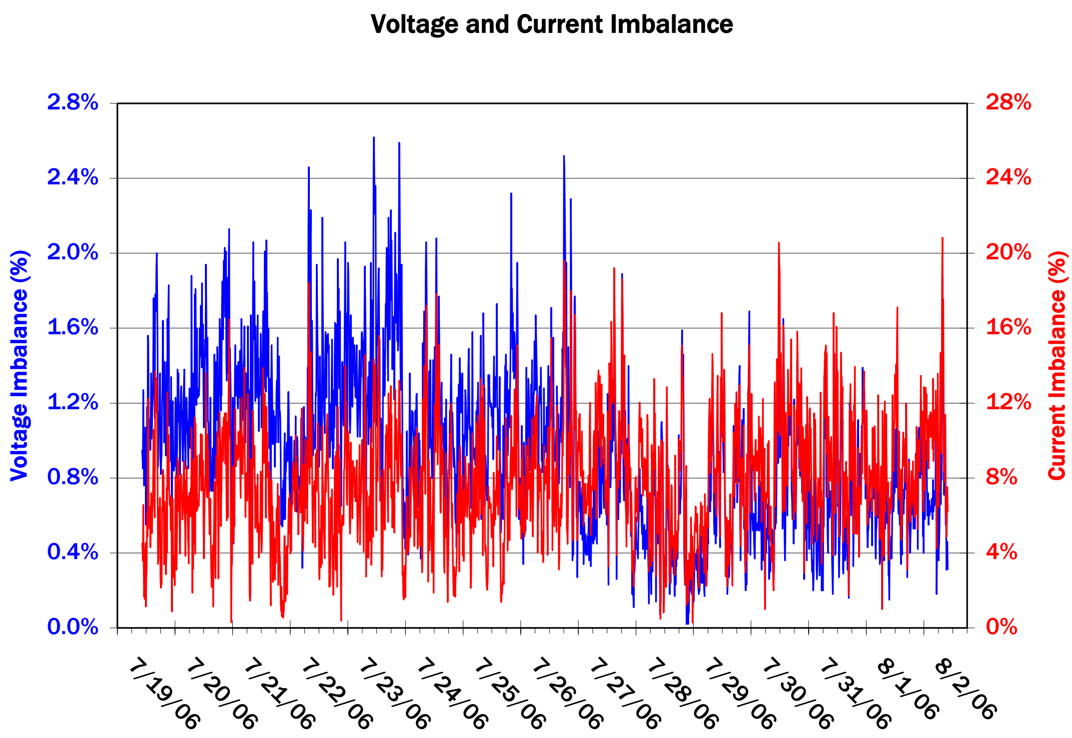

Figure 15[21]: Comparison of voltage and current imbalance of the generator room 480 V main distribution panel July 19-August 2

Phase A functions below the benchmark value of 5% for THD, for the most part, but Phases B and C experience significantly higher THD (Table 8).

Table 8: Generator room 480 V main distribution panel THD sample statistics for July 19-August 2

	Date & time	Maximum	Average	Samples exceeding benchmark
Phase A	7/31/06 3:15	5.68%	3.95%	1.39%
Phase B	7/21/06 3:05	7.57%	4.74%	34.34%
Phase C	7/31/06 3:15	7.56%	4.63%	30.42%

Voltage drops are not a significant problem for SML. Only one phase in one building experienced a voltage drop greater than the benchmark value of 5%. Laighton exceeded the benchmark value by 2.83% (Table 9).

Table 9: Voltage drops at the Laighton 208/120 V distribution panel on July 19

	Laighton	
	Voltage (V)	Drop
Phase A	119.5	-0.42%
Phase B	110.6	-7.83%
Phase C	118.0	-1.67%

[21] Krell, Paul, P.E. "Shoals Marine lab – generator measurements". Observations and spreadsheets of meter data on the Utility Building 480 V Main Distribution Panel. Email. 12 August 2006.

Generator efficiency

The maximum and average real power values are low, implying that the Caterpillar generators are underutilized (Table 10). As expected near the generator, the power factor is relatively high since the power has yet to encounter many inductors or capacitors.

Table 10: Generator room 480 V main distribution panel power statistics over the collection period

	Minimum		Maximum		Average	Std Dev
	Date & time	Value	Date & time	Value	Value	Value
Real Power (kW)	7/31/06 3:15	15.15	7/25/06 20:25	48.99	26.90	5.12
Reactive Power (kVAR)	7/20/06 5:35	16.88	7/29/06 13:25	28.83	20.91	1.72
Apparent Power (kVA)	7/31/06 3:15	23.17	7/25/06 20:25	56.86	34.23	4.79
True Power Factor	7/24/06 3:55	0.64	7/19/06 21:15	0.90	0.78	0.05

There is a high likelihood that wet-stacking is occurring in the Caterpillar generator. Figure 16 shows that he vast majority of the time, the generator operates at 30%-50% of full nameplate capacity 68 kW. The average load is 26.9kW, or 39.56% of capacity, placing the generator at the border of the "danger zone" for wet-stacking. Since the collection period coincided with the busiest period during the operating season, the danger of wet-stacking is probably understated by the data. The rest of the season likely experience even lower loads more frequently, increasing the probability of wet-stacking.

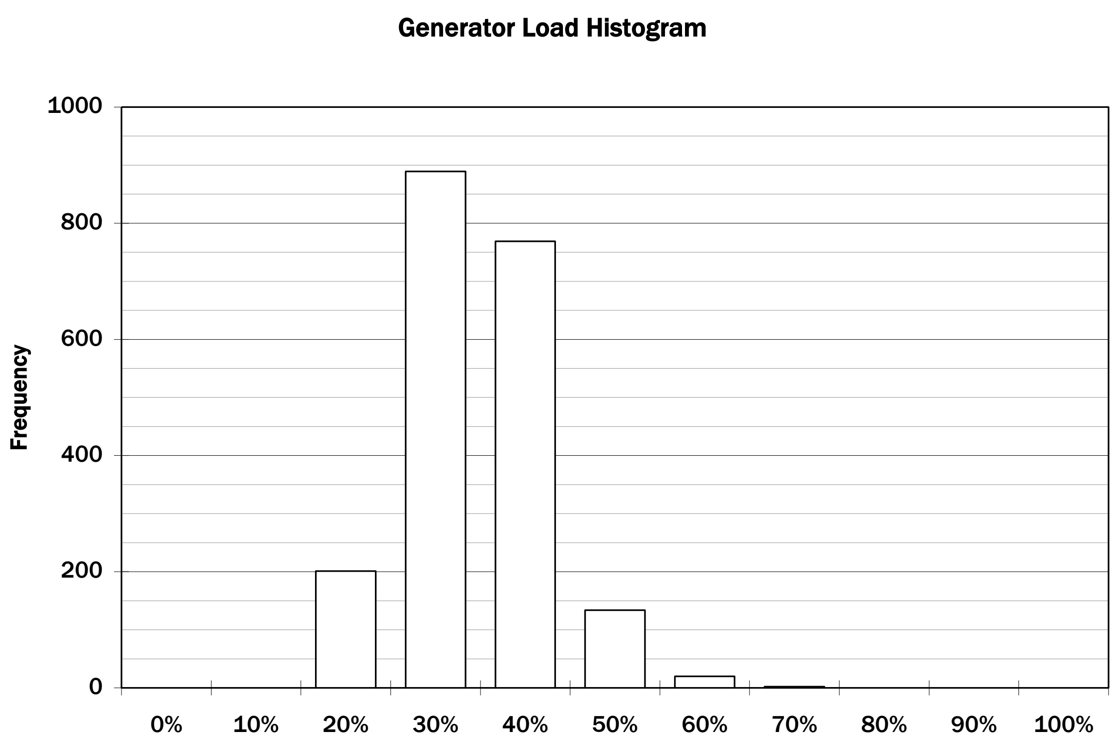

Figure 16: Histogram of generator load as a percentage of 68 kW nameplate capacity

A comparison between actual cost efficiency and theoretical cost efficiency based on manufacturer specifications shows that the generator is slightly less cost-efficient than expected (Figure 17). This discrepancy may be due to wet-stacking. Note that the generator is operating close to the segment of the curve where there is a sharp upswing in cost inefficiency because of its consistently low loads.

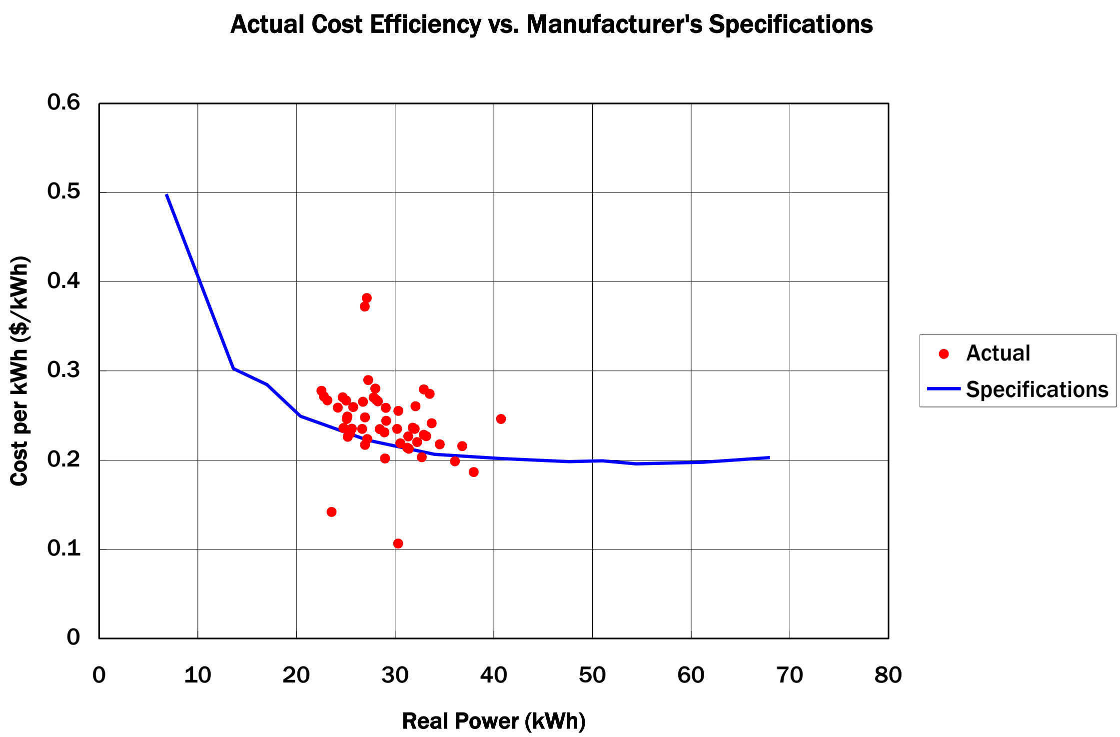

Figure 17: Comparison between actual cost efficiency from July 20-26 and fuel efficiency based on manufacturer-provided specifications
Based on this season's diesel price of $2.42/gallon

Recommendations

Supply quality

Overall, the quality of power generation appears to be relatively healthy. Therefore, measure to increase quality are probably not necessary. However, sensitive equipment and 3-phase equipment, such as the reverse osmosis unit and the main salt water pump, should be monitored for adverse effects. Should they evince adverse effects, power conditioners could be purchased to protect them.

The voltage drop between Kiggins and Laighton should be further examined. The presence of a significant voltage drop should be verified, and possible causes for drop, including undersized wiring, should be investigated.

Generator efficiency

Since the data show that wet-stacking is probably occurring, the Caterpillar generators should be tested for physical evidence of wet-stacking.

If signs of wet-stacking are found, then there are several options to reverse the effect and prevent future occurrences. Applying an increase load over time until the accumulated fuel is burned away and system capacity is reached can usually reverse wet-stacking. The load can be increased in two ways: by using a load bank, which places an artificial load on the generator, and by increasing the building load. Increasing the load to optimal conditions using either means can prevent future occurrences of wet-stacking; however, these measures will also increase total fuel consumption.

SML could purchase a new generator better sized for its needs. Loads never exceeded 50kW during the data collection period, and the average load was approximately 25kW. A smaller generator, in conjunction with load levelling measures to decrease peak demands, may be a better size to prevent wet-stacking. However, the purchase of a new generator is a large capital investment that may not be affordable for SML.

The smaller 30 kW Detroit generator currently owned by SML could be rebuilt to allow it to be used with a paralleling switch controller which would automatically switch between the 30 kW Detroit and the 68 kW Caterpillars. Thus, loads below 30 kW could be placed on the 30 kW Detroit instead of the 68 kW Caterpillar, reducing the possibility of wet-stacking and fuel inefficiency in the 68 kW Caterpillar. This recommendation is very applicable to SML because for most of the day, the load on the generators is under 30 kW, rising above that threshold only during the peak evening hours (Figure 18).

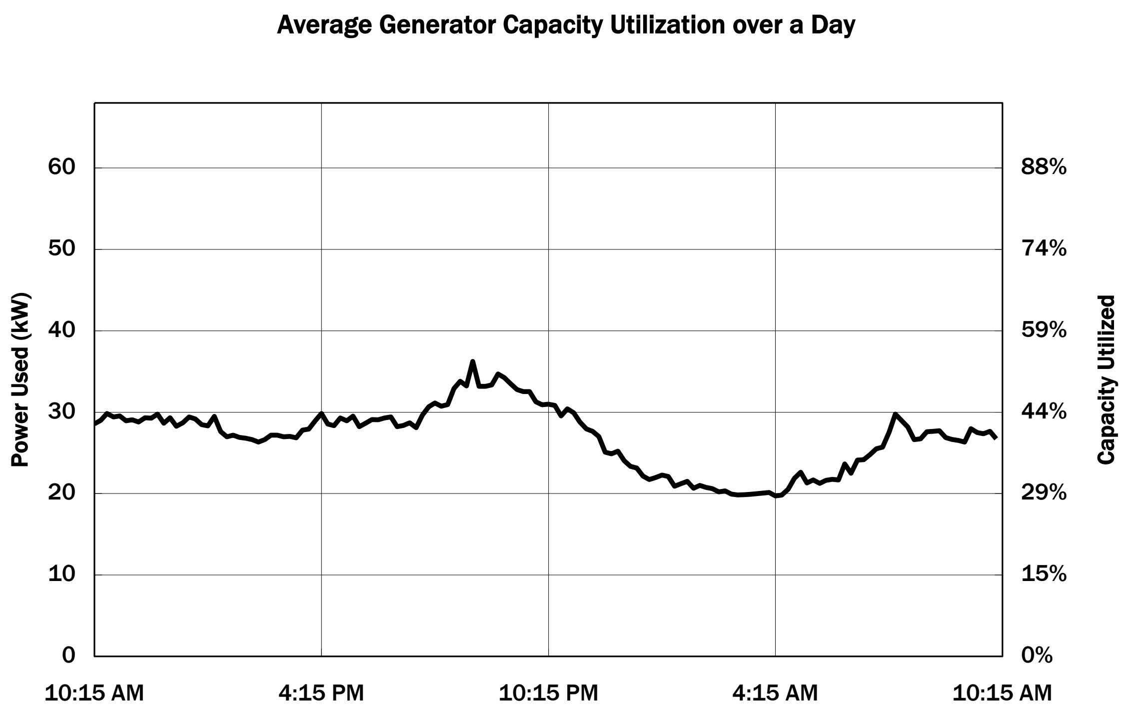

Figure 18: Average generator capacity utilization over a day from July 19-August 2

Alternative energy sources, including renewable sources such as wind and solar, could reduce the island's load on the generators to less than 30 kW, allowing the 30 kW Detroit to be used full-time. The largest generators would thus only be used when the reverse osmosis unit is in use. See "Solar Panel Feasibility" in this report for a more detailed examination of this recommendation.

Solar panel feasibility

The feasibility, requirements, and options to utilize a donation of solar panels from Cornell University was explored.

Background[22,23]

As technology improves and the cost of fuel rises, solar energy has gradually become a more appealing alternative. Multiple photovoltaic(PV) arrays, forming a solar panel, produce direct current(DC) electricity from sunlight using the photoelectric effect and a semiconductor, usually silicon. This electricity is then converted to alternating current(AC) using a power inverter in order to satisfy industrial and residential needs. Shoals Marine Lab hopes to utilize this technology in order to reduce diesel consumption.

Shoals Marine Lab(SML) produces and distributes all of its own power using three diesel generators. During the summer months the island is powered by one of two 68 kW generators and during non peak months, the 30 kW Detroit generator is used. When the reverse osmosis machine and the air compressor are not in use, the island requires approximately 30 kW of power. Since the generator becomes is less efficient when operating at this low load, SML could benefit from using the 30 kW generator more often. Thus, SML is hoping to employ additional energy sources in order to render the 65kW generators unnecessary. One possibility is to utilize solar energy supplied by solar panels donated by Cornell University. As of now, the exact wattage of the donated solar panels is unknown, however most likely it will be between 7 and 8 kW.

Although a solar panel may be rated to produce a set amount of power, rarely will the user actually be able to utilize the entire amount. Power will be lost in the wiring of the system and the conversion from DC to AC power. Cloudy weather or shade from trees and buildings can also hinder the panels' capabilities. An accumulation of snow, dirt, or in the case of Appledore Island, gull guano will further reduce power production. Finally, as the panels age, their efficiency gradually declines. Although the donated cells may have a nameplate rating of 7 or 8kW, in reality SML may only be able to utilize less than 1.5 kW of that power. Up to 30% of the power output will be lost in DC to AC conversion and in the battery charging process. Furthermore, the panel will only produce power for 6 out of 24 hours during June and July, however the buildings need power for all 24 hours per day. Although the exact rating of the panels is still unknown, SML can expect to receive between 1.225kW and 1.4kW of power.

Overall, solar panels require very little maintenance and have proven to be quite durable. Since there are no moving parts, repair needs should be limited, although seasonal inspections might be necessary to check efficiency. The companion equipment is more prone to break down, but even so the operation and maintenance costs should be minimal. The lifespan of a solar panel usually exceeds 25 years, and are known to last up to 50 years. The efficiency does degrade over time, but not significantly. The panels are designed to withstand the snow and freezing temperatures associated with New England winters. The panels, themselves, will not be negatively affected by the salty and humid atmosphere of Appledore Island, but the additional hardware and wiring will be prone to corrosion if the correct materials are not used. Due to the large number of gulls on the island the panels should be mounted in an accessible location so that frequent cleaning is possible as gull guano will lessen the panels' output.

The effectiveness of a solar panel is obviously closely tied to the amount of sun to which the panel is exposed. Since SML is a seasonal facility, the panels will only be in operation during the summer months when the sun's irradiance is greatest. During the summer hours, the panels will be the most efficient if installed at 0° (horizontal to the ground). During June and July they will get 6.1 hours of maximum output at this angle during the day. This length of time gradually decreases the angle becomes steeper. If the panels were ground mounted, it would be simple to change their angle to receive maximum output throughout the entire summer.

[22] A Performance Calculator for Grid-Connected PV Systems. National Renewable Energy Lab. 5 August 2006. < http://rredc.nrel.gov/solar/calculators/PVWATTS/ >.
[23] Krich, Abigail. Phone Interview. 2 August 2006.

Equipment and installation[24,25]

In addition to the PV panels, themselves, a power inverter, a battery pack, support trays and appropriate fastenings will be needed. The equipment Cornell is receiving is already 13 or 14 years old, and while age has a limited effect on the panels, the accompanying equipment is past its prime, so SML will need to purchase it separately. Finally, a charge controller should be installed to regulate the batteries' charge level. As batteries should not be overcharged or over drained. Either case decreases their lifespan. Although the cost of this equipment may be significant, when viewed in terms of the overall goal of sustainability and the rising price of diesel, the equipment appears to be a worthwhile investment. Currently the power produced by the generators costs approximately $.20 - $.25/kW-hr depending on the load. Thus the panels will save SML between $5 and $8 per day.

Between the 2006 and 2007 season, SML will be installing a wind turbine on the island in order to power the equipment used by AIRMAP. Seacoast Consulting Engineers have specified the OutBack VFX3648, 3600W inverter to be used in conjunction with the wind turbine. This inverter is considered durable enough to withstand the harsh climate on the island, and also offers a unique feature in that it can also back charge the batteries. These inverters also have a high surge capability, making it possible to start up large motors such as washing machines and pumps. A similar product would be recommended for the solar panels, however in order to manage the large power input, two inverters should be connected in parallel. The wattage of the inverter must always be greater than the total AC load in order to be sure that the load always ahs power. It is best to use a sine wave inverter as it can power the largest variety of load types and is unlikely to cause damage to equipment. SML can expect to spend approximately $2,000 - $2,500 per inverter. A more sophisticated inverter will more efficiently convert the power and will also reduce the harmonic distortion caused by the PV panels.

Seacoast also selected a GNB Absolyte IIP battery for the wind turbine project. This is a lead-acid, deep cycle battery able to discharge small amounts of energy over a long period of time. The capacity and number of necessary battery cells will vary depending on how the solar panels are being used and how much energy might need to be stored. The purchase of the battery strings will be the most expensive part of this project and may cost anywhere between $15,000 and $60,000. The batteries come in various different voltages (typical voltages include 12V, 6V, 2V) and different amp-hour capacities. The size, weight and cost of the systems must be balanced with the capacity to make sure that the most practical model is purchase. Exact sizing and costs for the battery packs is included in Appendix A.

The fastenings and supports needed for the installation of the panels will depend on where and how these panels are mounted. Cornell is receiving a rotating Shadowband pyranometer for measuring the sun's irradiance and a pulse initiating energy meter for monitoring electrical consumption, and may be willing to donate this pyranometer to SML if desired. This equipment might be useful in monitoring the performance of the panels and in selecting, sizing and mounting new panels in the future. Finally, disconnect switches will be needed in order to safe guard the equipment should a fault occur in the wiring.

The panels can either be mounted on the roof or on poles coming from the ground. An electrician will be needed to install the panels and a contractor will be needed to approve the method/location of installation. Thirty panels at 50.5" by 70.5" provide 6kW of power, thus 35-40 panels will be needed to provide 7-8kW of panel. The entire surface area will come to approximately 168' by 235', or almost 40,000 square feet. Although the panels can be mounted separately, each site would require its own wiring, power inverter and battery pack.

[24] Consavage, Lee. Email and Personal Interview. 3 August 2006.
[25] Outback Power Systems. 5 August 2006. < http://www.outbackpower.com/index.html >

Applications

SML could use these panels in multiple ways depending on how much power these panels can actually produce and where they are mounted. The panels can be carefully connected to the grid, or used as the sole power source for a building or series of buildings. Connecting solar panels to a small grid can contribute to harmonic distortion in the system. These harmonics distort the sine wave, causing large drops in voltage and thereby damages equipment. However, a sophisticated inverter and connecting the panels near the generators will minimize harmonic distortion. Connecting the panels to the grid, thus eliminating the need for batteries, will also significantly increase the usable power, as the battery charging process is very inefficient. Connecting the panels to the grid would eliminate the need for batteries, thus lowering the cost of this project significantly.

Alternatively, the panels can be used in a variety of ways as the sole provider for a load. The panels could be used to power a computer charging station for the students and staff at SML. When plugged into a normal power outlet, laptops contribute greatly to the harmonic distortion and decrease the efficiency of the island's electric system. A typical laptop generates a 30W load to charge its battery when turned off. At any one time approximately 20laptops could be expected to be charging requiring 750 W or .75 kW of power.

Based on the energy audit conducted by Ed Mailloux of Unitil Corporation, Dormitories 1, 2, and 3 each require approximately 2kW at maximum power. This is only if all the lights including desk lamps and water heaters are on simultaneously. On average, each building would require 1 kW of constant power. If a timer were installed on the water heaters so they only heated water once in the morning and once in the evening, the load could be reduced even further. In this case, two of the three dorm buildings could be powered by the panels. Since Dorm 2 and 3 are located close to each other, and could share a centrally located battery pack, this would be the more economically feasible option.

The solar panels could be used to power the proposed composting toilet outbuildings. These outhouses would require little power, needing electricity only for the vent fan, liquid removal pump, and lighting. Depending on the unit size and number or units, each outhouse would require approximately 1 kW – 1.5 kW. However, the problem with a decentralized use is that a separate battery pack would be necessary at each site. Furthermore, if a problem did occur and the units lost power, the vent would stop and the compost would immediately begin to smell. For this use, it might be best to also purchase a small backup generator in case the solar panels fail.

Finally, AIRMAP and NOAA have arranged to purchase a wind turbine and battery back to provide year-round power for their equipment in the tower. It might be possible to tie these PV panels into the battery pack and then could be used to provide power for the Palmer-Kinne Laboratory. PK currently draws 4.2 kW of power. Most likely, the solar panels would not be able to completely support this load.

Documentation of Island Systems

Background

The freshwater, salt water, and wastewater systems are not documented or mapped. The electrical system is documented by one-line drawings which are out of date (see Electrical System – Documentation above for a report on this project). Like the other island infrastructural systems, the electrical system is not mapped. System level drawings for each of the island systems need to be developed in order to support future studies and upgrades.

Projects

Mapping

One of the beginning goals of the engineering internship at Shoals Marine Laboratory was to create an all inclusive Geographic Information System (GIS) map of Appledore Island. Prior to the internship's start, a GIS course at SML began this process by creating a base map of the island. This basemap includes an aerial photograph with paths, roads, buildings, topography, tidal information, pictures, important features, mooring locations, other marine data, and various information on it. Part of the internship's scope was to expand this basemap to include mapping of the electrical, wastewater, freshwater, and saltwater systems on the island. Each of these systems could be on an individual layer in the GIS program and color coded to match the organizational system devised and implemented by the interns. The system is outlined below.

Table 11: GIS map layer standards

Layer Name	Layer Color
Electrical systems	Red
Wastewater system	Brown
Salt water system	Green
Freshwater system	Blue

Table 12: Summary of work

GPS	Tracks of all piping and waypoints for major features
Photographs	Hyperlink photos of major features to correspond with matching waypoints
Other	Any relevant CAD drawings, building or system schematics be hyperlinked to appropriate system/waypoint

Sample GPS readings were taken and successfully added to the GIS basemap in order to confirm that work can be done in the future to create the layers that are requested.

At this time, no further mapping has occurred on the island. This project should be completed during the fall or spring when the island has less vegetation and the pupes can be followed with ease. Once GPS coordinates are mapped for each system, they can easily be loaded into GIS and the basemap can be expanded.

Line Labeling

A color coded system has been implemented for Shoals Marine Lab to indicate the utility of each pipe on the island. Multi-colored electrical tape was used to mark the piping of the island wherever it was visible and useful to mark. Specifically as it enters and exits the various buildings. Ross Hansen's experience with the island's systems and careful observation were used to label each of the pipes. This should provide easier identification for future interns as well as staff on the island. It will especially aid the training of the island engineers at the beginning of each season. Below is a chart explaining the color coding system that was implemented.

Table 13: Line labelling standards

Line Contents	Color Code
Treated wastewater	Brown
Untreated wastewater	Brown with black bands
Fresh water	Blue
Saltwater supply	Green
Saltwater discharge	Green with black bands
Electrical	Red
Communication	Orange

Phase two of this coding process will take place during the GPS mapping of the piping in the fall or early winter. With less vegetation, the pipes can be labeled in previously inaccessible areas. This will prove especially handy when maintenance is required anywhere along the system.

Future Projects

Throughout this 4 week inaugural engineering internship at SML, a great deal of work and data collection was done on many of the island's main systems. Below is a list of possible follow up assignments for future interns as well as new projects that were not looked into this summer.

Biodiesel

Research the possibility of using Biodiesel for the generators and trucks. It was brought to the intern's attention late in the program that Proulx Oil of Portsmouth, NH may be interested in working with the island on this. They are already working with UNH on alternative energy projects.

Wind Power

An evaluation of wind turbine power efficiency as well as the possibility of using wind power as a future alternative to the generators.

Solar Power

A more in depth look into solar panel technology and the feasibility of using this as an alternative energy source for the entire island. If the solar panels that were researched this summer have been put in place, then an evaluation of their efficiency, placement, and other factors should be performed.

Other Alternative Energy

A look into other alternative energy sources for the island in addition to solar and wind. The possibilities of tidal power and other such innovative ideas could be researched.

Greywater Treatment

Further research into greywater treatment systems including consultations by a hydrologist and a soil scientist. The possibility of using new and innovative technology should be investigated. New technologies could create an educational opportunity for classes in sustainability as well as a point of interest for all.

Freshwater System

The freshwater system on the island would be an interesting project for future investigation. The condition of the cistern, well, and storage tanks can be evaluated as well as the quality of the water. Along with this idea, rain water collection systems could be researched as a supplement to well and r/o water. The overall efficiency of the fresh water system could also be analyzed as well a the performance of the r/o system when in operation.

Composting Toilets

If composting toilets have yet to be installed on the island, that project could be continued by future interns. Placement of the outhouse structures as well as their design could be determined by the interns with the help of architects and civil/environmental engineers.

Conclusion

The focus of this year's internship at Shoals Marine Lab was sustainable engineering. While performing day-to-day operations it is easy to lose sight of the need to minimize SML's toll on the environment. SML future planning rarely takes precedence over the daily maintenance needed to keep the island running smoothly. When sustainability enters the discussion we tend to judge new technologies solely based on cost. We compare the cost of implementing an entirely new system against the cost of maintaining or modifying the current system. This comparison rarely comes out in favor of new technology. There are very few instances where the cost of a new system will save so much money that it will pay for itself in a short time period, this usually takes several seasons to do. However, sustainability requires examining the bigger picture: bigger than money and beyond common practice.

Sustainability does not necessarily mean paying more for equivalent output, either. We have to look to the future to see which technology will still be practical. For instance, the generators running on diesel today will not be as practical as a wind turbine when the price of diesel gets too high for SML's budget.

SML needs to consider factors other than cost when weighing the options as well. The island engineering team spends long days running from problem to problem trying to do repairs. SML has a history of staying within budget by cutting corners and using temporary solutions to the island's problems, which results in an increased number of necessary repairs. Overhauling any system for a more sustainable alternative will be costly, but it is time for Shoals Marine Lab to utilize more grant opportunities. SML may even have to take out a loan to make large changes, but it is more effective and efficient to do it right the first time and save countless man-hours on repairs.

Sustainability should not be viewed as a luxury, but rather a means to make a statement and get jobs done. As a scientific and educational institution, sustainability should be high on SML's list of priorities, yet it is often overshadowed by more immediate concerns. Sustainable wastewater treatment does not include throwing money into a new system that only accomplishes what is already getting done. The current system is failing and causing unacceptable environmental damage. While a new system will cost money, it will run smoothly and reliably without harming the environment. Many sustainable technologies are available in low-tech variations, which often work better than their high-tech counterparts. For example, SML is investigating a wind turbine that has only three moving parts and will require less operations and

maintenance than the diesel generators.

A large portion of the sustainable technology movement is dedicated to going back to basics, making new sustainable technology more reliable than older technology. Sustainable engineering is not just a method of purchasing environmental friendliness. Sustainable technology is educational, efficient, reliable, modern, and usually cost effective in the long-run as well. It should be viewed as a realistic option to making SML operate smoothly.

The engineering interns have the unique opportunity to come to Appledore and study the island systems without being distracted by the day-to-day maintenance and budgetary concerns. This allows the interns to make recommendations on the island systems that may seem unrealistic, but in actuality are just different. Shoals Marine Lab

has announced that it wants to become a sustainable campus and the island will have to implement innovative technologies to do so. The pay off might not be monetary, or it might not be felt immediately, but it will be there.