SHOALS MARINE LABORATORY

SUSTAINABLE ENGINEERING INTERNSHIP

FINAL REPORT 2008

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Introduction

The Sustainable Engineering Internship at Shoals Marine Laboratory (SML) began in 2006 with the goal of evaluating island systems and collecting more detailed data. The ultimate purpose of the program is to make recommendations for SML to improve the efficiency and decrease the environmental impact of the Appledore community.

Building off of the incredible amount of information gathered over the last two years, the five 2008 interns spent four weeks collecting data and conducting research to further improve island operations. This year, the focus was on eliminating blackwater, researching a suitable method to treat gray water onsite, assessing the trash taken off the island, simplifying daily data collection, evaluating chlorine fluctuations in freshwater, and proposing ways to incorporate more alternative energy. Additionally, the interns conducted a survey of the current systems on White Island to propose the best ways for the Tern Restoration Project to spend its grant money.

These projects were completed with oversight from Ross Hansen, Operations Manager, as well as extensive assistance from the rest of the SML staff and visiting industry professionals.

The following report follows each project through its completion, detailing methods of data collection and presenting results and recommendations. Although the interns were significantly limited by the given time frame, the information presented here will hopefully guide Shoals Marine Laboratory in the direction of greater sustainability and efficiency.

White Island

System Overview

White Island is currently inhabited by members of the Tern Restoration team. The Tern Restoration Project began in 1997 in response to declining populations of the common tern along the Atlantic coast and offshore islands. The terns live mainly on adjacent Seavey Island, while the biologists and researchers live on White Island. The team lives on the island from the end of April until mid-September. The regular population is four people, but that population sometimes increases to eight people during short periods during the summer. As of 2006, the Tern Restoration Project is managed by SML.

White island was once inhabited by three Coast Guardsmen, who operated the lighthouse that still stands on the island. While the Coast Guardsmen lived on the island, the buildings had functioning plumbing as well as electricity, which came from diesel generators. In 1986, the light was automated, and there was no longer any need for operators to live on the island. From 1986 until 1997, the structures that once housed the Coast Guardsmen were abandoned.

Problem Overview

The facilities on White Island have fallen into disrepair. The roof of the generator room has large leaks, rendering the room unusable. The plumbing no longer works, so the Tern Restoration team has no running water. The electrical wiring is also non-functional.

The Tern Restoration team is living in less than ideal conditions. All of the electricity is provided by photovoltaic (PV) panels. The panels charge automotive batteries, which are stored inside, posing a health risk to the residents. Nearly all of the energy generated is used to power computers and other research equipment. The two indoor light fixtures in the house do not provide enough light, so flashlights are the primary source of light. The electric oven is rarely used because of the power it requires.

As stated earlier, the plumbing is not functional, so all water must be transported in buckets or jugs. Drinking water is transported from the mainland. Water used for cooking and teeth brushing comes from Appledore Island. Rainwater is collected from the gutter of the house roof, stored in a cistern in the basement, and used for showers and dishwashing.

There are two SunMar composting toilets on the island, located in an outbuilding. They are designed to accommodate two people each, so the occasional increased population overloads them. The toilets usually fill up and must be dumped before the composting process is complete.

Objective

It is of interest to SML to document the power, fresh water and wastewater systems that currently exist on White Island. It is also of interest to determine the appropriate levels of sustainable power, fresh water and waste systems to support both the season-long residents and the extra visitors who occasional inhabit the island. The objective is to provide a concept plan for an integrated system to improve the overall living conditions for the island inhabitants with a $4,500 initial budget designated for solar technology.

Data Collection/Methodology

On July 11th, 2008 the engineering interns visited White Island to speak to the residents and tour the facilities. Along with visual observations, the interns obtained information about the current state of the systems from Dan Hayward, the Tern Restoration Project Coordinator. Dan Hayward also provided insight into the changes that the residents would like to see.

Results/Discussion

The facilities were found, as expected, to need much improvement. Each system is detailed and discussed below.

Power

All of the power is currently generated by photovoltaic panels. There are several panels, with a total rating of 120 W. The power is stored in two sets of automotive batteries, each made up of four 6 V batteries. The brand of the first set is Trojan, and the brand of the other is Napa. A 12 A, 3 stage charge controller limits the current added or drawn from the batteries, preventing the batteries from being overcharged or drained. Each set of batteries is also hooked to an inverter (rated at 600-750 W) so that AC current can be delivered to the loads. The power is mainly used for laptops, wireless internet and radios. It also lights the two bulbs in the house, which are ineffective and only used occasionally, as well as the oven, which is rarely used.

Dan and Melissa Hayward installed additional photovoltaic panels upstairs. These are used to provide light for the Hayward’s room, which is quite helpful when taking care of their 7-month-old baby.

Table 1 details all of the key components of the power system. The items powered by the PV panels are further detailed in Tables 2 and 3. All of the power used is AC. The average daily energy demand is approximately 3.12 kWh.

Table 1: Key Components of White Island Power System

	Item	Qty	Rating	Installed	Manufacture	Comments
Downstairs, used for main equipment	PV panel	1	120 W			
	Charge controller	1	12 A, 3 stage		Trace Engineering	
	Batteries	4	6 V	~2000	Trojan, lead acid	At their end
	Inverter	1	750 W		Die Hard	
	Batteries	4	6 V	~2007	NAPA	
	Inverter	1	600 W		Portawattz	
Upstairs, used for Dan and Melissa Hayward	PV panel	1	50 W			
	Inverter	1	350 W			
	Batteries	1	12 W			
	Charge Controller	1			Solar Pro CC20	
Items powered by downstairs PV	Laptops	4				
	Wireless internet	1				
	Radio	1				
	Light	1	14 W			
	Stove/Oven	1	Uses 400 W continuously while on			Mostly powered by propane; has some electricity requirement
Items powered by propane	Refrigerator	1		2007	Crystal Cold	
	Hot camp shower	1			Zodi	
	Stove/Oven	1				*see above

*Cells left blank indicate unknown information

Table 2: White Island Appliances and Power Demand

Description	**Load (kW)**	**Hours of use per day (h/d)**	**Days of use per week (d/wk)**

Desktop	0.060	24.00	7
Oven	0.400	0.75	7
Stereo	0.050	5.00	7
Service Lights	0.060	5.00	7
Laptops	0.040	12.00	7
AC Pump	1.200	0.17	7
Microwave	0.900	0.17	7

Table 3: White Island Energy Demand

	Daily average	*Annual*
DC energy demand KWh (DC)	0.000	0.0
AC energy demand kWh (AC)	3.120	477.4
AC peak load kW (AC)		2.710

The Tern Restoration Project received a grant from the NH Fish and Game Department's Non-game and Endangered Wildlife Program for the purpose of installing more solar systems on White Island. The grant is worth approximately $4,500. It is unclear what the money can be used for; it is assumed that it can be applied to anything related to solar energy, including PV panels, solar hot water heating, batteries, inverters, and charge controllers.

The lead-acid batteries are currently located in the same room as the computers. These batteries leak harmful gases and pose a threat to the residents of the house. According to Dan Hayward, they are stored inside to minimize losses. However, if the batteries were stored outside and the electricity inverted to AC in the same location, there would be minimal losses in the wires running the AC to the house. A vented cabinet could be installed in the generator room to store the batteries, as well as the charge controller and inverters. The cabinet should be made waterproof to protect the batteries from leaks in the roof. Alternate battery storage locations include the walkway from the house to the generator room and the room that currently serves as a guest room. From the battery storage location, standard electrical wiring should be run through the walls. Outlets and lights do not need to be installed everywhere, but some rooms should have access. For instance, it would be helpful to have outlets in the computer room. Ultimately, it is up to the Tern Restoration team because they know best what is needed. As mentioned earlier, there would be minimal line losses with this setup.

The current battery bank stores 12 volts. Battery banks of lower voltages have more line losses than those of higher voltages (assuming the same power for both banks).[1] Therefore, a larger battery bank would further reduce the power loss in the lines. According to Dorthy Wolfe, cofounder of GroSolar, a 48-volt battery bank is the best option. New batteries should be selected and configured so as to correspond with the daily energy demand. The energy capacity of the battery bank should be roughly three to

[1] Email correspondence with Lee Consavage, see digital appendix

four times the anticipated daily energy consumption, which is currently approximately 3kWh.[2] Therefore, the energy capacity of the battery bank should be between 9 and 12 kWh.

Currently, the 120 W photovoltaic panel powering the equipment downstairs is located on the ground right outside the house. The NH Audubon Society may remove this panel in the near future. Some of the grant money should be used to replace it and perhaps install additional panels. A possible location for these panels is the roof of the generator room, but it would need to be measured and checked for stability to make sure it could support the panels. This arrangement (battery bank in the generator room and the panels on the roof) would make it easy to connect the panels to the batteries.

The Tern Restoration team should consider installing more PV panels to produce more power. PV panels manufactured by Sharp have a good reputation. A panel that seems to fit the needs of White Island is the Sharp ND-123UL. The panel's dimensions are 4.92 ft by 2.17 ft.; it is rated at 123 W and 12 V. Panels should be combined in series to get either 24 V (two in series) or 48 V (four in series). A possible configuration uses eight panels: four in series, in parallel with another four. This configuration would provide a total voltage of 48 V, a current of 20.50 A, and power output of 984 W. Alternatively, two Sharp panels could be combined to have a total voltage of 24 V, and a current of 10.25 A, with a power output of 246 W, which is about twice the output of the panel currently installed on White Island. This arrangement would be a recommended start for White Island; more panels could be added later.

The old charge controller and inverters should also be replaced, especially if new batteries and PV panels are installed. The PV charge controllers and inverters on Appledore are made by Outback. Outback makes high quality products, and SML already has experience installing and using them—for instance, the Outback MX60 has proven to be reliable and effective on Appledore. Its most appealing feature is power-point tracking. When charge controllers were compared using RETScreen, the ones that used power-point tracking consistently output 30% more power than the charge controller without power-point tracking. Essentially, the purpose of power-point tracking is to keep the PV panels at their ideal voltage output in order to maximize power. The Outback FX2024 inverter is also known to be of high quality and efficiency. A matching inverter and charge controller would work best together; less expensive devices are available, but familiar devices that are known to work well are preferable.

The charge controller, inverters and batteries are the backbone of the system. If these components are selected wisely, the system should last a long time and cope well with changes to the PV panels. The batteries in particular must be selected wisely. Once a battery bank is installed and used, no more batteries should be added. Therefore, the new battery bank should be purchased with future plans in mind.

Table 4 shows the estimated costs for the PV panels, charge controller, inverter, and batteries. Although the total comes out to more than $4500, the system is worth the cost.

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[2] www.vonwentzel.net/Battery/02.size/index.html

The extra expenditure now will pay off in the long run. The proposed system should last a long time. It is also expandable. The charge controller would be able to accommodate at least eight of the Sharp 123 W photovoltaic panels.

Table 4: White Island PV System Cost Estimate

Company	Model	Type	Cost/unit	Quantity	Cost
Sharp	ND-123UL	PV Panel	$500	2	$1000
Outback	MX60 PV MPPT	Charge Controller	$600	1	$600
Outback	FX2024	Inverter	$1,800	1	$1,800
		Battery*	$400	6	$2,500
*See text above for details on battery selection.				Total Cost	$5,800

The existing solar panels are taken down and stored at the end of each season, to protect them from the harsh winters. Dan Hayward expressed a desire for more permanent panels that would somehow be protected during the winter months. One idea would involve replacing the roof of the generator room, and building a new pitched roof. Plywood could be installed at the end of each season to protect PV panels mounted on the roof. If strapping were attached to the roof between the panels, plywood could be bolted into it. It would be easier to implement this tactic on a new roof, because the existing roof of the house is made of tile.

As of summer 2008, the Tern Restoration team uses a propane hot water heater, designed for camping, to heat water for showers. The shower is located in the outbuilding with the composting toilets. Water is stored in buckets, and a sprayer is used while standing in a tray on the ground. A passive solar water heating system could provide hot water to the bathroom upstairs. Such a system would eliminate the need to use the outbuilding to bathe, allow the residents a more satisfying wash, and reduce the use of propane. A thermosiphon solar heating system would work well for this application. A thermosiphon system is composed of flat collectors with a tank mounted at the top—as the sun heats the water in the collectors, it rises into the tank, and the colder water in the tank flows to the bottom, heats up, and then rises again. Systems made by Solahart® and Edwards seem promising. Although both companies are based in Australia, there are several US dealers. Eco-$mart is the closest one, and is based in Florida.

Freshwater

The team's water is collected from several sources. Drinking water is picked up in five-gallon jugs from the mainland. The bottles are refilled on Appledore (from the hose behind Kiggins), and this water is used for cooking and teeth-brushing. Rainwater is collected from the gutters, siphoned to a 1400-gallon cistern in the basement, and used for showers and dishwashing. The cistern is almost always full; according to Dan Hayward, there is never a shortage of water in the cistern.

Considering the abundance of rainwater and shortage of drinking water, perhaps the rainwater should be treated to meet drinking quality standards. The water would need to be tested to help determine the proper treatment technique. According to Jennifer Perry, rainwater is considered surface water, and therefore needs to be filtered and disinfected. A water specialist should be consulted in further investigations. Jennifer Perry suggested contacting Bob Mann (rmann@des.state.nh.us) or Bernie Lucey (blucey@des.state.nh.us) of the New Hampshire Department of Environmental Services. Treating the cistern water would save the residents of White Island a considerable amount of time and money. They would no longer need to buy and transport water from the mainland or from Appledore.

As stated above, the plumbing in the house does not work—water must be transported in buckets or jugs. The cistern is located in the basement, and carrying buckets of water up the stairs is not an easy task. Retrofitting the plumbing would improve the living conditions for the Tern Restoration team. The priority is to make the kitchen sink usable for cooking and washing dishes. Plumbing could also be supplied to the sink in the bathroom upstairs, and a shower upstairs. In order to retrofit the plumbing, the water must first be pressurized or pumped so that it will flow up from the basement. A pressure tank is the traditional method, but is more expensive and uses more energy. A pump would also work quite well. The pipes must also be replaced—they are currently corroded and would not hold water.

Wastewater

The gray water generated from dishwashing and showering on White Island is discharged into the ocean. The quality of the gray water is unknown, and should probably be tested to determine if it is suitable for dumping without any treatment. There is a Pak-a-Potti (made by Sears) in the upstairs of the house; it seems to be functioning properly. The composting toilets, however, clearly do not fit the needs of the residents. There are two Sun-Mar non-electric Excel composting toilets on the island. The toilets are self-contained; the entire unit sits in the outbuilding. Each toilet is sized to accommodate two people. With the extra visitors on the island, the toilets usually fill up before the composting process is complete, and are emptied into the ocean. This is not healthy for the ocean ecosystem, nor is it sanitary for the residents to handle the waste. It is unclear if the toilets are functioning properly; the issue appears to be overuse. A simple solution is to add another composting toilet. The existing units are non-electric, which is ideal for White Island because of their power limitations. There are a number of non-electric models available. The current toilets are made by Sun-Mar. Sun-Mar toilets have not received positive reviews from Appledore; however, the units on White are different from the unit that was installed on Appledore. Other manufacturers of self-contained units include Biolet, Envirolet, and Sancor Industries (Blooloo composting toilets). Because the outbuilding is raised, it may also be possible to install a system with the toilet on the floor connected to a tank below. Blooloo offers such a system. Most of the more reputable composting toilet units require electricity for fans or pumps, and thus were not considered for White Island. In the future, if enough power is generated, perhaps a different composting toilet would be more suitable for White Island. Any new additions to the wastewater system will require further investigation and consultation with the residents.

General Facilities

Currently the house has no heating system. It is much colder at the beginning and the end of the season than during the summer months. Dan Hayward suggested installing a pellet stove where the unused fireplace is located.

The roof on the generator room leaks and leaves the room completely unusable. Although the entire room needs to be remodeled, the roof poses a safety concern. In addition, a south-facing pitched roof would be a great place to mount solar panels.

The power system does not include any kind of back up power source for the PV panels. A small diesel generator for this purpose is worth looking into.

There is no smoke detector or fire alarm installed anywhere on the island—this is an important safety concern. Installing one in the house would be relatively inexpensive and should be a priority.

Recommendations

Below are recommendations for projects to be implemented (or further researched) on White Island. They are listed in order of priority.

The grant from NH Fish and Game Departments needs to be used for solar equipment. It is recommended that it be used to purchase:

(2) Sharp	ND-123UL photo voltaic panels
(1) Outback	MX60 PV MPPT charge controller
(1) Outback	FX2024 inverter
(6) 12 V batteries, or (12) 6 V batteries	

The batteries should be selected so that their energy capacity is three to four times the daily energy demand. The new batteries should be stored outside of the house so that the gasses they release do not harm the residents. The recommended storage location is in a waterproof cabinet in the generator room. From the batteries, hard wiring should be installed throughout the house.

Install a smoke detector or fire alarm in the house on White Island as a basic safety measure.

Install a pump or a pressure tank and repair pipes so that water no longer needs to be transported from the basement to the kitchen in buckets.

Install lights in the house.

Investigate whether the rainwater collected and stored in the basement can be treated and used for drinking.

Add a supplementary composting toilet to accommodate the island population and visitors.

Put in a thermosiphon solar hot water heating system on the roof and fix plumbing for the upstairs shower so that residents no longer need to take showers while standing in a tray.

Replace the roof on the generator room.

Install a heater for the house to make it more habitable for the residents during the beginning and end of the season.

Investigate whether a small back-up diesel generator would be appropriate for White Island.

Data Collection

System Overview

Appledore Island has several different systems on the island. A freshwater system provides clean water for drinking, dishwashing, showers, etc. The saltwater system supplies toilets, sea tables, and fire hoses. The generators, along with the wind turbine and solar panels, provide electrical power for the island.

There is a Badger compound flow meter measuring the flow rate of the freshwater coming out of the pressure tank in the generator room. The meter uses a positive displacement meter for low flow rates. A pressure valve allows higher flow rates to flow into a separate chamber through a turbine meter. This configuration allows the meter to be accurate for a wide range of flow rates. However, there is no analog output.

A flow meter at the salt water pump measures the flow rate of the salt water coming out of the pump. Pressure gages at the inlet and outlet to the pump indicate the pressure head created by the pump.

An Allen-Bradley power monitor keeps track of the power being produced by the generators.

Island engineers take certain readings every day to insure that the various systems on the island are working properly. At the wastewater chapel, the freshwater is tested for chlorine levels, turbidity, and pH. Also, the numbers displayed on the batch and EQ counters are recorded. In the cistern, the freshwater is again tested for chlorine. In the generator room, power readings are taken from the Allen-Bradley power monitor and the Badger flow meter. Also, checks are performed on Generator 1 and results recorded.

Problem Overview

Keeping track of all the different systems on Appledore Island can be difficult and time consuming. With Appledore's drive for sustainability, obtaining additional data on the existing systems and their performance is becoming more and more important. Keeping track of energy usage and the output of the various energy sources on the island will help formulate ideas as to what is possible in terms of renewable energy in Appledore's future. Likewise, information on freshwater and saltwater usage can help shape new, more sustainable systems, such as a wastewater system that would get SML off of its overboard discharge license.

One way of addressing these issues is to set up an automated data collection system on the island. Detailed records of measurements such as flow rates or power consumption would give SML staff members a better idea of how efficiently the different systems on the island are operating and allow future engineering interns to make more informed recommendations as to how to improve those systems. Also, closely monitoring island processes might make it easier to locate and fix problems with those systems. An automated system would allow SML to collect this data without assigning additional tasks to staff members.

Records of the daily measurements taken by island engineers can be helpful when analyzing the systems on the island. The spread-out nature of the record logs makes it difficult to look up information when needed.

Objective

It is desired that the interns recommend a method of automating data collection on the island. Also, determining locations where measurements could be taken, which instruments could be used, and how to connect those instruments to a central database for the island would be desirable. Additionally, it is hoped that recommendations be made for ways to make daily measurements easier to record and access at later times.

Data Collection/Methodology

Extensive research was done into the different ways data collection could be automated. Professors Joe Klewicki and Tom Ballestero of the University of New Hampshire and Professor Darren Hitt of the University of Vermont were contacted while searching for an appropriate flow meter for the freshwater system. The engineering interns accompanied Kevin Jerram while he took daily measurements to better understand the island's current data collection and the current expectations of island engineers.

Results/Discussion

Overview

There are several locations where useful measurements could be taken and automatically recorded in a database. These locations are listed below:

- Flow meters that output an electric signal could replace the flow meters currently in use for the freshwater and saltwater systems.
- Pressure transducers for pumps on the island, particularly the saltwater pump.
- Temperature sensors for the freshwater and saltwater systems.
- Level sensors for well and chlorine tank

Automated data collection could be done by a data acquisition system. Data acquisition systems take inputs from various sensors and interface with a computer to record and analyze data.

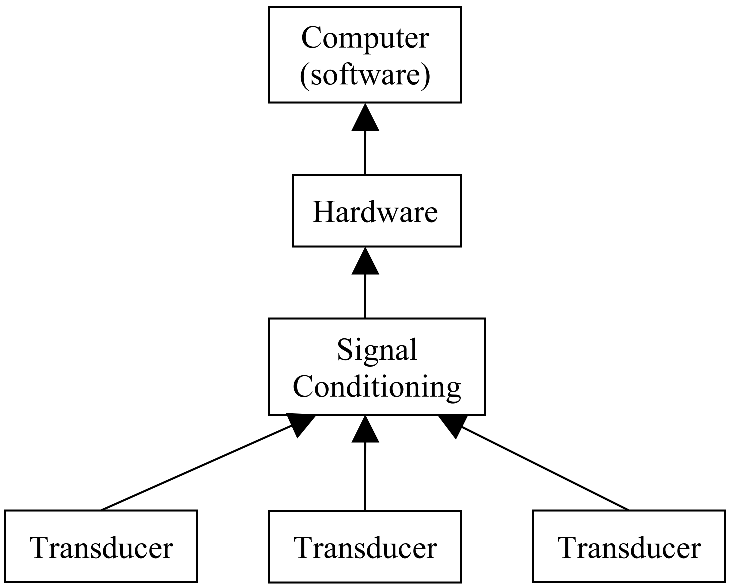
Data Acquisition Systems

A simple data acquisition system has the following components:

- Transducers
- Signal conditioning
- Data acquisition hardware
- Computer
- Data acquisition software

Each component is explained in more detail below.

Figure 1: Layout of a Typical Data Acquisition System



<u>Transducers</u>

Data acquisition systems use transducers, or sensors, to measure various physical quantities, such as flow rate or temperature. There are many factors to consider when choosing the appropriate transducers. In order to be connected to a data collection system, a transducer needs to be able to output an electric signal that can be read by the system's hardware. There are three main types of output signals:

mV
Voltage (usually 0-5V)
4-20 mA (current)

A mV signal is a low voltage signal that is inexpensive and works well for short distances. However, these signals can be disrupted by noise from the surrounding environment. Also, the low voltage limits the distance that the signal can be sent over. Sometimes this signal is amplified to produce a voltage signal, which is less susceptible to interference and can travel farther. Some transducers, usually called transmitters, output a small electrical current. This type of signal is the least effected by noise, and is useful for sending information long distances. The current can be converted to a voltage using a resistor. This may be required if the data acquisition hardware only accepts voltage inputs.

Two other important aspects of choosing a sensor are the accuracy and range of the device. The range is the span of values over which the transducer remains accurate. Accuracy is generally reported a couple of different ways. Percent of full scale (FS) or full range means that the accuracy is based on the range of the sensor. For example, if you have a flow meter with an accuracy of 1% FS and a range of 2 gpm to 30 gpm, your reading could vary by 0.01 * 30 gpm = 0.3 gpm. If the flow rates you would be measuring are around 5 gpm, this would mean an actual accuracy of 0.3/5 * 100% = 6%.

Percent of reading, on the other hand, means that the instrument is accurate within a certain percentage of the actual reading. So if the flow meter in the case above had an accuracy of 1% of reading, the measurement would only vary by 0.01 * 5 gpm = 0.05 gpm.

Signal Conditioning

Sometimes the signal output of a transducer is not compatible with the data acquisition hardware. In this case, signal conditioning is required. There are several kinds of signal conditioning listed below:

Amplification: Amplification is used to increase the size of the signal, which can also help increase resolution.

Filtering: Filtering out unwanted electrical interference, such as magnetic fields from nearby motors, helps to produce a cleaner signal.

Multiplexing: Multiplexing offers a way to combine signals from several different sensors.

Excitation source: Some transducers require a power source in order to generate an output signal. Choosing an appropriate power source can insure a cleaner signal.

Data Acquisition Hardware

The data acquisition hardware is what receives the signals from the transducers and converts them to a format readable by the computer. The different specifications to consider when choosing data acquisition hardware are listed below:

Analog inputs:

Analog signals are time-varying currents or voltages, and are what would typically be output from a sensor. There are two main types of analog signal inputs:

- Single-ended: Signal transmitted through one wire and compared with a common ground. These inputs are more appropriate for signals of more than 1 volt and short distances.
- Differential: Signal transmitted through two wires, difference is taken between two wires. These inputs are generally less affected by electrical interference, because taking the difference between the two wires cancels out noise common to both wires and amplifies the desired signal. This makes them more appropriate for smaller voltages and longer distances.

Digital Input/Output:

Digital signals encode information in bits. These signals can store more information than analog signals. However, some of the quality of the signal is lost when compressing the signal.

Sampling Rate:

Analog signals need to be converted to digital signals in order to be read by the computer. The sampling rate is a measure of how fast the system can convert these signals.

Accuracy

Resolution:

The resolution of the hardware determines the smallest change in a signal that can be detected. Typical resolutions are 12-bit and 16-bit. The resolution in engineering units can be found by dividing the measurement range by 2 to the power of the bit resolution. For example, if you have a measurement span of 0-100V, the resolution for a 12-bit system would be 100V / 2^12 = 100V / 4056 = 0.025V[3].

The two main types of data acquisition hardware are described below:

Plug-in Cards:

Plug-in cards can plug directly into a computer and are wired to the various sensor inputs. A typical plug-in card might have 16 inputs with 12 or 16-bit resolution. They are generally less expensive than networked systems that communicate with a host. It is important to select the right architecture bus for the card. A table of the various buses that are available can be found on Omega's website.[3]

Stand-alone systems:

Data acquisition systems consisting of stand-alone data acquisition hardware that communicates with a host through some sort of network offer more capacity than plug-in cards. They are easier to upgrade and are not limited by the amount of space available on the computer. Internal memory allows the unit to store data until it can be downloaded to a host computer. Some systems can even communicate with a host computer over the internet or through a cell phone.

Data Acquisition Software

Special software packages such as LabVIEW allow the computer to read and analyze the data sent to it by the data acquisition hardware.

Flow Meters

There are many different types of flow rate measurement devices, and choosing the right instrument involves having a general understanding of how each one works. The first step is to determine the range of flow rates that would need to be measured. Some flow meters are more accurate than others within certain ranges. Preferably, you want your nominal flow rate to be somewhere in the middle of the flow meter's range.

There are many different methods to measure the flow rate of a fluid. A summary of some of the most commonly used flow meters is shown in Table 5. More detailed explanations of some of the flow meters are given below.

[3] http://www.omega.com/literature/transactions/volume2/dataacq.html

Table 5: Some Different Types of Flow Meters

Category	Type	Description	Advantages	Disadvantages
Pressure	Pitot tube	Measures static and stagnation pressure, which can be used to find velocity of flow at a point.	Many can be used at once to get rough picture of flow profile Simple, sturdy	Disrupt flow – pressure drop
	Venturi	Smooth transition to smaller diameter and then back again – change in velocity and pressure.	Simple, sturdy	Disrupt flow
	Orifice plate	Flat plate with hole inserted into flow – creates pressure drop which can be measured and used to find velocity (using Bernoulli equation).	Simple, sturdy	Disrupt flow
Electromagnetic		Coils generate a magnetic field, conductive liquid passes through and generates a current which reads as a change in voltage between electrodes.	No moving parts (low maintenance) Doesn’t interrupt flow High linearity Can have higher accuracy than similarly priced meters	Fluid needs to be conductive Zero drifting at low/no flow – may not be good for freshwater system Requires constant power to generate field (for AC – DC pulse requires less power)
Ultrasonic	Transit time	Two transducers, each with a transmitter and a receiver - one upstream, one downstream. Sound wave takes more time to travel upstream than downstream - difference in times can be used to find velocity of fluid.	No moving parts (low maintenance) Doesn’t interrupt flow High accuracy	One-beam models may not be suitable for liquids with high range of Reynolds numbers (freshwater?)
	Doppler	Measures shift in frequencies of sound waves bounced off of particles in fluid.	No moving parts Doesn’t interrupt flow	Needs solids in fluid – may not be suitable for freshwater
Mass	Coriolis	Liquid flows through U-shaped flow tube – momentum of fluid going in and out results in a coriolis acceleration which causes the tube to twist. Displacement sensors measure this twist, which is used to find velocity.	High accuracy Independent of temp Can measure a variety of different types of flow Low pressure drop	Clogging possible – hard to clean Larger size than most flow meters Limited line size

				availability
Positive Displacement	Nutating disc Oscillating piston Oval gear Roots	Counts number of fills and discharges of a fixed. volume of water passing through the meter	Can be used for viscous flow	High pressure drop – completely obstructs flow High maintenance Not good for low flow rates Gas bubbles in liquid can significantly decrease accuracy
Target		Target on a shaft inserted into flow, strain gages on shaft measure force on object	Can measure random, complicated flows Low cost	Pressure drop
Thermal		Measures heat loss when fluid passes over a hot wire – heat loss is related to heat capacity of fluid (known), temperature difference between wire and fluid, which is monitored, and mass flow rate of fluid	Low pressure drop	Fragile, costly to repair For gas only
Turbine		Uses angular velocity of turbine blades to find velocity of fluid	Reliable – thoroughly tested method	Fluid needs to be clean Pressure drop
Variable Area	Movable vane Rotameter Weir, flume	Cross-sectional area flow passes through changes with flow	Simple, robust Low pressure drop	Low accuracy Not good for low flow rates
Vortex		Measures frequency of vortices formed when fluid hits an obstruction	Low-maintenance in clean fluid applications	Pressure drop from obstruction[4]

[4] *Introduction to Flowmeters, 2008,* http://www.efunda.com/designstandards/sensors/flowmeters/flowmeter_intro.cfm (July 6)

Differential Pressure

Differential pressure flow meters generally use a form of flow obstruction to create a pressure drop, which can be measured using pressure transducers. This pressure drop can be related to the velocity of the fluid using fluid dynamics principles; in particular, Bernoulli's principle. Bernoulli's principle states that the sum of the dynamic, static, and hydrostatic pressures in steady, incompressible flow is constant:

$$P + \frac{1}{2}\rho V^2 + \rho g h = C$$

There are several different types of differential pressure flow meters. A venturi tube has a cone-shaped decrease in diameter, followed by a more gradual increase back to the original diameter. The decrease in diameter creates an increase in velocity, which can be measured by measuring the pressure drop in the narrow section.

Electromagnetic

Electromagnetic flow meters use Faraday's law to measure flow velocity. For an in-line meter, two coils on either side of the pipe create a magnetic field. When a conductive fluid flows through this field, it creates a voltage which is proportional to the velocity of the fluid.

Ultrasonic

There are two kinds of ultrasonic flow meters. A Doppler flow meter has transmitters that emit sound waves which will bounce off of solids in the liquid. Receivers will then measure the frequency of the returning signal, which can be related to the velocity of the fluid.

A transit-time flow meter has two transducers, each with a transmitter and receiver, one downstream and one upstream. The idea is that a signal emitted from the downstream transmitter will take longer to go upstream than a signal going downstream, because of the movement of the fluid. The difference in the time it takes for each signal to reach the opposite receiver can be related to the velocity of the fluid.

Mass (Coriolis)

The operation of a mass flow meter is based on the Coriolis principle. In a mass flow meter, the fluid flows through a U-tube. The momentum of the fluid going in and out of the tube creates a coriolis acceleration which twists the U-tube. Displacement sensors measure this twist, which can be used to find the mass flow rate of the fluid.

Target

A target flow meter measures the flow rate using an object placed in the flow path. The object is attached to a shaft which has strain gages on it to measure the force exerted on the object by the fluid. These force measurements can be used to find the flow rate of the fluid.

Pressure Sensors

Pressure sensors generally consist of some sort of mechanical diaphragm or spring that is deflected by the pressure of the fluid. Pressure sensors placed at the intake and outlet of the saltwater pump and possibly the cistern and well pumps could give an indication of how well the pump is performing. There are several different kinds of pressure that can be measured:

Absolute pressure: Pressure relative to a vacuum pressure of 0.
Gage pressure: Pressure relative to atmospheric pressure. This can be useful for measuring pressures in places with differing atmospheric conditions.
Differential pressure: The difference in pressure between two points. This kind of pressure reading is useful for determining flow rates with differential pressure flow meters such as venturi tubes or orifice plates.

Daily Measurements and Recording

Daily measurements taken by island engineers could be simplified by consolidating all of the readings that need to be taken onto one or two sheets. A data recording sheet was created in excel, which includes the readings needed for the generator room, cistern, and wastewater chapel for a week. These values could then be entered into a database on a computer in the Grass Foundation Lab. A prototype database was created using Microsoft Access, which could allow for easy retrieval of records. The fields in the database were designed in the same order that appears on the recording sheet, allowing the recorder to enter the values from the sheet straight into the database. Both the recording sheet and database are included in the digital appendix.

Recommendations

Data acquisition can be a fairly complicated endeavor. There are many different systems available and extensive research should be done to make sure that the best system is chosen for Appledore Island's specific needs. There is a wealth of information on data acquisition on Omega's web site, www.omega.com.

In order to a get an approximate cost for a data acquisition system, it would be useful to look into the different components that might be desired. Given the spread-out nature of the measurements that might be taken, a communications based system might be more appropriate at SML. This system would also allow SML to start small and upgrade the system as time goes on. A small, initial system might include:

2 data loggers, one near generator room and cistern, one at salt water pump
Flow meter in generator room for freshwater system
Flow meter at saltwater pump
Pressure sensors on intake and outlet of saltwater pump.

A data logger with 8 analog inputs placed near the generator room could be connected to the freshwater flow meter and a level sensor in the chlorine tank, and allow for future expansion, such as pressure sensors for the cistern and chlorine pumps or a level sensor for the chlorine tank. The Campbell Scientific CR1000 data logger has 16 single-ended inputs or 8 differential inputs, with 16 bit resolution. The differential inputs would provide better protection against noise.

It is difficult to source a flow meter for the freshwater supply line because the pipe is fairly large at two inches and the flow can be very low and at times even stop. This presents a problem because flow meters have a minimum flow that they can measure and their accuracy is better for flows in the middle of their flow range. It was found that flow meters for larger pipes need a greater minimum flow than do flow meters for smaller pipes. This makes sense because, given a constant flow, a liquid will pass more quickly through a smaller diameter pipe than it would through a larger diameter pipe.

The turbine style flow meter stands out as the meter of choice for the freshwater supply line mostly because the other flow meters drop out either because they need higher flows, they are overly expensive, they cannot be easily configured to work with the appropriate data loggers, or they cause too great of a pressure drop. Turbine flow meters are also widely used for freshwater supply applications and so the performance and reliability are well known. After calling the technical support at Omega Engineering, the first thing they recommended was a turbine flow meter. Unfortunately, even with a turbine meter the pipe size would have to be reduced in order to measure flows down to 0.5 gallons/minute which is the minimum flow we decided was necessary to measure. If the pipe was reduced to a ¾" pipe, a Clarks Solution ultrasonic flow rate transmitter for $576.16 could be used. A pressure gauge was installed by Kevin Jerram on the low pressure side of the existing flow meter and the pressure on the other side was found by reading the pressure gauge on the tank and then adding the pressure from the water head. It was found that the existing gauge causes a pressure drop of around 4 psi.

The saltwater pump generally runs somewhere between 20 to 40 gpm. The pressure at the intake ranges from -10 to -22 mm Hg, while the discharge pressure is generally between 40 and 60 psi. A turbine flow meter would probably work well in this situation. Omega sells a $773 turbine meter with a range of 2 to 150 gpm and an accuracy of 1% of FS. For an average flow rate of about 30 gpm, this would mean an actual accuracy of around 5%. The meter can output a 4-20 mA signal. This could be converted to a 1-5 V voltage signal if needed using a 250 ohm resistor. Two Omega PX209 pressure sensors could be used to measure the pressure at the intake and outlet of the saltwater pump. These sensors can be selected to output 0-5 V or 4-20 mA signals. The current signals are slightly more expensive.

National Instruments sells a program called LabVIEW that can be used to analyze and record data from the data logger. The program uses a graphical interface to interpret data and connect to instruments. The base program costs $1199. A cost analysis of the entire system described above is shown in Table 6. This shows that a data collection system on Appledore Island is certainly feasible. The most useful part of the system for SML currently might be a flow meter and pressure sensor on the saltwater pump, since measurements are not taken there during dailies. Automated pressure and flow measurements for the saltwater pump would help SML staff evaluate how well the pump is working and alert them to any problems the pump is having. It is recommended that more research is done into the various types of data acquisition components.

Table 6: Data Collection System Cost Analysis

Type	Company	Model	Cost/unit	Quantity	Cost
Data logger	Campbell Scientific	CR1000	$1,390.00	2	$2,780.00
Software	National Instruments	LabView	$1,199.00	1	$1,199.00
Flow meter	Omega	FTB720	$773.00	1	773
Flow meter	Clark Solutions	CSLFB34	$576.16	1	576.16
Pressure sensor	Omega	PX209-100G5V	$195.00	2	390
				Total	$5,718.16

Freshwater

System Overview

Freshwater at SML is sourced primarily from a 20-foot well under the influence of surface water and secondarily from a saltwater-fed reverse osmosis (R/O) unit during times of peak demand or reduced rainfall. A simple manually monitored chlorine injection system treats all freshwater at SML; measurements of pH, temperature, turbidity, and chlorine levels are performed daily to verify compliance with State of Maine regulations.[5]

When the well is in use, the chlorine pump and the well pump are both activated by a float switch in the cistern, which turns on when the water level drops too low. The pump injects chlorine into the well water after it passes through the primary filter. The chlorinated water then travels through another filter before entering the cistern. At the beginning of the season (or when the cistern is close to full), the water has a detention time of approximately nine days, providing a long contact time to allow the water to be properly disinfected. From the cistern, the water is pumped to a pressure tank, and then through a flow meter and up to Kiggins Commons, where it is distributed to the other buildings. The R/O unit is typically used only at the end of the season when the water level in the cistern gets too low. It was not activated during the interns' stay on the island this year.

For more background information and a layout of the chlorination system, see the section titled Freshwater System in the 2007 report.

Problem Overview

Over the last couple of years, SML noticed fluctuations in chlorine levels. The fluctuations caused either potentially dangerous drinking water from under chlorination or an unpleasant taste from over chlorination. Currently, in order to adjust for changes in chlorine levels, island engineers manually adjust the feed rate control of the chlorine pump, but these changes take up to a day to have an effect. The interns of 2007 determined that the fluctuations could be caused by a number of factors, but noticed that the six-year-old pump was not operating correctly and recommended a replacement. A new peristaltic pump was installed during the off-season.

Objective

The objective is to determine if replacing the pump was effective in decreasing the chlorine fluctuations. A second objective is to explore other options for freshwater disinfection, such as an ultraviolet (UV) radiation system.

Data Collection/Methodology

In order to determine whether the chlorine levels are still fluctuating, three tests were conducted that simulated the tests performed by the 2007 interns. The free, or residual, chlorine was tested at several locations over four days; the chlorine pump was tested in order to determine if it meets

[5] 2007 Intern Report

manufacturer's specifications; and the well pump was tested to determine whether the water output was consistent.

Water was tested for chlorine residual three times each day for four days at five locations. The tests were conducted June 30-July 3 at 9am, 11am and 7pm (based on data found in the 2006 report for medium, low and high demand, respectively) at the cistern, wastewater treatment shed (Chapel), Kiggins kitchen sink, Bartels first floor sink, and the K-House kitchen sink. The water was tested for free chlorine using a HACH digital colorimeter and reagent packets. The test was conducted immediately after turning on the faucet, which raised concern about stagnant water in the pipes, but it was done this way because most people collect water for drinking as soon as the faucet is turned on.

The 2007 interns found that the chlorine pump did not function as specified by the manufacturer. A similar test was conducted on July 14 to test the new chemical feed pump over its operating range. Using a graduated cylinder and a stopwatch, 20mL of chlorine was collected at three different pump settings to determine flow, which was compared to the manufacturer's specifications.

The well pump was tested for consistency of flow by manually switching on the pump and recording the amount of time it took to fill a five gallon bucket.

Each morning the island engineers test the chlorine level in the cistern and at the wastewater treatment shed (the Chapel). The chlorine levels from 2007 and 2008 were compiled and compared to observe any changes since the pump change.

Results/Discussion

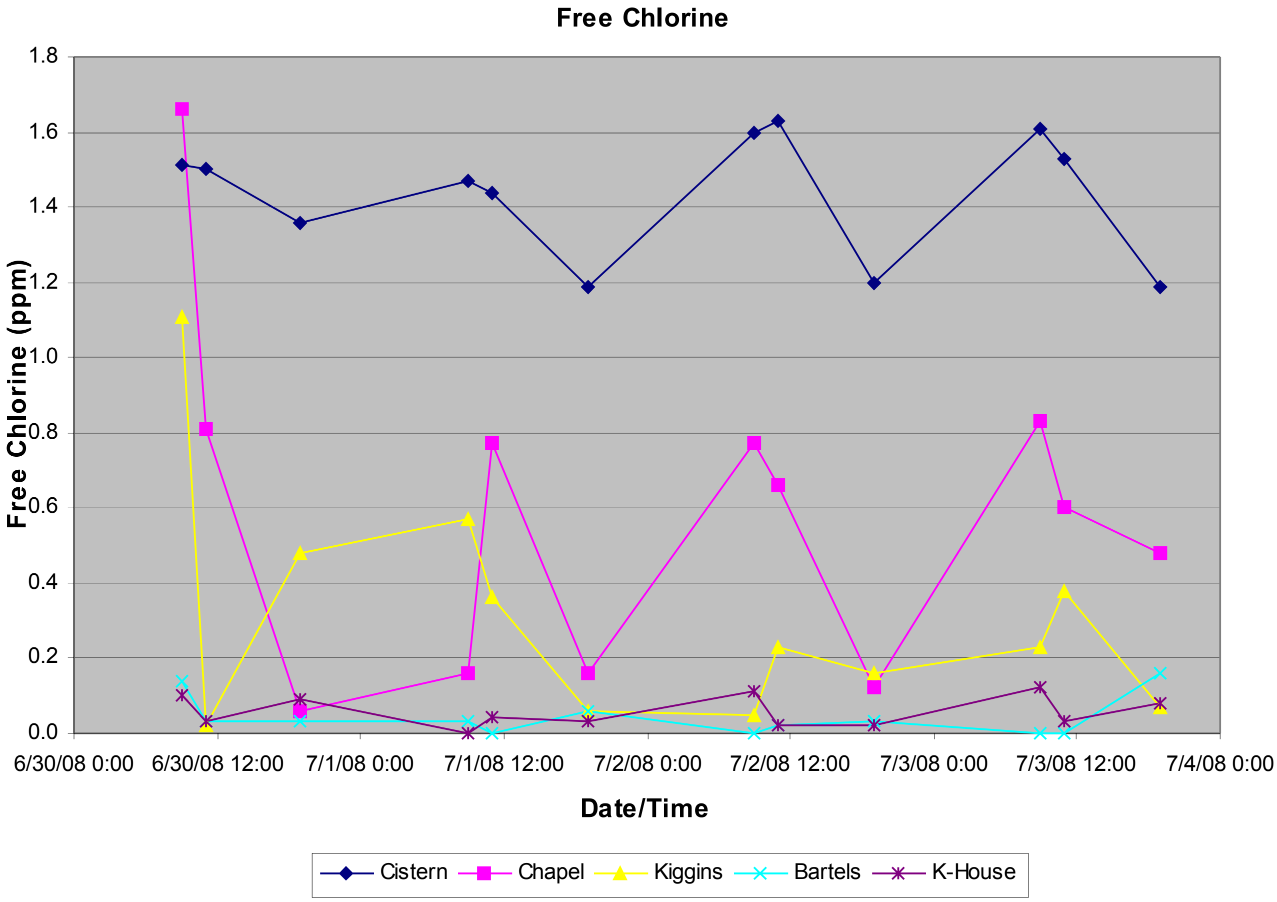
Chlorine Residuals

The test results from June 30-July 3 indicate that the chlorine levels are still fluctuating. The biggest difference was seen at the Chapel, where concentration swung from 1.66 ppm to 0.06 ppm in ten hours. The water in Bartels and the K-House had the smallest fluctuations and smallest residuals, which makes sense because these buildings are the farthest from the chlorine injection point.

The results are shown in Figure 2. According to Maine regulations, there should be approximately 1 ppm chlorine residual at the cistern, 0.2 ppm at Kiggins, and trace amounts in Bartels.[6] Full results, as well as charts of free chlorine levels at individual locations, can be found in the Digital Appendix under Freshwater.

[6] 2007 Intern Report

Figure 2: Chlorine Residuals



A direct comparison to last year's data (Figures 3 and 4) shows that the fluctuations have not significantly decreased. The comparison is not quite accurate because the 2007 group allowed the water to run before sampling, which decreased the contact time and increased the level of free chlorine. For more information on contact time and its effect on chlorine residuals, see the 2007 report.

Nevertheless, the data from the Chapel last year shows that the highest jump was from 1.66 ppm to 0.91 ppm.[7] These results suggest that there was actually a more dramatic fluctuation in 2008 than 2007, but there are too many variables to draw a conclusion. See Figure 3.

Another comparison can be made with the data collected at the cistern. Figure 4 shows that fluctuations have not decreased significantly since last year.

[7] 2007 Intern Report

Figure 3: Comparison of 2007 and 2008 Chlorine Residuals at the Chapel

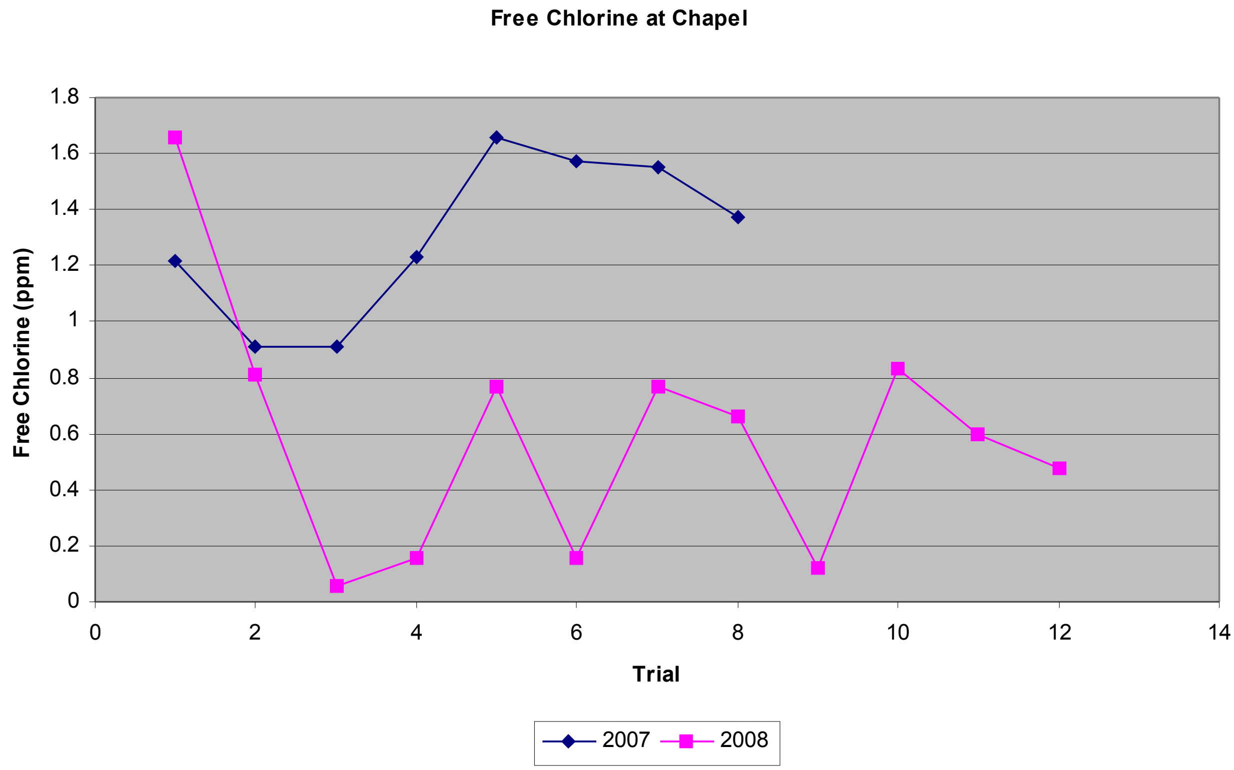
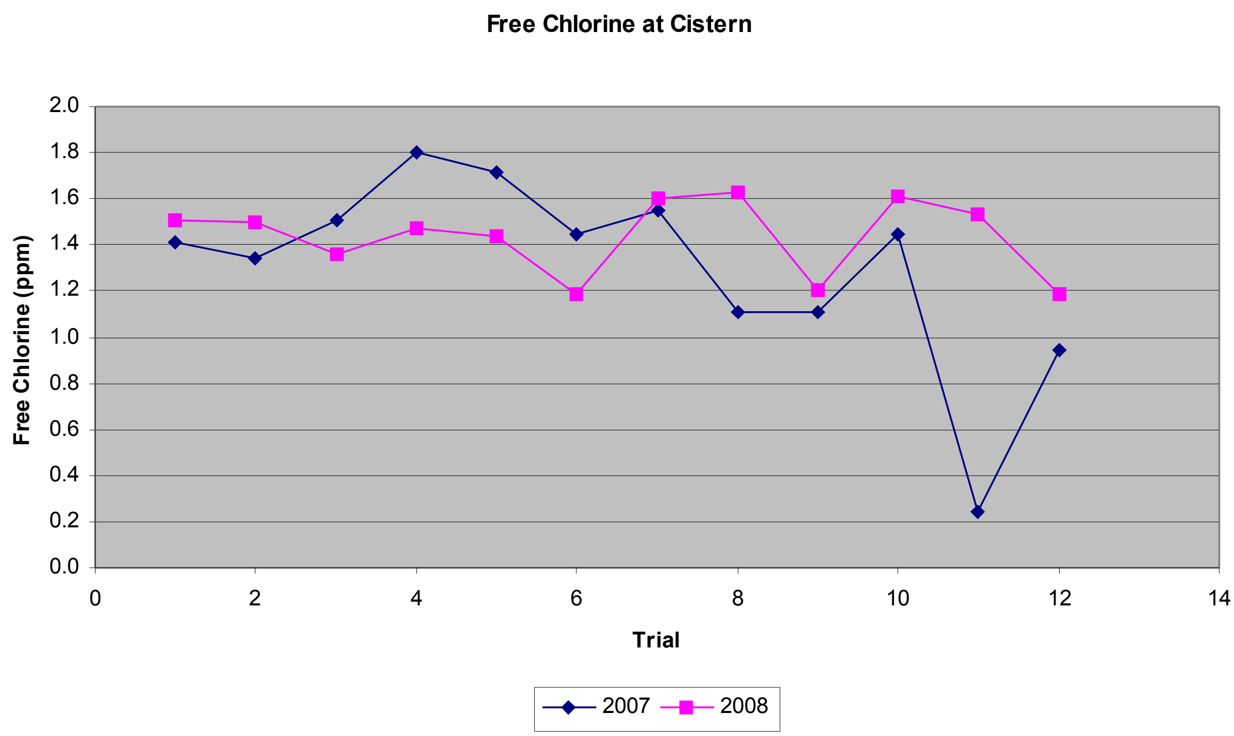


Figure 4: Comparison of 2007 and 2008 Chlorine Residuals at the Cistern



Pump Performance

Chlorine Pump

The results from the chlorine pump test are shown in Table 7:

Table 7: Chlorine Pump Test Results

Pump Setting	Flow (mL/min)	
	Current Pump	Manufacturer Spec
8	6.38	6.336
9	7.02	7.128
10	7.89	7.92

The new pump is operating according to the manufacturer's specifications. However, during three of the four days of testing for chlorine residuals, the pump was set at the highest level (10), and no trace of chlorine was detected in a couple of buildings on campus, which raises some concern. The pump should be delivering the most chlorine at its highest setting. If the water demand increases significantly, the pump might not be able to inject enough chlorine to properly disinfect the water and meet state regulations. Island engineers should be aware of this issue and note when chlorine levels are exceedingly low. On the other hand, changes to the pump take at least a day to be seen in the system, and this may not be such a significant issue.

Well Pump

To determine the flow rate of the well pump, a test was conducted using a similar method used by the 2007 interns. The pump was tested over the course of several days, and sometimes multiple times during one day. This should show if and how the flow rate of the well pump changes with water demand throughout the day. The results are shown in Table 8.

Table 8: Well Pump Flows

Date	Time	gal/min
7/2/2008	8:45 AM	12.182
7/2/2008	3:00 PM	12.865
7/2/2008	5:45 PM	12.796
7/3/2008	9:00 AM	12.041
7/14/2008	3:45 PM	11.937
7/14/2008	3:45 PM	11.632
7/14/2008	9:00 AM	11.055

Except for the first measurement, the data shows a decreasing flow rate. This change is explained by the change of head in the well. As head increases, flow rate decreases. The significance of this test is that the chlorine pump remains at the same level until an operator notices the need to adjust it, while the well pump output is gradually changing. The results of the 2007 group are drastically different, with no reasonable explanation.

Because the chemical feed pump appears to be functioning correctly, the chlorine fluctuations were likely not caused by the faulty pump. According to the 2007 report, it is evident that chlorine fluctuates with the fluctuations in freshwater use—chlorine residuals increase when water demand increases, because there is less contact time. The water is pumped through the pipes without any stagnation time. When water is allowed to sit in the pipes (i.e. when demand is low), the additional contact time, as well as temperature changes, cause a decrease in the chlorine residuals.

Freshwater use on Appledore ranges from roughly 1000 to 1800 gallons per day. The majority of the water is used in Kiggins for dishes, cooking, showering and hand washing. The pipe to Kiggins has a 2 in. diameter, and the pipe leading to the rest of the buildings has a 1 in. diameter. Assuming all of the water passes through Kiggins before a portion is moved to other buildings, it is easy to see that the detention time is much shorter for Kiggins than other buildings that are further from the injection point and have lower demands. In the K-House, for instance, the demand is low enough and the pipe long enough to allow water to sit in the line between Kiggins and the K-House for as long as a full day. This explains why residuals were so low in Bartels and the K-House, even when Kiggins had high levels.

Ultraviolet Disinfection

Jennifer Perry and Jim Malley were consulted to assess the feasibility and benefit of installing a UV treatment system. Recently, UV radiation has experienced an increased interest due to concerns over toxic chemical byproducts produced by the chlorination process. A UV system eliminates the transportation, storage and handling of chemicals, has no unpleasant taste or odor and can be used regardless of pH or temperature. UV radiation works particularly well for eliminating *Cryptosporidium* and *Giardia*.

Disinfection using ultraviolet (UV) radiation was considered in order to reduce the amount of chlorine used in disinfecting the drinking water. Unfortunately, according to Jim Malley, a founding President of the International Ultraviolet Association, the amount of chlorine is determined “not by disinfection kinetics but by the chlorine demand of the piping system which will not change, so adding UV insures multiple disinfection barriers and arguably better disinfection and public health protection but will not reduce the chlorine used.”[8] Since the water at SML meets State of Maine regulations, there may be no reason to expend more energy on further water treatment.

UV radiation cannot be used alone for drinking water disinfection because it does not meet the 4-log removal of viruses requirement, which is why the same amount of chlorine would have to be used. In addition, it does not provide a residual, which makes it potentially dangerous to use for drinking water anyway. In the future, an UV system might be a worthwhile consideration for a gray water system on Appledore. Jim Malley, a professor at the University of New Hampshire, offered to donate a system that is no longer in use there. For more information about UV radiation, see the Digital Appendix.

Recommendations

The fluctuations in chlorine residuals may be caused by biological growth in the lines. As contact time increases, the amount of free chlorine decreases because of the extra disinfection that occurs in the lines. SML already over-chlorinates the system at the beginning of each season to flush out potential biological growth, but perhaps a new approach could have different results. It is recommended that SML focuses on one

[8] Digital Appendix > Freshwater > Email Correspondence > “UV”

building at a time—for example, over-chlorinate and run the water full blast in Kiggins, without turning on faucets anywhere else on the island; then move to the next building. According to Jennifer Perry, the town of Exeter, NH does this twice a year. It would be easy to determine if this method works—test the residuals at the beginning and end of the season, keeping demand the same if possible, to see if fluctuations become worse.

If there is no biological growth in the pipes, a better idea would be to change the chlorination injection point. The data from this year as well as from 2007 proves that chlorine residuals directly correspond to contact time and freshwater demand. Currently, chlorinated water sits in the cistern for as long as nine days. The average contact time for the well water was approximated at about 600 minutes, although the State of Maine requires a minimum of 18 minutes.[9] Because chlorine evaporates, keeping the water in the cistern for such a long time might be causing some of it to go to waste. In addition, the current injection system is not working as well as it could be, since the flow rate of the well pump appears to change with well height while the chlorine pump stays at the same operating level. One way to improve the system is to move the chlorine injection point further along the line. If chlorine was injected after the cistern (but before the pressure tank), the contact time would decrease and likely decrease the fluctuations. In addition, it would be easier to install a flow meter and have more consistent amounts of chlorine injected into the line.

It is recommended that the pressure tank be more closely examined. The tank is old and in need of replacement, and it might also be causing the fluctuations. Chlorine can evaporate into the air even in the pressure tank, until the point where the water and air reach equilibrium. It is possible that the equilibrium is never reached because water is moving through too quickly, causing chlorine levels to fluctuate.

An easier (but not as efficient) solution would be to create a chart that displays island population versus freshwater demand, contact time and chlorine pump level. Because population is easy to predict, island engineers could use the chart to adjust the injection pump for each day. Another relatively easy to implement improvement would be a system that allows operators to measure the flow in real time to catch pump problems immediately. This system could be as simple as a graduated cylinder and stopwatch, but might take more time for island operators conducting daily checks.

For the sake of keeping accurate records, it is also recommended that island engineers measure chlorine residuals with the digital colorimeter.

[9] 2007 Intern Report

Wastewater System

System Overview

Currently, SML's wastewater system consists of two separate systems. A small system that handles wastewater at the K-House was recently installed and involves composting toilets (two composting units with three Nepon foam flush toilets), a FRICKle Filter, and Eljen In-Drain leach field. The remaining island wastewater flows to a 1000 gallon primary settling tank, two more 1000 gallon tanks in series where further settling of solids occurs, and two batch tank where it is disinfected with chlorine, then dechlorinated with the addition of sodium metabisulfite, and finally discharged into the ocean.

Problem Overview

A 1997 study, led by Dr. Nancy Kinner, analyzed the system, evaluating various secondary treatment options. Given the difficulties and many disadvantages of these systems, Dr. Kinner and her team concluded that SML should employ disinfection and overboard discharge to handle island wastewater for the current time. The recommendation was followed and SML obtained an Overboard Discharge License, which will now expire on February 5, 2009.

The 2006 Sustainable Engineering Interns concluded in their report that even with the disinfection process, SML's current discharge could be causing adverse impacts on the discharge locale. Also problematic in their assessment is the current sludge disposal method and intense chemical usage, which pose a health risk to operators and generates the associated costs of purchasing and transporting the chemicals.

In June of 2008 a renewal application to the existing system was submitted to the State of Maine and is pending approval. However, the State of Maine has indicated that it is hoping to reduce the number of discharge permits given out. Given the need to eliminate the Overboard Discharge Permit and the unsatisfactory condition of the wastewater system, a Master Plan to detail the island's future wastewater treatment is to be developed. Plans are in place to put in more composting toilets to help SML eliminate blackwater discharge completely, but it may not be feasible with the use of composting toilets alone.

Objective

Further research into methods of black water reduction and alternative wastewater treatment is desired. Consideration would be given to previous evaluators' recommendations, SML's current composting toilet plan, and any previously unexplored alternatives. A cost analysis and overall comparison for the island's different options in handling both black and gray water is also desired. Additionally, the interns would investigate possible locations on the island where treatment and disposal could take place. Overall, a feasibility and time phased implementation plan to eliminate the overboard discharge of black water is desired.

Data Collection/Methodology

Summary

Developing a wastewater treatment plan involved two general parts: evaluating the current island systems; researching the most suitable options to replace the overboard discharge system.

In their evaluation of the current systems, the interns focused on the K-House system. They assessed the performance of the current system through both visual observations and through collecting water samples, which they collected from the composting toilet leachate and from groundwater at the edge of the leach field.

Researching the feasibility of different systems to replace overboard discharge began with significant research into general techniques, especially those employed for decentralized treatment when traditional septic systems are not suitable. The interns next reviewed previous recommendations made in reports by Dr. Kinner, Albert Frick, and the 2006 interns.

Once an overall approach and few specific products were decided upon, the interns began a more thorough comparison of the potentially compatible options. They formulated a list of criteria encompassing SML's unique physical, monetary, and philosophical attributes. By weighting the various criteria, the interns produced numerical rankings to assign to each treatment method.

Several mass balance calculations were performed to determine the effect of adding certain effluents to an otherwise gray water system, which would replace the current main wastewater system. These effluents would come from composting toilet leachate and four toilets that were determined, in the initial composting toilet feasibility plan, as more highly problematic to be replaced by composting toilets.

The interns contacted a variety of sources to obtain cost estimates and generated rough comparisons for the cost of implementing different treatment options, including different combinations of black water reduction, secondary treatment, and methods for returning treated effluent to biogeochemical cycles.

To recommend potential locations for a new wastewater system, the interns calculated the necessary space for primary and secondary recommended options. They used island maps to look for areas that might be suitable and then made approximate measurements at these sites.

Finally, recommendations were compiled for further study of the current system, choosing a new system, and pursuing a plan for implementation.

Evaluation of K-House System Methodology

Visual observations of the K-House system gave the interns some indication as to the effectiveness of the system. Observations were made by opening the composting units to notice their effectiveness. Further observations were made by removing covers for the multi-chambered septic tank and multi-chambered FRICKle Filter.

The engineering interns collected samples from the leachate produced by one of the K-House composting units. The pipe connecting the larger composting unit to the gray water flow was disconnected (before a point where the two liquids mixed) and drained into the sampling bottles, which were provided by Eastern Analytical, Inc. (EAI). These samples were collected at two different times in order to get enough water to fill the sample bottles.

Dr. Kinner sent equipment to the island so that the interns could drive micro-wells at the edge of the leach field and pump up samples from the groundwater. However, on the morning of the tests, the interns were unable to draw enough water through the tubes and instead had to dig larger holes and allow groundwater to collect in these. This allowed the interns to retrieve enough water to fill the sampling bottles, but caused the samples to have extra soil particles.

All water samples collected from the gray water system were sent to (EAI) to determine the concentrations of biological oxygen demand (BOD), total suspended solids (TSS), and total Kjeldahl nitrogen (TKN), as well as with the presence of Fecal Coliforms.

Research Methodology-Black Water Reduction

The 2006 Sustainable Engineering report, as well as manuals obtained from Joe Ducharme, a Clivus representative, provided much of the background information about Clivus units. Information about the Carousel and Phoenix was obtained through online manuals, as well as email correspondences and phone conversations with David Del Porto, Ried Nelson and Paul Doscher. Some of these can be found in the Digital Appendix under Composting Toilets.

The interns evaluated the current composting toilet units at the K-House and researched other composting units to determine the most suitable method for black water reduction on the rest of the island. Based on the apparent success of the current composting toilets, SML seemed to be in favor of installing more of these units to eliminate wastewater discharge. Although the lab is satisfied with the Clivus composters, these units are extremely expensive; as a result, several other options were explored for composting units for the rest of the campus.

Research Methodology-Treatment Systems

The interns utilized a wide variety of sources to obtain information on wastewater treatment. Dr. Kinner spent a day on Appledore Island to share some basic knowledge on wastewater systems and she also acted as a resource contact throughout the internship. David Del Porto's book, Composting Toilet System Book, provided a significant amount of background information in composting toilets and gray water treatment and reuse. Several internet resources were also consulted. These included publications on decentralized wastewater treatment from the Virginia Polytechnic Institute and State University, the University of Minnesota Extension, the National Association of Home Builders, and the Environmental Protection Agency. Articles were also found in journals such as Onsite Water Treatment and Ecological Engineering. Additionally, interns consulted previous reports on treatment alternatives produced by Dr. Kinner, Albert Frick, and the 2006 interns. These sources can be found in the physical or digital appendices and are referenced appropriately throughout the report.

The interns compiled and organized the information on each treatment method. To present their findings, they chose to skip detailed summaries, which could be found in the appendices, and instead focus on the main advantages and disadvantages. They also identified specific technologies to evaluate for SML given its unique attributes and limitations.

Treatment System Evaluation Methodology

With the help of Dr. Kinner, the interns brainstormed some initial criteria to compare various wastewater treatment systems. After completing some initial research, the interns refined this list and ended up with 13 main criteria. Some of the criteria were broken down into sub-categories to consider multiple aspects that all fell into a general group.

Information for making comparisons came from a variety of sources. Much of the previous research, especially the review of previous reports was helpful in evaluating the chosen technologies. Additionally, the interns made contact with company representatives and read through informational brochures and manuals. All email correspondences and documents are included in the digital appendix to this report.

Evaluations were made on a scale from one to seven for each of the individual criterion. The engineering interns weighted each of the criteria to reflect their respective priorities and these weightings can be clearly seen in the spreadsheet comparison of technologies. This will also allow adjustments to be made if others desire to re-evaluate the systems by assigning different weightings to the criteria. The weighting system then allowed the ratings to be compiled and averaged, giving each technology an overall rating on the one-to-seven scale.

The general correspondence for each number to a qualitative basis is listed below. Also, the various criteria are listed below along with a description of how they were considered in respect to wastewater systems.

Rating Scale:

- 1...............Unacceptable, does not meet criterion
- 2...............Poor
- 3...............Slightly poor
- 4...............Average
- 5...............Good
- 6...............Very good
- 7...............Excellent

Criteria:

- Regulatory Standards
  This criterion involves the likelihood and difficulty of receiving approval for the wastewater system from the State of Maine. Systems must meet all requirements set by the Department of Health and Human Services, Division of Licensing and Regulatory Surfaces. These can be found in the Maine Subsurface Wastewater Disposal Rules (CMR 241). Given the fact that some methods are more well-known and widely practiced, it will be easier to receive approval for conventional systems in comparison to systems implementing more novel technologies. Additionally, the system must allow SML to treat all wastewater on the island, instead of requiring an overboard discharge permit.
- Reputation
  This criterion considers how highly people recommend the particular treatment system. Some

sources include previous interns' reports and employees with the Department of Health Engineering and the Department of Environmental Protection for the state of Maine.

- Wastewater Characteristics
  This criterion deals with a particular technology's suitability to SML's wastewater. Comments were made when the systems performed differently for black water systems than for gray water systems. Ideally, treatment systems would work well with a mainly gray water system, possibly including composting toilet leachate and black water from just a few toilets. Also, the interns noted the system's ability to handle salt water.
- Staff Requirements
  - Training
    This criterion relates to how much training will be necessary for island engineers who must maintain the system. The amount of previous training as well as on-the-job training would ideally be minimal to facilitate hiring appropriate staff members when necessary.
  - Labor
    This criterion involves the amount of labor required to maintain the system. Ideally, general maintenance as well as any larger problems that might occur with the system could be accomplished by a small number of employees.
- Design Life
  A new wastewater system will require a sizeable investment of time and money. It would therefore be ideal to implement a system that would last a long time before needing to be replaced. This criterion also dealt with how easily and expensively the system could expand (to meet higher demand if island water usage increased), although the island director, Willy Bemis, has indicated that expanding maximum capacity of the island is not expected in the near future. Given this expectation and the fact that most systems would need to be replaced with a new model or would require additional materials to expand the disposal field, comments were only made when this was significantly different for the given technology.
- Compatibility
  - Existing Systems
    SML currently has a wastewater treatment system with pipes running to all of the current buildings. It would be preferable to implement a system that could add on to the existing system rather than require a large amount of new infrastructure. Also, most systems evaluated in this report would require a new septic tank, but Ross Hansen has expressed plans to replace the septic tank regardless of the new system choice (a septic tank is required according to the State of Maine regulations[10]).
  - Island Life + SML Mission
    SML has a unique culture because of its history, location, and deeply committed community. A wastewater system plays an important role on the island and, ideally, its principles would align with those of the island. For example, the system would reflect a respect for all life and provide opportunities to learn.
  - Climate
    Aspects of SML's climate were taken into consideration when evaluating wastewater systems, including temperature, precipitation, and salinity of the atmosphere.
  - Geography
    SML's rocky geography, with limited soil depth and area, was reflected in this criterion.

[10] 2006 Sustainable Engineering Internship Report, page 14

Since most systems required suitable sand, soil, or gravel to be brought in (creating the necessary backfill between the system and bedrock), comments on the need for backfill material were limited to instances where this was not the case or where there were significant differences.

Hydrology

The island's hydrology was given consideration because SML's water supply comes from the island's well, the sole freshwater source, during the beginning of the season. While all systems are designed to protect groundwater sources, special note was given to the likelihood of contamination involved with each treatment system.

- Implementation

  Time

  The system would need to be installed in a reasonable amount of time before or after classes in order to have the system working when water use begins in April.

  Materials

  This criterion deals with the transportation and construction needs based on the materials used in the system. Any materials that are currently on the island and could be utilized in implementing the system would be ideal. Since many materials will likely need to be brought onto the island for the installation, the choice of materials is very important. Lightweight and compact materials would be easier to transport.

  Environment

  This criterion accounted for both initial and long-term impacts on the island's environment. All evaluated methods avoid the chemical use that is found in the current system, making their impact on the local environment more favorable than overboard discharge. Construction projects can largely impact the island environment, so all of treatment systems involved a significant initial impact, but, in time, ecological succession would likely restore conditions to be suitable with the rest of the island environment. Therefore, comments were limited to extended impacts or those not mentioned above.

- Aesthetics

  Aesthetics were considered with respect to visual, noise, and odor characteristics. Unpleasant aesthetics naturally produce an overall unfavorable disposition, but they additionally can be problematic if they cause responsible parties to feel less inclined to properly monitor and maintain the systems.

- Residual/Byproducts

  Effluent Quality

  This criterion evaluates each system's ability to reduce the concentrations of BOD, TSS, TKN, and the amount Fecal Coliforms in the wastewater. It also notes if any harmful byproducts are produced as a result of the treatment mechanisms or processes.

  Final Location

  This criterion deals with the location of the final products when treatment is complete.

- Repair

  The difficulty in repairing malfunctioning systems is of extra importance in comparison to many mainland locations given the difficulty of bringing professionals onto the island. This criterion, therefore, looks at the complexity of the system and how easy it would be for island engineers to make repairs without needing mainland assistance.

- Reliability
  This criterion deals with the treatment system's overall performance record. The system's ability to handle variations in wastewater flow and strength is noted when available.
- Safety
  - of Product
    This criterion encompasses any health risks associated with the treatment system itself whether these risks are related to people, animals, vegetation, or non-living components of SML's environment. Any hazardous chemicals or dangerous mechanical parts discovered by the interns are noted in this category.
  - for Operators
    Since operators could potentially have more direct exposure to the treatment system, this criterion looked at any health or safety risks associated with normal operation and maintenance.
- Cost
  - Capital
    SML is not a public entity and will have only a limited amount of funding to allocate towards the capital investment of a new wastewater treatment system. The capital costs are all considered in 2008 dollars and include only components for which the interns were able to obtain estimates for. Other potential capital costs are noted.
  - O + M
    Operation and maintenance costs include cleaning or replacing system components as well as electricity demand for pumps, blowers, and other components.

Mass Balance Methodology

The engineering interns received information from Dr. Kinner on how to perform a mass balance. Several mass balances were calculated to show the differences depending on how many non-composting toilets were left on the wastewater system, as well as whether these toilets were replaced with low-flush toilets (to reduce the total wastewater flow, although the use of these toilets could lead to problems with clogs as noted in the Results/Discussion section).

As many sources as could be found were consulted in obtaining values for these calculations. The following table summarizes values obtained.[11,12,13] Since information was not found on Fecal Coliforms and TKN in gray water, these parameters were not included in the mass balance.

Table 9: Typical Wastewater Constituents

Wastewater Type	BOD (mg/L)	TSS (mg/L)	TKN (mg/L)	Fecal Coliforms (MPN/100mL)
Gray Water	70	40	--	--
Typical Household	300	250	50	30,000
Weak Sewage	100	100	15	--
Medium Sewage	200	200	40	--

[11] http://www.compostingtoilet.com/Public/Ap_Guide/Ap_Guide.htm
[12] Cantor, Larry W. and Robert C. Knox. Septic Tank System Effects on Ground Water Quality. CRC Press, 1985.
[13] Del Porto, David. Composing Toilet System Book. Concord, MA: The Center for Ecological Pollution Prevention, 2000.

Strong Sewage	450	375	60	--

All assumed values used in the calculations, along with a sample calculation (not replacing all four of the non-composting toilets that are difficult to replace with composting units) are detailed in the physical appendix. All other values and calculations are summarized in an Excel spreadsheet that can be found in the digital appendix. Charts comparing the results of these mass balances (for current, non-low-flush toilets) are also included in the Results/Discussion section.

Site Assessments/Cost Estimates Methodology-Black Water Reduction

It is important to note that the cost estimates for composting units were not performed in order to compare the different composters. A decision should not be made based on prices calculated for this report. The calculations for the Clivus system were done by Joe Ducharme, who is familiar with Appledore Island and much more qualified to present a final price. The other estimates were done by the interns and based on numbers found via online manuals, as well as emails and phone conversations with David Del Porto and Ried Nelson. These estimates do not include installation costs. Because Clivus provides one price for an entire system (rather than breaking it down into components), it is in the best interest of SML to look into the total cost of installing other systems before making a final decision.

Cost Estimates Methodology-Treatment Systems

The engineering interns consulted various sources to obtain cost estimates for treatment systems to accompany the proposed installation of composting toilets. These costs were obtained via phone conversations, email correspondence, and product brochures/publications. The email correspondences and brochures/publications can be found in the appendices to this report. A summary of the capital cost estimates are listed in the Results and Discussion section. In some cases, these estimates did not cover all of the expenses involved in the system, so omitted components are noted when known.

For the SeptiTech system, the interns received a price quote of approximately $17,500 for the entire treatment system with an HDPE tank (slightly more expensive than the concrete tank). Budget price for a MicroFAST 3.0 including blower with enclosure and control panel and alarm was given as $20,000, but did not include the tankage.[14] No direct price quote was available for the EcocyclET system, but a similar system (Solar Aquatic System) from the same company was priced as $55 times the design flow, so this price was used in the intern's estimates.[15] The cost for the FRICKle Filter at the K-House was estimated at about $1,500 by Ross Hansen. Although a larger system for the rest of the island would likely be more expensive, no information was obtained on this price, so $1,500 was used in the estimated calculations. No price information was obtained on the cost of an effluent tank filter that would be used within a new septic tank. Al Frick had commented that such a component is very inexpensive, so the interns made a rough estimate of $500 for use in the calculations. Since the majority of the costs for this system would come from the cost of a disposal field, the estimate is likely a valid assumption for the purpose of this report.

[14] Digital Appendix > Gray Water > Email Correspondences > SeptiTech System
[15] Digital Appendix > Gray Water > Email Correspondences > Constructed Ecosystems

The estimates also include costs for a disposal field when appropriate. Each system was priced using an Infiltrator disposal system and an Eljen disposal system for comparison. The prices reflect the cost of the required plastic chambers or geotextile mats, along with the necessary backfill. The approximate yards of backfill needed were determined according to the rules in the State of Maine's Subsurface Disposal Rules (see the Treatment Site Assessment Methodology section). Rough estimates for the cost of backfill materials were made by assuming sand to cost $10 per cubic yard and soil to cost $15 per cubic yard. The cost of transporting the backfill to the island was omitted from these estimates. Hourly prices for using a barge and dump truck were unknown, but calculations for the number of required trips and total cost once these prices are obtained.

Estimates for operation and maintenance costs were not specifically calculated and included in the cost analysis. The interns noted the operation and maintenance requirements for each of the treatment systems evaluated in the criteria-list comparisons. They also provided information on the estimated power requirements, since these were the source of most of the operation costs.

Site Assessments Methodology-Treatment Systems

As noted in the 2006 Sustainable Engineering Internship Report, an on-island wastewater treatment system would be governed by the State of Maine Subsurface Disposal Rules (CMR 241). These rules indicate how to determine design flow rates, required disposal field dimensions, and minimum separation between the system and other significant locations (i.e. wells, water supply lines).

Previous studies have found toilet effluent constitutes a large portion of SML's total wastewater flow. Since the new system will likely be entirely, or almost entirely, a gray water system, the engineering interns concluded that the best estimate of flow in this new system would correlate with the island's freshwater use. Section 503 of Maine's Subsurface Disposal Rules dictates that for water use data collected on a daily basis, the 80th percentile value, calculated using standard statistical methods, shall be used for the design flow. The engineering interns collected water use data from April 2004-June 2008 from the logs kept in the cistern. They recorded the flows in gallons per day and calculated the 80th percentile values for each year. These values can be found in the Results/Discussion section and the full spreadsheet of freshwater usage can be found in the digital appendix. The highest of the 80th percentile values was 1720.63 gpd in 2007. Based on this value, the interns then chose to use a value of 1750 gpd for their design flow. Al Frick informed them that Appledore Island's soil was classified as Soil Profile 3 as described in Table 600.1 of CMR 241. The engineering interns also found the appropriate adjustment factor in Table 603.1 of CMR 241 for each of the evaluated technologies.

With this knowledge, the interns used an Excel spreadsheet to calculate the required disposal field area for each of the various treatment systems, along with variations for different flows and disposal devices. This spreadsheet with full calculations can be found in the digital appendix. The devices included for disposal field calculations were Infiltrator Equalizer 24 chambers, Eljen In-Drain A-type units, and Geoflow drip irrigation tubes. The total yards required for each of the various systems (for a given treatment method) are listed in the Results/Discussion section. There were discrepancies between the sizing instructions for the Geoflow system listed in CMR 241 in comparison to those listed in the Geoflow design manuals. The interns attempted to contact Geoflow to resolve this discrepancy, but did not receive an informative response by the time of this report's completion. For this reason, and other reasons discussed in the Results/Discussion section, the Geoflow calculations (as set forth in the Geoflow manual) are included in the Excel spreadsheet, but are omitted from the table in the Results/Discussion.

The only treatment system whose sizing was not estimated by use of CMR 241 was the EcocyclET system. David Del Porto, the system designer at the Ecological Engineering Group, informed the interns that a rough estimate could be made by multiplying the design flow by 4 square feet.[15] This gave the interns an area of 7,000 square feet. Since construction would be a considerable project given the amount of sand and gravel needed for this system, the interns set out to find a location with enough space, little elevation change, and proximity to existing roads/paths on the island. A map showing a potential location is included in the Results/Discussion section of the report.

Additionally, the interns decided to find a potential location for their second choice system. This involved using the dimensions as calculated in accordance with CMR 241 and the appropriate design manuals. Again, the interns looked to find a location with enough space, little elevation change, and proximity to existing roads/paths on the island. A map showing a potential location is included in the Results/Discussion section of the report. Locations for both the primary and secondary choice systems were only roughly estimated because most areas were heavily covered in vegetation, including poison ivy, and also because sizes would need to be confirmed by a qualified professional.

Results/Discussion

<u>*Summary*</u>

The results of the interns' work provided information as desired from their objectives and scope of work. Their work also raised more questions that can be investigated in the future and it uncovered instances where more time and data would allow for more precise and appropriate recommendations.

The evaluation of the K-House system showed that it may not be working properly and more testing may be desired. Specifically, visual observations confirmed that the FRICKle Filter had not been properly installed. This system was not performing as designed and the interns question the reliability of the synthetic media, even when properly installed. Water samples indicated potential problems with the Clivus leachate, FRICKle Filter, and Eljen leach field.

Research into composting toilets and various wastewater treatment systems indicated that several options are possible for SML with some differences in costs and compatibility. It may be desirable for SML to use a combination of different brands of composting toilets and to collect more data on treatment systems while composting units are being installed and the current wastewater system is still in use. With current information, using all composting toilets with the EcocyclET zero-discharge system seems the most appropriate choice for SML's new wastewater system. The next best option according to the interns' evaluations would be installing the MicroFAST 3.0 unit and Infiltrator leaching chambers.

The results of the mass balance calculations only provided insight into concentrations of BOD and TSS in the various wastewater scenarios. Further information would be necessary to evaluate the effects of non-gray water sources to the Fecal Coliforms and TKN concentrations. The interns found that including composting toilet leachate would likely be similar to a strictly gray water system, while adding toilets would provide wastewater strengths mid-way between gray water and black water. They also concluded that low-flush toilets would provide little advantage if non-composting toilets were to be used. Overall, the interns discovered that this mass balance information will be most helpful in appropriate sizing of the system, but will likely have little other effect in regards to the State of Maine regulations.

Cost estimates and site assessments are shown in tables and pictures in their respective sections. The interns found that the cost of installing composting toilets would likely range from $350,000 to $450,000. Treatment system prices ranged from $10,000 to $150,000, but these estimates did not include some small expenses or the large expense of transporting materials, specifically backfill, to the island. All prices were calculated in 2008 dollars, include a contingency as described, and are listed to an appropriate number of significant figures. Comments were made (in the Data Collection/Methodology section) in regards to the specific components included and omitted from the estimates. Site assessments were only rough estimates because of heavy vegetation in the proposed areas. However, the interns concluded that these locations could potentially be used, but a SML should have a professional choose the most appropriate sites.

SML should draft a Master Plan based on the Implementation Plan Timeline. Review of this report should allow appropriate decision-makers to determine the most suitable black water reduction and wastewater treatment system. The Master Plan should also include further research and data collection as recommended in the report.

Evaluation of K-House System

Dr. Kinner, as a visiting lecturer assisting the interns, discovered foul odors and questionable performance at the K-House system. When Al Frick investigated the system, it was realized that improper installation could have caused the unacceptable performance because not enough synthetic media was put in the final chamber, which was designed to complete the aerobic portion of the treatment. Dr. Kinner had also alerted the interns to the movement of the synthetic media through the chambers. Mr. Frick asserted that the media movement was part of normal functioning and that the media was not in fact disintegrating. However, the interns question this assertion on the basis of research into general treatment systems. No other system in their research involved similar movement of media from one portion of treatment zone to another. Additionally, some media pieces were small enough to enter the piping to the distribution box, which could potentially cause clogs in the leach field, if such clogs have not formed already.

Given the fact that no one had been aware of the improper installation of the FRICKle Filter or had performed tests of the effluent quality, the interns recognized this as a major point of concern in regards to the system. It emphasizes the importance reliability in a treatment system and in assuming responsibility for appropriate monitoring.

Results obtained from the water sampling yielded useful information, although it did not achieve the original goals of the experiment. Results from these tests are listed in the table below.

Table 10: K-House Wastewater Test Results

Location	Characteristic Tested	Test Result

Composting Leachate	BOD	65 mg/L
Composting Leachate	TSS	53 mg/L
Composting Leachate	TKN	1,200 mg/L
Composting Leachate	Fecal Coliforms	300,000 MPN/100mL
Edge of Leach Field	BOD	8 mg/L
Edge of Leach Field	TSS	1,300 mg/L
Edge of Leach Field	TKN	18 mg/L
Edge of Leach Field	Fecal Coliforms	8,000 MPN/100mL

These results provide insight into possible problems with the K-House system. The data from the composting toilet leachate raises questions as to the performance of the Clivus model used at the K-House. Typical levels of BOD, TSS, TKN, and Fecal Coliforms in composting leachate were found for both Clivus and Phoenix composting toilets.[16,17] The BOD and TSS concentrations were expected to be between 10 mg/L and 80 mg/L, while TKN was expected to be around 1,300 mg/L. The EAI results indicate that the BOD, TSS, and TKN in the K-House leachate do not raise any significant concerns. The Clivus information showed less than 10 MPN/100mL, Phoenix estimated less than 200 MPN/100mL for Fecal Coliforms in leachate, and SunMar Composting Toilets were listed as having a mean count of 18,800 MPN/100mL.[18] These were the only numbers found by the interns and given this information, the Fecal Coliforms in the K-House Clivus model looks significantly problematic. There is a substantial possibility that SML is using the model improperly or the model is not properly functioning.

Originally, island operators and the engineering interns expected the State of Maine to set regulations on the characteristics of groundwater after it finishes passing through a disposal field. However, the interns discovered that this is not the case and Maine regulations only dictate the construction of a disposal field based on water characteristics, soil profile, and devices used.[19] Following these regulations for the volume of disposal field required is set to ensure enough time and surface area for water treatment.

However, the Clivus publication also provided data on typical effluent quality after passing through a soil absorption field. Given this data, the level of BOD looks reasonable, but SML should consider contacting water quality experts to confirm this. The Clivus data also indicates that the TKN levels may be higher than would be expected given that the water should be fully treated after leaving the leach field and have a concentration below 10 mg/L. The high concentration of TSS is likely attributable to the soil particles that were taken up during the sampling procedure, so further tests should be well-planned to ensure better methodology. This was challenging for the 2008 interns because of the limited time frame to obtain materials, take samples, and receive results from EAI. No information on the expected presence of Fecal Coliforms was found by the interns, so further research into acceptable levels should take place before any conclusions are drawn on the effective reduction of this indicator by the K-House system.

[16] Digital Appendix > Composting Toilet > Clivus Report
[17] http://www.compostingtoilet.com/Public/Ap_Guide/Ap_Guide.htm
[18] Del Porto, David. Composting Toilet System Book. Center for Ecological Pollution Prevention, 2000.
[19] Digital Appendix > Gray Water > Email Correspondences > State of Maine Agencies

Overall, visual observations and lab results indicate a need to contact the appropriate companies and conduct additional, more accurate tests of the K-House effluent. Also, the water sample results could not provide information on whether the FRICKle Filter or Eljen leach field might not be effective, so it would be advisable to collect tests at additional locations, such as the end of the septic tank (entering the FRICKle Filter) and the distribution box (entering the leach field).

Research-Black Water Reduction

Summary

Clivus New England has exclusive distribution rights for Nepon foam-flush toilets, which are currently installed in the K-House. These toilets are extremely clean and user-friendly, and operate almost like conventional toilets. SML is satisfied with the performance of these toilets and would like to install them with the other composting units. The toilets are compatible with all of the composting units researched.

The Master Plan for Appledore includes almost all of the buildings on the island—if the majority of current toilets are replaced with composting toilets, it would be interesting to install different composters to accommodate different loads, particularly when there is such a wide range of prices. Although the island is satisfied with the Clivus system, it might be worth it to consider installing either Phoenix or Carousel composters for several of the buildings, particularly those that are not often used or have limited space. Additionally, concern over the leachate from the K-House system indicates that a Clivus representative should be consulted before installing these toilets throughout the rest of the island.

Clivus composters have the advantage of not containing any moving parts; however, the composting pile has to be directly mixed and the unit itself appears to be the most expensive of the three compared. In addition, it is difficult to add heat directly to the composting unit and there is greater potential for fresh waste to mix with old waste, both of which slow down the composting process. The composting units have not caused any concern so far, but the load in the K-House is small and the units have only been in place for a year. Both the Phoenix and the Carousel composting units have also received good reviews, and were considered for use on Appledore.

Table 11: Comparison of Composting Toilet Models

Clivus	Phoenix	Carousel
Direct contact during mixing	No direct contact during mixing	No direct contact during mixing
Local	Not local	Local
Leachate pump included	No leachate pump	No leachate pump
Highest chance of fresh/old mixing	Medium chance of fresh/old mixing	Lowest chance of fresh/old mixing
Familiar	Not familiar	Not familiar
Difficult to heat	Heat added via air stream	Heat added via air stream
Not insulated	Insulated	Not insulated
No upgrade to larger unit	Easy upgrade to larger unit	Easy upgrade to larger unit

	Most electrically efficient	

Clivus

The K-House currently has the island's only composting toilets, made by Clivus Multrum. Clivus is probably the most widely recognized company in the composting toilet industry. Clivus composters sit at an angle to allow waste to compost as it moves down through wood chips or another medium. Liquid moves through the pile and is collected at the bottom and pumped into a holding tank if needed.

The composter uses in-line centrifugal blowers to ventilate the unit, but does not come with heaters or any effective way to keep the unit warm. Some make-up air comes through a vent panel, but is not well directed to promote aeration of the pile. Maintenance includes addition of a carbonaceous material, usually monthly, and manual raking of the pile. Raking is unpleasant because it requires direct contact with the compost pile and cleaning of the rake afterwards. Clivus has been working on a unit with a built in rake, but it is not yet available.[20]

Phoenix

The Phoenix composters from Advanced Composting Systems (ACS) come in three sizes with identical footprints of 40 x 62 in. sq. Unlike the Clivus, the composter does not have an inclined tank; it has rotating tines to control the downward movement of compost, which assures the removal of only the oldest compost. The porous floor separates leachate from compost and allows the bottom of the pile to remain aerated. In the bottom, liquid receives secondary aerobic treatment as it flows through a peat moss medium. The unit is initially filled with wood shavings, and it is recommended that bulking agent be added weekly. Mixing is done with a wrench that turns the upper shaft from the front of the unit and requires no direct contact with the composting pile.[21]

For use on Appledore, the greatest concern is Phoenix's moving parts—these have potential to rust and malfunction in the corrosive environment. However, the company insists that these units have been used on ocean beaches and islands, as well as near volcanoes where they are exposed to acid fog as well as salt spray, without any problems. The rotating tines are made of pultruded fiberglass, designed for corrosive environments. All of the fasteners are stainless steel, and the ratchet and socket wrench used to drive the tine shaft are sandblasted and powder coated against corrosion. The windings and electronics in the fan are also encapsulated with a urethane conformal coating to allow the fan to run under water.[22]

The Phoenix composter can be used with waterless, ultra-low flush or Nepon foam-flush toilets. It does not come with a leachate pump—leachate must be drained manually or allowed to move into an adequate gray water system. The unit contains a tank to store surge flows and an evaporation tower with a large surface area to volume ratio. A pump moves leachate from the bottom to the top of the pile, which keeps the top of the pile moist and encourages faster composting by delivering microorganisms to fresh material. The Phoenix also promotes

[20] http://www.buildinggreen.com/features/mr/waste.cfm
[21] Sent by Ried Nelson, 7/7/08
[22] Sent by Glenn Nelson, 7/12/08

evaporation with an airflow system that circulates air over the leachate and through a series of baffles.[23]

Unlike other composting units, the Phoenix tank provides some insulation with a wall of 5/8 inch foamed polyethylene inside ¼ inch solid polyethylene. It does not come with a heater, but can be connected to a source of heat. The Phoenix conserves the most electricity out of all the other composters evaluated. It contains a 5 Watt fan that runs continuously and a 30 Watt pump that runs for 30 seconds every 8 hours. It is possible that the Phoenix is more susceptible to back drafting than other units with higher airflow, but this problem could be resolved easily with a larger fan, if needed. ACS has also modified Nepon foam-flush toilets to operate more efficiently on 12V DC; however, an inverter is supplied if standard 120V AC is preferred.

ACS also designs, manufactures and installs prefabricated buildings to house the composting toilets. These structures feature built-in photovoltaic systems, solar hot air collectors to heat the compost and computerized controls to regulate pumps, fans and lights.[24]

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Website: http://www.compostingtoilet.com

Carousel

The Carousel Composting Toilet System, made by EcoTech, consists of an outer container and an inner rotating carousel. The carousel is divided into four chambers. One chamber is used at a time, and when it fills up, the next is rotated into position. This system allows the first chamber to further compost while the others are being used, and prevents new compost from mixing with the old. Each chamber is emptied only when it needs to be used again. The waste is reduced to 10% of its original volume by the time it needs to be emptied. The entire chamber is circular, about 52 inches in diameter, and comes in two sizes: the large unit is 51.5 inches high and serves about six people year-round, and the medium is 24.8 inches high and serves about four people year-round. The capacity increases to 15 people for the medium and 22 people for the large Carousel when used seasonally. [25] Additionally, the capacity is determined with the assumption that a waterless toilet is used; when installed with a micro-flush toilet (like the Nepon foam-flush), the capacity actually increases.

The Carousel is ventilated by a 43-Watt fan, and a 4-inch diameter opening at the top of the tank allows warm air to enter into the composter and pipe into the bottom of the unit. An electric heater can be purchased with the unit, and is placed on the tank exterior for easy maintenance. The Carousel has a hose connection for leachate, but no leachate pump. The level of leachate must be monitored through a piece of transparent tubing, or can be drained to a leach field or other gray water system. It is recommended that a bulking agent be added every tenth use.

[23] http://www.buildinggreen.com/features/mr/waste.cfm
[24] Public Facility Application Guide, 2005 Edition (Phoenix guide p. 4)
[25] Carousel Guide sent by David Del Porto

The Carousel is compatible with several types of toilets, including waterless, ultra-low flush and Nepon foam-flush toilets. EcoTech offers two different waterless types, one of which has a rotating cup to seal off the chute. This toilet is better than the traditional waterless toilets because it overcomes some aesthetic concerns and is much cheaper than the Nepon foam flush toilet.[26]

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Research-Treatment Systems

Information was collected on a wide variety of systems, including sand filters, peat filters, and re-circulating media filters. Much of this information is widely available in literature, and this Results/Discussion section will be limited to systems that the interns considered possibly suitable to SML's wastewater characteristics and needs. These include both treatment methods and disposal methods. The treatment methods are aerobic treatment units and constructed ecosystems, while the disposal methods include plastic chambers, substitute aggregate pipes, and drip irrigation systems.[27]

There was also a wealth of information on gray water reuse. Gray water would need to be completely separated, treated, and disinfected before it could be reused. Even at this point, most government health agencies warn about potential health risks and often limit reuse applications to water for toilet flushing, dust control, and fire suppression. Given SML's desire to install composting toilets and the large availability of salt water for fire hoses, gray water reuse was not extensively researched by the 2008 interns. However, references are made throughout the section when the potential for gray water reuse presents itself.

Russell Martin from the Maine Subsurface Disposal Program provided a link to products approved for use in the State of Maine.[28] Information for many of the specific technologies was obtained on the EPA's website via their Wastewater Virtual Trade Show.[29] Selected technologies are included in the Digital Appendix.[30] The aerobic treatment units considered also stood out because they have received recognition through the Environmental Technology Verification (ETV) Program, an EPA program that verifies the performance of innovative technologies with the potential to improve protection of human health and the environment in order to accelerate their use in the worldwide market. The EcocyclET stood out as a constructed ecosystem from its many reviews in journals and publications. The FRICKle Filter was evaluated on the basis of its Maine approval and low energy and maintenance requirements. The in-tank septic tank filter would only be applicable if SML used a strictly gray water system.

26 http://www.buildinggreen.com/features/mr/waste.cfm
27 Digital Appendix > Gray Water > General Treatment Systems
28 http://www.maine.gov/dhhs/eng/plumb/lists.htm
29 http://www.epa.gov/ne/assistance/ceitts/wastewater/vtshow.html
30 Digital Appendix > Gray Water > EPA Virtual Tradeshow

Aerobic Treatment Units

Summary: Anaerobic treatment performed in the settling tank is usually followed by an aerobic treatment process in an oxygen-rich chamber. There are three main types of aerobic treatment units:

Suspended-growth tank: consists of two chambers, and needs to be mixed. Bacteria can form chains that won't sink and can clog pipe.

Fixed-film reactor: one chamber contains media that bacteria grow on and is supplied air. Settling occurs in a second chamber.

Sequencing batch reactor: only has one chamber. Air bubbler runs for a certain amount of time, and then stops to let solids settle. After settling, the chamber is emptied and the process repeats. Settling is more consistent than with other aerobic treatment units, but there are more mechanical and electrical components.

Advantages:

More efficient at removing organic material than anaerobic treatment
High quality effluent reduces the load on disposal field

Disadvantages:

Needs to be supplied with power
High maintenance
Can cost 2 to 3 times more than a septic tank
Requires an alarm system to detect aeration pump failures and high water levels

Specific Products Evaluated: SeptiTech Wastewater Treatment System and MicroFAST Wastewater Treatment System

Constructed Ecosystems

Summary: Constructed ecosystems use plants to filter out organisms in the wastewater. They provide aerobic treatment after the septic tank, with the plant roots acting similarly to a fixed-film reactor. These systems can be constructed inside of a greenhouse to protect the system from harsh climates.

Advantages:

Beneficial interactions between organisms and plants
Good at reducing nitrogen
Provides educational opportunities in a pleasant environment
Can last longer than conventional treatment systems

Disadvantages:

Can be expensive
Sometimes don't work well for seasonal use
Requires electricity to run pumps

Specific Products Evaluated: EcocyclET

Plastic Leach Field Chambers

Summary: Plastic leach field chambers help to spread the wastewater influent out over the sides of the chambers and through a network of openings, allowing a larger area of the soil to be used than conventional leach fields. The arch shape of the chamber supports the weight of the soil above the system.

Advantages:

Distribution of wastewater prevents clogs
Good reputation for over 15 years in the US and Canada
No additional maintenance is required
Doesn’t require any gravel
Cheap, lightweight material

Disadvantages:

Size reductions not as large as some systems

Specific Products Evaluated: Infiltrator Equalizer 24 Chambers

Substitute Aggregate Leach Field

Summary: Substitute aggregate leach fields replace gravel with lightweight synthetic material to increase the surface area. Some material (often a geotextile) is wrapped around the drainage pipes to increase the biological activity as the water flows into the drain field. Otherwise, these systems perform in the same way as a traditional drain field.

Advantages:

Increased surface area allows for a reduction in leach field size
Geotextile material reduces amount of fill needed

Disadvantages:

Biomat may be subject to clogging as with a traditional drain field

Specific Products Evaluated: Eljen In-Drain (type A) Units

Drip Irrigation System

Summary: Drip irrigation systems disperse the wastewater evenly throughout the ground and utilize plants to extract nutrients such as nitrogen. Unlike spray irrigation, drip irrigation provides slow, even distribution at a shallow depth below the soil surface. Back-flushing helps to prevent clogging. This type of drip irrigation reduces odor and pathogens, but relies on the root systems of the grass or plants above for evapotranspiration and additional surface area.

Advantages:

Pressurized dosing might reduce phosphorous
Even distribution reduces clogging
Water recycled to plants
Trenches are flexible
Timed doses increases the aeration capabilities of the soil

Disadvantages:

The shallow depth means that heavy loads (i.e. large vehicles) should not be used on the ground above the drip pipes

Requires electric power for back pumping and filtering

Needs to be designed by a registered professional engineer.

Specific Products Evaluated: Geoflow Wasteflow Classic

Treatment System Evaluation

Summary: Overall, SML should look to implement a wastewater treatment system that has shown consistent and reproducible results for pathogen removal. All of the systems evaluated have the potential to be used at SML as long as proper care is taken to ensure that the system is installed and operated as designed. Given the timeline for implementing a new wastewater system, appropriate persons at SML have approximately another year to further consider the different treatment options and contact companies who could design and install these systems. It was concluded based on the intern's evaluations that the EcocyclET system would be the most suitable choice for SML. Nevertheless, it is important to note that this system, and all other evaluated systems, have disadvantages and should be implemented with an emphasis on the health and safety of all living and non-living components of Appledore Island's ecosystem.

Below is a chart summary of the intern's evaluation of the selected treatment systems. An in-depth itemization of how the interns determined the values for comparison follows this table.

Table 12: Specific Treatment System Evaluations

Criteria	Weighting	SeptiTech	MicroFAST	EcocyclET	FRICKle	Septic
Regulatory Stand.	6%	6	6	5	6	6
Reputation	7%	5	6	6	3	4
Wastewater Char.	7%	3	5	5	4	2
Staff Req.	[8%]	--	--	--	--	--
*Training	3%	3	6	6	7	7
*Labor	5%	6	6	6	7	7
Design Life	7%	4	4	4	4	5
Compatibility	[9%]	--	--	--	--	--
*Existing Systems	1%	6	6	6	6	7
*Island Life & SML Mission	3%	4	4	7	5	5
*Climate	1%	7	7	7	7	7
*Geography	1%	5	5	4	4	2
*Hydrology	3%	5	5	7	4	4
Implementation	[6%]	--	--	--	--	--
*Time	1%	4	4	3	3	3
*Materials	3%	4	4	3	4	4

*Environment	2%	5	5	5	5	5
Aesthetics	2%	5	5	7	5	3
Residuals/Byproducts	[10%]	--	--	--	--	--
*Effluent Quality	7%	6	6	7	4	1
*Final Location	3%	5	5	7	5	5
Repair	7%	2	4	6	6	7
Reliability	7%	5	5	5	3	4
Safety	[12%]	--	--	--	--	--
*of Products	7%	6	6	7	6	6
*for Operators	5%	5	6	6	6	4
Cost	[12%]	--	--	--	--	--
*Capital	4%	4	4	2	4	4
*O & M	8%	3	3	4	5	5
Overall	100%	***4.43***	***4.92***	***5.28***	***4.79***	***4.68***

SeptiTech Treatment System [31,32]

Summary: SeptiTech's technology focuses on electrical controllers that manage the mixing of water and air to create an ideal aerobic environment and provide significant secondary treatment. SeptiTech was rated the lowest of the evaluated treatment system. The system provides reliable treatment, but similar treatment could be achieved by some of the other systems that have less mechanical parts. Overall, this treatment system could work well for SML though.

Criteria:

- Regulatory Standards: 6
  SeptiTech is approved by the state of Maine and it should not be too difficult to obtain permission to use this system.
- Reputation: 5
  SeptiTech has been verified through the EPA's Environmental Technology Verification (ETV) Program, indicating strong results considering its novelty. We did not find any other sources to provide feedback on the system, but several successful projects are listed on their website which, along with the ETV verification, provides a positive overall reputation.
- Wastewater Characteristics: 3
  SeptiTech representatives indicated that their system would work best with full-strength wastewater (not just gray water). This would give a larger flow of total wastewater and previous reports have shown toilet effluent to contribute heavily to SML's wastewater flow because of water conservation in other uses. An alternative option to needing blackwater would be to bring in start-up sludge at the beginning of the season. It also indicates that composting toilet leachate and a few regular toilets, which would have been difficult to replace with composting toilets, could remain on SML's wastewater system. However, the representatives also advised against using saltwater, which would place additional demand on

[31] http://www.septitech.com/

[32] Digital Appendix > Gray Water > SeptiTech Info

the island's freshwater supply. These needs for a higher total wastewater flow (or start-up sludge) and for freshwater are not ideal.

- Staff Requirements

  Training: 3

  Staff members would need to be familiar with the control panel for the system. The treatment process is controlled electronically, which, although unlikely, has the potential to cause problems if the control panel malfunctioned and needed to be repaired.

  Labor: 6

  No routine maintenance would be required. This would not put a large burden on the number of staff members since they would only be needed for an emergency.

- Upgrade Capability/Design Life: 4

  The manufacturer provides a 2-year warranty with the product and the option for an extended warranty. Although SeptiTech has mechanical and electrical components, the company claims that their high strength, non-corrosive components, minimal moving parts, self-cleaning media, highest quality, long-life pumps promote long life for the system.

- Compatibility

  Existing Systems: 6

  The SeptiTech model could easily be installed where the septic tank and treatment center are currently located. The only new piping that would be that required would be for sending the effluent to a leach field.

  Island Life + SML Mission: 4

  Treated effluent from the SeptiTech system could be pumped to a disposal field, which would allow SML to get off of its overboard discharge permit. However, the system does require a significant amount of electric power to run the controller and pumps, which do not run constantly, but more often than the current batch pumps. SML is looking for ways to reduce their load and meet their energy demand with green power.

  Climate: 7

  The system is contained underground and careful choice of tanks and pipes could help prevent damage and corrosion from Appledore's climate conditions.

  Geography: 5

  The State of Maine gives SeptiTech the largest reduction in leach field size for most disposal options (not Eljen In-Drains), making it easier to find a suitable leach field location. SeptiTech allows for a 50% reduction in leach field area and a one foot reduction in required depth of backfill needed between bedrock and the bottom of the system.

  Hydrology: 5

  The system provides reliable secondary treatment and after traveling through a disposal field, the effluent should be safe to re-enter the ground water supply. However, given SML's concern for the quality of their well water, it may be desired that a professional be brought in to conduct a thorough evaluation of the island's hydrology.

- Implementation

  Time: 4

  Installation of the SeptiTech system seems to be a fairly involved process. The wiring for the controller and pumps would need to be done by an experienced electrician. The total installation time would likely be similar to any choice involving a disposal field.

Materials: 4
Most of the needed materials could be chosen to be light and easy to transport. The exception to this is the sand, soil, or mulch needed for a disposal field.
Environment: 5
Large impacts could be made on the local environment from the construction of a disposal field, but these would be similar to any option involving a disposal field.

- Aesthetics: 5
The majority of the system would be underground and would not cause significant noise disturbances since the pumps would be comparable in size to those currently being used in the wastewater treatment system. Also, SeptiTech claims that their system has no odors.
- Residual/Byproducts
Effluent Quality: 6
SeptiTech claims to reduce BOD and TSS levels by 98%. These reductions are enough to allow significant reduction in leach field size. Also, recognition through the ETV verification indicates the high quality of effluent.
Final Location: 5
The effluent would meet requirements set by the State of Maine for subsurface disposal, avoiding the need to discharge water to the ocean. The system includes a pump, which would be needed to send the effluent to a disposal field and safely return it to the island's groundwater supply.
- Repair: 2
SeptiTech includes several moving parts and complicated electronic controls. This increases the likelihood of parts breaking and a need for repair. Also, this repair may be more difficult since the system is installed underground.
- Reliability: 5
A benefit of the controller systems used by SeptiTech is that the system can make adjustments and provide consistent performance even with fluctuations in flow rates. However, if the system is to be used as a gray water system, the reliability would depend on bringing in bacteria to start up the system at the beginning of the season.
- Safety
of Product: 6
SeptiTech does not require any chemicals and relies only on mixing air, water, and microorganisms in the wastewater. The system should not pose any significant health risks since it meets requirements for lowering BOD, TSS, Fecal Coliforms, and additionally provides denitrification.
for Operators: 5
Operators would not be exposed to any dangerous chemicals or machinery. They should use caution when pumping the septic tank, as would be expected with any system. Additional caution should be used if SML decides to keep a mainly gray water system and bring in start-up sludge.
- Cost
Capital: 4
Capital costs are fairly high for the SeptiTech system. The system components would cost approximately $17,500. This does not include installation, a new septic tank, or costs for

purchasing/installing a disposal field. Some savings would be realized in the reduced size of the leach field.
O + M: 3
The pumps used in this system would require roughly 22kWh/day, placing an additional load on the island's energy source. Additionally, the need to use freshwater in some of the toilets might require that the Reverse Osmosis machine be started slightly earlier in the season. This is not ideal since SML is looking to reduce demand and run a 30kW generator instead of their 65 kW generators.

MicroFAST Wastewater Treatment System [33,34]

Summary: MicroFAST was evaluated as the 2nd choice treatment system. Like SeptiTech, it is an aerobic treatment unit that uses technology to combine several older techniques more efficiently. It less complex than the SeptiTech system though, which would be a benefit for SML. Overall, it would provide excellent secondary treatment and could work well as part of SML's new wastewater system.

Criteria:

❖ Regulatory Standards: 6
MicroFAST is approved by the state of Maine and it should not be too difficult to obtain permission to use this system.
❖ Reputation: 6
MicroFAST has been verified through the EPA's Environmental Technology Verification (ETV) Program, indicating strong results considering its novelty. The system was also evaluated in the wastewater study conducted by Dr. Kinner and Geoffrey Grant in 1997. In this report, the system was not explicitly recommended. However, the study concluded that SML should use overboard discharge for the current time and skip a secondary treatment unit. FAST was the only evaluated system that was not specifically listed as inappropriate for SML.
❖ Wastewater Characteristics: 5
MicroFAST representatives indicated that their system would work for both freshwater and saltwater influents. As indicated in Dr. Kinner's report, the system would require sludge to start-up at the beginning of the season. Otherwise, SML's wastewater should work with the system and considerations as to whether gray or black water was used would probably be based on freshwater and energy requirements among these options. Also, the total volume of effluent should be taken into consideration.
❖ Staff Requirements
Training: 6
MicroFAST's only moving part is an air blower that would be located above ground. Electricity would be needed to run the pump, but the system would require much less expertise or training than other systems that are part of the island's infrastructure, such as the controls in the radar tower.
Labor: 6
No routine maintenance would be required. This would not put a large burden on the number of staff members since they would only be needed for an emergency.

[33] http://www.biomicrobics.com/Products/MicroFAST/about_MCF.html
[34] Digital Appendix > Gray Water > MicroFAST Info

- Design Life: 4
  MicroFAST's design life could be extended by routinely pumping the septic tank as recommended. Also, as mentioned in Dr. Kinner's report, a protective epoxy-coating could be applied if the system used saltwater. Otherwise, corrosion would likely be minimal and the system should last approximately as long as other secondary treatment units.
- Compatibility
  - Existing Systems: 6
    The MicroFAST model could easily be installed at the location of the current wastewater septic tank and all of the current wastewater lines could feed into it as they currently do. The only new piping would be that required for sending the effluent to a leach field.
  - Island Life + SML Mission: 4
    Treated effluent from the MicroFAST system could be pumped to a disposal field, which would allow SML to get off of its overboard discharge permit. The system does require a significant amount of electric power to run the controller and pumps, however. SML is looking for ways to reduce their load and be able to meet their demand with green power, so having these pumps run more frequently than the current wastewater batch pumps would not be ideal.
  - Climate: 7
    The system is contained underground and careful choice of tanks and pipes could help prevent damage and corrosion from Appledore's climate conditions.
  - Geography: 5
    The system would most likely be about the size of the current septic tank, so it should not be difficult to find a site for it. It also provides for a significant reduction in leach field size, making it easier to find a suitable leach field location. It requires fewer tanks than SeptiTech and like SeptiTech allows for a 50% reduction in leach field size, but does not reduce the necessary distance between the bedrock and the bottom of the system.
  - Hydrology: 5
    The system provides reliable secondary treatment and after traveling through a disposal field, the effluent should be safe to re-enter the ground water supply. However, given SML's concern for the quality of their well water, it may be desired that a professional be brought in to conduct a thorough evaluation of the island's hydrology.
- Implementation
  - Time: 4
    Installation of the MicroFAST system should not be very involved beyond putting in the new tanks. The total installation time would be similar to any choice involving a disposal field, although it could be slightly lower since this system allows a smaller size field.
  - Materials: 4
    Most of the needed materials could be chosen to be light and easy to transport. The exception to this is the sand, soil, or mulch needed for a disposal field.
  - Environment: 5
    Large impacts could be made on the local environment from the construction of a disposal field, but these would be similar to any option involving a disposal field.
- Aesthetics: 5
  The majority of the system would be underground and would not cause significant noise

disturbances since the pumps would be comparable in size to those currently being used in the wastewater treatment system. Also, MicroFAST claims that their system has no odors.

- Residual/Byproducts

  Effluent Quality: 6

  MicroFAST claims to reduce BOD and TSS by over 90% with effluent concentrations of less than 10mg/L for each characteristic. These reductions are enough to allow significant reduction in leach field size. The system has also shown to produce 70% nitrogen reductions. Also, recognition through the ETV verification indicates the high quality of effluent.

  Final Location: 5

  The effluent would meet requirements set by the State of Maine for subsurface disposal, avoiding the need to discharge water to the ocean. The system includes a pump, which would be needed to send the effluent to a disposal field where it could safely return to the island's groundwater supply.

- Repair: 4

  MicroFAST's air blower is the only moving part. Also, these systems come equipped with a simple control panel. Common malfunctions (including blower interruption/failure and high water conditions) would trigger both visual and audible alarms. These panels could also be adjusted based on the user's preferences for timing and alarms. Repair for the system may be more difficult since the system is installed underground.

- Reliability: 5

  MicroFAST's microbial processes are self-regulatory and the system can adjust for variable water loads. However, if the system is to be used as a gray water system, the reliability would depend on bringing in bacteria to start up the system at the beginning of the season.

- Safety

  of Product: 6

  MicroFAST does not require any chemicals and relies only on mixing air, water, and microorganisms in the wastewater. The system should not pose any significant health risks since it meets requirements for lowering BOD, TSS, Fecal Coliforms, and additionally provides denitrification.

  for Operators: 6

  Operators would not be exposed to any dangerous chemicals or machinery. They should use caution when pumping the septic tank, as would be expected with any system.

- Cost

  Capital: 4

  Capital costs are fairly high for the MicroFAST system. Budget price for a MicroFAST 3.0 including blower (with enclosure) and control panel and alarm is: $20,000 according to the local distributor, J & R Engineered Products. This price does not include the tanks, installation, or costs for purchasing/installing a disposal field. Some savings would be realized in the reduced size of the leach field.

  O + M: 2

  The pumps used in this system would use roughly 56kWh/day, placing a significant additional load on the island's energy source. This is not ideal since SML is looking to reduce demand and run a 30kW generator instead of their 65 kW generators.

EcocyclET [35,36,37]

Summary: EcocyclET was evaluated as the best option for SML's new wastewater system. The constructed ecosystem would effectively treat the wastewater, protect the health and safety of those on Appledore Island, and provide many opportunities for learning. During the internship Final Presentation, it was suggested that a similar system be constructed at SML's mainland facility in Portsmouth, NH. This would allow SML to grow plants on the mainland and transport them quickly to the island in case of a garden failure. It could also allow additional studies to compare the performance of the system on the mainland and the island. Additionally, it may be possible to find funding for this project via Cornell's public College of Agriculture and Life Sciences. The system would be more expensive the construct and would require more maintenance, but the appeal of a greenhouse environment could likely improve people's willingness to take responsibility for monitoring and maintenance.

Criteria:

- Regulatory Standards: 5
  EcocyclET and similar systems have been installed in several locations in Maine and the New England area. The company that designs the system, the Ecological Engineering Group, assists in obtaining permitting and approval. The innovative nature of the system may make it more difficult to obtain a permit in comparison to the other evaluated systems.
- Reputation: 6
  Articles highlighting the success of such systems have been featured in many sources, including a professional journal, Ecological Engineering. Also, the engineering interns met Paul Doscher, from the Society for the Protection of New Hampshire Forests, who was visiting SML and gave excellent reviews of the evapotranspiration system used by his company to treat the gray water at their Conservation Center building.
- Wastewater Characteristics: 5
  EcocyclET could be engineered to handle both freshwater and saltwater influents. SML's wastewater should work with the system and considerations as to whether gray or black water was used would probably be based on freshwater and energy requirements among these options. Also, the total volume of effluent should be taken into consideration.
- Staff Requirements
  - Training: 6
    EcocyclET does not involve mechanical components. Maintenance only involves basic gardening that could be completed by working interns or possibly the garden volunteers, who currently take care of Celia Thaxter's garden. The choice of plants would determine how much maintenance they require.
  - Labor: 6
    Working interns currently maintain the grounds by mowing, weed-whacking, and other related tasks, and the garden volunteers already come on a weekly basis. The system could be chosen to have minimal maintenance, which could easily be incorporated into the current staff routines.
- Design Life: 4
  The greenhouse structure is designed to last for a long time and uses a reliable liner to

[35] http://www.ecological-engineering.com/
[36] http://www.wixnet.ca/watersheds/whatwedo/wwg.html
[37] Digital Appendix > Gray Water > Ecological Engineering Group Info

prevent leakage. Like the other evaluated technologies, bringing in more materials to expand the system could be a sizable task and be limited by space. The beds in the greenhouse are lined, usually with 30 mil PVC and are then filled with gravel that would last for many years without deteriorating.

- Compatibility

  Existing Systems: 6

  Estimates given by David Del Porto allowed the interns to calculate an approximate area needed for the greenhouse. The possible location is drawn on the map in the Treatment Site Assessment portion of this section and would involved only slight modifications in piping since pipes currently run in that direction to discharge effluent into the ocean. Construction of greenhouse beds would be comparable to construction of a leach field for treatment systems that require disposal.

  Island Life + SML Mission: 7

  EcocyclET could potentially fit very well with SML's mission and culture. The system would have zero discharge, protecting the valuable water resources on the island. Also, the process would be sustainable since the harvested plants could provide additional biomass to the island compost. Furthermore, EcocyclET would provide various opportunities for learning, both for engineers and biology students. Similar greenhouses have also become eco-tourist attractions in other areas and would be a great addition to island tours.

  Climate: 7

  The system would likely be contained in a greenhouse and has been shown to work well in colder climates, especially with seasonal use. Also, containment would protect the system from the island's corrosive atmosphere and prevent unplanned interactions with other island inhabitants, such as the gulls.

  Geography: 4

  The system would be larger than most of the leach fields associated with the evaluated technologies, but would require similar construction. The potential location investigated by the interns is somewhat flat in elevation, assisting in construction.

  Hydrology: 7

  The system provides excellent treatment and no effluent, eliminating the risk of groundwater contamination. Also, an island hydrology report would not be necessary.

- Implementation

  Time: 3

  The total installation time would likely be longer than constructing just a disposal field, since the greenhouse structure would be needed also. It may be required to harvest plants at the end of the season and plant new ones at the beginning, although designers could assist in choosing plants to minimize or possibly eliminate this requirement.

  Materials: 3

  Most of the needed materials would need to be brought onto the island, including plants, greenhouse materials, new settling tanks, and sand/gravel for the plant beds.

  Environment: 5

  Large impacts could be made on the local environment from the system's construction, but these would be similar to any option involving a disposal field.

- Aesthetics: 7
  The greenhouse would be a pleasant and enjoyable addition to the island. It could be visually appealing and have no unpleasant odors.
- Residual/Byproducts
  - Effluent Quality: 7
    The system would likely be designed as a zero-discharge system, thereby eliminating concern over effluent quality. However, water that passes through the greenhouse is of high enough quality that it could be diverted for reuse, which might offer an option to keep regular toilets in the Grass Foundation Lab. Reuse would involve disinfection; however, it may be possible to obtain a donated UV machine for this purpose from Dr. Jim Malley at the University of New Hampshire.
  - Final Location: 7
    No effluent would need to be sent to the ocean or SML's groundwater supply. Using a zero-discharge system would be an excellent option for the final location. After treatment, water would return to the plants and the atmosphere, bacteria would digest pathogens, and other nutrients would be returned to their various chemical cycles. If SML chooses to keep regular toilets in the Grass Lab, treated water from the greenhouse could be used in those toilets and then retreated there after its second use.
- Repair: 6
  EcocyclET does not have any moving parts or complicated electrical components that could need repair. Repairs would likely be limited to pump or settling tank problems, which are needed for any wastewater treatment system.
- Reliability: 5
  EcocyclET would be sized to handle variability in water loads. Also, the tanks involved in the system prevent flow rate changes from lowering the reliability of the system. Choice of plants that thrive reliably would help ensure reliability of the system.
- Safety
  - of Product: 7
    EcocyclET does not involve any chemicals and relies only on ecological interactions among organisms in the system. There are no health risks since the system treats the water to remove BOD, TSS, Fecal Coliforms, nitrogen, and other components of wastewater without exposing anyone to contact with pathogens.
  - for Operators: 6
    Operators would not be exposed to any dangerous chemicals or machinery. They should use caution when pumping the septic tank, as would be expected with any system.
- Cost
  - Capital: 2
    Capital costs are the highest for EcocyclET compared to other evaluated treatment systems. David Del Porto provided a rough estimate of $85,000 for design and construction. The cost for plants, sand & gravel, settling tanks or filter to remove solids, and pipes would depend on the system design. Also, the price does not include transportation of materials to the island, which would be higher than those for transporting leach field materials since are larger area is required.
  - O + M: 4
    No estimates were available to the energy usage of the system. The interns found that a

single pump was required to send water from settling tanks through the plant beds, so these costs may be similar to those involved with pumping from other systems to a leach field. Maintenance could likely be carried out by current island workers without much labor time or cost, but this would depend greatly on plant choice.

<u>FRICKle Filter</u>

Summary: The FRICKle Filter was evaluated as the 3rd choice for SML's new wastewater system. If operating properly, the system has been shown to be effective and would require little maintenance or electricity demand. Possible failure of the synthetic media at the K-House would be a reason for SML to obtain more data before installing this system on a larger scale.

Criteria:

- Regulatory Standards: 6
  FRICKle Filters are approved by the state of Maine and it would most likely be easy to obtain permission to use this system. Also, SML currently uses a FRICKle Filter with the K-House wastewater system, indicating its likelihood for approval on Appledore Island.
- Reputation: 3
  The interns did not discover any sources for information on the FRICKle Filter other than experiences with the system at SML. Mr. Frick cited excellent performance in other installations where chambers were filled. Nonetheless, interns and several Engineering Mentors questioned the system's performance at the K-House. Results from EAI could neither confirm nor deny performance based on sources of error as discussed in that section of the report.
- Wastewater Characteristics: 4
  No information was found on whether salt water could be included in wastewater treated by a FRICKle Filter. These filters are designed to handle both black water and gray water, making it possible to add composting toilet leachate and a small volume of toilet water. As with other systems though, composting toilets would be preferable and SML should consider availability of freshwater and energy, as well as total effluent volume in deciding whether to use a black or gray water system.
- Staff Requirements
  - Training: 7
    FRICKle Filters have no moving parts and no electrical components. No specific knowledge would be needed except having new staff be familiarized with the system.
  - Labor: 7
    No routine maintenance would be required. If properly installed, the system should only need to be looked at periodically to ensure that the media does not need replacement.
- Design Life: 4
  The design life could be extended by routinely pumping the septic tank and filter media as recommended. Otherwise, corrosion would likely be minimal and the system should last approximately as long as other secondary treatment units. The tank at the K-House is constructed from concrete, but new models can also be made out of plastic materials now.
- Compatibility
  - Existing Systems: 6
    A FRICKle Filter could easily be installed at the location of the current wastewater septic

tank and all of the current wastewater lines could feed into it as they currently do. The only new piping would be that required for sending the effluent to a leach field.

Island Life + SML Mission: 5

Treated effluent from the FRICKle Filter system could be pumped to a disposal field, which would allow SML to get off of its overboard discharge permit. Unlike the other treatment systems that require a leach field, this one does not require any electricity to operate. It would require power to pump effluent to a disposal field. This pump would likely need to be less powerful than the pump that current pumps used for discharging wastewater out to the ocean though.

Climate: 7

Appropriate choice of tanks and pipes could help prevent damage and corrosion from Appledore's climate conditions.

Geography: 4

The system would most likely be about the size of the current septic tank, so it should not be difficult to find a site for it. It also provides for some reduction in leach field size, making it easier to find a suitable leach field location. Unlike SeptiTech and MicroFAST, the FRICKle Filter only allows for a 20% reduction in leach field size. It also does not reduce the necessary depth of the leach field.

Hydrology: 4

The system provides reasonable secondary treatment and after traveling through a disposal field, the effluent should be safe to re-enter the ground water supply. However, given SML's concern for the quality of their well water, it may be desired that a professional be brought in to conduct a thorough evaluation of the island's hydrology. Additionally, there may be more concern regarding water quality given the questionable performance of the model at the K-House.

- Implementation

Time: 3

Installation of the FRICKle Filter system should not be very involved beyond putting in the new tanks and filling them with the chosen media. The total installation time would be similar to any choice involving a disposal field, although it could be expected to be longer since a larger disposal field would be needed.

Materials: 4

Most of the needed materials could be chosen to be light and easy to transport. The exception to this is the sand, soil, or mulch needed for a disposal field.

Environment: 5

Large impacts could be made on the local environment from the construction of a disposal field, but these would be similar to any option involving a disposal field.

- Aesthetics: 5

The tanks would be installed partially underground and would not cause significant noise disturbances since the pumps would be comparable in size to those currently being used in the wastewater treatment system. Also, the system should not produce very strong odors when working properly.

- Residual/Byproducts

Effluent Quality: 4

FRICKle Filters reduce the concentrations of BOD, TSS, Fecal Coliforms, and TKN before sending the effluent to a disposal field for groundwater recharge. However, it may be possible that the synthetic media does not perform as well or could deteriorate and clog the disposal field.

Final Location: 5

The effluent would meet requirements set by the State of Maine for subsurface disposal, avoiding the need to discharge water to the ocean.

- Repair: 6
  Repairs on the FRICKle Filter should not be difficult since it is easy to remove the covers and does not have any moving parts or required electrical components. Malfunctions with the tank or pump are possible, but those could occur with any wastewater treatment system.
- Reliability: 3
  The FRICKle Filter works as water flows into the treatment tanks and using a settling tank with baffles should prevent problems with variable loads. It does not include a monitoring system or performance indicator like the other treatment systems and, if not checked, could be malfunctioning without anyone being aware of the problem.
- Safety

  of Product: 6

  This system does not require any chemicals and relies only on anaerobic and aerobic processes of the microorganisms in the wastewater on the surface of the chosen media. The system should not pose any significant health risks since it meets requirements for lowering BOD, TSS, Fecal Coliforms, and additionally provides denitrification when performing properly.

  for Operators: 6

  Operators would not be exposed to any dangerous chemicals or machinery. They should use caution when pumping the septic tank, as would be expected with any system.
- Cost

  Capital: 4

  FRICKle Filter costs are relatively low in comparison to other evaluated treatment systems. The system at the K-House cost approximately $1,500. A larger system for the rest of the island's wastewater would likely cost more, although an actual price estimate was not obtained. The costs of a disposal field for this system would be higher than those for SeptiTech or MicroFAST since a larger area would be required. The total capital cost savings in comparison to other treatment systems would depend on the disposal method chosen and would likely be minimal.

  O + M: 6

  This system would probably involve less power for pumps than the current wastewater system and should not have any significant operation and maintenance costs. The media in the filter would need to be replaced, although it should last around 12-15 years and could be dependent on the wastewater characteristics (black or gray water). As with any treatment system, the settling tank would need to be pumped every few years as well.

<u>Septic Tank Filter</u> [38]

Summary: An effluent filter for the new septic tank could be feasible for SML's new wastewater treatment. Such a filter would promote longevity of the leach field, but would likely only be allowed if SML used a completely gray water system.

[38] Digital Appendix > Gray Water > Email Correspondences > State of Maine Agencies

Criteria:

- Regulatory Standards: 6
  Russell Martin from the State of Maine's Subsurface Wastewater Program indicated that it may be possible for SML to receive approval for using a disposal field without secondary treatment if SML used a strictly gray water system. SML would need to determine the characteristics of their gray water before such a system would likely receive approval. There are several filters approved by the State of Maine to filter small solids in the septic tank before sending effluent to a disposal field.
- Reputation: 4
  The interns did not discover any sources for information on the reputed performance of any in-tank filters and would recommend any of the ones listed as approved products for the State of Maine. One such filter is used in a settling tank in the current wastewater system.

- Wastewater Characteristics: 2
  Use of a septic tank filter would be limited to a strictly gray water system. This would mean that all toilets would need to be composting toilets and the leachate from these would need to be stored and disposed of in some other way.
- Staff Requirements
  - Training: 7
    The filter would not require any special training and staff members who might clean it would simply need to follow instructions, such as making sure water used to rinse the filter remains in the septic tank.
  - Labor: 7
    No routine maintenance would be required. If properly installed, the system should only need to be looked at periodically to ensure the filter does not need to be rinsed.
- Design Life: 5
  The design life of the product was not determined, but since they require cleaning about every 3 years, it would probably last many years beyond this. Replacing the filter with another one designed to handle larger flows could be easily accomplished. However, disposal fields would need considerable expansion if flows increased since the filter does not provide treatment.
- Compatibility
  - Existing Systems: 7
    An in-tank filter can easily be installed into existing tanks or new tanks that may be purchased.
  - Island Life + SML Mission: 5
    The filter could help trap solids in the anaerobic treatment atmosphere, which could help extend the life of the septic tank and disposal field.
  - Climate: 7
    Climate should not have a significant impact on the performance of the filter.
  - Geography: 2
    A larger disposal field would be required if filtration of solids without secondary treatment was chosen. This would make the task of finding an appropriate site for disposal more challenging.

Hydrology: 3
The system does not provide any secondary treatment, but could possibly meet the State of Maine's requirements for safety to re-enter the ground water supply with an appropriately designed disposal field. However, given SML's concern for the quality of their well water, it may be desired that a professional be brought in to conduct a thorough evaluation of the island's hydrology.

- Implementation
  Time: 3
  Installation of the filter itself would not involve much time. However, the time of installing the complete treatment system would likely be longer since a larger disposal field would be needed.
  Materials: 5
  The materials needed would be similar to those needed for the other secondary treatment systems with disposal fields. New septic tanks could be chosen to be lightweight materials and the filter itself is small and light.
  Environment: 5
  Large impacts could be made on the local environment from the construction of a disposal field, but these would be similar to any option involving a disposal field.
- Aesthetics: 3
  The tanks would likely be installed underground and would not cause significant noise disturbances since the pumps would be comparable in size to or smaller than those currently being used in the wastewater treatment system. The septic tank would likely produce undesirable odors, but these should be less foul than the odors currently present if the wastewater was only a gray water system.
- Residual/Byproducts
  Effluent Quality: 1
  Since the filter does not provide treatment, the effluent quality would be highly dependant on the island's water usage. It would be advisable for SML to evaluate the products being used in the bathrooms and kitchens to be aware of the possible contaminants.
  Final Location: 5
  The effluent would meet requirements set by the State of Maine for subsurface disposal, avoiding the need to discharge water to the ocean.
- Repair: 7
  Repairs on an in-tank filter should not be necessary since it does not have any moving parts or required electrical components. Malfunctions with the tank or pump are possible, but those could occur with any wastewater treatment system.
- Reliability: 4
  The filter works as water flows into the treatment tanks and using a settling tank with baffles should prevent problems with variable loads. No other information on the product's reliability was found.
- Safety
  of Product: 7
  This system does not require any chemicals and the interns found no reasons for the product to pose safety risks during its operation.

for Operators: 4
Operators would not be exposed to any dangerous chemicals, machinery, or extra electrical parts. They should use caution when pumping the septic tank, as would be expected with any system. Additionally, operators should use caution when rinsing/cleaning the filter in order to avoid contact with untreated wastewater.

- Cost

  Capital: 7
  An in-tank filter would be very inexpensive compared to secondary treatment systems. However, the larger disposal field would increase capital costs enough to make those costs comparable to the other treatment systems that require a disposal field.

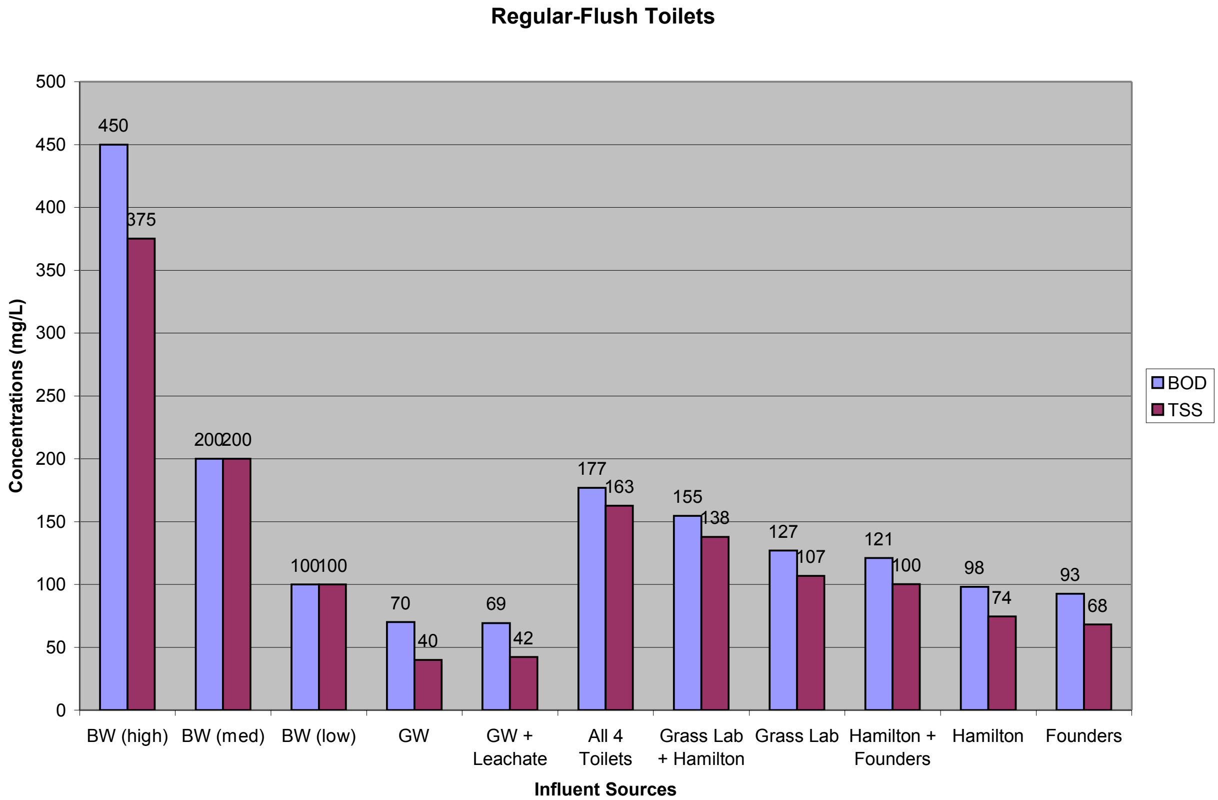
  O + M: 6
  This system would probably involve less power for pumps than the current wastewater system and should not have any significant operation and maintenance costs. The filter would need to be replaced at some point and as with any treatment system, the settling tank would need to be pumped every few years as well. There is also the possibility of maintenance costs if the filter fails or does not perform as well as the secondary treatment units that lead to clogs in the disposal field.

Mass Balance

The calculations for the mass balance, summarized in the chart below, indicate the likely effects on concentrations of BOD and TSS entering the septic tank with respect to different wastewater sources. The chart shows calculations based on using the toilets currently installed in each of the buildings where non-composting toilets may remain. The first bars in the chart show BOD and TSS levels commonly found in high strength, medium strength, and low strength black water and household gray water as reference points for comparison. The remaining bars in the chart show BOD and TSS concentrations for including the following sources to an otherwise gray water system respectively: composting toilet leachate only; composting toilet leachate and toilet effluent from the Grass Lab, Hamilton, and Founders; composting toilet leachate and toilet effluent from the Grass Lab and Hamilton; composting toilet leachate and toilet effluent from the Grass Lab; composting toilet leachate and toilet effluent from Hamilton and Founders; composting toilet leachate and toilet effluent from Hamilton; composting toilet leachate and toilet effluent from Founders.

Overall, since most treatment systems could be designed to handle black water, the mass balance calculations indicate that it might be feasible for SML to keep some or all of the 4 non-composting toilets on the system. However, these charts do not show the variations in TKN or Fecal Coliforms in the wastewater, so it may be advisable to perform further calculations for these parameters before making decisions related to adding non-gray water effluent to the new wastewater system. Another important point to remember is the extra water and energy requirements of having non-composting toilets since they would require freshwater to run on. Higher energy and monetary costs would also be necessary to handle a greater total flow of wastewater, so the cost and difficulty of replacing all toilets may be justifiable.

Figure 5: Mass Balance Results



A similar chart was also generated assuming that the non-composting toilets be replaced with new, low-flush toilets. This option was considered because it would allow for more conservation of fresh water. The chart for this data can be found in the Digital Appendix and it will only be noted in the report that BOD and TSS concentrations differed very little (approximately 1-3 mg/L) between low-flush and regular-flush concentrations. The chart is not included since low-flush toilets might not work well with SML's water conservation plan. SML currently limits toilet flushing so that the toilet is used multiple times before flushing. This practice was included in all mass balance calculations, but may not be possible with low-flush toilets, which could clog more easily. In this case, the toilets may need to be flushed after every use and SML might not lower their freshwater use to fill the toilets or their total volume of wastewater, which would have a large impact on the size of the treatment system needed.

Site Assessments/Cost Estimates-Black Water Reduction

Summary

Feasibility for replacing island toilets with composting toilet units are described below, giving consideration to the layout of each building or location. The costs are detailed for Clivus and Carousel models, as well as construction where appropriate. In 2008 dollars, these totals range from approximately $350,000 to $375,000. However, with a 20% contingency, this range could be as high as $415,000 to $450,000.

Kiggins

Kiggins Commons is the priority for SML. Clivus proposed two M-35 composters, sized for 65,000 uses annually for year round use, or 180 uses per day. These composters may be oversized considering SML's seasonal use of the island, but for a central location such as Kiggins, it can't hurt to oversize. The M-32 model would likely work just as well. In order to install these composting units, an outbuilding will have to be built on the east side of the building. The building would connect to the current bathrooms, which would remain in place for showers and sinks.

The cost estimate for Kiggins, prepared by Clivus, is:

2 Model M-35 composters with wooden support cradles
2 Liquid removal assemblies
2 Fantech FR100 AC ventilation fan assemblies
6 Nepon foam flush toilet fixtures
1 Year supply of Neponol soap for each fixture
3 C-106 porcelain dry urinals
All necessary internal composter components for proper operation
Total without construction = $52,500
Construction = $125,000
TOTAL = $177,500

Considering the current layout of the bathrooms in Kiggins, the SML interns believe it would be enough to have three toilets in each bathroom and no urinals, so the total price presented by Clivus is slightly high. Also, construction costs could vary widely. For two M-35 composting units, Clivus recommends a 21' x 21' building. This building includes two large handicap stalls, which would not be applicable to Appledore Island. Instead, that space could be used to store hot water tanks. The roof of the outbuilding could be used for solar hot water collectors, and the tanks would have to fit inside the outbuilding, since there is no room in or under Kiggins.

<u>Bartels</u>

Bartels houses 13 people throughout the season. Clivus has recommended two M-10 composters be installed in the basement to handle the load. M-10 composting units are designed for 60 uses per day when used year round. With staff taking different days off, Bartels isn't usually full to capacity, and even if it was, 120 uses per day for a seasonal facility might not be necessary. SML might want to consider downsizing to a smaller Clivus composter, or using another composting unit. The Phoenix models that would be suitable are too tall for the basement, but two large Carousels would also work. Each is sized for six people year round, but can accommodate up to 22 when used seasonally.

Cost estimate for Bartels:

Clivus (by Clivus):
2 Model M-10 composters with wooden support cradles
2 Liquid removal assemblies
2 Fantech FR100 AC ventilation fan assemblies
4 Nepon foam flush toilet fixtures
1 Year supply of Neponol soap for each fixture
All necessary internal composter components for proper operation
Total without construction = $28,700

Carousel (by SML interns):
2 L Carousel at $4,400 each = $8,800
4 Nepon foam flush toilets at $2,000 = $8,000
Accessories for Carousel at $1,016 per unit = $2,032
Marine bilge pump at $100 each = $200
Total without construction = $19,032

Construction = $6,000
Construction involves taking out a portion of the porch in order to fit the unit inside

These are rough estimates, and comparisons should be made with care, since Clivus typically presents one price for the entire package. For example, it is unknown how much the year's supply of soap costs.

Dorms (1, 2, and 3)

Clivus recommends one M-12 composter for each dorm. These composters are sized for 30,000 uses annually, or 80 per day, for full time use. If kept at 65 degrees, these units will be underused since SML is a seasonal facility. Also, the dorms are completely full (20 people in each) for only short periods of time during the season. SML might want to consider downsizing to an M-10 composter, which can accommodate 60 uses per day, or the large Carousel composting unit. The large Carousel is sized for six plus people on a year-round basis, but up to 22 people for seasonal use (up to 60 days at maximum). According to the Ecological Engineering Group, Inc., the capacity should actually increase with the use of foam-flush toilets because the extra liquid will hydrate and frequently shift the compost pile. In addition, piping warm air into the unit can significantly speed up the composting process. However, if SML is expecting a population rise so that the dorms are full to capacity for the entire season, the large Carousel should be researched more thoroughly—it is unclear exactly how much the capacity would increase with added heat and foam-flush toilets.

According to the master population chart for 2008, the island's population is not expected to exceed 93 people over the course of the whole season. From May 10 through August 1, 2007, there were only 40 days during which more than 65 people were on the island, and only 16 days with more than 85. Although it is unclear where everyone was living, considering the island's capacity of about 148, it is safe to say that the dorms were not full to capacity for more than 60 days during either of the seasons. Because the dorms are not the highest priority and composting toilets will probably not be installed for two or three years, it is recommended that the SML staff keep track of how many people live in each dorm and for how long over the next couple of seasons. After a summer or two, this data would help SML better size the composters for the dorms.

The large Carousel is almost nine inches shorter than the M-10, which is helpful for installing the units underneath the existing buildings. Dorms 1 and 2 have the space necessary under the existing buildings to fit either the Carousel or M-10 composting units without the addition of an outbuilding. The current bathrooms would have to be moved to the opposite side of the building. Dorm 3 does not have quite enough space, and an additional outbuilding would have to be constructed—however, this building could be small enough to house just the bathroom stalls, since the ground level drops off rapidly enough at the northwest corner of the building. The large Carousel composting unit is just an inch or two too tall, and with the use of foam-flush toilets, which allow 45 degree piping to the composting unit, it may be possible not to construct the outbuilding (see drawings).

Cost estimate for the dorms:

Clivus (by Clivus):
3 Model M-10 composters with wooden support cradles
3 Liquid removal assemblies
3 Fantech FR150 AC ventilation fan assembly
6 Nepon foam flush toilet fixtures
1 Year supply of Neponol soap for each fixture
All necessary internal composter components for proper operation
Total without construction = $43,050

Carousel (by SML interns):
3 L Carousel at $4,400 each = $13,200
6 Nepon foam flush toilets at $2,000 each = $12,000
Accessories for Carousel at $1,016 per unit = $3,048
Marine bilge pump at $100 each = $300
Total without construction = $28,548

Construction:
9.5’ x 12.5’ at $150/sq.ft. = $17,813 X three dorms = $53,439

<u>Founders</u>

According to the evaluation by Clivus, the two toilets on the uphill side of Founders would need to be removed because composters cannot fit under the south side of the building. There are two toilets on each of the first two floors, so it would not be a problem to remove one. However, there is only one toilet on the third floor, and unfortunately it is also on the south side. The third floor toilet would have to be left on the current system or completely taken out, depending on the gray water system that will be installed.

For the two toilets installed on the north side, Clivus recommends one M-12 composter, sized for 80 uses per day. Since Founders can hold up to 39 people, it is recommended that SML keep track of Founder’s use for a couple of seasons before installing an M-12 composting unit. Although Founders is rarely full, if SML is planning to expand and house more people in Founders in the future, a bigger composting unit, like an M-18, which is sized for 120 uses per day, would be a better option. The north side of the building has plenty of space in the basement, seven feet sloping up to about five feet, but a shorter unit than the M-18 (at 83 in.) might be required. See the Appendix for dimensions of all researched composting units.

Cost estimate for Founders:

Clivus (by Clivus):
1 Model M-12 composter with wooden support cradle

1 Liquid removal assembly
1 Fantech AC ventilation fan assembly
4 Nepon foam flush toilet fixtures
1 Year supply of Neponol soap for each fixture
All necessary internal composter components for proper operation
Total without construction = $23,300

Construction = $10,000

Hamilton

Hamilton has one bathroom on the second floor, in the office. A composting toilet and composter would be difficult to install in this building because there is only about 57 inches of space under the building, and a classroom sits directly beneath the second floor bathroom. If it is required for SML to have all composting toilets for the gray water system to be installed, it might be worth considering installing a medium Carousel or one of the models from Clivus and Phoenix under the building. If necessary, a column could be extended through the classroom to contain the piping.

Cost estimate for Hamilton:

Carousel:
1 M Carousel = $2,700
1 Nepon foam flush toilet = $2,000
Accessories for Carousel = $1,016
Marine bilge pump = $100
Total without construction = $5,816

Construction = $10,000

Grass Lab

The Grass Lab currently has two toilets, one in the lab and one in the apartment upstairs. There is no room under the building to install a composting unit, so if these toilets had to be taken off the system, an outhouse would have to be constructed. It would be a good idea to put a composting unit on the first floor to accommodate the apartment; or to install a self-contained unit—this shouldn't cause any trouble since the upstairs bathroom is so infrequently used. The outbuilding could be constructed for interns and students in the lab, and for garden tour attendees, who would not have to disrupt classes to use the bathroom.

Cost estimate for Grass Lab:

Clivus (by Clivus):
1 Model M-54 Composter Base Unit, which includes a waterless toilet fixture and ventilation fan
Total = $14,500

Cost Estimates-Treatment Systems

The tables below show estimated costs for installing the evaluated treatment systems in 2008 dollars with a 20% contingency added on. The tables also list the estimated cubic yards of backfill required for each system. The first table shows estimates if SML were to replace all non-composting toilets on the island, while the second table estimates are based on leaving four non-composting toilets on the wastewater system. The in-tank septic tank filter is omitted from the second table since this would not be suitable unless SML used a strictly gray water system.

The components included in each system's costs can be found in the appropriate portion of the Data Collection/Methodology section. Furthermore, a breakdown of the details and calculations can be found in an Excel spreadsheet in the Digital Appendix.[39]

These costs are listed to help budget for a new wastewater system, but the cost of composting toilets and transportation/construction must also be considered.

Table 13: Cost Estimates for Treatment Systems Using All Composting Toilets

All Composting Toilets		
Treatment System	**Cost (2008 dollars)**	**Backfill Needed (yards)**
EcocyclET	$130,000.00	780
SeptiTech-Infiltrator	$ 30,000.00	190
SeptiTech-Eljen	$ 40,000.00	270
MicroFAST-Infiltrator	$ 30,000.00	260
MicroFAST-Eljen	$ 50,000.00	360
FRICKle-Infiltrator	$ 10,000.00	420
FRICKle-Eljen	$ 20,000.00	260
Septic-Infiltrator	$ 10,000.00	520
Septic-Eljen	$ 20,000.00	360

Table 14: Cost Estimates for Treatment Systems Using Some Composting Toilets

Some Composting Toilets		
Treatment System	**Cost (2008 dollars)**	**Backfill Needed (yards)**
EcocyclET	$150,000.00	890
SeptiTech-Infiltrator	$ 30,000.00	210
SeptiTech-Eljen	$ 40,000.00	300
MicroFAST-Infiltrator	$ 30,000.00	290
MicroFAST-Eljen	$ 50,000.00	400
FRICKle-Infiltrator	$ 20,000.00	480
FRICKle-Eljen	$ 20,000.00	400

Site Assessments-Treatment Systems

Below is a table of the freshwater usage for operational periods from April 2004 through June 2008. This table lists the 80th percentile values of the collected data in gallons per day, which will be a good indicator of the design flow necessary for the new system.

[39] Digital Appendix > Gray Water > Intern Spreadsheets > Cost Estimates-Treatment Systems

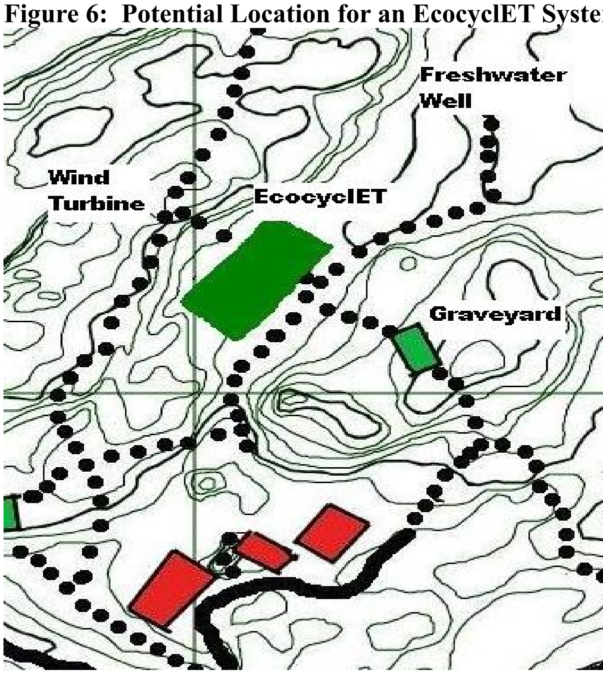
Table 15: Yearly Freshwater Usage Data

Freshwater Usage Data	
Year	**80th Percentile (gpd)**
2004	1645.82
2005	1645.82
2006	1541.09
2007	1720.63
2008*	1062.302

*Data for 2008 was only taken through June 30th

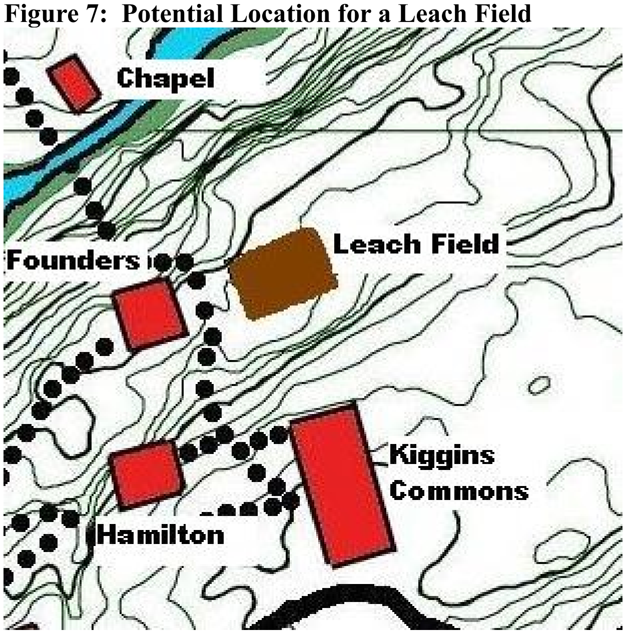
Any wastewater treatment system should be installed in a location that is safest and most accessible for those living and working on Appledore Island. The EcocyclET system only involved assessing one location for the plant beds and greenhouse. The required area for this system was estimated at 7,000 square feet. A location alongside the path leading towards the island well was chosen. The island well water is classified as ground water under the influence of surface water. The EcocyclET is designed to protect water supplies from contamination; however, given concern for the protection of the island's freshwater supply resource, it will be vital that the appropriate staff at SML confirm the system's ability to prevent all wastewater from either overflowing or seeping into the surrounding soil. Below is a map of a potential location for the EcocyclET system.

Figure 6: Potential Location for an EcocyclET System



One of the original goals at the onset of the interns' work had been to locate a location for a leach field for a new wastewater treatment system. It was also proposed that the interns investigate the feasibility of locating this leach field alongside Kiggins Commons and that the space be used for a dual purpose of a sports or recreation field for students and staff living on Appledore Island. To meet these objectives, the interns assessed a possible site for the secondary treatment choice as evaluated in this report: a MicroFAST Wastewater Treatment system with Infiltrator Leaching Chambers. The MicroFAST system dimensions can be found in the design manual, located in both the physical and digital appendices. This system would likely be installed at the current wastewater treatment location since pipes currently run to this location and there is room for the required tanks. A leach field for this system would require approximately 1,600 square feet and could potentially be located below Kiggins Commons and next to Founders as shown in the map below.

Figure 7: Potential Location for a Leach Field



The choice of the MicroFAST system is detailed in the Treatment Evaluation section. Choice of the Infiltrator chambers for a leach field was also based on a number of factors. These chambers offer the benefit of using a reduced leach field area, while minimizing the chance of biomat build-up and clogging. These chambers are also lightweight and stackable for transportation, one of the most commonly installed systems in the New England region, and less expensive than the Eljen In-Drain products. Drip irrigation products, such as the Geoflow system could potentially work at SML given their effectiveness in evenly disposing effluent and sending the effluent to the most biologically active section of the soil. However, the interns were unable to find correct sizing information for this system. Additionally, a drip irrigation system would require more energy, is less widely used, and would require that no heavy loads be moved over the leach field to prevent damaged in pipelines.

Implementation Plan Timeline

2008: Kiggins Composting Toilet Installation (Sept-Nov)

2009: Bartels Toilet Installation (April-May); Dorm Toilet Installations (Sept-Nov); Design New Treatment System

2010: Grass Lab, Hamilton, and Founders Toilet Installations; Begin Construction of New Wastewater Treatment System

2011: Complete New Wastewater Treatment System

2012: Operate on More Sustainable Wastewater System (this year also provides a buffer to stop overboard discharge in five years if construction of the new system takes longer than anticipated)

Recommendations

- Review "Implementation Plan Timeline" and other sections of the report to create a Master Plan for a new wastewater system
- Contact Al Frick (Albert Frick Associates) and Joe Ducharme (Clivus New England, Inc.) to discuss questionable performance of units installed at the K-House
- Replace all toilets on the island with composting toilets
- Conduct additional tests of the K-House system to isolate the separate components (FRICKle Filter and Eljen In-Drain)
  Contact water quality expert to help assess test results
- Collect more water use data to help accurately size a new wastewater system
- Research chemicals/products for kitchen and bathrooms
- If interested, research UV disinfection for water reuse in toilets or fire hoses
- Identify correct sizing regulations for drip irrigation to give more complete comparison between other disposal methods (plastic chambers, geotextile pipes)
- Contact the Ecological Engineering Group to discuss an EcocyclET system for SML and the mainland facility at Creek Farm

Trash Control Plan

System Overview

Each week SML transports trash and recyclable material to the mainland. Everything brought to the island that is not consumed or composted returns to the mainland as garbage or recycling.

Objective

The objective is to pinpoint significant sources of trash in order to reduce the waste that must be transported to the mainland.

Data Collection/Methodology

Surveys were passed out to students, interns and staff after dinner on June 29th 2008. The purpose of the surveys was to determine what kinds of items people bring with them and then dispose of on the island. The surveys included three questions about trash:

- Have you brought any items onto the island that you have disposed of in the island trash containers?
- Have you brought any items onto the island that you have disposed of in the island recycling or compost containers?
- Do you have any suggestions for specific ways to reduce island waste?

The first two questions elicited many "yes" or "no" answers. The questions could have been better worded to ask about specific items brought onto the island. Even so, some people wrote down specific items they had brought with them and then thrown away.

On June 30, 25% of the island's trash for the week was sorted. There were a total of sixteen garbage bags, and four were inspected. Two of the bags were clearly from the kitchen, one from Bartels, and one included bathroom trash. Four of the interns sorted through items in the trash bags and reported each item to the fifth intern who kept tallies for various types of items.

Trash bags were counted every week in order to approximate how much trash was being transported off the island. Unfortunately, this data could only be gathered for three weeks because of the interns' limited time on the island, and no specific trends were observed. See the Digital Appendix for results.

Results/Discussion

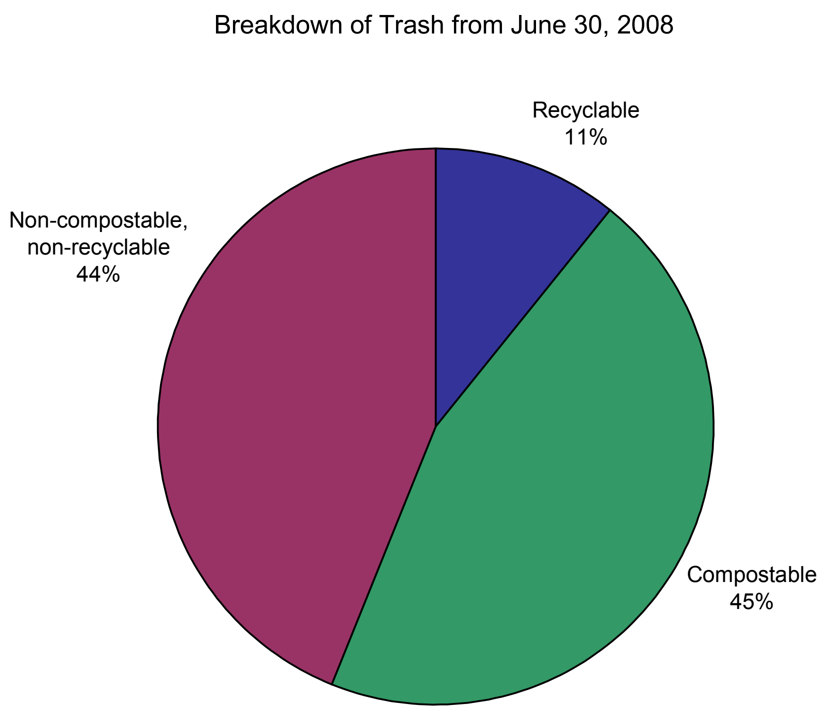
The trash surveys provided some insights into current trash habits and recommendations for a trash control plan. Based on the survey responses, the items most commonly brought to the island and thrown away are: packing materials, plastic bags, toiletry items (packaging, floss, contacts, etc.) and food packaging. The item most commonly brought to the island and recycled is beverage containers. Items most often composted include tissues and paper. Also, the most helpful suggestions to reduce island waste are listed below.

- Reduce left-over food.
- Reduce food packaging—for instance, encourage the use of durable food containers that could be reused.

- Encourage use of Nalgene-type bottles to reduce drink packaging (and dishes).
- Use an automated cloth dispenser for drying hands (cycles through one big cloth roll), or limit the amount of paper towels supplied.
- Provide paper towel dispensers (it is hard to get just one from a stack on the counter)
- Post additional information flyers about recyclable and compostable materials in high traffic locations.
- Have commonly needed supplies available, and mail a master list of what is available to students and interns (e.g. shampoo, toothpaste, foods offered in Kiggins).
- Explain the importance of waste reduction in preliminary information packets. Include a more specific list of things to bring, and suggest biodegradable items.

It was expected that the trash sorting would provide insight to what individuals bring onto the island and then dispose of. However, the results indicate that those items make up a small percentage of the trash generated by SML. The majority of the trash could have been composted or recycled. The bag from the kitchen contained large quantities of bread and fried rice. Food can be composted or fed to the gulls; it does not need to be transported off the island. There was also a significant amount of paper towels, which can be composted, as well as paper or cardboard packaging that can be recycled. The bag from Bartels contained a surprising number of beer cans, bottles and boxes, all of which should have been recycled. Figure 8 shows the breakdown of what belonged in the trash and what should have been recycled or composted.

Figure 8: Items Found in Weekly Trash Run Bags



As mentioned in the Data Collection/Methodology section, the items found were tallied during the sorting. For instance, there were 135 rubber gloves, 2 coffee filters, and 5 glass beer bottles.

The percentages shown in Figure 8 do not correspond to weight or volume, but merely represent the number of times each item was counted.

The larger issue is related to proper disposal of garbage, food, and recyclables. Educating staff, students, and visitors about what should be composted, recycled or thrown away would be an effective way of reducing unnecessary trash. Perhaps some information about waste disposal should be included in the "Fire and Water" talk. There are already signs posted in bathrooms and in Kiggins informing people how to dispose of various items. For the most part these guidelines seem to be followed.

Large quantities of rubber gloves and plastic wrap were found in the garbage bag from the kitchen. Plastic wrap is used primarily to cover food between mealtimes. Although the kitchen staff could use containers with lids, these opaque lids make it difficult to find specific food. Gloves are used both in the kitchen and in several classes. They could be replaced with biodegradable latex gloves made from natural rubber; however, these are more expensive and the kitchen staff is reluctant to spend extra money on gloves. More importantly, some people are allergic to latex, including one of the current chefs, so switching to biodegradable latex gloves is not the best option at this time.

Paper towels, tissues and toilet paper were also found in the trash. Signs are posted in bathrooms around campus to inform people that paper towels should be composted. Tissues and toilet paper can also be composted; there should be signs to remind island residents of this fact.

Some of the snacks provided in Kiggins come in individual packages. Such items include instant oatmeal, granola bars and yogurt. Of the food wrappers found in the trash, a considerable amount came from granola bars. It would reduce island trash if such individually wrapped snacks were not provided. Kiggins already offers a large container of oats with which to make oatmeal; yogurt could also easily be purchased in larger containers.

Several audience members at the final presentation speculated that the improper disposal of waste was caused by inconsistently marked receptacles, and that the ever-changing island population did not understand the how waste was supposed to be disposed. Although these issues should also be addressed, the results of the trash sorting do not indicate that new students are largely accountable for improper disposal. Unfortunately, it seems that the staff was responsible for most of the wrong disposal of compostables and recyclables. This conclusion was drawn based on the amount of food, paper, and cardboard disposed of by the kitchen, as well as the beer cans and paper packaging found in the trash from Bartels. Therefore, in addition to instructing new students at the "Fire and Water" talk, staff members should be specially instructed not only what to do with their waste, but also the importance of doing so.

Recommendations

- In order to reduce island waste, residents should be educated about the importance of waste reduction. As one survey response suggested, this should begin before students or staff arrive at SML. If students are aware that island waste is an issue before arriving on the island, perhaps they will bring less packaging with them (e.g. take the package off the flashlight before arriving). The education should continue once residents arrive. A segment about proper waste disposal could easily fit into the “Fire and Water” talk.

- It is recommended that compost buckets be placed in Bartels and the K-House. Both buildings have had compost buckets in the past, but may not have them now. It is also recommended that residents of both building be instructed on how to obtain compost buckets or recycling bins if either is missing from their building.
- It is recommended that staff be specially instructed about the importance of proper waste disposal. It is recommended that the kitchen staff be further encouraged to reduce the use of plastic wrap, as well as to compost any left over food and to recycle paper food packaging. It is also recommended that any staff living in Bartels be encouraged to recycle cans and paper packaging. Perhaps more reminder signs should be placed in the kitchen of Bartels.
- Recycled materials should be reused as much as possible. Plastic and glass containers can be used for storage. There are also many creative ways to reuse recycled objects. For example, if signs need to be made reminding island residents to turn off lights, they could be written on a piece of plastic cut from a milk jug.

Alternative Energy

System Overview

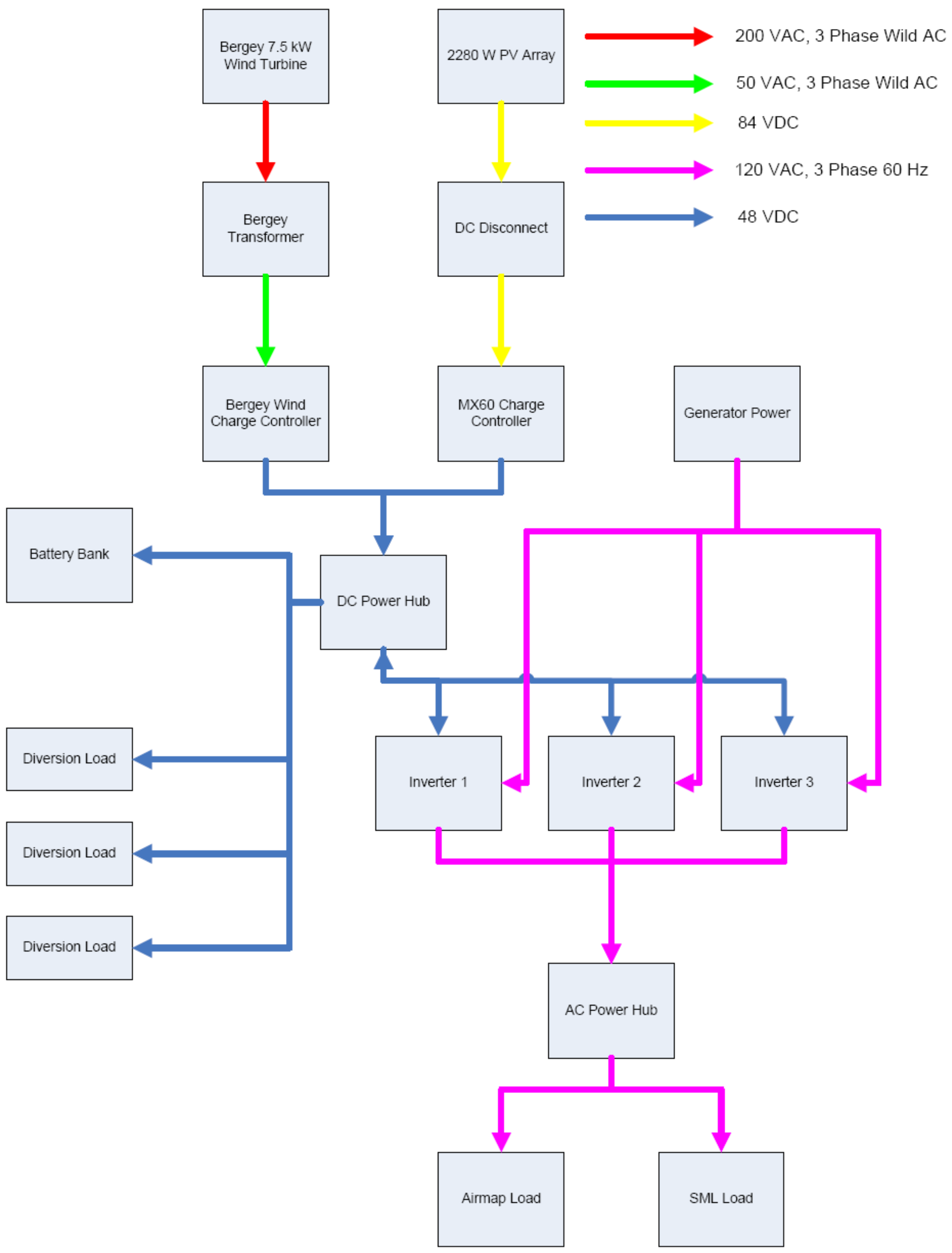
SML must meet the energy needs of all the students, staff and researchers who inhabit the island from mid April to mid September every year. What would be a challenge for any campus becomes even more difficult on Appledore because all energy must be generated on the island.

Fossil fuels are used to generate electricity and heat water. Diesel generators provide the bulk of the electricity into an island wide electrical grid. There are currently two 65 kW diesel generators running in parallel that share the island load. The generators can run simultaneously or one at a time. A new 27 kW generator has been ordered and will be installed by the end of the summer.

There is also a “green” electrical grid, supplied by a 7.5 kW Bergey wind turbine and a 4.56 kW solar array, which feed power to a DC bus and an 88 kW hour 48-volt battery bank. The green grid is configured to support the Radar Tower and two dormitories. However, so far in the 2008 season, the green grid supports only the Radar Tower; the generators power the dormitories. Propane is used to heat water in Kiggins Commons, Bartels and the K-House. Figure 9, drawn by the 2007 interns, shows the green power grid. In the current system, the green power is conditioned and then sent through a DC power hub that charges the batteries and provides power to three inverters. The inverters turn the DC into AC to be used in the AIRMAP tower. If the battery voltage runs too low, a generator will provide power through the inverters and bring the voltage back up. When Shoals Marine Lab shuts down in the off-season, so do the generators, leaving the tower completely reliant on the turbine and solar arrays. Last year, the AIRMAP equipment lost power only once; that was without the additional 2.28 kW solar array installed this year.

The generator grid is not tied into the green grid except to charge the batteries. In other words, the energy used to heat Kiggins or pump water always comes entirely from the generators. If the green grid is producing too much power, it cannot share with the generator grid, so it dumps the power as excess heat through three diversion loads.

Figure 9: Green Energy Grid Schematic



Problem Overview

There are opportunities to use additional renewable energy sources on the island. It would be ideal to greatly reduce or eliminate the island's reliance on fossil fuels. SML currently uses around 10,000 gallons of diesel every season, which must be delivered by a ship and then pumped over land and into the fuel tanks. This use of diesel and propane presents a number of problems:

1. *Cost of fuel:*
   The price of fuel is rising fast. Last year, SML paid $2.60 for every gallon of diesel delivered to the island. This year the price has increased by 73 percent to $4.50 per gallon delivered. This increase has brought the price, per kW hour of electricity generated, up to 46 cents—and that is merely from a fuel standpoint. If the cost of the generators and maintenance were included, the price per kW hour would be much higher. For reference, at 46 cents per kW hour, the average home would be paying over $400 per month to the electric utility.[40]

2. *Danger of a fuel spill:*
   SML is located on Appledore Island because the location provides an ideal place to study marine life in a natural habitat. Students and researchers come from all over the world to learn more about the many creatures inhabiting the island. Although great care is taken during the transport of fuel, there is always some risk of a spill. Such an accident would be extremely detrimental to the island and lab.

3. *Emissions:*
   The 2007 interns worked with Clean Air-Cool Planet to determine the carbon footprint of SML. They discovered that the diesel generators were responsible for releasing 87 metric tons of CO_2 in 2006 and that the use of propane released 8 metric tons. In addition to generating greenhouse gasses, the generators are extremely loud.

4. *Market Vulnerability:*
   Each year, SML must secure a shipment of diesel fuel and negotiate a price on it. This fuel is a diminishing resource.

5. *Sustainability:*
   Sustainable development has often been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[41] SML seeks to meet the current needs of the lab, and indeed does not want to compromise its future and contaminate the environment on which it depends. SML seeks to implement sustainable solutions, with the support of Cornell University and UNH. The burning of large amounts of fossil fuels conflicts with this mission.

Objective

The objective is to determine what sources of renewable energy and technology would be well suited for the island and to recommend a method for integrating them with the existing system in order to reduce or eliminate the need for fossil fuels.

[40] According to the department of energy the average U.S. household consumes 10,654 kW hours per year.
[41] *Our Common Future*, Brundtland, 1987

Data Collection/Methodology

Wind speed data was downloaded from AIRMAP's database. The wind speed comes from an anemometer on top of the radar tower at a height of 18.29 meters. The downloaded data represents the wind speed averaged over ten minute intervals for the last year.

Paul Krell and Nathan Sherwood of Unitil visited the island and attached a device to the wind turbine transformer that recorded data. The voltage and current were recorded every five minutes for each of the three wild AC phases coming out of the turbine. The collection period was one week, from July 2^{nd}-8^{th}, 2008.

Generator load data was recorded from the Allen-Bradley Power Monitor 3000, which is hooked into the generator grid. The data was taken on five days, every hour from 8am to 7pm.

Pumping load data was obtained from the cistern pump, the well pump, and the saltwater pump in order to determine what percentage of the island's energy production is used on these pumps. The data was obtained by using ammeters and voltage meters on the pump wires, as well as determining the rate of flow.

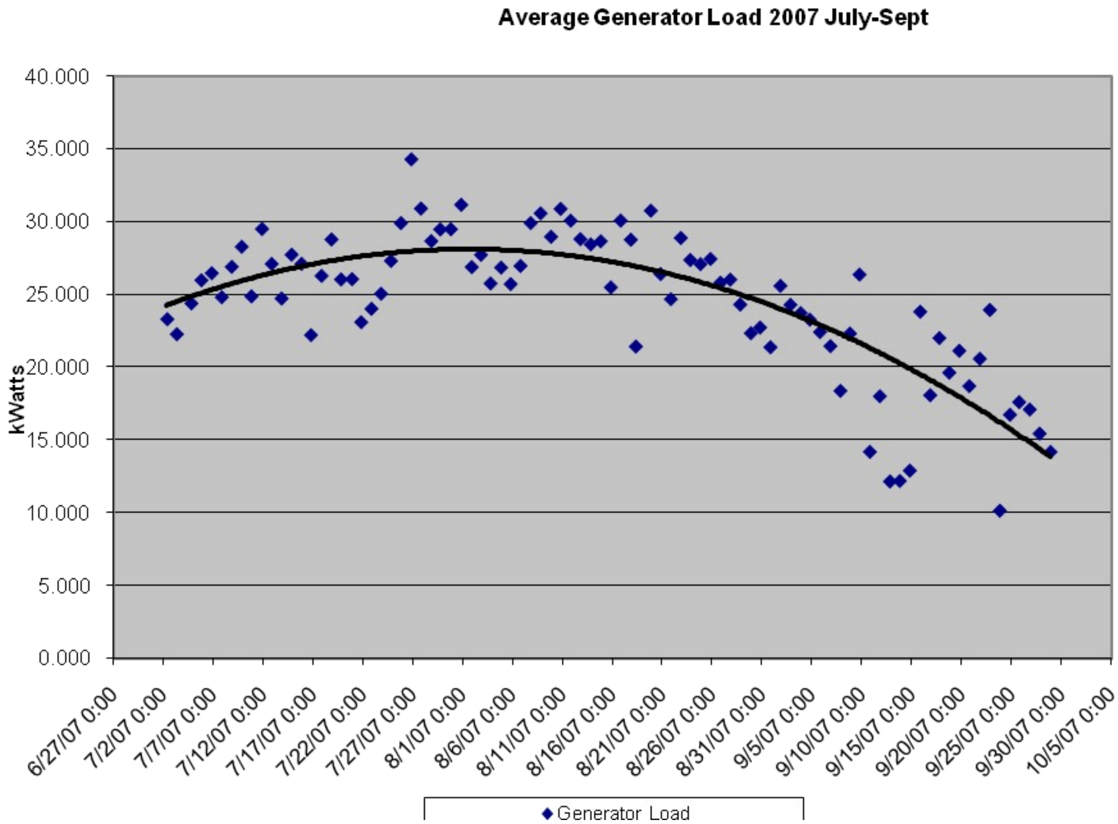
Hot water use data for Bartels and Kiggins was collected by handing out surveys, as well as taking flow and temperature measurements. There was an attempt to find the hot water usage for Bartels by weighing the propane tanks; however, the tactic was abandoned after the measurements showed the tanks were gaining weight.

Solar data was downloaded from AIRMAP and used to determine the effectiveness of the solar arrays in operation, as well as to develop an estimate of the solar energy recourses on Appledore Island. In addition, the RETScreen program was used to estimate the effectiveness of various photovoltaic panels.

Results/Discussion

To develop a plan of action for SML's energy system, the first step was to gain a better understanding of how much energy is being used and where. The generator control panel has an Allen-Bradley power monitor wired to it, which enabled data on the loads that the generator supplies to be gathered. In addition, the island engineers have kept records on how much power has been generated over the last few years. It was found that last year the generator loads exceeded 86 MW hours for the season and they are on track to do the same this year. Peak power consumption occurs during August, since more students are on the island during that time and the reverse osmosis water supply is usually running. To further understand how the energy use varies over time, a plot was made of the average power demand (Figure 10). The data confirms that the heaviest energy use is in August and that as the season winds down, so does the energy production.

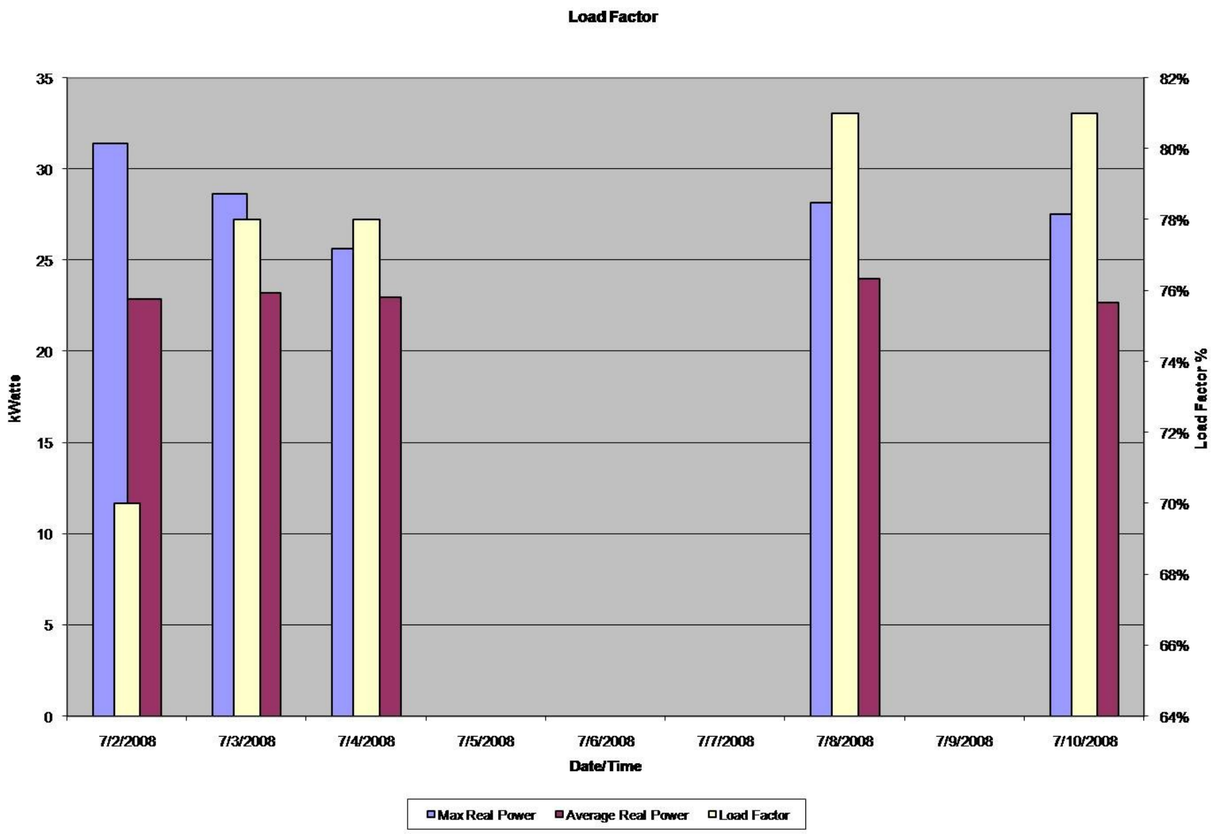
Figure 10: Generator Load



It is important to understand what types of loads are drawing the power in order to correctly size a generator. The loads can be measured in volt amps (VA) or in watts or kilowatts (kW). Volt amps represent the total apparent power, a measure of the power in the system at any given time. The real power, a time-averaged measure of the power, is usually in kilowatts. The ratio of the real power to the apparent power is called the power factor. The power factor is a value between 0 and 1. Loads that have a high power factor may require a larger generator than the kilowatt ratings would suggest. Using the Allen-Bradley power monitor, the real and reactive power was recorded every hour from 8am-7pm for five days. In that duration, the average power factor was 0.77 with a standard deviation of 0.05. The 65 kW generator running at full blast can only handle a power factor of 0.8, so it would be necessary to keep an eye on the power factor if SML were to run the 27 kW or 65 kW generators near their capacity.

One of the difficulties with sizing a power system, whether using generators or alternative energy, is making sure it can handle the fluctuations in the power demand. These fluctuations can be seasonal, day to day or even hourly. Figure 10 shows both seasonal and day to day fluctuations. The ratio of the average energy demand to the maximum energy demand is called the load factor. A load factor close to one means that the load demand is fairly constant and a generator with a limited power band can be sized to supply the load. Figure 11shows the average power, maximum power, and load factor for the days during which data from the power monitor was collected. The load factor from this time period was reasonably good; however, it only represents five days and should be expected to be lower at other times of the year. For example, the reverse osmosis filter does not significantly affect the daily average but requires a large amount of power—if it was switched on for a brief period of time, it would decrease the load factor for the day.

Figure 11: Load Factor



One way to increase the load factor is to make sure heavy loads do not stack up. That is, the devices that require the most power should not be turned on at the same time. Some of the most demanding electric loads on the island were identified and are listed below:

Reverse osmosis unit
Pumps
Refrigeration
Electric water heating elements
Dive shack compressor
Kitchen oven fan
Kitchen ventilation fans
Icemaking

Smaller loads such as lights bring the total consumption up by combining in large numbers. It would be difficult to stop some of these loads from stacking—for example, the refrigerators need to run whenever the temperature inside is too high, and when the kitchen is in use, the cooks will be using ovens and fans. It might be possible to implement a plan to keep some of the other loads from stacking—for example, by running the reverse osmosis unit at night or putting timers on water heaters in the dorms.

It was suspected that pumping water was one of the most energy intensive activities on the island, so the loads and flow rates for the well pump, cistern pump, and saltwater pump were measured. These are summarized in Table 16. The power for the single phase pump equaled volts multiplied with amps. There is an additional factor of square root of three for three-phase. Investigations confirmed that the pumps are energy intensive. The well, cistern, and salt water pump combined account for about one-fifth of the island's energy demand. This amounts to over $8,000 dollars each season in fuel costs. The reverse osmosis unit accounts for approximately 6 percent of the SML's annual energy demand. It may be worth looking into a saltwater storage tank that could disperse the water as needed. This would enable the pump to run intermittently rather than continously.

Table 16: Pumping Costs

PUMP	PHASE	AMPS	VOLTS	POWER	FLOW RATE GPM	MAX HEAD	HOURS PER YEAR IN USE	KW HOURS PER YEAR	COST PER YEAR[42]
Well	1	6.7	208	1.394 KW	12	62 dynamic	280	390	$180
Cistern	3	4.5	208	1.621 KW	20.76	104 feet	160	260	$119
Salt water	3	7 - 7.4 depending on tide	480	5.8-6.1 KW	29-32	145 dynamic	around 2900	17300	$8000
RO unit	3	13.7	480	11.4kw	~27 intake		447[43]	5100	$2350

Appledore Island has two renewable resources with which energy can be made: wind and sunlight. There may also be opportunities to obtain energy from tidal power, but this source was not included in the 2008 project scopes. There is no doubt that all of the energy demands of the island can be met by taking advantage of the two evaluated resourses. Some intelligent planning of the system would go a long way towards reducing the cost. This undertaking can be broken into three more manageable tasks:

1. Evaluation of the available solar resources along with the technology and products that could be used for capturing solar energy.
2. Evaluation of the available wind resources along with the technology and products that could be used for capturing wind energy.
3. Designing a system that can integrate solar, wind, and diesel generated energy and make efficient use of it.

These three tasks will each be looked at in detail below.

[42] Cost per season is based on the 2008 fuel price, which is roughly $4.5 per gallon of diesel delivered.
[43] Hours of use is based on 2007 data. R/O power is based on findings from the 2007 intern report

Solar Energy

Solar energy can be utilized at SML in two ways: it can be used to heat water with solar hot water collectors or to make electricity with photovoltaic panels.

Solar Hot Water

Heating water with solar energy is probably the most cost-effective method to incorporate green power. For SML, a solar system would be most beneficial in Kiggins or Bartels, where demand is large enough. In order to size the system correctly, hot water demand was approximated through various measurements and surveys, as described below.

Table 17 shows the temperature approximations for different water uses. The desired hot water temperature for showering was estimated based on the interns' preferences. The dishwasher uses water at 150 F to thoroughly clean and disinfect the dishes. The cold water temperature is based on the daily temperature measurements taken at the chapel.

Table 17: Water Temperatures in Bartels and Kiggins

	Kiggins	Bartels
Cold Water Temp	60 F	60 F
Desired Hot Water Temp (bathroom)	102 F	102 F
Desired Hot Water Temp (kitchen)	150 F	N/A
Combined Temp	134 F	102 F

Kiggins:

The hot water in Kiggins is used for the kitchen and bathrooms. In the kitchen, hot water is used by the dishwasher and the dish sprayer and to fill up sinks for dishwashing. The dishwasher uses 1.7 gallons per load. In order to estimate the loads put through the dishwasher each day, a tally sheet was posted for two days. On July 8th, 2008, the dishwasher was run 120 times; on July 9th, 2008, it was run 96 times. The 2007 interns also put up a tally sheet and found that on August 1st, 2007, the dishwasher was run 87 times. The dish sprayer is used for each load, except for mugs and cups. It was observed that the dish sprayer is used for an average of 1 minute per load. The sprayer was tested and found to have an approximate flow rate of 0.66 gpm. This equates to about 0.66 gallons per load. There are three large sinks in the kitchen. These sinks are usually filled once and sometimes twice a day to wash large pots and pans. Each sink gets filled with about 20 gallons of hot water.

These numbers are influenced by a number of factors, including but not limited to: island population, number and variety of meals cooked, who is operating the dishwasher, and how much the sprayer is used. The approximations, however, help to estimate the total hot water use.

In the bathrooms, hot water is used for showering and hand washing. The flow of the showers was determined with a bucket and a stopwatch. Two of the showers in the women's bathroom were tested. The flow rate was found to be about 2 gpm. The maximum population on the island is about 110 people. It is estimated that about 87 of those people would be living in the dorms or in Founders, and therefore showering in Kiggins. Although residents are only supposed to shower twice each week with the water running for two minutes, it was assumed that residents shower twice each week with the water running for five minutes for hot water demand calculations. The interns calculated the average volume of water used for hand washing and assumed that the rest of the island residents would use about the same amount of water. Surveys were distributed, asking people to estimate the number of times they wash their hands in Kiggins each day. The average was five times per day. The results are summarized and totaled below:

Table 18: Estimated Daily Hot Water Demand in Kiggins

Use	**Calculation**	**Gal/day**
Dishwasher	120 x 1.7 gal = 204 gal/day	204
Dish Tanks	20 gal x 3 tanks = 60 gal/day, or if filled up twice, 120 gal/day	120
Sprayer	1 min/load = 0.66 gal x 120 loads = 79.2 gal	~80
Showers	at max, 110 people on island; approximately 23 shower in the K-House and Bartels; 87 x 2 showers/week @ 5 min each @ 2gpm = 1740 gal/week or 250 gal/day	250
Hand Washing	based on our test, average of 750 mL/wash = 0.298 gal x 100 people x 5/day = 149 gal/day	149
	Total:	**803**
	Demand from kitchen:	**404**
	Demand from bathrooms:	**399**

Island engineers were consulted to find out the size and configuration of the existing hot water tanks. One stores 75 gallons, and the other stores 82 gallons; both are heated using propane and are located in the basement below the kitchen.

Bartels:
In Bartels, hot water is used for showers, hand washing and laundry. Eight of the thirteen staff members who live in Bartels were surveyed to help determine the hot water usage. The survey asked the following questions:

- On average, how many times do you shower each week in Bartels?
- Average minutes per shower?
- On average, how many times to you wash your hands/face in Bartels each day?

Results indicate that about 85 gallons of water are used for showers each day and 24 gallons for hand or face washing. A tally sheet was posted on the washing machine, asking people to indicate when they do laundry, and whether they use hot, cold or warm water. The washing machine uses about 3.6 gallons of water for every cubic foot of clothing, and has a capacity of about 3 cubic feet.[44] The tally showed that, over five days, no one used hot water, but warm water was used occasionally. The maximum number of loads of laundry in any one day was four. If all of these loads were washed with warm water (assuming warm = half hot + half cold) and filled to capacity, the hot water demand for laundry would be 21.6 gallons.

Table 19: Estimated Daily Hot Water Demand in Bartels

Use	**Calculation**	**Gal/day**

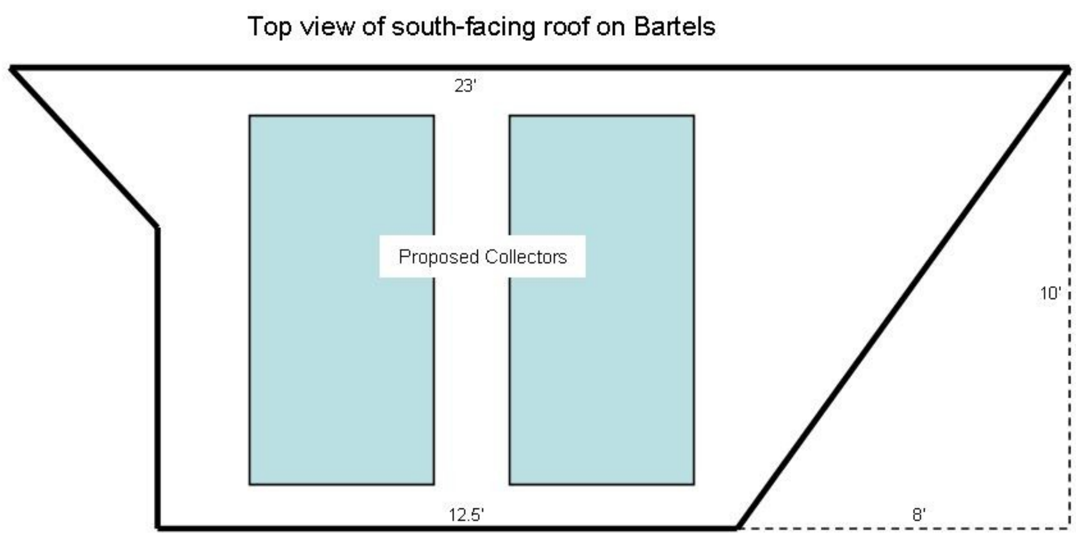
[44] ENERGY STAR Clothes Washers Product List (see digital appendix)

Laundry	Maximum of 4 laundry loads/day; 4 warm loads/day = 2 hot loads/day; 2 loads/day * 3.6 gal/cu.ft. * 3 cu.ft./load = 21.6 gal/day	~22
Showers	Average of 18 minutes in shower/week/person * 13 people = 242 minutes/week; 242 minutes/week * 2.5 gal/min = 605 gal/week total = 86.5 gal/day total	~87
Hand and Face Washing	Average of 3.6 washes/day/person 3; 6 washes/day * 0.5 gal/wash = 1.18 gal/wash/person; 1.18 * 13 people = 23.6 gal/day total	~24
	Total:	**133**

The existing hot water heater in Bartels is located in the basement and supplies hot water to the entire building. The tank capacity is 40 gallons. The water is heated with propane.

If solar hot water collectors were placed on the roof of Bartels, they would have to be mounted on the only south-facing roof, above the storage room. The pitch of the roof is 37 . The dimensions are indicated in the drawing below.

Figure 12: Bartels South-facing Roof



Discussion:
There are two different types of collectors: evacuated tubes and flat plates. Evacuated tubes are more efficient than flat plates and often require less surface area. However, flat plate collectors are easier to maintain and less likely to break. When consulted, Lee Consavage of Seacoast Consulting Engineers recommended glazed collector panels, as did Bob Jennings of Mechanical Innovations, a solar heating consulting firm in New Hampshire. Both Consavage and Jennings also recommended Heliodyne collectors. Heliodyne is a reputable company that has been manufacturing solar heating equipment since 1976.

Lee Consavage recommended using an Excel-based program called RETScreen to determine the number of collectors needed. RETScreen allows the user to specify location, water-usage, tank size, months during which the system will be used, desired water temperature, and specific collector manufacturer and model. The program takes these inputs and displays a "solar fraction"—the percentage of hot water demand met with solar energy for a given number of panels. The number of panels can be adjusted in order to increase or decrease that percentage.

The 2007 interns recommended installing evacuated tubes made by Apricus. Although these are more efficient, the low maintenance and better durability of glazed flat panels is more important for Appledore Island. Also, a comparison of Apricus and Heliodyne collectors on RETScreen displayed an almost unnoticeable difference in terms of the number of collectors needed. The comparisons and strong recommendations from experienced industry professionals indicate that Heliodyne panels are the best option, particularly in Appledore's harsh, salty environment. The frame of the collectors is made from anodized aluminum, which is durable and holds up well in marine settings.[45]

Heliodyne collectors come in two main sizes – Gobi 408 and Gobi 410. Their respective dimensions are 4' by 8' and 4' by 10'. Lee Consavage recommended sticking with the Gobi 408 collectors because they are the most popular collector made by Heliodyne and therefore the least expensive.[46]

Most solar water heating systems are closed loop systems, meaning the water that runs through the solar collectors is not the water that reaches the faucets. Closed-loop is preferred because open-loop systems require the pipes to be kept clean. There are multiple variations of closed-loop systems. One is generally referred to as "closed" and the other is called "drain-back." Propylene glycol is usually used in closed-loop solar water heating systems to protect against freezing. Since SML will only use the system from May to September, freezing is not an issue. The alternative to propylene glycol is distilled water, which is actually more efficient. At SML, a drain-back system using distilled water is the best option. All of the water in the collectors can be drained at the end of the season, which will protect the collectors from ice damage.

Drain-back tanks can be purchased with a hot water storage tank or separately. For the sake of simplicity in installation, it is better to get a drain-back tank that comes packaged with a storage tank. Drain-back tanks generally come in 10 gallon or 15 gallon sizes. The drain-back tank size should be determined by the number of collectors. The drain-back tank needs to have a large enough capacity to hold all of the water in the collectors, as well as the water in the pipes running up to the collectors. Each Gobi 408 can hold 1.14 gallons of water. There should be one drain-back tank for every 10 collectors. According to Lee Consavage, if a larger tank is needed, a standard 20-gallon tank could be turned into a drain-back.

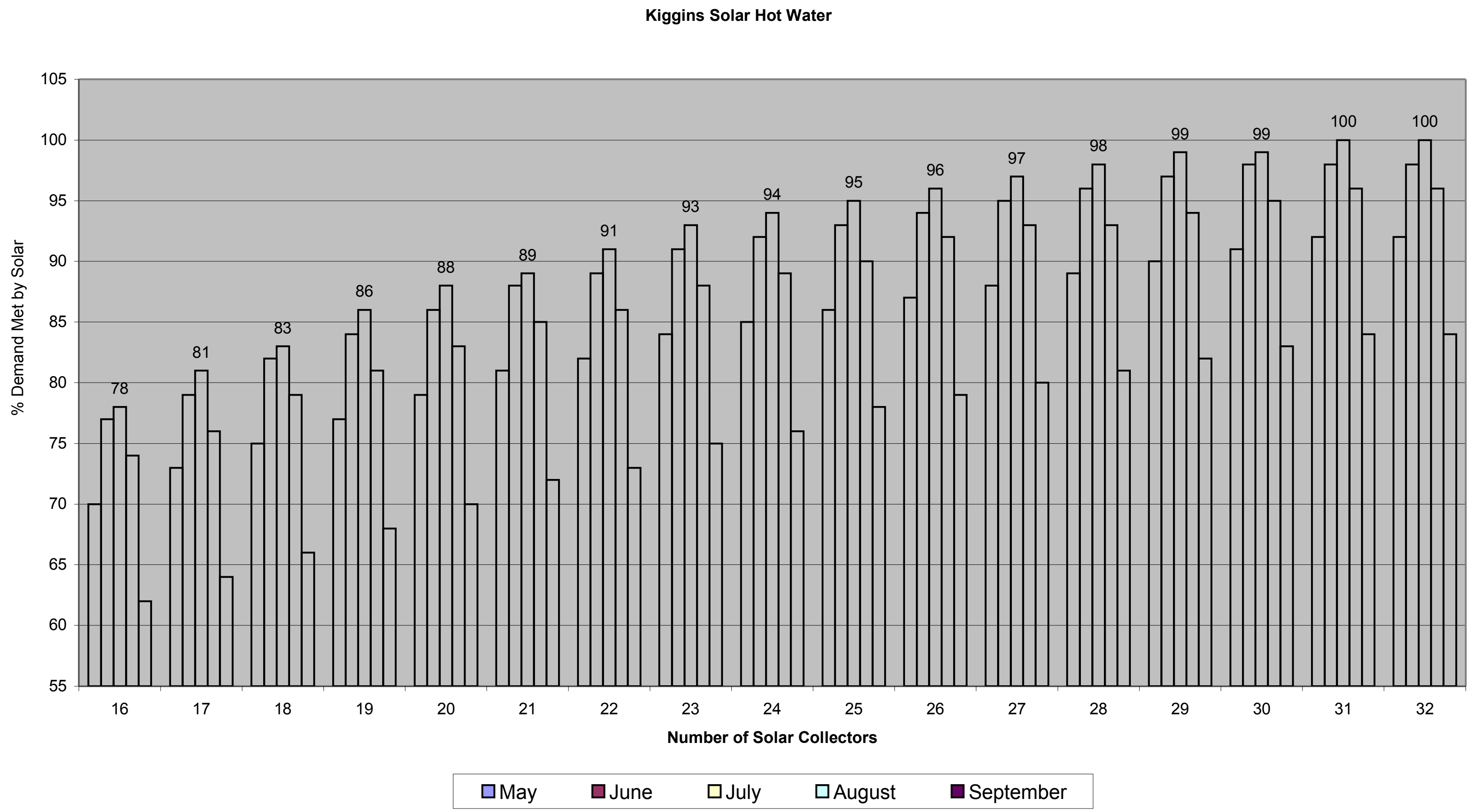
The capacity of the hot water storage tanks should match the daily hot water use. The hot water demand in Kiggins in July is estimated to be between 700 and 800 gallons. Most standard storage tanks hold a maximum of 120 gallons. The existing water tanks in Kiggins should be incorporated into the system as back up water heaters. These tanks account for 157 gallons of the 800-gallon demand. Six additional 120-gallon tanks would provide enough storage to meet the demand (877 gallons). If larger storage tanks can be found, that may be a better option. The drain-back and storage tank units are also only available with capacities up to 120 gallons.

[45] Gobi Technical Specifications (see digital appendix)
[46] Lee Consavage, 7/15/2008. (See the digital appendix for the complete correspondence.)

In order to keep water in the tanks at roughly the same temperature, the water must be allowed to circulate. A differential temperature controller in conjunction with a pump could be programmed to circulate the water when the temperature difference between the tanks reached a specified number. Or, a simpler option is to situate the back-up water heater higher than the solar storage tanks. In this configuration, the hot water would automatically flow into the higher tank.

Because SML only operates during the summer, almost all of the hot water demand can be met by solar energy. Each month has slightly different potential for producing hot water; in general, more water can be heated in July than any other month. RETScreen allows the user to specify which months the system will be in use. Each month was considered separately to determine the number of collectors needed. The best option is to install a system that can meet 100% of the hot water demand with solar energy in the month of July. For Kiggins, it would take 31 Heliodyne Gobi 408 collectors to completely meet demand. Figure 13 shows how the number of collectors affects the solar fraction for each month that SML is open. As the number of collectors is reduced, the percentage decreases nearly linearly. It is important to note that this graph assumes that demand remains constant throughout the season.

Figure 13: Number of Collectors Compared for Kiggins



A limiting factor when installing collectors on Kiggins is the roof space. Kiggins does not currently have a south-facing roof. If the structure to house the composting toilets is built, a south facing roof will be available. The building is tentatively sized to be 21' by 21' with the same roof pitch as Kiggins; this arrangement should be able to fit about 19 collectors. Nineteen collectors would meet about 86% of the hot water demand in July. There are several options to increase the number of collectors that can be installed. Some options are listed below. Drawings are included in Appendix F.

- Put some collectors on the east-facing roof of Kiggins. Collectors facing east will not be as efficient as collectors facing south; this is especially true because the roof actually faces about 10-20 north of east. More hot water would be available during the morning than the evening, which is not ideal because there is a demand for hot water throughout the day.
- Extend the roof overhang of the new building to fit more collectors. If this is done, it is important that the all of the collectors remain above the drain-back tank so that the water can flow back into it.
- Make a shed roof for the new building. This may look a little odd, but it would likely be large enough to fit all of the collectors.

It should be noted that collectors should be installed vertically. One of the drawings shows the collectors installed horizontally. Although this configuration would allow more panels to be mounted, it would compromise the ability to fully drain the collectors.

The tanks should be located as close to the collectors as possible. The existing hot water tanks in Kiggins are located in the basement, which is far enough from the proposed bathrooms to cause significant heat loss. Since a new building is being constructed, it would be best to include a place for tank storage directly under the collectors.

The estimated costs found in Table 20 are based on correspondence with Lee Consavage.[47] Lee Consavage provided the per collector estimates. It is suspected that installation costs on Appledore Island would be less than the cost listed below because SML staff will likely complete most, if not all, installation themselves.

Table 20: Estimated Cost for Solar Hot Water Heating in Kiggins

Kiggins Cost Estimate	Per collector	31 collectors (100% in July)	29 collectors (99% in July)	25 collectors (95% in July)
Estimated system cost	\$2,700	\$83,700	\$78,300	\$67,500
Estimated installation cost	\$1,250	\$38,750	\$36,250	\$31,250
Contingency (20%)	\$790	\$24,490	\$22,910	\$19,750
Estimated total cost	\$4,740	\$146,940	\$137,460	\$118,500

As mentioned earlier, there is only one suitable roof on Bartels to mount the solar collectors. This roof is only large enough to accommodate two collectors. The hot water demand in Bartels is probably between 100 and 150 gallons per day, depending on laundry and shower use. The current hot water heater in Bartels holds 40 gallons of water. An additional water storage tank with drain-back should be added. The storage tank could

[47] The complete correspondence with Lee Consavage can be found in the digital appendix.

have a capacity of 80 or 120 gallons. When compared in RETScreen, the larger storage capacity does not significantly impact the percentage of the demand met by the solar collectors.

The existing tank is located in the basement, which is far from the roof for the collectors and would cause heat loss. The collectors could be placed directly under the south-facing roof, in the room that is currently used to store linens and cleaning supplies. If some shelves were removed, a couple of hot water tanks would easily fit in the room.

For use in Bartels, the Gobi 408 and 410 were further compared. Two Gobi 410 collectors consistently meet about ten percent more of the hot water demand than two Gobi 408 collectors would. The complete comparison can be found in the Digital Appendix.

The cost estimate below compares a system with Gobi 408 collectors and Gobi 410 collectors. The difference in cost (~$500) is insignificant for such a dramatic increase in performance (~10%) with the use of Gobi 410.

Table 21: Cost Estimate for Solar Hot Water Heating in Bartels

Bartels Cost Estimate	(2) Gobi 408 collectors	(2) Gobi 410 collectors[48]
Estimated system cost	$5,400	$5,800
Estimated installation cost	$2,500	$2,500
Contingency (20%)	$1,580	$1,660
Estimated total cost	$9,480	$9,960

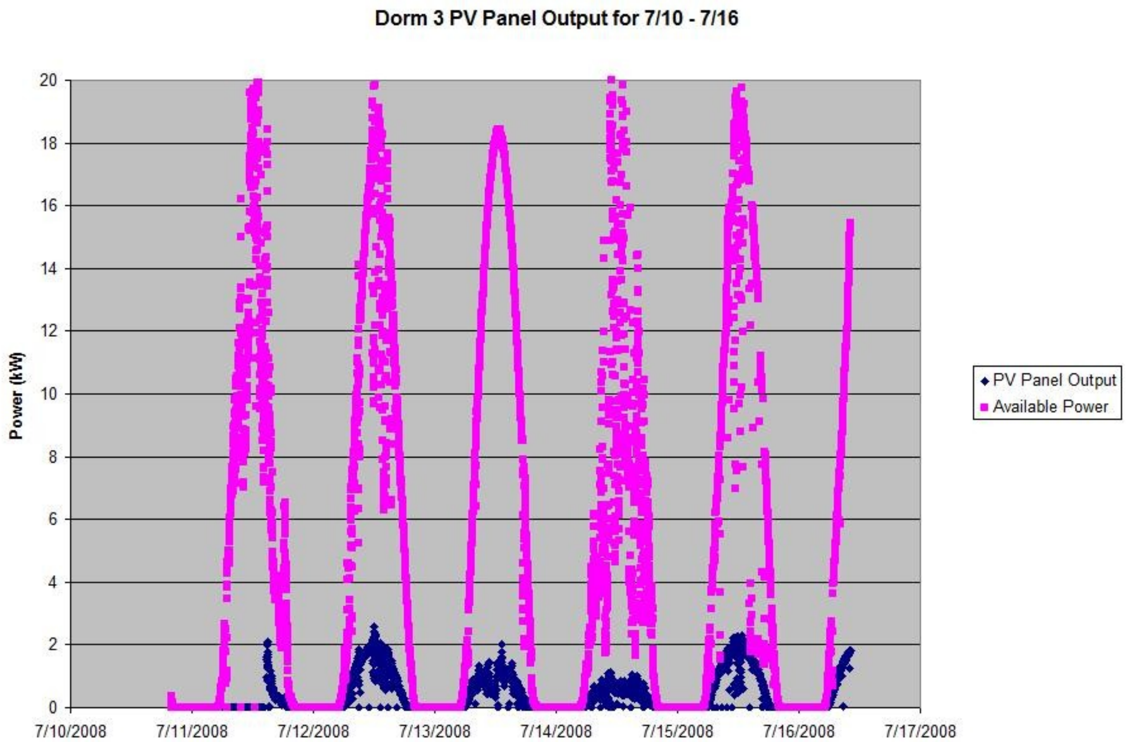
Recovering heat from water leaving the dishwasher was also investigated. It was determined that standard methods for heat recovery would not be appropriate. The standard methods, such as the Power-Pipe™, require vertical piping. The piping from the dishwasher, located in the basement of Kiggins, has very little vertical piping. An alternate method could work, however. A heat exchanger could be made from PVC and copper coiled pipe. Alternately, the pipes from the dishwasher could be modified so that there is more vertical drop. These options should be further investigated.

Photovoltaic Energy

The first step in evaluating the potential of photovoltaic solar power is to analyze the effectiveness of the solar panels currently in place. Figure 14 shows the power output of the PV panels for a week (from AIRMAP data on Dorm 3) compared to the available power measured by AIRMAP's pyranometer.

[48] Cost difference of Gobi 408 and Gobi 410 based on listed prices on www.altenergystore.com

Figure 14: Dorm 3 PV Panel Output for the Week of 7/10/08 to 7/16/08



The efficiency of the solar panels was calculated by dividing the output of the panels by the available power. Unusually high efficiencies were obtained during the early morning and late afternoon times. As seen in Figure 15, the power output of the solar panels read by the meter gets much closer to the available power as the light intensity drops. This suggests that one of the meters may lose accuracy in low-light conditions. To obtain a reasonable approximation of the efficiency of the solar panels, only the mid-day data was used. A graph of the average efficiencies throughout the middle of the day is shown in Figure 16.

Figure 15: Dorm 3 PV Panel Output for a Single Day

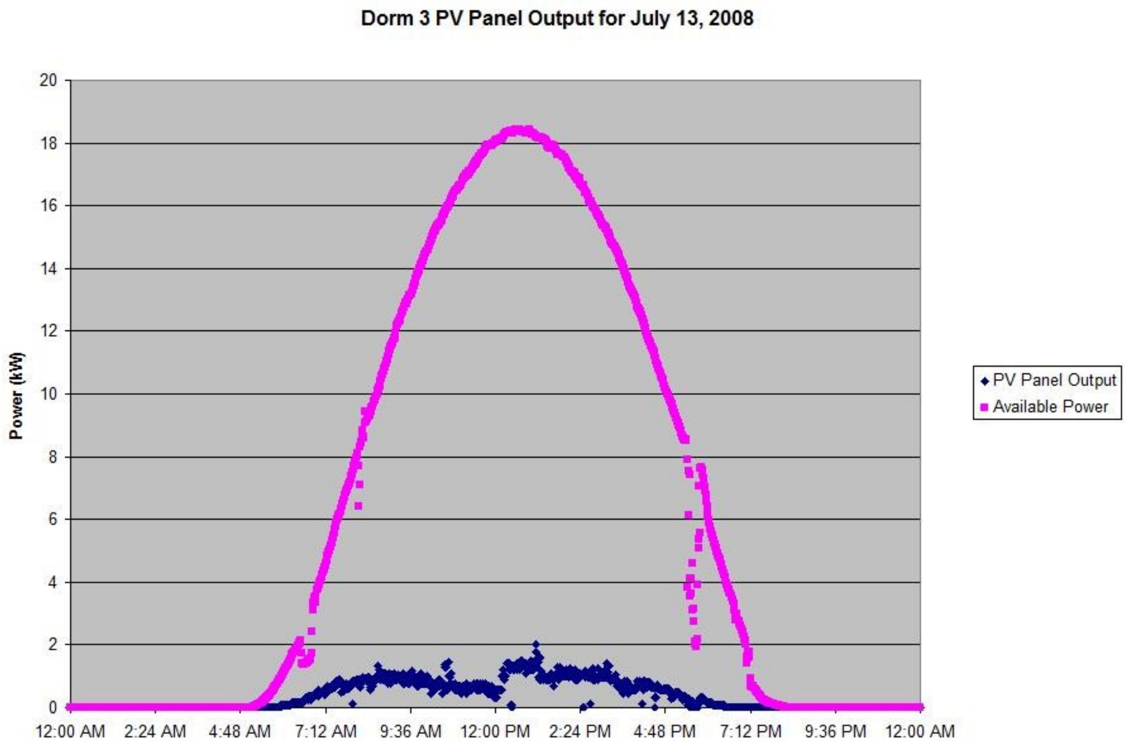
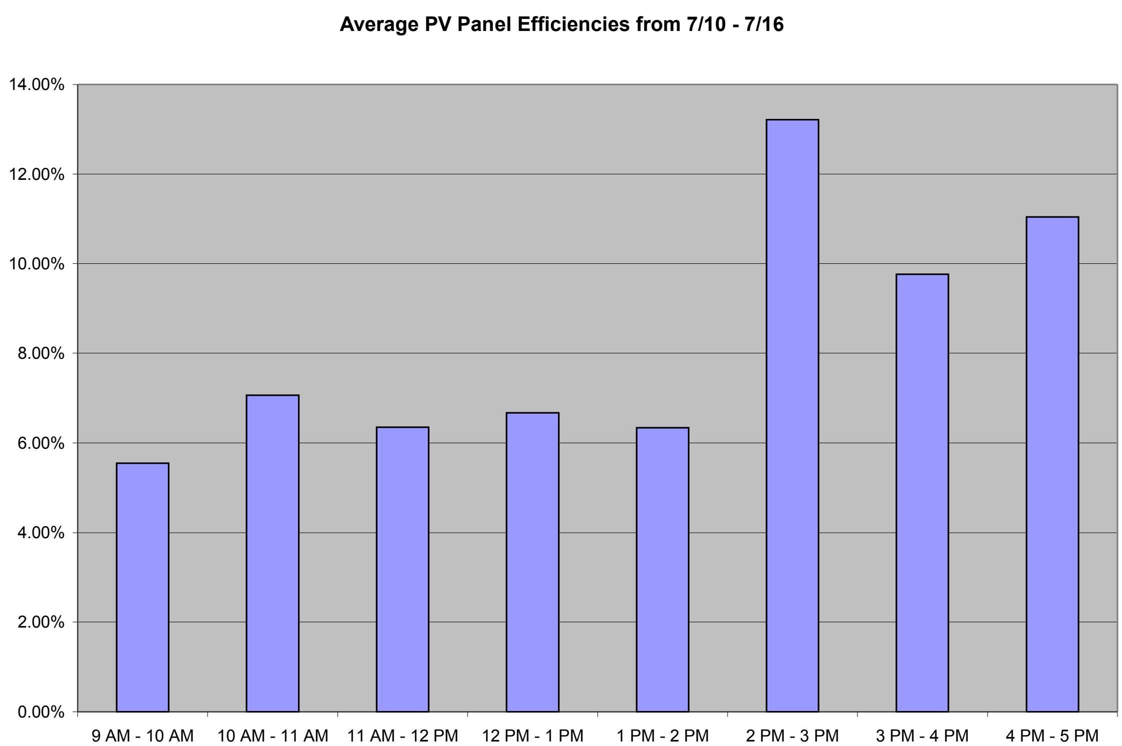


Figure 16: Average Efficiencies of PV Panels at Different Times During the Day



The overall average efficiency of the solar panels was calculated to be around 8.25%. Typically, solar panels have efficiencies between 11 and 14%. The low efficiency of the current panels could be due to the age of the panels, seagull droppings, and line loss.

In order to install new panels, a new system would need to be set up. The inverters installed in the radar tower would not be able to handle another solar array, and the batteries are at full capacity. A charge controller is needed to interface between solar panel arrays and batteries to limit the current added or drawn from the batteries, which prevents them from being overcharged or drained. An inverter converts DC power from the batteries into AC power. Several solar panels, charge controllers, and inverters are shown in the tables below.

Table 22: Prices and Specifications for Selected Solar Panels

Company	Model	Cost	Power (W)	Volts (V)	Length (ft)	Width (ft)	Efficiency (%)
Schott Solar	ASE-300-DGF/50	* $1,480.00	285	50.6	6.21	4.21	11.74
Sharp	ND-224U1F	$995.99	224	20	5.38	3.26	13.75
Kyocera	KC200GT	$939.99	200	16	4.68	3.25	14.14
Evergreen Solar	ES190 RL/SL	$906.39	190	18	5.15	3.13	12.71
Sharp	ND-216U2	$1,032.70	216	18	5.38	3.26	13.25
General Electric	GEPVp-200	$1,100.00	200	18	4.88	3.22	13.73
Sanyo	HIP-200BA3	$1,392.72	200	42	4.33	2.93	16.97

* Price for Schott Solar panel was not given – cost was estimated by averaging cost/watt for other solar panels

Table 23: Prices and Specifications for Selected Solar Charge Controllers

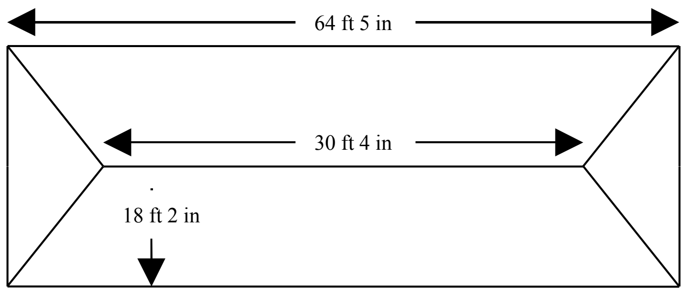
Company	Model	Price	Battery Size (V)	Max Solar Output (W)	PV Voc(V)	PV Operating Max (V)	Power Point Tracking?
Outback	FLEXmax 80 MPPT	$580.00	60	7500	150	145	Yes
			48	5000			
Outback	MX60 PV MPPT	$580.00	60	4500	150	145	Yes
			48	3200			
Apollo Solar	T100 Turbocharger	$995.00	48	5200	200	160	Yes
	T80 Turbocharger	$850.00	48	5200	140	112	Yes
Xantrex	XW MPPT60-150	$524.16	48	3500	150	140	Yes
Morningstar	TriStar	$185.00	48	4000	125	125	No

Table 24: Prices and Specifications for Selected Inverters

Company	Model	Price	Battery Size (V)	Max Solar Output	Surge Power Capacity	Efficiency
Apollo Solar	TSW3648	$2,495.00	48	3600 W	7200 W for 10s	90%
Outback	GTFX3048	$1,875.00	48	3000 VA	4800 VA for 5 s	93%

A site survey was conducted to determine the feasibility of placing solar panels on dorms 1 and 2. The long side of the roof of Dorm 1 faces 30 degrees east of South, which is about the same orientation as that of Dorm 3. Dorm 2 faces 45 degrees east of South. Dimensions of the roof of Dorm 3 are shown in Figure 17, and were assumed to be the same for all three dorms.

Figure 17: Dorm 3 Roof Dimensions



Several different configurations for a new solar panel array were considered. Panels were placed in series to increase the voltage and in parallel to increase power output, with space left between them to allow for wiring and cleaning.

A charge controller was chosen that would be able to handle the power output and voltage of the array. In most cases, the array was split in two, each half with its own charge controller. The battery bank was assumed to be 48 V, although a higher voltage would be possible. An inverter was then selected based on the power output of the array. The new solar system could have one or two inverters as long as it only powers single-phase AC loads. Three phase motors and pumps would require three inverters.

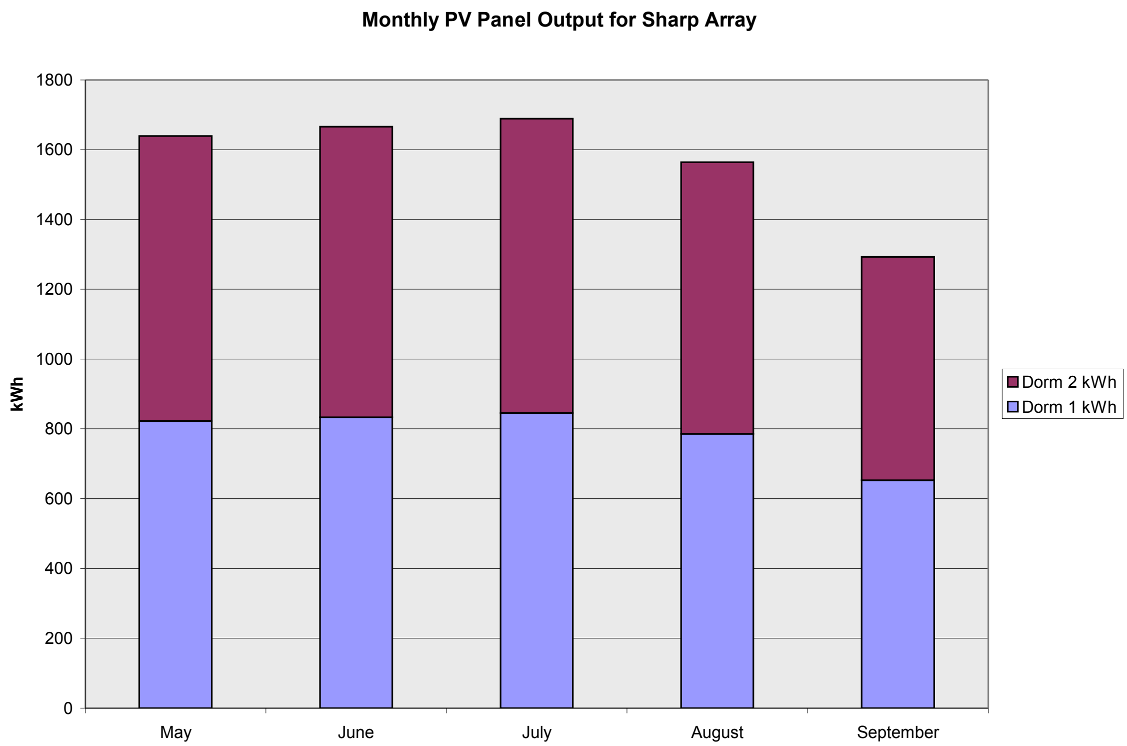
One of the configurations considered is shown in Table 25. The solar array would consist of 28 Sharp ND-224U1F 224 watt panels, wired with 7 in. series and 4 parallel branches. Each panel is 20V, so this setup would give an array voltage of 7 * 20V = 140V and a nominal power of 28 * 224W = 6272W. Two Apollo Solar T100 Turbocharger charge controllers were chosen because each could handle array voltages up to 200 V and up to 5200 W; and the array was split in two. Two Apollo Solar TSW3648 inverters would be used to convert battery power to AC.

Table 25: Cost Analysis for a Possible Solar Panel Configuration

Configuration: Sharp 1					
Company	Model	Type	Cost/unit	Quantity	Cost
Sharp	ND-224U1F	PV Panel	$995.99	28	$27,887.72
Apollo Solar	T100 Turbocharger	Charge Controller	$995.00	2	$1,990.00
Apollo Solar	TSW3648	Inverter	$2,495.00	2	$4,990.00
				Total Cost	$34,867.72

The RETScreen excel application for PV panels was used to estimate the potential power production of each configuration. Analyses were conducted for both Dorm 1 and Dorm 2. If arrays were set up on both dorms, up to 7851 kWh could be generated annually. This is close to a tenth of the island's annual energy demand (around 86 MWH). At $0.46 cents per kWh of diesel fuel, the solar panels could save Appledore $3,600 every year. The solar panels would pay for themselves in about 20 years if gas prices stayed constant. However, gas prices are constantly rising. Factoring in rising gas prices[49] and inflation[50], the payback period could drop down to 13 years. The monthly kilowatt hours that could be produced by the Sharp panel configuration are shown in Figure 18.

Figure 18: Predicted Output of Solar Panels on Dorm 1 and Dorm 2



Wind Energy

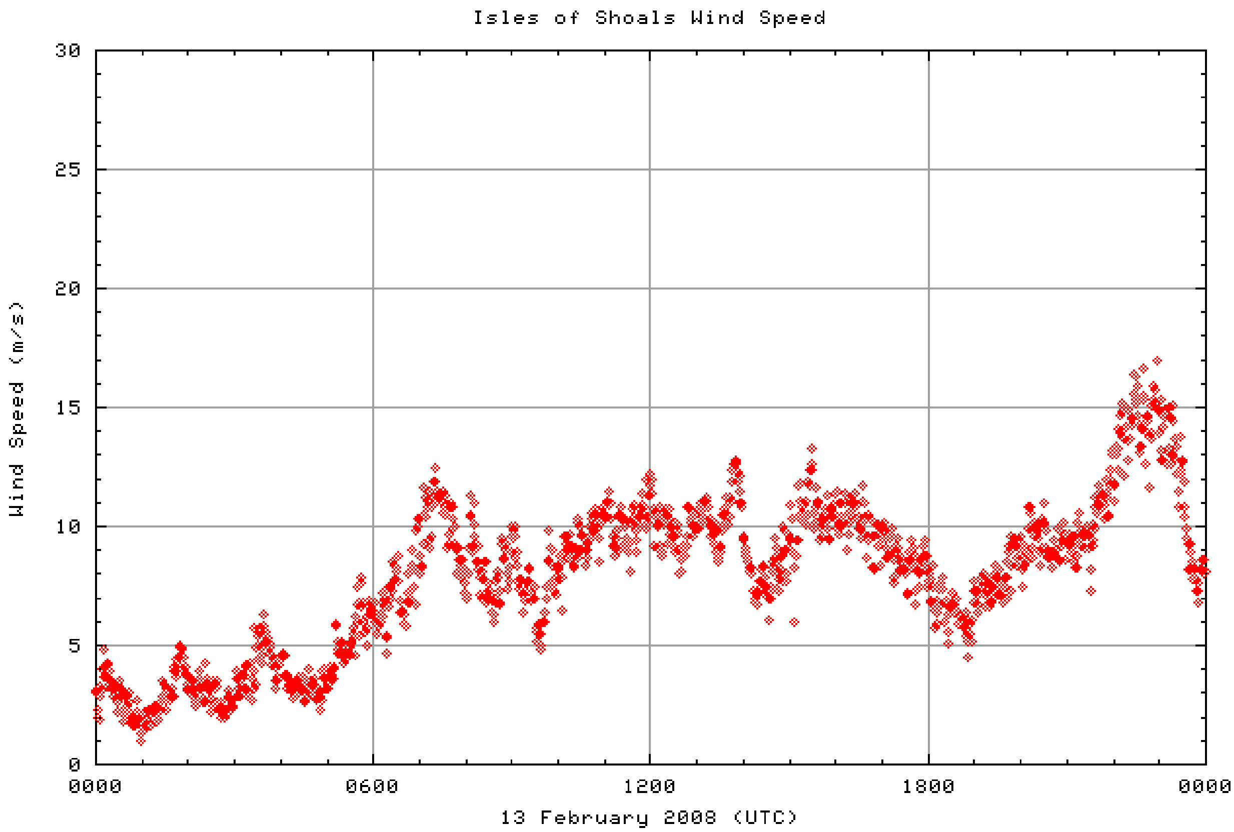
There are two ways to try to evaluate the wind resources on Appledore. The first would be to see how well the existing wind turbine has been working; unfortunately, there are no direct records of its performance because instrumentation was not installed for the turbine prior to the arrival of the engineering interns. Another option is to look at the battery charge records for the green grid's battery bank. The following images were downloaded from AIRMAP and illustrate the correlation between wind speed and battery charge. The plots are from February 13th, 2008, when the generator is not running. There is one 2.28 kW solar panel array in use as well; however, another plot (not shown here)

[49] One case projected by the Energy Information Administration predicts a 1.4% annual increase in diesel fuel

[50] Using a 4% inflation rate, based on information found at http://www.inflationdata.com/inflation/inflation_rate/CurrentInflation.asp

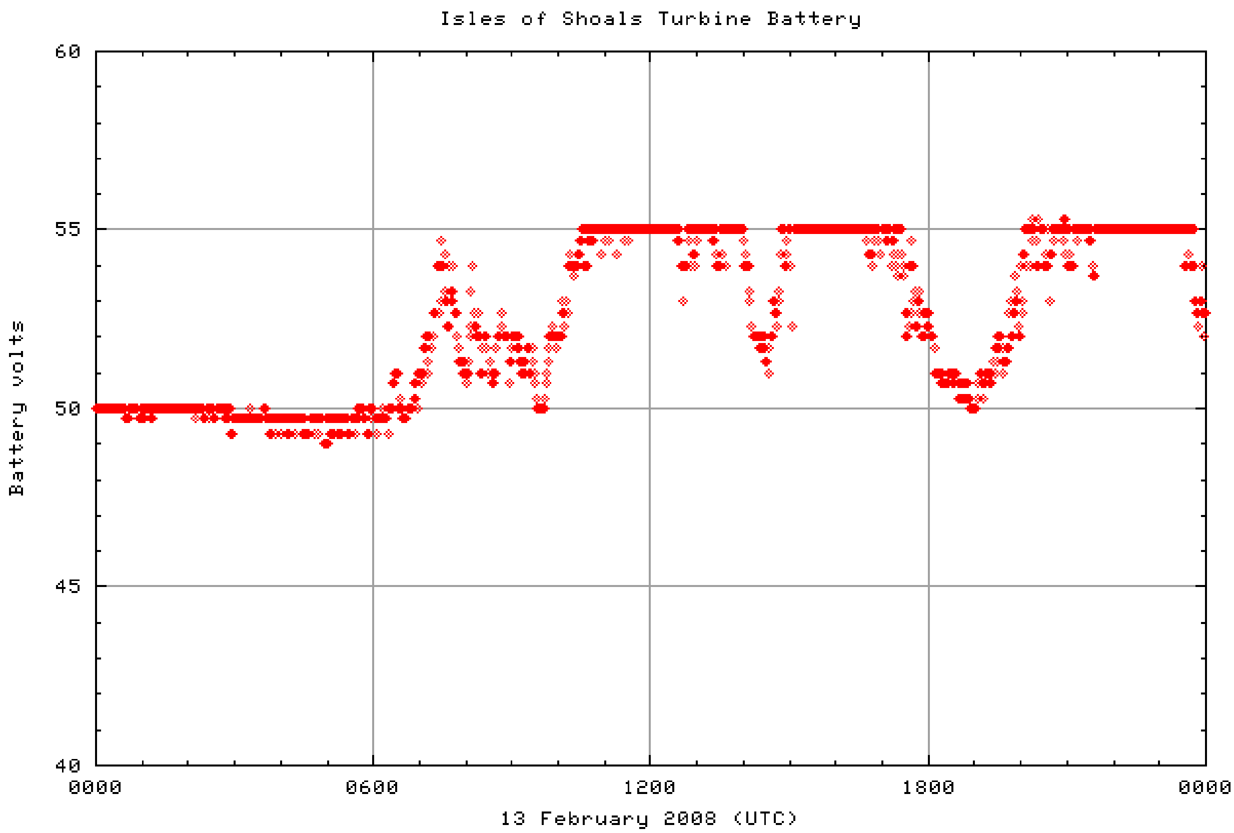
shows the solar resources that day to be minimal so it would be reasonable to assume that all power is coming from the turbine.[51] The total load drawn is fairly constant at 1.09 kW[52], which indicates that when the battery voltage goes up, the wind turbine is generating at least that much power. When the voltage evens out at 55 V, the turbine controller is burning off energy because there is no place to store or use it. The wind speed and battery charge graphs downloaded from AIRMAP make it clear that the wind turbine is indeed producing enough power and sometimes even too much. According to Kevan Carpenter, who runs AIRMAP on Appledore, the tower only lost power once during the 6 months that the generators were turned off.

Figure 19: Wind Speeds on 2/13/08



[51] Digital Appendix > Alternative Energy > Wind Power > 'Pyranometer'
[52] Digital Appendix > Alternative Energy > Wind Power > 'Lee Consavage AIRMAP summary'

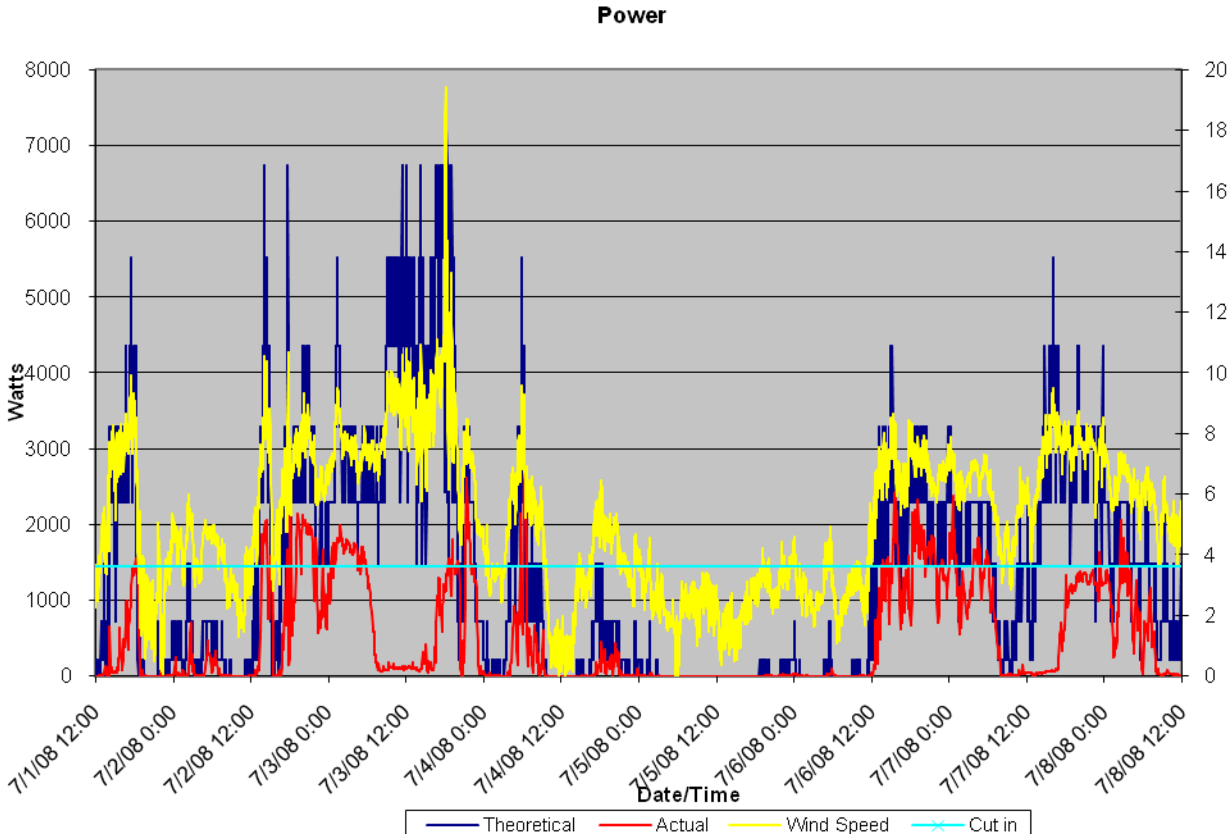
Figure 20: Battery Voltage on 2/13/08



During the interns' stay, the output of the turbine was measured for a week. Paul Krell and Nathan Sherwood from Unitil installed a power meter on the high voltage side of the Bergey transformer. The power meter was set up to measure wild AC. The purpose was to use the wind speed files from the same time period to determine if the wind turbine was performing according to Bergey's claims. Data was taken from July 2nd to July 8th from both the power meter and from the anemometer on the AIRMAP tower. The data was averaged every five minutes. A plot of the recorded power versus wind speed can be seen below in Figure 21. The theoretical power based on a Bergey power curve[53] for that particular turbine is also shown. The horizontal line represents the cut in speed of the turbine.

[53] Digital Appendix > Alternative Energy > Wind Power > 'Efficiency Plots'

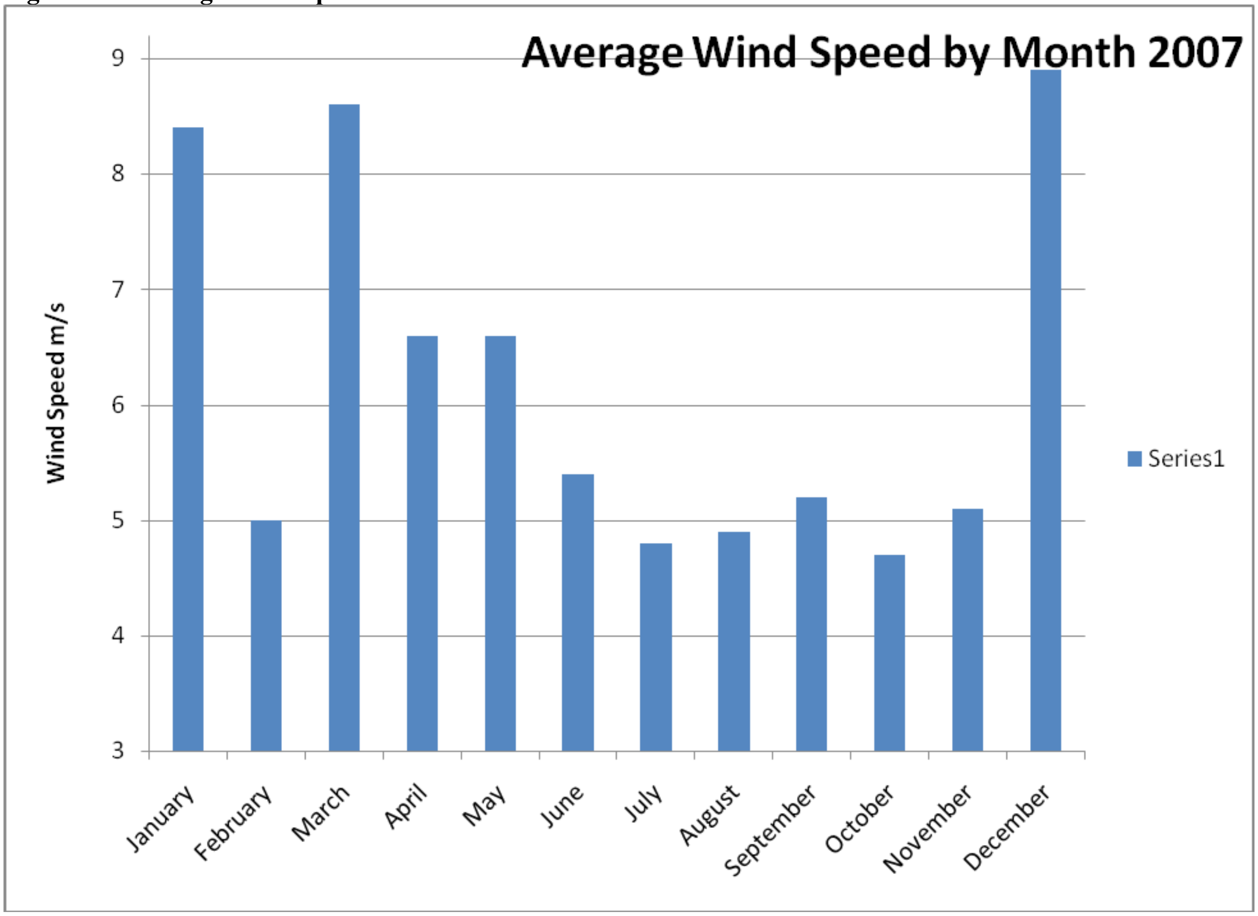
Figure 21: Measured Wind Power



After looking at the data, it became clear that either the turbine or the power meter was not working correctly. Nathan Sherwood at Unitil had a Unitil employee, Jacob Aho, look through the numbers. Jacob Aho came up with the same hypothesis, that either the power meter or turbine was disfunctional. Further tests will have to be done in order to find the source of the error and to determine whether the turbine is producing power as it should be.

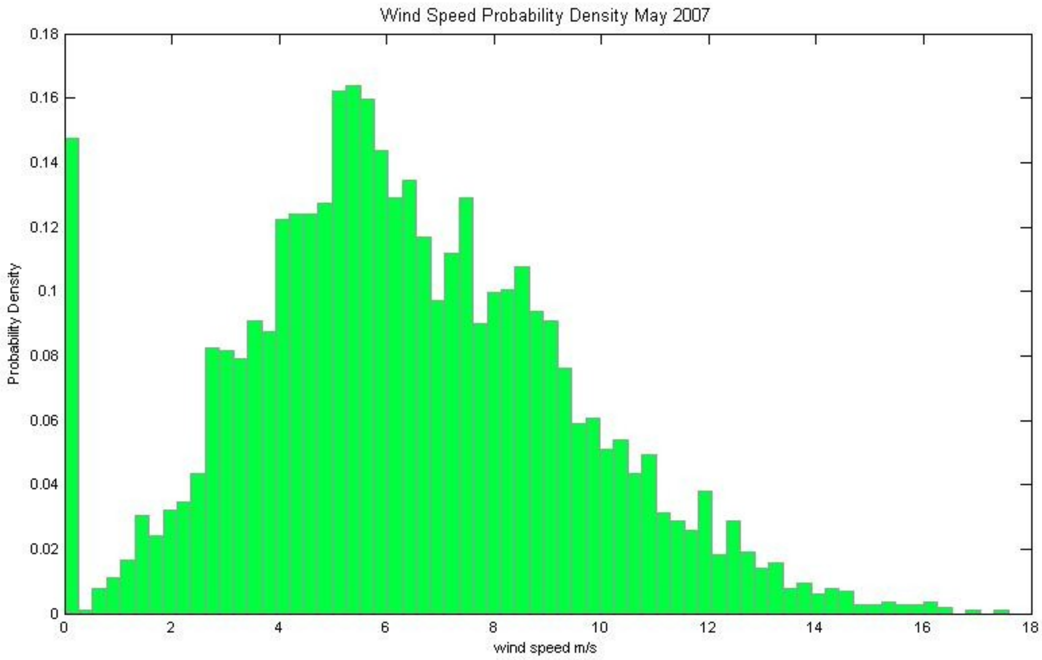
The second way to evaluate the island's wind resources is to gather data from the anemometer on top of the radar tower. AIRMAP makes this data available through a public server. The wind speed averaged over ten minute intervals, from July 2007 to June 2008, was downloaded and analyzed. Figure 22 shows the average wind speed for each month over that year.

Figure 22: Average Wind Speed in 2007



The average wind speed per month is an appropriate starting point, but more data is needed in order to estimate the amount of energy in the wind. Wind power is proportional to the cube of the wind speed, so estimating the wind energy based on the average wind speed will always be an underestimate. It is more important to know how often and for how long the wind blows at different speed regimes. Figure 23 shows the wind speed density for April 2008. Similar plots for other months can be found in the digital appendix.

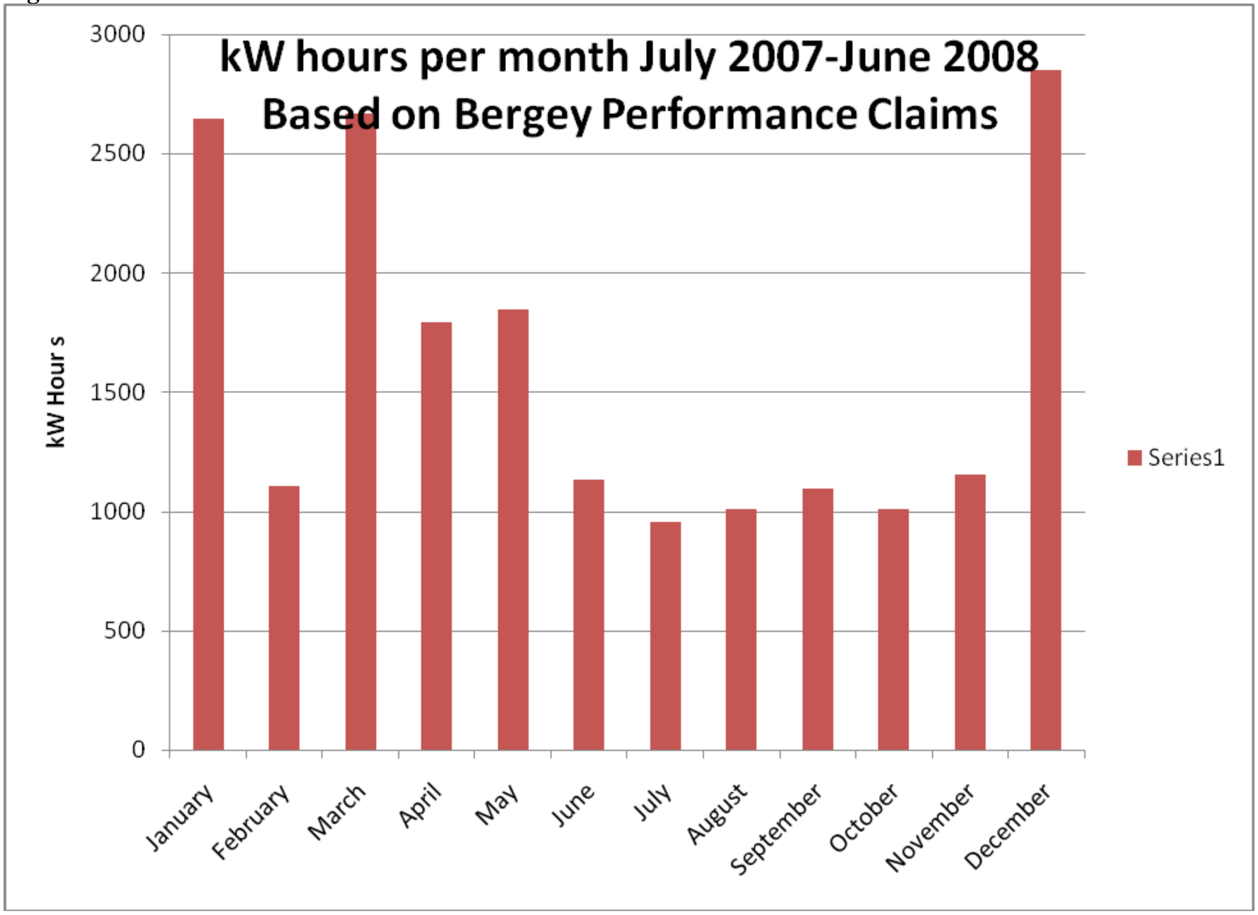
Figure 23: Wind Speed Density in May 2007



Using these plots, it is easy to calculate the energy that can be produced by a wind turbine, as long as the power produced at corresponding speeds for the turbine is known. A spreadsheet downloaded from the Bergey website[54] provided the necessary information, and the theoretical kW hours per month for the existing 7.5kW turbine were calculated for the previous year using the wind speed data, as shown in Figure 24.

[54] Digital Appendix > Alternative Energy > Wind Power > 'Bergey Tested Datasheet'

Figure 24: 7.5 kW Wind Turbine Performance



It is clear that the wind turbine is producing power on Appledore and taking some of the load off of the generator by powering the AIRMAP tower. Adding more wind turbines to the island or replacing the existing turbine with a larger one would be effective ways to reduce the fuel requirements of SML. Bob Pechie, the engineer who designed the existing tower, was contacted to see if the same tower could be used for a 30 kW turbine. He said that it was not designed to carry that kind of load, but it might be possible to attach a 20 kW turbine to the tower. However, the expense is not easily justified.

The problem with generating power with smaller turbines (7.5-20kW) is that many of them would be required to meet SML's demand. The engineering interns agreed that it would be more asthetically pleasing to have one or two larger turbines than to have many smaller ones. Table 26 lists some of the turbines that offered information; more can be found in the digital appendix.

Sustainable Engineering Developments Inc. of New York used a spreadsheet to estimate the amount of power and energy that a Nothwind 100 turbine would deliver. [55] They estimated the average power to be 19.17 kW and the annual energy provided to be 170 MW hours. Using the same spreadsheet, the Bergey 7.5 was projected to have an average

[55] Digital Appendix > Alternative Energy > Wind Power > Northern Power > 'Appledore Island'

output of 2 kW and produce 17 MW hours annually.[56] In other words, it would take ten Bergey 7.5 turbines to match the production of the 100 kW turbine and the cost would be much higher.

Table 26: Wind Turbine Comparison

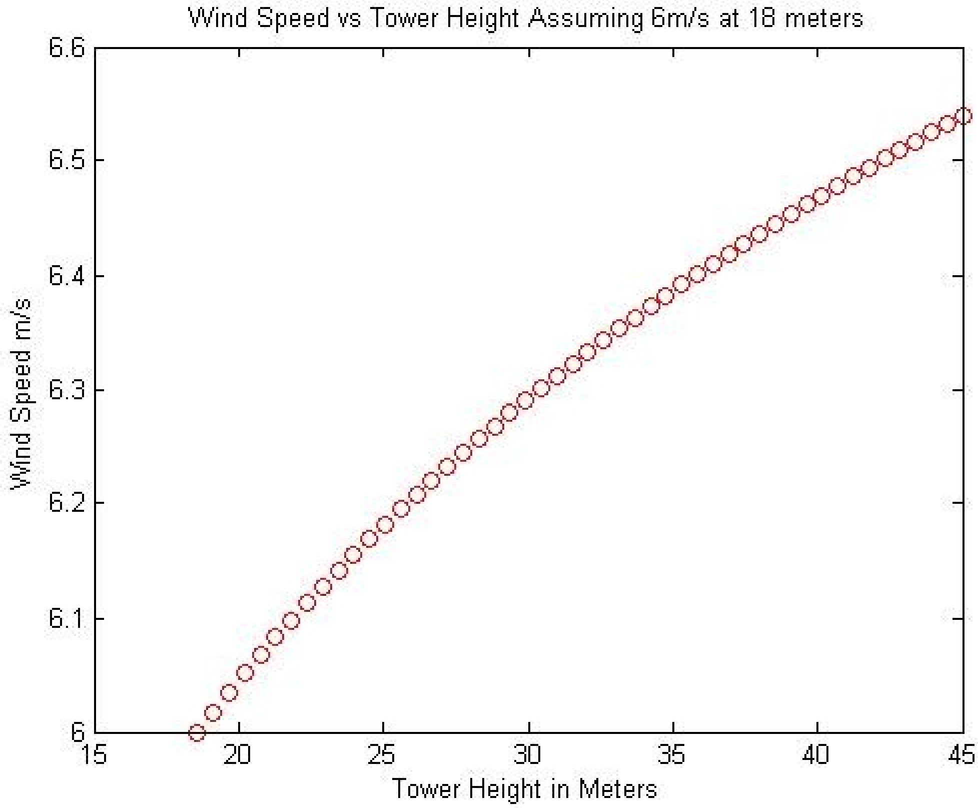
Company	kW Rating	Useful Life in Years	Tower Height in m	Cut in Speed m/s	Rotor Diameter in m	Cost
Integrity Wind systems EW50	50	30	30	4	15	$275,000 on mainland
Bergey 50 kW	50	unable to find that information at this time	variable	3	14	unknown Note: this model is not available yet
Northwind 100	100	20	40	3	21	$475,000 installed

Bergey also provided a spreadsheet to calculate the power and energy that the 50 kW model would provide, which is an average power of 15 kW and an energy total of 130 MW hours per year.

Overall, the wind resourses on Appledore seem to be plentiful. The average wind speed in 2007 at the anemometer was about 6 m/s or 13.4 miles/hour. One way to increase the wind speed at the turbine is to increase the tower height. Wind speed is related to tower height by the equation $V = [\log(H/Z_o)/\mathrm{Log}(H_o/Z_o)]*V_o$ where H is the new tower height, H_o is the old tower height, Z_o is the surface roughness (0.001 meters for coastal sites[57]), and V_o is the wind speed at the original height. Figure 25 shows the wind speed at the top of a tower as the tower height increases, assuming a 6 m/s wind speed at a height of 18 meters.

[56] Digital Appendix > Alternative Energy > Wind Power > 'Bergey 50 Tested'
[57] Paul Gipe, *Wind Power,*© 2004

Figure 25: Wind Speed vs. Tower Height



System Integration

Understanding the solar and wind resources on the island is the first step to determining how to best take advantage of them in one complete system. The problem is that both loads and sources are fluctuating. Solar power is only available during daylight hours and changes with the time of day and the weather. Wind power is only generated when the wind is blowing and changes dramatically with the wind speed. The island loads are constantly changing as well; the load is dependent on island population and how many lights and pumps are operating, etc.

One way to design a power system is to invest in large battery banks with the ability to hold the energy generated when it is not needed. The AC power from the turbines can go through charge controllers, where it is converted to DC and used to charge the batteries. The DC power from the solar arrays can go through separate charge controllers and into the battery bank. All the loads can draw current from the battery bank. The advantage of this system is that if the battery bank is large enough, and there is enough power generation from wind turbines and solar arrays, it is possible to have a completely green system with no fossil fuels burned. The disadvantage is that the sources of renewable energy have to be sized larger and the battery banks must have enough capacity. Generally, it is recommended to have enough charge in the battery bank to supply the grid for two days without any power generation[58]. For SML, that means a battery bank

[58] William H. Kemp, *The Renewable Energy Handbook,* ©2004

with at least 1000 kW hours of capacity. Appropriate battery banks of this size would cost over $250,000.[59]

A more conservative but less sustainable alternative is to keep a generator in place to charge the batteries when they drop too low. It would be possible to reduce the size of the battery bank, at the cost of burning more fossil fuel. The main advantage to this configuration is that a smaller battery bank could be used. A disadvantage of this method (besides being less sustainable) is that without the extra battery capacity, excess power would have to be thrown away more often. There would have to be a large proportion of energy coming from renewable sources to justify this configuration because of the losses suffered from having generator power go through the battery bank.

A third alternative is to keep the generator on the grid, store reserve and excess energy in batteries and supply loads directly from AC power sources without letting them pass through the battery bank. This is the most complicated of the three options outlined because it would require sophisticated controls on an AC hub to keep the wind turbines and generators from working against each other. Normally, a generator adjusts its power according to the loads it is supplying. When power comes in from the wind turbine, a generator doesn't know what to do with it because it isn't a load. Implementing a hybrid system controller would make it possible to have the generators work with wind turbines.[60] The efficiency of the system would increase because the AC power from the wind turbines doesn't always have to be converted to DC for storage. Also, the generators would only run when required and would not have to push energy through a battery before it can be used.

According to Steve Drouilhet from Sustainable Automation, a secondary load controller could be used to send power to pumps and water heaters when the system supplies more power than needed. This would increase overall efficiency by reducing the amount of energy thrown away during windy periods.

A fuel cell style energy storage system called the Zess 50, made by ZBB Energy, was recommended by Kevin Dennis, PE, of ZBB as a way to add to the island's storage capacity. The Zess 50 is a 50 kW hour battery that pumps a flowing electrolyte through plastic cells. The system is more environmentally friendly than traditional batteries because the fluid is a zinc bromide solution rather than lead/acid. Two other advantages of the Zess 50 are that it can be completely discharged without harm and the storage capacity of the system can be increased by adding more units. Although Kevin Dennis sounded optimistic about using the storage systems on Appledore, he never sent the information that was requested and has not replied to further e-mail requests.

Recommendations

Power Grid:

[59] Based on the price of the existing batteries

[60] Digital Appendix > Alternative Energy > System Integration > Sustainable Automation > 'A Primer On Hybrid Power Systems'

Implement a wind-solar-diesel power grid with an AC bus. Steve Drouilhet of Sustainable Automation has submitted a proposal to come to Appledore to conduct a site evaluation and create a plan for the power grid. His proposal should be accepted because his company specializes in large off grid power systems and utilizes new and effective technology. A high level of expertise is needed to implement a cost effective and efficient green power system on the island.

Both solar and wind power should be used because these systems tend to balance each other.

The south facing rooftops of Dorms 1 and 2 should be outfitted with photovoltaic panels as outlined in the Sharp 1 configuration in the solar power section. It would be worthwhile to replace the roofing with higher quality roofing on the buildings that have mounted collectors; the current roofing has to be replaced frequently and removing and then reinstalling the panels every time would add to the cost. A light colored or painted metal roof might help keep the temperature down, which would improve the efficiency of the panels.

Add another larger wind turbine. The Bergey 50 kW turbine is an attractive option because it has a low cut in speed and comes from a reputable manufacturer. This turbine is not yet available; SML should contact Bergey to find out when it will reach the market.

Keep the generator load under 27 kW so that the new generator will be able to run without turning on the larger generators. The load is usually low enough to do this but it would be necessary to conserve more electricity if the R/O unit is in use. See the Recommendations for General Energy Conservation below for suggestions on keeping the load under 27 kW.

Solar Water Heating:

Kiggins:

A shed roof is recommended for the new building because it would allow for the most collectors. A shed roof could fit enough collectors to account for 100% of the hot water demand in July. The collectors should be installed vertically to ensure proper drainback.

The combined tank capacity should be about 800 gallons to match the demand.

The existing propane water tanks should be situated higher than the solar tanks to allow circulation.

All of the tanks should be located in the new bathroom building to reduce heat loss in the pipes.

Bartels:

Use the south-facing roof above the storage area for the collectors. Although the collectors would be partially shaded in the early morning and in the late afternoon, they will be in full sun from 9am-3pm, which is the most solar intensive period of the day.

Two Gobi 410 collectors should be installed on the south-facing roof of Bartels.

One 80-gallon tank with drain-back should be added to the existing 40-gallon tank.

All of the tanks should be placed in the storage room right below the roof so as to minimize heat loss in the pipes.

General Energy Conservation:
A practical first step in reducing SML's use of fossil fuels is to simply conserve energy, and to avoid using it unnecessarily. One way to conserve energy is to turn off lights in buildings around the island when they are not in use. There are several locations where it has been noted that lights are left on unnecessarily. These locations include the bathrooms in Kiggins, the commons, the shop in the Grass Lab, the generator room, and the basement of Bartels. There are a couple of ways to address the issue of lights left on.

The first is to encourage staff and students to turn off lights if they are the last ones to leave a room. In the Kiggins bathrooms, however, there is no light switch to be found. Signs should be posted next to doors and light switches, reminding people to turn the lights off.

Another way to make sure that lights are only on when necessary is to install lighting controls triggered by motion sensors. The best locations to install these in are Kiggins Commons, the shop in the Grass Lab, and the generator room. It is understandable that the lights in the generator room are always on at present. If there was an emergency with one of the generators, it would be annoying to have to find the lights and turn them on before staring to deal with the problem. Motion sensors would alleviate this issue. Anytime someone enters the room, the lights will turn on.

The refrigerator in Bartels is very old and is obviously not energy efficient. The side of the refrigerator feels cold, indicating bad insulation and wasted energy.

This refrigerator should be replaced as soon as possible, in order to reduce the load on the generator.

Each dorm has a 6 gallon hot water heater. The heater in Dorm 1 uses 2000 W; and the tanks in Dorms 2 and 3 each use 1500 W. The hot water demand in the dorms is relatively small. The 2007 engineering interns surveyed students to determine whether they would be willing to go without hot water in the dorms. Many students thought it was a great idea, while others were vehemently opposed. The most compelling reason to continue heating water for the dorms is that the weather gets quite cold in May and September. Even so, Kiggins is close by, and it would still have hot water.

It is recommended that the hot water heaters in all three dorms be turned off. A compromise would be to turn of the hot water heaters during the warmer summer months, but leave them on during the colder months.

The recommended actions to conserve energy are summarized in Table 27.

Table 27: Recommended Energy Conservation Tactics

Issue	Action

Lights left on	Explain the importance of turning off lights and conserving power use to visitors and students during the opening “Fire and Water” talk.
	Post signs reminding people to turn lights off if they are the last one out of a room.
	Install motion sensor lighting controls in the following locations: o Generator room o Shop in Grass Lab o Kiggins Commons o Bartels basement Recommended brand: Watt Stopper
Energy inefficient appliances	Replace refrigerator in Bartels. Look for one with a high EnergyStar rating. Look into purchasing one without a freezer; the freezer in Bartels is rarely used.
Energy demand from potentially unnecessary water heaters	Turn off hot water heaters in all three dorms.