Table 2: Summary of greywater treatment alternative evaluations

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

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

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

Salt Water System

System Overview

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

Problem Overview

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

Data Collection

System Flow Monitoring

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

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

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

Salt Water Pump Testing

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

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

Results

System Flow Monitoring

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

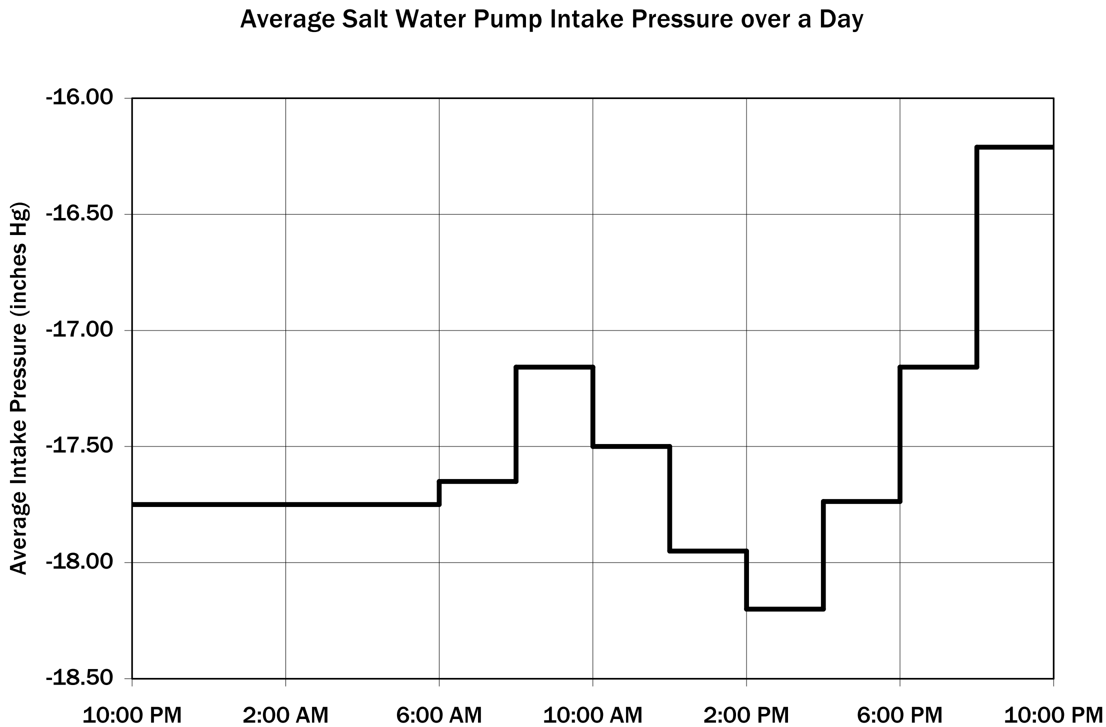

Figure 5: Average salt water intake pressure shown as a function of time over the day. Average intake pressure between 10:00pm and 6:00am is an estimation using 10:00pm and 6:00am data values.

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

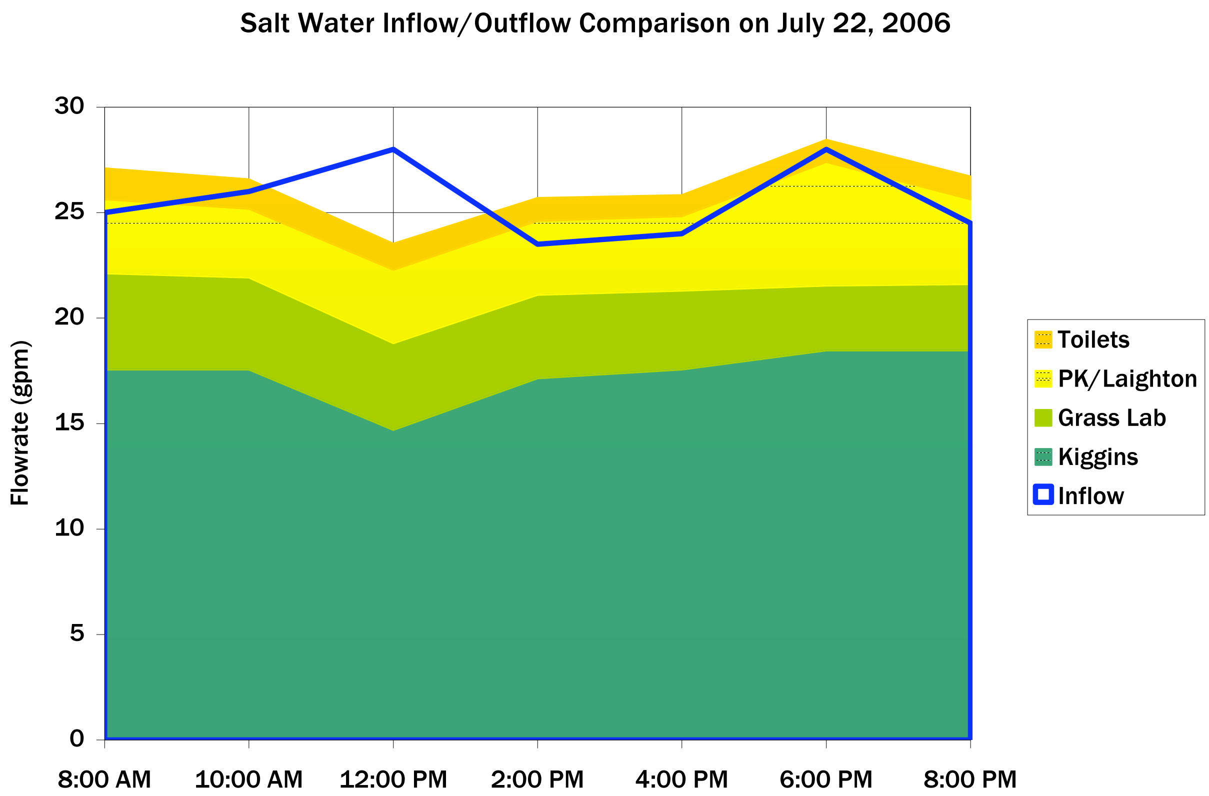

Figure 6: Comparison of salt water system inflow and outflow on Saturday, July 22nd, 2006

Salt Water Pump Testing

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

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

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

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

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

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

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

Recommendations

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

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

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

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

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

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

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

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

FRESHWATER SYSTEM

System overview

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

Problem

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

Data Collection

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

Results

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

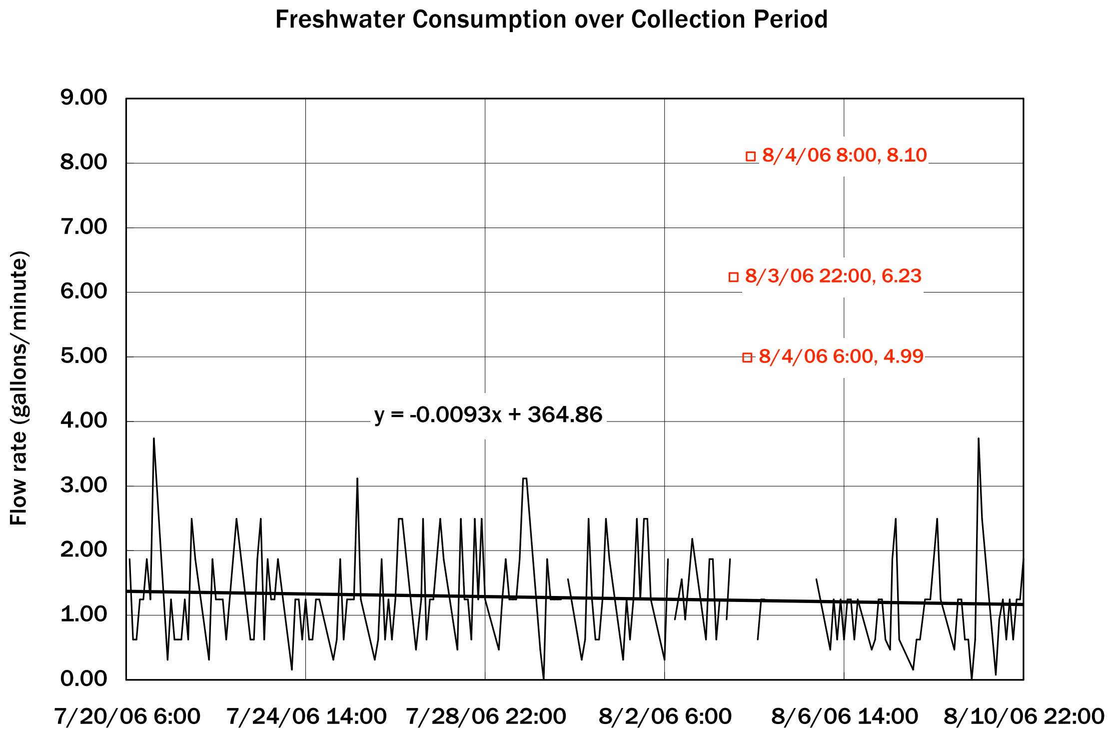

Figure 7: Freshwater consumption rate over entire collection period

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

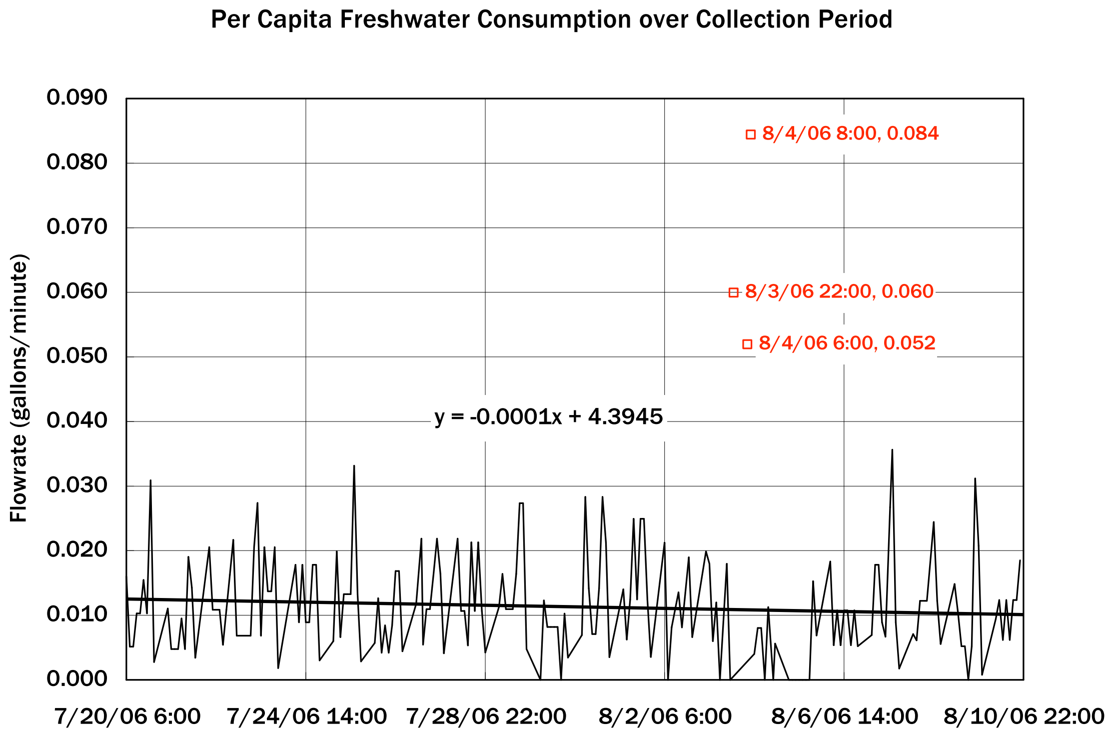

Figure 8: Per capita freshwater consumption over the entire collection period

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

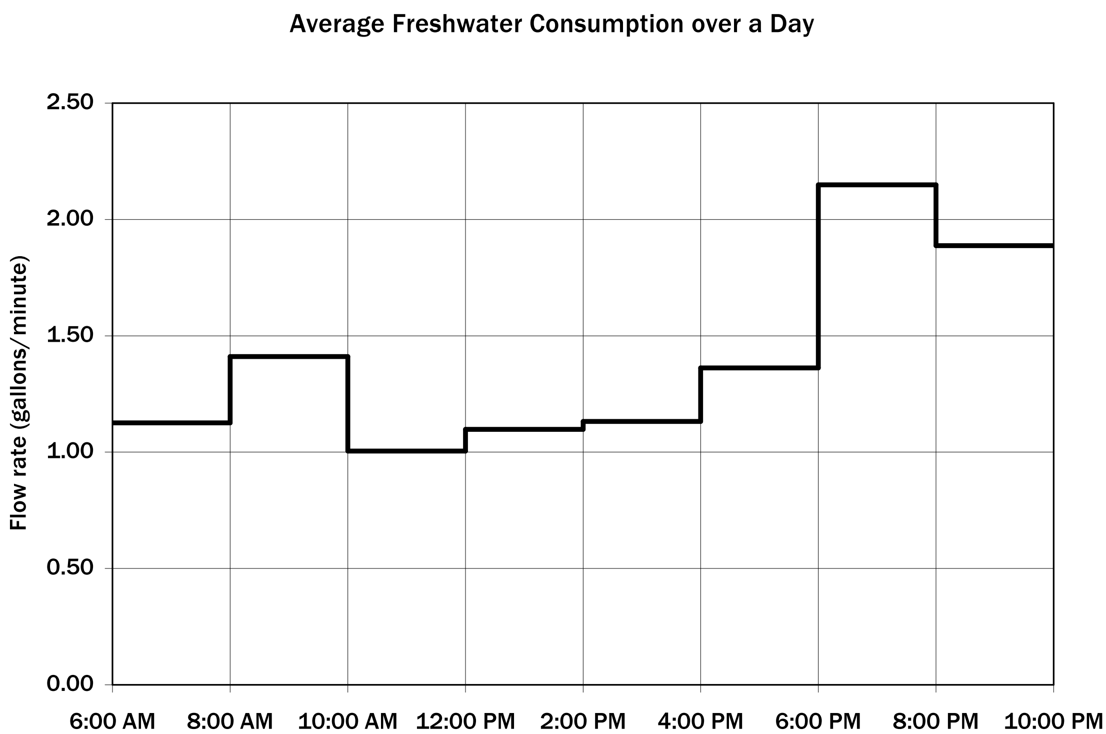

Figure 9: Average freshwater consumption rates over a day

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

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

Table 3: Yearly average of freshwater consumption historical summary

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

Recommendations

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

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

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

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

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

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

Electrical System

System overview

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

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

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

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

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

Projects

Documentation

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

Background

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

Problem overview

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

Data collection

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

Results

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

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

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

Recommendations

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

Energy consumption

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

Problem overview

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

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

Data collection

Energy audit

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

Usage patterns

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

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

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

Results

Energy audit

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

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

Usage patterns

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

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

Figure 10: Generator fuel consumption July 20-August 10

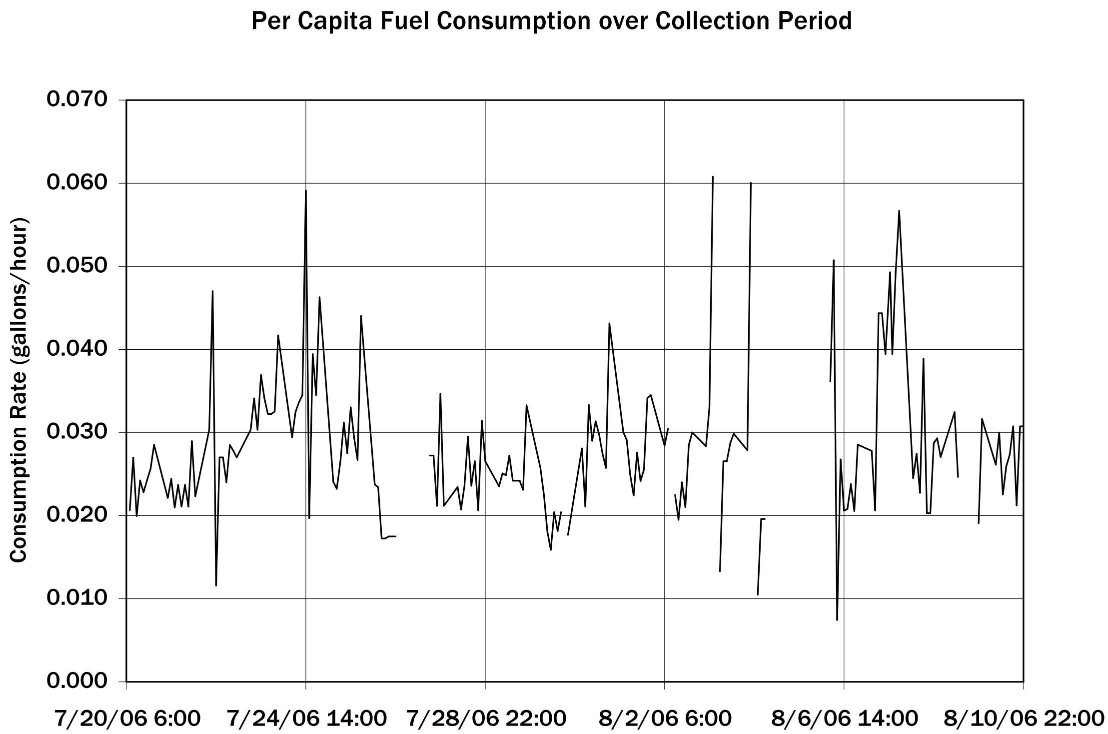

Figure 11: Per capita generator fuel consumption July 20-August 10

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

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

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

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

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

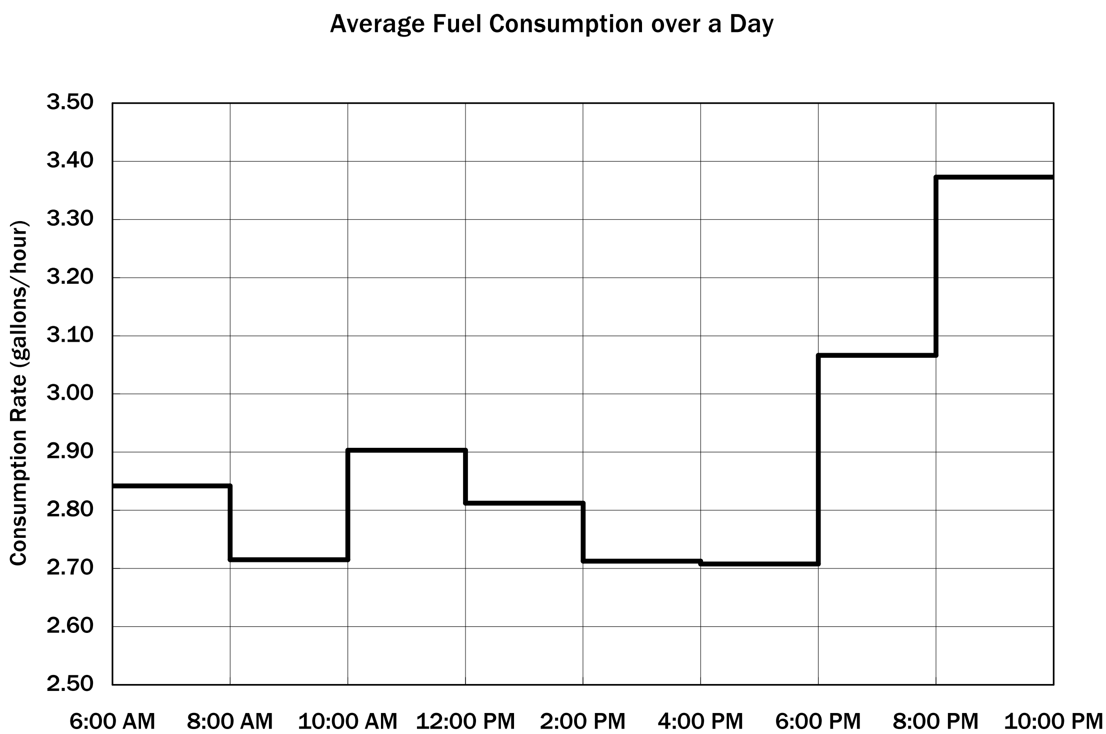

Figure 12: Average fuel consumption over a day

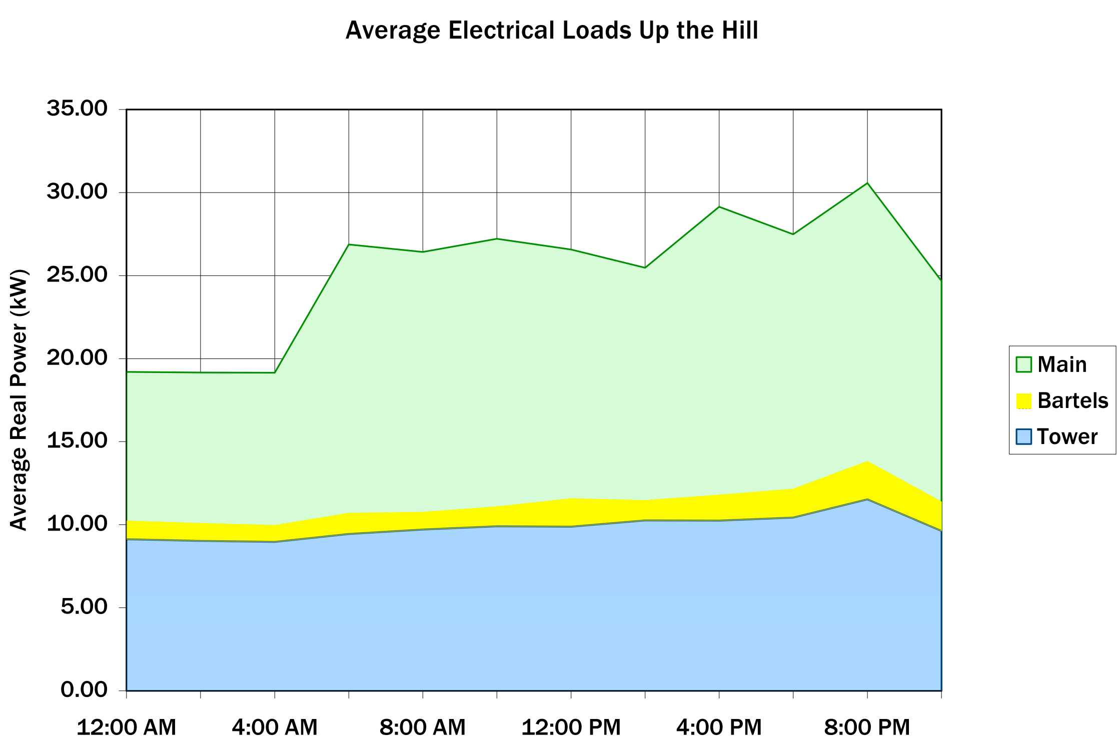

Figure 13: Average electrical loads on the Kiggins 480 V distribution panel.
Note that Bartels and Tower averages are stacked, while Main averages are not.

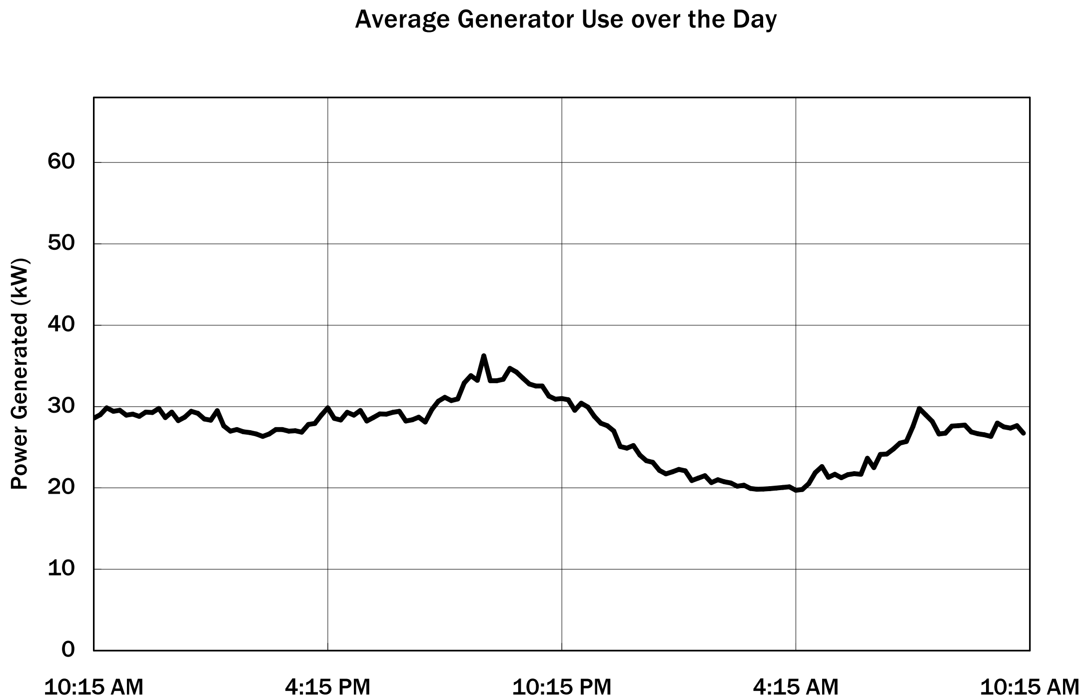

Figure 14: Average generator use over the day July 19-August 2

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

Table 4: Yearly average fuel consumption historical summary

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

Recommendations

Energy audit

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

Usage patterns

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

Power system quality

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

Background

Supply quality[15]

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

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

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

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

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

Generator efficiency

Generator power output is composed of four measurements: real power, reactive power, apparent power, and the power factor.Real power is a function of resistance. Reactive power is a function of reactance. Apparent power is a function of impedance, and is thus the sum of real and reactive powers. The power factor is the ratio of real power to apparent power, and is thus a measure of the relative effect of inductors and capacitors which dissipate no energy but drop voltage and draw

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

current.[18] The higher the power factor, the less voltage and current is lost to non-load bearing components.

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

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

Problem overview

Supply quality

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

Generator efficiency

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

Data collection

Supply quality

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

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

Generator efficiency

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

Results

Supply quality

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

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

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

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

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

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

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

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

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

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

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

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

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

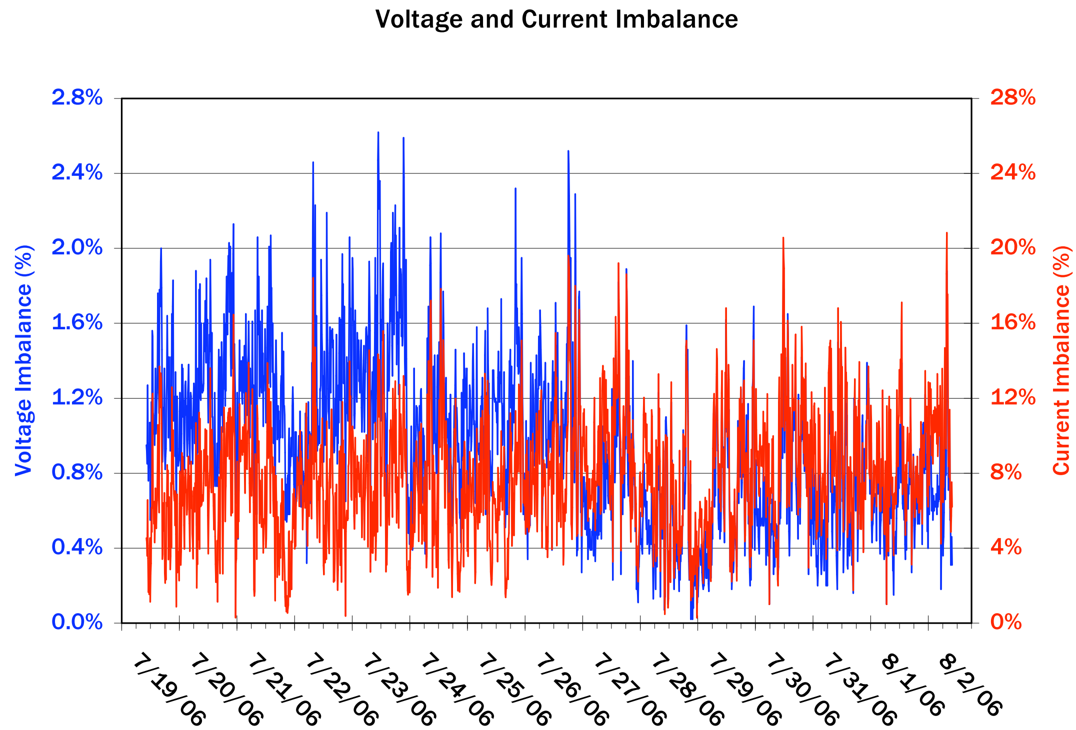

Figure 15[21]: Comparison of voltage and current imbalance of the generator room 480 V main distribution panel July 19-August 2

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

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

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

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

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

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

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

Generator efficiency

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

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

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

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

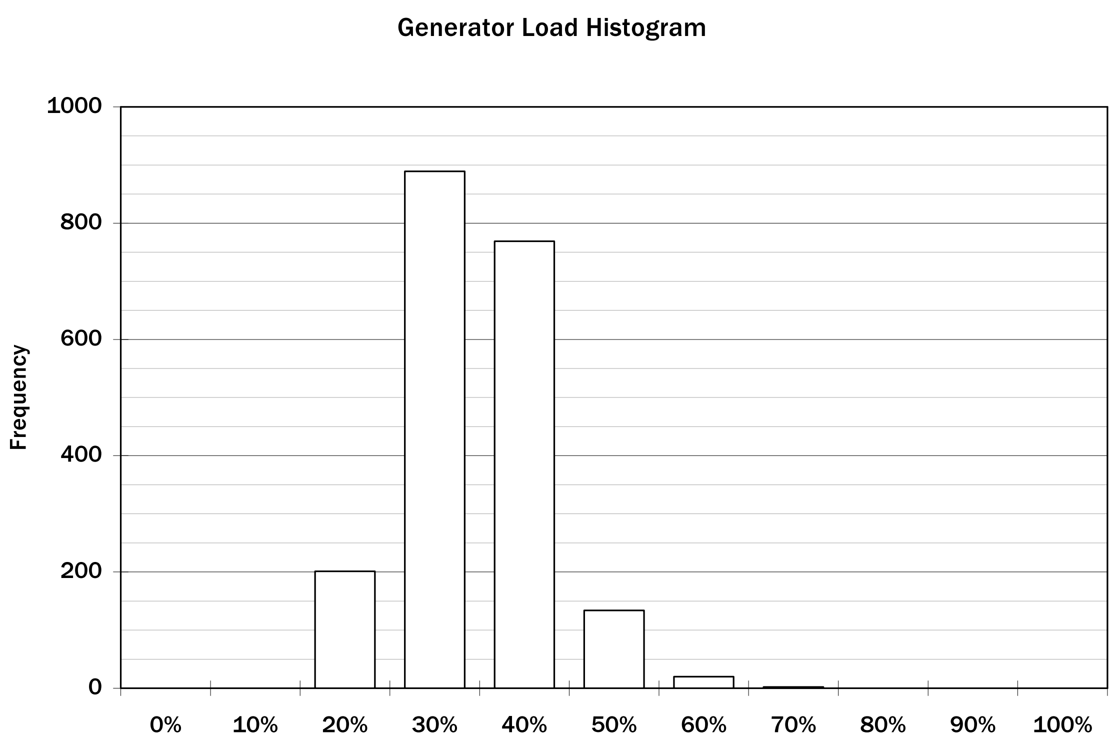

Figure 16: Histogram of generator load as a percentage of 68 kW nameplate capacity

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

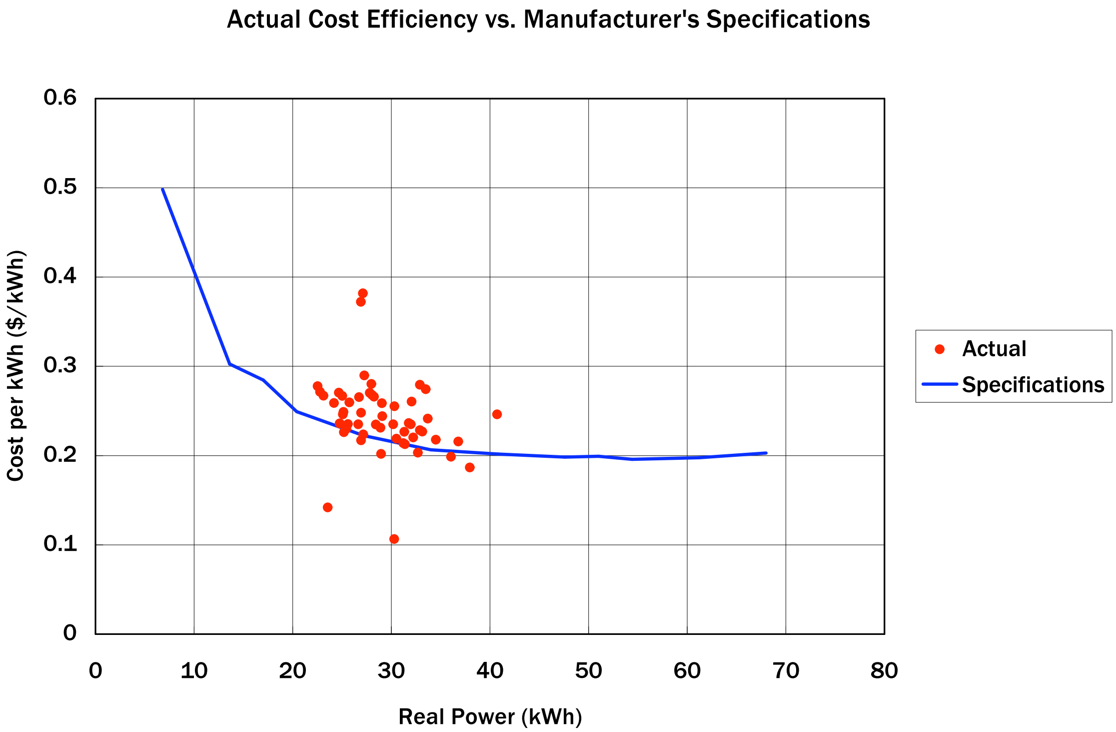

Figure 17: Comparison between actual cost efficiency from July 20-26 and fuel efficiency based on manufacturer-provided specifications
Based on this season's diesel price of $2.42/gallon

Recommendations

Supply quality

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

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

Generator efficiency

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

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

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

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

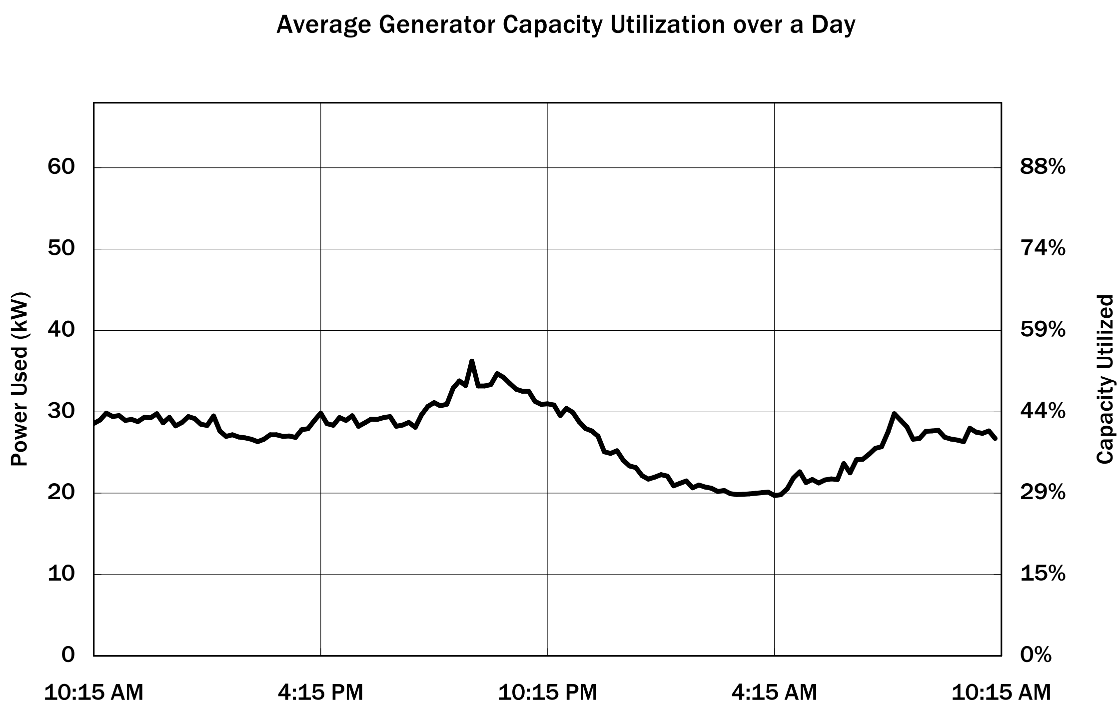

Figure 18: Average generator capacity utilization over a day from July 19-August 2

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

Solar panel feasibility

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

Background[22,23]

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

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

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

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

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

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

Equipment and installation[24,25]

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

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

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

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

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

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

Applications

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

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

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

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

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

Documentation of Island Systems

Background

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

Projects

Mapping

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

Table 11: GIS map layer standards

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

Table 12: Summary of work

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

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

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

Line Labeling

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

Table 13: Line labelling standards

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

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

Future Projects

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

Biodiesel

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

Wind Power

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

Solar Power

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

Other Alternative Energy

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

Greywater Treatment

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

Freshwater System

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

Composting Toilets

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

CONCLUSION

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

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

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

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

maintenance than the diesel generators.

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

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

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