2012 Sustainable Engineering Internship

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Executive Summary

The Sustainable Engineering Internship at Shoals Marine Laboratory (SML) on Appledore Island has provided engineering undergraduates with the opportunity to solve sustainability problems since 2006. Sustainability is important to the island because of limited resources, including water and energy. Recent additions to the island's systems have allowed SML to make great strides toward becoming sustainable. Such additions include a solar water heater, composting toilets, photovoltaic panels, wind turbine, and battery bank. The goals of the engineering interns are to evaluate the degree of effectiveness of these systems and make further recommendations for improvement. In 2012, the engineering interns investigated the capacity of the Green Grid, efficiency of the solar water heater, possible uses of Crystal Lake water, expanding the Green Grid, and populating the geographic information systems (GIS) database. They also developed a grant proposal for a composting toilet, and they evaluated the showering restrictions.

Green Grid Capacity

The Green Grid currently powers several buildings on the island. This grid uses electricity generated by the photovoltaic (PV) panels and the wind turbine to charge a battery bank that is then used to power these buildings. Two generators power the rest of the island, and these generators also power the Green Grid when the batteries hit a minimum threshold voltage. The interns were tasked with analyzing energy usage through the creation of visuals which displayed instantaneous kW and daily kWh usage on the Green Grid. They also investigated whether low periods of demand existed where the batteries could be charged using the generator. During the internship, the Palmer-Kinne (PK) lab was added to the Green Grid, and the interns evaluated the sustainability of this decision.

A period of low demand was found at night from midnight to eight a.m. and a method was found using the Grid-Use mode on the Mate to charge the Green Grid Batteries during this period. The demand of the Palmer Kinne lab was successfully quantified and found to be about 8.4kWh per day. The supply of power on the grid is uncertain because of lack of software to measure output of the PV panels and Turbine. The sustainability of keeping PK on the grid was evaluated using data from the Powermonitors and it was decided that for now PK should be kept on the grid because it is successfully reduced the demand on the generators by 6.95kWh per day. Further evaluation should be done however because only one week of data was available.

Solar Water Heater Performance

The solar water heater, located in the Water Conservation Building, was installed in July 2011. Hot water was originally provided for Kiggins Commons by a single 82-gallon propane water heater. The solar water heater pre-heats the water before it is fed to the propane tank, reducing the amount of propane required to obtain the desired 150 degree Fahrenheit water temperature. The interns evaluated the effectiveness of the new solar water hear in terms of propane saved. In addition, the interns were tasked with optimizing the solar water heater by analyzing the temperature differentials, which control how the water circulates through the system.

The interns considered the relationship between propane use and weather data. They also analyzed the incoming and outgoing water temperature and flow rates to determine how much energy it would have taken for the propane tank to heat the water.

The interns found that the solar water heater saved approximately 84 cubic feet of propane per day during the month of June. The savings are equivalent to 2400 cubic feet of propane in a month or 2.7 hundred pound tanks of propane, and 0.37 metric tons of CO2.

The interns recommend looking into the interaction between pumps and the glycol/water ratio in order to optimize solar water heater performance. The interns also recommend calibrating and recording T6, the temperature of the water exiting the solar water heater, and recording pyranometer data to correlate weather with system performance.

Crystal Lake Water Usage

Freshwater is a highly limited resource on the island. Currently, the only usable water supply is a dug well. To supplement the water supply, previous years' interns have evaluated possible uses for Crystal Lake, a rain-fed freshwater pond on the southern side of the island. This year, the interns' task was to design a filtering and settling water treatment system to reduce turbidity enough to augment the drinking water well. As another alternative, the interns explored the possibility of using Crystal Lake water for toilet water.

The interns studied the turbidity of Crystal Lake during filtering and settling tests. It was determined that using a 5 micron filter along with four days of settling achieved high removal percentages. They also determined a possible route for pumping the water to the island's toilets using the former saltwater lines. Options for pumping the water were also determined.

New Green Grid Building

The island currently has a Green Grid with an 87kWh battery bank powered by a 7.5kW wind turbine and a 7.5kW PV array. The island was awarded a grant with which to buy a battery bank to use as the foundation for a new island wide Green Grid. The interns were tasked with sizing the battery bank to fit the island's needs and designing a building to hold it. The initial goal of this project would be to shut the existing generators off at night and rely solely on the new battery bank to power the island.

Energy usage on the island was monitored in order to size the battery bank correctly. The interns also investigated the effect of different battery discharge levels on lifespan. From this, the interns created designs for possible new buildings.

GIS Database Population

Undergraduate students from the University of New Hampshire created a GIS database for the Appledore Island Shoals Marine Lab. The interns were given the assignment of updating the database, specifically the freshwater system on the island. They also populated the database with information about old saltwater toilet lines and where these lines join with the freshwater system. They applied this knowledge to the Crystal Lake water usage assignment in determining how to bring Crystal Lake water to the toilets without risking contamination of the freshwater lines.

Composting Toilet Grant

The Palmer-Kinne Lab was sited by the island engineers as a potential location for a new composting toilet facility as it does not currently have restrooms. The interns were tasked with determining the potential usage and sizing of the toilet, as well as writing a grant to obtain funding for the project. In conjunction with installing a composting toilet, improvements to the specimen preparation and dissection area as well as an observation deck were developed.

A few plans were created based the grant that the island engineers apply for and how much funding is granted. These plans include having the observation deck and the enlarged specimen prep area in addition to the composting toilet, having the enlarged specimen prep and the composting toilet only, and only having the composting toilet addition. Suggestions were given for grants that focus more on the goal of adding a sanitation facility or helping the environment as opposed to improving the educational value of the sight.

Showering Restrictions

The interns were tasked with evaluating the current showering restrictions as the island has received some negative feedback. The current restrictions are two “Navy” showers per week and no showers around mealtimes. These restrictions are in place because of limited freshwater resources on the island, as well as limited wastewater and power capacities. The interns evaluated the restrictions independently, looking at showering around mealtimes and allowed number of showers per week.

Based on the work done by the interns, there is information to suggest that the restrictions around meal times are not necessary. However, it was not decidedly determined if increasing the number of showers per week allowed to students and interns could be allowed by the island. There was not sufficient information to determine the amount of freshwater available.

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Introduction

The Sustainable Engineering Internship at Shoals Marine Laboratory (SML) on Appledore Island has provided engineering undergraduates with the opportunity to solve sustainability problems since 2006. Sustainability is important to the island because of limited resources, including water and energy. Recent additions to the island's systems have allowed SML to make great strides toward becoming sustainable. Such additions include a solar water heater, composting toilets, photovoltaic panels, wind turbine, and battery bank. The goals of the engineering interns are to evaluate the degree of effectiveness of these systems and make further recommendations for improvement. In 2012, the engineering interns investigated the capacity of the Green Grid, efficiency of the solar water heater, possible uses of Crystal Lake water, expanding the Green Grid, and populating the geographic information systems (GIS) database. They also developed a grant proposal for a composting toilet, and they evaluated the showering restrictions.

Green Grid Capacity

Background

Appledore Island has two different grids which supply electricity to the island; the conventional grid fed by two generators, and the "Green Grid." The island has three generators, two 65kW and one 27kW. The power situation on the island used to be out of control and the existing generators were almost not enough to supply the demand. Since then Shoals Marine Lab has put a focus on sustainability and has reduced their power usage such that only the 27kW generator needs to be run. The Green Grid is powered by the 7.5kW Bergey wind turbine and 7.5kW photovoltaic (PV) arrays. Since these renewable energy sources cannot constantly provide energy to the grid, there is an 87kW battery bank which can effectively be viewed as the power source for the green grid. The battery bank is backed up by the diesel generators because of the nature of wind and solar energy and its inconsistency. If the battery bank hits a minimum voltage of 46.8V, power is drawn from the generators to recharge it. On the hand it is considered fully charged when it reaches 56.3V, and at this point surplus power is directed to a resistor bank where it is burned off as heat. The University of New Hampshire used to run an AIRMAP weather and pollution monitoring station on the island which needed power all year round. This was the original reason for installing the wind turbine, but more recently the grid has been expanded because of an increasing desire for sustainability. This past year however, the AIRMAP station in the tower has been shut down due to loss of funding leaving SML with a surplus of energy on the Green Grid. There will always be some energy that gets wasted, but since the AIRMAP station has been shut down demand on the grid is so low that there is a lot of energy being wasted and being burned off on the resistors.

Objective

The island engineers were interested in the electrical load on the existing Green Grid. The interns were asked to gather data from newly installed power monitors and graph the instantaneous kW and daily kWh usage of the Green Grid and Generator Grid. The interns were also asked to record when and how often the battery bank is charged by the generators. Based on a daily trend from this data, the interns were expected to ascertain whether there were periods of low demand on the generators when they could be programmed to charge the batteries. The interns also had to determine how to program the generators to charge on a time scale if a pattern of low demand appeared. During the internship, the Palmer-Kinne (PK) Lab building was added to the Green Grid. The sustainability of this decision was examined by the interns, especially concerning if the Green Grid can handle the additional load from the PK building.

Theory

Power Monitor

Shoals Marine Lab (SML) recently installed three Allen Bradley Powermonitor 3000s to capture data regard power used on the island by both the Generator Grid and the Green Grid. The Powermonitors have the capability to log vast array of parameters in very fine intervals. They also are able to keep two different kinds of logs, a trend log and a min/max log. The trend log records data over any set interval and can log the value and timestamp of thousands of data points. The min/max log keeps a live update of the maximum and minimum values of all parameters and the timestamp for when these values occur. Through the combination of these two types of logs a clear representation of power usage can be given.

Fluke Meter

Shoals Marine Lab has also recently purchased a Fluke Industrial Multimeter. The meter has an AC Current Clamp which, through the properties of magnetism and inductance, allows the user to simply place the clamp around the conductor and measure current without putting the meter in series with the circuit. The current clamp on SML's model has a 1000:1 turn ratio meaning that the output will read 1mA for every 1A measured.

Power Factor

In circuits with alternating current and alternating voltage it is import to consider additional demand by inductive loads. When measuring current and voltage in a.c. circuits, the value used is the roots mean squared (RMS) value. In d.c. circuits power is expressed in watts and is the product of volts and amperes. When calculating power in a.c. circuits however, the product of the RMS voltage and current is not the real power, but the apparent power which is measured not in watts, but in volt-amperes (VA). Reactive Power is the portion of power which does not do work but is required to maintain the inductive loads.

$$Apparent\ Power^2 = Reactive\ Power^2 + Real\ Power^2 \qquad \text{(Eq. 1-1)}$$

Since alternating current has the effect of creating inductive loads, this adds to the demand. This means that it is important to consider the conversion between the two. This conversion is the concept of power factor. Power factor depends on the inductive and capacitive loads but can be traced back to phase angles. Simply, power factor is the ratio of real power to apparent power.

$$Real\ Power = Power\ Factor \times Apparent\ Power \qquad \text{(Eq. 1-2)}$$

This means that, in an a.c. circuit, if the RMS voltage and current can be found then they can be used to calculate apparent power and if the power factor is known then it can be used to find real power.

Three Phase Power

The generators on the island produce what is called three phase power. This means that there are three conductors leaving the generator each carrying their own current. The reason for this is because some motors on the island require three phase power and because using three phase power helps to reduce line loads. The concept behind it is that because in A.C. current the voltage and current fluctuate, if you can offset each of the three phases you can have a constant supply of power delivered instead of if the three coincided with each other there would be a period of zero voltage and current.

Fuel Curve

Generators burn fuel at different rates when different demands are placed on them. If more power is demanded, they have to work harder to produce it and therefore will burn more fuel. The interns contacted Milton CAT, the manufacturer of SML's 27kW generator and inquired about the fuel curves. Summarized below in figure **Figure 1-1** is the information the interns compiled about the 27kW generator.

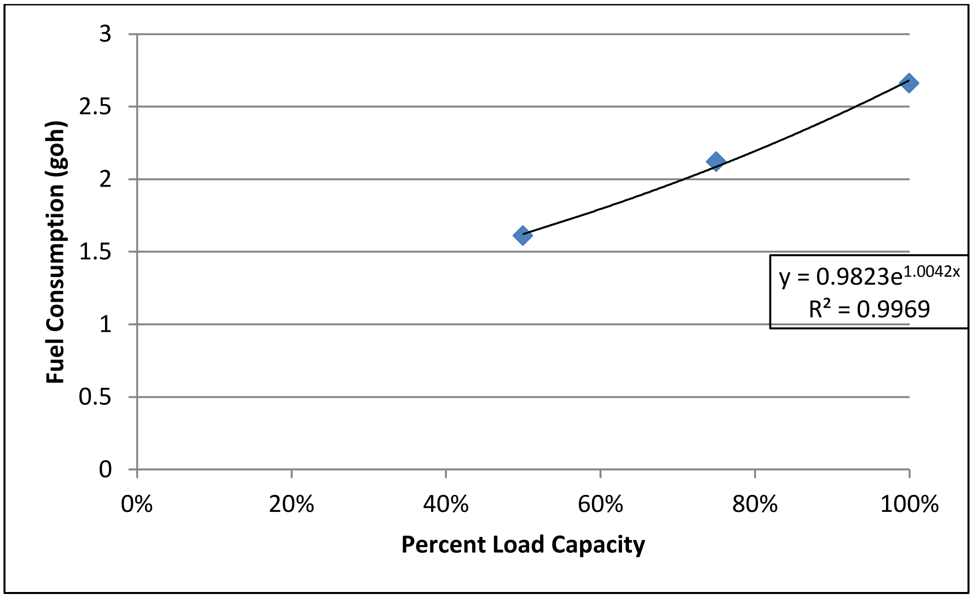

Figure 1-1: Fuel curve for 27kW CAT Generator

Methods

Previous Season Power Use Analysis

An Alan Bradley Powermonitor 3000 was used to record data in the summer of 2011 from the grid powered by the 27kW Cat Generator. This data was logged in five minute intervals and saved in an excel sheet every 2-5 days from June 10th to September 10th. It was suggested to the interns that there may be a period of low demand at night in which the generator may be used to charge the green grid. The interns compiled this data and proceeded to organize it by time of day in order to look for a daily trend of low demand.

Power Monitor Data Collection

This year two new Powermonitors were installed to monitor the green grid and the generator backup for the green grid. The interns collected data from all three Powermonitors throughout their stay. This data was downloaded and the meters cleared every three to five days. The Powermonitors were set to log trend data on five minute intervals. This data was then analyzed in order to get a picture of power consumption on the island.

Palmer-Kinne Lab Demand

The interns were tasked with investigating the current loading of the green grid and whether the Palmer-Kinne lab could be added to the grid. The interns analyzed the loading in PK by attaching a Fluke Multimeter to each of the three phases and measuring the incoming current in minute intervals. The voltage on each of the three phases is 120V. Knowing the incoming current and voltage, apparent power can be calculated. The sustainable engineering interns in 2011 spent time monitoring the islands power factor and found it to range based on demand from 65% to 85%. With this information apparent power can be converted to the real power use of PK.

Green Grid Loading Analysis

In order to determine if adding PK lab was a sustainable decision, the interns first investigated the daily energy use of PK. Three methods were used to do this, the first being direct measurement using a Fluke digital multimeter. The second and third methods involved looking at Powermonitor data before and after PK was added and examining the difference. Each method has error however, hence the reason why the three methods were combined and viewed as a whole. The island only has one power monitor but the power in PK is three phase so this means the current had to be measured at different times and the use of the building was different each time. The problem with the second two methods was that island power use varies greatly on a day to day basis. Therefore it is difficult to determine whether the difference from before and after PK was added is the load of PK or due to other load changes on the island. Since the island lacks software to monitor the output of the PV panels and wind turbine the supply of power on the green grid cannot be measured. Theoretical measurements would be inaccurate at best and interns in previous years have attempted to theoretically quantify the output of the panels. This year a different approach was taken. The approach taken was that if the generators had a lower demand and therefore used less fuel then the decision would be considered sustainable. In order to do this the interns analyzed the data taken from the Powermonitors before and after the lab was added. They quantified the increase in load on the green grid and decrease on the generators. They also investigated trends between weather and the need to charge the battery bank and evaluated total generator load at times of charging.

Conclusions

Charging the Green Grid Batteries at Night

The interns averaged data from the Generator Powermoniter and found the average total real power from the generator for the summer of 2011 at five minute intervals and organized the information in **Figure 1-2**. When this was done, a trend of low demand at night became apparent. The dip in demand is most apparent between mid-night and seven thirty.

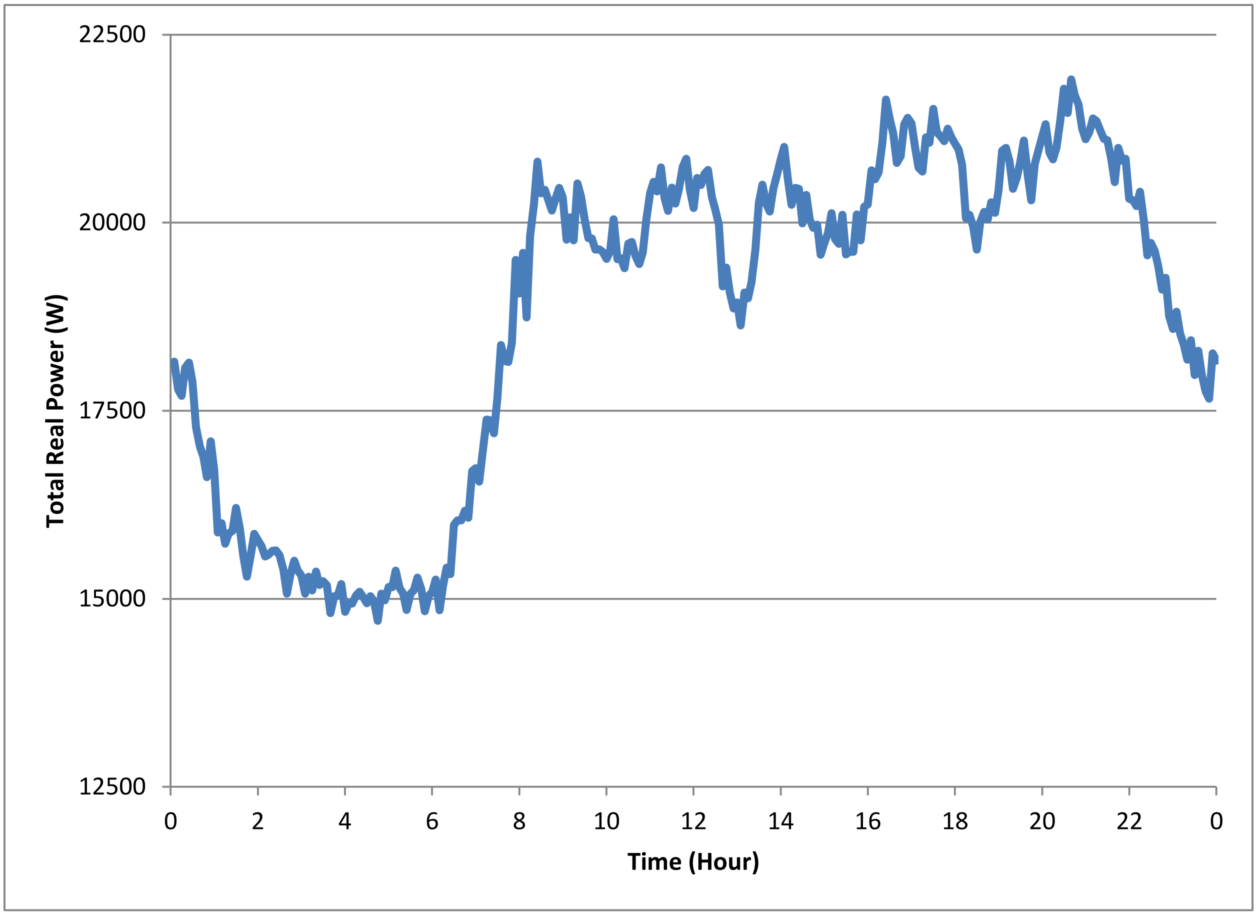

Figure 1-2: Average Total Real Power from 27kW CAT Generator

Palmer-Kinne Lab Demand

The Fluke Multimeter was used to measure the current on each phase of PK at one minute intervals. The data for each minute interval was multiplied by 120V to find the average VA usage at minute intervals. This data was then added all up and divided by sixty to find the average daily VAh usage of each phase in PK and then the demand of each phase was added to find total power demand of the lab. The total volt-amp demand of PK was found to be 11.221 kVAh. Using the average power factor for the island found by last year's interns, this number can be converted to kWh.

$$11.221\text{kVAh} * .75 = 8.4\text{kWh} \qquad \text{(Eq. 1-3)}$$

This means that the total daily power requirement of PK is 8.4kWh. This number may be inaccurate however due to the fact that the current on each phase could not be measured concurrently as there is only one Fluke meter. The interns attempted to take data on what could be considered average class days, days when there were two classes on the island. However, lab use varies greatly on a day to day basis, and therefore this method is not highly accurate. It is assumed that it gives a reasonable enough estimate to use for these purposes however.

The interns analyzed the data from the power meters and looked at the difference between daily power uses of the Green and Generator Grids. Shown below in **Figure 1-3** and **Figure 1-4** are graphs of the daily kWh demand of both the generator and the green grid before and after PK was added.

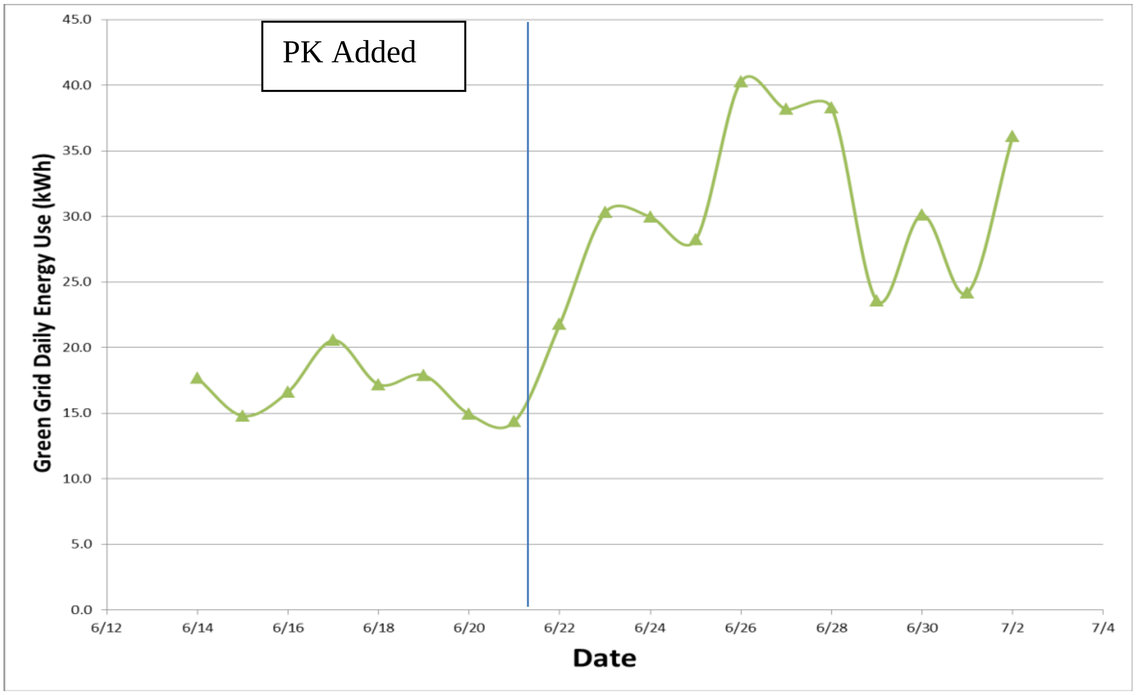

Figure 1-3: Average daily energy use on Green Grid before and after PK was added

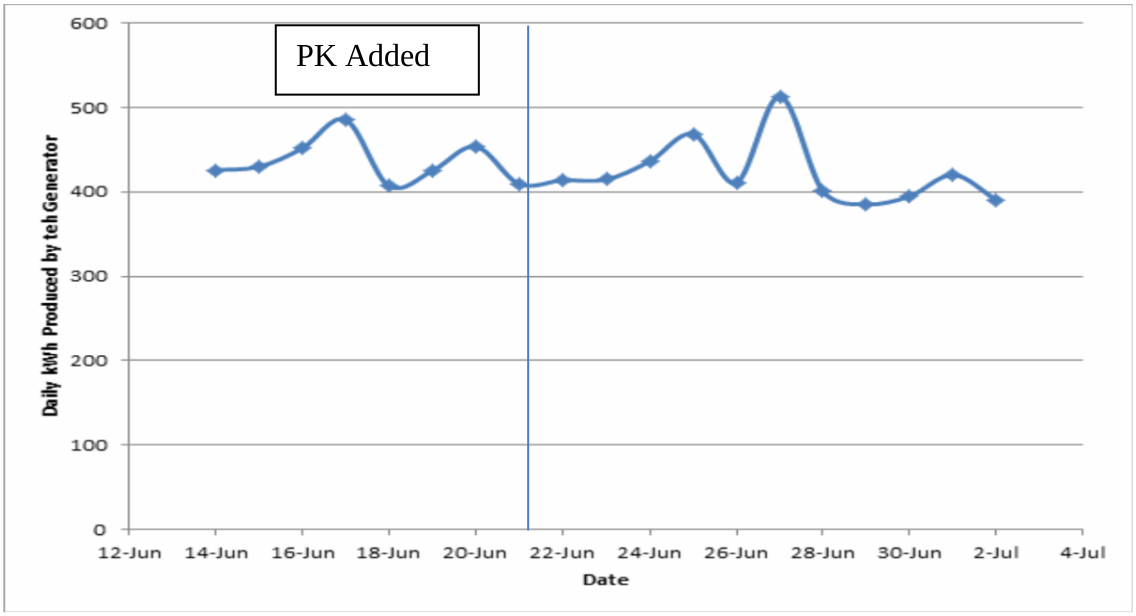

Figure 1-4: Average daily energy use on Generator Grid before and after PK was added

It shows that the load on the generator was lightened by 6.95kWh per day and the load on the Green Grid increased by 10.68 kWh per day. These numbers may be different for a number of reasons. First of all, the generator has had to kick in and charge the Green Grid batteries twice since PK has been switched over; it still maintains part of the load. Another inconsistency is that island power use fluctuates considerably by the day as illustrated below in **Figure 1-5**.

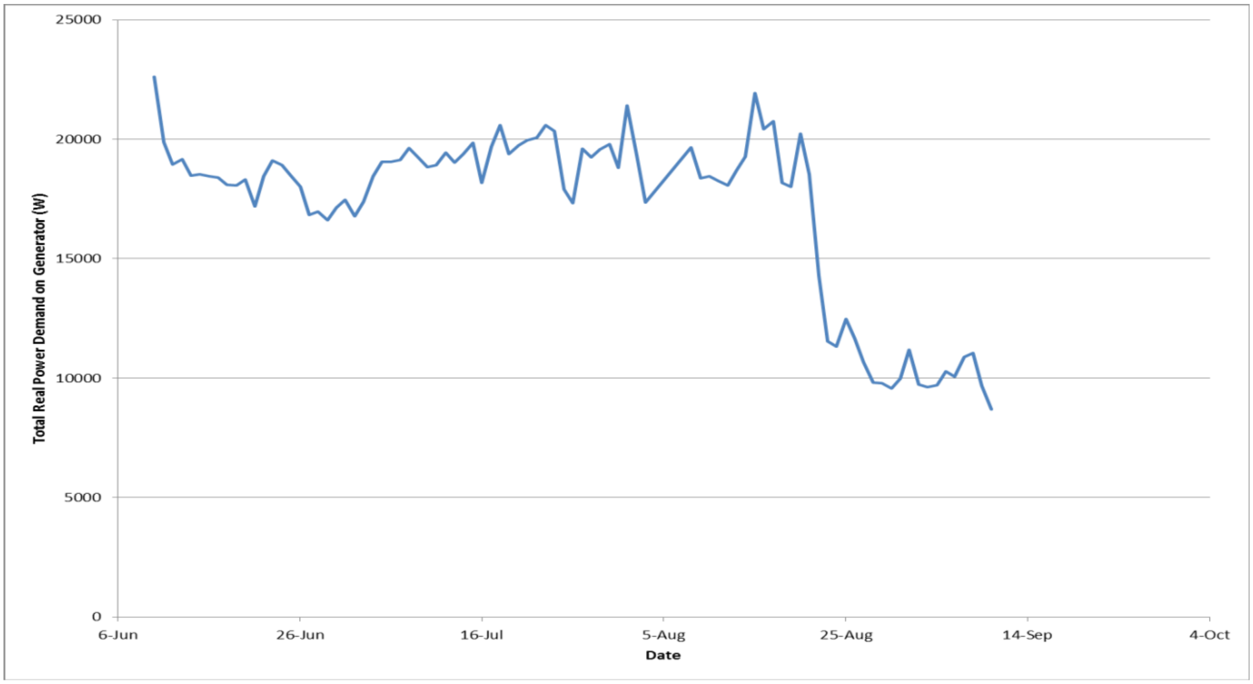

Figure 1-5: Average power demand use on Generator during the summer of 2011

This graph illustrates the daily fluctuation of island power demand and shows why a direct comparison alone is insufficient. When the data from directly measuring the load of PK is considered in conjunction with this data however, it helps to give a picture of what the demand of PK is like. The daily energy demand of PK as calculated by direct measurement is 8.4kWh. This value falls in the range of the values determined by the before and after grid analysis shown in **Table 1-1.**

Daily kWh	Generator	Green Grid
Before PK	428.72	16.67
After PK	421.77	27.35
Difference	-6.95	10.68

Table 1-1: Average daily kWh use of green grid and generator for three days before and after PK was added

The interns carefully examined the power data for the week after PK was added to try to evaluate the sustainability of this decision. They found that the generator had to kick in to recharge the battery bank after two periods of cloudy days. The first time this happened the generator ran from 23:30 on June 23 to 10:55 on June 24 and dumped 20.5kWh. This worked perfectly and balanced the generator load by adding load during the low period at night just as the interns were hoping to program the generators to do. The second time the generator kicked in to charge the batteries it ran from 22:55 on June 25 to 18:25 on June 26 and dumped 45.7kWh. This is less than ideal because the generator was unable to fully charge the battery overnight, and when the morning came and demand on the green grid increased the generator effectively carried the load for the grid. This was because the generator was programmed to charge the batteries until the battery voltage hit a certain level and then power was being drawn from the batteries faster than it was being provided during the day. A closer inspection of the demand on the generator during this charging period showed that the generator spent in total an hour running at about its maximum capacity of 27kW. It hit a maximum of 33.7 kW total real power. There was large possibility that the generator could have been knocked out that day. The demand on the generator is displayed in **Figure 1-6**. The graph uses average total real power over 2 hour intervals, so the spikes above 27kW are not seen, but the trend is still clear.

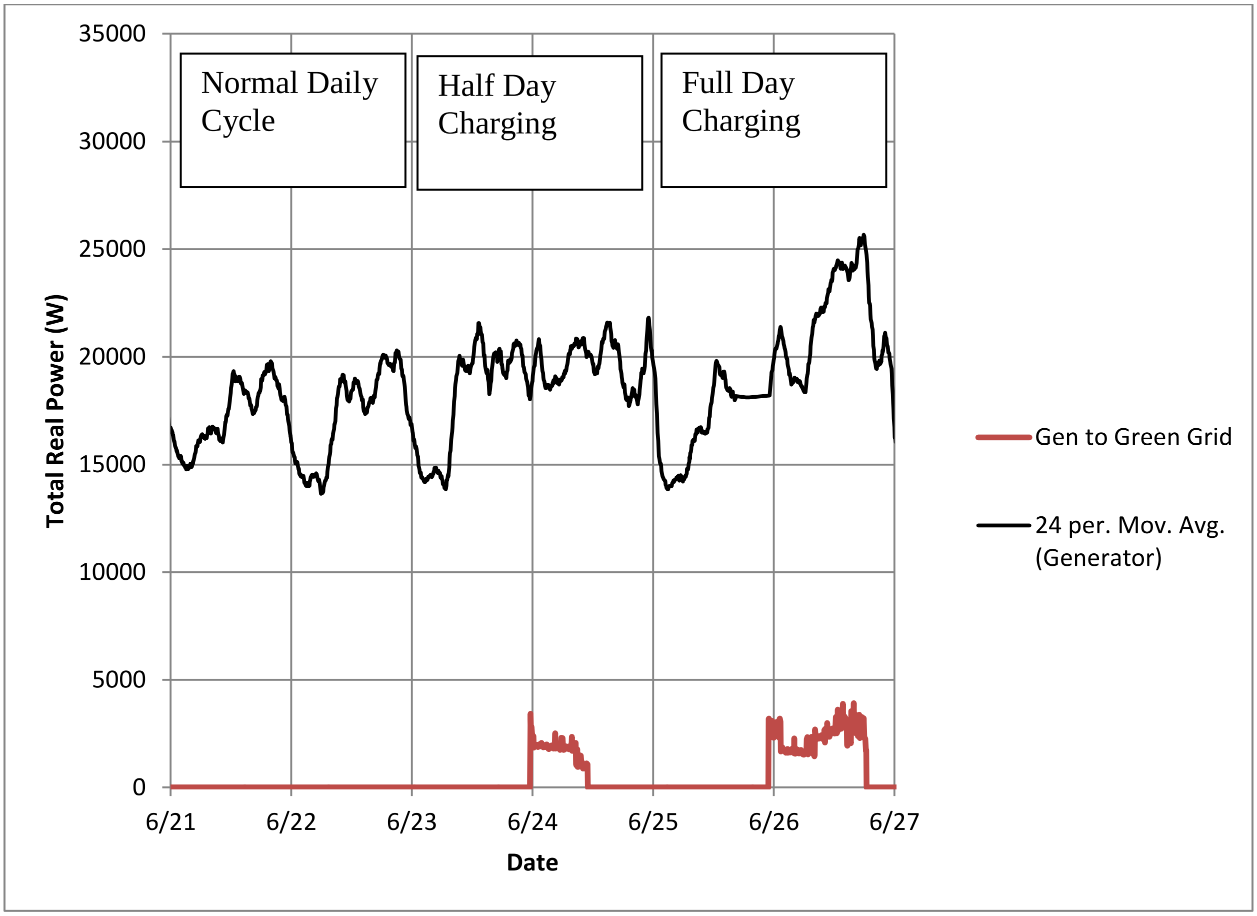

Figure 1-6: Average Total Real Power on Generator and Generator to Green Grid after PK was added

Percent Renewable Analysis

The interns used the data from the Powermonitors to determine the percent of the island power consumption that comes from renewable energy sources since PK has been added to the green grid. This was done by finding how many kWh has been logged on each of the three monitors from June 22 to July 7. The amount of energy used by the Green Grid however was not entirely generated by renewable energy sources. The generator had to kick in twice to add power to the Green Grid which distorts the reading. Therefore the amount of energy supplied by the generator was subtracted from the amount used by the Green Grid before percent of total load calculations were made. The results can be seen summarized below in **Table 1-2**.

	kWh forward as of 22-Jun	kWh forward as of 7-Jul	Difference (Kwh)
Generator	66563.3	72742.5	6179.3
Generator to Green Grid	0.4	66.6	66.2
Green Grid	177.9	606.1	428.3
True Renewable Generation			362.1
Percent Renewable Generation			5.5%
Percent Generator Generation			94.5%

Table 1-2: Percent of Energy Generated by Renewable Sources since PK was Added

Recommendations

Charging Green Grid Batteries at Night

When the interns investigated daily power usage in search of a period of low demand in which to charge the green grid battery bank, they found there was a definite low period at night. The MATE system controller that governs power usage of the green grid has an option called Grid-Use Mode where you can program the time of day the inverters will use the backup input source. The full description can be found in section 4.2 in the Outback MATE manual. Enabling Grid-Use mode however will disable the current setting, HBX mode, found in section 4.1 of the manual. HBX mode is the mode that tells the inverters to draw power from the generator when it hits a certain low voltage and then shuts this connection down when it hits a certain high voltage. The current settings for the HBX voltages are summarized below in **Table 1-3**.

Generator On	47.6 V
Generator Off	54.4 V
Resistors On	56.3 V
Resistors Off	56 V
Depth of Discharge	14.50%

Table 1-3: Summary of Current Set Points on Mate for HBX mode

In Grid-Use mode, if the battery voltage hits the FX Low Battery Cut-off Voltage, then it will override the time settings and charge the battery. It is important that the FX low battery cut-off voltage be set because this is what will maintain the depth of discharge of the batteries. The depth of discharge must be closely controlled in order to optimize battery lifespan. This means that if the switch is made from HBX mode to Grid-Use mode that the island engineers must be certain to set the correct low battery cut off. Direction for doing this can be found on page 29 of the MATE manual. If the decision is made to switch the MATE controller to Grid-Use Mode, then it is important to consider the time period and rate of charge that would be most beneficial.

Summarized below in **Table 1-4** are several options.

Charge Time	Start	End	kW
4	02:00	06:00	3.25
6	01:00	07:00	2.17
8	00:00	08:00	1.63
10	23:00	09:00	1.30
12	22:00	10:00	1.08

Table 1-4: Summary of Charging Time and Rates for the Green Grid Batteries

When the interns talked with Lee Consavage, the engineer who designed the island green grid, he said that it is best to charge batteries as slow as possible. He said that if they experience a large influx of power over a short period of time, the batteries may believe they are fully charged before they truly are, and the charge will not last as long as it should. **Figure 1-7** summarizes the impact different charging times would have on the total real power output of the generator.

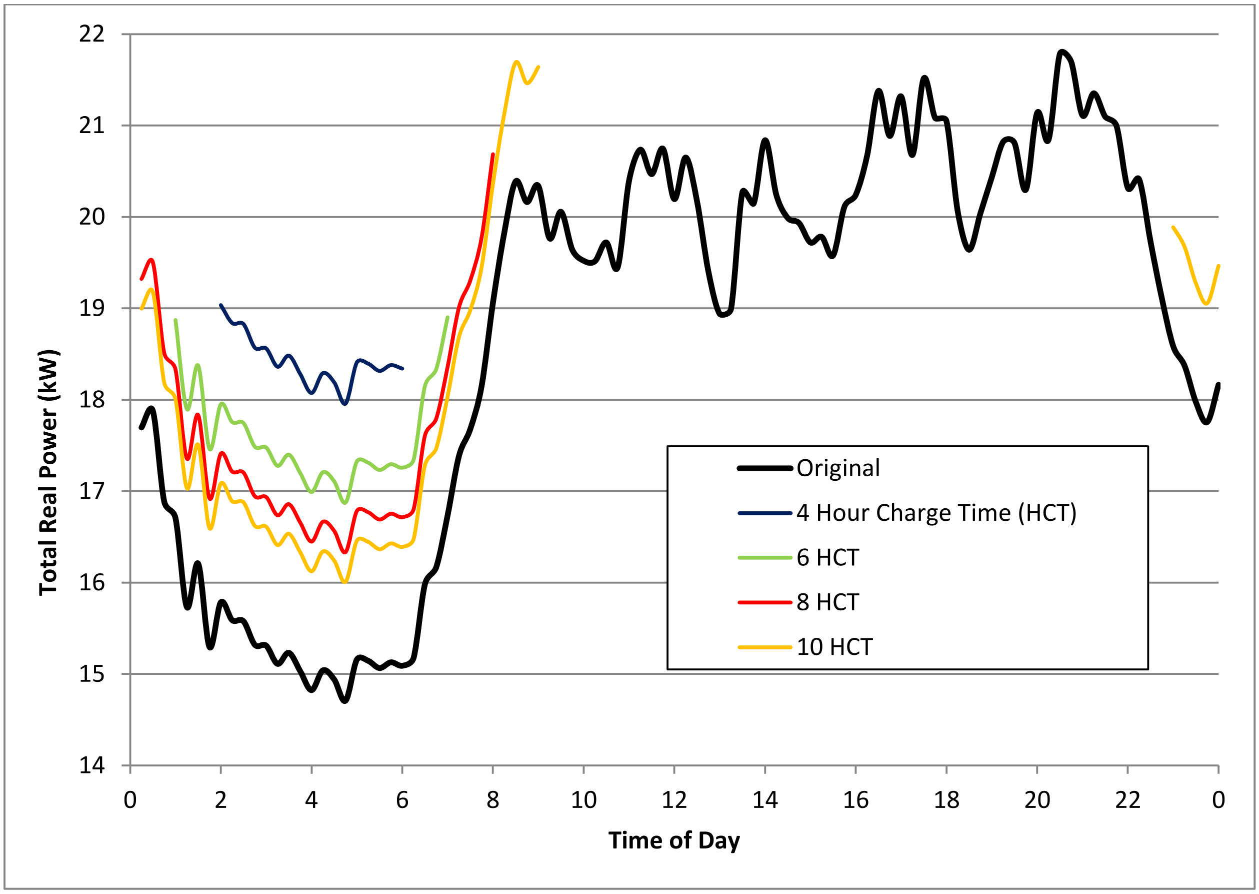

Figure 1-7: Impact of Charging Green Grid Batteries on Generator Daily Output

Sustainability of Adding the Palmer – Kinne Lab to the Green Grid

The decision to add PK to the Green Grid appears to be a sustainable one, however more analysis is recommended. From the investigations of the interns, it appeared that taking PK off the Generator Grid lowered the demand by 8.4kWh of energy per day. However, at the same time power was required from the generator in order to recharge the Green Grid batteries. Net power saved appears to be around 7kWh per day. More monitoring is recommended to observe long term trends. The impact of charging the green grid batteries on the daily power demand profile of the generators should be inspected more carefully. One possible option that should be explored would be to consider increasing the rate at which power is drawn from the generators to recharge the batteries. It appears that because of the nature of the island's renewable energy sources, the generator is needed to charge the batteries mainly at night. This is also because that is when there is a period of low demand on the generator. The issue however comes in when the generator does not manage to fully charge the batteries overnight and has to charge them all day because the rate of demand is greater than the rate of supply. This increases the risk of knocking out the generator from overdraw. It is possible that switching to Grid-Use Mode on the MATE will alleviate this issue.

Solar Water Heater Performance

Background

A solar water heater was installed in July 2011 in the Water Conservation Building. The solar water heater is designed to store heat and raise the temperature of the water to alleviate the amount of propane needed in providing hot water to Kiggins Commons. The hot water is primarily used for showers and dishwashing for the kitchen. The performance of the solar water heater and quantification of propane savings is unknown.

The solar water heater (SWH) system works by absorbing heat from the sun using a glycol-water medium and storing the heat in the Big Tank, a large 600 gallon tank. The incoming water, or "City Water", is sent to the Big Tank, picks up the heat, and leaves the SWH system as "Hot Water." The Hot Water is then heated by the propane tank to the desired 150 degrees Fahrenheit.

Figure 2-1 is a basic diagram on how the solar water heater operates. The glycol-water medium's temperature on the roof is represented by T1. T2 is the temperature of the same medium after the heat exchanger, and this water is then looped back to the roof. If the temperature of the roof is above the Big Tank's temperature, T3, by 20 degrees Fahrenheit, a pump turns on to send the glycol-water medium to the Big Tank for short term storage. The Phase Change Material (PCM) is in the Big Tank, and its temperature is recorded as T5. The PCM is used for long term heat storage.

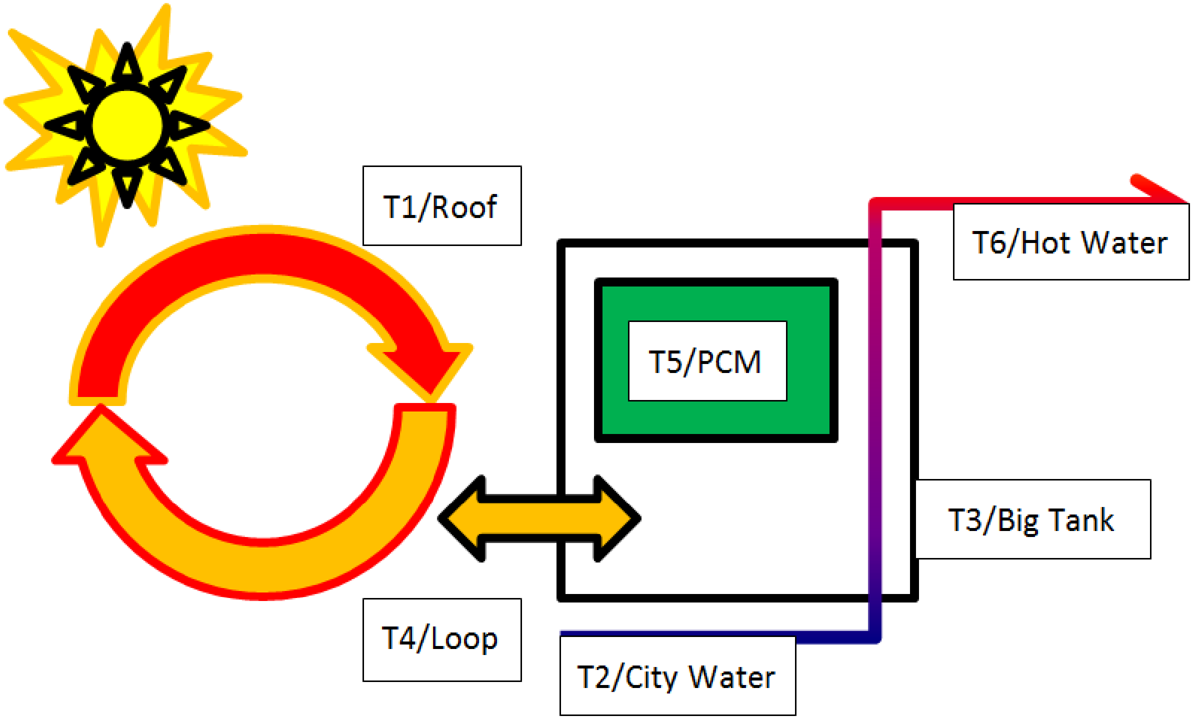

Figure 2-1: Basic Diagram of Solar Water Heater

Objectives

The interns were tasked with quantifying the performance of the solar water heater in the Water Conservation building, as well as determining the capabilities of the system. The island engineers hoped to determine the propane savings from the new solar hot water system in order to determine how much the new system is saving the island. Propane savings was selected as the measurement for quantifying the performance of the system. As well, the island engineers wished to determine the optimal performance characteristics of the system.

General Solar Water Heater Performance

Figure 2-2 shows the solar water heater temperature readings for June 2012.

- T1 is the temperature of the water on the roof.
- T2 is the temperature of the City Water.
- T3 is the temperature of the Big Tank
- T5 is the temperature of the PCM.
- T6 is the temperature of the Hot Water.

T4 was excluded in the figure because of how closely it follows with T1 as shown in **Table 2-1**.

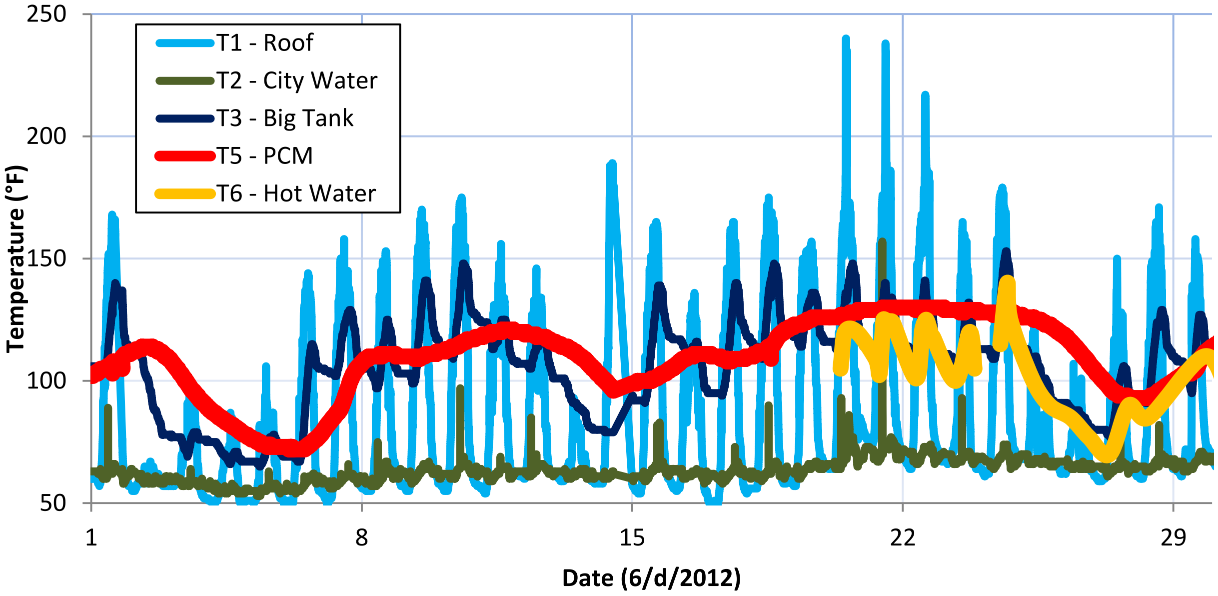

Figure 2-2: Solar Water Heater Temperature Readings for June 2012

Table 2-1 summarizes the average temperature and standard deviation for each of the temperature readings for the month of June. The data shows that T1 and T4 are close in temperature with 87.0 ± 35.7 and 86.2 ± 31.1 degrees Fahrenheit respectively. For this reason, T4 was excluded from **Figure 2-1**.

	T1	T2	T3	T4	T5	T6
Average	87.0	63.4	106.3	86.2	109.5	108.7
STDEV	35.7	4.7	19.5	31.1	15.4	16.3

Table 2-1: Average Temperatures and Standard Deviations in SWH System

Theory: Projections from Propane Logs

Propane savings can be calculated based on the rate of propane consumption. The propane heater would be used more when the solar water heater is heating the water, and the propane heater would be used less when the solar water heater is not heating the water. The difference in propane consumption estimates how much propane is saved based on the use of the solar water heater. This approach assumed that the propane savings when the solar water heater is not performing well is negligible.

Procedure: Projections from Propane Logs

Propane logs from the Kiggins Commons basement were correlated with weather data and solar water heater performance. Due to the lack of a pyranometer, irradiance was based off of historal weather data for Portsmouth, New Hampshire[1]. A weather scale was made by the interns and is shown in **Table 2-2**. Generally, a sunnier day would receive a high number (1) while more cloudy days would receive lower numbers (<1).

Scale	Weather Condition
0.00	Rain
0.25	Hazy Fog / Cloudy
0.50	Mostly Cloudy
0.75	Partly Cloudy
1.00	Sunny

Table 2-2: Weather Scale

It was expected that the propane logs to show that there is a higher rate of propane consumption during rainy days and lower rate of propane consumption during sunny days. The difference in the rate of consumption will estimate how much propane is saved based on the usage of the solar water heater.

Results and Analysis: Projections from Propane Logs

Figure 2-3 shows the initial and final water temperature in degrees Fahrenheit in the solar water heater system, propane use in hundred cubic feet of gas, and weather data. It is important to note that there are occasionally spikes in the temperature reading for T2, the incoming water temperature. This could be due to the lack of water usage and the heat from the heat exchanger migrating into the T2 temperature gauge.

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[1] Cowdin, Aaron. *Weather Underground*. wunderground, 2012. Web. 6 July 2012. <http://www.wunderground.com/about/background.asp>.

According to the weather data, the first week of June 2012, indicated by the blue shading, experienced several days of rain. The difference in the temperature between the City Water and Hot Water was lowered to within 5 to 15 °F. The second week of June 2012, indicated by the red shading, experienced several sunny days. The difference in temperature between the City Water and Hot Water was over 40 °F.

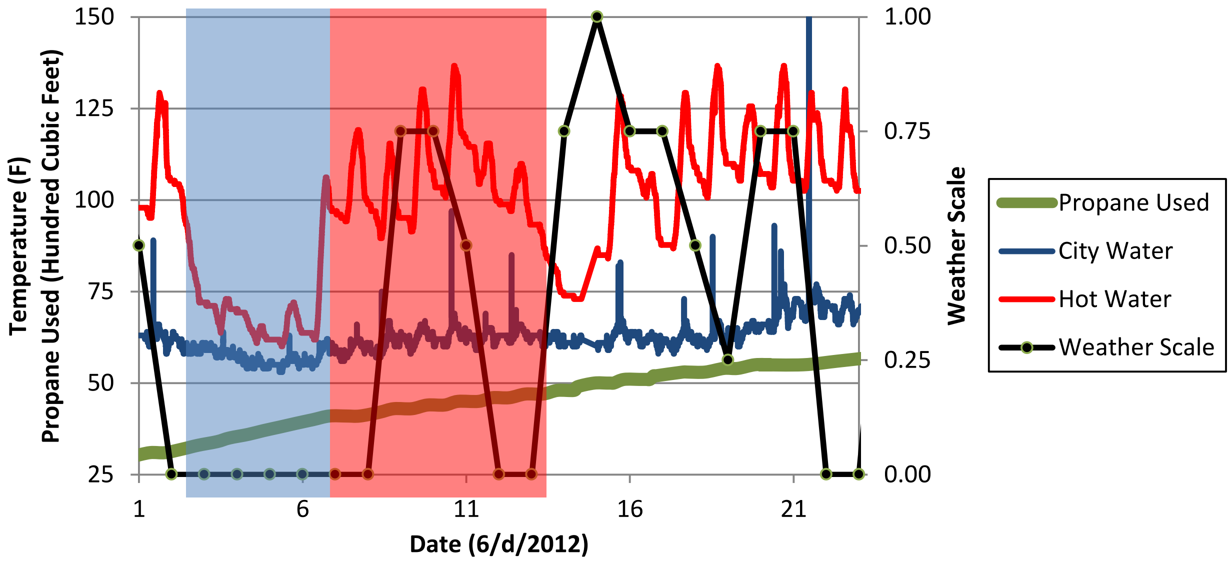

Figure 2-3: Initial and Final Water Temperature Compared with Weather Data and Propane Logs

The rate of propane consumption was observed to be different between the first and second week of June. **Figure 2-4** details the propane consumption from the propane tank in the Kiggins Commons basement. Trend lines were created for when the propane consumption was higher (rainy weather) and lower (sunny weather). It should be noted that the y-intercept value is not accurate due to Excel's general number to date conversion.

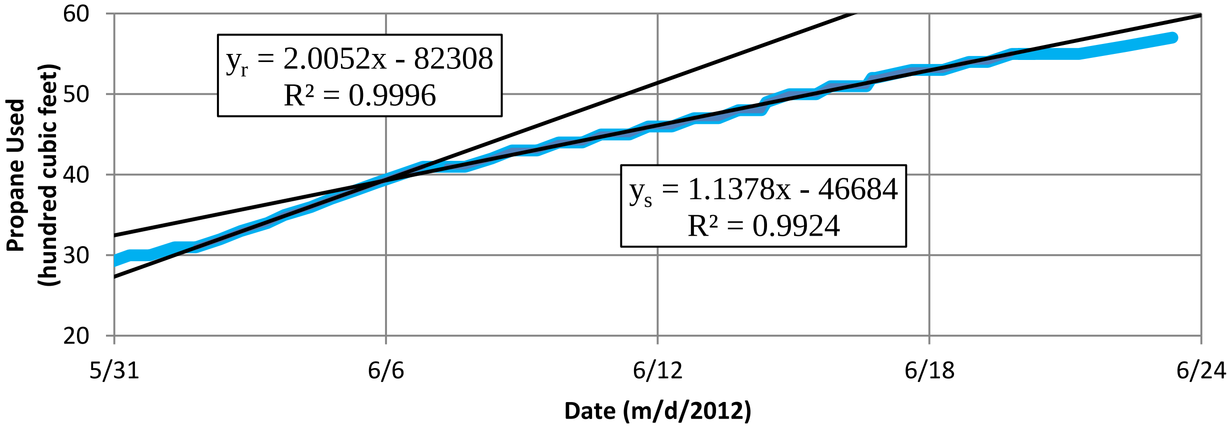

Figure 2-4: Propane Log Projections

The two trend lines - y_r for rainy and y_s for sunny - indicate the amount of propane used in hundred cubic feet per day. Taking the derivatives of the equations will yield the rate of propane used, y_r' and y_s'. The difference between y_r' and y_s' is the amount of propane the solar water is saving assuming that the rate of propane saved during rainy days from the SWH is negligible.

The rate of propane used in hundred cubic feet per day for y_r and y_s are 2.0052 and 1.1378 respectively. The amount of propane saved in cubic feet per day is then 86.7 ± 0.7.

Theory: Solar Water Heater Data Analysis

Another method used by the interns analyzed propane savings by observing the incoming and outgoing water temperature from the solar water heater. The interns then calculated the equivalent amount of propane it would have taken to raise the temperature of the water.

Equation 2-1 was used to determine the amount of propane saved.

$$P_S = k \int_{t_0}^{t_1} [T6(t) - T2(t)] * \cancel{V}(t) * dt \qquad \text{(Eq. 2-1)}$$

Where...

- P_S is propane saved in cubic feet per day
- t_0 is the initial time
- t_1 is the final time
- $T6$ is the final water temperature (°F)
- $T2$ is the initial water temperature (°F)
- $\cancel{V}$ is the volume of water used (gal) from t_0 to t_1
- k is a constant based on propane tank efficiency, and the propane to water energy equivalent

Equation 2-2 shows how the constant *k* was calculated.

$$k = \frac{1}{\varepsilon_{TANK} \times EE_{PW}} \qquad \text{(Eq. 2-2)}$$

Where…

- ε_{TANK} is the propane tank efficiency
- EE_{PW} is the propane to water energy equivalent

The propane tank efficiency is 80% and the propane to water energy equivalent is 2,488 BTU per cubic feet of propane.

$$k = \frac{1}{80\% \times 2{,}488 \frac{btu}{ft^3_{C_3H_8}}} \times 8.3 \frac{lb_{H_2O}}{gal_{H_2O}} \times 1 \frac{btu}{lb_{H_2O} \times {}^\circ F}$$

$$k = 0.00417 \frac{ft^3_{C_3H_8}}{gal_{H_2O} \times {}^\circ\mathrm{F}}$$

Equation 2-1 can be simplified to a series of summations between small intervals of time.

$$P_S = k \times \sum [T6 - T2]_i \times \cancel{V}_i \qquad \text{(Eq. 2-3)}$$

Where…

- $[T6\text{-}T2]_i$ is the difference in temperature (°F) between the City Water and Hot Water in the *i*th interval.
- V_i is the volume of water used (gal) in the *i*th interval.

Procedure: Solar Water Heater Data Analysis

Totalizer and T6 data was collected from hand-written logs in the Water Conservation Building. Data for T1 through T5 in 1 minute intervals was collected from the SD card in the system controller also in the Water Conservation Building. The data was logged and analyzed in Excel.

The SD card does not record T6 (Hot Water) data, which is the outgoing temperature of the water. Instead, T6 data was recorded by hand and put in a ratio with T3 to determine the average difference between the two temperatures.

Due to the difference in frequency at which Totalizer data was logged and T1 through T5, the average gallons of water used per day was used, changing **Equation 2-3** to **Equation 2-4**:

$$P_S\left(\frac{ft^3_{C_3H_8}}{day}\right) = \frac{k\sum[T6-T2]_i}{M_{REC}} \times \bar{\cancel{V}} \qquad \text{(Eq. 2-4)}$$

$$\bar{\cancel{V}} = \frac{\cancel{V}_1 - \cancel{V}_0}{D_{REC}} \qquad \text{(Eq. 2-5)}$$

Where…

- $[T6\text{-}T2]_i$ is the difference in temperature (°F) between T6 and T2.
- M_{REC} is the recording time (minutes) from the SD card.
- $\bar{\cancel{V}}$ is the average hot water use in Kiggins Commons in gallons per day.
- $\cancel{V}_1$ is the totalizer reading at time 1.
- $\cancel{V}_0$ is the totalizer reading at time 0.
- D_{REC} is the recording time (days) for the totalizer.

Results and Analysis: Solar Water Heater Data Analysis

The data shows that the outgoing water temperature (T6) is, on average, 92.3% ± 2.5% of the temperature of the Big Tank (T3).

Table 2-3 summarizes the calculations done for **Equation 2-4**.

k	0.00417	[ft^3 C_3H_8/gal H_2O-°F]
$\sum T6\text{-}T2$	1,468,208	[°F]
M_{REC}	43,199	[min]
V_{BAR}	578	[gal/day]
$V_1\text{-}V_0$	16,764	[gal]
V_1	46,846	[gal]
V_0	30,082	[gal]
D_{REC}	29	[day]

Table 2-3: Equation 2-4 Calculations

The average propane saved per day from June 1st to June 30th is 81.9 ± 6.3 cubic feet per day.

Summary: Solar Water Heater Data Analysis

Table 2-4 summarizes the results from Method 1 (Projections from Propane Logs) and 2 (Solar Water Heater Data Analysis). The propane logs estimated propane savings of 86.7 ± 0.7 cubic feet per day during the month of June while the solar water heater estimated 81.9 ± 6.3. Over the entire month of June, the solar water heater, according to the SWH data, saved about 2,400 ± 470 cubic feet of propane a day, a 43% savings. This is equivalent to 2.7 hundred pound cylinders of propane, and 0.37 metric tons of CO_2 saved. Calculations and assumptions are shown in Appendix B.

Method	Propane Log	Propane Savings	86.7 ± 0.7	[ft^3 C_3H_8/day]
		Percent Savings	43%	[%]
	SWH Data Analysis	Propane Savings	81.9 ± 6.3	[ft^3 C_3H_8/day]
		Total Propane Saved	2400 ± 470	[ft^3 C_3H_8]
		Tanks Saved	2.7	[Tanks]
		CO_2 Saved	0.37	[Metric Tons]

Table 2-4: Summary of Propane Log Projections and SWH SD Card Data Analysis

Recommendations

Optimizing Solar Water Heater Performance

Changing the temperature differentials to optimize SWH performance is possible but not recommended. Trial and error would need to be done, while also keeping track of several other variables including water usage based on population and time of day, ambient temperature, cloudiness, and initial temperature of the PCM and Big Tank. The interns believe that an experiment like this would not be worth the time investment for a small increase in propane savings.

Doug Gerry made some adjustments to the Solar Water Heater during the end of June and beginning of July to increase its performance. He adjusted the ratio of glycol to water in the SWH and changed around some of the pumps. However, this had an effect on the R3 pump and line when the glycol-water medium began migrating down the pipe, the opposite direction is it is supposed to go. The interns recommend investigating the best sizing of the pumps and ratio to glycol and water to optimize the Solar Water Heater. Doug Gerry recommended using 3 speed pumps for variable flow rates based on whether or not the other pumps are on.

Recording Data

The interns recommend adding T6, the outgoing water temperature, to the system controller for data and accuracy. Adding T6 would allow for greater accuracy in determining propane savings. The temperature gauge for T6, as noted by Doug Gerry, does not seem to be calibrated accurately as it should be very close to the big tank temperature - the conclusions for propane savings would then be a conservative estimate. Thus, the T6 temperature gauge should be calibrated or checked for accuracy.

The system controller is capable of recording one more temperature reading (T6 is empty when looking at the raw data) and the frequency at which SD card's memory is full will not be affected greatly.

However, if the calibrated T6 temperature gauge shows that it is very close to the T3 Big Tank temperature gauge, then adding T6 to the system controller is not needed. Instead, adding a pyranometer to the roof and recording the meter by the system controller would be more beneficial in correlating weather with system performance.

In addition, adding in a new flow meter that can be digitally recorded to get more accurate readings on how much water is used based on the time of day would help greatly in determining when hot water is used based on how well the solar water heater is performing. This will allow the propane savings calculation to also be more accurate.

Crystal Lake Water Usage

Background

Crystal Lake is small pond located on Appledore Island. This body of water is mostly fed by rainwater. Recently, the Shoals Marine Lab received a permit from the state of Maine allowing them to draw water from the pond. In previous years, the pond has been looked at as a drinking water source. One method included releasing water around the well directly from the pond. This led to high turbidity in the well and drinking water, and the well had to be shut down. Previous interns looked at the possibility of using a slow sand filter to pretreat the water before using it to augment the well. However, due to the nature of a slow sand filter this was determined to not be feasible for this situation. If Crystal Lake water could be used as a water resource, this would possibly help to alleviate the stress on drinking water resources on the island. By the end of the season, in about August, the well starts to run dangerously low. The island engineers stop using the well when the depth reaches 10 feet to prevent mixing between the freshwater and saline water tables. When the well is shut off, a reverse osmosis (RO) machine is used to make water. However, this is a large energy and cost consumer.

In the past, saltwater was used to flush the island's toilets. This practice was discontinued when the leach field and septic system were installed, as the saltwater was shown to have a negative effect on the bacteria in the system. However, the infrastructure for supplying saltwater to the toilets still exists on the island. If Crystal Lake water were decided to be used for flushing the toilets, then the water would utilize these lines. The only concern would be the saltwater freshwater crossover lines, where contamination of the freshwater supply with the Crystal Lake water could occur. In the past when saltwater was used, this was less of a concern as people would notice a salty taste in the drinking water if a contamination had occurred. With the Crystal Lake water, bacterial contamination would be most likely and hard to notice until sickness occurred.

Objective

In order to help alleviate stress on freshwater resources, the interns were asked to look into the possibility of using Crystal Lake water to augment the well. In order to reduce the turbidity of the Crystal Lake water, the interns investigated using a settling tank and a filter to pretreat the water before it is released around the well. The goal turbidity was decided to be the turbidity of rainwater, which was measured by interns to be about 1.2 NTU.

The possibility of using Crystal Lake water for toilet water was also investigated. The interns were asked to map out a route for Crystal Lake water to reach the island toilets using the former saltwater lines. The toilets used to be flushed with saltwater, so the lines connecting the toilets still exist. Particular concern was made for the saltwater freshwater crossovers to prevent contamination of the drinking water lines should this option be selected.

Theory

Turbidity

Settling is a common way to remove turbidity from drinking water. Turbidity is a measure of the number of particles in water. Turbidity is measured in NTU, or nephelometric turbidity units. Higher turbidities equate to more particles in the water. Typical drinking water turbidities are less than 1 NTU.

During the settling process, leaving water undisturbed allows the particles with a higher density than that of water to settle out. Once the particles have settled to the bottom, the less turbid top layers can be pumped out for use or further treatment. The bottom layer is then disposed of. Adding filtering to this process can help to further polish the effluent. Filtering can be done either before or after the settling process, though it is typically done afterward to further remove fine particles that do not settle as easily due to particle charges.

The efficiency of the filtering and settling can be measured in terms of removal efficiency. This is calculated using **Equation 3-1** below:

$$Percent\ Removal\ (\%) = \left[\frac{Initial\ Turbidity - Final\ Turbidity}{Final\ Turbidity}\right] \times 100\% \qquad \text{(Eq. 3-1)}$$

Using **Equation 3-1**, the effectiveness of the filters and settling process can be established and compared.

Evaporation and Rainfall

The amount of evaporation and precipitation that occurs in a body of water can be estimated mathematically. Evaporation can be calculated using the pan evaporation equation[2]:

$$E = A \times E_{pan} \times C_{pan} \qquad \text{(Eq. 3-2)}$$

In **Equation 3-2**, evaporation is measured by multiplying the area over which evaporation is occurring by the pan evaporation (see Appendix C) and the pan coefficient. The pan coefficient is assumed to be 0.75, based on typical pan evaporation equations. Rainfall is measured based on the surface area of the pond and the average rainfalls for the island. This was done because it was difficult to delineate a watershed for the area.

Methods

Settling Test

The first test performed on the Crystal Lake water was to see if settling alone could achieve a low enough turbidity for use around the well. A large tank, with a capacity of around 800 gallons, was positioned on a level site where the water would not be disturbed. The tank was covered to prevent the water from being disturbed by the wind or contaminated. The tank was

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[2] Gulliver, J.S., A.J. Erickson, and P.T. Weiss (editors). 2010. *"Stormwater Treatment: Assessment and Maintenance."* University of Minnesota, St. Anthony Falls Laboratory. Minneapolis, MN.http://stormwaterbook.safl.umn.edu/

filled by running a line from Crystal Lake to the tanks and using a siphon to draw up the water. The siphon allowed a steady flow of about 4.5gpm. The initial turbidity of the water was taken directly from the hose, and the turbidity was measured at several times over the course of four days. The turbidity was measured at one foot intervals from the bottom of the tank to the top of the water line (approximately five feet) using a Sludge Judge ® sampler. The foot intervals were marked on the Sludge Judge ® sampler, and each foot of water was released into marked jars for turbidity testing. Triplicate samples were run using an Orbeco-Hellige Portable Turbidimeter model 966.

Filter Analysis

Several filters were available for use by the interns, ranging from 1 micron to 400 microns. The filter optimization test was run by testing 1 micron, 5 micron, 10 micron, and 25 micron filters. The turbidity of the water was recorded before and after running through the filter. The water was then allowed to run through the filter until the filter failed, or was 75% clogged. This was the determined failure point because the high water mark in the tank is equal with 75% full mark on the filter. The strength of the rope holding the filter to the tank also became a concern when the filter was 75% clogged and full of water. The goal of the filter test was to determine if there was a filter size that optimized removal with filter run time.

Filter and Settling Test

The filter and settling test was run very similarly to the settling test described above. The only difference was the addition of a 5 micron filter. This was determined to be the optimal filter for this situation during the filter analysis. The water coming from Crystal Lake was first run through the filter before it entered the tank. The water was then tested as described in the settling test method section above.

GIS Mapping

GIS mapping was used with the Shoals Marine Lab (SML) GIS database to find saltwater pipes for pumping water to the island’s toilets. The database was also used to locate saltwater freshwater crossovers. A line from the pond to a connection line into Kiggins Commons was determined as well.

Results and Analysis

Filter and Settling Results

During the filter analysis, it was determined that 5 micron filter was the smallest filter that could be used and would not clog before the tank was filled. This was established to be the optimal filter because the 1 micron filter clogged after only 30 minutes, which did not fit with the system design of making this a simple process to run. The filter would have to be changed six times over the course of filling the tank, which was decided by the interns to be impractical. The 10 micron filter was able to be used for over five hours without clogging, but this was also unnecessary as the tank would have been filled after three hours. The 10 micron filter also let more particles through than the 5 micron filter. **Table 3-1** shows the results of the filter analysis.

Size of Filter	Duration (hr)	Percent Removal (%)
1 µm	1.3	28.6
5 µm	3.2	40.3
10 µm	5.9	33.9
25 µm	-	16.7

Table 3-1: Filter analysis data

The filter analysis has some discrepancies, like the percent removal for the 1 micron and 5 micron filter. It would be assumed that the 1 micron would have better removal than the 5 micron filter; however it was hypothesized by the interns that this may have been caused by the great variance in Crystal Lake water. The 1 micron and 5 micron tests were run on different days, so the water coming out of Crystal Lake may have had different pollutants causing turbidity. If the water had finer suspended solids during the 1 micron test than the 5 micron test, there is a chance that the 1 micron filter may not have been able to stop all of them from going through the filter. Likewise, the 5 micron filter would have had an easier time of stopping larger suspended solids if that was what was coming out of the hose that day. However, because the interns did not have data on the chemistry of the water from day to day other than turbidity, which is not affected by the size or amount of particles as much as the light refracted by particles, it was difficult to come to a conclusion. The 25 micron test also does not have duration for the test because the interns decided it was not necessary to run as the 5 micron filter had already been selected as the best choice for the experiment.

Both settling tanks showed some decrease in turbidity over the course of the four day testing period. The tank with the filter showed the largest percent removal at the end of the experiment.

	Percent Removal (%) over Depth (after 4 days)				
Tank Type	**1 ft**	**2 ft**	**3 ft**	**4 ft**	**5 ft**
No Filter	-228.6*	85.8	84.7	37.2	31.0
Filter	-67.3*	68.7	91.4	92.0	91.9

Table 3-2: Results of settling tests (*negative values denote percentage increase in turbidity)

As shown in **Table 3-2**, the tank with the filter had the highest removal percentage of turbidity, as well as the most consistent removal percentage over the entire depth of the tank. In the tank without a filter, high removal percentages appeared around two and three feet from the bottom of the tank. Some removal was seen in the top two feet of the tank also, but much less than in the middle. This was attributed to the pollen layer that formed at the top of the tank. When the Sludge Judge was used to extract water from the tank, it was observed that the water in the top layer of the Judge mixed slightly with the first two feet of water. It is hypothesized that if the top layer of pollen was removed manually, than the top four feet may show more consistent removal percentages. However, with the high level of turbidity in the pond, removal percentages of around 85% were not enough to clean the water enough for use around the well.

The tank with the filter showed much more consistent and higher removal percentages after four days than the tank without the filter. The filtered tank also had more consistent removal over the course of the entire experiment.

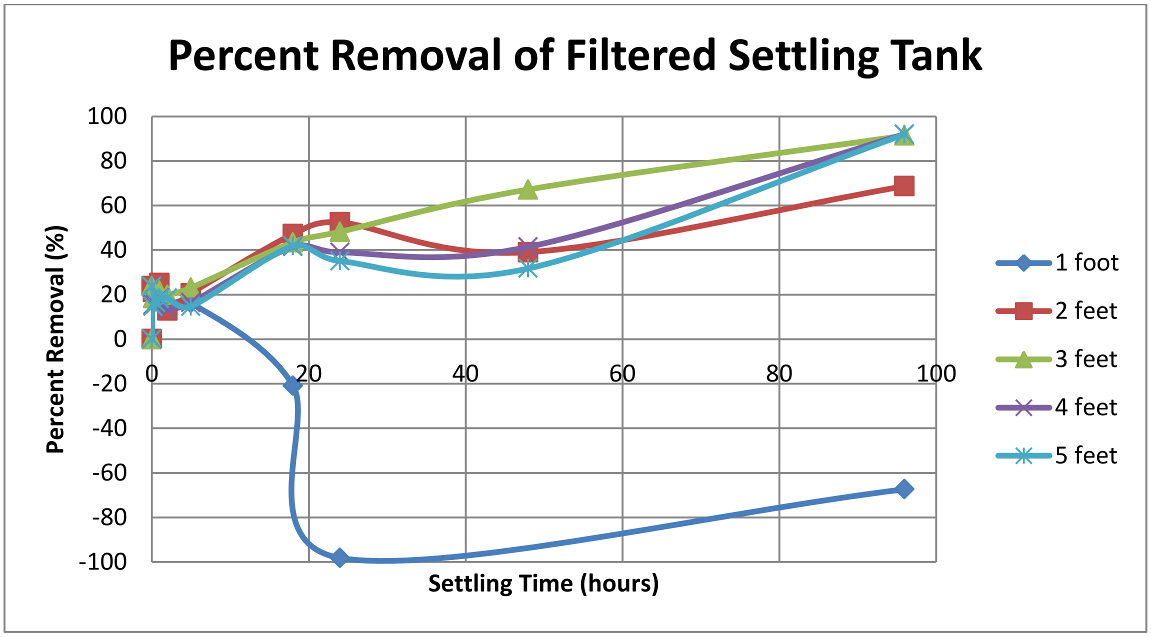


Figure 3-1: Percent removal of turbidity in filtered settling tank as shown in depth over the course of testing period

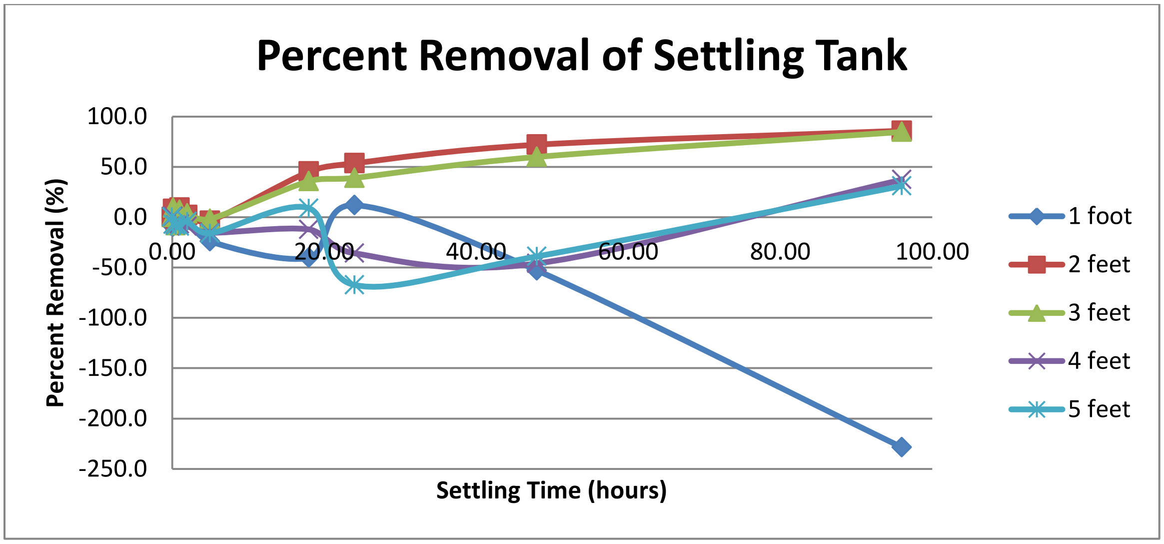


Figure 3-2: Percent removal of turbidity in settling tank as shown in depth over the course of the testing period

The graphs above show how the filtered tank has more consistent settling than the non-filtered tank. This was attributed to interactions between particles in the non-filtered tank. Even though typical practice dictates that filtering be done after settling has occurred, the large amount of fine particles in Crystal Lake water required pre-filtering for more effective settling. Having the water run through the filter first helps to remove excess particles, aiding in the prevention of charged reactions between particles. Charged reactions between particles are what prevent particles from settling, as the force of these interactions overcomes the force of gravity on the particles. The filter helps to remove some of these excess charged particles. One of the large difficulties with this experiment was the large differences in turbidity in the Crystal Lake water from day to day and year to year. Comparative to the numbers from last year, the turbidity in Crystal Lake is much higher this year. More settling may have been necessary this year as opposed to other years, and the pattern shown by the filtered settling tank shows more promise for variability based on settling time.

Based on NTU values, it is also apparent that the filtering and settling method worked better than the settling alone. Initial turbidity values during the intern's experiment ranged from about 35 NTU to 60 NTU. After the settling only tests, the turbidity was inconsistent throughout the depths of the tank, and at best it was 5.6 NTU. After the filtering and settling tests, the turbidity was fairly consistent and around 3 NTU throughout the majority of the tank.

However, in 2011, island interns measured the turbidity of Crystal Lake to be between 10 and 20 NTU for several months. This is considerably lower than the measured turbidity during 2012, which was between 35 NTU and 60 NTU. This higher turbidity was reasoned to be caused by the mild winter and large rainfall events occurring in early 2012, which caused increased pollen in the pond. The goal was of the treatment was to achieve a turbidity of rainwater, measured by the interns to be about 1.3 NTU. This was suggested by the island engineers to be a good baseline as rainwater is known to filter well through the ground and not alter the turbidity of the well. The turbidity in the well was altered in previous years when island engineers added Crystal Lake water with a turbidity of between 10 NTU and 20 NTU; the turbidity in the well increased from about 0.1 NTU to above 1 NTU. At this point the well was shut down and the RO machine was run.

Using Crystal Lake for Drinking Water

Based on the permit granted by the Maine Center for Disease Control and Prevention in 2010, SML is permitted to extract 83,000 gallons annually, plus any additional refill that occurs naturally, from Crystal Lake. However, the water from the pond cannot be drawn down more than six inches below the mean high water line established in May. Using rainfall and evaporation calculations, an estimate of the amount of water that can be drawn from Crystal Lake was created. These numbers would help to account for the natural refill that would occur over the season.

Total Rainfall Collection over Crystal Lake (gal) per month	
May	58,640
June	60,023
July	56,704
August	48,267
September	56,012
Sum of Rainfall Collection in Crystal Lake	279,647

Table 3-3: Precipitation estimates for Crystal Lake

Total Evaporation over Crystal Lake (gal) per month	
May	45,640
June	52,486
July	57,879
August	46,781
September	30,496
Sum of Evaporation in Crystal Lake	233,281

Table 3-4: Evaporation estimates for Crystal Lake

From **Table 3-3** and **Table 3-4** above, the estimated net gain in volume for Crystal Lake from May through September is approximately 46,000 gallons. In addition to the 83,000 gallons that are allowed to be drawn from Crystal Lake, it is estimated that another 46,000 gallons can be removed due to natural refill over the course of the season.

Crystal Lake Water for Flushing Toilets

Because of its inconsistent nature and high turbidity, the Crystal Lake water was considered for flushing the toilets. The amount of water needed from Crystal Lake was determined based on the regulations stated in the permit (see Appendix C). The interns assumed that people on the island would flush twice a day, and each flush would use approximately 1.6 gallons. These numbers are based on the previous interns' surveys of flushes on the island, and the amount of water used in the low flow toilets. Based on the numbers shown in **Table 3-3** and **Table 3-4**, is it calculated that the island can support approximately 337 people flushing toilets twice a day for the entire season. The allowed flow from Crystal Lake based on the permit and expected natural recharge would allow approximately 1078gpd to be pumped from the lake from May to September. This would be enough supply, as based on numbers that the 2009 interns generated, for the approximately 60 toilet flushes a day. The possibility of another composting toilet in the PK building would also help to reduce toilet flushes on the island. However, without contemplating the evaporation and rainfall occurring over Crystal Lake throughout the season, the flow from the pond would be enough to support 216 people flushing twice a day for the entire season.

The population data shown in **Figure 3-3** shows the number of people on the island during the day in the 2011 season. The maximum island occupancy population is 123, but the island can see spikes in population of 160 people during the day.

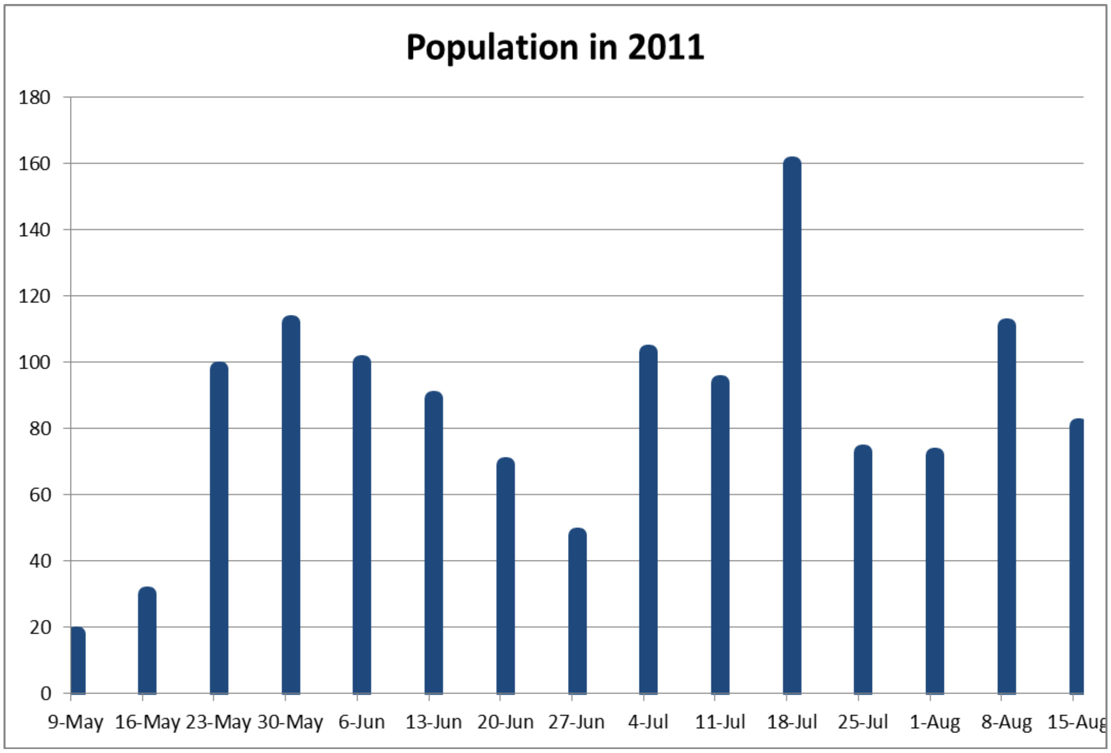


Figure 3-3: Graph of population in 2011 season

Based on the information in **Figure 3-3**, despite the spikes in population, it would be expected that Crystal Lake would be able to supply enough water for the island. This is based on the fact that **Figure 3-3** only has three weeks above with a population of more than 105 people, and multiple weeks of less than 80 people. As well, **Figure 3-3** does not include the few weeks at the beginning and the month at the end of the season when the island population is less than 10 people. This would mean that more draw during the high population weeks would be balanced by the several weeks of less than maximum capacity. The large population increases are also caused by day-trippers, who would use the bathrooms in the Kiggins Commons Water Conservation building the most, which are compostable toilets and do not use water. As well, the addition of another compostable bathroom in the Palmer – Kinne Lab building would help to alleviate concerns during high populations or very dry summers. As well, the amount of water able to be drawn from Crystal Lake, whether taking into consideration evaporation and precipitation or not, would be more than sufficient to handle the island population. This is shown in **Table 3-5.**

	Amount Available (gal)	People Can Support	Pumping Rate (gpd)
With Precip/Evap	129,366	337	1,078
Without Precip/Evap	83,000	216	560

Figure 3-5: People Crystal Lake can support and pumping rate

Based on the assumption that the island population does not go above 175 people, from previous population data, a storage tank of 450 gallons would be recommended.

Using GIS, a line for the diverting Crystal Lake water to the toilets was established. The line would run from Crystal Lake using an existing freshwater line, and a connection would be added to divert the Crystal Lake water to the saltwater freshwater crossover in the basement of Kiggins Commons. Here the water would be directed to the island's toilets via the existing saltwater lines. **Figure 3-4** displays the proposed plan for using Crystal Lake water for the toilets. Another proposed idea is to run the line adjacent to the current saltwater line running into Kiggins Commons already. This would allow island engineers a known safe location to run a line.

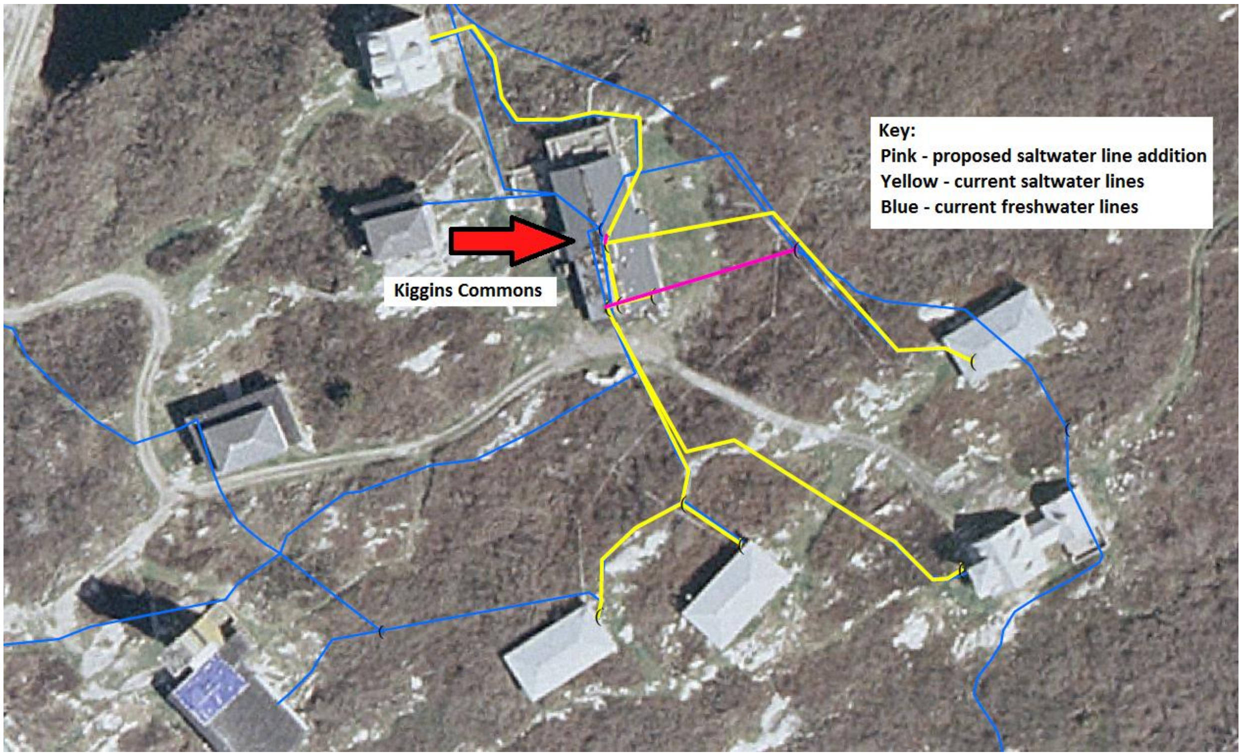


Figure 3-4: Proposed Crystal Lake water for toilet water infrastructure plan

The largest concern for using Crystal Lake water for flushing toilets would be the effect on the leach field. If the turbidity is high in Crystal Lake, there is a chance that it could clog the fine sand in the leach field and cause a system back-up. As well, depending on the turbidity of the pond, some staining could occur in in the toilets.

Recommendations

Based on the results of the turbidity tests and the calculations performed by the interns, several options were created.

Option 1: Adding Water to the Well

The first option for using the Crystal Lake water is to use the water for augmenting the well. The two large, 800 gallon tanks would be brought up to the well and placed approximately 50 feet from the well. The line from Crystal Lake would be used to pump water from the pond to fill these tanks. A solar powered pump would be required to bring the water up from Crystal Lake to the well, as currently water is supplied to this area using a siphon. A 5 micron filter would be suggested, and once the tanks were filled the water would be allowed to settle for approximately four days. After removing any scum layers that develop on top of the water, the first four feet of the tank would be pumped out using a sump pump onto the ground near the well. This would equate to approximately 700 gallons per tank being added to the ground. The water could be added approximately every 4 to 5 days. The last foot of water, with the highest turbidities would have to be removed and dumped away from the well, or evaporated. If the water was evaporated, the algae could possibly be added to the island's compost pile.

However, it would be recommended that more testing be taken to further understand the nature of the water during different points of the season and different years. As the water was more turbid than in years past, it may not have been a representative year for the typical nature of the water. This would have a large effect on the ability of the water to settle out turbidity. The turbidity was about two to three times higher than last year, but the turbidity was able to be reduced to close to the turbidity of rainwater. The turbidity values are shown in **Table 3-6.**

Crystal Lake Turbidity in 2012	35 NTU – 65 NTU
Crystal Lake Turbidity in 2011	10 NTU – 20 NTU
Turbidity of Rainwater (measured in 2012)	1.2 NTU
Final Turbidity after Filtering/Settling	3.0 NTU

Table 3-6: Turbidity measurements

Another option for achieving better values of turbidity, in case of high turbidity years like this one, would be to add another 5 micron or finer filter to the water being removed from the tanks. This is only suggested if necessary because it would be more difficult than just allowing the water to just pump out of the tanks. The end of the hose would have to be supported to prevent the water from flowing back out of the filter. However, a cleaner effluent would be achieved.

It is also difficult to understand how much of the water would enter the well as the groundwater hydrology of the island is not well understood. It is hard to tell where the water would flow once released from the large tanks, and it might be difficult to supply enough water to have any effect on the well depth.

Option 2: Flushing Toilets

Another recommendation for the Crystal Lake water is to use the water for the toilets. This would help to cut back on the freshwater use on the island, as toilet water does not need to be potable. The water would be pumped from Crystal Lake using one of two options: a submersible solar-powered pump or a siphon with a foot valve.

The solar-powered pump would be one like a Sun Pumps™ SDS – Q 135 DC submersible pump (see Appendix C). This 12.25-inch pump would be contained in a milk crate or other open flow box with a mesh screen to prevent large items from damaging the pump. The pump would be powered by an 85W solar array (see Appendix C). The line from Crystal Lake would run along the current Crystal Lake to well line, but a T-valve would be inserted to redirect the water to Kiggins Commons, where it would be further diverted to the buildings.

The pump would need to pump at approximately 4gpm in order to supply enough water during the assumed five hours of sunlight a day. This would supply the water necessary to support 175 people (assumed maximum island population) flushing twice a day. A 450 gallon pressurized tank would be required to store the water for island's toilets. Due the large size of the pressurized tank required, the tank would most likely not be able to be stored in the basement of Kiggins Commons. As well, the size of the tank would be difficult to obtain. Another option would be to pump the water to a large (450 gallon) storage tank, and then again to a smaller pressurized tank for use on the island. The storage tank would be necessary because the pump at Crystal Lake can only work for five hours a day, so storage would be required for supplying water to the island during the other 19 hours. The smaller tank would have to be fed by an electric powered pump. Currently, SML has an unused 31.8 gallon Goulds Aqua-Air pressure tank. Using this as a reference, this tank would require a pump capable of approximately 1.0gpm in order to fill the tank in one hour. If island engineers decided, the size of the storage tank could be smaller in order to fit inside the Kiggins Commons basement. However, a long 450 gallon tank would be able to fit along the wall across from the saltwater freshwater crossover. The tank would be approximately 60ft^3, and if it was 3ft x 3.5ft x 6ft it would fit in the basement. The size of the storage tank could also be sized down if another composting toilet is added to the Palmer – Kinne Lab building. This would require further evaluation and how much of a safety factor the island engineers would be comfortable with.

The other option is to use a foot valve at the end of the line in Kiggins Commons along with siphoning the water from Crystal Lake. This would be less expensive and less energy intensive than the pump, but it would be prone to losing the siphon if the foot valve malfunctioned. Using the foot valve should keep the line primed. Again, the siphon could be used to fill a 450 gallon storage tank, and then a pressurized tank and pump could be used to supply the water to the island's toilets as needed.

New Green Grid Building

Background

SML recently received a grant to buy a new battery bank to expand the Green Grid. The original Green Grid was designed with help from Lee Consavage, from Seacoast Consulting Engineering. SML is planning to begin construction on a new building to house the batteries this fall. The proposed site is off the road leading down to the Grass Lab building, across from the Dive Locker. Ideally, these batteries will be able to store enough power during the day to get through the night; they would not need to be charged by the generator during the night. In the first stage, the batteries will be charged by the existing generators. In the future, PV panels will be installed on the roof of the building and mounted on the ground, and these will aid in charging up the batteries.

Objective

The task for the Engineering Interns was to determine optimal sizes for the battery bank and the generator that charges up the battery. They also were to design a layout and floor plan of the building, determine floor structural requirements, and research how to best connect the new and existing Green Grids. The interns investigated multiple options: a fixed battery bank size with no PV panels, a fixed battery bank size with PV panels, and a battery bank large enough to get through the night with PV panels.

Theory

Depth of Discharge

The depth of discharge (DOD) is the percentage of the battery capacity that is available for use. Scott Williams from Solar Electric Supply, Inc. advised the interns that the depth of discharge rate influences the battery's lifespan. **Table 4-1** summarizes depth of discharge and the corresponding battery lifespan.

DOD	Battery lifespan (years)
30%	3-5
20%	5-7
5-10%	7-10

Table 4-1: Depth of discharge and battery lifespan relationship

Since the DOD directly affects the battery lifespan, the engineering interns took DOD into account when designing battery building and sizing options. The hope is that the battery banks that will be purchased for the new Green Grid building will not have to be replaced in the next 3 – 5 years.

Diesel Generator

One of the tasks of the interns was to determine which diesel generator (the 27kW or the 65kW generator) would be more effective in charging up the new battery bank. Lee Consavage explained that batteries perform better when they are charged slowly over a long period of time. For this reason, the 27kW generator would be the best option to charge the batteries. Fast charging a battery may overcharge it and decrease its lifespan.

Photo-Voltaic (PV) Panels

To find the optimal size of the PV array, the interns used the Excel spreadsheet, provided by Lee Consavage, which calculates generator run time based on PV array size, island energy usage, battery size, and generator size. It was assumed that the PV array system efficiency was 65%. At a fixed battery size, there is only so much energy that the PV panels can store in the battery because of the battery size limitation. Assuming a 300kWh battery bank size and a 10% depth of discharge rate, a graph of generator run time versus PV array size was created.

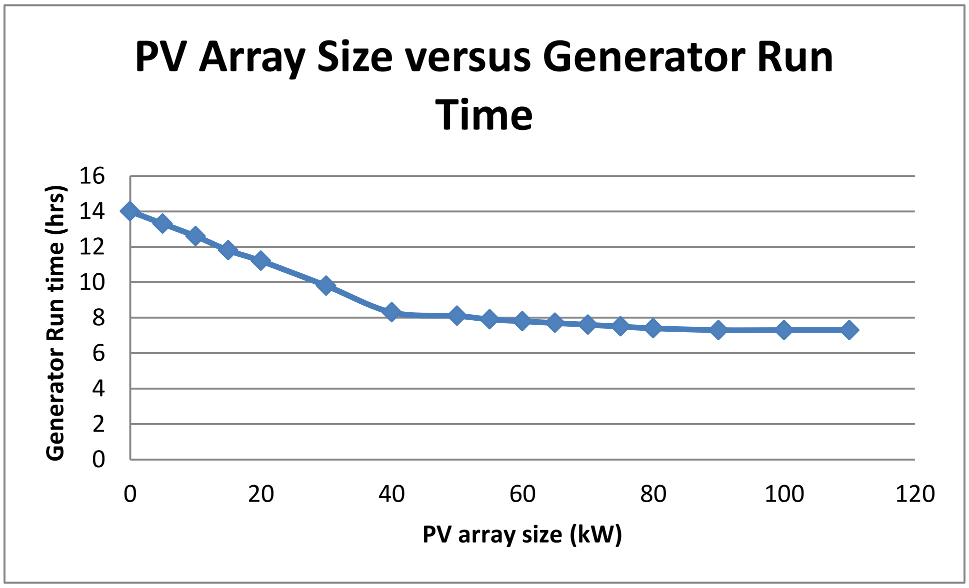


Figure 4-1: Generator run time against PV array size relationship

Figure 4-1 shows that by increasing the PV array size, the generator run time can only be decreased so much; the run time begins to level off at a 50kW PV array size. Using an array size twice as large only reduces the generator run time by less than 1 hour, and it would cost twice as much. For this reason, a 50kW size array was chosen as the optimal size. In all further designs using PV panels, a 50kW size is used.

Battery Sizing

SML has been working with Lee Consavage in the design of the new Green Grid. Current designs call for a 300 kWh battery bank. However, the interns investigated whether this size would be able to store enough energy to supply the island's energy demands during the night without needing to be charged by the generator.

To do this, the interns used an Excel sheet made by Lee Consavage, which calculates generator run time based on island energy use, depth of discharge rate, battery sizing, PV array size, and generator size. Average island energy usage was found using generator trend logs from the summer of 2011 that had been downloaded onto the engineering laptop. Nighttime was defined as 9pm to 5am, an 8 hour period. Total energy usage during this time period was calculated to be 153.19kWh. This is how much energy the battery needs to have stored up in the beginning of the night in order to provide power to the island all night without being charged by the generator. Since the battery can only provide a certain percentage of its total capacity (the DOD), the total energy consumed through the night was divided by DOD to determine the size of the battery bank needed. Results are summarized in **Table 4-2** below.

DOD	Nighttime energy usage (kWh)	**Battery Bank Size Required (kWh)**
10%	153.19	**1531.85**
20%	153.19	**765.93**
30%	153.19	**510.62**

Table 4-2: Results from DOD and battery bank size requirements comparison

Connecting the Existing and New Green Grids

Lee Consavage advised the engineering interns that the existing and proposed green grids cannot be connected and should be kept as two separate systems. This is because once a battery bank has been installed, additional batteries cannot be added onto the bank as they deteriorate the capacity of the existing batteries.

Floor Structural Requirements

At the engineering interns' request, Lee Consavage sent them a floor plan for Star Island's proposed Green Grid building. This building is set to have a concrete floor 5 inches thick with 2 inches of rigid insulation under slab and fiber reinforcing, all over 8 inches of crushed stone. Since Star Island has a 350kWh battery bank, which is larger than the proposed 300kWh battery bank that Appledore Island is considering installing, their floor requirements should be appropriate for Appledore Island's new Green Grid building. A 5 inch floor is a conservative value and allows for expanding the battery bank if necessary.

Conclusions

Building Options

Using Lee's spreadsheet, multiple options for the new battery building were considered and the results are summarized below in **Table 4-4**. The generator run time values in Options 1 and 2 were obtained from Lee Consavage's spreadsheet. It is important to note that the generator run time is a total for the day, and it does not mean that the generator charges the battery for x amount of hours straight. The generator kicks on and off based on how low the battery charge gets. In **Table 4-3**, it is demonstrated that once the battery reaches its low capacity of 225 kWh, the 27 kW generator kicks in. However, once it becomes charged up to above 225 kWh, the generator stops charging it. This on-off cycle continues throughout the day. In actuality, this is not how the battery should be charged, however it was a limitation of the way the spreadsheet was set up. Regardless, the total hours that the battery is charging should be similar to the total hours it would charge if the charging were more constant.

Time	Island Energy Usage (kW/5 min)	Island Energy Usage (kW/hr)	Batt Capacity (kWh)	Energy From PV Panel (kWh)	Batt Capacity (kWh)	Genset #1 Running 0 = No 1 = Yes
5:00 PM	1.76	21.11	300		298	0
6:00 PM	1.69	20.26			277	0
7:00 PM	1.73	20.74			257	0
8:00 PM	1.78	21.35			236	0
9:00 PM	1.75	21.05			**224**	**1**
10:00PM	1.64	19.73			**225**	**0**
11:00PM	1.52	18.24			**224**	**1**

Table 4-3:Generator run time

The battery sizes in **Table 4-4** for Option 3 were obtained by the procedure explained in the Battery Sizing section under Theory.

Option 1: 300 kWh battery with no PV's		
DOD	lifetime	gen run time (hours)
10%	7-10 years	17.8
20%	5-7 years	16.7
30%	3-5 years	15.6
Option 2: 300 kWh battery with 50kW PV's		
DOD	lifetime	gen run time (hours)
10%	7-10 years	8.1
20%	5-7 years	7
30%	3-5 years	5.8
Option 3: battery big enough to get through the night		
DOD	lifetime	battery size (kWh)
10%	7-10 years	1531.85
20%	5-7 years	765.93
30%	3-5 years	510.62

Table 4-4: Battery options comparison

Battery Layout

For the 300kWh battery bank, the batteries will be laid out in 10 stacks, each stack having four batteries. Each battery is 7296W, so 40 batteries will provide 292kWh, which is reasonably close to the 300kWh goal. Since there is a short cable that connects between batteries in each stack, the stacks must be laid out right next to each other. It was decided to line the batteries up next to the wall, as this allows for more open space in the middle of the room.

Transporting Batteries into the Building

In order to move the batteries into the building, the interns proposed the use of a hydraulic cart. The batteries will be moved through the overhead garage door through the use of the island’s front loader. The overhead garage door was designed by the interns to be wide enough for the front loader to enter the building and tall enough for it to enter the building enough so that the batteries were completely in the building. It was decided by the island engineers that it was only necessary to fit the majority of the front loader, and the not the entire front loader, into the building. Once the batteries are inside, a hydraulic cart can be used to move the batteries around inside. Other systems were considered for transporting the batteries into the building, such as an I-beam and block and tackle system. However, this option is limiting because the batteries can only be moved up and down the I-beam. Another possibility considered was an I-beam with block and tackle that could move in the X and Y direction. This was ruled out because of the significant weight of the moving I-beam system and the additional supports that would be necessary. Therefore, the best option is the hydraulic cart system, because it does not place strain on the building structure, and it allows the batteries to be moved around anywhere in the building.

Roof Pitch and PV Panels

To find the optimum roof pitch and orientation for the solar panels, findings were used from last year's engineering interns. Through parametric analysis, they calculated that the optimum roof angle for solar panels was 13.8°. Increasing the tilt angle 4.6° away from ideal only decreases the energy production by less than one percent, so anything in a close range of 13.8° would optimize production. Canadian Solar makes 200 watt solar panels with dimensions 5.374ft x 3.222ft x 0.131ft. On the large building design (see Building Floor Plans section), 3 rows of 12 solar panels each can fit on the roof. This gives a 7.2kW output. On the small building design (see Building Floor Plans section), 2 rows of 11 panels each can fit on the roof, adding up to a 4.4kW array. These panels will all be mounted on the south facing roof of the building. Since a 50kW array may be used, the remaining PV panels will be mounted on the ground.

Building Floor Plans

In **Table 4-3**, it is demonstrated that Option 3, having a battery bank large enough to get through the night, requires a battery so large that it is unreasonable, both in terms of cost and size. For this reason, the engineering interns designed buildings only for the 300 kWh battery bank. The following floor plans were designed using Google SketchUp®.

Figure 4-2 is a drawing of the larger size building, 40 feet by 20 feet. This larger size building is a good option if the Green Grid were to be expanded or if other equipment needed to be stored in the building.

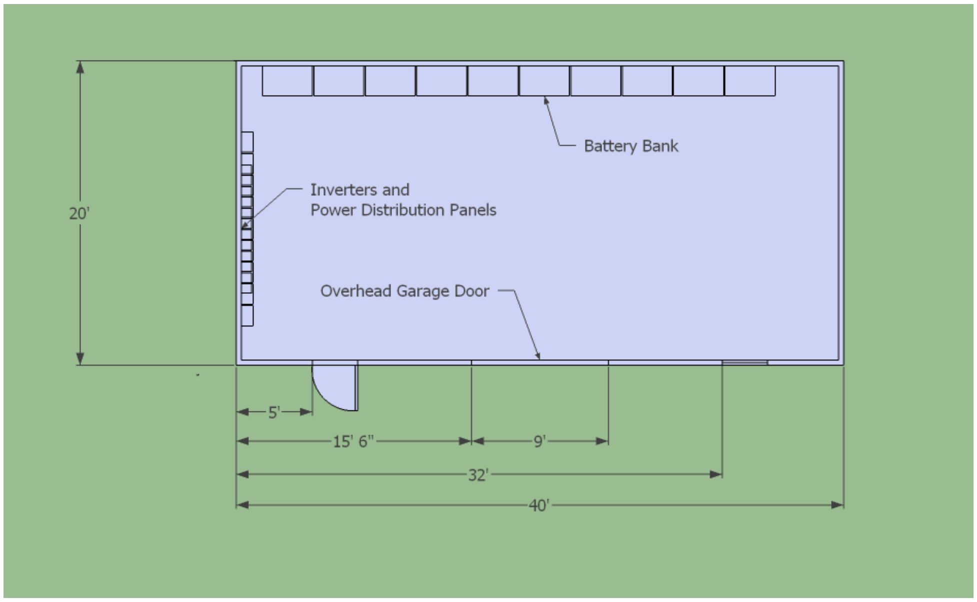


Figure 4-2: Aerial view of large building design

Figure 4-3 is a drawing of the smaller sized building, 38 feet by 15 feet. This option was created because the larger building had extra space and cutting down the building size could save construction costs. Otherwise, **Figure 4-2** and **Figure 4-3** are identical.

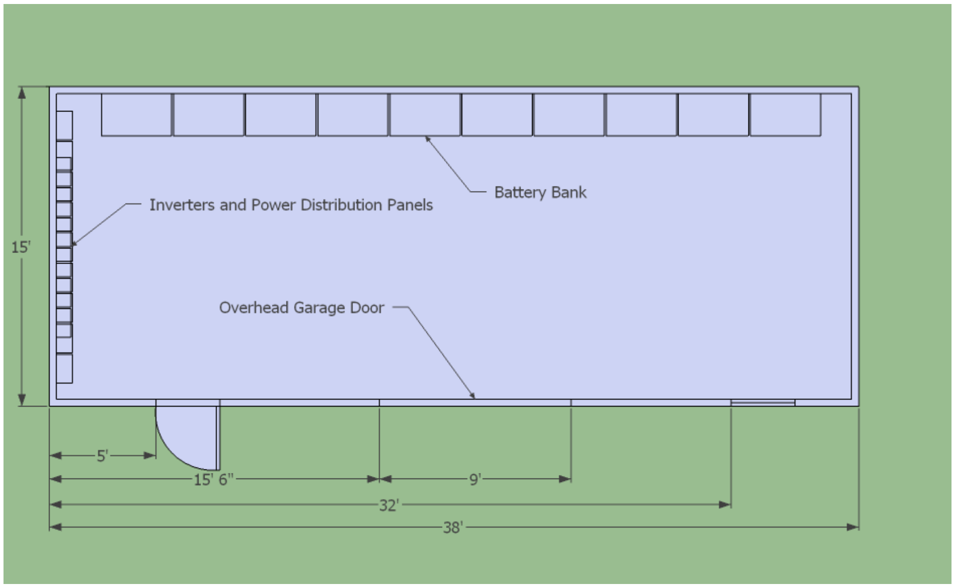


Figure 4-3: Aerial view of small building design

Figure 4-4 depicts the smaller sized building and shows a side view, with the roof pitch at 13.8°. The overhead garage door is also shown, along with a smaller side door for convenience. A window on the side of the building is also shown, to bring natural lighting into the building.

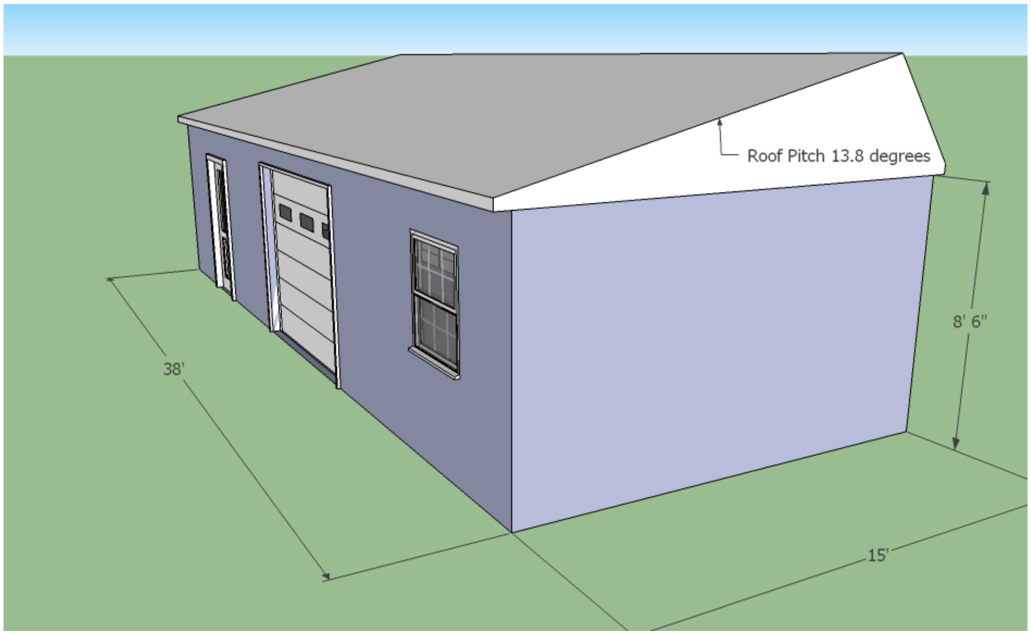


Figure 4-4: Small building design, side view to show roof pitch

Figure 4-5 shows the inside view of the smaller sized building. In this view, the battery stacks are shown (10 stacks of 4 batteries each) along with the inverters and power distribution panels which are both wall mounted. According to Lee Consavage's estimates, 9 Xantrex XW hybrid inverters and 6 Xantrex XW power distribution panels are needed.

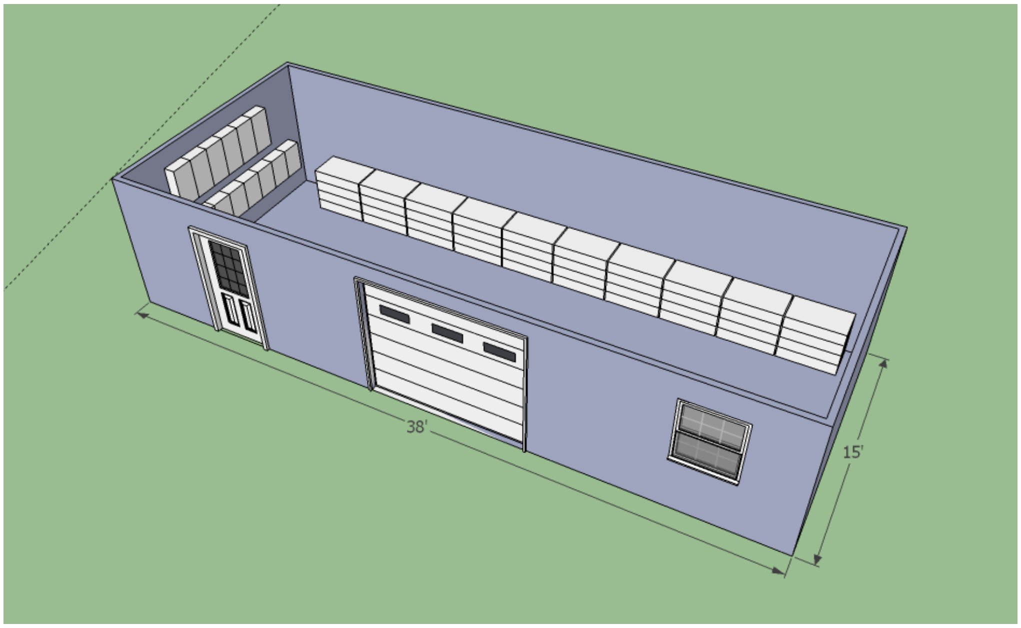


Figure 4-5: Inside view of small building design

Recommendations

Depth of Discharge

The engineering interns have provided multiple options for the new Green Grid building, however some options are more practical than others. One important consideration is the depth of discharge rate. It is important to keep in mind that the DOD be set low enough to increase battery longevity. While the estimates of battery life based on DOD may be conservative, it is crucial that the batteries last as long as they can. Because of this, the interns recommend that the DOD of the new battery bank be set at no more than 20%. However, this means that less energy will be able to pulled off of them.

Battery Sizing

In looking at what battery size is necessary to not need to charge the batteries by the generator at night, some results obtained are impractical. For example, at a 10% DOD rate, a 1531.85kWh battery bank is necessary. This is unreasonable for the island financially. For this reason, it is recommended to use the 300kWh battery bank, which can fit in a reasonably sized building and which we may be able to afford with the grant money received.

Alternate Ways of Using Green Energy

Alternate options should be looked into for storing or using Green energy. It has been observed that in the current Green Grid building, the solar panels and wind turbine are generating extra energy that cannot be used and is simply being burned off as heat. One suggestion to make use of this extra energy is to use it to make ice. Ice is commonly used on the island to store specimens, so the extra energy would be put to valuable use. Another option is to use the extra energy during the day to pump water up to a tower and store in a holding tank. This will then provide gravity fed water that is ready to be used when necessary. During the night, when the PV arrays are not generating any energy, excess water will already be stored in the tower and can simply be gravity fed down to necessary buildings.

GIS Database Population

Background

A GIS map of Appledore Island was begun in 2009 by engineering students from the University of New Hampshire as part of a senior project. The map documents piping for freshwater, saltwater, wastewater, and electrical lines.

Objective

The goal of this assignment was to update the freshwater lines in the database. While nearly all of the lines and points for the freshwater system are drawn, certain details were missing. Parameters such as pipe material, flow type, pipe diameter needed to be found and documented for most of the freshwater system.

Methods

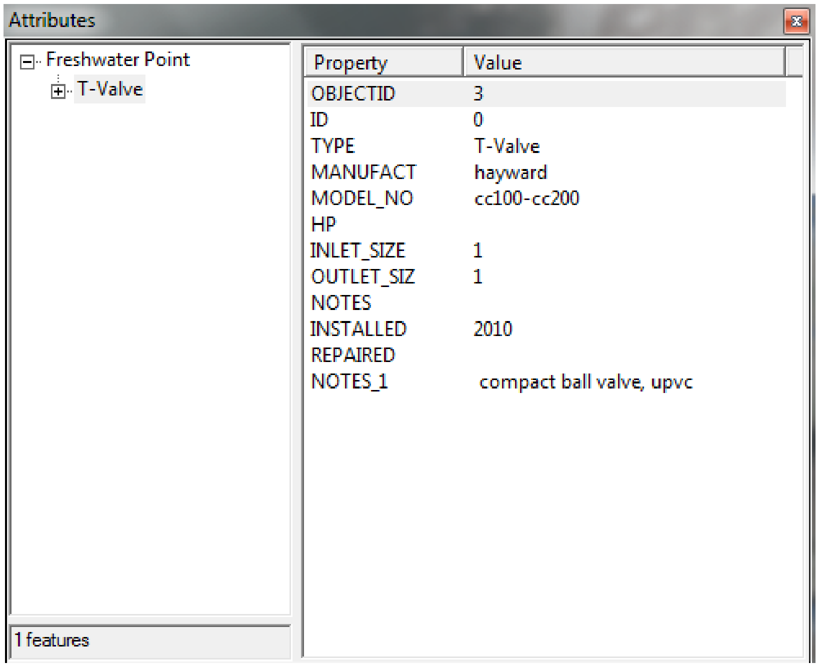
Using the existing GIS map of Appledore Island, the interns surveyed the island's freshwater system. In GIS, there are two types of freshwater data: points and lines. Points can be pumps, junctions, distribution boxes, valves, intake sites, or discharge sites. Pipe material, pipe diameter, flow type, and flow direction were updated for each line. Manufacturer, model number, horsepower, inlet and outlet size were updated for each point.

Results

Figure 5-1 shows the freshwater lines and points which were updated in the GIS database.

Figure 5-1: Updated points in the SML GIS database

Figure 5-2 is an example of a freshwater point update for a T-valve in the freshwater line. All other freshwater points and lines were similarly updated.



Property	Value
OBJECTID	3
ID	0
TYPE	T-Valve
MANUFACT	hayward
MODEL_NO	cc100-cc200
HP	
INLET_SIZE	1
OUTLET_SIZ	1
NOTES	
INSTALLED	2010
REPAIRED	
NOTES_1	compact ball valve, upvc

Figure 5-2: GIS freshwater point update

Recommendations

The first recommendation is to populate other layers besides the freshwater lines. Detailed information, besides just location, about the saltwater, electrical, and wastewater lines could be useful to have on record in the future.

During assignment three in which saltwater crossovers were found and documented in GIS, it was observed that the old saltwater toilet lines in which freshwater is currently running through are not documented on GIS. The interns updated our GIS document with these lines, but the location of these pipes was only approximated. In order to keep the map as accurate as possible, these toilet lines should be documented and drawn in using a GPS. Drawing in these toilet lines accurately is also crucial if Crystal Lake water is run through them to ensure that the right valves are closed or opened and that Crystal Lake water cannot mix with freshwater. Assignment three expands upon the crossover locations and how to run Crystal Lake water to the toilets.

Composting Toilet Grant

Background

In 2011, the Shoals Marine Lab put in two Clivus Multrum composting toilets in the new Water Conservation building connected to Kiggins Commons. The nepon-foam flush toilets were put in to replace the traditional flush toilets. Previous years' interns had determined that the bathrooms in Kiggins Commons were the best candidate for composting toilets as they accounted for approximately half of the islands toilet flushes.

Composting toilets are a beneficial choice on ecologically sensitive areas like Appledore Island. They reduce the impacts from freshwater use and wastewater generation drastically. They also help to reduce the impacts from wastewater treatment and septic tank pump-outs. SML received a grant from the National Science Foundation (NSF) to put in the current composting toilets in the Water Conservation building.

Objective

The goal of Shoals Marine Lab is to put another composting toilet in the Palmer-Kinne Lab building. The site does not currently have a bathroom, and students have to go to the flushing toilets in the dorms or Hamilton to come across the closest bathroom. This causes a strain on the freshwater resources on the island, and it is disruptive to students to have to walk out of class for so long to use the restroom. A map of the area in question is shown in **Figure 6-1**.

Figure 6-1: Map of island classrooms, Kiggins Commons, and dorms, aerial view courtesy of GoogleMaps

The map shown in **Figure 6-1** shows the relative distance between the different classrooms, dorms, and Kiggins Commons on the island. Kiggins Commons currently has the only composting toilets available for student use on the island, but it is the furthest building from the PK building. Dorm 2, dorm 3, and the Hamilton building have restroom facilities; however these have flushing toilets which negatively impact the island.

As well, the site currently has a former oil and gasoline storage that can be modified into a composting toilet facility. By retrofitting the storage facility, concrete costs and transportation can be reduced. Island staff has also been looking for a way to repurpose this storage location, as the site has no current purpose and has little aesthetic value.

The Shoals Marine Lab hopes to fund the composting toilet at the PK building with another grant from NSF. The interns were asked to consider construction and sizing of the new restroom facility and write a grant to pay for the new facility.

Theory

Clivus Multrum composting toilets work using nepon-foam flushing toilets and a recycling composter below the toilets. Multiple toilets can be hooked up to one composter, and there are various sizes for different situations. The nepon-foam flushing toilet utilizes a foam "blanket" that keeps the bowl of the toilet clean and lubricated. The foam is made of Neponol, an alcohol-type, biodegradable soap, and only requires 3 ounces of water to flush. The composter consists of a 45° or steeper 4" plastic pipe leading from the toilet to the plastic composting unit. A fan draws down air from the toilets to prevent odors and to aerate the composter. Bacteria and wood shavings are added to the composter occasionally after the starter bed has been prepared. The starter bed typically consists of peat moss and shavings. Vermiculture can also be used to aid in the degradation process.

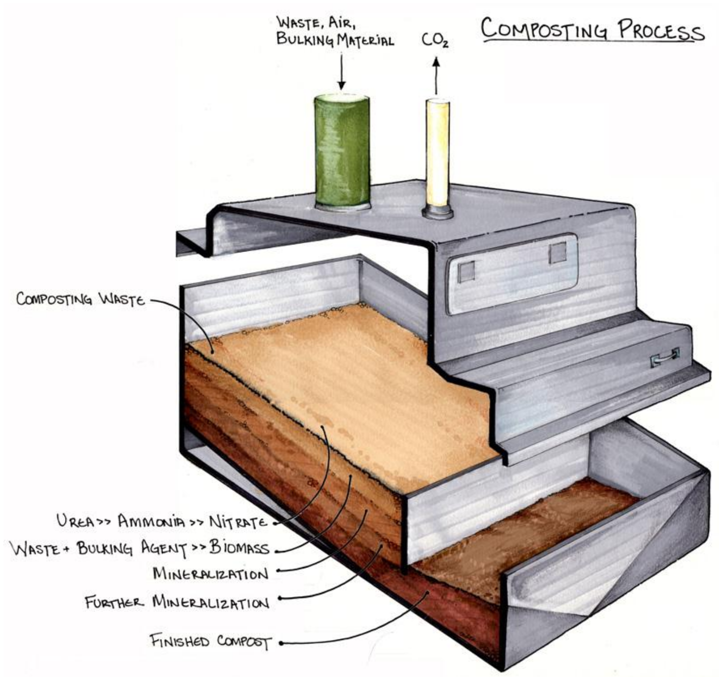


Figure 6-2: Image of Clivus Multrum composting process, image courtesy of Clivus Multrum, Inc.

Figure 6-2[3] shows the design of Clivus Multrum composting process. As well, in order to prevent the spread of human pathogens, no compost is removed until at least a year after it has entered the system. This reduces the threat of human pathogens either due to predation in the composter or from the long retention time. The end-product of the process is either solid compost or liquid compost in the form of a nitrogen-rich stabilized liquid.

Methods

In order to size the composting toilet, the number of people who would use the facility and the number of times per day they would use the facility had to be estimated. The interns did this by surveying the students.

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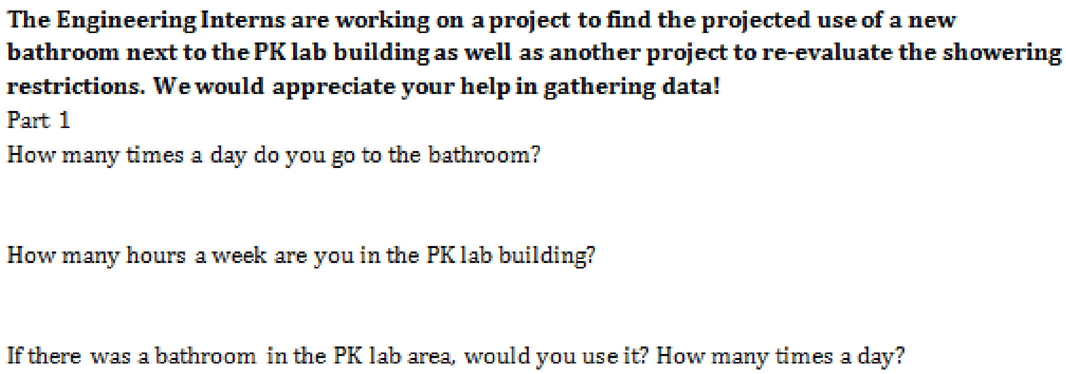
[3] "Science and Technology." *Clivus Multrum Incorporated* . Clivus Multrum Inc., 2010. Web. 3 July 2012. <http://www.clivusmultrum.com/science-technology.php>.



The Engineering Interns are working on a project to find the projected use of a new bathroom next to the PK lab building as well as another project to re-evaluate the showering restrictions. We would appreciate your help in gathering data!

Part 1

How many times a day do you go to the bathroom?

How many hours a week are you in the PK lab building?

If there was a bathroom in the PK lab area, would you use it? How many times a day?

Figure 6-3: Sample from the survey handed out to students and staff at dinner

From the survey shown in **Figure 6-3**, the interns were able to establish a baseline about the use that the new facility would see. The results of the survey showed that students spend an average of four hours per day in the PK building, and that on average a toilet in the PK building would be used about 20 times per day.

In addition to the survey, the interns evaluated population data from previous years for both the PK building and Laighton. Laighton is another classroom near PK building, and the island engineers suggested that students from Laighton might also use the composting toilet near the PK building as there is also no bathroom in Laighton and are close to the PK building. **Figure 6-4**, shown below, shows the number of students expected based on 2011 class and population data.

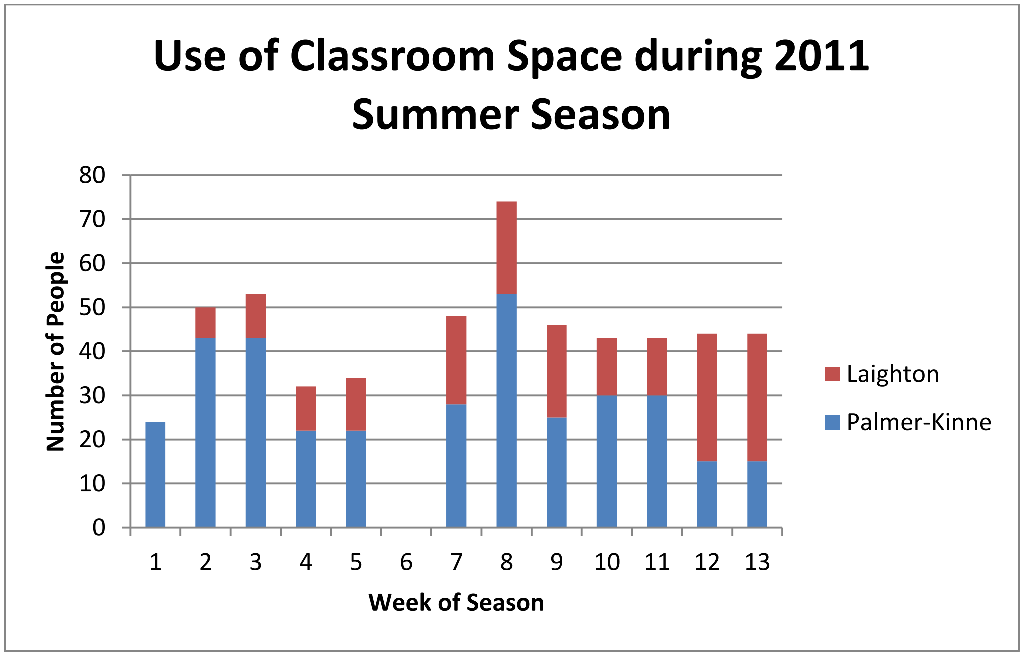


Figure 6-4: Number of students who used the PK and Laighton buildings daily during 2011

In **Figure 6-4**, the large majority of students taking class on the island take class in the PK building until the last two weeks of the season. This makes the PK building as opposed to the Laighton building, which also does not have a bathroom facility, the better choice. Students in the Laighton building would have the option to go to either the PK building composting toilet or the Kiggins Commons composting toilets.

The interns were given the opportunity to speak with Clivus Multrum, Inc. representative, Joe Ducharme, during their stay on the island. During this talk, Joe Ducharme introduced the interns to the science and theory behind the composting toilets. Joe Ducharme also used the data given by the interns to size the composting toilet based on the number of students who would use the facility daily and how many times per day the students would use the facility. The interns also considered peak and minimum numbers for the facility, weekly numbers of students, and the effect of overflow from nearby buildings. Based on these numbers, Joe Ducharme suggested a Model M-10 composter unit with one nepon-foam toilet. System information is available in Appendix F.

Recommendations

After speaking with Joe Ducharme, the model selected was a Model M-10 composter unit. However, the interns considered multiple options in order to gain funding for the project.

Option 1

The first option is to include an addition to the current PK building specimen preparation and dissection area and to add a walk-around observation deck on the Radar Tower. This would increase the educational benefit of the grant. The current specimen prep and dissection deck is very small, so it is difficult to fit entire classes on the deck for dissections, and it also poses a safety hazard as students can easily step backward off the deck by accident. The deck would be enlarged by extending the deck to the edge of the small deck behind the lab. This would approximately double the size of the specimen prep and dissection area. The interns also propose adding railings to the deck to prevent students from falling off accidentally.

The composting toilet facility would be built in the former gas storage building behind the Radar Tower. This would allow the necessary storage underneath the facility for the composter. Additional concrete would need to be added to build the walls up another two feet in order to meet the composter specifications. A doorway to allow easy access to the composter would also need to be cut out of the current concrete wall. This could be done by renting a concrete cutter, available at most home improvement stores. Steps would be built leading up to the toilet room. A deck would be built on the remaining space supplied by closing in the storage area, which would allow space to walk around the facility. Railings would be added to this deck area. The deck area would also allow space for possible future expansion to the toilet facility.

The interns wrote the grant for the scenario listed in option 1. A copy of the grant is located in Appendix F. The proposed design floor plan is shown in **Figure 6-5.**

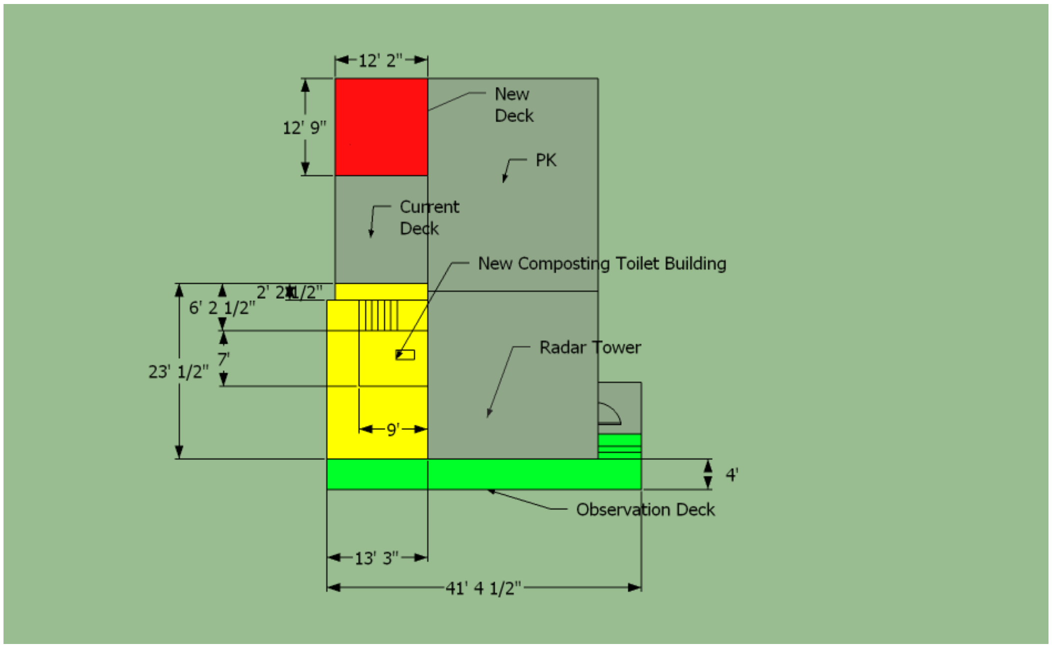


Figure 6-5: Proposed floor plan for option 1 and grant

In order to take advantage of the scenic views from this high island elevation point, it is also proposed to add an observation deck that would connect the new toilet deck area with the existing stairway leading up to the Radar Tower. The proposed design for the deck is shown in **Figure 6-6.** The deck would have railings and would wrap around the front side of the tower. It would also provide students with another route around the tower without disrupting the gulls that nest in the area, and it would allow students and staff to take advantage of the clear views of the western side of the island and ocean. It is suggested by the engineers that some sort of protection from the birds be provided for the deck area. Currently, decks all around the island require power washing on a regular basis to clean up bird excrement that is the result of the large gull population on the island. The constant power washing however requires a lot of diesel fuel and freshwater. A permanent design, like bird wire along the railings or a roof over the deck, would help to prevent more usage of valuable island resources.

With the quote from Clivus Multrum and Ricci Lumber, the approximate cost for option 1 would be approximately $12,925 for the composting toilet and $3,390.56 for the decking and building. The approximate grand total for this option would be $16,315.56.

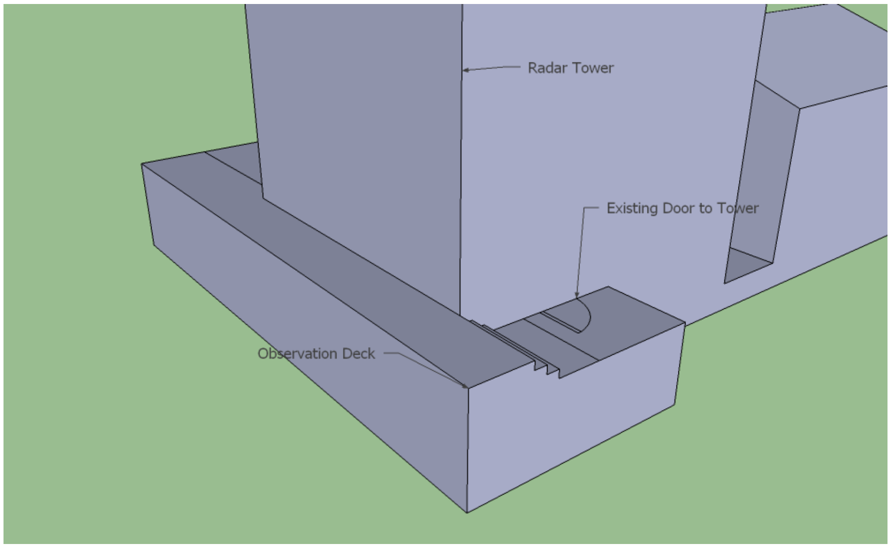


Figure 6-6: Design of proposed observation deck

Option 2

The second option the interns proposed was similar to option 1, with the only difference being that the wrap-around observation deck would not be considered in the plan. Instead the specimen lab deck would be expanded, the composting toilet facility added, and the remaining space on top of the former oil and gas storage area would become a small deck for maneuvering around the composting toilet. This design is shown in **Figure 6-7.** It would also be available still for future possible addition of another toilet. This option would require less cost and construction than option 1, and it could be considered if not enough money was granted.

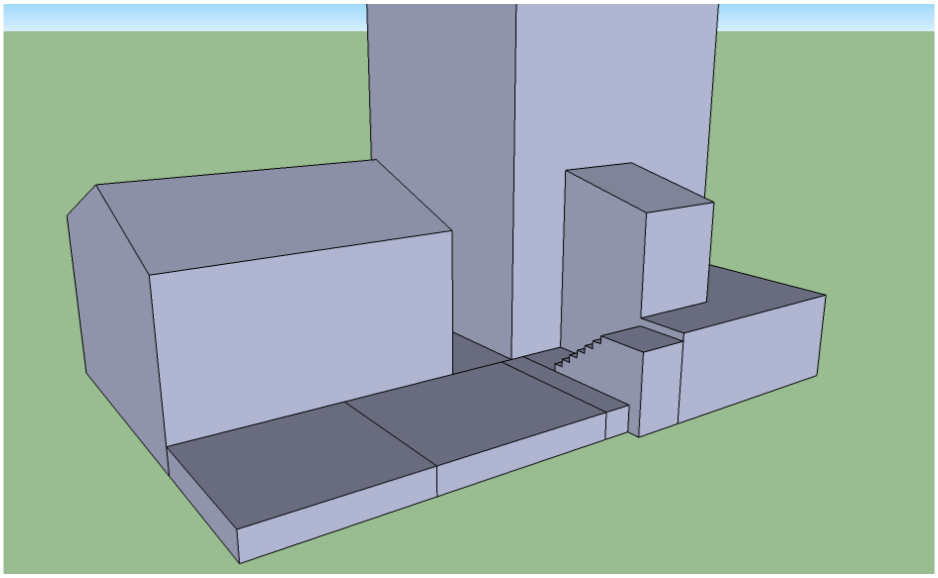


Figure 6-7: Design of proposed composting toilet building and deck

The approximate cost for option 2 would be based on the quotes from Clivus Multrum and Ricci Lumber. The composting toilet system would be approximately $12,925 and the decking and housing for the facility would be $2,538.35. The approximate grand total would be $15,463.35.

Option 3

A third option proposed by the interns is to not expand the specimen prep and dissection area. This design is shown in **Figure 6-8.**

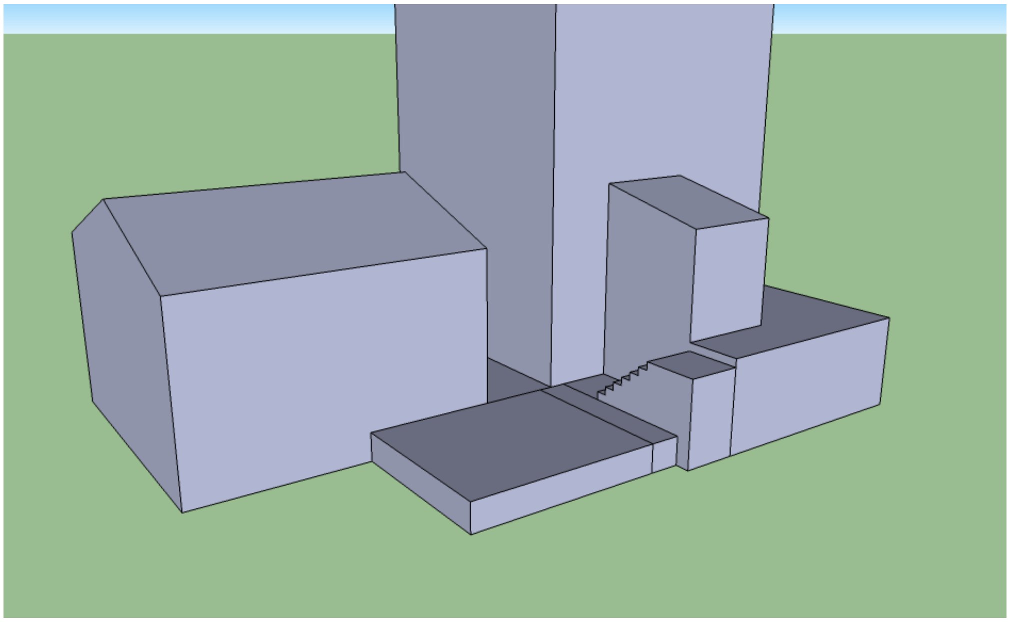


Figure 6-8: Design of composting toilet building addition only

The approximate cost for option 3 would include the cost quote from Clivus Multrum and the building quote for the facility from Ricci Lumber. The composting toilet system cost was approximately $12,925, and the building quote was approximately $1,542.71. The total approximate cost for option 3 would be $14,467.71. The quotes are available in Appendix F. This expansion does not specifically increase the intellectual merit of the project, so if necessary other grants could be considered. These grants are aimed more specifically toward the creation of sanitation facilities.

One such grant is the EPA Clean Water Act Section 319 Nonpoint Source Pollution Management grant. Section 319 was established by the EPA in 1987 as an amendment to the Clean Water Act (CWA). Its purpose was to address the need for greater federal leadership to aid and direct states in mitigating nonpoint source pollution. Under Section 319, the EPA can provide funding to state and tribal agencies to implement approved nonpoint source management[4]. This project would be considered a nonpoint source management as the composting toilet would eliminate the need for a leach field and septic tank system to treat the waste. Failing leach field and septic tank systems are a major cause of this type of pollution[5]. Eliminating the need for this system would eliminate the risk of this pollution. The submission process for this award is suggested to be started early in the year to allow states enough time to consider the grant.

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[4] *Clean Water Act Section 319*. USEPA, 10 Jan. 2012. Web. 3 July 2012. <http://www.epa.gov/owow_keep/NPS/cwact.html>.

[5] Somboonlakana, Donna. "Nonpoint Source Pollution (Polluted Runoff)." *Region 2 Water*. USEPA, n.d. Web. 5 Oct. 2010. <http://www.epa.gov/region2/water/npspage.htm>.

Another grant available for consideration is the Land and Water Conservation Fund (LWCF) grant from the National Park Service. LWCF grants are committed to the reinvesting in resources, emphasizing leadership roles for states, and the concept of a permanent, national recreation estate. This grant supplies funds to programs that change out a nonrenewable, unsustainable practice for a renewable, sustainable one. The program also requires that all properties that receive assistance from the LWCF be maintained perpetually for public recreation use, so that the site will forever be available for future generations[6]. Based on the island's mission to educate undergraduates and perform research in an immersed setting, along with the goal to reduce impact on natural resources with the new composting toilet, the requirements of the grant appear to be step with the needs and requirements of the island. The submission process for this grant suggests having the grant in at least 60 days before the desired start of the project.

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[6] "LWCF Grants." *National Park Service*. National Park Service, US Dept. of the Interior, 19 Sept. 2008. Web. 3 July 2012. <http://www.nps.gov/ncrc/programs/lwcf/grants.html>.

Showering Restrictions

Background

Since Appledore Island relies solely on one well to generate water for the entire island, water is a scarce resource and is conserved at all costs, especially towards the end of the summer when there is typically less rainfall. Because of its limited availability, water restrictions have been set in place. The current shower policy restricts those staying on the island for more than three days to two navy-style showers per week. Furthermore, showers cannot be taken a half hour before and one hour and a half after meals. The program has received negative feedback over the years regarding these restrictions and program coordinators wish to be able to more properly evaluate these restrictions.

Objective

The goal of this task was to determine whether or not the current shower restrictions could be lifted. In order to determine whether or not this was feasible, the current wastewater system capabilities, well capabilities, electrical generation capabilities, and water heating capabilities were evaluated. The two restrictions, showers per week and showering around meal times, were considered separately.

Methods: Showering Around Meal Times

To evaluate whether showering around meal times was possible, the interns decided to investigate amount of hot water available during meal times. Since the number of showers per week would not be increasing, no extra strain would be placed on freshwater, wastewater, or electrical generation capabilities. The interns needed to determine whether the solar water heater and the propane water heater could heat up a sufficient amount of water around meal times while still providing the kitchen with hot water. Three parameters were looked into: amount of water the solar water heater and propane water heater are capable of heating up during meal times, amount of hot water used by the kitchen during meal times, and anticipated volume of extra water that would be used around meal times by lifting the restriction. Each meal was considered separately. The time period during meals was considered as the time period that the showering restrictions are in place: one half hour before each meal, two hours after breakfast and lunch, and one and a half hours after dinner.

Amount of Hot Water Available

To determine the amount of water the solar heater and propane water heater are capable of heating up during meal times, the performance of the solar water heater on a sunny day versus a cloudy day was considered. After recording and analyzing solar water heater data that the interns had extracted from the water heater’s SD card, it was found that on a sunny day, water leaving the solar water heater is on average 110 °F. Then propane must heat the water up the last 40 °F, as hot water is heated up to 150 °F total. On a cloudy day, water leaves the solar water heater at an average of 80 °F, and propane heats the water up 70 °F more to reach 150 °F. The rate that the propane tank is capable of heating water was found in the propane water heater manual: to increase the temperature by 40 °F (on a sunny day), the propane water heater can heat the water up at 6.3 gallons per minute; to increase the temperature by 70 °F (on a cloudy day) the propane heater can heat the water up at 3.6 gallons per minute. In the time period that the kitchen staff reported they are using hot water, the interns calculated how many gallons of water can be heated, on both a cloudy day and on a sunny day.

$$Volume\ of\ hot\ water\ available\ on\ a\ cloudy\ day = 6.3\ gallons\ per\ minute\ (gpm) * duration\ of\ meal \tag{Eq. 7-1}$$

$$Volume\ of\ hot\ water\ available\ on\ a\ sunny\ day = 3.6\ gpm * duration\ of\ meal \tag{Eq. 7-2}$$

Results are summarized in the **Table 7-1** below:

Meal	Duration	**Available hot water (sunny day)**	**Available hot water (cloudy day)**
breakfast	135 min	**850.5 gal**	**486 gal**
lunch	150 min	**945 gal**	**540 gal**
dinner	180 min	**1134 gal**	**648 gal**

Table 7-1: Results of comparison of hot water available on sunny and cloudy days

Amount of Hot Water Used Currently

To determine the amount of hot water used by the kitchen during each meal time, the interns collected totalizer data (total volume of water flowing through the solar hot water heater), before and after meals. All water going through the totalizer was assumed to be kitchen hot water usage. The time period that the kitchen used hot water was also recorded (based on interviews with kitchen staff), and from this a flow rate of hot water used by the kitchen for each respective meal was calculated. Results are summarized in **Table 7-2**.

Meal	Volume of water used	**Flow rate of water**
breakfast	78.3 gal	**.58 gpm**
lunch	117 gal	**.78 gpm**
dinner	140.4 gal	**.78 gpm**

Table 7-2: Results of flow rate of hot water used around meals

Anticipated Additional Volume of Water Used

To determine the anticipated additional volume of water used by showers if the meal time restriction was lifted, a survey was conducted to all present students and interns at a meal on June 15th. The following are the survey questions:

1. Would you shower around meal times if you could? If so, what meal time(s)?
2. Do you take a typical “navy” shower (30 seconds to rinse, 45 seconds to rinse off, 45 seconds for hair)? If not, how long does the water run during your typical shower?

Table 7-3 summarizes the results the interns obtained:

Would you shower around meal times if you could?	yes	67%
	no	33%
What meal time(s)?	breakfast	26%
	lunch	9%
	dinner	44%
	none	33%
Do you take a typical navy shower (2 minutes)?	yes	65.1%
	no	34.9%
If not, how long is your shower?		5.9 min

Table 7-3: Results of shower survey

Using these results, the average shower length can be calculated:

$$average\ shower\ length\ =\ 2*.651\ +5.9*.34=\ 3.4\ minutes \qquad \text{(Eq. 7-3)}$$

The interns wanted to verify this number by examining water usage logs and population data. Hot and cold shower water data was collected during the first two weeks of the internship and put into an Excel spreadsheet. The average volume of water used by showers per week was calculated to be 1441 gallons. Population data was obtained from the Island Coordinator, and it was estimated that an average of 60 people were using Kiggins showers those first two weeks.. The interns also conducted a simple test to determine the shower head flow rate. A stopwatch ran for 5 seconds, and all the water that flowed through the shower head was collected in a bucket and then measure. Since the pressure gauge can be changed by the shower taker, the test was conducted with the gauge set on three different pressures: full, half, and low. The results are summarized in **Table 7-4** below:

pressure gauge	flow volume(mL)	time (s)	flow volume (gal)	**flow rate(gpm)**
full	1522	10.65	0.402	**2.27**
half	477	5.44	0.126	**1.39**
low	214	5.56	0.0565	**0.610**

Table 7-4: Results of shower test

In evaluating shower restrictions around meals, it is assumed that showers are taken at full pressure, or 2.27gpm in order to make a conservative estimate.

To find the average length of showers using water meter and population data and assuming students and interns take an average of two showers per week, the interns used **Equation 7-4.**

$$\begin{aligned}&average\ shower\ length\\&\quad = \frac{gallons\ of\ water\ used\ per\ week}{2\ showers\ per\ week\ per\ person * number\ of\ people * shower\ flow\ rate}\end{aligned}$$

$$= \frac{1441\ gallons\ per\ week}{2\ *\ 60\ people\ *\ 2.27\frac{gallons}{minute}}$$

$$= \ 5.29\ minutes \qquad \text{(Eq. 7-4)}$$

This estimate is significantly higher than what was reported in the survey, leading the interns to believe the survey may have been slightly biased. In further calculations, the length of showers was assumed to be 6 minutes to give a conservative estimate of projected water use around meal times.

To calculate the number of projected showers taken around each meal, results from the survey were used. To give a conservative estimate, maximum capacity for the dorms and Founders was also used. These are the people that use the Kiggins showers. The dorms can house 60 people at maximum capacity and Founders can house 39 people at maximum capacity, for a total of 99 people.

$$\begin{aligned}&Number\ of\ showers\ during\ a\ meal\\&\quad = percentage\ of\ interested\ people\\&\quad\ * maximum\ number\ of\ people\ showering\\&Breakfast\ = \ .26\ *\ 99\ = \ 25.74\ people\\&Lunch\ = \ .09\ *\ 99\ = \ 8.91\ people\\&Dinner\ = \ .44\ *\ 99\ = \ 43.56\ people\end{aligned} \qquad \text{(Eq. 7-5)}$$

Taking into account that students and interns can take 2 showers per week:

$$Number\ of\ showers\ during\ breakfast = \ 15.6\ people * \ 2\ \frac{showers}{week} * \frac{1\ week}{7\ days}$$
$$= \ 7.35\ \ showers/day \qquad \text{(Eq. 7-5a)}$$

$$Number\ of\ showers\ during\ lunch = \ 5.4\ people * \ 2\ \frac{showers}{week} * \frac{1\ week}{7\ days}$$
$$=2.55\ showers/day \qquad \text{(Eq. 7-5b)}$$

$$Number\ of\ showers\ during\ dinner = \ 26.4\ people * \ 2\ \frac{showers}{week} * \frac{1\ week}{7\ days}$$
$$= \ 12.45\ showers/day \qquad \text{(Eq. 7-5c)}$$

The total number of gallons used around each meal can be found using **Equation 7-6.**

$$Gallons\ around\ meal = number\ of\ showers\ during\ meal * shower\ length * flow\ rate$$
(Eq. 7-6)

$$Gallons\ around\ breakfast = 7.35\ showers * 6\frac{min}{shower} * 2.27\frac{gallon}{minute} = 100.2\ gal$$
(Eq. 7-6a)

$$Gallons\ around\ lunch = 2.55\ showers * 6\frac{min}{shower} * 2.27\frac{gallon}{minute} = 34.7\ gal$$
(Eq. 7-6b)

$$Gallons\ around\ dinner = 7.54\ showers * 6\frac{min}{shower} * 2.27\frac{gallon}{minute} = 169.5\ gal$$
(Eq. 7-6c)

Another factor to take into account is the average temperature of a shower. Since the water coming out of the propane water heater is at 150 °F, and most people don't shower using 150 degree water, some combination of hot and cold water is used. According to the Lotus Living Laboratory at Stanford[7], the average shower temperature is 107.5 °F.

$$Percent\ of\ shower\ water\ that\ is\ hot = \frac{107.5}{150} = 72\ \% \qquad \text{(Eq. 7-7)}$$

Therefore, the calculated gallons of water used around each meal time must be multiplied by a factor of 0.72 to give gallons of hot water used at each meal.

$$Gallons\ of\ hot\ water\ used\ at\ breakfast = 100.2 * .72 = 71.8\ gallons$$
(Eq. 7-8a)

$$Gallons\ of\ hot\ water\ used\ at\ lunch = 34.7 * .72 = 24.8\ gallons$$
(Eq. 7-8b)

$$Gallons\ of\ hot\ water\ used\ at\ dinner = 169.5 * .72 = 121.5\ gallons$$
(Eq. 7-8c)

These equations give the anticipated volume of hot water used around each meal if the meal time restrictions were lifted.

Conclusions: Showering Around Meal Times

To determine if there is enough available hot water during each meal to lift the meal time showering restrictions, **Equation 7-9** was used.

$$Shower\ water\ available = hot\ water\ available - hot\ water\ used \qquad \text{(Eq. 7-9)}$$

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[7] Ketterle, Jonas. "Shower Use Profiling." *Lotus Living Laboratory*. Ed. Andreas Viklund and Selena Simmons-Duffin. Stanford University, 2006. Web. 5 July 2012. <http://www.stanford.edu/group/greendorm/research/water.html>.

Table 7-5 is representative of a sunny day.

	Hot water available (gal)	Hot water used (gal)	**Shower water available (gal)**	**Shower water needed (gal)**
Breakfast	850.5	78.3	**772.2**	**71.8**
Lunch	945	117	**828**	**34.7**
Dinner	1134	140	**994**	**121.5**

Table 7-5: Hot water available on a sunny day

Comparing shower water available and shower water needed, it is clear that there is more water available than needed, showing that there is sufficient water to allow people to shower around every meal time on a sunny day, when the solar water heating is performing well and heating the water to around 110 °F. Each meal has over 600 extra gallons of water that could be heated up to use for shower water.

Table 7-6 is representative of a cloudy day.

	Hot water available (gal)	Hot water used (gal)	**Shower water available (gal)**	**Shower water needed (gal)**
Breakfast	486	78.3	**407.7**	**71.8**
Lunch	540	117	**423**	**34.7**
Dinner	648	140	**508**	**121.5**

Table 7-6: Hot water available on a cloudy day

Even on a cloudy day, there is sufficient water available during meals, around 300 to 400 gallons extra of hot water that could be provided to use for shower water.

Recommendations: Showering Around Meal Times

The conclusions section demonstrates that there is sufficient hot water available during meals to lift the meal time shower restrictions during all meals and on both sunny and cloudy days. Therefore, the interns recommend that the shower restrictions around meal times be lifted. This analysis was done assuming max capacity of the dorms and overestimating the length of a typical shower. Therefore, the amount of hot water needed for showers around each meal is a conservative number, and assumes worst-case scenario. However, a couple concerns to keep in mind is that the kitchen could use more water than anticipated and more showers could be taken around meals than the survey found. For this reason, if the restrictions are lifted, hot water should be monitored closely, and if the kitchen does not have enough hot water available, the restriction may have to be put back in place.

Methods: Increasing the Number of Showers per Week

Currently, the showering restriction allows two showers per week. The interns investigated this restriction and whether the island's current wastewater, electrical generation, and well water systems had the capacity to handle more showering per week.

For the new shower policy, the interns decided to implement a schedule, both for the sake of calculations as well as to even out the spikes the island sees every third or so day of the week. In **Figure 7-1**, there are spikes both in total shower water use and hot water shower use every four days or so. This is because most programs start on a Monday, and thus most people wait three to four days to shower. The majority of students and interns end up showering on Thursday or Friday, and again on Sunday or Monday. To balance out daily water usage, the new policy would allow people staying in even numbered rooms to shower on even days, and it would allow people staying in odd numbered rooms to shower on odd days. This would help to ensure a more constant water usage on the island, especially when island population increases. For the calculations in this section, we assume the new shower policy will be showering every other day, which is 3.5 times per week.

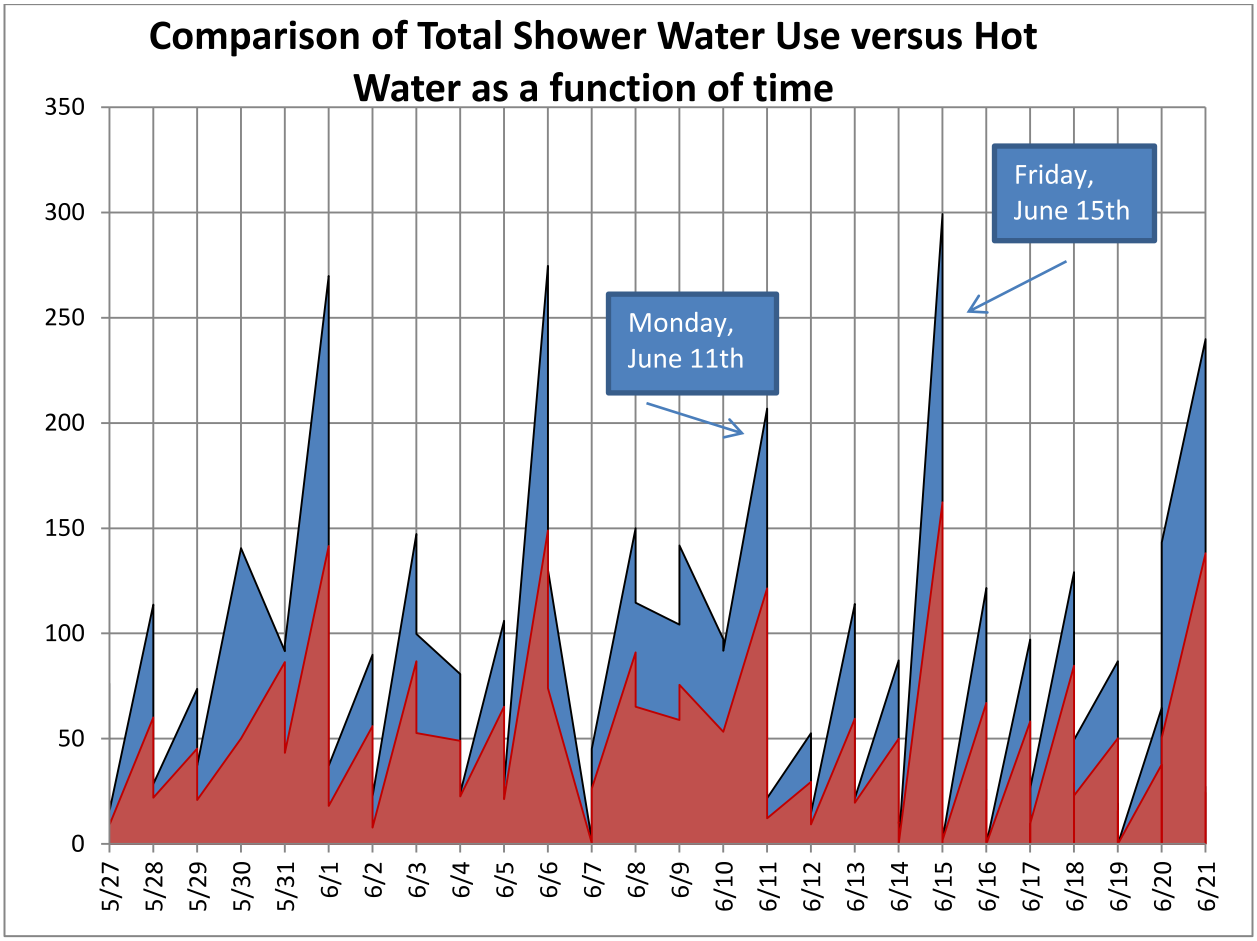

Figure 7-1: Hot water used for showering based on date

Wastewater Capabilities

The current wastewater system on the island involves three different septic systems; there is one for Bartels, one for Kingsbury House, and one for the rest of the island located by Kiggins Commons. The water from the showers goes to the system outside of Kiggins Commons, so the capabilities of this system were evaluated. The system consists of 1 1,000 gallon septic tank and 2 1,500 gallon septic tanks in series, and the system is designed to handle a flow of 1,890gpd. Based on the flow measured entering the island using a meter on the cistern, the amount of wastewater currently entering the septic system was calculated. The current cistern flow rate, C was calculated using cistern logs to be on average 1617gpd.

Because Bartels and the Kingsbury House have their own septic systems, their water usage was calculated and subtracted from the water entering the island system through the cistern. There are currently no water meters on either of these buildings, so their water usage was estimated based on approximate toilet, shower, and washing machine usage. The Kingsbury House currently has no data collected on how many people stay there, so based on number of beds and information from Willy Bemis, it was estimated that on average 5 people stay at the Kingsbury House. It was also assumed that these people take on average 4 10-minute showers a week and that 14 loads per week of laundry are done. Since the Kingsbury House has only composting toilets, no water is used for toilets. In Bartels, using population data it was found that there are on average 13 people staying in Bartels in the summer. Using old toilet flushing data from previous interns, it was estimated that there are 11 flushes per day, and that each flush is 1.6 gallons (low flow toilets were installed last year). Based on interviews with various staff members living in Bartels, it is estimated that each member takes 2 5-minute showers per week on full water pressure (2.5gpm) and that 25 loads of laundry per week total are done. The model numbers of the washing machines in each building were found and approximate gallons per load were considered. See Appendix G showering restrictions for more details. **Table 7-7** summarizes the corresponding water usage.

Kingsbury House Water Use (gpd)	
Toilets	0.00
Showers	71.43
Laundry	40.00
Total	**111.43**
Bartels Water Use (gpd)	
Toilets	17.60
Showers	46.43
Laundry	50.00
Total	**114.03**

Table 7-7: Water usage in Kingsbury House and Bartels

Thus, the total water usage of Bartels and the Kingsbury House, T, is 225.46 gallons per day. The remaining water was assumed to all enter the septic system outside of Kiggins Commons. From this, the current shower usage was subtracted and the proposed shower usage, with showers every other day allowed, was added.

$$Current\ usage, CU = \frac{n*sw*sl*sr}{7} = 353.6gpd \qquad \text{(Eq. 7-10)}$$

where…
$n = number\ of\ people = 99$
$sw = showers\ per\ week\ per\ person = 2$
$sl = shower\ length = 6\ min$
$sr = shower\ flor\ rate = 2.5\ gpm$

$$New\ usage, NU = \frac{n*sw*sl*sr}{7} = 618.8gpd \qquad \text{(Eq. 7-11)}$$

where…
$n = number\ of\ people = 99$
$sw = showers\ per\ week\ per\ person = 3.5$
$sl = shower\ length = 6\ min$
$sr = shower\ flow\ rate = 2.5\ gpm$

From this we were able to see if the increased water use would overload the septic system.

$$\begin{aligned} New\ gpd\ going\ to\ leach\ field &= C - T - CU + NU \\ &= 1617 - 225.46 - 353.6 + 618.8 \\ &= 1656.74\ gpd \end{aligned} \qquad \text{(Eq. 7-12)}$$

where…
$C = current\ cistern\ flow\ rate$
$T = total\ water\ usage\ in\ Bartels\ and\ Kingsbury\ House$

Since this number is lower than the leach field capacity of 1890gpd, it was evaluated that the current wastewater system would be able to handle the increased flow if the new proposed shower policy was instituted.

Electrical Generation Capabilities

There are two components in bringing water to the Kiggins Commons showers that require electricity: the well pump and the cistern pump. After the shower water is used, a pump brings the water to the leach field. Each pump was looked at separately to see how much extra load showering every other day would place on Appledore Island's electrical generation system.

The increase in electricity used by the Solar Water Heater (SWH) to heat water for showers was assumed negligible. The increase in electricity used by the pumps is dependent on several variables such as the weather at the time of shower use, big tank temperature, and phase change material temperature, how much water was used, and so forth. Thus, figuring out how much more electricity would be used by the SWH pumps would be time-consuming. In addition, the pumps used by the Solar Water Heater are 1/35 to 1/25 horsepower or 0.02 to 0.3kW while the cistern and well pumps are 0.75kW. So, even if the extra electricity used by the SWH did matter, it is still very small.

To find the extra energy that the well and cistern pumps would require, 2011 data from May 11 to September 16 was considered. This data included water usage and hours that the cistern pump and the well pump were each on per day. A trend line, between hours that each pump ran and gallons of water used for the day was found. **Figure 7-2** below shows gallons of water versus hours that each pump was on.

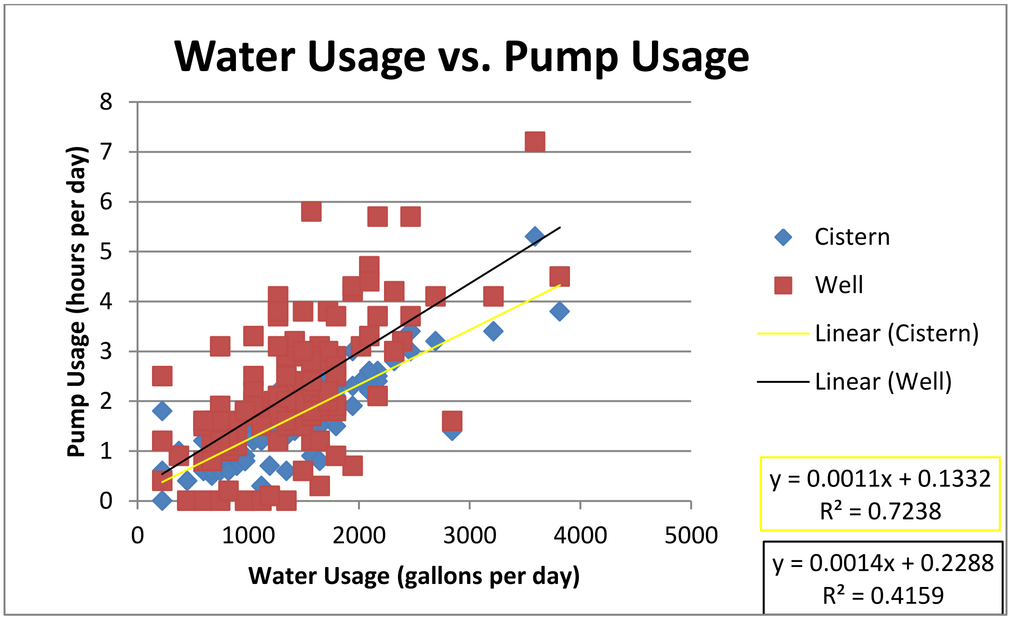

Figure 7-2: Gallons of water pumped for each hour the pump is on

The amount of extra water per day that showering 3.5 times a week would generate is $NU - CU = 265.2\ gpd$. To find the extra amount of hours per day that each pump would have to run, 265.2 gallons was multiplied by the slope of each line (the average hrs/gallon).

$$cistern = 0.0011 * 265.2 = 0.2917\ hours \qquad \text{(Eq. 7-13)}$$

$$well = 0.0014 * 265.2 = 0.3713\ hours \qquad \text{(Eq. 7-14)}$$

Each pump runs at 0.75kW. The following equation was used to find the extra kilowatt hours that showering 3.5 times per week would require by these pumps.

$$cistern\ increase = 0.2917\ hrs * 0.75\ kW = 0.219\ kWh\ per\ day \qquad \text{(Eq. 7-15)}$$

$$well\ increase = 0.3713\ hrs * 0.75\ kW = 0.278\ kWh\ per\ day \qquad \text{(Eq. 7-16)}$$

To better understand the scope of this number, the average kWh per day of the cistern and well pumps was found using the 2011 data.

$$cistern\ average = 1.69\ hrs * 0.75kW = 1.27\ kWh\ per\ day \qquad \text{(Eq. 7-17)}$$

$$well\ average = 2.18\ hrs * 0.75kW = 1.64\ kWh\ per\ day \qquad \text{(Eq. 7-18)}$$

The percent increase in kilowatt hours per day for the cistern and the well is calculated using the following equation:

$$percent\ increase = \frac{increase}{average} * 100\% \tag{Eq. 7-19a}$$

$$cistern\ increase = \frac{0..219}{1.27} * 100\% = 17.2\% \tag{Eq. 7-19b}$$

$$well\ increase = \frac{0.219}{1.64} * 100\% = 17.0\% \tag{Eq. 7-19c}$$

These slight percent increases show that showering every other day will not place great strain on the cistern and well pumps.

The last electrical generation component to be considered was the leach field pump and the additional stresses that would be placed on Appledore Island's electrical system by showering every other day. Water runs from the showers through the drains and by gravity down to the septic tank. Then two pumps pump shower water from the septic tank up to the leach field. Specifications for these pumps were provided by Mike Rosen, and it was determined that they both operate at 1.12kW. Totalizer logs were examined to determine how many hours each pump ran throughout the 2011 season (June through October), and projections for how many additional hours they would need to operate during the entire season were determined. From this, total energy used currently and additional energy associated with showering every other day was determined. Results are summarized in **Table 7-8**.

	Time (hrs)	**Energy (kWh)**	Volume of water (gpd)
Pump 1	8.10	9.07	-
Pump 2	10.70	11.98	-
Total	18.80	21.06	1422.71
265.2 gpd projection	-	**3.92**	265.2

Table 7-8: Additional energy from showering every other day

$$\begin{aligned} Percent\ increase &= \frac{projection\ energy}{total\ energy} * 100\% \\ &= \frac{3.92}{21.06} * 100\% = 18.6\% \end{aligned} \tag{Eq. 7-20}$$

Table 7-8 shows that by taking a shower every other day, only about 3.92 kWh additional would be necessary for the leach field pumps for the entire summer season.

Freshwater Capabilities

The well log data, RO usage data, and precipitation data were compiled in order to determine if there would be enough freshwater on the island to allow people to shower every other day. Based on the challenges with running the reverse osmosis system on the island, including costs, monitoring the machine, and turning the machine on and off daily, it was decided that if showering more times a week would necessitate the RO machine to run, then the new policy would not be a viable option. The well would have to be able to supply sufficient water for all of the island's needs including the additional showers.

Showering every other day requires an extra 265.2 gpd more than what our current estimated water usage is. This means that throughout the entire main season when students are here (approximately June 1 through August 15, or 76 days total), an extra 20,155.3 gallons would be necessary. This is assuming a maximum capacity of 39 people staying in Founders and 60 people in the dorms. A more accurate number, based on actual amount of people staying in Founders and the dorms, was hard to estimate because there is no island population data available for the number of people staying in each building.

With the data supplied, the interns looked at well depths and RO usage. This information was combined with precipitation data, including amount of precipitation and number of precipitation days, for the recorded periods in the well and RO logs. Precipitation data was considered during the season from May to September, prior to the season from December to May, and on a month by month basis for April through August for each year going back to 1995. The interns looked for a correlation between amount of rainfall and hours that the RO machine had to run, with the thought that if there was not sufficient rainfall for the year, the well level would get too low and the RO machine would have to run. Essentially, the interns were examining the data for a minimum rainfall amount in which the RO machine never had to run. This could then be applied to the showering restrictions: if the minimum amount was not met, then the showering restrictions could not be lifted, as there would not be sufficient freshwater available. **Figure 7-3, Figure 7-4,** and **Figure 7-5** show RO usage versus rainfall from May to September (during the summer), from December through May (the winter before the summer) and from December through September (the winter before and the summer during).

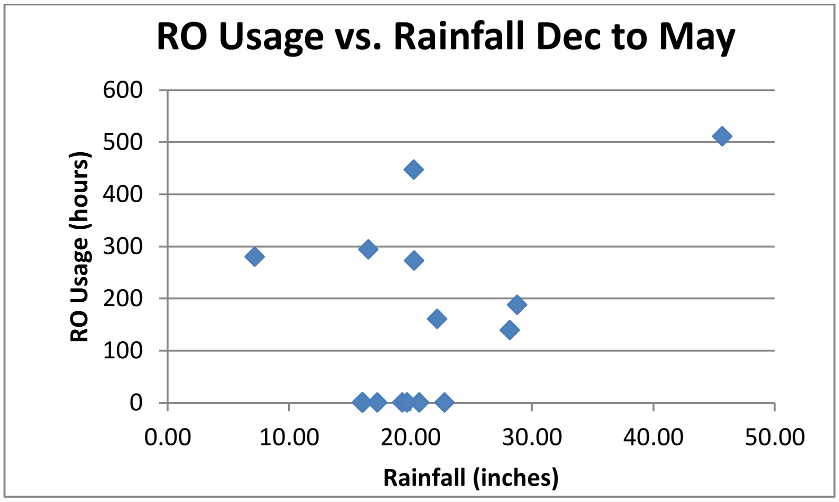

Figure 7-3: Graph of RO usage versus the amount of precipitation the winter before

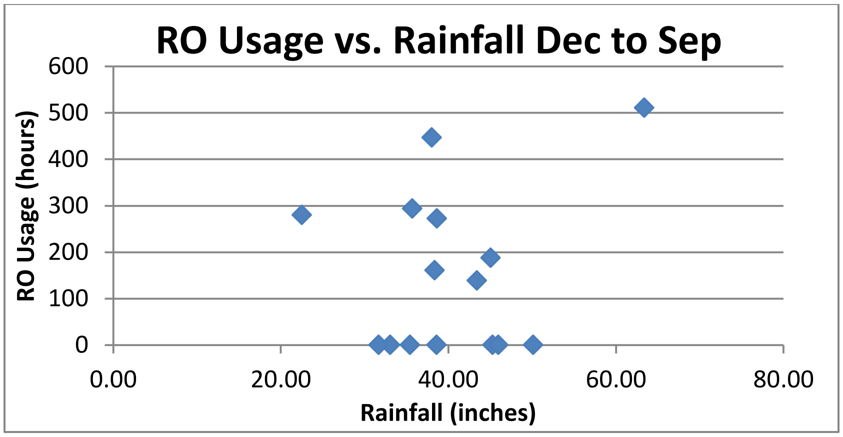

Figure 7-4: Graph of RO usage versus the amount of precipitation during the winter and summer

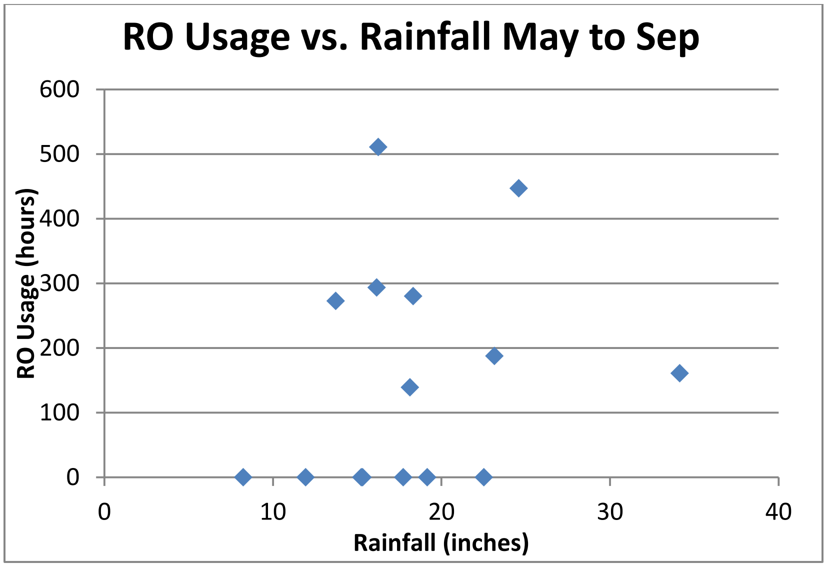

Figure 7-5: Graph of RO usage versus precipitation during the summer

No correlation could be drawn between the amount of rainfall and hours that the RO machine had to be used to make water for any of the three graphs. There does not appear to be any pattern or trend in the graphs.

Additional data from the summer of 2011 was examined: well depth, water usage, and precipitation were graphed together to see if there was a trend between precipitation and well depth. **Figure 7-6** shows that well depth steadily decreased during the majority of the summer, despite significant rainfall events. There did not appear to be any clear correlation between rainfall and well depth.

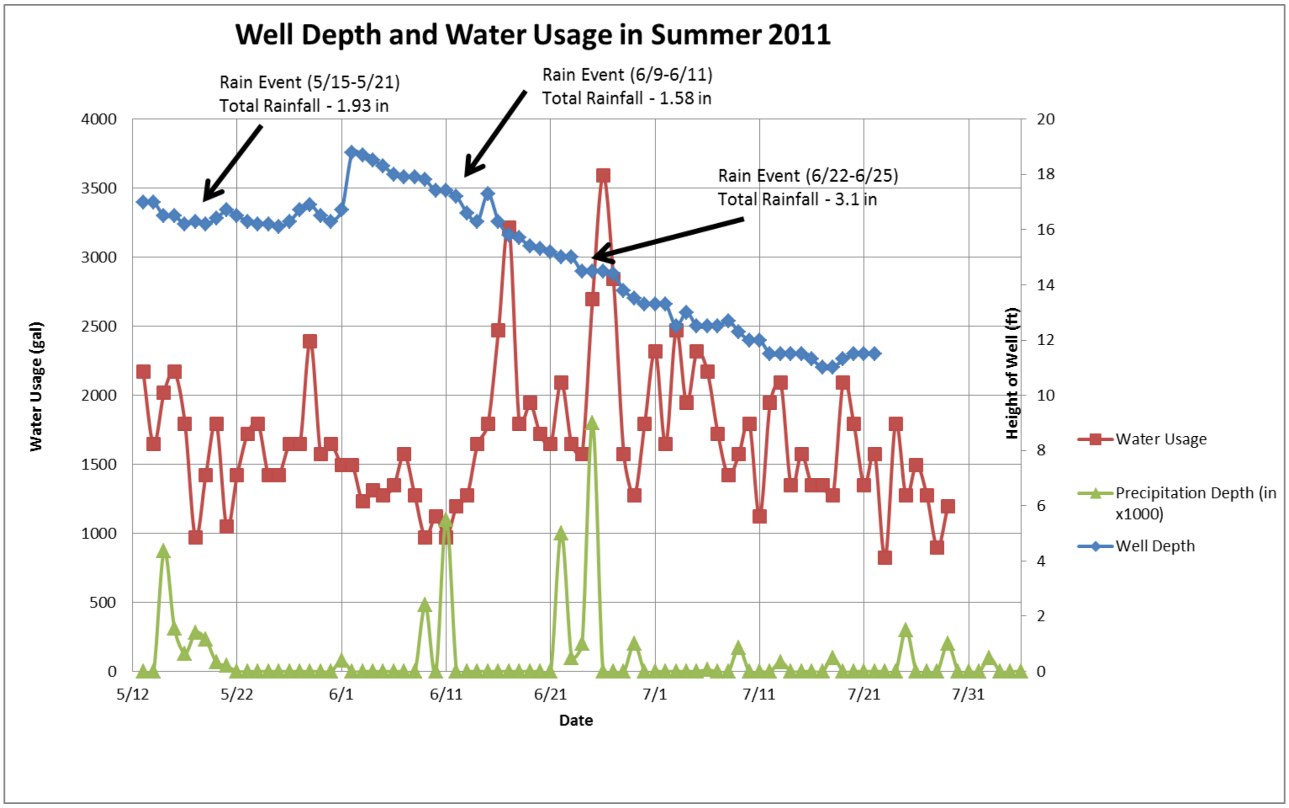

Figure 7-6: Graph of relationship between well depth, water usage, and precipitation during summer 2011

Because there did not appear to be a clear pattern between rainfall and well level, the interns examined other factors that would influence the well level. The groundwater hydrology of the area surrounding the well is currently unknown, however this would be crucial in determining how much freshwater is available and whether the amount of showers per week could be increased. A more in depth look at the groundwater hydrology of the island would provide insight to how deep the well can go before saltwater intrusion occurs, which could allow for more pumping during the season. As well, mapping the groundwater tables would create a better understanding to where the water going to well comes from and where recharge of the well occurs. It also may give insight to how the tides affect the groundwater tables on the island. Ultimately, more knowledge of how much water is actually available for use on the island would be determined through mapping of the groundwater hydrology.

Conclusions and Recommendations: Increasing the Number of Showers per Week

In evaluating whether showers can be taken every other day, three factors were investigated: wastewater capabilities, electrical generation capabilities, and fresh water available. After examining data, it is determined that the leach field's capacity is large enough to handle the increased shower water. Furthermore, showering more times per week does not draw a significant amount of energy that would place strain on the electrical generation system. In determining freshwater available, however, no conclusion can be made as to whether there is sufficient water available in a season because a better understanding of the groundwater hydrology on the island is necessary. It is recommended that the groundwater hydrology of the area be mapped out, which will help in determining freshwater available and provide a clearer understanding of the freshwater and saltwater interactions underneath the well.

Another recommendation is paying more close attention to what water pressure showers are taken at. In the test done to determine the shower flow rate, it was observed that the flow rate varies significantly based on what the pressure gauge is set at. For example, at full pressure the flow rate is 2.27gpm whereas at the lowest pressure the flow rate is only .61gpm. This means that a 2 minute shower taken at full pressure uses a very different amount of water than a 2 minute shower taken at low pressure. Clarification in the shower policy should be made to standardize how much water each shower is using. Another option is to lock the pressure gauge in place at medium pressure, for example.

Future Project Recommendations

Updating the GIS Database

While the 2012 interns were examining various buildings for crossover locations, they learned that the old saltwater toilets lines that currently run freshwater to the toilets in are not documented on the GIS map. Because of this, the interns updated their version of the map with these toilet lines, however the pipe locations were only approximated. The rest of the map has been made very precisely using a GPS, so a recommendation for next year's interns is to more accurately document these lines to keep the entire map as precise as possible.

Storing Excess Green Grid Energy

In looking at the current Green Grid, the interns noticed that the grid was oftentimes producing extra energy that was just being burned off as heat through the resistors in the Radar Tower. In order to store all this excess energy, a very large battery bank would be needed, which may be impractical for the island. Because of this, additional ways of storing this surplus energy should be looked into. Two ideas to consider are making ice to use in specimen preservation or pumping water up to a tower that can then be gravity fed down at night when the Green Grid isn't producing energy. Next year's interns could consider both of these possibilities.

Groundwater Hydrology

The interns suggest that future interns look into mapping the groundwater hydrology of the island. This would help the island engineers and future engineering interns to have a better understanding of the amount of freshwater available for use. As well, it would increase knowledge of how the groundwater on the island moves and where it is recharged by rainwater. This knowledge would also help determine the best place to try and augment the well as well as where pollution on the island would be the most harmful. Finally, mapping the groundwater hydrology would let island engineers know with more certainty how deep the well can be pumped before saltwater intrusion becomes a concern.

Island Sustainability

Future interns could also look into a general evaluation of island sustainability. This project would look into different aspects of the island's practices that have either been determined to need improvement or believed to need improvement. One of these practices is the power washing done to clean the decks around the island. Power washing is done by the work interns on a semi-daily basis, and it appears to require a considerable amount of water. Determining the impact of power washing and then finding more sustainable ways to keep the island's decks clean could be a portion of this project.

Another large water user, the kitchens, could also be evaluated. The kitchen uses water for washing dishes, mopping floors, and hosing down the mats. Several kitchen workers have expressed concern over the unsustainability of these practices, and the interns noticed the large amount of water consumed by the kitchen on a daily basis during their evaluation of showering restrictions. Some suggestions from the kitchen workers included a more efficient method of dishwashing and steam mopping. The amount of water used by the kitchens is displayed in **Figure 8-1**. The amount of water shown by the blue totalizer line is the hot water used by the showers, the kitchens, and the sinks in the Water Conservation building. The red line is the hot water used by the showers and the sinks in the shower room. The volume represented by the dark blue scribble in between the lines is the volume of hot water used by the kitchens and the sinks. The volume of hot water used by the sinks is considered to be negligible, however.

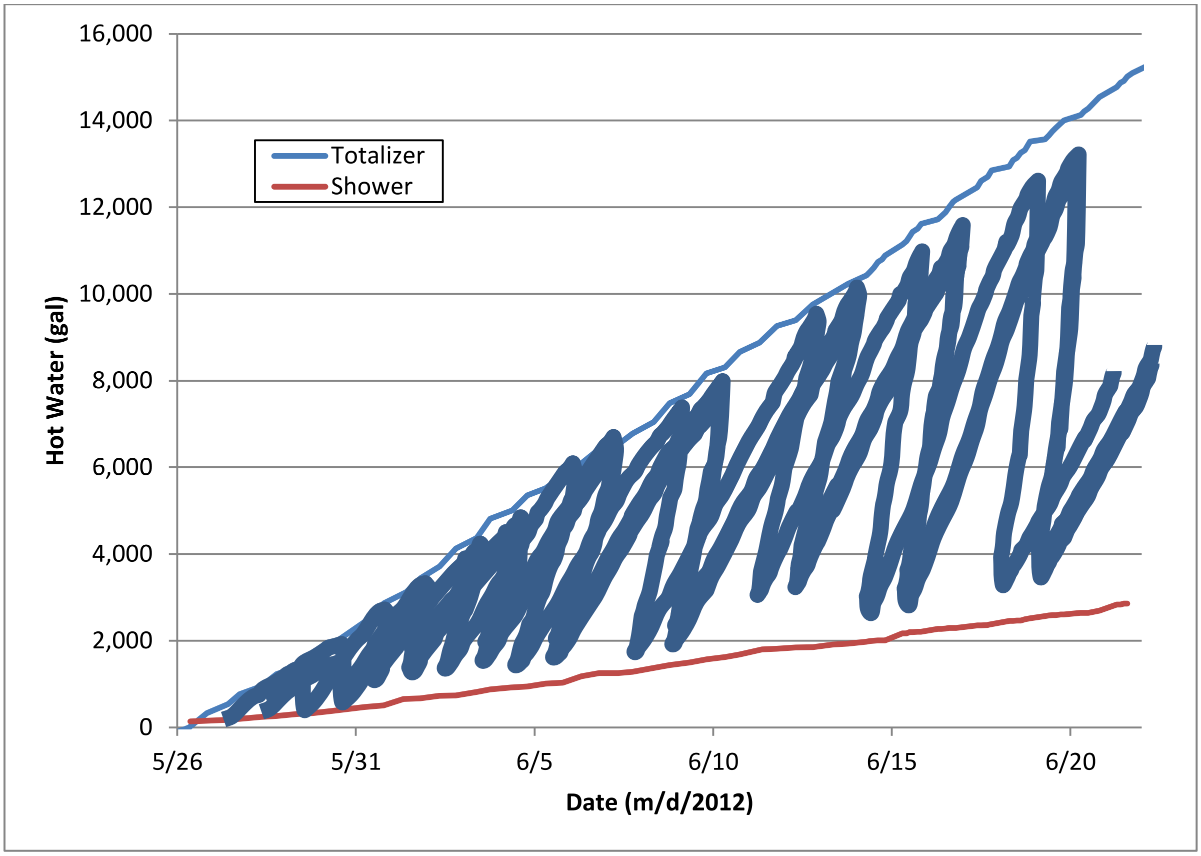

Figure 8-1: Volume of hot water used by the kitchens, showers, and sinks in Kiggins

More general suggestions were made for the island in general, including installing spring-loaded low-flow faucets to reduce water use and leaking faucets in the bathroom, installing motion sensor lights, and finding a more efficient way to dry hands. Finally interest was expressed over analyzing the sustainability of the staff and faculty staying on the island, particularly the energy and water usage of Bartels, Founders, and Kingsbury House.

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