2013 Sustainable Engineering Internship

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Executive Summary

Introduction

As an on-going program for the sustainability of Shoals Marine Lab (SML) since 2006, the Sustainable Engineering Internship brings students in close contact with the island's energy and water systems. Internship assignments aim to design, implement, and assess sustainable or necessary changes to these systems. This year, the students worked on monitoring use, conservation practices, and on- and off-season supply of island water. Additionally, the interns updated the island's GIS database as well as evaluated the existing green grid batteries, island fire safety, and hand drying methods. This report describes the methods and conclusions of their work.

Assignment 1: Kitchen Hot Water Use

Due to the limited freshwater available on Appledore Island, SML is always looking at ways to reduce its consumption. The bulk of the hot water use is in the Kiggins Commons kitchen, where about 1550 gallons are used weekly by three main appliances: the dishwasher (25.4%), the pre-rinse sprayer (14.8%), and the three-pot sink faucets (23.5%). Compare this 1550 gallons weekly to the 8400 gallons of total island per week The remainder of the hot water (36.3%) is assumed to be used during meals and by the bathroom sinks in the Water Conservation Building.

The hot water is pre-heated by a solar water heater and then raised to the state regulated temperature of 120 °F by a propane heater located in the Commons basement. The weekly hot water use requires about 11 gallons of liquid propane (C_3H_6), which emits 12.92 pounds of CO_2 into the atmosphere each week. Several recommendations were made to decrease freshwater use and reduce SML's CO_2 emissions. The kitchen should use a sponge and tub to pre-rinse the dishes rather than relying on the pre-rinse sprayer. Doing so would decrease hot water use by over 23 gallons per day and reduce CO_2 emissions by over 205 pounds per summer. If the kitchen staff wanted to continue using the sprayer, a flow restrictor or low-flow sprayer should be installed. Additionally, as a long-term investment, SML could look into buying a new, more water-efficient dishwasher. Investing in a new dishwasher and using the "sponge-only" method for pre-rinsing, the daily hot water savings would amount to about 50 gallons/day and CO_2 emissions would be reduced by 427 pounds each summer.

Assignment 2: Off-Season Water Storage for K-House

This past year Shoals Marine Lab received a NSF grant that enabled the purchasing of a 300kWh battery bank, a 26kW solar array, and materials to build the housing for the batteries. This was rewarded with the understanding that it would allow researchers to come to SML during the winter months to conduct research comfortably. In order to achieve this the Kingsbury House, which is where the researchers will stay, needs an off-season water source since the island's main freshwater system must be winterized at the end of each year. This need has driven the deliverables of this assignment to design a water storage system for K-House.

The interns considered both indoor and outdoor cistern designs with the assumption that these tanks would be filled with the remaining freshwater at the end of the regular season. It was determined that the storage system must be at least 1500 gallons and serve, at the maximum, five people for two weeks. After considering the constraints of the indoor and outdoor systems, such as temperature, space, surrounding geology, and water treatment, five designs were considered. Simplifying assumptions were made for each design yet the tank size and heating methods differed for each. The indoor system considered insulation of the entire basement versus using submersible heaters with insulated tanks while the outdoor designs considered aboveground and belowground options. After analyzing based on cost, ease of use, and reliability it was decided that overall, the indoor designs proved to be optimal for K-House. Specifically the interns recommended that Design 2 be implemented. This design involves connecting three 500 gallon tanks together in series. The interns recommend that this design be heated either by insulating the basement or by insulating the tanks while also using submersible heaters in each tank. The cost for the design was cheaper than the other four designs considered with the price ranging from $3,330 to $3,444, depending on the heating method chosen.

Assignment 3: Population of Green Grid Data into GIS system

The systems in place and in use on Appledore Island have been mapped out over the years onto the GIS. The GIS provides useful information on the physical layout of these systems as well as specific component information. The Interns updated the GIS to include Green Grid electrical lines and fixed electrical equipment. The new Energy Conservation Building and ground mounted PV arrays were added. Any problems that the interns found with the existing electrical mapping were fixed.

Assignment 4: Hand Dryers or Paper Towels

The project was assigned to determine what is the best hand drying system for the Water Conservation Building (WCB). This bathroom receives a lot of traffic (41% of the total island use), especially from the kitchen staff, so the operational costs and hygienic ramifications are much greater for the WCB than for other bathrooms across the island. After comparing five options of hand drying including the existing method, paper towels appear to be the best choice for the WCB. This decision was most heavily influenced by the fact that paper towels were much more cost effective at five- and 10-year cost projections. The bathrooms in WCB, despite hosting the highest traffic on the island, operate seasonally and have a low use-count compared to buildings in which the electric hand blowers become feasible.

Assignment 5: Fire Suppression System for Student Sleeping Areas

The current Fire Safety of the sleeping areas on Appledore Island were documented and evaluated with respect to state, national, and university regulations. Appledore Island's facilities were found to be in compliance with the requirements. If, in the future, Shoals Marine Lab decides to install a sprinkler system the State of Maine Fire Marshal should be contacted to determine which dorms require NFPA 13, 13R, or 13D sprinkler design standards. The sprinkler system would most likely involve a 300- to 600-gallon water storage tank, a two-horsepower pump, and a retrofitted sprinkler system in each of the larger dorms.

Assignment 6: Freshwater Supply

Freshwater is a valuable resource on Appledore, but it is not readily available in plentiful supply. Many methods to sustainably increase the freshwater supply, including roof and surface run-off after heavy rain events, alternate well locations, and drawing the current well to a deeper depth have been evaluated.

The surface run-off showed high levels of fecal coliforms and *E. coli* (≥1600 MPN/100 mL) that may not be sufficiently treated with SML's current disinfection strategies. Other methods of filtration would have to be explored if SML were to supplement the well with surface run-off. While the roof rainwater catchment also contained fecal coliforms and *E. coli*, 100-300 MPN/100 mL and 14-28 MPN/100 mL, respectively, these levels could be treated with the current SML freshwater system.

Since little is known about the hydrogeology of Appledore Island, the watershed hydrology was examined with soil tests and well pump experiments to better understand the filtering capacity of the soil and the 20-foot dug well's aquifer capacity. While more tests need to be completed before the filtering capacity can be determined, an analysis of well height versus water usage yielded 150,350 to 300,700 gallons as an estimate for the well's aquifer volume. Additionally, salinity and chloride tests were run on water column samples so that a groundwater expert may determine whether the well can be pumped below 10 feet without salt water intrusion.

In order to distribute collected freshwater in the 20-foot dug well's watershed, an estimate of the watershed area was found using the topography of Appledore as shown on Google Earth. The area was estimated at 61600 ft^2. Two watershed areas for proposed alternate well locations were also mapped using Google Earth. The two locations, depressions behind Bartels and Palmer-Kinne Lab, each have a watershed area of approximately 9760 ft^2. These locations need be further evaluated using more precise equipment to determine their feasibility for an alternate well.

Assignment 7: Test and Project Life of Green Grid Batteries

The current 88 kWh battery bank serves five buildings on the green grid. The projected lifespan of the batteries at 60% state of discharge is 20 years. Since the state of discharge has been lower than 60%, the lifetime of the batteries is much less. SML tasked the 2013 interns at finding the remaining lifetime of the batteries by analyzing their current condition. By finding the current capacity of the batteries, the remaining lifetime can be determined. The interns recommend that SML perform the IEEE-1188 standard capacity test. This test includes very extensive and involved steps. Because of this, the interns were not able to complete it.

The power loss associated with the green grid was determined by finding the measured difference between the amount of total charging energy going into the batteries and the total discharged energy going out of the batteries. Total watt-hour losses ranged from 8% to 25%.

The Absolyte IIP batteries at SML contain lead and cadmium. At the end of their life, these hazardous metals will need to be recycled. Exide offers lead recycling facilities across North America and free pickups for all lead type batteries. SML will need to properly package the batteries and provide a means for getting them into pickup truck.

Assignment 8: Freshwater Usage in K-House and Bartels

Past interns have estimated the water consumption in K-House and Bartels at over 100 gallons per day. This year, water meters have been installed in each of these building in order to quantify the amount of water used. From June 12th to July 2nd, 2013, K-House consumed an average of 58.4 gallons of fresh water per day. The average per capita, daily freshwater use in K-House was 8.03 gallons. From June 12th to July 2nd, 2013, Bartels consumed an average of 86.8 gallons of fresh water per day. The average per capita, daily freshwater use in Bartels was 7.89 gallons. The interns concluded that these two buildings are not abusing the availability of fresh water.

Assignment 9: Rock Talk

A 30-minute "Rock Talk" was presented to the island population on July 2nd to inform students how SML acquires electricity, supplies drinking water, distributes salt water, and treats its wastewater. The objective of this talk was to raise awareness among the island population of how SML provides these necessities and how resources are conserved. The presentation was well received, and is available in the Appendix.

1 Kitchen Hot Water Usage

1.1 Introduction

Deliverable: *The Interns will work with the kitchen staff to determine the sources of hot water usage and how it can be modified. The interns will document the modifications and post signs in the kitchen for kitchen staff to go by.* –Engineering Staff

1.2 Purpose

There is limited fresh water on Appledore Island and a cost is involved in generating hot water. The hot water source for Kiggins Commons is supplied by an 85 gallon propane water heater that is pre-heated by an 85 gallon solar water heating system. While the propane is donated to Shoals Marine Lab, the environmental cost of using a propane heater and the potential to be charged for this propane in the future should not be dismissed. Less hot water use means less propane use and a more sustainable SML. The hot water heaters feed two areas of the Commons: the showers and the kitchen. The 2012 Sustainable Engineering Interns determined that the greatest source of hot water use is in the kitchen. The interns did this by recording daily meter readings of the total water heated by the solar heater and used by the showers.

1.3 Scope

This project evaluates hot water use in the kitchen by three main appliances: the dishwasher, the pre-rinse sprayer, and the three-pot sink. The hot water use by each appliance is quantified and ways to reduce that use are presented and evaluated. Both behavioral and appliance-related water conservation methods are considered.

1.4 Background

Both state regulations and the dishwasher specifications require water at a temperature of 120°F. According to the Energy Policy Act of 2005, all pre-rinse sprayers manufactured after January 2006 must have flow rates below 1.6 gallons per minute (PRSV Study Report, 2011).

The environmental cost of burning propane for the gas heaters is roughly 5.8 kilograms or 12.9 pounds per gallon.

Carbon (C) makes up,

$$\frac{C_3}{C_3H_8} = \frac{3\times 12.01\ ^{g}/_{mol}}{3\times 12.01\ ^{g}/_{mol} + 8\times 1.0\ ^{g}/_{mol}} = \frac{36.03}{44.03} = 0.8183 = 81.83\% \text{ of propane } (C_3H_8).$$

The density of propane is

$$493\ \frac{\text{kg}}{\text{m}^3} \times \frac{.003785\ \text{m}^3}{\text{gal}} = 1.866\ \frac{\text{kg}}{\text{gal}}.$$

Multiplying this by the carbon percentage of propane and the ratio of carbon dioxide to carbon yields

$$1.866\ \frac{\text{kg}}{\text{gal}} \times .8183 \times \frac{44.01\ ^{g}/_{mol}}{12.01\ ^{g}/_{mol}} = 5.595\ \frac{\text{kg}}{\text{gal}} \text{ or } 12.34\ \frac{\text{lbs } CO_2}{\text{gal Propane}}.$$

1.5 Objective

1. Quantify kitchen hot water use and compare use to past year's estimates.

2. Make recommendations for appliance and behavioral modifications to reduce *unnecessary* water use.

3. Raise awareness of hot water use and create signs to stress the importance of conservation.

1.6 Methods

1.6.1 System Overview

Three main appliances were identified to be responsible for the majority of hot water use in the kitchen: the sprayer, the dishwasher, and the three-pot sink. See the schematic below, **Figure 1**: A schematic of hot water flow from the solar water heater to the kitchen., for a depiction of hot water flow through Kiggins Commons.

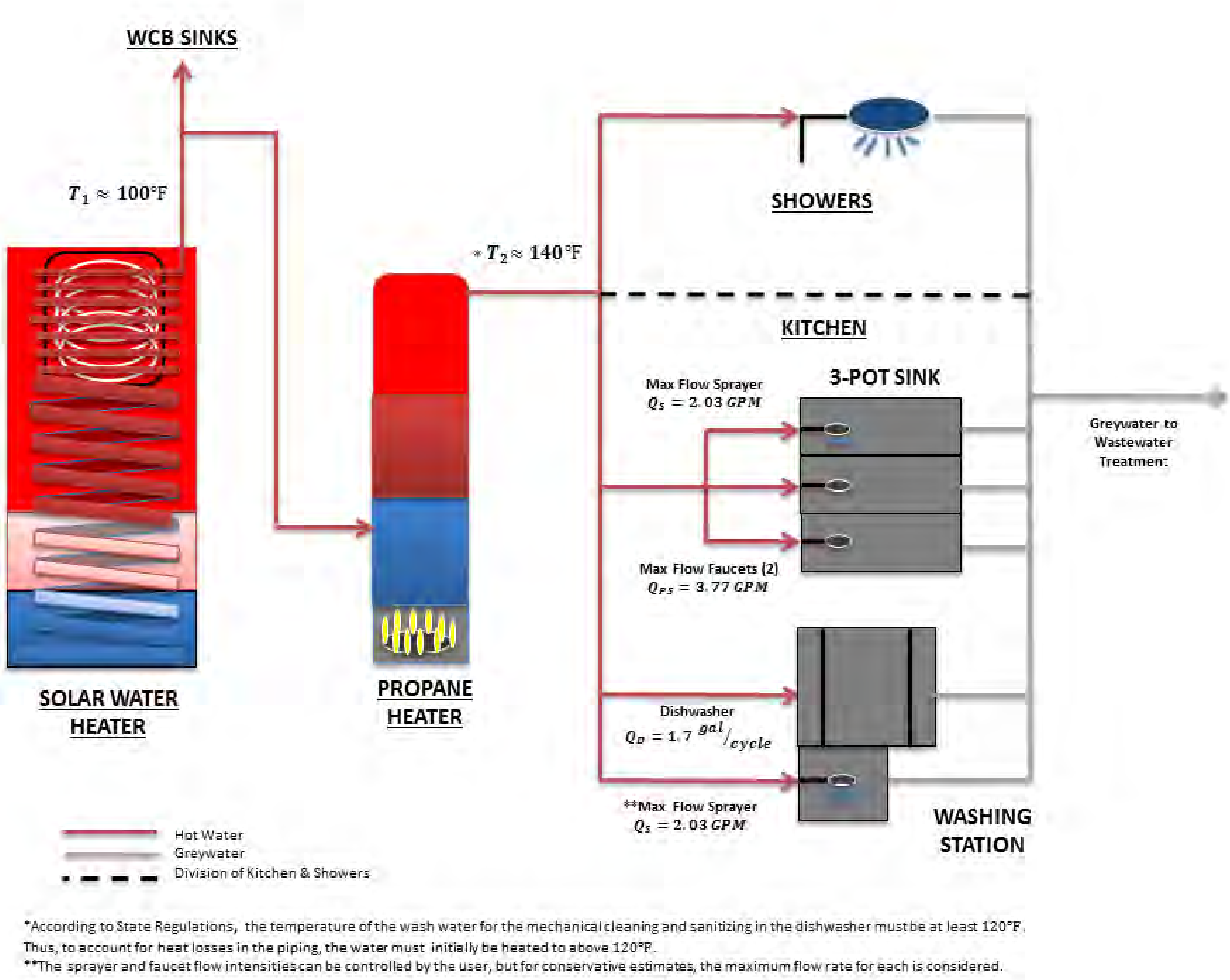

Figure 1: A schematic of hot water flow from the solar water heater to the kitchen.

The kitchen staff using these appliances varies from day to day due to a rotation of the cleaning tasks. In addition, according to the head chef on the island, Charlotte, non-staff members sometimes volunteer to wash dishes. Thus, user variance became a large factor in water consumption for each appliance. Island population fluctuates weekly with students, staff, and visitors coming and going on different schedules. It was important, then, to monitor hot water usage over the four weeks of the internship to gain the best estimate of daily and weekly consumption. While reducing hot water use is the main concern, it should be noted that hot water is necessary for sanitation purposes under state regulations. SML kitchen staff cannot rid the kitchen of hot water use, but behaviors and appliances can be modified to reduce unnecessary waste.

1.6.2 Daily Water Meter Readings

In order to quantify kitchen hot water use, daily meter readings were recorded for both the solar hot water heater and the hot water lines feeding the showers. It was assumed that the kitchen and showers were the only two areas responsible for significant hot water use in Kiggins Commons. The volume of hot water used in the Water Conservation Building for the bathroom sinks was considered negligible. As such, the shower meter values were subtracted from the total water running through the solar heater to determine the volume of hot water used by the kitchen.

$$\text{Kitchen Hot Water} = \text{Total Hot Water} - \text{Shower Hot Water}$$

The readings were taken daily from June 12 to July 2 at around 10:00 AM each day to maintain consistency in the data collection periods. Charlotte, the head chef, recommended that the readings be taken at 10:00 AM (12:00 PM on brunch days) to account for the hot water used for cooking and washing dishes after breakfast each day.

1.6.3 Daily Propane Meter Readings

While the propane that SML uses to heat its hot water is donated, the theoretical cost of the propane was calculated to gain insight into the total cost of generating hot water. From June 22 to July 2, propane heater meter readings were recorded at 10:00 AM daily. Using the cost of propane ($1.74 per gallon, 12.34 pounds $CO2$ per gallon) and the average daily usage, two cost estimates were calculated. Since the pre-heating of the water done through solar power does not require energy, the only cost of generating hot water is the price of propane.

1.6.4 Dishwasher Tally

To quantify dishwasher hot water use, a tally sheet was placed on the wall behind the dishwasher, and the kitchen staff was asked to make a mark after each cycle. From this data and the dishwasher specifications for volume of water use per dishwasher cycle, the average volume of hot water used was calculated.

1.6.5 Time of Use Measurements

Plate/Bowl/Silverware Process

1. Debris is removed from the plate/bowl/silverware with a sprayer (Record Time)
2. Plate/Bowel/Silverware placed in the dishwashing rack
3. Dishwashing rack slides into the dishwasher
4. Dishwasher closes and runs through its cycles.

Pots/Pans Process

1. Fill each of three sinks to specified level once per washing shift (Record Time)
2. Larger pots sprayed down for debris removal (Record Time)
3. Large/small pots/pans are placed in the first washing sink
4. Items are sponged down and moved to the second rinsing sink
5. Debris/soap is washed off in the second sink, and items are placed in third sink to be sanitized.

Beginning in the week of June 10, the kitchen staff members using the sprayer and three-pot sink faucets were timed two to three times per week after each of the three daily meals. The timing continued until July 2 to account for the island population fluctuations. The flow rates of the faucets and sprayer were measured using a six liter bucket and a stop-watch. Multiplying the flow rates of the faucets and sprayers by the respective time of use, the volume of hot water use was calculated.

1.6.6 Research

Methods of kitchen water conservation were investigated and evaluated for their feasibility in the SML kitchen. Both behavioral modifications and more water-efficient appliances were considered.

1.6.7 Sponge-Only Experiment

An experiment was conducted on June 29th to test one of the hot water conservation recommendations: using only the sponge and a tub of water rather than the pre-rinse sprayer.

1.7 Results

1.7.1 Collected Kitchen Data

See Table 1 below showing the weekly kitchen hot water usage. Daily meter readings are located in the Assignment 1 Appendix.

Table 1: Weekly Kitchen Hot Water Usage

Dates	Weekly Total Hot Water Use (gal.)	Weekly Shower Use (gal.)	Weekly Kitchen Hot Water Use (gal.)
6/12-6/18	1771	312.5	1458.5
6/19-6/25	2024.3	420.5	1603.8
6/26-7/2	2083.8	500.9	1582.9
Averages	**1959.7**	**411.3**	**1548.4**

These results confirm the finding from 2012 that the kitchen uses the bulk of hot water in Kiggins Commons. Of these 1548.4 gallons of hot water used weekly in the kitchen, approximately 25.4% is used by the dishwasher, 14.8 % by the pre-rinse sprayer, and 23.5% by the faucets. See Table 2 below for the data collected on sprayer and faucet use after meals. Water use assumes sprayers and faucets are used at full flow.

Table 2: Sprayer and Faucet - Time of Use. *Indicates dishwashing shift done by the interns to gain insight into where hot water was being used. These values are not used for further calculations, as they are not representative of the current kitchen staff.

Date	Meal	Faucet Time	Sprayer Time	Faucet Water Usage (gallons)	Sprayer Water Usage (gallons)
12-Jun	Lunch	---	3:40	---	7.44
13-Jun	*Dinner	7:30	8:40	28.28	17.59
15-Jun	Dinner	5:30	3:50	20.74	7.78
19-Jun	Lunch	4:22	17:09	16.46	34.81
20-Jun	Breakfast	---	2:40	---	5.41
23-Jun	Dinner	4:30	---	16.97	---
25-Jun	Dinner	4:00	2:25	15.08	4.91
27-Jun	Breakfast	---	2:26	---	4.94
Averages		4:35	5:21	17.31	10.88

This still leaves about 36.3% of the kitchen hot water unaccounted for. The collected data only accounts for hot water use after meals; it does not account for the hot water used for cooking or cleaning between meals. In addition, an assumption was made that the total hot water use was split between two main usage sites: the kitchen and the showers. Hot water is also used in the Water Conservation Building's bathroom sinks. The combination of bathroom sinks and hot water use between meals could make up that excess 36.3% usage. The discrepancy could also have been caused by the human error in the timing measurements of the sprayer and dishwasher.

According to the Kiggins Commons propane logs kept from June 22nd to July 2nd, about 11 gallons of propane are used per week, amounting to a weekly cost of $19.08 ($1.7634/gal.) and 135.69 pounds of CO_2. See the daily propane log, Table 3, below

.

Table 3: Weekly Propane Use

Date	Propane Vapor (ft^3 x 100)	Liquid Propane (gal)
22-Jun	130	357.14
23-Jun	131	359.89
24-Jun	--	--
25-Jun	131	359.89
26-Jun	131	359.89
27-Jun	--	--
28-Jun	133	365.38
29-Jun	--	--
30-Jun	134	368.13
1-Jul	135	370.88
2-Jul	135	370.88
Weekly Use:	**4**	**10.99**

According to the data collected, the dishwasher accounts for most of the weekly hot water use and has a weekly operational cost of $2.79 due to the propane water heater. This was found by taking the percent of kitchen hot water used by the dishwasher and multiplying it by the weekly propane cost.

1.7.2 Sponge-Only Experiment

The experiment was conducted during the lunch-time dishwasher shift on June 29th to test how using a sponge and a tub of water in place of the pre-rinse sprayer would affect hot water usage. The dishwasher on-duty filled up the tub with three gallons of hot water at the start of the lunch shift and used the sponge throughout to wipe off debris. The tub did not need to be filled again during the experiment, so the total pre-rinse water used was three gallons. This is significantly less water used even at the most efficient dishwasher time for all meals. Comparing the sponge-only method to using the sprayer, the quickest sprayer time was 2 minutes, 25 seconds. This resulted in a savings of 1.91 gallons of hot water $\left(2.4167 \text{ min.} \times 2.03 \frac{\text{gal}}{\text{min}} = 4.91 \text{ gallons used}\right)$.

While the time spent using only the sponge was about equal to that spent using the pre-rinse sprayer, the work intern noted that the sponge method is better for washing plates than bowls and silverware. This is because plates were easy to sponge off. The work intern thought that washing bowls made the bucket water extra dirty, but this was a null issue, as the water did not need to be replaced even as it became dirtier.

Silverware is also easier to rinse with the sprayer according to the work interns. Rinsing with the sponge requires grabbing the silverware by the handful, dunking it into the tub, and then placing it on the dishwashing rack. Under the current system, the silverware are dumped into the dishwashing rack and easily rinsed with the sprayer. The silverware is always run through two dishwasher cycles to be sure the it is clean. Although the sponge-only method was reported slightly less effective for the interns than using the sprayer, all debris was removed from the silverware regardless of the method used because of the double dishwashing procedure.

1.7.3 Installing New Equipment

A flow restrictor could be installed on the sprayer head to reduce its flow rate from the measured 2.03 gpm to 1 gpm. Such restrictors can be found at online at freshwatersystems.com and cost about $10-15 USD. After examining the sprayer head for a way to increase the pressure, it was determined that only the flow rate can be modified on-site. Without increased pressure, the effectiveness of the sprayer in debris removal may decrease.

Another option would be to replace the Pre-Rinse Sprayer altogether. As shown in Table 4 below, the T&S model B-0107-C shows the overall lowest cost while conserving 68.0 % more water than the current sprayer used in the kitchen. The on-site pressure may remain the same with the sprayer replacement, and may not be as effective in removing debris. Furthermore, the *T&S Family of Spray Valves* guide recommends this sprayer for use on "trays and plates without baked-on residue." The kitchen staff would need a sprayer capable of removing this residue, so the T&S Model B-0107-J (highlighted in blue) may be a better choice, as it still conserves 47.3% more water than the current sprayer.

Table 4: Pre-Rinse Sprayer Comparison

	T&S B-0107	T&S B-0107-J	T&S B-0107-C	T&S equip 5SV-C	T&S equip 5SV
Captial Cost (USD)	51.19	**58.99**	49.95	34.39	32.95
Flowrate (gpm)	1.42	**1.07**	0.65	1.2	1.42
Daily Use (gal)	22.79	**17.17**	10.43	19.26	22.79
Source	FoodService Warehouse	**WEBstaurantStore**	Global Industrial	WEBstaurantStore	Global Industrial
Use	Heavy use,commercial kitchen	**Baked on or sticky residue while still conserving water**	Trays and plates without baked-on residue	General Applications	General applications
Choose this when (according to the *T&S Family of Spray Valves* PDF)	You need a superior quality spray valve suited for general applications	**Time, energy and water conservation are all primary concerns while cleaning stubborn residue effectively**	Water and energy conservation is the foremost need	Equipment cost is the primary consideration, but water conservation is also important	Equipment cost is primary consideration
Daily Kitchen Hot Water Gallons Used	182.03	**137.16**	83.32	153.83	182.03
Weekly Propane Use by Sprayer (gal)	0.96	**0.72**	0.44	0.81	0.96
Weekly Propane Cost (USD)	1.67	**1.26**	0.76	1.41	1.67
Weekly CO2 Cost (lbs)	11.85	**8.88**	5.43	10.0	11.85
Yearly Total Cost (USD)	77.90	**79.12**	62.18	56.96	59.66
Yearly Water Use (gal.)	2734.92	**2060.82**	1251.60	2311.20	2734.92

It was found that the dishwasher is the main culprit of hot water use. The kitchens current dishwasher model, the CMA AH-2 uses 1.7 gallons per cycle. Newer models with the Energy Star certification are available for purchase that would cut the hot water consumption to 0.93 gal/cycle (for the CMA E-AH highlighted in blue). See Table 5 below for dishwasher comparisons between the kitchen's current model and three energy saver models, and the Appendix for specifications on each dishwasher model. Both CMA options use the same amount of energy, but reduce water consumption by 35-45%. As shown in the table, the most cost effective model is the CMA E-AH, with a ten-year cost estimate of $3,556.50.

Table 5: Dishwasher Comparison

	CMA AH-2	CMA E-AH	CMA EST-AH	ADS AF-ES
Initial Cost	3229	**2799**	2879	3404
Water Use (Gal/cycle)	1.70	**0.93**	1.09	0.936
Avg. cycles/day	33	**33**	33	33
Daily Water Use (gal.)	56.10	**30.69**	35.97	30.89
Dishwasher Yearly Hot Water Usage (gal)	6732	**3682.80**	4316.40	3706.56
Cycle Length (min)	1.5	**1.5**	1.5	1.5
Yearly Use (hr)	99	**99**	99	99
Operation Capacity (Racks/hr)	40	**40**	40	37
Energy Star	NO	**YES**	YES	YES
Energy Use (W)	745.70	**745.70**	745.70	1125.0
Yearly Power Use (kWh)	73.82	**73.82**	73.82	111.38
Cost/kWh	0.54	**0.54**	0.54	0.54
Yearly Energy Cost ($)	39.87	**39.87**	39.87	60.14
Weekly Propane Use for Dishwasher (gal)	2.36	**1.29**	1.51	1.30
Weekly CO2 Emitted (lbs)	29.12	**15.92**	18.63	16.04
Yearly Propane Cost (USD)	65.57	**35.89**	42.02	36.06
5-year Total Cost	3756.18	**3177.75**	3288.45	3885.032
10-year Total Cost	4283.36	**3556.50**	3697.90	4366.06
Percent Reduction of Dishwasher Hot Water Use	--	**0.4529**	0.3588	0.4494

With a newer dishwasher, it is possible that less pre-washing with the sprayer would be needed. It would be beneficial for the dishwashers to test how much pre-washing is actually necessary in the current model. In some cases, the sprayer may be eliminated all-together, as in the Sponge-Only experiment conducted on June 29th.

1.8 Analysis

In order to reduce hot water use in the kitchen, several methods can be implemented:

1. Modify dishwashing behavior
2. Install a flow restrictor or replace pre-rinse sprayer

3. Eliminate the pre-rinse sprayer
4. Replace the dishwasher

The simplest and least expensive method is modifying dishwasher behavior. The average water use for those who use the sponge and sprayer is 5.08 gallons. Interns using only the sprayer use an average of 16.68 gallons. Thus, by encouraging interns to use the sponge for debris removal, there is potential to cut back 69.5% of water use per dishwashing shift.

If, however, the kitchen wanted to continue using the pre-rinse sprayer with little sponge use, a flow restrictor should be installed, or the sprayer should be replaced with a more water-efficient model. The T&S model B-0107-J sprayer is recommended, as it reduces hot water consumption and CO_2 emissions 47.41% when compared to the sprayer currently used.

Weighing all the options for hot water use reduction, it is recommended that the kitchen eliminate the use of a pre-rinse sprayer and instead use a tub and sponge for removing debris. This would save at least 23 gallons of hot water per day, and 12.29 pounds of CO_2 per week, as shown below:

Current System: $5.35 \frac{\text{min.}}{\text{meal}} \times 2.03 \frac{\text{gal}}{\text{min}} \times 3 \frac{\text{meals}}{\text{day}} = 32.58 \ {}^{\text{gal}}/_{\text{day}}$

Recommendation: $3 \frac{gal}{meal} \times 3 \frac{meals}{day} = 9 \ {}^{gal}/_{day}$

Total Savings: $32.58 \, {}^{gal}/_{day} - 9 \ {}^{gal}/_{day} = 23.58 \, {}^{gal}/_{day}$

Percent Savings: $\frac{23.58}{32.58} = 72.4\%$ less hot water and CO_2 emitted during pre-rinsing.

9 gal/day of hot water uses .38 gal of propane per week, which releases 75 pounds of CO_2 into the atmosphere per summer. This is a significant reduction from the 271.66 pounds currently released per summer from sprayer use.

In the long run, replacing the current dishwasher with a more water-efficient model would yield a large CO_2 emission reduction due to decreased propane use. The current dishwasher uses about 56.1 gal. hot water/day, whereas the suggested model, the CMA E-AH, uses 30.69. This yields a reduction of 25.41 gallons daily. Thus, if Shoals Marine Lab were to invest in a new dishwasher and use the “sponge-only method” for pre-rinsing, the daily hot water savings would more than double, from 23.58 gal./day to 50 gal./day, and the CO_2 emissions would be reduced by about 408 lbs each summer. Based on available funds, SML should decide if this large investment is worth the environmental savings.

1.9 Recommendations

After comparing the waste reduction options the recommended method to conserve hot water in the Kiggins Commons is to reduce the use or get rid of the pre rinse sprayer and save a projected 23 gallons of hot water per day. Additioanlly, when the current dishwasher is due for replacement a more efficient brand and model should be selected.

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2 An Off-Season Fresh Water System for the K-House

2.1 Introduction

Deliverable: *The interns will design a water storage and delivery system for the K-House that will withstand the winter temperatures. Preferably, the storage tank will be located outside but other options should be explored.* – Engineering Staff

2.2 Purpose

This past year, SML received a grant from the National Science Foundation to install a 300 kWh battery bank, two photovoltaic solar arrays (26kW total), and a building to house the battery bank. This grant was provided on the condition that it enabled SML to house researchers in the Kingsbury House at any time during the year. In order to achieve this SML must provide a water source to K-House that is operable during the winter months as the island's normal freshwater system is winterized at the end of the season. As a result, the interns have been asked to design a water storage system that can reliably serve the needs of K-House's winter researchers.

2.3 Scope

The scope of this project involves investigating the use of a cistern(s) for providing non-potable water to the residents of K-House during the off-season months. In order to achieve this, the interns needed to investigate the current water use of K-House residents in order to accurately project the needed water supply. Once the water supply was determined, the interns were to explore the available locations for a cistern and specify the needed adjustments to keep the water useable for the specified locations. A schematic and the associated costs were to be displayed for the recommended system.

2.4 Background

In the design of the water storage system there were several obstacles which the interns needed to consider. The first was the temperature both inside and outside of the K-House basement. Because the K-House basement is not insulated, the temperatures both inside and outside of the house regularly reach levels below freezing. The outside temperature data was obtained by using the NOAA's National Climatic Data Center data base and selecting historical "Temperature Data" and selecting the "Isle of Shoals" station on the interactive GIS map (NOAA). This daily temperature data was obtained for every month from 2008 to 2013. The average and low temperatures were then averaged for each month and taken as the Average Temperature and Average Low for that month respectively. The lowest temperature recorded for each month was also recorded. A sample of this data can be seen below in **Table 6**.

Table 6: 2012 Monthly Outdoor Temperature Data

	2012		
	Avg Temp	Avg Low Temp	Low
Jan	32.5	27.8	5.0
Feb	35.2	30.9	13.6
Mar	42.5	37.5	18.7
Apr	47.2	43.1	34.7
May	55.0	51.8	42.4
Jun	61.5	57.8	48.7
Jul	69.2	64.7	60.4
Aug	69.4	65.6	58.6
Oct	61.4	57.9	49.5
Sep	54.7	51.4	37.4
Nov	42.4	39.2	26.8
Dec	38.0	33.6	21.0

The indoor basement temperature was obtained through files from SML's Mike Rosen. This temperature was collected for the winter months from fall 2008 to winter 2010. A sample of this data is shown below in **Table 7**. The lowest temperature recorded in this two year range was 18.2 degrees Fahrenheit and was taken to be the temperature an indoor tank must withstand. The complete temperature data for both outside and inside K-House can be found in Assignment 2 Appendix.

Table 7: 2010 Monthly K-House basement temperature

	2010		
	Avg Temp	Avg Low Temp	Low
Jan	31.4	N/A	19.8
Feb	33.2	N/A	24.9
Mar	41.4	N/A	33.5
Apr	49.6	N/A	43.8
May	70.1	N/A	60.6
Jun	73.4	N/A	64.4
Jul	77.5	N/A	65.7
Aug	75.8	N/A	67.6
Oct	76.7	N/A	70.6
Sep	N/A	N/A	N/A
Nov	N/A	N/A	N/A
Dec	N/A	N/A	N/A

The second obstacle, which applied to both indoor and outdoor cisterns, was the disinfection of the stored water. SML is currently required to meet the State of Maine's chlorination requirements of 0.2 mg/L for useable water. This regulation was met in all of the interns' cistern designs. However, it should be noted that the NSF grant states that the “new domestic water tank in Kingsbury House… [is] to provide water for off-season cooking, washing, and cleaning; off-season researchers will bring five gallon containers of drinking water with them.” (Bemis, 9)

There were also constraints that applied to either indoor or outdoor designs. Concerning the indoor system, the largest constraint was the ease of access for installation of a cistern. The largest doorway into the K-House basement is 70.75 in. by 63 in. All cisterns considered for indoor use were required to fit these dimensions, as cisterns are typically shipped and installed completely built in one piece. An additional design constraint for the indoor cistern design was the space available in the basement for the cistern(s). In the past, SML poured a concrete slab to support a cistern and composting toilet. Presently, this slab serves as support for one composting toilet, while storage takes up the rest of this slab. The items stored on this slab could be moved to numerous places on the island, so this was not a significant issue. The remaining available concrete slab space was measured to be 90 in. by 144 in. Although SML does own a concrete mixer, it is still relatively difficult to pour concrete on the island, so the interns only considered indoor cisterns that fit on the available concrete slab space. The final constraint for the indoor cistern designs was the ceiling height. The first floor of K-House is supported by special engineering joints which protrude 18 in. down from the basement ceiling, making the space available from the concrete slab to the bottom of the truss 76 in. However, there is 20.5 in. of space between each row of trusses, creating a maximum of 94 in. available from concrete slab to basement ceiling in between these trusses. The height and manway location of the indoor cistern designs were affected by this constraint.

Outdoor cistern designs were also constrained by several factors. The first is concerned with the possibility of designing an underground cistern. The ground on Appledore is extremely rocky with hundreds of bedrock exposures. This fact makes it very difficult to locate a spot which is first accessible by the SML backhoe, and second, absent in enough bedrock to dig a deep enough cavity for the cistern. The final design consideration is that on the backside of K-House, there is a large raised plateau of bedrock exposure, creating the possibility for a gravity fed, above-ground cistern. This exposure is also covered in poison ivy, although this would seem to be a minor obstacle if a cistern were chosen for that particular location.

2.5 Objectives

1. Determine the current water usage at K-House in order to predict the cistern capacity.
2. Evaluate the basement and outside K-House as locations for a cistern.
3. Evaluate and present several cistern design options and costs.
4. Provide a schematic of the recommended cistern design.

2.6 Methods

The driving requirement for every considered cistern design, and thus the first to be considered was the volume of water the K-House needed for the off season researchers. Three factors needed to be considered when determining this: the typical daily water use of K-House residents, the expected number of researchers, and their expected length of stay during the off season. The daily usage of K-House residents was determined first. Past engineering reports, 2007 and 2012 respectively, have given two numbers for personal daily water usage, 20 gallons per person per day (g/p/d) and 22 g/p/d. The 2007 engineering interns found that the average water usage per capita was 0.014gpm. Thus, by converting to g/p/d, a personal daily usage of 20.16 g/p/d is found. In 2012, the engineering interns estimated the water usage in K-House, finding a total of 111.43 gallons per day were used (consisting of toilets, showers, and laundry). Because no population data for K-house was available, Willy Bemis directed them to assume that the average occupancy of K-House was 5 people. Thus, using this five person estimate, it can be estimated that the personal daily usage of K-House residents is 22.29 g/p/d, based on 111.43 gallons per day and an occupancy of five people. In order to make the interns' estimates reliable, the larger number was used to ensure that enough water was available for K-House residents for the allotted amount of time. The additional two factors, number of researchers and length of stay, needed to determine cistern capacity were obtained by talking to Island Director, Willy Bemis, the author of the NSF grant which enabled SML to obtain the 300 kWh battery bank. Dr. Bemis recommended that the interns take a worst case approach to sizing the cistern and size it to the upper limits of both K-House occupancy and length of stay. From this conversation, the interns learned that an expected maximum of five people would stay in K-House for two weeks. The needed cistern capacity was then sized based on the following assumptions:

Occupancy = Five people

Length of Stay = 14 days

Per Capita daily water usage: 22 gallons

Based on these numbers, it was determined that a cistern of 1540 gallons would satisfy the off-season fresh water needs. It should also be noted that due to manufactured tank sizes, obtaining a cistern that held exactly 1540 gallons was impractical. In order to account for this, a cistern of 1500 gallons was taken as the minimum capacity requirement for considered cistern designs.

Discussion of the project with both Mike Rosen and Ross Hansen allowed the interns to determine the preferred method of filling the tank with the needed amount of water. To ease in the design and operation of this off-season water storage system, both Mike and Ross suggested that the interns assume that the tank would be filled at the end of the typical season with water from the exiting 20-foot dug well on the north side of the island. As a result, the considered designs assume that the cistern would be filled with the island's existing freshwater source.

Other assumptions made include the installation of three one-inch ball valves to allow/impede the flow of water from the well to the tanks, from the well to the house, and from the tanks to the house. This will allow the system to be easily filled by the well at the end of the season. Secondly, for the indoor systems, it was assumed that 20 feet of one-inch copper piping was needed to connect the tank(s) to each other and to the existing pressurized water tank and pump. For the outdoor systems, the amount of piping needed was assumed to be double that of the indoor system: 40 feet.

Before investigating available cisterns on the market, the interns were able to obtain professional advice from Dr. Jim Malley, a water storage and sanitation expert from the University of New Hampshire. After explaining the goal of the project and the situation around and inside K-House basement, Dr. Malley suggested that, based on his 30 plus years of experience, the interns consider an indoor system due to ease of access and an ease of insulting/heating the tank and its piping. Although both indoor and outdoor designs were still considered, more time was spent on the indoor design than the outdoor due to the bias created by Dr. Malley. In addition, Dr. Malley stated that due to the extended storage time, some degree of water fouling would occur between the time of fill at the end of the season and use during the off-season. He recommended manually dosing the tank with chlorine until the necessary 0.2mg/L was achieved. This method of treatment is assumed to be used in each cistern design. Dr. Malley also suggested a number of companies to contact regarding cisterns including FW Webb, RH White, Pentair, Nalco, and Chem-tainer. These companies were used to obtain the cost of the cisterns, heaters, installations, and other materials associated with the water storage system.

2.7 Results

Overall, five designs were considered, with three inside, one outside aboveground, and the last outside below ground. For two of the inside systems, the desired minimum tank capacity of 1500 gallons was obtained by creating manifolds of two and three tanks respectively. The first design considers the combination of two 850 gallon tanks in series, while the second design considers manifolding three 500 gallons tanks together in series. The other three designs discussed in this report only require one tank to satisfy the minimum capacity requirements of 1500 gallons. **Table 8** below shows the capacity of each design and the number of days it can support one to five occupants, assuming 22 g/p/d.

Table 8:Capacity and Length of stay for X amount of people

		People				
		5	4	3	2	1
Design	**Gallons**	**Days Available**				
1	1700	15.5	19.3	25.8	38.6	77.3
2	1500	13.6	17.0	22.7	34.1	68.2
3	1762	16.0	20.0	26.7	40.0	80.1
4 & 5	2000	18.2	22.7	30.3	45.5	90.9

2.7.1 Design 1:

The first design considered placing two polyethylene 850 gallon Pentair 900850 tanks in series. The size of these tanks fits the basement constraints as a diameter of 56 in. will fit through the 70 in. by 63 in. doorway. At a height of 74 in., the two tanks will also fit under the engineered joists 76 in. above the floor. Due to the low temperatures experienced in the K-House basement, heating these two tanks had to be considered. The first option considered was using a Pentair HTS5 3000W submersible titanium heater in each tank. Each heater is 25 in. long, has a sensor and control, and operates at 230V at a max of 12.5A. In addition, the sides of the two tanks would be insulated with 3.5 in. Owens Corning Eco Touch Kraft R-13 fiberglass insulation. This option was recommended after talking with a Pentair technical service assistant. The second heating option considered was insulating the entire K-House basement to keep the temperature above freezing. This design was previously completed by the 2010 engineering interns. These interns suggested insulating the basement walls with 4 in. Rigid Foam Board (R-20) and a plastic vapor barrier. The costs of each option are considered below.

Heater Option

Item	Quantity	Cost
3000W Heater	2	$1,376
3.5” Insulation	6	$60
		$1,436

Basement Insulation Option

Item	Quantity	Cost
4” Rigid Foam Board	100	$1,500
Vapor Barrier	3	$180
		$1,680

Additional costs for Design 1 include:

Item	Quantity	Cost
850 Gal Cistern	2	$1,985
Shipping (estimated)	2	$400
10ft 1" Copper Pipe	2	$60
1" Brass Ball Valve	3	$45
		$2,490

Comparing the two heating options shows a small difference in total cost of Design 1, with the heater based design totaling to $3,926 and the insulated basement design coming to $4,170. Although the heater based option is $244 less expensive, it is recommended that if Design 1 is chosen, then the option to heat via insulating the basement be chosen. This is because this option does not rely on a mechanical system that could potentially fail, need maintenance, and be replaced over the course of time. The absence of a heater will also lessen K-House's demand for power. In addition, an insulted basement would allow for the storage of other items that may need protection from such low temperatures. Thus, it is the interns' recommendation that, if Design 1 be chosen, the insulated basement option, totaling to $4,170, be chosen based on reliability and lack of maintenance.

2.7.2 Design 2:

The second design considered placing three polyethylene 500 gallon Chem-Tainer N-43101 tanks in series. The size of these tanks fits the basement constraints as a diameter of 48 in. will fit through the 70 in. by 63 in. doorway and on the 12ft by 7.5ft concrete slab. At a height of 73 in., the two tanks will also fit under the engineered joists 76 in. above the floor. Again, due to the low temperatures experienced in the K-House basement, heating these two tanks had to be considered. The first option considered was using a Pentair HTS3 1800W submersible titanium heater in each tank. Each heater is 19 in. long, has a sensor and control, and operates at 115V at a max of 15A. In addition, the sides of the two tanks would be insulated with 3.5 in. Owens Corning Eco Touch Kraft R-13 fiberglass insulation. This option was recommended after talking with a Pentair technical service assistant. The second heating option considered was, again as in Design 1, insulating the entire K-House basement to keep the temperature above freezing, as researched by the 2010 engineering interns. The costs of each option are considered below.

Heater Option

Item	Quantity	Cost
1800W Heater	3	$1,734
3.5" Insulation	6	$60
		$1,794

Basement Insulation Option

Item	Quantity	Cost
4" Rigid Foam Board	100	$1,500
Vapor Barrier	3	$180
		$1,680

Additional Design 2 costs include:

Item	Quantity	Cost
500 Gal Cistern	3	$1,155
Shipping (exact quote)	3	$390
10ft 1" Copper Pipe	2	$60
1" Brass Ball Valve	3	$45
		$1,650

Comparing the two heating options shows a small difference in total cost of Design 2, with the heater based design totaling to $3,444 and the insulated basement design coming to $3,330. Based on both cost and reliability, it is recommended that the basement insulation option be pursued. This is because this option does not rely on a mechanical system that could potentially fail, need maintenance, and be replaced over the course of time. The absence of a heater would, again, lessen the energy demand for K-House. An insulted basement would also allow for the storage of other items that may need protection from such low temperatures. Thus, it is the interns recommendation that, if Design 2 be chosen, that the insulated basement option totaling to $3,330 be chosen based on price, reliability, and lack of maintenance.

2.7.3 Design 3:

The third design considered using a cistern that would be specifically designed by Mass-Tank to fit the dimension constraints of the basement. The design presented by Mass-Tank was a stainless steel 1762 gallon tank with a diameter of 60 in. and a length of 144 in. This tank design would sit on two saddles on the concrete slab. Again, there were two heating options considered for this design, however, both included insulation only. The first was provided in a quote by Mass-Tank, which offered adding 2 in. Armacell insulation for an additional $2,850. The second option was again, as considered in Designs 1 and 2, to insulate the entire basement, costing $1,680. However, before considering any additional costs such as piping or shipping it should be made apparent that the price of this specialty Mass-Tank was quoted at $11,750. Due to extremely prohibitive cost for a design that provides no benefits over the previous two indoor designs, Design 3 will not be considered further.

2.7.4 Design 4:

The fourth design considered an outdoor cistern. Mass-Tank was again consulted for providing a 2000 gallon above ground, stainless steel cistern. In order for this tank to withstand the sub-zero temperatures which it would experience outdoors Mass-Tank gave the option of providing trace heat in combination with insulation. The prices for which are shown below in **Table 9**.

Table 9: Insulation and Trace Heating Costs

Item	Cost
Insulation	$2,000
Trace Heat	$1,200
	$3,200

Again, before considering the additional costs associated with Design 4, it should be noted that the cost of the steel tank was quoted at $7,750, which is by itself more expensive than the total cost of Designs 1 and 2 *combined*. Combining this with the heating cost gives a cost of $10,950 before considering piping, piping insulation/burial, delivery, or saddles to hold the tank. It should also be noted that keeping this tank above freezing is dependent on a mechanical system that will need maintenance, service checks, and eventual replacement. Due to this reliance and the high cost, it is recommended that Design 4 not be considered further.

2.7.5 Design 5:

The final design was also an outdoor design. This design considered an underground stainless steel 2000 gallon cistern provided by Mass-Tank for $7,750. The benefit of this design is the fact that it would not require insulation of heating as long as it was buried beneath the frostline. The external coating and internal lining would also be provided by Mass-Tank. However, the hole for the tank would have to be dug using the SML backhoe in a location where the tank could be placed under the frostline. Due to the geology of Appledore Island, this could be a challenging task, and a location would need to be determined before completion of this design. Regardless, if a suitable location is in fact determined, the additional costs would include piping, estimated at $205 for 40 ft. of copper pipe and three brass ball valves. Also, while Mass-Tank will provide delivery to the mainland SML office, SML would have to transfer this 2,500 pound tank to Appledore. The total cost of Design 5 is thus $7,960, plus any fuel and transport costs. The additional costs for digging or transporting the tank have not been estimated or included in the total cost.

2.8 Recommendations

When considering the optimal design for off-season water storage at K-House, one must consider cost, reliability, and ease of use. Cost will be considered first, as the total price of each design is shown in **Table 10** below:

Table 10: Total Costs: Design 1-5

Design	Total Cost
1	$3,926
2	$3,444
3	> $13,430
4	> $10,950
5	> $7,960

Based on cost alone, it is apparent that Designs 1 and 2 are the superior designs. Additionally, although the labor cost associated with each design was not considered, it seems apparent that the costs associated with the indoor labor associated with Designs 1-3 would be less than that of the outdoor designs. Indoor designs also benefit from the shelter of a basement enclosure which will protect them from severe weather or other events which outdoor tanks must withstand.

The reliability of each design must also be considered. First, concerning heating, the underground tank appears to have the best reliability of staying above freezing as the ground will keep it above freezing during the course of the winter. Second, as it was already recommended that all indoor designs be heated via insulation of the K-house basement, the reliability of keeping these designs above freezing is good if insulated correctly, making these designs the second most reliable option considering heating. Design 4 however, is assumed to be the least reliable design concerning heating as it depends on a mechanical trace heater which has the potential of failing over the course of its lifetime. When considering the reliability of water delivery to the occupants of K-House, it is assumed that Designs 1-3 are most reliable, as their indoor location, shielded from the elements, minimizes the chance of pipe damage. The indoor designs also require less piping, which further minimizes the area in which a pipe could become damaged.

The final consideration is ease of use. One factor to consider in this category is the ability to treat the water with chlorine. Due to the fact that Designs 1-3 have 16-inch top mounted manways, dosing the water with chlorine will be relatively simple as the user can just open the manway and pour the chlorine in. Chlorination could also be achieved in this manner in Design 4. However, because Design 5 is an underground design, this will complicate the chlorine dosing process. Additionally, the ability to easily perform maintenance on these tanks should be considered. Because Designs 1-3 are located in the basement of K-House, these designs exhibit the best ease of use in regards to maintenance. The outdoor tank designs, on the other hand, require underground piping, or the cistern, which complicates the maintenance process as servicing these systems will require unearthing them.

This analysis shows that in terms of ease of use and reliability, the indoor designs prove the most optimal, with the exception of Design 5 having the most reliability in regards to heating. However, the complications of excavating, servicing, and using Design 5 outweigh the benefit of using the ground as an insulator. Thus, since the indoor designs all equally prove to be overall more reliable and easy to use, they can be compared by cost alone. Based on this assumption, it can be seen that Design 2 is the optimal design for off-season water use at K-House, as it is $482 cheaper than Design 1. A schematic for the recommended Design 2 is shown below in **Figure 2**.

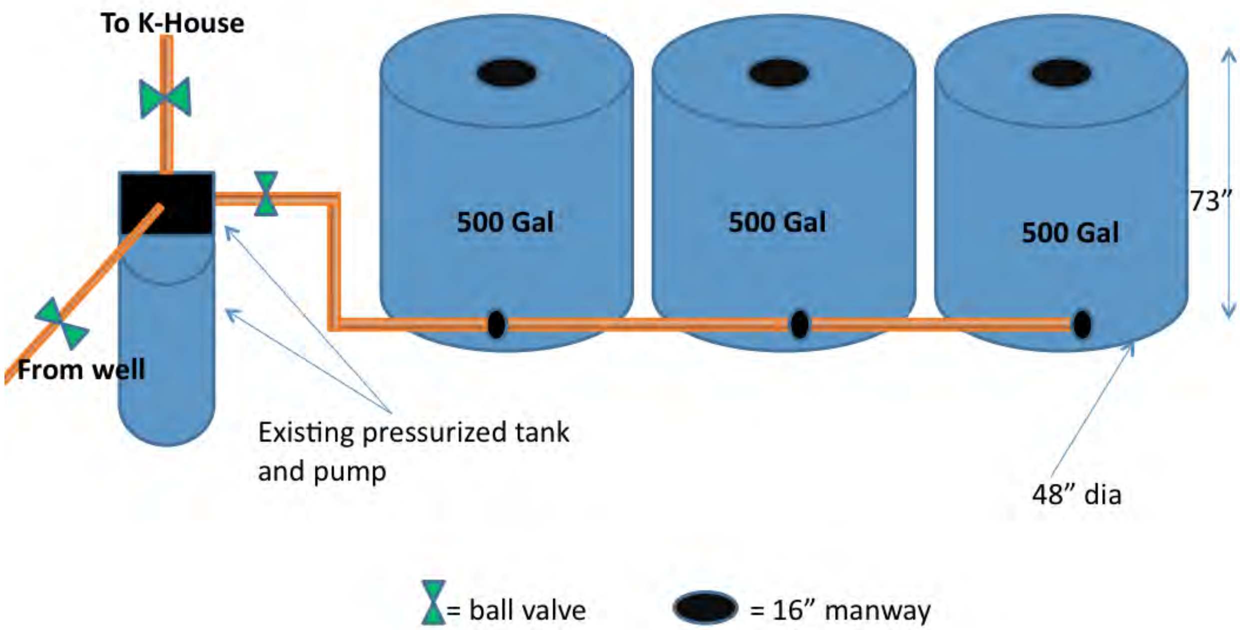

Figure 2: Recommended Cistern Design (Indoor)

This design is also preferred due to the data collected this year concerning Assignment 8, determining the freshwater usage in K-House and Bartels. After monitoring the water usage versus population data for the month the interns were on Appledore, it was found that the average daily usage per capita was 8 g/p/d, with a maximum of 18 g/p/d. Although this is much lower than the 22 g/p/d used in the analysis of this project, it should be noted that because it is the summer, the residents of K-House regularly use water at other locations on the island. It would be expected that daily per capita use of freshwater at K-House would increase during the off-season when it is the only place residents can eat, cook, wash, shower, and use the bathroom. Assuming that this usage will be 15 g/p/d, a new tank size would be required. Using this assumption with the desired occupancy of five people for 14 days yields a tank size of 1050 gallons. Thankfully, the recommended Design 2 can be modified to satisfy this need by simply taking away one of the three 500 gallon tanks. This modification then changes the total cost of Design 2 to $3,059. However, because of the small sample size used to determine this new daily usage rate of 8 g/p/d, it is recommended to still use the 22 g/p/d as this can be satisfied for $3,444, a $385 difference. Assuming occupancy of 5 people, using Design 2 will allow for a reliable source of freshwater for 14 days if the usage is 22 g/p/d, yet if the usage is closer to 10 g/p/d, as recorded this summer, it will allow for a stay of 30 days.

Although beyond the scope of this project, the drilling of a second freshwater well near K-House should also be considered. This would allow for a reliable source of freshwater during the off-season while also helping to increase the freshwater supply of the island during the regular season.

2.9 References

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3 Population of Green Grid Data into the GIS System

3.1 Introduction

Deliverable: *The interns will collect location and equipment data specific to the existing green energy system and enter it into the database. Additionally, interns will update the GIS system to include SML's energy conservation building currently under construction.* – Engineering Staff

3.2 Purpose

Over the years of SML operation, all of the existing island systems, except for the Green Grid, have been added into the GIS. The engineering interns were asked to collect location and fixed equipment data of the existing green energy system and enter it into the database. Additionally, interns will update the GIS system to include SML's energy conservation building currently under construction. This will ultimately act as a useful operations and planning tool for island engineers and managers.

3.3 Scope

The scope of this project includes entering location and specific information on the current and new green grids into the GIS.

3.4 Background

The existing systems on Appledore Island including fresh water, saltwater and electric are mapped out on a Geographical Information System (GIS). This software allows one to gain specific information of the physical layout of the systems in place on the island. Lines, points and polygons representing real physical systems (electrical, freshwater, etc.) can be superimposed onto a satellite picture of the island.

3.5 Objectives

1. Update the current GIS to include the existing and new Green Grid features including electrical lines and fixed electrical equipment.

3.6 Methods

First the interns needed to learn how to operate the GIS system which is why Shawn Herrick, who is a GIS expert from UNH, came to the isalnd to instruct the interns. He traveled to Appledore Island Wednesday, June 19th to teach the interns basic features of the GIS and aid with their data collection. He brought GPS and surveying equipment in order to acquire information (locations, features, dimensions, etc.) on existing outdoor electric lines and important components of the existing Green Grid. This information was imported into the current GIS. In order to analyze this data further, specific line voltages, current types, and significant features, as well as electrical components (transformers, distribution panels, disconnects, battery bank, inverters, charge controllers, etc.) located in buildings were added into the system. The Energy Conservation Building and approximate outlines of the new ground arrays were added to the system.

3.7 Results

It should be noted that the most current version of the GIS is saved on the engineering laptop as "SEI 2013." Existing Green Grid (**Figure 3**).

Figure 3: Radar Tower schematic of existing green grid. Note that the green lines and points represent the existing green grid electrical lines and electrical equipment, respectively. The red lines and points represent the dirty grid electrical lines and equipment.

Past GIS students incorrectly or vaguely mapped many of the existing Green Grid features. Each electric line and component was looked at and the problems were fixed and updated. The interns used the one-line electrical schematics of both the Green Grid and Dirty Grid system to map out a clear flow pattern of electricity and the various electrical points in the system. The updated schematic does not have points within the Radar Tower (battery bank, inverters, charge controllers, etc.) in the exact physical location, but rather in a clear and simple directional pattern. Each electrical point (component) has specific information and notes under its attributes table to make for easier identification of each feature.

With the new, updated Radar Tower, the parts associated with the wind turbine were removed, as they will be replaced in the Energy Conservation Building. See **Figure 4** below.

Figure 4: Energy Conservation Building (ECB) schematic of the new green grid. Note that the green lines and red points represent the new green grids electric lines and components, respectively.

Although the new Energy Conservation Building (ECB) is built, none of the electrical system is installed. The one-line schematic of the system was available to use in updating the GIS for the

ECB. The GIS has been updated with the electrical system within the building as well as the exterior Photo Voltaic array areas that are being constructed east of the building.

3.8 Recommendations

While much work was done on updating the GIS system during the 2013 internship, some errors still remain. It is recommended that future interns work to correct these errors and continue updating the system with new island developments, such as the Energy Conservation Building qnd adding pictures to each component. It is also recommended that Shawn Herrick be contacted to teach Ross Hansen and Mike Rosen how to use GIS. Assitionally, SML should look into purchasing Shawn Herricks old equipment as they are in the process of updating and will no longer need it. It should cost around $2,000.

4 Hand Dryers or Paper Towels

4.1 Introduction

Deliverable: *The interns will investigate the available hand dryers and their operating characteristics including, electric load, air velocity, ease of use, and cost. They will recommend to SML if they should go with electric blowers and which one or stay with the paper towels.*

–Engineering Staff

4.2 Purpose

Kiggins Commons, which houses the kitchen, dining room, and new Water Conservation Building, has two composting toilet bathrooms. Initially the issue of hand drying methods was raised after faculty members noticed paper waste overflowing in these bathrooms in the hand washing station. Although this was a sanitary and aesthetic issue that could be fixed, the engineering team saw past the trash and wanted to know if there was a more cost effective or more sustainable method of drying hands in these high traffic bathrooms.

4.3 Scope

This project evaluates several methods of hand drying including the existing paper towels, Cotton Roll Towel cabinets, and four individual types of air hand dryers. The team has decided to exclude the analysis of presenting the option of not providing hand drying because of the sanitation issue of kitchen staff using the bathrooms. Options are evaluated based on their projected five and ten year cost, effectiveness, sustainability, ability to be composted, and ease of use.

4.4 Background

Previous life cycle assessments (LCA's) have been completed to assess the sustainability and effectiveness of hand drying methods. LCA's evaluate the full lifespan of the desired method, in this case method of drying hands, with respect to desired parameters. The interns used a study called *Life Cycle Assessment of Hand Drying Systems*, prepared be the Material Systems Lab at MIT, to look into the sustainability of their selected options. Additionally, a case study by Excel Dryers was used in evaluating the effectiveness of hand dryers.

4.5 Objectives

1. Recommend the best option of hand drying for Shoals Marine Lab's Water Conservation Building.
2. Provide a qualitative and quantitative analysis of how this recommendation was decided upon.

4.6 Methods

Preliminary research was conducted to determine which hand drying options to pursue. This research included Internet research of the various options, which produced a range of blower dryers to choose from and the Darman Cotton Roll Towels (CRT), which is a less common option. The preliminary research also found a popular MIT life cycle analysis of methods of drying hands that has been used as a reference.

The four hand dryers selected for analysis were the Dyson Airblade, Xcel Dryer Inc. Xcelerator, Toto Clean dry electric hand dryer, and a Standard Air dryer. To calculate the cost of the hand dryers, the dry times and wattage per use were recorded from specs list, and the initial values were found online. To add to the energy and initial cost, a standard cost of $500 for installation was estimated for a technician's half day of work. In estimating the energy cost, an estimate of the number of dryer uses a year was needed. This estimate was achieved by looking at past engineering intern reports (2006 and 2009) which had collected flush data for the Kiggens Commons bathrooms. This flush data was then compared to the daily population to get a daily Kiggens flushes per capita of 0.82 (See Assignment 4 Appendix, "Flush Data" for calculations). Using this value in combination with the 2013 population data, actual and estimated (from 7/8-9/1/13), the total flushes per season was found to be 5,679. This number was assumed to be the number of uses per year for all hand drying options. Past records of bathroom use were used to estimate an average yearly number of uses.

To estimate the costs associated with Cotton Towel Rolls, Darman Manufacturing Company was contacted for a price quote on two cabinets as well as cost per reusable roll. This was taken as a typical price quote for the industry. Installation costing was assumed to be minimal, as they do not require specialists to set up. The more arbitrarily defined aspect of costing was washing and reusing the rolls. Usually these systems are used in large company settings where there are industrial washers and machines specifically designed to recycle the towel roll. For Shoals, however, this would not be feasible. Work interns were presumed to work on washing and then re-wrapping the roll, a process (very roughly) estimated at two total hours.

In assessing the current paper towel option, initial cost of the dispensers was ignored. The current dispensers are a sunken cost. After talking with Charlotte about the cost and quantity of towels purchased a year, the interns decided that looking more in depth as to the amount of towels used was needed. This led to the aforementioned calculation of uses per year. Concerning paper towels, it was assumed that for each "use" one person used two paper towels, making the number of paper towels used per year twice that of the flushes per year, 11,357 (2 x 5,679). With the cost per box, number of uses per box, and number of uses per year a cost per year could be calculated.

After the research was conducted as to the cost of the various options, parameters of sustainability, effectiveness, ease of use, and compostability were investigated.

When looking at the sustainability of each option, the *Life Cycle Assessment of Hand Drying Systems* was used, taking into account how our options differed from the studies' in use patterns. The two main differences related to CRT's and Hand dryers. CRT's were much less practical on

Appledore Island than in the study because washing, drying, and rewrapping the rolls for every reuse on Appledore would require an individual washer/dryer cycle and hand folding. In industrial settings, many rolls are being washed together, and machines are doing all of the work to recycle the rolls. The industrial setting makes for an efficient reuse cycle of CRT's, whereas the small setting of Appledore does not.

Hand dryers in larger company settings where they receive a high volume of uses consistently throughout the year are considered the ideal choice in hand drying methods. On Appledore Island, they're less sustainable because the projected use is approximately 5,700 drys per season. Thus, both CRT's and Hand Dryers should be considered relatively less sustainable on Appledore Island, with respect to paper towels, than on the mainland.

4.7 Results

4.7.1 Cost

Research into the pricing and energy usage of the four investigated hand dryers yielded the data shown in **Table 11**. The assumed cost per kilo-Watt-hour (kWh) is also given as 54 cents. 54 cents was calculated by previous interns as a standard for Appledore Island. The kWh cost is high because of the added cost of supplying electricity through the island generators and green grid versus the industrial scale utility companies on the mainland. The initial cost included two units, one each for the male and female bathrooms.

Table 11: Cost and Energy Usage Comparison

	Standard Air	Xcelerator	Airblade	Toto Electric
Initial Cost ($)	600	1,000	2,400	700
Install Cost ($)	500	500	500	500
Energy use (W)	2300	1500	1400	510
Time of Cycle (s)	31	15	12	12
Cost per kWh ($)	0.54	0.54	0.54	0.54

The issue with a standard cost calculation for the hand dryers is that each has a warrantee between one and five years but they're projected to last much longer than that based off the number of uses expected. To account for this, each dryer was said to last between 5 and 10 years. The choice was a judgment call. The Toto brand's warrantee is only one year, but under low use we assumed it could last for another four to nine years. The Dyson Airblade is rated for 350,000 uses which would last on Appledore Island for upwards of 60 years but there is no guarantee the Airblade will not malfunction much sooner.

The calculations for paper towels included the price of a box of twelve paper towel rolls and the minimal maintenance required to change the rolls in the towel cabinet once they've run out. Cotton Roll Towels generally are used in an industrial setting with industrial washers, dryers, and re-folding instruments. For use on Appledore Island, the process of reusing the towel rolls incorporated a wash of laundry and two hours of intern work to wash, dry, and refold the rolls.

To calculate the yearly, five year, and ten year cost projections a yearly estimate of 5,700 hand dryer and CRT uses and approximately 11,400 paper towel uses (two paper towels per use) was assumed. This number was taken from past interns who calculated the average bathroom use and extrapolated for a season. With this number, the cost analysis was completed, as shown in **Table 12** below. These calculations are supported by an Excel document in the *Assignment 4 Appendix*.

Table 12: Complete Cost Analysis. *Does not include initial and installation costs.

Hand Dryers	Standard	Xcelerator	Airblade	Toto
Initial Cost	600.00	1000.00	2400.00	700.00
Install Cost	500.00	500.00	500.00	500.00
Energy Costing				
Energy use (w)	2300.00	1500.00	1400.00	510.00
Time Cycle	31.00	15.00	12.00	12.00
Number uses	5700	5700	5700	5701
ws/year	4.06E+08	1.28E+08	9.58E+07	3.49E+07
5Yr wh	564.46	178.13	133.00	48.46
10 yr kh	1128.92	356.25	266.00	96.92
Cost/kwh	0.54	0.54	0.54	0.54
5 year energy cost	304.81	96.19	71.82	26.17
10 yr energy cost	609.62	192.38	143.64	52.34
Total Costing				
Cost per year* ($)	60.96	19.24	14.36	5.23
5 yr cost ($)	**$1,404.81**	**$1,596.19**	**$2,971.82**	**$1,226.17**
10 yr cost ($)	**$1,709.62**	**$1,692.38**	**$3,043.64**	**$1,252.34**

	Paper Towels	Cotton Roll Towel
Initial Cost	0.00	211.98
<u>Towel Costing</u>		
Cost per Box,Roll	30.00	20.00
Use per Box	5040.00	20000.00
Use per year	11400.00	5750.00
<u>Maintenance Costing</u>		
Maintain (min)	2.00	3450.00
cost per hour ($)	8.00	8.00
Cost per roll ($)	0.27	N/A
Cost per Wash ($)		2.00
Maintain year ($)	7.30	575.00
<u>Total Costing</u>		
Cost per year*	75.75	580.75
5 yr Cost	**$378.77**	**$3,115.73**
10 yr Cost	**$757.54**	**$6,019.48**

The final two rows for each option list the five and ten year cost projections. Paper Towels were the cheapest option at each interval. The Toto dryer was the second cheapest option, and the cheapest of the hand dryers. The Xcelerator and Standard Air were the third and fourth cheapest, and were assumed to be ranked at the same price because their ten-year projections were very similar. The most expensive option was calculated to be Cotton Roll Towels. This was because of the issues with washing and drying the rolls.

4.7.2 Sustainability

Since the actual work involved in calculating the sustainability, or global warming potential, of the various options would require an extensive amount of work, the *Life Cycle Assessment of Hand Drying Systems* study was used as a standard of comparison. From this study, the hand dryers were ranked from most sustainable to least sustainable as follows: Dyson Airblade, Xcel Xcelerator, Toto Electric Dryer, and Standard Air. The Airblade, Xcelerator, and Electric Dryer all feature modern technology which is proven to be much more efficient and hold shorter dry cycles. For Appledore, these three were ranked in order as the top three sustainable options. The next most sustainable option was paper towels. From the study, this would have been CRT but due to the lack of industrial washers and dryers this method becomes the least sustainable as small loads of wash would need to be done for every 200 towel uses. Standard air dryers were ranked between paper towels and CRT for this reason, whereas they are generally the least sustainable on larger use scales.

4.7.3 Effectiveness

In evaluating effectiveness of hand drying methods it’s important to note that the majority of cleaning and disinfection is done during the hand washing with soap. The purpose of drying hands afterwards is to complete that process by making sure any leftover bacteria cannot easily spread through the wet surfaces of your hand. This is why the overall effectiveness of hand drying isn't as important as hand washing, and its effectiveness is correlated to removing excess water.

According to the National Sanitation Foundation (NSF) the Dyson Airblade is the only hand dryer that fulfills the NSF Protocol P335, which is a high standard of hygiene among hand dryers. The Toto Electric Dryer research did not give many results other than to say that the ADA approved of their design. The Xcel Dryer website supported the fact that the rapid heated air dryers are the most effective and in particular presented a case study as to the effectiveness of their Xcelerator. This argument partially has to do with the fact that people tend to only spend 15 seconds drying their hand, so lower speed dryers don't end up fully drying the user's hands. Cotton Roll Towels and Paper Towels are said to be the most effective at removing bacteria from user's hands.

The interns found many articles on towels versus dryers with respect to the effectiveness of removing bacteria and the articles argued for both sides. This amount of contradictory literature makes the decision on effectiveness difficult. Most scientists agree however that removing the moisture on one's hands is the best way to reduce the spread of bacteria, and paper towels and cotton roll towels in this case take less than 15 seconds to dry hands. Thus Paper Towels and CRT's were ranked the most effective, followed by the Airblade, the Xcelerator tied with the Toto dryer, and finally the Standard Air dryer which was much less effective based on length of drying period.

4.7.4 Compostablity

The only method that leads to compostable material was paper towels. All other options were ranked equally. It should be noted that after talking to Mike Rosen it was assumed that if SML were to replace the current paper towel system with another option, an additional barrel of hay would have to be purchased each year. A barrel of hay costs $5 so this cost is minimal.

4.7.5 Ease of Use

After examining the methods and discussing the parameter "ease of use" the interns decided that the significance of this parameter was very small because all options were very similar. The most important factor in ease of use is the time it takes to dry ones hands, or how long a user is willing to spend trying to do so. In the case of a standard air dryer, one would use the same amount of time drying hands as a rapid air dryer. The difference would be that their hands aren't fully dry after the 15 seconds spent on average drying, as a result this impacts the effectiveness of the method. When drying takes less than 15 to 20 seconds, all methods are considered to have the same ease of use.

4.8 Analysis

The parameters investigated in section 2.2 Results present the order of option competitiveness for each parameter. To evaluate each option while considering all options, decision matrices are a valuable tool. To do this, each parameter must be weighted such that is importance with relation to the other parameters is established. See the explanation regarding the weight of the parameters below in **Table 13**.

Table 13: Explanation of Parameter Weights

	Weight	**Explanation of Weighting**
Cost	0.5	Very important because the options are relatively similar with respect to other categories, and adding unnecessary costs should be avoided.
Composting	0.05	5% of the weight. The paper towels do get composted, but the cost trade off for switching to hay is low ($5/yr), and the composting is not very effective currently.
Sustainability	0.15	Considering the lifecycle of these options, we weighted sustainability with respect to global warming potential (GWP) at 15%. This is because they're not in extremely high use so the magnitude of GWP will be low.
Effectiveness	0.3	Located near the kitchen, the ability of these options to effectively further reduce the bacteria during drying is important. Effectiveness received the second highest ranking of 30%.
Ease of Use	0	Although considering the user is important, in this case the options are similar in this category, and the island is more concerned with other factors.

With the weighting established, the comparisons between options within a parameter are presented in a table. Within each row, a rank between one and six is given to each method, with six being the most competitive option. The final column of this table is the sum of all the rankings. Since not all parameters had rankings 1 through 6, this column is used to standardize this issue. By dividing every ranking by the sum of the rankings for that column, each parameter will not start out with more value than another parameter before weighting is added. See **Table 14** below.

Table 14: Ranking of Options

	Weight	Standard	Toto	Xcelerator	Airblade	Paper Towels	Cotton Roll T	Total
Cost	0.5	4	5	4	3	6	1	23
Composting	0.05	1	1	1	1	6	1	11
Sustainability	0.15	2	6	4	5	3	1	21
Effectiveness	0.3	1	4	4	5	6	6	26
Ease of Use	0	0	0	0	0	0	0	0

Finally, to calculate the weighted value of each option, the ranking in each cell is multiplied by the weight of that parameter and divided by the total for that parameter. The weighted value is the sum of all the weighted values for an option. Note that summing up every cell in the matrix will add up to one.

Table 15: Calculating the Weighted Values

Sample Calculation: Paper Towel Cost = (Ranking: 6) / (Total: 23) * (Weight: 0.5) = 0.130

	Weight	Standard	Toto	Xcelerator	Airblade	**Paper Towel**	Cotton Roll T
Cost	0.5	0.087	0.109	0.087	0.065	**0.130**	0.022
Composting	0.05	0.005	0.005	0.005	0.005	0.027	0.005
Sustainability	0.15	0.014	0.043	0.029	0.036	0.021	0.007
Effectiveness	0.3	0.012	0.046	0.046	0.058	0.069	0.069
Ease of Use	0	0	0	0	0	0	0
Total	**1**	**0.117**	**0.202**	**0.166**	**0.163**	**0.248**	**0.103**

Once the Decision Matrix is complete, the most competitive option is the option with the highest "Total" value. The winning option is Paper Towels.

This end result is not entirely unexpected. For one, Paper Towels are a standard method of drying hands because they're cheap and effective. Generally when high-tech hand dryers are selected for new building use they're done so at the discretion of the architect because "the health impacts of various hand-drying methods are poorly understood" (Dyson, Inc). In many cases, hand dryers may be the proper solution Appledore Island presents a unique case in that the amount of uses per week and per year is very low. If these drying machines were built with a longer warrantee, and the companies could assure a lifespan of 30 years then Paper Towels would no longer be the best option.

4.9 Recommendation

After evaluating the options presented, the interns advise to continue using paper towel rolls. From a cost and effectiveness perspective, Paper Towels are the superior choice. The interns wish to note that this study was evaluated with the recycled brown paper towels, which work well in the dispensers, and may not hold true if the brand of paper towels purchased is changed.

4.10 References

Darman Manufacturing Company. (n.d.). DriGiene Cotton Roll Towels. Retrieved June 28, 2013, from http://www.darmanco.com/DriGiene.asp

Dyson Inc. (n.d.). Sustainable Hand Drying and Life-Cycle Assessment. Retrieved June 28, 2013, from http://continuingeducation.construction.com/crs.php?L=159&C=925

MIT Material Systems Lab. (n.d.). Life Cycle Assessment of Hand Drying Systems. Retrieved June 28, 2013, from http://msl.mit.edu/publications/HandDryingLCA-Report.pdf

5 Fire Suppression Evaluation

5.1 Introduction

Deliverable: *The interns will review the State of Maine requirements for fire protection, document the present fire protection for the student sleeping areas, and investigate possible improvements that won't require water.* –Engineering Staff

5.2 Purpose

The Shoals staff wants to know how to improve the safety of the students sleeping areas as well as what Maine and Cornell University expect of them. This initiative, evaluating the potential to upgrade residential fire safety, is in response to the Administration at Cornell University's push to "have a sprinkler above every bed."

5.3 Scope

This project pertains to the fire safety of sleeping areas for faculty, staff, students and researchers. The project involves investigating current safety laws, the fire safety of Appledore, and the feasibility of future fire suppression system additions. The fire safety systems should consider the scarcity of freshwater on the island.

5.4 Background

Ross Hansen contacts the Fire Marshal in Kittery every year with Appledore fire safety information.

If Shoals Marine Lab (SML) elects to install a sprinkler system, the sprinkler system standards pertinent to SML are NFPA 13 D Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes, NFPA 13 R Standard for the Installation of Sprinkler Systems in Low-Rise Residential Occupancies, and NFPA 13 Standard for Installation of Sprinkler Systems.

5.5 Objectives

1. Examine the current State of Maine, Cornell University, and University of New Hampshire fire safety protocol.
2. Document the current fire protection for sleeping areas.
3. Investigate possible improvements to sleeping area fire safety via the addition of a sprinkler system.

5.6 Methods

5.6.1 Contacts

The following people were contacted to gain insight into the laws Shoals Marine Lab is subject to and potential suppression systems available. Their contact information is listed in the 2013

Appendix, under Assignment 5 Appendix.

Ronald Flynn, Cornell University Fire Marshall, and Jim Gibbs, Cornell University's Director of Facilities, were contacted through email to inquire about the Cornell University fire safety codes.

Sean Toomey, University of New Hampshire alumni and fire protection engineer, was contacted via email and phone for insight about possible fire suppression systems specific to Appledore Island's needs.

Marshal Frye, Star Island Engineering Technician, was contacted by Ross Hansen to set up a tour of Star Island's facilities and more specifically the hotel fire suppression system.

Eric Schneider, Hog Island Facilities Coordinator, was contacted by phone to inquire of the fire systems on Hog Island. Since Hog Island is in the State of Maine, any state protocol they must abide by also applies to Appledore Island. John McBride, ex-Island Coordinator of Hurricane, was also contacted and he suggested calling Eastern Fire Protection about sprinkler systems. John McBride had previously worked with an island building containing a wet pipe sprinkler system.

Sam Halloway, facilities coordinator at Hurricane Island, was contacted through phone to investigate the current suppression systems in place.

Frank P. Welch of Eastern Fire Protection (EFP) was contacted to investigate low flow systems and retrofit work (adding sprinkler system to existing buildings) for the EFP contractors. Mr. Welch also reached out to Eric Ellis, a State of Maine fire marshal, about which bracket of codes Founders falls within.

David Emanuel and John Powers, Captain and Deputy Chief of Protection for the Durham Fire Department respectively, were contacted to discuss the University of New Hampshire sprinkler systems.

5.6.2 Research

The State of Maine fire safety website was searched for applicable material. The National Fire Protection Association (NFPA) website was searched and a fire safety manual read through for national codes. The Cornell University fire code was also investigated and thus the State of New York code was searched because Cornell follows the New York State's fire regulations.

5.6.3 Current Fire Safety Review

The interns walked through Founders Hall, Grass Lab, Bartels Hall, Dorms 1, 2, and 3, and the Kingsbury House to mark down the existing alarms, detectors, extinguishers, fire hoses, exit signs, and fire escapes. The interns also talked with Ross Hansen about the current system as well as the prevention methods he addresses in the Fire and Water speech and in the Appledore Island Handbook.

5.7 Results

Documentation of the current safety measures is located in the Assignment 5 Appendix: *Current SML Fire Safety*.

According to Jim Gibbs and Ron Flynn, the state and local laws followed by Cornell University do not pertain to Shoals Marine Lab. The island must, however, follow the NFPA rules as well as the State of Maine laws. For a sprinkler system, SML would have to follow either 13D or 13R at the discretion of the Maine State Fire Marshal's Office. The State of Maine laws for Appledore Island require safety measures that are already in place: fire detectors, alarms, and extinguishers. Additionally from Mr. Gibbs, Cornell University has decided to go beyond the laws by ensuring a sprinkler above every bed for their students on campus. This rule is not a requirement for Shoals Marine Lab but the feasibility of putting in a sprinkler above every bed on Appledore Island is being investigated.

David Emanuel and John Powers stated that the University of New Hampshire campus has gone above the minimum requirements for fire safety by requiring all residential dorms to have an NFPA 13 sprinkler system. NFPA 13 is the top of the line system. NFPA 13 covers the entire building, and although it does not mandate a "sprinkler above every bed" the coverage is similar to what Cornell University requires. Additionally, it should be noted that complete coverage of a room can be achieved with one sprinkler head as long as the sprinkler head is properly rated to the size of the room (Viking Technical Data, 3). It is expected that having a sprinkler in each room would satisfy Cornell's forthcoming requirement.

From discussions with Sean Toomey, suppression systems involving chemicals or foam have been ruled out because they're not typically used in residential areas around humans. The hope with these systems was to avoid the issue of freshwater usage in the sprinkler system because it is a limited resource on the island. Mr. Toomey also suggested that brackish grey water could be used in the sprinkler system as it is on Star Island. Star Island uses water, at a salinity level of 35,000 ppm, collected from roof run-off that is stored in a large cistern. According to Mr. Toomey, systems using brackish water would need plastic or galvanized piping. Because of the distance each of SML's residential buildings are from each other, Mr. Toomey recommended installing an individual sprinkler system for each building. Mr. Toomey suggested a 300-gallon water tank and a two or higher horsepower pump for each building's sprinkler system.

After discussing the potential for low flow systems with Frank Welch, it became clear that a low flow system is not a commonly used term with EFP. Mr. Welch suggested that Appledore Island could be protected by a system hydraulically calculated to supply two heads for the desired flow rate and flow time rather than calculate water for the full system that could have upwards of 40 heads. This is the standard under 13D NFPA codes for a one to two family home (K-House, Dorms and Bartels). In this system sprinkler heads would be distributed around the house but, assuming the whole house does not light on fire simultaneously, only two sprinklers need the water supply for enough time for people to exit the building safely. This water demand would be two sprinkler heads at 26 gpm for 10 minutes. This system would also require a 300-gallon tank and a two-horsepower pump, according to Mr. Welch.

With any sprinkler design, the winterizing of the system and potential for roof run-off storage water should be considered.

5.8 Analysis

The current fire safety for Appledore Island is in line with the code requirements from Cornell University, the State of Maine, and the NFPA. These requirements include the detectors, fire alarms, extinguishers, and fire escapes that every residential building has. Shoals Marine Lab has done an excellent job of keeping up to date with this current system. However, the administrative push from Cornell to install a "sprinkler above every bed," goes beyond the regulations listed in Cornell's code. Yet this expected push would require SML upgrade to a sprinkler system to meet Cornell's new, administrative-driven requirements.

If Shoals Marine Lab wishes to upgrade their fire safety the best option to do so would be with sprinkler systems. The sprinkler system upgrade would involve finding a contractor to design the system for the desired buildings. Eastern Fire Protection is a company located in Maine that does the retrofit work that would be required. The details of the sprinkler system are roughly outlined in the Results section, from conversations with Frank Welch and Sean Toomey. The state of Maine Fire Marshal's Office would need to be contacted for permitting and to determine which sprinkler standard - NFPA 13, 13R or 13D - to install.

5.9 Recommendation

The current fire safety of sleeping areas was documented and the current national and state fire safety laws were examined. Shoals Marine Lab is in accordance with the law. If a sprinkler system is to be installed in the future, a contracting company, such as Eastern Fire Protection, and Eric Ellis, a State of Maine Fire Marshall, should be contacted. Freshwater systems were recommended by both Sean Toomey and Frank Welch, although it is also recommended that SML look into salt water systems if corrosion in pipes, pumps, etc. can be avoided.

The CEO of Star Island was interested in future collaboration, or at least discussing Appledore fire safety.

5.10 References

"Viking Technical Data: Sprinkler Heads." *Viking*. The Viking Corportation, n.d. Web. 1 July 2013. <http://www.vikinggroupinc.com/databook/sprinklers/residential/082411.pdf>.

6 Increase the Freshwater Supply

6.1 Introduction

Deliverable: *The interns will look for ways to capture fresh water during heavy rain events and get it to the well's watershed.* –Engineering Staff

6.2 Situation of Deliverable

The fresh water supply of Appledore Island is a 20-foot dug well. Later in the summer season, if there is a shortage in rainfall or excess in water use, the well is drawn lower than is considered safe. Once this happens, the Reverse Osmosis (RO) machine needs to be turned on. The island's Facility Managers want to avoid turning on the RO machine because it is costly and time consuming. To avoid turning on the RO machine, fresh water can be captured and transported to the well's watershed to replenish the height of the well.

6.3 Scope

This project evaluates methods of obtaining freshwater to supplement the 20-foot dug well during the dry season. One such method explored was roof and surface run-off catchment. The watershed hydrology was examined to assess whether the collected water distributed around the well would be sufficiently filtered by the soil before entering the well aquifer.

Other methods explored to increase the freshwater supply included drilling another well or drawing the current well to a lower depth, which was previously considered unsafe. These inquiries required testing the water column and investigating the island for feasible aquifers.

6.4 Background

The aforementioned 20-foot dug well water is pumped to a cistern, chlorinated, and then stored in a pressurized tank that supplies enough pressure for water distribution throughout the island. Freshwater is served to all toilets, showers, and sinks on Appledore. In the past few years, the well water level was maintained above ten feet, even through the end of the season when rainfall events are less frequent. However, during especially dry seasons, the water level falls below this ten foot mark and the island engineers are forced to run the RO machine that forces pressurized salt water through a desalinating membrane. The treated effluent is then directed to the cistern for island use. The RO runs on a 65 kW generator that consumes a large amount of diesel fuel.

Other freshwater options have been explored in the past. The 2009 Sustainable Engineering Interns evaluated the Bartels roof for rainwater run-off that could be used to flush the toilets in Bartels. They also began to explore using Crystal Lake, a 60,000 ft^3 rain-fed pond on the southern end of Appledore, as a source for flushing toilets throughout the island. The rainwater or Crystal Lake water would be fed through the old saltwater pipe system that crosses the freshwater line. As such, the Island Engineers are concerned with cross-contamination of the fresh and greywater lines, and the recommendation was never implemented.

More recent interns have evaluated processing Crystal Lake water to use as a drinking water source. The result of this test was that the water could be cleaned to a nearly safe level of turbidity (~3 NTU); however, the time required to make the system operational each season was beyond that which the head engineer was willing to spend.

Due to the variety of freshwater sources explored, background information regarding federal standards and regulations for drinking water is described in the relevant sections.

6.5 Objectives

1. Evaluate and present ways to capture fresh water during heavy rain events and deliver it to the well's watershed.
2. Investigate the groundwater hydrology surrounding the well to determine the watershed and filtering capacity.
3. Determine the total well capacity and proximity to saltwater.
4. Determine other feasible locations on Appledore Island for well placement.

6.6 Freshwater Source Research

The interns held a brainstorm session on the freshwater alternatives. During this session, it was determined that focus would be placed on finding a location for an alternate well, capturing roof and surface run-off, and investigating the hydrology of the area around the well to determine if the well could be pumped lower than ten feet. In recent years, the island has practiced greater water conservation, and the RO machine has not been needed. However, during an especially dry season, a need may arise for the extra source of freshwater. Additionally, if there were a sustainable way to increase the fresh water, the current conservation restrictions regarding freshwater use could be lightened.

According to historical data from 1995-2012 regarding RO usage, if the alternative freshwater source were to replace the RO machine, it would need to provide an average of about 82,500 gallons per season (from May-August, a period of about four months). This was calculated by taking the average of the yearly freshwater generated by the RO in the years that it was turned on. See the Appendix for RO usage history.

6.7 Runoff Data Collection

6.7.1 Methods

Water samples were taken from the Utility Building and Dive Shack roofs, as well as from various areas of significant surface run-off on the island. Some of these surface run-off areas included the footbridge by Central Pond, the rocks by the low-tide dock, and the road above K-House. The samples were taken after rainfall events by either collecting water from a surface flow or attaching a collection bucket to a roof to collect the water that normally runs to the ground. The samples were tested in the Grass Lab for turbidity, pH, and total dissolved solids

(TDS) and sent to the mainland for coliform testing by Eastern Analytical Inc.

An estimate for theoretical roof rainwater catchment was made for the Dive Shack and Utility Building roofs. These roofs were chosen for their proximity to the well's watershed and for the differences in roof material. The Utility Building roof has metal shingles, whereas the Dive Shack roof is covered in asphalt.

The flow rate of surface run-off near the footbridge was measured one day after it rained to evaluate it as a source for supplementing the well. Of all the surface run-off sources, this source is most feasible due to its proximity to the current 20-foot dug well's watershed.

6.7.2 Results and Analysis

The theoretical runoff for the Dive Shack and Utility Building was calculated based on the projected surface area of each building and the average summer precipitation data for Portsmouth, NH (Weather Source, 2005-2009). (Data for multiple years was not available for Appledore Island.) The Dive Shack roof area was calculated to be 883.89 ft^2. The runoff coefficient for an asphalt roof is .90, yielding 795.50 ft^2 as the usable roof area for collection. For the Utility Building, with its metal roof and runoff coefficient of .95, the usable roof area is 1967.85 ft^2. The mean summer precipitation, 4.28 inches/month, was calculated by averaging the May-August monthly rainfall data from 2008-2012. Multiplying the monthly summer rainfall by the usable roof area gives an estimate for seasonal runoff per month.

See **Table 16** below showing annual precipitation data in inches for Portsmouth, NH from 2008-2013.

Table 16: Portsmouth, NH Annual Precipitation Data

Year	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
2013	0.99	3.21	2.46	2.01	3.64	--	--	--	--	--	--	--
2012	2.97	1.1	2.22	3.28	3.53	7.37	1.69	1.55	--	--	--	--
2011	3.02	2.29	3.44	4.26	4.28	3.88	1.28	6.71	3.74	7.77	2.75	5.87
2010	2.36	5.48	14.03	1.85	3.01	2.91	3.2	5.48	1.74	4.06	4.49	3.4
2009	2.7	2.76	2.31	3.84	3.9	6.05	8.29	3.64	1.59	4.13	4.73	3.02
2008	3.02	6.98	5.38	3.46	1.32	5.64	8.86	2.6	9.3	2.26	3.4	4.35

The following equation was used to calculate monthly roof runoff for the summer months. See **Table 17** below for monthly collection data.

Table 17: Monthly Collection
Usable Roof Area × Average Monthly Summer Rainfall = Monthly Collection

	Projected Roof Area (ft²)	Roof Material	Runoff Coefficient	Usable Roof Area (ft²)	Average Monthly Rainfall (in.)	Monthly Collection (ft³)	Monthly Collection (gal.)
Dive Shack	883.89	Asphalt	.90	795.50	4.28	283.56	2121.20
Utility Building	2309.85	Metal	.95	1967.85	4.28	701.46	5247.26

Figure 5, **Figure 6**, and **Figure 7** below show the proposed cistern locations and gutter installations for the Utility Building and Dive Shack.

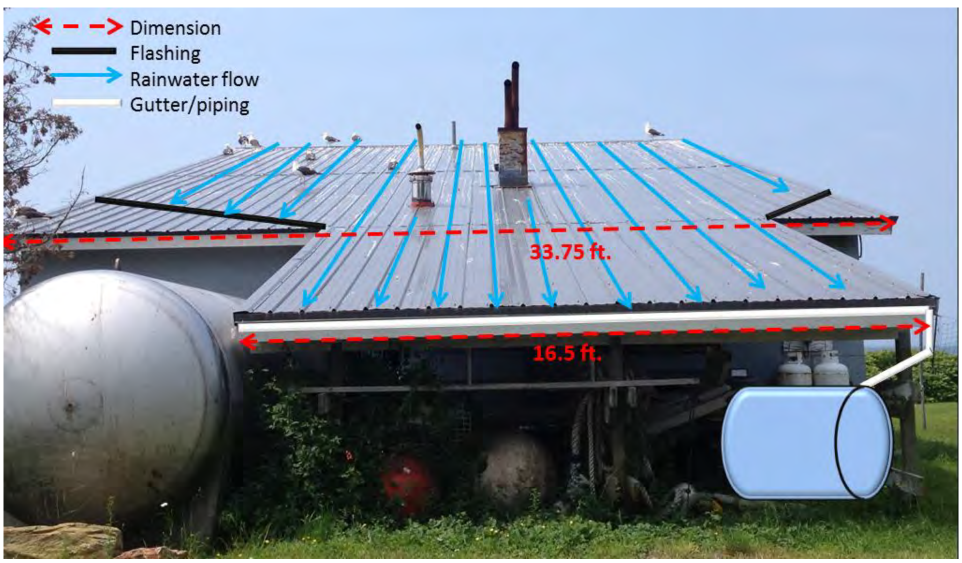

Figure 5: Utility Building with flashing and horizontal 500 gallon HDPE cistern for catchment and gutter system.

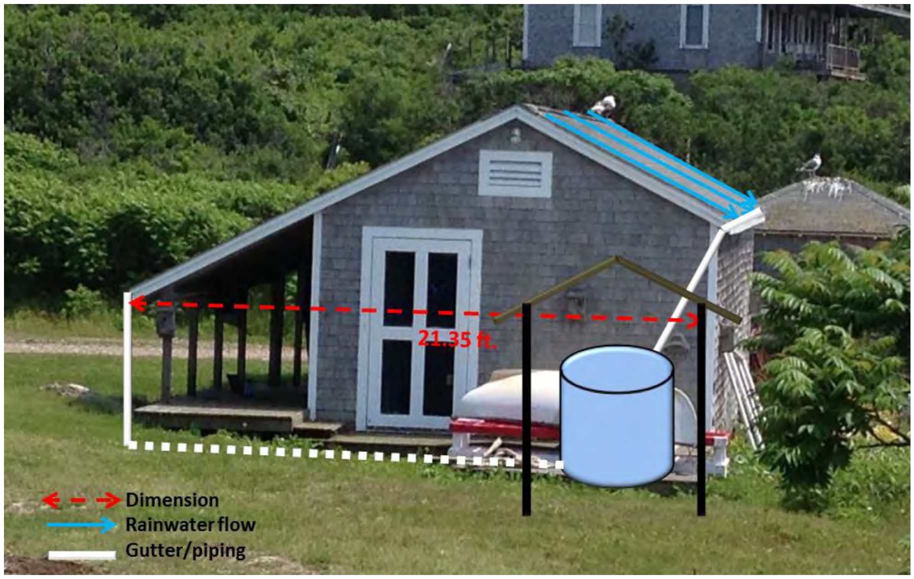

Figure 6: Side view of the Dive Shack, with a vertical 550 gallon HDPE cistern for catchment and a covering to protect it from the elements.

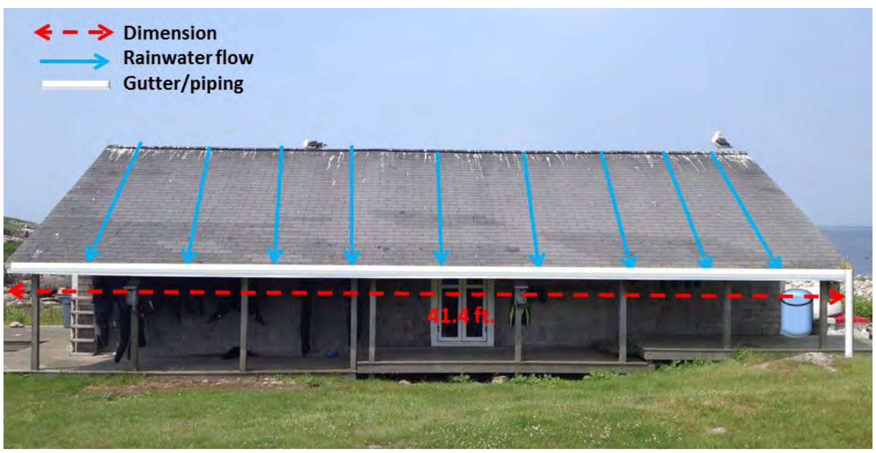

Figure 7: Front view of the Dive Shack, with a vertical 550 gallon HDPE cistern for catchment and a gutter system.

In order to capture the rainwater, a gutter system would need to be installed on either or both roofs. For the Dive Shack, the gutters would run along each edge and into a vertical 550 gallon high density poly-ethylene (HDPE) cistern, priced at $383 from the Ryan Herco Products Corporation website. Dr. Jim Malley suggested that a first flush diverter be considered, as it is probable that for about the first 10 minutes of the rain event, the majority of the gull guano will be washed off the roofs. In order to catch the cleanest water, the first "flush" of water would be wasted, either by filling up a capped pipe and then diverting the remaining flow to the cistern, or by a manual wasting valve. In addition, some form of cover should be designed and installed for the cistern to protect it from the elements. For the Utility Building, flashing would be installed on either side of the roof to divert the water to the central portion of the roof to be collected. This would cut down on the cost of installing gutters along the entire edge of the roof. A 500 gallon horizontal HDPE tank, priced at about $930 from *Usco-FW Webb Utilities Supply Co.'s* website, is suggested for the Utility Building, as HDPE is a durable material that will be able to withstand the temperature cycles during the summer season. During the winter, the cistern would be drained and left under the over-hang on the Utility Building for storage.

To avoid the cost of buying a cistern large enough to hold the monthly catchment, a smaller cistern could be installed at each building with a float valve that turns the pump on when the cistern fills to capacity. The 500 gallon cistern would hold the water temporarily and allow sediment to settle before pumping to the well to be dispersed in an infiltration gallery. The infiltration gallery would be similar to a leach field in that the rainwater would be diverted through buried perforated pipes throughout the watershed.

Water samples were taken from the roofs on June 18th and 24th. See **Table 18** showing the test results for pH, fecal coliforms, E.coli, turbidity, and total dissolved solids (TDS), below.

Table 18: Water Sample Test Results

***The flow rate of the Boardwalk runoff one day after it began to rain on June 19th was 1.39 gpm. Capturing that runoff and delivering it to the watershed over twenty-four hours would yield: $1.39\ \frac{gal}{min} \times \frac{1440\ min}{1\ day} = 2001.6\ gal.$ The surface run-off coliform levels were much higher than expected, and it is likely that natural soil filtration would not be enough to rid the water of these contaminants.**

	Date	Average Turbidity (NTU)	Total Coliforms (MPN/100mL)	E. Coli (MPN/100mL)	TDS (g/L)	pH
Utility Building	6/18	8.81	307.6	27.5	---	---
	6/24	15.75	---	---	0.076	6.20
Dive Shack	6/18	2.56	143	14.8	---	---
	6/24	4.01	---	---	.26	6.45
***Boardwalk Runoff**	6/24	3.22	≥1600	≥1600	.884	7.15
Southeast Runoff	6/18	---	>2419.6	117.8	---	---
Pathway	6/24	---	≥1600	≥1600	---	---
Low-tide Dock Rocks	6/24	---	≥1600	≥1600	---	---

The roof catchment samples showed a high level of fecal coliforms due to gulf activity on the roofs. The Dive Shack roof sample had a lower fecal coliform count than the Utility Building roof sample, 143 versus 307 MPN/100 mL, respectively. The Drinking Water Standard Maximum Contaminant Level Goal for total coliforms (including fecal and *E.coli*) is zero mg/L and the Maximum Contaminant Level is 5.0%. As taken from the EPA Drinking Water Standards website, the 5.0% denotes that no more than 5.0% of samples taken during a month's time can contain total coliform counts. For systems that collect less than forty samples each month, no more than one sample can be positive for total coliforms. While these levels exceed the national standard at the source, they are treatable through chlorination.

The samples collected from surface run-off showed much higher coliform levels than were expected (≥1600 MPN/100mL). It is likely that natural soil filtration would not be sufficient to rid the water of these contaminants, so another method of filtration must be implemented.

The National Secondary Drinking Water Standards, also found on the EPA's website, is a set of contaminant guidelines that are not enforceable, but suggested to lessen cosmetic or aesthetic effects in drinking water. Under these guidelines, the recommended TDS content is less than .5 g/L. The only sample that exceeds this recommendation is the Boardwalk Runoff sample. Furthermore, the secondary standards suggest a pH level of 6.5-8.5. The levels of the samples, shown in the table above, all meet this level with the exception of the Utility Building Roof sample taken on 6/24, which was slightly more acidic (pH=6.20).

6.8 Watershed Mapping

6.8.1 Methods

Using the Google Earth map of Appledore Island from 2003 to analyze the topography of Appledore, the main 20-foot dug well watershed was mapped out along with two additional alternate well watersheds. An accurate watershed area was needed for the 20-foot dug well in order to determine where to disperse the new freshwater source so that it may be naturally filtered by the soil and enter the well.

The two additional areas, depressions behind Palmer-Kinne Lab and Bartels Hall, are both off-trail, but could be made accessible by cutting away brush. Little is known about the hydrogeology of the island, so locating a well without more advanced instrumentation is difficult. A more precise tool is needed to analyze the soil composition in proposed well locations; if the areas contain a high level of bedrock, digging a well may prove to be infeasible.

6.8.2 Results and Analysis

In order to pump the collected freshwater sources to the main well's watershed for ground filtration, an accurate estimate of the watershed was necessary. Using the topography from the 2003 aerial view of Appledore on Google Earth, the watershed area was estimated. See the aerial photograph below in **Error! Reference source not found.** and the Assignment 6 Appendix for alternate watershed views.

Figure 8: Aerial view of the 20-foot dug well watershed on the northern part of the island. The greatest elevation gradient of the watershed is about 0.119 ranging from 36 feet above sea level to about 26. The total approximate area was calculated to be 61603.26 ft².

Another well on the southern side of the island would provide an additional source of fresh water to the island and eliminate the need to pump the water from the 20-foot dug well across large distances to buildings such as K-House and the Palmer-Kinne Lab. Two major depressions were found using the 2003 aerial view of Appledore on Google Earth, and the watershed for each was mapped out. The depression near Palmer-Kinne Lab was initially noticed by the Island Engineers, whereas the area behind Bartels runs near a trail that leads to the well-known island "Shoe-Tree." **Figure 9** and **Figure 10** below are two aerial views of the watershed areas for the proposed wells.

Figure 9: Aerial view of the proposed well watershed watershed by the Palmer-Kinne Lab. The elevation gradient of the watershed is about 0.092 ranging from 64 feet above sea level to about 56. The approximate watershed area is 9757.08 ft².

Figure 10: Aerial view of the proposed well watershed behind Bartels. The elevation gradient of the watershed is about 0.124 ranging from 66 feet above sea level to about 53. The approximate watershed area is 9756.08 ft².

The proposed Bartels Hall well location's main downfall is its proximity to the leach field used for wastewater treatment. The EPA standard, found under the "Basic Information" on the Private Wells section of the EPA website, suggests that wells must be greater than 50 feet away from septic leach fields. The proposed well meets this standard, as it is about 75 feet from the leach field; however, there is a risk of contamination involved in locating the well near the leach field. The Island Engineers should evaluate this risk before deciding to locate the well.

Given these watershed areas of about 9760 ft² and the yearly rainfall, 51.21 in., the amount of rain collected in each area is approximately 41648.77 ft³/year or 311554.45 gal/year. Subtracting the rate of evapotranspiration, which according to the United States Geological Survey, is 51-60 cm/year, yields about 17611.53 ft³/year or 131743.40 gal/year. This estimate, however, does not take surface run-off into account, and is thus an over-estimate of stored water. As mentioned previously, surface run-off samples were taken from the rocks below K-House, by the low-tide dock. It is possible that some of the water from the proposed Palmer-Kinne Lab watershed runs off to that area to be collected after a rainfall event, as shown in **Figure 11** and **Figure 12** below.

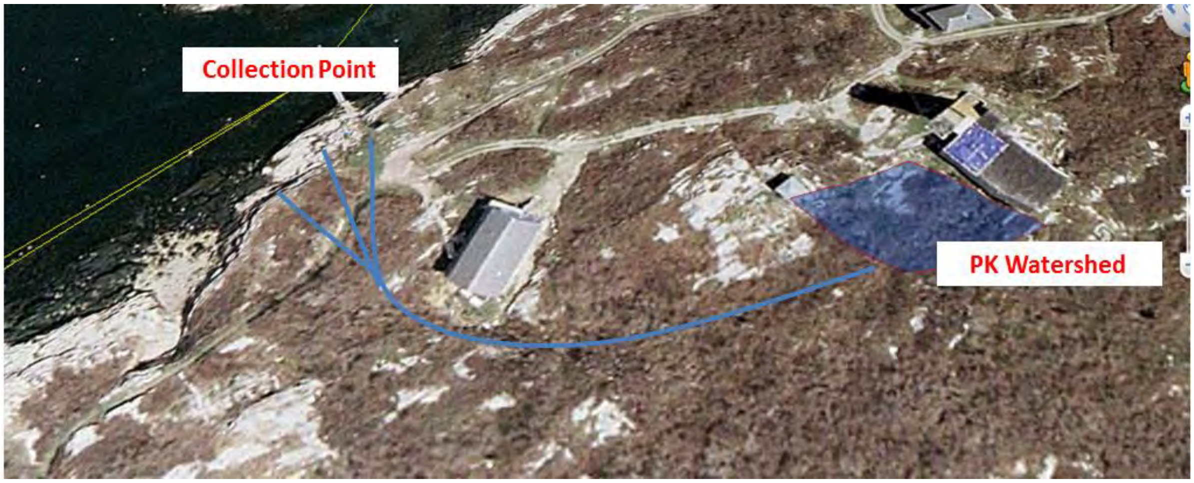

Figure 11: Aerial view of projected stream run-off from the PK watershed to the run-off collection point near the high-tide dock. The change in elevation is from 57 feet at the PK watershed to about 20 feet at the collection point.

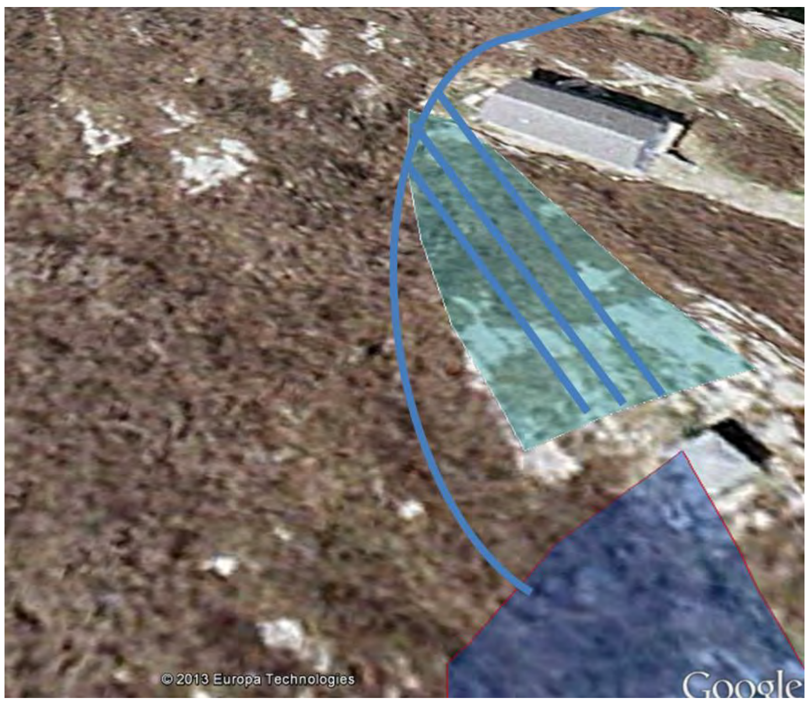

Figure 12: Looking closely, one can notice the valley by which the stream could run. Even greater surface run-off would flow off the other side of the gazebo, as shown in the figure above.

While the topography and proximity to roads lends these locations as ideal alternate well locations, more research needs to be done with precise technology, such as ground penetrating radar to determine the feasibility of digging wells in these areas.

6.9 Soil Testing

6.9.1 Methods

A soil transect was sampled at 50, 100, and 200 feet from the main well on June 24th to better understand the soil type of the well's watershed. The soil texture was analyzed according to the EPA's Soil Screening Guide (Clark et al. 1996). In addition, a percolation test was done at these sample sites to determine the percolation rate of the soil, another important parameter in understanding the soil's filtration capacity. Unfortunately, since little is known about the hydrology of the island, the Dilution Attenuation Factor (DAF) of the soil could not be calculated given this data. The DAF requires knowledge about the thickness of the aquifer and the soil infiltration rate, which have yet to be determined.

6.9.2 Results and Analysis

Soil transects were sampled on June 24th, however, it proved difficult to sample more than a handful of areas due to the soil composition. While soil texture analysis according to the EPA's Soil Screening Guide (Clark et al. 1996) showed that the soil texture is of the silt loam variety, it proved difficult to take multiple samples deeper than two feet, as the auger would hit impassable stones. The soil texture was determined using three samples (shown in **Figure 13**): from next to the well, 100 feet away, and 200 feet away. The soil texture appeared to be uniform among the three samples.

Figure 13: Samples from left to right: 100 feet, 2 feet, and 200 feet from the 20-foot dug well.

A percolation test was done on the sample sites to determine the percolation rate of the soil. Each site was filled to a certain height with water and monitored over 60 minutes (with the exception of the site two feet from the well). The height of the water was recorded again at the end of the 60-minute percolation time and the percolation rate was calculated in cm/s. See **Table 19** below for the results.

Table 19: Results of Percolation Test
***Hit water, so initial water depth is 9 in. above water height (water height before test was 5.25 in.). Height was not checked at 60 minutes.**
****Sample taken from on the trail, as this was the most accessible point to sample**

Distance From Well (ft)	Direction	Hole Depth (in.)	Initial Water Depth (in)	Final Water Depth (in)	Change in Water Depth (in.)	Total Percolation Time (min)	Perc Rate (mpi)	Perc Rate cm/s
*2	West	16	9	2.75	6.25	30	4.8	0.00882
50	Southwest	14	14	4.5	9.5	57	6	0.00706
**100	Southwest	30	30	15	15	60	4	0.01058
200	Southwest	17.25	14.75	1.25	13.5	62	4.59	0.00922

The results of the percolation test are relatively consistent, yielding values right around 0.01 cm/s. According to the *Portage County Groundwater Conditions Report* website, these percolation rates correspond to the permeability of well sorted sands or glacial outwash. This is contrary to the texture of silt loam determined by the EPA's Soil Screening Guide, which would have a slower percolation rate. It may be possible, then, that these rates correspond to the soil further below the surface that may contain more sand and glacial outwash.

The percolation test aids in determining the filtration capacity of the soil. One such method of calculating that capacity is the DAF, a method developed by the EPA to quantify the reduction in contaminants from infiltration into the soil to the receptor well. It is defined as the "ratio of soil leachate concentration to receptor point concentration" (Clark et al. 1996). The lowest DAF possible is a value of 1, where there is no difference in contaminant concentration in the soil and the concentration in the well. High DAF values correspond to a large decrease in contaminant concentration from the soil to the receptor well. For soil sources up to 0.5 acres in size, a default DAF value of 20 is considered protective. Analyses done by the EPA using mass-limit models suggest that a DAF of 20 may be considered protective for larger sources as well. Appledore's 20-foot dug well watershed was estimated to be about 61,000 ft^2, or about 1.4 acres. Thus, depending on the contaminant entering the soil, a DAF of 20 may or may not suffice to decontaminate the infiltrating water.

The equation for the DAF is as follows:

$$DAF = 1 + \frac{Kid}{IL}$$

Where

i = gradient (m/m)
d = mixing zone depth (m), calculated below
I = infiltration rate (m/yr)
L = length of area of concern parallel to ground water flow (m)
K = aquifer hydraulic conductivity (m/yr)

The equation for calculating the aquifer mixing zone depth, d is:

$$d = (0.0112L^2)^{0.5} + d_a(1 - e^{-\frac{LI}{Kid_a}})$$

Where
da = aquifer thickness (m)

The infiltration rate can be measured using the methods outlined in the USGS's publication "A Field Method for Measurement of Infiltration" (Johnson 1963).

The aquifer hydraulic conductivity can be measured from the recharge rate of the well during two pump tests in June and the capacity of the aquifer. The recharge rates of the first and second tests were 16600 and 5000 min/foot respectively. This rate was measured by recording both time and well height after the well drawdown test. These numbers signify that over the period during which the well was recharging to its pre-test height, the height rose at rates of 16600 and 5000 min/foot. The large variation between the two numbers may be explained by inconsistent precipitation before the test or during the recharge period, as one would assume the recharge rates to be consistent.

The gradient, i, of the watershed and length, L, were calculated using the topography depicted on Google Earth for Appledore Island. The steepest gradient was 0.122, from the wind turbine ridge down to the well, while the shallowest was 0.0075, from about 40 meters northeast to the well. These are relatively gross estimates for the gradient, as they assume the water surface elevation is right at the ground surface. With the current instruments on the island, it is not possible to measure the gradient of the groundwater flow. L, as used to calculate the steepest gradient, is 25.75 m.

There are still many unknowns, however: the mixing zone depth, d, which as shown above, can only be calculated from knowledge of the aquifer depth, da. Proper instrumentation must be acquired in order to determine these parameters. In addition, an experiment must be done to calculate the infiltration rate, and the hydraulic conductivity must be calculated based on the recharge rate of the well and the capacity of the aquifer.

6.10 Well Drawdown Test

6.10.1 Methods

Using a Solinst Water Level Meter (model 101) borrowed by Nancy Kinner from the University of New Hampshire, the well level could be measured precisely. Prior to borrowing this instrument, the water level could be roughly estimated by looking at a PVC pipe inside the well, which had a coupling spaced every foot vertically in the well. With the Solinst, the accuracies of the measurements were within one hundredth of an inch.

The well is usually pumped daily into the cistern for one or two hours. In order for the interns to have a longer pumping period to analyze (making for a more precise rate of well decline), the well was held from pumping for two days prior to each test. This was done by switching the well pump from “Auto” to “Off” until the time of the test. By switching to “Auto” at the beginning of the test and recording the well pump hours listed, the well pump would function at a constant flow rate until the second float in the cistern (a measure of when the cistern is full) triggered the pump to shut off. This flow rate was determined experimentally, with a five-gallon bucket and a stopwatch, to be exactly twenty gallons per minute.

Once the test had begun, the level of the well was measured every 20 to 30 minutes and recorded along with the time. Since the flow rate from the well was constant, the volume of water pumped out of the well could be accurately recording using the time measurements.

As mentioned above, the regeneration rate of the well was measured once the test was completed. This data was collected in the same manner as the pumping data. The results from this experiment can be used along with the aquifer capacity to calculate the hydraulic conductivity of the surrounding soil, which can then be used in calculating the soil’s filtering capacity, or the Dilution Attenuation Factor (DAF) (Clark et al. 1996).

6.10.2 Results

Test 1

Conditions: Precipitation within the last 24 hours, cloudy.

Table 20: Pump Test 1 Results

Pump Drawdown			Regeneration	
Time (min)	Depth (ft)	Pumped (gal)	Time (min)	Depth (ft)
0	3.89	0	165	4.09
10	4.02	200	244	3.96
20	4.03	400	984	3.99
30	4.03	600	1345	4.03
50	4.04	1000		
70	4.05	1400		
90	4.07	1800		
110	4.08	2200		
130	4.08	2600		
165	4.09	3300		

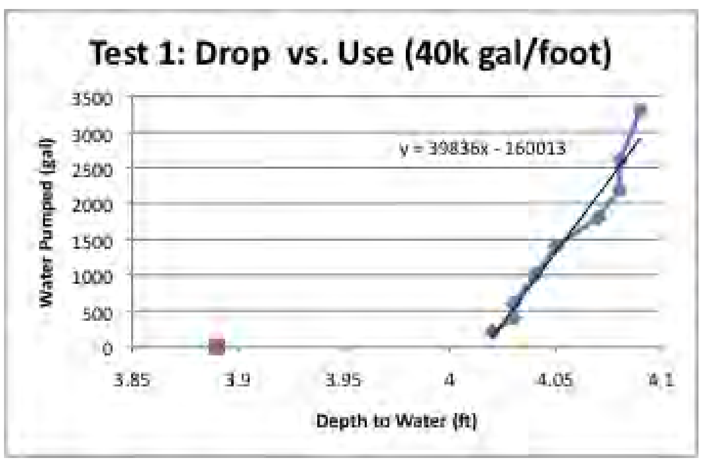

Figure 14: Graph showing Drop vs. Use for Test 1

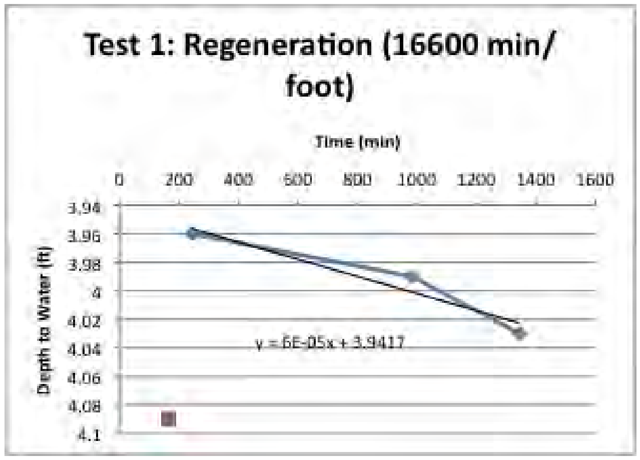

Figure 15: Graph showing well regeneration for Test 1

Test 2

Conditions: Precipitation within the last 24 hours, cloudy and slight sprinkle.

Table 21: Test 2 Pump Test Results

Pump Drawdown			Regeneration	
Time (min)	Depth (ft)	Pumped (gal)	Time (min)	Depth (ft)
0	4.45	0	0	4.66
20	4.64	400	45	4.63
40	4.67	800	80	4.62
70	4.72	1400	115	4.61
100	4.75	2000	230	4.6
130	4.79	2600	N/A	N/A
160	4.81	3200	1190	4.39

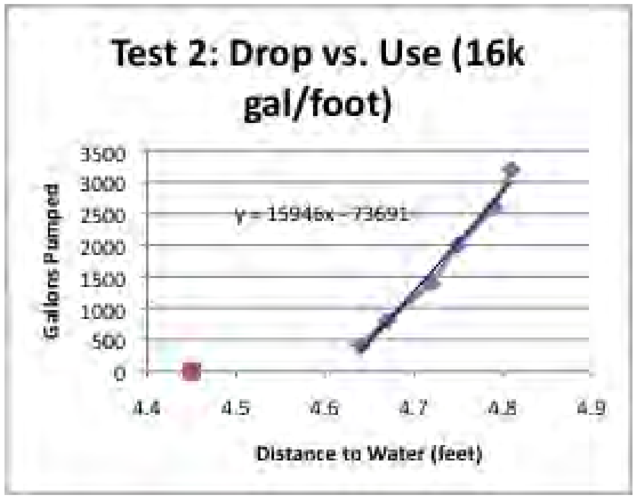

Figure 16: Graph showing Drop. vs. Use for Test 2

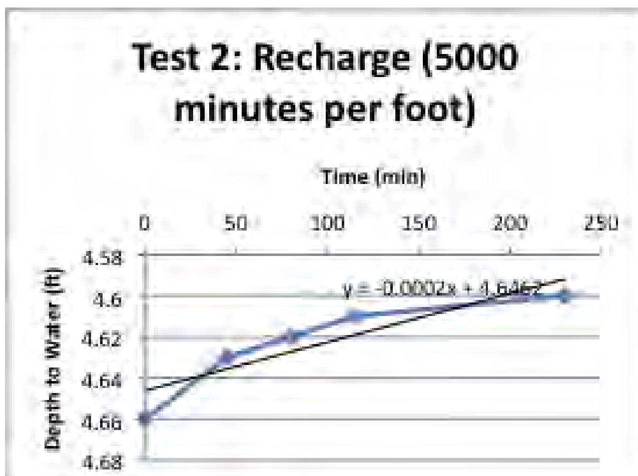

Figure 17: Graph showing well recharge rate for Test 2

6.10.3 Analysis

Two tests were performed in order to estimate the rate at which the height of the well drops with respect to gallons pumped out of it. The end result of this test was to estimate the capacity of the aquifer at these well heights.

The rate of drop for the tests were estimated, using the measured data, to be 39,800 and 15,950 gallons pumped per foot drop in well height. These numbers did not use the first data point in each test, shown in red on Drop vs. Use charts. This data was excluded because in both cases it seemed to be an outlier and atypical of the overall trend in rate of decline.

This number gives a rough estimate of the volume of the well aquifer at this height, which is roughly eighteen feet to the bottom of the well. If the aquifer were assumed to be a rectangular valley (**Figure 18**, Assumption 1), with its walls essentially vertical, these numbers would lend an estimate of 319,000 to 796,000 gallons in the aquifer at full capacity. However, when assuming the well has more of a triangular shape (**Figure 18**, Assumption 2), narrowing towards the base of the aquifer, this range would be closer to half that, or 177,200 to 442,200 gallons at full capacity.

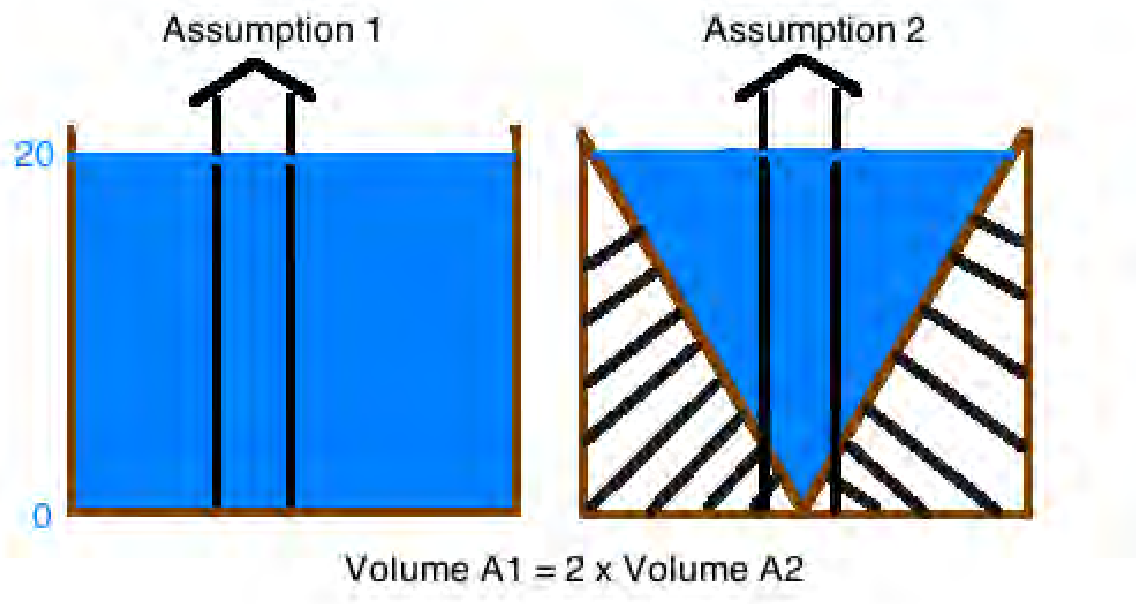

Figure 18: Aquifer Shape Assumptions

From these two assumptions as well as the range of well height rate, the total range of aquifer capacity is between 172,200 and 796,000 gallons. This is a large range. More details of the ground hydrology are required to refine the estimate. To give the reader an idea of the water demands of the island, a record of the past decade's total water consumption and reverse osmosis fresh water production is given in **Table 22**.

Table 22: Historical Water Consumption and RO Usage

Year	RO Usage (gal)	Total Consumed (gal)
2012	0	103535
2011	0	164505
2010	37530	135443
2009	0	150589
2008	0	124219
2007	120612	176524
2006	0	183075
2005	43359	192627
2004	88086	184663
2001	86722	204535

The second chart for each test shows the rate of recharge, measured in minutes since there is no volumetric input to measure, of the well. This number should give an idea of the rate at which the well height was changing during the test due to recharge from the well's surroundings. The significance of this number is that during a short test, it should be excluded since the test is determining how much water is being taken from the well's immediate surroundings without taking into account the recharge from further away and rainfall. Over a longer test period, this number would be significant in measuring how a large amount of water usage affects the well height.

In examining the post-test regeneration, there were mixed results. One would expect that the level of the well would slowly rise close to the level at which it started. This was true in Test 2, but not in Test 1. The regeneration of well height is assumed to be a function of areas further from the well in addition to its immediate surroundings. The regeneration should also be a function of the rainfall during the time before and during the test. Both of these factors would suggest that the well height should increase, or distance to the water should decrease, which is not true in the first test. Test 1 saw a quick increase in the well height and a slow rate of declining well height afterwards.

6.11 Well Column Sampling

6.11.1 Methods

The 20-foot dug well and the Grass Lab well were sampled at varying depths using the Niskin Bottle and tested for turbidity and salinity on-site.

The Niskin Bottle was lowered on a wire into the well. To determine the depth of the bottle when the sample was taken, intervals were marked on the wire such that when the mark was at the water surface, the Nisken bottle was at -2' to -5', -8' to -11', and -17' to -20'. Note that the surface water level is at -2' depth, because the well water was 2' below the ground surface. See

Figure 19 below.

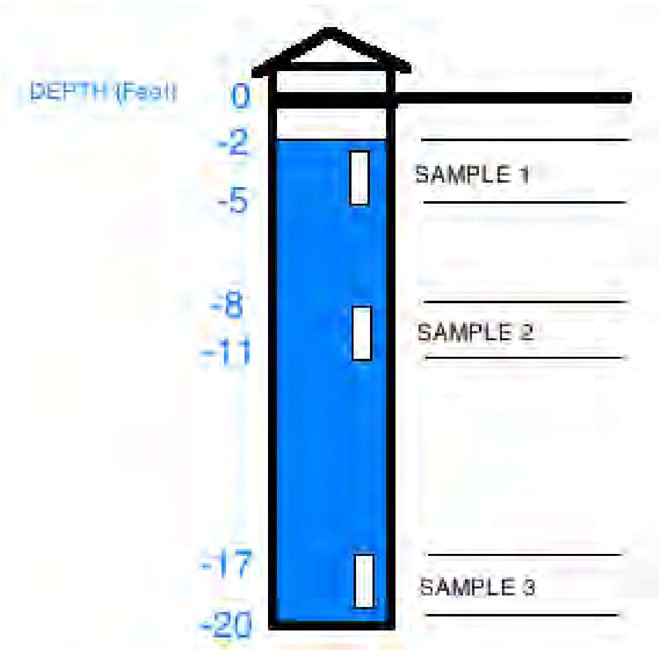

Figure 19: Depth of well samples taken using the Niskin Bottle

Two samples were taken at each depth. One sample was a 50 mL sample for Eastern Analytical Inc. to analyze for Chloride content. This was at the suggestion of Dr. Matt Davis, an Associate Professor of Hydrogeology from University of New Hampshire, as an indicator of how far the well is from salt water. The other sample was collected in a larger jar to keep at the Grass Lab and test for salinity with the EcoSense EC300 Portable Conductivity, Salinity and Temperature Instrument.

A sample was taken from the ocean, off the end of the high tide dock, to use as a baseline sample for chloride and salinity. This sample was included with the three 50mL samples sent to Eastern Analytical, Inc.

Jay Gingrich's well on the south end of the island appeared to be fed from ground water run-off. He noted that it recharges higher after rain, but never gets too low. This suggests a constant level of water below the surface. His well was estimated to be five to six feet deep. A sample was taken from his well and tested for salinity level.

The Grass Lab has water provided from a military well near the water to the east of the building. It is used in the spring when the Island Engineers are opening up the island for seasonal use. In the past, it has been slightly brackish, so it is not feasible to use it to supplement the island's freshwater supply. At the request of Ross Hansen, it was analyzed for salinity levels. The well was calculated to extend 9.6' below ground level and had a water height of 6.6 feet at the time of measurement. Note: Samples were taken at high tide.

6.11.2 Results

Table 23: Well Sample Test Results

***Sample 1 – Surface Level Well Water – Depth of -3.3 to -6 feet**

****Sample 2 – Bottom Level Well Water – Depth of -6.3 to -9 feet**

	Salinity (+-.2ppt)	Turbidity (NTU)	pH	Chloride (mg/L)
Main Well Sample 1	0.2	1.02	6.53	97
Main Well Sample 2	0.2	1.06	-	97
Main Well Sample 3	0.2	6.73	-	120
Ocean Water Sample 4	35	-	-	17,000
Grass Lab Sample 1*	0.1	0.71	6.59	-
Grass Lab Sample 2**	0.2	0.37	-	-
Jay Gingrich Well	0.1	0.86	5.97	-

6.11.3 Analysis

Matt Davis was contacted concerning the results of the chloride tests. As he has not yet responded, there is no definite conclusion to make. One would assume that these chloride levels correlate to salinity levels, as chloride is the primary salt ion in salt water.

The basic salinity and chloride levels show a consistently low number within the main well and extremely high numbers in salt water. The well salinity profile is constant. This is an indicator that the salt water is not mixing at all in the bottom of the well. This trend, however, becomes less convincing when the error margin of the EcoSense instrument is so great. The chloride samples show a nearly constant well profile, but an expert should be contacted to make an analysis of the significance of these numbers.

6.12 Well Height and Water Usage Comparisons

6.12.1 Methods

A comparison could be made from day to day, or over longer intervals, to evaluate a slope of well height drop versus water use. The interns decided that a period of time with regular height measurements and a relatively stable slope was the ideal sample. This decision was made because these time frames were later in the summer and assumed to be periods of little or no precipitation.

The logs of water use from the past decade were transferred to an Excel file. The data showed the cumulative water use for the season for every day recorded. The logs for well height were also transferred to an Excel file. These logs were less consistent, with missing years and many missing days. Due to the lack of available well height logs, only four years could be compared. By matching the cumulative water use and well height at each date available, graphs were made to show the overall relationship between well height and water use. Using periods that were assumed to have low rainfall, the rate of well height decline compared to the water used could be estimated and compared across years.

6.12.2 Results

The years that the interns had access to well height and water usage records were 2004, 2005, 2006 and 2011. The specific periods of interest were July of 2004, all of 2005, mid-July to mid-August of 2006, and July to August of 2011.

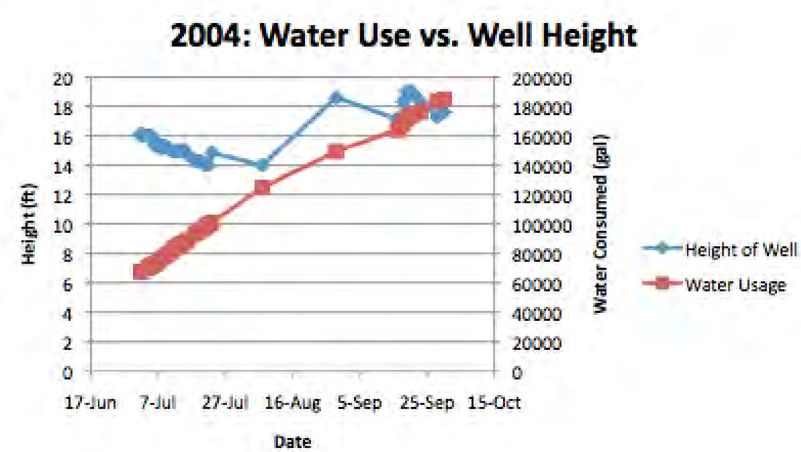

Figure 20: Graph showing Water Use vs. Well Height for 2004

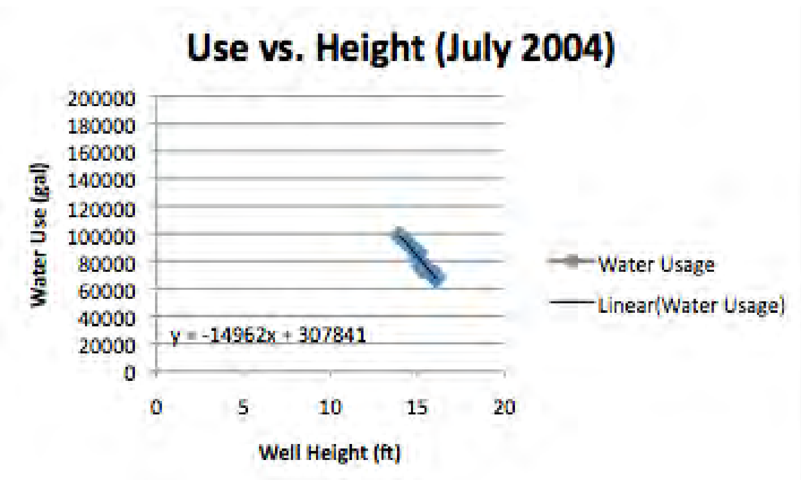

Figure 21: Graph showing Use vs. Height for July 2004

From the 2004 overview (**Figure 20**), the month of July stands out as having a constant slope. Looking further into the month of July, **Figure 21** shows the slope of the water use versus well height to be 14,962 gallons per foot.

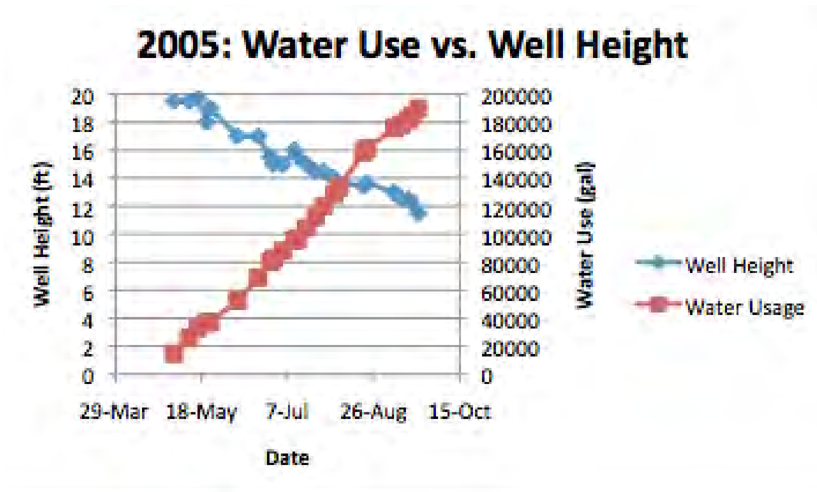

Figure 22: Water Use vs. Well Height for March-October 2005

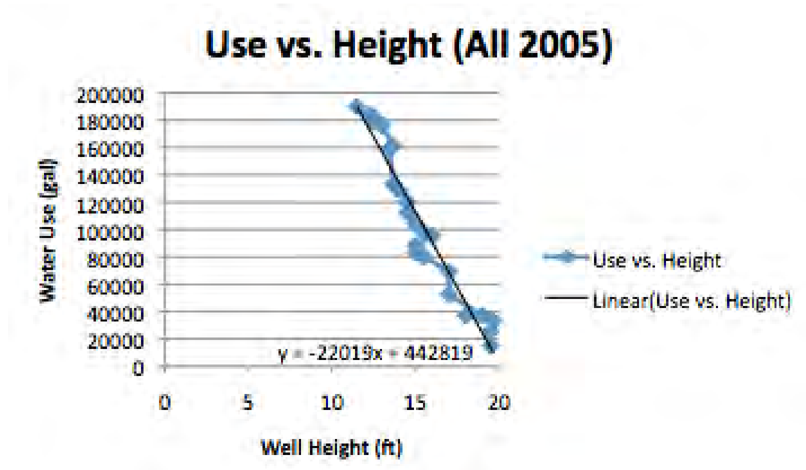

Figure 23: Use vs. Height for all of 2005

Figure 22 appeared to have a relatively stable slope throughout the season. The 2005 year saw 43,000 gallons of fresh water produced by the RO, suggesting that it was a dry year. The whole season was used to calculate this slope, shown in **Figure 23**, which was 22019 gallons per foot.

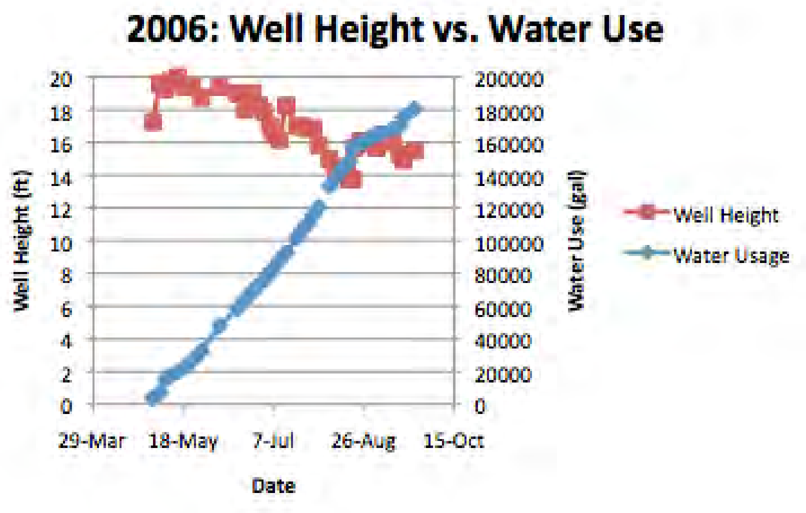

Figure 24: 2006 Well Height vs. Water Usage

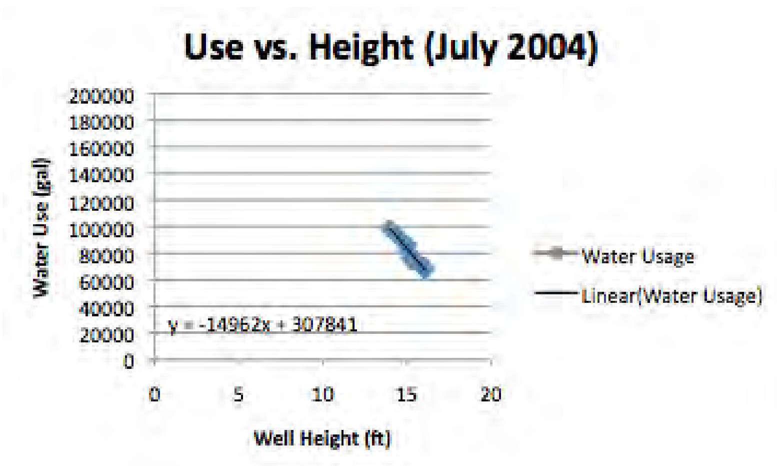

Figure 25: Use vs. Height from July 14-August 18, 2006

In 2006, the analyzed period showed a slope of 12,404 gallons per foot drop in well height.

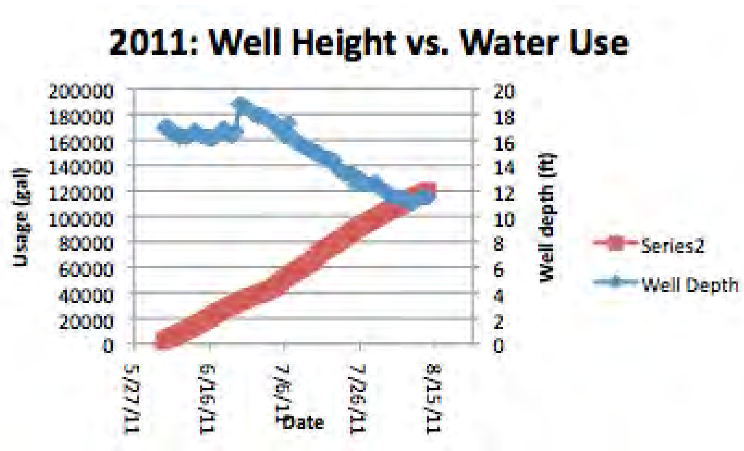

Figure 26: 2011 Well Height vs. Water Use (Series 2 represents Water Use)

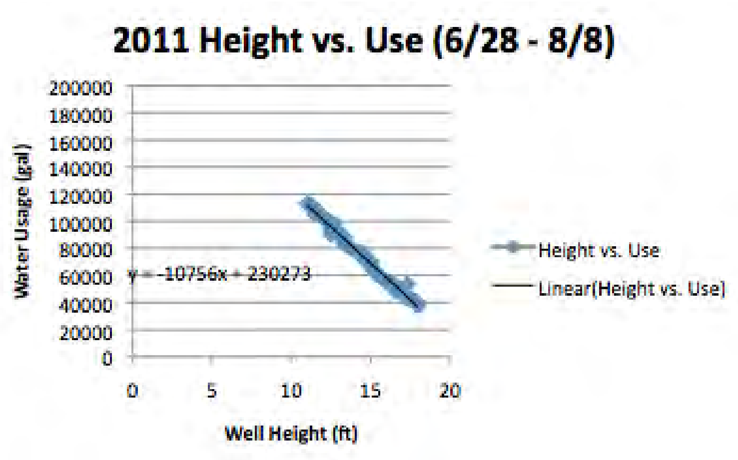

Figure 27: Height vs. Use from June 28-August 8, 2011

Figure 26 was plotted using an Excel file from the 2011 Engineering Interns. The selected period was very stable and the file contained precipitation data showing little water input during the period plotted in **Figure 27**.

Table 24: Summary of Historical Water Use vs. Height data

Year	Gallons/Foot Drop in Height	Height Range
2004	14,962	14 - 16
2005	22,019	12 - 20
2006	12,404	14 – 18
2011	10,756	11 – 18
Average	**15,035**	N/A

6.12.3 Analysis

There was consistency in these data sets. The range of slopes was smaller than in the pump test analysis and their accuracy should have been higher because they are averaged over a longer period of time. If one were to question these calculated slopes, they may argue that the trend was skewed by selecting periods of constant slope. This, however, is only an estimate and because the presumed precipitation droughts could not be proven easily by precipitation records (most only dated back to 2007), they serve as an accurate representation.

Given the average of these measured slope values, 15,035 gallons per foot, the capacity can be calculated in the same manner as mentioned previously. This results in an aquifer capacity range of 150,350 to 300,700 gallons. Note that this is the raw capacity and does not take into account added precipitation that may have renewed the aquifer.

6.13 Conclusions and Recommendations

There are many possibilities for increasing the freshwater supply, but with so little known about the hydrogeology of the island, it is difficult to definitively make one recommendation for the best option. Instead, it is recommended that future interns continue to look into the hydrology and hydrogeology of Appledore in collaboration with the United States Geological Survey or other groundwater professionals to make more informed decisions about an alternate well location and using the 20-foot dug well past 10 feet. Specifically, the interns may want to look into finding records of the hydrogeological history of the island and acquiring the proper instruments to measure aquifer depth. Depending on the effectiveness of the soil filtration, SML may be able to supplement the well with other freshwater sources that may be dirtier than the roof catchment (such as the surface run-off). With the abundance of surface run-off on the island after a heavy rainfall, discovering ways to treat it sufficiently would be extremely beneficial to the island's freshwater supply.

According to Dr. Jim Malley, the fecal coliform levels in the roof catchment were low enough that they may be treated using Appledore's current disinfection practices. Thus, it is recommended that future interns continue to explore roof catchment options, specifically those close to the 20-foot dug well's watershed, so that the water may be easily pumped to an infiltration gallery. With roof catchment water supplementing the well and SML's continuing conservation efforts, SML may not have to resort back to the RO system.

Additionally, future interns may wish to re-open the case of siphoning Crystal Lake water to the 20-foot dug well's watershed. Past interns found that the effluent turbidity after settling and filtration was ~3 NTU and may be further reduced using natural soil filtration.

6.14 References

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7 Test and Project Life of Green Grid Batteries

7.1 Introduction

Deliverable: *The interns will test the green grid battery bank AGM batteries, contact the manufacturer to help predict the present remaining life span of the battery bank. They will also design a plan for disposal and replacement.* –Engineering Staff

7.2 Purpose

Shoals Marine Laboratory (SML) currently employs a 7.5kW Mobil Solar Energy Corp. photovoltaic solar panel array and a 7.5kW Bergey wind turbine. In order to optimize the use of these renewable energy sources, SML installed an 88kWh Absolyte IIP lead-cadmium battery bank in 2007. This system has worked well since its installation and because it is now seven years old, it was desired to determine the remaining capacity (battery life) of the batteries. Determining the battery capacity will also help promote a better understanding of Absolyte battery banks which is beneficial to SML as it is acquiring a new 300kWh battery bank this coming year. Determination of remaining battery capacity will allow SML to prepare for disposal and possible replacement. This project will also help SML decide if replacement is a beneficial plan by determining the losses associated with the current battery bank.

7.3 Scope

Determination of the remaining battery capacity is an involved process requiring a sound understanding of electricity, power distribution, battery technology, and the specific operation of the battery system at SML. Due to this complexity much of this project was spent gaining a conceptual understanding of the battery system. This understanding allowed the interns to communicate with professionals in the battery and power distribution industries to determine a plan of action for determining the remaining battery capacity. The original scope of this project required that the interns perform the capacity test on the batteries. However, after determining two plans of action it was found that the complexity and time required to complete the test was beyond the scope of this internship. The plans are outlined in later sections of this paper. Additionally, after the realization that battery capacity testing was not a possibility the scope of this project was altered to include the determination of the losses associated with the current battery system to help optimize the use of the new battery bank.

7.4 Background

The existing battery bank under investigation in this project distributes power to five buildings on the "Green Grid." The green grid currently supplies power to Dorms 2 &3, P-K Laboratory, K-House, and the Radar Tower. The battery bank consists of 72 2V cells. Each unit is made up of six cells connected in series. Four of these units are then connected in series to give a battery block of 48V, which is the batteries rated voltage. Three of these 48V battery blocks are then connected in parallel. The specific product type of these Absolyte GP batteries is the 90G15. The Green Grid system is powered by a PV array, a wind turbine, and occasionally a diesel generator. The use of the generator is minimized by the use of inverters that only draw power from the generator when the batteries are drawn down to their minimum set voltage (47.6V) and the solar and wind power cannot provide enough power to recharge. In other words, if the power provided by the solar and the wind power is greater than the load from the four green grid buildings, than the solar and wind simultaneously satisfy the grid load and charge the battery. When the solar and wind are not providing energy, the stored energy in the battery satisfies the grid load. If the battery is fully discharged and the conditions are such that there is no wind or solar, the inverters begin drawing power from the generator to simultaneously satisfy the load and recharge the battery. The inverters disconnect from the generator when the solar or wind begin providing power again or the battery reaches its maximum voltage setpoint (54.4V).

The battery bank outputs 48V in DC which is then converted to 3 phase AC by the inverters and distributed to the five building load. The PV array produces power in wild DC, which also requires an inverter to power the battery. Likewise, the wind turbine produces power in wild AC, meaning two inverters are needed to power the battery bank, one to convert from wild AC to AC, the next to convert from AC to DC.

The testing of the battery bank requires knowledge of the battery's operation and set points. Two terms of particular importance are the absorb and float voltages. The absorb voltage is the voltage at which the battery achieves a full charge while the float voltage is the voltage at which battery operation is optimized. David Plante of Seacoast Consulting Engineers LLC, the designers of the green power system, advised that both the absorb and float voltages be set to 54.4 V. The battery voltage is monitored by the three Outback inverters which use voltage set points and a HBX (high batter transfer) function to switch between charge/discharge cycles and between power sources (PV and Wind to diesel generator). The HBX function is currently set so that when the battery reaches a state of 54.4 V (a 86% state of charge) and maintains that voltage for 6 minutes it stops charging, all excess power is then dumped to two space heaters located in the radio tower. The HBX function also uses a minimum voltage setpoint to communicate when the battery has gone through a discharge. This minimum voltage setpoint is currently set at 47.6 V (a 39% state of charge); once the battery has reached this voltage and maintained it for 6 minutes it begins to recharge from either solar and wind or the diesel generator if the renewable sources are not available.

7.5 Objectives

1. Develop a plan for testing remaining battery life
2. Perform test and determine whether resulting capacity suggests battery replacement
3. Determine requirements for battery disposal and develop plan to dispose and possibly replace battery bank
4. Determine the losses involved in the Green Grid system

7.6 Methods

In order to understand the workings of both the Green Grid and the Absolyte IIP Battery bank the interns devoted time to researching and gaining a conceptual understanding of the battery. This was achieved through talks with two professional visitors in particular. First, the interns spent half a day with Lee Consavage of Seacoast Consulting Engineers, LLC to gain an understanding of how the Green Grid was set to operate. Lee was also consulted regarding the development of a plan to test remaining battery life. Lee's suggestions required the interns to read the battery Operation Manual and the IEEE-1188 Standard in order to figure out the correct testing procedure needed. The second visitor provided the interns with a conceptual understanding of power distribution and general electrical engineering. This visitor was Justin Eisfeller a professional engineer from Unitil. Justin assisted the interns in gaining an understanding of how to calculate the losses within the Green Grid System.

In order to prepare a plan to determine remaining battery life, multiple GNB engineers were contacted. Craig Danner provided the most useful information and helped the interns develop the plan outlined in this report.

Computing losses within the battery system was done under the supervision of SML's own Mike Rosen and Ross Hansen. This was completed by disconnecting the solar inputs from the Green Grid system (the wind turbine was already disconnected due to maintenance) and allowing the batteries to completely discharge to their programmed minimum voltage setpoint of 47.6V. The battery bank was then recharged to its maximum setpoint voltage of 54.4 V solely by the diesel generator. Due to the Green Grid controls, the battery system is then programmed to disconnect from the generator and power the load solely with its stored energy. With the use of the two Allen-Bradely Powermonitor 3000 meters the interns were able to determine both the energy input to battery by the generator and the resulting amount of energy output to the load by the battery after the generator disconnected. This method then allows for the calculation of the occurring losses between battery charging and discharging by subtracting the input power (power to charge battery) from the output power (power from the batteries to power the load).

Figure 28 below shows time-trace data from the Allen Bradley power monitors during the charge/discharge battery test. The batteries were disconnected from the PV panels at approximately 10:30 AM on June 28th and were allowed to go through four cycles of discharge/charge before being reconnected.

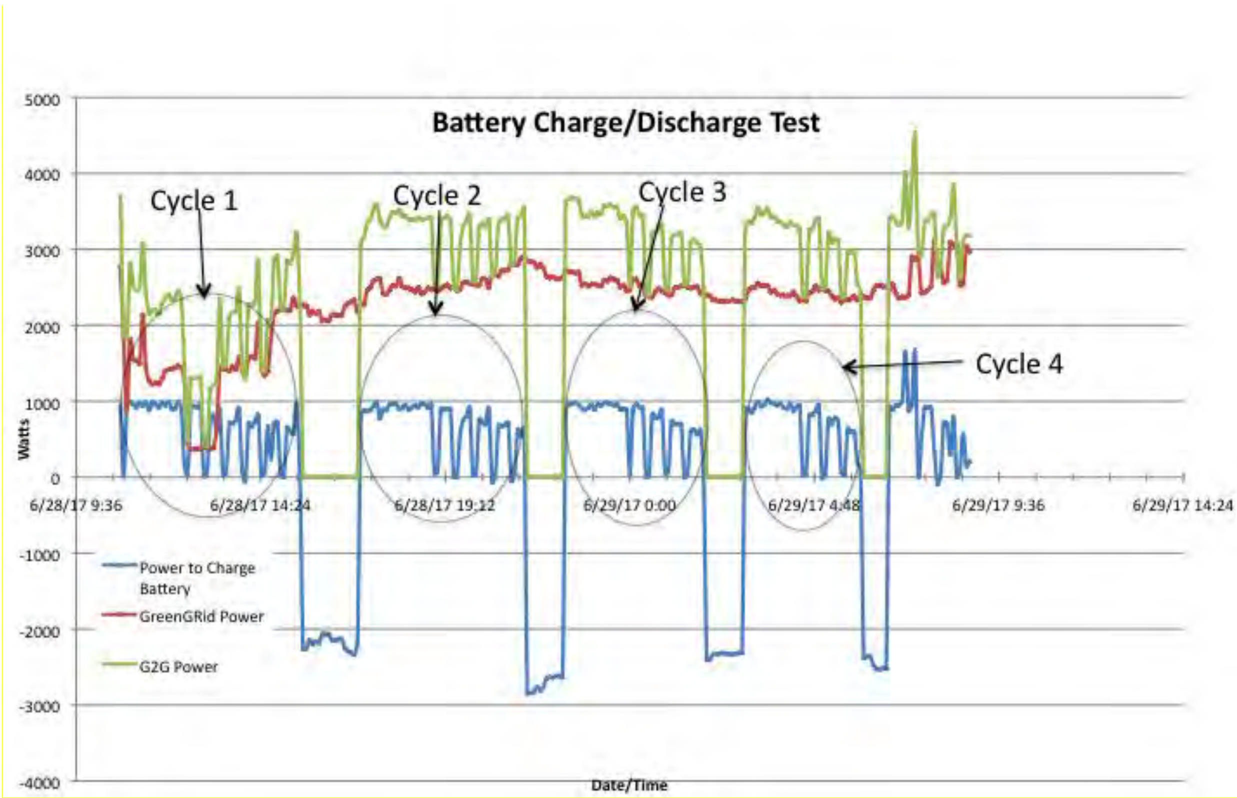

Figure 28: Time trace data from Allen Bradley power monitors. The red line represents instantaneous power to the green grid. The green line represents the power charging the batteries while simultaneously satisfying the power to the green grid load.

The interns defined the power losses of the system as the difference between the total work going into the batteries and the total work going out of the batteries. The total work in and out of the batteries, W in watt-hours, is defined by the following equation.

$$W = \int P dt \tag{2}$$

Where P is the instantaneous power in watts and t is time in hours.

Since an instantaneous power reading is taken every five minutes, it was assumed that the power remained constant through the five minutes. Each reading from the charge period (circled sections in **Figure 28**) time-trace was multiplied by .083 hours and summed in order to calculate total work put into the batteries. The total work output from the batteries was calculated in the same way but for periods of discharge. This method effectively solved the definite integral of the power curve as defined in Equation 2.

As the batteries near the end of their useful life SML desires to have a plan in place to properly dispose and recycle these batteries. The correct procedure for this task was determined by visiting the battery manufacturers, GNB Industrial Power, website and by contacting a GNB representative

7.7 Results

The first of the two investigated methods to determine reaming battery life is the performance of a capacity test in accordance with IEEE-1188: Recommended Practice for Maintenance, Testing, and Replacement of VRLA Batteries for Stationary Applications (Exide Technologies, 21). After talking to Craig Danner of GNB Industrial Power, the interns were able to develop an understanding and detailed plan of how to properly perform a capacity test. The procedure to perform a proper capacity test is outlined in Section 7 of the IEEE Standard, which can be found in Appendix 7 (IEEE Power Engineering Society). This report will also outline this procedure as follows:

1. Perform Equalizing Charge
    a. Before recharging the temperature of several battery cells must be recorded to determine an average battery temperature. This will be used to calculate a temperature adjusted factor correlating to the battery capacity.
    b. Disconnect the Green Grid loads (Dorms 2&3, P-K Lab, K-House, and Radar Tower) from the battery bank. This will be done so that the battery may be charged beyond its float/absorb voltages, which is required in an equalizing charge.
    c. Set a constant voltage charger to a constant of 2.4 volts per cell (VPC). Although the operation manual states in section 13.2 to not exceed 2.35 VPC (Exide Technologies, 19), after consulting with Craig Danner of GNB It was determined that the SML battery bank follow the specifications listed in the Absolyte GP Photovoltaic & Alternative Energy Section 62.61, a 2.4 VPC charge (GNB Industrial Power 62.61, 3). Because the SML battery bank is part of a Photovoltaic system this document applies.
    d. Record the time and current of the individual cells regularly, every hour as a minimum,
    e. Continue charging the batteries until there is no change in current for three consecutive hours.
    f. Once the current has stabilized continue charging at 2.4 VPC for an additional 12 hours.
        i. Monitor the cell voltages over the last three hours of this charge time. If the charge time has completed and the lowest cell voltage is still rising, continue charging until the lowest cell voltage has ceased to rise.
    g. After step 1f. is completed the equalizing charge is complete. However, in order to perform an accurate capacity test the battery must be maintained at the equalizing charge voltage for an extended amount of time. Craig Danner of GNB recommended 72 hours at this voltage. Because of the impracticality of keeping the battery disconnected from the load for a long duration Craig Danner suggested that “even 12 hours would be good.”
2. Begin Capacity Test
    a. It is recommended that before performing the capacity test Section 7 and Appendix E of the IEEE-1188 standard be read in depth.
    b. Based on conversation with two GNB engineers of the two capacity test methods

outlined in Section 7 of IEEE-1188, the time-adjustment method is the optimal choice for the SML battery bank. This is because it is desired to run a capacity test of longer than three hours due to the batteries typically long charge/discharge cycles.

   i. In order to determine the discharge current of the capacity test, a test length must be chosen based on the Absolyte GP Constant Current Specifications Section 26.10. GNB has published multiple discharge currents for several end voltages and test lengths.
   ii. In order to best simulate the batteries typical discharge cycle and minimize the time required to recharge the battery after the capacity test a GNB voltage discharge close to 1.98 VPC (due to 47.6 V minimum set point) should be chosen. GNB has a published rate of 1.94 VPC (46.56V); it is recommended to choose this rate. (GNB Industrial Power, Section 26.10, 13)
   iii. Referring to the GNB 1.94 VPC published rate and locating the SML battery product, 90G15, a discharge current can be determined for a desired test length. In this report it will be assumed a 4 hour test is desired, thus a constant current of 96 A is the needed discharge current

c. Disconnect the diesel generator, wind, and solar inputs from the battery bank so that the Inverters do not begin recharging the battery at 47.6 V (1.98 VPC).
d. Begin discharging the battery bank at a constant current of 96 A. Note the load will need to be varied in order to maintain a constant current equal to the rate determined in 2biii (IEEE Power Engineering Society, 12).
e. During test periodically check the voltage of several cells. Make sure to record voltages at the beginning and at a minimum of five more times.
   i. NOTE 1: Individual cell voltage readings should be taken between terminals of like polarity of adjacent cells so that the voltage drop of intercell connectors is included. (IEEE Power Engineering Society, 12)
   ii. NOTE 2: When monitoring individual cell voltages if it is apparent that an individual cell is nearing a voltage of 1.2 V, action is required. First, stop the test, then disconnect the problem cell from the string of cells, and jumper (use jumper cables) around the missing cell. This must be done within 6 minutes of stopping the test so that the test is not compromised (IEEE Power Engineering Society. 12). Finally the load can be reconnected and the test can be continued. The new minimum voltage should be calculated based on the remaining cells
f. Increase the rate of cell voltage checks as the test approaches the estimated time of four hours. For example, check every 30 minutes after two and a half hours have passed.
   i. NOTE: it is important to get an accurate measurement of the time it takes for the all the cells to reach 1.94 VPC. This time will be used to estimate the remaining capacity.
g. Maintain constant current discharge rate until the entire battery terminal voltage drops to a value equal to the rated selected minimum VPC multiplied by the number of cells. For example in this scenario, maintain constant current discharge until the battery terminal reaches a voltage of 45.56V (24cells x 1.94VPC).

h. Using the following equation calculate the battery capacity

$$C = \left(\frac{t_A}{t_S \times K_T}\right) \times 100 \quad (3)$$

Where C is the remaining % battery capacity, t_A is the measured time it took the battery to reach 1.94 VPC, t_S is the rated time to reach the minimum voltage (in this case four hours), and K_T is the temperature factor based on the pretest temperature measurements. K_T can be found using Table 1 in the IEEE-1188 Standard, found in Appendix 7.

3. Restoration
    a. Disconnect all testing apparatus and immediately perform a second equalizing charge as outlined in steps 1a-1f.
4. Battery Capacity Analysis
    a. As stated in the IEEE-1188 Standard, generally, the criteria for battery replacement is that a capacity test yields a resulting capacity, calculated in 2h above, of 80% or below. This is 80% of the manufacturers rating, which shows that the batteries rate of deterioration is increasing even if there is ample capacity to meet the requirements of the connected system. Other factors that may contribute to the need for battery replacement are unsatisfactory service tests (outlined in IEEE-1188 Standard section 7.6), abnormally high/low cell temperatures, or the addition of new loads to the battery. (IEEE Power Engineering Society, 13).

The second method to determine the remaining battery capacity involves the use of the Midtronics CELLTRON MAX, a stationary battery analyzer, which is able to measure conductance and impedance which it uses in an algorithm to determine the viability of each cell. The CELLTRON MAX advertises that is able to use these parameters to determine with a high accuracy the current battery state of health. The interns were notified of this product through Jon Spencer of Support Power. Although the CELLTRON MAX appears to be a device capable of testing the capacity of the SML battery bank it will cost SML at least $2,000 because the product requires software and a trained professional to operate.

7.7.1 Power Losses:

Power losses were calculated after following the procedure outline in the methods section of this report. These results are tabulated below for three charge/discharge cycles defined in **Figure 28**. Cycle 1 was not used because there is no definitive start to the charging of the batteries.

Table 25: Power losses calculated by integration method. Total work in and out represents work into and out of the battery in one charge/discharge cycle, respectively.

Cycle #	Total Work In (Watt-hours)	Total Work Out (Watt-hours)	Total Loss (Watt-hours)	Percentage of Work Lost
2	2965.5	2716.2	249.3	8.4 %
3	2613.4	2332.6	280.8	10.7%
4	2147.4	1634.8	512.6	23.9%

Additionally, even after computing the losses for the three charge/discharge cycles, the losses test was useful in determining other information about the battery by graphing the charge/discharge cycles as seen in **Figure 29** below.

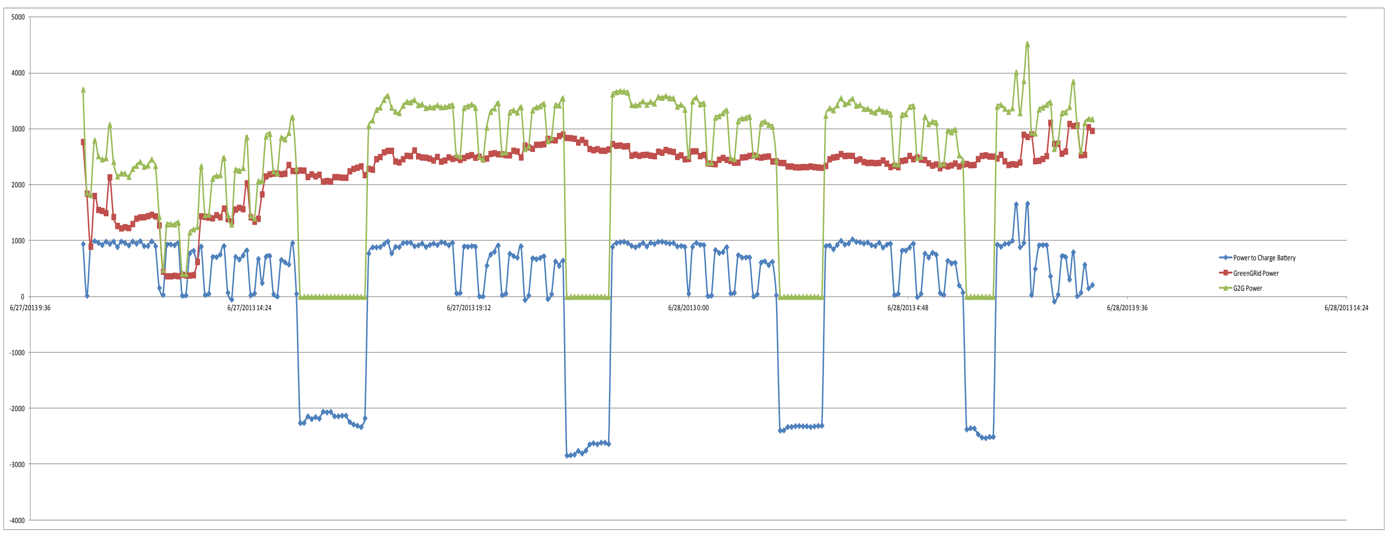

Figure 29: Battery Losses Test- Trend Lines

Of particular inertest to the interns was the blue line in **Figure 29**, which represents the amount of instantaneous power provided to the battery by the generator during charging (the negative cycles represent periods where the battery is discharging/powering the load). After sharing these results with Lee Consavage several features of this graph were identified as areas to be investigated further.

A. During charge cycles the battery is receiving around 1kW for the duration of its charging state. This shows that the battery is being charged at about 20amp-hours. As 1kW / 48 VDC = 20.8 amp-hours, as this follows Equation 4 below:

$$P = VI \quad (4)$$

Where, in this case, P equals 1kW, V is equal to the rated battery capacity of 48 V, and I is the resulting current of 20amp-hours.

B. During charging cycles, after initial stabilization at 1kW, the battery begins to undergo periodic cycles of drops in power to near 0kW every 20 minutes. This is represented by the "sawtooth" shaped curves preceding a battery discharge. These cycles were observed for every recorded charge/discharge cycle with fluctuations of 20 minutes each time. This pattern could not be deciphered by the interns or Lee Consavage who stated that further review of the NREL research papers could shed light on the reason behind these occurrences.

C. The largest area of concern is the relatively short amount of time each discharge lasts (represented in **Figure 29** when the blue line becomes negative), ranging from 90-60 minutes. The load on the battery during these discharges was approximately 2.5kW. Because the battery was only able to provide this power for about an hour, the discharge range of the batteries is only 3% [(2.5kW x 1hour)/ 88kWh] of the batteries rated 88kWh capacity. It was originally thought that the Outback Mate was causing this problem with faulty generator charge/discharge voltage limits; it is recommended that the upper voltage limit be placed so that it is 85% of battery capacity. However after checking the HBX controller settings on the Outback Mate it was confirmed that the upper voltage limit for the generator was 54.4V which is 86% of the battery capacity. Likewise, the minimum setpoint voltage is 47.6V, which is 39% of battery capacity. This 47% difference in battery capacity is appropriate for the SML battery bank As the set voltage limits were ruled out as reasons for this behavior, Lee Consavage consulted David Plante, the engineer who did the original battery research for the SML battery bank. David Plante suggested that the graphs in **Figure 29** could indicate a resistance problem with either the internal workings of the battery and/or with the actual connections at the battery posts.

7.8 Recommendations

In order to most accurately determine the remaining capacity of the battery bank, it is recommended that SML perform the IEEE-1188 standard capacity test. Although the CELLTRON MAX would be an elegant, quick, and simple solution to determining battery capacity, little is known about this product or how it works. Because the CELLTRON MAX option was discovered later in the internship, the interns were not able to perform enough background research on the product to confidently make a recommendation concerning its use. The interns recommended performing more background research on the CELLTRON MAX and getting opinions from Lee Consavage, David Plante, and a GNB engineer (preferably Craig Danner) regarding whether or not the Midtronics product can be used to give an accurate capacity estimate.

However, due to the accuracy of the IEEE-1188 test the interns recommend that SML take the time to plan and execute this test. It is recommended that GNB be consulted before completing the test so that SML can figure out how to put a constant discharge of 96A on the battery. Also, SML should make sure a trained electrician is on site during step 2 of the IEEE-1188 test so that they may safely deal with any individual cells that near 1.2V.

The following are the recommendations concerning the issues discovered during the battery loses test:

A. Check with Lee Consavage to determine if a 20amp-hour rate of charge is optimal for the SML battery bank

B. David Plante and Lee Consavage should be consulted to determine whether the NREL paper explains the periodic drops in charge. If not, this issue should be investigated further.

   It is also recommended that SML graph the voltage data from the battery versus the power losses data. This will allow SML to determine if the sawtooth drops are triggered by certain voltage setpoints in the battery, and if so, what these voltage points are.

C. Due to the fact that the graph in **Figure 29** seems to indicate a resistance problem with the battery, measures should be taken to eliminate some of the resistance. This is because of the idea that the small discharge range is in fact caused by resistance problems. If there is a resistance problem with the actual battery connections, these posts should be cleaned. It is recommended that when David Ayers, the island electrician, next comes out to the island that he be asked to clean the battery posts and bus bars. This would eliminate the external resistance the battery experiences. It is also recommended that an equalizing charge be performed to clean the internal plates of the battery to eliminate some of the internal resistances in the battery. The procedure to perform an equalizing charge is outlined in steps 1a.-1f, in the results section above. After these measures are taken the batteries should be put through another losses test to determine if the 3% discharge range was caused by battery resistances. If it is found that the cleaning and equalizing charge did not remedy the small discharge range then this issue must be investigated further.

   The fact that the discharge was only 3% of the rated 88kWh capacity is also an area of concern. This is because one would expect that with a voltage window of 54.4V to 47.6V (86%-39% state of charge), with a discharge window of 47%, a discharge much larger than 2.5kWh would result. As a "back of the napkin" calculation and assumption, this could indicate that the batteries have in fact reached their end of life capacity. However, it is still recommended that SML perform the IEEE-1188 capacity test in the correct procedure to truly test the battery capacity, as the 3% discharge could be a function of battery controls and not the battery capacity itself.

Concerning recycling, it is recommended that SML read through the "GNB Recycling Request Form," found in the Assignment 7Appendix. GNB provides free pickup of the batteries, all SML must do is package the batteries, get them to the mainland, and load them into the GNB truck a location of SML's choosing (such as the UNH dock). SML staff should read the Recycling Request form to determine the packaging requirements and to identify where this form must be sent.

7.9 References

Exide Technologies. *Installation and Operating Instructions for Absolyte IIP Batteries*. Owners Manual. N.p.: n.p., n.d. Print.

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GNB Industrial Power, 62.61. *Absolyte GP Photovoltaic & Alternative Energy Section 62.61*. N.p.: GNB Industrial Power, n.d. Print.

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8 Freshwater Usage at K-House and Bartels

8.1 Introduction

Deliverable: *The Interns will read the meters each day. They will also count the number of people occupying each building each day. They will document the fresh water usage and compare it with the data that last year's interns predicted. They will also look for ways that fresh water could be conserved in each of those buildings.* – Engineering Staff

8.2 Purpose

Freshwater is a valuable and limited resource on Appledore Island. Currently, a 20-foot dug well satisfies most of the fresh water needs for the island including faucets, showers, toilets, dishwashers, washing machines, etc. All of the fresh water used is potable. Raising awareness of sustainable practices relating to water usage is of SML's top priority. Monitoring and regulating water usage is the best way to ensure that the water is being used in a conservative manner.

8.3 Scope

This year's interns were asked to obtain more accurate measurements of the daily freshwater use in K-house and Bartels. Measurement devices (water meters) were placed on the fresh water lines that enter the buildings and recorded daily. Sustainable recommendations for decreasing freshwater use were to be made if it was found that K-House and Bartels occupants were using large amounts.

8.4 Background

The 2012 engineering interns estimated that K-house was using 111.43 gallons of fresh water per day (gpd) and that Bartels used 114.03 gpd.

8.5 Objectives

1. Accurately quantify water usage in K-House and Bartels and compare this quantity to estimates from 2012.
2. Make recommendations to reduce water use, if necessary.

8.6 Methods

The interns recorded daily water readings for the K-house and Bartels on a water usage log (found in Appendix…). This provided an average daily consumption for each house.

The interns examined the inside of Bartels and K-house to see exactly where the fresh water was being used. There are four toilets, two showers, and a washing machine located in Bartels. K-House, on the other hand, has three showers, a dishwasher and a washing machine. Fresh drinking water is used to run all of these appliances. Tally sheets were posted in the bathrooms in order to acquire total number of flushes, total time of showering, total number of washing machine cycles and total number of dishwasher cycles. The water use of each appliance and flow rates of each faucet were found in order to equate the information on the tally sheets to gallons of water consumed. Relevant information is documented in the Assignment 8 Appendix . By documenting freshwater usage in this manner, the interns had a better sense of where in the house the most water was being used. The occupants of the houses were encouraged to participate in marking the tally sheets honestly.

Information on current daily occupancy of these buildings was acquired from the Island Coordinator, Kara **Pellowe**. This provided useful information in correlating water consumption to current building occupancy.

8.7 Results

The daily water readings for Bartels and K-house from June 12th to July 2nd , 2013 are shown below in **Table 26** and **Table 27**, respectively.

Table 26: Water log for Bartels. Water readings were taken every day in the morning whenever possible. Weekly occupancy information for Bartels can be found in Assignment 8 Appendix.

Date	Time	Bartel Totalizer Reading (gallons)	Bartel Daily Use (gallons)	# Occupants in Bartels	Gallons of Water per Person
6/12/13	10:10 AM	0	98.5	11	8.95
6/13/13	10:00 AM	98.5	62.2	11	5.65
6/14/13	9:45 AM	160.7	98.1	11	8.92
6/15/13	10:15 AM	258.8	59.2	11	5.38
6/16/13	11:00 AM	318	95.5	11	8.68
6/17/13	10:50 AM	413.5	74.3	11	6.75
6/18/13	10:50 AM	487.8	121.7	11	11.06
6/19/13	10:50 AM	609.5	98.1	11	8.92
6/20/13	10:15 AM	707.6	87.2	11	7.93
6/21/13	10:15 AM	794.8	89.9	11	8.17
6/22/13	10:00 AM	884.7	70	11	6.36
6/23/13	10:00 AM	954.7	89.2	11	8.11
6/24/13	10:00 AM	1043.9	89.1	11	8.10
6/25/13	10:00 AM	1133	57	11	5.18
6/26/13	11:30 AM	1190	63	11	5.73
6/27/13	11:00 AM	1253	34	11	3.09
6/28/13	10:00 AM	1287	84	11	7.64
6/29/13	10:00 AM	1371	185	11	16.82
6/30/13	5:00 PM	1556	88	11	8.00
7/1/13	10:40 AM	1644	92	11	8.36
7/2/13	9:30 AM	1736		11	
Average			**86.8**		**7.89**

On average, 86.8 gallons of water were used in Bartels on a daily basis. This total daily usage corresponds to an average of 7.89 gallons of water used per person per day in Bartels. The tally data collected from Bartels are located in Assignment 8 Appendix. The data collected from these tally sheets show that the majority of water consumption in Bartels is attributed to the showers. An estimated average of 240 gallons per week goes to the showers. Toilet flushes consume an estimated average of 103 gallons per week. The washing machine uses an estimated average of 100 gallons per week.

Table 27: Water log for K-house. Water readings were taken every day in the morning whenever possible. Weekly occupancy information for K-House can be found in Assignment 8 Appendix

Date	Time	K-House Totalizer Reading (gallons)	K-House Daily Use (gallons)	# Occupants in K-House	Gallons of Water per Person
6/12/13	10:10 AM	0	51.4	4	12.85
6/13/13	10:00 AM	51.4	46.1	4	11.53
6/14/13	9:45 AM	97.5	0	4	0.00
6/15/13	10:15 AM	97.5	0.5	4	0.13
6/16/13	11:00 AM	98	0.4	4	0.10
6/17/13	10:50 AM	98.4	19.4	7	2.77
6/18/13	10:50 AM	117.8	43.6	7	6.23
6/19/13	10:50 AM	161.4	81.7	7	11.67
6/20/13	10:15 AM	243.1	93.2	7	13.31
6/21/13	10:15 AM	336.3	83.3	7	11.90
6/22/13	10:00 AM	419.6	68.2	7	9.74
6/23/13	10:00 AM	487.8	132.6	7	18.94
6/24/13	10:00 AM	620.4	132.5	9	14.72
6/25/13	10:00 AM	752.9	31.8	9	3.53
6/26/13	11:30 AM	784.7	45.3	9	5.03
6/27/13	11:00 AM	830	104.6	9	11.62
6/28/13	10:00 AM	934.6	93.4	9	10.38
6/29/13	10:00 AM	1028	75	9	8.33
6/30/13	5:00 PM	1103	48	9	5.33
7/1/13	10:40 AM	1151	17	7	2.43
7/2/13	9:30 AM	1168		7	
Average			**58.4**		**8.03**

On average, 8.03 gallons of water were used per person per day in K-house. The tally data collected from K-house are located in Assignment 8 Appendix. The data collected from these tally sheets show that the majority of water consumption in K-house is attributed to the showers. An estimated average of 123 gallons per week goes to the showers. The washing machine consumes an estimated average of 43 gallons per week. The sinks use an estimated average of 20 gallons per week. The dishwasher consumes an estimated average of 14 gallons per week.

8.8 Analysis

The 2012 engineering interns estimated that Bartels consumed 114.03 gallons of water per day. Using the water meter on the Bartels freshwater feed, the 2013 interns measured a daily average water consumption of 86.6 gallons. The discrepancy between these results could have arose because of assumptions made by the interns last year. The 2012 interns estimated that each resident takes two five-minute showers per week on full water pressure (2.5gpm) and that 25 loads of laundry per week are done. Two five-minute showers per person per week is an accurate estimate based on this year's tallies. This year, it was found that an average of four loads of laundry were done per week. Last year's estimate of 25 loads of laundry is a very high and explains the relatively high water usage calculation.

The 2012 engineering interns estimated that K-House consumed 111.43 gallons of fresh water per day. The 2013 interns measured that at maximum occupancy (7-9 residents), K-House consumed an average 75.8 gallons of water per day. 2012 interns based their calculations on five residents taking an average of four 10-minute showers a week and doing 14 loads of laundry per week. 2013 tally sheets show that each resident in K-House took an average of two four-minute showers per week. 2013 tally sheets also show that there was an average of seven loads of laundry done per week. Last year's estimates were high resulting in a relatively high daily water use.

When analyzing these results, it is necessary to realize that honesty and participation of the residents directly affects the accuracy of the tally sheets.

The GPI water meters on K-House and Bartels are rated to measure flow rates of 3 to 30 gallons per minute. A test of the accuracy of the meters was conducted where a single faucet in K-House and Bartels were set to a slow trickle. The water meter totalizers did not respond or show an increase when a gallon bucket was filled at a trickle. This test showed that the daily gallons of water taken from the meters, if anything, were on the low side.

8.9 Conclusion and Recommendations

From this year's quantification of water use in Bartels and K-House, it is apparent that the residents are doing a relatively good job of conserving water. One minor recommendation that the interns would make is to install flow restrictors on the sinks. Looking into more water efficient washing machines will also help to reduce the water used.

Summary of Future Project Recommendations

Composting Evaluation

Assess the current status of composting on Appledore and determine how to improve the system. While the composting toilets have not yet needed to be cleaned out, it might be interesting to look into locations in which to use this compost, such as Celia Thaxter's garden.

Engineers Assist Research Interns

There may be some biological research projects that require engineering assistance. Jim Cunningham has been working with the Marine Mammal interns on a project in which a design for a floating camera stand is needed for surveying seals on Duck Island. Perhaps future interns could continue to look into projects such as these that help with data collection and analysis for the biological research interns.

Future Battery Monitoring

If Mike Rosen and Ross Hansen do not have time to perform the IEEE-1188 standard capacity test before the summer of 2014, it is recommended that the SEI interns plan and execute this test. GNB should be consulted before completing the test so that it can be run as accurately as possible. Additionally, a trained electrician should be on-site during Step 2 of the IEEE-1188 test as a safety precaution.

If the interns are pressed for time and do not think the IEEE-1188 test is feasible, more background research on the CELLTRON MAX should be done. The interns may turn to Lee Consavage, David Plante, or a GNB engineer for expert opinions on the accuracy of the Midtronics product.

It is also recommended that the interns work to interpret and better understand the results of the battery losses test executed this year. See Error! Reference source not found. under **Test and Project Life of Green Grid Batteries** for more information.

Lastly, after the new battery bank is installed, it will be important to monitor it frequently so that its capacity can be tracked. As such, the Facility Managers will have a better idea of when the batteries are nearing the end of their lifespan and need to be replaced.

Increasing the Freshwater Supply

It is recommended that future interns continue to look into the hydrology of Appledore in collaboration with groundwater professionals to make more informed decisions about an alternate well location and further drawdown of the 20-foot dug well. Specifically, the interns may want to look into finding records of the hydrogeological history of the island and acquiring the proper instruments to measure aquifer depth.

Due to the abundance of surface run-off on the island, it might be beneficial for future interns to research and design ways to treat it sufficiently, as it cannot be treating with the island's current disinfection practices.

Roof catchment options, specifically those close to the well's watershed, should continue to be explored. Tom Johnson suggested that rainwater catchment systems could be installed at Bartels and Founders to collect water for flushing toilets. Rainwater could also be dispersed in Celia Thaxter's garden during periods of little rainfall.

Additionally, future interns may wish to re-open the case of siphoning Crystal Lake water to the 20-foot dug well's watershed. Past interns found that the effluent turbidity after settling and filtration was ~3 NTU and may be further reduced using natural soil filtration. Nancy Kinner has a contact at UNH who would be interested in working with interns on implementing slow sand filtration to treat Crystal Lake water.

Solar Evaporator

During the 2013 SEI, the interns entertained the idea of building a solar evaporator to desalinate saltwater. Two small-scale solar evaporators were designed to experiment with evaporating saltwater and using the condensed freshwater to supplement the 20-foot dug well. The apparatus consisted of two trays, one for salt water and the other for freshwater collection, covered by a pitched transparent sheet of plexi-glass. Cold water was gravity-fed to wash over the plexi-glass to allow for condensation. The water droplets that formed on the inside of the glass then dropped into the freshwater collection tray. The interns saw up to a 12% yield of freshwater through solar evaporation. This might be an interesting research and design project to continue for future interns.

Updating the GIS

Some errors still remain in the GIS layout of SML. It is recommended that future interns work to correct these errors and continue updating the system with new island developments, such as the Energy Conservation Building.

VFD for Salt Pump

During the 2013 Engineering intern assignment, the interns visited Star Island to investigate their current fire system. While their they were told about a Star Island water pump that had recently had a VFD installed with a good degree of success. This has motivated the recommendation to investigate the installation of a VFD pump for the SML salt water pump that is currently running 24/7 to supply salt water to the sea tables on the island. The 2013 interns did a quick assessment of the savings that could be achieved by the installation of a VFD. First the pump specifications were recorded as shown below

Salt Water Pump Specs	
HP	7.5
Nom Eff	86.5
Voltage	208
Frequency (Hz)	60
RPM	3475

Using this data the interns were able to use the following spreadsheet estimate the yearly savings that VFD could achieve.

Annual Energy Savings Estimate for VFD addition and Electric motor efficiency upgrades

Compares VFD capacity control versus other types capacity control.

Location/Use: **Salt Water Pump**

To make Comparisons and Estimate Savings, need to know following:

a. Motor horsepower (Total HP that use xx% efficient motors)
b. Cost of Kwh of electricity.
c. Total hours of operation per year.
d. Present method of capacity control (guide vanes, fan curves, discharge vanes, cv's, etc.) That VFD will replace

Efficency Upgrade:

OLD:	**86.5%**	**eff motors**
	11,456	kwh/yr
	$6,187	per yr
NEW:	**95.0%**	**eff motors**
	10,431	kwh/yr
	$5,633	per yr
Savings:	**1,025**	kwh/yr
	$554	per yr

Step 1: Converting motor Horsepower to Kw

7.5 HP x .746 = 5.595 Kw_A

Step 2: Multiply the Adjustable Frequency Drive Power Ratio (from table below) times Kw_A from Step 1.

0.4 Ratio x 5.595 Kw_A = 2.238 Kw_B (using VFD)

Step 3: Multiply the Power Ratio of the presently employed control (see below) times Kw_A from Step 1.

1 Ratio x 5.595 Kw_A = 5.595 Kw_C (method now employed)

Step 4: Subtract Step 2 Kw_B from Step 3 Kw_C.

5.595 Kw_C - 2.238 Kw_B = 3.357 Kw_D (savings using VFD)

Step 5: Multiply Step 4 KW_D savings, times hours per year of operation, times cost of electricity per KwH.

3.357 Kw_D x 2952 Hrs x $ 0.54 $/Kwh = **$ 6,187** VFD Annual calculated savings

11,456 kwh/yr

Ratios For Above Calcualtions:

Fans at 60% of maximum flow

Ratio	Flow Control Method
0.28	Variable Frequency Drive
0.62	Inlet Guide Vane
0.88	Outlet Damper
0.88	Fan Curve
1.00	Bypass Damper

Ratios For Above Calcualtions:

Pumps at 70% of maximum flow

Ratio	Flow Control Method
0.40	Variable Frequency Drive
0.94	Discharge Valve
1.00	Bypass Valve
1.00	No control

The "maximum flow" of fans/pumps based on the accepted assumption that they operate at 60% and 70% of maximum flow or capacity rates respectively, in HVAC applications.
The same accepted assumption is true of the "Ratios" of various flow control methods.
Substantiation data may be found in the ASHRAE Handbook, HVAC Applications Volume.

Savings based on conservative assumptions, do not include additional savings associated w/improving the Power Factor with VFDs (~.98), reducing Demand Charges, and increasing Electric Rates.

By finding the kW generated with the present pump control method (none) and then subtracting the kW generated by a pump with a VFD control, one can find the savings in kW resulting from the installation of a VFD. Then by assuming the pump operates 24/7 from May to August each year the hours of operation per season is found to be 2,952 hours. Using this number with the Appledore Island price of electricity of $0.54/kWh allows for the yearly savings to be calculated using the following equation:

$$Yearly\ Savings = \frac{kW\ saved\ \times hrs\ operated}{Motor\ Efficiecny} \times \frac{\$}{kWh}$$

This yields a savings of $6,187 per year, assuming that the pump runs 24/7 from May to August. The assumptions made using this method also apply typically to pumps in HVAC systems. The effect on this calculation is unknown, but one would assume that the pump operation would be similar. Nevertheless, this calculation was made to provide a rough estimate of the potential savings a VFD could bring, which is why the interns recommend that the 2014 engineering interns investigate this further

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Island Engineers: Justin Shapiro and Alex Brickett

And the rest of the SML staff.