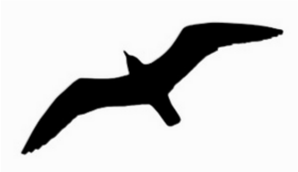
# 2014 Sustainable Engineering Report



Alan Bach, Michelle Bowen, Paroma Chakravarty, Sean Snow

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# Executive Summary

### Introduction

Shoals Marine Lab has always had a desire to better its environmental sustainability. Being a completely self-dependent island, it relies on its own energy producing systems to power the laboratories, kitchen, and dorms. The island owns three diesel generators that power the island if needed, but through the installation of a wind turbine and several solar arrays it is becoming much less dependent on diesel fuel.

Appledore Island's systems provide an excellent environment for sustainable engineering studies because they allow students to see entire systems at small scales. Starting in 2006, Shoals Marine Lab has provided an internship that allows future engineers to be exposed to sustainable systems. They are able to study each system, manage its performance, and offer suggestions to island staff for future advancements. This year the interns were tasked with examining the total cost of electricity, the performance of the new energy conservation building, generator performance versus battery charging rate, a new maintenance program for the green grid battery system, wind turbine performance, new well locations, and the waste water treatment system on the island.

### Calculate the Cost of Electricity

Island staff and engineers are interested in data regarding the cost of producing electricity on the island. Although the wind turbine and solar panels do not cost money to run and operate, the initial installation cost must still be considered. Using meters provided by the island, engineering interns will determine the approximate cost of producing electricity per kilowatt hour for the wind turbine, diesel generators, and PV panels. Currently, diesel appears to be the cheapest fuel and solar the most expensive, but with solar infrastructure set up its future cost is the lowest of all sources.

### Performance of the Energy Conservation Building (ECB)

The recent addition of the Energy Conservation Building has lead island engineers to wonder about its performance. Since it is relatively new, not much is known about how it operates or if it is meeting the manufacturer's specifications. The engineering interns have been tasked with monitoring the ECB and comparing their findings to the specifications provided by the manufacturer. This study will let the island engineers know whether or not their system is working up to standards. It was found that the solar array should be expanded to about 50 kW. Furthermore, a graphical interface was made for Dashboard, a program to display energy grid data in a user friendly format.

### Generator Performance vs. Battery Charging Rate

Earlier this year a battery bank was installed in the Energy Conservation Building that would serve as the power supply to most of Appledore Island. The batteries themselves are very particular regarding the charging and discharging rate and capacity. In general, the slower the charge, the longer the battery life, but there is usually an optimal charging rate that will allow the battery bank to charge to its capacity on time, while allowing for the maximum possible lifetime. Due to the newness of the battery bank, the optimal charging rate is not yet known, so the engineering interns focused on determining it. The optimal charging voltage was found to be 57V, and the optimal charging current was found to be as high as the generator will support. It was not possible to determine a specific number for the optimal charging current, due to the variability of the island load and population, but it was determined that the 27kW generator cannot put out enough power to damage the batteries. The optimal DOD was found to be 30%. However, it was also found that the way battery charging and discharging was controlled, through voltage setpoints, was resulting in much lower DODs than were expected.

### Designing a Maintenance Program for the Green Grid Batteries

The new battery bank located in the ECB are very sensitive to extreme weather conditions such as high and low temperatures. Since the batteries are a new addition, little is known about how much they are affected by these certain conditions. The interns were tasked with coming up with a feasible maintenance program to prevent the batteries from being harmed during the cold winters and hot summers. It was determined that temperatures on the island are not high enough to significantly impact battery lifetimes during operation. It was also determined that the batteries should be unharmed by winter temperatures provided that proper storage procedures are followed.

### Wind Turbine Performance

In 2007 Shoals Marine Lab installed a 7.5 kW Bergey Wind Turbine to help provide power to the weather station during the winter months when the sun exposure was less, and the wind was stronger. Since then, not much data has been recovered from the turbine to determine how much power it is actually producing. This is mainly because there is no measuring device located on the turbine to record or display the data. This year, the island is receiving a meter that will help engineers keep track of the turbines power output. The interns will use this meter to perform a quick analysis and see if the turbine is running as the manufacturer expected. It was found that the turbine was exceeding manufacturer’s expectations by about 27%.

### Siting a New Well on Appledore

Although the old well located on the northern end of Appledore provides the island with a water throughout the summer, it can get low due to over usage or lack of rain that season. One issue with the twenty foot well is that if it gets down to a certain level, it will mix with the saltwater watershed which would deem the well unusable for consumption. Past interns have designed and tested alternate forms of freshwater sources including rain water, Crystal Lake, and solar stills. Several groups of interns have explored these options, but none have found an adequate alternative for the primary well. The 2014 interns have been instructed to locate a place for a new well to access the freshwater aquifer from a different part of the island. Using watershed data from previous interns and new calculations, the 2014 interns identified the current well’s watershed and attempted to add a watershed layer to the GIS.

Further, interns worked with Tom Ballestero from UNH to design a winter experiment to identify leakage from the aquifer.

### Waste Water Treatment

Appledore Island has come a long way with its waste water treatment systems since Shoals Marine Laboratory was started in 1966. The island has since installed four septic systems, three leach fields, four compost toilets, and one FRICKle Filter ™. All of these different waste water treatment processes require maintenance and inspection. The 2014 interns were tasked with sampling the various systems and determining their effectivenesses. Through inspection, the interns found that the FRICKle Filter ™ was not working as the manufacturer specified. The foam medium in the last chamber was breaking down and risking clogging the leach fields. The foam was removed, and it was requested that a plastic medium be used in place of the foam. The interns found that most of the septic tanks need to be pumped, but the water quality coming out of the tanks is adequate. The composting toilets are in need of some additional maintenance, but are overall doing well.

### Rock Talk for Appledore Residents

Appledore Island offers numerous marine education classes for students in high school and in college. Because most of the students coming to Appledore have a background in biology, many are not familiar with the engineering systems on the island. The interns have been asked to give a 30 minute “rock talk” to students and faculty who may not be familiar with the sustainable engineering practices on the island. The goal of this talk was to increase awareness of power generation on the island and encourage conservation of the resource.

# Calculate the Cost of Electricity

## Background

The 2011 Engineering Interns calculated the cost per kWh to produce electricity using the diesel generator at $0.54/kWh, the solar panels installed on Dorms 2 and 3 at $0.69/kWh and the wind turbine at $0.94/kWh. Significant changes in the electrical generation on Appledore Island have been made and the cost to produce electricity needs to be recalculated to reflect the current operations.

## Objectives

The cost of generating electricity from solar, wind, and diesel on Appledore Island will be calculated.

## Theory

The diesel calculation was simple multiplication between energy generated, fuel used, and cost of fuel using the generator fuel logs. Solar and wind were not quite as simple, as most of their costs are up front rather than during energy production. Therefore, after figuring out costs a theoretical lifetime energy production had to be calculated for wind and solar (split into old solar and ECB solar). By measuring actual energy output from the renewable sources and comparing it to their theoretical output, a projected actual lifetime energy generation was found. Dividing cost by generation allowed the attainment of the cost of electricity. All costs had to factor in transmission losses from production site to load input. Monetary depreciation effects were not considered.

## Procedure

Diesel electricity generation cost was calculated via **Equation 1.1**:

$$\frac{\$}{\boldsymbol{kWh_{DUseful}}} = \frac{\$}{gal} * \frac{gal\ used}{kWh_{produced}} * \frac{kWh_{produced}}{kWh_{DUseful}} = \frac{\$}{\boldsymbol{gal}} * \frac{\boldsymbol{gal\ used}}{\boldsymbol{kWh_{produced}}} * \frac{\boldsymbol{1}}{\boldsymbol{PF}}$$

Where PF is the power factor and accounts for transmission losses. The 2011 interns calculated that the power factor of the island ranged from .65 to .85, and so a value of .75 was used. In reality, transmission losses are probably a little bit larger, as some diesel energy is stored in the batteries, which results in further losses (there was no ECB battery bank in 2011 and so the past interns could not have factored in these losses into their calculations). Note that the $/gal cost accounts for both the cost of the actual fuel and the cost to ship the fuel to the island. The gallons used vs. kWh produced was found during an arbitrary day by dividing cumulative fuel use up to that day by cumulative energy production. As the major costs of most fossil fuels are during the use phase, initial and end of life costs were ignored.

For wind and solar, battery bank losses could not be ignored because all of their energy passes through the battery bank. Based on calculations of energy losses, it was estimated that the battery bank path had an efficiency of about 68% (see assignment 2 for more details of this estimate). Furthermore, costs of solar have to factor in the costs of their respective battery banks, and, in the case of the ECB solar, the cost of the ECB building itself, as these would not be needed if there were no renewables. However, while the wind energy utilizes the ECB battery bank, all costs related to the ECB was attributed to ECB solar, as prior to the ECB solar the wind turbine did not generate enough intermittent energy to warrant such batteries. Maintenance costs were ignored for the renewable sources, which is a quite accurate assumption for solar, but less so for wind (presumably due to its moving parts).

ECB Solar was calculated via **Equation 1.2**:

$$\frac{\$}{\boldsymbol{kWh_{SUseful}}} = \frac{\$_{PV} + \$_{ECB} + \$_{Bat}}{e_W * E_{TS}} * \frac{kWh_{produced}}{kWH_{SUseful}} = \frac{\boldsymbol{\$_{PV} + \$_{ECB} + \$_{Bat}}}{\boldsymbol{e_W * E_T}} * \frac{\mathbf{1}}{\boldsymbol{eff_{bat} * PF}}$$

Where

- \$ = the cost of the PV panels, ECB building, and ECB batteries respectively.
- $eff_{bat}$ = the conversion efficiency of the battery bank system (68%).
- $E_T$ = the theoretical lifetime energy production of the panels
- e = the effectiveness, defined as the ratio of energy produced on sampling days vs. theoretical energy production on those sampling days is **Equation 1.3**:

$$e = \frac{E_{actual}}{E_T}$$

Basically, the denominator of the first fraction of **Equation 1.2** is the projected lifetime actual energy production.

Note that since effectiveness has theoretical energy in its denominator the calculated theoretical energy production actually had no effect on projections for lifetime actual energy production, as long as the effectiveness for days where there was actual data was consistent compared to days where no data was available. Theoretical energy production was for the period of May-September, the approximate time period where there are people on the island, using daily solar radiation information from the NREL, with corrections for the fact the panels are tilted via tabulating the formulas found at http://www.pveducation.org/pvcdrom/properties-of-sunlight/solar-radiation-on-tilted-surface (see "Radiation on a Tilted Surface" spreadsheet in file "Solar Radiation" on digital appendix).

First, **Equation 1.4a**:

$$S_{PV} = \frac{S_h \sin(\alpha + \beta)}{sin\alpha}$$

Where:

- S = solar irradiation in $W/m^2$, for the PV panels and for a horizontal surface respectively
- $\beta$ = Tilt angle of the panels (the roof or panel angle)

- α = is the elevation angle, defined by **Equation 1.4b**:

$$\alpha = 90° - \ \varphi + \delta$$

Where:

- $\varphi$ = the latitude: 42.99°
- δ is the declination angle, defined by **Equation 1.4c**:

$$23.45° sin[\frac{360}{365}(284 + d)]$$

Where d = day of the year.

Note that NREL has average daily radiation for the month, yet each day in a month will have different radiation amounts, which would throw off effectiveness if the days where there was actual data were abnormally sunny or cloudy. The theoretical energy production from the panels for the given solar radiation was $174 W/(W/m^2)$ for the roof panels and $178 W/(W/m^2)$ for the ground panels respectively per module, with 36 roof and 72 ground modules total (CS6P). The panels were grouped together by their tilt angle and their theoretical output calculated via **Equation 1.4d**:

$$nP \sum_{i=121}^{273} a_i S_i$$

Where:

- n = number of panels at that tilt angle
- P = the performance of the panels, 174 or 178 $W/(W/m^2)$
- i = the day of the year, from May to September
- a = the angle correction for solar radiation
- S = solar radiation in units $kWh/m^2/day$

Afterwards, the output from each tilt angle group were summed together to get total output.

Old Solar had to be calculated using a different approach, as specifications for the old solar panels could not be found. Furthermore, Old Solar used costs relevant for its own equipment (the old solar did not have building costs because it is housed in the radar tower, which was preexisting). Since the same batteries were used as in the ECB, it was assumed the cost per battery was the same, which may or may not be true. The total panel costs (including presumably batteries) were taken from the 2011 report with the battery portion of the cost doubled to account for the expected lifetime of the panels is twenty years, while the expected lifetime of the batteries is about ten years. Because there is much less information available about the old grid, it was assumed battery conversion efficiency was at the same level as the new grid. The final equation for Old Solar was thus **Equation 1.5**:

$$\frac{\$}{kWh_{OSUseful}} = \frac{\$_{tot} + \$_{Bat}(\frac{y_{PV}}{y_{Bat}} - 1)}{y_{PV} * E_{sam} * \frac{X_{yr}}{X_{sam}}} * \frac{1}{eff_{bat} * PF}$$

Where:

- $\$_{tot}$ = total initial cost calculated by the 2011 interns including the batteries
- $\$_{bat}$ = cost of the batteries
- y = lifetime in years (the term in numerator with years accounts for the fact that battery costs should be applied twice due to the shorter lifetime while factoring in that the total cost already accounts for the battery cost once)
- $E_{sam}$ = the energy produced on the sample days where data was available
- X = the kWh/m$^2$ produced

Basically, the denominator of the first fraction found the energy production on the sampling days, found the solar radiation on the panels for those days to get a ratio of energy production vs. solar radiation, and then multiplied that by total solar radiation form May-September to find annual energy production. This was then multiplied by lifetime to find total lifetime energy production. Besides the aforementioned tweak in cost, the rest of the equation remained the same from ECB solar.

Wind was calculated in a similar manner as ECB solar via **Equation 1.6**:

$$\frac{\$}{kWh_{WUseful}} = \frac{\$_W}{e_W * E_T} * \frac{1}{eff_{bat} * PF}$$

With an assumed similar battery conversion efficiency and power factor as solar. The theoretical energy production was calculated by first gathering ten minute interval wind speed data from NOAA for May-September for the last five years and separating each speed into a wind speed bin (a wind speed bin is all occurrences of wind speeds from a certain range, for example between 3.15-3.25 m/s). While interval wind speed averages should slightly underestimate available energy, as available wind energy has a cubic relationship with wind speed, the ten minute time interval was small enough that there should not have been large variations in wind speed within each interval. The frequency of each wind speed bin was counted, and the probability of each wind speed occurring calculated via the fraction of times the wind speed was recorded. The values of the wind speed bin were then corrected for the wind speed at the turbine height via **Equation 1.7**:

$$u_{turbine} = u_{ref}\left(\frac{z_{turbine}}{z_{ref}}\right)^{\mu}$$

Where:

- u = wind speed
- z = height above sea level

- μ = a wind shear coefficient, which from the 2011 report is 0.11 for open waters.

The reference height was the NOAA station at 32.3m above sea level and the turbine was estimated to be about 125 feet above sea level (since it is on elevation from 40-50 feet above sea level, and the turbine tower is 80 feet tall).

A power curve graph of power produced vs. wind speed was then found to convert wind speed bin into power. Because the actual values of each point on the graph was not known, instead different points on the graph was tabulated and power output equations were calculated via a graphing calculator for different wind speeds. It was found the power curve was best modelled by a 3-part piece-wise function: 0 for wind speeds of below 7.5 mph, a quartic equation for speeds up to 35 mph (roughly the speeds where increased wind speed meant increased power), and a cubic equation for speeds above 35 mph, as power tapered off afterwards. Note that unlike most wind turbines, the unique pivoting of the Bergey wind turbine meant that there was no cutoff wind speed where the turbine had to shut down due to fear of damage (although power output does decrease above about 30 mph).

Once the power for each wind speed was found, the annual theoretical energy production was found via **Equation 1.8**:

$$T \sum_{i=0}^{\infty} p_i P_i$$

Where:
- T = the time the turbine is operating per year.
- i = a wind speed bin.
- p = the probability for that particular wind speed to be occurring at any given time.
- P = power output for that wind speed bin.

When the annual energy production was multiplied by the lifetime (which was estimated to be 36 years based on 15 year lifetime until major renovations / [(5 months in operation)/(12 months/yr)]) the total lifetime theoretical energy output was calculated (altE Store).
(see "Wind Calculations" in the appendix of the electronic version of this report for tabulated data. Note that in "Wind Calculations" originally Weather Underground was used for the weather data, but it was found NOAA had much more consistent and frequent sampling intervals. There are calculations from both sources in the appendix).

The effectiveness originally was to be calculated via comparing instantaneous wind speeds (and thus using the power curve to find theoretical power output) with actual power output, but it was found that power output had too large of a variance even from second to second. Therefore, instead the total actual energy production was found over several days, and then the wind data was gathered over these same days in order to use the power curve to find the sample time's theoretical energy production via **Equation 1.8** with the time period modified. Effectiveness was then calculated via **Equation 1.3**.

## Results and Analysis

In mid-June, it was recorded that 958.5 gallons of diesel were used to produce 10.066 MWh of electricity. At \$3.71/gal and using a 0.75 power factor, it was calculated that diesel had a cost of \$0.47/kWh. It is interesting that the 2011 interns made no mention of power factor and got a similar result (\$0.54/kWh), while having similar diesel costs (about \$4/gal) and having similar energy generation per gallon diesel. Whether the 2011 interns did factor in power factor but failed to mention it or made some miscalculation is unknown. Diesel prices are expected to have end-use prices of \$3.50/gal by 2017 and \$4.73 by 2040 (EIA). While the current \$3.71/gal also accounts for the cost of a barge to transport the fuel to Appledore, Appledore buys fuel in bulk, and so the cost of the barge is roughly offset that Appledore can get a better deal on the diesel (as shown that \$3.71/gal is approximately the current cost for end-use diesel in the U.S). Therefore, unless a more precise value for power factor is calculated, the island's grid is reworked, or there was a gross error in calculation, this \$0.47/kWh should be roughly correct for quite some time to come.

The ECB solar was found to have an effectiveness of 69.2%, with a theoretical annual energy production of 21943 kWh after accounting for the 14 degree tilt of the roof (36 modules) and measured 16 (18 modules), 16.5 (36 modules), and 17.5 degree (18 modules) of the surrounding panels on the ground via **Equations 1.3 and 1.4d** (see spreadsheet "Solar Radiation" on the digital version of this report for details. Note that the effect of tilt angle was calculated to be much more significant than given by the 2011 interns). It was assumed the panels have an effective lifetime of 25 years due to their 25 year warranty (the panels presumably will last a bit longer than their warranty, but panels decline to about 80% initial effectiveness in 25 years) (CS6P). The following cost calculations are summed up in **Table 1.1**.

**Table 1.1:** ECB Solar Costs

| Expense | Cost (\$) | Lifetime (yr) | Lifetime Cost (\$) |
|---|---:|---:|---:|
| PV Panels | 50,000 | 25 | 50,000 |
| ECB Building | 25,000 | 25+ | 25,000 |
| ECB Electrical (inverters, etc.) | 150,000 | 25+ | 150,000 |
| Batteries | 100,000 | 10 | 250,000 |
| Total | 325,000 | N/A | 475,000 |

The panels' cost with charge controllers and installation had a cost of \$50,000. With charge controllers having a lifetime of 177,000 hours and the panels only operating from May to September, it was assumed they would last the lifetime of the panels. However the total cost of the ECB was a much larger \$175,000, again presumably lasting the lifetime of the panels. The batteries had a cost of \$100,000 but only an estimated ten year lifetime (a twenty year lifetime is for constant float voltage, the ten year lifetime is a ballpark estimate), and so had a total lifetime cost of $250,000 (note that battery technology will likely vastly improve with time and so this is an overestimate). With the 68% estimated battery bank efficiency and 75% power factor, utilizing **Equation 1.2** gave a cost of solar at $2.45/kWh. However, the marginal (or future installation) cost of solar energy is much lower, $0.26/kWh (assuming similar panels, installation and no significant price changes), as no new ECB or batteries have to be purchased for additional solar, at least up to a certain point. Note that this $0.26/kWh does not account for the batteries possibly wearing out faster due to increased solar influx. In terms of environmental benefits, each ton of $CO_2$ abated by using cleaner solar generation vs. diesel had a cost of $2,791, but marginal costs of $CO_2$ abatement actually had savings of $300/ton (solar emits about 139g $CO_2$/kWh whereas diesel emits about 849 based on the island's current fuel consumption to energy generation ratio with a 86% by mass carbon content, 44g $CO_2$/12gC, 0.745kg/L. Note that emissions might actually be significantly higher due to the construction of the ECB building and island specific factors, Stokes).

The "2012 Master" file (see digital appendix) provided data on solar power for the last eight days of August. There was immense difficulty interpreting the spreadsheet that retrieved data from an Outback MATE3 controller in the radar tower, but it was discovered that ports 4 and 5 represented the solar panels. Of the four currents, only charge and buy current had the characteristic peak during noontime and a value of zero at night that solar has. However, unless the panels are functioning extremely poorly buy current provided too low values, and so it was assumed charge current was the solar input. For voltage, intuitively input voltage made more sense as the solar input, and also while both input and output voltages had feasible magnitude of numbers, input voltage had the more characteristic 100+V voltage of solar. The energy production values from each five second interval were summed to obtain a 247 kWh energy production over the eight sampling days (see "Old Solar Energy Production" in digital appendix). From the 2011 report the old solar panels are tilted an angle of 18.4 degrees, so for the eight days in August about 48 kWh/m$^2$ irradiated the panels compared to 927 from May to September, for an annual energy production of 4749 kWh, similar to the 2011 intern's theoretical annual energy despite a large disagreement between the 2014 and 2011 interns on the effect of the tilt angle. The twenty year lifetime estimated of the 2011 interns was used.

The cost for old solar was calculated as $100,722, from the 2011's report $70,722, with the cost of the batteries doubled ($100,000/40 batteries *12 batteries) since their lifetime is approximately half of that of the panels (again, battery technology will probably improve and so this cost is an overestimate). With assumed similar power factor and battery bank efficiency as the ECB panels, the cost of old solar was calculated to be $2.08/kWh, almost three times the value calculated by the 2011 interns. The difference was due mainly to the efficiency of transmission (factor of 2) and accounting for the cost of future batteries (factor of about 1.5). Assuming a similar pollution per kWh as for the ECB solar (which should be roughly true) this gave a premium of $2,265 per ton of $CO_2$ abated. The marginal cost of future solar installations connected to the old grid was assumed to be the same as those connected to the ECB, as panel prices have decreased in recent years beyond the cost of the old solar panels.

For wind, the power production calculated from the power curve was calculated to be **Equation 1.9**:

$$\boldsymbol{P = 0}, u < 7.5mph$$

$$\boldsymbol{P = 3.4794 * 10^{-5}u^{4} - 4.015 * 10^{-3}u^{3} + .1503u^{2} - 1.8041u + 6.932}, 7.5mph \leq u \leq 35mph$$

$$\boldsymbol{P = 4.945 * 10^{-4}u^{3} - 5.69 * 10^{-2}u^{2} + 2.076u - 16.35}, u > 35mph$$

Where P is power and u is the wind speed at turbine height. After obtaining the wind speed data and correcting for height above sea level via **Equation 1.7, 1.8 and 1.9** to calculate an annual theoretical energy production of 6057 kWh/yr, significantly larger than the 3537 kWh/yr calculated by the 2011 interns (see "Wind Calculations" in digital appendix). Considering that the percent variation in energy between the windiest and least windy years should be on approximately 38%, using different wind speed data should not account for such large discrepancies (Wan 2). The 2011 and the 2014 interns used practically the exact same method to calculate annual wind energy production, and so it is unknown where the difference came from. From July 5th, 2014 9:10am till July 8th, 2014 10:10am, a totalizer was run to find actual energy production during the sample period, while theoretical calculations for wind generation was performed at the same time. It was found that the turbine had produced 253 kWh during the sampling period, with a theoretical output of 200 kWh. This gave an effectiveness using **Equation 1.3** of 1.27. With a 36 year lifetime, 6057 kWh/yr, 1.27 effectiveness, and $125,000 total cost, it was calculated that the turbine had an electricity cost of $0.89/kWh, similar to the value of the 2011 interns. At approximately 9g $CO_2$/kWh (Stokes), wind has a premium of about $496 per ton of $CO_2$ abated. It is interesting to note that wind had a total cost of $125,000, yet the turbine and tower itself has a cost on the order of $30,000. Therefore, if installation and maintenance costs could be reduced wind would have a much lower marginal cost, and thus might become cost competitive.

Of the renewables, the payback period of current renewable installations are greater than the lifetime of the product, as they are all more expensive than diesel. However, the payback period of future PV panels (assuming no energy beyond current levels is wasted) is 13.7 years.

**Tables 1.2** and **1.3** sum up costs of electricity and cost of conserved $CO_2$ on the island. Note that regardless of source, electricity costs on the island are significantly higher than on the mainland (roughly $0.10/kWh).

**Table 1.2:** Cost of Electricity

| Source | 2011 Calculations ($/kWh) | Current Cost ($/kWh) | Marginal Cost ($/kWh) |
|---|---:|---:|---:|
| Diesel | 0.54 | 0.47 | 0.47 |
| ECB Solar | N/A | 2.45 | **0.26** |
| Old | 0.69 | 2.08 | 0.26 |

| | | | |
|---|---|---|---|
| Solar | | | |
| Wind | 0.94 | 0.89 | 0.89 |

**Table 1.3:** $CO_2$ Emissions

| Source | Type | Emissions ($gCO_2$/kWh) | $CO_2$ Savings Cost (\$/ton $CO_2$) | Marginal Cost (\$/ton $CO_2$) |
|---|---|---|---|---|
| Diesel | Emissions | 849 | N/A | N/A |
| ECB Solar | Savings from diesel | 710 | 2791 | -300 |
| Old Solar | Savings from diesel | 710 | 2265 | -300 |
| Wind | Savings from diesel | 840 | 496 | 496 |

For future interns: if a more detailed explanation of methodology is needed email alan.bach@comcast.net.

## Recommendations

Because solar has the lowest marginal cost (at least until there is so much solar that the battery bank can no longer store the majority of the energy) while being significantly better for the environment than diesel, it is recommended that more solar panels be installed. For calculations on optimal panel size, see Assignment 2. However, note that since the marginal cost of PV is only about half of diesel, PV can still be profitable with significant energy losses. After the interns gave their final presentation, it was discovered that Star Island also had performed calculations on diesel and found that the assumption that initial costs are insignificant may not be true (their calculated diesel cost was approximately \$0.80/kWh). While the overall message is still solar is the cheapest marginal source, if more accurate diesel costs are needed the value should be recalculated.

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# Performance of the Energy Conservation Building (ECB)

## Background

The 2012 Engineering Interns evaluated and determined a battery bank size to power Appledore Island. In the spring of 2014, a 300kWh battery bank and an additional 26kW of solar power will be installed for this purpose. Also, SML plans to display the performance of the "system" through a program called Dashboard which allows users anywhere to see the "system's" performance through the Internet.

## Objectives

Using actual operating data, determine if the system proposed in 2012 functions as expected. The Interns will compare the theory based sizing of the battery bank and photovoltaic input with the performance of the actual installed system. The interns will make recommendations for future photovoltaic installations. The Interns will work with SML staff to set up widgets and apps in Dashboard to best display the "system's" performance.

## Theory

It was found early on that while the 300 kWh battery bank recommended by the 2012 interns was implemented, their optimal 50 kW PV array size was not. Also, the current batteries use an approximately 30% depth of discharge (DOD, the capacity of the battery that is used each cycle. A 30% DOD for a 300 kWh battery bank means usage of 90 kWh of the battery), whereas the calculations for the 50 kW PV size assumed a 10% DOD. Having a higher DOD means that the optimal PV size should be even larger than 50 kW. Since the current 26.28 kW PV array is much smaller than the recommended 50 kW, clearly, the battery bank was deemed more than sufficient, yet the panel size was much too small, and so the current system does not exactly function as "expected". Clearly, the recommendation should be for more PV panels to be installed. Therefore, the non-Dashboard part of this assignment was focused on gathering actual data on island energy usage and ECB solar energy production to more accurately model what PV panel size was optimal.

Little could be done on the Dashboard section of this assignment, as there were unforeseen delays out of the interns' control on implementing the system. Therefore, the only progress that could be made with Dashboard was brainstorming what data should be displayed for public perusal and how such data should be presented.

## Procedure

The sizing of the PV arrays was modelled using the same battery sizing spreadsheet provided by Lee Consavage as the 2012 interns (see Excel file "Battery Sizing" in the appendix of the electronic version of this report). Basically, the spreadsheet requires the user to input PV array size, efficiency of the PV panels, and battery bank size, and outputs hours per day the diesel generator must be on, along with the

DOD the batteries are put through per cycle. The spreadsheet makes several simplifications of the system:

- The spreadsheet causes the generator to toggle on and off for five minute intervals whenever the batteries fall below some minimum threshold, with all energy flowing to the batteries. In actuality, the generators supply energy directly to the island, bypassing the batteries except to store excess generation. All in all, this misrepresentation does not have an effect on deciding PV panel size (except diesel is modelled as having 100% efficient transmission to the inverters while the PV panels don't); the spreadsheet just centralizes all energy demand from the battery.
- The generator on time is the time required if the generator was running at full power. Since the generator often runs at lower capacity, it will actually be on for much longer than this number.
- The spreadsheet uses the solar irradiance for a "typical day" and so does not distinguish between cloudy and sunny days
- The spreadsheet does not account for wind energy. As the meter for wind at the time of writing still needed fine tuning to obtain minute by minute generation, there was no way to implement it into the spreadsheet.
- Power factor was not considered because the inverters (where load output is recorded) is very close to the batteries/diesel generators, and so most transmission losses are already accounted for.

In addition, several key changes were made to the spreadsheet:

- The spreadsheet as set up often had the start of the time simulation have a different battery charge percentage as the end. This was an issue, as the calculated generator on time per day does not factor in the remaining energy of the battery compared to the beginning. Yet if for example the batteries were more fully charged at the end than at the beginning, then the next day would require the generator on time to be less than the one before. Similarly, if the battery percentage decreases in the simulation, the generator on time should run on following days more than that calculated. To have roughly the same battery percentage at the start and beginning, the starting battery percentage was set close to the minimum allowed percentage (when the generators kick in), and the start time was set in the morning, so that the batteries have a chance to fall back to the minimum allowed percentage at the end of the simulation (at night).
- The DOD range which the battery is allowed to operate in is relatively fixed for Appledore's system. When the batteries would surpass their DOD, the energy is burned off by the dissipaters, and thus is wasted. However, the spreadsheet had a free flowing DOD, and in fact the battery could reach above 100% charged. It therefore seemed more realistic to have the spreadsheet fix DOD, having all energy burned off when the battery would exceed the DOD instead be treated as zero production. In the process, DOD was changed from an output into a required input. Note that the DOD range can be much lower than the maximum allowed DOD if PV array size is

small. Also, since the DOD is only checked every five minutes, the DOD can be exceeded slightly.
- The solar panels were previously assumed to be 65% efficient at supplying energy. Using the 10.192.0.43 IP address for the Schneider Electric monitoring system in the ECB it was found that energy load output (recorded at the inverters in the ECB) was about 83% of that produced. Assuming most losses came from the PV panels (while not true, diesel losses are probably much smaller due to most diesel energy not passing through the battery bank and most transmission losses occurring after the inverter, as the generators are close in location to the inverters) and ignoring wind power due to lack of data, the following equation was used to find a panel efficiency of about 68% (the uncertainty for this number is quite large and has a large effect on optimal panel size). This 68% was also used for the battery bank efficiency in assignment 1 (E is the energy for panels, diesel, and load respectively, x is panel/battery bank efficiency of 68% that had to be found) via **Equation 2.1**:

$$xE_S + E_D = E_L$$

- It was apparent that Appledore Island has very different energy consumption at different periods in the season. Also, looking at past energy trend logs, it seemed that energy usage has gone down in recent years (for example, in the last few years the beginning of the season saw usage of about 300 kWh/day, while this year usage was as low as about 250 kWh/day. Therefore, the five minute interval energy usage found by the 2012 interns now serves as an upper limit of energy usage, and so data was gathered for “low” and “medium” usage days too, as energy usage is one of the main factors that affects how many panels are optimal.
- Actual five minute interval solar production data was gathered to replace the theoretical data previously in the spreadsheet. The new solar production data had production more spread out during the day, and possibly because the data was collected from a relatively sunny week overall solar production was greater.

Since current battery bank size is 300 kWh, with approximately 30% DOD, these were the parameters used for the spreadsheet. The PV array size was varied from 26.28 kW (current size of ECB solar) to 100 kW for three different scenarios: “low energy” usage (252 kWh used during the day), “medium energy” usage (369 kWh/day), and the 2012 interns usage (representing high usage, 468 kWh/day) (see last four spreadsheets in “Battery Sizing” on digital appendix).

For Dashboard, information on what data the current meters collected were found so as to figure out what info could be feasibly displayed. The focus was to express the info in terms tangible to the layman.

## Results and Analysis

The three scenarios, low, medium, and 2012 energy usage, are illustrated below in **Figure 2.1, 2.2,** and **2.3** for the current 300 kWh battery bank.

**Figure 2.1:**

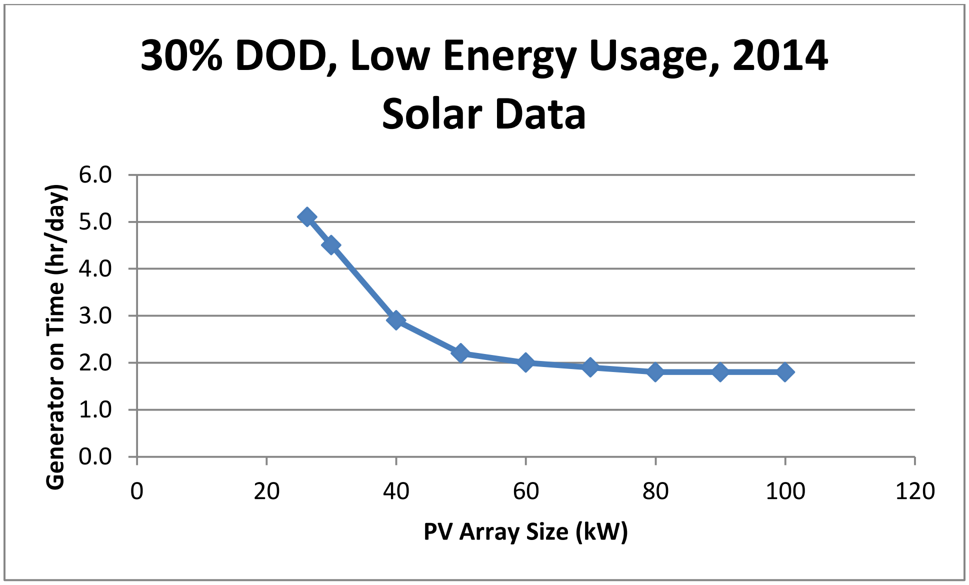


**Figure 2.2:**

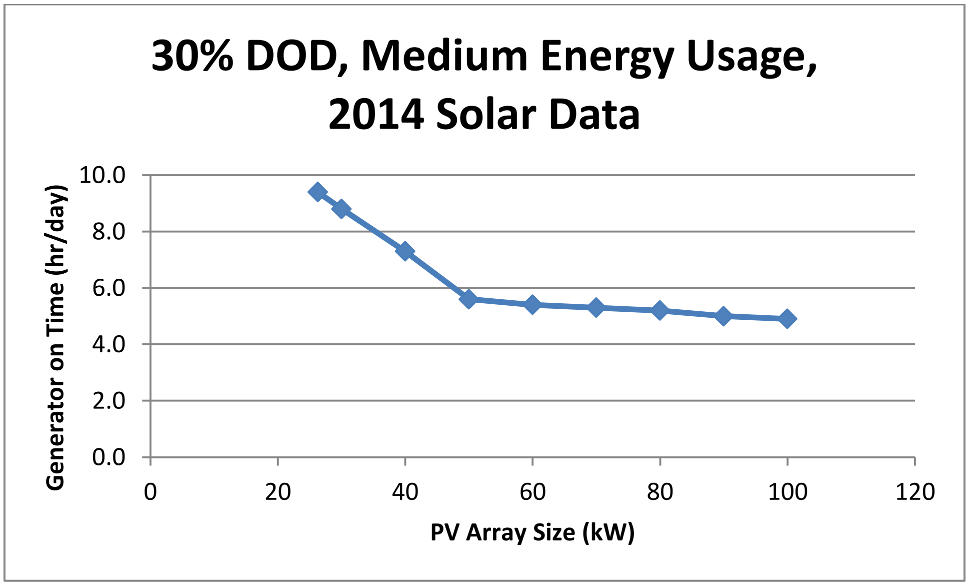
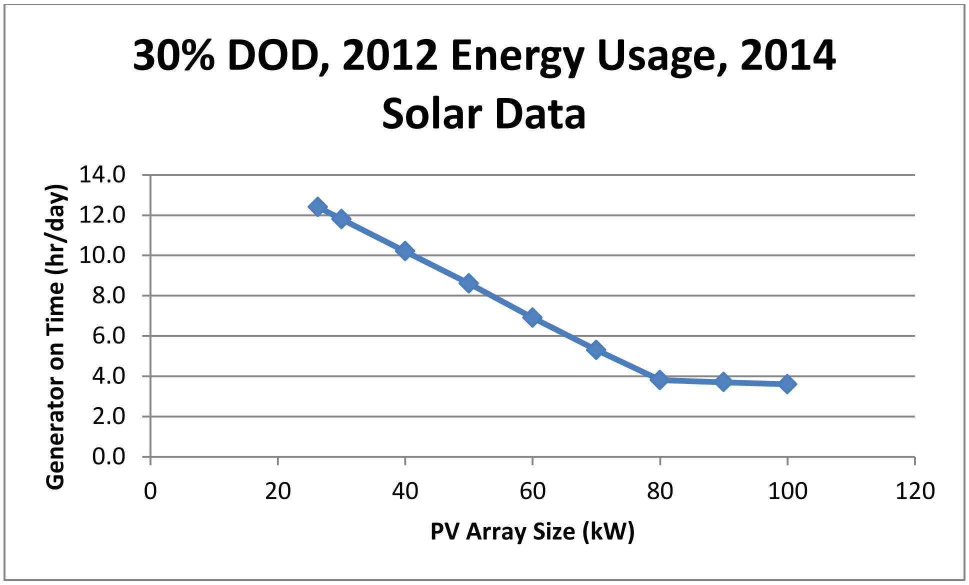


**Figure 2.3:**



Other scenarios are illustrated in the spreadsheet “Generator on Time vs. PV Size” in the Excel File “Solar Radiation” in the digital appendix (note that having for example a 40% DOD for a 300 kWh battery bank is equivalent to having a 30 % DOD for a 400 kWh battery bank).

For each “hour” less of generator on time (actually each 27kWh less generator production) per day, $0.471/kWh* 153 days/yr *25 yrs = $48,600 saved. At a marginal cost of $50,000 per 26.28 kW capacity, this means that panels are worth it if they reduce generator on time by one “hour” per 25.6 kW of panels. By this logic, the optimal PV size when there is low, medium, and 2012 interns energy usage respectively is approximately 50 kW, 50 kW, and 80 kW. Therefore, a 50 kW array size appears to be optimal, the same number found by the 2012 interns. However, there are many factors that affect optimal panel size:

Factors that would increase optimal PV array size:

- Dry years that cause the need to turn on the energy intensive reverse osmosis machine,
- Expansion of programs on the island.
- Diesel generator having a lower than 100% efficiency of transmission to the inverters (not entire system).
- The week for which solar radiation data was collected was fairly sunny. Actual solar radiation will probably be lower.
- Performance of panels will probably decrease over time.

Factors that would decrease optimal PV array size:

- The Battery Sizing spreadsheet does not account for production from the wind turbine.

- Future panels having solar tracking features or being at a more optimal tilt angle (the calculated optimal angle was approximately 27 degrees, about double of that of the 2011 interns, including factoring in that the panels would mostly only be operating from May-September).
- There is no data of whether the predicted DOD matches the actual DOD. However, it is predicted that the actual DOD is higher, as the generator operates generally at least 60% capacity regardless of the load, and so when turned on can supply quite a bit of energy to the batteries.

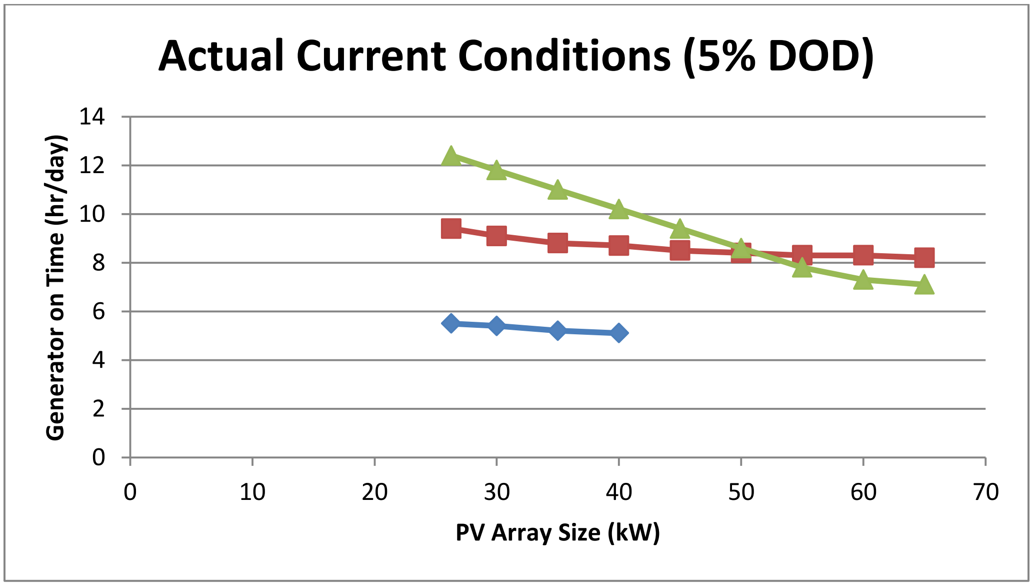
Factors that would have an unknown effect on optimal PV array size:

- Individual days will not only have different energy usage than the spreadsheet, but will have different hourly or even 5 minute energy usage. Massive spikes of usage at unforeseen times can especially throw the spreadsheet off.
- The 68% assumed efficiency of the PV panel energy through the battery bank is highly uncertain. However, if a more accurate number is found the correction is very simple: optimal PV panel size is inversely proportional to efficiency.
- Future panels having different daily energy production per kW capacity.
- Cleanliness of panels (cleaner panels e.g. if past intern's gull deterrent solutions are implemented would decrease optimal panel size, or dirtier panels if future cleaning efforts are not undertaken).

Because of all these uncertainties, any modelling can at best achieve a ballpark estimate of optimal PV array size. Note that slight increases in kW capacity from optimal have very quick diminishing effects. Therefore due to the uncertainties it may be better to err slightly on the more conservative side of panel size.

However, it was found that the 30% assumed DOD was actually incorrect for the current system; while intended to be 30% DOD the current system actually only uses about 5% DOD (see assignment 3 for details). Therefore, the above graphs are only relevant once the battery bank is fixed to function as expected. In the meantime, the generator on time vs. DOD for low, medium, and high energy usage is displayed in **Figure 2.4** below.

**Figure 2.4:**



The optimal PV size becomes current size or smaller for low usage, about 35 kW for medium, and about 60 kW for high usage. The reason high energy usage has lower generator on time at some points is because the energy usage is distributed at different portions of the day than the medium usage. Therefore, the optimal PV size for the current faulty system is very roughly 5-10 kW larger than the current 26.28 kW array (or perhaps 0-5 when factoring in the wind turbine).

Note that despite the batteries running into their DOD limits even with no additional PV installations for low energy usage, increases in the battery bank size is still not recommended. For example, for the lower energy usage scenario with the current PV array size and the actual 5% DOD generator on time only decreases from 5.5 to 5.1 hours when an additional 200 kWh of batteries are added.

The interns sat down with Mike Rosen to figure out what data should and could feasibly be displayed on Dashboard. Several names of the meters were changed, some data constraints were found, and additional things were suggested to display (e.g. $CO_2$ abatement). Furthermore, the interns were tasked with creating a graphical interface. After the discussion, the interns made a draft graphical interface organized into five tabs (see the below table “Dashboard” and the illustrations “Dashboard Interfaces”). Within each tab there was a selection for two graphs, usually between the ECB grid system and the old grid. For the non-advanced tabs, the graphs displayed the energy production or consumption (in kWh) on the y-axis and the time interval on the x-axis, with an option to switch between time intervals (hourly, daily, monthly, and yearly). To the left of each graph was displayed power and $CO_2$ emissions/savings that changed with which time interval was selected (note that $CO_2$ calculations uses standard values, not ones specific to the island. Actual emissions will probably be higher.). On the bottom was an illustration relevant to the current tab, unit equivalents (e.g. normal household equivalent) to describe the energy usage in more tangible terms (also changing in value based on time interval selected), and information of the system. For the Island Power tab, a pie chart was added on the bottom that showed the current power sources for the entire island. For both renewables, the pie charts instead showed percent of renewables. For the Solar tab, the vertical axis included a label on its right side that displayed solar irradiance, PV panel temp, or ambient air temp along with energy output. For the diesel tab, a static graph showing the island’s reduction of diesel fuel consumption over the last few years was shown. These designs appear in **Figures 2.5, 2.6, 2.7, 2.8,** and **2.9.**

The Advanced tab differed significantly from the other four tabs. On the right was a graph for “Generator Charging”, the energy the ECB battery bank has to supply to the old battery bank, that displayed energy vs. time interval that was the same as the other four tabs (option to choose between hourly, daily, etc.), except the graph also included power in hourly intervals rather than having power being displayed off to the side. To the left, a graph for battery voltage and charging amps from the ECB inverters were displayed, in hourly intervals. Above each graph was information relevant to each system. **Table 2.1** below summarizes each section of the graphical interfaces.

**Table 2.1: Dashboard** (asterisked data change values based on which option and time interval are selected)

| Tab | Constraints | Option 1 | Option 2 | Top Graph | Left Sideboard Data | Bottom Left Data | Bottom Right Data |
|---|---|---|---|---|---|---|---|
| Island Power | None | Main Island Grid Power (meter 1) | Old Grid Power (meter 8) | Energy (hourly, daily, monthly, yearly)* | Power (kW)*, $CO_2$ Savings (lb)* | Island grid map, Normal Household Equivalent* | Description, % sources pie chart |
| Generator | None | Generator Power (meter 2) | none | Energy (hourly, daily, monthly, yearly)* | Power (kW)*, $CO_2$ Emissions (lb)* | Photo, Normal Household Equivalent* | Description, historic graph |
| Solar | Currently raw data for power output is not available for old solar without a large amount of modification or a 3rd party software | ECB Solar Radiation (meter 3) | Tower Solar Generation (meter 9) | Energy (hourly, daily, monthly, yearly)*, Solar Irradiance ($W/m^2$)/PV Panel Temp (F)/Ambient Air Temp (F)* | Power (kW)*, $CO_2$ Savings (lb)* | Photo, Normal Household Equivalent* | Description, % renewables pie chart |
| Wind | None | Wind Generation (meter 5) | none | Energy (hourly, daily, monthly, yearly)* | Power (kW)*, $CO_2$ Savings (lb)* | Photo, Normal Household Equivalent* | Description, % renewables pie chart |
| Advanced | Energy totalizer may not be available for inverters | ECB Inverters (meter 4) | Generator Charging (displayed simultaneously with ECB Inverters, meter 7) | none | Links to SML | Inverter Description, Inverter voltage/amps graph | Generator Charging description, Generator Charging power (kW) and energy (hourly, daily, monthly, yearly)* |

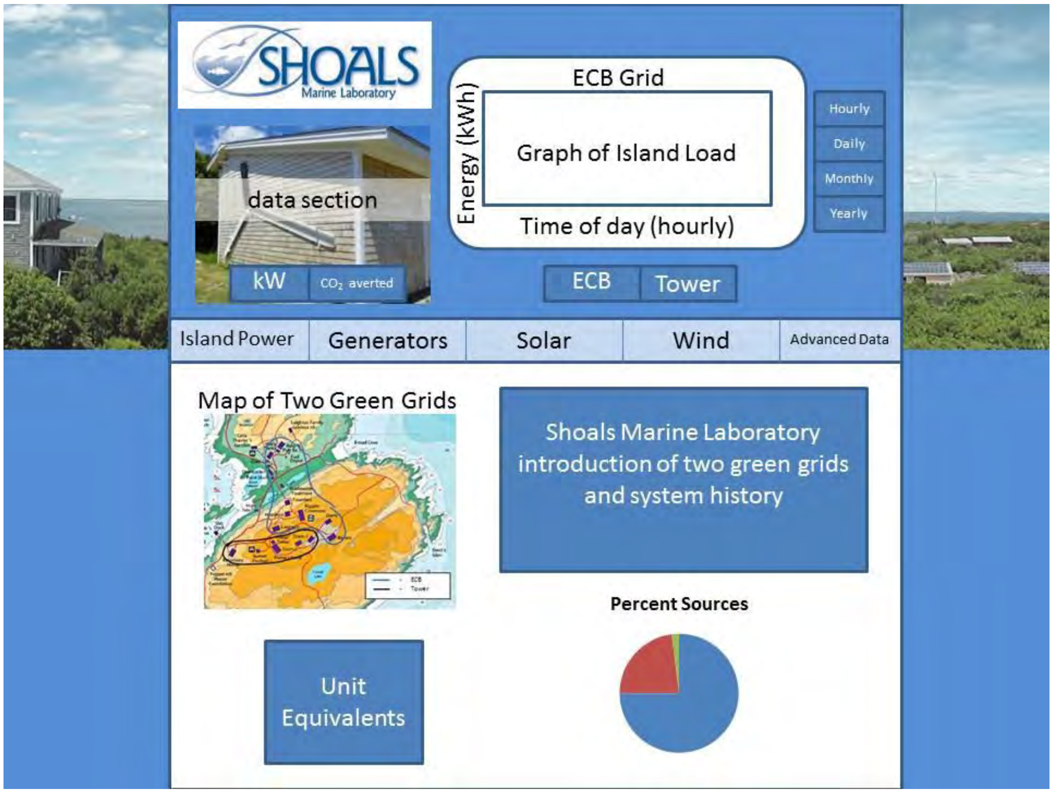


**Figure 2.5:** Dashboard home page (Island Power Tab)

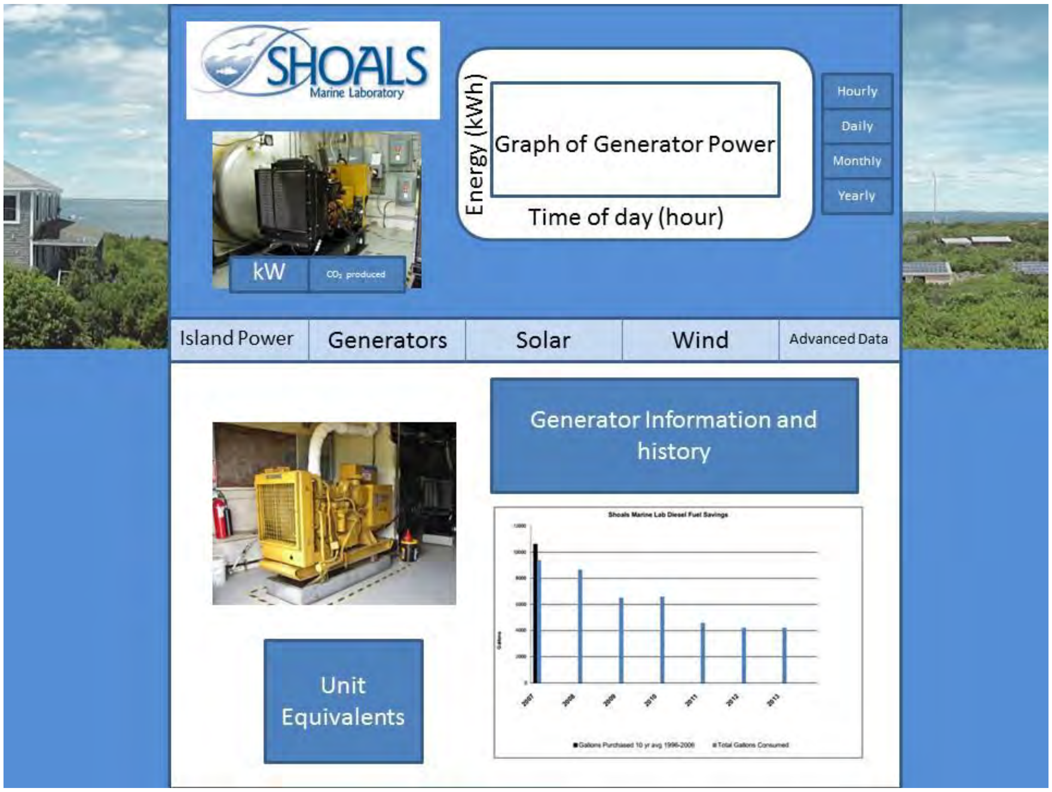


**Figure 2.6:** Generator tab

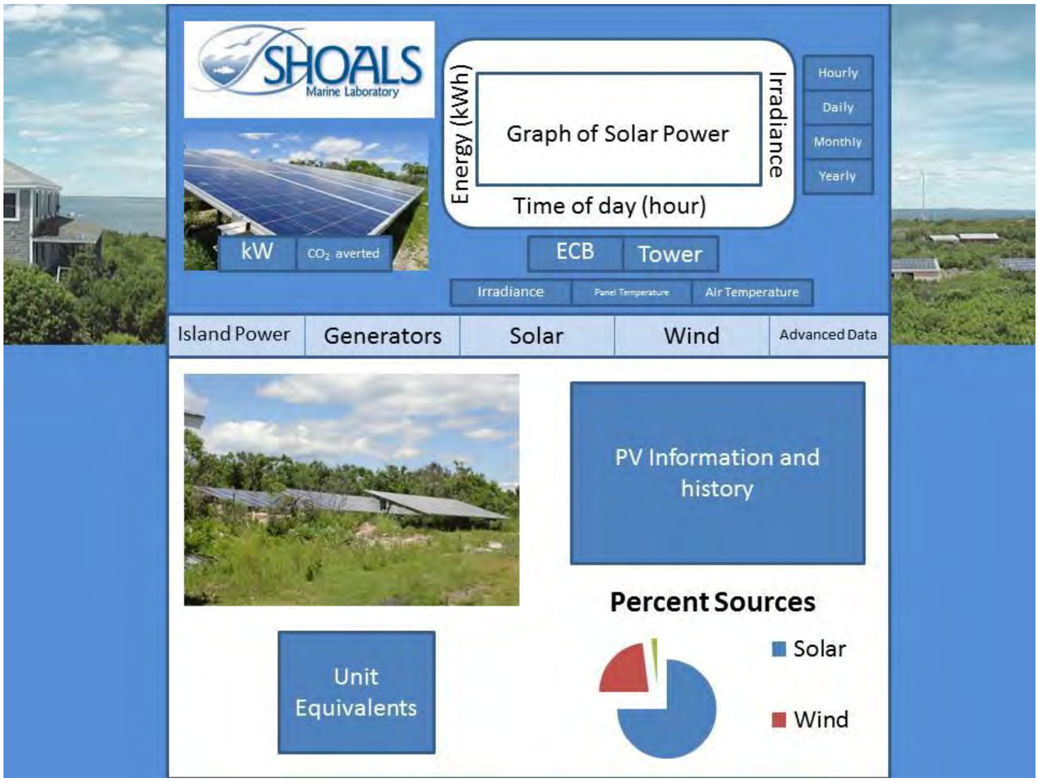


**Figure 2.7:** Solar tab

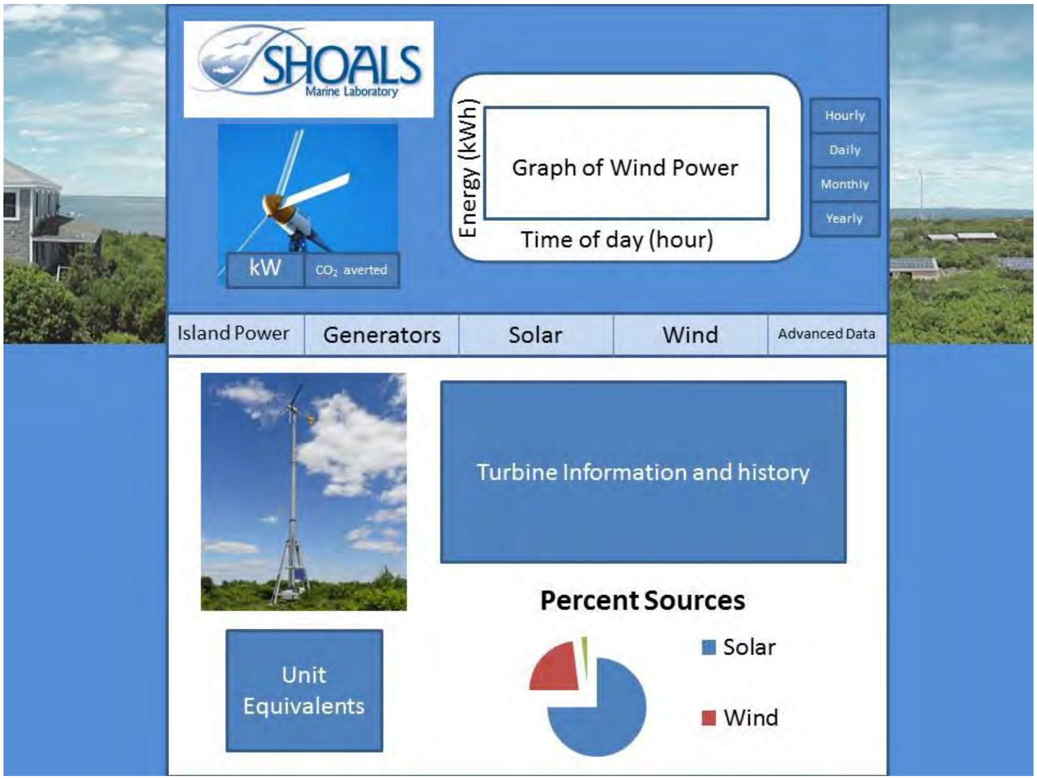


**Figure 2.8:** Wind tab

**Figure 2.9:** Advanced Data tab

Equations used to calculate all of the values that are not given by the meters are listed in "Dashboard Equations" on the digital appendix.

For future interns: if a more detailed explanation of the methodology is needed email alan.bach@comcast.net.

## Recommendations

It is recommended that once the batteries are correctly using 30% DOD that the ECB have its PV array size increased to roughly 50 kW, with no changes to the battery bank unless further expansion of the PV array is desired. If the battery DOD cannot be fixed 5-10 kW can still be added to the ECB PV array while staying within reasonable amounts of energy wastage.

A method to find the efficiency of energy transmission from production site to the inverters should be found for each electricity source (including the generators), and the battery sizing spreadsheet changed accordingly (for solar this would simply involve changing the 68% of "Efficiency of Total PV System", for diesel, multiplying column "I" by diesel's efficiency percentage would achieve the desired result). Furthermore, once a large amount of wind data is collected, the battery sizing spreadsheet should seek to implement the effects of the wind turbine.

Wind energy production should be observed to incorporate its effects on optimal PV size. Other uncertainties listed above, while generally expected to be of lesser magnitude, should also be investigated if possible.

Considering the significant energy losses through the battery bank, there should be research on whether there could be a smart toggle that would send renewable energy directly to the inverters when power is needed (bypassing the batteries), sending only excess to the batteries. This would also decrease the numbers of cycles in the batteries, increasing lifetime.

It is recommended that Dashboard be designed roughly in the layout proposed in the Results and Analysis section. Furthermore, if population data could be gathered an option that switched between total power/energy to power/energy per person could be implemented. Also, on the left sideboard for wind gathering wind speed data may be useful so that people can see the effects of wind speed on wind power generation. Finally, it might be beneficial to expand Dashboard to also include water usage, as water is heavily tied to energy on Appledore Island due to the reverse osmosis machine. Finally, a large screen in Kiggins Commons that displays Dashboard would be useful to raise awareness of energy usage upon the island.

## References

Consavage, Lee. Email. 23 June 2014.
Hamilton, David. Email. 2 July 2014.
Schneider Electric. Email. 26 June 2014.

# Wind Turbine Performance

## Background

Determine the effectiveness and level of usable output of the 7.5kW Bergey wind turbine.

## Objectives

Compare the manufacturer's specifications with the actual output of this system. Report findings and provide recommendations for usage and improvements

## Theory

Ever since the wind turbine was erected in 2006, island engineers have not had a device that could measure and record power production. During the summer of 2014, such a meter was installed allowing engineers and interns to see just how much energy the turbine is producing. Although the interns were not able to get much data from the meter due to its recent installation, they were able to obtain enough to calculate energy output over several days.

The task given to the interns asked them to determine if the wind turbine has the energy output given by manufacturer's specifications. In essence, the interns were tasked with finding the effectiveness of the turbine (the ratio of actual to theoretical energy output, **Equation 1.3**). Furthermore, methods to improve turbine performance were researched.

## Procedure

The calculations to figure out effectiveness were already performed in assignment 1. However, in this case the value of theoretical output actually has a huge bearing on the results. To reiterate the steps, actual energy output was gathered for several sample days using the new wind meter. Theoretical output was calculated via first gathering 10 minute interval wind speed data from NOAA and separating each wind speed range into wind speed bins. The frequency of each wind speed bin was counted and thus the probability of each wind speed bin occurring was calculated. The wind speed bins from the NOAA tower were then corrected for the height of the turbine via **Equation 1.7**. A power curve that related power output to wind speed was then found. An equation was derived for the power curve (**Equation 1.9**), and using **Equation 1.8 and 1.9**, the theoretical energy production was found (the time period in this case were the sample days that actual energy output was gathered). Using **Equation 1.3**, the actual output was divided by the theoretical to get effectiveness. Note that the effects of temperature and wind turbulence were not factored in, although being on open ocean turbulence is fairly low anyways.

In terms of improved performance, turbines can be made more efficient mainly in 3 ways: increase swept area, increase wind speed, and increase efficiency of transmission. Because swept area increases would require a new turbine and efficiency of transmission is a system-wide problem, the focus was on increasing wind speeds.

## Results and Analysis

The theoretical annual output was calculated to be 6057 kWh, compared to 8859 kWh (57.9 kWh/day over 153 days) from a WindCAD model and 3537 kWh from the 2011 report. As stated previously, it is strange that despite using the same methodology the 2011 and 2014 interns obtained such different results in theoretical output. Comparison to the 2010 interns was not performed because the 2010 interns used average monthly wind speeds (which would only be acceptable if wind speeds and power output had a linear relationship) and had a unit conversion error (failed to convert from mph to m/s).

During the sampling period of 9:10 am July 5th, 2014 to 10:10 am July 8th, 2014, the theoretical output was calculated as 200 kWh (see the "Effectiveness, Elec. Cost 2" worksheet in the "Wind Calculations" file on the digital appendix). However, the actual energy generation during the period was 253 kWh, an effectiveness of 1.27, greater than one. Note that this does not mean that the conservation of energy is being broken or that the calculation is necessarily wrong (although a miscalculation is certainly not out of the realm of possibility). There are several possible reasons for this greater than 100% efficiency:

- The given power curve may not be completely accurate, or it may have already been corrected for "standard" conditions and Appledore Island's conditions are more ideal.
- The ten minute intervals give the average wind speed, but as for low values power has a cubic relationship with wind speed, a large variation within each ten minute interval will cause more power to be actually available than would be produced if the wind stayed at the speed of the ten minute average.
- The NOAA weather station is on White Island. While White Island and Appledore Island are very close, the variation in wind between the two islands might be significant.
- The height correction (**Equation 1.7**) is only approximate, and may vary by location.
- It was noticed that over half of the theoretical energy production during the sample days came from times when the wind was blowing at 9.3 and 9.8 m/s at the NOAA station. Even slight underestimations of the power curve in this region might have a large effect on theoretical production.

It was discovered that the fan for the turbine's charge controller is currently broken, causing the controller to overheat when there is a large amount of power passing through, and thus turn off sporadically, wasting all power generation during these off periods. However, during the sampling days wind speed never exceeded 9.8 m/s (22 mph), and so this overheating probably never occurred during the sample days (thus meaning that the effectiveness was uncorrupted). All in all, besides the broken fan and large operating costs the turbine appears to be operating magnificently, assuming no gross errors in theoretical calculations were made.

In terms of increasing wind speeds delivered to the turbine, wind speed data on Appledore was not of high enough resolution, so alternate siting locations for the turbine with faster wind could not be suggested. Increasing the tower height of the turbine was explored, as winds are generally of higher speeds at higher altitudes (as given by **Equation 1.7**). It was found that a 125 foot tall turbine would increase theoretical output from the operating months of May through September by 7.6% (by adjusting the turbine height in **Equation 1.7**) while having a tower cost (based on a packet in the interns' bin) of $6,735 for the tower, an increase in cost of only 5.4%. However, not only does wind have a higher marginal cost than solar, but also additional installation costs for a new tower would probably make the new tower infeasible. The only way a new tower could be economically feasible is if the tower was so tall that installation made up only a small portion of the costs.

For future interns: if a more detailed explanation of the methodology is needed email alan.bach@comcast.net.

## Recommendations

It is recommended that the broken fan in the turbine's charge controller be fixed. However, all other methods to improve turbine performance were deemed not cost effective or difficult to test with current available data, and because the marginal cost for wind is greater than solar, it is not recommended to install more turbines. Instead of improving turbine performance, perhaps a better solution would be to utilize the wasted wind energy during the winter, via shifting some passive, energy intensive system to be utilized during the winter rather than the summer.

# Generator Performance vs. Battery Charging Rate

## Background

With the installation of a 300 kWh battery bank and associated power inverters, SML's diesel generators will function as a battery charger when wind and solar inputs cannot keep up with the island's energy demand. The battery charging rate and high/low battery voltage set-points affect the capacity and life of the batteries.

## Objectives

The Interns will study the generator and battery specifications and make recommendations regarding the optimal charging rate of the batteries. Based on the manufacturer's recommendations and electrical demand requirements the Interns will make recommendations regarding the high/low voltage set-points.

## Theory

In the spring of 2014 SML installed a 300 kWh battery bank to reduce the fuel usage of the diesel generators, which will in turn decrease SML's fuel costs and carbon footprint. The battery bank reduces generator use in two ways. First, it stores energy produced by the solar panels and wind turbine when their production exceeds the island load, which occurs during daylight hours. The batteries are then discharged when the production of those sources drops below the island load, which allows the generator to stay off. During the night, the generator charges the batteries while supplying the island load; once the batteries are sufficiently charged the batteries supply the island load, allowing the generator to turn off.

For the batteries to be used as effectively as possible, certain parameters related to battery use must be determined. This task required the interns to come up with a recommended charging rate and high/low voltage set points. Determining the charging rate is important because the charging rate affects how long the generators must run and charge the batteries before the batteries can be discharged. Determining the high/low voltage set points is also important because in the current system the depth of discharge (DOD) is being itself determined by the voltage set points. The DOD of the batteries is the percentage of the battery capacity that is used each time the batteries are charged, and therefore affects how long the batteries can discharge before they need to be charged again.

The main challenge involved in determining these parameters is figuring out how they affect both the fuel usage of the generators and the lifetime of the battery bank. Ideally, the generator fuel usage would be as small as possible and the battery bank lifetime would be as long as possible. Unfortunately, these are competing goals, because the strategies that would allow the generator to run less also decrease the lifetime of the batteries. Therefore, this task also involves balancing the effect of the charging rate and voltage set points on generator fuel usage and battery lifetime.

Before moving to the procedure involved for this task, a brief discussion of the battery bank setup is required. The battery bank is composed of 240 2V Absolyte GP 90G15 battery cells. The cells are connected in series in strings of 24, and there are 10 strings connected in parallel. One of the strings is shown in **Figure 4.1.**

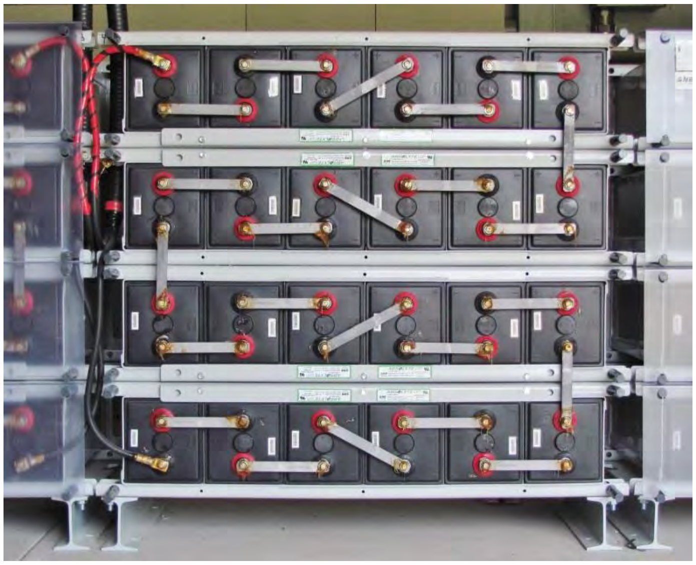


**Figure 4.1:** Battery Stack

This arrangement increases both the voltage and current that the batteries can supply. A single 90G15 cell has a voltage of 2V and a 608Ah capacity at the 8-hour discharge rate. When batteries are connected in series, their voltages add and their Ah capacities remain unchanged. Each string is 48V, because it contains 24 2V batteries in series, and a 608Ah capacity. When batteries are connected in parallel, their Ah capacities add and their voltages remain unchanged. Therefore, the entire battery bank has a voltage of 48V and a capacity of 6080Ah.

## Procedure

### Charging Rate

To determine the charging rate, both the charging voltage and charging current had to be determined, as both affect how quickly the batteries can charge. Charging voltage is a factor in the charging rate of the battery because it affects the current acceptance of the batteries.

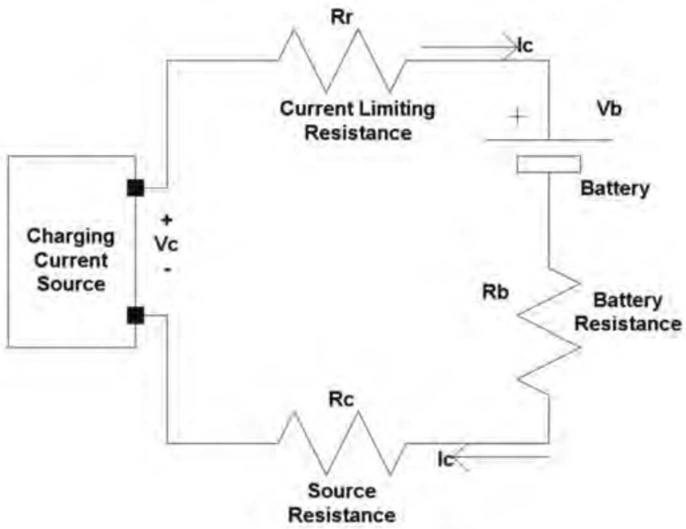


**Figure 4.2:** Battery Charging Circuit

**Figure 4.2** is a simple representation of the circuit involved in battery charging, and as a result the charging current can is described by the following equation:

$$Ic = \frac{Vc - Vb}{Rc + Rr + Rb}$$

The resistances and their change during charging are relatively small compared to the other quantities in the equation, so the charging current is primarily defined by the difference between the charging voltage (Vc) and the open circuit battery voltage (Vb). As the battery voltage rises during charging, the current acceptance decreases. A higher charging voltage will maintain the difference between charging voltage and battery voltage for longer, extending the period of time that the battery will be able to accept the maximum available current. Consequently, a higher charging voltage will result in a shorter battery recharge.

However, a higher charging voltage also results in higher battery temperatures, which results in a greater risk of thermal runaway occurring. Information regarding thermal runaway was found in a technical bulletin on VRLA charging: “Thermal runaway is the condition when heat is generated within the battery at a rate greater than that at which it can be dissipated. Should this condition exist for an extended period of time, the battery will experience accelerated dry-out and temperature elevation.” From the same technical bulletin, “to avoid complications that could lead to thermal runaway, the VRLA battery temperature rise during charging should be limited to 10°C” (C&D Technologies). Therefore, information was found relating charging voltage to temperature rise and DOD.

In order to find the proper charging voltage, the Installation and Operating Instructions for Absolyte® GP Batteries (I&O manual) was consulted and Exide, the battery manufacturer, was contacted.

The other factor of the charging rate that had to be determined was the charging current limit, which is the highest current available during charging. To recharge the batteries, approximately 105-110% of the ampere-hours removed from the batteries must be returned, per the I/O Instructions. A higher current limit will restore the required ampere-hours faster, and will therefore shorten the charging time. To determine what the limit should be, Exide was contacted again. This limit was then compared to the theoretical maximum output of the inverters.

At this point the capabilities and specifications of the generators were considered. First, the power output required at the maximum possible charging current was calculated and compared with the power output of the 27kW generator. The 65kW generator was not considered, because it consumes more fuel than the 27kW generator and would therefore be detrimental to the goal of reducing fuel consumption.

**Voltage setpoints**

As detailed in the theory section, the high and low voltage setpoints determine the battery bank's DOD, so this section is mainly focused on determining the optimal DOD. First, electric data recorded in the ECB was collected to determine the behavior of the system with the current voltage set points. Due to the variance in the island's energy use and the amount of energy production by wind and solar sources, it was decided that it would be more helpful to examine individual days instead of trying to compile multiple days of data.

Of particular interest was the amp-hour output of the batteries during their discharge cycles and how this compared to expected values. To begin, the theoretical amp-hour output during a discharge cycle was calculated using the following equation:

$$Theoretical\ Output = \%\ DOD \times Total\ Capacity$$

This number was then compared with battery current data, which was taken using a Fluke Multimeter. The total amp-hours produced during each cycle were calculated and the following equation was used to find the DOD that had occurred during the cycle.

$$Actual\ DOD = \frac{amp\ hours\ discharged\ during\ cycle}{total\ amp\ hour\ capacity}$$

This calculation only included discharge cycles that occurred during the night or early morning to ensure that the batteries were supporting the majority of the load. In addition, the battery current data was used to determine how long a discharge cycle would be if the batteries were discharging to their expected DOD. This was done by dividing the length of each cycle by the DOD that occurred, which gave a number describing the length of discharge time that could be expected for a 1% DOD. Finally, the theoretical length of a discharge cycle was calculated by multiplying this number by the expected DOD. This process is simplified in the equation below.

$$Theoretical\ cycle\ length = \frac{Actual\ cycle\ length}{Actual\ cycle\ DOD} \times Expected\ DOD$$

Once the analysis of the current system was completed, the process of determining the optimal DOD was begun. The main concern with DOD was balancing the island's energy needs with the lifetime of the batteries. A higher DOD will let the batteries last longer, but at the cost of decreasing battery lifetime. To quantify this relationship Exide was contacted to determine the expected number of cycles at different DODs. From the data they provided approximate battery lifetimes were determined using the equation below. For these calculations, the season length was assumed to be 150 days and the number of cycles per day was assumed to be two.

.

$$Lifetime\ (yrs) = \#\ of\ cycles \times \frac{1\ day}{2\ cycles} \times \frac{1\ year}{150\ days}$$

From this analysis an optimal DOD was selected, and using the same calculation from the battery current data, the discharge length was found for this DOD.

## Results and Analysis

### Charging Rate

**Figure 4.3** shows the relationship between the DOD, battery charging voltage, and temperature rise during charging.

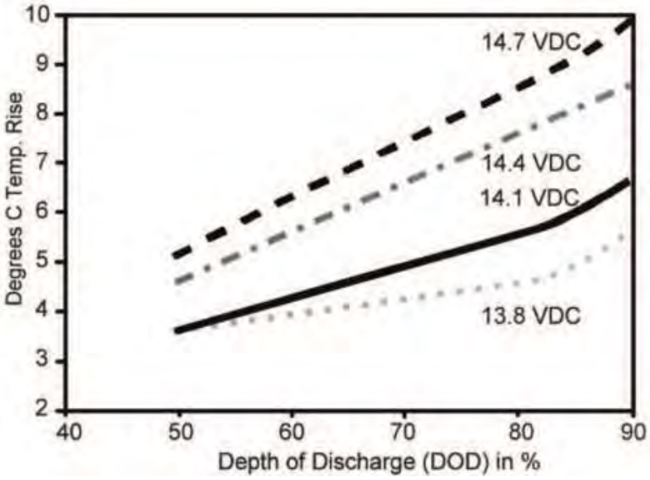


**Figure 4.3:** Temperature Rise, DOD, and Charging Voltage

The DOD being used for the battery bank is approximately 26%, and it is highly unlikely that a DOD above 50% would ever be used. From this data, it is clear that for DODs below 50% the temperature rise during charging is unlikely to be above 5ºC, significantly below the 10ºC at which thermal runaway becomes a risk. As a result, thermal runaway should not be a concern.

With regard to the battery's specifications and recommendations, the I&O manual provided the information found in **Table 4.1** regarding upper voltage settings for cycle operation.

**Table 4.1:** Charging Voltages

| DOD | Charging Voltage |
|---|---|
| 0-2% | 2.28 ± 0.02 VPC |
| 3-5% | 2.33 ± 0.02 VPC |
| >5% | 2.38 ± 0.02 VPC |

Given that the DOD was 26% and will never be lower than 5%, the recommended upper voltage setting from this table is 2.38 ± 0.02 VPC. When contacted regarding charging rates, two Exide representatives suggested that the charger voltage be set to 2.35 VPC or 2.40 VPC. A reasonable compromise of these numbers is 2.38 VPC, which is equivalent to 57.12V for our system.

When Exide was contacted about the charging current, they provided the information that "the current limit should be limited to 18A per 100Ah." Given that the capacity of the battery bank is 6080Ah at the 8 hour discharge rate, the maximum charging current limit is 1094A. Each inverter is capable of charging at a rate of 100A, and there are six inverters. Therefore, the maximum charging rate that the inverters are capable of is 600A. This is below 1094A, so there is no risk of exceeding the maximum charging current limit given by Exide.

Additionally, assuming a charging voltage of 56.4V, a charging current of 600A would require 33.8kW of power. Given that it is desired to have only the 27kW generator be used for both supplying the island load and charging the battery bank, a charging current of 600A is clearly not feasible.

### Voltage Setpoints

At the time of analysis, the green grid system was set up with two low voltage setpoints and one high voltage set point. The two low voltage setpoints were 50V for 15 minutes or 49V for 30 seconds. This means that the generator turned on when the batteries have been at or below 50V for 15 minutes or 49V for 30 seconds. The high voltage setpoint was 54V, meaning that the generator turned off when the batteries were charged to 54V. The batteries are at 100% capacity at 57.12V and are at 20% capacity at 42.0V, so the DOD is 26% if the 50V setpoint is the trigger or 21% if the 49V setpoint is the trigger. To simplify later calculations, a DOD of 25% will be used.

For a DOD of 25%, the theoretical output during a discharge cycle is 1520Ah. In terms of actual output, the **Figure 4.4** below shows the battery current data from the Fluke Multimeter for a period of approximately 40 hours. The numbered peaks represent the selected discharge cycles.

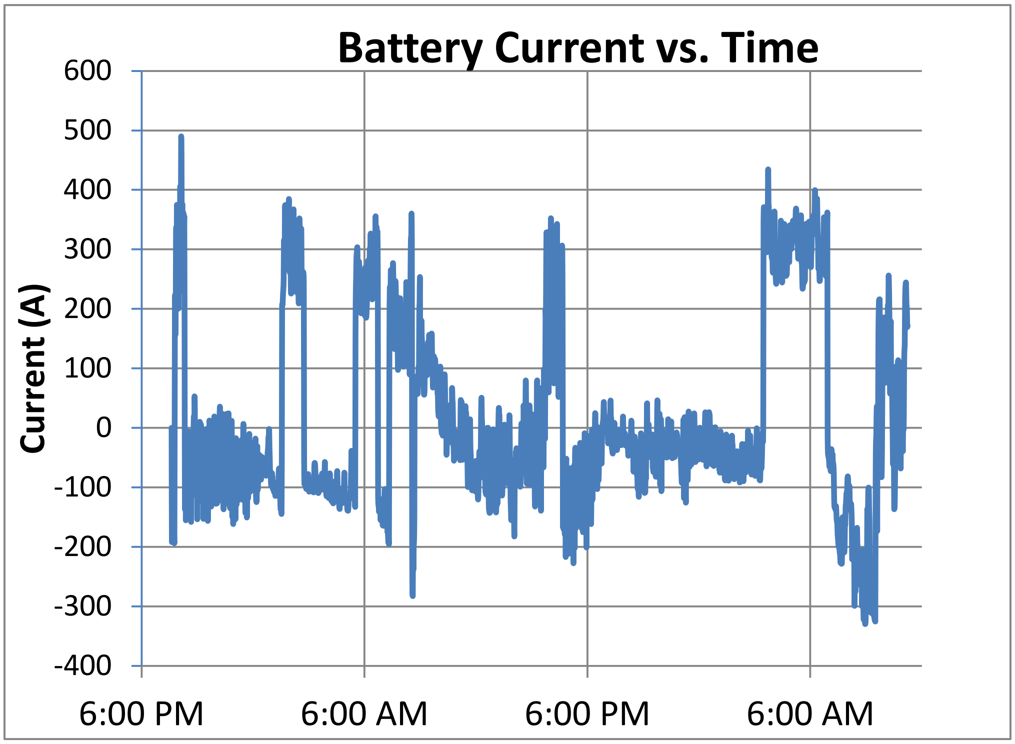


**Figure 4.4:** Battery Current Data

It should be noted that for this plot the batteries are charging when current is negative and are discharging when the current is positive. The amp-hour, DOD, and discharge time data for the selected discharge cycles is given in **Table 4.2**.

**Table 4.2:** Battery Current Data

| **Cycle** | **Discharge** (Ah) | **DOD** (%) | **Discharge time** (min) | **Discharge time/DOD** (min/%) |
|---|---|---|---|---|
| 1 | 165 | 2.7 | 33 | 12.22 |
| 2 | 330 | 5.4 | 71 | 13.15 |
| 3 | 307 | 5.0 | 73 | 14.6 |
| 4 | 1060 | 17.4 | 208 | 11.95 |
| | | | **Average:** | 12.98 |

Two important conclusions can be drawn from this table of information. First, the batteries are not performing to the expected DOD, and are in fact performing far below the expected DOD. During the fourth cycle the batteries got much closer to the expected DOD, but upon looking at the data it was found that the batteries reached and stayed at voltages below 49V for significant periods of time. Therefore, this only occurred due to some electrical malfunction with the controller system. Secondly, if the batteries were achieving the expected DOD of 25%, the discharge cycle would be approximately 5.4 hrs. There is some uncertainty in this number due to the single sampling period, but it is clear that if the system allows the batteries to discharge to the expected DOD, the batteries will be discharging for longer than they currently are.

After analyzing this data, the question that had to be answered was "Why are the batteries not achieving the expected DOD?" The assumption that was reached is that the battery voltage does not accurately reflect the SOC of the batteries. In conversation with Exide, this assumption was confirmed. Exide's suggested method for determining the SOC was tracking the amp-hours going into and coming out of the batteries. **Figure 4.5** provides some explanation of why battery voltage is not directly correlated to the SOC.

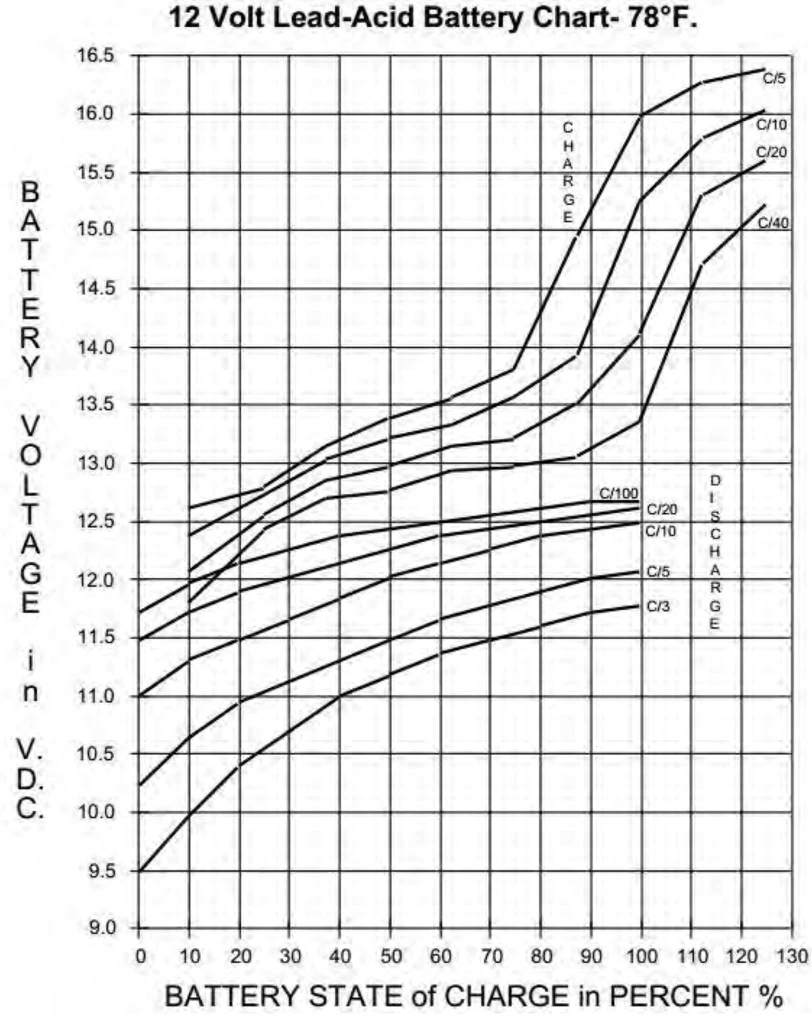


**Figure 4.5:** Battery Voltage and SOC

While the numbers may not be accurate for our system, this graph does show that there is a large drop in voltage between the charge and discharge cycles. Voltage data from the Schneider Communication Boxes confirms that this is occurring, as seen in **Figure 4.6**.

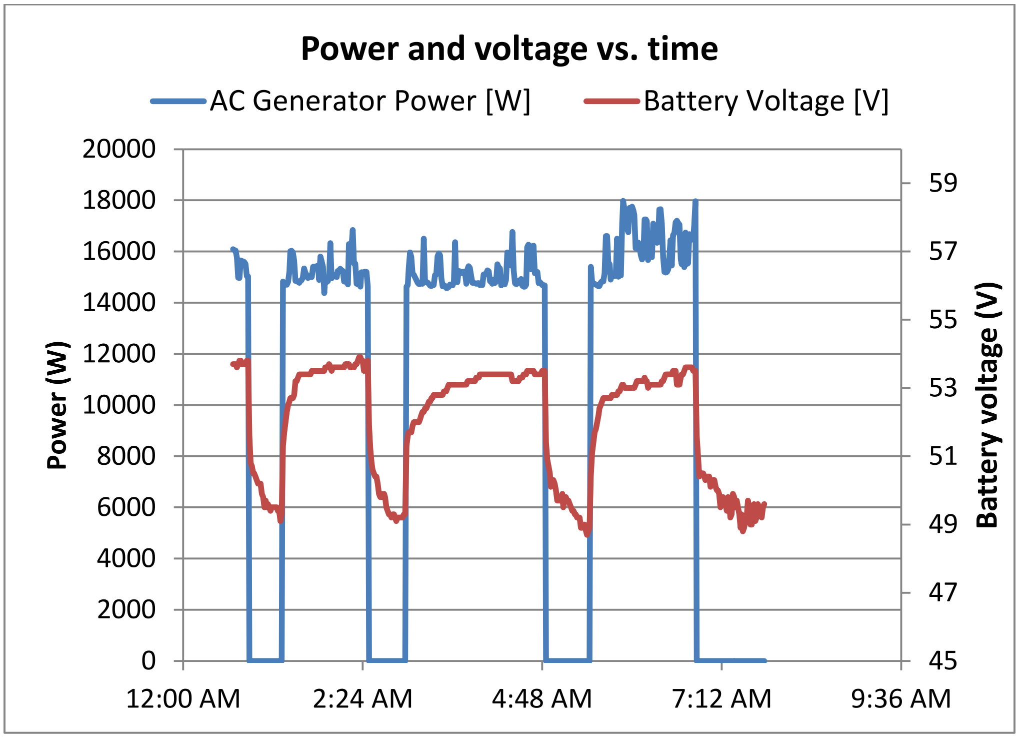


**Figure 4.6**: Battery voltage over discharge cycles

The batteries are discharging when the AC Generator Power drops to 0 W, and at the beginning of each discharge cycle there is clearly a large drop in voltage in a very short period of time. Likewise, when the batteries begin charging there is a large jump in voltage.

Finally, the optimal DOD was determined. **Table 4.3** shows the data received from Exide regarding DOD and expected number of cycle along with the calculated lifetimes.

**Table 4.3**

| **DOD** | **Cycles** | **Years** |
|---|---|---|
| 80% | 1200 | 4 |
| 70% | 1600 | 5.333 |
| 60% | 2000 | 6.667 |
| 50% | 2500 | 8.333 |
| 40% | 3000 | 10 |
| 30% | 4000 | 13.333 |

From this table it can be seen that there is a significant decrease in battery lifetime as the DOD increases from 30% to 40%. Furthermore, at a 30% DOD the battery should be able to supply the island load for 6.5 hours.

# Recommendations

### Battery Charging Rate

It is recommended that the charging voltage be increased from 56.4V to 57V. This change is unlikely to have a large impact on the overall charging rate, but it could increase it some amount. It is also recommended that the charging current be set as high as possible through whatever setting will allow this to be done. This will allow the batteries to be charged more rapidly, therefore decreasing the runtime of the generators.

### Voltage Setpoints

First and foremost, it is recommended that voltage setpoints not be used as a control mechanism for the batteries, as they do not provide an accurate representation of the battery state of charge. It is instead recommended, per Exide's suggestion, that amp-hours be used as control mechanism for the batteries. However, to do this there must first be equipment installed to record amp-hours over time on a regular basis, as the battery current data used for this analysis was found by bringing in a separate instrument. Additionally, the inverter manufacturer should be contacted to determine if it is possible to use amp-hours as a control mechanism for the batteries. Finally, it is suggested that a DOD of 30% be used for the battery bank. This number extends the lifetime of the batteries to approximately 13 years while still providing a long discharge time.

# References

"Batteries Parallel vs. Series." 12 Volt Battery Information and Resources. n.p, n.d. http://www.12voltbattery.info/index.php?page=batteries_parallel_vs_series

C&D Technologies. "Charging Valve Regulated Lead Acid Batteries." 2012 http://www.cdtechno.com/pdf/ref/41_2128_0212.pdf

Exide Technologies. "Absolyte® GP Batteries Constant Current Specifications Section 26.10" 2013 http://www.exide.com/Media/files/Downloads/IndustAmer/Section%2026_10%202013-09%20Absolyte%20GP%20Constant%20Current%20Specs.pdf

Richard Perez. "Lead-Acid Battery State of Charge vs. Voltage." Home Power #36. August/September 1993. http://www.arttec.net/Solar_Mower/4_Electrical/Battery%20Charging.pdf

# Designing a Maintenance Program for the Green Grid Batteries

## Background

The 300 kWh battery bank will require a maintenance plan in order to optimize its life span. Due to the harsh weather conditions on Appledore Island additional precautions may need to be taken into consideration.

## Objectives

The Interns will develop a maintenance plan based on the environmental conditions and the manufacturers recommendations.

## Theory

With the construction of the new battery bank, one of the main concerns was the effect of the weather on the batteries. In particular, it was necessary to determine the effect of summer and winter temperatures on the batteries and the insulation capabilities of the ECB. It was also necessary to develop a plan for the winter storage of the batteries. The island is rarely inhabited during the winter, so the batteries will be taken out of operation when people leave in the fall.

## Procedure

### Temperature Effects

The first step in determining if the batteries would be negatively affected by the weather was collecting basic temperature data for Appledore Island. This was done using the history function of Weather Underground to retrieve data from the weather station at Kittery Point, ME (KMEKITTE1). The Kittery Point station was used because the Appledore Island station only had data back to 2012 and a longer time range was desired.

The next step in figuring out the effect of the weather on the batteries was figuring out the relationship between the outside temperature and the temperature the batteries experience. This was done by taking temperature measurements for a total of 10 days inside and outside the ECB at regular times: 8:30 AM, 1:30 PM, and 7:00 PM. These measurements were taken from 6/24/14 to 7/3/14.

The final step in determining the effect of temperatures on the batteries was consulting battery specifications and contacting the battery manufacturers. Additional sources of information were also consulted regarding the effect of low temperatures on battery performance and lifetimes.

### Maintenance Plan

The main concern of the maintenance plan was how to properly prepare the batteries for winter storage. This winter maintenance was determined by consulting the I&O manual and contacting the manufacturer.

## Results and Analysis

### Temperature Effects

Temperatures for the last four years and their averages appear in **Table 5.1**. January and July were selected because they represent the coldest and warmest months of the year, respectively.

**Table 5.1**: Kittery Temperature Data

| **Year** | **2010** | **2011** | **2012** | **2013** | **Average** |
|---|---|---|---|---|---|
| High Temp (F) | 93.2 | 98.4 | 93.7 | 94.4 | 94.925 |
| Low Temp (F) | 0 | -6.6 | 0 | 0 | -1.65 |
| Average Temp (F) | 49.9 | 48.1 | 49.2 | 47.3 | 48.625 |
| January Average Temp (F) | 26.8 | 23.9 | 30.2 | 28.1 | 27.25 |
| July Average Temp (F) | 71 | 70.2 | 68.7 | 71.3 | 70.3 |

It should be noted that these temperatures are from a coastal mainland weather station, so the actual temperatures on the island may be less extreme, due to the temperature regulating effects of the ocean. In addition, temperature data recorded inside the ECB from late October of 2013 to July of 2014 shows that the lowest temperature recorded over that time period was 15.7ºF.

The results of the ECB temperature tests are shown in **Table 5.2**, with the two thermometers inside the ECB averaged to get a single inside temperature.

**Table 5.2**: ECB Temperature Data

| | **Battery** | **Outside** |
|---|---|---|
| **Average Overall Temperature** | 77.2 | 77.7 |
| **Average High Temperature** | 80.825 | 83.93 |
| **Average Low Temperature** | 75.335 | 74.57 |

This data shows that ECB does slightly regulate outdoors temperature swings; the high temperature inside is lower than it is outside, and the low temperature inside is higher than it is outside. However, this difference is not large, so it should be assumed that the batteries will experience temperatures similar to those of the island.

From the I&O manual for the batteries it was found that the optimal operating temperature for the batteries is 77ºF. There was ample information describing the decrease in battery lifetimes if the average temperature of the batteries rises above 77ºF, but this will likely not be a concern, as the average annual temperature of Kittery, ME is approximately 49ºF.

With regard to storing the batteries in cold temperatures, little information could be found in the battery specifications or through online research, so the manufacturer was contacted with a brief description of the expected battery bank conditions. Craig Danner, from Exide, explained that, "When the battery is subjected to cold temperature (and not connected to a charger), the voltage of each cell is reduced (cold drives down battery voltage). This in turn allows sulfate to build on the positive plates, which decays the battery capacity and life."

### Maintenance Plan

By contacting Exide it was determined that the batteries should be given an equalizing charge prior to the storage period. An equalizing charge restores all cells to a fully charged state, and it is recommended that it be performed annually to ensure uniform cell performance. The procedure to perform an equalizing charge may be found in the I&O manual, and the process will be outlined here:

<u>Step 1</u>

A. Set constant voltage charger to either 2.30 or 2.35 VPC, corresponding to actual voltages of either 55.2 or 56.4V.
B. Record time and current every hour until there is no drop in charge current over 3 consecutive hours.

<u>Step 2</u>

A. Continue the charge for 24 hours if 55.2V is being used or 12 hours if 56.4V is being used.
B. Record cell voltages hourly during the last 3 hours of the charge period. If the lowest cell voltage has continued to rise after the charge period has completed, the charge period may be extended, monitoring cell voltages hourly, until the lowest cell voltage ceases to rise.

<u>Step 3</u>

The equalization charge is now complete. The charger and loads can be removed, or the charger can be reduced to float voltage setting.

With regards to the effects of low temperatures on the batteries, through contact with Exide it was determined that the cold would likely reduce the voltage of the batteries. This reduction in voltage could lead to the accumulation of sulfate on the positive plates of the batteries. However, this sulfation is reversible provided that another equalization charge is performed within six months.

## Recommendations

As far as the temperature of the batteries is concerned, they will most likely remain below the suggested average temperature. To be sure however, it is suggested to keep a temperature gauge in the ECB throughout the summer which is hottest part of the year, and record average temperatures. If the average temperature does not break 25°C, ventilation should not be necessary.

Since no evidence has been found that cold affects the lifetime of the Absolyte batteries, insulation also should not be necessary. To prepare the batteries for the winter, an equalization charge should be given to the batteries, and another equalization charge should be given to the batteries at the beginning of the season in the spring to reverse any sulfation that may have occurred during the storage period. While six months is the maximum storage period given by Exide, it is assumed that a storage period slightly longer than six months will not be very harmful to the batteries. Therefore, it is not expected that a second equalization charge will be required before the start of the season in the spring.

For more information regarding general maintenance and record-keeping procedures, see the "Installation and Operating Instructions For Absolyte® GP Batteries" and IEEE Std. 1188™-2005, which can be found in PDF form in the digital appendix.

## References

Weather Underground Weather History. http://www.wunderground.com/personal-weather-station/dashboard?ID=KMEKITTE1

GNB Industrial Power. Installation and Operating Instructions For Absolyte® GP Batteries. Section 92.61 2013-09. 2013. Print.

# Siting a New Well on Appledore Island

## Background

SML receives its potable water from a twenty foot deep, six-foot diameter dug well that is treated through a simple process of filtration and chlorination. A reverse osmosis unit that desalinates salt water is used when there is a dry summer and the well cannot meet the lab's potable water demand. The reverse osmosis unit is an energy intensive process that requires running a generator that consumes a large amount of diesel fuel. To avoid turning on the unit, SML requires either a very wet summer or a second groundwater supply. For the existing and any proposed new well, SML also requires watershed information documented to serve as a future resource for scientists and engineers.

## Objectives

The interns will identify the wellhead area of the watershed for the current well and add a watershed data layer to SML's GIS base map.

## Theory

Located on the north side of the island, a twenty foot deep well has provided adequate amounts of freshwater to SML for the last three seasons without the aid of the reverse osmosis machine. Though it has met the water demand of the lab, island engineers monitor the well closely in case the well water level falls too low. If the well water level falls to a certain height, salt water upconing results in the fresh groundwater above mixing with the salt water below, which can ruin the well for many years afterwards. Once the water level falls to ten feet below ground, island engineers switch the water supply to the RO machine, but this is an expensive and labor intensive option. Island engineers desire to increase freshwater supply to the island without resorting to the RO machine by locating and constructing another well. Siting a new well is a multiple step process begun by the 2013 interns. The 2014 interns were tasked to expand upon the work of the 2013 interns as well as to add a watershed layer to Appledore's GIS database. Ultimately, this year's work should enable future interns to explore for and precisely locate a new well site.

## Procedure

After consulting with Tom Ballestero from the University of New Hampshire, the interns decided to check the 2013 intern's wellhead area calculations by identifying the well's watershed on a topographic map of the island. The wellhead area is defined as that footprint of land that delivers water to a well. For overburden wells such as at SML, under non-pumping conditions, the wellhead area is all uphill of a well, however during pumping, the wellhead area can expand downgradient. The wellhead area was outlined on Google Earth and input to an online software program called Daft Logic that calculated the surface area of the region. From there, the interns added the region as a shapefile to the existing GIS layout of Appledore. The updated GIS map of Appledore Island can be found in the digital appendix.

The 2013 interns suggested that future interns use more precise technologies to map the geology of the island. This year's interns determined that these technologies could be Ground Penetrating Radar (GPR) or Very Low Frequency radio waves (VLF), but Tom suggested using VLF. This year's interns researched various VLF devices and made some recommendations for which ones to use.

Tom also suggested designing an experiment to run during the winter months to determine how much leakage the well suffers. Leakage in this case is the normal flow of the groundwater from higher elevations, through the overburden, to the ocean. Winter is an ideal time to run a leakage experiment because SML is not operating, therefore the well is not being pumped. Evapotranspiration is also minimal; the only inflow to the well is precipitation and the only outflow is leakage. The interns worked to design an experiment for this winter to calculate this leakage. Once the leakage is calculated, island engineers can design methods of preventing it and therefore conserving freshwater for lab use.

## Results and Analysis

The shape of the existing well's watershed was determined by examining a topographic map and identifying the peaks near the existing well. The watershed the 2014 interns found is similar to the 2013 interns' calculations, but the area calculated this year is less than the calculation from last year. The 2013 interns calculated the existing well to have a watershed area of 61,603 $ft^2$; this summer's calculations are 53,840 $ft^2$. The identified area is shown in **Figure 6.1** below.

**Figure 6.1**: Watershed calculation on software program Daft Logic. The area was first found on Google Earth and the surface area calculated by using the pink markers as borders.

Tom also identified a larger area around the watershed that could be good location for a new well, which is shown in **Figure 6.2**. If the soil depth in that area is greater than ten feet, a new well could be constructed there. The watershed area has been added to the GIS of Appledore as a shapefile for ease of access for future engineers.

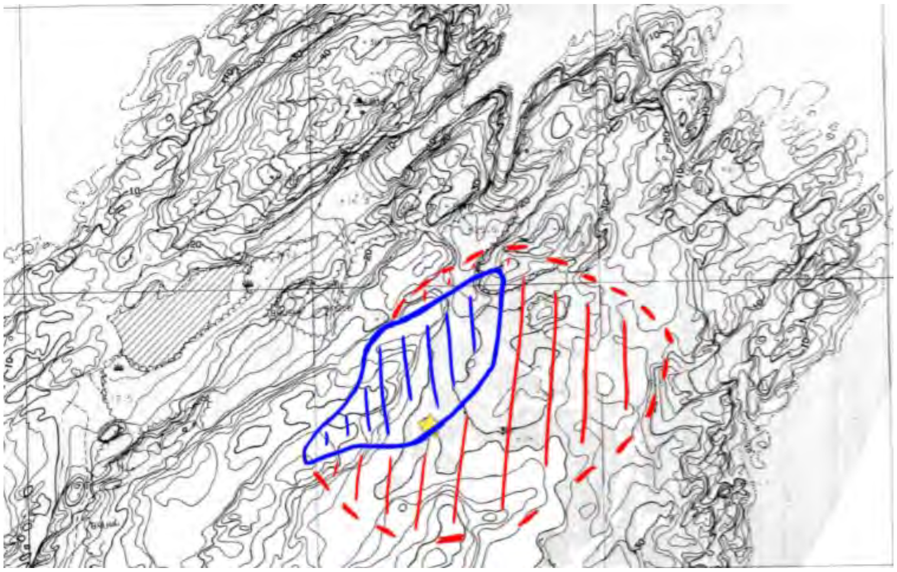


**Figure 6.2**: The blue area is the current well's wellhead area and the yellow star identifies its current location. The red area is the watershed for a potential new well.

To place a new well  on the north side of the island, the interns had to determine if there was enough recharge in that area during the year to ensure no interference with the current well. Tom aided in most of these calculations and suggested that average annual recharge rate be compared to SML average seasonal water usage. If the recharge rate is larger than the usage, a well near the existing well is plausible because extra water is around the area and is not being utilized. Based on the rainfall data from last year, the island receives 32 inches of rainfall. If 40% of this water is assumed to be for recharge, then the island receives 1.06 feet of recharge water. This multiplied by the area of the wellhead and converted to gallons gives 426,913 gallons of recharge water. SML uses an average of 157,029 gallons of water a season, so when the two numbers are compared, a new well on the north side of the island is feasible because there is enough water present, but not being captured.

In designing a winter experiment, the interns and Tom set up a "bathtub" model of the system (**Figure 6.3**). The purpose of a winter experiment is to determine if there is leakage and therefore if it is beneficial to have a second well in the area to capture the extra water. The inflow of this model is precipitation; the outflows are evapotranspiration, leakage, and well pumping. Losses to the bedrock below are assumed to be negligible. SML is closed in the winter, so there is no outflow due to pumping. Additionally, weather conditions on the island minimize or prevent evapotranspiration, so the only outflow from the bathtub model would be leakage (**Figure 6.4**). Leakage is water lost to the ocean that feasibly could be captured by another well and used as an additional potable water supply. After a known precipitation event, it is expected that the well water level would rise, and from this rise and the wellhead area, the volume of recharge per unit of precipitation can be determined.  Similarly, between precipitation events, the well water level is expected to fall due to the natural leakage to the ocean.  The leakage rate times the wellhead area integrated over time is a volume of water lost to the ocean. Rearranging the bathtub continuity equation as in figure 4, flow due to leakage can be isolated to measurable quantities (**Figure 6.5**). By placing a pressure sensor in the well, the well water level can be recorded and logged for the winter months. According to Weather Underground, average precipitation in recent years for the island is 2.29 inches in January and 3.16 inches in February. Based on this data and the wellhead surface area calculation of the watershed area, leakage can be calculated for the winter months. Ideally, there would not be any leakage; the change in volume over the change in time should be equal to the inflow of precipitation, and in between precipitation events, the water level should be constant. If the pressure sensor monitors decreasing water levels after precipitation events, then there is leakage in the watershed and fresh water is not being completely retained. Understanding the rate of leakage could lead to another possible management strategy and that would be to create some form of underground dam to slow it down.  One way to do this would be to recharge water to the overburden close to the coastline as is done in California and other water short coastal regions.

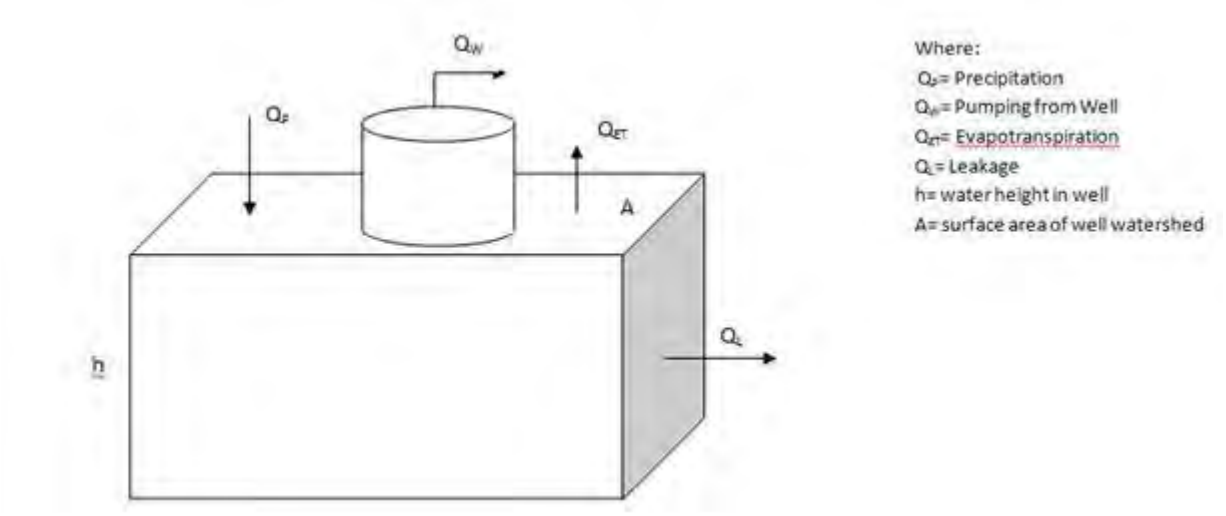


**Figure 6.3**: The bath tub model of Appledore's well demonstrates its inflow and outflows.

$$\frac{\Delta V}{\Delta t} = \frac{A\Delta h}{\Delta t} = Q_P - Q_{ET} - Q_W - Q_L$$

**Figure 6.4**: An equation for the bath tub continuity equation for the overburden aquifer.

$$\frac{A\Delta h}{\Delta t} = Q_P - Q_L$$

$$Q_L = Q_P - \frac{A\Delta h}{\Delta t}$$

**Figure 6.5**: Rearranging the equation from **Figure 6.4**, leakage from the well can be defined in measurable quantities.

One aspect of this assignment the interns briefly touched upon is the cost of constructing a new well versus running the reverse osmosis system (**Figure 6.6**). A cost analysis is important to determine if implementing a new well is financially more beneficial than just running the existing RO machine. The cost of digging a well centers around supplies, such as money needed to install a pump, piping and casing of the well, as well as the cost to pump the water in the future. Drilling a well is more cost intensive due to the equipment needed to finish the task. A drilling rig would need to be shipped out to the island on a barge which alone is $10,000. The RO system, comparatively, has a smaller initial cost. Over a life cycle of twenty years, however, the RO system incurs a cost of about $108,000. After the initial cost of constructing a well, the only cost over twenty years for a new well would be the cost associated with pumping water from it. With the current well, these costs are minimal, so the twenty year amortization of a new well is negligible compared to the RO costs. The numbers in **Table 6.1** are coarse estimates; a consultant more familiar with the task of finding and digging a well should give specific numbers.

**Table 6.1**: The cost estimates for digging a well versus using the reverse osmosis machine.

| **Dug Well** | | | **Drilled Well** | | | **RO Machine** | |
|---|---|---|---|---|---|---|---|
| Component | Cost | | Component | Cost | | Component | Cost |
| GPR/ VLF | 0 | | Barge | 10,000 | | Membrane priming | 4,000 |
| Labor | 0 | | Equipment | 40,000 | | Fuel | 1,400 |
| Supplies | 3,000 | | Supplies | 3,000 | | | |
| | | | GPR/ VLF | 0 | | | |
| Total | 3,000 | | Total | 53,000 | | Total for 60 days | 5,400 |

The numbers here are broad, but should provide a general idea of the benefits of digging a new well over a long time period.

## Recommendations

With the new watershed layer in GIS, SML should rent, or borrow from UNH, equipment such as a VLF or GPR device to investigate the geology of the area identified. This investigation will determine the depth to bedrock, the overburden thickness, the depth to groundwater, and therefore the saturated thickness of overburden aquifer. Future interns should plan on doing this near the beginning of the internship to provide enough time to have the equipment delivered to the island. If possible, island engineers should order the equipment before the beginning of the internship to provide adequate time for surveying. Once the geology is better known, the watershed layer should be revised and edited. The soil depth of the area Tom identified as a potential new well location should also be investigated because if it is over ten feet in depth, a well could be constructed there. On his visit to the island, Tom also mentioned the potential for a watershed and well near the Parker-Kinne lab. A survey with the equipment near the lab could provide a better idea of its potential as a new well location.

In an effort to capture as much water as possible from the existing well's watershed, island engineers should run the winter experiments outlined in the procedures and results sections. If a significant leakage is found, another well downgradient from or to the side of the existing well could be constructed to capture some of the water. Wastewater or rooftop rainwater could also be pumped down to the edges of the aquifer to create a hydraulic barrier between the freshwater and saltwater and prevent or minimize leakage.

Further, to investigate the financial aspects of constructing a well versus using the reverse osmosis system, a consultant with knowledge of similar systems should be recruited to give a more accurate estimate of the supplies and equipment needed for a new well.

# Waste Water Treatment

## Background

Two leach fields and several septic tanks were installed in the spring of 2009 to handle the majority of SML's wastewater needs. Additionally two buildings at SML have composting toilets and one building has a greywater treatment system that uses a FRICKle Filter and a leach field. The leachate from the composting toilets is pumped into the gray water system.

## Objectives

The Interns will take samples to evaluate the treatment effectiveness of the leach fields and determine the solids content of the septic tanks. The interns will also test the water quality of the composting toilet leachate and the effectiveness of the FRICKle Filter. The Interns will sample solids from the composting toilets and compare the effectiveness of the different wastewater treatment techniques used on Appledore Island.

## Theory

After the installation of the current waste water systems in 2009, the 2009 and 2010 engineering interns took samples of the treatment systems to measure how the systems were performing. Since then, the systems have been allowed to run independently with minimal alterations. By taking samples this summer, the systems can be evaluated for continued successful operation or needed maintenance.

## Procedure

### 1. Examination

The interns began this assignment by examining all of the wastewater treatment systems located around the island including 8 Septic Tanks, 4 Compost Toilets, 3 Leach Fields, and 1 FRICKle Filter ™. The first step in determining how well a system is working is to understand how it is supposed to work. The interns spent a day examining the septic systems and taking various measurements including dimensions and sewage levels. From these measurements, they were able to determine sludge and water levels in each tank using the sludge judge. The interns used these dimensions to develop detailed AutoCAD drawings of all four systems. The AutoCAD drawings can be found in the digital appendix.

### 2. Sampling

One of the tasks involving the waste water system was to determine whether or not the septic tanks needed to be pumped. As a general rule, if the sludge level in the last tank of the system gets above 25% of the total height, the tank should be pumped. Using a sludge judge, sludge levels were recorded and percentages of total sludge per volume were calculated.

Another objective of this task was to sample the water going through the three leach fields on the island to determine the water quality going into the environment from the fields. After inspecting them however, it was determined that it would be impossible to take samples from the leach fields. Both the Commons and Bartels leach fields have monitoring wells throughout their length, but none of them showed any signs of water passing through them. Since the island waste water load is relatively low and dependent on the fluctuating population on the island, there is not a large flow of water leaving the septic tanks. The leach fields for the systems are very large, and allows for small amounts of water to disperse very easily without being detected. Because of this, it would be very hard to notice any standing water in the leach field. Taking a sample of water entering the Distribution Box (D-Box) is relatively easy because there is usually a steady flow of water coming in, but the flow is very low which makes it almost impossible to determine where it will exit the leach field. Because of this problem, the interns decided to instead take samples at other locations to see if the water going into the leach field is as it should be as per specifications.

Much research was done to try and find a table showing allowable contaminant levels in subsurface wastewater disposal in the state of Maine, but no such information could be located. Because of this, there was nothing to compare the lab test results to besides previous data taken by other interns.

Thanks to Mike Rosen and Eastern Analytics the interns received five sets of sampling bottles to use for testing water quality in the septic system. These bottles allowed them to test for BOD, TSS, TKN and Fecal Coliform. The interns tested water sampled from the Kiggins Commons D-Box, Bartels D-Box, both Water Conservation Building Compost Toilets, and the Kingsbury House Compost Toilet (M10).

Unfortunately, since the FRICKle Filter ™ was not working properly, it might be advisable to test the system in a later year when bacteria have been able to develop on the new media. When sampling from the commons D-Box, water was pumped from the lower septic system to get flow through the system. The water in the D-Box was relatively stagnant and may have settled out within the box which would have given a bad representation of the water quality. At Bartels, there was not much flow coming into the D-Box, but the interns were still able to acquire a sample from what was left in the D-Box. The compost toilets in the water conservation buildings were relatively easy to sample. There was a valve connected to the sump pump that allowed the interns to take liquid samples. By unplugging the pump, and plugging in the outside-most plug back in, the pump was manually activated and caused a flow through the pipes. The plug system is shown in **Figure 7.1**.

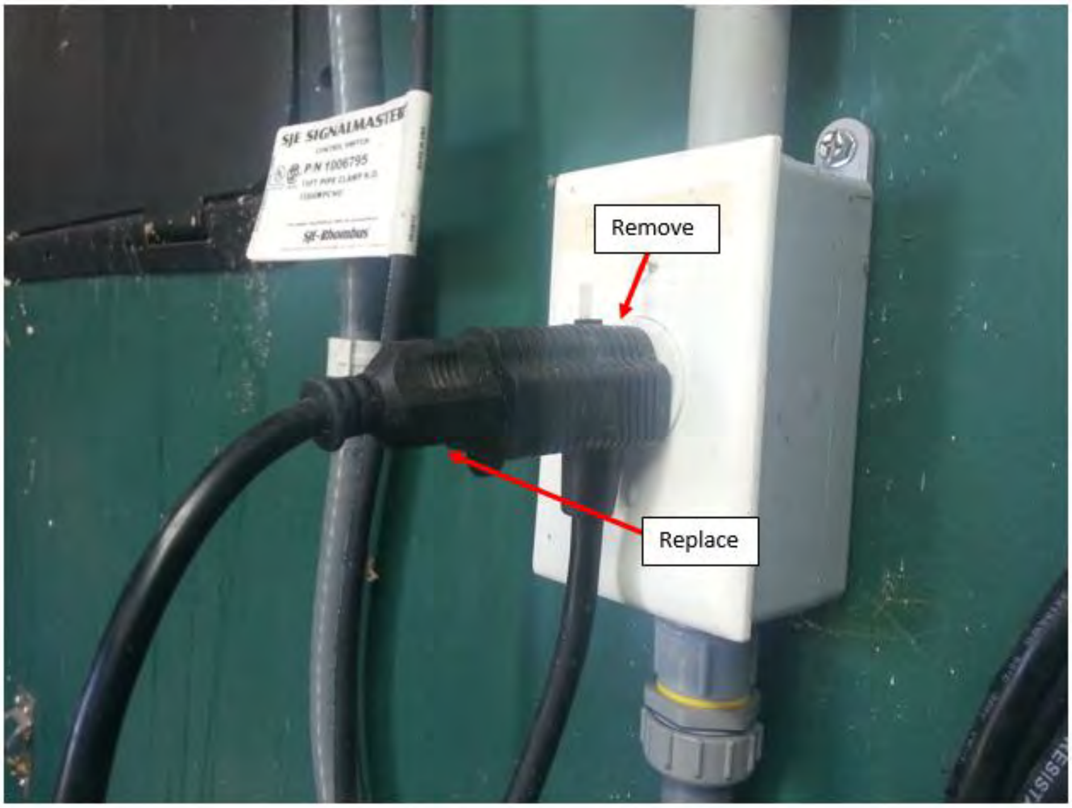


**Figure 7.1** - Plug system for the compost toilet containers.

The compost toilet at the K-House was much harder to sample. The pipe system had to be temporarily disassembled in order to receive any fluids from the system. Once the pipes were taken apart, sampling was easy, but the whole process was messy. If this process is repeated, it is advised to wear clothes that are not important as well as rubber gloves.

## FRICKle Filter ™

The interns ran into several problems with the FRICKle Filter ™. The main reason for all of the problems is that there is not enough flow going through the system. The Kingsbury House only houses a few people at a time, and they are not usually using much water while there. A diagram of the filter is shown in **Figure 7.2** to show how the water moves through the system.

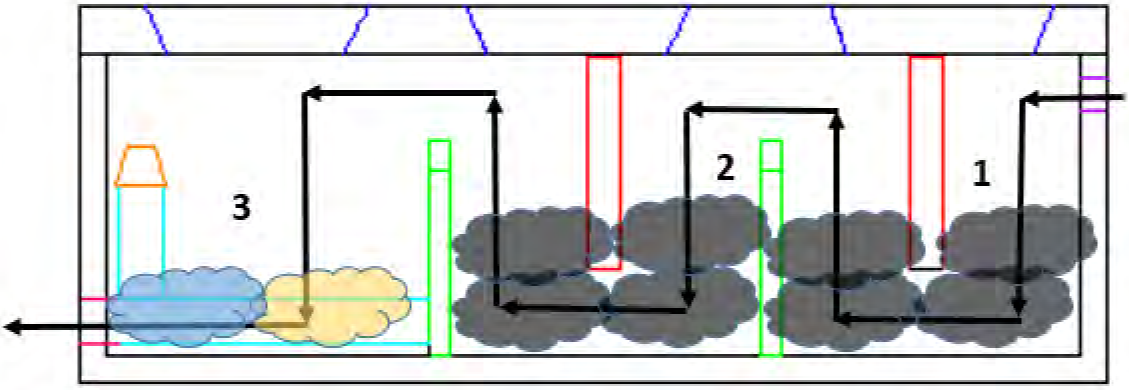


**Figure 7.2** - FRICKle Filter™ diagram showing the flow path of water through the foam media.

Each section of the system contains a foam media that provides a lot of surface area for bacteria to grow on. This bacterial growth allows for anaerobic respiration which cleans the water upon passing. The media contained in the first two sections look to be performing properly due to its black color shown in **Figure 7.3** below.

**Figure 7.3** - Foam media in section 1 & 2 shows signs of anaerobic activity.

In comparison, the media in section 3 is still colored, and does not seem to be properly growing bacteria. **Figure 7.4** shows the media in section 3. Notice the foam media retained its natural color instead of turning black. There are some black pieces, but those are believed to have always been black.

**Figure 7.4** - Foam media in section 3 shows no sign of anaerobic activity, and still retains its natural color.

There are several reasons why this third section is not working the way it is supposed to. First, there is not enough flow going through the system to keep the media constantly saturated. Since only small amounts of water pass through at a time, most of the media remains dry most of the time. When foam dries up, it begins to break down into smaller pieces. These pieces become small enough to actually fit through the holes along the outlet pipe. If these pieces make their way into the leach field, they could potentially clog it and become unusable. Another problem with the filter is that since the outlet is located at the bottom of the system, it does not allow water to build up in the 3rd section and react with the bacteria. Another problem with the FRICKle FILTER ™ is that it does not seem to be sealed at the outlet pipe. Upon inspection of the last section, it was noted that a root system had been growing within the foam media. After clearing the foam out, the interns noticed that the main root had entered on the side of the outlet pipe. **Figure 7.5** shows the root system connected to the foam media, and **Figure 7.6** is a picture showing where the root was entering the system.

**Figure 7.5** - Root system attached to foam media in FRICKle Filter ™

**Figure 7.6** - Root entering the outlet of FRICKle FILTER ™

## Pump and Flow Rate

The main septic system located in the valley of the island contains a holding tank and pump system in order to get the waste water up to the Commons leach field. The holding tank has a series of floats that trigger or turn off the pump and secondary pump. If the water level reaches the lowest float, the pump turns off. When it reaches the second lowest, the primary pump turns on. At the third float, the secondary pump turns on, and once it reaches the final float, an alarm is sounded that indicates the pumps cannot handle the load being put on them. The interns decided to calculate the primary pump flow rate to see how much water is being pumped into the Commons D-Box while the pump is on. First a measurement was taken from the water line to the top of the holding tank and ended up being 56 inches. The pump was then run for exactly a minute, and a new height was measured to be 61 inches. The diameter of the tank was determined to be 5 feet (60 in). Using the equation for the area of a circle, an area of 2827.4 $in^2$ was found. Using the area and change in height, a volume of 14137.2 $in^3$ was calculated. To find the flow rate, the volume was divided by the elapsed time. A flow of 235.6 $in^3/s$ was found and then converted to 0.136 $ft^3/s$.

This number means that the pump is sending 0.136 $ft^3$ of water into the D-Box and leach field every second the pump is running. Unfortunately, it is not known how long or how often the pump is running for since this time varies depending on island population, and changes daily. There is no meter telling how long the pump is running for, so that is also difficult to measure without standing by the pump all day. One way to determine how much is pumped per day is to look at how much freshwater is being used in each supplying building per day. The volume of fresh water used, and the volume of waste water produced should theoretically be the same. Obviously it will not be exactly the same, but it should still give a good representation on how much waste water is produced per day. Once this value is determined, one can see how much should be entering the leach field that particular day.

To determine the amount of water entering the leach field each time the pump runs, a distance was measured between the first and second float in the holding tank. A distance of 11.5 inches was measured. This height multiplied by the area of the tank determines the volume of fluid leaving the tank every time it is pumped. This value ends up being roughly 27.1 $ft^3$ (~203 gallons). If this volume were to enter the leach field evenly and if the bottom of the field was level, this would mean that there would be about 0.011 ft (0.13 in) of fluid throughout the entire leach field. This is not the case however since the leach field contains seven serrated pipes that extend the length of the field that do not disperse the fluid evenly throughout the entire area. Since there are seven pipes in the system, 3.87 $ft^3$ (29 gallons) are entering each pipe every time the pump runs. This divided by the length of the pipes (~97 feet) gives roughly .04 $ft^2$/pipe. The length of the field is 92 feet, but some pipes have to extend to the edge of the leach field, so an average was taken to be roughly 97 feet. The area of each outlet pipe is roughly .087 in, so if water were to not be able to leak out of the pipes, they would be about half full. This simply gives a perspective of how little water comes in each pump session. Although it seems like a lot, the amount of water entering compared to the total size of the leach field is miniscule. Assuming the leach field is around 4 ft, based on dimensions found in diagrams of the system, the volume of the field would be 9967 $ft^3$ or 3488 $ft^3$ of open space, compared to the volume of water entering which is 27.1 $ft^3$. This means the water is filling up about 0.78% of the leach field open space every pump session, and would take about 128.7 sessions to completely fill the open space in the leach field. This is assuming the bottom was confined, and no water could possibly leave, but the purpose of a leach field is to trickle water into the surrounding soil. Because of this, much less water would be in the leach field at any given time. This shows how little water actually goes into the leach field every pump session, which is why it is nearly impossible to find the water in either the monitoring wells or along the fringe of the field.

Measuring the flow rates at Bartels and K-House are nearly impossible since the flow is extremely low if not zero. These two locations have the same problem as the Commons leach field in that it was hard to tell where the water is going if there is not very much going into it. The monitoring wells were dried up, and no leakage was found surrounding the fields.

One experiment that was conducted by the interns is the dumping of around 40 gallons of water from the septic tanks into the last access hole of the Commons leach field, and looking at the surroundings to see if it was actually leaching through the soil. Some of the puddles around the end of the leach field did show more water than before the experiment meaning that the water was probably moving through the leach field. The problem with the experiment is that it only showed that water moved through the very end of the leach field. In order for the leach field to work properly, it must disperse water from beginning to end, and this was not possible to determine in the length of time the interns were on the island. Future interns may wish to perform a dye test at the beginning of their time on the island to have more time to look for leakage.

## Regulatory Checks

As per the manufacturers handbook for the leach fields located on Appledore, regular maintenance checks are required to keep the septic systems working properly. These checks were performed by the interns this summer and reported in **Tables 7.1, 7.2, 7.3,** and **7.4** below.

**Table 7.1** - Check sheet for the main septic tank.

| **Main Septic Tank** | | | |
|---|---|---|---|
| **Check** | **Passed** | **Failed** | **Notes** |
| Clogged Outlet Filter | X | | |
| No outlet baffle or tee | X | | |
| Infiltration of ground water or surface water | X | | |
| Solids not between 25% and 33% of total volume | X | | Solids at 23% |
| Line to distribution box is blocked or broken | X | | |
| Cracked or leaking septic tank | X | | |
| Line to septic tank is clogged or not at proper grade | X | | |

**Table 7.2** - Check sheet for the Commons septic tank.

| **Commons Septic Tank** | | | |
|---|---|---|---|
| **Check** | **Passed** | **Failed** | **Notes** |
| Clogged Outlet Filter | X | | |
| No outlet baffle or tee | X | | |
| Infiltration of ground water or surface water | X | | |
| Solids not between 25% and 33% of total volume | | X | Solids at 25% |
| Line to distribution box is blocked or broken | X | | |
| Cracked or leaking septic tank | X | | |
| Line to septic tank is clogged or not at proper grade | X | | |

**Table 7.3** - Check sheet for the Bartels septic tank.

| **Bartels Septic Tank** | | | |
|---|---|---|---|
| **Check** | **Passed** | **Failed** | **Notes** |
| Clogged Outlet Filter | X | | |
| No outlet baffle or tee | X | | |
| Infiltration of ground water or surface water | X | | |
| Solids not between 25% and 33% of total volume | | X | Solids at 46.6% |
| Line to distribution box is blocked or broken | X | | |
| Cracked or leaking septic tank | X | | |
| Line to septic tank is clogged or not at proper grade | X | | |

**Table 7.4** - Check sheet for the Kingsbury House septic tank.

| **Kingsbury House Septic Tank** | | | |
|---|---|---|---|
| **Check** | **Passed** | **Failed** | **Notes** |
| Clogged Outlet Filter | X | | |
| No outlet baffle or tee | X | | |
| Infiltration of ground water or surface water | X | | |
| Solids not between 25% and 33% of total volume | | X | Solids at 25.3% |
| Line to distribution box is blocked or broken | X | | |
| Cracked or leaking septic tank | | X | Outlet pipe of FRICKle FILTER allowed root to enter |
| Line to septic tank is clogged or not at proper grade | X | | |

## Results and Analysis

The sludge levels for each septic tank were calculated and are displayed in **Table 7.5**. All of the septic tanks are close to or above 25% solids, so they are ready to be pumped. Bartels' septic system, specifically, is 47% full and should be pumped as soon as possible. The interns also found the filters between the septic tanks to be filled, so any maintenance on the septic tanks should include a cleaning of the filters.

**Table 7.5** - Septic tank levels for all locations.

| Sample Name | Water Height (in.) | Sludge Height (in) | % of Solids by Volume |
|---|---|---|---|
| **Khouse** | | | |
| S1A | 48.0 | 20.0 | 41.7 |
| S1B | 48.0 | 9.0 | 18.8 |
| S1C | 48.0 | 7.5 | 15.6 |
| **Average for last tank** | 48.0 | 12.2 | 25.3 |
| **Commons** | - | - | - |
| S1A | 29.0 | 10.0 | 34.5 |
| S1B (1) | 29.0 | 7.0 | 24.1 |
| S1B (2) | 29.0 | 15.0 | 51.7 |
| S1B (3) | 29.0 | 10.0 | 34.5 |
| S2A | 29.0 | 4.0 | 13.8 |
| S2B (1) | 29.0 | 8.0 | 27.6 |
| S2B (2) | 29.0 | 10.0 | 34.5 |
| S2B (3) | 29.0 | 7.0 | 24.1 |
| **Average for last tank** | 29.0 | 7.3 | 25.0 |
| **Bartels** | - | - | - |
| S1A | 29.0 | 9.0 | 31.0 |
| S1B (1) | 29.0 | 12.0 | 41.4 |
| S1B (2) | 29.0 | 29.0 | 100.0 |
| S1B (3) | 29.0 | 11.0 | 37.9 |
| S2A | 29.0 | 6.0 | 20.7 |
| S2B (1) | 29.0 | 18.0 | 62.1 |
| S2B (2) | 29.0 | 17.0 | 58.6 |
| S2B (3) | 29.0 | 13.0 | 44.8 |

| | | | |
|---|---|---|---|
| **Average for last tank** | 29.0 | 13.5 | 46.6 |
| **Main** | - | - | - |
| S1A | 50.0 | 24.0 | 48.0 |
| S1B (1) | 50.0 | N/A | N/A |
| S1B (2) | 50.0 | 18.0 | 36.0 |
| S1B (3) | 50.0 | 8.0 | 16.0 |
| S2A | 48.5 | 5.0 | 10.3 |
| S2B (1) | 48.5 | 6.0 | 12.4 |
| S2B (2) | 48.5 | 5.0 | 10.3 |
| S2B (3) | 48.5 | 4.0 | 8.2 |
| S3A | 25.0 | 6.0 | 24.0 |
| S3B (1) | 25.0 | 5.0 | 20.0 |
| S3B (2) | 25.0 | 6.0 | 24.0 |
| S3B (3) | 25.0 | 6.0 | 24.0 |
| **Average for last tank** | 25.0 | 5.8 | 23.0 |

There are a few interesting numbers in the data returned from the lab. The TSS for the K-House composting toilet is particularly high when compared to the two in the Commons. This could be due to the sampling location for the K-House as explained in the Procedures section above. Clivus, the composting toilet manufacturer, does not mention an expectation for TSS, so it could not be determined if the K-House or the Commons were performing well based on this criteria **Table 7.6**. In their health testing manual, Clivus does set a standard for TKN and fecal coliform. The lab test results show that all the toilets are meeting the manufacturer's TKN standards. K-House is the only composting toilet that is meeting Clivus' standard of 200 MPN/100 mL. The high results for the Commons' toilets could indicate that they are not working properly, but the interns could not determine what the exact issue was. The interns attempted to find guidelines for septic tank effluent in the state of Maine, but could only find a report from Clivus in 1989 that says typical septic tank effluent is around 430,000 MPN/100ml fecal coliform, which is greater than the value taken from the Commons' D-Box. Based on this standard, the septic tank is working properly.

**Table 7.6** – Composting toilet test results

| **Composting Toilet** | **TSS** (mg/L) | **TKN** (mg/L) | **BOD** (mg/L) | **Fecal Coliform** (MPN/100 mL) |
|---|---|---|---|---|
| Clivus Standard | N/A | 2000 to 10000 | N/A | 200 |
| Commons Compost Left | 10 | 200 | 16 | 160000 |
| Commons Compost Right | 6 | 590 | 31 | 50000 |
| K-House | 140 | 690 | 24 | 40 |

**Table 7.7** - Sample results for previous and current years interns.

| **Year** | **Location** | **TSS (mg/L)** | **TKN (mg/L)** | **BOD (mg/L)** | **Fecal Coliform (MPN/100mL)** |
|---|---|---|---|---|---|
| **2009** | Commons D-Box | 94 | 670 | 89 | <2 |
| **2010** | Commons D-Box | 310 | 1200 | >300 | >1600 |
| **2014** | Commons D-Box | 160 | 90 | 94 | 160000 |
| **2014** | Bartels D-Box | 320 | 240 | 800 | >160000 |
| **2014** | K-House Compost | 140 | 690 | 24 | 40 |
| **2014** | Commons Compost Right | 6 | 590 | 31 | 50000 |
| **2014** | Commons Compost Left | 10 | 200 | 16 | >160000 |

The BOD for the Bartels D-Box was much higher than the rest, but BOD is not as important for subsurface wastewater disposal, so this should not be a problem.

## ArcGIS Basemap

The interns noticed that the most updated GIS Basemap did not have the correct layout for the septic system in the valley. The interns updated this system along with the ECB electrical lines. They did notice that the K-House lacked any kind of wastewater system on the map, but did not have time to tackle that task.

## Recommendations

Based on observations, and measurements from the septic tanks themselves, it is recommended that all of the tanks be pumped. The sludge level is greater than 25% in all but the septic tanks located at the bottom of the valley. Even those are approaching 25% and will most likely surpass that percentage within the next year or so.

The FRICKle Filter ™ is having issues with its performance. The foam media is not working well in the last compartment, and the outlet pipe is not properly sealed. It is recommended that a plastic media is used at least for that section of the system, and a seal be placed around the outlet pipe so that water is not leaking out of the opening where the root system was entering.

The septic tank samples came back without any problems, besides the high BOD in the Bartels D-Box, but that should not be much of a problem. No specifications of BOD in subsurface wastewater disposal were found leading the interns to believe that it is not important. The tanks should probably be pumped, but they still seem to be functioning properly and should not need any further maintenance at this time.

The compost toilets did have some problems with the amount of Fecal Coliform since there should be less than 200 MPN/100ml, and the commons' toilets show much higher than that. There is either something wrong with the toilet, or the sample was taken improperly. Future interns should look into this problem. The K-House also showed high levels of TSS and could show that the toilet is having problems. This should also be analyzed by future interns.

# Rock Talk for Appledore Residents

## Background

SML's new Energy Conservation Building (ECB) houses a 300 kWh battery bank which is charged by solar, wind and diesel power in order to keep the "lights on". The functionality of this system will be affected by SML participant's energy use patterns.

## Objectives

The Interns will give a 30 minute "rock talk" to Appledore residents early in the fourth week on how the electrical system works on Appledore. The focus will be on explaining how solar and wind power work, the function of the Energy Conservation Building in powering the island, and what charge controllers, inverters and transformers do in the system. The talk will include discussions about energy conservation and peak loading with special attention given to personal behavior/energy conservation and how it affects the system.

## Theory

Most of the students, faculty, and interns that spend part of the summer on Appledore Island do not know how the energy they use is produced. Since they do not know the value of electricity on the island, they tend to be less conscious about energy conservation. In order to educate non-engineering islanders about how the energy system runs and operates, the Sustainable Engineering interns will talk to them about where their energy comes from. This will hopefully convince them to use as little energy as possible.

## Procedure

The interns created an easy to follow and understandable presentation that outlined the basic concept behind how the energy system operates. Since most people viewing the presentation do not have an extensive background in engineering, the interns presented ideas in a way they will understood without exploring a lot of detail. The presentation included how each energy producing system works, the background of the islands power grid, and how all the components of the system connect.

The presentation took place on July 1st in Kiggins Commons and several classes as well as professors and staff attended. Many interesting questions were asked about the system, and the interns answered to the best of their ability. There seemed to be a lot of interest in the topic, so hopefully they will be much more conscious of their energy usage.

# Future Project Suggestions

## 1. Alternate Water Sources for Garden Irrigation

The island's garden has a long history and it is important that it is being taken care of properly. One issue with this is that it requires fresh water to keep the plants and flowers healthy. In summers where water is limited, it is hard to justify using water on the garden when there are other needs for it around the island. If future interns could develop a way to obtain fresh water from a different source than our well (desalination, rain collection, etc.) the garden could use that water instead of well water.

## 2. Introducing Grass Carp in Crystal Lake

Previous interns have looked into collecting water from Crystal Lake as a source of freshwater, but they have run into problems with clogging pipe filters and have been unsuccessful with properly collecting water from the lake. One suggestion this year's interns came up with is to introduce grass carp to the lake. Grass carp are a natural filter for ponds and lakes, and might be able to help clear up the waters of Crystal Lake. They do not require a large body of water, and can thrive in dirty water making them ideal for Crystal Lake.

## 3. Bird Deterrent on Campus Roofs

Previous interns have looked into collecting rain water off of the roofs of buildings, but the rain becomes contaminated from bird droppings. One solution to this could be to find a way to deter birds from standing on the roofs in general, or to find a way to avoid the droppings. After observing the roofs, it was noticed that the birds typically stand on the peak of the roofs. If there was a way to keep the birds off the peak, they may ignore the roof all together. Alternatively, a divergent wall could be placed about a foot from the peak to redirect the water from the peak off the roof, and the water below the wall could be collected contaminant free.

## 4. Addition of Wastewater Lines to K-House

It was noticed that on the ArcGIS basemap located on the engineering computer does not have any wastewater lines around the K-House. The house has its own septic system, and it is important that it makes its way onto the ArcMap. The interns this year began to look at the map, but did not have enough time enter an entire septic system at the K-House. There is an ArcMap file on the engineering computer named "SEI 2013" that is the most updated, but should be looked at by future interns.

# Acknowledgements

Thank you to all the following people that guided us during the internship:

Shoals Marine Laboratory and Staff

Nancy Kinner

Ross Hansen

Mike Rosen

Mike Dalton

Alex Brickett

Tom Ballestero

Justin Eisfeller

Lee Consavage

Sam Lingerman

Dave Plante

Exide Staff