SUSTAINABLE ENGINEERING INTERNSHIP

18 July 2016

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Assignment 1: Siting a New Well

Appledore Island is the only island in the Isle of Shoals with a freshwater well. This 20-foot dug well provides water to Shoals Marine Laboratory (SML). However, it is only drawn down to 10 feet above the bottom of the well due to concerns of saltwater intrusion. This leads to many restrictions on water use, the notable one for residents being the two showers a week policy. Sustainable Engineering interns have worked on many projects in past years to increase the island's freshwater reserves, but none have provided an effective solution. Some of these projects included drawing water from Crystal Lake and attempting to site a new well. This year, the interns worked with Emery & Garrett Groundwater Investigations, LLC (EGGI) to map the aquifer supplying the current well and to explore potential sites for a new well. The expertise and equipment provided by EGGI helped the 2016 interns to conceptualize the subsurface hydrology of Appledore Island.

Assignment 2: Drinking Water from the Sun's Energy

On a sunny day SML produces enough electricity to fully charge the 300 kWh green grid battery bank by early afternoon. Once the batteries are fully charged, the solar charge controllers regulate the charging rate so overcharging of the batteries does not occur. This energy could be made available for other uses. In very dry summers, the use of a reverse osmosis water-maker is required to make up shortages of drinking water in the SML well. The water-maker requires a large quantity of electricity to operate and exceeds the starting capacity of the green grid's inverters. The current 8,000 gallons per day reverse osmosis system is not necessary since the island only needs 1,000-2,000 gallons a day. The current system draws too much power and thus cannot be powered by the green grid. A reverse osmosis system is itself expensive, so running an unnecessarily large system will accrue unneeded costs.

Assignment 3: Effective Power Usage

On sunny days, SML is able to fully charge the 300 kWh battery bank in the Energy Conservation Building (ECB) by early afternoon while also supplying the island's electrical load. When the batteries are full, the solar charge controllers will tell the arrays to solely supply the island load as to not overcharge the batteries. Because there is not enough battery storage, this leads to wasted power. Other systems may be able to run off of this excess power.

Assignment 4: Power Generation: Master Plan

SML has 14 buildings plus additional structures to support engineered systems. These buildings and engineered systems create SML's electrical load. Electricity is produced from a combination of wind, solar and diesel generation. The energy from the wind and sun is stored in two separate banks of batteries. One battery bank was installed in 2007 (Radar Tower) and one in 2013 (Energy Conservation Building). Based on the battery set points and current use, each bank is predicted to last approximately 10 years. The batteries in the Radar Tower are nearing their predicted end of use. A plan needs to be developed for when this occurs.

Assignment 5: LED Lighting Upgrade Study

SML is constantly looking for ways to reduce the base electrical load on Appledore Island. Lighting loads are a significant part of the island's total energy use. In 2006 and 2007, SML upgraded T-12 fluorescent and incandescent bulbs to T-8 fluorescent and compact fluorescent bulbs. SML upgraded most of the campus lighting again with LED technology in 2015 and 2016 and seeks a thorough analysis of its performance. LED lights are expensive to install. Whether these lights did indeed save energy and reduce spending needs to be checked.

Assignment 6: Solar Panel Efficiency

SML installed two new rooftop solar arrays in the summer of 2015. Shortly after the installation, gulls decided the solar panels were a nice surface to sit on and soil (all the time). It is dangerous for personnel to get up on the roof to clean these panels so the efficiency of the panels is reduced. A system must be devised to keep the solar arrays clean and at maximum efficiency.

Assignment 7: Rooftop Rainwater Collection

The 2015 SEI Interns researched and designed an alternative watering system that uses rooftop water and drip irrigation for Celia Thaxter's historic garden at SML. The new watering systems were installed in 2016. These must be tested and potentially improved.

Assignment 8: Grease Trap Effectiveness

SML's commercial kitchen has an in-line grease trap that services the dishwasher, three-pot sink, and a washdown sink. The purpose is to keep grease from entering SML's septic system. It is expensive and time-consuming for SML to have the septic tanks pumped by a septic hauler. The more grease that enters the septic tanks, the more frequently the tanks need to be pumped. Grease entering the septic system is expensive to be pumped out since the septic trucks need to be transported on a barge to reach the island. Whether the grease trap is undersized and cleaned frequently enough must be determined.

Assignment 1: Siting a New Well

1.1 Background

Appledore Island is the only island in the Isle of Shoals with a freshwater well. This 20-foot dug well provides water to Shoals Marine Laboratory (SML). However, it is only drawn down to 10 feet above the bottom of the well due to concerns of saltwater intrusion. This leads to many restrictions on water use, the notable one for residents being the two showers a week policy. Sustainable Engineering interns have worked on many projects in past years to increase the island's freshwater reserves, but none have provided an effective solution. Some of these projects included drawing water from Crystal Lake and attempting to site a new well. This year, the interns worked with Emery & Garrett Groundwater Investigations, LLC (EGGI) to map the aquifer supplying the current well and to explore potential sites for a new well. The expertise and equipment provided by EGGI helped the 2016 interns to conceptualize the subsurface hydrology of Appledore Island.

1.2 Purpose

The well is the only freshwater source in the Isle of Shoals. Although it is 20 feet deep, when the water level lowers to 10 feet, SML switches to a reserve osmosis (RO) machine to meet its water demands. This process is energy intensive and requires use of the 65 kW diesel generator, hindering SML's goals of sustainability. The RO machine has not been used for five years, but low precipitation and high island population may require starting the use of RO in late July this year. An assessment of the island's hydrogeology was conducted in an attempt to "retire" the RO machine.

1.3 Scope

The interns worked with EGGI to determine the subsurface hydrologic characteristics of the northern half of Appledore Island. Through weekly visits, the interns worked with John Brooks, Dan Tinkham, and Mike O'Brien, all employees of EGGI, to gather increasingly detailed information. The results of the analyses conducted led recommendations on how to continue this investigation.

1.4 Methods

1.4.1: Rose Diagrams and Lineaments

On EGGI's first visit, John Brooks and Dan Tinkham met with the interns. Basic groundwater concepts were covered, with special attention paid to well withdrawal and saltwater intrusion. After this lesson, everyone went into the field to learn about geology and fracture measurements. The interns used the iPhone App "GeoCompass 2" to collect orientation data on the island's rock fracture families, the preliminary step in a groundwater investigation. Fracture families can reveal the directions of potential preferential water flow directions beneath the ground surface. Data collected at 13 different outcrop sites on the northern half of the island was compiled into rose diagrams. Rose diagrams visually demonstrate the orientation of fracture families, fractures with similar orientations. For example, the rose diagram for Site 13, shown below, shows that the dominant fracture families at this outcrop trend to the NNW and ENE.

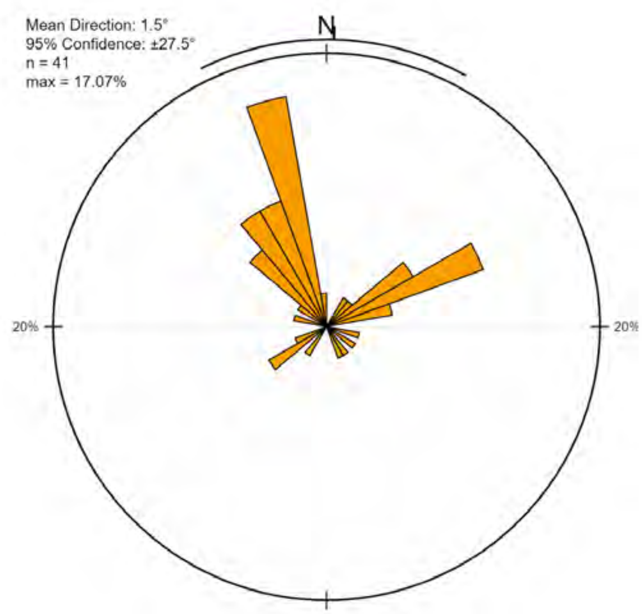


Figure 1: Rose Diagram for Site 13

After collecting field data, a lineament analysis of the island was conducted. This was done using shaded relief models of LiDAR data (six different lighting directions), slope analyses of the LiDAR data, and an aerial photograph of the Island, all provided by EGGI. The interns traced linear features identified on each image onto clear vinyl paper. The lineament sheets were overlain and coincident lineaments were drawn to identify the most prominent lineaments on the island. These coincident lineaments may be underlain by bedrock that is preferentially fractured, and therefore, may be dominant pathways for groundwater flow.

1.4.2: Very Low Frequency and Magnetometer Survey

During week two of the internship, EGGI's Mike O'Brien visited the island to help the interns conduct very low frequency (VLF) and magnetometer surveys of the island's northern half with an Exelis Visual Information Solutions (ENVI) geophysical equipment. The ENVI measures variations in the earth's magnetic field and VLF radio waves that travel through the ground. The VLF readings compare an original (in-phase) wave to a distorted (out-of-phase) wave in order to reveal properties of the subsurface. The perpendicular origins of these VLF waves allow subterranean features in all directions to be detected. Anomalies in the magnetic field and VLF radio waves can be correlated to changes in rock type, the presence of fracture zones, and other structural discontinuities in the bedrock.

1.4.3: Electroresistivity Survey

During week three, Mike O'Brien returned to run Aktiebolaget Elektrisk Malmletning (ABEM) geophysical survey lines with the interns. This electroresistivity survey runs current through two metal stakes in the ground, and two separate stakes act as electrodes that measure the potential. Resistance can be calculated from this survey, and a map of subsurface resistance is produced. Two different arrays (tests) were used: the Wenner and Dipole-Dipole. These arrays are useful for measuring horizontal and vertical resistivity changes in the ground respectively, which can be related to changes in the subsurface geology/hydrology. These tests helped the interns determine the area of recharge for the current well, as well as a potential site for a new well.

1.4.4: Well Monitoring

Pressure transducers were placed in the main pumping well and the Grass Lab well to measure water level and temperature changes during three week study. The transducers were downloaded by EGGI and corrected for changes in barometric pressure to give an accurate assessment of water levels in the wells. This allowed the interns to estimate the amount of recharge into the main well and to quantify the natural, ambient, lowering of the water table in the aquifer in the Grass Lab.

1.5 Results & Analysis

1.5.1: Rose Diagrams and Lineaments

The fracture surveys, from which emerged rose diagrams, and the lineament analysis gave insight to potential groundwater flow on the island. The compilation of site survey data is shown below.

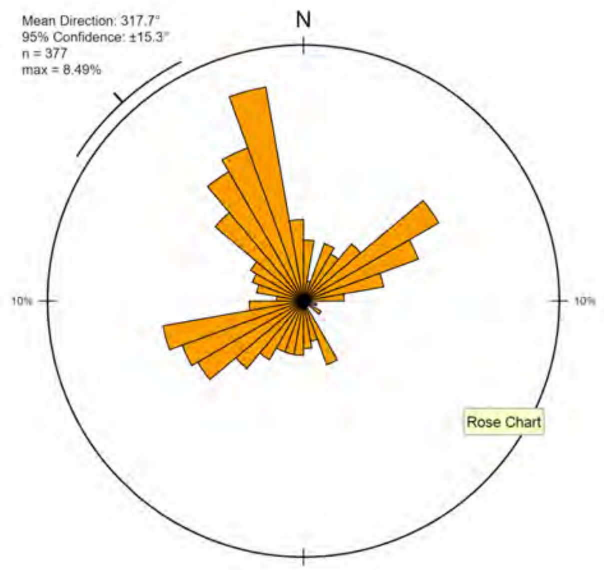


Figure 2: Total Rose Diagram

This rose diagram shows two predominant fracture families on the island. One is a northeast trending family, and the other a north-northwest. This diagram reveals that if a well were drilled into bedrock, special attention would need to paid attention to these directions, as drawing too much water could allow seawater to infiltrate those trending fractures.

The lineament analysis showed slightly different results. After overlaying several LiDAR shots, the interns drew a coincident lineament sheet for the whole island. The northeast trends are evident, but the north-northwest fractures are sparse. Several north-south trending coincident lineaments were also defined.

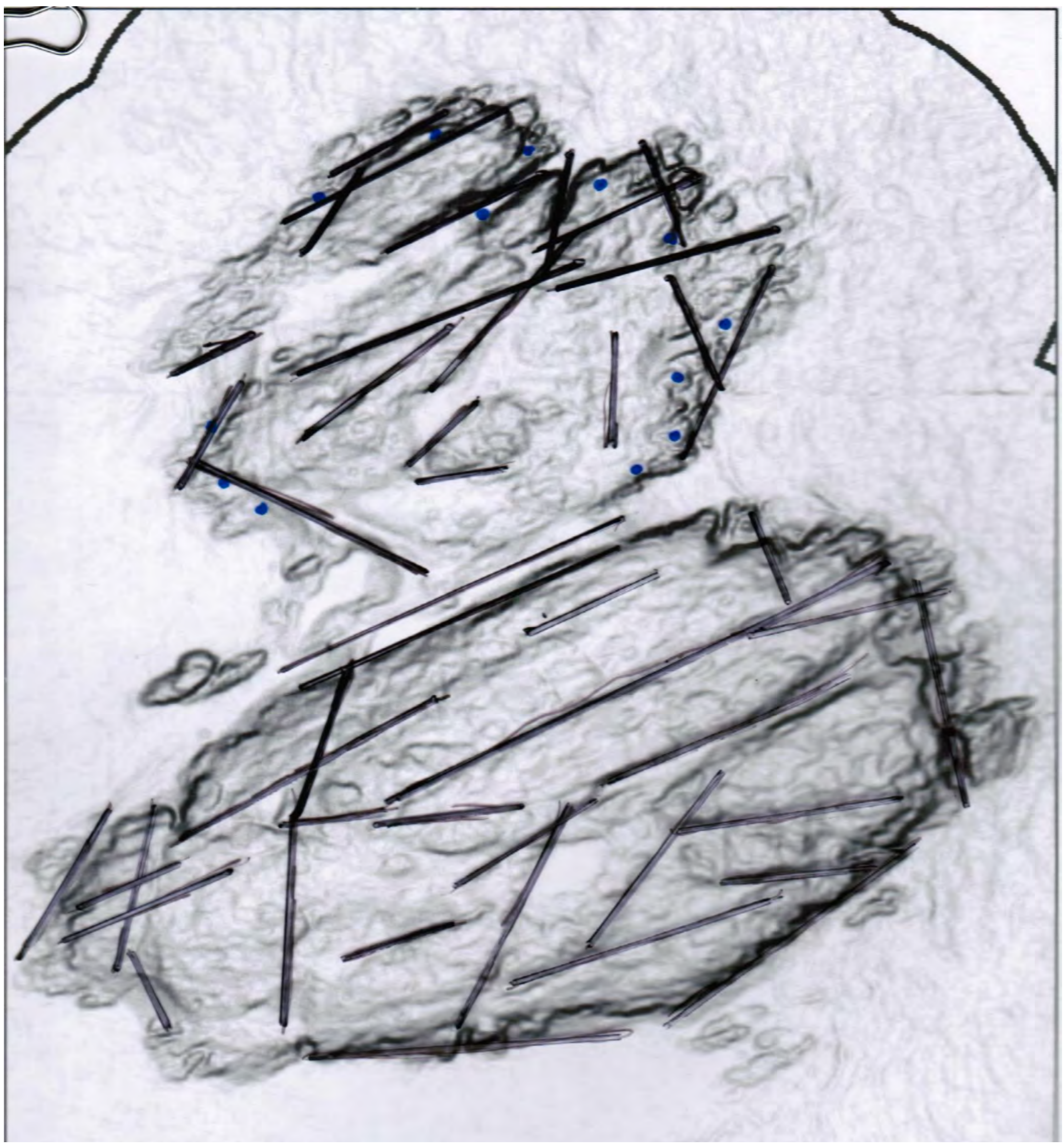


Figure 3: Coincident Lineament Overlay

1.5.2: Very Low Frequency and Magnetometer Survey

Six different survey lines were conducted with the ENVI machine. The readings from the ENVI machine were then graphed using an Excel template provided by EGGI. Readings at two different VLF frequencies were measured in addition to magnetometer measurements. EGGI marked the anomalies found in these graphs and asked the interns to return to the field to look for possible explanations. Data for one of the survey lines is shown below.

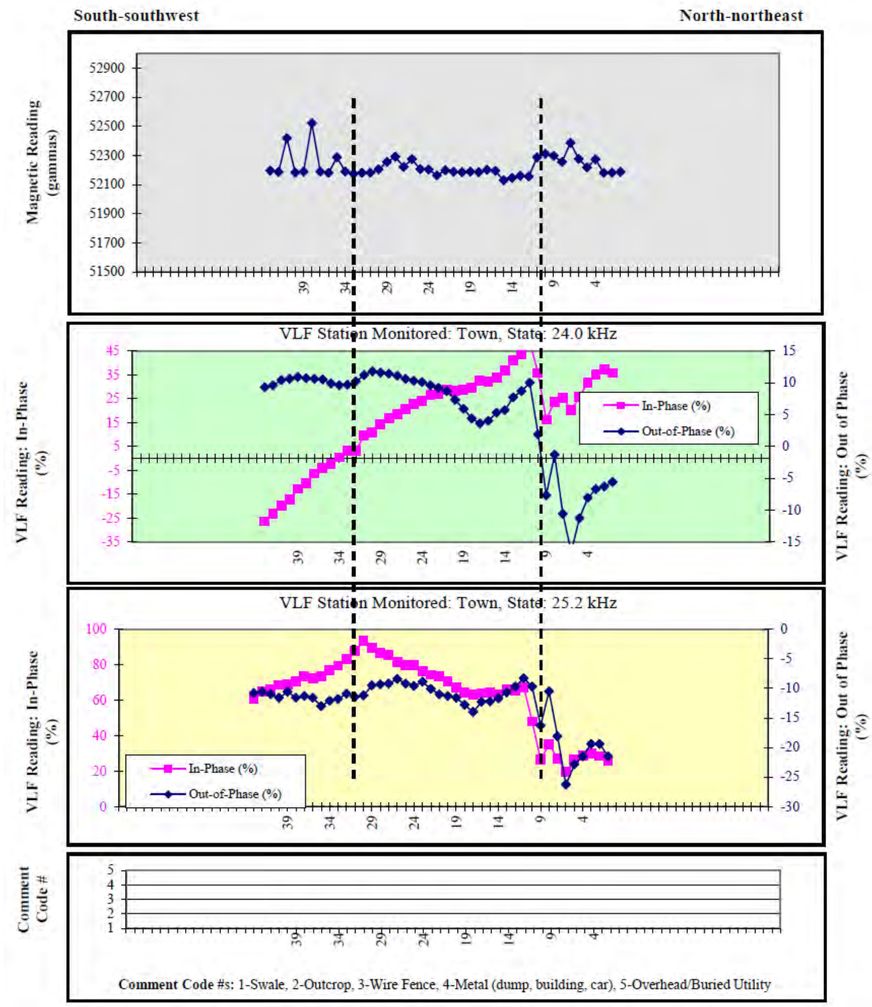
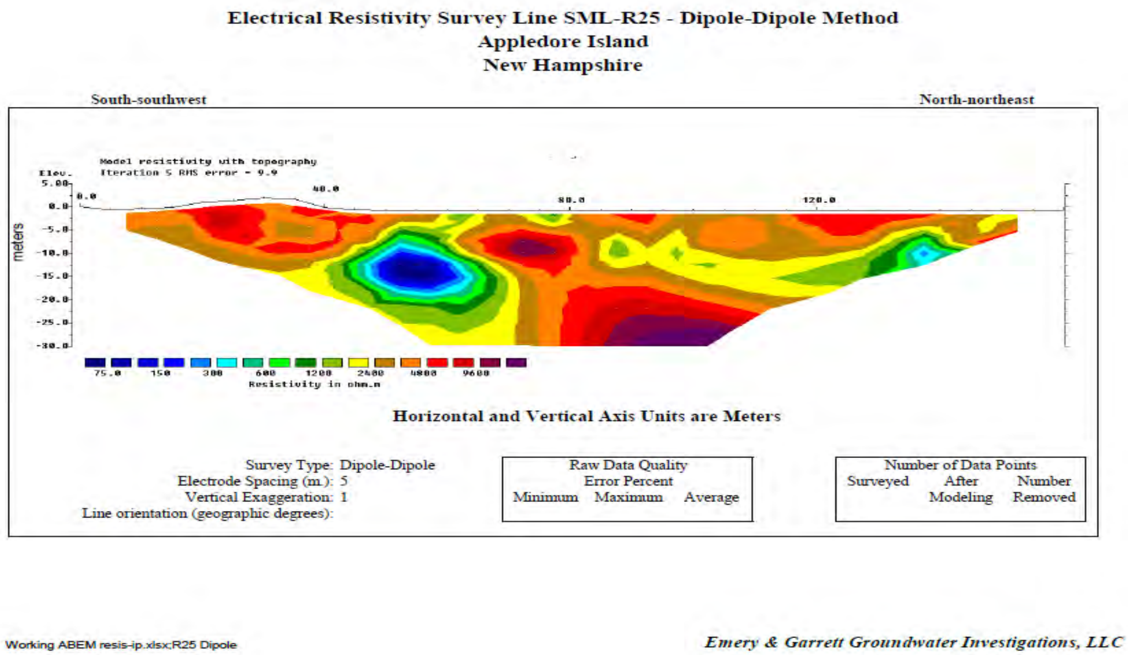


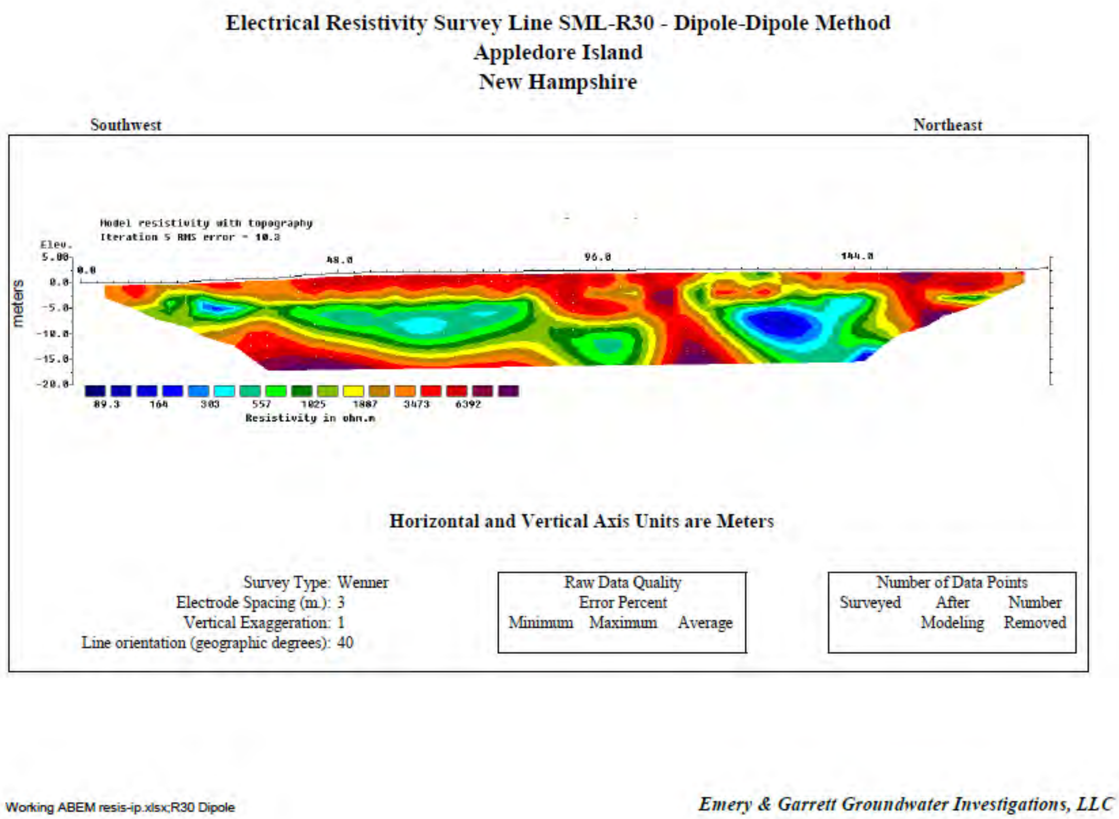
Figure 4: ENVI Data for Line L5

Because the ENVI measurements are sensitive to anthropogenic objects, a majority of the anomalies were due to such things as metal on the wind turbine, electrical wires, etc.

1.5.3: Electroresistivity Survey

Two lines from the ENVI survey, L25 and L30, were followed to conduct an electroresistivity surveys (Lines R25 and R30). This geophysical method provides more detailed data than the ENVI surveys, but data collection was more limited due to the amount of time needed to set up and run the surveys. The Wenner and Dipole-Dipole arrays were used to gather a composite picture of the subsurface. The Dipole-Dipole arrays, which measure to a greater depth, are pictured.





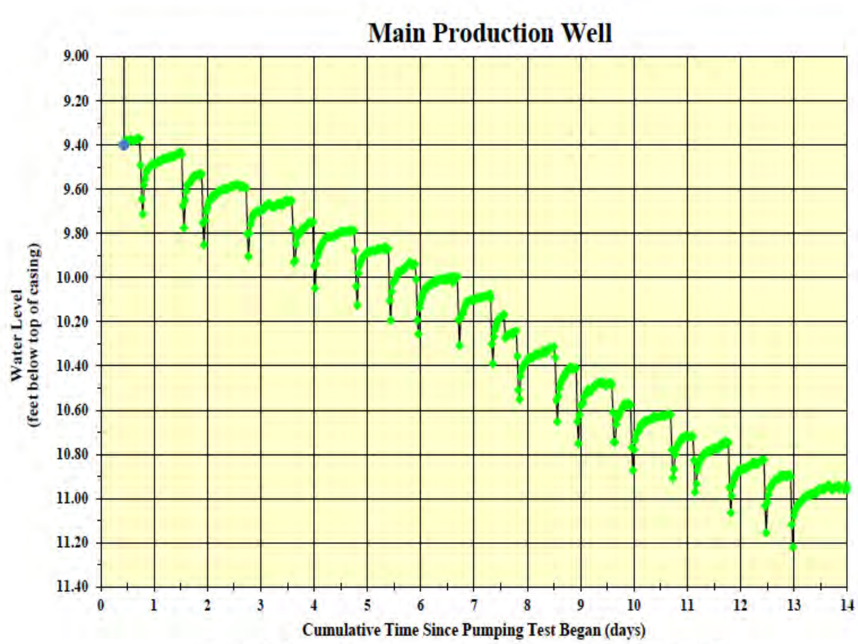
Figures 5 & 6: Dipole-Dipole Electroresistivity Maps

These models show cross sections of the subsurface electrical resistivity beneath the survey lines conducted. The dark blue portion on the right is where the current well is located and the larger light turquoise portion on the right is where the monitoring well is proposed to be installed.

After reviewing this data, the interns returned to the field to map the probable recharge area of the current well. Based on surficial observations, it appears that a second aquifer is located south of the current well. What is left to be determined is whether the two aquifers are hydraulically separate. The high resistivity between them appears to suggest that they may be separated by bedrock, but it cannot be said with certainty that impermeable bedrock forms a continuous hydraulic barrier between them.

1.5.4: Well Monitoring

During their visits, EGGI downloaded data from the pressure transducers and produced the graph shown below. Groundwater is removed from storage and the water level in the well and surrounding aquifer lowers about 0.8 inches each day. Therefore, it is anticipated that the reverse osmosis machine will be needed this season to meet the water supply needs of the island.



Plot of Water Level versus Time for June 23 to July 6, 2016
Shoals Marine Lab Well Assessment
Appledore Island, Maine

Figure 7: Well Water Level

1.6 Conclusions & Recommendations

Usage of the current well, while an invaluable resource to SML, comes with a degree of uncertainty. Water supply demands on the island can typically be met with the water restrictions in place. However, reverse osmosis is sometimes needed, which strains SML's goals of sustainability. This year's interns were able to gain an understanding of Appledore Island's hydrogeology with the assistance of Emery & Garrett Groundwater Investigations. Based on the project, we propose that a monitoring well be installed on one of the survey lines. This will enable SML to check the water level in the monitoring well with relation to the water level in the main pumping well to see if the two aquifers mapped out during the electroresistivity survey are indeed separated by impermeable bedrock. If this is the case, a new well may be able to be drilled in that location.

1.7 References

Emery & Garrett Groundwater Investigations

Assignment 2: Drinking Water from the Sun's Energy

2.1 Background

On a sunny day SML produces enough electricity to fully charge the 300 kWh green grid battery bank by early afternoon. Once the batteries are fully charged, the solar charge controllers regulate the charging rate so overcharging of the batteries does not occur. This energy could be made available for other uses. In very dry summers, the use of a reverse osmosis water-maker is required to make up shortages of drinking water in the SML well. The water-maker requires a large quantity of electricity to operate and exceeds the starting capacity of the green grid's inverters. The current 8,000 gallons per day reverse osmosis system is not necessary since the island only needs 1,000-2,000 gallons a day. The current system draws too much power and thus cannot be powered by the green grid. A reverse osmosis system is itself expensive, so running an unnecessarily large system will accrue unneeded costs.

2.2 Purpose

The purpose of this assignment is to determine the amount of excess solar energy that is available for use on sunny days. The interns will research and make recommendations for a new reverse osmosis system water maker that will start and run on the excess energy production. Set points will be outlined for starting and stopping the water-maker so that energy is not drained from the battery bank.

2.3 Scope

The interns will analyze the excess solar energy available each day and select a reverse osmosis (RO) system that can be started and powered by the green grid. Startup power for RO systems are much higher than normal operation. The chosen reverse osmosis system will be placed in the room with the current RO system and together they must not exceed the size of the room. The cost and effectiveness of the system must also be considered.

2.4 Methods

By using past logs, excess solar energy available per day will be measured according to how long the battery bank remains at 100 percent. By monitoring the amount of energy drawn from the main grid during this time, we can see how much energy was not being captured by the batteries. Alex Brickett, a former island engineer, assisted with the use of the software that monitors power usage. This step will allow for the selection of a smaller, more energy efficient RO system such as those used for boats. In selecting this system, the ratio of influent seawater to permeate freshwater to saltwater concentrate should be analyzed to justify energy usage and affirm that it will be the best option for supplementing the freshwater well.

2016 June diesel generator energy output (kWh)=sum of each night's diesel energy output (kWh)

2016 July diesel generator energy output estimate (kWh)=2016 June generator output * ratio between July 2015 generator energy output and June 2015 generator energy output

A similar calculation applies for 2016 August and September calculation

2016 total estimated power (kWh) supplied by generators is the summation of May, June, July, August, and September 2016 data

Total extra battery capacity (kWh)=number of sunny days (90) *extra battery capacity

Extra battery capacity as a % of diesel power = total extra battery capacity/2016 total estimated power supplied by generators

Estimated diesel spending reduction ($) per year due to additional batteries=extra battery capacity as % of diesel generator power *estimated 2016 diesel total cost

2016 estimated diesel cost=total estimated consumption* 3.70 (price for a gallon of diesel, purchased 3 yrs ago)

2.5 Results and Analysis
From last year's interns' analysis of our batteries:

DOD	Cycles
80%	1200
70%	1600
60%	2000
50%	2500
40%	3000
30%	4000

Table 1: Battery Discharge Cycles

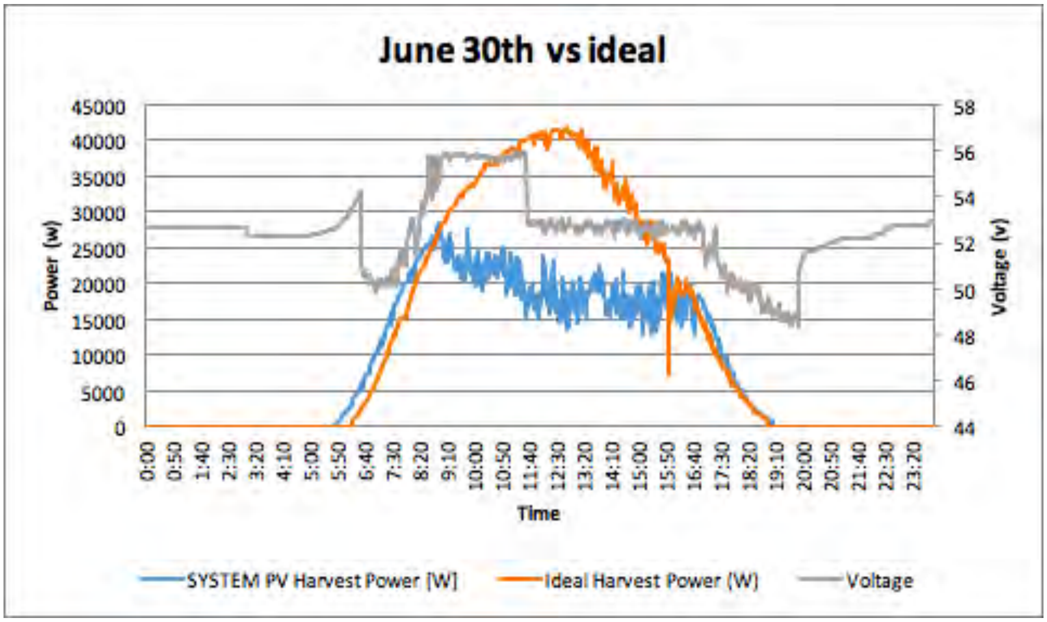


Figure 8: PV Harvest Power versus Ideal Harvest Power

The ideal curve pictured is August 17, 2015. On this day, the batteries were completely discharged. The interns integrated the "ideal harvest power curve" and the "system PV harvest power" curve. This integration was completed using the Riemann sum method at 1 minute intervals. The difference between the two integrations was then found. This subtraction was not over the whole curve, but instead started when the ideal harvest power first overtook the system harvest power and ended when the ideal harvest power was below the system harvest power.

On June 22nd, there was 133 kWh of excess energy. On June 30th, there was 110 kWh of excess energy. On June 25th, there was 96 kWh of excess energy. On an ideal day, the solar panels can produce 312 kWh of energy. There are three options for new batteries: lead acid (same as the ones SML currently uses), lithium ion, and saltwater batteries. Lead acid batteries are proven, inexpensive, but also very heavy. In addition, in order to achieve a ten year lifespan, only the top 30% can be drawn. The interns recommend purchasing 90 kWh effective (300 kWh rated) worth of batteries, which would cost $100,000 including installation ($2,500 for each 6 cell group). For lithium ion batteries, 80% of its capacity can be drawn without compromising lifespan. Tesla powerwalls cost $3,000 for a 6 kWh unit. A new generation of powerwalls will arrive this year so the interns would recommend waiting for a newer product.

A 10 year warranty for Tesla powerwalls would include the following, as quoted by the manufacturer:
"Specifically, the warranty covers 740 cycles or 85 percent of 6.4 kilowatt-hours (so 5.4 kilowatt-hours) of capacity for the first two years -- whichever comes first. Then it covers 4.6 kilowatt-hours for three years or 1,087 cycles. And finally, it covers 3.8 kilowatt-hours for five years or 2,368 cycles."

Saltwater batteries do not use rare earth metals and are thus more environmentally friendly. They include most of the benefits of lithium ion batteries. However, they cannot be stored at a temperature lower than 14 degrees Fahrenheit. Aquion energy says that at 100 percent depth of discharge (DOD), these batteries will survive 3,000 cycles. For 60 or 70% DOD, 4000 – 5500 cycles can be achieved. By survival, the manufacturer means that the batteries will still have at least 70% capacity at the end of these cycles.

For 150 kWh (full discharge), the manufacture gave SML two options: one in 24V and the other in 48V. SML will need approximately 69 Aspen 48S battery stacks or 6 Aspen 48M modules. One advantage of using modules is that BMS can closely monitor voltage, current, and temperature.

If an additional 90 kWh of capacity is added to the system, SML would achieve a cost reduction of $2,262 in diesel spending reduction. This is assuming that there are only 90 out of 120 sunny days during the summer. Factoring in the cost of batteries ($30,000), the final cost would come down to $7,737.67 per year over 10 years. Diesel spending reductions are calculated based on $3.70 per gallon as Shoals had bought three years worth of diesel at that price and are still using that batch. Diesel runtime and fuel consumption would decrease by 50%. In 2015, diesel generators provides on average 135 kWh of energy per night.

Final Emission Standards in grams per horsepower-hour (g/hp-hr)

Rated Power	First Year that Standards Apply	PM	NOx
hp < 25	2008	0.30	-
25 ≤ hp < 75	2013	0.02	3.5*
75 ≤ hp < 175	2012-2013	0.01	0.30
175 ≤ hp < 750	2011-2013	0.01	0.30
hp ≥ 750	2011-2014 2015	0.075 0.02/0.03**	2.6/0.50† 0.50††

* The 3.5 g/hp-hr standard includes both NOx and nonmethane hydrocarbons.
† The 0.50 g/hp-hr standard applies to gensets over 1200 hp.
** The 0.02 g/hp-hr standard applies to gensets; the 0.03 g/hp-hr standard applies to other engines.
†† Applies to all gensets only.

Table 2: Diesel Generator Emission Standards

The table above is the tier 4 emission standards for diesel generators. This applies to SML's 27 kW Caterpillar units. In 2015, they were estimated to produce 75,546g of NOx emissions and 432g of Particulate Matter emissions. By installing additional battery capacity, SML could reduce both numbers by 50%.

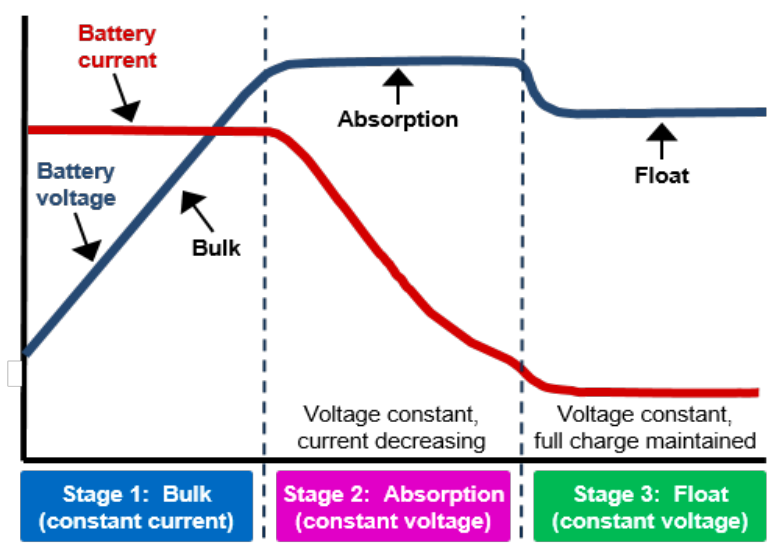


Figure 9: The Three Stages of Battery Charging

Ideally, the batteries should always be operating under bulk charge. This is when current is at the maximum and the full output of the batteries can be utilized. However, by looking at the voltage of the batteries on June 30th, it can be seen that absorption charging is reached very early during the day.

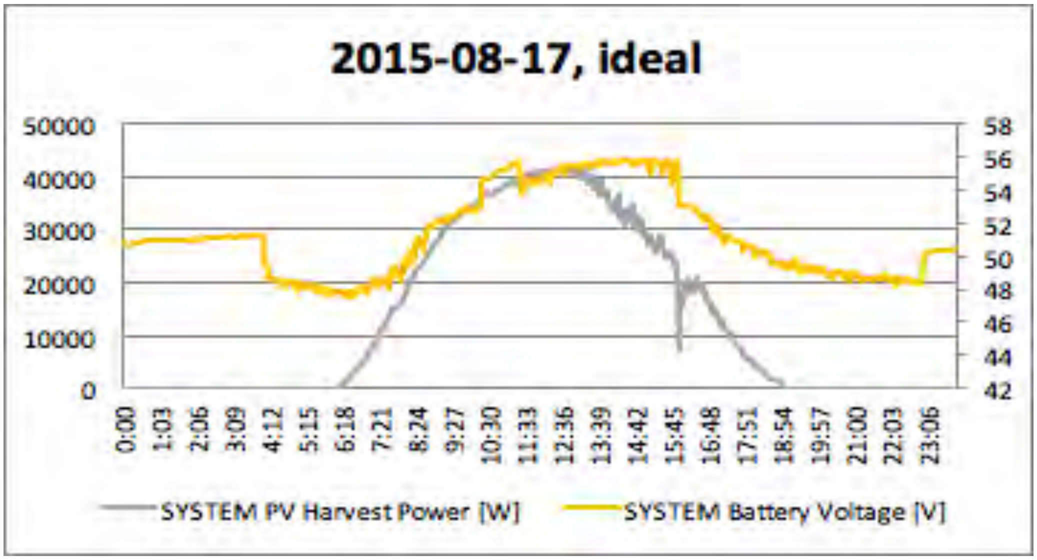


Figure 10: Ideal Charging Curve

The figure above shows the battery voltage curve on an ideal day. The battery stays in bulk charge mode throughout the day until sunset in the evening.

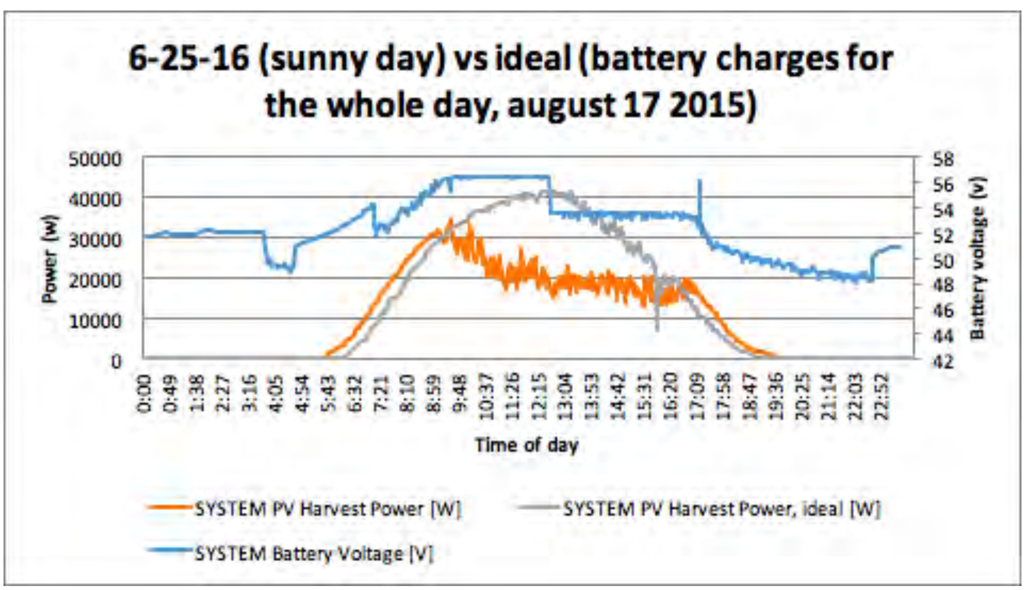


Figure 11: Sunny Day versus Ideal

The interns used the June 25th solar power chart and compared it with the ideal chart. From 10:50 am to 1:50 pm, there is at least a 15 kW gap between the ideal and the real power output. This shows that SML can run a 15 kW system during that time without worrying about power.

ABSOLYTE GP

Absolyte GP Performance Specifications - Constant Current
Amperes to 1.75 Final Volts Per Cell @ 25°C (77°F)

CELL TYPE	HOURS								
	120	100	72	48	36	24	20	16	12
50G									
50G05	1.2	1.4	1.9	2.8	3.6	5.1	6	7.3	9.3
50G07	1.8	2.1	2.9	4.2	5.5	7.7	9.1	11	14
50G09	2.4	2.9	3.9	5.6	7.3	10	12	14	18
50G13	3.7	4.3	5.9	8.5	11	15	18	22	28
90G									
90G07	3.0	3.6	4.9	7.0	9.1	12	15	18	23
90G09	4.0	4.8	6.5	9.4	12	17	20	24	31
90G11	5.0	6.0	8.1	11	15	21	25	30	39
90G13	6.1	7.2	9.8	14	18	25	30	36	47
90G15	7.1	8.4	11	16	21	30	35	42	55

Table 3: Battery Performance Specifications

From the battery monitor, the interns saw that the current of the island load hovers around 3 or 4 amps. For capacity calculations, the interns were conservative and chose 11 amps, which corresponds to 72 hours on the table above. The manufacture usually quotes capacity for an 8 hour draw. Star Island uses 12 hours for their capacity calculations.

Real capacity (kwh)=11 amps*72 hours*48 volts* 10 banks/1000
Equation 1: Real Battery Capacity

By calculating the equation above, the interns found 380 kWh of actual capacity. This is because SML doesn't draw much power. As a result, the batteries have more than 300 kWh of capacity.

SML might need to upgrade the breakers for overload if the reverse osmosis system is connected to the grid. Right now the systems are 175 amps, so the breaker needed may be 250 amps like the breakers on Star island. Star Island has a 50 kWh grid-load and a maximum 12 kW operating load for their RO.

The following instructions come from the battery charge monitor manual, and were recommended to the interns by Dick Case, an electrical engineer on Star Island:

"Change float voltage to 56.7. Setting F1.0 under battery monitor (hold ok button for 3 seconds)." This solves the synchronization issue: SML is presently seeing a big, instantaneous jump in charge from 85 to 100 percent which is obviously incorrect.

Amp hours * voltage = watt hours
Equation 2: Converting Ah to wH

Setting F2.0, change to around 792 (11*72) amp hours instead of the current 700 amp hours upper limit because of the lower current draw.

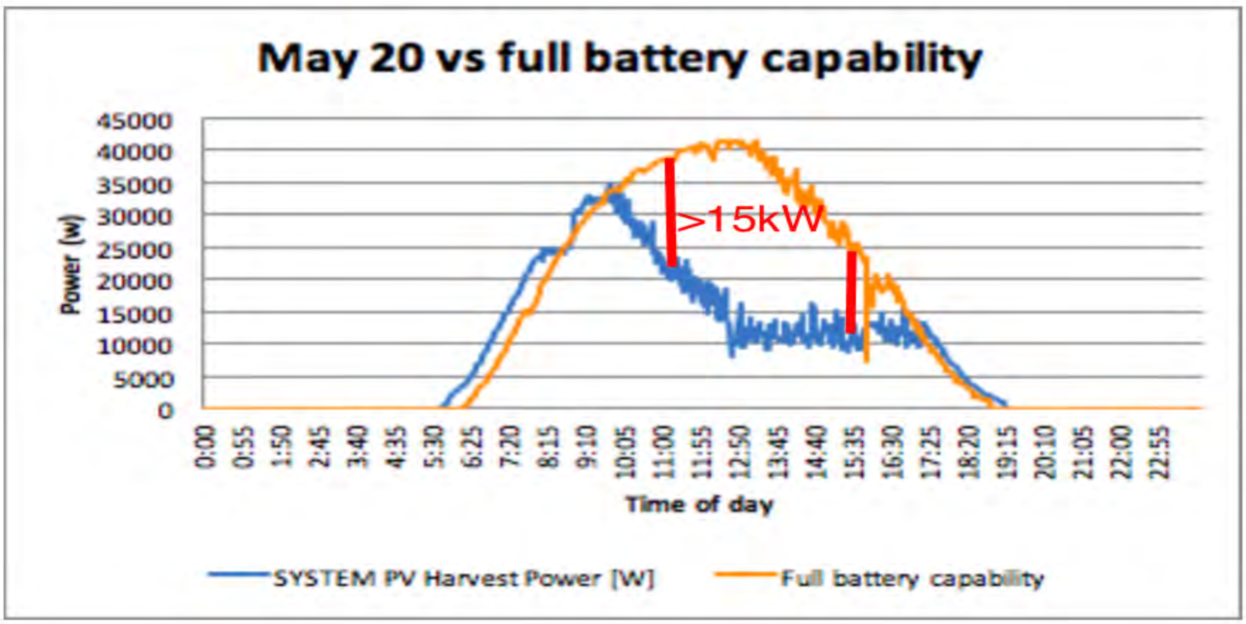


Figure 12: Low Population Excess Power

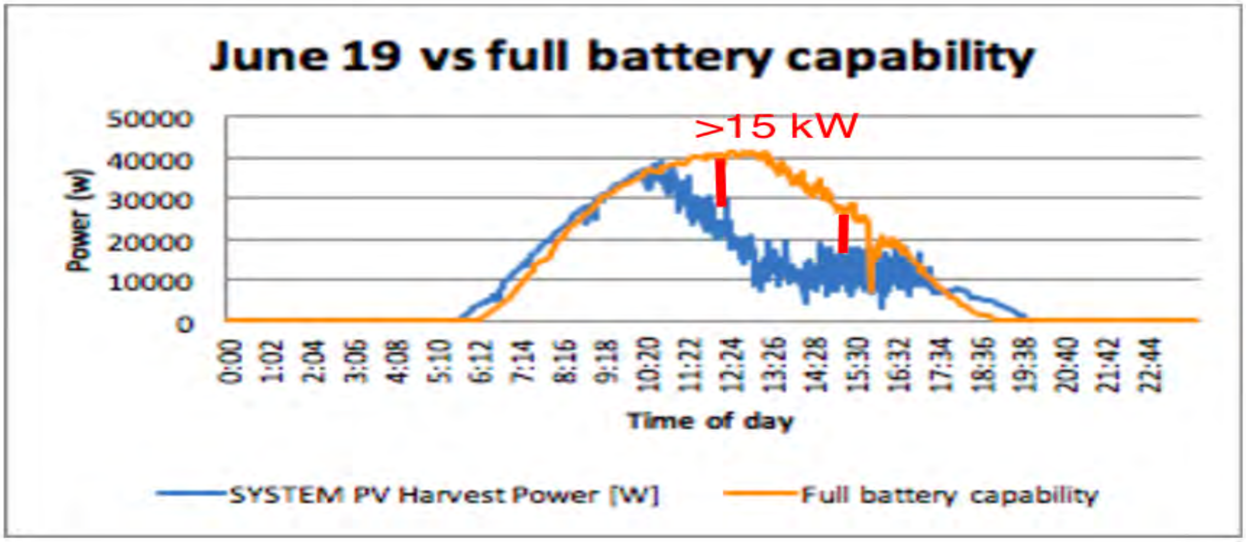


Figure 13: Medium Population Excess Power

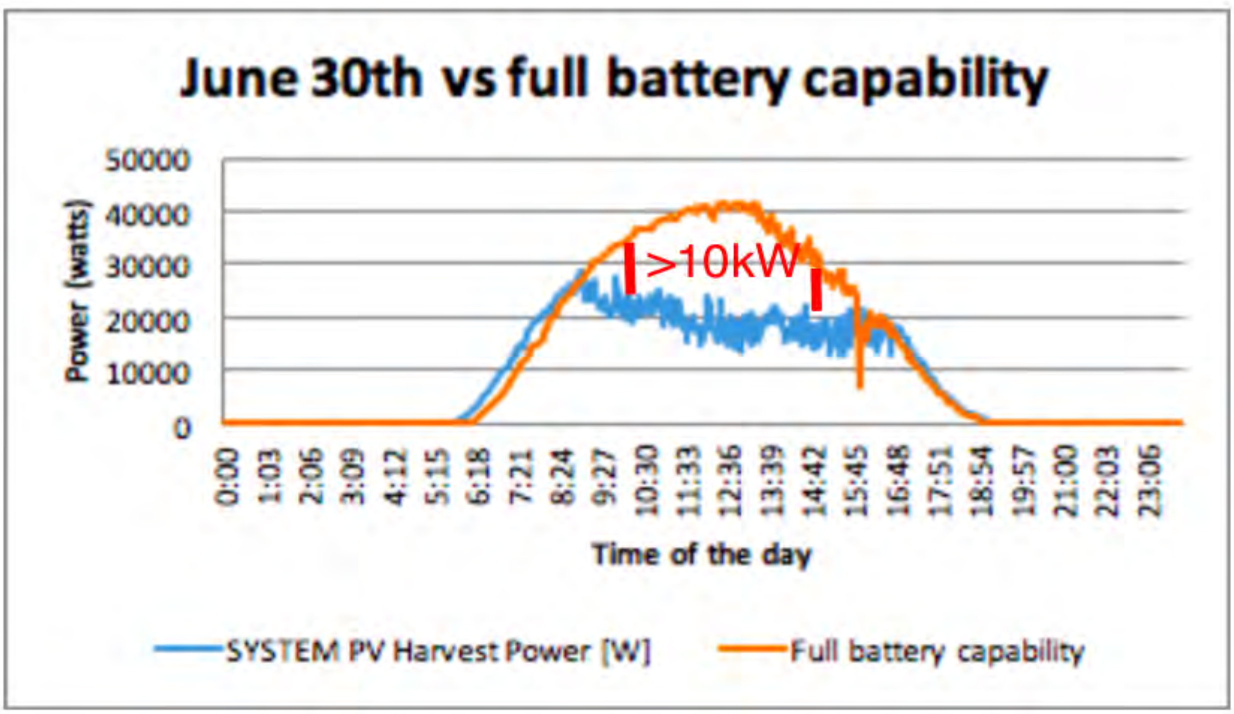


Figure 14: High Population Excess Power

SML's inverters can handle 72kW for 20 seconds.

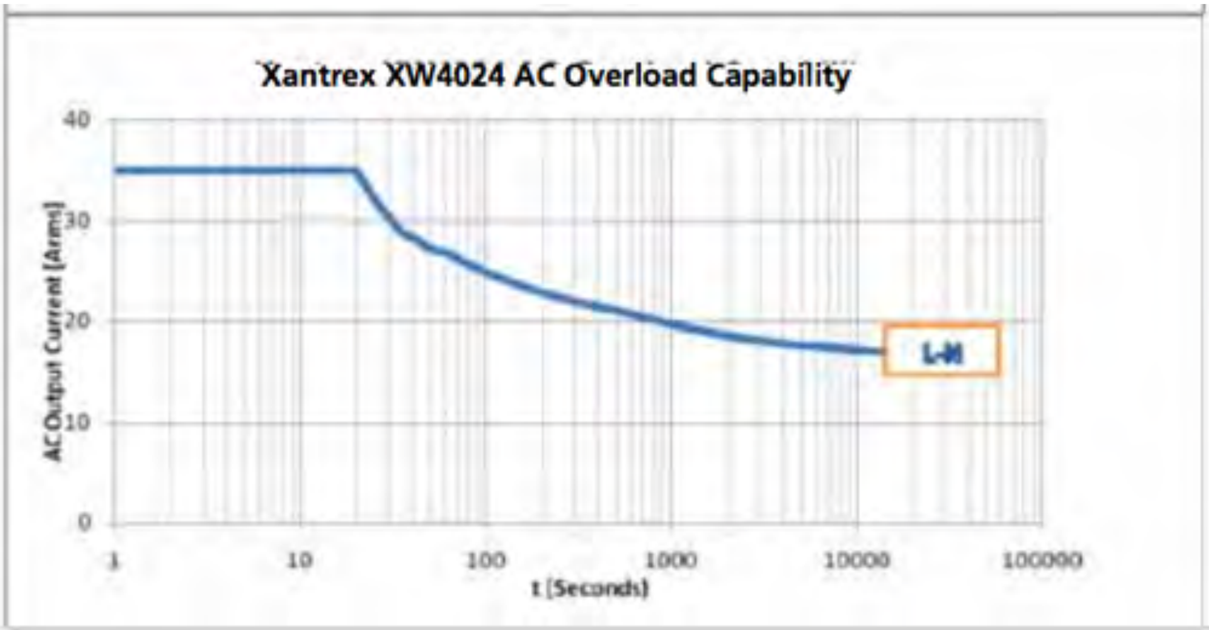


Figure 15: Inverter Overload Capability

- Limitations
  - For 1,800 GPD
    - Run if excess power is >10 kW
  - For 2,600 GPD
    - Run if excess power is >15 kW
  - Start up load
    - Batteries can help to supply additional power
  - May 20 (population: ~20 people)
    - 10:55am until 3:30pm, >15 kW
    - Similar times for >10kW
  - June 19 (population: ~50 people)
    - 11:58am until 3:08pm, >15 kW
    - Similar times for >10 kW
  - June 30 (population: ~80 people)
    - 10:50am to 1:50pm, >15 kW
    - 10:00am to 2:57pm, >10kW
  - As population increased from 50's to 80's, the island grid load line flattened, producing a wider >10 kW zone
- 1,800 GPD system (10 kW excess minimum)
  - When the population is in the 20's, run the RO from 11am-3:30pm

        - 375 gallons
    - When the population is in the 50's, run the RO from 12pm-3pm
        - 215 gallons
    - When the population is above 80, run the RO from 10am-3pm
        - 375 gallons
    - Assuming the RO can only run for ¾ of the season
        - RO produces 28,140 gallons per season
        - 2016 water consumption estimate: 127,851 gallons
        - RO, running on excess solar power, can supply 22% of our water needs
        - In 2010, the RO produced 46,331 gallons, 36% of 2016 consumption
- 2,600 GPD system (15 kW excess minimum)
    - When the population is in the 20's, run the RO from 11am-3:30pm
        - 650 gallons
    - When the population is in the 50's, run the RO from 12pm-3pm
        - 433 gallons
    - When the population is above 80, run the RO from 11:15am-1:45pm
        - 361 gallons
    - Assuming the RO can only run for ¾ of the season
        - RO produces 37,905 gallons per season
        - 2016 water consumption estimate: 127,851 gallons
        - RO, running on excess solar power, can supply 30% of our water need.

2.6 Conclusions and Recommendations

If a new well cannot be successfully drilled, the interns would recommend that SML purchase a new RO system that can be run on the excess solar energy. There are numerous options in the $3,000-3,500 range. However, they can only treat brackish water. These systems deliver around 1,800 GPD. Brands include US Water, Flexeon, Axeon, and APEC systems. Lifestream gave a quote of $13,000 for an 1,800 GPD system (6.4 kW operating load, 10.4 kW start up) including a VFD. A 2,600 GPD (18hrs) system costs $27,940 and has an operating load of 10.7 kW (13.2kW startup). This system can handle seawater. VFDs ensure that the start up load is not higher than operating load. Axeon also has a saltwater RO system (S3).

2.7 References

Lifestream Watersystems Inc.
US Water
EPA
Exide

Aquion Energy
Tesla
(http://www.greentechmedia.com/articles/read/is-teslas-powerwall-luster-already-fading)

Assignment 3: Effective Power Usage

3.1 Background

On sunny days, SML is able to fully charge the 300 kWh battery bank in the Energy Conservation Building (ECB) by early afternoon while also supplying the island's electrical load. When the batteries are full, the solar charge controllers will tell the arrays to solely supply the island load as to not overcharge the batteries. Because there is not enough battery storage, this leads to wasted power.

3.2 Purpose

Due to limited battery capacity, one of the 27kW diesel generators must be run every night to meet island loads. If certain loads could be moved to daytime, when there is excess solar power, the batteries could power the island later into the night and reduce SML's dependence on diesel fuel.

3.3 Scope

The interns looked at possible load shedding options. If any options seemed worthy, the interns were asked to determine the necessary improvements to realize these changes.

3.4 Methods

3.4.1: Handheld Electronics

Most island residents have a cell phone and laptop. These electronics are often charged at night, when they are not being used. While the individual energy demand of these electronics are small, the sheer volume of them on the island makes them a prime research target for load shedding. A wattmeter was used to measure the energy demand of laptops and cellphones. Assuming that everyone on the island charges both of these devices every night, a total energy demand for handheld electronics was calculated. This number was then compared to the efficiency of the diesel generator to estimate the reduction in fuel that could be realized if all electronics were charged during the day.

3.4.2: Well and Cistern Pumps

Hour logs for the well and cistern pumps were analyzed to determine the amount of energy they consume throughout the season. A similar calculation to the one described above was used to determine the reduction in diesel fuel if the pumps only ran during the daytime.

3.4.3: Scuba Compressor

The scuba compressor log was analyzed as well. As this piece of equipment requires use of the 65kW generator, the diesel consumption of the generator was multiplied by the number of hours the scuba compressor is used per season to determine the reduction in diesel usage.

3.4.4: Energy Conservations Strategies

Matt Smith, project manager for the Emerging Technologies Energy Efficiency Program at San Diego Gas & Electric, was consulted for possible conservation strategies. Some of these options involve load shedding, while others are general strategies.

3.5 Results and Analysis

3.5.1: Handheld Electronics

A Watts Up meter was used to measure the energy demand of cell phones and laptops. For the cell phone test, a fully discharged iPhone was charged for approximately 7.5 hours during the night (11:58pm to 7:23am). The charging required 1.8 Wh of energy, and is expressed in gallons of diesel below.

A cell phone requires 1.8 Wh of energy to fully charge; kWh is a common energy unit:

$$\frac{1.8wH}{phone} * \frac{1kWh}{1{,}000wH} = \frac{.0018kWh}{phone}$$

For the week of July 10 to July 16, an average of 92 residents were on the island every day:

$$\frac{.0018kWh}{phone} * \frac{92\ phones}{day} = \frac{.1656kWh}{day}$$

(Note: the average island population for the season is less than this number)

A season consists of 120 days:

$$\frac{.1656kWh}{day} * \frac{120\ days}{season} = \frac{19.872kWh}{season}$$

One gallon of diesel fuel contains 37.656 kWh of energy:

$$\frac{19.872kWh}{season} * \frac{1\ gallon\ diesel}{37.656kWh} = .52772\ gallons\ diesel$$

However, a diesel engine is only about 35% efficient based on Carnot efficiency:

$$\frac{.527\ 2\ gal\ onsldieseli}{.35\ ef\ \ iciencyfratingi} = 1.5078\text{gallons diesel}$$

The CAT D30-10 has a Power Factor of .8:

$$\frac{1.5078\ gallons\ diesel}{.8\ power\ factor} = 1.9\ gallons\ diesel$$

Equation 3: Diesel Use of Cell Phones

Assuming that cell phones are currently charged only by the diesel generator, SML could reduce diesel consumption by about 2 gallons for the season if all cell phone charging occurred during the day. This is trivial, but the laptop study was more promising. Two different Lenovo laptops were tested, and they both required 100 Wh to charge (56 times more energy than a cell phone). Using the above equation:

1.9 gallons diesel * 56 (laptop/cellphone energy factor) = 106 gallons diesel

Equation 4: Diesel Use of Laptops

On July 11, the U.S. Energy Information Administration measured the price of on-highway diesel in New England at $2.469/gallon. This could reduce purchases of diesel by about $260 per season.

3.5.2: Well and Cistern Pumps

The well and cistern both use a .75 kW Franklin Electric submersible motor. The hour logs from June 1 to June 29 were analyzed, and it was determined that the well and cistern pumps run for 1.738 and 1.479 hours per day, respectively. Extrapolating this data for a 120 day season, the pumps run for a total of 386 hours per season, consuming 290 kWh of energy. Using equation 3 for the pumps produces the results below.

One gallon of diesel fuel contains 37.656kWh of energy:

$$\frac{290kWh}{season} * \frac{1\ gallon\ diesel}{37.656kWh} = 7.7013\ gallons\ diesel$$

However, a diesel engine is only about 35% efficient based on Carnot efficiency:

$$\frac{7.7013\ gal\ onsldieseli}{.35\ ef\ \ iciencyfratingi} = 22.004\text{gallons diesel}$$

The CAT D30-10 has a Power Factor of .8:

$$\frac{22.004\ gallons\ diesel}{.8\ power\ factor} = 28\ gallons\ diesel$$

Equation 5: Diesel Use of Well and Cistern Pumps

With diesel prices at $2.469/gallon, SML could reduce diesel purchases by $70/season at most. Both of the pumps run off switches based on water level for the cistern and pressure for the pressure tank. These pumps may run then during day or night. Allowing them to only run during the day would require purchasing timers than tell the pumps when they can run. While this would be fine for the well pump, running the cistern pump (which pumps water to the pressure tank) on a timer would risk the pressure in the tank becoming too low. If the pressure tank goes below 40psi, water may not be able to reach all the buildings on campus.

3.5.3: Scuba Compressors

Switching the scuba compressor to the grid would reduce spending by $200 a season. This is based on the 65 kW generator base load consumption of 4 gallons of diesel per hour. The scuba compressor runs for 20 hours a season. If we do switch, we would recommend Bauer or Poseidon compressors. 10 or even 7.5 cuft systems might be enough. Second hand options should be pursued.

3.5.4: Energy Conservation Strategies

Matt Smith, project manager for the emerging technologies energy efficiency program at San Diego Gas and Electric, spoke with the interns about other possible load shedding options. SML's situation is unique because it is desired to move loads to the daytime, when electricity on the mainland is more expensive, but is free (provided by solar) on the island.

One of these ideas was Viking Cold refrigeration, a system that cools units below their necessary temperature when electricity is less expensive and shuts off when electricity rates are high. The San Diego Food Bank is currently using this system, but it is not known if there is a system of appropriate size for the island.

Another option was outlet load controllers. These controllers only allow electronics to draw power from outlets at certain times of the day, and could be used to minimize nighttime loads.

However, these controllers would be expensive to purchase in bulk, and would likely regulate the charging of handheld electronics, which have already been shown to have minimal savings.

3.6 Conclusions and Recommendations

Though several methods of effective daytime load shedding were investigated, none were able to achieve significant savings. These dollar savings are further reducing when considering the necessary equipment purchases and behavioral changes needed to put them into effect. The best solution to our power storage problem would be to buy more batteries.

3.7 References

Bauer Compressors

Assignment 4: Power Generation - Master Plan

4.1 Background

SML has 14 buildings plus additional structures to support engineered systems. These buildings and engineered systems create SML's electrical load. Electricity is produced from a combination of wind, solar and diesel generation. The energy from the wind and sun is stored in two separate banks of batteries. One battery bank was installed in 2007 (Radar Tower) and one in 2013 (Energy Conservation Building). Based on the battery set points and current use, each bank is predicted to last approximately 10 years. The batteries in the Radar Tower are nearing their predicted end of use.

4.2 Purpose

SML desires a master plan to handle the predicted end of use of the battery bank in the Radar Tower. These batteries power five buildings during the summer months, and SML's webcam, weather station, and Internet connection year round. One potential solution is the use of grid-tie inverters at individual buildings using dedicated solar arrays. The interns will evaluate this proposed solution and, if feasible, outline a plan for implementation. The batteries banks in the Radar Tower, installed in 2007, are near the end of their life cycle. An alternative needs to be found for the 5 buildings that use this grid, especially the Radar Tower, which holds instrumentation that must be powered year round. The main grid is shut down for the winter, ruling such an option out.

4.3 Scope

This project aims to find an alternative power system for the 5 buildings (Dorms 2 & 3, K-House, P-K Lab, and Radar Tower) currently using the smaller Green grid. This plan must ensure that off-season demands are met for weather instrumentation, webcam, and internet in the Radar Tower. The main grid does not operate during the off-season.

4.4 Methods

4.4.1: Measuring Building Loads

In order to better understand the energy demands of the Green Grid, buildings were switched on and off the grid, and the Powermonitor 3000 was used to measure these demands. This allowed the interns to see how reconfigurations of the electrical grid could be affected by increased or decreased needs. The power for the Radar Tower and PK come from the same breaker box, and so these combined loads were used as a baseline measurement. Dorms 2 & 3 and K-House were switched onto the grid at different times, and the increase in energy demand was assumed to be the load for that particular building. Measurements were taken for Dorms 2 & 3 when a class of 20 was occupying the two dorms.

4.4.2: Demand from the ECB

One number that would be helpful when devising new power plans as the Green Grid is phased out is how often the Green Grid already borrows from the main grid. Interns from the 2013 SEI ran a test to determine the capacity of the Green Grid battery bank, and their tests revealed 2.5 kWh of storage remained in the 88 kWh bank. A similar test was conducted by this year's interns to compare results and determine how much longer this system would last.

4.4.3: Power Generation Master Plans

With help from the data collected from the first two methods of this assignment, master plans for SML's electrical grid were devised. One particularly important constraint is the necessity of the Radar Tower being powered year round. The Tower hosts weather instrumentation and a webcam that allows Appledore Island to be observed throughout the winter. When considering options, cost of equipment and necessary labor were noted, as well as long-term operation requirements.

4.5 Results and Analysis

4.5.1: Measuring Building Loads

The trend log of the Powermonitor 3000 in the Radar Tower was recorded to measure individual building loads. Each configuration was measured for three 24-hour cycles except for the Radar Tower. Several different measurements are shown below.

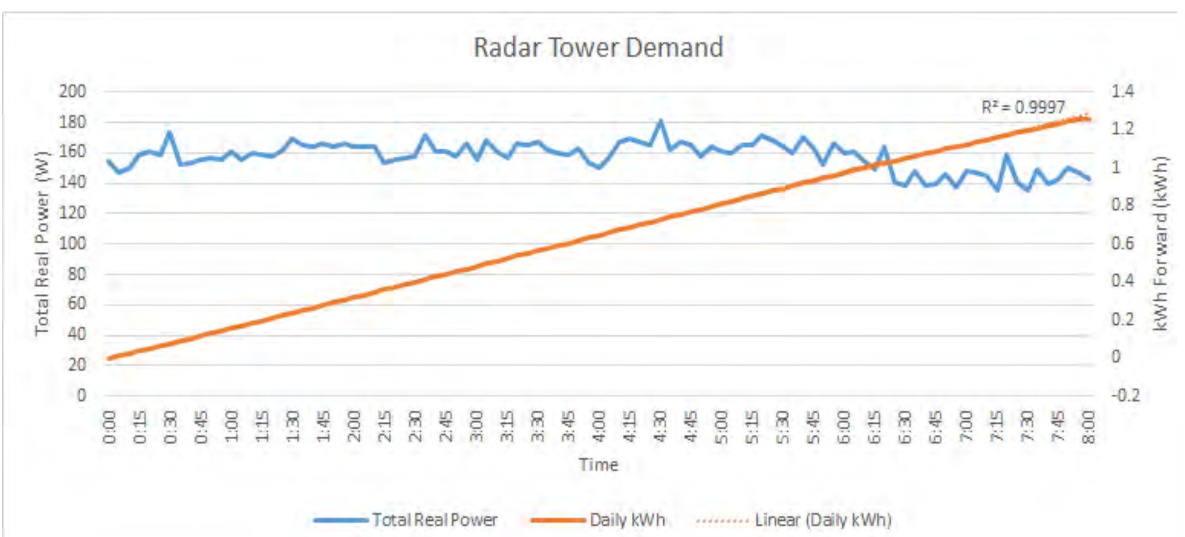


Figure 16: Radar Tower Demand

Shortly before midnight on July 2, Dorms 2 & 3 and K-House were shifted to the main grid. Because the Radar Tower and PK have their power supplied from the same breaker box, power to the lab was completely shut off. This time was chosen to avoid disrupting classes. Ross Hansen and Mike Rosen agreed with the interns that this configuration would be representative of the Radar Tower's demand during the off-season. For this eight-hour test, power demand for the Tower stayed around 160 W, showing a linear energy demand represented by the orange line. Because of the r-squared value of the energy demand trendline, the data should safely be extrapolated to a 24-hour cycle. This showed that for a 24-hour cycle, the Radar Tower requires 3.78 kWh of energy. For any system (generation and batteries) supplying power to this system, it must be safely reach these requirements. The combined 7.5 kW solar arrays on Dorms 2 & 3 have met this bar the past few winters, and the wind turbine did before then.

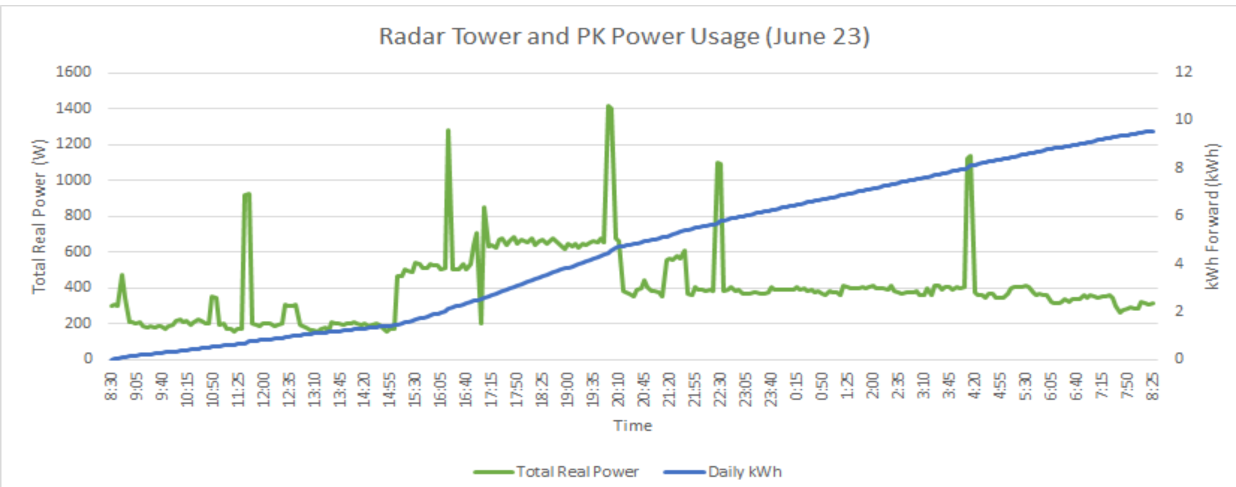


Figure 17: Radar Tower and PK Demand

Data for this configuration was taken for three days. There were three classes in session during this collection. The interns asked the professors from these classes how often they were in PK, and the total came to 25 hours per week, not including independent study. From averaging the daily kWh for those days, the energy demand of PK and the Radar Tower was measured at 9.58kWh/day. By subtracting the known Radar Tower demand from this number, we can assume the daily power demand for PK is 5.80 kWh.

A similar method was used to determine Dorms 2 & 3 energy demand as well as K-House, except the 9.58 kWh was used as the baseline since classes were in session. These numbers will vary with island population, but as they were taken when many students and guests were present, they can give an idea of the upper limit energy demands. A table of the individual building loads is shown below.

Building	Daily kWh
Radar Tower	3.78
PK	5.80
Dorms 2 & 3	3.86
K-House	3.48

Table 4: Individual Building Loads

4.5.2: Demand from the ECB

There are two Powermonitors in the Radar Tower. The Powermonitor 3000 measures power going to the Green Grid buildings, and the 1000 measures power coming into the Green Grid from the ECB. In order to measure the remaining effective capacity of the batteries (based on voltage setpoints) the two solar arrays supplying power to this grid were disconnected. The only power going to the Green Grid buildings then was either from the batteries or the ECB. The ECB can supply power to the Green Grid while simultaneously charging the batteries. Once the batteries reach their maximum charge, the ECB stops supplying power to the Green Grid, and the batteries are allowed to fully discharge before the ECB begins supplying power to the grid again. The graph below shows a discharge cycle for the Green Grid batteries.

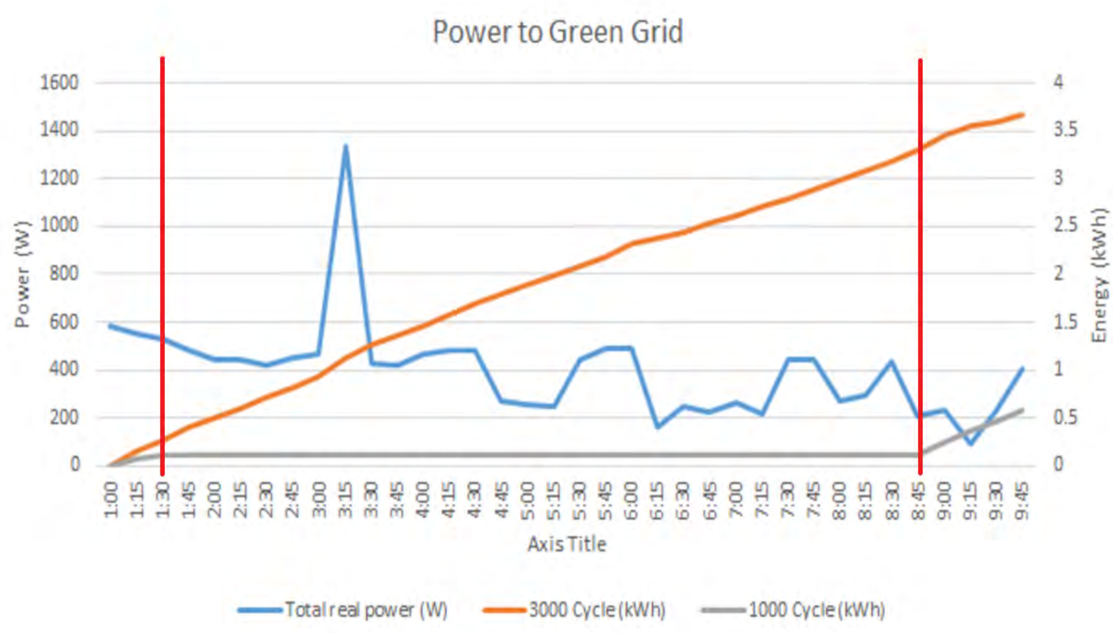


Figure 18: Green Grid Battery Capacity

The blue line represents instantaneous power going to the Green Grid buildings, and the orange and gray lines represent total energy going out to and coming into the Green Grid, respectively. The red lines are where the gray line is horizontal, meaning no power is coming to the Green Grid from the ECB. Measuring the difference in the orange line between these two points reveals power going out to the Green Grid buildings via the batteries. This cycle shows around 3 kWh of energy supplied, and a second test showed similar capacity. This result is slightly higher than the one calculated by 2013's interns, who measured the Green Grid battery capacity at 2.5 kWh.

The battery bank for the Green Grid is rated at 88 kWh. This number is misleading because the batteries stop supplying power at a 30% depth of discharge, so their rated effective capacity is 26.4 kWh. This is almost ten times higher than the measured capacity, indicating that these batteries are nearing the end of their lifespan.

4.5.3: Power Generation Master Plans

Throughout this program, it has been identified that SML does not have a power generation problem, but a power storage problem. This lack of power storage is the main reason why diesel still supplies around 40% of the island's electrical load. It is suggested that the 88 kWh Radar Tower battery bank at least be replaced, if not improved upon. The following plans attempt to cope with the end of the Radar Tower battery bank.

Option 1:

All buildings are moved onto the Main Grid. The current Green Grid buildings will add an additional 16.62 kWh daily energy demand onto the Main Grid. However, as the current daily energy demand from the Main Grid is almost 300 kWh, there should be no issue. With the exception of the Radar Tower/PK, the Green Grid buildings already can directly draw power from either grid.

To minimize line losses, the combined 7.5 kW solar arrays on Dorms 2 & 3 should be moved to the northern side of the island to be closer to the ECB. It is recommended that new Schneider charge controllers be purchased for these arrays to assist in data logging. The Conext XW 80-600 MPPT model was found online for $1,328.00. These charge controllers could be connected to the current DC load center in the ECB if the wind turbine and load diverters are removed from this grid.

The Radar Tower/PK will have a mini-grid due to winter power demands. The wind turbine will supply power to this grid, as it has in the past. The batteries in the current grid will be replaced with one or two 6.4 kWh Tesla Powerwalls, which cost $3,000. These lithium-ion batteries are rated for a much higher depth of discharge than the AGM batteries SML owns with a similar lifespan.

This plan will likely cost most in terms of labor and materials, but would be the easiest to maintain. The DC load center in the ECB will only have one open breaker if the above configurations are realized, meaning a second switchboard will need to be purchased if more than one additional battery stack is desired. The interns were unable to discern the necessary current capacity of a second switchboard for it to function with the one already in place.

Option 2:
The Radar Tower/PK and K-House each receive dedicated solar arrays, the 4.5 kW and 3 kW respectively. These buildings were chosen as they are the highest individual buildings loads on the Green Grid, shown by Table 4. Once again, the Tesla Powerwall is the suggested battery system. Each could have one or two of these 6.4 kWh batteries, and if solar and battery power are not sufficient, they could draw power from the ECB.

Having these individual systems could reveal a lot about where loads are generated from and help detail future energy conservation strategies. However, these solar arrays are likely oversized for individual buildings, and even with ample storage, insufficient demand to could lead to wasted power in-season. Additionally, it is unknown if a single solar array would provide ample power to the Radar Tower during the winter, when there is less direct sunlight.

Option 3:
The third option is to simply keep the grid configurations as they are. While not exciting, the current grids have proved reliable and no labor would be required aside from replacing the batteries. To replace the current Green Grid battery bank with one of similar capacity would cost about $30,000. With the current system, thorough data is unable to be collected. The Powermonitor 3000 is able to measure power going out from the grid but not its source. Purchasing new charge controllers would allow data on the two solar arrays to be collected.

4.6 Conclusions and Recommendations
There is no single solution to cope with the end of the Green Grid's battery bank, but the above proposed options show directions in which the electrical system could go. Although the plans have different methods, they all require the purchase of batteries. The Powermonitor 3000 was

extremely effective in measuring individual building loads, and a similar test could be used in the future to gain insights into where and what draws power on Appledore Island.

4.7 References

Wholesale Solar

Assignment 5: LED Lighting Study

5.1 Background

SML is constantly looking for ways to reduce the base electrical load on Appledore Island. Lighting loads are a significant part of the island's total energy use. In 2006 and 2007, SML upgraded T-12 fluorescent and incandescent bulbs to T-8 fluorescent and compact fluorescent bulbs. SML upgraded most of the campus lighting again with LED technology in 2015 and 2016 and seeks a thorough analysis of its performance. LED lights are expensive to install. The interns need to check whether these lights did indeed save energy and reduce spending.

5.2 Purpose

Evaluate the effectiveness of LED lighting installed in 2015 and 2016. Compare results in efficiency gains with predictions made by 2015 interns

5.3 Scope

This project focuses on analyzing the energy output reduction as a result of LED lights. The diesel fuel use reduction was quantified as part of this analysis. Additionally, light intensity data was collected and compared to fluorescent lighting in order to assess the quality of light.

5.4 Methods

5.4.1: Light Intensity

The first task was to determine how many LEDs had been installed since 2015 and in which locations. After consulting with Ross Hansen about this data and making our own observations, it was determined that LEDs had been installed in the Grass Lab, most parts of Kiggins, Hamilton, Laighton, the Radar Tower, and PK Lab. Using a light meter, sample locations in each building were tested. 1-4 samples were taken at work surface level in one or multiple rooms of each building identified above. The following lighting guide, which outlines ideal light intensity for given environments, was utilized.

LIGHT GUIDE
LED Recommended Light Levels

Illuminance (lux)	Space
50	Dark public spaces
100	Corridors, loading bays
150	Warehouses, theaters
200	Foyers, homes, bathrooms
300	Classrooms, assembly halls
400	Offices, libraries, kitchens
500	Computers, labs, stores
750	Workshops, supermarkets
1000	Detailed workspaces
Too Dim	< Recommended-150
Good	> Recommended-150, < Recommended+150
Too Bright	> Recommended+150

Table 5: Recommended Light Levels Guide

Samples were taken at night, on a cloudy day, and a sunny day with the lights both on and off to account for ambient lighting. Once these values were obtained they were averaged for each building and compared to 2015's data. These numbers were then analyzed in accordance to the ideal lighting values given above and ranked as superior or inferior depending on which year had a lighting intensity closest to the ideal.

5.4.2: Quantitative Improvements

Using records of energy usage from both 2015 and 2016, energy consumption of specific buildings was measured. This data was supplemented by information about average island population for each month in both seasons, which was obtained from Amber Litterer and used to calculate average energy usage per capita. Proper disposal of old lighting was also researched.

The interns found SML's LEDs and Fluorescent lights on Home Depot. After matching the brand and product type, the price and energy consumption provided by Home Depot were used. The following equations were used:

Annual Energy (kWh)=Annual usage (hrs)*wattage*# of bulbs

Energy cost ($)= Annual energy (kWh) * Price per kWh

Real kWh per gallon of diesel=average daily grid power demand (kWh)/average daily diesel usage (gallons)

Price per kWh ($)= price per gallon of purchased diesel ($3.70)/Real kWh per gallon of diesel

Bulb Life (yrs)=manufacture listed lifespan/Annual usage (hrs)

Replacement Cost ($)=number of bulbs*price per bulb/bulb life (yrs)

Annual cost=Energy Cost+Replacement Cost

Implementation cost=number of bulbs*price per bulb

Energy usage reduction=Annual energy (2016)-Annual energy (2015)

Payback time (yrs)=Implementation cost/cost reduction

Less diesel used=Energy usage reduction/Real kWh per gallon of diesel

Equation 6: LED Cost Analysis

5.5 Results and Analysis

5.5.1: Light Intensity

Below is the resulting spreadsheet from the light intensity analysis described in the previous section, showing data for nighttime, cloudy day, and sunny day data collection and the tallies calculated for each section indicating which year had lighting closer to ideal values.

LED TESTING	*(All units in lux, refer to Sheet 2 for Light Guide)	Night		Sunny Day						Cloudy					
		6/25/16 (9:30-10:15pm)	7/10/15	6/23/16 (3:30-5:30pm)			7/8/15			6/28/16 (8:15-9am)			7/18/15		
GRASS LAB	Main Room (10 LED (1 broken), 2 F)-2016, 2015	Lights On	On	On	Off	Minus Ambience	On	Off	Minus Ambience	On	Off	Minus Ambience	On	Off	Minus Ambience
		378	521	960	246		536	98		583	53		590	88	
		614	479	1150	840		1700	1293		647	29		1005	573	
		289	318	400	100		433	45		342	13		409	16	
Avg		427-Good (Rec 400)	440-Good (Rec 400)	837	395	442 -Good (Rec 400)	890	479	411-Good (Rec 400)	524	32	492-Good (Rec 400)	668	226	442-Good (Rec 400)
	Entrance Room (4 LED)-2016, 2015	635-Too Bright (Rec 400)	432-Good (Rec 400)	544	140	404-Good (Rec 400)	505	61	444-Good (Rec 400)	1182	485	697-Too Bright (Rec 400)	452	25	427-Good (Rec 400)
	Utility Room (16 LED, 4 flourescent)-2016	389	138	320	49		223	98		314	4		266	163	
	(18 LED)-2015	552	299	668	470		340	60		467	10		337	28	
		365		540	12					383	167				
		435-Too Dim (Rec 750)	218.5-Too Dim (Rec 750)	509	177	332-Too Dim (Rec 750)	281.5	79	202.5-Too Dim (Rec 750)	388	60	328-Too Dim (Rec 750)	301.5	95.5	206-Too Dim (Rec 750)
	Diesel Gen. Room (2 LED, 16 flourescent)-2016	425	323	490	27		430	7		454	3		373	4	
	(2 LED, 14 F)-2015	285	280, 318	900	526		441, 346	68, 5		424	217		167, 400	25, 5	
		355-Too Dim (Rec 750)	307-Too Dim (Rec 750)	695	276.5	418.5-Too Dim (Rec 750)	406	27	379-Too Dim (Rec 750)	439	110	329-Too Dim (Rec 750)	313	11	302-Too Dim (Rec 750)
KIGGINS	Cleaning Storage Room behind Kitchen (8 LED)	372		320	NA					347	13				
		432		380	65					445	15				
	Kitchen (36 LED)-2016, (46 F)-2015	506	73	500	24		342	35		520	3		284	6	
		509	332	630	45		831	38		664	7		819	8	
		595	472	1190	662		523	60		1104	523		483	4	
		537-Good (Rec 400)	292-Too Dim (Rec 400)	773	244	529-Good (Rec 400)	565	133	432-Good (Rec 400)	763	178	585-Too Bright (Rec 400)	529	6	523-Good (Rec 400)
	Entrance Hall (8 LED)	391		942	706					446	113				
		374		478	84					423	27				
	Basement Entrance (16 LED, 1 broken)-2016	309	411	363	206		551	61		512	56		201	24	
	(24F)-2015	428	637, 145, 591	406	134		971, 2100, 407	27, 173, 183		543	45		1135, 545, 231	156, 6, 39	
		368.5-Good (Rec 500)	446-Good (Rec 500)	384.5	170	214.5-Too Dim (Rec 500)	1007	444	563-Good (Rec 500)	527.5	50.5	477-Good (Rec 500)	528	205	323-Too Dim (Rec 500)
HAMILTON	Main Office (24 LED)-2016, (22 F)-2015	460	972	872	357		866	201		788	83		978	24	
		720	210, 451	891	391		476, 1235	39, 1182		388	60		142, 190	29, 55	
		820-Too Bright (Rec 400)	544-Good (Rec 400)	881.5	374	507.5-Good (Rec 400)	859	474	385-Good (Rec 400)	588	71.5	516.5-Good (Rec 400)	437	36	401-Good (Rec 400)
	Classroom (24 LED, 2 broken)-2016, (12 F, 3 I)-2015	153	359	NA	NA					NA	NA				
		225	266, 906	NA	NA					NA	NA				
		189-Good (Rec 300)	510-Too Bright (Rec 300)												
LAIGHTON	Downstairs (48 LED)-2016, (48 F)-2015	335	647	350	83		750	104		412	14		532	18	
		662	406, 917	715	74		722, 964	179, 80		675	26		287, 807	22, 15	
		498.5-Too Bright (Rec 300)	657-Too Bright (Rec 300)	532.5	78.5	453.5-Too Bright (Rec 300)	812	121	691-Too Bright (Rec 300)	543.5	20	523.5-Too Bright (Rec 300)	542	18	524-Too Bright (Rec 300)
	Upstairs (42 LED)-2016, (28 F)-2015	601	988	865	259		1332	364		654	16		1102	38	
		613	896	675	76		1242	273		690	41		1084	17	
		607-Too Bright (Rec 400)	942-Too Bright (Rec 400)	770	167.5	602.5-Too Bright (Rec 400)	2574	318.5	2255.5-Too Bright (Rec 400)	448	28.5	419.5-Good (Rec 400)	1093	27.5	1065.5-Too Bright (Rec 300)
RADAR TOWER	1st Floor (8 LED, 2 flourescent)-2016, (6F)-2015	336	21	315	85		61	36		130	11		19	5	
		258	108	250	16		489	65		279	2		48	14	
		297-Good (Rec 150)	64.5-Good (Rec 150)	282.5	50.5	232-Good (Rec 150)	275	50.5	224.5-Good (Rec 150)	204.5	6.5	198-Good (Rec 150)	33.5	9.5	24-Good (Rec 150)
PK	Main Room (86 LED)-2016, (42F)-2015	243	836	1530	1410		1890	686		1228	1182		647	82	
		605	550	246	219		1058	238		148	30		238	23	
		640	745	1500	964		994	203		682	231		203	41	
		474		1900	1200					529	9				
		490.5-Too Bright (Rec 300)	710-Too Bright (Rec 300)	1294	948	346-Good (Rec 300)	1314	356	958-Too Bright (Rec 300)	647	363	284-Good (Rec 300)	363	49	314-Good (Rec 300)
POLE BARN	(12 flourescents)-2016, 2015	NA	42	130	63					NA	NA				
		NA	114	160	12					NA	NA				
TOTAL BETTER		8	4			8			3			6			5

Figure 19: Lighting Quality Analysis Spreadsheet Overview

Figure 20 contains a graph showing what the numerical data looks like for nighttime light intensity values. The bars on the left represent 2015 and the ones on the right represent 2016. The green bars are those that are closer to the ideal value, which is symbolized with a red horizontal line for each building. Results show that for nighttime in 8 out of 12 cases the lighting was closer to ideal, on a sunny day in 8 out of 11 cases, and for a cloudy day in 6 out of 11 cases. The discrepancy in total cases is due to the fact that the downstairs Hamilton classroom could not be measured during the day because of classes taking place there, so no data was taken for this location for the sunny or cloudy day analysis. Nonetheless, the trend is very clear: LEDs have improved the quality of lighting overall in each of the conditions studied.

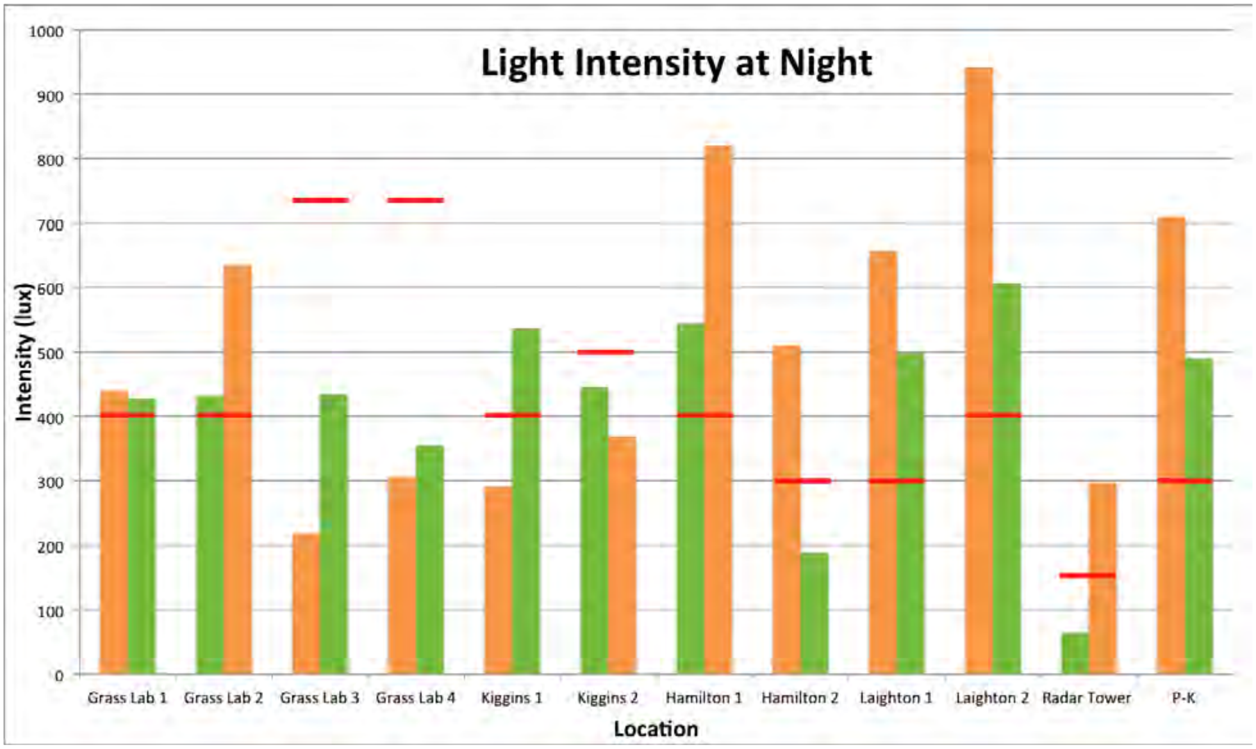


Figure 20: Light Intensity at Night for 2015 versus 2016

5.5.2: Quantitative Improvements

	2015 interns' cost analysis			
	Implem Cost ($)	**Energy usage reduction(kWh)**	**Spending reduction($)**	**Diesel usage reduction(gal)**
sum	16230	10299	5477	921

Table 6: 2015 Cost and Energy Analysis

	2016 Interns' Cost Analysis			
	Implem Cost ($)	**Energy spending reduction(kWh)**	**Spending reduction ($)**	**Diesel spending reduction (gal)**
sum	3884	14199	1738	488

Table 7: 2016 Cost and Energy Analysis

This year's lighting upgrade results in a cost reduction of 14,199 kWh, which equates to 488 gallons of diesel. This calculation is based on a summation of both solar and diesel generator output, assuming that solar power costs nothing. These LEDs reduce energy spending by $1,738 per year. This figure also factors in the longer lifetime of LEDs as well as its higher replacement cost.

In 2015, 60% of the island's power came from diesel generators. Using an hourly average island load of 16 kWh in 2015, it can be said that 46,080 kWh (120 days) of energy is used per year. The interns assumed that 70% of LED light power consumption is outside of maximum sunlight hours. Maximum sunlight hours refers to the period between 8:30am to 5:00pm. During this period, solar energy output is larger than the load of the island, and as a result, energy use is practically free. From 2015 figures, it can be seen that a gallon of diesel produces 11.18 kWh of energy. As a result, in 2016, the switch to LEDs reduce diesel usage by 7.4 gallons of diesel per day. The island used 20.8 gallons of diesel per day in 2015.

Reasons for the large discrepancies from the 2015 predictions

- Last year's interns used $30 per LED bulb, this year's used $9 per bulb
- Last year's interns used 10,000 hrs as lifespan for T8 Fluorescent, this year's used 30,000 hrs
- Last year's interns used 50,000 hrs as lifespan for LEDs, this year's used 36,025 hrs
- Power reduction of 2.1 kW in 2016 due to LEDs
    - Instantaneous power: when all lights are on at the same time
- Used last year's interns' estimates on annual light usage
- The engineers replaced more bulbs than last year's estimate
- Each gallon of diesel effectively produces more energy than last year due to better solar integration. This includes solar energy, which is assumed to be free
- Using last year's method, replacement cost is spread over the lifespan of the bulbs
    - Affects spending reduction
- Diesel price: $3.70, purchased 3 yrs ago
    - Price will most likely be lower if another batch is purchased in the near future
- 2016 estimated total diesel consumption: 1,222 gallons
- 2015 total diesel consumption: 2,151 gallons
- 53% of diesel usage reduction is due to LEDs (estimate)

LED Disposal
LEDs do not contain mercury, unlike fluorescents. After researching online and speaking to UNH's recycling manager, the interns realized that there is no set protocol for disposing LEDs. LEDs are a relatively new technology. The UNH manager has asked the interns to send him their used LED lights so he can experiment with them to find a good way to dispose them.

Carbon footprint reduction
From the data above, it can be seen that a 35.6% reduction in generator runtime was achieved. The generators ran for 10 hours per day in 2015. As a result, it can be concluded that NOx emissions will be reduced by 52,920g and particulate matter emissions by 302g in 2016.

NOx emissions reduction (g)=percentage reduction in generator runtime * hours the generator ran per day in 2015 * horsepower of generator * EPA tier 4 max NOx output per hp-hr *days in a season (120)

Final Emission Standards in grams per horsepower-hour (g/hp-hr)

Rated Power	First Year that Standards Apply	PM	NOx
hp < 25	2008	0.30	-
25 ≤ hp < 75	2013	0.02	3.5*
75 ≤ hp < 175	2012-2013	0.01	0.30
175 ≤ hp < 750	2011-2013	0.01	0.30
hp ≥ 750	2011-2014 2015	0.075 0.02/0.03**	2.6/0.50† 0.50††

* The 3.5 g/hp-hr standard includes both NOx and nonmethane hydrocarbons.
† The 0.50 g/hp-hr standard applies to gensets over 1200 hp.
** The 0.02 g/hp-hr standard applies to gensets; the 0.03 g/hp-hr standard applies to other engines.
†† Applies to all gensets only.

Table 2: Diesel Generator Emission Standards

In 2016, 40% of the island's power came from diesel generators. Switching to LED lights definitely made a significant difference. For 2017, the interns would recommend that SML change the lights in Kiggins Commons showers to LED. The shower lights are on throughout the day. A 10 or 15 minute motion timer, similar to the system in the compost bathrooms, should be installed in the showers.

5.6 Conclusions and Recommendations

The switch to LEDs did not produce as much energy usage reduction as the 2015 interns had predicted. This is because energy has become “cheaper.” Each gallon of diesel can now effectively produce a lot more energy. This is because several solar arrays were installed after the 2015 interns left. Nonetheless, energy and cost savings were realized to a significant extent.

This project reflects on a paradox in sustainability. As SML become more “green” and energy becomes cheaper, it makes less financial sense to switch to devices that consume less energy. This is an issue that governments and companies must confront.

5.7 References

Home depot
UNH recycling manager

Assignment 6: Solar Panel Efficiency

6.1 Background

SML installed two new rooftop solar arrays in the summer of 2015. Shortly after the installation, gulls decided the solar panels were a nice surface to sit on and soil (all the time). It is dangerous for personnel to get up on the roof to clean these panels so the efficiency of the panels is reduced.

6.2 Purpose

Design a system to keep gull excrement off of the two rooftop solar arrays either through an automated washdown system using collected rooftop water or the installation of a gull deterrent system

6.3 Scope

This project is one that has been tackled in the past but has never yielded a successful solution. This year's aim was to better understand the two means by which the gull excrement problem might be solved, namely a washdown system or deterrent system, and narrow down the alternatives based on a collection of knowledge about gull behavior, solar panel efficiency loss rates, and restraints on the design, such as limitations on water.

	Pros	Cons
Washdown System	-Reduces need for dangerous maintenance of rooftop panels -Does not waste potable water for washing, uses rainwater instead	-Not as thorough as manual washing
Gull Deterrent System	-Preventative rather than reactionary measure	-Has been explored in past years without success

Table 8: Pros and Cons of Different Systems

6.4 Methods

6.4.1: Measuring Efficiency Loss and Simulated Washdown System

In order to determine the extent of efficiency reduction as a result of solar panel coverage, three ground arrays, oriented back to back, were used to measure relative efficiencies before and after washing. These arrays were all identical in model and subjected to the same conditions due to their proximity. Because solar panel coverage does not display a linear relationship with efficiency loss, the interns wanted to determine how much efficiency could actually be gained by a clean panel and how long this boosted efficiency would last.

A washdown system simulation was devised in which a bucket of water was repeatedly filled to a consistent line and poured over the array from one end to the other at a constant flow rate. The goal was to see how clean the array became after simply rinsing it rather than scrubbing it down.

A second test was done in which the interns scrubbed the same array clean shortly after the first test in order to accurately compare the full gains in efficiency. This way potential versus current production of solar panels could be compared.

6.4.2: Gull Deterrent Systems

An alternative to the washdown system was the gull deterrent system. The interns first had to learn about what gulls might dislike or stay away from, such as certain colors or physical blockades. Julie Ellis, a gull behavior expert from UNH, was contacted in order to receive insights and recommendations on potentially effective deterrents. The SEI interns also spoke to the gull interns on the island to ask about what behaviors they have seen the gulls exhibit around the solar panels.

After collecting this information and learning from experimentation, the interns proposed five possible solutions including:

Red string: According to multiple sources, gulls do not like the color red (supposedly because it reminds them of fire). Red string was therefore attached to the perimeter and across portions of the center of the panel about 6 inches off the face in order to detract from the appeal of landing on the array.

Aluminum foil: Shiny surfaces make it difficult for a gull to land. Aluminum foil was wrapped around the perimeter string of the array already containing red string.

Perch: The interns learned that gulls will tend to land on the highest point of a given structure. Therefore, a tall, wooden perch was constructed and placed directly behind the test array in order to get gulls to land on the perch rather than on the array below.

Extended perch with spikes: Bird spikes are commonly used on porches or other small surfaces where people don't want birds. However, because spikes are relatively expensive and it would be difficult to fasten them all over the array, screws were drilled into an elongated perch in order to keep gulls from comfortably sitting on the perch and eventually find a new place to watch over their territory. The screws were placed far enough apart that a gull could still land on the perch without hurting itself (this was tested and proven to be true).

Hydrophobic coating: This new technology is most commonly used for glass surfaces, but has recently been developed for solar arrays by the company Alpha Nanotechnology, who offered to send a sample of their product for testing on Appledore's arrays. The coating is advertised as being able to increase solar panel efficiency, be dirt and water repellant, protect from irreparable abrasion, and reduce costs of cleaning and care. A representative from Alpha Nanotechnology claimed that a simple breeze would clear the panel from collected debris. Unfortunately the sample did not arrive in time to be tested by the interns, but should arrive and be tested before the end of this season.

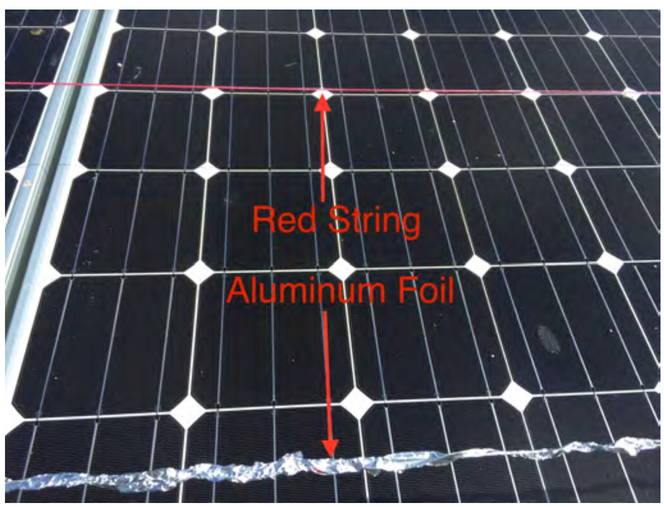


Figure 21: Red String and Aluminum Foil Deterrent Systems

Figure 22: Perch Deterrent System

Figure 23: Elongated Perch with Spikes Deterrent System

In order to collect data on all of these gull deterrent methods, a GoPro camera was used to take photos in 30-second increments to compare the array with the deterrent in place and a neighboring control array. The number of gull landings on each of these arrays were counted and the results can be found in the table below.

6.5 Results and Analysis

6.5.1: Measuring Efficiency Loss and Simulated Washdown System

After testing the simulated washdown system, not only was it found that the array was nearly as dirty as before, seeing as the gull guano was still stuck to the array, but that an excessive amount of water had to be used in order to just rinse the panel. 40 gallons of water were used for one array alone. Even if rainwater were to be used to clean all the arrays, an additional rainwater catchment roof and storage would need to be implemented in order to meet the demand for rainwater from both the washdown system and the garden. As the rainwater collection system currently stands, the two 800 gallon tanks can only supply the garden for approximately a week without recharge from a rain event.

The more thorough cleaning of the array revealed the trend shown in the figure below, which compares the clean array (depicted with red dots) with the two dirty arrays behind it (shown in blue and green). The interns observing that the slope of the uppermost line, corresponding to the clean array, was the least steep, representing a smaller decline in efficiency compared to the other arrays as the afternoon progressed. The interns were then able to calculate that this difference in slope corresponds to a 19% advantage in efficiency for the clean array.

Graphs were also made for the same set of arrays one day and one week later in order to determine how long the advantage would last. In the figures below, Array 5 is the clean one (represented in blue), while Array 4 is one of the two dirty arrays (represented in red). This analysis yielded a 14% and 1% advantage, respectively. These results indicate that after a week the panel is essentially as dirty as it was before the washdown, meaning that the washdown would need to take place at least that often to have an effect on overall efficiency.

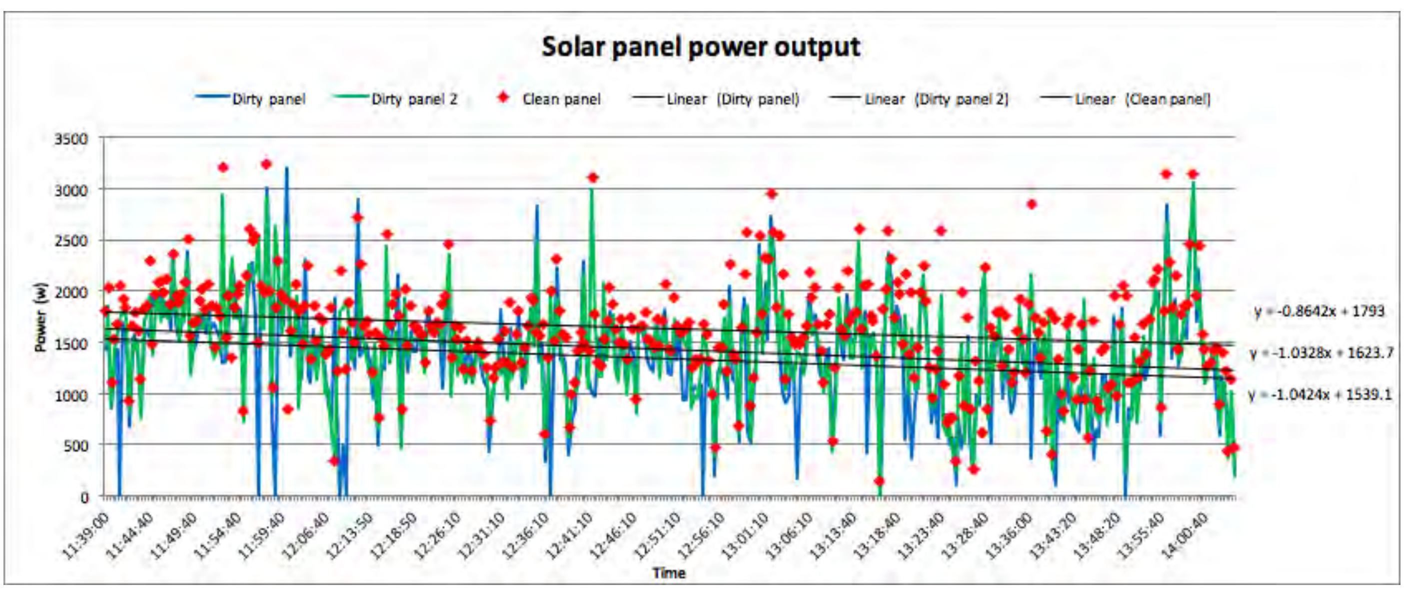


Figure 24: Solar Panel Outputs for Clean vs Dirty Arrays

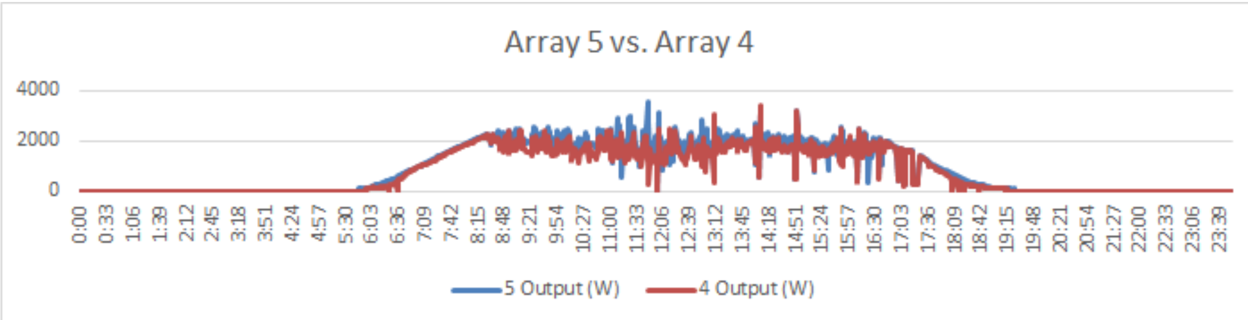


Figure 25: Array Efficiency After One Day

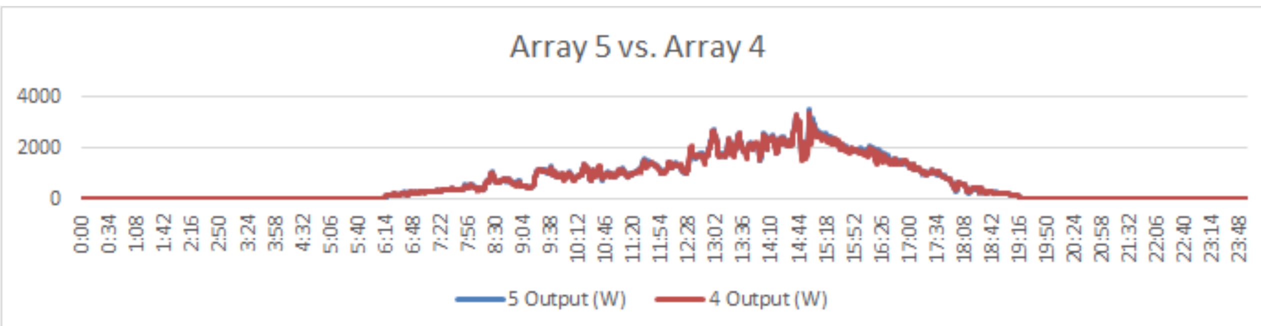


Figure 26: Array Efficiency After One Week

What the interns ultimately found was that the washdown system would use an excessive amount of rainwater. As a result, the focus shifted to the gull deterrent system.

6.5.2: Gull Deterrent Systems

Analysis of the photographs taken of each system shows that none of the deterrent systems are a perfect solution. In fact, in most cases the gulls preferred to land on arrays that contained the deterrent than those without it. In the case of the aluminum foil and the perch, the deterrent seemed to *attract* gulls to the site. When the perch became full, gulls would simply hop down to the array below and congregate there, regardless of whether the spikes were present or not. In many cases the control array had fewer gulls on it, showing that doing nothing might be the best option.

Gull Deterrent Systems

Test	Number of Photos	Deterrent Panel Landings	Control Panel Landings
Red String #1	272	4	7
Red String #2	383	1	6
Red String #3	390	7	5
Foil #1	243	4	1
Foil #2	245	16	1
Perch #1	305	7 (+5 on perch)	1
Perch #2	188	4 (+2 on perch)	4
Spikes #1	327	8 (+9 on perch)	2
Spikes #2	329	8 (+9 on perch)	8

Table 9: Gull Landings on Different Deterrent Systems

Although none of the methods solved the problem, a lot of insight was gained about gull behavior and smarter ways of tackling the issue.

6.6 Conclusions and Recommendations

6.6.1: Measuring Efficiency Loss and Simulated Washdown System

After testing the efficiency of a clean solar array compared to a dirty one by using a simulated washdown and subsequent scrubbing, it was found that a 19% increase in efficiency might be gained. However, after considering the amount of rainwater that would be required to thoroughly clean all the arrays on the island and the fact that occasional dangerous rooftop maintenance would still be required, the interns decided to abandon the washdown system approach.

6.6.2: Gull Deterrent Systems

Even though none of the deterrents were particularly effective, there is still the option of the hydrophobic coating, which has not yet been tested. Additionally, as stated in an earlier project, the island currently produces more energy than it uses, so the unused capacity of the solar panels is not crucial at this time. Perhaps in the future this problem can be tackled again more thoroughly, but for the time being the island is not suffering as a result of the lost efficiency.

6.7 References

Glenn Shwaery (representative from Alpha Nanotechnology)
Alpha Nanotechnology (http://www.alphananosolutions.com)

Assignment 7: Rooftop Water for Drip Irrigation

7.1 Background

2015's interns devised a plan to water Celia Thaxter's garden with a drip irrigation system. The system was installed after their internship by UNH's Thompson School of Applied Science. This system uses rainwater collected from the roof of the Grass Lab that is stored in two 6' feet deep 800 gallon tanks. Not only is drip irrigation a more sophisticated system than using sprinklers, but using rainwater reduces demand on SML's well.

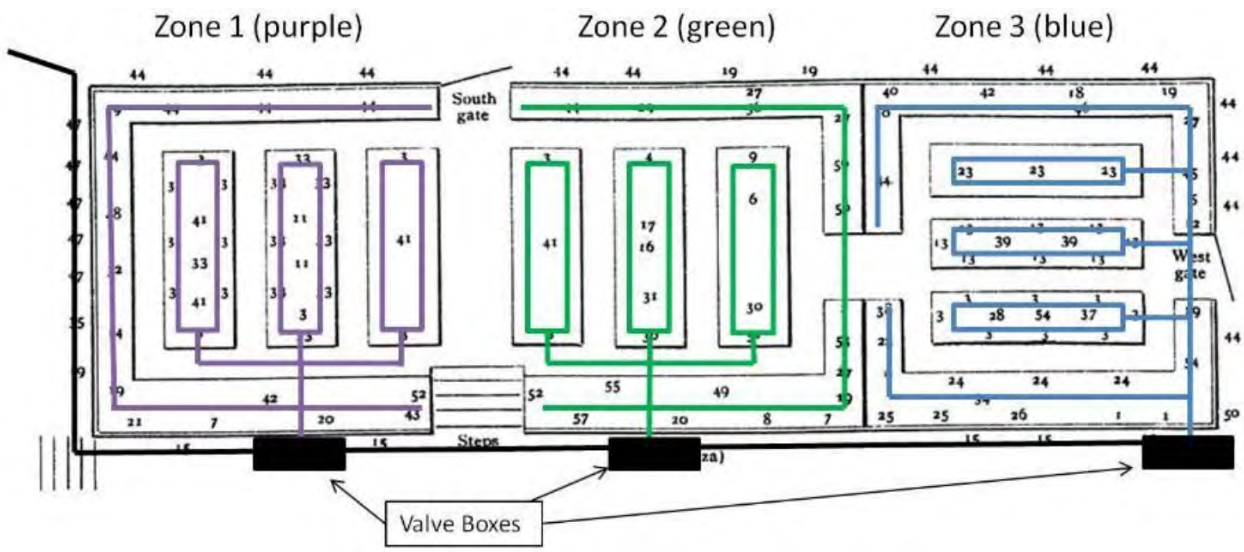


Figure 27: Drip Irrigation System Design

7.2 Purpose

As this is a new system, SML wants to investigate its effectiveness.

7.3 Scope

The interns were asked to evaluate the new drip irrigation system using collected rainwater. They documented the amount of freshwater usage reduction due to the implementation of this system, and were asked to suggest improvements to make the system more effective.

7.4 Methods

7.4.1: Freshwater Usage Reduction and Precipitation Data

Drip irrigation is more efficient than sprinklers in delivering water to plants. This means that ample watering of the garden can be achieved with less water. The interns investigated the frequency of watering cycles and how much water they used. As there is no flow meter for the system, the interns measured the volume of water used by the system by measuring water height in both tanks before and after a watering cycle. Last year's interns predicted the system would use about 80 gallons per day, and this year's measurements were compared to theirs.

After measuring the volume of water required for this system, it was desired to know if weather patterns allow this amount of water to be used. By analyzing precipitation data from the UNH Weather Station, the amount of recharge to the tanks was determined.

7.4.2: Water Quality

Rooftop water is not of the same quality as the water stored in the pressure tank. Contaminants in the collected water may make it unsuitable even for use in the garden. The interns consulted with Marie Nickerson, Master Gardener and Celia Thaxter's Garden Steward for concerns about water quality. The interns sent samples to a lab on the mainland to be tested for nitrate and ammonia. A pH test of the collected rainwater was conducted on-site.

7.4.3: Improvements to the System

The interns gained a thorough understanding of the system and identified where problems could arise. In addition to water quality, filtration was identified as a key area for improvement. Several tests were run to see how the current filtration was working, and ideas for future filtration were suggested.

7.5 Results and Analysis

7.5.1: Freshwater Usage Reduction and Precipitation Data

The water level in both tanks was measured before and after watering cycles. The water levels between the two tanks differentiate by half an inch from the top, but always change by the same amount. Both tanks were measured to have an area of 4,071.5in². The data for one tank is multiplied by two in the volume calculation to get total water use during a cycle.

Date	Height to Top Before (in)	Height to Top After (in)	Change in Height (in)	Volume (gallons)
June 26	33.25	30.75	2.5	88.1
July 3	39.625	42	2.375	83.7
July 7	48.25	50.75	2.5	88.1

Table 10: Drip Irrigation Water Usage

Last year's interns measured the amount of effective watering from the sprinkler system to be 112 gallons taking into effect a 30% evapotranspiration rate. This means the sprinklers were using 160 gallons of freshwater per day to water the garden. The drip irrigation system uses almost half that amount, but that it is only for a single cycle. The system has two cycles per day, one from 8:00am to 9:20am and the second from 5:00pm to 6:20pm. For a single day then, the system uses about 173 gallons of water, more than the amount the sprinklers used. However, since all of this water is coming from rooftop collection, a fresh water usage reduction of 160 gallons a day is still realized. The gardeners were asked if having a shorter cycle or moving to one cycle per day was a possibility, but they did not want to lower the amount of watering.

After learning that the system was using double the volume of water predicted, it was desired to know if precipitation patterns would be sufficient to recharge the collection tanks. Data was looked at from May 1 to August 31 of each year. Precipitation data from UNH's Weather Station from 2011 to 2015 was quantified and helped produce the results below:

- There were 1.51 dry days per wet day.
- Out of 615 days, 370 (60.2%) were dry, and 245 (39.8%) were wet.
- It rained 0.317" on wet days.
- On average, in a single season, there were 49 wet days, totaling 15.53" of rain.

In the *Increase the Freshwater Supply* assignment from 2013, the interns measured the effective roof area of the Grass Lab to be 1,968ft^2. This means that during a typical rainfall event, 389 gallons of water is recharged into the tanks. Assuming the tanks are full at the beginning of the season and cannot be pumped to lower than 6" to allow settling of sediment, there are about 1,467 available gallons of water. This means that during a typical season, there should be more than enough recharge to allow the system to pump more than 170 gallons per day.

7.5.2: Water Quality

The three parameters measured for water quality were pH, ammonia, and nitrate. pH was measured using the same device SML uses to test the tap pH. The tap water, and previously the water used for the garden, had a pH around 6.5 after testing. This matched with readings present in the water quality log, in which pH was often between 6.4 and 6.5. The pH of the water in the collection tanks was measured twice and averaged at 7.4. This is slightly more basic than the water previously used. While Marie was not concerned with pH, methods for increasing acidity were researched. Two solutions included placing pine needles or compost in the soil. SML has a rudimentary composting system, but it will need to be attended to more frequently to be suitable for the garden.

To test for nitrate and ammonia content, two samples of tank water were collected and sent to Eastern Analytical in Concord, New Hampshire. Nitrogen in the water was a concern because it is found in gull guano, which is present on all roofs on the island. The results from this lab measured the ammonia content at 27g/mL and nitrate at >0.5g/mL. Marie said the nitrate content was fine, but that she needed to do additional research on the plants in Celia Thaxter's garden to see if the ammonia content was suitable.

7.5.3: Improvements to the System

Filtration was seen as the biggest and most immediate area for improvement. Franklin Electric, the manufacturer of the pump for the drip irrigation system, was contacted about use of their pump in such a system. The pump has an inlet screen, but they suggested adding additional filtration to the system before pumping. Ross Hansen installed window screens on the gutter drains to prevent large particles from entering the system. The system proved valuable, but it is recommended that these screens be cleaned after each rainfall event to optimize performance and prevent clogging. The filter prior to the valve box in the garden was checked, and there was little particulate matter in it. It seems that most of the suspended solids in the collection tanks are settling to the bottom of the tank prior to pumping.

Last year's interns recommended the installation of a first flush system. This system works by diverting the first 30 gallons of rainwater (based on roof area) into a separate collection tank. A ball valve seals this tank after filling and allows the rest of the stormwater to flow to the main collection tanks. These steps are pictured below. Based on observations made this year, this system may not be necessary.

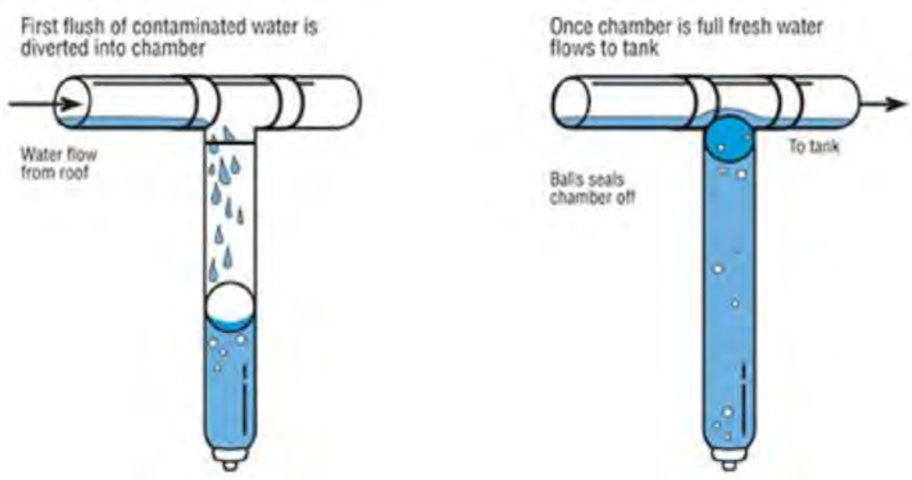


Figure 28: First Flush System

7.6 Conclusions and Recommendations

The drip irrigation system using collected rainwater is working well. Island staff have commented on how great the garden looks this season, and this is likely due to the fact that the system is using twice the volume of water predicted last year. However, the dry season SML is experiencing means that the collection tanks will soon run dry, and will require more well water than previously to meet their demands. The gardeners are currently satisfied with water quality. If pH is determined to be too high, compost could be added to the soil. If ammonia content is too high, a first flush system would prevent nitrogen-rich gull guano from entering the garden.

7.7 References

Franklin Electric

Assignment 8: Grease Trap Effectiveness

8.1 Background

SML's commercial kitchen has an in-line grease trap that services the dishwasher, three-pot sink, and a washdown sink. The purpose is to keep grease from entering SML's septic system. It is expensive and time-consuming for SML to have the septic tanks pumped by a septic hauler. The more grease that enters the septic tanks, the more frequently the tanks need to be pumped. Grease entering the septic system is expensive (approximately $14,000) to be pumped out since the septic trucks need to be transported on a barge to reach the island.

8.2 Purpose

The purpose of this assignment is to research how grease traps work, perform field measurements on SML's grease trap system to determine the effectiveness of the installed system, and to make recommendations on design changes such as the size of the trap, its location in the system, and system type.

8.3 Scope

The solution to this problem should involve reducing the frequency of septic tanks needing to be pumped by the septic hauler and considering that the quantity of grease may vary depending on time of day and type of meals prepared that day.

8.4 Methods

The initial step in solving the problem was to research how grease interceptors work. The system works under the premise that the substances involved have different densities. The fats, oils, and greases (FOGs) will float to the top of the water column, the food particles will settle to the bottom of the interceptor, and the water will flow through the interceptor to the settling tanks in the septic system. The grease contained in the interceptor is considered brown grease since it is comprised of more than just yellow greases such as olive oil or canola oil.

Figure 29: Grease Interceptor

Preliminary testing was performed on the grease interceptor by comparing the temperature of the water leaving the dishwasher (130°F) to the temperature of the water entering the grease interceptor (120°F). This 10 degree cooling process is sufficient for the FOGs to coagulate and rise, allowing water to pass through the system.

Coring samples were then taken to observe the relative thicknesses in substance layers. Unfortunately, the layers in the sample from the center section of the interceptor were indistinguishable since such a large amount of grease had accumulated in the interceptor and the sampler was consequently clogged.

Figure 30: Grease Interceptor Coring Sample

The image below illustrates a core sample of the effluent of the grease interceptor after the solution has passed through each section. As evidenced by the core, a significant portion of grease and food particles pass through to the outlet, which is seen floating on the top and sitting at the bottom, respectively. Although a large portion of the core is relatively clear water, over time the amount of grease that gets through the interceptor builds up and causes issues downstream in the settling tanks, as discussed above.

Figure 31: Grease Interceptor Coring Sample of Effluent

Andre Cardoso, a grease trap specialist who works with dining halls at the University of New Hampshire, visited SML to assist the interns with further testing. He noticed immediately that the current interceptor was unable to handle peak loads during the day. Meal types and quantities are variable so it is important that the interceptor be able to handle water from the greasiest meals served to a large number of people on the island. It was evident during coring sampling that the system was not a steady state one in that the water level remains constant and flow in equals flow out, but a transient one where the water level rises and falls. The sizes and flow rates of the sink and dishwasher systems feeding into the grease trap were then examined to verify that the grease trap was undersized.

Maintenance was another possible source of error in the operation of the grease interceptor. The interns explored whether the grease trap could be cleaned more frequently, possibly by island staff. This removed grease could be stored in plastic drums and every so often would be taken to Portsmouth on one of SML's boats for final disposal. Because the weight limit for transportation is 4,000lbs, hauling a 55 gallon drum should not present an issue for SML staff. The final stage in the analysis was to research a more effective grease interceptor model to consider the size, location in the system, and system type.

8.5 Results and Analysis

In order to properly size the grease trap, the interns worked with Andre Cardoso to identify all the sinks, drains, sprayers, dishwashers, and other sources of wastewater leading into the grease interceptor. The plumbing for these sources was correlated to the pipes in the basement beneath the kitchen in Kiggins Commons in order to confirm which pipes from above are leading directly into the interceptor and which are being diverted downstream, such as the shower waste water, which doesn't need to go through the interceptor before being sent into the septic system. Below is the spreadsheet provided by Zurn, the interceptor manufacturer, which allows the customer to input data about various sink dimensions, as well as flow rates. The first three rows depict the three sinks in the kitchen, including the center sink, the 3-pot sink, and the handwashing sink near the back. The sink near the entrance has a sprayer nozzle attached to its head and was therefore measured in terms of flow rate instead of dimensions, and was added onto the dishwasher flow rate which was approximately 2 GPM (gallons per minute) and 1.23 GPM, respectively. The dishwasher flow rate was found using the second figure below in which the dish washer specifications include a flow rate of 74 GPH (gallons per hour), which could easily be converted to GPM.

A	ENTER MEASUREMENTS FOR SINK #1 (INCHES)							
	LENGTH:	18	WIDTH:	18	DEPTH:	10	NUMBER OF COMPARTMENTS:	1
A	ENTER MEASUREMENTS FOR SINK #2 (INCHES)							
	LENGTH:	24	WIDTH:	24	DEPTH:	14	NUMBER OF COMPARTMENTS:	3
A	ENTER MEASUREMENTS FOR SINK #3 (INCHES)							
	LENGTH:	16	WIDTH:	22	DEPTH:	10	NUMBER OF COMPARTMENTS:	1
B	ENTER TOTAL GPM FLOW OF ALL OTHER SOURCES FEEDING INTERCEPTOR							3
	ZURN GREASE INTERCEPTOR SIZE PER PDI METHOD (ONE-MIN. SINK DRAIN TIME)							
	SIZE 1100 MODEL Z1172							
	ZURN GREASE INTERCEPTOR SIZE PER PDI METHOD (TWO-MIN. SINK DRAIN TIME)							
	SIZE 900 MODEL Z1172, Z1173							

Table 11: Grease Interceptor Sizing

Specifications:

MODEL AH/C	USA	METRIC
OPERATING CAPACITY		
RACKS PER HOUR		
(NSF RATED)	40	40
OPERATING CYCLE		
WASH TIME-SEC	45	45
RINSE TIME-SEC	30	30
DWELL TIME-SEC	15	15
TOTAL CYCLE TIME	90	90
WASH TANK CAPACITY	1.7 GAL.	(6.45 L)
PUMP CAPACITY	52 GPM	(197 LPM)
OPERATING TEMPERATURE		
REQUIRED	120°F	(49°C)
RECOMMENDED	140°F	(60°C)
WATER CONSUMPTION		
PER RACK	1.7 GAL.	(6.45 L)
PER HOUR	74 GPH	(280 LPH)
WATER REQUIREMENTS		
WATER INLET	3/4"	(1.9cm)
DRAIN-I.P.S.	2"	(5.1cm)

	USA	METRIC
WASH PUMP MOTORS HP	1	1
DIMENSIONS		
DEPTH	25-3/4"	(65.4cm)
WIDTH (OUTSIDE DIMENSION)	25-3/4"	(65.4cm)
HEIGHT	56"-57"	(142.2cm-144.8cm)
STANDARD		
TABLE HEIGHT	34"	(86cm)
MAXIMUM CLEARANCE		
FOR DISHES	17"	(43cm)
STANDARD DISHRACK	1	1
DIMENSIONS	19-3/4"X19-3/4"	(50X50cm)
ELECTRICAL RATING	**VOLTS**	**AMPS**
	115	16
SHIPPING WEIGHT		
APPROXIMATE	270#	(122.5kg)

Table 12: Dishwasher Flow Rate

8.6 Conclusions and Recommendations

By this calculation, a 1 minute sink time requires a 100 GPM capacity and 2 minute sink time requires a 75 GPM system. The sink time refers to the amount of time it takes for 75% of the volume of the sink to drain, which is referred to as the drainage load. Zurn suggested the 1 minute sink drain time recommendation in SML's situation in order to ensure functionality.

Using a slower 2 minute sink drain time would have resulted in a recommendation for a smaller unit. Below is the recommended unit based on the sizing spreadsheet above.

Grease Trap Capacity 200 lbs 100 GPM by Zurn w 4" Inlet

[GT2700-100]

$1,374.97

Model #: GT2700-100

GT2700-100 Zurn Grease Trap, 200 LB., 100 Gallons Per Minute Capacity.

Recommended for removing and retaining grease from wastewater in kitchen and restaurant areas where food is prepared.

- Grease trap is corrosion-resistant coated fabricated steel with no-hub connections,
- Flow diffusing baffle, integral trap, and vented inlet flow control device.

Specifications of the Plumbing & Drainage Institute

Dimensions:

Model GT2700-100

- 100 GPM
- Inlet 4"
- Width Front to Back 42-3/4"
- Length Side to Side 36"
- Height Floor to top 27"
- Bottom to Center of Inlet 23"
- **Product weight 458 lbs with pallet Liftgate highly recomended**

Figure 32: Recommended Grease Interceptor Specifications

The cost of purchasing a 100 GPM grease interceptor, specifically Model #GT2700-100, from Zurn is $1,374.97. An acid resistant version is not necessary since the current interceptor is not constructed from acid resistant plastic and has shown no damage from sulfuric acid which is created from decomposing food. This decision would avoid the extra expense of purchasing a model made from acid resistant plastic.

The new grease interceptor would have double the flow rate compared to the current unit (50 GPM). This larger unit would have a volume of more than three times that of the current one ($24ft^3$ compared to $7ft^3$), which would also correspond to a larger surface area in which grease could accumulate on the top layer without disrupting the flow of water underneath. An additional suggestion would be to install a solids interceptor with a finer mesh in the sink with the sprayer where plates are rinsed off before being put in the dishwasher. This would prevent small food particles, such as rice, from getting through the drain and collecting at the bottom of the interceptor, reducing storage capacity.

In terms of frequency of cleaning, the grease interceptor is definitely being cleaned too infrequently. Andre Cardoso recommends starting out with cleaning once per week and if this seems unnecessary, shift to once per month, but not less than that. Besides the fact that more frequent maintenance will clearly improve the efficiency of the interceptor, the interceptor is much easier to clean out if regular maintenance takes place and becomes a much less unpleasant task. For perspective, the neighboring Star Island, which has an average summertime population of about 450 people and more than one grease interceptor, cleans theirs three times per week. As stated above, the plan would be to store pumped grease into large plastic drums, which are already available on-island, and transport these to Portsmouth when necessary. This grease can be recycled at waste facilities, but should not be burned as it currently is, as kitchen grease is considered industrial waste and burning it has a negative impact on the environment.

After analyzing the plumbing, it was determined that the placement of the interceptor is correct. All and only those pipes that need to enter the interceptor are currently doing so, while other gray water sources, such as showers and kitchen floor drains are entering the septic system downstream. However, the suggestion was made that a second grease trap might be added in series to the new on in order to ensure catchment of any grease that may have escaped the first one.

Overall, findings indicated the need for a grease interceptor that can handle double the current flow rate of the current one and more frequent cleaning at intervals of at least once per month.

8.7 References

Zurn (www.zurngreasetraps.net)

9: Future Project Suggestions

Improved Compost System

Currently, Appledore uses a very rudimentary system for composting. Compost is collected and stored, but has minimal usefulness even after several years due to lack of attention. Besides just using the compost for some landscaping, Appledore could develop a better system in which compost is regularly turned over and aerated in order to help with decomposition. The product could then be used for Celia Thaxter's garden rather than buying and shipping soil to the island, which is expensive and inconvenient. Improvements can be modeled off of Star Island's composting system, which is very successful.

Toilet Upgrades

Locations for new composting toilets can be investigated, or alternatively, the use of greywater (such as water from showers) could be used for flushing toilets rather than fresh, potable water, as is currently the case.

Electrifying the Gators (and all Island Vehicles)

Gators, as well as the other vehicles on the island, currently depend on diesel to run. Changing these out for electric vehicles might be worth looking into, especially because these vehicles might be capable of capturing some of the excess energy produced by solar panels that is currently not being absorbed by batteries.

New Battery Technology

As discussed in the report, new batteries will soon need to be obtained for the Radar Tower, and as battery technology continues to improve and develop, it would be wise to research the most suitable technology at the time of purchase.

Second Grease Trap in Series

The possibility of using a second grease trap in series with an existing one might be explored in order to capture any grease that manages to escape. This would only be necessary if, after implementing the suggestions of purchasing a larger unit and cleaning it more frequently, there is still grease in the settling tanks.