2019

Assessment of Alternative Power Sources for Remote Water Infrastructure Sites

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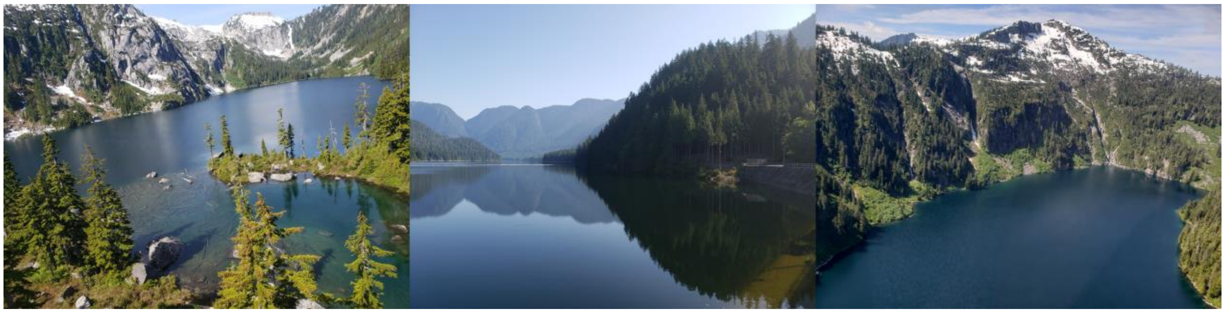
in collaboration with Metro Vancouver
May to September 2019



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This project was conducted under the mentorship of Metro Vancouver staff. The opinions and recommendations in this report and any errors are those of the author and do not necessarily reflect the views of Metro Vancouver or the University of British Columbia.

Project Summary:

a. **Project Title**: Assessment of Alternative Power Sources for Remote Water Infrastructure
b. **Project Location**: Metro Vancouver
c. **Start Date**: May 14, 2019
d. **End Date**: September 20, 2019[1]
e. **Industry Mentor**: Jeff Carmichael, Metro Vancouver
f. **Other Resources**: Ian Manning, Peter Marshall

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[1] One additional review was conducted and sent after the project end date (October 21, 2019)

Contents

Acknowledgements

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1.0 Introduction

The Water Services Department at Metro Vancouver manages several assets that feed the city's drinking water and monitor meteorological conditions in the surrounding areas. Two main assets include the Capilano and Seymour watersheds which are sourced through rain and snowmelt from the surrounding area [1]. Within these watersheds, there are smaller regions which are sites to dams or meteorological stations. As these sites are not connected to the BC electrical grid, they require remote power sources for their instruments to function. Instruments at these sites include sensors, valves, and communication devices.

Metro Vancouver's Cleveland Dam and Seymour Falls Dam are classified as extreme consequence under BC Dam Safety Regulation. As such, it is important for Metro Vancouver to monitor various real-time properties of the dams, surrounding ground, and run-off water (Figure 1). Although the Cleveland and Seymour Falls dams are accessible by vehicle, they require monitoring by remote sensors and therefore require off-grid power sources. Other assets are in much less accessible areas which require access by air. The Burwell, Palisade, and Loch Lomond dams are classified as Significant consequence dams, and are located within the Capilano and Seymour watersheds. These sites are accessed by air as vehicle access is not possible; remote monitoring is required. Initiatives are also on-going to allow limited remote control of outlet valves at these alpine lake dam sites.

Within the watersheds, Metro Vancouver monitors weather patterns through the year using remote sensors. For example, these sensors monitor precipitation, temperature, wind speed and direction, and solar irradiance. These sites are also only accessed by air, and off-grid power sources are also required (Figure 2).

Remote areas encounter several challenges, including:

- Existing sources provide limited amounts of power;
- Access available by air only;
- Ice conditions in the winter months; and
- Inability to access the site up to 3 months at a time.

Currently, these sites are powered by a combination of battery systems, solar power, and/or thermoelectric generators. In some locations solar power is sufficient, whereas in others the solar is blocked by tree cover or the panels ice over in the Winter months. In order to provide more baseload power and more conveniently serviced power at these sites, Metro Vancouver wishes to consider alternatives to existing power sources. This report describes various alternative energy technologies which supply a micro-level of power (10 mW to 10 W), provides examples of the technology tested in the field, and then conducts a high-level feasibility study of each.

Figure 1 – Seymour Dam: Monitoring instruments for creeks (first th); Vibe wire for piezometer in wells (fourth)

Figure 2 - Meteorological Stations in Orchid Lake (left) and Disappointment Lake (middle); Cathedral Mountain telecommunications (right)

1.1Remote Instrumental Requirements

Metro Vancouver has numerous instruments which require remote power. These instruments monitor various aspects of operations including water levels, water flow, temperature, pressures, humidity, wind speeds, solar irradiation, etc. Generally, these instruments are ground sensors in that may come in the form of thermocouples, thermistors, anemometers, rain gauges, piezoelectric, electrochemical, and electromagnetic. Individually, each sensor requires a range of 1 to 50 mW to function [2]. At each site, numerous instruments are connected to the same power source. Additional power is required to remotely communicate the sensor data to a central location. For the study, the rough range of 10 mW to 10 W is used as a baseline power requirement.

Currently, the instruments that are in remote locations have pre-scheduled maintenance. These trips are in remote areas and each require a helicopter ride, which is an estimated $2000/hour. For the three alpine lake dams, two 2.5 hours trips are taken a year for inspections and maintenance (~$10,000). For the six alpine meteorological sites, 45-minute trips are required to each site six times a year (~$27,000). These cost estimates were used to compare alternative technologies for the high-level feasibility, in section 7.2.

2.0 Objectives

The objective of this project is to conduct a high-level feasibility study of various technologies appropriate for each remote site, providing between 10 milliWatts to 10 Watts of baseload power. The solution should be innovative and focus on providing power for electrically powering sensors, automatic valves, and communication. These objectives work with Metro Vancouver's Drinking Water Management Plan goals to:

1. Ensuring the sustainable use of water resources by reducing the greenhouse gas emissions associated with operations, and
2. Managing the watersheds to provide clean, safe water by reducing the risk from chemical contamination.

3.0 Project Details

The scope of the project is intended to scale the project to 250 hours.

In Scope

To fully comprehend the intention of the project, the following will be considered:

- Find technologies for range of relevant remote sites in the Lower Mainland:

    - Temperatures range from -15°C to 35°C;
    - Accommodate no access to area for maximum 2 months;
    - Assume 12 inches of ice will build up in the winter months;
- Assume technology should accommodate between 10 mW and 10 W of electrical power;
- Assume electricity is required 24 hours 7 days a week 365 days a year;
- Literature reviews conducted in last 20 years are relevant; and
- Air temperature, solar irradiance, and wind speeds obtained from the Lower Capilano weather station.

Out of Scope

To limit the duration of the project, the following will not be considered:

- Specific site data for weather and topography;
- Replacement of energy load in its entirety with new technology (i.e. no supplemental diesel energy should be required) or replacement of same amount of energy/power between each alternative power source for comparison;
- The technology will not necessarily accommodate energy load increases in future years;
- Exploration of all manufacturers, most common to be used; and
- Extensions to power sources (i.e. cables, valves, connectors, electronics).

3.1 Risks

Risks associated within the scope of the project are listed in the Appendix Table 11-1.

3.2 Project Timeline

The project starts on May 14, 2019 and ends on September 20, 2019. Further details on deliverables and responsibilities can be found in Table 11-2 and Table 11-3 in the Appendix.

4.0 Data and Methodology

This report utilized both on-site knowledge and literature review. On-site knowledge was gained from bi-weekly calls, industry-relevant data collection, and site visits (to Disappointment Lake and Seymour Dam). Literature review was researched through technical papers, scholarly articles, and trust-worthy internet sources. The aim of the literature review was to understand and describe a variety of micro-generating technologies. The criteria in finding various alternate power sources was generally:

- Ability to power the required instruments (between 10 mW to 10 W)
- At minimum, research has been conducted in powering low-power instruments.

After a list of technology was determined, a high-level feasibility of the technology was conducted. The criteria included:

- Ability to power the required equipment (i.e. the ranges of power available)
- Resource availability for the technology
- Capability to function hands-free from December to February
- Capital costs of technology
- Operation and maintenance required through lifetime

Where applicable, the resource assessment required for technology dependant on sensitive to air temperature, wind speed, or solar irradiance was conducted using meteorological data from the Lower Capilano station (Latitude 49.38, Longitude-123.12, elevation 235 m). An array of each monthly and hourly can be found in the Appendix Figure 17, Figure 18, and Figure 19. It can be seen in Figure 3, that the average air temperature does not fall below 2°C or above 18°C at the Lower Capilano station. This temperature range was used to determine general feasibility of all technologies.

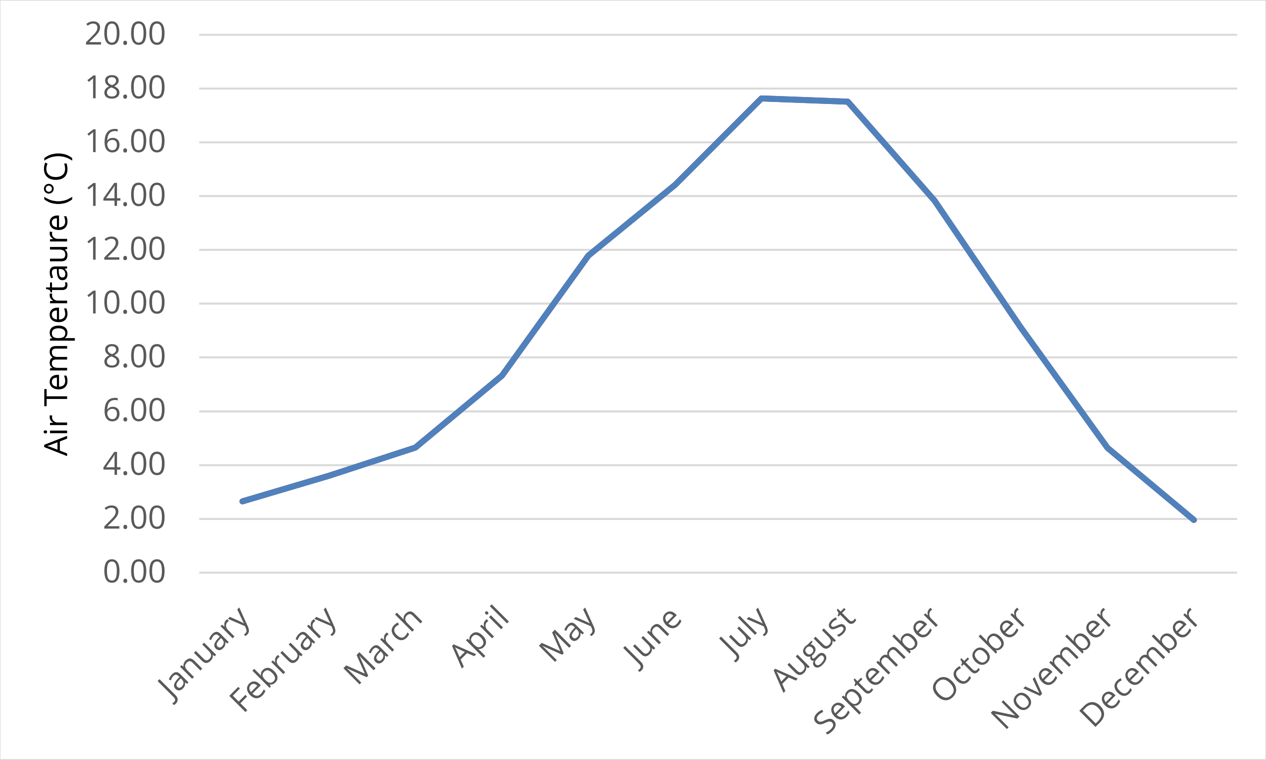

Figure 3 - Lower Capilano Air Temperature (°C) Averages by Month (2002 to 2019)

5.0 Current Technologies

5.1 Battery Storage

Battery banks are deployed at each site. At most locations, batteries are charged by solar panels and when required act as a standalone power source. They are commercially available, have various power densities and voltages, and their output voltage for sensors range from 1.2V to 12V [3]. Typically, one or two 70 to 100 Amp-hour 12 V deep cycle AGM lead-acid batteries are used. North Star's NSB-AGM31 battery is used in the Seymour dam location. It can operate in low temperature ranges (maximum -18°C) and has a reserve capacity of 220 minutes.

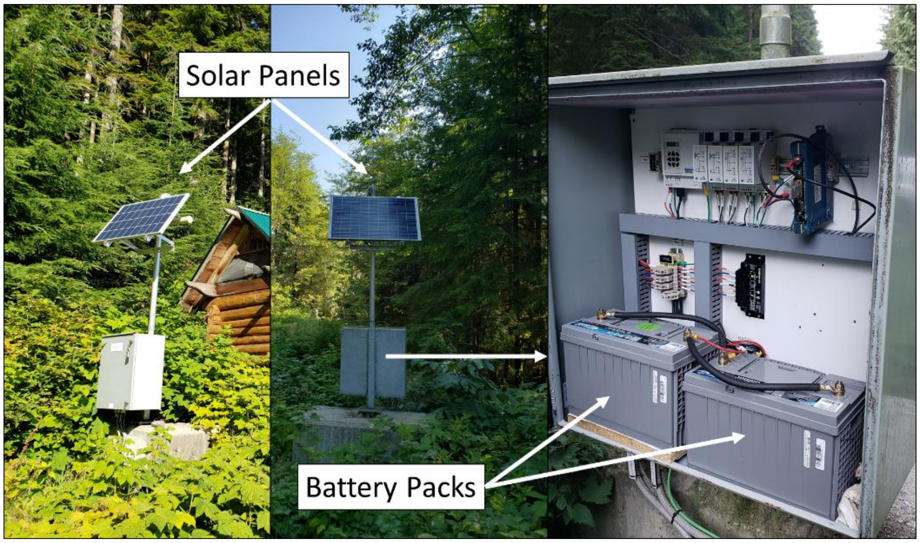

Figure 4 - Solar Panel and Lead-Acid AGM Battery Currently Used at the Seymour Dam Location

5.2 Solar Energy

Solar energy utilizes the energy that is available from the sun in the form of solar irradiance. Solar panels collect this energy through the numerous photovoltaic cells that are linked together within a panel. In the Metro Vancouver area, the hours the resource is available are between 8am and 6pm. The location solar panels are placed is also crucial and the resource can be obstructed by overhanging tree canopy. In the Winter months, the resource can also be obstructed by cloud cover or ice build up. The ice build-up requires maintenance to remove.

Currently, 20 W to 100 W solar panels are used in each remote location. The panels are either fixed to pre-existing infrastructure (Figure 4) or affixed to a stand (Figure 2). Due to the fixed nature of these panels, a minimum amount of maintenance is required. The capital cost of one solar panel stand with solar panels is approximately $5,700. In addition, any maintenance required on the solar panels can be conducted in-sync with the required maintenance on the various instruments on site.

The potential for these solar panels was estimated using the Equation 1 and Figure 5.

Equation 1

$$E = A * r * H * PR$$

Where A is the area of the solar panels [m2], r is the solar panel efficiency [%], H is the hourly solar irradiation [W/m2], and PR is the performance rate of the system [%]. For a 40 W solar panel, an area of 0.45 m^2 was used. As a general measure for solar panel efficiency and performance, the values 9% and 75% were respectively used. Hourly solar irradiance was based on the information in Figure 5. Figure 6 demonstrates the amount of power that is available for capture from solar irradiance in January and July in the Lower Capilano area. Peak hours of power are longer in July than January. However, as long as the solar panel is not covered with snow/ice, energy is still available to store in the Winter months.

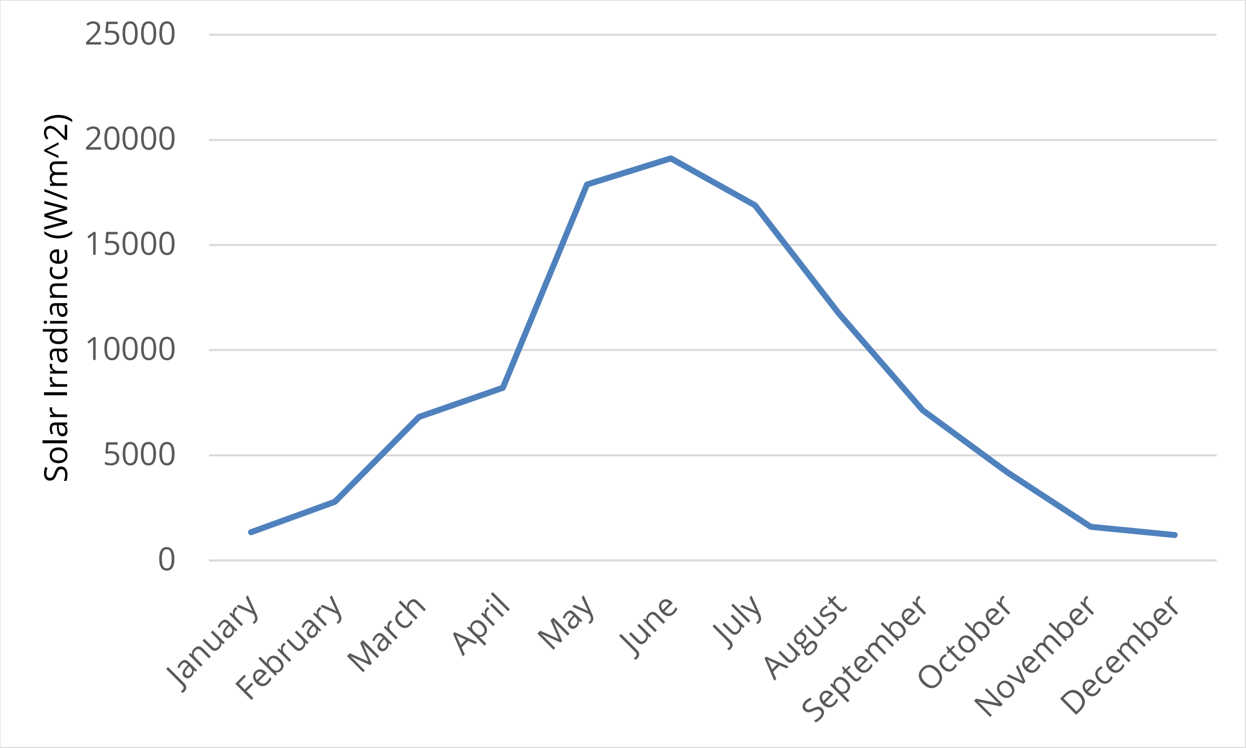

Figure 5 - Lower Capilano Solar Irradiance (W/m^2) Averages by Month (2017 to 2019)

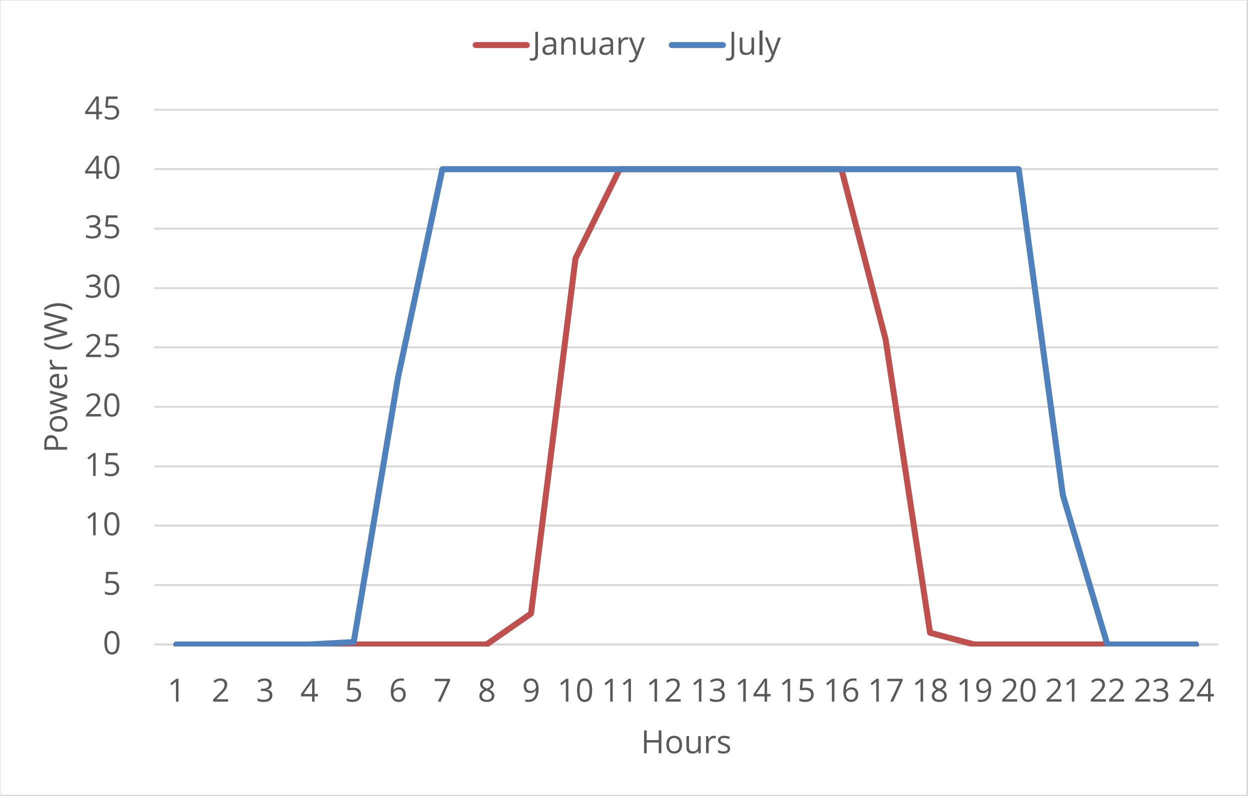

Figure 6 - Lower Capilano Solar Irradiance for a 40 W Module (W), Averages by Hour (2017 to 2019)

5.3Thermoelectric Generators

Technology

Thermoelectric generators (TEGs) uses heat energy from a steep temperature difference between two mediums in close proximity (air/water, water/soil, air/soil) [3]. The temperature differences needed can also be found between a human and the surrounding environment, or with a hybrid solar system between the solar cell and ambient air. TEGs have been deployed for a variety of ground, underwater, and floating sensors.

The design of a TEG depends on its use. Generally, TEGs consist of thermocouples and heat exchangers. The thermocouples are composed of thermoelectric modules and the heat exchangers allow heat flow through the modules. One design used to power remote sensors involved one side of the device immersed in water and the other side exposed to air. While the air temperature is higher than the water temperature, heat is able to flow through the TEG module.

Performance of the thermoelectric module is measured by the figure of merit (ZT) [3]. A higher figure of merit is required for a more efficient thermoelectric module. This can be achieved through decreasing the thermal conductivity or increasing the thermoelectric conductivity.

Equation 2 - Figure of Merit

$$ZT = \frac{\sigma S^2}{\lambda}\left(\frac{T_h - T_c}{2}\right)$$

Where λ is the thermal conductivity, σ is the electrical conductivity, S is the Seebeck coefficient, T_h is the temperature of the hot side, and T_c is the temperature of the cold side. The Seebeck coefficient $\left(\frac{V}{T}\right)$ represents the ability for a thermoelectric material to carry both electricity and heat.

Current Site

Currently, Metro Vancouver has three TEGs in use at selected sites. They use SCADA RTU's on site for communication. For maintenance, each TEG requires a refill of propane twice a year. For 3 sites, this amounts to $4000 in maintenance each year. They were each installed 10-15 years ago.

6.0 Alternative Power Sources

All alternative power sources described below have been tested in remote locations to power low-powered instruments in research and experimental situations.

6.1 Micro-hydropower

Technology

Small hydro-powered systems are capable of delivering up to 100 kW of electricity [4]. For a main component they require either a turbine, pump, or waterwheel to convert the kinetic energy from flowing water into electricity. Turbines come in the form of impulse turbines, which rely on the velocity of water to rotate them, or reactive turbines, which rely on pressure. Impulse turbines commercially available for the micro-hydro system are generally used for high-head systems (where the infeed of the water system is higher than the outfeed). Common turbines include a Pelton wheel, Turgo impulse wheel, and Jack Rabbit turbine. The Pelton and Turgo both require jet force energy to spin them, funneling water into pressurized pipelines to form a water spray. The Jack Rabbit turbine, or Aquair UW Submersible Hydro Generator, can run in a stream of water a minimum of 0.33 m high, requiring no head [5]. It can operate in a stream velocity between 2.8 m/s and 4 m/s, generating between 70 W and 100 W, respectively. Reaction turbines generally are not used for micro hydro projects due to their high costs [4]. Another option is to use a reverse pump to operate like a turbine. Pumps are more readily available and less expensive; however, they are less efficient and more prone to damage. The last option, a waterwheel, is an older technology that is slower and bulkier than a turbine or pump.

Specifically, run-of-the-river micro-hydropower systems do not require large storage reservoirs [4]. This system is composed of a form of water conveyance, a turbine/pump/waterwheel, an alternator/generator, a regulator, and wiring. The water conveyance is a channel, pipeline, or penstock (pressurized pipeline) which carries water to the turbine/waterwheel, where the water rotates the turbine/waterwheel to spin a shaft. The shaft is generally a component of the alternator/generator and generates electricity through the mechanical rotation motion.

Environment

Run of the river operations, unlike large scale hydro, do not require large dams or water storage reservoirs and therefore have a very little impact on the local ecosystem [6].

Example Product

Ampair Energy Ltd[2] is a manufacturer of wind and water turbines, power systems, and single to 3-phase inverters based out of the UK [7]. They manufactuer the Aquair-UW100, a commonly used micro-hydro generator and has a capital cost of approximately $3,500 [4]. A minimum depth of 0.33m and water flow of 1 m/s is required for power generation. It can generate 1.5 kWh in one day in a water flow velocity of 2.5 m/s. Assuming 10 W of power is required for Metro Vancouver's purposes once per hour each day, the equipment would be able to power the instruments for a week without having to recharge. Since this is a conservative power requirement estimation, this would be much longer in reality.

It is 28 lbs and is approximately 17 inches x 17 inches x 14 inches [5]. The maintenance required on the produce includes regular inspection of suspension lanyards, shaft connector and shackle, tow rope attachments and gimbal pivot components. Inspection is also required in case foreign objects damage the propeller and the equipment output is not optimized. Since the propeller is made of aluminum, this is easy enough to bang back into place. Due to the dynamic nature of the technology, it will require replacement of

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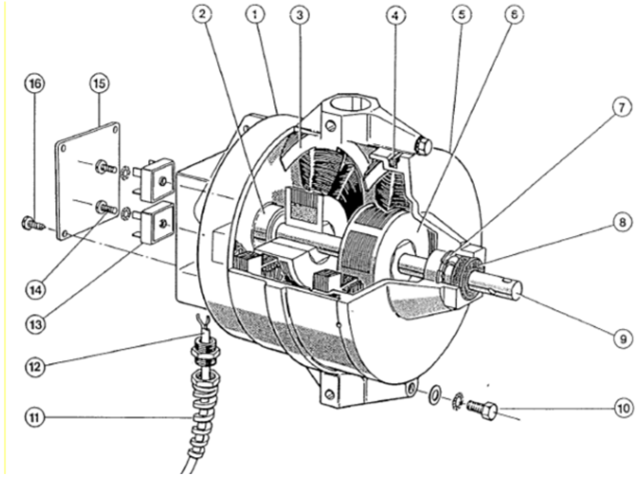
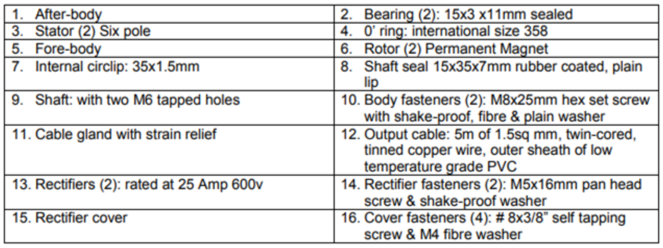
[2] Ampair Energy Ltd was placed into Administration on 3rd February 2015 by its directors. The Company ceased trading on that date, and all of the employees were made redundant and phone numbers, email addresses and website changed. Seamap has taken over the assets and IP of Ampair Energy Ltd and we have moved production and inventory to our existing facility in Singapore. Although the Ampair Aquair UW100 is still in manufacturing, the supply of Ampair Wind Turbines 100, 300, and 600 have been discontinued as of May 1, 2018.

parts throughout its lifetime (i.e. o-rings and seals) due to wear. To replace these parts, training will be required on rebuilding the machine.



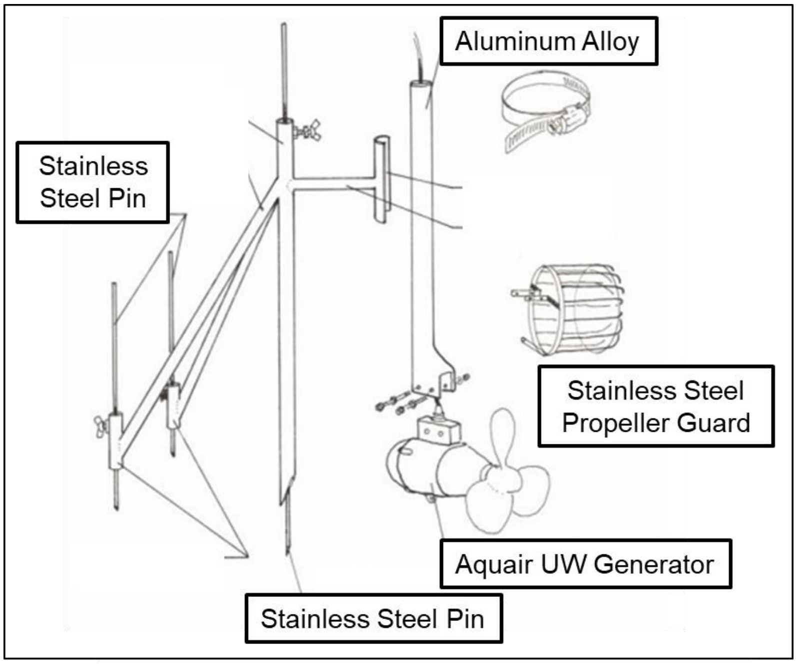


1. After-body	2. Bearing (2): 15x3 x11mm sealed
3. Stator (2) Six pole	4. 0' ring: international size 358
5. Fore-body	6. Rotor (2) Permanent Magnet
7. Internal circlip: 35x1.5mm	8. Shaft seal 15x35x7mm rubber coated, plain lip
9. Shaft: with two M6 tapped holes	10. Body fasteners (2): M8x25mm hex set screw with shake-proof, fibre & plain washer
11. Cable gland with strain relief	12. Output cable: 5m of 1.5sq mm, twin-cored, tinned copper wire, outer sheath of low temperature grade PVC
13. Rectifiers (2): rated at 25 Amp 600v	14. Rectifier fasteners (2): M5x16mm pan head screw & shake-proof washer
15. Rectifier cover	16. Cover fasteners (4): # 8x3/8" self tapping screw & M4 fibre washer

Figure 7 - Aquair-UW parts breakdown

Application

The Canadian Fisheries and Oceans department conducted an experiment in 2007, using solar, wind, and water to create a sustainable form of off-grid power [2]. For their water generation, they deployed an Ampair UW submersible hydro generator in Sweltzer Creek. The generator was affixed to a tripod constructed of galvanized pipe and stainless-steel anchoring pins (Figure 8). The unit had a capacity of 1.5 kW per day with a water velocity of 2.6 m/s. Sweltzer Creek had a velocity of 1.44 m/s and depth of 0.7 m between April and May of 2007. The site was able to produce 1.7 Amps continuously. This average was measured by the charge on the battery power-pac it was connected to. The Canadian Fisheries and Ocean Department deemed the product consistent with its manufacturers performance metrics (Figure 8), producing a reliable and consistent source of electricity which was limited by the lower velocity flow.



Flow rate (m/s)	Amps at 12 V
1.0	<0.5
1.5	2.2
2.0	4
3.0	6+
4.0	8.3 (maximum)

Figure 8 - Aquair UW Water Generator Schematic (top); Aquair Production Capability (bottom) [2] [8]

Feasibility

The Aquair-UW100 or similar model would be feasible in some but not all locations requiring power. Specifically, Metro Vancouver may find benefit deploying the technology in the naturally occurring dam run-off creeks where a constant flow of water occurs year-round (Figure 9); these models would not benefit the still alpine lake regions. However, the feasibility of a micro-hydropower system at a site depends on the historical streamflow of the water [2]. Historical data will be required to provide information on how the creek depth and flow varies seasonally and annually. The total energy estimation can then be determined throughout the year. For example, although for the Aquair-UW100 a velocity of 1 m/s is required to generate power, a flow of 4 m/s is required to power the total 100 W. Since minimal power levels are required at these locations, a 1 m/s flow is potentially enough. Next, it is important to evaluate the historical depths of the creek because this specific model will not function in depths less than 0.33 m. There may be slight variation in environment conditions when looking at other models.

Specifically, the 18” and 24” drains off the Seymour dam (Figure 9) may have the necessary resource requirements. As these run-off creeks are generally accessible by vehicle, the maintenance inspections required could easily be tasked with inspections of the instruments in the region. However, when worn parts require replacement, personnel will be required training to replace them or hire an outside contractor.

An energy storage system will be required to collect the energy and discharge when required.

Figure 9 – Seymour Dam run-off 18" drain

6.2 Micro-Wind

Technology

The standards used to design wind turbines for large-scale application differ from those used for a smaller output power [3]. As they use the wind as an input fuel, they are able to be deployed in remote locations like forests, mountains, rivers, lakes, and ocean surfaces provided the required range of wind resource in the area. Wind speeds between 3 m/s and 10m/s are optimum. The major components of a micro-wind turbine are an alternator and rotor [9]. Wind direction should be determined to select between the type of turbine (horizontal/vertical) and other specifications (i.e. blade type). Smaller wind turbines have low efficiencies mainly due to the viscous drag on the turbine blades, bearing and thermal loss, and high electromagnetic interferences. Though, the smaller size is necessary to reduce costs and minimize technical difficulties [3]. For the micro-generation wind, a turbine that ranges between 4cm and 34 cm will generate between 0.75 mW to 200 mW. This is enough power to operate a variety of sensors including thermocouples, anemometers, humidity, and ambient light sensors.

Example Products

Ampair Energy Ltd[2] is a manufacturer of wind and water turbines, power systems, and single to 3-phase inverters based out of the UK [7]. The Ampair 300 and Ampair 100 are medium and small power wind generators, respecitively, that are able to connect to a 12 V battery in DC. For the application required, the Ampair 100, producing a maximum of 100 W, would be better suited for the required application. To operate, a cut-in speed of 3 m/s is needed. Ideally this model operates within a wind speed range of 3 m/s and 9 m/s. It has 6 blades, composed of fiber reinforced polypropylene, has a rotor diameter of 928 mm, and weighs 12.5 kg. As for operations, regular maintenance is required, particularly after severe weather. Minor nicks on the blade can be dressed, though is there is sign of damage or cracking the blade will need to be replaced. To keep the turbine balanced, the opposite blade will also need replacing. It is possible to run the wind turbine without two blades (at a lowered performance level) while the blades are being repaired.

A USA manufacturer makes a wind generator with similar requirements and dimensions, the MN Chinook 200. It requires a cut-in speed of 3.5 m/s, has 3 blades made of fiber reinforced nylon, and produces 200 W of power at 11 m/s. The capital cost of this turbine is $1000, and includes the tower mount.

Application

In 2009, an experiment was conducted on the Jindo Bridge in South Korea to determine the type of wind micro-generation best suited for the windy bridge [9]. Comparing varying windspeeds between 3.5 m/s and 7 m/s blowing from a horizontal direction, the 6-blade horizontal-axis wind turbine offered the highest performance level. Due to the slight variation in wind azimuths with time, a tail fin was incorporate to align the rotor with oncoming wind. For this specific site, the turbine is able to power the existing sensor set up for up to 2.7 hours a day provided 4 m/s of wind speed or greater.

Other small-size wind speeds have been trialed to power sensors. The University of Berkley testing a 4-blade wind turbine indoors using an airflow turbine to generate wind (averaging 2.5 m/s). This generated a maximum power of 8mW and power density of 0.10 mW/cm^2 [10]. The Japan Society of Physics tested the piezoelectric 12-blade windmill using a piezoelectric biomorph actuator as it's source, which generated about 4.4 m/s. This setup generated a maximum power of 5 mW and a power density of 0.06 mW/cm^2 [11]. Another experiment was conducted on centimeter-scale micro wind turbines using a swirl-type 8-blade micro-wind turbine [12]. At an average wind speed of 6.5 m/s, a maximum power of 2.72 mW was generated with an efficiency of 3.42%.

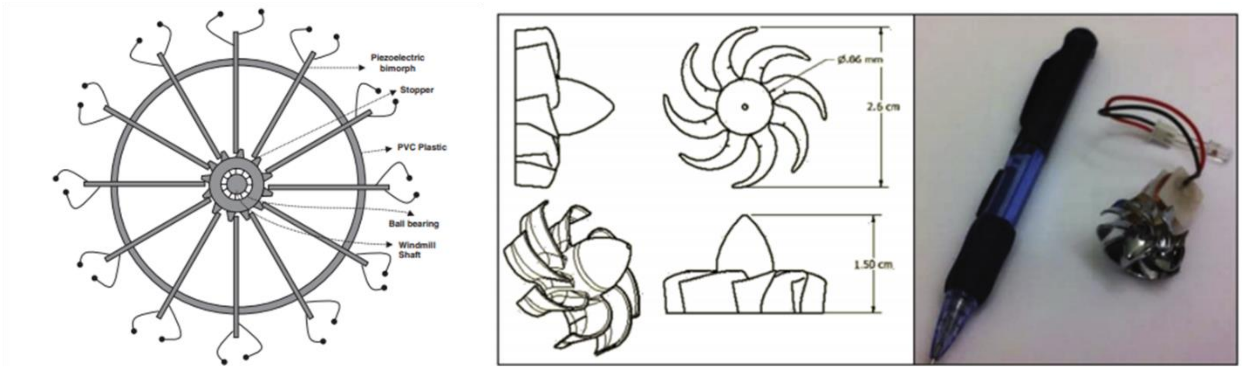


Figure 10 - Piezoelectric 12-blade piezoelectric windmil (left); swirl-type 8-blade micro-wind turbine (right) [11] [12]

The Canadian Fisheries and Oceans department conducted an experiment in 2007, using solar, wind, and water to create a sustainable form of off-grid power [2]. For their wind turbine, they used an AIR-X wind turbine that had a capacity of 400 W at a wind speed of 12 m/s. The turbine weighed 6 kg and was 1.17 m wide in rotor diameter. The mast to mount the wind turbine is similar to what is used to mount the solar panels for Metro Vancouver sites currently. However, the site chosen was mostly protected from wind and they were unable to receive power from this source.

Feasibility

For a micro-wind system to be considered feasible it will need to be placed in a location that contains consistent winds. On average, the wind speeds at the Lower Capilano weather station measure in the range of 1.75 m/s and 3 m/s (Figure 11). For most small-scale wind turbines, this speed is too low to even spin the turbine to produce any energy. For the Ampair wind turbines, a cut-in speed of 3 m/s is required. In the 16.7 years of collected data, the wind speeds in Lower Capilano have ranged from 0 m/s to 8.6 m/s. A further analysis was conducted of the Lower Capilano wind speeds to determine the amount of resource available through the year in Figure 12. Assuming a cut-in speed at 3 m/s would produce at least 10 W of power, there is a 22% annual resource availability.

However, a thorough analysis will be required to determine if this is a better option than the current solar module installation (in terms of resource availability and costs throughout the lifetime). Generally, wind turbines require more maintenance than solar panels due to wear of the moving parts. Often this includes regular lubrication, and replacement of specific parts (i.e. seals, blades) at least once throughout the lifetime of the turbine.

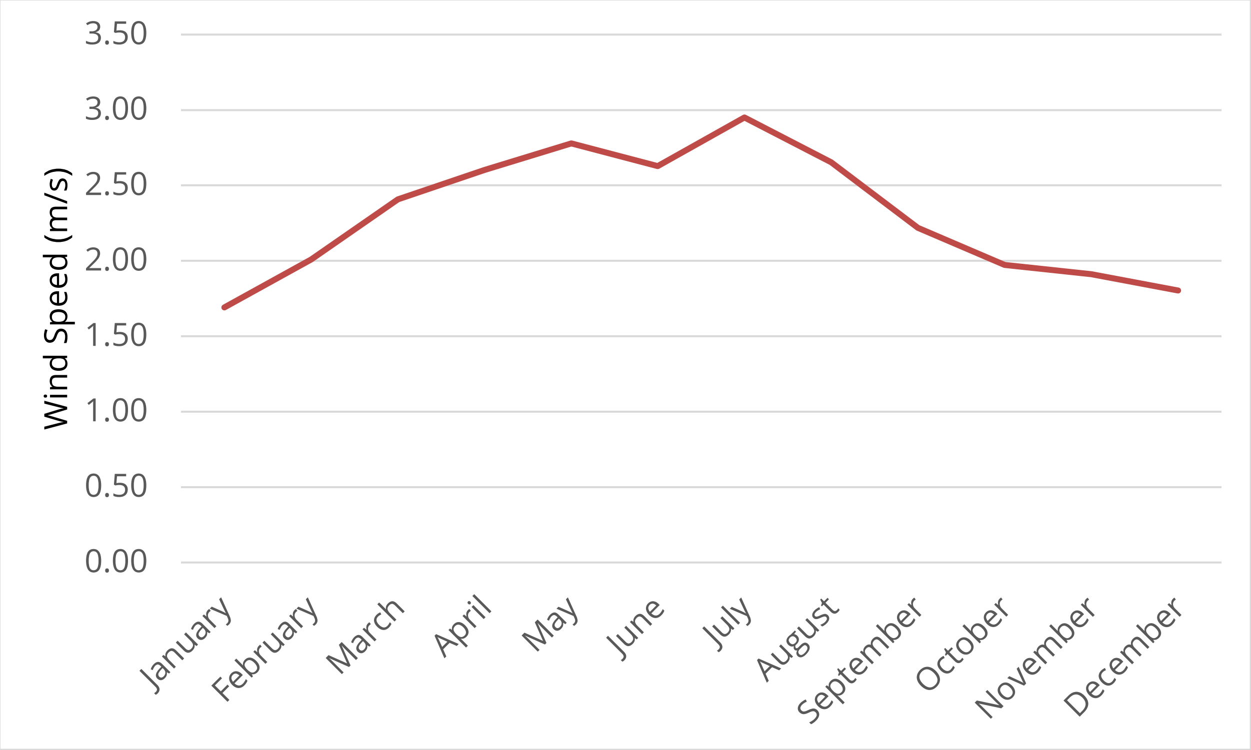


Figure 11 - Lower Capilano Wind Speed (m/s) Averages by Month (2002 to 2019)

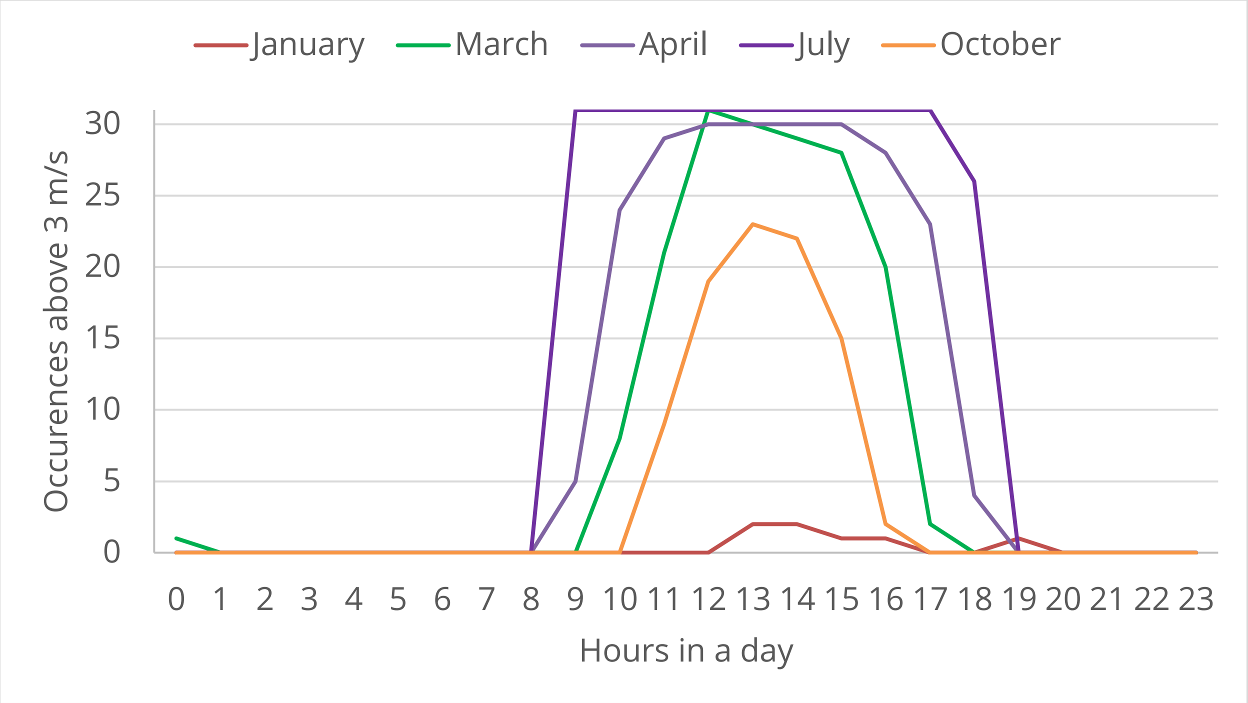


Figure 12 - Lower Capilano Wind Speeds above 3 m/s (Overall 22% of the year)

It should be noted that only one location has been reviewed in this feasibility study. Metro Vancouver reservoir raft locations may be a more suitable fit for the wind speed required. They have the highest and most consistent winds and require a higher range of power due to their quantity of sensors. Therefore, micro wind power may be feasible in specific locations. Due to the intermittent nature of the wind resource, an energy storage system would be required as part of the whole system.

6.3Biomass

Technology

Biomass uses an organic renewable resource or fossil-based carbonaceous materials and a controlled amount of oxygen and/or steam at high temperatures to form usable by-products. Examples of fuel sources include agricultural crop residues, forest residues, special crops grown specifically for energy use, organic municipal solid waste, and animal wastes [13]. There are variations of biomass processes dependant on the fuel source. For example, with wood fuels the wood-waste is burned, and the heat is used boil water to create steam to generate a turbine. With solid waste, the by-product of this reaction forms syngas (a mixture of carbon monoxide, hydrogen, and carbon dioxide) which are burned to boil water and create steam to generate a turbine. Figure 13 shows examples of biomass fuel sources used in the biomass power system. The energy per volume or renewable resources is compared with that of 1 L of fossil fuel.

Through gasification, by-products such as syngas or hydrogen can be produced which in-turn generates electricity through an internal combustion engine. Attempts to produce bio-mass electricity on a small-scale have had issues due to tar build up in the engine. A specific model of biomass gasification, Entrade’s E3, proved more efficient in converting agricultural and wood waste pellets into high-quality syngas which can generate 25 kW of electrical output and 60 kW of thermal output. A more efficient E4 is capable of generating 50 kW of electricity and 120 kW of thermal energy [14].

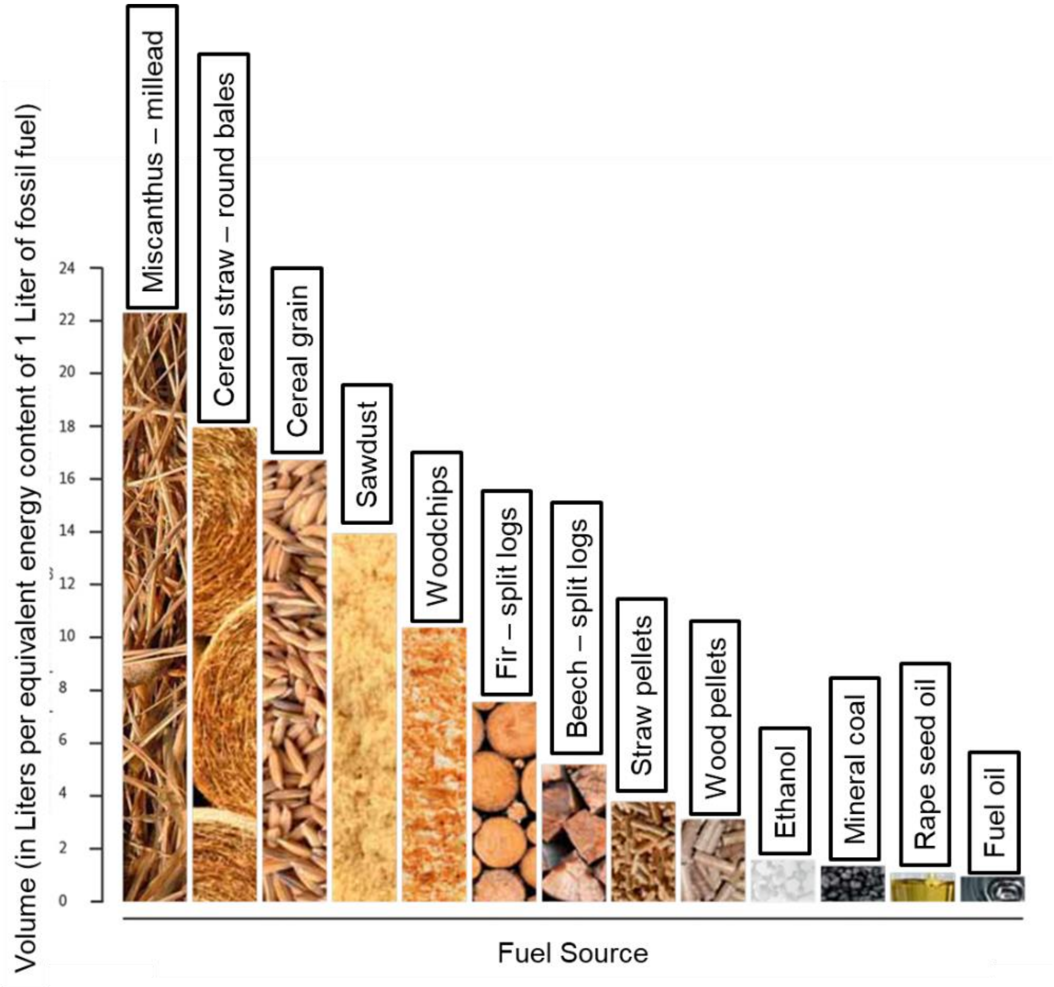


Figure 13 - Examples of biomass fuels in equivelency to 1L of fossil fuels [15]

Application

The world's smallest biomass powerplant is located in Cheshire, UK and produces 22 kW of electrical energy and 55 kW of thermal energy [16]. For 1000 hours, the Entrade Energiesystems E3 micro-scale biomass CHP plant required no human interference. For fuel, it uses transforms solid biomass pellets into high-quality syngas [17]. The syngas is fed into an internal combustion engine to generate electricity [16]. Heat is captured through the process.

Currently, Pamoja Cleantech is working with Entrade to deploy the E3 throughout Africa with the intent to replace diesel generators and use of charcoal for cooking [17].

Feasibility

An electrical power requirement of the chosen technology requires an output power range between 10 milliWatts to 10 Watts. The smallest-scale commercially-available generation for biomass gasification technology is 25 kW. Prototypes have been built with smaller electrical outputs but have yet to be tested successfully in a remote location. Therefore, biomass is not a feasible option for the purposes of this report. However, it is a high possibility there may be successfully tested and commercially available options for biomass within the required power output range in the coming decade.

6.4Ambient Radio Frequency

Technology

Ambient radio frequency converts electromagnetic waves into electric energy [3]. This technology, a radio frequency energy harvesting system, has been deployed to power various wireless sensors (temperature sensors, humidity sensors, sensor nodes). Ambient radio frequency power sources are approximately 0.026 cm^2 to 226 cm^2 in size and can generate between 0.4 mW to 85 W of power.

In recent years, there has been an enormous increase in communication using radio, satellite, television, cellular phones, wireless internet, and other wireless devices. These devices all emit radio frequency. The radio frequency available in the environment is called ambient radio frequency. Each of these communication devices creates an electromagnetic wave, or radio frequency, through application of an alternating voltage of current to an antenna. Any excess radio frequency waves are emitted from the antenna at the same applied voltage at approximately the speed of light. Like light waves, radio frequency energy form clusters of photons which form the ambient radio frequency found in the environment.

To collect and convert the radio frequency signals into usable energy, a harvesting system is created using an antenna, rectifier, capacitor, microprocessor, and output device (i.e. wireless sensors). The antenna first receives the electromagnetic waves. Next, the rectifier converts the waves into direct current (DC) and increases the voltage to the appropriate level that would be required to power a specific device (i.e. sensors). A capacitor stores this energy. A microprocessor controls the harvested energy in the capacitor by determining whether to charge or discharge, at what output voltage the energy will discharge, and how much energy the output devices will receive.

Physical Properties

The Friis equation for radio frequency power harvesting shows that the radio frequency power decreases with increasing distance [3]. The largest amounts of ambient frequency are available in urban areas, and therefore the sensors efficiency would be maximized in or near cities. Therefore, the power will be limited in remote locations such as forests, mountains, or in the middle of an ocean.

Equation 3 – Friis Equation

$$P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi)^2 R^2}$$

Where P_R is power received, P_T is power transmitted, G_T is transmitting antenna gain, G_R is receiving antenna gain, λ is the wavelength of the electromagnetic radio wave, and R is the distance between the radio frequency transmitter and receiver.

Example Product

The company E-peas based out of Mont-Saint-Guilbert, Belgium produces energy harvesting products and a micro controller. Specifically in the field of radio frequency, the E-peas AEM 40940 PMIC is capable of harvesting between -19.5 dBm and 10 dBm [18]. The unit dBm is used to measure radiofrequency and audio frequency. Using Equation 4, this converts to a power range between 11.2 µW to 10 mW.

Equation 4 - Radiofrequency to power conversion [19]

$$S_{dBm} = 10logP$$

Where P is power measured in mW.

The AEM 40940 requires emitters in the range of 925 MHz and 2500 MHz, emitted by various types of cellular frequencies including GSM900, GSM1800, 3G, and Wi-Fi [18]. The technology requires a battery or capacitor combination for a consistent discharge of power when required. The storage component and sizing option allow for some variation for output power.

Feasibility

The antenna is only able to harvest power that is radiated from a close bank of frequencies and must be placed in a specific spatial orientation to the bank of frequencies [20]. Due to the remoteness of each application, it is assumed that the areas requiring alternative power are not wireless wave rich environments. The emitters would include minimum communications between staff where mobile network coverage is available, minimal satellite communications between staff, and sensor communications between sensor power management systems. Ambient radio frequency technology is deemed unfeasible for this application based on resource availability at required deployment locations.

Capital costs and maintenance requirements were researched and will require contact with specific manufactures to determine. Further contact was not made due to assumptions of low resource availability and unfeasibility of the technology.

6.5Piezoelectric Generator

Technology

Piezoelectric energy is harvested from the mechanical energy created from vibration, motion, or flow [3]. These movements create pressure on a piezoelectric material which is then converted to electrical energy. Examples of movements include machine vibrations, flow of water/wind, ocean waves, motion of an animal. A power generation between 0.03 mW and 3.5 mW has been used for a variety of remote sensors, including radio transmitters, temperature sensors, H_2-sensors, Hg^{2+} sensors, LEDs, and humidity sensors.

This technology is dependant on the use of materials which exhibit permanent electric polarization, also called ferroelectric materials (ceramics, crystals, and composite materials). On a molecular level, pressure on a ferroelectric material will disintegrate the central crystals forcing the material to become polarized. This forms a dipole, a pair of equal and oppositely charged surfaces.

A popular piezoelectric power generator design is the two-layer cantilever. Two ferroelectric materials (piezoelectric sheets) sandwich a metal shim. When the cantilever is force down, the bottom sheet is compressed, and the upper sheet is strained. This creates positive polarization in the middle of the beam and negative polarization on the outside surfaces. The opposite occurs when the cantilever is forced up. A mass is placed at the end of the cantilever to exaggerate this movement.

Physical Properties

The total charges and voltages generated are dependant on the dimensions of the cantilever:

Equation 5 - Total charge

$$Q = \frac{3FL^2}{T^2} d$$

Equation 6 - Voltage

$$V = \frac{3FL}{4WT} g$$

Where F is force, L is length of the cantilever beam, W is width of the beams, T is thickness of the beams, d is the piezoelectric charge constant, and g is the piezoelectric voltage constant [3].

Example Products

The company E-peas also has a piezoelectric energy harvesting technology, the AEM 30940, as well as radiofrequency tech [18]. The AEM 30940 produces between 3 μW and 400 mW, dependant on the frequency of vibration. Generally, the examples of application for this model include energy dissipated by machines such as motors or trains. Again the technology is recommended in combination with an energy storage system for a constituent power output.

Cypress, based in San Jose, USA, also produces a piezoelectric generator: the Energy Harvesting PMIC and PRoC CY39C811.

Feasibility

From visiting the Seymour dam, Disappointment lake, and Orchid lake in the summer of 2019, it appears the sites are generally very still. Unless the instruments are moving or there is a flow of water, there does not seem to be any consistent motions or vibrations. This would leave piezoelectric as an unfeasible option for this project due to lack of resources.

6.6Sediment Microbial Fuel Cells

Technology

The Sediment Microbial Fuel Cells (SMFC) is a renewable energy source which utilizes a natural reaction between the sediments at the bottom of water bodies (i.e. lakes, rivers, or oceans) and microorganisms as a source of fuel [3]. Due to the ongoing nature of this reaction, the organic chemicals used as reactants in the SMFC are in unlimited supply. SMFCs have been used for underwater, ground, and floating sensors generating between 3.4 mW to 36 mW.

Figure 14 displays a schematic of a sediment microbial fuel cell, where the anode is buried under sediment and the cathode floats above in water. At the bottom of these water bodies, there are native microorganisms present in the sediments. Electricity is harvested from the microbial activity, in which these microorganisms oxidize the organic or hydrogen sulfide compounds within the sediment:

Organic compound: $C + H_2O \rightarrow CO_2 + H^+ + e^-$

Hydrogen sulfide compounds: $HS^- \rightarrow S + H^+ + e^-$

The technology is deployed within the sediment, where the anode is buried beneath the sediment and the cathode is placed in the water. These two electrodes are inert and conductive, either composed of graphite, stainless steel, or carbon cloth. The organics and hydrogen sulphide in the microorganisms are used as oxidizing agents to produce protons and electrons. At the cathode, these products are captured to form either water or hydroxyl ions:

Cathode Reaction 1: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

Cathode Reaction 2: $O_2 + 2H^+ + 2e^- \rightarrow 2OH^-$

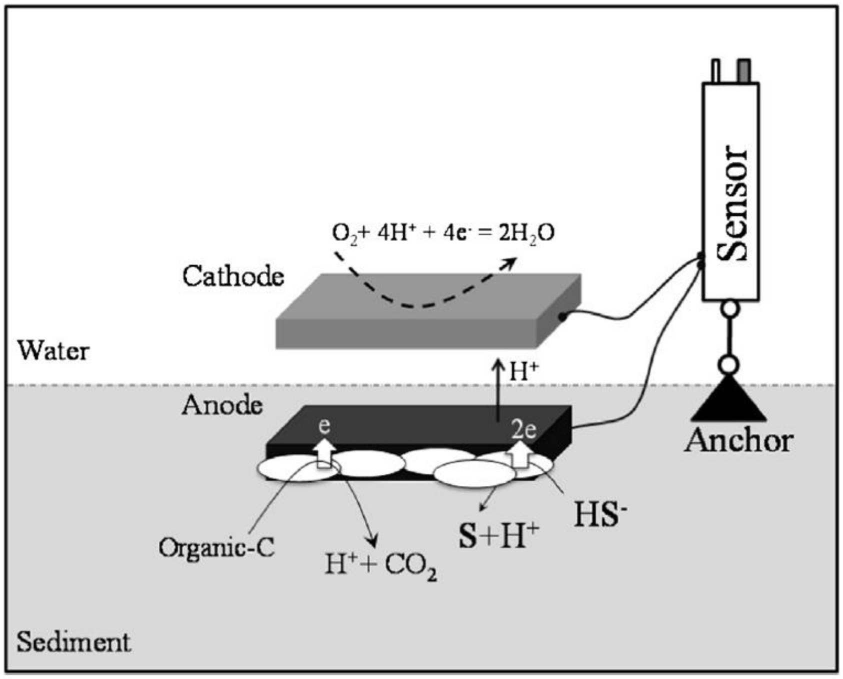


Figure 14 - Sediment Microbial Fuel Cell Schematic [3]

The SMFC is a renewable energy, as its fuel source is continuous and naturally occurring [3]. The electrodes the technology uses are inert, and therefore they do not limit the SMFCs lifetime either. However, the SMFC is limited by the low power generation and low voltage inputs. The size of the electrodes does not linearly relate to generation and therefore it is not cost-effective to build the SMFC on a larger scale. However, to generate larger amounts of energy, it may be possible to generate larger amounts of energy in small bursts through an energy harvesting scheme.

Example Product

Through thorough research, it appears the sediment microbial fuel cell is still in the early stages of technological development, researching to prove its feasibility. There are not yet commercially available products that are ready to be deployed.

Application

A demonstration of a benthic microbial fuel cell (BMFC) used to power a meteorological buoy (measuring air temperature, pressure, relative humidity, and water temperature) was conducted in the Potamac River in Washington, DC, USA [21]. The buoy consisted of a custom-made power conditioner which regulated the discharge voltage of the BMFC and charged a 1 F capacitor. The BMFC demonstration consisted of seven subunits connected in parallel and separated by a distance of 30-45 cm. The subunits each had two graphite plates, 61 cm x 61 cm x 2.5 cm in size. The BMFC sat at the bottom of the Potamac River at a depth between 1-3 m, dependant on the tide. Electrical leads were used to connect the BMFC to a power conditioner in the meteorological buoy. For nearly 7 months (October 2004 to March 2005), the BMFC operated without incident before it was pulled down the river by an ice flow and the electrical connection was severed. It generated a low power density between 3.5 $\frac{W}{m^2}$ and 4.6 $\frac{W}{m^2}$, which is due to the low ionic content of the freshwater river that is used as an electrolyte. Though, the power output (approximately 24 mW) was sufficient enough for the meteorological buoy.

Feasibility

To determine whether the sediment microbial fuel cell would be a reliable opportunity for Metro Vancouver, resource tests would need to be conducted at the ground level of each lakes to determine the concentration of organisms available for the technology. However, for the meteorological stations, all sensors are away from bodies of water and so this technology would require unnecessary cabling or additional communication equipment to power the instruments. In addition, this technology is still in the researching phase and not yet commercially available. It is not a viable option for this project.

6.7Seawater Batteries

Technology

Seawater batteries use a combination of hydrodynamic flow and the salt in seawater to activate the battery's electrodes [3]. Seawater batteries are capable of delivering 6 W of power, between 133 Wh to 1080 Wh of energy at 1.6 V.

The salt in the seawater acts as an electrolyte, so the technology must be deployed in the sea. The hydrodynamic flow is used so the salt water can flow through the cathode of the battery. Hydrodynamic flow can be found deep in the sea or created by attaching the seawater battery to a moving device. By allowing the seawater to flow through the battery, the cathode can renew its supply of oxygen:

Anode: $2Mg \rightarrow 2Mg^{2+} + 4e^{-}$

Cathode: $O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-}$

Oxygen is not very soluble in seawater, especially in the deep-sea bed. Due to the lower levels of oxygen, it is necessary to increase the surface area of the cathode and capture as much oxygen as is available. Fiber brushes are used to increase the cathode surface area.

In these reactions, unwanted layers form on both the anode and cathode. $Mg(OH)_2$ is formed on the anode due to a reaction between the anode and cathode products. $CaCO_3$ deposits form on the cathode from the calcium Ca^{2+} ions present in the seawater. The hydrodynamic flow of water helps to remove both these deposits.

Physical Properties

The constraints of the batteries longevity and performance depend on the conditions in the sea where the technology is deployed and the location's hydrodynamic conditions. [3]. Hydrodynamic conditions determine the amount of oxygen diffusion to the cathode as well as the formation of deposits on the anode and cathode. The location also determines the concentration of salinity and oxygen in the water, which determines the overall cell voltage. For example, 20 ppm of saline and 3 ppm of oxygen can deliver 1.6 V.

Application

Two teams in France (DGA/BEC) and Norway (FFI) developed an autonomous underwater vehicle using a semi-fuel cell power source that uses oxygen dissolved in seawater as an oxidant, seawater as an electrolyte, and magnesium as fuel [22]. See Each seawater battery cell was able to power 133 W (6 cells were used), with hydrodynamic losses of 24 W for 504 hrs or 17 W for 430 hrs. The vehicle moved through the water at a speed of 2 m/s.

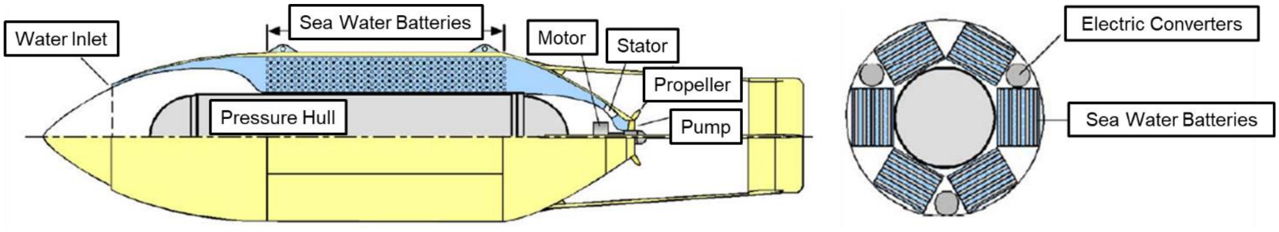


Figure 15 - Autonomous Sea Water Battery Fueled Underwater Vehicle (left); Sea Water Battery Cross-Section (right)

Lifetime
The lifetime of the battery is dependant on the size of the anode, as they are sacrificial in this system. A larger anode of 120 kg magnesium can last for 5 years producing 6 W of power. The lifetime can be further limited if the hydrodynamic conditions are not enough to remove the deposits formed on either the anode or cathode.

Feasibility
Metro Vancouver's alpine lakes have been tested for conductivity, ranging from 5 to 20 micro-siemens. As sea water is around 50,000 micro-siemens, the alpine lakes salinity is extremely low. Therefore, the seawater battery is not a feasible technology for this report due to low resource availability.

6.7.1 Energy Storage

Although the salt water battery is not feasible for energy generation, it may be an alternative to the currently used 12 V AGM lead-acid battery packs as a form of energy storage.

Example Product
BlueSky Energy, an energy storage company based in Vöcklamarkt, Austria, produces the GreenRock salt water energy storage system [23]. The battery's capacity ranges between 5 kWh and 30 kWh, meaning if a 5 kWh battery were installed and fully charged, it would take a minimum of 20 days to discharge if 10 W of power were required 23 times a day (i.e. every hour). Though, if in the right environment, this battery would continue to charge and discharge throughout these 20 days. The GreenRock operates between -5°C and 50°C, an appropriate temperature range for lakes in the Metro Vancouver region.

Aquion was the first to come out with the seawater battery, a company that was funded by Bill Gates. They first began manufacturing in Westmoreland, PA, US in 2012 [24]. There company went bankrupt in March 2017 and was funded and producing again by July 2017. There products are bought through distributors. The product itself is made of Aqueous

Hybrid Ion (AHI) technology, claiming to be the safest battery on the market. The battery is composed of abundant, nontoxic materials and use modern low cost manufacturing techniques (Figure 16). The Aquion Energy Aspen 48M-25.9 batteries come in stacks, each with a capacity of 2 kWh. If the maximum required load is 10 W for Metro Vancouver instruments, a fully charged battery would discharge for up to 8 days without needing a charge. These batteries are measured to have an 85% efficiency. The batteries operate in a temperature range between -5°C and 40°C, limited by a freezing point at -10°C [25] [26]. .

Figure 16 - Aquion Salt Water Battery

Feasibility

The salt water batteries vary in size, however, neither the Greenrock nor Aquion batteries are produced lower than 24 V. Therefore, the salt water battery would not be a feasible direct replacement for the currently used 12 V AGM lead-acid battery.

7.0 Technology Comparison and Feasibility

7.1 Eliminated Alternative Power Sources

The technologies researched have all been tested in a research setting specifically to power low-powered remote instruments [2]. However, they were not necessarily the most suitable for Metro Vancouver's purposes. A summary is shown in the Table 7-1 below. Both sedimental microbial fuel cells and biomass were ultimately deemed unfeasible due to lack of technology maturity. The sediment microbial fuel cell seems a promising technology for underwater applications, however, the technology is still in its research stages. The smallest biomass plant produces energy in the kW range, which is too large for Metro Vancouver's microgeneration scale. Technology to produce power within the required instrument range is in its early stages of research. Until this technology has matured further in remote applications, it is not viable.

Table 7-1 Alternative power high level feasibility summary

	Technology Maturity	Power Output	Resource Availability	Feasibility
Micro Hydro	🟩	🟩	🟩	Select Areas
Micro Wind	🟩	🟩	🟩	Select Areas
Micro Biomass	🟥	🟥	🟩	No
Ambient Radio Frequency	🟨	🟩	🟨	Further tests required
Piezoelectric	🟨	🟩	🟨	Further tests required
Sediment Microbial Fuel Cell	🟥	🟩	🟨	No
Sea Water Battery	🟨	🟩	🟥	No

Legend
🟥 Poor
🟨 Medium
🟩 Good

Due to lack of resources, the sea water battery was deemed unfeasible. Sea water batteries require high salinity levels which were not available in Metro Vancouver's alpine lakes.

With the current information available, it cannot be determined whether ambient radio frequency energy harvesting or piezoelectric generation are feasible technologies. Ambient radio frequency may be best suited for remote operations in more urban area where a mobile data signal can be received and there is enough technology density to receive optimum power. However, the levels of ambient radio frequency will need to be tested with a spectrum analyzer to determine this result. Piezoelectric generation has been commonly practiced on heavy machinery that naturally vibrates or placed where motion will be more reliable (i.e. where there is human foot traffic). It is recommended that Metro Vancouver staff most familiar with the site brainstorm to determine if there is an available application at any of the remote sites, i.e. a vibrating pipe/dam equipment.

Of the alternative power sources researched, micro hydro power and micro wind were the most feasible. The technology is mature and has been tested in the field, powers the required range, and utilizes available resources. For micro hydro, there is potential to deploy the Ampair Aquair-UW in the run-off creeks from the dams where solar power is blocked by tree cover. For micro wind, there is potential to deploy the Ampair Wind 100 in areas in higher elevation which will require further resource analysis. A high-level cost analysis was conducted in section 7.2 comparing these technologies with the solar power and thermoelectric generation that is currently used.

7.2Feasible Technology Analysis

A high-level cost analysis was conducted comparing solar power (currently used), thermoelectric generation (currently used), micro wind power (alternative technology), and micro hydro power (alternative technology). The analysist consists of the capital cost of the product, maintenance required, amount of access needed, and lifetime. To accurately compare these technologies, the capital costs were scaled to $1 per Watt and the lifetimes were assumed to be 15 years for each technology. In reality, the capital costs will vary dependant on the size of the technology available and variations in price due to purchases in bulk and different suppliers. Each technology does also vary in lifetime, for example, solar technology is progressing to much longer lifetimes ranging from 20 years to 35 years. These factors are mentioned in recommendations for future work.

Some of these remote sites require helicopter access to maintain the instruments on a consistent frequency. Costs for this purpose were estimated in Table 7-2, assuming a helicopter costs $2000 per hour. Table 7-2 was used as a baseline to determine access costs for the technology comparison in Table 7-3.

Table 7-2 Estimated Annual Helicopter Costs for Remote Metro Vancouver Sites

Helicopter	$2000/hour

	Number of Sites	Maintenance Required (hr)	Site Visits per year	Total Costs
Alpine Dams	3	1	2	$12,500
Alpine MET Stations	6	0.75	3	$27,000

The capital cost for a solar panel was based on a cost range 2019 100 W solar panels. It should be noted that technology has improved, and costs have declined since Metro

Vancouver's original purchases. However, this was not considered for conduction of a fair analysis of the latest technologies on the market. The only maintenance assumed for the solar modules throughout its lifetime are cleaning of its surface to mitigate for weather conditions (i.e. ice, dirt). Since these sites are visited at a consistent frequency to service the various instruments that require the solar power (Table 7-2), access to the sites specifically for the purposes of solar are considered low. An additional 10 minutes is added each year to clean the module. This amounts to a total cost of $6,600 throughout a 20-year lifetime for one site.

The capital cost for a thermoelectric generator was estimated from an online search, averaging to approximately $3000. The cost of fuel was provided by Metro Vancouver, estimating a $4000 value to refill 3 TEGs twice a year. This amounted to a rounded-up value of $1400 annually to account for any other inspections/maintenance required. An estimation of 13 minutes to fill up the TEG per year was used. This totalled $10,870 for a 15-year lifetime. This was the highest costing power source of the four technologies in comparison, almost doubling their costs. Though, it is the most reliable and only source that does not require energy storage.

The capital cost of a micro-wind turbine is approximately $1000, not including costs to manipulate current solar module infrastructure to work for the wind generator. Unlike wind power on a larger scale, the small-scale wind turbines do not require lubrication through use of low friction polymer bearings. Bearings, however, will wear and require replacement. The cost of the bearings is considered negligible in comparison to the maintenance and access costs, and time for replacement is added to pre-existing and regularly scheduled site visits. It is assumed that each of the blades on the wind turbine will require replacement at least twice throughout its lifetime. This is also assuming proper inspection is conducted, and small repairs can be made before full replacement during regularly scheduled site visits. A cost of replacing a pair of blades is approximately $400 for the Ampair Wind 300 (if one blade is replaced, the opposite must also be replaced to keep the balance of the turbine). This amounts to a total of $2400, or $160/year over a 15-year life of the turbine. Assuming a spare set of blades is prepared ahead of time for any replacement/repair, and bearing replacement would occur twice in a lifetime, an overall estimation of 4 hours of maintenance is assumed for the lifetime of the turbine. Overall costs through the lifetime are estimated at $6,500 for one site.

The capital cost of an Aquair-UW100 is approximately $3,500. Regular inspection of the machine is required as well as replacement of seals, o-rings, and any other damaged parts. The parts that require replacing will be of low costs and are estimated at a conservative value of $100 per year. Monthly 10 min inspections will also be required on top of repair;

however, it is assumed that the technology will be deployed in vehicle accessible areas and each site is accessed at lease once a month. If there were opportunities to deploy the Aquair in more remote locations, the costs may rise significantly. Assuming the maintenance manual is enough guidance for an abled body at Metro Vancouver to rebuild the machine, costs of training is not considered. Overall costs through a 15-year lifetime is estimated at $5,000 at one site.

Table 7-3 Estimated Lifetime Costs of Feasible Technology for 1 site

	Capital ($/100W)	Maintenance Costs (per year)	Access Costs (per year)	Lifetime (years)	Total ($/100W)
Solar	$330	$0	$300	15	$4,503
TEG	$2400	$1,332	$0	15	$20,004
Micro Wind	$1000	$160	$535	15	$10,435
Micro Hydro	$3500	$100	$0	15	$5,000

8.0 Conclusion

A high-level feasibility study was conducted to find alternative power sources for Metro Vancouver's water infrastructure sites. A variety of available resources were explored, including solar irradiation, wind, flowing water, radio waves, microbial organisms, flowing salt water, motion, and biomass. Of all the energy sources that were analyzed, solar irradiation, wind, and flowing water were the most viable sources. The salt water battery was investigated as a replacement to the currently used 12V lead-acid AGM battery and was deemed unfeasible as the product manufacturing sizes were too large. Solar irradiation was found to be the only source of energy available at majority of the sites. Due to resource availability, solar power is concluded as the best resource. Wind and hydro may be feasible in selected locations with further investigation on resource availability at specific sites, or even in combination with solar to account for hourly or seasonal fluctuations of the sun. Further investigation into resource availability is still required for ambient radio frequency and piezoelectric generation to deem whether they are feasible.

9.0 Recommendation for Future Work

An initial analysis of available technologies was conducted. A deeper dive is required to determine whether replacement of the solar and lead-acid battery combination or TEG is feasible. The following steps are recommended:

- Resource investigation at each specific site for wind speeds and/or water flow;
- Resource investigation for ambient frequency using a spectrum analyzer;
- Site investigation and resource research into available locations for piezoelectric generation;
- Site specific cost analysis, including 8760 of resource availability through lifetime;
- Analysis of company targets for greenhouse gas reductions;
- Establishing contact with manufacturers in the low power generation market. Experts in the field can help with capital costs, make recommendations on maintenance, and provide a higher level of detail specific to the commercial products available for purchase;
- Establishing contact with utilities and other relevant companies who have tested new technologies in the field (expand to global reach);
- Further research into various types of solar modules, including monocrystalline, polycrystalline, thin-film amorphous silicon, concentrated PV cell etc.;
- Further research into various types of wind generation, including airborne wind energy, micro offshore, small turbine technologies, etc.;
- Further research into various battery energy storage systems, including lithium ion and sea water feasibility; and
- Further research into types of energy storage applicable for the project purpose, i.e. capacitors, flywheels, compressed air storage systems.

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11.0 Appendix

Table 11-1 - Project Risks

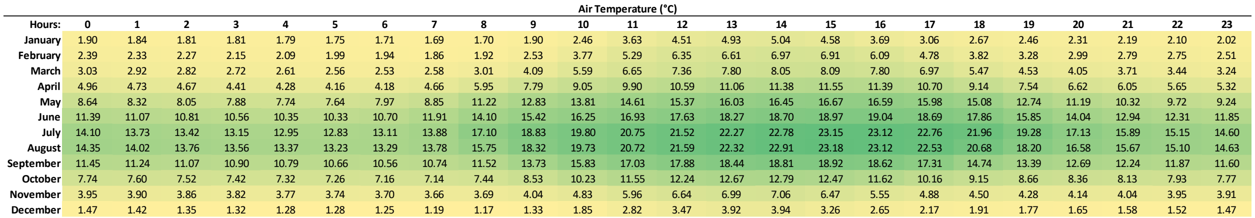
Risk	Impact if Risk Happens (L, M, H)	Probability of Risk (L, M, H)	Response: Path to Solution
Lack of data from Client	L	L	Project to proceed using best available information: recommendations and overall accuracy may be compromised.
Scholar Leaves Appointment	L	L	In this unlikely event, work would resume or recommence once another Scholar has been retained for the project.
Project Lead becomes unavailable	L	L	In this unlikely event, Ian Manning/ Scott Pelow would proceed as contact person.
Delayed approvals for security clearance	H	L	In this unlikely event, the Project Lead will have to manage all matters requiring security clearance until clearance is approved.
Scope too large for the theoretical aspects of project	L	M	To talk to Project Lead to adjust scope

Table 11-2 - Project Communications

Action Item	Deliverable	Dates	Accountable
Bi-Weekly Updates	Progress Report / Updated Report	Thursdays	Narain Khera accountable; Project Lead to be involved
Technical Meeting Attendance (in person where possible)	Project Proposal Draft	May 9 May 23	Project Committee
Information sharing as it becomes available	Project Specific Information	Ongoing	All stakeholders to provide information in a timely manner and to provide prior and reasonable notice of dates when they will be unavailable

Table 11-3 - Roles and Responsibilities

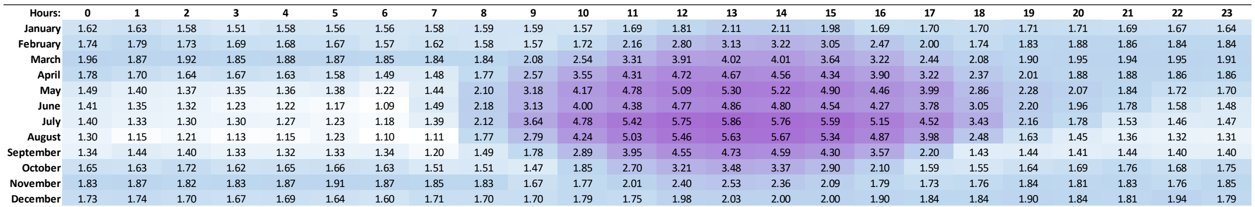
Name, Role & Organization	Responsibilities
Project Manager [the Scholar: Narain Khera]	• Lead all project phases • Create Project Plan and update as needed • Lead and manage project team for all phases of project • Produce all deliverables as per the Project Plan • Save all project reports, data and analysis to shared file server or a drive that is regularly backed up • Complete post-project survey to enable continuous improvement of the Program
Project Partner/Client [the Project Lead: Jeff Carmichael]	• Provide high level guidance and approve scope, budget and schedule • Provide workspace (as appropriate) • Provide connections and linkages with industry professionals/contacts • Ensure scholar has everything needed to successfully deliver the project (i.e., equipment, software, data, introductions, etc.) • Sign off Project Plan • Sign off on changes to Project Plan • Sign off on the final deliverables • Complete post-project survey to enable continuous improvement of the Program
Project Sponsor(s) – USI/UBC and Funding Partner	• Provide high level guidance • Provide overview of program and administrative support (including basic IT and security access) • Remove roadblocks with stakeholders that cannot first be resolved by the Project Lead, as requested by scholar • Hold monthly office hours to help provide support, answer questions and resolve any issues that cannot be resolved between the Scholar and the Project Lead • Payment of scholar



Air Temperature (°C)

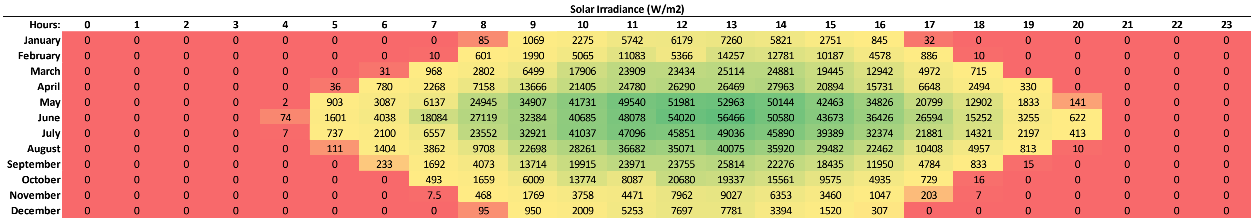
Hours:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
January	1.90	1.84	1.81	1.81	1.79	1.75	1.71	1.69	1.70	1.90	2.46	3.63	4.51	4.93	5.04	4.58	3.69	3.06	2.67	2.46	2.31	2.19	2.10	2.02
February	2.39	2.33	2.27	2.15	2.09	1.99	1.94	1.86	1.92	2.53	3.77	5.29	6.35	6.61	6.97	6.91	6.09	4.78	3.82	3.28	2.99	2.79	2.75	2.51
March	3.03	2.92	2.82	2.72	2.61	2.56	2.53	2.58	3.01	4.09	5.59	6.65	7.36	7.80	8.05	8.09	7.80	6.97	5.47	4.53	4.05	3.71	3.44	3.24
April	4.96	4.73	4.67	4.41	4.28	4.16	4.18	4.66	5.95	7.79	9.05	9.90	10.59	11.06	11.38	11.55	11.39	10.70	9.14	7.54	6.62	6.05	5.65	5.32
May	8.64	8.32	8.05	7.88	7.74	7.64	7.97	8.85	11.22	12.83	13.81	14.61	15.37	16.03	16.45	16.67	16.59	15.98	15.08	12.74	11.19	10.32	9.72	9.24
June	11.39	11.07	10.81	10.56	10.35	10.33	10.70	11.91	14.10	15.42	16.25	16.93	17.63	18.27	18.70	18.97	19.04	18.69	17.86	15.85	14.04	12.94	12.31	11.85
July	14.10	13.73	13.42	13.15	12.95	12.83	13.11	13.88	17.10	18.83	19.80	20.75	21.52	22.27	22.78	23.15	23.12	22.76	21.96	19.28	17.13	15.89	15.15	14.60
August	14.35	14.02	13.76	13.56	13.37	13.23	13.29	13.78	15.75	18.32	19.73	20.72	21.59	22.32	22.91	23.18	23.12	22.53	20.68	18.20	16.58	15.67	15.10	14.63
September	11.45	11.24	11.07	10.90	10.79	10.66	10.56	10.74	11.52	13.73	15.83	17.03	17.88	18.44	18.81	18.92	18.62	17.31	14.74	13.39	12.69	12.24	11.87	11.60
October	7.74	7.60	7.52	7.42	7.32	7.26	7.16	7.14	7.44	8.53	10.23	11.55	12.24	12.67	12.79	12.47	11.62	10.16	9.15	8.66	8.36	8.13	7.93	7.77
November	3.95	3.90	3.86	3.82	3.77	3.74	3.70	3.66	3.69	4.04	4.83	5.96	6.64	6.99	7.06	6.47	5.55	4.88	4.50	4.28	4.14	4.04	3.95	3.91
December	1.47	1.42	1.35	1.32	1.28	1.28	1.25	1.19	1.17	1.33	1.85	2.82	3.47	3.92	3.94	3.26	2.65	2.17	1.91	1.77	1.65	1.58	1.52	1.47

Figure 17 - Lower Capilano Air Temperature (°C) Hourly Averages by Month (2002 to 2019)



Hours:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
January	1.62	1.63	1.58	1.51	1.58	1.56	1.56	1.58	1.59	1.59	1.57	1.69	1.81	2.11	2.11	1.98	1.69	1.70	1.70	1.71	1.71	1.69	1.67	1.64
February	1.74	1.79	1.73	1.69	1.68	1.67	1.57	1.62	1.58	1.57	1.72	2.16	2.80	3.13	3.22	3.05	2.47	2.00	1.74	1.83	1.88	1.86	1.84	1.84
March	1.96	1.87	1.92	1.85	1.88	1.87	1.85	1.84	1.84	2.08	2.54	3.31	3.91	4.02	4.01	3.64	3.22	2.44	2.08	1.90	1.95	1.94	1.95	1.91
April	1.78	1.70	1.64	1.67	1.63	1.58	1.49	1.48	1.77	2.57	3.55	4.31	4.72	4.67	4.56	4.34	3.90	3.22	2.37	2.01	1.88	1.88	1.86	1.86
May	1.49	1.40	1.37	1.35	1.36	1.38	1.22	1.44	2.10	3.18	4.17	4.78	5.09	5.30	5.22	4.90	4.46	3.99	2.86	2.28	2.07	1.84	1.72	1.70
June	1.41	1.35	1.32	1.23	1.22	1.17	1.09	1.49	2.18	3.13	4.00	4.38	4.77	4.86	4.80	4.54	4.27	3.78	3.05	2.20	1.96	1.78	1.58	1.48
July	1.40	1.33	1.30	1.30	1.27	1.23	1.18	1.39	2.12	3.64	4.78	5.42	5.75	5.86	5.76	5.59	5.15	4.52	3.43	2.16	1.78	1.53	1.46	1.47
August	1.30	1.15	1.21	1.13	1.15	1.23	1.10	1.11	1.77	2.79	4.24	5.03	5.46	5.63	5.67	5.34	4.87	3.98	2.48	1.63	1.45	1.36	1.32	1.31
September	1.34	1.44	1.40	1.33	1.32	1.33	1.34	1.20	1.49	1.78	2.89	3.95	4.55	4.73	4.59	4.30	3.57	2.20	1.43	1.44	1.41	1.44	1.40	1.40
October	1.65	1.63	1.72	1.62	1.65	1.66	1.63	1.51	1.51	1.47	1.85	2.70	3.21	3.48	3.37	2.90	2.10	1.59	1.55	1.64	1.69	1.76	1.68	1.75
November	1.83	1.87	1.82	1.83	1.87	1.91	1.87	1.85	1.83	1.67	1.77	2.01	2.40	2.53	2.36	2.09	1.79	1.73	1.76	1.84	1.81	1.83	1.76	1.85
December	1.73	1.74	1.70	1.67	1.69	1.64	1.60	1.71	1.70	1.70	1.79	1.75	1.98	2.03	2.00	2.00	1.90	1.84	1.84	1.90	1.84	1.81	1.94	1.79

Figure 18 - Lower Capilano Wind Speeds (m/s) Hourly Averages by Month (2002 to 2019)



Solar Irradiance (W/m2)

Hours:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
January	0	0	0	0	0	0	0	0	85	1069	2275	5742	6179	7260	5821	2751	845	32	0	0	0	0	0	0
February	0	0	0	0	0	0	0	10	601	1990	5065	11083	5366	14257	12781	10187	4578	886	10	0	0	0	0	0
March	0	0	0	0	0	0	31	968	2802	6499	17906	23909	23434	25114	24881	19445	12942	4972	715	0	0	0	0	0
April	0	0	0	0	0	36	780	2268	7158	13666	21405	24780	26290	26469	27963	20894	15731	6648	2494	330	0	0	0	0
May	0	0	0	0	2	903	3087	6137	24945	34907	41731	49540	51981	52963	50144	42463	34826	20799	12902	1833	141	0	0	0
June	0	0	0	0	74	1601	4038	18084	27119	32384	40685	48078	54020	56466	50580	43673	36426	26594	15252	3255	622	0	0	0
July	0	0	0	0	7	737	2100	6557	23552	32921	41037	47096	45851	49036	45890	39389	32374	21881	14321	2197	413	0	0	0
August	0	0	0	0	0	111	1404	3862	9708	22698	28261	36682	35071	40075	35920	29482	22462	10408	4957	813	10	0	0	0
September	0	0	0	0	0	0	233	1692	4073	13714	19915	23971	23755	25814	22276	18435	11950	4784	833	15	0	0	0	0
October	0	0	0	0	0	0	0	493	1659	6009	13774	8087	20680	19337	15561	9575	4935	729	16	0	0	0	0	0
November	0	0	0	0	0	0	0	7.5	468	1769	3758	4471	7962	9027	6353	3460	1047	203	7	0	0	0	0	0
December	0	0	0	0	0	0	0	0	95	950	2009	5253	7697	7781	3394	1520	307	0	0	0	0	0	0	0

Figure 19 - Lower Capilano Solar Irradiance (W/m2) Houlry Averages by Month (2017 to 2019)