Green Senior Living Communities:
CEE 5051 M.Eng. Project Final Report

Cornell University

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1 Executive Summary

The number of seniors (older than 65) is expected to increase to about 60-70 million people by 2030, about 1/5 of the US population[118]. The demand for senior living centers (SLCs) will be increasing dramatically with this increasing population. Simultaneously, there is new and increasing focus on making buildings efficient, green, and sustainable. In New York State specifically, the governor has set a goal to reduce statewide greenhouse gas emissions 40% by 2030 and at least 85% by 2050 compared to 1990 levels[84]. As a result, this paper aims to look at the intersection of these two trends and explore the design requirements of a hypothetical senior living center. This SLC will be located just outside of Seneca Falls, NY, and our design will consider the energy, heating, and stormwater demands and needs, as well as building efficiency and will be defined as a Green SLC (GSLC).

Our SLC is designed as a 86-unit apartment complex. Each unit will have two bedrooms and one bathroom, housing on average 1.4 people. Space and water heating will be provided by geothermal heat pumps. A total of 240 tons of capacity will be installed, and slinky looping for the heat source will require 13 acres. The heat pump system will have a capital cost of $1.1 million. Rooftop solar and additional carport solar totalling 819 kW is designed for the GLSC in Seneca Falls, NY with a total capital cost of $1.35 million and a capacity factor of 15.8%. Four Level-2 EV charging stations will be installed in the parking lot for a total capital cost of $18,000 and will cost customers $0.2756/kWh of electricity used to charge their vehicles. Any additional electricity demand not met by the on-site solar will be purchased from a new hydroelectric plant at Mud Lock Dam near Seneca Falls. The hydropower plant will consist of 4-bulb tubrines for a total rated capacity of 970kW and producing an average of 4.78 GWh/year. The GSLC will be able to purchase this power for $0.03/kWh. A stormwater management plan involving a detention pond and bioretention areas has also been created as part of our analysis based on characteristics of typical watersheds in the Seneca Falls region.

We project these sustainable designs will cost about $10.3 million to construct, annualized to $653,100 per year after factoring in costs of operations, maintenance, and necessary system overhauls. Residents can expect to pay in the range of $1,000-$1,500 per month in rent in addition to $158-$207 in monthly energy costs.

2 Project Motivation

According to the U.S. Census Bureau, 1 in 5 Americans will be of retirement age by 2030 [118]. With longer life expectancies and the Baby Boomer generation reaching retirement age, the U.S. will experience a critical need for senior living communities in the coming decade. The National Investment Center for the Seniors Housing and Care Industry (NIC) estimates 80,000 to 140,000 new senior housing units will be needed to meet the demands from the aging Baby Boomers by the late 2030s, in comparison to the approximately 30,600 facilities currently in operation in the U.S. [63]. This increased demand is already placing immense stress on our healthcare system and senior living centers. The average wait time to currently get into a CCSHC is typically 180 days, and experts recommend that families help seniors start planning years ahead and place their names on wait lists [30].

Caring for our aging population is not the only crisis the U.S. will be grappling with in the coming years. Climate change due to the global rise in greenhouse gas emissions will only continue to worsen in the coming decades, with many parts of the world being subject to extreme weather events, sea level rise, and high temperatures. Much of the increase in atmospheric greenhouse gas concentrations is a result of centuries of fossil fuel (i.e. coal, oil, and natural gas) combustion to generate electricity. One way of mitigating this is by switching our electricity generation to clean, renewable energy sources that do not emit greenhouse gases, such as solar, wind, and hydroelectric power, which tend to be smaller and more distributed. The challenge of mitigating climate change exists in addition to what many see as a constantly ongoing struggle between developing our infrastructure and economy versus protecting our environment from dangers like pollution and deforestation.

Looking at the challenges of an aging population and the risk of further environmental degradation, it is evident that not only does the U.S. need more senior living communities, but these communities must be environmentally sustainable. The goal of this project is therefore to design a theoretical sustainable, "green" senior living community (GSLC) that will provide its residents with the best possible quality of life while also working with its surrounding natural environment to provide clean, renewable energy and preserve the ecological health of nearby water bodies. Our design seeks to incorporate electrified heat pumps to fulfill heating and cooling demand without natural gas, provide electricity from renewable sources with solar and small-scale hydroelectric power, and safely manage and treat stormwater with green infrastructure. This engineering analysis and design of this theoretical community demonstrates different ways of incorporating sustainability into senior living centers and reveals areas in which future research can take this field further.

It is also our goal throughout this project to ensure that our designs are completed with affordability at the forefront of our considerations. Many Americans, especially senior citizens, are struggling with access to affordable housing and keeping pace with rising inflation. Solutions are often presented with a trade-off between sustainability and cost, where sustainable options are significantly more expensive than "unsustainable" and non-traditional options, simply because sustainable solutions tend to be newer and less common. Our hope is that our analysis demonstrates that is possible to design living communities with both sustainability and affordability in mind, and that achieving either of these objectives does not have to be at the expense of the other.

3 Goals of Project

Our group's goals:

- Develop our understanding of SLCs, building efficiency, solar PV, hydropower, heat pumps, and green infrastructure and get "hands-on" experience in applying it for this project.
- Interact with experts outside of the CEE Department at Cornell University to get a broader perspective on the issue at hand.
- Provide a detailed, cohesive, understandable report to be read by the academic and senior living community about a hypothetical green senior living center that can be used as a model for future developments.
- Learn how to navigate the intersection of society, economics, and policy in community-oriented designs to uphold ideals of Environmental Justice and equity.
- Design with realistic consideration for the needs of the residents and the natural environment.

4 Market Analysis

4.1 Demographics

According to the U.S. Census Bureau, 1 in 5 people will be of retirement age in 2030, every Baby Boomer will be at least 65 years of age, and approximately 10,000 people will turn 85 each day [118]. Currently, there are 30,600 assisted living communities serving 818,000 residents nationwide. 50% of the residents are older than 85, 31% of the residents are 75-84, 13% of residents are 65-74 and 6% of residents are younger than 65 in specifically assisted living [7]. The median stay in assisted living is 22 months. Often, 60% of residents will have to move out and transition to a nursing home with a higher level of care [7]. In New York State alone, there are 523 assisted living communities with 38% of these residents relying on Medicaid for their long term care financing. According to the National Institute on Aging (NIA), 8.5% of the population is aged 65 and above due to the increased life expectancy and the large population. The Population Reference Bureau states that the number of Americans aged 65 and above is projected to be 95 million in 2060 compared to 52 million in 2018. Furthermore, with the ratio of older patients to younger caregivers increasing, there are a greater number of adults that move into continuing care senior housing communities (CCSHCs) [66].

Not only is there a demand for CCSHCs from seniors that need physical help to perform daily tasks, there is a mental health aspect as well. A study of a senior housing facility that showed that the accessible physical and social environment encourages residents to remain physically active and independent which promotes healthy aging and mental health [105]. According to the American Health Care Association and the National Center for Assisted Living, 29% of all residents suffer from depression often due to their loss of physical mobility and independence [7]. For some residents, the benefit of living in an SLC was not having to deal with physical upkeep of their home allowing them to focus on their own physical mobility and social interactions [105]. The idea of aging in place has become a policy goal to ensure that older people can continue living in their homes and familiar surroundings improving overall mental health [78]. However, as seniors age and require more and more care, they cannot remain in a place that has no access to a caregiver or around the clock nursing. Senior living communities can help to solve this problem. Seniors can move into a living community and as they need more and more help, they can transition to assisted living or around the clock nursing without moving from their original unit [105]. Thus, solving the demand crisis for senior living facilities while also making them a place in which seniors can age in place is critical.

Healthcare facilities in general produce a significant amount of greenhouse gases. According to the U.S. Energy Information Administration, inpatient healthcare facilities, including senior living centers, represented the third most energy intensive building among all commercial buildings with an overall requirement of 193,300 BTU per square foot [33]. According to Energy Star, the requirements for Senior Living Facilities range from 100 to 1,000 kBtu per square foot with a median at about 210 kBtu per square foot. As the number of living units per 1,000 square feet increases, the energy increases as well following a positive linear trend as seen in figure 1 [34].

Various factors that contribute to this high energy demand include advanced systems

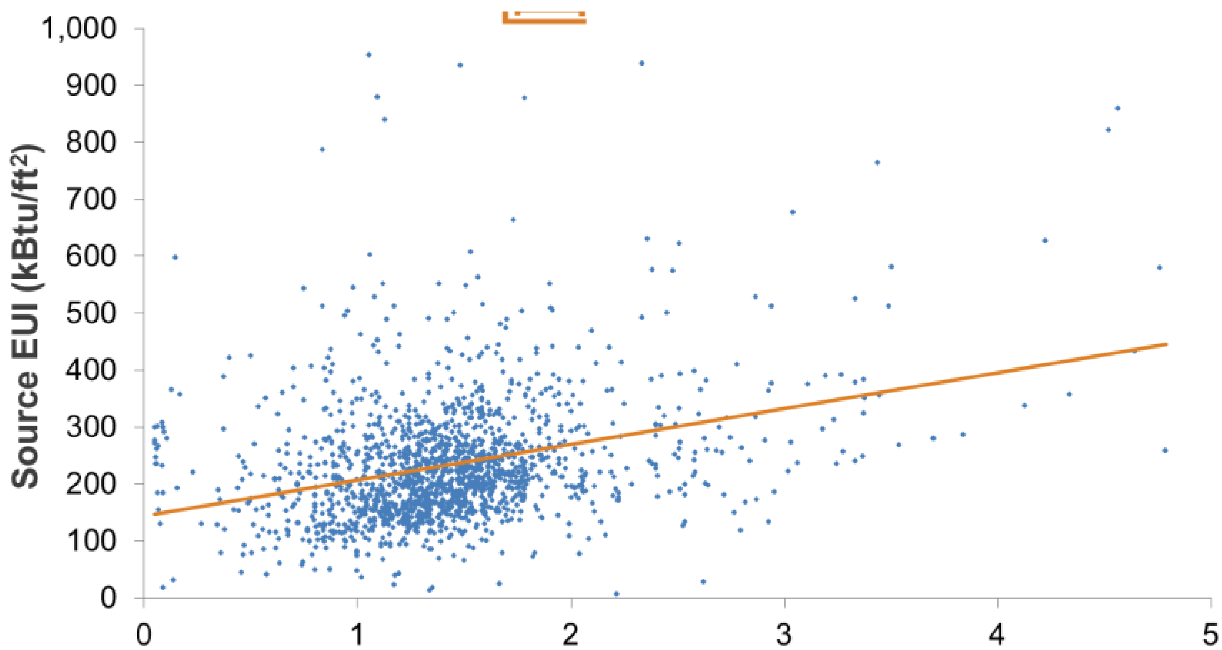


Figure 1: Source EUI (kBtu/ft^2) versus Living Units per 1,000 ft^2 adapted from Energy Star for senior living communities. Positive linear trend line shown. Energy use affected by business activity and climate [34]

for heating, cooling, energy-intensive equipment for medical purposes, and increased lighting [33]. Additionally, increased indoor temperature regulation is required as older people have issues with thermoregulation [78]. The inflation reduction act (IRA) can include numerous tax benefits for healthcare facilities when implementing renewable energy [33]. This would allow for facilities that are breaking construction to be more likely to implement renewable energy features in new projects.

Not only is having a GLSC important for combating climate emissions, there is a connection between green communities with healthy environments and the mental and physical health of senior residents [9]. Harvard conducted a study indicating that cognitive scores were 61% higher for those in green building conditions and 101% higher in enhanced green building conditions CO_2, VOCs and ventilation rate all had significant effects on cognitive function [6]. Therefore, from a healthcare and environmental perspective, new GLSCs are critical to meet the housing demand and emission reduction goals.

4.2 Heat Pumps

4.2.1 Background

Heat pumps are composed of four basic parts: two heat exchangers (numbered 1 and 3 in figure 2, one compressor (numbered 2), and one expansion valve (numbered 4). A blend of water and a refrigerant are pumped through the circuit, gaining or discharging heat through the heat exchangers. The heat pump cycle is reversible, allowing the system to both heat and cool a building, depending on the time of year. When the building is being

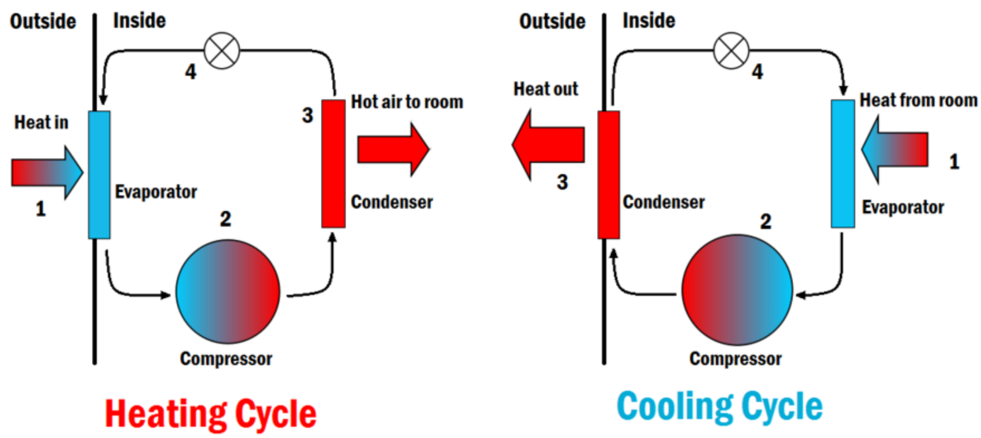


Figure 2: The heat pump cycle in both heating and cooling mode [28].

	Air-Source	Water-Source	Ground-Source
Installation Cost	$	$$	$$$
Efficiency (COP)	3	4.5	3.5-4
Lifetime	15 years	20-25 years	25 years
Operating Costs	$$$	$$	$
Other	Can be unpleasant to look at	Need stable temperature water source	Requires digging

Table 1: Comparison of heat pump sources.

heated, an external medium acts as a source of heat, and energy is discharged into the building. When the building is being cooled, the cycle is reversed. The medium now acts as the discharge location and heat is absorbed from the building. Heat pumps are gaining popularity due to their large coefficients of performance (COPs). Typical COP values are around three, meaning for every unit of energy put into the system by the compressor, three units are pumped out in the form of heat [44]. Heat pumps are typically sized in units called tons. One ton of heating is equivalent to 12,000 British thermal units (Btus).

4.2.2 Heat Pump Sources

There are three general sources for heat pumps: water, air, and ground. True to their names, each type uses a different medium as its source of heat, or discharge location. Water-source heat pumps are not very common as they require a suitable body of water that maintains a constant temperature year round. Water-source heat pumps are more efficient than air-source, but less so than ground-source. They are more expensive to install than air-source and less expensive than ground-source. Water-source represents the middle ground, but it is often difficult to find a water body that meets the requirements [20]. Air-source heat pumps are currently the most common due to the ease of installation and comparatively low expense, especially when added to a pre-existing building [109]. Ground-source, or geothermal, heat pumps cost the most to install due to the digging required to access the heat source. However, geothermal systems are the quietest, cheapest to operate, require the least maintenance, and have the longest expected life [110]

4.2.3 Types of Ground-Source Heat Pumps

There are two categories of ground-source heat pumps: closed-loop and open-loop systems. Open-loop systems are less common, using groundwater as a refrigerant and a well, lake, or pond as a source of and sink for heat. Finding an adequate supply of clean water can be difficult. Closed-loop systems use a mixture of water and non-toxic antifreeze as their refrigerant, and it remains in the tubing at all times. There are three types of closed-loop systems: horizontal, vertical, and lake or pond. Horizontal looping is the cheapest option, costing between $1,000 and $2,000 per heat pump ton to install in a residential capacity, though the amount of land required can be restricting. Trenches are dug between four and ten feet into the ground and rows of tubing are laid in the trenches [23].

An alternative type of horizontal looping is called "slinky" looping, in which the tubing is coiled into two to three foot circles to increase the length of piping within a footprint. Vertical looping is expensive, between $1,600 and $4,200 per heat pump ton to install, but can be ideal for locations with limited space, typically industrial or commercial systems. Boreholes are drilled 100 to 400 feet into the ground and tubing is run up and down the boreholes. This enables the necessary piping for the system to fit within a much smaller footprint [24]. Ponds or lakes can also be used if they are adequately sized. Piping can run from the building underground to the body of water. Coils can rest at the bottom, at least eight feet under so as not to freeze [111] [69].

4.2.4 Types of Heat Pumps

The three main types of heat pumps are liquid-to-air, liquid-to-water, and liquid-to-air and water. Liquid-to-air heat pumps are the most common, operating through duct work. They can also be adapted to heat hot water for the building. Liquid-to-water systems work best for pool heating or in-floor radiant heat. Liquid-to-air and water heat pumps are best for a system with in-floor heating and ducted air conditioning. This system is most popular in new construction due to its flexibility [31].

4.3 Solar Technology

4.3.1 Active Solar PV Cells

Incorporation of renewable energy sources reduces greenhouse gas emissions, separate dependence on fossil fuels, and decreases health risks and environmental impacts [15]. When implementing renewables, it is important to have a diverse profile of renewables so that during times of low production of intermittent renewables, energy demand is still met [15]. One of those renewables for the SLC will be solar. New York State has a goal to power 100% of its electrical demand with renewables including solar by 2040 [104].

There have been many developments for various types of solar panels. Pastuszak et al. conducted a review article detailing the current types of solar and the ideal panel specifications [94]. The ideal panel has a band gap between 1.1 and 1.7 eV with a direct band structure. A band gap is the minimum energy that is required to excite the electron to a higher energy state in the semiconductor. Direct band gap materials absorb the light in a thinner coating, meaning that less active materials are required for the panel overall. The panel material should be easily accessible and non-toxic with a high photovoltaic conversion efficiency.

The various generations of solar panels have produced a large spread of different types of panels. The first generation of panels included thick crystalline films. The second generation transitioned to thin-film cells with a slight loss of efficiency. The third generation focused on novel and emerging technologies such as organic, perovskite, dye sensitized and other materials. The fourth generation combined the technology of the first two generations with the third generation to create a hybrid cell [94]. The efficiencies of the various types of cells are shown in figure 3. An extensive review of the literature led us to the conclusion that, despite the development of newer types of photovoltaic cells, silicon monocrystalline cells still have the largest market share with one of the higher module efficiencies.

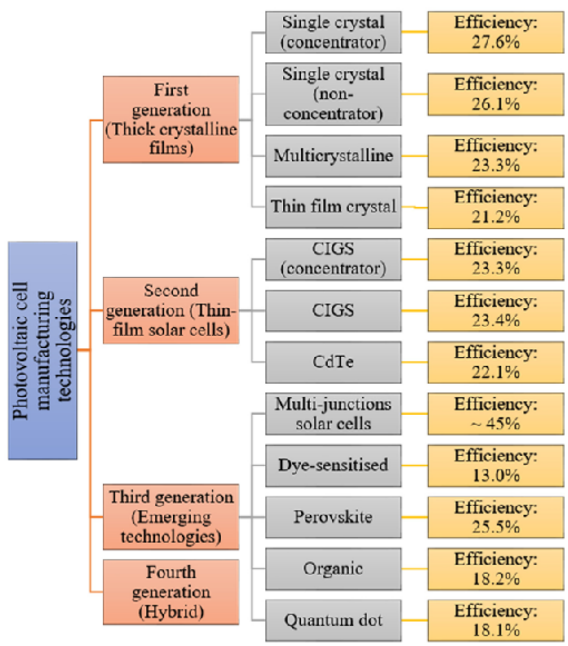


Figure 3: Adapted from Patsuzek et al. highlighting different types of Solar PV cells and their efficiencies.[94]

Inverters are required to convert the DC current, what the PV panel produces, to AC current, what the grid uses so that the panels can be connected into the GSLC power supply [89] . There are two main types of inverters: central inverters in which the panels are connected together through a series of string inverters and then connected to the central inverter, and microinverters which are much smaller and placed on very panel. When the panels are connected in series, there is a potential for reduced power production because if one panel experiences losses, such as soiling or shading, then it will affect the chain. Microinverters however avoid this as soiling and shading of one panel will not affect the others, but this method is much more expensive [89]. Due to the vast scale of this project, central inverters will be used.

A senior community is similar to that of a typical apartment building. The main disadvantage of solar is its relatively low power generation efficiency [125]. To increase this efficiency, many solar installations either rely on rotation or an optimal angle placement of the solar panel. Standard expected optimal angle is to add 15 degrees in the winter and subtract 15 degrees during the summer however that is not as feasible to transition for a large building and carport. There have been many studies done using machine learning and various models to calculate the optimal slope and expected power generation [125]. Vanek et al. developed a simple model that is applicable for the upstate New York location that simply matches the tilt of the panels with the latitude of the location [119].

The main installation of solar power is rooftop or commercial utility solar [15]. NREL states that anywhere from 5% to 65% of rooftop is usable for PV cells depending on the building and the model system [47].

Because of the limited amount of rooftop solar that is available alternative forms of solar are considered. Carport solar panels open the door for traditionally unused space while providing covered parking for elderly residents [41]. This allows residents to avoid having to remove snow or ice from their car in the winter, a concern due to the harsh winters experienced in Seneca Falls, NY. There are possibilities to incorporate single row canopies or double row canopies with mono pitch, duo pitch or barrel arch canopies [41]. However, carports are traditionally 18% more expensive for installation than rooftop solar. The average levelized cost of energy (LCOE) of carport solar is 0.085 USD/kWh in 2018, however the LCOE is projected to drop to 0.020-0.080 USD/kWh in 2030 [32].

When looking at integration of PV cells into community design, the main issue is capital cost [108]. If government subsidies are used to aid in the installation of solar panels, this gives the senior living community an overall lower cost for residents as 40% of seniors rely solely on social security as their income [108] [67].

4.3.2 Passive Solar

To maximize the energy efficiency of this building passive solar designs will be incorporated. Passive solar is influenced by a range of intrinsic and extrinsic factors with one such factor being the orientation of the window [18]. The sensitivity of the orientation of the windows decreases with increasing latitude. Because Seneca Falls, NY is at 42.9°N, it is right in the area in which sensitivity is at its median. Passive solar should have properly oriented windows that should face within 30°of true south. Ideally, these windows would not be shaded during the heating season, the winter, from 9 am to 3 pm for maximum heat absorption. During the cooling season, fall winter or summer, the windows should be shaded [35]. At a higher latitude climate, this is optimal as the differences between the summer orientation and winter orientation are smaller, meaning that there are less rigid requirements for passive solar [18]

The building should have a high thermal mass that absorbs heat from sunlight during the heating season and absorbs heat from the warm air during the cooling months. Typically, these materials are concrete, stone, brick, or tiles. Other thermal mass materials that could be used include water tanks as heat storage or using phase change materials to store or absorb heat. In order for optimal heating or cooling, heat transfer is critical via conduction, convection or radiation. Sometimes this is done by having small fans or water movement [35]. Constructing high thermal inertia building elements to regulate temperature will increase energy savings [18].

Finally, roof overhangs can provide shade to the south windows during the cooling season. There are three ways to design these overhangs: direct gains, indirect gains also known as the trombe wall, or isolated gain also known as sunspaces. Direct gain is where the sunlight enters the windows directly and strikes the thermal mass of the house. Indirect gain design has the thermal storage in between the windows and the living space using a trombe wall. A layer of glass is mounted in front of the dark colored walls to act as a greenhouse and concentrate the solar heat in the wall's thermal mass. This heat can then be transferred into the living space. Typically, the walls are roughly 8 inches thick [35]. Other solar applications include heating water to store heat with porous media as a potential energy source with reported 40% energy savings [91].

4.4 Small-Scale Hydropower

Hydropower is a renewable energy source based on the movement of water that is often considered a crucial component of a sustainable and green energy mix. Currently, hydropower makes up about 6% of the electricity generation in the United States, as of 2021 [37].

Hydropower does have some associated emissions, mostly from construction, but overall it has a very low carbon footprint. Replacing fossil fuels with hydropower over the past 50 years has reduced over 100 billion tons of CO2. To put that number in perspective, that is approximately equivalent to the carbon footprint of the United States for 20 years [61].

While hydropower is dependent on river flow, which can vary a lot throughout the year, it does not see much variation throughout the day. As a result, hydropower has the ability to offset the inconsistency of wind and solar, and still provide power at night. Due to this, it's considered to be crucial to a sustainable energy portfolio, such as the one we are trying to build for the SLC [56]. Additionally, it's a good choice because it is a secure source of energy. While energy security and sustainability have always been a large consideration for the US energy market, the Russia-Ukraine war has really brought those concerns to the forefront [57].

The main draw-back of hydropower is site-availability and capital cost. Clearly, hydropower can only be built where there is a body of water, of which rivers are traditionally used though there is some experimentation and research going into wave and tidal energy. Most hydro has been large-scale hydro, like the Hoover Dam, though there are not many sites left in the US for large-scale hydro. A report by Paish found that the US has already built out 50% of it's technical capacity for hydropower [93]. Most of the remaining sites are only viable for small-scale hydro, which the US DOE defines as less than 10 MW of capacity [117].

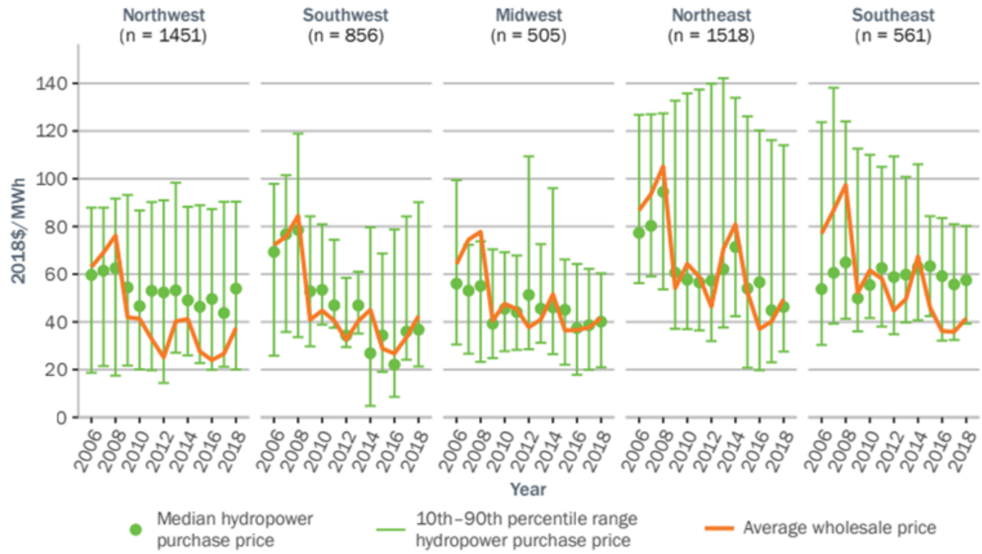


Figure 4: Hydropower price by region and report year from power sales reported on FERC Form 1

As hydropower projects require lots of infrastructure and heavy construction their capital costs are steep, which can be a barrier to developing new hydropower. New hydropower plants (after 1980) have generally ranged between $2,500/kW and $7,500/kW in capital costs. For powering non-powered dams (NPD), that average was around $4,236/kW, $4,774/kW for hydropower in canal or conduits, and $5,320/kW for new stream-reach development projects (NSD). These numbers are 2-3 times higher than typical capital costs for wind and solar (Stehly and Duffy, 2022), but the longer lifetimes of hydroelectric projects and higher capacity factors compared to wind and solar help keep their electricity prices competitive. Hydropower is often sold by making power purchase agreements with the consumer for a specified price instead of exporting to the grid and being purchased by consumers at grid prices. Typical hydropower power purchase (PPA) prices tend to be right on track with other renewables, the DOE found that median national hydropower PPA price was $0.0484/kWh in 2018, compared to other renewables at $0.0476/kWh [117].

The "U.S. Hydropower Market Report" researched into operation and maintenance cost trends within the US hydropower market. They reported that "in 2018, the average O&M cost was $6/kW for very large plants (>500 MW), $20/kW for large plants (100–500 MW), $42/kW for medium plants (10–100 MW), and $122/ kW for small plants." In general, O&M costs are on the rise, especially for small scale hydro plants, though the year they were put into operation may have a large effect on the price. Older plants (before 1960) have much higher O&M costs that are on the rise, but newer plants (after 1960) seem to have much lower O&M costs on average (around $12/kW-yr) and those costs are more stable over time [117].

To help combat the steep costs for hydropower, the Inflation Reduction Act passed in 2022 creates new legislation around funding for renewable energy projects. Under the new law, any project put into service on or after after January 1, 2025 are eligible to receive

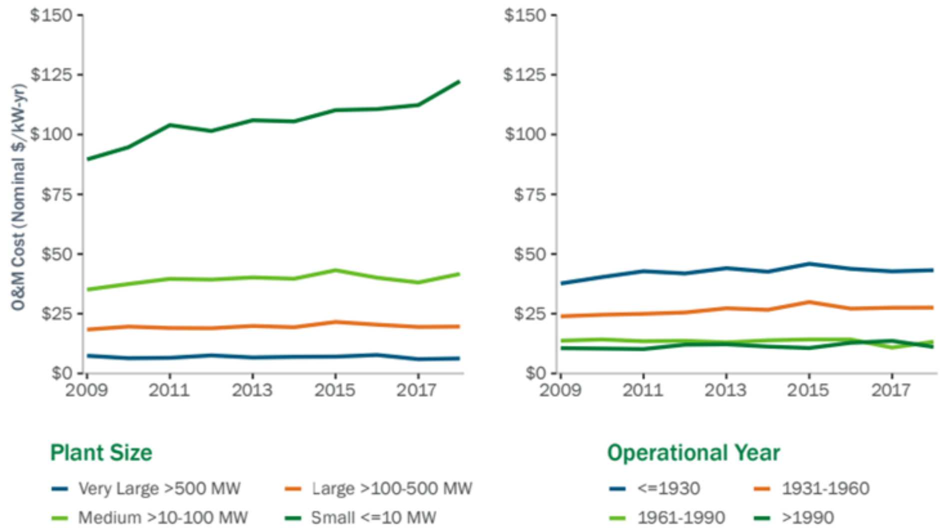


Figure 5: Trend in operations and maintenance costs for hydropower projects by size class

up to either a 30% investment tax credit (ITC) or a 2.75 cents/kWh production tax credit (PTC) [116].

4.5 Green Infrastructure

In natural ecosystems, both the quantity and quality of stormwater is "managed" by natural processes carried out by healthy plants and soils that intercept, retain, utilize, and evaporate precipitation and runoff. One of the biggest factors in a landscape's ability to treat its stormwater is the amount of impervious surfaces, including concrete roads and rooves; by preventing stormwater from being absorbed by plants and soils, impervious surfaces create more runoff and expose the stormwater to potentially dangerous pollutants found throughout urban environments. This overall increases the risk of flash-floods, erosion, water quality degradation of nearby water bodies, and danger to human health [70].

Because urbanization of landscapes significantly decreases their ability to naturally manage stormwater, urban planners have had to develop human alternatives for managing stormwater in impacted areas. Historically, the goal of stormwater management in major urban areas focused on preventing floods by diverting runoff away from populated areas as quickly as possible. As cities and industrial areas expanded, this was traditionally achieved with "gray infrastructure," where systems of pipes, sewers, gutters, and channels convey stormwater away from roads and buildings to be discharged into nearby water bodies.

4.5.1 Development and Modern Applications

Gray infrastructure has dominated American urban planning since the post-WWII era, but this infrastructure significantly altered the natural functions of many watersheds across the country by channelizing flow paths and reducing the lag time between rainfall events

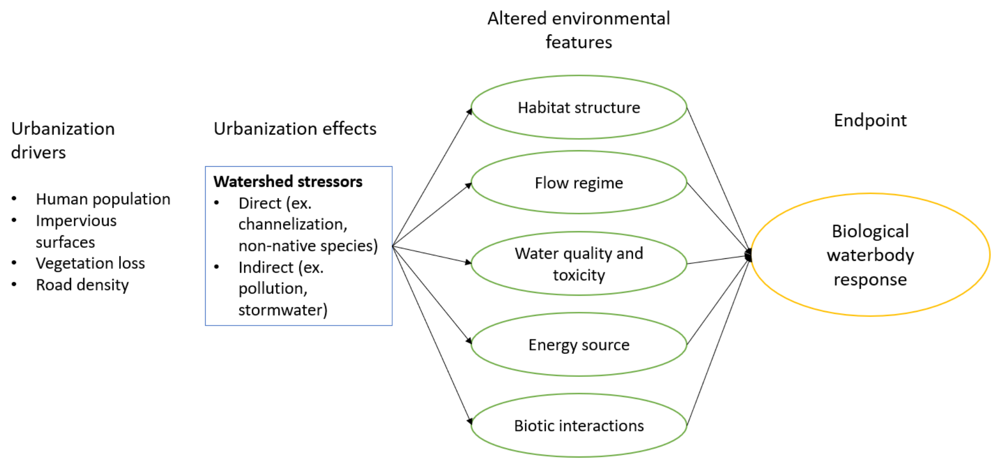


Figure 6: Diagram showing how changes in urbanization impact quality and health of watersheds. Adapted from [82].

and peak runoff [82]. Moreover, gray infrastructure is often designed for areas in isolation and fails to consider potential watershed system impacts, which can diminish its overall effectiveness. As a result of these changes, our reliance on gray infrastructure over the years has led to significant erosion, water quality, and groundwater depletion problems.

Green infrastructure is a product of research since the 1970s into the failings of gray infrastructure and the benefits of natural stormwater management. It largely stems from the ideas of low-impact development (LID) and conservation design developed in the 1980s and 1990s with the goal of preserving the natural hydrology of a watershed as much as possible by treating stormwater on-site and enabling bioretention and groundwater infiltration [82]. Ultimately, green infrastructure systems try to bridge the gap between gray infrastructure systems and natural landscapes by mimicking natural processes to manage stormwater before it enters storm sewers or nearby water bodies, and typically incorporate plants, organic soils and other porous media, and drainage pipes and channels. Common applications of green infrastructure include bioswales, permeable/porous pavements, rain gardens, rain harvesting, downspout disconnection, green rooves, and urban forestry.

The relevance of green infrastructure is increasing as our gray infrastructure systems are aging and in need of replacement; the EPA estimates that this task of updating our stormwater infrastructure will cost over $150 billion over the next couple decades [25]. Green infrastructure projects can help significantly reduce this cost because they utilize inexpensive materials and do not require extensive digging or construction. For example, in the early 2000s the city of Philadelphia began noticing that discharges of untreated stormwater and combined sewer overflow were causing significant pollution and water treatment challenges. Rather than building a $9.6 billion tunnel to convey their untreated stormwater away from the city, they invested $2.4 billion into a 25-year project in 2011 to expand green infrastructure across the city [107]. This plan has already exceeded expectations and has so far prevented 2.7 billion gallons of untreated stormwater from entering nearby waterways. Preliminary studies estimate that each "green acre" in the city that is

Figure 7: Example of bioswale in Wakefield, Massachusetts. Initial construction (left) and vegetation growth after one year (right).

designed to intercept the first 1 inch of runoff costs around $200,000-300,000 on average, though green infrastructure for our SLC will likely be less expensive because it will be located in a less intensely urbanized region [97]. Similar green infrastructure plans have been implemented in cities across the country, most notably in Milwaukee, Portland, OR, and Seattle, and similar cost savings have been observed [45].

4.5.2 Additional Health and Safety Benefits

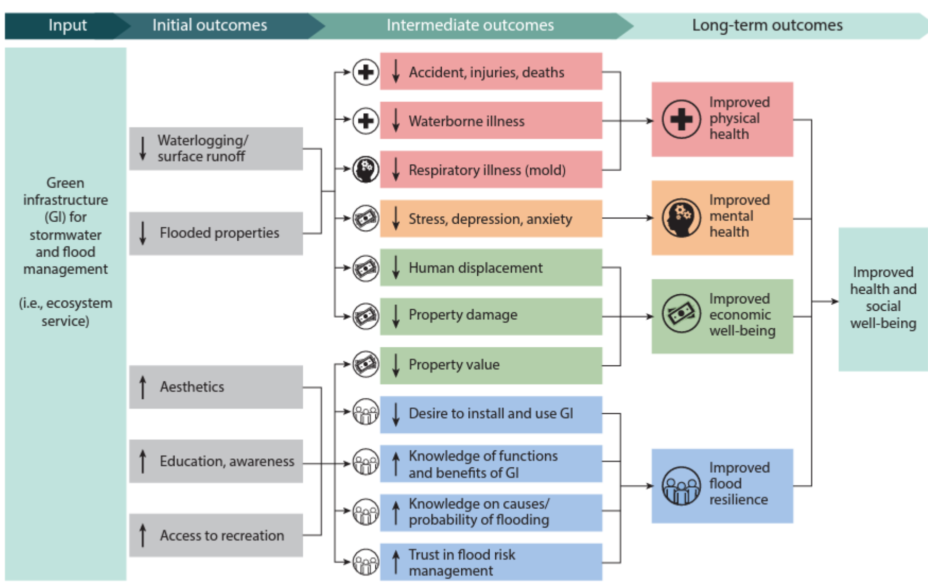


Figure 8: Illustration of the short and long-term benefits of green infrastructure [85].

By improving the overall environment, green infrastructure also provides many benefits not immediately apparent through economic analysis. First of all, cleaner stormwater reduces the risk of waterborne diseases and surface water quality degradation, creating a healthier environment for both people and ecosystems. This can also reduce the costs of water treatment, as Philadelphia observed after implementing their 2011 plan [107]. Particularly relevant for our SLC design, studies have also shown that having more green spaces significantly reduces psychological stress and improves air quality [85]. Reducing the risk of illness from air pollution and improving our residents' mental well-being by incorporating green infrastructure into our design will ensure that our SLC is a healthy and comfortable place to reside.

Lastly, it is an undeniable fact that our climate is changing, and so it is also important to consider the ways that green infrastructure can help mitigate the impacts of climate change for our SLC to ensure our sustainable community is around for years to come. Planting trees and installing green infrastructure as opposed to darker, heat-absorbing surfaces like asphalt will be able to reduce heat pollution and combat the higher overall temperatures climate change will bring, which will also help decrease energy demand for air conditioning in the summer [85]. Climate change will also likely increase the frequency and intensity of storms, resulting in floods that our gray infrastructure is not adapted to handle as this time. Green infrastructure can reduce this risk of flooding by being designed to naturally accommodate stormwater resulting from these more intense storms, which in turn has already been shown to reduce flood insurance and property damage costs [45].

5 Scoping and Assumptions

5.1 Building and Siting

In order to design the heat pumps, solar, hydropower, and green infrastructure a location needed to be picked for the GSLC and a building designed. We decided we wanted to keep the GSLC in New York state and based on hydropower availability, Seneca Falls was chosen. There is no specific lot within Seneca Falls for the GSLC, but it is being assumed it will be slightly outside of the city in a slightly more rural area where land is cheaper and more abundant. The hydropower project will be locted nearby at Mud Lock Dam.

Based on many of the senior living centers nearby, including Longview Senior Care Center, we decided that a reasonable building size was 99,000 ft^2 split across three floors. It contains a total of 86 two-bed one-bath units and it is assumed that 200 people will be in the building at any point in time which includes residents, staff, and visitors. The elevator and stairs are centrally located and each floor has two lounge areas for the residents enjoyment.

In order to optimize the roof for solar, the building runs East-West so there is a big area for rooftop solar. More than half the roof area is available for rooftop solar because the south-facing roof has a shallower slope than the north facing side. In addition, skylights were added to the roof to bring more natural light into the top floor apartments on the northern side and reduce electricity consumption from lights.

Passive solar overhangs will also be added above all South-facing windows to provide

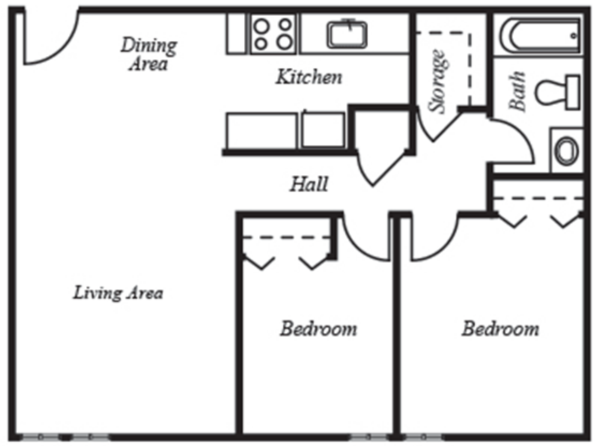


Figure 9: Example apartment layout. Each is 25 ft by 40 ft [1]

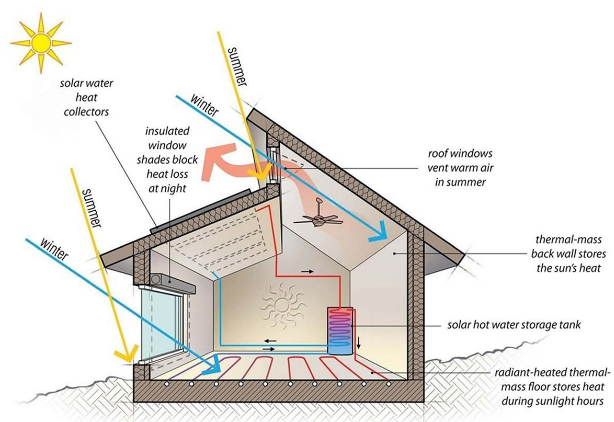


Figure 10: Drawing of what the passive solar roof would look like, not to scale [95]

more heat in the winter and more cooling in the summer. In order for the passive solar to work effectively, the building will be faced with brick, which has a high thermal mass and is more eco-friendly than alternatives such as concrete [42]. The rest of the building will also be made with sustainable alternatives when possible.

The parking lot is located immediately south of the building and is designed to be the same length as the building. The parking lot size will be designed to be large enough for 150 total spots, 100 spots for each unit with 50 additional spots for staff and visitors. While the Americans with Disabilities Act (ADA) only requires 5 accessible parking spots for a lot of 150 spaces, we have observed that this number is greater for senior communities in the Ithaca area, with closer to 10-12% of total parking spaces being accessible [2]. As a result, 18 of our 150 spaces will be in compliance with the standards laid out in the ADA for Accessible Parking Spaces [2]. The parking stalls are in rows that run East-West so that solar carports may be added over the majority of the parking stalls. The drive aisles between parking rows are extra wide to minimize shading on the solar carports and also making navigating the parking lot easier for the older drivers. In addition, there is a bus

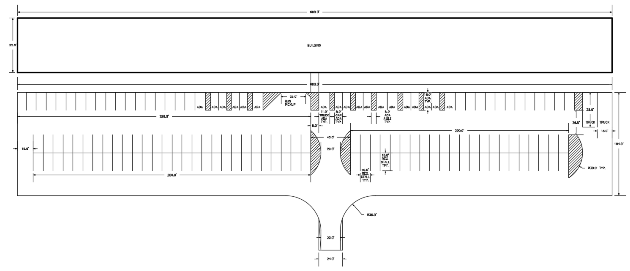


Figure 11: Bird's-eye-view of building and parking lot, drawn in Civil3D

stop right outside of the main entrance so seniors who cannot drive can be picked up and brought into Seneca Falls or to other nearby attractions, such as the golf course. There is also two parking areas for semi-trucks to park and bring in supplies for the GSLC such as hospital beds, medical equipment and more. This configuration of the parking lot has some spots that are located immediately in front of the first floor South-facing apartments, so those units have one exterior door each so the residents may go straight from their cars to their apartment and walk a shorter distance.

Activity	U.S. Residential, 5+ Apartments	U.S. Hospital, Climate Zone 1
Space Heating	25%	42%
Air Conditioning	7%	2%
Water Heating	32%	22%
Lighting	7%	15%
Refrigeration	5%	2%
Ventilation	-	2%
Other	24%	15%
Total Electricity	**36%**	**34%**

Table 2: Energy consumption profiles from average U.S. Residential 5+ Apartments complexes [114], average U.S. Hospitals in the same climate zone as Seneca Falls [13].

We will use 200 kBtu/ft^2 as the energy demand for the entire building including heating, of which we will assume 35% of this is "conventional" electricity demand (i.e. lighting, ventilation, refrigeration) based on average energy consumption portfolios of U.S. hospitals and large residential complexes, shown below. This comes out to a baseline electrical demand of approximately 174 MWh per month. A higher electricity allotment is made for lighting due to the fact that additional lighting is required in senior living homes. The additional lighting includes lower hallway lighting, extra bathroom lighting, and non-motion sensor lighting so the lights do not turn off due to inactivity. We will assume that this number is constant throughout the year, though in reality, it will fluctuate month to month just based on how the electricity is used by residents that month. We will then also factor additional electricity requirements for the heat pump and EV charging stations in the parking lot into the total electricity demand for our building.

We will assume that the energy demand that is not met by the hydropower and the solar panels will be provided by the grid. Similarly, excess energy that is produced will be exported to the gird. Thus, the grid will act as a battery for the GSLC.

5.2 Heat Pumps

Zone	Material	Thickness (inch)	R-Value
Exterior Wall	Common Brick	4	0.8
	Sheathing	1/2	1.32
	R-11 with wood studs	16	12.44
	Gypsum Wall Board	1/2	0.45
Exterior Wall Windows	Double pane	1/2	2.04
Roof	Asphalt Shingles		0.44
	Commercial Insulation		7.2
Ceiling Windows	Triple Pane	1/2	3.23

Table 3: R-values used for heat balance calculations.

Heating and cooling demand calculations will be based on extreme temperatures: -22°F, the lowest recorded temperature in 20 years, and 98°F, the highest recorded temperature in 20 years. A constant ground temperature of 50°F will be assumed [73]. We also assumed there is negligible heat exchange between floors and between the building and the ground. Our calculations are based on the R-values seen in table 3. Our project assumes that heat pumps will run at exactly their rated efficiency throughout their lifetime, neglecting any degradation with age and use. For geothermal sourcing, we have assumed that the site is suitable for horizontal looping, neglecting space limitations or the possibility of soil that is not suitable. We will assume that the heat pumps provide adequate dehumidification and will not require additional machinery [40].

5.3 Active Solar Technology

Solar technology is a well established technology, thus the performance of the panels have been studied. The output thus requires less assumptions, however the lifetime of the panel varies based on location, material, weathering, and other factors. Because the building has three floors, we assume a rooftop area of 33,500 $ft\hat{2}$. NREL states that anywhere from 5% to 65% of rooftop is usable for PV cells depending on the building and model system. Because of the sheer size of the apartment building, we will assume that 50% of the roof space can be outfitted with solar panels. In Seneca Falls, we will assume a tilt of 30 degrees and an azimuth of 180 degrees is optimal [75]. We will assume that the pitch of the roof is at the correct angle for the solar panels, or there can be different types of mounting frames that can be used for the rooftop solar panels to ensure this tilt. The costs of these frames are considered to be the same as if regular frames are installed.

Because of the height of the building, the shading of the rooftop solar panels is considered negligible. The carport solar panels, specifically the row closest to the building has shading losses, however the first row does not experience shading losses because it is assumed that the landscaping is designed in a way such that there is no shading on the panels.

We will assume a lifetime of 25 years with one overhaul. In general, solar panels have a degradation of 0.5% per year [8].

Leap years were not accounted for in the total production. Each year is assumed to have 365 years.

5.4 Passive Solar Technology

Passive solar is highly variable based on the climate, thus we will estimate that a range of savings from 0-5% can be applied. It is assumed that all south facing windows will have overhangs installed.Because this is a new construction project, passive solar will be included in the design anyways as overhangs.

5.5 Small-Scale Hydropower

We will retrofit an existing non-powered dam outside of Seneca Falls, NY to install small-scale hydropower. This dam is located on the Seneca River and is directly west of C-S Canal Lock 1 (Mud Lock). Coordinates for the dam are: 42.947306, -76.735555. All hydrology data is collected from the USGS Streamflow Gauge #0423406130 (Seneca River at Free Bridge), which is just downstream (North) of the dam in question. The data collection period used from this stream gauge starts 12/9/2014 and ends 10/02/2023, nearly nine years of data. It is assumed that the streamflow gauge is an accurate representation of the flow through the dam, however we know that the dam experiences slightly less due to some flow being diverted to power the lock to the East. However, we were unable to obtain data of how much is redirected to the lock, though we do know the lock is run very infrequently. When the data was gathered into Matlab, the zeros in the data were replaced with "NaN" values since it was assumed that these zero values were not actual readings and occurred due to the gauge being turned off, malfunctioning, or no longer being submerged. This river does not dry up in this location, so there could not have been periods of zero flow in the data without some kind of error.

For some scenarios that required a mapping of flow data to a probability density function, a Weibull distribution was used. This distribution was fitted to the available data using Matlab and was assumed to be an accurate representation of the flow regime for the site. Additionally, effects of climate change on the flow regime were not taken into consideration. For this specific site, it is still uncertain how climate change would affect the flow regime so all analysis was based on the past nine years of data and the Weibull distribution.

It is known that the difference in head at those chosen site is not consistent throughout the year. A previous report on the dam has indicated this, but not specified how much it changes [52]. Additionally, one of the sources of the water, Cayuga Lake, is known to drop about 4.4 feet on average from summer to winter which would have some impact on the head at the dam (though it will flux by less than the 4.4 feet at Cayuga Lake) [16].

Turbine assumptions are also detailed in the methods section, but the assumptions for turbine specifications and power calculations came from the manufacturer, Voith. This includes the minimum and maximum flows for each turbine size used as well as the efficiency.

Lastly, there are some engineering assumptions that were made in the calculations. Gravity is 9.807 m/s/s and the density of water was assumed to be 1000 kg/m^3.

5.6 Green Infrastructure

Without establishing an exact site, we will have to make several assumptions about the nature of the watershed and hydrology our community will be constructed in. First, we will assume that our GSLC will be a new development site, as opposed to a redevelopment. As a result, we will therefore have to minimize the impact of development on the natural hydrology of the site by meeting the runoff reduction quantities specified by the New York State Dept. of Environmental Conservation (NYS DEC) [106].

Given that our design is in Seneca Falls, which is in both the Finger Lakes region and the greater Great Lakes Basin, we will assume that our designs must meet standards for phosphorus removal. Phosphorus is already a major concern both for Cayuga Lake and the Great Lakes as it can lead to eutrophication, harmful algal blooms, and overall degradation in freshwater systems. Our site is not located in a sole source aquifer region, so we will assume that infiltration is not a major concern for our design [38].

A 1-year, 24-hour design storm will be used to calculate necessary runoff reductions as specified by the NYS DEC. Given the hydrology of the Seneca Falls region, we will also assume that our runoff ultimately discharges into a first- or second-order stream, in which case we will need to analyze our pre- and post-development peak runoff flows to determine whether possible storage for overbank flood control and extreme flood control are needed [115] [106]. The 10-year, 24-hour and 100-year, 24-hour design storms will be used in these calculations to determine overbank flood and extreme flood protection measures. All needed precipitation data will be obtained through the Northeast Regional Climate Center, run by Cornell University [86].

Where applicable, we will use design standards established in TR-55 to ensure compliance with NYS guidelines. This includes using the Curve Number method to analyze the impact of land use on runoff generated.

6 Methods

6.1 Heat Pumps

6.1.1 Heating and Hot Water Loads

Heating loads for the building were determined using a heat balance, seen in equation 1, where A is the area of the material, R is the R-value for the material and ΔT is the difference between the temperature outside and the desired internal temperature. When calculating the energy demands for a year, the outdoor temperature used was the average temperature for each month of the year[123]. Our initial heat balance calculation resulted in a value that seemed much too low when compared to other large buildings such as

Building Type	Square Footage	Tons Capacity	Tons/Sq Ft
University	172,000	420	0.00256
Residential	12,600	32	0.00254
Office	20,573	51	0.00248
Initial GSLC	99,000	160	0.00160
Modified GSLC	99,000	240	0.00242

Table 4: Comparison to case studies to guide the sizing of our system [58, 14, 19].

Building Type	**Annual Energy Usage** (kWh/sq ft)
Hospital[51]	35.2
Hospital[46]	30.4
Commercial[59]	7.1
Nursing Home[92]	17.4
Average NY Home[113]	8.6
Initial GSLC	6.6
Modified GSLC	13.1

Table 5: Typical energy consumption for heating and cooling by building type.

hospitals, schools and apartment complexes, seen in table 4. We cut all of our R-values in half, and the new calculations were much more realistic.

$$Q = A/R * \Delta T \tag{1}$$

To calculate the necessary capacity of the system we used the extreme external temperatures of 98°F and -22°F. These values were chosen as conservative sizing values, as they represent the most extreme temperatures experienced in the past 20 years. We found that the maximum heating demand was much greater than the maximum cooling demand (165 tons versus 31 tons), so we sized our system based on the heating needs. Additionally, we took the hot water demands into consideration. While most homes do not add capacity for hot water, we wanted to ensure our system was not undersized. We used a peak hot water use value of 7 gallons per hour[36] and assumed a population of 200 within the building to be conservative. The average peak demand for a home is 10 gallons per hour, but we decided 7 gallons per hour, the value for hospitals, was sufficient as many of the assumed 200 do not live in the building. Assuming the water enters at 60°F and must be heated to 140°F, the peak heating required is 75 tons. The two tonnages were added together to find the final size of our system: 240 tons.

6.1.2 Annual Energy Usage

Energy delivered to the building was determined using the average external temperature for each month, an internal temperature of 76°F, and the adjusted R-values. Using equation 1, the change in temperature is represented by the difference between the external and internal temperatures. We solved for the demand of each month given the number of days in that month and summed the results to get the yearly energy delivered to the building.

As discussed in section 5.2, heat pumps deliver more energy than the compressor uses. The ratio of energy delivered to energy added is described by the COP. As temperature differences become more extreme, COPs decrease. However, since geothermal is the heat source, the source temperature is assumed to be constant, so calculating a new COP for each month was unnecessary. The calculated energy demand of the building represents the energy delivered, but to analyze costs and energy usage we must determine the energy added to the system using equation 2.

$$\text{Energy Added} = \frac{\text{Energy Demand}}{COP} \tag{2}$$

Our calculated yearly heating demand, 1.3 GWh/year, becomes 0.405 GWh/year of electricity when using a COP of 3.2. A COP of about 3 is typical, but some heat pumps can have COPs up to 4.5. Cost analysis was done using COPs of 3.2 and 4.4, and though higher COP models cost more up front, the yearly energy costs are significantly lower (over $25k), making the investment in more efficient technology worth it over the life of the system.

Using an average daily hot water consumption of 25 gallons per person [36] and a heat lift of 80°F, a conservative value [27] as most homes can lift to only 120°F instead of 140°F, the energy demand of hot water was calculated to be 0.479 GWh/year.

6.1.3 Looping and Land Requirements

Looping requirements were calculated using the size of the heat pumps and typical energy extraction for the soil types in the region. Soil in the Cayuga region is generally clayey, moderately well drained and deep, but the area we choose has a combination of soil types[81]. A soil study would enable a more accurate description, but the boundary of dry clay and moist clay in table 6 was used to determine the specific extraction rate for horizontal looping. Bedrock in the Cayuga region is limestone, shale and sandstone, so the bedrock was categorized as unconsolidated, dry in table 7 [112]. Using these values and the size of the system (846 kW), the requirements were determined for straight horizontal, slinky and vertical looping types. The costs and area requirements for all three types can be seen in table 8. Since we are not considering area as a constraint, the best choice for looping is slinky. If area became a limiting factor, boreholes would be the best alternative.

6.2 Solar Analysis

6.2.1 Active Solar Methodology

The position, orientation, and tilt for solar panels are governed by the latitude of Seneca Falls, 42.9°N. Roof tilt and position, as well as the carport structure, must also be taken into consideration. Solar PV panels have a rated module capacity, however there are additional

Type of Ground	**Specific Extraction Rate** (W/sq m)
Dry Sandy	10-15
Moist Sandy	15-20
Dry Clay	20-25
Moist Clay	25-30
Ground with Groundwater	30-35

Table 6: Specific energy extraction by soil type for horizontal looping[102].

Rock Type	**Specific Extraction Rate** (W/m)
Hard Rock	Up to 70
Unconsolidated Rock, Saturated	45-50
Unconsolidated Rock, Dry	Up to 25

Table 7: Borehole heat exchanger performance[102].

	Straight	**Slinky**	**Vertical**
Ft looping/Ft trench	2	5	2
Trenching needed (ft)	141,318	56,527	55,496
Number of trenches	707	283	111
Trench width (ft)	3	3	0.667
Trench length (ft)	200	200	0.667
Between trenches (ft)	10	10	20
Trench depth (ft)	8	8	500
Total area (acres)	42	13	0.035
Cost, low ($mil)	0.706	0.283	1.387
Cost, high ($mil)	1.696	0.678	3.385

Table 8: Borehole heat exchanger performance[102].

factors that affect the actual energy produced, thus an adjusted efficiency needs to be applied to the panel output. The adjusted efficiency is calculated based on location, tilt, average temperatures, and PV cell specifications[119].

6.2.2 Module Efficiency

Active Solar total output productions were calculated based on the adjusted efficiency as shown in equation 3 where η_{panel} represents the adjusted efficiency of the PV panel, η_r represents the rated panel efficiency, β represents the temperature coefficient of efficiency (C^{-1}), T_c represents the temperature of the cell, T_a represents the ambient temperature of the air, T_M represents the monthly average temperature, T_r represents the temperature at which the cell is rated, γ represents the insolation flux density coefficient, and I_i represents the insolation flux density.

$$\eta_{panel} = \eta_r 1 - \beta[(T_c - T_a) + (T_a - T_M) + (T_M - T_r) + \gamma * log(I_i)] \tag{3}$$

The insolation flux density term was considered to be insignificant when adjusting the efficiency, thus equation 4 is used[119].

$$\eta_{panel} = \eta_r 1 - \beta[(T_c - T_a) + (T_a - T_M) + (T_M - T_r)] \tag{4}$$

The average monthly temperatures for Seneca Falls, NY were taken from historical data, see Appendix A.1.

The monocrystalline cell chosen has certain optimal operating temperature ratings as well as a rated efficiency that is specific to this cell. A standard monocrystalline cell that is popular on the market was chosen[4]. The optimum cell operating temperature, the temperature at which the module efficiency is reported, is 112.5 °F +/- 3.6 °F, and the efficiency is 20.31%. The temperature coefficient of efficiency for monocystalline solar panels is 0.004°C[17].

The difference between the cell temperature (T_c) and the air temperature (T_a) can be viewed as the monthly average difference between the cell and the air temperature, which is directly related to the amount of insolation during daylight hours. Because insolation is a function of the cloud cover, tilt, and cell heat loss, (T_c-T_a) can be estimated using equation 5 where C_f is the tilt correction factor, U_L is the heat loss coefficient, α is the cell absorbance, taken to be 90.3%[103], τ is the cell protective covering transmittance taken to be 95% for the given tilt of the panel[10], and U_L is the clearness index shown in table 9. The heat loss coefficient can be estimated using the nominal operating cell temperature (NOCT) properties, however due to the error in manufacturing a heat loss coefficient of 20 W/m^{2}K is accepted[119].

$$(T_c - T_a) = C_f * (0.219 + 0.832 - K_T) * \alpha * \tau * U_L \tag{5}$$

The tilt correction factor can be determined by equation 6 where S_M represents the ideal tilt angle for the month and S represents the actual tilt.

$$C_f = 1.0 - 0.000117(S_M - S)^2 \tag{6}$$

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0.41	0.45	0.49	0.49	0.52	0.52	0.53	0.52	0.47	0.46	0.37	0.38

Table 9: Clearness indexes for Buffalo, NY located at a latitude of 42.9°N [98]

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
L+29	L+18	L+3	L-10	L-22	L-25	L-24	L-10	L-2	L+10	L+23	L+30

Table 10: Ideal Panel tilt based on latitude

The optimum tilt angle for each month is shown in table 10. The tilt, S, for the rooftop solar panels is 30°, whereas the tilt for the carport solar panels is 10°.

(T_c-T_m) was studied for 15 cities in various locations. The average was reported to be 3 K +/- 2K however due to the small number in comparison to the (T_c-T_m) and (T_m-T_r) this error was considered negligible[119]. Thus, (T_c-T_m) is equal to 3K in this model. The resulting adjusted efficiencies are shown in figure 12.

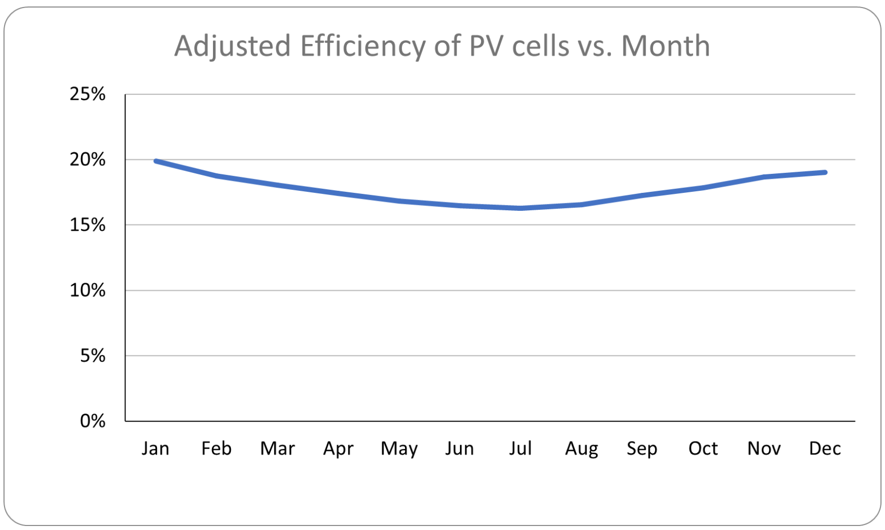


Figure 12: Adjusted Efficiency of the Monocrystalline Solar Panel per Month Based on calculations

6.2.3 System Efficiency

The efficiency of the wiring system, η_{system}, is determined by the derating factors in table 11. These factors include any losses to the wiring system or inverter.

The derating factor for the aging of the solar panels is assumed to be 0.5% per year[75]. The soiling of the surface includes any dirt, debris or snow that is present on the solar panels. For the winter, the solar panels have a higher albedo, so the snow will melt off of the panels faster than the roof. If it proves to be a problem additional maintenance can be implemented for clearing the snow off of the panels.

It is important to note that these derating factors are a conservative estimate. NREL currently suggests an estimate of 14% for system losses. However, because of the scale of

Derating Category	Derating Factor
Losses in the inverter and transformer	0.92
Mismatch of panels and inverter	0.98
Losses in diodes and connections	0.995
Resistances losses in DC wiring	0.98
Resistance losses in AC wiring	0.99
Soiling of the panel surface	0.925
System availability	0.98
Sun tracking	1.00
Aging	1-(0.005*year)
η_{system}	0.75*(1-(0.005*year))

Table 11: All derating factors are multiplied together to assess the overall system efficiency. Derating factors based on cell specifications and assumed losses in system wiring[4, 119]

the system, a conservative estimate makes more sense as there are more opportunities for large system losses. Because the panels are placed in series with the central inverter, there is a higher likelihood of loss of efficiency in the DC wiring and losses in the inverter and transformer. Additionally, this will help to account for any error found in the insolation data.

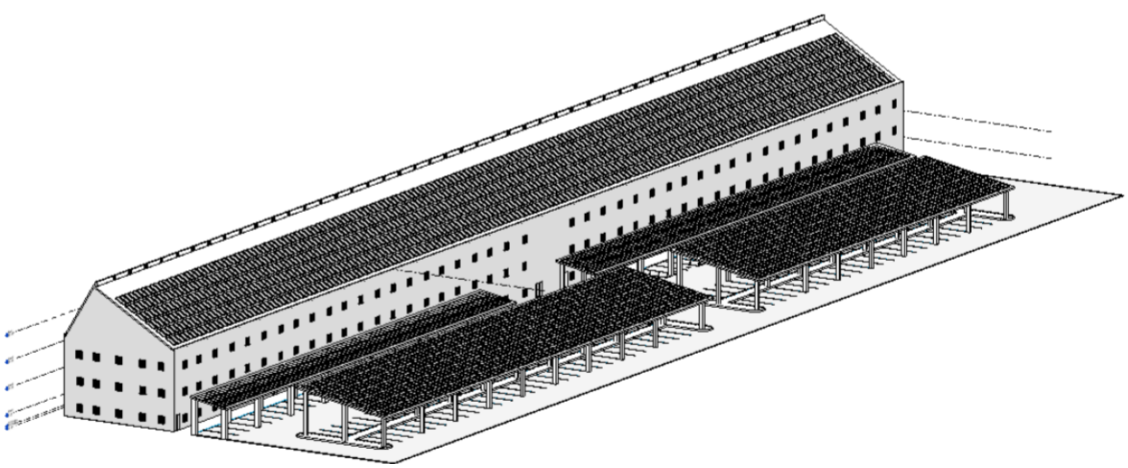


Figure 13: Illustration of building with rooftop solar and carport solar.

6.2.4 Rooftop and Carport Specifications

The tilt of the rooftop is 30°. The total square footage of the rooftop that can be used for solar panels is 15,381.5 ft^2 (1,471 m^2), which allows for 808 panels with a rated capacity of 370 W to be placed for a total capacity of 299 kW. The tilt for the carport was tested to get the optimum efficiency through ranges of 0°to 30°. The tilt with the optimum efficiency is at 10°. The clearance of the carport must be at least 12 feet to accommodate all sizes of potential vehicles. Carports will not be placed in truck parking or in bus pull offs, only in ADA and regular parking spaces. Thus, a total of 30,740 ft^2 (2,856 m^2) of the parking lot is covered with solar panels, totaling 1,405 panels with a capacity of 520 kW. This results in a total capacity of 819 kW. The total solar is illustrated in figure 13.

6.2.5 Shading Factor

The main difference in considerations between carport and rooftop solar is the shading that affects the last row of PV panels on the carport. There are three components of insolation: direct, diffuse, and ground reflection. The shading from the first row of solar panels affects all three of these types of insolation seen in figure 14

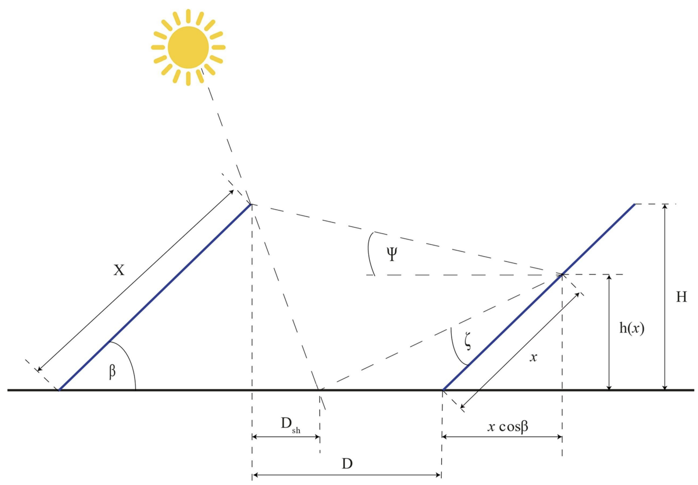


Figure 14: Solar Shading from the 1st row of Carport Solar Panels on the 2nd row of Solar Carport Panels [121].

The obscuring angle, ψ, and the southern projection of the solar elevation angle, α_s', are used to determine the affect of the shading on the insolation [121]. In equation 7, H is the height of the solar panel, x is the point on the solar panel, D is the distance between the solar panels, and β is the tilt of the solar panels visually shown in figure 14. In equation 8, the α_s is the solar elevation angle and γ_s is the solar azimuth. The solar elevation angle is governed by the declination, δ, the Latitude, L, and the hour angle, ω, shown in equation 9

$$\psi(x) = arctan((H - x * sin(\beta))/(D + x * cos(\beta))) \tag{7}$$

$$\alpha_s' = arctan(tan(\alpha_s)/cos(\gamma_s)) \tag{8}$$

$$\alpha = arcsin(sin(\delta) * sin(L) + cos(\delta) * cos(L) * cos(\omega)) \tag{9}$$

The shading factor is determined for direct shading based on the relationship of the obscuring angle (ψ) to the southern projection of the elevation angle, equation 8, of the sun 10 [121]. When the obscuring angle is larger than the southern projection of the elevation angle, than the panels are shaded. When the obscuring angle is less than the southern

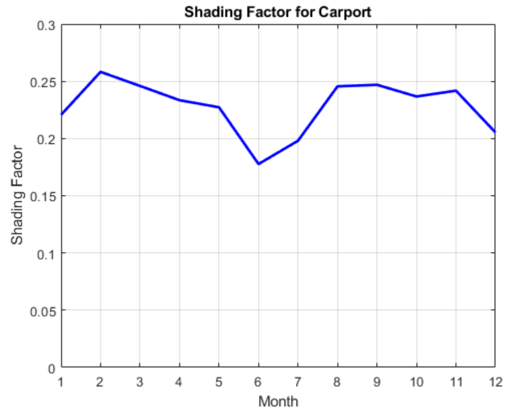


Figure 15: Average Shading Factor on 2nd row of solar panels for one year

projection of the elevation angle, then the panels are not shaded and can operate at full capacity. Thus, $S_{direct}(x)$ represents the percentage of time that the panels are shaded.

$$S_{direct}(x) = \left\{ \begin{array}{ll} 1 & \text{if } \psi(x) \geq \alpha_s' \\ 0 & \text{if } \psi(x) \leq \alpha_s' \end{array} \right\} \tag{10}$$

For diffuse shading, the magnitude of the obscuring angle and the southern projection of the elevation angle is again compared as shown in equation 11.

$$S_{diffuse}(x) = \left\{ \begin{array}{ll} C(x) & \text{if } (\alpha_s' - \psi(x)) \geq 0 \\ |1 - C(x)| & \text{if } (\alpha s' - \psi(x)) \leq 0 \end{array} \right\} \tag{11}$$

The shading factor is then governed by the circumsolar function, $C(x)$ shown in equation 12 where r is the circumsolar radius of the sun, which was taken to be 15°.

$$C(x) = arcsin(sqrt(r^2 - (\alpha_s' - \psi(x)^2))/r)/180 - sqrt(r^2 - (\alpha_s' - \psi(x)^2))/2 * \pi * r \tag{12}$$

The ground shading factor is the ratio of the percentage of the ground that is shaded, $D_s h$ to the total ground in front of the solar panel, D. The percentage of ground shaded can be determined with equation 13. Varga et al. took an approach that ignored insolation data reported and based the ground shading factor on insolation numbers that were calculated using theoretical models[121]. Because the insolation data is provided based on the sun's position in the sky and the daylight, the ratio of shaded to total ground is used as a replacement calculation for the shading factor.

$$D_{sh} = H/tan(\alpha_s') \tag{13}$$

The total solar shading factor is shown in equation 8. This equation is used to estimate a shading factor for each month based on calculations for every hour of every day and averaged over each month resulting in a range of shading factors from as low as 0.17 in the summer months to as high as 0.255 in the winter months as seen in figure 15.

$$ShadingFactor = S_{direct} * S_{diffuse} * D_{sh}/D \tag{14}$$

6.2.6 Output

$$Energy = (1 - ShadingFactor) * \eta_{system} * \eta_{panel} * Days * \hbar * Area_{Panels} \quad (15)$$

Incorporating all of the efficiency adjustments including the η_{panel}, η_{system}, and the shading factor, the energy output of the solar panels can then be determined with the days per month, the monthly insolation ($\hbar$), and the area of the panels. $\hbar$ is the monthly insolation ($W/m^2 day$) based on the sun's position and daylight for the given altitude shown in figure 16.

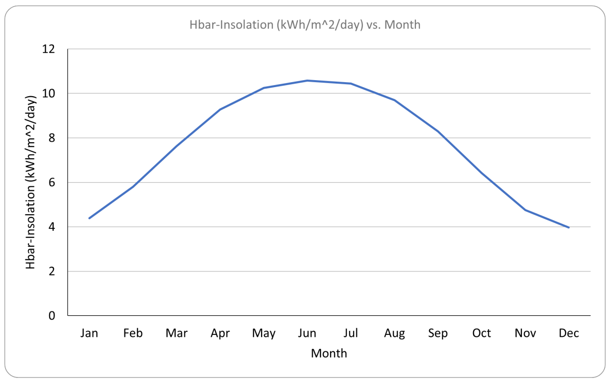


Figure 16: Insolation for Seneca Falls, NY over one year[54]

The total production from the rooftop and carport solar panels is summed for every month and displayed in figure 17. The calculations were performed for year one, meaning that the degradation of the panels is not considered in these calculations. The total solar output for one year is 1.126 GWh, resulting in a capacity factor (CF) of 15.8%. The U.S. average CF for solar is 24.5%, which is higher than the theoretical calculated CF. The higher capacity factors are mainly states located in the southwest. New England and Mid-Atlantic CFs are in the range of 16-17%, which is more in line with the calculated CF [60].

The real source of error between theoretical and actual output is the changes in the weather. The insolation data shown in figure 16 are theoretical values and are based on the position of the sun and the daylight for the corresponding latitude. It does not take into account any weather data for the local area.

6.2.7 PV Watts Calculator

NREL (National Renewable Energy Laboratory) developed a software that calculates the output from PV panels based on given latitude, direct current system size, module type, rooftop or open rack array type, system losses or derating factors, the tilt of the panels, and the azimuth of the panel position. Additional inputs applicable to this model include the inverter efficiency and the monthly irradiance losses[3]. The PV Watts calculator is used to evaluate the rooftop output, the 1st row of carport panels with no shading, and the second row of carport panels with shading as shown in figure 13. The same inputs that were used for the theoretical calculation model are put into the PV Watt Calculator. The sizes of the various solar panel mounts are as follows: rooftop = 299 kW, carport without

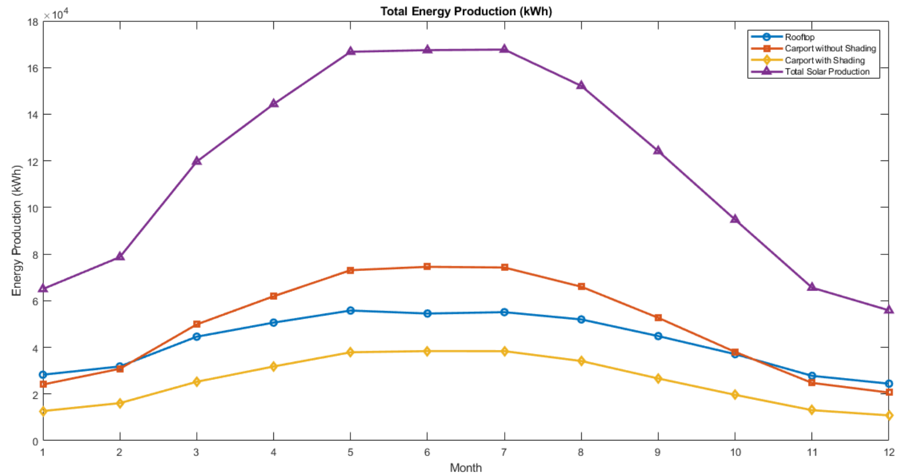


Figure 17: Total Solar Output based on theoretical calculations.

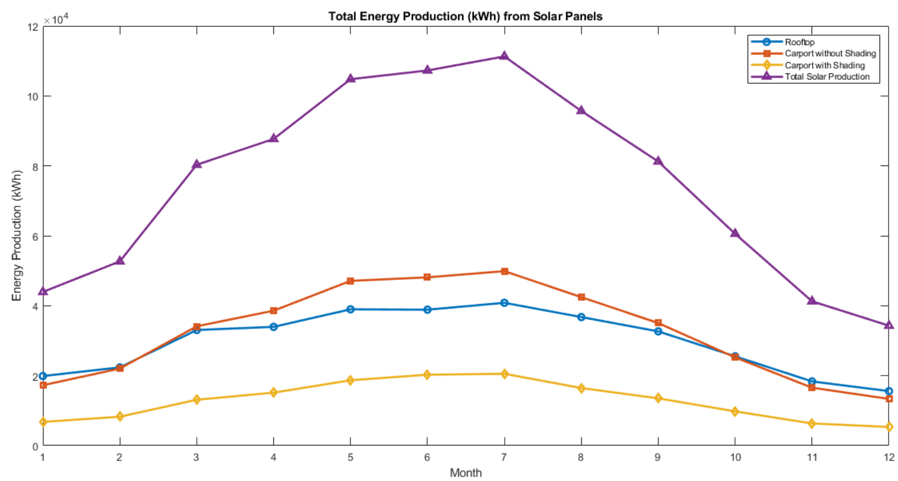


Figure 18: Total Solar Production calculated by PV Watts Calculator summed together[3]

shading = 354.2 kW, carport with shading = 174.6 kW. The shading factors taken from figure 15 were inputted as monthly irradiance losses.

As seen in figure 18, the total production peaked at 111,279 kWh in July, with the largest contributor being the carport panels that did not receive any shading. The carport has a lower total percentage output in the winter due to the lower tilt. The total calculated annual production was 0.9 GWh.

In comparing the theoretical calculations in figure 17 to the PV Watt Calculator in figure 18, the PV Watt output was only 80% of the theoretical calculations. This is potentially due to differing weather data. PVWatts uses insolation data based off of the closet weather station, Buffalo, NY, where as the insolation data used is calculated based on the sun's position in the sky throughout the year. Thus, specific insolation data for Seneca Falls, NY was not used in either model. After one year of operation, a more accurate predication of

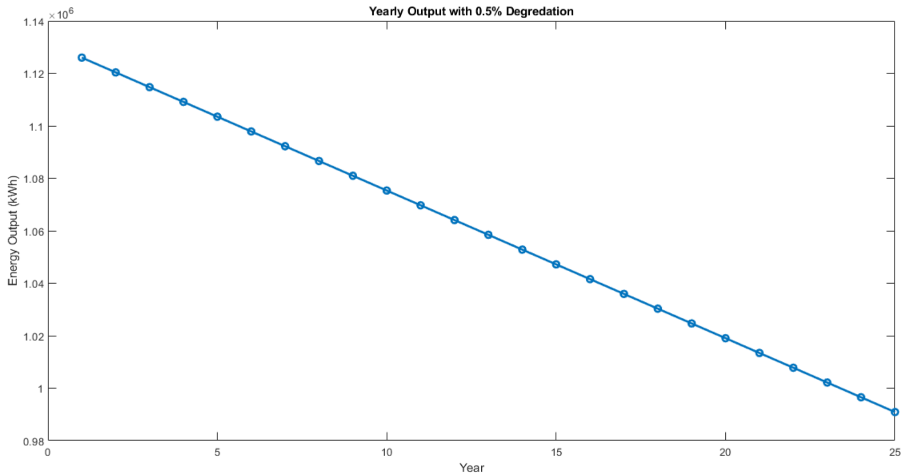


Figure 19: Solar degradation based on 0.5% reduced capacity over 25 years

the output from the PV panels can be given.

6.2.8 Panel Aging

Based on the derating factors, the degradation of the solar panels over 25 years is shown in figure 19. Ultimately, at year 25, the solar panels are operating at 87.5% of their initial capacity. Thus, an overhaul will be completed at year 25 replacing all panels so that they will operate at 100% of their capacity again.

6.3 Passive Solar

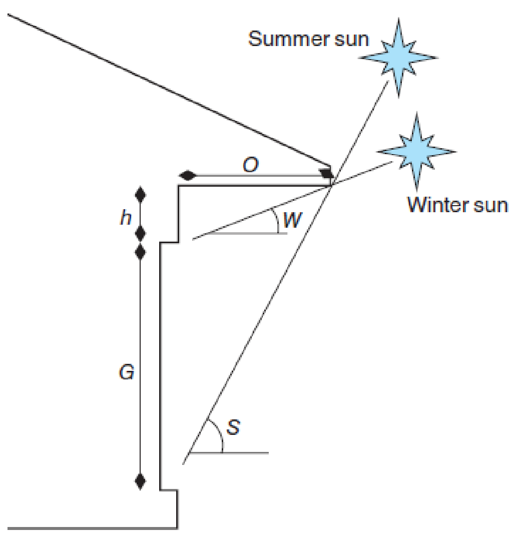


Figure 20: Illustration of the short and long-term benefits of green infrastructure [120].

The ideal design for a solar overhang is governed by the height of the window and the angles of the summer sun and the winter sun shown in figure 20. The length of the overhang, O, can be determined by equation 16 and the height of the overhang can be determined by equation 17 where S is the solar declination for the summer and W is the solar declination for the winter[120]. The summer reference day is May 10, or the 130th day, and the winter reference day is November 15th, or the 319th day. G is the height of the window.

$$O = \frac{G}{[tan(S) - tan(W)]} \tag{16}$$

$$h = O * tan(W) \tag{17}$$

The calculations indicate that the overhang length should be 1 m (3.293 ft) and the overhang height should be 0.71 m (2.33 ft).

It has been reported that passive solar can save on heating and cooling costs from anywhere from 1% to 50% depending on the location, building style, passive solar type, and orientation[74]. With this wide range reported in multiple articles, it is difficult to predict the savings for this GSLC. Therefore, a sensitivity analysis will indicate the significance of the passive solar. If the assumption is made that the passive solar technology saves 5% on energy heating costs and lighting costs when the sun is shining and the overhang is either letting light in during the winter or blocking it in the summer, then the passive solar can save up to 13,100 kWh per year, or 0.39% of the total energy demand of the building (appendix C).

6.4 Hydroelectric

6.4.1 Analysis of Flow Regime

Flow data was collected from the USGS Stream Flow Gauge #0423406130 (Seneca River at Free Bridge Corners, NY). It is located just over a mile downstream of the dam, and it is assumed that the flow there is equal to the flow through the dam, since the lock is rarely operated. Daily flow data was obtained from Dec 9, 2014 to Oct 2, 2023 and analyzed using a combination of Matlab and Excel. There are a significant number of zero values in the data, but this is assumed to be an error with the gauge since they do not occur during periods of exceptionally low flow, and this is not a river that runs dry. These values are set to NaN so they are not be counted in the analysis. The data is organized into a histogram plot being split into bins 50 cfs wide.

From the histogram it is apparent that low flows below 100 cfs are frequent, and all other flows have a significantly lower probability of occurrence. However, there is another increase in probability around 3000 cfs, which is more common than 1000 or 2000 cfs, and super high flows are not unusual. Thus, the new hydropower design would have to be able to operate at low flows, but would also have to be designed to pass through very high flows without failure.

A 95% confidence Weibull distribution is fitted to the data using Matlab, and is found to have a scale factor of 0.9164 and a shape factor of 1762.9. The Weibull distribution does not match the shape of the histogram perfectly, since the histogram shows that second

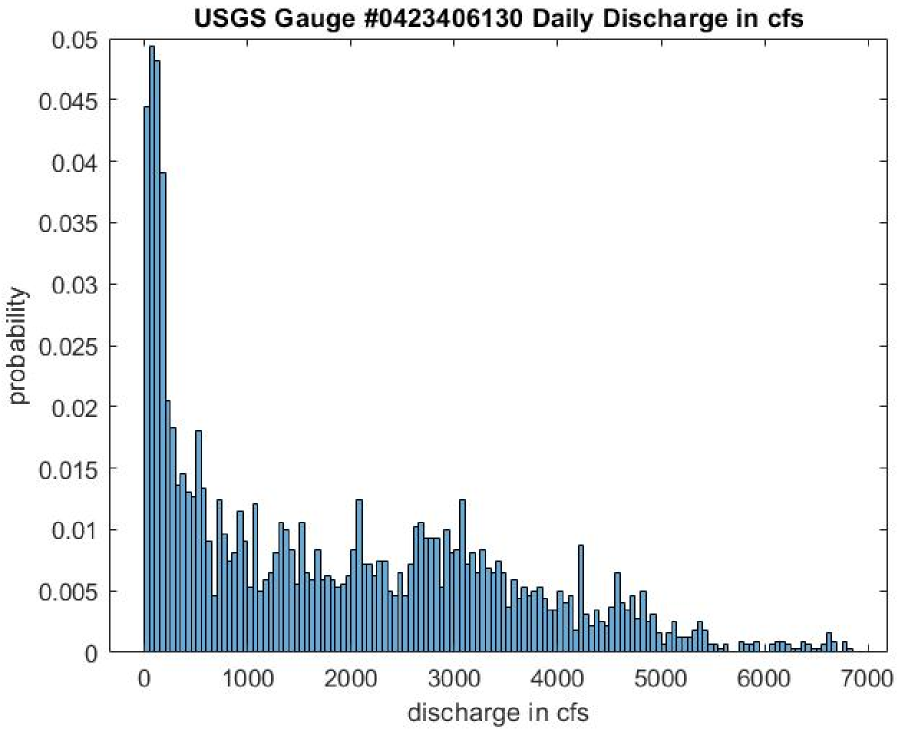


Figure 21: Histogram of daily stream gauge data split into bins 50 cfs wide. Data collected from USGS Gauge #0423406130 from Dec 9, 2014 to Oct 2, 2023.

bump around 3000 cfs and does not quite represent the frequency of 50-200 cfs. However, it is a decent approximation. This gives a way to identify how probably any specific discharge is.

For this project, it was also important to examine the distribution of flow throughout the year. This was done by averaging the daily flow values for each day across all years using Matlab. Due to the data including multiple leap years, the year shown below is actually 366 days long (with leap year occurring on the 60th day).

The Cayuga-Seneca Canal as well as Cayuga Lake drain through this dam, and Lake Cayuga specifically is responsible for most of the flow through the dam. In the late fall every year, the level of the lake is artificially dropped until it is about 4.4 ft lower than its summer value. Then, every spring snow melt replenishes the lake levels to their summer high [16]. This results in high flows through the dam in late fall and late spring, and low flows in the late summer and late winter.

This can be visualized using a box and whiskers plot for daily flow values grouped by month. In figure 24, it is visible that the flows are high in April and May, likely due to snow melt, and then high again in November, December, and January, likely due to the draining of Lake Cayuga. There are a significant number of outliers in June, August, and September that should be noted. Interestingly, every month has low flow values near zero, though they may not be common.

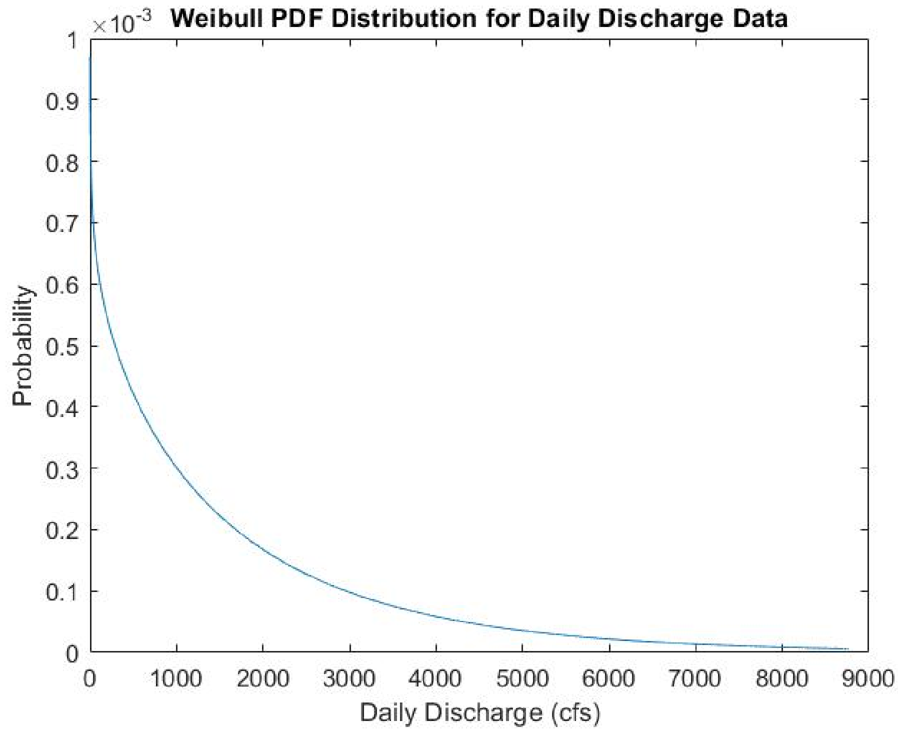


Figure 22: Weibull probability density function with a scale factor of 0.9164 and a shape factor of 1762.9. The Weibull distribution is fitted to the daily discharge data obtained from USGS Gauge #0423406130 from Dec 9, 2014 to Oct 2, 2023.

6.4.2 Turbine Choice and Sizing

There are a few aspects of this site that make installing hydro particularly challenging. The first is the variation in flow regime. The majority of the time, this dam experiences very low flow (based on the historical data, it is under 200 cfs 19.99% of the time). However, it frequently experiences very high flow conditions as well (<3000 cfs 25.00% of the time). As a result, the turbine needs to be able to produce power at low flows, but the dam also needs to let extremely high flows bypass without damaging the turbines or the structure. The second challenge is the low head of 7.5 ft (2.3 m), which is assumed to be constant, though in truth it varies depending on the time of year as well as the amount of flow being let through the site. This is a challenge because it is very difficult to produce power at low heads, and when it is possible, it is not often economical. Turbines need to be spun fast enough to turn the gearboxes and generate power, but when the head is low or the flow is too low, this becomes a difficult task to use conventional turbines. The main three types of turbines (Kaplan, Francis, and Pelton) can only operate at heads higher than 6.5 ft (2 m), but are often not economical until much higher heads [124]. There has been significant research into low head hydroelectric plants that use a variety of means to amplify head or use the energy in water in different ways compared to conventional hydro. Some examples include venturi-enhanced turbines, archimedes screws, and gravitational water vortex.

The initial research into this site examined these technologies; however most of these

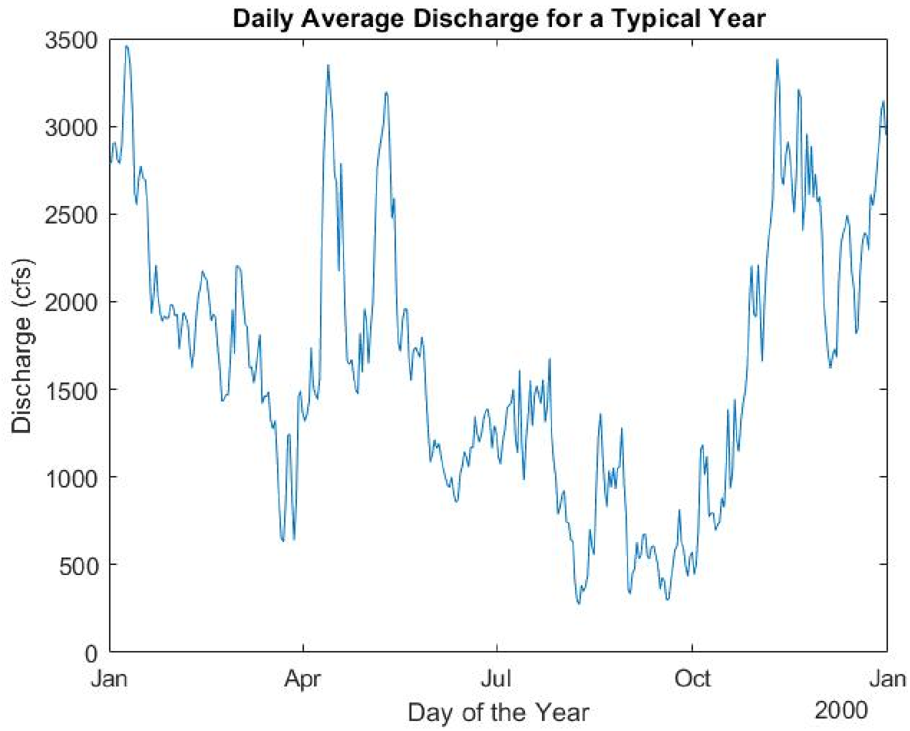


Figure 23: Daily average discharge for a typical year. Data taken from USGS Gauge #0423406130 from Dec 9, 2014 to Oct 2, 2023.

may have required an extreme amount of new construction and are not ideal for an existing dam, or are still in the research phase and the technology is expensive. More conventional hydro turbines that could operate at very low heads and are ideal for retrofitting are more applicable. Since the construction costs often account for about 40% of a hydro project's budget and is the major barrier to making this site economical, decreasing the construction costs was decidedly more important than maximizing the power produced at low heads [90].

Companies such as Voith offer modular turbines for low heads that could be easily added to most existing structures. The turbines come pre-made in seven standard sizes that can handle different levels of flow and produce different levels of power. SD7.90 is their smallest unit and SD16.95 is the largest and can handle the most flow and produces the most power. The operating regimes of these turbines is illustrated in figure 25 from Voith's documentation. More information on the turbines can be found on Voith's website [122].

After a call with Voith engineer, Albin Atzmueller, three SD16.95 turbines and one SD13.10 are used. This is based on the amount of flow it can handle as well as a cost analysis of the additional value of an additional turbine. It is typical to design turbines to handle up to the 60-70th percentile flows, for most locations, designing beyond this is not economical and designing under causes loss of potential profit. For this location, the 69-70th percentile flows corresponds to 1600-2160 cfs (45.4-61.1 m^3/s). Therefore, the total capacity of all the turbines installed should handle a max flow within these bounds.

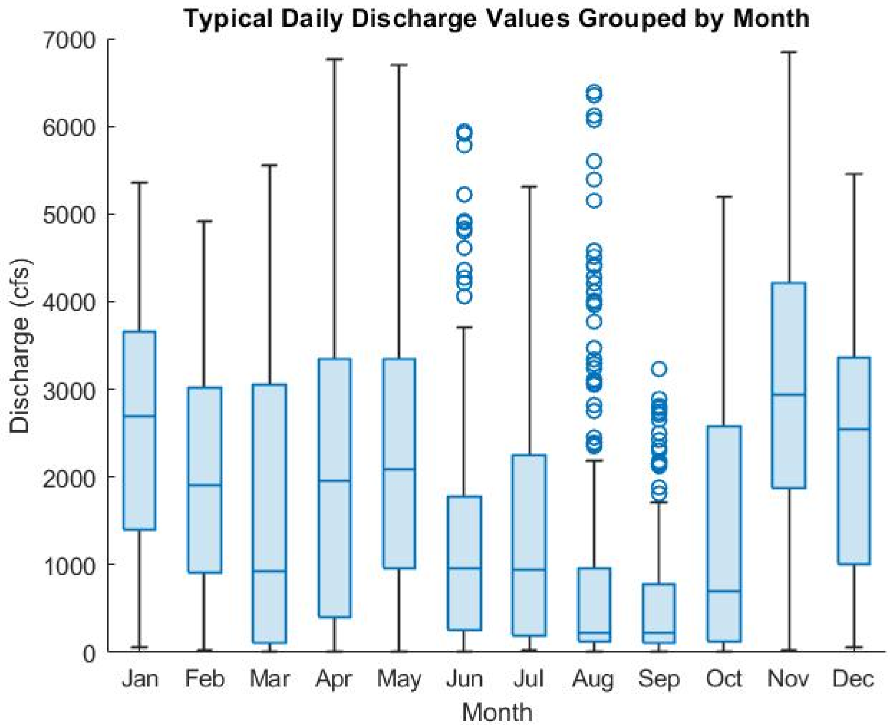


Figure 24: Daily discharge distributions grouped by month. Data taken from USGS Gauge #0423406130 from Dec 9, 2014 to Oct 2, 2023.

Because of the frequency of low flow values at this site, it is important to capture as much of that as possible, so one small turbine with a low minimum flow was a must. After that, the goal is to maximize the range of flow values that could be used to produce power while minimizing the number of turbines installed, and therefore the cost. The result is one small turbine, the SD13.10 which can handle flows from 3-7 m^3/s and three SD16.95 (the biggest turbines) which can handle flows from 7-15 m^3/s each. This gives a maximum capacity of 52 m^3/s which is right in between the desired 60-70th percentile values.

To visualize the additional value each turbine provides, a marginal revenue analysis is done on each additional turbine added to the site by taking the Weibull distribution of the flows split into buckets with a 1% probability of occurrence. For the minimum and maximum flows for each bucket, the amount of energy available to be turned into electricity is calculated with the following power equation:

$$P = Q * \Delta h * g * \eta * \rho / 1000 \tag{18}$$

Where Q is the volumetric flow rate in m^3/s, the head (Δh) was assumed to be a constant 7.5 ft (2.3 m) and the efficiency (η) was assumed to be a constant 83%, which was a typical value obtained from Voith. Gravity (g) was truncated to 9.807 m/s^2 and density (ρ) was assumed to be 1000 kg/m^3.

The marginal revenue of energy provided by each bucket is then calculated by taking the difference between the minimum and maximum energy available values, multiplied by the chance of occurrence (1%) and the hours in a year to get the resulting electricity

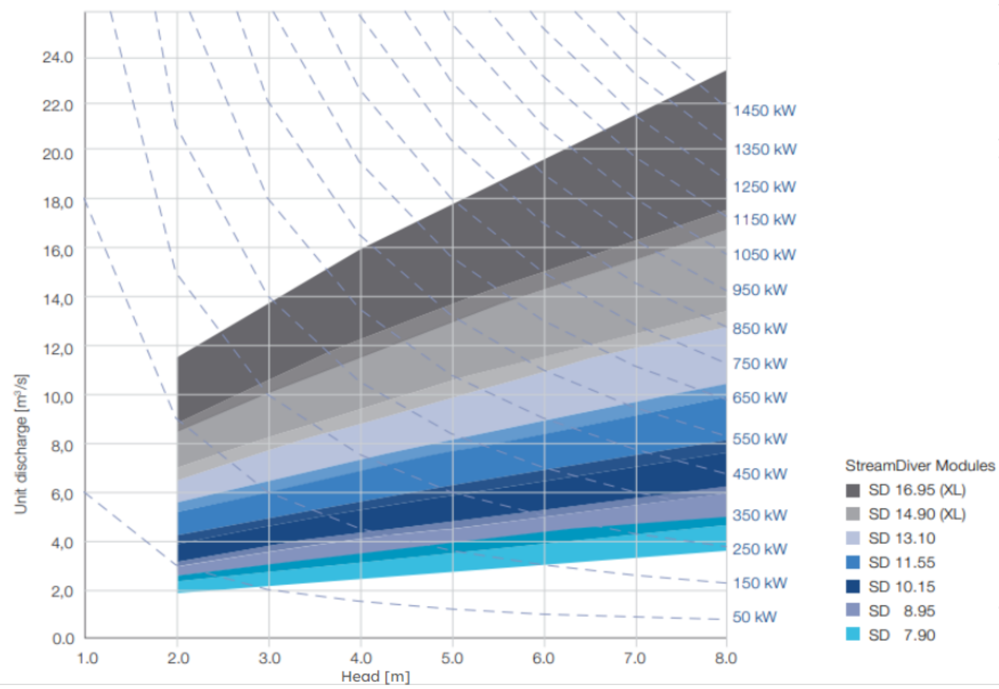


Figure 25: Image of operating regimes for Voith StreamDiver turbines taken from their website [122].

provided in kWh/year, and then multiplied by an assumed PPA price of $0.10/kWh:

$$\text{Marginal Revenue of Electricity} = (\text{P}_{\text{max}} - \text{P}_{\text{min}}) * 1\% * 8760\frac{\text{hrs}}{\text{year}} * \$0.10/kWh \tag{19}$$

These values are multiplied by 35 years to get the marginal revenue of electricity over the lifetime of the turbines shown in figure 26.

The first turbine (SD13.10), which has a smaller range of operation than the others will produce less power over it's lifetime and therefore produce less revenue. However, a smaller turbine is important nonetheless because it allows the dam to produce power when flows are low. Without the smaller SD13.10 turbine and only SD16.95, the minimum flow that would allow the dam to operate would be 7 m^3/s, which flows do not exceed that number 15.23% of the time, according to the Weibull distribution. With the SD13.10, that minimum flow for operation is 3 m^3/s, which is not met only 7.32% of the year. Even though the small turbine would produce less revenue for the city, it provides the region with more security of electricity. After that, the first few SD16.95 turbines would create lots of electricity over their lifetime and bring in significant revenue, though that starts declining with each additional turbine. This is because higher flows have a smaller chance of occurrence. For example, in order for the 6th turbine to be operational, turbines 1-5 would have to be running at max capacity and still have additional flow to funnel into turbine 6, which would only occur at flows greater than 67 m^3/s, but 73.00% of the time the flow is less than that. While at this point, variable and fixed costs for the operation and installation of the turbines is unknown, as well as the actual price of the electricity

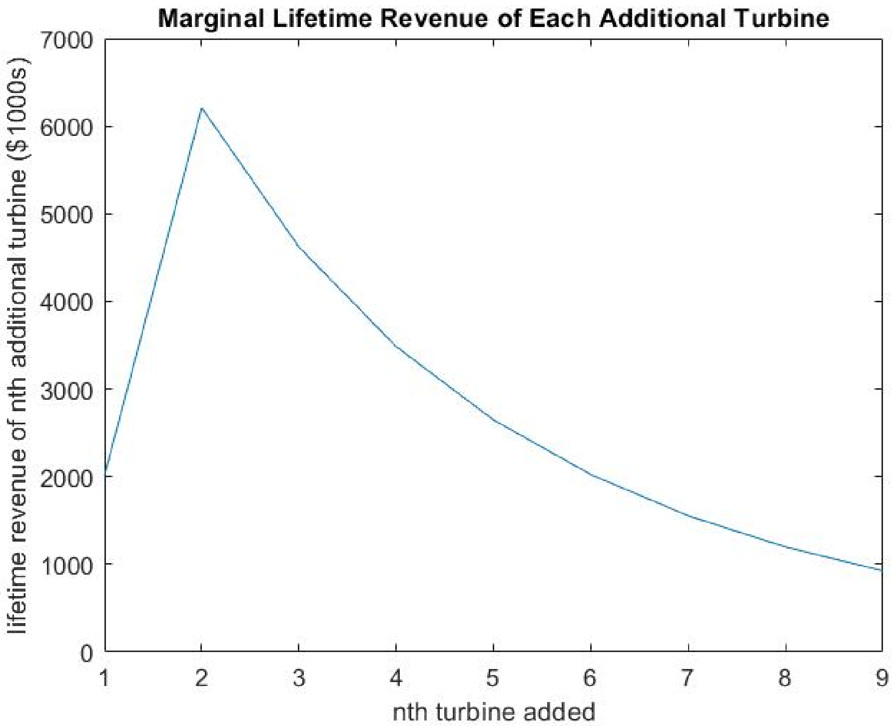


Figure 26: Graph of the lifetime revenue each additional turbine brings based on a PPA of $0.10/kWh and a lifetime of 35 years. The first turbine is an SD13.10 and all turbines after that are SD16.95s.

produced, figure 26 shows the decreasing returns for each additional turbine after the second one. Using this information, 4 turbines total seems like a reasonable number since the 4th turbine still adds quite a bit of value, and is rated to capture 60-70th percentile flows.

To maximize the power produced by each turbine, there needs to be control over the flow to each turbine. Otherwise, the operating range of the dam could be much smaller than the 3-52 m^3/s planned out. Luckily, this dam already has six existing tainter gates that can be operated separately. As a result there is an enormous amount of control over flow, as the dam already has the ability to leave some gates fully open, others only partially, and some closed, or any combination of these. For maximum control and power production, there will be one turbine per gate. If the gates are numbered 1 through 6 from West to East (see aerial picture below), then the SD13.10 unit will be placed in Gate 2, and the three SD16.95 units will be placed in Gates 3 through 5. Gates 1 and 6 will remain empty, since the operators seem to prefer to open those gates last, based on various images and videos of the dam online.

To be able to produce power through all flow values from 3 to 52 m^3/s, the order in which the gates are opened matters. At flows between 106 cfs (3 m^3/s) and 247 cfs (7 m^3/s), only Gate 2 should be in operation, then from flows between 247 cfs (7 m^3/s) and 530 cfs (15 m^3/s) only Gate 3 should be in operation. From 530 cfs (15 m^3/s) up to 777 cfs (22 m^3/s), Gates 2 and 3 would both be open, and so on. The operational order of each

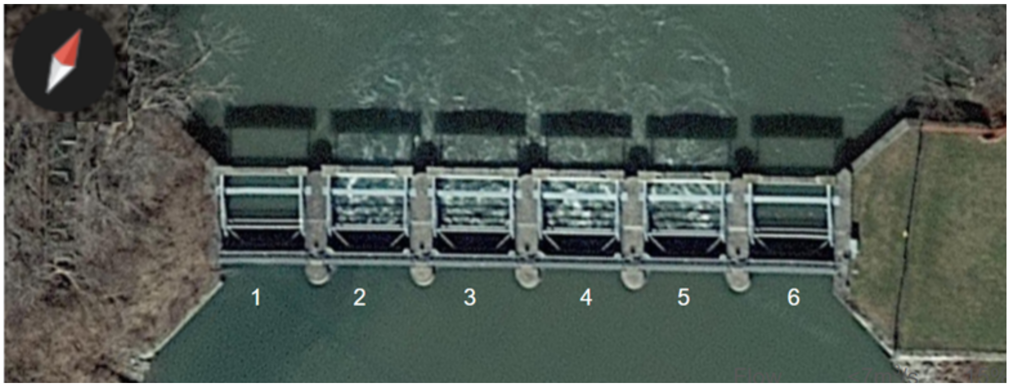


Figure 27: Image from Google Earth of Mud Lock Dam, imagery dated 3/15/2020. North is indicated by the red arrow in the upper left hand corner. The six tainter gates of the dam have been numbered 1 through 6 from West to East. In the photo, Gates 2 through 5 are in operation, and 1 and 6 are closed.

Gates Open	Min Flow (cfs)	Max Flow (cfs)	Min Flow (m^3/s)	Max Flow (m^3/s)
None		<106		<3
2	106	247	3	7
3	247	530	7	15
2, 3	353	777	10	22
2, 3, 4	600	1307	17	37
2, 3, 4, 5	848	1836	24	52
All	>1836		>52	

Table 12: Operational Order of Gates: This table summarizes the flow range in which different combinations of gates should be opened to produce maximum power. Note that when all gates are closed, no power is produced, and when all gates are open, power is produced at the rated capacity of the plant (970 kW).

gate are summarized in the table below. This assumes that all water entering the gate is funneled to the turbine installed there and none leaks out elsewhere. Since the turbines are smaller than the width of the gates, this would require some additional construction which will be discussed later in the costs section.

6.4.3 Power Production

To calculate the amount of power produced by a hydroelectric turbine, the equation for hydroelectric power must be used (equation 18). To change this equation into units of Watt-hours, the result must be multiplied by the number of hours the turbines produce power at that rate.

From the call with the Voith engineer, they typically assumes a constant turbine efficiency of 83%, so that is what will be used in this paper too. In reality, turbine efficiencies depend on the flow rate of water through the turbine and may degrade over time. A 2000 paper by Ramos and Borga examine the efficiencies of multiple types of turbines over different flow regimes, as illustrated in figure 28 [101]. The efficiencies are significantly lower when the flow through the turbine is low, high near the max flow rate, and then slightly lower again at the max flow rate the turbine can handle. This would be something put into consideration when designing the plant for construction. However for the purposes of this paper, assuming a flat rate of 83% is accurate enough. The change in head is also assumed to be constant 7.5 ft (2.3 m), though it does actually change depending on the flow through the gates and the time of year. This would have a more significant effect on the power production, as the head might be too low to produce power (under 2 m), however we are unable to consider that in this report since there is no data available. For more information on why the head changes, see the Analysis of Flow Regime section.

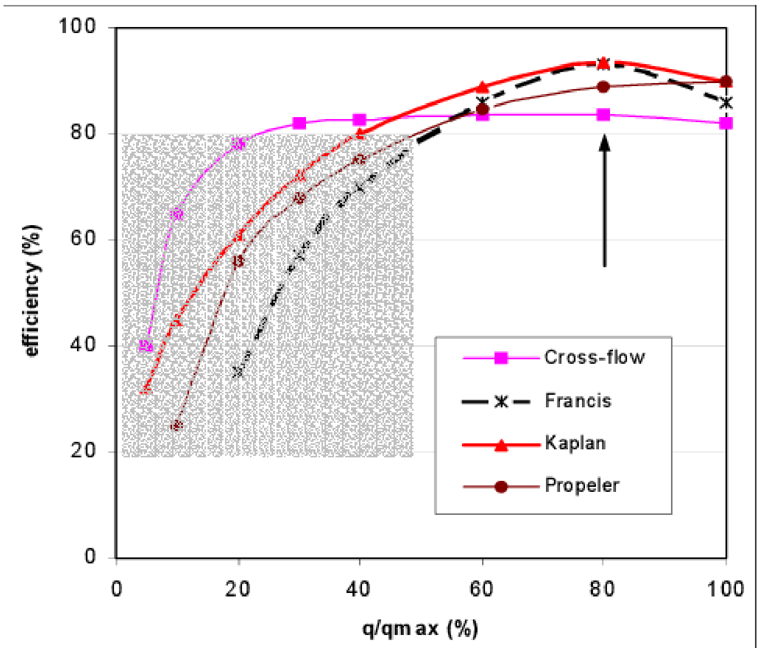


Figure 28: Image shows efficiency over different flow regimes for common turbine types. [101]

Using equation 18 and our assumptions, power output can be calculated, making sure that when flows are less than 106 cfs (3 m^3/s), no power is produced, and when flows are above 1836 cfs (52 m^3/s), the power output is capped at the rated capacity of the plant (970 kW). The rated capacity of the plant was calculated by plugging in the max flow value (106 cfs or 52 m^3/s) into the power equation.

If this is calculated with the data from figure 23, the result is shown in figure 29. The average flow for each day of the year was put into the power equation to calculate the wattage of the turbines each day, and then multiplied by 24 hours to calculate the total power output each day, which is given below in MWh per day. As can be seen in figure 29, the dam often reaches its maximum capacity in the winter, but generally has very low production in late summer and fall.

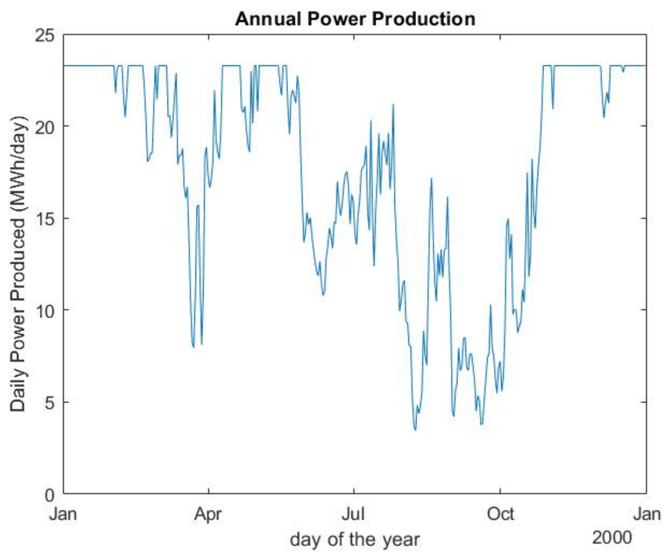


Figure 29: Average daily power production throughout a typical year in MWh/day

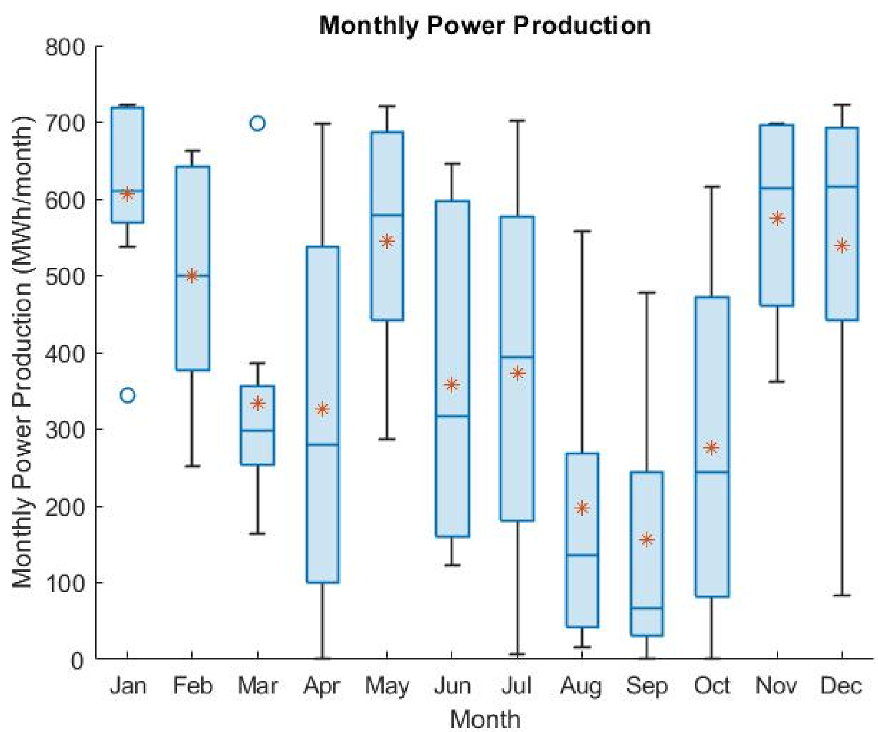


Figure 30: Monthly power production boxplot, where the red stars are the average. Data used was January 2015 through September 2023). The total average electric production per year is 4.785 GWh/year.

The same data was also analyzed by the amount of power that could have been produced each month. The two partial months (December 2014 and October 2023) at the start and end of the data set were left out of this analysis. With this format, it is very clear to see that August through October often have low flows and power production and the best months are November, December, and January followed by May. April, July, and October have some of the greatest variability in the amount of power that could be produced. There is a low outlier for January though the outlier is still greater than the average power produced in August and September and about the same as the average power produced in March and April. Power production will depend heavily on the season from year to year. Since this flows in this stream are so heavily impacted by rainfall, snow melt, and the emptying of Lake Cayuga in winter, power production will be highly variable and weather dependent, which is reflected in figure 30.

Month	Average Power Produced (MWh)
January	607.1
February	499.3
March	332.9
April	326.4
May	545.2
June	358.0
July	372.0
August	197.9
September	156.4
October	276.2
November	575.0
December	538.4
TOTAL	4,784.8

Table 13: Average monthly power production using stream gauge data.

From these numbers the capacity factor (CF) can be calculated:

$$CF = \frac{\text{actual power produced}}{\text{theoretical maximum power produced}} \tag{20}$$

In this case, the maximum power is equal to the rated capacity multiplied by the number of hours in a year: $(970kW) * (8760hrs/yr) = 8,497,200kWh/yr = 8,497.2MWh/yr$

Therefore: $CF = (4,784.8MWh/yr)/(8,497.2MWh/yr) = 56.31\%$

6.4.4 Flood Design

One point of concern for this dam design is potential for flooding. Since installing the turbines in Gates 2 through 4 minimizes the area in which the water can flow through, the dam cannot handle as high of flows as initially designed. The dam does have an existing spillway with a length of 180 feet to let off additional water when the dam cannot control all of it [22]. Between the dam and the spillway, the max discharge is rated at 34,392 cfs, though how much of that is through the dam or the spillways is unknown, along with other aspects of the dam and spillway that would allow estimations [22]. As a result, this part of the design will be out of scope for this report, though for a project to be continued past initial design it would need to be determined if it can handle appropriate design flood. This would be of extreme importance since this site is classified as NYSDEC Class C high hazard, meaning dam failure would result in high economic, environmental, or even human losses [83]. If it is found that the dam cannot handle the design flood, the spillway would have to be expanded which would ultimately increase costs.

6.4.5 Environmental Impacts

Since this project would be powering an already existing dam, the environmental impacts are minimal. As with any construction project, it will involve heavy machinery, dredging, pouring concrete, and some demolition as well. There is of course CO2 emissions related to all of these activities and concrete is known for producing significant amounts of CO2 however alternative materials have not been proved to work well enough over long periods of time for hydroelectric projects. The first sustainable concrete for hydroelectric projects was unveiled recently in 2021 and has had limited testing [55]. Even so, the amount of electricity produced by the plant will offset more CO2 emissions than what construction put in [62].

There are also more terrestrial impacts of the project, construction activities will disrupt the soil and plants in the areas where the machines are operating will be destroyed, though they should grow back on their own. Additionally, flow of the river will have to be diverted temporarily while construction is occurring. To mitigate the impacts it would be recommended to send the excess river flow through the lock on the other side of the river, and also conduct the construction during periods of low flow, such as August and September.

Lastly are the environmental impacts of the dam operation. Generally a huge concern with hydropower projects is the change it will cause to the hydraulic regime and how that can affect life in the area. However since this is a retrofit, there will be no change to the current hydraulic regime. The current regime is already disrupted from the natural regime due to the dam, but this has now been the norm for over a hundred years since the dam was initially constructed in 1912 [22]. Disrupting the flow regime yet again will disturb the ecosystem that has adapted to live there over the past century. Additionally is the question of fish passage. Fish can be harmed by turbines. In this design, there will be trash racks and smaller grates that will stop larger fish from swimming into the turbines and smaller fish can pass through most turbines unharmed [99]. There is already a fish ladder on site that has not been in operation for a while, part of this project will be to get it up and running again so larger fish can pass around the turbines when gates 1 and 6 are closed [83]. When gates 1 or 6 are open, the fish will also be able to pass freely through those.

6.5 Stormwater Management and Green Infrastructure

6.5.1 Watershed Data Collection

Without having an exact location specified for our GSLC development, we first needed to gain an understanding of typical watersheds in the Seneca Falls region in order to plan how to manage stormwater. To accomplish this, we used USGS StreamStats to select five sample watersheds in the region and gather data on (1) watershed size, (2) average slope, (3) longest flow path length, (4) % of type B hydrologic soil group (HSG), and (5) current % of forest coverage. These watersheds were selected based on their size (within a moderate range of 20-100 acres) and whether or not they met our initial assumption of draining into a first- or second-order stream.

Once these watersheds were selected, we then had to calculate the time of concentration (tc) in minutes for each given the estimated longest flow path (ft) and the slope (ft/ft) using equation 21. The time of concentration represents how long it takes a watershed to respond to rainfall and generate runoff at the "outlet" (the lowest point) of the basin based on the topography of the area. Using the values obtained from StreamStats, we calculated an average t_c of 21.7 min for an average watershed area of 48.86 acres.

$$t_c = 0.0078 * L^{0.77} * S^{-0.385} \tag{21}$$

In addition to the physical characteristics of runoff flow in our sample watershed, we also had to consider current land use and hydrologic soil group (HSG) composition of the soils. Both of these factors strongly influence the averaged "Curve Number" (CN) of the watershed. The CN is a measure of how easily the watershed generates runoff (ex. land with CN = 0 acts as a sponge and generates no runoff, whereas land with CN = 100 will convert all rainfall to runoff) and it used with the time of concentration to characterize the timing and magnitude of runoff generated by a watershed for any given storm.

In order to analyze the impact of developing our GSLC on a typical Seneca Falls watershed, we have to consider how the development will change the overall land use composition, as this will have a significant impact on the post-development CN. To do this, we first analyzed the existing land use and soil type breakdown of each watershed using Google Earth and data downloaded from the U.S. Dept. of Agriculture's National Resources Conservation Service into QGIS. The pre-development land use was broken into five categories: forest, meadow, agricultural, paved roads, and residential (farmstead), although only one watershed had significant residential land use. We then estimated the weighted CN of each watershed using data provided from StreamStats of the % of HSG B soils and forested areas, the map of HSG composition developed in QGIS (figure 31), and CN estimates for varying land use and soil types provided in TR-55 (figure 32). Land use and CN breakdown is shown for one of the sample watersheds below in figure 33. From the weighted CN for each watershed, we were then able to obtain an average pre-development CN of 76.4.

Based on our CAD model of the building and parking lot footprint, after development we can expect 2.3 acres of the watershed to be convert to 100% impervious surfaces (including the roof, carport, and parking lot). Another 20 acres of land will be impacted by well digging and construction for the heat pump system, termed "repurposed land" in

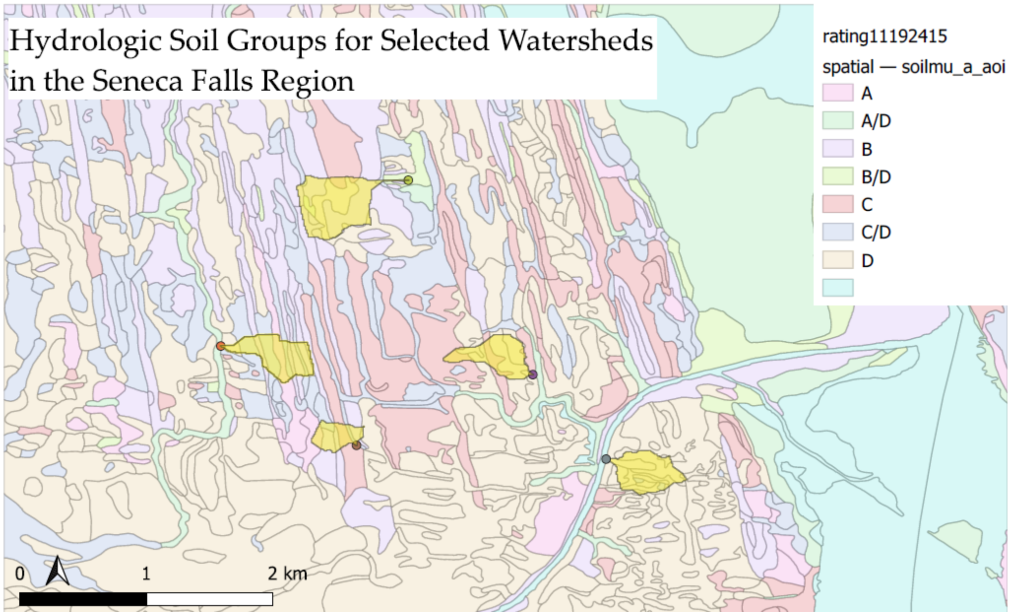


Figure 31: Map showing distribution of hydrologic soil groups throughout Seneca Falls region.

Curve Numbers Based on Land Use, Soil Type			
Land Use	HSG		
	B	C	D
Meadow	58	71	78
Agricultural	71	79	83
Forest	60	73	79
Road	98	98	98
Farmstead	74	83	86

Figure 32: Curve numbers for varying land use and HSG types.

figure 34. Because the soil quality of these combined 22.3 acres of land will be significantly impacted by construction and land use change, we assumed that each HSG type will move down a level, as recommended by the NYS DEC without being able to complete a detailed site-specific soil study. For example, in the sample watershed shown in figure 34, the 35% type B soils will become type C soils after development, and the 30% of type C soils will become type D. This soil degradation results in a higher averaged CN for the 20 acres of repurposed land than the remaining "untouched land" in the watershed. Based on this redevelopment and change in soil quality, we were then able to compute a post-development weighted CN for each sample watershed, with an average post-development CN of 80 across all watersheds.

Area (acres)	*Watershed Characteristics*			
49.02	% area	CN	HSG Breakdown	
% wood	0.25	70.55	B	35%
% meadow	0.43	68.9	C	30%
% paved road	0.02	98	D	35%
% agricultural	0.3	77.6		
		72.5		

Figure 33: Land type and curve number breakdown for a selected watershed in the Seneca Falls region.

Watershed 1

Subcatchments	*Area (acres)*	*Area %*	*CN*	
Roof	0.758	1.55%	98	
Carport	0.631	1.29%	98	
Parking lot	0.912	1.86%	98	
Repurposed land	20	40.78%	82.25	fair, open land
Untouched land	26.739	54.52%	72.5	same land mix as before w/ ag
Total watershed	**49.04**		**77.67**	

HSG Breakdown	
B	-
C	35%
D	65%

Figure 34: Land type and curve number breakdown for a selected watershed after GSLC development.

6.5.2 Watershed Storm Response Analysis

Having characterized a typical watershed in the Seneca Falls region, the next step in designing our stormwater management plan was to obtain extreme precipitation frequency data from the Northeast Regional Climate Center. New York State recommends designing stormwater infrastructure using the rainfall depth for 1-yr, 10-yr, and 100-yr 24-hr design storms, which are shown for Seneca Falls in table 12.

Storm Event	**Rainfall Depth (in)**
1-yr, 24-hr	1.92
10-yr, 24-hr	3.21
100-yr, 24-hr	5.36

Table 14: Rainfall depths for selected storm events of varying intensities [86].

The NYS guidelines involve three major steps for analyzing stormwater management. The first is to use the percentage of new impervious area to calculate the Water Quality Volume, WQv, which is a measure of how much generated stormwater should be treated on-site, primarily via green infrastructure techniques. The second is to calculate the Channel Protection Volume (Cpv), which is the storage necessary to provide extended detention of the 1-yr, 24-hr rainfall event to prevent stream erosion and degradation. The last step is to evaluate how peak flow rate of runoff from the 10- and 100-yr 24-hr events will change post-development and determining whether Overbank Flood (Qp) and Extreme Storm Protection (Qf) measures are needed to reduce the runoff flow to pre-development rates. We initially calculated the WQv and peak discharge rates for our entire average watershed of 48.86 acres with t_c 21.7 min.

The WQv was calculated using equation 22, where P is the rainfall depth, A is the area of interest in acres, and I is the percent of impervious surface. For systems such as ours where phosphorus is a concern, the DEC recommends using the 1-yr, 24-hr rainfall depth as the rainfall depth, P. Assuming that the roof, carport, and parking lot are all 100% impervious, the 20 acres of open, repurposed land is 5% impervious, and the untouched land is 3% impervious, we calculated a WQv of 1.046 ac-ft for the entire watershed.

$$WQ_v = \frac{1}{12}P_{1-yr} * (0.05 + 0.009I) * A \tag{22}$$

We then used HydroCAD modeling software to analyze both pre- and post-development peak runoff flow rates by specifying our watershed parameters and the rainfall event of interest. HydroCAD then outputs a hydrograph showing the runoff flow distribution vs. time, an example of which is shown for a 1-yr storm post-development in figure 35. Our results show that peak runoff flows do significantly increase after development (figure 36), so we will need to implement a stormwater mitigation system to effectively capture and slow down these runoff flows to pre-development peak rates.

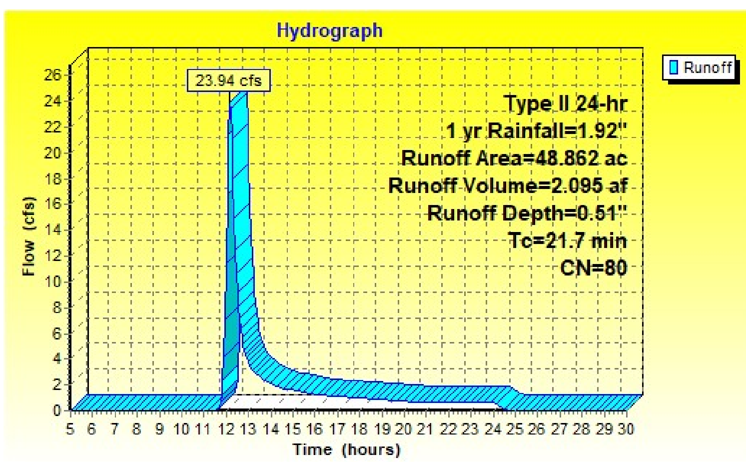


Figure 35: HydroCAD output showing hydrograph for average watershed subject to 1-yr, 24-hr storm post-development.

6.5.3 Stormwater Management Plan

After the analysis above showed that our development would adversely affect a typical watershed's response to intense rainfall events, we moved onto designing stormwater management systems to help mitigate these impacts. To adequately manage runoff from these storms, we first decided to break the watershed up into three regions. The first region of 12.3 acres contains the 2.3 acres of land the GSLC is to be built on as well as 10

	pre-development peak runoff flows (cfs) CN = 76	post-development peak runoff flows (cfs) CN = 80
1-yr 24-hr event	15.32	23.94
10-yr 24-hr event	57.66	71.91
100-yr 24-hr event	146.27	165.59

Figure 36: Peak flows before and after development.

acres of the closest surrounding land that will be repurposed into a park and gardens after geothermal wells are constructed. Because this area will experience the greatest change in impervious surface and land use, it will experience the most adverse impacts in terms of stormwater quality and quantity as a result of development. To manage this, we decided to divert the runoff from this land into a stormwater detention pond via a system of pipes and landscape grading. The second region contains the remaining 10 acres of repurposed land used for geothermal well construction. While stormwater will still be impacted by development in this region, the land use change and resulting impacts will not be as drastic, so we expect to be able to manage resulting stormwater with basic green infrastructure bioretention and soil restoration techniques.

The last region contains the remaining land in the watershed, which will be untouched by our development and may not be entirely on the property owned by the GSLC. Because the area around Seneca Falls is predominantly agricultural, our plan for this land (assuming the GSLC does have the rights and opportunity to develop here) is reforestation. This will not only help improve long-term stormwater quality throughout the watershed, but will also increase native biodiversity and provide a small carbon sink to help partially offset any emissions resulting from the construction and operation of the GSLC. However, given that the GSLC may or may not own this portion of land, we will design our stormwater management system without considering the impacts of this reforestation, with the implication that any reforestation that can occur on this land will only further benefit the water quality of this area.

6.5.4 Gutter and Drainage System Sizing

To treat the stormwater collected in our first region of interest (the 12.3 acres of developed and repurposed land) in a detention pond, we first had to design a gutter and drainage system to capture and transport the runoff from our completely impervious surfaces (i.e. the roof and parking lot) to the pond. This was done by analyzing the peak flows resulting from the 100-yr rainfall event in three subcatchments of interest in HydroCAD – the north roof, the south roof, and the parking lot/carport. For each subcatchment, we entered the drainage area, estimated slope, length of longest flow path, and approximate CN. Once the 100-yr peak runoff flows were obtained, we had to convert the flow from cfs to gpm (gallons/minute) to match the data given for pipe and gutter flow capacities in the 2020 NYS Plumbing Code. We then divided the flow based on how many drainage points we selected for each subcatchment. For example, the Plumbing Code recommends having at

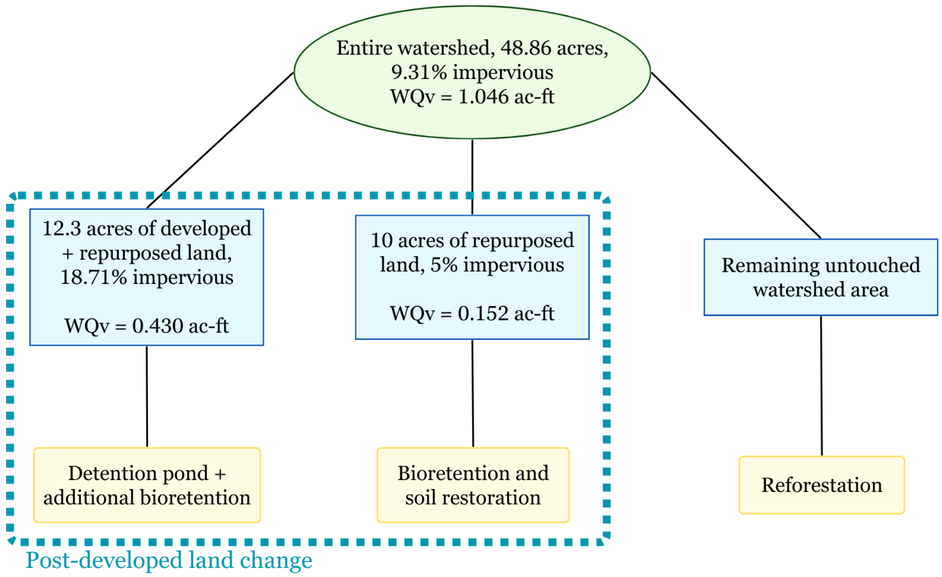


Figure 37: Plan for managing regions of watershed based on intensity of post-development land use change.

least four drains for a roof greater than 2,000 ft^2, so we selected our north roof to have four gutters, with each being able to handle 210.95 gpm in a 100-yr event. We then used these estimates to determine the sizes of the horizontal and vertical gutters and storm drain pipes (for the parking lot) based on the capacities listed in the Plumbing Code. For instance, all the horizontal gutters on the north and south roof sides are semicircles with a diameter of 10 in and a slope of 1/16 in/ft and a capacity of 331 gpm, well above the 100-yr peak flows they would be required to handle. All of the pipes were designed in a similar manner, and for each junction it was assumed that the flows from the two connecting pipes would add together. We ended up with two 15-in pipes with slopes of 1/8 in/ft running down the landscape towards the detention pond (full dimensions and layout shown in appendix E).

6.5.5 Detention Pond Design

According to NYS guidelines, detention ponds in phosphorus-limited watersheds must provide (1) 24-hour extended detention (ED) of the WQv and Cpv they receive and (2) reduce the peak runoff flows from the 10- and 100-yr storms to pre-development levels by providing adequate storage for Qp and Qf volumes. For the combined 12.3 acres of land draining into the pond with an impervious surface coverage of 18.71%, a WQv of 0.430 ac-ft (18,720 ft^3) was calculated using equation 22. To ensure that 24-hour WQv-ED is met, we need to ensure that the net outflow rate of the pond is lower than the WQv divided by 24 hours = 0.217 cfs.

To find the Cpv for this land, we first used HydroCAD to compute the peak runoff flow for the 1-yr, 24-hr storm resulting from the combined runoff flows of four subcatchments: the north roof, south roof, parking lot/carport, and 10 acres of repurposed land. From this, we found a peak runoff of 13.61 cfs, which we then converted to a peak unit discharge (q_u) of 885.1 cfs/mi^2/in (csm/in) given a runoff depth of 0.8″ and drainage area of 12.3 acres (0.0192 mi^2). Based on the graph in figure 38, this translates to an outflow:inflow ratio (q_o/q_i) of 0.015 for q_u = 885.1 csm/in, which can be achieved by a storage volume:runoff volume ratio of 0.661 as calculated by equation 23 provided by NYS. Using equation 24, we can calculate the total storage volume required, V_s, given V_s/V_r, the runoff depth, Q_d, and the watershed area, A to be 0.542 ac-ft.

$$V_s/V_r = 0.682 - 1.43(q_o/q_i) + 1.64(q_o/q_i)^2 - 0.804(q_o/q_i)^3 \tag{23}$$

$$V_s = \frac{1}{12}(V_s/V_r)(Q_d)(A) \tag{24}$$

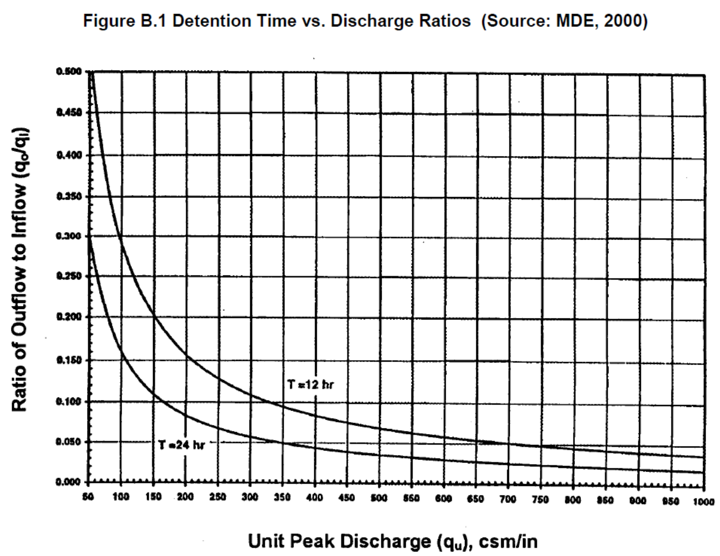


Figure 38: Relating desired ratio of outflow:inflow to unit peak discharge.

The next stage in designing the detention pond is to calculate estimated storage able to be provided given the planned dimensions and slopes recommended by NYS (see figure 39). Given these recommendations, our design will consist of a circular forebay that will permanently hold approx. 10% of the WQv, a 70 ft long gravel channel, and an elliptical main pool basin that will permanently contain at least another 10% of the WQv. The forebay dimensions were sized using the equation for volume of a truncated circular cone (equation 25) and a length:height ratio of 4:1, where we calculated that a radius of 20 ft at a height of 4 ft will contain 11.1% of the WQv. The dimensions of the main pool were determined with a similar method, but instead using equation 26 to estimate the volume given that the basin has an elliptical shape. We also assumed that the bottom of this basin will be 1 ft lower than the forebay and will be broken up into two parts, where the lower part will have a depth of 4 ft and a length:height ratio of 3:1 and the upper part will be 1 ft deep with a length:height ratio of 15:1 to form an "aquatic bench" recommended by the DEC for pools with slopes steeper than 1/4. Given these slopes and depths, we found that the pool will be 78 ft long and 74 ft wide at the permanent surface, which gives us a storage of 6,750 ft3, or 36.0% of the WQv.

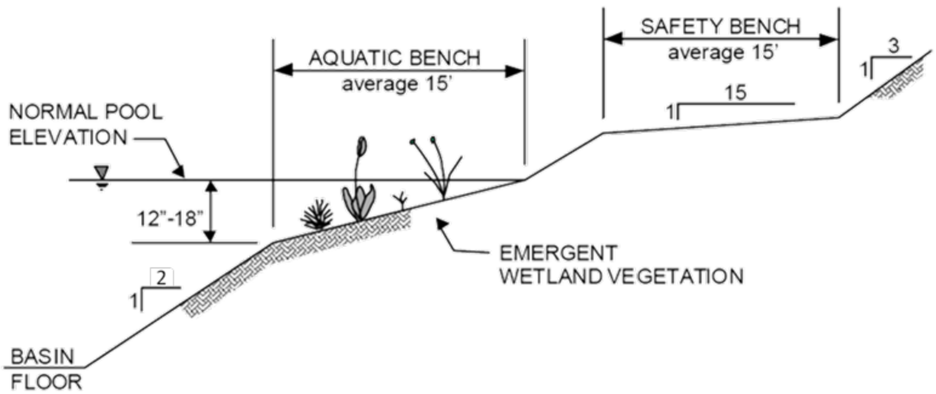


Figure 39: Recommended incremental slopes to promote safety and aquatic health in detention ponds.

$$V_{trunc.cone} = \frac{1}{3}\pi * h(R^2 + r^2 + rR) \tag{25}$$

$$V_{trunc.ellipticalcone} = \pi[a_1 b_1 h + \frac{1}{2}h^2 s(b_1 + a_1) + \frac{1}{3}s^2 h^3] \tag{26}$$

Once these permanent dimensions were decided, the next step was to determine the elevation required to meet storage requirements for Cpv, Qp, and Qf given the overall shape of the pond basin, which has a total fixed length of 192 ft. As the water level rises, the pond will increase in width but stay the same length to avoid disrupting the outlet infrastructure. Based on NYS guidelines, we designed the pool to have a 2:1 slope for an additional 2 ft above the permanent surface, then a 15:1 slope for another 1 ft above this to provide a required "safety bench," and then if needed in extreme cases, another 2 ft of additional storage above this, giving us a total available storage volume of 2.11 ac-ft at a pond depth of 10 ft and a basin width of 128 ft, which more than satisfies the Cpv, Qp, and Qf requirements. A map of the storage volume available at each pool depth from these calculations can be seen in figure 40.

The final part of designing the pond was sizing the outlets to properly manage discharge so as to not overwhelm the watershed, which was done by adding the pond and its storage projection into our HydroCAD model used earlier for estimating the peak runoff for this drainage area. For this design, NYS recommends having a vertical riser with orifices in the side to drain into an outlet culvert for less intense storms, and for extreme cases (i.e. in the 100-yr event), to provide an overflow weir and channel. To achieve 24-hour detention of both WQv and Cpv, we provided a 2" diameter orifice at an elevation of 5 ft, at the permanent surface level along the 4" diameter vertical riser, which reduces the 1-yr peak discharge from 13.61 cfs to 0.14 cfs, well below the 24-hr WQv-ED required maximum discharge of 0.217 cfs. For the 10- and 100-yr storms, we provided two additional outlets to slow the discharge rates to pre-development, one of which was simply by

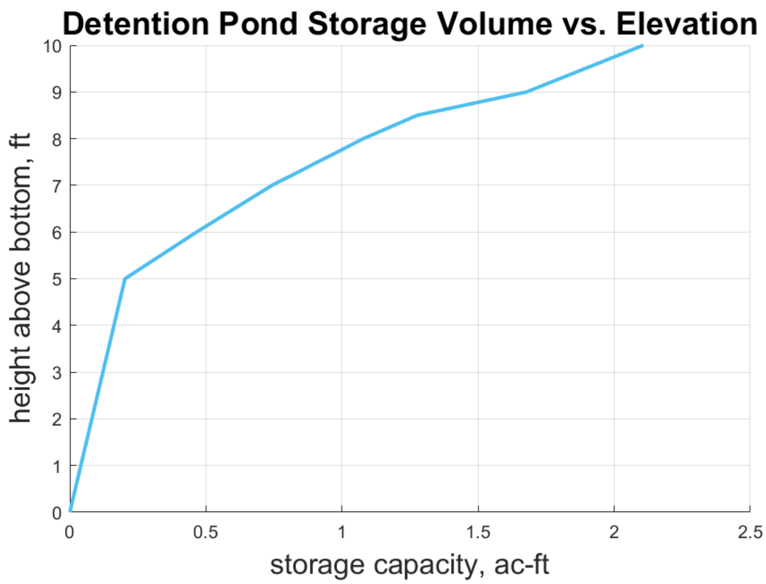


Figure 40: Pond storage elevation vs. elevation above bottom of main pool basin.

opening up the vertical riser where it ends at a 7.8 ft elevation to provide a horizontal 4" orifice. The other consists of a weir with a length of 4 ft at 8 ft in elevation and 6 ft and 10 ft in elevation. The vertical riser drains to a 6 in diameter round corrugated plastic culvert with a slope of 0.10 and a Manning's coefficient, n, of 0.020 (specified in HydroCAD), whereas the weir empties into a rectangular concrete open channel 6 ft wide, 1 ft tall, and 60 ft long with a slope of 0.10. These dimensions were selected using Manning's equation open channel flow (equation 27) to ensure the 100-yr peak outflow does not exceed the channel's capacity.

$$v = \frac{1}{n} R^{2/3} S^{0.5} \tag{27}$$

Finally, to avoid erosion and disperse the discharge coming from both the culvert and the channel, two bioretention areas were sized to accommodate the volume coming from these outlets by subtracting the permanent volume from the Cpv and Qf, respectively, and computing the required surface area using equation 28, a depth of 4 ft, a ponding depth of 0.2 ft, a hydraulic conductivity, k, of 8.7 ft/day (common for organic leaf debris), and a filter drain time of 2 days.

$$A_f = \frac{WQ_v d_f}{k(h_f + d_f)t_f} \tag{28}$$

6.5.6 Remaining Repurposed Land

The last part remaining of our stormwater management plan is to mitigate the WQv of the remaining 10 acres of repurposed land. This land will also be impacted by geothermal well construction and park development, but is located slightly farther away from the actual GSLC development. Assuming that the post-development land is 5% impervious, we calculated a WQv of 0.152 ac-ft that will need to be captured and treated.

The soil quality in this region will likely suffer as a direct result of construction activities, and although an effort should be made at soil restoration post-construction, we should not rely on soil restoration alone to mitigate the adverse impacts on stormwater quality, especially since any maintenance conducted on the geothermal wells or other underground utility service lines in this area could easily undo restoration.

Instead, we chose to utilize inexpensive bioretention techniques to treat the remaining WQv from this area, where we will create areas of dense vegetation (essentially large rain gardens) to mimic what the native vegetation and healthy soils of untouched land can accomplish. To determine the size of these areas, we assumed a depth of 3 ft (NYS recommends 2.5-4 ft) that would be filled with organic debris (i.e. leaves, other landscaping waste products) with a hydraulic conductivity of 8.7 ft/day. We then assumed 2 days are required for bioretention and to avoid mosquito breeding assumed a negligible ponding depth. Again using equation 28, we calculated that an area of 381 ft^2 should be devoted to bioretention on this repurposed land. To minimize overland flow, we recommend dividing this required area up into several different bioretention areas scattered throughout the region. For example, one proposed solution could be to break this up into 15 roughly circular areas of 25.4 ft^2 and a radius of approx. 2.8 ft.

6.6 Electric Vehicle Charging Stations

In order to decide how many electric vehicle (EV) charging stations to install, we first needed to determine the demand for these charging stations. Based on the current estimation of EVs sold in the US in 2022, we assumed that approximately 6% of the total cars in the parking lot on any given day would be electric, which would give us an average of around 9 cars [68]. Given that older people tend to drive much less than the average American and that some of these EVs would belong to employees utilizing the stations for a quick recharge during work hours, we assumed that these cars on average would be driving 20 miles/day, about half as much as the average American drives (37 miles/day) [50]. According to estimates, the average electric car currently has an efficiency of 0.32 kWh/mi, which would mean that each car (to drive 20 miles/day) would use 6.4 kWh/day, for a total of 57.6 kWh/day required across all assumed EVs [39]. Given that charging stations can typically provide 10-20 kWh/day based on demand, we decided that 4 Level 2 charging stations would be the minimum required to meet the GSLC's demand [72]. Level 2 stations were chosen due to being more efficient than Level 1 stations, but significantly cheaper than Level 3 stations, and are currently used across the US in commercial parking lots [26].

We next had to analyze the cost of installing the 4 charging stations. A 2021 report put out by NYSERDA estimates that installing Level 2 stations currently costs around $6,500 total per station before tax rebates [26]. Because the NYS government offers a $2,000 tax rebate per station installed for large residential customers, this would come out to a total capital cost of $4,500/station, or $18,000 total [87]. Assuming an operational lifetime of 12 years (about the average lifespan of a car) and a discount rate of 5%, this comes out to an annualized capital cost of $2,030.86. If the charging stations provide an average of

21,038 kWh per year (based on 57.6 kWh/day), this comes out to a levelized capital cost of $0.0965/kWh. Because we want to avoid passing the installation costs of the charging stations onto residents without EVs, this levelized cost will be added onto the cost of electricity provided to users of the charging station, which essentially means that the charging stations will "pay for themselves" over the course of their lifetime if they are used as often as we estimate.

Given that the average cost of electricity in New York for commercial customers is 17.91 cents/kWh, the total cost of electricity provided by the charging stations will be $0.2756/kWh [88]. If an EV has a range of 200 miles (typical for current EVs and hybrid vehicles) and has an efficiency of 0.32 kWh/mile, it will cost the charging station user $17.64 for a full charge. This translates to approximately 8.8 cents/mile traveled, which is significantly cheaper than current estimated costs per mile for gas-powered vehicles that start around 14 cents/mile and are frequently increasing due to international events and global instability in the costs of oil [76].

7 Design Summary and Costs

7.1 Energy Demand and Output

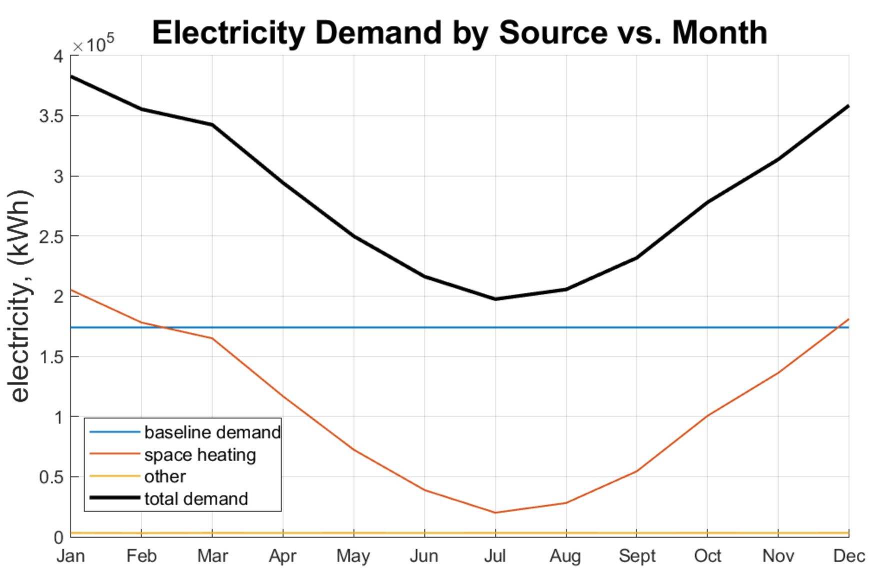


Figure 41: Breakdown of electricity demand by source.

The electricity demand is shown in figure 41. The baseline demand consists of all lighting and electricity demands that does not include the heating demands of the geothermal heat pump. The other category includes the electricity requirements for hot water and EV charging stations. The geothermal heat pump demand peaks in winter completely surpassing the baseline demand and dips down in the summer.

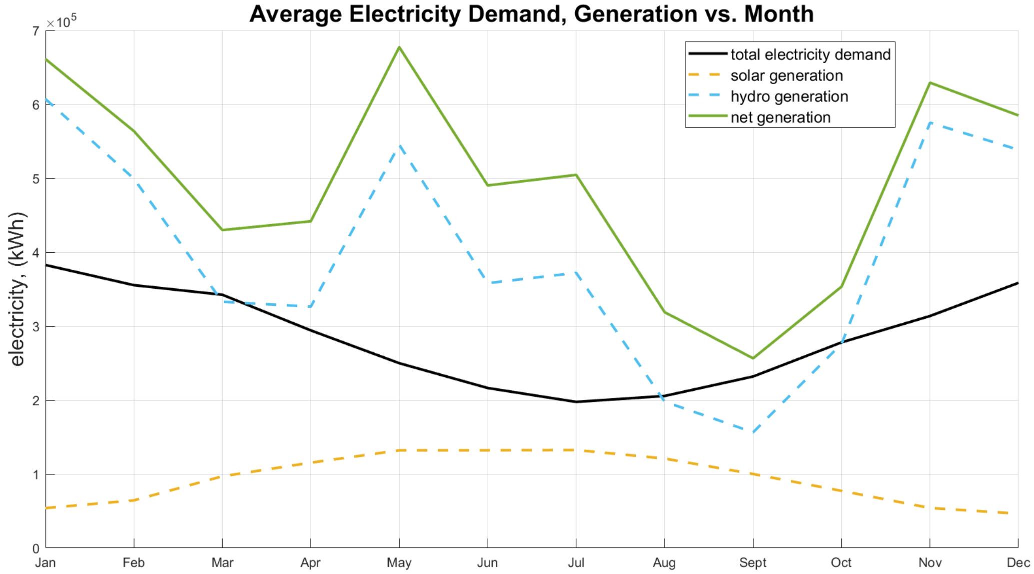


Figure 42: Breakdown of electricity generation by source and comparison with monthly demand.

Figure 42 shows the electricity demand and the net generation of the solar and the hydropower. All demand was able to be met with the solar and hydropower. The solar peaks in the summer and early fall, while the hydro peak in the winter and late spring creating a diverse energy profile to meet the demand, which peaks in the winter due to heating costs. Because the solar and hydropower generation are based on historical data, there is an uncertainty as to the actual production, however, because the building will be connected to the grid, if the demand outpaces the supply, extra electricity can be imported from the grid to the GSLC. Similarly, excess energy generated can be exported to the grid.

7.2 Economics

Economic calculations were conducted using a 5% discount rate and a lifetime of 50 years.

7.2.1 Heat Pump Economics

The total cost of the heat pump system is made up of four main costs: capital costs of the pumps, capital costs of the looping, maintenance costs and a system overhaul at 25 years. Heat pumps vary in cost depending on efficiency and capacity within a range of $250,000 to $500,000. We used the middle value of $375,000, though we would recommend investing in pumps with a higher COP. The looping makes up almost half of the total costs, however looping systems can have a lifetime of 100 years and require little to no maintenance. The chosen slinky looping system will cost $680,000, much less than the vertical alternative which would cost $3.4 million. For maintenance costs we assumed each pump will need one minor repair each year, costing around $200, and there will be one major repair a year, costing $1,000. The maintenance costs sum to $290,000 over a 50

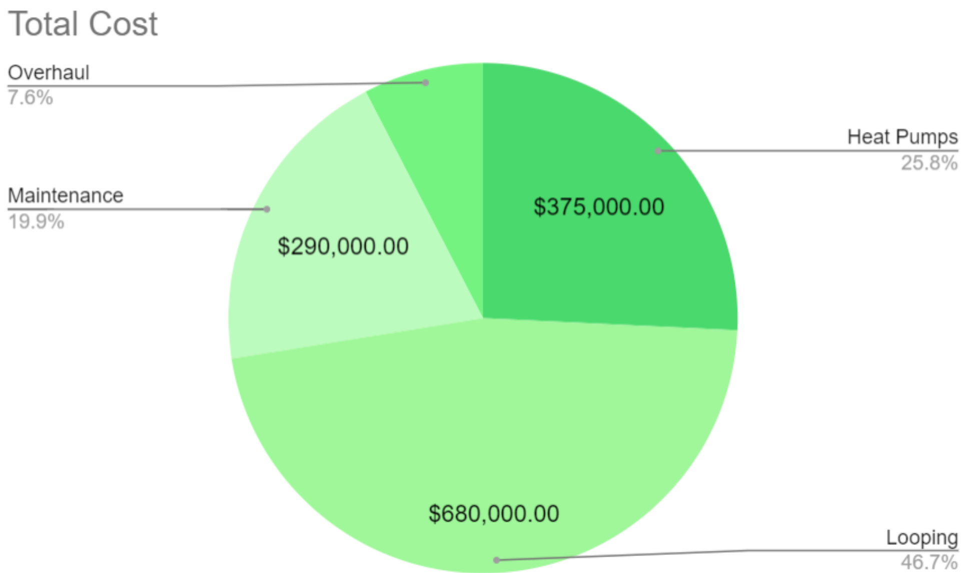


Figure 43: Breakdown of heat pump costs.

year period. The 25 year overhaul assumes replacement of all heat pumps. The lifespan of a heat pump can be more than 25 years, but it is unlikely that any of them will work for 50 years without replacement. We used a 5% discount rate over 25 years to determine the present value of the overhaul at $111,000. The lifetime cost of the heat pumps totals to $1.5 million.

7.2.2 Solar Economics

Capital Costs The NREL gives metrics for installation costs for solar power based on the size of the of the installation broken down into three categories: residential, community, and utility. The distinction between residential and commercial is the number of PV panels. Because the total of number of panels is 2,213, the capital costs are calculated considering this solar installation as community solar. NREL gives $1.76 per W as the modeled market price (MMP) benchmark and $1.49 per W for the minimum sustainable price (MSP) benchmark. MMP benchmarks capture the macroeconomic factors and include analysis of market trends i the estimation which gives a more realistic cost. MSP benchmarks represent the lowest prices in which suppliers can maintain financial stability in the long term. Because this energy is not being sold to the gird, MSP costs can be used for the economic analysis.

The MSP costs for installation include the costs for the modules, the inverters, electrical storage system, the structural balance of the system (SBOS), the electrical balance of the system (EBOS), fieldwork, and office costs [100]. The module costs include purchasing the physical 270 W module produced by sunwatts priced at $230 per panel [4]. The cost of the inverter includes the physical power devices, the rest of the inverter, packaging, shipping, and maintenance. The SBOS includes the torque tubes, the driven piers, the module rails, the different fasteners for the frame to the module, and other structural components to

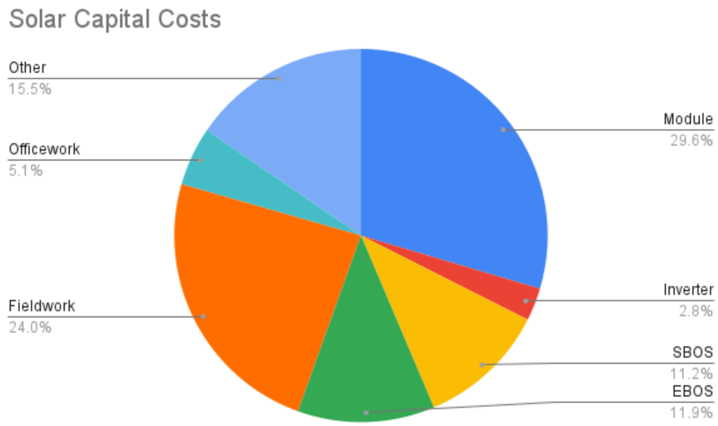


Figure 44: Capital Cost Breakdown for Active Solar [71].

actually attach the panels to the mount, whether that be the rooftop frame or the carport. The EBOS includes the transformers, switches, breakers, conductors, transmission, and other shipping and installation costs that are required to dial the solar panels into the building's grid system. The fieldwork costs account for all of the labor including the preparation of the site and the equipment needed. The include the permits, logistics, warehousing and engineering of the PV system to make the installation possible. Because the system does not have batteries, the electrical storage costs are neglected in the final price per kW. The cost breakdown is shown in figure 44.

The total capital cost comes out to be $1.48 per W for the rooftop. Costs for carports are reported to be 18% higher due to the additional structural costs. Therefore, the carport capital cost comes out to be $1.75/W. This results in the rooftop costing $442,520 and the carport costing $907,780 with a total capital cost of $1,350,300.

Operation and Maintenance Costs The operation and maintenance costs include cleaning, inspection, new modules, and new inverters. For community solar, the operation and maintenance costs are $40.51/kW/year resulting in a total of $33,170 per year.

Overhaul Costs The overhaul will occur at year 25 when the solar panels are operating at 87.5% of their original capacity. The overhaul will include new modules, new inverters, and the fieldwork required giving an ultimate cost of overhaul to be $604,400.

Total Annualized Cost The total annual cost can be calculated by annualizing the capital cost and the future cost of the overhaul and adding it to the operation and maintenance costs. The discounting rate is 5% and the lifetime is 50 years. The total annual cost is $90,800. With a total annual production of 1,126,000 kWh, this gives a LCOE-50 of $0.10. LCOE.

Passive Solar The cost can vary depending on many factors including the overhang size, specific building, and materials used for the project. Thus, there is a lack of valuable resources completely depicting the cost of putting passive solar in new construction. The cost of the passive solar will be considered out of the scope of this project and will not be evaluated in the overall construction costs. It is important to note that the cost to install the overhangs will be negligible compared to the rest of the construction costs as this is a new construction project. This assumption would not be accurate if a building was to be retrofitted with the solar overhangs.

7.2.3 Hydropower

Capital Costs The capital costs for hydropower plants are very high and are highly dependent on the existing site and dam conditions. How much additional concrete is needed, how much dredging is needed, if the dam needs repair, and many other conditions would have a considerable impact on the overall capital cost.

To estimate our capital cost for this dam, a study done by Oak Ridge National Lab on the costs of installing hydropower at existing non-powered dams was followed [48]. This study broke the capital costs of lake dams and lock dams into seven different categories: Site Preparation, Water Conveyance, Powerhouse, Electro-Mechanical, Electrical Infrastructure, Engineering and Construction Management, and Environmental and Regulatory Compliance. For our site, which is a lock dam site, the major costs go to the powerhouse and the electro-mechanical equipment, which is mostly the cost of the turbines.

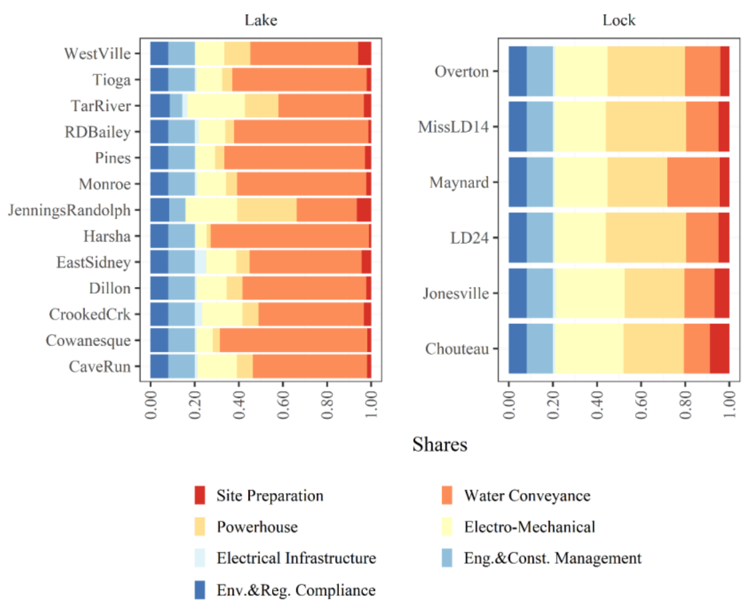


Figure 45: Capital Cost Breakdown for Typical Lake and Lock Non-Powered Dams [48]

The report analyzed a number of sites, but four of them were lock dam sites with matrix bulb-type turbines, which are the same as ours. Using the average capital costs for those sites, an estimate for the capital cost for our site was made in Matlab, which came out to a total of \$7.41 million. This estimated the electro-mechanical cost to be \$3.65 million, however based on the call with Albin Altzmueller at Voith, our turbine selection would cost about $4 million. Editing the electro-mechanical cost to be $4 million results in a total capital cost of $7.77 million for 970kW installed, or $8,010/kW.

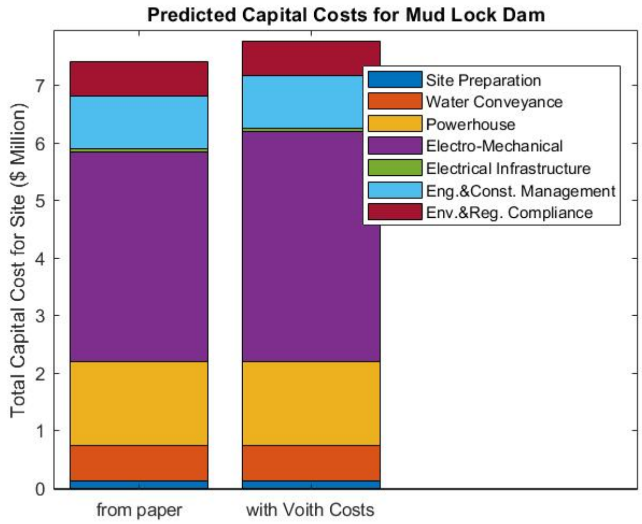


Figure 46: Capital Cost Breakdown for Hydropower using two different estimates for turbine cost [48].

This number seems quite reasonable for the circumstances, it is lower than Voith's estimate of about $10 million, but it is a bit higher than the U.S. average for retrofits that was reported by the DOE. The U.S. Hydropower Market Report from the DOE reported that retrofits since 1980 had an average of $6,096/kW, where as ours is $8,010/kW. In general, hydropower capital costs have been increasing since 2020, so it is not unusual ours would be more expensive than the past 40 year average [117].

Maintenance and Replacement There are a few different estimates for how much operations and maintenance costs annually for hydropower, however they are all pretty similar. IRENA reported that the average operations and maintenance cost for small hydropower plants (5-100 MW by their definition) ranges between 1% and 4% of the initial capital cost, with a global average around 2.5% [64]. Using the 2.5% global average, our yearly operations and maintenance cost would come out to $194,197.5/year, which is equivalent to saying $200.2028/kW installed. This estimate would include refurbishment of mechanical and electrical components, fixing things that might commonly break, rewinding of the generator, and upgrades for the communication and control systems. The major items not included in the estimate are the replacement of major electro-mechanical equipment or the repair of penstocks, tailraces, and other structural components [64].

To check that this number is reasonable, the U.S. Hydropower Market Report was referenced again. They reported that small hydropower plants (<10MW by their definition) have seen a significant increase in operation and maintenance costs over the past 10 years, ranging from about $150/kW to about $225/kW, however these extrodinarily high costs were driven by only a handful of plants with very high costs of about $500/kW. If those handful of plants are taken out of the analysis, the average operations and maintenance

	Installed costs (USD/kW)	Operations and maintenance costs (%/year of installed costs)	Capacity factor (%)	Levelised cost of electricity (2010 USD/kWh)
Large hydro	1 050 – 7 650	2 – 2.5	25 to 90	0.02 – 0.19
Small hydro	1 300 – 8 000	1 – 4	20 to 95	0.02 – 0.27
Refurbishment/upgrade	500 – 1 000	1 – 6		0.01 – 0.05

Figure 47: Hydropower economic numbers, including operation and maintenance costs [64]

cost for a small hydropower plant in 2020 was $127/kW [117]. Since the IRENA estimate is within the range reported by the DOE, it is a reasonable value, though it is higher than the average. For this analysis, we will use the IRENA estimate to be a little more conservative rather than the value from the U.S. Hydropower Market Report.

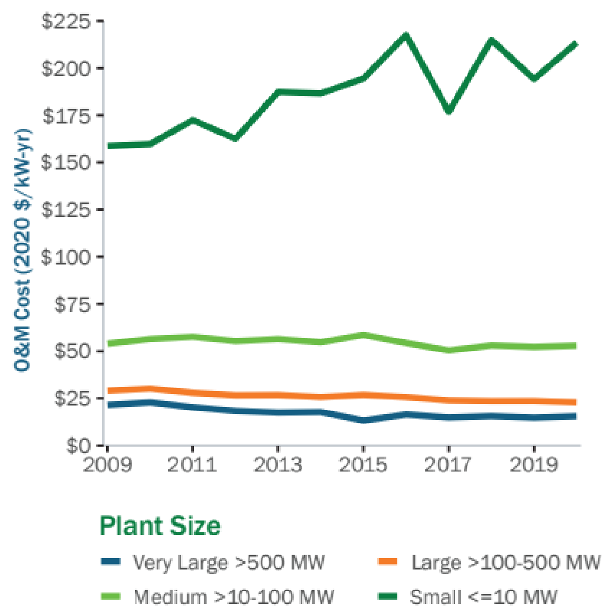


Figure 48: Operation and maintenance trends for hydropower [117]

Levelized Costs and Price The next step was to calculate the LCOE of the hydropower plant over it's lifetime. Three different lifetime lengths were considered for this section, 35 years (one turbine lifetime), 50 years (the standard lifetime considered for every other component in this report), and 70 ears (two turbine lifetimes). In order to calculate these, an initial capital cost of $7.77 million was applied in year 0, a turbine replacement cost of $4 million was applied in year 36, and every year after year 0 had an annual operation and maintenance cost of $194,197.5/year. The LCOE for the three time periods studied is reported in figure 49. The cost for a 35 and 50 year period are very expensive due to the high investment costs at year 0 and year 36, however since there are no more investment costs after that, the LCOE drops substantially for the 70 year period.

Period (yr)	LCOE ($/kWh)
35	$ 0.140
50	$ 0.137
70	$ 0.051

Figure 49: Calculated LCOE values for un-subsidized hydropower

Because of the Inflation Reduction Act, new hydropower subsidies have been introduced that our plant would be eligible for since it is under 1 MW of capacity and wont begin construction until after 2024 [116]. The plant is eligible for either a 30% investment tax credit (ITC) or a $0.0275/kWh producer tax credit (PTC). For shorter project lifespans, the ITC would be more beneficial as it would save a significant amount of the initial capital cost. For longer project lifespans or a smaller investment budget, the PTC is significantly better since over the course of 70 years, the initial capital cost has far less influence on the overall cost relative to the annual maintenance costs. We are assuming a company with hydropower background and experience would be financing this project, we are not worried about the high initial investment cost and a lifetime of 70 years would be pretty typical for a power plant such as this. As a result, we are using the 70 year lifespan, PTC subsidized LCOE for this project.

	LCOE ($/kWh)		
Period (yr)	Unsubsidized	with ITC	with PTC
35	$ 0.140	$ 0.110	$ 0.112
50	$ 0.137	$ 0.111	$ 0.110
70	$ 0.051	$ 0.051	$ 0.024

Figure 50: Calculated LCOE values for un-subsidized and subsidized hydropower.

LCOE is the amount of money it costs the owner to produce a unit of electricity, but it is not the true cost of the electricity itself. If the senior living center enters a power purchase agreement (PPA) with the hydropower plant owners, the SLC can pay the hydropower plant and agreed upon PPA price instead of the standard electricity prices from the grid operator. There are not many studies looking into the correlation between LCOE and PPA for hydropower, though there was a study investigating this in US wind power plants. They found that for a single ownership wind farm, the PPA price averaged $0.006/kWh more than the LCOE [77]. If we use the same assumption, our GSLC would be paying $0.03/kWh for electricity, which is significantly lower than Seneca Fall's average grid price of $0.211/kWh [43]. This is a pretty typical PPA price for hydropower. In general, hydropower PPA prices in the Northeastern USA ranged between approximately $0.02/kWh and $0.13/kWh in 2020 with a median just under $0.04/kWh [117].

7.2.4 Green Infrastructure and Parking Lot

Since most of the materials required for green infrastructure are relatively cheap and easy to come by (ex. soil, plants, compost), the overall cost of green infrastructure for our GSLC is significantly cheaper than many of our other electrification recommendations. Many government agencies publish worksheets and tools designed to help engineers analyze the anticipated costs of their stormwater water management designs. These tools provide current estimates of costs of materials, labor, and repairs, although it is worth noting that supply chain issues and delays have led to unpredictable construction costs in recent years. It also is important to keep in mind that many of the benefits of green infrastructure cannot be explicitly quantified. These benefits may include cleaner air and water, stress reduction, decreased urban heat pollution, and long-term savings on flood insurance, all of which work to improve the lives of residents at the GSLC.

Bioretention and Detention Pond To evaluate the capital and O&M costs of the detention pond and bioretention areas, we used the estimates provided by the Minnesota Pollution Control Agency's Stormwater Manual and the Washington D.C. Dept. of Energy and Environment's Green Infrastructure Construction Price Calculator [79] [21]. Our analysis assumes that mowing, inspections, and general maintenance would need to be conducted every 0.5-2 years over the 50-year lifetime of the GSLC and that vegetation would need to be replanted every 10 years as recommended by the NYS DEC [106].

Drainage System The costs of the drainage system were calculated assuming that the labor required to install the underground pipes is already accounted for in the cost of building and geothermal well construction. Cost estimates of pipes, downspouts, and gutters were obtained from landscaping and construction supply websites such as Home Depot, Lowe's, and Gutter Supply. Catch basins were assumed to be $400 each, and O&M estimates were derived from similar inspection and repair costs associated with bioretention areas [80].

Parking Lot The capital cost of the parking lot was assumed to be just the cost of paving the area with concrete, since this will be the most significant cost after factoring in the drainage system and general construction. The cost of paving was taken to be \$6.00/ft^2, which is typical for concrete (typically \$4-7/ft^2) [53]. Given the lifespan of concrete, we assumed the parking lot will have to be repaved at least once over the 50-year lifetime of the GSLC, and we assumed that this repaving will happen in year 30. Since concrete has a long lifetime with limited maintenance, we assumed the only major O&M cost for the parking lot would be snow clearing. Costs of snow removal were estimated from typical snow plowing costs for commercial areas and knowledge of how snow accumulation in the Finger Lakes region [49]. Based on these assumptions, the parking lot is estimated to have a $296,000 capital costs, and O&M cost of $6,100/year, and a present value of repaving of $68,500.

Excluding the parking lot, we can see that the total capital cost comes out to $101,000 with the annual O&M cost expected to be around $3,400/year. Overall, we can see that

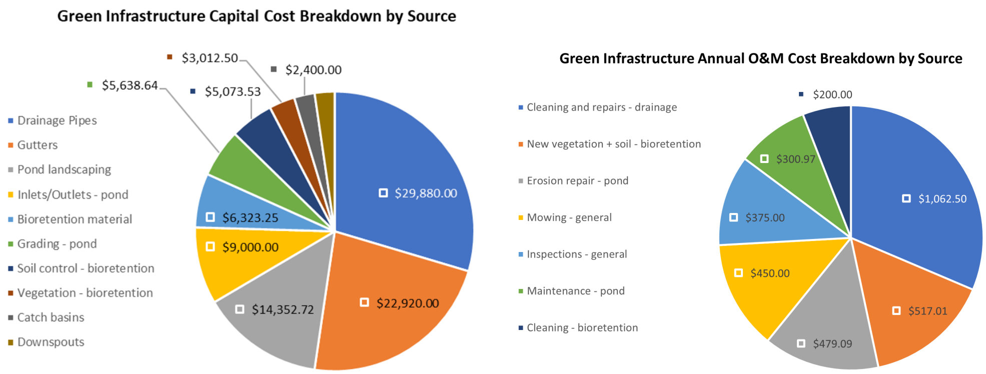


Figure 51: Overall capital and O&M cost breakdown by source for green infrastructure.

Capital Costs	
Detention pond	$ 28,991.35
Bioretention areas	$ 14,409.28
Drainage system	$ 57,526.32
total	**$ 100,926.95**

Annual O&M Costs	
Detention pond	$ 1,205.07
Bioretention areas	$ 992.01
Drainage system	$ 1,187.50
total	**$ 3,384.58**

Figure 52: Summary of green infrastructure costs.

the largest contributor to the capital cost (excluding the parking lot) was the drainage system due to the high cost of pipe materials. Similarly, replacing the pipes and other drainage system maintenance was the largest contributor to annual O&M cost, following by vegetation replacement, erosion repair, and general mowing and upkeep. This again highlights the inexpensive and low-maintenance nature of green infrastructure practices.

See Appendix F for detailed breakdown of capital and O&M costs.

7.2.5 Tax Credit and Grants

Because this is a senior living center and a renewable energy based commercial building, there are many opportunities for tax credits and grant applications. From the Inflation Reduction Act (IRA), a tax credit of 22% in 2023 and 10% in 2024 can be applied to the capital costs for solar installations [12]. This would save $135,000 if applied in 2024. There are various clauses in the Investment Tax Credit (ITC) that can be applied to the GSLC [96]. Section 48 (a) of this tax credit clause indicates that new construction projects that feature renewable energy can have a 6% reduction applied to the capital costs if construction begins before January 1, 2025 [96]. This would lead to a savings of $823k. Additional clauses in this act, section 48 (e), indicate there are potential bonuses that can be applied if the project meets certain criteria. If the project is an energy community, meaning that it provides a significant portion of its energy from renewable sources, an additional 10% bonuses can be applied. If the project is considered affordable housing, then there is an additional 20% bonus that can be applied [96]. Because most SLC's are for profit businesses, only the bonus associated with renewable energy will be considered. If that additional tax credit is applied, it will save an additional $1.37 million giving total savings from the ITC to be $2.19 million.

A more significant area that this project could fall under is using rural funding sources. Seneca Falls, NY is located in Seneca County which is defined by the United States Department of Agriculture (USDA) as a rural county [5]. Therefore, any tax credits or grants available for private businesses or non profits in rural areas can be applicable for this GSLC. The USDA and the Rural Business-Cooperative Service put out "Notice of Solicitation of Applications for the Rural Energy for America Program for Fiscal Years 2023 and 2024" under the Rural Energy for America Program (REAP). This program has $1.05 billion in funding from the IRA specifically for rural businesses in the form of grants, guaranteed loans, or a combination of the two. This notice states that a privately owned business or a non-profit business in a rural area that constructs and implements underutilized technologies that is defined as any technology that does not have carbon emissions associated with them can have up to 50% of the project costs funded by grants. A conservative estimate would be to assume that 10% of the capital cost would be funded with this grant. Because this center uses geothermal heat pumps, solar, and hydropower, is located in a rural area, and will either be defined as a privately owned business or a non-profit business, it can qualify for this grant. Thus, up to $5.1 million dollars can be saved through this grant program with the liberal estimate and $1.02 million can be saved with the conservative estimate.

Overall, with the various tax credits and grants, there is a potential to divert anywhere from $2.94 million to $ 7.01 million from the overall capital cost of the project. This would reduce the out of pocket costs by 26%.

7.2.6 Overall Economics

Before considering tax credits, the overall present value of our GSLC designs come out to $11.92 million, with an overall annualized cost of $653,100 per year, shown in figure 15.

	Capital Cost	Annual O&M	Overhaul PV	Total Annualized
Heat Pumps	$1.055m	$5.3k	$111k	$69.66k
Solar Panels	$1.35m	$33.2k	$605k	$160.22k
Hydropower	$7.8m	$194k	$725k	$657.54k
Green Infrastructure	$101k	$3.4k	n/a	$8.91k
Parking Lot	$296k	$6.1k	$68.5k	$26.66k
Total	$10.27m	$243.2k	$1.41m	$653.1k

Table 15: Total costs of the design broken down by part, before considering tax credits.

After factoring in tax credits and federal grants made available by the Inflation Reduction Act for heat pumps, solar panels, and hydropower (summarized in figure 53), we were able to significantly reduce the LCOEs of electricity from solar and hydropower as well as reduce the annualized total cost of heat pump construction. We assumed that

10% of the capital costs of heat pumps and solar, were able to be covered with grants from REAP funding (a conservative estimate), and that an additional 10% tax credit was available for solar capital costs and overhaul based on provisions laid out in the IRA [12]. We also took into consideration a producer tax credit (PTC) of $0.0275/kWh of energy produced from hydropower for any facilities constructed on or after January 1, 2025, provided by the IRA [116].

	Tax credit & federal grant	New Annualized Cost	New LCOE ($/kWh)	Monthly Cost per Unit
Heat pumps	10% of capital costs covered by grant	$ 63,876.41	-	$ 61.90
Solar	10% tax credit for capital cost & overhaul, additional 10% in capital grant	$ 122,126.19	$ 0.1085	varies
Hydropower	Producer tax credit (PTC) of $0.0275/kWh	-	$ 0.02373	varies
Green Infrastructure	-	$ 8,913.03	-	$ 8.64

Figure 53: Summary of costs after factoring in tax credits and federal grant incentives.

Assuming that the GSLC only uses electricity from its on-site solar and the hydropower PPA, we were able to calculate an estimated monthly cost of energy per unit using the cost of electricity from hydropower from the PPA ($0.02973/kWh), the levelized cost of electricity from solar ($0.1085/kWh), and the fraction of electricity derived from each source in different months. The anticipated monthly costs for each unit, shown in figure 54, range from $158 to $207, which is slightly less than the average monthly bill for combined electricity and natural gas in New York State at around $212 per month [29]. Moreover, our estimated costs will not significantly fluctuate compared to energy from the grid because we do not use any sources (like natural and petroleum) with prices sensitive to changes in global affairs.

We also wanted to provide an estimate of what residents could expect to pay for total monthly rent after factoring in our green infrastructure and heat pump construction. Given that constructing a typical mid-rise apartment ranges in cost from $185-$270 per ft^2, building our GSLC complex will cost in the range of $18.32 million to $26.73 million [65]. Annualized at a 5% discount rate over 50 years, this comes out to a cost of $1,003,000 - $1,464,000 per year, which translates to a cost ranging from $972-$1,419 per unit per month. If we add in the monthly cost of constructing our green infrastructure and heat pumps (which we will assume are not included in this building construction cost estimate), each unit can expect to pay $1,043-$1,489 per month. This does not include the cost of more intense care, so we can consider this to be a baseline rent price for independent residents, with costs increasing for residents with higher levels of care. Assuming that food, transportation, and medical care will add additional expenses, the overall cost of living in our community is actually on the lower end of the cost of independent senior living in the U.S., which typically ranges from $1,500-$4,000 per month without including utilities [11]. As one of our initial goals was to ensure that we maintain affordability and keep rising inequality in mind, it is really important and encouraging that these results show sustainable designs are not necessarily cost-prohibitive.

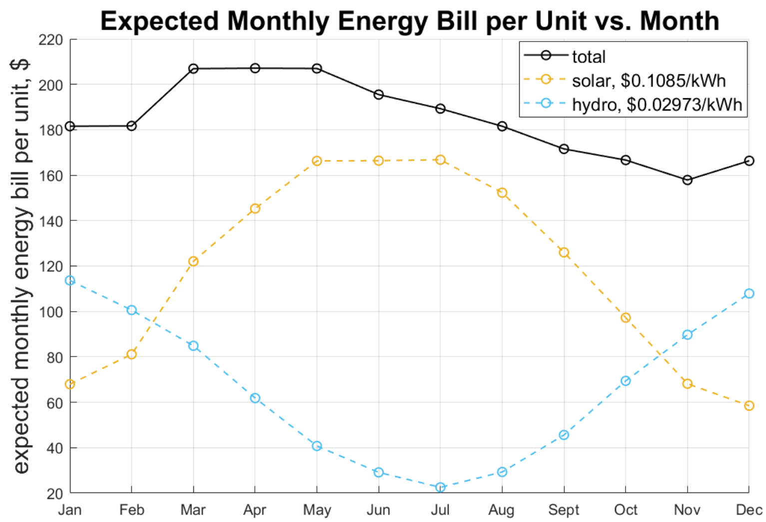


Figure 54: Anticipated monthly energy bill per unit based on cost of solar and hydropower.

8 Conclusions and Future Research

The goal of this GLSC was to meet the growing demand for senior housing while maintaining a minimal carbon footprint. Our technical analysis highlighted specific renewable energy technologies that can be implemented on a large, commercial scale that will meet all of the energy demands for both electricity and heating for a specific demand profile. The design for the energy profile and heating demand were based on typical requirements for nursing homes and information based on energy demands of other senior living homes to meet the physical and mental health needs of the residents. As a result, the geothermal heat pump used 555 MWh per year, which was sourced from a combination of solar and hydropower. Combined, the renewable sources produced a total of 5.91 GWh annually. We also incorporated green infrastructure designs such as a detention pond and bioretention areas to offset the impacts of land disturbances on stormwater quantity and quality. This stormwater management plan also helps create a green environment and recreational space to help residents maintain good mental and physical health.

Overall, the project costs $10.27 million to construct. Annualizing the capital costs, operation and maintenance costs, and the overhauls brings the total annual cost to $653.1k. The main contributor to capital cost is the hydropower plant, making up $7.8 million of the $10.27 million total cost. With the potential of applying for tax credits and grants, roughly $3 million of the capital cost can be saved. Many of the tax credits have certain guidelines that the commercial entity must fit into and many of the grants have application processes, thus this is a rough estimate. The tax credits available for the hydropower project face a little more uncertainty since it is being paid for and built by another entity that is not the GSLC. We anticipate that each unit can expect to pay in the range of $1,000-$1,500 in monthly rent, with an additional $158-$207 per month for utilities. Our rent prediction includes the expected building costs for the GSLC, heat pumps, solar, and green infrastructure and the utilities cost is mostly the cost of buying enough electricity from the hydropower plant to cover the GSLC's demand. These costs are on the lower end of both the U.S. and New York State ranges for rent and utilities.

While our design provides a baseline of expected energy demands and costs of building a theoretical GSLC, each GSLC will be different and as such require a more detailed analysis specific to the selected site and anticipated community needs. For green infrastructure, the exact design and stormwater management requirements heavily depend on the hydrology, climate, and land use of the site. For solar, the theoretical calculations were based on weather predictions, or historical weather data, thus one year of information about panel production will give a more accurate output profile.

To proceed beyond a theoretical heat pump system, an official soil profile would need to be conducted. Energy extraction rates from the ground may differ from the predicted values and result in a larger or smaller looping system, or reveal that looping options are more limited than we assumed. Additionally, our building envelop model was very simplified. Many consulting firms have access to software to more accurately model the heat flows and losses in the building. Finally, as new refrigerant legislation is enacted, systems may become more or less efficient with the implementation of new chemicals. COPs or energy requirements for the pump may change, resulting in annual costs that differ from our findings.

To gather a more accurate design and cost estimate for the hydropower plant, better flow data would need to be gathered at our desired site along with data on the net head through the year. Better flow data would give a better estimate of power production and gathering net head data would allow the engineers to ensure that the turbines will have enough head to operate through the year. Additionally the current conditions of the dam and site would need to be inspected. Discovering how much dredging is needed and if the dam needs repairs before turbines can be installed will give a much more accurate capital cost estimation which may significantly impact the price of electricity for the GSLC.

Furthermore, sustainable energy technologies are rapidly advancing and changing as society recognizes the need to move away from fossil fuels. While our design reflects common technologies and practices in 2023, it is very possible that these could change in the future. Any truly sustainable community will have to be ready to adapt to these changes as they occur.

A Active Solar Data

A.1 Average Monthly Temperature for Seneca Falls, NY

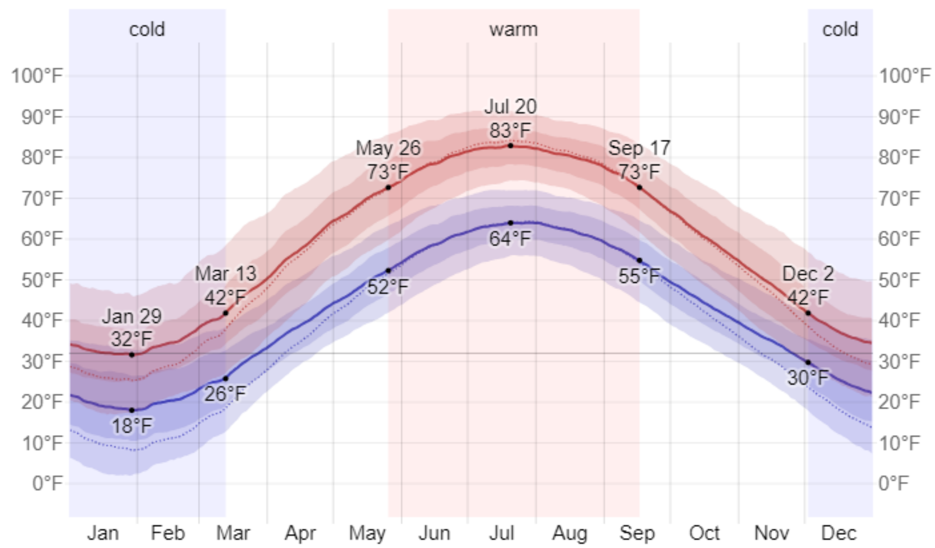


Figure 55: Average High and Low Temperatures in Seneca Falls, NY. 10th and 90th percentiles included in a lighter shade. 25th and 75th quartiles included in a darker shade.

B Active Solar Capital Cost

Component	Cost ($/kW)
Module	621
Inverter	35
Structural Balance of System	137.81
Electrical Balance of System	146.29
Officework	62.78
Fieldwork	295.40
Other	190.64

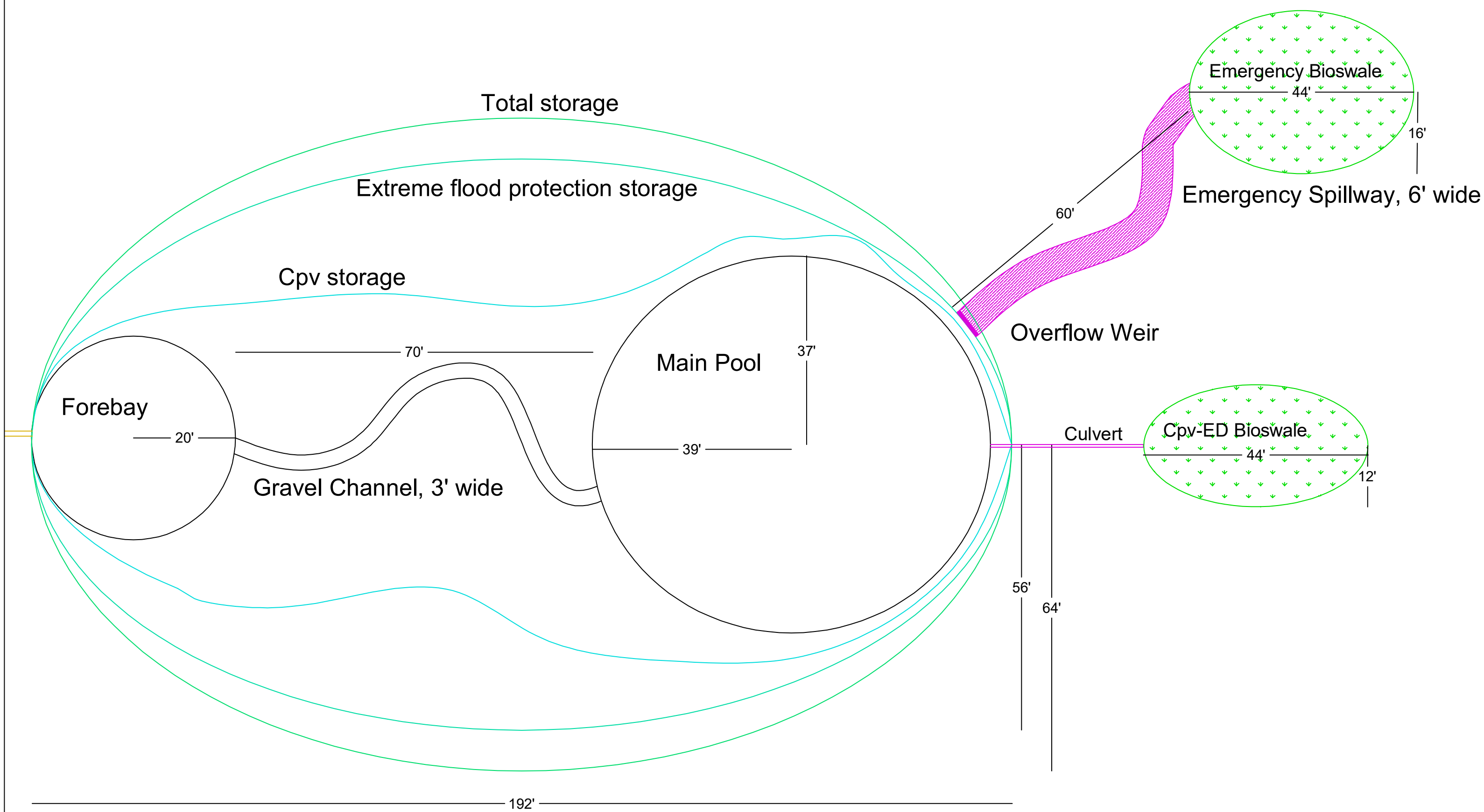
Table 16: Breakdown of Capital costs for Active Solar PV Installation

C Passive Solar Savings

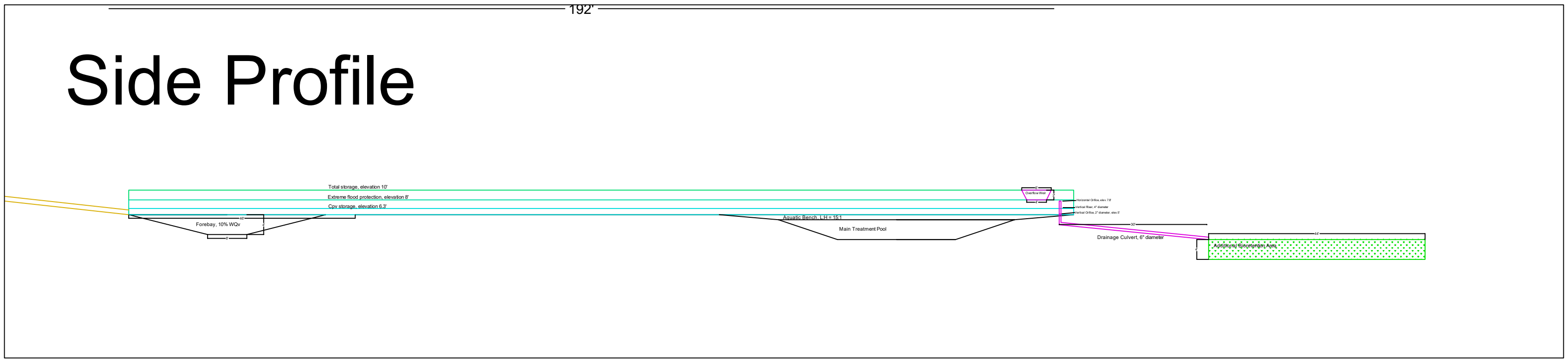
Cloudy	Clearer	Hours of Daylight	Hours Overhang would have an Impact	Heating Savings	Lighting Savings	Total Energy Savings	% Energy Savings
71%	29%	9.4	2.726	1165.627661	988.619054	2154.246716	0.5679166667
68%	32%	10.6	3.392	1258.670573	1230.152543	2488.823115	0.7066666667
60%	40%	12	4.8	1650.018873	1740.7819	3390.800773	1
54%	46%	13.5	6.21	1511.597738	0		0
51%	49%	14.7	7.203	1087.050543			0
46%	54%	15.3	8.262	670.360736			0
39%	61%	15	9.15	383.5790826			0
36%	64%	13.8	8.832	518.3473923			0
38%	62%	12.4	7.688	873.3026717			0
45%	55%	11	6.05	1268.116639			0
56%	44%	9.7	4.268	1212.036877	1547.845239	2759.882116	0.8891666667
66%	34%	9.1	3.094	1167.338047	1122.079	2289.417047	0.6445833333
					Total Energy Savings (kWh)	**13083.16977**	
					Total Energy Savings %	**0.3863485267**	

D Detention Pond Layout

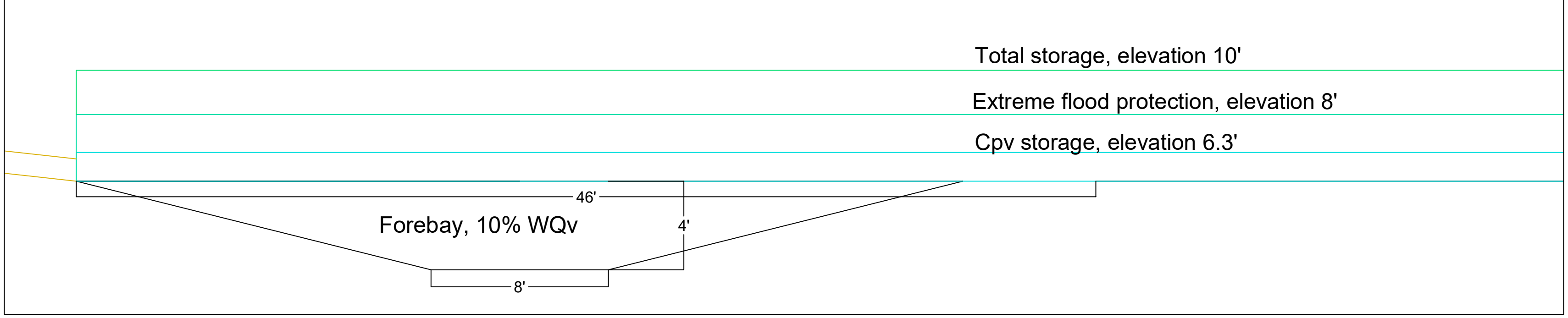
Top View - Detention Pond



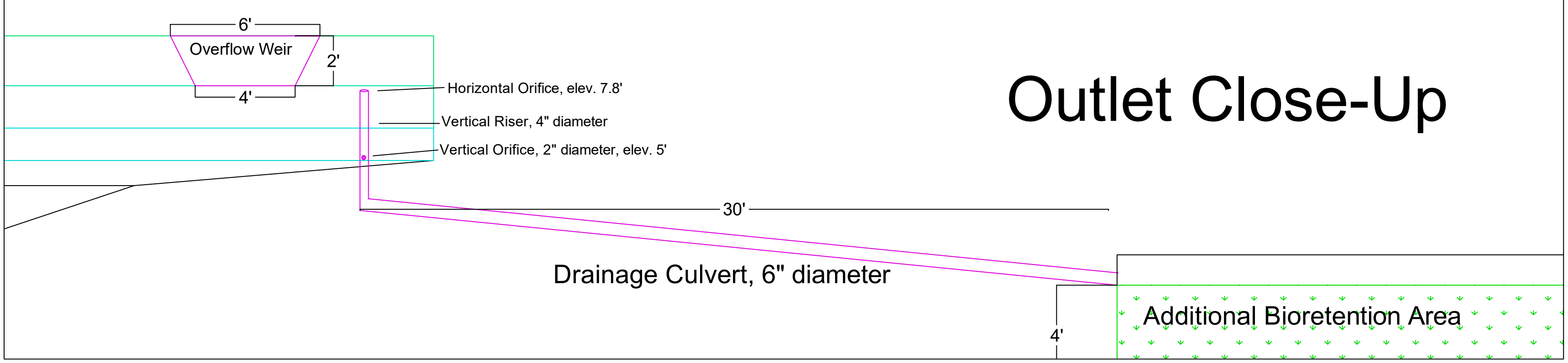
Side Profile



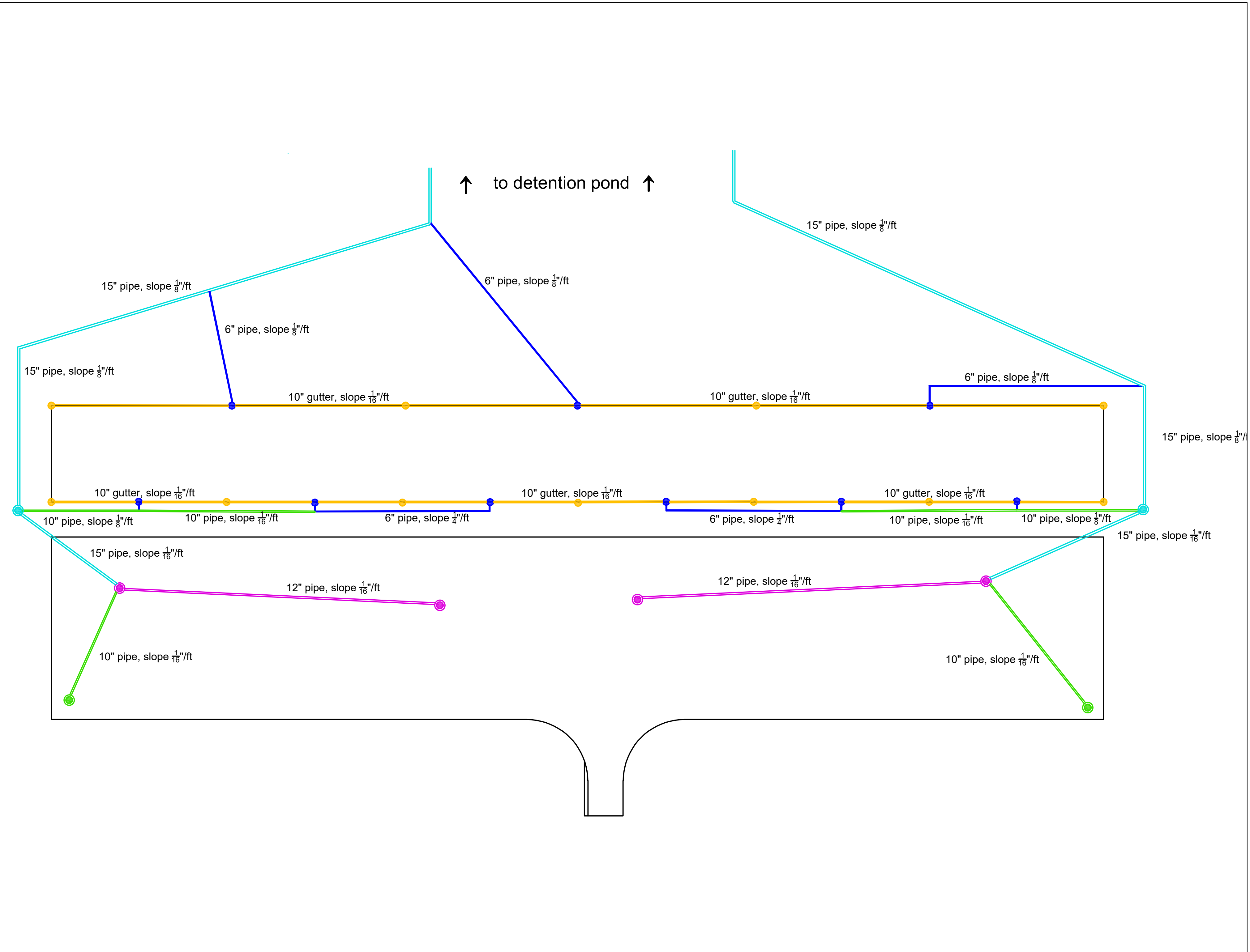
Forebay Close-Up



Outlet Close-Up



E Pipe Drainage Layout


to detention pond
15" pipe, slope 1/8"/ft
6" pipe, slope 1/8"/ft
15" pipe, slope 1/8"/ft
6" pipe, slope 1/8"/ft
15" pipe, slope 1/8"/ft
6" pipe, slope 1/8"/ft
10" gutter, slope 1/16"/ft
10" gutter, slope 1/16"/ft
15" pipe, slope 1/8"/ft
10" gutter, slope 1/16"/ft
10" gutter, slope 1/16"/ft
10" gutter, slope 1/16"/ft
10" pipe, slope 1/8"/ft
10" pipe, slope 1/16"/ft
6" pipe, slope 1/4"/ft
6" pipe, slope 1/4"/ft
10" pipe, slope 1/16"/ft
10" pipe, slope 1/8"/ft
15" pipe, slope 1/16"/ft
15" pipe, slope 1/16"/ft
12" pipe, slope 1/16"/ft
12" pipe, slope 1/16"/ft
10" pipe, slope 1/16"/ft
10" pipe, slope 1/16"/ft

F Green Infrastructure Detailed Inventory Costs

Detention Pond - Capital Cost				
Site Formation				
Component	*unit*	*quantity*	*unit cost*	*total cost*
Grading	square yard	3759.09	$ 1.50	$ 5,638.64
Structural Components				
Inlet structure	each	1	$ 2,000.00	$ 2,000.00
Overflow structure	each	2	$ 3,500.00	$ 7,000.00
Site Restoration				
Sod - above vegetative bench	square yard	2519.208	$ 4.50	$ 11,336.44
Soil preparation	square yard	319.3953	$ 5.00	$ 1,596.98
Seeding - vegetative bench	square yard	319.3953	$ 0.50	$ 159.70
Mulch	square yard	629.8021	$ 2.00	$ 1,259.60
			Total capital cost	**$ 28,991.35**

Figure 56: Capital cost breakdown for detention pond based on materials and labor [79].

Bioretention Areas - Capital Cost				
material	*unit*	*quantity*	*unit cost*	*total*
filter fabric	square yard	258.9	$ 4.00	$ 1,035.64
topsoil	cubic yard	43.2	$ 50.00	$ 2,157.58
erosion matting	square yard	250.0	$ 2.75	$ 687.50
gravel bed	cubic yard	10.0	$ 67.50	$ 675.00
bioretention material	cubic yard	316.2	$ 20.00	$ 6,323.25
small shrubs	each	60.0	$ 35.00	$ 2,100.00
small herbs	each	75.0	$ 8.50	$ 637.50
native seed mix	lb	2.0	$137.50	$ 275.00
mulch	square yard	258.9	$ 2.00	$ 517.82
			Total capital cost	**$ 14,409.28**

Figure 57: Capital cost breakdown for bioretention areas based on materials and labor [21].

Drainage System + Parking Lot - Capital Costs				
Drainage System				
system component	*unit*	*quantity*	*cost/unit*	*total cost*
10" gutters	ft	1200	$ 19.10	$ 22,920.00
6" downspout	ft	324	$ 7.18	$ 2,326.32
6"-diameter pipe	ft	700	$ 3.60	$ 2,520.00
10"-diameter pipe	ft	400	$ 8.00	$ 3,200.00
12"-diameter pipe	ft	400	$ 10.40	$ 4,160.00
15"-diameter pipe	ft	1600	$ 12.50	$ 20,000.00
catch basin	each	6	$ 400.00	$ 2,400.00
Parking lot				
parking lot	square ft	39726.72	$ 6.00	$238,360.32
			Capital cost of drainage system	**$ 57,526.32**
			Total capital cost of drainage + parking lot	**$295,886.64**

Figure 58: Capital cost breakdown for drainage system [80] [53].

Detention Pond - Annual Operation and Maintenance Cost				
Component	*unit*	*quantity*	*unit cost*	*total cost*
Debris removal	per visit	25	$ 100.00	$ 2,500.00
Remove invasive plants	per visit	10	$ 500.00	$ 5,000.00
Replant wetland vegetation	per plant	250	$ 10.00	$ 2,500.00
Repair erosion	square yard	319.40	$ 75.00	$ 23,954.64
Sediment removal and disposal	cubic yard	192.37	$ 10.00	$ 1,923.74
Mow	per visit	100	$ 150.00	$ 15,000.00
Gate / valve operation	per visit	25	$ 125.00	$ 3,125.00
Inspection	per visit	50	$ 125.00	$ 6,250.00
			Total lifetime maintenance	$ 60,253.38
			Annual O&M cost	**$ 1,205.07**

Figure 59: Detailed breakdown of O&M costs for detention pond based on materials and labor [79].

Bioretention Areas - Annual O&M Cost				
item	*unit*	*quantity*	*unit cost*	*total cost*
inspection	per visit	50	$ 125.00	$ 6,250.00
mow	per visit	50	$ 150.00	$ 7,500.00
new vegetation	each time	5	$3,012.50	$15,062.50
new topsoil	each time	5	$2,157.58	$10,787.88
general cleanup	per visit	100	$ 100.00	$10,000.00
			Total O&M lifetime cost	$49,600.38
			Annual O&M cost	**$ 992.01**

Figure 60: Detailed breakdown of O&M costs for bioretention areas based on materials and labor [21].

Drainage System - Annual O&M Cost				
item	*unit*	*quantity*	*unit cost*	*total cost*
inspection	per visit	50	$ 125.00	$ 6,250.00
debris cleaning	per visit	25	$ 125.00	$ 3,125.00
repair	per repair	50	$ 1,000.00	$ 50,000.00
			Total O&M lifetime cost	$ 59,375.00
			Annual O&M Cost	**$ 1,187.50**

Figure 61: Detailed breakdown of O&M costs for drainage system [21].

Parking Lot - Annual O&M Cost				
item	*unit*	*quantity*	*unit cost*	*total cost*
salting	each time	18	$228.00	$4,104.00
plowing	per hour	10	$100.00	$1,000.00
sidewalk clearing	per hour	20	$ 50.00	$1,000.00
			Annual O&M Cost	**$6,104.00**

Figure 62: Detailed breakdown of O&M costs for parking lot [49] [86].

References

[1] 2023. URL: https://www.montecitoapartments.com/floorplans.

[2] "U.S. Dept. of Justice, Civil Rights Division. *Accessible Parking Spaces*. URL: https://www.ada.gov/topics/parking/.

[3] National Renewable Energy Laboratory (NREL). *PVWatts Calculator*. URL: https://pvwatts.nrel.gov/index.php.

[4] *370 watt ZNShine Mono Black Solar Panel*. URL: https://sunwatts.com/370-watt-znshine-mono-black-solar-panel/. (accessed: 11.21.2023).

[5] United States Department of Agriculture. *New York - Rural Definitions*. URL: https://www.ers.usda.gov/webdocs/DataFiles/53180/25589_NY.pdf?v=0.

[6] J. G. Allen et al. "Associations of cognitive function scores with carbon dioxide, ventilation, and volatile organic compound exposures in office workers: A controlled exposure study of green and conventional office environments". In: *Environmental Health Perspectives* 124.6 (2016), pp. 805–812. DOI: https://doi.org/10.1289/ehp.1510037.

[7] American Health Care Association. *Facts and Figures*. URL: https://www.ahcancal.org/Assisted-Living/Facts-and-Figures/Pages/default.aspx.

[8] American Solar Energy Society. *Monocrystalline vs. Polycyrstalline Solar Panels*. URL: https://ases.org/monocrystalline-vs-polycrystalline-solar-panels/. (accessed: 10.25.2023).

[9] American Speech-Language-Hearing Association. *Senior Living Trends: Green Senior Living Communities*. 2023. URL: https://www.whereyoulivematters.org/green-senior-living-communities/.

[10] A. Arias-Rosales and P. LeDuc. "Modeling the transmittance of anisotropic diffuse radiation towards estimating energy losses in solar panel coverings". In: *Applied Energy* 268 (2020). DOI: https://doi.org/10.1016/j.apenergy.2020.114872.

[11] AssistedLiving.org. *The Average Cost of Senior Living: Can You Afford It?* 2023. URL: https://www.assistedliving.org/senior-housing/the-average-cost-of-senior-living/.

[12] American Healthcare Association. *Clean Energy Funding Opportunities for Health Care from Inflation Reduction Act of 2022*. 2023. URL: https://www.ahcancal.org/News-and-Communications/Blog/Pages/Clean-Energy-Funding-Opportunities-for-Health-Care-from-Inflation-Reduction-Act-of-2022-.aspx.

[13] K. Bawaneh et al. "Energy Consumption Analysis and Characterization of Healthcare Facilities in the United States". In: *Energies* 12.19 (2019). DOI: https://www.mdpi.com/1996-1073/12/19/3775.

[14] Buffalo Geothermal Heating. *Siano Building*. URL: https://www.buffalogeothermalheating.com/property/siano-building/. (accessed: 11.14.2023).

[15] J. J. Buonocore et al. "Climate and health benefits of increasing renewable energy deployment in the United States". In: 14.11 (2019). DOI: 10.1088/1748-9326/ab49bc.

[16] Cayuga Lake Watershed Network. *Lake Level Information*. URL: https://www.cayugalake.org/the-watershed/lake-level-information/.

[17] S. Chander et al. "A study on photovoltaic parameters of mono-crystalline silicon solar cell with cell temperature". In: *Energy Reports* 1 (2015). DOI: https://doi.org/10.1016/j.egyr.2015.03.004.

[18] G. Cillari, F. Fantozzi, and A. Franco. "Passive solar solutions for buildings: Criteria and guidelines for a synergistic design". In: 11.1 (2021), p. 376. DOI: https://doi.org/10.3390/app11010376.

[19] ClimateMaster. *Geothermal Heat Pump System from ClimateMaster Helps Sonoma County Water Agency Achieve Renewable Energy Goals in HVAC Retrofit Project*. URL: https://files.climatemaster.com/lc997-climatemaster-commercial-sonoma-water-treatment-plant-case-study.pdf. (accessed: 11.14.2023).

[20] Control Air Systems, Inc. *Water Source Heat Pumps Explained*. URL: https://www.controlairsystems.com/water-source-heat-pumps-explained/. (accessed: 10.16.2023).

[21] D.C. Dept. of Energy & Environment. *Stormwater Management Guidebook*. 2020. URL: https://doee.dc.gov/node/610622.

[22] *Dam Safety Inspection: Mud Lock C&S Canal Dam (Cayuga County, NY)*. URL: https://data.news-press.com/dam/new-york/cayuga-county/mud-lock-cs-canal-dam/ny00416/.

[23] Dandelion Energy. *Horizontal Ground Loop*. URL: https://dandelionenergy.com/resources/horizontal-ground-loop. (accessed: 10.16.2023).

[24] Dandelion Energy. *Vertical Ground Loop*. URL: https://dandelionenergy.com/resources/vertical-ground-loop. (accessed: 10.16.2023).

[25] M. Denchak. *Green Infrastructure: How to Manage Water in a Sustainable Way*. 2022. URL: https://www.nrdc.org/stories/green-infrastructure-how-manage-water-sustainable-way#whatis.

[26] J. Di Filippo and N. Nigro. *Cost and Usage Trends for Electric Vehicle Chargers: Evidence from NYSERDA-Funded Level 2 Charging Stations in New York State*. New York State Energy Research and Development Authority (NYSERDA), 2021.

[27] Direct Energy. *How Much Energy Does my Water Heater Use?* URL: https://www.directenergy.com/learning-center/how-much-energy-water-heater-use. (accessed: 11.14.2023).

[28] J. Donev et al. *Heat Pump*. URL: https://energyeducation.ca/encyclopedia/Heat_pump. (accessed: 10.12.2023).

[29] Ana Durrani. *Monthly Utility Costs In The U.S. By State*. Mar. 2023. URL: https://www.forbes.com/home-improvement/living/monthly-utility-costs-by-state/.

[30] Eagle Senior Living. *How Long Does it Take to Find an Assisted Living Community?* URL: https://www.eagleseniorliving.org/blog/how-long-does-it-take-to-find-assisted-living/.

[31] ECS Geothermal. *Types of Geothermal Heat Pumps For Your Home*. URL: https://ecsgeothermal.com/types-of-geothermal-heat-pumps-for-your-home/. (accessed: 10.16.2023).

[32] L. Eicke, A. Eicke, and M. Hafner. "Solar power generation. In M. Hafner & G. Luciani (Eds.)" In: (2022), pp. 157–169. DOI: https://doi.org/10.1007/978-3-030-86884-0_9.

[33] Energy Information Administration. *Commercial Buildings Energy Consumption Survey Consumption and Expenditures Highlights*. 2018. URL: https://www.eia.gov/consumption/commercial/.

[34] Energy Star. *Datatrends energy use senior care communitities*. URL: https://www.energystar.gov/buildings/tools-and-resources/datatrends_energy_use_senior_care_communities.

[35] Energy.gov. *Passive solar homes*. URL: https://www.energy.gov/energysaver/passive-solar-homes.

[36] Engineering Toolbox. *Hot Water Consumption vs. Occupants*. URL: https://www.engineeringtoolbox.com/hot-water-consumption-person-d_91.html. (accessed: 11.14.2023).

[37] EPA. *Electric Power Sector Basics*. 2023. URL: http://www.epa.gov/power-sector/electric-power-sector-basics.

[38] EPA. *Sole Source Aquifers*. URL: https://epa.maps.arcgis.com/apps/webappviewer/index.html?id=9ebb047ba3ec41ada1877155fe31356b.

[39] EVBox. *How much electricity does an electric car use?* URL: https://evbox.com/en/ev-home-charger-electricity-usage.

[40] Extreme Weather Watch. *Ithaca Weather Records*. URL: https://www.extremeweatherwatch.com/cities/ithaca/lowest-temperatures-by-year. (accessed: 10.23.2023).

[41] H. Fakour et al. "Evaluation of solar photovoltaic carport canopy with electric vehicle charging potential". In: 13 (2023), p. 2136. DOI: https://doi.org/10.1038/s41598-023-29223-6.

[42] Brionna Farney. *Fiber Cement Siding vs. Brick Siding: Comparing the Cost, Durability, and More*. Jan. 2022. URL: https://www.angi.com/articles/fiber-cement-siding-brick.htm.

[43] Findenergy.com. *Seneca County, New York Electricity Rates & Statistics*. Nov. 2023. URL: https://findenergy.com/ny/seneca-county-electricity/#:~:text=Seneca%20Falls%20CDP%2C%20NY%20Electricity%20Overview&text=On%20average%2C%20citizens%20living%20in,States%20average%20of%2015.90%20cents.

[44] Focus on Energy. *Heat Pump 102: How does a heat pump work*. URL: https://focusonenergy.com/blog/heat-pump-102-how-does-a-heat-pump-work. (accessed: 10.16.2023).

[45] J. Foster, A. Lowe, and S. Winkelman. *The Value of Green Infrastructure for Urban Climate Adaptation*. The Center for Clean Air Policy, 2011.

[46] Friendly Power. *Hospitals*. URL: https://esource.bizenergyadvisor.com/article/hospitals#:~:text=They%20use%20a%20lot%20of,gas%20per%20square%20foot%20annually. (accessed: 11.14.2023).

[47] P. Gagnon et al. "Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment". In: (). URL: https://www.nrel.gov/docs/fy16osti/65298.pdf.

[48] Jeremy Wells Gbadebo Oladosu Lindsay George. *2020 Cost Analysis of Hydropower Options at Non-Powered Dams*. ORNL/TM-2020/1656. Oak Ridge, TN, USA, Mar. 2021. URL: file:///C:/Users/susie/OneDrive%20-%20Cornell%20University/College/8.%20M.Eng%20Project/Pub145012.pdf.

[49] T. Grupa. *Snow Removal Prices*. 2023. URL: https://homeguide.com/costs/snow-removal-cost.

[50] C. Hardesty. *Average Miles Driven Per Year: Why It Is Important*. 2023. URL: https://www.kbb.com/car-advice/average-miles-driven-per-year/#:~:text=The%20average%20miles%20driven%20per,to%20Department%20of%20Transportation%20statistics.

[51] Healthcare Environmental Resource Center. *Facilities Management - Energy Efficiency*. URL: https://www.hercenter.org/facilitiesandgrounds/energy.php. (accessed: 11.14.2023).

[52] Historic American Engineering Record. "HAER NY-521: NEW YORK STATE BARGE CANAL, LOCK CS1 (Cayuga-Seneca Canal, Lock CS1)". In: ().

[53] HomeAdvisor. *How Much Does It Cost To Build A Parking Lot?* 2022. URL: https://www.homeadvisor.com/cost/outdoor-living/pave-a-parking-lot/.

[54] C. Honsberg and S. Bowden. *Calculation of Solar Insolation*. URL: https://www.pveducation.org/pvcdrom/properties-of-sunlight/calculation-of-solar-insolation.

[55] Hydro Review Content Directors. *Vattenfall develops "climate-smarter concrete" for hydropower structures*. June 2021. URL: https://www.hydroreview.com/dams-and-civil-structures/dam-design-and-construction/vattenfall-develops-climate-smarter-concrete-for-hydropower-structures/#gref.

[56] IEA. *Hydropower has a crucial role in accelerating clean energy transitions to achieve countries' climate ambitions securely*. 2021. URL: http://www.iea.org/news/hydropower-has-a-crucial-role-in-accelerating-clean-energy-transitions-to-achieve-countries-climate-ambitions-securely.

[57] IEA. *Russia's War on Ukraine*. URL: http://www.iea.org/topics/russias-war-on-ukraine.

[58] P Im and X Liu. *Case Study for ARRA-funded GroundSource Heat Pump (GSHP) Demonstration at Oakland University*. URL: https://info.ornl.gov/sites/publications/files/Pub53853.pdf. (accessed: 11.14.2023).

[59] P. Im and X. Liu. *Case Study for ARRA-funded GroundSource Heat Pump (GSHP) Demonstration at Oakland University*. URL: https://info.ornl.gov/sites/publications/files/Pub53853.pdf. (accessed: 11.14.2023).

[60] U.S. energy Information Administration. *Southwestern States have better solar resources and higher solar PV capacity factors*. URL: https://www.eia.gov/todayinenergy/detail.php?id=39832.

[61] International Atomic Energy Agency. *Climate Change and Nuclear Power 2020*. IAEA in Austria, 2020.

[62] International Hydropower Association. *Hydropower's carbon footprint*. URL: https://www.hydropower.org/factsheets/greenhouse-gas-emissions#:~:text=The%20IPCC%20states%20that%20hydropower,490%20gCO%E2%82%82%2Deq%2FkWh..

[63] Investment Guide. *National Investment Center*. URL: https://www.nic.org/analytics/publications/investment-guide/.

[64] IRENA. "Hydropower". In: *Renewable Energy Technologies: Cost Analysis Series* 1 (3 June 2012).

[65] Jamie Jacobs. *How Much Does It Cost to Build an Apartment Complex?* June 2022. URL: https://apxconstructiongroup.com/apartment-complex-cost/.

[66] D. Jeste et al. "Study of Independent Living Residents of a Continuing Care Senior Housing Community: Sociodemographic and Clinical Associations of Cognitive, Physical, and Mental Health". In: *American Jounral of Geriatric Psychiatry* 27.9 (2019). DOI: 10.1016/j.jagp.2019.04.002.

[67] K. Kenneally. "New report: 40% of older Americans rely solely on social security for retirement income". In: *National Institute on Retirement Security* (2020). URL: https://www.nirsonline.org/2020/01/new-report-40-of-older-americans-rely-solely-on-social-security-for-retirement-income/q.

[68] G. Kilgore. *How Many Electric Cars Are There in the United States? We Found Out*. 2023. URL: https://8billiontrees.com/carbon-offsets-credits/cars/how-many-electric-cars-in-the-us/#:~:text=Currently%2C%20the%20administration%20estimates%20about,eco%2Dcost%20of%20an%20EV.

[69] Kocher's Water Pumps & Tanks Inc. *Geothermal Loop Configurations*. URL: https://kochergeowelldrilling.com/loop-configurations/. (accessed: 10.16.2023).

[70] Prashant Kumar et al. "The nexus between air pollution, green infrastructure and human health". In: *Environment International* 133 (2019), p. 105181. ISSN: 0160-4120. DOI: https://doi.org/10.1016/j.envint.2019.105181. URL: https://www.sciencedirect.com/science/article/pii/S0160412019319683.

[71] National Renewable Energy Laboratory. *Q1 2023 U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks With Minimum Sustainable Price Analysis Data File*. 2023.

[72] J. Marsh. *How many watts does an electric car charger use?* 2023. URL: https://www.energysage.com/electricity/house-watts/how-many-watts-does-an-electric-car-charger-use/.

[73] Martin Energetics. *(Ground source) heat pumps*. URL: https://www.martinenergetics.com/ground-source-heat-pumps.html#:~:text=Once%20you're%204%2Dto,%2Dto%2Dair%20heat%20pumps.. (accessed: 11.14.2023).

[74] J. Mathias and D. Mathias. "Energy Efficient, Cost Effective, Passive Solar House". In: *OpenSIUC* (2009). URL: https://opensiuc.lib.siu.edu/cgi/viewcontent.cgi?article=1002&context=meep_articles.

[75] J. Melius, R. Margolis, and S. Ong. *Estimating Rooftop Suitability for PV: A Review of Methods, Patents, and Validation*. Tech. rep. National Renewable Energy Laboratory, 2013.

[76] S. Meyer. *Fuel Cost Calculator*. 2023. URL: https://www.thezebra.com/resources/driving/fuel-cost-calculator/.

[77] Lindsay Miller et al. "Evaluating the link between LCOE and PPA elements and structure for wind energy". In: *Energy Strategy Reviews* 16 (2017), pp. 33–42. ISSN: 2211-467X. DOI: https://doi.org/10.1016/j.esr.2017.02.006. URL: https://www.sciencedirect.com/science/article/pii/S2211467X17300160.

[78] W. Miller, D. Vine, and Z. Amin. "Energy efficiency of housing for older citizens: Does it matter?" In: 101 (2017), pp. 216–224. DOI: https://doi.org/10.1016/j.enpol.2016.11.050.

[79] Minnesota Pollution Control Agency. *Stormwater pond cost estimate worksheet*. 2022. URL: https://stormwater.pca.state.mn.us/index.php?title=Stormwater_pond_cost_estimate_worksheet.

[80] T. Moore. *How Much Does It Cost To Install A Drainage System In Your Yard?* June 2023. URL: https://www.forbes.com/home-improvement/plumbing/drainage-system-cost/#:~:text=Catch%20basins%20themselves%20may%20only,range%20from%20%241%2C000%20to%20%244%2C000.

[81] National Cooperative Soil Survey. *Cayuga Series*. URL: https://soilseries.sc.egov.usda.gov/OSD_Docs/C/CAYUGA.html. (accessed: 11.14.2023).

[82] National Research Council. *Urban Stormwater Management in the United States*. The National Academies Press, 2009. DOI: https://doi.org/10.17226/12465.

[83] New York Power Authority. "Request for Proposal (RFP): Cayuga Watercourse Q20-7103NF". In: ().

[84] New York State Senate. *Climate Leadership and Community Protection Act - Senate Bill S6599*. 2019. URL: https://www.nysenate.gov/legislation/bills/2019/S6599.

[85] M. J. Nieuwenhuijsen. "Green Infrastructure and Health". In: *Annual Review of Public Health* 42 (2021), pp. 317–328. DOI: https://doi.org/10.1146/annurev-publhealth-090419-102511.

[86] Northeast Regional Climate Center. *Extreme Precipitation in New York and New England*. URL: https://precip.eas.cornell.edu/#/.

[87] NYSERDA. *Installing a Charging Station*. URL: https://www.nyserda.ny.gov/All-Programs/ChargeNY/Charge-Electric/Charging-Station-Programs/Charge-Ready-NY/Installing-a-Charging-Station.

[88] NYSERDA. *Monthly Average Retail Price of Electricity - Commercial*. 2023. URL: https://www.nyserda.ny.gov/Energy-Prices/Electricity/Monthly-Avg-Electricity-Commercial.

[89] Solar Energy Technologies Office. *Solar Integration: Inverters and Grid Services Basics*. URL: https://www.energy.gov/eere/solar/solar-integration-inverters-and-grid-services-basics.

[90] B. Ogayar and P.G. Vidal. "Cost determination of the electro-mechanical equipment of a small hydro-power plant". In: *Renewable Energy* 34.1 (2009), pp. 6–13. ISSN: 0960-1481. DOI: https://doi.org/10.1016/j.renene.2008.04.039. URL: https://www.sciencedirect.com/science/article/pii/S0960148108001900.

[91] M. Owrak et al. "Experiments and simulations on the thermal performance of a sunspace attached to a room including heat-storing porous bed and water tanks". In: 92 (2015), pp. 142–151. DOI: https://doi.org/10.1016/j.buildenv.2015.04.022.

[92] P3 Cost Analysts. *Average Nursing Home Electric Bill*. URL: https://www.costanalysts.com/average-nursing-home-electric-bill/. (accessed: 11.14.2023).

[93] O. Paish. "Small hydro power: technology and current status". In: *Renewable and Sustainable Energy Reviews* (2002).

[94] J. Pastuszak and P. Węgierek. "Photovoltaic cell generations and current research directions for their development". In: 15.16 (2022), p. 5542. DOI: https://doi.org/10.3390/ma15165542.

[95] Saniya Patel. *Passive Solar Design Retrofits*. July 2020. URL: https://images.squarespace-cdn.com/content/v1/5b51df5812b13fce46a6868b/1595255875699-98SDZ8KMAYG0YPQ7PEN7/220_220-Passive-Solar-Heating-1200.jpg.

[96] R. Paul. *Overivew of the new Renewable Energy Tax Credit Under Section 48*. URL: https://www.pbmares.com/overview-new-renewable-energy-tax-credit-under-section-48/.

[97] Philadelphia Water Department. *Green City Clean Waters*. URL: https://water.phila.gov/green-city/.

[98] *Published Solar Data*. URL: https://www.homerenergy.com/products/pro/docs/3.12/published_solar_data.html. (accessed: 11.21.2023).

[99] J. Radinger, R. van Treeck, and C. Wolter. "Evident but context-dependent mortality of fish passing hydroelectric turbines". In: *Conservation Biology* 36.3 (2022), e13870. DOI: https://doi.org/10.1111/cobi.13870. URL: https://conbio.onlinelibrary.wiley.com/doi/abs/10.1111/cobi.13870.

[100] V. Ramasamy et al. "U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis: Q1 2023". In: *National Renewable Energy Laboratory* NREL/TP-7A40-87303 (2023).

[101] H. Ramos and A. Borga. "Pumps yielding power". In: *Int Water Power Dam Constr* 10 (Jan. 2000).

[102] D. Romanov and B. Leiss. *Geothermal energy at different depths for district heating and cooling of existing and future building stock*. URL: https://www.sciencedirect.com/science/article/pii/S1364032122006165?ref=pdf_download&fr=RR-2&rr=827aa83f39bc42e4. (accessed: 11.14.2023).

[103] R. Santbergen and R.J.C van Zolingen. "The absorption factor of crystalline silicon PV cells: A numerical and experimental study". In: *Solar Energy Materials and Solar Cells* 92.4 (2008). DOI: 10.1016/j.solmat.2007.10.005.

[104] C. Schelly and J. C. Letzelter. "Examining the key drivers of residential solar adoption in upstate new york". In: 12.6 (2020), p. 2552. DOI: https://doi.org/10.3390/su12062552.

[105] K. Sen and G. Prybutok. "A Quality Mobility Program Reduces Elderly Social Isolation, Activities, Adaptation & Aging". In: 45.1 (2021), pp. 14–26. DOI: 10.1080/01924788.2019.1700881.

[106] *Stormwater Management Design Manual*. New York State Dept. of Environmental Conservation, 2022.

[107] B. Stutz. *With a Green Makeover, Philadelphia is Tackling Its Stormwater Problem*. 2018. URL: https://e360.yale.edu/features/with-a-green-makeover-philadelphia-tackles-its-stormwater-problem.

[108] H. L. Thadani and Y. I. Go. “Integration of solar energy into low-cost housing for sustainable development: Case study in developing countries”. In: *Heliyon* 7.12 (2021). DOI: https://doi.org/10.1016/j.heliyon.2021.e08513.

[109] U.S. Department of Energy. *Air-Source Heat Pumps*. URL: https://www.energy.gov/energysaver/air-source-heat-pumps. (accessed: 10.16.2023).

[110] U.S. Department of Energy. *Geothermal Heat Pumps*. URL: https://www.energy.gov/energysaver/geothermal-heat-pumps. (accessed: 10.16.2023).

[111] U.S. Department of Energy. *Guide to Geothermal Heat Pumps*. URL: https://www.energy.gov/sites/prod/files/guide_to_geothermal_heat_pumps.pdf. (accessed: 10.16.2023).

[112] U.S. Department of the Interior. *Geophysical, Stratigraphic, and Flow-Zone Logs of Selected Wells in Cayuga County, New York, 2001–2011*. URL: https://pubs.usgs.gov/of/2011/1319/pdf/ofr2011-1319_pageproof_011112.pdf. (accessed: 11.14.2023).

[113] U.S. Energy Information Administration. *Household Energy Use in New York*. URL: https://www.eia.gov/consumption/residential/reports/2009/state_briefs/pdf/ny.pdf. (accessed: 11.14.2023).

[114] U.S. Energy Information Administration. *Use of energy explained - Energy use in homes*. URL: https://www.eia.gov/energyexplained/use-of-energy/homes.php.

[115] U.S. EPA Office of Water. *The National Hydrology Dataset Plus (NHDPlus) - EPA WATERS GeoViewer 2.0*. URL: https://epa.maps.arcgis.com/apps/webappviewer/index.html?id=074cfede236341b6a1e03779c2bd0692.

[116] United States Environmental Protection Agency. *Summary of Inflation Reduction Act provisions related to renewable energy*. Oct. 2023. URL: https://www.epa.gov/green-power-markets/summary-inflation-reduction-act-provisions-related-renewable-energy#:~:text=Eligible%20for%20PTC&text=Through%20at%20least%202025%2C%20the,projects%20over%201%20MW%20AC..

[117] R. Uría-Martínez, M. M. Johnson, and R. Shan. *U.S. Hydropower Market Report (January 2021 edition)*. US Department of Energy, 2021.

[118] US Census Bureau. *2020 Census Results*. 2023. URL: https://www.census.gov/programs-surveys/decennial-census/decade/2020/2020-census-results.html.

[119] L. D. Vanek F. M. Albright et al. *Energy Systems Engineering: Evaluation and Implementation*. McGraw Hill, 2022. Chap. Design and Operation of Practical PV Systems.

[120] L. D. Vanek F. M. Albright et al. *In Energy Systems Engineering: Evaluation and Implementation*. McGraw Hill, 2022. Chap. Designing window overhangs for passive solar systems.

[121] N. Varga and M. Mayer. "Model-based analysis of shading losses in ground-mounted photovoltaic power plants". In: *Solar Energy* 216 (2021). DOI: https://doi.org/10.1016/j.solener.2021.01.047.

[122] *Voith.com*. URL: https://voith.com/corp-en/index.html.

[123] Weather Spark. *Climate and Average Weather Year Round in Ithaca*. URL: https://weatherspark.com/y/22130/Average-Weather-in-Ithaca-New-York-United-States-Year-Round. (accessed: 11.14.2023).

[124] S.J. Williamson, B.H. Stark, and J.D. Booker. "Low head pico hydro turbine selection using a multi-criteria analysis". In: *Renewable Energy* 61 (2014). World Renewable Energy Congress – Sweden, 8–13 May, 2011, Linköping, Sweden, pp. 43–50. ISSN: 0960-1481. DOI: https://doi.org/10.1016/j.renene.2012.06.020. URL: https://www.sciencedirect.com/science/article/pii/S0960148112003710.

[125] S. Yoon et al. "Optimal orientation of solar panels for multi-apartment buildings". In: *Mathematics* 11.4 (2023), p. 938. DOI: https://doi.org/10.3390/math11040938.