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Original Research Article

Reducing Energy Burden and Flood Damage Using Energy-Water Nexus Approach

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ABSTRACT

This paper presents an innovative, original approach to co-design retention ponds and floating photo voltaic solar plants as a water-energy nexus approach to reduce flooding and energy burden for one location. Case-study analysis was conducted in Waimanalo, Hawai'i. A flood model—from a previous study—was used to provide a potential location for a retention pond and floating solar photovoltaic panels. This study found the co-design of retention ponds and floating PV solar can not only reduce future stormwater runoff by up to 50% but provide a total of 50% of onsite solar energy at a neighbourhood scale, demonstrating how clean energy and green infrastructure can help advance environmental and social justice. Several takeaways from this study were taken into account and things to consider for a follow-up paper. One of the major challenges was finding a potential suitable location. Overcoming this challenge required using Google Maps and the flood model to pinpoint high flood accumulation and searching for a large green space that is in close vicinity to a developed neighbourhood.

KEYWORDS

Clean energy, Green infrastructure, Disadvantaged communities, Environmental justice, Flood mitigation, Energy burden, Retention pond, Floating solar.

INTRODUCTION

Many of the environmental problems many countries are facing stem from an increase in CO_2 emissions as a result of urbanization [1], [2] Urbanization is defined as "the process leading to increasing amounts of urban areas" [3]. It is an accelerating trend in which there is and continues to be, growth of existing urban development as the population count continues to grow [1], [4].

Technology (i.e., robotics, machinery, construction, etc.) has helped with this ongoing growth trend as it has increased impermeable pavement, altering patterns in land cover from what the original ecosystem used to be, affecting both the natural geomorphic and hydrological

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processes (i.e., natural landscape) [3], [5], creating an "ecological deficit" [6]. As climate change continues to intensify globally, combined with rapid urban development in both existing urban and rural areas, environmental problems such as intense flooding, wildfires [7], erosion, sea level rise, etc. will continue to increase at large geographic scales [5], [8].

The combination of technological advancement and urbanization - means utility-scale energy generation will be in higher demand as population count increases. The majority of electricity in the United States is produced from fossil fuel non-renewable energy sources [2], [9]. The U.S. is ranked as the second highest country in the world that has and still is contributing global carbon emissions [2] mainly due to an accelerating utilization of energy. This high demand can result in rapid amounts of carbon dioxide and other air pollutants (i.e., toxic air releases, greenhouse gas emissions) released into the earth's atmosphere [10], [11]. These sources include carbon fuels such as coal, oil, and natural gas [10], [12]. As mentioned earlier, greenhouse gas emissions are primarily accountable for global warming and related climate impacts. Urbanization is a sub-product of the development, and it is highly correlated with productivity, job opportunities, and total demand for energy [1], [13].These impacts pose risks to people and the planet with hotter temperatures, more severe storms, etc. raising human insecurity, and threatening basic survival needs such as access to clean water, food production, mental and physical health, and land use [2], [14].

The existing global vulnerabilities we see today - particularly in disadvantaged and under-served communities will continue to increase as long as greenhouse gas emissions continue to be released into the Earth's atmosphere [2]. The current rate at which emissions are released has resulted in fluctuating heat intensity and stronger and more frequent storms [15]. This combination creates urban heat intensity, intense hurricanes and storms, wildfires, erosion, landslides, and flood disasters. Across the U.S., disadvantaged communities are bearing the brunt of flooding and urban heat. Traditional grey infrastructure (i.e., storm sewer networks, storm management, and treatment facilities) does not have the capacity to properly drain extra runoff volume [16], [17]. The infrastructure thresholds are often exceeded, meaning any extra runoff will result in flooding of public and private properties, increasing property damage and repair costs [18]. In addition to flooding, many areas containing disadvantaged communities (i.e., low-income and/or people of color communities) are also experiencing heat intensity impacts which drastically increase the demand for air conditioning. This action alone causes an increase in energy consumption, creating a financial burden, and also impacts associated emissions. Disadvantaged communities across the U.S. are increasingly susceptible to both flood impact and energy burden climate risks, a holistic energy-water nexus approach to resilience planning that considers systems interconnections can minimize vulnerabilities and provide a myriad of co-benefits.

Literature review

The concept of green infrastructure has been defined by different authors in various ways. Some have defined it as a natural approach cities are adopting to meet their sustainability and environmental objectives [15]. Some have defined it as network of natural and restored native ecosystems and landscapes [19]. Others have defined it as a redevelopment strategy and multifunctional ecosystem-based approach improving areas from public health to flood reduction. It is "green space planning" [20]. The concept of green infrastructure, for this paper, is defined as a multi-spatial (i.e., site scale, neighbourhood scale, watershed scale, city scale, etc.) nature-based design approach to reduce stormwater runoff. This approach decreases stormwater runoff and, also allows communities to become more sustainable and resilient (i.e., less property damage, drought preparation, urban heat island reduction, land-use regulations, improving community wellbeing, etc.) when more flood events occur. Implementing green infrastructure solutions can help urban and rural areas reap the benefits (i.e., flood risk reduction) from the biophysical components that make up green infrastructure and provide social and economic benefits. Short and long-term benefits include increased habitat biodiversity, decreased operational cost of public infrastructure and services [21], stormwater management and water treatment systems [22], improved health, and a sense of place [23].

Solar photovoltaic technologies are becoming of higher importance to combat climate impacts, resulting in the growth of the solar power industry applying inland solar panels on households and commercial buildings [24]. Solar panels can also be placed on water as well. They are called floating solar photovoltaic technology (FSPV) The concept of FSPV technology is defined as photovoltaic panels installed on a floating structure on a water body rather than on land or building rooftops [25], [26]. FSPV is an renewable energy technology that is able to combat significant increases in electricity demand and water scarcity [27], [28]. Adoption and implementation of this technology is growing across the U.S. Advantages of floating solar plus green infrastructure include water quality improvement, higher energy efficiency, evaporation reduction, reduction in maintenance cost after initial installation [28], prevention of algae growth, and low risk to wildlife [29].

While there are many innovative approaches to reducing flood impact and energy burden in separate cases where the impact happens post-disaster, no literature was found focused on combining flood and energy burden reduction strategies. Especially applying both strategies in areas where there are disadvantaged communities who are impacted the hardest from climate change. Hence why this study will focus on determining an original approach that provides both flood and energy burden reduction for the same case. This idea stems from a previous research study [25] where there was a mention of how floating solar technology is more common and better applied to "inland applications" such as retention ponds (i.e., green infrastructure). From this study, the author's thought it would a good idea to add that idea to a previous study [18] that had already looked green infrastructure application to three case studies that were impacted from several major floods as a flood mitigation tool. Therefore, for this study, our approach entails a hypothetical scenario combining a retention pond with floating solar photovoltaic panel technology within a community that has experienced major flood damage.

This raises the key question: Can retention ponds and floating solar plants be codesigned to make disadvantaged communities resilient against energy burden and flooding disasters at the same time?

METHODS

To answer the research question, the methodology design will illustrate the pre-green and post-green infrastructure, floating solar PV technology, flood model, potentially suitable location for a retention pond (i.e., green infrastructure), sizing of a retention pond, runoff reduction percentage (theoretical), sizing of floating solar plants, and percentage of energy burden using floating solar PV on the proposed retention pond.

Flood model (2018): before green infrastructure implementation

Federal Emergency Management Agency's (FEMA) flood maps provide analysis of areas that are located within high- or moderate-flood risk zones. While those maps are beneficial, this research study is focused on understanding what areas were impacted by a flood event in real-time. The flood model was developed using the Hydrologic Engineering Center's River Analysis System (HEC-RAS). While there are several methods for developing a flood model simulation of the case study (e.g., 1D Unsteady State, 2D, FEMA), the 1D Steady Flow Model Simulation was chosen for this study as it provides a snapshot of the impacted area. The 1D Unsteady Flow Model can do the same; however, while developing it, there were a few errors requiring a more complex approach to perfecting the simulation. The 2D flow model was not needed as its main function is to analyze water flow moving across a surface.

A case study analysis focused on a specific neighborhood (Waimanalo) on the island of O'ahu is incorporated later in this paper. The last major flood event to have occurred in this neighborhood was in 2018. Thus, a flood model is required to show volume and flow in real-time to analyze further into the situation and solutions (i.e., green infrastructure). Several steps were taken to create the flood model [30].

The first step was to download a terrain digital elevation model (DEM) tif file of the City and County of Honolulu (island of O'ahu); including the watershed and river shapefiles. River centerlines were then digitized from upstream to low stream, using the river shapefiles as guidance. A Google Maps aerial view was also used to help guide the digitization process. Bank lines and flow paths were next to be digitized from the upper- to the lower stream. Next, the cross-sections were digitized from left to right in a perpendicular direction over the bank lines and flow paths. Cross-sections were digitized following along the flow paths spanning over the entire flood extent (i.e., high elevation to high elevation) and were based on the changes in the river slope [31]. Assigning the "Manning's n values" to each cross-section was next. Standard values of 0.06 (floodplain) and 0.035 (main river channel) were assigned to create the initial flood model.

The flow data and downstream boundary conditions were then provided by the United States Geological Survey (USGS). Flow data was entered before the boundary conditions. The peak flow (cubic feet/second) of each stream centerline needed to be determined and was entered as an "upstream condition". Three flow conditions (in columns) were then created and labeled as "Normal", "Increasing", and "100-Year" (or "100-Year and 2-Year for the Waimanalo case study). Peak flow data for Waimanalo and North Shore Kaua'i were found in the archived stream gage data from the USGS National Water Dashboard website, which can also be found on the USGS StreamStats website [32], [33]. There was limited archived peak flow data for the Ala Wai case study.

The downstream boundary conditions were then defined by the "Normal Depth" value. Normal depth was determined based on the slope of the main river channel.

Before creating the model, the "Steady Flow Analysis" needed to be run with the "Subcritical" flow regime selected. The last step was to run the analysis. The analysis was seen in the RAS Mapper where all three flow conditions are viewed.

Based on the property damage, flood exposure, and location of existing grey infrastructure, one set of green infrastructure was chosen as an optimal tool to reduce future runoff for the case study. This set was chosen using the intensity of the 2018 storm as a baseline.

Energy consumption before floating solar photovoltaic technology

The first step to calculate the energy capacity needed to provide solar energy to single households in Waimanalo was to determine how many households are currently located within the rural town on the island of O'ahu (sub-watershed Kahawai). Calculating the number of households will help with the next step, which is determining how much electricity usage is currently within the town. The 2020 Residential Energy Consumption Survey (RECS) [34] was referred to determine the electrical demand per house. The average demand per household is then multiplied by the number of households to calculate the total annual energy demand.

The closer the floating solar photovoltaic panels are to the facilities that will offtake, the energy costs will be less expensive long-term. Located in the Waimanalo sub-watershed, the Honolulu Polo Club was a prime site as not only did this area receive a high amount of stormwater runoff, but it is also adjacent to a residential neighborhood. See **Figure 1** for details. This will be the potential location for the retention pond and the floating PV plant. Flood reduction calculations and cost analysis for retention pond.

Limited literature sources were available to determine which calculations were needed to estimate stormwater runoff reduction (percentage-wise), based on the calculated retention pond surface area. The only source found provided two equations where the runoff reduction is not calculated at all, but the storage volume [35] and runoff volume are. A hypothetical percentage of flood volume reduction was to be chosen at random. The storage volume depth is based on the hypothetical percentage of flood volume reduction.

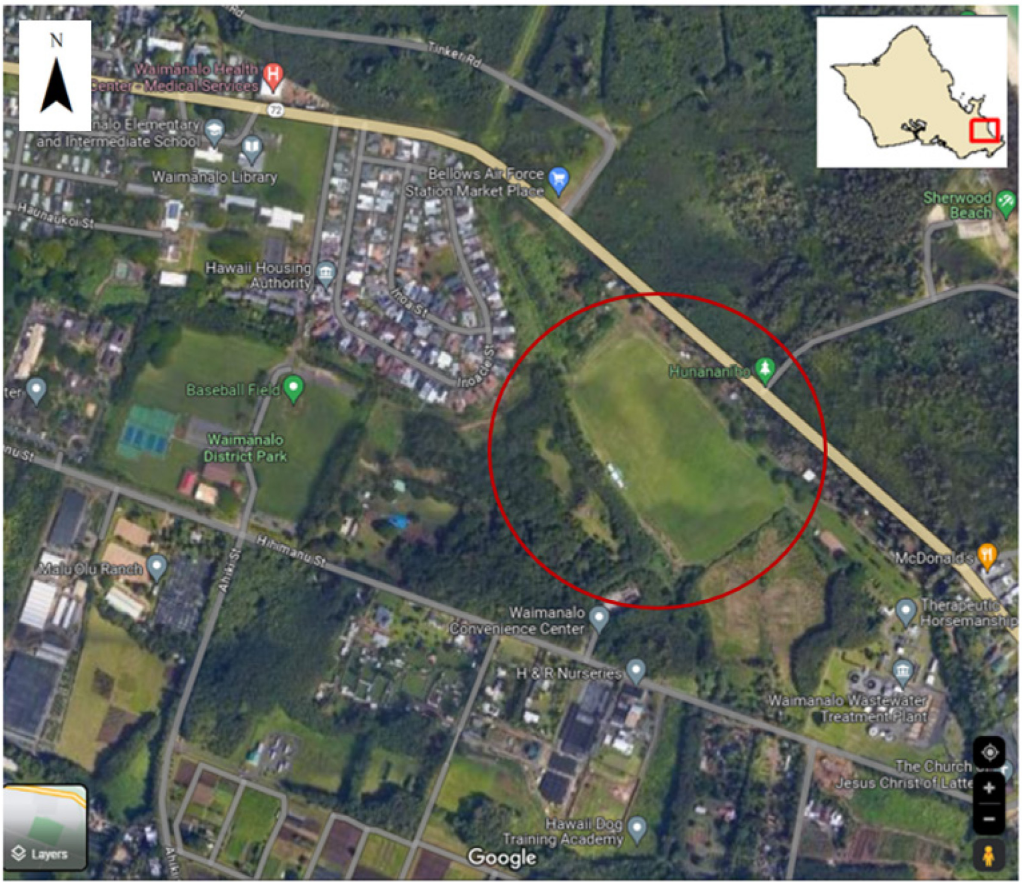


Figure 1. Close Aerial View of Honolulu Polo Club Location From Google Earth

To calculate the storage volume, the runoff volume was first estimated. The runoff volume was already calculated using eq. (1). The next step was to determine the peak outflow discharge and peak inflow discharge (ft^3/s) i.e. (m^3/s). For each case study, the largest volume recorded from the stream gauge data was used for peak inflow. Peak outflow was chosen as the desired outcome. All three case studies had a hypothetical peak outflow of 50%. The next step was to determine the outflow-to-inflow ratio. This was to determine the storage volume/runoff volume ratio. The storage volume/runoff volume ratio was found using the approximate detention basin routing type II rainfall chart [35].

The final step was to calculate the storage volume (m^2 cm). This was done by multiplying the ratio with the volume of runoff (m^2 cm). Based on the storage volume, it was determined whether the retention pond surface area (m^2), calculated from a previous section, could potentially reduce runoff based on the hypothetical percentage reduction.

NDPTC's engineering consultant provided cost information for each green infrastructure tool discussed in a previous sub-section more complex approach to perfecting the simulation.

Size calculations

Retention Pond. Runoff volume was first calculated to determine the size needed to reduce 50% of future stormwater runoff [36]. The runoff volume was computed using the following equation:

$$\begin{aligned} \textit{Runoff Volume}\ (\mathrm{m}^3) = \textit{Total Drainage Area}\ [\mathrm{ha}]\ \textit{of suitable site} \times \\ \textit{Impervious Percentage} \times \textit{Retention Requirement} \end{aligned} \tag{1}$$

The total drainage area where the proposed retention pond is located within the Waimanalo sub-watershed was converted from hectares to acres. The impervious percentage was determined based on land-use type (e.g.,commercial,residential, etc.) [35]. For example, if a retention pond was deemed suitable in an area that is a commercial or business district, the impervious percentage would be 85 percent.

Retention requirement (3.1410^{-6}/m) is one of the "most widely applied runoff methods" [35], particularly for water quality purposes. This would not need stormintensity.

The next step was to calculate the basin depth [36]. The equation is as follows:

$$\mathit{Basin\ Depth}\ (\mathrm{m}) = \mathit{Infiltration\ Time} \times \mathit{Infiltration\ Capacity} \times \mathit{Factor\ of\ Safety} \tag{2}$$

The maximum infiltration time is 72 hours to drain the basin. After 72 hours, the basin will remain consistently wet [36]. Regarding the case study, the maximum infiltration time will be set at 24 hours. That was the maximum amount of time it took for the site to flood [37].

The infiltration capacity is based on the type of soil material. It will be assumed the soil is made of loamy sand for the Waimanalo site. Based on this assumption, the [35] provides what the infiltration capacity would be†, with the unit set to inches/hour.

The factor of safety is set to 0.5 by default. The purpose is to "try to account for the compaction of the basin floor and the accumulation of sediments on the basin floor" [35].

The last step is to calculate the basin surface area [36]. The equation is as follows:

$$\mathit{Surface\ Area}\ (\mathrm{m}^2) = \mathit{Volume\ of\ Run\ Off} \times \mathit{Infiltration\ Available} \tag{3}$$

The volume of runoff is from the first step and the infiltration is available from the second.

<u>Electricity Capacity</u>. The goal of this study is to reduce the energy burden of Waimanalo by 50%. The 50 percent energy demand reduction was chosen to stay consistent with the retention pond methodology as it is also focused on reducing 50% of stormwater runoff; which was chosen at random. The following equations are as follows:

$$\mathit{Electricity\ Usage\ per\ household\ of\ Hawaii}\ (\mathrm{kWh}) = \frac{\mathit{Total\ site\ electricity\ consumption\ of\ Hawaii}\ (\mathit{billion}\ \mathrm{kWh}) \times}{\mathit{Number\ of\ housing\ units\ of\ Hawaii}(\mathrm{million})} \tag{4}$$

$$\mathit{Total\ Electricity\ Demand\ of\ City}\ (\mathrm{kWh}) = \mathit{Electricity\ Usage\ per\ household\ of\ Hawaii}\ (\mathrm{kWh}) \times \mathit{Number\ of\ Homes\ in\ Town} \tag{5}$$

$$50\%\ \mathit{of\ Total\ Electricity\ Demand\ of\ City}\ (\mathrm{kWh}) = \mathit{Total\ Electricity\ Demand\ of\ City}\ (\mathrm{kWh}) \times 0.5 \tag{6}$$

<u>Energy capacity with FSPV and cost</u>. As solar energy generation capacity reduces over time, the solar system was sized such that the amount of electricity generated at the 25th year of operation - the analysis period - typical life span of solar PV project [38] is at least equal to the 50% energy demand of the town. A trial-and-error method was used to determine the optimal

† The MDEQ Stormwater Management Guidebook (1999) does not provide the infiltration capacity of clay soil. Loamy sand was the closest soil type as it is made with varying amounts of sand, silt, and clay.

capacity of the floating solar PV needed for this study using the National Renewable Energy Laboratory's (NREL) System Advisor Model (SAM). The weather file and size of the module is changed according to the site location to determine the basin area size required for solar module (i.e., solar panels), which is taken from SAM. Area of the basin covered is calculated by dividing the solar module area (defined by SAM) by the area of the retention basin available.

$$\begin{aligned} &\mathit{Percentage\ of\ Basin\ Area\ Covered}\ (\%) \\ &= \frac{\mathit{Solar\ Module\ Area\ from\ SAM}\ (\mathrm{m}^2)}{\mathit{Retention\ Basin\ Area}\ (\mathrm{m}^2)} \times 100 \end{aligned} \tag{7}$$

Using NREL's Floating Photovoltaic System Cost Benchmark as a reference, direct and indirect capital cost was determined mentioned in **Table 4**. Equations were generated to get the costs for the selected size of the floating solar PV. The values are entered in SAM and along with it, state sales tax. Income tax is also adjected to the values corresponding to Hawai'i. Simulation is run by entering Power Purchase Agreement (PPA) price for the utility in the region **[39]** as assuming that the PPA price is same throughout the 25 years of operation. The net present value (NPV) was observed, which indicates the profitability of the analysis. Investment Tax Credit (ITC) is considered for the analysis as a default in SAM.

RESULTS/ANALYSIS

Case study

Severe flooding in portions of, Hawai'i's third largest island, O'ahu, occurred from April 13 to 15, 2018 due to an "upper-level, low-pressure system feeding off of enhanced moisture in the low-level trade winds". The intensity of rainfall resulted in an excessive amount of stormwater runoff, with floodwaters damaging multiple homes and cars, and debris blocked roads across the island from Kailua to Hawai'i Kai, including the Kalanianaole Highway, which is the main road for the southeast section of the island **[37]**, **[40]**.

Focusing on the town of Waimanalo located on the island of O'ahu - some of the irrigation ditches that run alongside the highway transported runoff to nearby streams, and the lack of maintenance on others resulted in flood inundation. Community and local government official participants who attended the Waimanalo Hawai'i Disaster Recovery Assistance Workgroup (HI-DRAW) community workshop believed it was the lack of maintenance of the existing drainage system not involving irrigation ditches was the second leading cause as they were just ignored over the years **[37]**.

A total of $100 million was appropriated through Act 12 to aid in flood disaster response and repairs. Act 12 was enacted to respond to, recover from, and mitigate damages from the April 2018 flooding in Kauai and other parts of the State (i.e., O'ahu). It addresses property and transportation infrastructure damage and other damages on Kaua'i and other parts of the state. O'ahu received a total of $25 million in which $10 million was "appropriated for the City and County of Honolulu to fix City and County facilities, infrastructure, and lands impacted by the flooding". The remaining funds were submitted to the Federal Emergency Management Agency (FEMA) for public assistance. State and non-governmental organizations (NGOs) (i.e., Department of Hawai'i Homelands and Department of Agriculture) also submitted projects to the assistance program; however, some did not qualify for funding.

According to Kim *et al.* (2019), the drainage system is distributed across land owned by the federal government, state government, private individuals, and other entities. Due to multiple ownership, the responsibilities are not assigned to a single landowner to care for the entire drainage system. Thus, system maintenance is limited.

From evaluating the City and County of Honolulu's current hazard mitigation plan (HMP) and the State of Hawai'i hazard mitigation plan, several alternative solutions were mentioned to help mitigate future flood events. However, green infrastructure was not mentioned as one of the alternative solutions (City and County of Honolulu, 2019). Additionally, while the State of Hawai'i clean energy plan [41] implemented and installed clean energy (i.e., residential solar photovoltaic roofs and wind farms), they have not considered providing additional green energy technology (e.g., floating solar photovoltaic technology) elsewhere that can benefit residential communities.

According to the State of Hawaii's Department of Business, Economic Development and Tourism (Research and Economic Analysis Division) [42] in 2021, low-income households carry a heavier energy burden compared to households that are above the poverty threshold. These households spend five times more than the average Hawai'ian on energy bills. This is because of an increase in oil prices, weather fluctuations, and number of people per household.

In addition, households at or below the poverty level were found to spend seven times higher of their income on electricity bills than all of Hawai'i.

As stated in the methodology section, a 1D steady flow flood model was created exhibiting the flood exposure. The model replicates the 2018 flood in Waimanalo watershed area (Figure 2 and Figure 3).

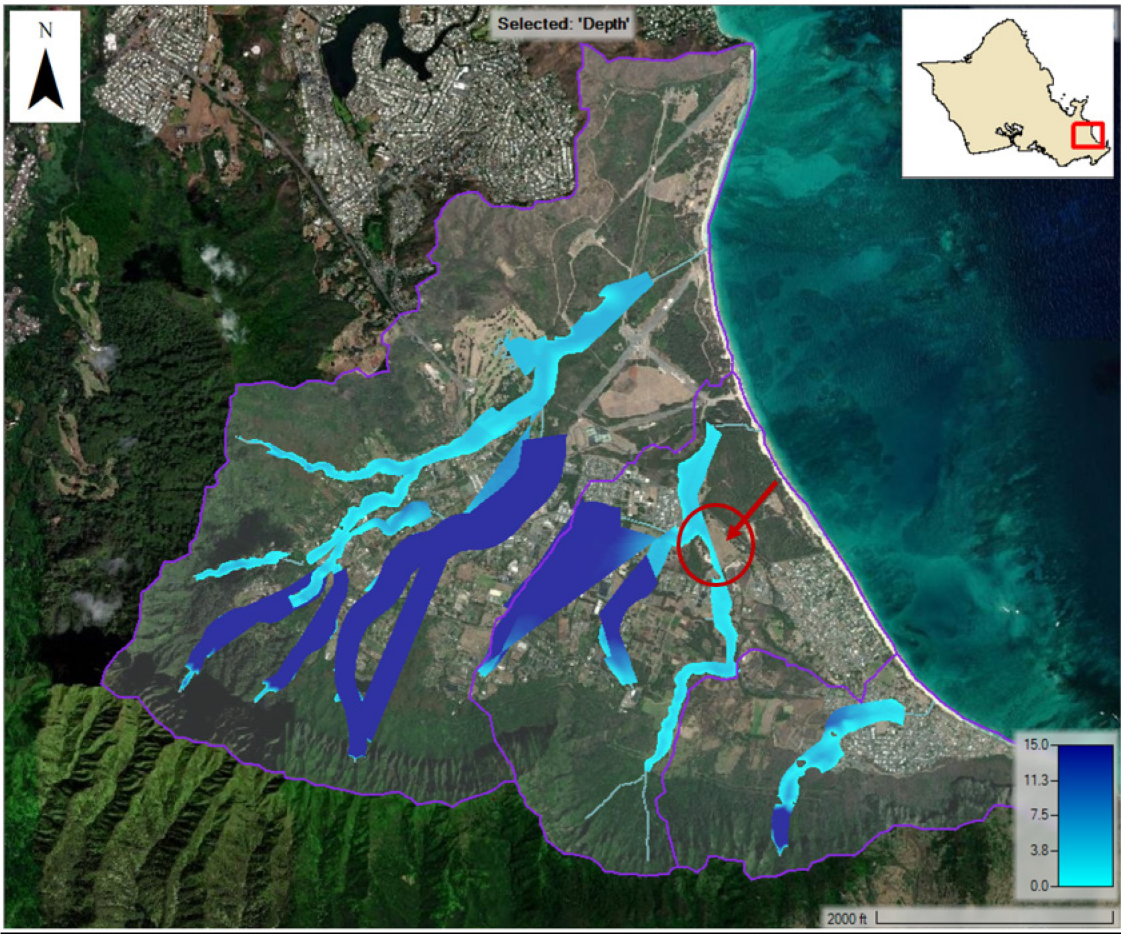


Figure 2. Flood extent in Waimanalo from the April 2018 storm event using the hec-ras program. Legend shows measurement of flood inundation in feet (1 ft = 0.3048 m)

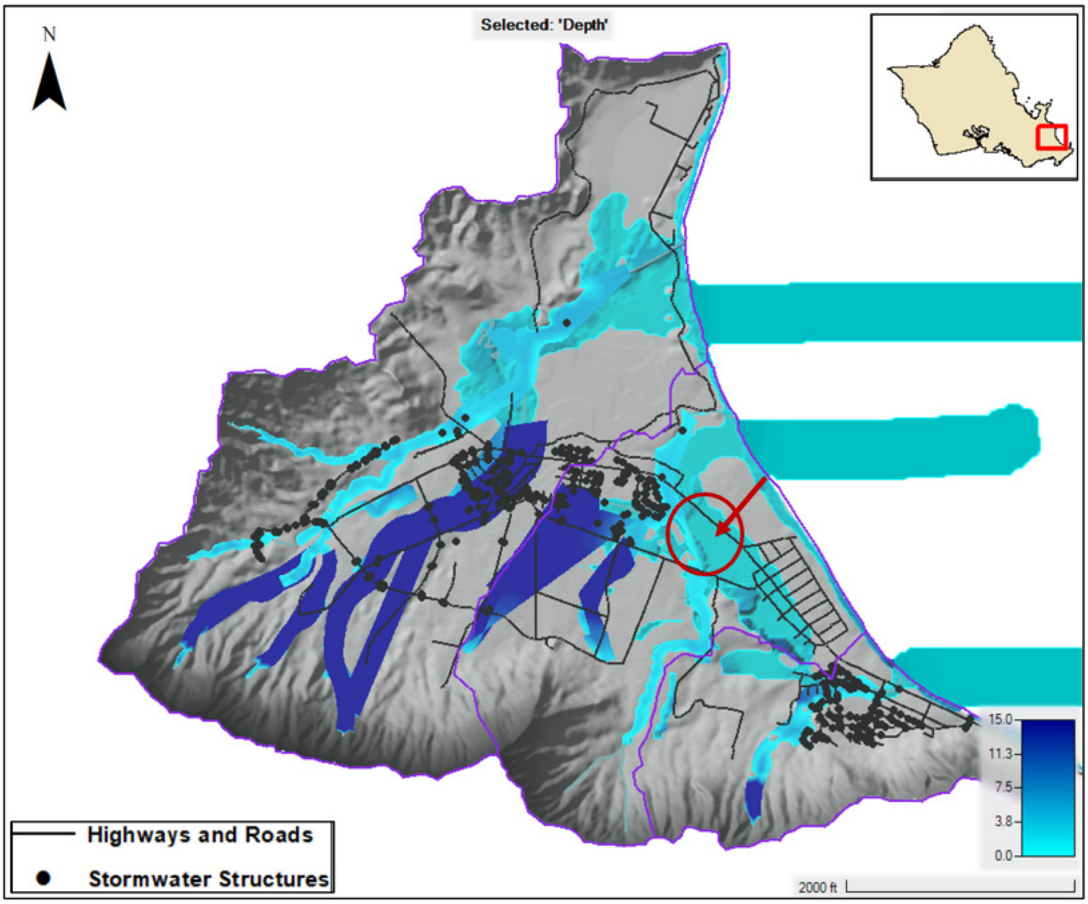


Figure 3. Flood extent coverage over several grey infrastructure tools in Waimanalo from the April 2018 storm event integrating flood data from both the hec-ras program and the HAZUS program. Legend shows the measurement of flood inundation in feet (1 ft = 0.3048 m)

According to Kim *et al.*, (2019), the flood extent was difficult to determine as maps were not produced by either the state or local emergency management agencies. **Figure 2** and **Figure 3** illustrate the 2-year flood in addition to what a 100-year flood would like. This was done using the Waimanalo and Inoaole stream gauge data. The 2-year recurrence interval was measured by the Waimanalo stream gage with peak flow at 8:27 PM with 1,240 ft^3/s (35.113 m^3/s) (USGS, 2016a; USGS, 2016b). The 100-year (1-percent peak AEP flood) recurrence interval was measured by the Inoaole stream gage with the flow at 2,570 ft^3/s (72.774 m^3/s).

Traditional grey infrastructure tools were mapped in HEC-RAS. These include road networks and several stormwater structures (i.e., catch basins, manholes, drain inlet, inlet, or outlet) (**Figure 3**).

Developing the flood model to cover the entire Polo Club using HEC-RAS (**Figure 3**) was challenging as there were some technical issues with digitization over the DEM terrain file. It is evident the polo club was completely inundated based on what is seen in **Figure 3**.

The green infrastructure tool chosen was a retention pond. The retention pond was found to potentially work that particular area of within the watershed in this case study based on past consultation with NDPTC's engineering consultant, Jimmy Yamamoto.

As stated in the previous section, a retention pond was chosen for this site. It is presumed the water level in the pond will be kept at a certain level to keep the floating solar PV panels afloat. The Honolulu Polo Club will be the main focus to determine what size the retention pond would hypothetically need to be to reduce 50% of flood volume. To determine the potential size of a retention pond, the runoff volume, basin depth, and surface area need to be solved (eqs. (1), (2) and (3). Calculations are as follows:

$$\begin{aligned} &Runoff\ Volume \\ &= Total\ drainage\ area\ of\ suitable\ site\ \times\ Impervious\ percentage \\ &*\ Retention\ Requirement\ =\ 47914.82\ \mathrm{m}^2\ \times\ 0.5\ \times\ 3.14\times 10^{-4}\ \frac{\mathrm{cm}}{\mathrm{m}^2} \\ &=\ 7.52\ \mathrm{m}^2\mathrm{cm} \end{aligned}$$

$$\begin{aligned} &Basin\ Depth\ =\ Infiltration\ Time \\ &\times\ Infiltration\ Capacity\text{: } Assuming\ the\ Soil\ is\ Made\ of\ Loamy\ Sand \\ &\times\ Factor\ of\ Safety\ =\ 24\ \mathrm{hr}\ \times\ 2.0\frac{\mathrm{in}}{\mathrm{hr}}\times\ 0.5\ =\ 24\ \mathrm{in.}\ (\mathrm{in}\ 2\ \mathrm{hr}) \\ &=\ 60.96\ \mathrm{cm} \end{aligned}$$

Therefore, surface area = 7.52 m^2 cm/60.96 cm = 68.48 m^2.

Calculations were conducted as follows to determine if the size of the surface area can hold 50% of the peak inflow (i.e., incoming runoff):

Runoff volume = 7.52 m^2 cm.
Peak Outflow = 620 cfs.
Peak Inflow = 1240 cfs

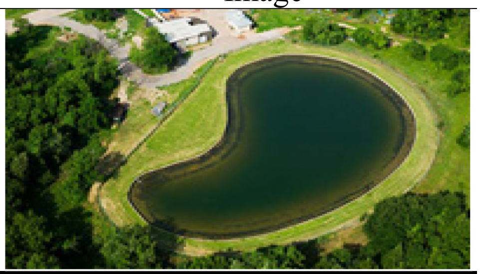
$$\text{Ratio}\ =\ 620\ \text{cfs}/1240\ \text{cfs}\ =\ 0.5\ (0.28\ \text{according to Type II Chart}) \tag{8}$$

$$\text{Hence}, 0.28\ \times\ 7.52\ \mathrm{m}^2\ \mathrm{cm}\ =\ 2.1056\ \mathrm{m}^2\ \mathrm{cm}\ (\text{storage volume}) \tag{9}$$

Therefore, to reduce runoff volume in 2018 by 50%, the surface area must be 68.48 m^2, with a storage volume of 2.1056 m^2 cm.

The cost of the retention pond has been estimated in **Table 1**.

Table 1. Cost analysis of implementing green infrastructure for the City and County of Honolulu

Feature and Location	Purpose	Costs	Image
Retention Pond: vegetated open space, and residential and commercial areas	Runoff Control	\$116.14-259/m^2 of wetland	

Solar power currently aids some of the single households on the island of O’ahu by offsetting electricity costs resulting in lower electricity costs for all single households. These households also stated solar energy is their main heating source. It can be assumed the reason for this is because solar energy utilizes either air or liquid as a heat transfer fluid. This means the solar energy is used as a fuel to heat the fluid which then translates thermal energy to the interior space. When air is utilized as the heating fluid, heated air from the solar collector is delivered promptly to the desired space. However, if liquid is employed as a heating fluid, the heat exchanger inside a blower unit will be used similar to how traditional forced air heating systems operate. A liquid system is preferred when accompanied by storage and is applicable for several uses in a household (i.e., radiant heating systems, boilers with hot water radiators, absorption heat pumps and coolers) [43]. As the liquid systems have a similar process as the domestic solar water heating system which is widely available - this makes the liquid-based heating system preferable to use and is considered more suitable for sustainable central heating.

Table 2 provides the factual basis needed to determine the total electricity demand to cover 50% of the total electricity demand. The components include the total site electricity consumption, number of housing units, and electricity usage per household on the island of O'ahu. This data was provided from the RECS data, along with applying the data to equations 4-6. The total number of single households located within the town of Waimanalo was found from Point2Homes [44], Based on the data, the total site electricity consumption (i.e., total electricity demand) within the town is 9.8 million kWh. 50% of the total electricity demand within the town of Waimanalo is 4.9 million kWh.

Table 2. Current 100 and 50 percent electricity consumption for single households in Waimanalo

Variables	Corresponding Information
Total site electricity consumption of a State (billion kWh)	3.8
Number of housing units of a State (million)	0.47
Electricity Usage per household of a State (kWh)	8085.10
Number of Homes in Waimanalo (-)	1,206
Total Electricity Demand of Town (kWh)	9,750,638
50% of Total Electricity Demand of Town (kWh)	4,875,319

Table 3 reveals the capacity of floating solar PV (MW_{dc}) required to cover 50% of the total electricity demand of the town (kWh) for the 25-year operational lifespan. The area of the basin was provided from the retention pond size calculations illustrated in the results section. With these three components, they applied to SAM to calculate the area required for floating solar PV. The percentage of basin covered was calculated using eq. (7). **Table 4** shows the direct and indirect cost considered for this study.

Table 3. Data used in SAM calculations to provide solar capacity in proposed retention pond and percentage of space needed to install floating solar PV

Floating Solar Details	Corresponding Values
Floating Solar Capacity (MW_{dc})	4.00
Electricity Production at 25th year of operation (kWh)	4,925,824
Area required for Solar PV (m^2)	21,052
Area of basin (m^2)	47,900
Percentage of basin covered (%)	43.95

Using the NREL case study illustrated in a previous section, the capital cost associated with the floating solar was entered in SAM (**Table 4**). The PPA price from Hawaii Electric for the O'ahu region was also applied in this analysis, which is 15.07 cents/kWh with 0% escalation per year. State income tax of 2023 was at 11% with 4.5% in sales tax. As mentioned before, an ITC of 30% was already included in the calculations. Based on the case study and the components needed to calculate the cost of floating solar PV, calculations showed the net capital cost to be 7.1 million dollars (USD) with an NPV of 3.4 million dollars (USD). As stated previously, the cost of implementation includes the initial cost for installment and maintenance for a lifespan of 25 years (**Table 5**).

Table 4. Direct and indirect cost of floating solar pv

Direct and Indirect Cost Variables	Corresponding Values ($/$W_{dc}$)
Direct Cost Variables	
Module ($/$W_{dc}$)	0.33
Inverter ($/$W_{dc}$)	0.04
Balance of system equipment ($/$W_{dc}$)	0.56
Installation labor ($/$W_{dc}$)	0.06
Installer margin and overhead ($/$W_{dc}$)	0.02
Contingency (% of above subtotal)	5.41
Indirect Cost Variables	
Permitting & environmental studies (% of direct cost)	9.12
Engineering and developer overhead (% of direct cost)	19.9
Grid Interconnection ($/$W_{dc}$)	0.09
Land Prep & transmission ($/$W_{dc}$)	0.02
Sales Tax (%)	4.5
Operation & Maintenance Cost ($/$W_{dc}$ yr)	15.5

Table 5. Cost for floating solar PV

Financial Variables	Corresponding Financial Outcomes
Net Capital Cost ($)	7,192.635
NPV ($)	3,375,270
Internal Rate of Return (IRR)	514.94%
Year IRR is achieved	25

DISCUSSION

According to the analysis, the proposed retention pond location can not only reduce future stormwater runoff should a similar storm of the same magnitude occur in Waimanalo but it is also a technically feasible location to install floating solar PV in the proposed basin.

Equitable deployment of green infrastructure solutions is necessary to improve resident and neighbourhood resilience, especially for disadvantaged communities, and provide long term social and economic co-benefits. These benefits include increased habitat biodiversity, decreased operational cost of public infrastructure and services [21], stormwater management and water treatment systems [22], improved health, and a sense of place [23], [45].

Floating solar photovoltaic technology can produce cheap and clean energy while increasing resiliency from extreme natural disasters (i.e., flooding), higher energy efficiency, evaporation reduction, reduction in maintenance cost after initial installation, prevention of algae growth, and low risk to wildlife (Spencer and Barnes, 2019). The PPA includes a flat pricing structure, which means that the residents will be reimbursed on a one-to-one scale with no escalation. The utility company will charge the residents 15.07 cents for every kWh consumed and the owner of the solar plant will sell the energy produced to the utility at 15.07 cents per kWh. In addition, floating solar provides greater energy density than roof solar PV [28], reduces land acquisition for future developed energy infrastructure for future residential and commercial development, and expands water from the retention pond for other uses (e.g., irrigation for existing agricultural lands). Similar to retention ponds, floating solar PV provides multiple triple-bottom-line benefits from social, environmental, and economic perspectives. As stated from an earlier section, benefits include reduction of carbon emission[28], economic development (e.g., job opportunities for disadvantaged community members[46], water quality improvement [47].

Initial installment costs for both floating solar PV and a retention pond for the Waimanalo case study would be high compared to traditional grey stormwater infrastructure and standard electricity from fossil fuels. Operations and maintenance costs would be low, equating to a total cost. Based on the results, it is evident the approach is financially feasible and can lead to profitability at the end of 25 years of operations along with reducing the energy burden of the town. With the net present value for floating solar PV shows to be significant, allowing for the utility providers to earn revenue and reduce costs for single households. Especially for low-income residents. This information is provided from the analysis (Table 1, Table 3) and past consultation with NDPTC's engineering consultant, Jimmy Yamamoto.

CONCLUSION(S) AND NEXT STEPS

Innovative solutions (e.g., green infrastructure and renewable energy resources) are required to mitigate carbon emissions while supporting disadvantaged communities.The co-design for both a retention pond and floating solar PV can help residents reduce energy burden, improve flood resilience, and decrease property damage from future flooding. The combination of green infrastructure and clean energy would enable the community of Waimanalo to bounce back from extreme weather events more quickly as the results show a retention pond can reduce 50% of stormwater runoff, has enough room to place floating solar panels that can reduce energy burden by 50%.

There are several takeaways from this study. First and foremost, when properly designed and installed, green infrastructure can help traditional infrastructure make communities more resilient to catastrophic flooding events. It is also clear that high electricity prices in low-income households at or below the poverty level carry a high energy burden within that watershed region, so the co-location analysed approach in the paper has the potential to make those residents more resilient financially too. Third, there is an opportunity to local governments to:

(1) Look further into understanding how green infrastructure can protect their communities equitably from flood risk, with a focus on disadvantaged communities.

(2) Receive technical support to assess how clean energy technologies can equitably increase energy resilience at no cost [48]

(3) Better understand the benefits of co-locating green infrastructure and clean energy projects.

(4) Quantify the benefits to improve their community's resiliency and sustainability efforts with this approach equitably.

(6) Understand how beneficial for the community it is to install floating solar photovoltaic panels on the proposed water basin as it will reduce energy burden for low-income single households.

(7) Receive support to access federal funding available to execute these projects [49], [50].

The combined implementation and installation of green infrastructure and clean technology would require an increase in pilot studies across the U.S., specifically in urban and rural areas. The hybrid approach presented in this paper (a combination of traditional grey infrastructure, green infrastructure, and clean energy technology) would provide multiple benefits to the community.

Increasing the adoption of a hybrid approach will require increasing advances in the regulatory and engineering fields. Feasibility analyses need to factor in the triple bottom line (economic, social, and environmental) benefits and trade-offs green infrastructure and clean energy can provide. There is also an opportunity to fill a knowledge gap for regulators, engineers, and communities on the potential of the approach presented in this paper. Training topics should include costs and benefits analysis, design strategies and tools, monitoring and maintenance, equity, existing local and state design standards, and inter-organizational coordination and communication. These educational topics should be integrated into existing community-based organizations and educational institutions like community colleges with the goal to create new job opportunities in disadvantaged communities.

In addition, collaboration between professionals from different disciplinary fields (hydrologists, engineers, landscape architects, planners, government officials, and environmental stewardship organizations) in both research and practice is needed as this can likely lead to the development of local and state regulations and policies that push towards enabling a seamless implementation in urban and rural areas. Applying the planning tools from climate adaptation plans, coastal resilience plans, hazard mitigation plans, etc. can strengthen collaboration connections and collaborative learning.

This methodology can easily be applied to the integration of the energy-water nexus approach with urban planning to help reduce the impacts of flooding and the energy burden in communities containing low-income and/or people of color. This integration can help (1) planners and engineers incorporate innovative design solutions that would be beneficial for urban and rural communities as far as disaster preparedness is concerned, (2) engineers, local communities, local government agencies, and utility owners understand the benefits this approach will provide both from an economic and social standpoint, (3) learn why the conventional approach is in many occasions not resilient against natural disasters neither sustainable , and (4) reduce climate impacts and energy burden for communities equitably.

Some of the limitations in this study show that a suitability analysis is needed to determine suitable colocation to reduce future stormwater runoff and energy burden. Another limitation included conducting an analysis to pinpoint the location of specific households who are dealing with high energy burden. Lastly, analysis of determining what water level is needed to keep floating solar panels afloat was another limitation.

For these factors to occur, additional research is needed to identify suitable co-design, households with high energy burden, and existing barriers that are preventing an energy-water nexus approach from being applied to communities at the neighborhood level. Identifying the barriers will push forward in understanding what strategies are needed to combat them and push for an innovative approach. By identifying the barriers and strategizing on various innovative solutions to overcome them requires a major call to action for environmental justice and change in land use and science policy from the local, state, and regional levels. But the most effective way to make this happen must start at the local level as it is the local policies impacting the disadvantaged communities the most.

Additional research should be considered on the different components of the cost-benefit analysis like operational, management, and maintenance costs between traditional grey infrastructure, green infrastructure, and clean energy with the goal for them to include social, economic, and environmental benefits for Waimanalo and other locations within the U.S.

This paper presents an innovative approach since no literature was found focusing on combining flood and energy burden reduction strategies.

NOMENCLATURE

Abbreviations

NPV	Net Present Value
IRR	Internal Rate of Return
USGS	United States Geological Survey
HEC-RAS	Hydrologic Engineering Center's River Analysis System
RECS	Residential Energy Consumption Survey
FEMA	Federal Emergency Management Agency
DEM	Digital Elevation Model
VDOT	Virginia Department of Transportation
MDEQ	Michigan Department of Environmental Quality
HI-DRAW	Hawai'i Disaster Recovery Assistance Workgroup
USD	United States Dollars

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