Light Flow Solutions

To: Dr. McAvoy, Amy Kramer, Jonathan Moore, Serenity Carroll, Michael Pahutski
From: Sean Clapp, Leah Dickerson, Mary Beth Kappler, Chase Neville
RE: Floating Solar Power Generation Feasibility Analysis
Date: April 16, 2021

Dear Sir or Madam,

Light Flow Solutions is excited to deliver the complete report for analyzing the feasibility of floating solar power generation.

Attached is the proposal, detailing the following:

- Background and Scope of the issue
- Quantification of FPV Benefits
- Reservoir Design
- Energy Yield Analysis
- Cost Analysis
- Lightflow recommendations
- Explanation of LightFlow Solutions Qualifications

Light Flow Solutions is here to offer design and modeling services and is available to provide further information or answer any other questions. Thank you for your consideration of Light Flow Solutions.

Respectfully,

Sean Clapp
Leah Dickerson
Mary Beth Kappler
Chase Neville

# Analyzing the Feasibility of Floating Solar Power Generation

University of Cincinnati Environmental Engineering Senior Capstone Design Project

Light Flow Solutions

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04.16.2021

# Contents

# Executive Summary

The objective of this project is to determine expected costs and design implementation associated with the installation of a floating solar array on the southern reservoir of the Northern Kentucky Water District's Memorial Parkway Treatment Plant (MPTP). Design considerations analyzed in this report were overall size, array configuration and subsequent size of each array, inverter size, anchoring configuration and installation sites, and associated quantities of equipment. This report also analyzed the energy output over the next 25 years based on size and expected losses from the system. After appropriate sizing and energy yield analysis were performed, a cost analysis was performed in order to determine economic feasibility of the system from a savings and profit perspective. Additional expected benefits are the reduction in evaporation and algal growth within the reservoir, which were also quantified. Quantification of benefits was done by creating two models, one for algae and two for evaporation. Both the algal and evaporation models were used to simulate the effects of shading and potential benefits to the treatment plant operations.

Design sizing calculations determined that an appropriate size of the Floating Photovoltaic (FPV) system would be approximately 48.6 percent of the surface of the reservoir which would provide 1.96 MW annually based on energy yield results. Two separate cost analyses were performed. The first scenario assumed that the FPV would be a generating unit and all energy would be sold to the grid at calculated PJM prices. The results indicated that the payback period in which initial costs equal profit would be 29 years if the system was installed in 2021. The second scenario considered the FPV system as a generating unit and the energy generated was used to directly offset the NKWD's power consumption. Those savings would yield a payback period of 14 years which is 15 years sooner than if the energy was sold to the grid.

# 1. Introduction

## 1.1 Scope of the Issue

The Northern Kentucky Water District (NKWD or District) owns and operates the 10-million gallon per day (MGD) Memorial Parkway Treatment Plant (MPTP) in Fort Thomas, Kentucky. The plant draws water from the Ohio River and stores it in two parallel open reservoirs with a combined capacity of approximately 35 million gallons (Figure 1).

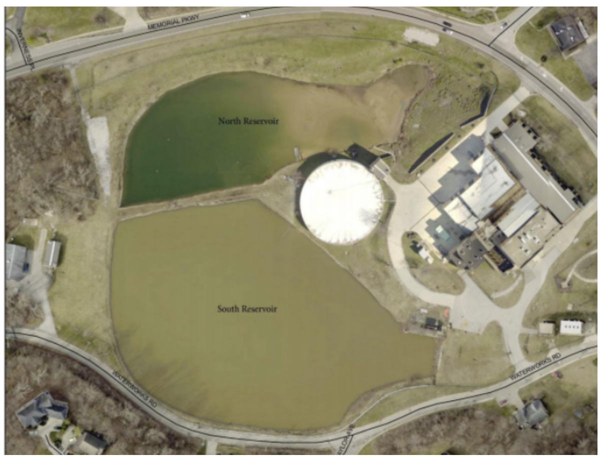


**Figure 1: Overview of the Memorial Parkway Treatment Plant**

The water treatment process involves several steps in order to provide clean drinking water to customers. The process becomes complicated when certain conditions exist, such as in the summer when warm water containing an abundance of nutrients can rapidly develop algal blooms and in some scenarios develop into harmful algal blooms (HABs) (Clean Water Action, 2019). The algal blooms not only occur in the river but also in the  reservoir. Once in the reservoir, some algae can release several toxins, the most common one known as cyanotoxins (Clean Water Action, 2019). The levels of this toxin can vary but in high enough concentrations can cause harm to human and wildlife health. While not all algal produces the toxin some create unpleasant odors, some affect the taste of the water, and others cause an interference with the treatment process itself (Clean Water Action, 2019). All of these issues  make it increasingly harder to treat the incoming water. In order to eliminate the threat from algae, NKWD treats the incoming water to the plant with Sodium Permanganate and Copper, which can increase operation costs.

With the rising power demands in conjunction with pressure to decrease usage and reliance on fossil fuel, solar photovoltaic has entered the market as a feasible renewable alternative energy solution. However, obstacles such as the large tracts of land needed and its associated costs have hindered its widespread installation. These factors, amongst others, are prevalent in countries such as China and Japan who are trying to implement more renewable energy but have limited options due to population density.

As a result of these two issues, NKWD proposed Floating Photovoltaic (FPV) as a means to remediate the algal blooms as well as generate power that can offset costs of the treatment plant. Light Flow Solutions analyzed several factors in this report; (1) economic feasibility (2) energy yield analysis (3) quantification of benefits such as evaporation and algae, and (4) design and size implementation.

# 2. Aspects to a FPV Plant

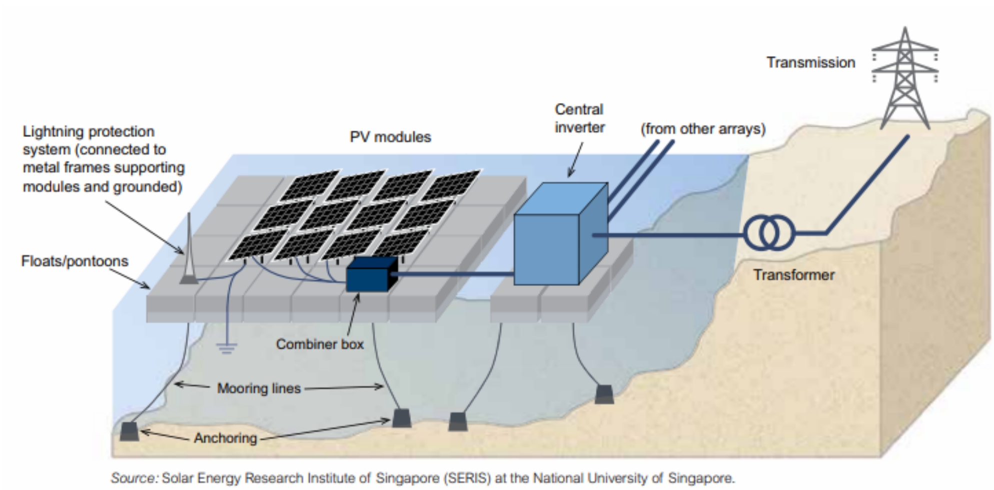


**Figure 2. Rendering of Several Aspects of a FPV (World Bank Group, 2019)**

A detailed visual representation of a FPV plant is provided in Figure 2. A typical FPV plant consists of a PV module, a supporting structure, floating structure, and the associated anchoring/mooring system. The floating structure is a buoyant platform for which the PV module support structure will be mounted on. The platform should be able to withstand the weight of the modules, the supporting structure and other electrical equipment. The support structure is attached to the floating structure and holds the PV module in place at a specific tilt angle. As per our alternative analysis performed last fall, Light Flow Solutions has decided to use Ciel et terre's HDPE hyderlio model, which combines the floating support structure into one low profile design. The PV module will sit on top of the floating structure and needs to be water resistant with low susceptibility to microcracking. Equipment recommendations from D3's preliminary report were used for the PV module, inverter, strings, and other items listed in their report.

The PV module Light Flow used in this design is the Longi Solar LR4-72HBD-450M, which is a 72 cell module (D3, 2020). The mooring system typically consists of anchors and tethers, which is intended to keep the entire system secure despite heavy weather conditions and to allow fluctuation with varying water levels. The final design will have an anchoring system as recommended in the package detailed on Ciel et Terre's website which includes: aluminum spreader bars, cables to link spreader bars to anchors, chains to adjust length, anchors and shackles to connect all components (Ciel et Terre, 2020 ). Lastly the electrical grid allows the solar power generated to be converted from and transferred to the grid. The inverters to be used are ABB: PVS-166-TL-POWER-MODULE-1-US[800V], which is different from D3's recommended ABB: PVS-175-TL-POWER-MODULE-1-US[800V] inverter (D3 2020). The change in inverter selection was due to the fact that when the energy yield analysis was performed, based on the size and configuration of the PV module, the inverters were not operating at full capacity. Hence we decided to use one that would be more efficient. The transformers meter and AC disconnect were parameters that are more generalized as the equipment would be specific to Duke Energy's standards.

# 3. Quantification of Benefits

Desired benefits of placing a floating solar array on the MPTP reservoir are a reduction in algae and reduction in evaporation rates. The degree to which shading can affect algal growth and evaporation rates is largely dependent on the climate of the reservoir and how much of the water's surface can be covered (Scavo et al., 2020). The next two sections will delve into how both parameters were affected and quantified by the deployment of a FPV system on the reservoir.

## 3.1 Evaporation Reduction

On a free body of water, evaporation can impact water levels. However, due to shading via FPV coverage, the evaporation could theoretically be reduced. For a municipal reservoir, a reduction in evaporation rates could potentially decrease the amount of pumping necessary to maintain necessary water levels. This section delves into quantifying the evaporation rates and determining whether the FPV array will impact the water levels enough that pumping costs can be taken into consideration in the cost analysis.

## 3.1.1 Methods & Results

The Priestly-Taylor equation was used to quantify the daily evaporation in millimeters per day over the past 5 years (Figure B-1 in Appendix B). Parameters such as daily average temperature, and maximum temperature, dewpoint, were collected from the NOAA station at Cincinnati/Northern Kentucky International Airport. Relative humidity data was not found for the county, so it was calculated from average temperature and dew point. After the preliminary data was collected other secondary variables were calculated such as saturation vapor pressure(es), actual vapor pressure (ea), slope of saturation vapor pressure curve (Δ), latent heat of vaporization (λ), psychrometric coefficient (y), and net radiation (Rn). Once all of the parameters have been calculated, solar radiation (Rs) data was used from The Kentucky Mesonet for Campbell County to calculate daily evaporation which was used as a control data set for which other simulations could be compared to. After the control data was calculated and graphed using a code in matlab, subsequent solar radiation (Rs) inputs that mimic various degrees of FPV coverage were calculated in Table A-1 in Appendix A. The solar radiation inputs in Table A-1 were calculated by using the highest solar radiation observed ( 34 MJ/m^2) and reducing it by subsequent percent coverage ranging from 0% to 90%. For example 20 % coverage would reduce the incoming solar radiation, 34 MJ/m^2, by 20%. The variation of evaporation results based on change in FPV coverage are provided in Appendix B (Figures B-2 and B-3). The percent coverage associated with the size of the FPV system was determined to be 48.6%, (~50%) and the associated solar radiation was 17 MJ/m^2. A simulation using 50% coverage was run and graphed. Results comparing the recommended percent coverage to the original data can be seen in Figure 3. Overall, comparing the original data to the several iterations using variation of solar radiation equivalent to different levels of coverage, there seems to be no significant reduction of evaporation based on the Priestly-Taylor model, thus not affecting water levels and subsequent pumping reductions.

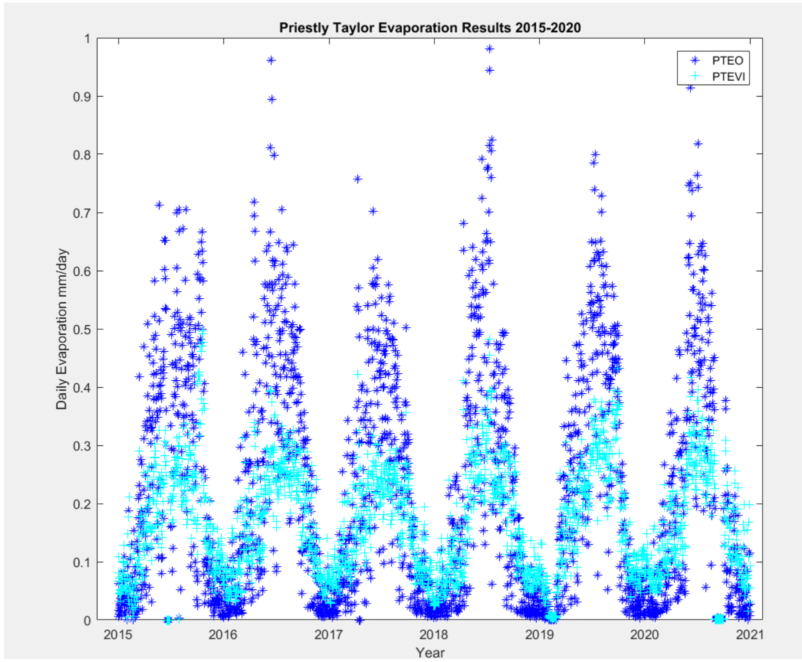


**Figure 3. Comparison of Priestly-Taylor Original Evaporation Data Set (PTEO) and Evaporation at 48.6% (~50%) Coverage (PTEVI)**

# 3.2 Algal Growth

## 3.2.1 Model Design

Our algae reduction model is a simplified version based on the EPA's QUAL2E water quality model (Linfield and Thomas, 1987). The simplified model simulates one day of growth using only the equations and functions related to algae growth and using assumptions and reservoir data to eliminate other simulated variables (see equations in Table A-2 Appendix A). The model finds the peak algae on an example day allowing us to represent the reduction of algae achieved by each interval of increasing coverage on the reservoir as the difference between the totally uncovered reservoir and a partially covered reservoir. Chlorophyll A concentration is used to approximate the concentration of algae in the reservoir, and is a typical benchmark representing a variety of different algae found in water quality samples.

To simplify the model and avoid additional data necessary to predict reservoir conditions it was assumed that the only limiting factor on algae growth in the reservoir would be the intensity of light available to the algae. This assumption is based on the fact that the reservoir has a history of algae problems and draws its feedwater from the Ohio river which is typically nutrient rich and unlikely to have low levels of nitrogen or phosphorus (the other typical limiters) that would reduce algae growth.

Therefore, the reduction of algae shown in this model is produced by reducing the light intensity entering the reservoir by a percent equal to the proposed percent coverage from the floating solar array. For example, 10% coverage by the solar array would reduce light entering the reservoir by 10%.

### 3.2.2 Model Assumptions

The parameters used in this model were the maximum algal growth rate, algal respiration rate, algal settling rate, linear algal self-shading coefficient and the Michaelis-Menton half-saturation constant for light. Parameter values were assumed to be the midpoint of the expected normal range supplied by the EPA's QUAL2E manual (Table A-3 included in Appendix A.). The algal growth, respiration, and settling rates were provided at standard conditions (20° C) and then corrected for temperature to the reservoir's conditions.

The reservoir's light extinction coefficient, which determines how deep into the reservoir algae can receive light, was taken as 25% of the average summer turbidity of the reservoir. This parameter has the most significant impact on the results and is a variable entirely dependent on the water quality conditions unique to the reservoir. Therefore, we relied on a method of retroactive estimation suggested for water treatment plant reservoirs in Brown. (1984) by using a low percentage of the relatively stable average turbidity that occurs during summer months as an approximation of the light extinction coefficient.

Due to these assumptions the model results have a high degree of uncertainty. Thus we recommend steps in our recommendations section that could be taken if North Kentucky Water District would prefer to do additional data collection for results with more confidence.

### 3.2.3 Model Data Inputs

Water quality data was provided by the North Kentucky Water District that included the reservoir's water temperature, Chlorophyll A concentration, and turbidity. Months that did not have temperature data were instead simulated using the average temperature from the closest ORSANCO sampling site on the Ohio River. The reservoir's average water depth was assumed to be 10 ft.

Light intensity was taken as a monthly average from data sets sampled at the Cincinnati - Northern Kentucky International Airport provided by Kentucky Mesonet, a division of the Kentucky Climate Center.

Daylight hours for each month were provided by Time and Date AS a website that describes itself as " the world's top-ranking website for time and time zones". Daylight hours were taken as the time between civil twilight and the end of daylight rounded to the nearest hour.

### 3.2.4 Model Results

Higher solar array coverage showed greater algae reduction. The most effective months for algae reduction are during the summer when light intensity and water temperature are at their highest, along with longer daylight hours providing more time for growth to occur over the day. Results for predicted percent algae reduction for each month at 10% coverage intervals of the reservoir's surface area are provided in Figure 4. Tabulated results can be found in Appendix A (Table A-4).

The 100% coverage simulation was omitted as it significantly skewed the plotted results, however, reduction in algae was found to be 80% during June and July. This result is comparable to reports by some reservoirs that use other methods (such as floating HDPE balls) to achieve 100% coverage of the reservoir.

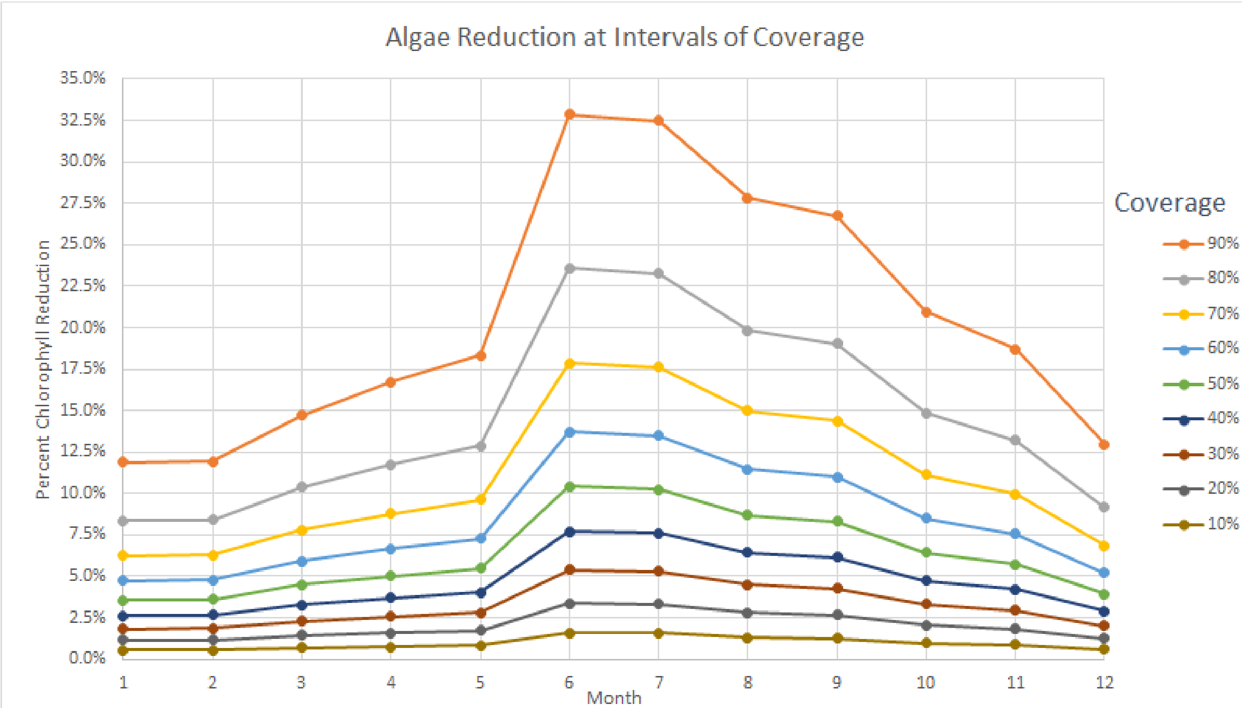


**Figure 4. Results of Algal Model Simulating Percent Coverage and Equivalent Percent Algal Reduction**

# 4. Design

## 4.1 Initial Sizing

As the reservoir's water level declines, the surface area available for the floats will decrease. For this reason, the design used the available space at lower water level conditions. The total available surface level at normal operating levels was estimated using the results from a surface area calculator tool. A tool was developed to determine the perimeter and surface area of the reservoir (AppendixC, Attachment 6). In order to determine a workable size at low levels, i.e., surface area after the reservoir drained 7.5 feet (5.33 m), it was assumed the reservoir took a circular shape at the surface and a triangular shape underneath to the deepest depth of the reservoir. Using the new found surface area, when the depth was reduced by 7.5 feet, the surface area was calculated to be 9,249 m^2 which takes up 48.6% of the surface area at normal operating conditions. This was the size we used for the scaling calculation discussed in the next section. Background calculations can be found in Figure 5.

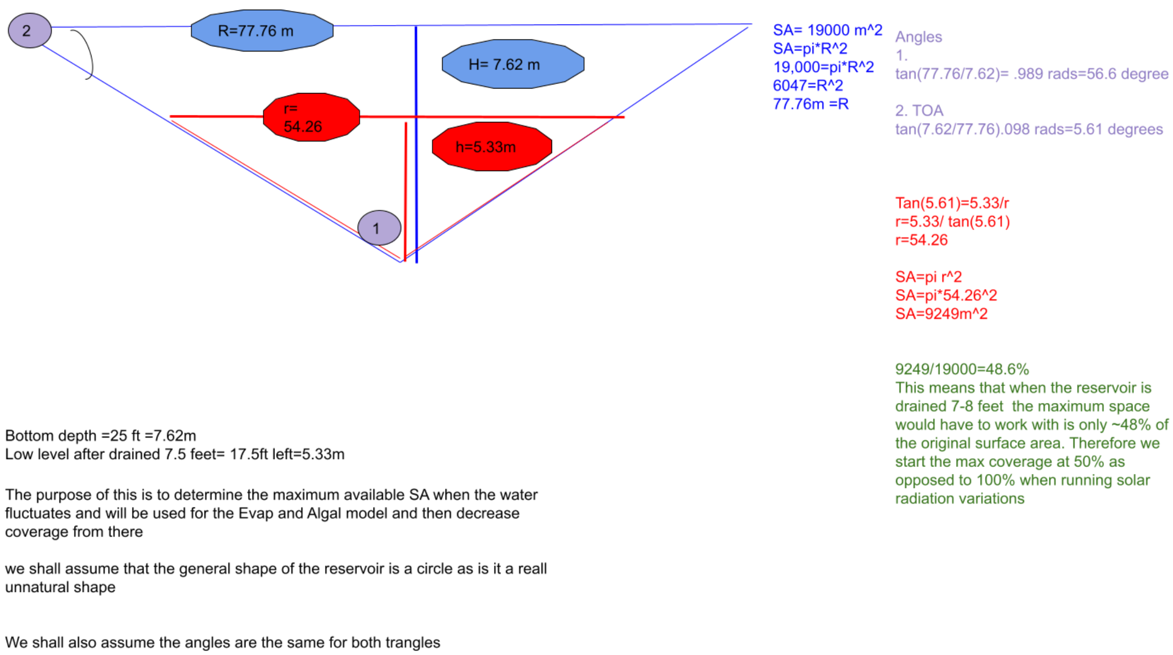


**Figure 5. Surface Area Calculations at Low Water Levels**

## 4.2 Scaling

The preliminary D3 design is provided in Appendix C (Attachments 1-3). The design came with several design parameters such as number of modules, inverters and strings, expected total annual solar output, azimuth, tilt angle, etc. After a sizing analysis was performed on their design it was determined to be half the surface area we used for our design. Therefore, we proceeded with using our recommended size and used D3's recommended parameters as reference, e.g., using the equipment models as discussed in Section 2. Based on their parameters we created a scaling ratio based on space (m^2) to determine how many modules and frames would fit in our recommended size. The calculations (Appendix A, Tables A-5 and A-6) shows the comparison between the D3 design and our design and the ratios that were derived in order to carry out the calculations. It should be noted that the number of modules (4,375) was updated from our original ratio calculation (4,383) based on results from our energy yield analysis. Annual energy output (MW), Annual Production (MWh), and the rated kWh/kWp listed in Table A-5 were also updated from our original ratio calculations as the SAM model provided a higher accuracy and took into consideration losses to the system of this particular size, of which the initial scaling calculations did not. After Table A-5 was completed, costs were then computed all of which are detailed in Section 6.

## 4.3 Implementation

After the sizing was calculated and checked for accuracy and feasibility, AutoCAD drawings of the site were composed. The drawings included the following: an existing conditions page using a Google Maps image of the site, a drawn out overview of the site and surrounding area using various colors and styles for clarification and grouping, and a design overview drawing of the size of the structure based on the sizing decisions. These drawings are demonstrated in Attachments C-4, C-6, and C-7 in Appendix C. The sizing of the floating structure was adjusted to find the optimal location that minimized the potential for the structure to make contact with the reservoir slopes.

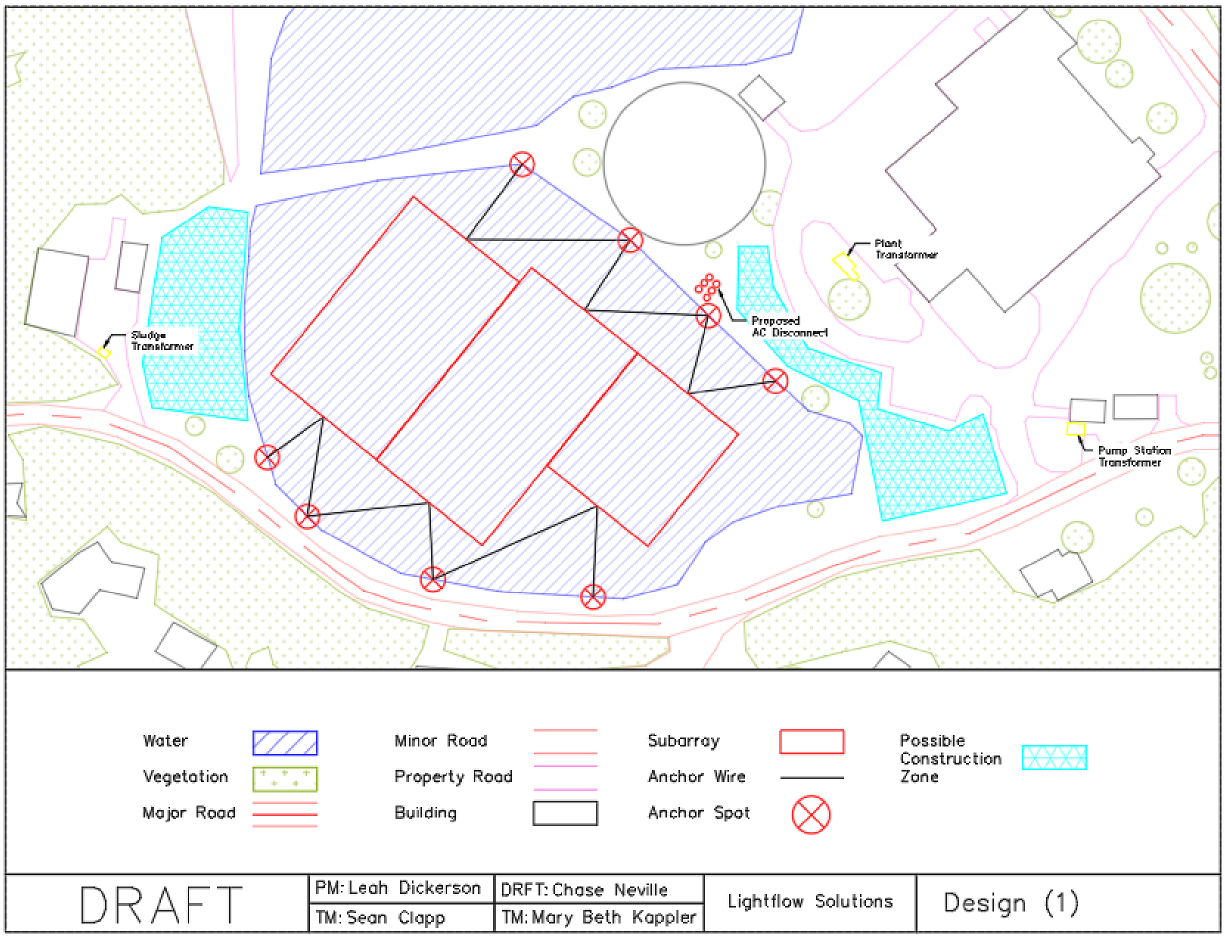


**Figure 6. PV Floating Structure for NKWD South Reservoir**

The anchor points were chosen so there would be overlap and less drilling needed thus increasing sturdiness while lowering the potential of drilling issues. Interior angles were prevented to the best of our ability by having the leftmost subarray be in line with the bottom of the middle subarray and have the right subarray be in line with the top of the middle subarray. The D3 location for the AC disconnect was kept. The possible construction zone for the subarrays to be assembled were marked based on the proximity to a road owned by NKWD as well as enough size for assembly.

# 5. Energy Yield Analysis

An energy yield analysis was performed to determine how much energy the system will produce in its lifetime. The System Advisor Model (SAM) from the National Renewable Energy Laboratory was used to determine the energy yield. The model requires the input of the module type, inverter type, and design parameters. Modules per string, strings in parallel in a subarray, panel tilt (12 degrees) , ground coverage ratio ( 0.16 GCR), and azimuth direction (25 degrees) are the design parameters that were necessary. The inputted length of each module is 2.11 m and the width is 1 m, with a module area of 2.11 m^2. Based on our design and calculations, there are 3 different sized subarrays that will be on the reservoir. To meet the sizing standard of the 11 inverters being used, each subarray has 22 modules per string. Subarray 1 will have 74 strings parallel resulting in a total of 1,628 modules. Subarray 2 is the largest and will have 80 strings parallel resulting in a total of 1,760 modules. Subarray 3 will have 47 strings parallel resulting in a total of 987 modules. All of the subarrays combined have a total 4,375 panels, 201 strings, and a total module area of 9,231.2 m^2. SAM also accounts for irradiance losses, DC losses, and AC losses. For each subarray, there is an average annual soiling loss of 5%. The DC power loss is 4.44% for each subarray and the AC wiring loss for the system is 1%. The model is using a 0.5% per year degradation rate for the multi-year simulations.

Once the necessary information was entered into SAM, the model was run to obtain results. It was estimated for the first year that the annual energy will be 2,028,106 kWh and an energy yield of 1,030 kWh/kW with a performance ratio of 0.83. The annual energy production will be the highest at year one and slowly decrease over the next 25 years, (Figure 6, Figure B-4).

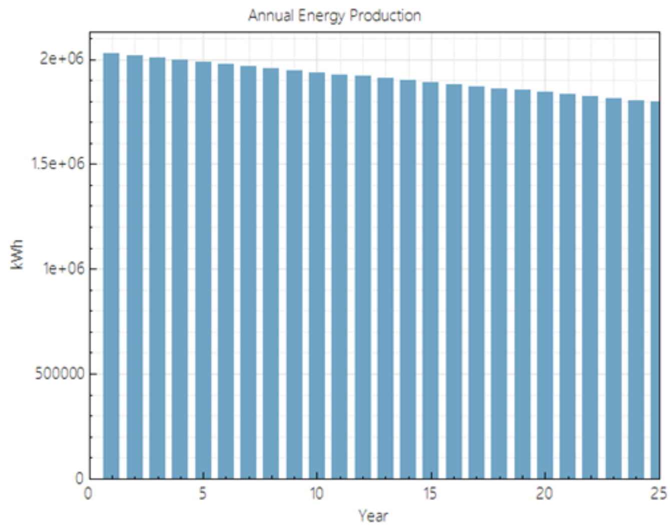


**Figure 7. Annual Energy Production from the FPVsystem over the next 25 years**

The simulation of the SAM model also produced the monthly energy production (kWh per month) for an average year. The peak energy produced was 309,619 kWh/mo in June and the least produced was 42,954.2 kWh/mo in December. The graph detailing the energy produced for each month is in Figure 8 (Appendix B, Figure B-5).

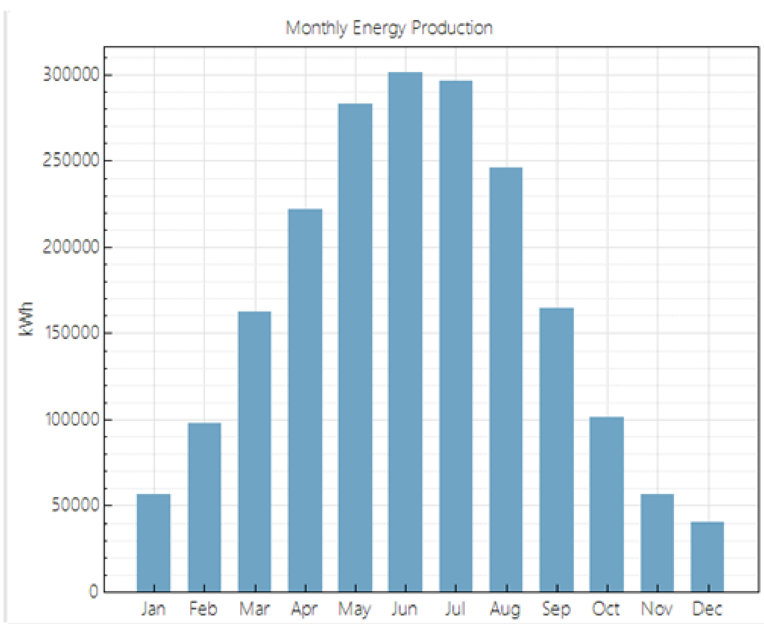


**Figure 8. Projected Monthly Energy Production From the FPV System**

The losses calculated for the system yielded a -1.23% inverter efficiency, -0.11% inverter nighttime consumption, and -0.73% inverter power consumption. More detailed description of losses can be seen in Appendix B (Figure B-6) .

# 6. Cost Feasibility

The determination of the economic feasibility of a 1.96 MW FPV system was based upon two cost analysis scenarios. The following sections details the process of determining inputs, and overall results of two different cost analyses.

## 6.1 Cost inputs

There are several economic parameters that needed to be determined. The parameters used in both payback period calculations are provided in Table 1 and 2.

**Table 1: Current Cost Parameter Upon Initial Installation**

| Current Cost Parameters | Quantity | Price Per Unit | Capital ($) |
|---|---|---|---|
| Initial Investment | - | - | 2,757,216.99 |
| Construction Labor | - | -- | 506,045.45 |
| Inverters | 11.00 | $ 11,290.27 | 124,192.97 |
| Strings | 201.00 | $280/ 304 m spool | 36,512.67 |
| Anchoring System | - | - | 506,045.45 |
| Panels | 4,375.00 | $225/panel | 984,375.00 |
| Support Frames | 230.00 | Unknown | 506,045.45 |
| Meter | 1.00 | $ /unit | 50,000.00 |
| AC Disconnect | 1.00 | $ /unit | 9,000.00 |
| Transformer | 1.00 | $ /unit | 35,000.00 |

**Table 2: Current Cost Parameters That Are Recurring**

| Current Cost Parameters | Monthly Demand | Units | Total Cost (Monthly ) | Total Cost (Annually ) |
|---|---|---|---|---|
| Maintenance | 30 hours | $33/hr | 1,000.00 | 12,000.00 |
| Pumping | 74,000.00 | kWh | 7,326.00 | 87,912.00 |
| Sludge House | 3,000.00 | kWh | 297.00 | 3,564.00 |
| Treatment Plant | 165,000.00 | kWh | 16,335.00 | 196,020.00 |
| Chemical - Copper | - | - | 1403.35 | 16,840.20 |
| Chemical - Permanganate | - | - | 1,526.88 | 18,322.58 |

### 6.1.1 Cost Upon Initial Installation

All equipment costs were determined by using the results from Appendix A (Table A-5) mentioned in Section 4. The capital costs were derived from the assumption that you could scale the costs from the D3 preliminary report. By scaling the projected solar output, the capital investment would be ~ $ 2.7 million dollars for a 1.96 MW system. Equipment such as the meter, disconnect and transformers are estimates provided by Duke as the equipment would be specific to their standards. Costs for construction, anchoring, and the support frames were not defined by D3 and hourly rates of labor costs are not easily obtainable without obtaining bids. Therefore placeholder amounts were inserted which used the initial capital cost ($2,757,216.99) and subtracted all of the known costs, of the inverters, AC disconnect, transformers, etc., which add up to $1,239,080.64 which leaves $1,518,136.36 to be divided equally amongst the unknown costs of construction, anchoring, and support frames for a place holder cost of $506,045.45.

### 6.1.2 Costs Recurring

NKWD provided energy demands from the treatment plant and were assumed to be consistent over the next 25-30 years. Additionally, it was assumed that the energy rate is $0.10 per kWh. Chemical savings were generated by taking the monthly chemical costs, applying the assumption that a 50% reduction in sunlight is equivalent to a percentage of reduction in algae (Figure 4) and that percentage is equal to the percent of monthly cost savings. The percentages used for each month were derived from Table A-4 in Appendix A when the algal model analysis was performed. The results of monthly savings are listed in Table 3 for Sodium Permanganate and Table 4 for Copper Sulfate for 2018. These monthly savings were then averaged over the course of the year to get average savings per month. For Sodium

Permanganate the average monthly savings is $180.75  and $193.06 for Copper Sulfate in 2018. After the average monthly costs for each year was generated, a three year average was taken, resulting in an overall monthly savings of $126.91 for Sodium Permanganate and $119.18 for Copper Sulfate. It should be noted that while these savings are not listed in Table 2, average monthly cost savings were used in determining the payback period in the savings approach, which will be discussed in Section 6.2.

The cost savings are not equivalent to what is spent treating the algae each month, resulting in outlying costs. The reduced monthly costs were calculated by subtracting the cost savings from the monthly cost and are listed in Table 3 and 4. The monthly costs were then averaged over the course of each year to get average monthly costs. Average monthly costs were then averaged over the course of three years to get $1403.35/ month for Sodium Permanganate and $1,526.88/ month for Copper Sulfate. It should be noted that these numbers were not used in payback period calculation but are still important as the FPV does not provide a 100% reduction in chemical costs.

**Table 3. Chemical Saving Calculation for 2018 for Sodium Permanganate**

| Savings Permanganate Costs - Example 2018 Calculations | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month - Year | Cost ($/Day) | Month Cost ($) | Reduction (%) | Monthly Savings ($) | Reduced Cost ($) | Avg. Savings ($/Month) | Avg. Costs ($/Month) |
| Mar - 18 | 33.9 | 1,050.90 | 4.5 | 47.29 | 1,003.61 | 180.78 | 2,086.31 |
| Apr - 18 | 56.70 | 1,701.00 | 5 | 85.05 | 1,615.95 | | |
| May - 18 | 76.5 | 2,371.50 | 5.5 | 130.43 | 2,241.07 | | |
| Jun - 18 | 111.3 | 3,339.00 | 10.4 | 347.26 | 2,991.74 | | |
| Jul - 18 | 113.535 | 3,519.59 | 10.3 | 362.52 | 3,157.07 | | |
| Aug - 18 | 114.70 | 3,555.55 | 8.7 | 309.33 | 3,246.21 | | |
| Sep - 18 | 121.66 | 3,649.65 | 8.3 | 302.92 | 3,346.73 | | |
| Oct - 18 | 112.38 | 3,483.63 | 6.4 | 222.95 | 3,260.67 | | |
| Nov - 18 | | 0.00 | 5.7 | 0.00 | 0.00 | | |
| Dec - 18 | | 0.00 | 3.9 | 0.00 | 0.00 | | |

**Table 4. Chemical Saving Calculation for 2018 for Copper Sulfate**

| Savings Copper Costs - Example 2018 Calculations | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month - Year | Cost ($/Day) | Month Cost ($) | Reduction (%) | Month Savings ($) | Reduced Cost ($) | Avg. Savings ($/Month) | Avg. Costs ($/Monthr) |
| Mar-18 | 42.79 | 1,326.35 | 4.50 | 59.69 | 1,266.67 | 193.06 | 2226.06 |
| Apr-18 | 47.38 | 1,421.47 | 5.00 | 71.07 | 1,350.40 | | |
| May-18 | 106.08 | 3,288.48 | 5.50 | 180.87 | 3,107.61 | | |
| Jun-18 | 129.42 | 3,882.53 | 10.40 | 403.78 | 3,478.75 | | |
| Jul-18 | 126.94 | 3,935.02 | 10.30 | 405.31 | 3,529.71 | | |
| Aug-18 | 109.22 | 3,385.94 | 8.70 | 294.58 | 3,091.37 | | |
| Sep-18 | 123.62 | 3,708.45 | 8.30 | 307.80 | 3,400.65 | | |
| Oct-18 | 104.61 | 3,242.96 | 6.40 | 207.55 | 3,035.41 | | |
| Nov-18 | | 0.00 | 5.70 | 0.00 | 0.00 | | |
| Dec-18 | | 0.00 | 3.90 | 0.00 | 0.00 | | |

| Year | 2018 | 2019 | 2020 | Avg. Year |
|---|---|---|---|---|
| Avg. Savings Perm. ($/Month) | 180.78 | 131.65 | 68.30 | 126.91 |
| Avg. Savings Copper ($/Month) | 193.06 | 84.84 | 79.63 | 119.18 |
| Avg. Costs Perm. ($/Month) | 2,086.31 | 1,602.83 | 891.51 | 1,526.88 |
| Avg.Costs Copper ($/Month) | 2226.06 | 1,076.13 | 907.86 | 1,403.35 |

Long term maintenance plans were not well defined in the initial literature review. However, it is known that soiling of the panels (i.e. fecal matter, dust ,etc) can lead to losses of the system (World Bank et al., 2019). Therefore the maintenance cost that was considered was due to removal of debris front he solar panels. It was assumed to take around 30 hours a month and at a personal rate of $33 an hour depending on the type of labor brought on to do the job. This totals to $990 per month which was rounded up to $1,000 per month ($12,000 per year) for all intensive purposes.

## 6.2 Scenario 1: Sell All Approach

For this scenario the FPV was considered a generating unit and all the energy generation was sold to the grid in dollar per MWh. The energy yield analysis estimated energy production over the next 25 years in order to gain an understanding of the potential profit over the lifespan of the system. Annual profit was determined by multiplying annual energy production, after a conversion from kWh to MWh, by annual averages of the Pennsylvania, Jersey, Maryland Power Pool (PJM) selling prices (data provided by Duke Energy). The revenue was then subtracted by the annual maintenance cost of $12,000. Maintenance cost was the only consideration. The annual net profit was then added onto each previous year in order to determine the cumulative profit over the next 25-30 to determine the payback period of the initial investment. The tabulated results are listed in Table 5 and graphed results are shown in Figure 8. Based on the results the amount of time it would take for the FPV to generate enough profit to offset the initial cost would be 29 years which is 4 years more than the expected lifetime of the system of 25 years.

**Table 5: Calculations for the Sell-All Payback Approach**

| Year | Average Sell Price ($/MWh) | Average Sell Price ($/kWh) | Annual Solar Output (kWh) | Profit ($) | Total Profit ($) | Cumulative Annual Profit ($) |
|---|---|---|---|---|---|---|
| 2021 | 33.89 | 0.03389 | 2.03E+06 | 68,732.65 | 56,732.65 | 56,732.65 |
| 2022 | 33.92 | 0.03392 | 2.02E+06 | 68,451.87 | 56,451.87 | 113,184.52 |
| 2023 | 33.78 | 0.033778 | 2.01E+06 | 67,817.44 | 55,817.44 | 169,001.96 |
| 2024 | 33.30 | 0.033298 | 2.00E+06 | 66,516.75 | 54,516.75 | 223,518.71 |
| 2025 | 33.30 | 0.033304 | 1.99E+06 | 66,193.03 | 54,193.03 | 277,711.74 |
| 2026 | 34.82 | 0.03482 | 1.98E+06 | 68,856.90 | 56,856.90 | 334,568.64 |
| 2027 | 37.58 | 0.037580 | 1.97E+06 | 73,941.79 | 61,941.79 | 396,510.43 |
| 2028 | 39.73 | 0.039725 | 1.96E+06 | 77,766.45 | 65,766.45 | 462,276.88 |
| 2029 | 44.49 | 0.04448 | 1.95E+06 | 86,650.53 | 74,650.53 | 536,927.41 |

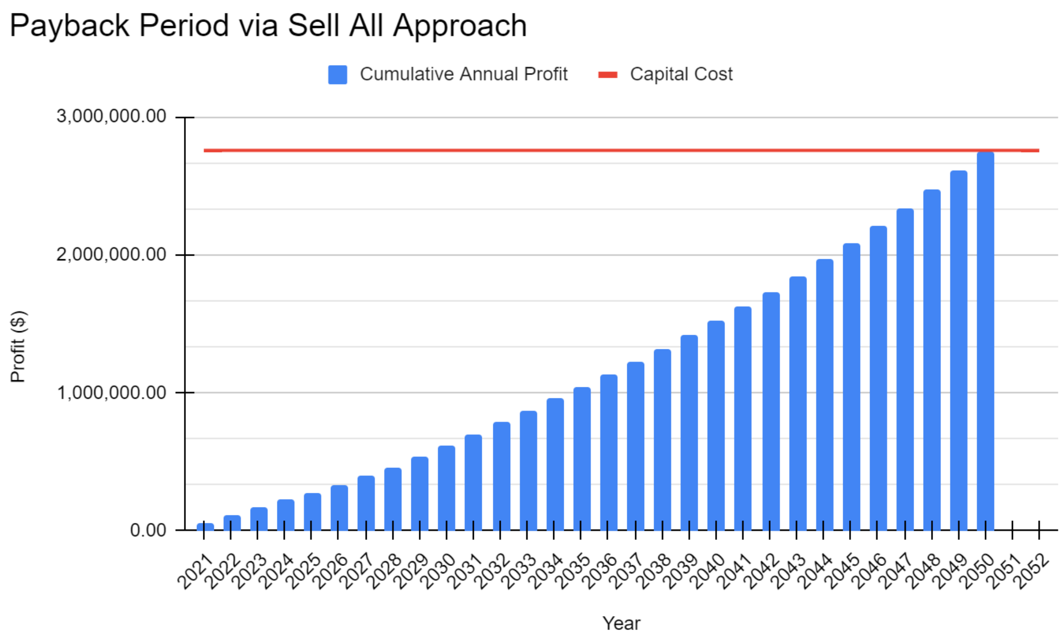


**Figure 8. Payback Period Curve Analyzing the Profit from Selling Energy to the Grid**

## 6.3 Scenario 2: Savings Approach

For this scenario the energy generation from the FPV system was used to offset the energy consumption of the water treatment plan (WTP). Calculations can be seen in Table 6 for reference in this section. There are two sources of what would be considered the savings: energy savings and chemical costs savings. The overall consumption of MPTP is a combination of energy consumption from the WTP building, sludge and pump house. The monthly energy amount that the PPV would be offset from NKWd's monthly energy needed to be determined using values from the energy yield analysis. Monthly energy input was calculated by dividing the annual production by 12. The amount of energy demand that was offset was then translated to a cost savings by multiplying monthly energy input by the rate they would normally pay for electricity at a rate of $0.10/kWh. The second source of savings was the reduction of monthly chemical costs which were determined to be $126.91 for Sodium Permanganate and $119.18 for Copper Sulfate.the method to calculate these numbers were described in Section 6.1.2 and are listed in Table 3 and 4. The costs that were considered was the monthly maintenance needed to upkeep the FPV already calculated to be $1,000 per month as described in section 6.1. Once all the savings and cost were determined, monthly savings was subtracted from monthly cost to get net monthly savings. Net annual savings were generated by multiplying net month savings by 12. It should be noted that the calculations were done on a monthly basis. Alternatively it could also be calculated from an annual basis from the beginning, the only parameter that would have to be modified would be the chemical costs savings. Each year the net annual savings is added from the  last year to get the cumulative annual savings.  Cumulative annual savings was plotted against the initial cost with the result being graphed in Figure 9. The figure shows that in order to get a full return on the initial investment it would take 14 years which is 15 years shorter than the sell-all approach.

**Table 6: Calculations for the Savings Payback Approach**

| Year | Annual Solar Output (kWh) | Monthly Energy Input to NKWD (kWh) | Monthly savings ($) | Net monthly savings($)  (S-C) | Net annual savings ($) ((S-C)*12) | Cumulative Annual Savings ($) |
|---|---|---|---|---|---|---|
| 2021 | 2,028,110.00 | 169,009.17 | 16,731.91 | 15,978.00 | 191,735.97 | 191,735.97 |
| 2022 | 2,017,890.00 | 168,157.50 | 16,647.59 | 15,893.68 | 190,724.19 | 382,460.16 |
| 2023 | 2,007,720.00 | 167,310.00 | 16,563.69 | 15,809.78 | 189,717.36 | 572,177.52 |
| 2024 | 1,997,600.00 | 166,466.67 | 16,480.20 | 15,726.29 | 188,715.48 | 760,893.00 |
| 2025 | 1,987,530.00 | 165,627.50 | 16,397.12 | 15,643.21 | 187,718.55 | 948,611.55 |
| 2026 | 1,977,510.00 | 164,792.50 | 16,314.46 | 15,560.55 | 186,726.57 | 1,135,338.12 |
| 2027 | 1,967,540.00 | 163,961.67 | 16,232.21 | 15,478.30 | 185,739.54 | 1,321,077.66 |
| 2028 | 1,957,620.00 | 163,135.00 | 16,150.37 | 15,396.46 | 184,757.46 | 1,505,835.12 |
| 2029 | 1,947,750.00 | 162,312.50 | 16,068.94 | 15,315.03 | 183,780.33 | 1,689,615.45 |
| 2030 | 1,937,930.00 | 161,494.17 | 15,987.92 | 15,234.01 | 182,808.15 | 1,872,423.60 |
| 2031 | 1,928,160.00 | 160,680.00 | 15,907.32 | 15,153.41 | 181,840.92 | 2,054,264.52 |
| 2032 | 1,918,440.00 | 159,870.00 | 15,827.13 | 15,073.22 | 180,878.64 | 2,235,143.16 |

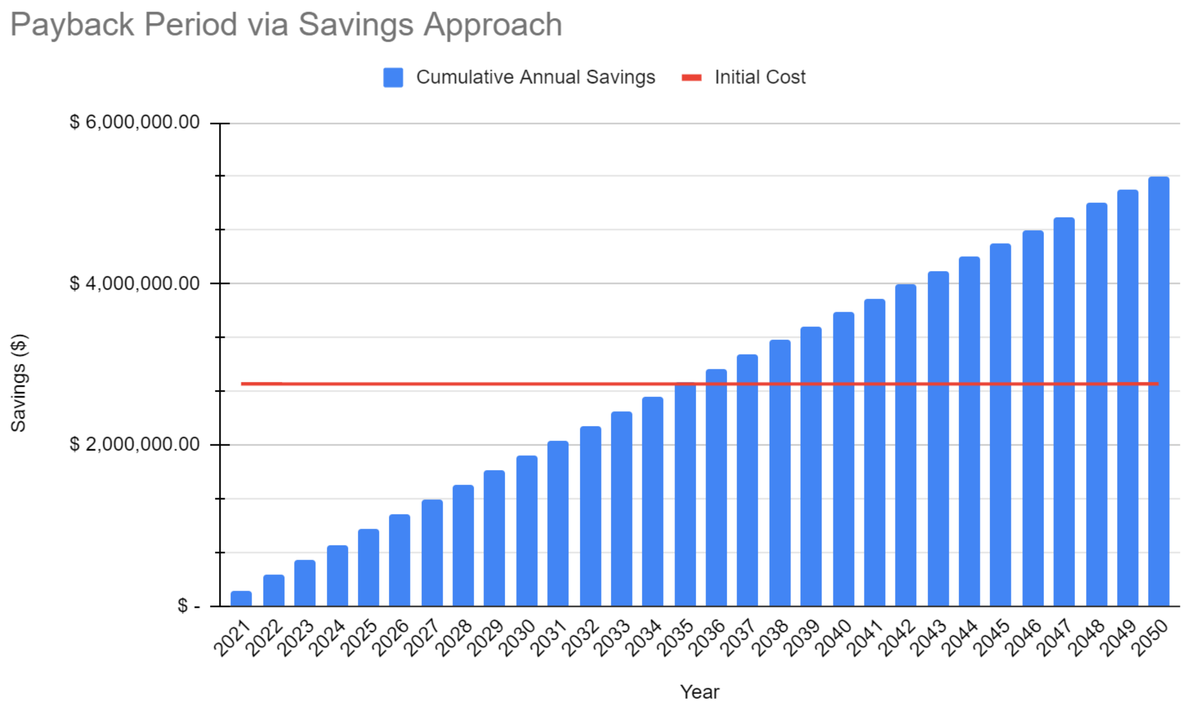


**Figure 9. Payback Period Curve Analyzing the Savings compared to initial cost**

# 7. Conclusion

The design of the FPV will consist of 3 smaller subarrays for a total of 4,375 Longi Solar modules using 48.6% of the total available surface area of the South reservoir and providing 1.96 MW of energy annually. The modules will have a tilt angle of 12 degrees and azimuth of 25 degrees. Floational structure will be Ciel et Terre's Hydrelio design to keep the panels afloat. Sizing did take into account operation limitation, algal and evaporation effects. With 48.6% coverage of the reservoir, evaporation reduction was negligible thus keeping pumping costs the same. Algae reduction was more substantial than the evaporation and with the assumption that the percent reduction in aglae is equal to cost savings, it was identified that percent savings were anywhere from 3.5%-10.5% in any given month with July being the highest reduction in algae. Based on the subsequent size of the FPV system it was determined that annual production would be roughly 2 million kWh (1.96 MW) of energy available to be sent to the grid. Monthly breakdown was available only for the first year because the system would decrease in efficiency over the next 25 years. Based on energy output it was determined how much profit could be generated by either selling it to the grid or by using it to offset costs at the treatment plant. The sell-all approach indicates that the payback period was 29 year, 4 years longer than the lifespan of the system. The cost saving approach would be substantially shorter than the lifespan, the payback period being 14 years. Therefore, from an economic perspective the preference would be to allow the system to offset water treatment operating costs as it would save the WTP $0.10/kWh whereas the energy would be sold at $0.03-0.08/kWh to the grid.

## 8. Recommendations

While Lightflow Solutions has designed the FPV system to the best of our capability, there are a few recommendations we would suggest prior to project implementation in order to make the project more accurate and practical:

1. Bathymetry study: This study will aid in the official shape, slope, and other parameter to help better estimate surface area that can be utilized at low levels
2. Space Limitations: Due to the general space and slope surrounding the reservoir a general plan tailored specifically to NKWD will need to be developed. Additionally due to the limited space around the reservoir, special plans are needed if the FPV plant is to be removed
3. Chemical usage collection: Further data would have to be collected in order to consider a better correlation between reduction in algal and reduced chemical costs, ideally a direct function for predicting treatment dosage and cost from algae concentrations would be found.
4. Algae model Improvement: The accuracy of the algae model could be improved if NKWD performed secchi disk tests to determine the regular state of light penetration into the reservoir, this could be used to find a more accurate light extinction coefficient, which was found to be the most impactful parameter on algae growth.

## 9. Acknowledgements

Light Flow Solutions would like to honor and thank the following teams and individuals for their contributions to the completion of this project:

- Dr. Drew McAvoy for his guidance and advice
- Northern Northern Kentucky Water District for providing us with pertinent information

- Duke Energy for providing us with guidance on the costs analysis align with pertinent information

## 10. Works Cited

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# 11. Appendices

## 11.1 Appendix A: Tables

Table A-1. Range of FPV % coverage and calculated equivalent Solar radiation

| | |
|---|---|
| Reservoir Surface Area: | 19000 $m^2$ of available space |

| Coverage (%) | coverage area ($m^2$) | Equivalent Solar Rad ($MJ/m^2$) |
|---|---|---|
| 0.00 | 0.00 | 34 |
| 10.0 | 1900 | 30.6 |
| 20.0 | 3800 | 27.2 |
| 30.0 | 5700 | 23.8 |
| 40.0 | 7600 | 20.4 |
| 50.0 | 9500 | 17 |
| 60.0 | 11400 | 13.6 |
| 70.0 | 13300 | 10.2 |
| 80.0 | 15200 | 6.8 |
| 90.0 | 17100 | 3.4 |
| 100.0 | 19000 | 0 |

Table A-2 Algae Model Equations

Algae Concentration Equation (I)

$$A = A_o \exp^{\left(u - p - \frac{\sigma_1}{d}\right)t}$$

$u$ = specific growth rate of algae (day$^{-1}$)

$p$ = respiration rate of algae (day$^{-1}$)

$\sigma_1$ = settling rate of algae (ft/day)

$d$ = average depth (ft)

$t$ = days

$A$ = Algal biomass (mg-A/L)

$A_o$ = Algae initial (mg-A/L)

Algae growth rate equation (II)

$$u = u_{max}(FL)$$

$u$ = specific growth rate of algae (day$^{-1}$)

$u_{max}$ = maximum specific growth rate of algae (day$^{-1}$)

$FL$ = algal growth limitation factor for light

Light Limit Factor Equation (III)

$$FL = \left(\frac{1}{\lambda\, d}\right) ln \left[\frac{k_L + I}{k_L + I\, exp^{(-\lambda d)}}\right]$$

$FL$ = algal growth limitation factor for light

$k_L$ = light intensity at which growth rate is 50% of the maximum growth rate

$\lambda$ = light extinction coefficient (ft$^{-1}$)

$d$ = average depth (ft)

$I$ = surface light intensity Btu/ft$^2$-hr

Light Limit Factor Equation (IIII)

$$\lambda = \lambda_0 + \lambda_1 A + \lambda_2 A^{2/3}$$

$\lambda$ = non-algal portion of the light extinction coefficient (ft$^{-1}$)

$\lambda_1$ = linear algal self-shading coefficient (ft$^{-1}$) (ug/L)$^{-1}$

$\lambda_2$ = nonlinear algal self-shading coefficient (ft$^{-1}$) (ug/L)$^{-2/3}$

$A$ = algae concentration (ug/L)

Table A-3. Algae Model Coefficients

TYPICAL RANGES FOR QUAL2E REACTION COEFFICIENTS

| Variable | Description | Units | Range of Values | Variable by Reach | Temperature Dependent |
|---|---|---|---|---|---|
| $\sigma_1$ | Algal settling rate | ft/day | 0.5-6.0 | Yes | Yes |
| $\mu_{max}$ | Maximum algal growth rate | $day^{-1}$ | 1.0-3.0 | No | No |
| $\rho$ | Algal respiration rate | $day^{-1}$ | 0.05-0.5 | No | No |
| $K_L$ | Michaelis-Menton half-saturation constant for light (Option 1) | $Btu/ft^2$-min | 0.02-0.10 | No | No |
| $\lambda_0$ | Non-algal light extinction coefficient | $ft^{-1}$ | Variable | No | No |
| $\lambda_1$ | Linear algal self-shading coefficient | $\frac{1/ft}{ug\ Chl\underline{a}/L}$ | 0.002-0.02 | No | No |

Table A-4. Algae Reduction Results - 10% Intervals of Coverage Across Monthly Conditions

| Coverage | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| None | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| 10% | 0.50% | 0.50% | 0.70% | 0.80% | 0.80% | 1.60% | 1.60% | 1.30% | 1.30% | 1.00% | 0.90% | 0.60% |
| 20% | 1.10% | 1.20% | 1.40% | 1.60% | 1.80% | 3.40% | 3.30% | 2.80% | 2.70% | 2.10% | 1.80% | 1.30% |
| 30% | 1.80% | 1.80% | 2.30% | 2.60% | 2.80% | 5.40% | 5.30% | 4.50% | 4.30% | 3.30% | 2.90% | 2.00% |
| 40% | 2.60% | 2.70% | 3.30% | 3.70% | 4.00% | 7.70% | 7.60% | 6.40% | 6.10% | 4.70% | 4.20% | 2.90% |
| 50% | 3.60% | 3.60% | 4.50% | 5.00% | 5.50% | 10.40% | 10.30% | 8.70% | 8.30% | 6.40% | 5.70% | 3.90% |
| 60% | 4.70% | 4.80% | 5.90% | 6.70% | 7.30% | 13.70% | 13.50% | 11.40% | 11.00% | 8.50% | 7.60% | 5.20% |
| 70% | 6.20% | 6.30% | 7.80% | 8.80% | 9.60% | 17.90% | 17.60% | 15.00% | 14.40% | 11.20% | 9.90% | 6.90% |
| 80% | 8.30% | 8.40% | 10.40% | 11.70% | 12.90% | 23.60% | 23.30% | 19.80% | 19.00% | 14.80% | 13.20% | 9.10% |
| 90% | 11.90% | 12.00% | 14.70% | 16.70% | 18.30% | 32.90% | 32.50% | 27.80% | 26.80% | 21.00% | 18.70% | 13.00% |
| 100% | 32.30% | 32.30% | 39.20% | 46.70% | 52.10% | 80.40% | 80.80% | 72.20% | 70.00% | 56.50% | 49.80% | 34.50% |

Table A-5: Respective Scaling results from calculations and energy yield analysis

| Parameter | D3 | LightFlow |
|---|---|---|
| Size ($m^2$) | 4,931 | 9,249 |
| Sol. Array Coverage (% of full space) | 25.95 | 48.60 |
| Inverters (#) | 6 | 11 |
| Strings (#) | 102 | 201 |
| Wire (m) | 20117 | 39642 |
| Power (MW) | 1.05 | 1.96 |
| PV Modules (#) | 2,337 | 4,375 |
| Module width (m) | 1.00 | 1.00 |
| Module height (m) | 2.11 | 2.11 |
| Module area ($m^2$) | 2.11 | 2.11 |
| Number of frames | 123 | 230 |
| Frame Size | 1x19 | 1x19 |
| Intra Row Spacing (m) | 0.50 | 0.50 |
| Annual Production (MWh) | 1,094 | 2,028 |
| kWh/kWp | 1,039.90 | 1,030.00 |

Table A-6. Ratios for Scaling Design Parameters for Light Flow Design Size

| Parameter | Ratios | Applied to Design Size | Result |
|---|---|---|---|
| Frames # / ($m^2$) | 0.02 | 9249 ($m^2$) | 230.71 |
| Modules # / ($m^2$) | 0.47 | → | 4383.4 |
| Annual Production kWh / ($m^2$) | 221.79 | → | 2051320 |
| Inverters # / ($m^2$) | 0.00 | → | 11.3 |
| Strings # / ($m^2$) | 0.02 | → | 191.3 |
| MW / ($m^2$) | 0.00 | → | 1.97 |
| kWh/kWp | 0.21 | → | 1950.5 |

## 11.1 Appendix B: Figures

$$\Delta = 4098\, e_s/(237.3 + T_a)^2$$

$$\gamma = 0.00163\, \frac{P}{\lambda}$$

$$R_n = R_s(1 - \alpha)$$

$$\lambda = 2.501 - T_a\, 2.361 \times 10^{-3}$$

$$e_a = 0.6108 \times \exp\left[\frac{17.27\, T_a}{T_a + 237.3}\right]$$

$$e_s = ea/RH$$

$$E_{P-T} = \beta\left[\frac{\Delta}{\Delta + \gamma} \times \frac{R_n}{\lambda}\right]$$

Figure B-1. Priestley -Taylor Equations Used to Determine Parameters Used to Calculate Evaporation in mm/day

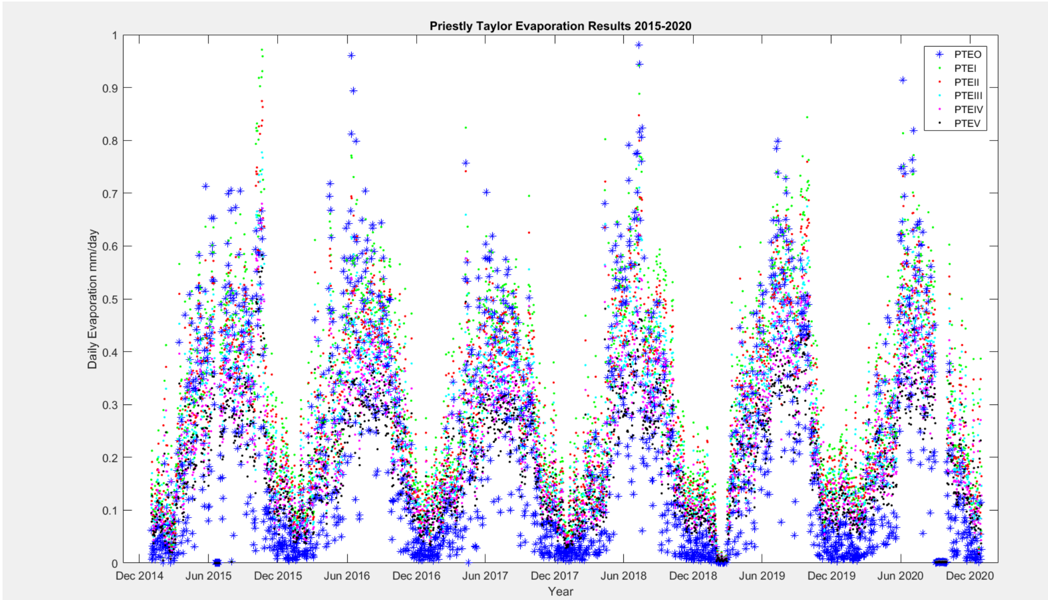



Figure B-2. Priestly-Taylor Evaporation Results for Incremental FPV Coverage Ranging from 0% Coverage (PTEI) to 40% Coverage (PTEV)

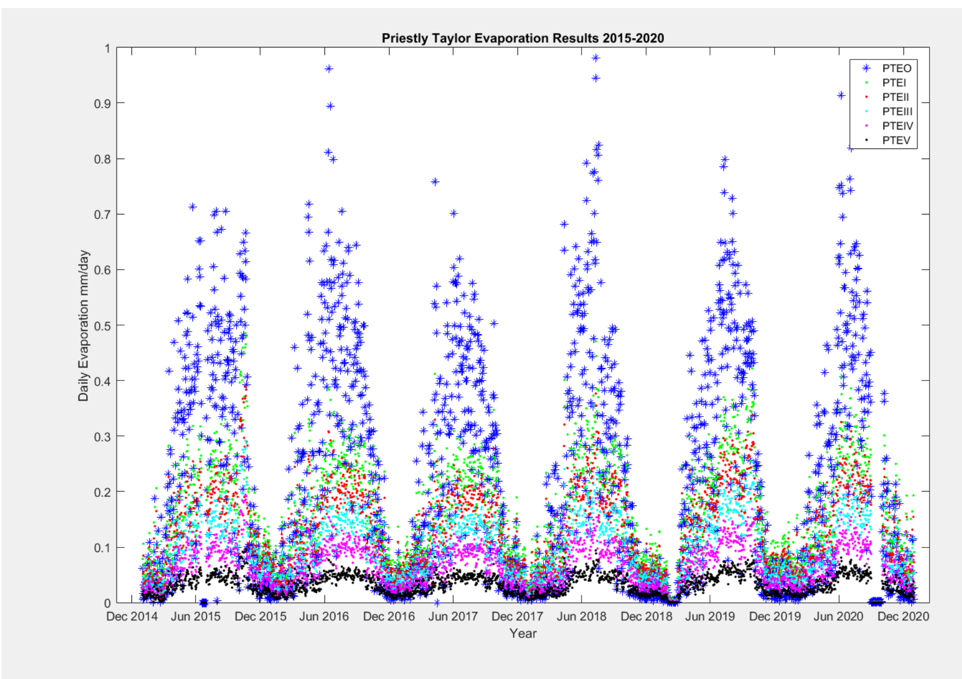



Figure B-3. Priestly-Taylor Evaporation Results for Incremental FPV Coverage Ranging from 50% Coverage (PTEI) to 90% Coverage (PTEV)

| | Energy (kWh) |
|---|---|
| 1 | 0 |
| 2 | 2.02811e+06 |
| 3 | 2.01789e+06 |
| 4 | 2.00772e+06 |
| 5 | 1.9976e+06 |
| 6 | 1.98753e+06 |
| 7 | 1.97751e+06 |
| 8 | 1.96754e+06 |
| 9 | 1.95762e+06 |
| 10 | 1.94775e+06 |
| 11 | 1.93793e+06 |
| 12 | 1.92816e+06 |
| 13 | 1.91844e+06 |
| 14 | 1.90876e+06 |
| 15 | 1.89914e+06 |
| 16 | 1.88956e+06 |
| 17 | 1.88003e+06 |
| 18 | 1.87054e+06 |
| 19 | 1.8611e+06 |
| 20 | 1.85171e+06 |
| 21 | 1.84237e+06 |
| 22 | 1.83307e+06 |
| 23 | 1.82382e+06 |
| 24 | 1.81462e+06 |
| 25 | 1.80546e+06 |
| 26 | 1.79634e+06 |

Figure B-4: Average Annual Energy Production (kWh/year)

| | DC energy (kWh/mo) |
|---|---|
| Jan | 59154.8 |
| Feb | 101347 |
| Mar | 167537 |
| Apr | 228217 |
| May | 290761 |
| Jun | 309619 |
| Jul | 304719 |
| Aug | 253393 |
| Sep | 169524 |
| Oct | 104902 |
| Nov | 59617.4 |
| Dec | 42954.2 |

| | AC energy (kWh/mo) |
|---|---|
| Jan | 56512.6 |
| Feb | 97849.9 |
| Mar | 162357 |
| Apr | 221663 |
| May | 282689 |
| Jun | 301104 |
| Jul | 296391 |
| Aug | 246258 |
| Sep | 164424 |
| Oct | 101195 |
| Nov | 56986.7 |
| Dec | 40673.3 |

Figure B-5: Monthly DC and AC Energy Outputs ( kWh/mo)

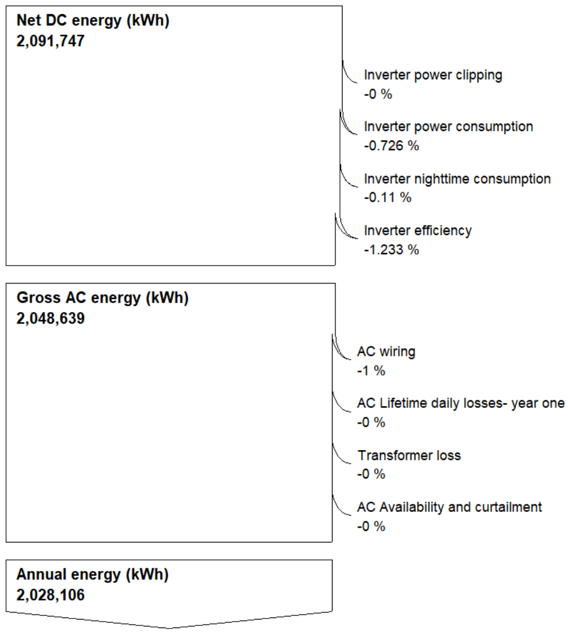



Figure B-6: System Losses for FPV System

# 11.3 Appendix C: Attachments

Attachment C-1: Page 1 of 3 of D3's Preliminary Design Results

Ciel Terre

Annual Production Report produced by Antoine Scoliege

## V1indA WUS491_NEWPORT RESERVOIR, 39.090133, -84.454080

**Report**

| | |
|---|---|
| Project Name | WUS491_NEWPORT RESERVOIR |
| Project Address | 39.090133, -84.454080 |
| Prepared By | Antoine Scoliege<br>eloock@cieletterre.net |

**System Metrics**

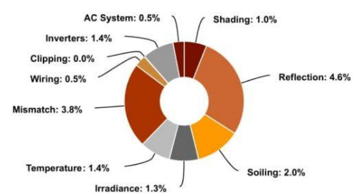
| | |
|---|---|
| Design | V1indA |
| Module DC Nameplate | 1.05 MW |
| Inverter AC Nameplate | 1.05 MW<br>Load Ratio: 1.00 |
| Annual Production | 1.094 GWh |
| Performance Ratio | 84.6% |
| kWh/kWp | 1,039.9 |
| Weather Dataset | TMY, CINCINNATI MUNICIPAL AP LUNKI, NSRDB (tmy3, II) |
| Simulator Version | 122f07cf44-8681935c6b-0f3930b611-978d9c5698 |

**Project Location**


**Monthly Production**


| Month | GHI (kWh/m²) | POA (kWh/m²) | Shaded (kWh/m²) | Nameplate (kWh) | Grid (kWh) |
|---|---|---|---|---|---|
| January | 66.7 | 48.7 | 48.2 | 44,959.7 | 43,457.9 |
| February | 66.4 | 55.8 | 55.2 | 53,276.4 | 51,507.4 |
| March | 100.1 | 88.8 | 87.9 | 86,044.5 | 81,789.8 |
| April | 137.1 | 127.8 | 126.7 | 125,433.5 | 115,598.4 |
| May | 154.2 | 149.4 | 147.7 | 146,673.5 | 133,842.2 |
| June | 175.8 | 171.9 | 170.2 | 169,856.5 | 152,259.8 |
| July | 180.4 | 175.2 | 173.3 | 172,762.9 | 152,440.4 |
| August | 148.8 | 141.3 | 139.8 | 138,488.8 | 123,583.8 |
| September | 124.1 | 110.7 | 109.7 | 107,799.8 | 97,896.9 |
| October | 83.1 | 71.1 | 70.4 | 68,479.3 | 63,492.1 |
| November | 69.9 | 53.0 | 52.5 | 49,600.7 | 46,291.7 |
| December | 46.9 | 35.7 | 35.3 | 33,160.7 | 31,492.9 |

**Sources of System Loss**




 1/3 February 24, 2021

Attachment C-2: Page 2 of 3 of D3's Preliminary Design Results

## Annual Production Report produced by Antoine Scoliege

### Annual Production

| | Description | Output | % Delta |
|---|---|---|---|
| Irradiance (kWh/m²) | Annual Global Horizontal Irradiance | 1,353.7 | |
| | POA Irradiance | 1,229.4 | -9.2% |
| | Shaded Irradiance | 1,217.0 | -1.0% |
| | Irradiance after Reflection | 1,160.9 | -4.6% |
| | Irradiance after Soiling | 1,137.7 | -2.0% |
| | **Total Collector Irradiance** | **1,137.7** | **0.0%** |
| Energy (kWh) | Nameplate | 1,196,536.1 | |
| | Output at Irradiance Levels | 1,180,976.8 | -1.3% |
| | Output at Cell Temperature Derate | 1,164,942.1 | -1.4% |
| | Output After Mismatch | 1,120,706.5 | -3.8% |
| | Optimal DC Output | 1,114,920.0 | -0.5% |
| | Constrained DC Output | 1,114,755.7 | 0.0% |
| | Inverter Output | 1,099,149.2 | -1.4% |
| | **Energy to Grid** | **1,093,653.4** | **-0.5%** |
| Temperature Metrics | | | |
| | Avg. Operating Ambient Temp | | 15.9 °C |
| | Avg. Operating Cell Temp | | 21.3 °C |
| Simulation Metrics | | | |
| | | Operating Hours | 4375 |
| | | Solved Hours | 4375 |

### Condition Set

| | |
|---|---|
| Description | Condition Set 1 |
| Weather Dataset | TMY, CINCINNATI MUNICIPAL AP LUNKI, NSRDB (tmy3, II) |
| Solar Angle Location | Meteo Lat/Lng |
| Transposition Model | Perez Model |
| Temperature Model | Diffusion Model |

Temperature Model Parameters

| Rack Type | $U_{const}$ | $U_{wind}$ |
|---|---|---|
| Fixed Tilt | 29 | 1.5 |
| Flush Mount | 15 | 1.5 |
| East-West | 29 | 1.5 |
| Carport | 29 | 1.5 |

Soiling (%)

| J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |

| | |
|---|---|
| Irradiation Variance | 5% |
| Cell Temperature Spread | 4° C |
| Module Binning Range | -2.5% to 2.5% |
| AC System Derate | 0.50% |

Module Characterizations

| Module | Uploaded By | Characterization |
|---|---|---|
| LR4-72HBD-450M (2020) (Longi Solar) | Folsom Labs | Spec Sheet Characterization, PAN |

Component Characterizations

| Device | Uploaded By | Characterization |
|---|---|---|
| PVS-175-TL (ABB) | Folsom Labs | Spec Sheet |

### Components

| Component | Name | Count |
|---|---|---|
| Inverters | PVS-175-TL (ABB) | 6 (1.05 MW) |
| Strings | 10 AWG (Copper) | 102 (20,117.1 m) |
| Module | Longi Solar, LR4-72HBD-450M (2020) (450W) | 2,337 (1.05 MW) |

### Wiring Zones

| Description | Combiner Poles | String Size | Stringing Strategy |
|---|---|---|---|
| Wiring Zone 1_1 | - | 22-24 | Along Racking |

### Field Segments

| Description | Racking | Orientation | Tilt | Azimuth | Intrarow Spacing | Frame Size | Frames | Modules | Power |
|---|---|---|---|---|---|---|---|---|---|
| Field Segment 1_1 | Fixed Tilt | Landscape (Horizontal) | 12° | 25° | 0.5 m | 1x19 | 123 | 2,337 | 1.05 MW |

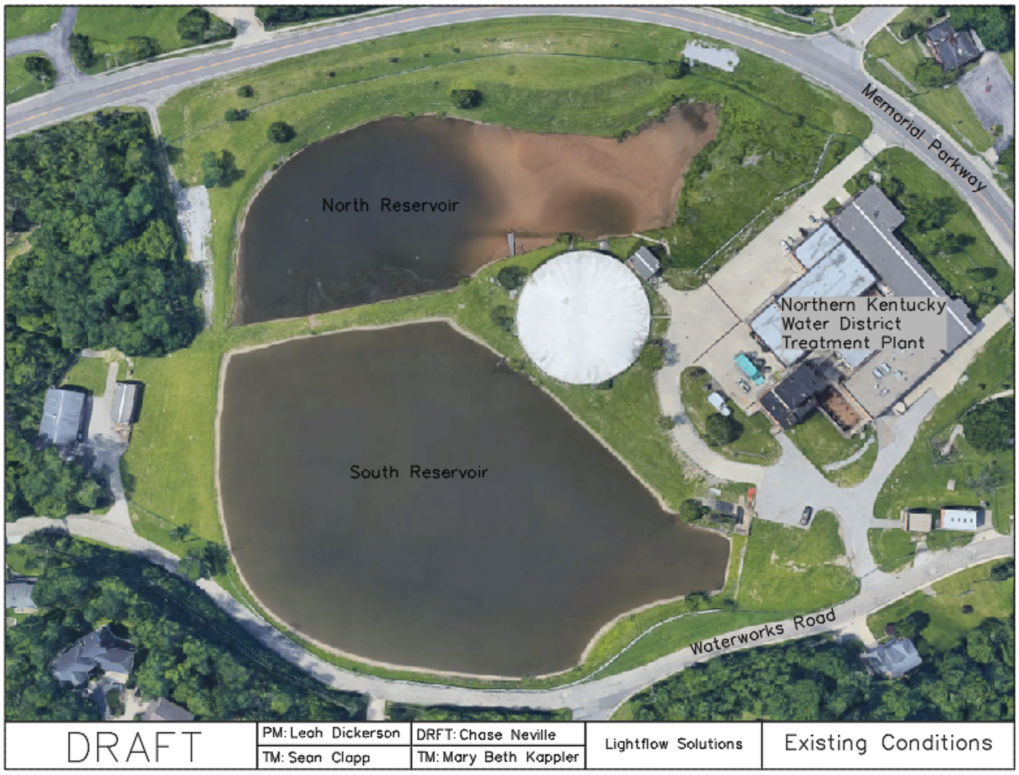
Attachment C-3: Page 3 of 3 of D3's Preliminary Design Results

Annual Production Report produced by Antoine Scoliege

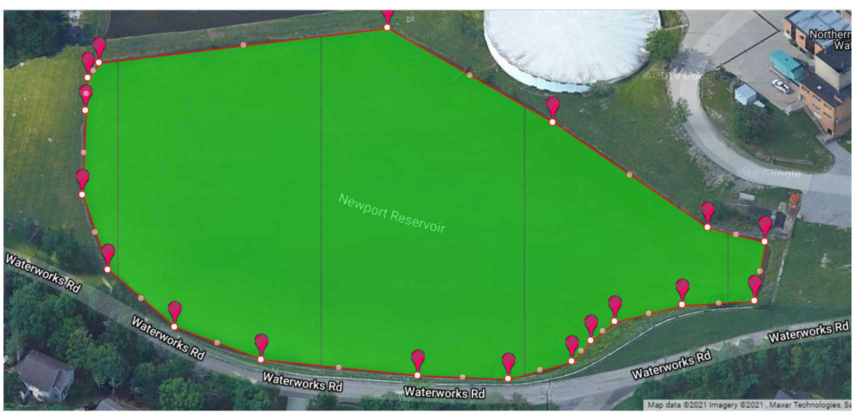
Detailed Layout


© 2021 Folsom Labs 3/3 February 24, 2021

Attachment C- 4: Existing Conditions (Image) with labels using Civil3D




Attachment C- 5: Calculated surface area and perimeter using Google Maps



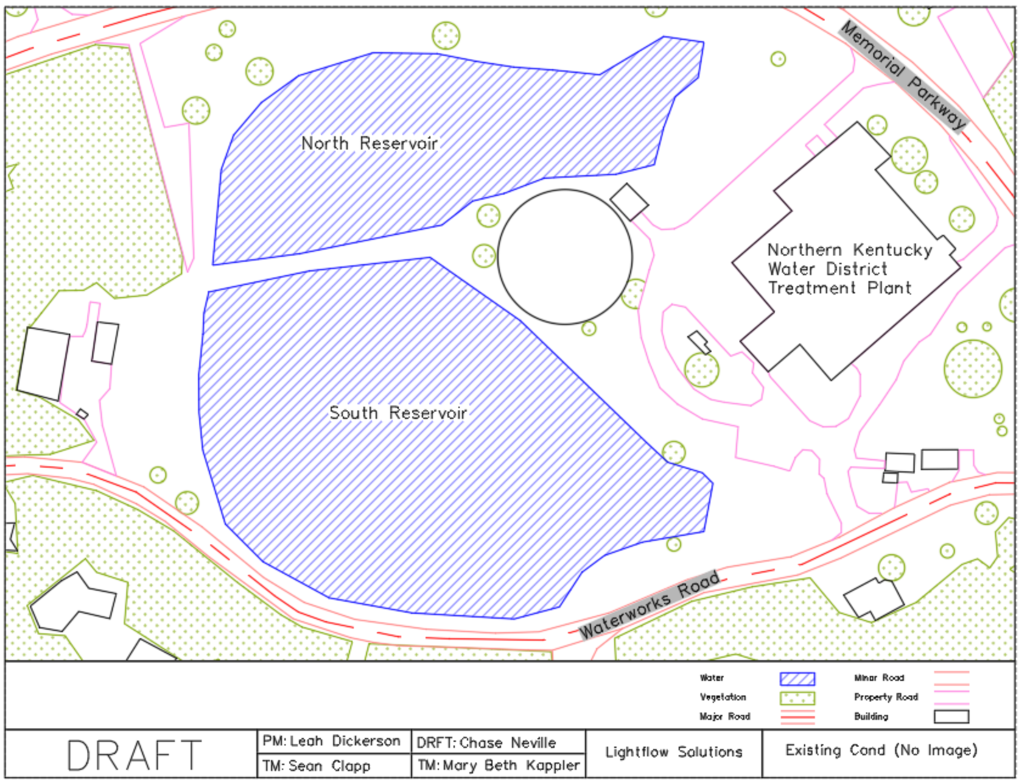

**Output : Current Area**

19594.29 m² | 0.02 km² | 4.84 acres | 1.96 hectares | 210911.13 feet² | 0.01 square miles | 0.01 square nautical miles

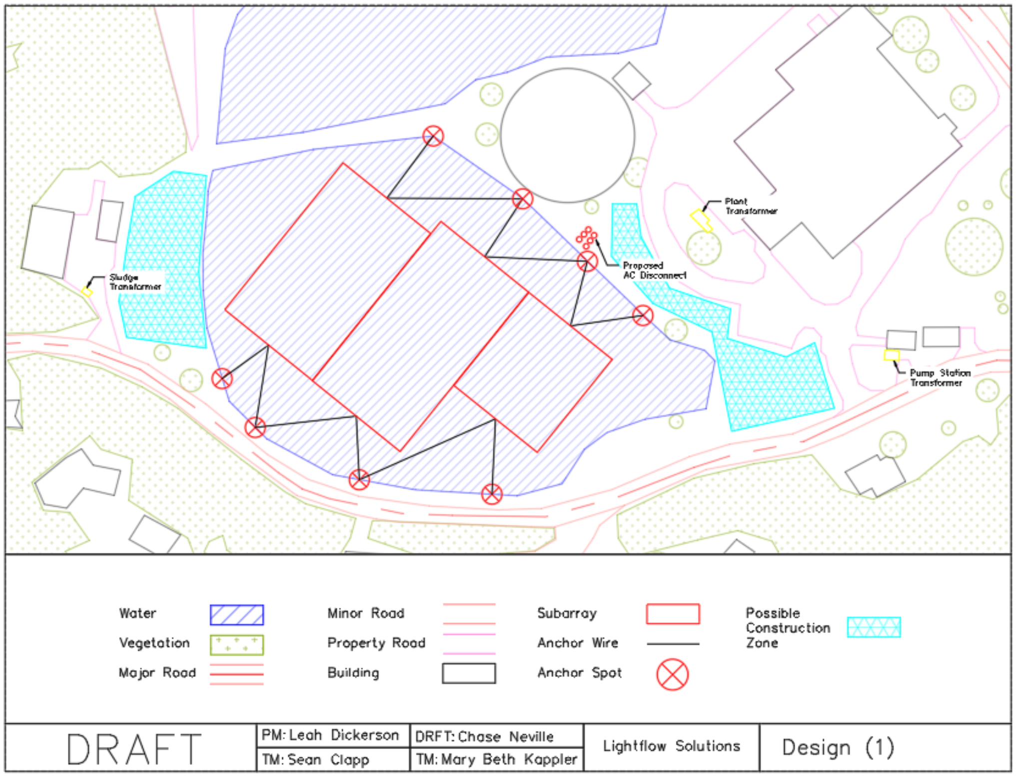
**Current Perimeter**

553.371m OR 1815.521feet

Attachment C-6: Existing Conditions (CAD version) with labels and legend using Civil3D



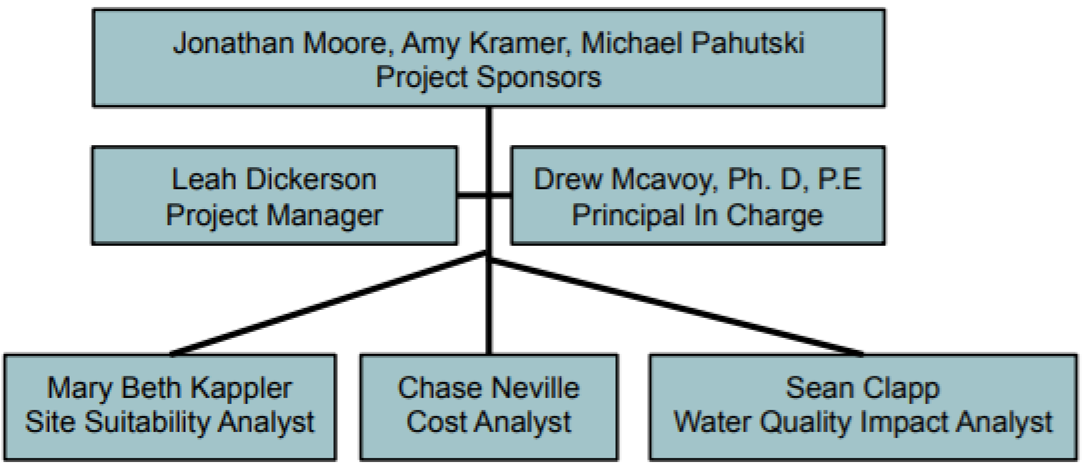
Attachment C-7: Example PV Structure design with labels and legend using Civil3D



## 11.4 Vision Statement

Founded on safety, durability, and quality, we provide innovative solutions to real-world challenges that meet the client's needs and elevate their performance using top of the line solar technology.

## 11.5 Organization Chart



## 11.6 Personal Backgrounds

Sean Clapp is a fifth-year environmental engineering major at the University of Cincinnati. His previous co-op at Alt & Witzig Engineering gave him experience in construction inspection and environmental site assessment. He oversaw site projects such as drilled piers installations and geo pier soil stabilization, working with clients to provide documentation and ensure compliance with structural design drawings. His co-op rotations in Cincinnati's Metropolitan Sewer District in watershed operations allowed him to become familiar with data management practices and connect concepts of hydrology learned in courses to real world systems.

Leah Dickerson is a fifth year Environmental Engineering student. Apart from classroom instruction, her applicable past experiences include water, air, and chemical management permits and programs water treatment processes both influent and effluent treatment. In her first two rotations at Pixelle Speciality solutions she learned about influent and effluent water treatment processes in a paper manufacturing setting. In addition she gained a foundation of knowledge pertaining to the state and federal regulations set for management of air, water, and hazardous chemical inventories. Her last three rotations were spent at LG&E and KU where she learned about water treatment processes that are applied to power plants and gained technical writing skills by creating new procedures for the onsite water facility.

Mary Beth Kappler is a fifth-year environmental engineering student at the University of Cincinnati. She completed five rotations of co-op where she gained communication skills, along with technical skills in AutoCAD. Her first three co-op rotations were at The Kroger Co. in the facilities engineering department. At Kroger she worked as an energy engineer and refrigeration designer. Her last two co-op rotations were spent at Sevan Multi Site Solutions working on efficiency projects for their client, Walgreens. She worked on projects for the installation of HVAC systems and energy management systems. This gave her the opportunity to work with project managers and learn how to manage a schedule and efficiently display data.

Chase Neville is a fifth year Environmental Engineering student at the University of Cincinnati. He previously worked for Environmental Engineering Incorporated where he monitored and did tests on a lead dust spill that had coated a laboratory which taught hazardous materials and how to handle them. His second co-op was at McWane Ductile Incorporated in the EHS department which taught site monitoring and EPA requirements pertaining to an end of year report. His final co-op terms were with a company named AECOM in their civil and environmental engineering department. This job taught AutoCAD, specifically Civil 3D, and working in a team while utilizing tasks done by others and submitting personal tasks to the team to create a complete project.

# 11.7 Resumes

The following four pages contain the resumes of each of each team member of Light Flow Solutions


SEAN CLAPP

**clappsn@mail.uc.edu · linkedin.com/in/seanmclapp** · 740-550-4564


## Education

Environmental Engineering, University of Cincinnati — Class of 2021

Bachelor of Science, College of Engineering and Applied Science — GPA : 3.4/ 4.0

## Experience

### Watershed Operations Intern — January 2020 – August 2020

Metropolitan Sewer District | Cincinnati, Ohio

- Monitored smart sewer alert system, investigating causes, and responded with maintenance requests or escalation of sensor issues to appropriate teams
- Managed site and equipment records on MSD servers updating new maintenance performed and conducting a total review of current records, where all inaccuracies were identified or corrected
- Performed biannual sensor data review to ensure accuracy and highlight any sensors drifting from calibration points
- Wrote procedures for monitoring alert system, reformatting contractor data submissions, and uploading data submissions to MSD's servers
- Partially automated transfer process for large CSV file sensor data submissions reducing task time from 20 work hours to 15 minutes
- Created new file directories containing all sites' sensor data for 2018, 2019, and half of 2020

### GeoTechnician Co-op — September 2018 – December 2018

Alt & Witzig Engineering | West Chester, Ohio — May 2019 – August 2019

- Assisted in compiling Environmental Site Assessment (ESA Phase I) reports for commercial and residential properties
- Referenced city directories in the Greater Cincinnati area, historic Sanborn maps, and historic county aerial images identifying site's previous uses of concern
- Performed site walks documenting current conditions of property and visible signs of potential contaminants
- Inspected foundation footings and internal rebar structure for compliance with structural design drawings
- Field tested concrete samples for water and air composition, recommending action to client when results were outside of compliance range
- Documented rammed aggregate geo-pier soil stabilization on sites
- Monitored drilled pier installations determining depth in accordance with geotechnical reports and design specifications for embedment in bedrock
- Submitted field reports to be reviewed by principle engineers

## Activities

Society of Environmental Engineers — August 2017 - Current

- Connecting to fellow student peers, professors, and graduates with real experience related to engineering sustainability

## Skills

- MATLAB, Microsoft (Excel, Word)

**Leah Dickerson**
leahddickerson@gmail.com / 419-277-8676 / 612 Bermuda Lane Louisville, Kentucky 40213

**EDUCATION**

**University of Cincinnati** | Cincinnati, Ohio — Class of 2021
Bachelor of Science in Environmental Engineering — GPA 3.7/4.0

**EXPERIENCE**

**Co-op III, LG&E and KU Energy LLC| Louisville, KY** — 5/2019- 8/2019 & 1/2020- 8/2020

- Sole trainer for the new Ultraviolet system for onsite technicians and operators
- Coordinated process improvement experiments for sludge disposal in water treatment following plant outage with projected savings of ~$50,000 annually
- Collaborated with third party contractors to formulate a proposal for the installation of  a 43 acres of pollinator habitat (with estimated savings of $28,000 per year in mowing costs)
- Collected and analyzed water samples on daily basis to ensure compliance with current Kentucky Pollutant Discharge Elimination System (KPDES) permit
- Conducted Spill Prevention, Control, and Countermeasure (SPCC) inspections at Ohio Falls
- Authored and illustrated 40 new standard operating procedures for the water treatment facility
- Updated and revised Water Treatment training material for incoming personnel
- Managed and  assessed installations that enhanced safety measures in the water treatment facility
- Created and organized the Asbestos Abatement Portfolio for the demolished coal plant

**Environmental Co-op, Pixelle Specialty Solutions LLC  | Chillicothe, OH** — 1/2018 - 5/2018 & 8/2018 - 12/2018

- Orchestrated and conducted Leak Detection and Repair (LDAR) walkthroughs for utilities and pulp mill areas onsite
- Executed annual SARA 312 hazardous chemical inventory for multiple sites
- Edited Continuous Emission Monitoring Systems (CEMS) and Continuous Opacity Monitoring Systems (COMS) compliance programs in accordance with federal regulations
- Facilitated, enforced, and implemented the new Clean Air Act section 608 & 609 rule revisions for HVAC units
- Wrote and collected  monthly and annual required reports submitted to the Department of Energy
- Executed National Pollutant Discharge Elimination System (NPDES) report on a monthly basis

**Environmental Intern, TTL Associates, Inc. | Toledo, Ohio** — 5/2017 - 8/2017

- Researched and retrieved information necessary for environmental assessment reports
- As an assistant project manager, documented information during the  investigations  of various  Phase I Environmental Site Assessments
- Tasked with archiving data into master database (paper and electronic format) to improve company organization
- Input lab results in data tables in compliance with environmental standards (BUSTR, OEPA, VAP)

**SKILLS**

- State and federal environmental reporting software
- AutoCAD
- CPR Certification
- Microsoft Office (Excel, Word, Powerpoint, etc)

**AWARDS**

- Dean's List — Fall 2016- Present
- UC CEAS Engineer of the Month — November 2020
- 2020 Ohio EPA Scholarship recipient — Fall 2020

**ACTIVITIES**

- Society of Environmental Engineers, *Demonstration Project Member* — August 2019- Present
- UC Hepcats — January 2019- Present
- Engineers Without Borders, *Community Outreach Committee* — January 2017-May 2017
- Cincinnati Navigators, *Servant Team Leader* — August 2016-Present

# Mary Beth Kappler

Email: kappleml@mail.uc.edu | Phone: (440)-876-7744


**Education:**

University of Cincinnati, Cincinnati, OH — Class of 2021
Bachelor of Science in Environmental Engineering — GPA: 3.4/4.0

Strongsville High School, Strongsville, OH — GPA: 4.1/4.0
Honors Diploma

**Work Experience:**

Assistant Project Coordinator, Sevan Multi-Site Solutions, Walgreens, Chicago, IL — Spring & Summer 2020

- Designed and published Power BI dashboards for programs to monitor the financials, schedule, and key milestones
- Reviewed and validated technical closeout out packages for the HVAC program
- Created weekly reports that display metrics of the Energy Management System and HVAC programs
- Communicated with program managers and installation contractors to manage the monthly schedule and forecast within Smartsheet

Refrigeration Application Design Co-Op, The Kroger Co., Cincinnati, OH — Summer 2019

- Completed mechanical redesign of 35 stores in AutoCAD. Coordinated and communicated new designs to multifunctional teams including refrigeration supervisors, engineers, procurement and energy groups.
- Created and screened technical drawings such as redlines, rough sketches and written work scopes
- Utilized refrigeration and/or Heating, Ventilating, & Air Conditioning (HVAC) fundamentals
    - Tested and analyzed refrigeration case performance on perspective new cases, assuring food safety and product quality standards were met
- Coordinated project timelines and worked with multifunctional teams to avoid any delays in job completion

Energy Engineering Co-op, The Kroger Co., Cincinnati, OH — Spring & Fall 2018

- Managed the Energy Maintenance Project for 19 divisions within Kroger.
    - Identified and fixed 132 maintenance issues during fall 2018 which led to $950,000 worth of annual energy cost savings.
    - Composed and analyzed energy data reports to identify issues causing high energy usage.
- Completed 52 Energy Star applications to provide data cleanup and benchmarking to all energy engineers in each division.
- Contributed to composing Kroger's yearly Carbon Footprint Report.

**Skills and Qualifications:**

MATLAB, AutoCAD, ArcGIS, Fluid Dynamics, Exposure to Tableau, Power BI, Smartsheet, Microsoft Office (Word, Excel, PowerPoint)

**Activities and Involvement:**

- Society of Women Engineers — 2016-Present
- Delta Delta Delta Sorority — 2016-2020
    - Volunteering for St. Jude
    - Involved in the Academic Committee
    - Leader of a group of new members

**Availability:** Full time starting May 2021

# Chase Neville

513-601-3100
nevillcm@mail.uc.edu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**Education**

**University of Cincinnati, Cincinnati, OH** — **Class of 2021**
- Bachelor of Science, Environmental Engineering — GPA 3.35/4.0

**Experience**

**AECOM, Civil Engineering Coop, Cincinnati, OH** — **5/19 – 5/20**
Coop, 40 hours per week
- Designed and modified coal ash removal plan sheets
- Researched elements considered hazardous to human health and how to remove them from groundwater
- Created figures and charts for coal ash removal project proposals

**McWane Ductile Ohio, Environmental Intern, Coshocton, OH 8/18 – 12/18**
Coop, 40 hours per week
- Began and completed two facility-wide environmental audits
- Inspected sewer drains for potential compatibility with biological filters
Coordinated with parents a drop off plan while also assisting in traffic control
- Completed daily and weekly inspections for EPA compliance

**EEI, Environmental Consultant / Technician, Cincinnati, OH** — **2/18 – 5/18**
Coop, 40 hours per week
- Sampled air for lead and provided oversight during lead cleanup project
- Assisted a team in transporting hazardous chemicals, draining an elevator shaft of sludge, and collecting hazardous material for proper disposal
- Reworked company organization for better clarity and simplification

**Cincinnati Zoo, Summer Camp Instructor, Cincinnati, OH** — **6/12 – 8/17**
Full-time seasonal, 40 hours per week
- Promoted from volunteer to paid instructor position

**Skills**

MATLAB, Microsoft Office, AutoCAD, Civil3D, ArcGIS
OSHA 8 hour refresher completed, hazardous material, blood born pathogen, ladder safety, forklift safety, hazardous waste removal certifications

**Activities**

**Bowling Club President, UC** — **8/16 – present**
- President since 5/19

**Society of Environmental Engineers, UC** — **8/16 – present**

**Bearcat Buddies, University of Cincinnati** — **1/19 – 5/19**
- Tutor at Rhees E. Price Elementary School

**Eagle Scout, Boy Scouts of America** — **9/09 – 8/16**
- Eagle Scout Project: created birdhouses for the Cincinnati Zoo

**Awards**

**Cincinnatus Scholarship** — **2016-2021**
**FOP Scholarship** — **2016**

# 11.8 Request for Proposal

**Environmental Engineering Senior Capstone Project**
**Request for Proposal**

**Floating Solar Power Generation Feasibility Analysis**

**Prepared by: Northern Kentucky Water District**

**Background**

The Northern Kentucky Water District (NKWD or District) owns and operates the 10-million gallon per day (MGD) Memorial Parkway Treatment Plant (MPTP) in Fort Thomas, Kentucky. The plant draws water from the Ohio River and stores it in two parallel open reservoirs with a combined capacity of approximately 35 million gallons. An aerial image of the drinking water treatment plant is provided in Figure 1.

The reservoirs provide storage and some sedimentation and pre-treatment for raw river water before it enters the primary treatment process. Only a portion of the water in each reservoir is drained and replenished each day during treatment activities, so like any large pseudo-stagnant body of water in the summer, algae growth can be a concern. Excessive algae growth in source water can pose a challenge for water treatment processes and increase operation and maintenance costs.

The District is interested in evaluating a floating solar installation on the reservoirs to both prevent algal growth and to potentially offset some of the plant's energy requirements. Duke Energy Kentucky is the electric utility for Northern Kentucky and is also interested in exploring potential floating solar developments in the region and learning more about the technology's effect on the host water body.

The ultimate goal of the project is (1) to determine what characteristics make a body of water a good candidate for floating solar power generation, and (2) to determine whether floating solar power generation is feasible and cost effective at the treatment plant site.

**Description of Services**

NKWD will coordinate all activities with the consultant team on this project. NKWD will provide project related data, technical, and analytical support. In addition to determining the best options for implementing solar panels on top of the open reservoirs, the consultant team will evaluate necessary permitting, community outreach, and electrical and site infrastructure upgrades at the treatment plant. The consultant team should also consider the water quality impacts on the reservoirs and the treatment process during and following the installation. In order to meet the goals of this project the consultant team will conduct a thorough literature review and investigation of solar power technologies implemented in other similar non-natural water impoundments. The consultant team should create a business case for each of the options identified and evaluate whether site considerations preclude the selection of any option.

1

**Deliverables**

The consulting team should complete the following tasks by the end of the Fall Semester.

- Perform a review of solar power generation in the Midwestern US and provide a summary of findings, technical background, and feasibility.
- Perform a review of floating solar deployments and technologies, including capital and O&M cost data and production estimates. Ancillary data and background information such as changes in water temperature or water quality parameters, impact on habitat, and community acceptance should be included.
- Conduct analysis using other similar non-natural water impoundments (e.g. power plant cooling ponds) and determine the fitness of the MPTP reservoirs for solar installation.
- Identify any concerns and potential mitigation measures for using this technology on a reservoir used at the front of a drinking water treatment process.
- Prepare a proposal report on the key findings and recommended options.
- Provide a presentation to the Sponsor on the key findings and recommended options.

The consulting team should complete the following task by the end of the Spring Semester.

- Conduct analysis of the ecosystem in the MPTP raw water reservoirs and project the effect of a solar installation on that ecosystem.
- Perform an engineering analysis and provide recommendation whether floating solar is an appropriate and cost-effective technology to implement. Cost analysis should include discussion of uncertainty and a present-worth analysis over the expected lifetime of the infrastructure.
- Develop conceptual design of the floating solar covers including the panel surface size, anchoring and floatation details, and improvements necessary to install and costs to operate and maintain.
- Provide a final report that includes key information from the Fall Semester, as well as an analysis on potential water quality impacts on the treatment process, a conceptual design of the floating solar cover, and an economic analysis including payback period of the final design.
- Provide a presentation to the Sponsor on the recommended design and cost-benefit analysis of implementing the recommended design.

Figure 1


MEMORIAL PKWY
INVERNESS PL
North Reservoir
South Reservoir
WATERWORKS RD
WATERWORKS RD
TAYLOR AVE

3