Application of Sustainable and Innovative FPV to Optimizes Reservoir Designs, Generate Power & Reduce Evaporation Water Losses

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Abstract *— This project evaluates the feasibility of integrating a floating photovoltaic (FPV) system with the proposed Valenciano Reservoir in Juncos, Puerto Rico, to improve both water and energy resilience. The study combines hydrologic analysis for reservoir design with an assessment of FPV technology as a dual-purpose solution for renewable power generation and evaporation reduction. Runoff hydrographs were developed for major design storms, including the 100-year and probable maximum precipitation events, to estimate inflows, reservoir behavior, and operating water levels. These results were then used to assess the available water surface for FPV deployment. The analysis indicates that the reservoir can support a practical FPV installation capable of contributing meaningful energy production while also reducing evaporative losses and improving water-quality conditions through surface shading. The proposed concept demonstrates how water-storage infrastructure can be enhanced with sustainable energy systems to address critical service challenges in Puerto Rico.*

Keywords *— FPV, Geographical Information System, HEC-HMS, Sustainability.*

JUSTIFICATION

Puerto Rico continues to face recurring interruptions in water and electrical services due to aging infrastructure, extreme weather, and limited system resilience. In Juncos, these challenges support the need for a new reservoir on the Valenciano River that can provide a more reliable water source while also creating an opportunity for renewable energy generation. Integrating an FPV system on the reservoir offers a practical dual benefit: it uses existing water surface area to generate clean power and reduces evaporation losses. This approach aligns with global trends in sustainable infrastructure and represents an innovative model for Puerto Rico’s future water and energy development.

INTRODUCTION

Juncos, Puerto Rico, is one of the municipalities on the island that has experienced persistent problems and inconsistencies with both water and electrical utility services. In response, the Government of Puerto Rico has pursued the design and construction of a new reservoir intended to provide residents with a more reliable and resilient water supply system. The proposed reservoir will capture water from the Valenciano River and is expected to address long-standing service deficiencies affecting the community, see Figure 1 for Valenciano Dam, Reservoir, and Spillway (CSA Group Render).

The proposed Valenciano Reservoir in Juncos is intended to strengthen potable-water reliability for nearby communities that have experienced long-standing service limitations. In addition to its water-supply function, the reservoir provides an opportunity to incorporate floating photovoltaic technology as a sustainable infrastructure component that supports Puerto Rico’s transition toward more resilient utility systems.

This study develops the hydrologic basis for reservoir design using available watershed data, major storm events, and reservoir-routing analyses to estimate inflows, storage behavior, and operating water levels. Those results are then used to evaluate the feasibility of installing an FPV system capable of producing renewable energy, reducing evaporation, and improving overall reservoir performance.

Figure 1
Valenciano Dam, Reservoir and Spillway (CSA Group Render)

Description of the Valenciano Reservoir Study Area

The Valenciano Reservoir study area is located in Juncos, Puerto Rico, approximately 1 mile southwest of the urban center, see Figure 2 for distance measured from the reservoir closing point to the Jucos town. The project captures runoff from the Río Valenciano watershed and forms part of a broader effort to modernize regional water infrastructure. Hydrologic and hydraulic analyses were used to define reservoir inflows, storage behavior, and operating elevations needed for both dam planning and FPV evaluation.

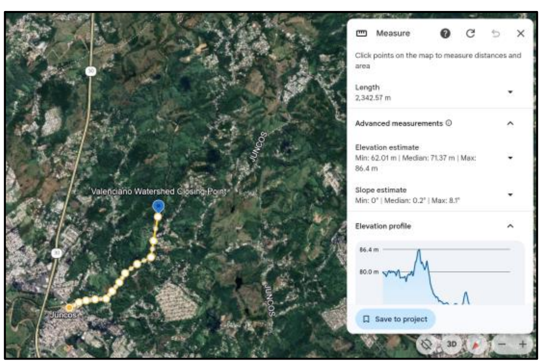

Figure 2
Valenciano Reservoir and Its Proximity to Juncos

Available watershed mapping, land-use data, soils information, and terrain models were compiled to support the delineation of basin characteristics and the estimation of runoff parameters used in the hydrologic model.

Hydrologic and hydraulic evaluations conducted for this project include the development of runoff hydrographs for the design of precipitation events. These hydrographs were applied to reservoir routing models to estimate inflow volumes, seasonal water-surface fluctuations, and long-term storage reliability. This information is essential for determining safe operating levels, spillway requirements, and monthly average water-surface elevations.

GIS Data

The geographic information system (GIS) shown on Table 1 sources were referenced during the development of this study:

Table 1
Referenced GIS Data Sources

NATURAL RESOURCES CONSERVATION SERVICE • **Soil Survey PR_686** • **Soil Survey PR_689**
Land Use Coverage – PR Office of Management and Budget, 2006, WMS Webserver, http://gis.otg.pr.gov/
Digital Elevation – CRIM PR OMB, 1998, WMS Webserver, http://gis.otg.pr.gov/ **DEM 30m x 30m resolution** **StreamStats US Geological System**

METHODOLOGY

HEC-HMS was used to model runoff hydrographs for the Valenciano watershed under selected design storms. The analysis focused on the 100-year and probable maximum precipitation events to estimate inflows to the proposed reservoir and support subsequent hydraulic and storage evaluations.

The model incorporated basin properties, rainfall inputs, runoff losses, direct runoff transformation, and travel-time parameters consistent with standard NRCS and HEC-HMS procedures [1].

General Approach

Runoff hydrographs and peak discharges were generated for the selected storm events and used to evaluate reservoir performance, including inflow magnitude, water-surface response, and spillway behavior using Hydrologic Engineering Center (HEC), River Analysis System (HEC-RAS) by USACE [2].

Runoff volume was estimated using the NRCS Curve Number method, which relates land use, soil group, and antecedent moisture conditions to watershed runoff response.

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \quad (1)$$

Where:

- Q = is runoff, in inches.
- P = is rainfall, in inches.
- I_a = is the initial abstraction (initial loss), in inches.
- S = is the potential maximum retention after runoff begins, in inches.

The initial abstraction consists mainly of intersection, infiltration, and surface storage, all of which occur before runoff begins. This initial loss includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. Initial abstraction is related to the potential maximum retention after runoff begins by the following empirical equation [3]:

$$I_a = 0.2S \quad (2)$$

Therefore, substituting the previous equation into the runoff equation gives [3]:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad (3)$$

S is related to the soil and cover conditions of the basin through the CN. This relation is expressed as follows [3]:

$$S = \frac{(1000 - 10CN)}{CN} \quad \text{(English units)} \quad (4)$$

The CN is a dimensionless parameter indicating the runoff response characteristic of a drainage basin. In the SCS method, this parameter is related to land use, soil type, and antecedent moisture conditions (AMC) in the drainage basin. Land use represents the surface conditions in the drainage basin and is related to land use degree of cover. Soil properties greatly influence the amount of runoff. Infiltration rates of soils vary widely and are affected by subsurface permeability as well as surface intake rates. The NRCS classifies the soils into four hydrologic soil groups (A, B, C, and D) according to their minimum infiltration rate, which is obtained for bare soil after prolonged wetting.

Another important factor influencing the CN value is the soil moisture condition in the drainage basin before runoff occurs. The soil moisture condition is classified by the NRCS in three AMC classes: AMC I (dry conditions), AMC II (average conditions), and AMC III (saturated conditions). This classification is based on the 5-day antecedent rainfall. To determine the appropriate CN value, the NRCS developed several tables that relate the value of CN to the factors discussed above. The CN values, shown in these tables, range from 30 (permeable soils with high infiltration rates) to 98 (impervious areas). Publications from the NRCS provide further background and details on the use of the CN Loss Model [3].

The SCS Unit Hydrograph method included in the HEC-HMS Basin Model was utilized to estimate the direct runoff from each of the simulated storm rainfall events. This method is based upon averages of unit hydrographs derived from gauged rainfall and runoff for a large number of small agricultural basins, which varied greatly in characteristics such as size and geographic location. The required input parameters are limited to basin area and are an estimate of time of concentration (T_c) or basin lag time (T_l). The T_c is defined as the travel time of flow from the most hydraulically distant point in the basin to the outlet of the basin.

The Kirpich equation was used to estimate the T_c for the Valenciano River drainage basin. This equation is expressed as follows [4]:

$$T_c = 0.0078 L^{0.77} S^{-0.385} \quad (5)$$

Where:

- Tc = is the time of concentration, in minutes.
- L = is the length of main channel, in feet.
- S = is the slope, equal to H/L. Where H, in feet, is the difference in elevation between the most hydraulically remote point in the basin and the outlet.

Once the time of concentration is determined, the lag time (T_l) is computed as follows [4]:

$$T_l = 0.6T_c \quad (6)$$

The lag time is the time-of-travel parameter used by the HEC-HMS Basin Model. This method is well documented by the NRCS [4].

Basin Properties

The Valenciano watershed covers approximately 15 square miles and is characterized by mountainous, vegetated terrain with scattered rural areas and low-density development. These features influence runoff generation, travel time, and storage behavior within the proposed reservoir system, Figure 3 shows the Valenciano watershed delimitation.

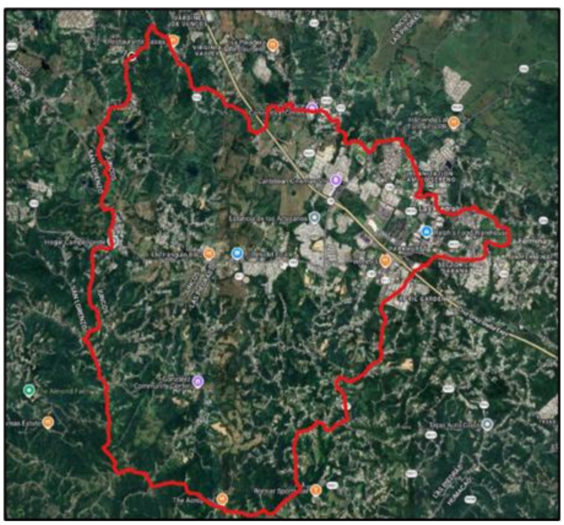

Figure 3
Valenciano Watershed

Land Use

Land use within the watershed is dominated by forested cover, pasture, limited urban development, and minor water-surface areas, as shown in Figure 4. These categories were used to estimate runoff characteristics and develop the weighted curve number applied in the hydrologic model.

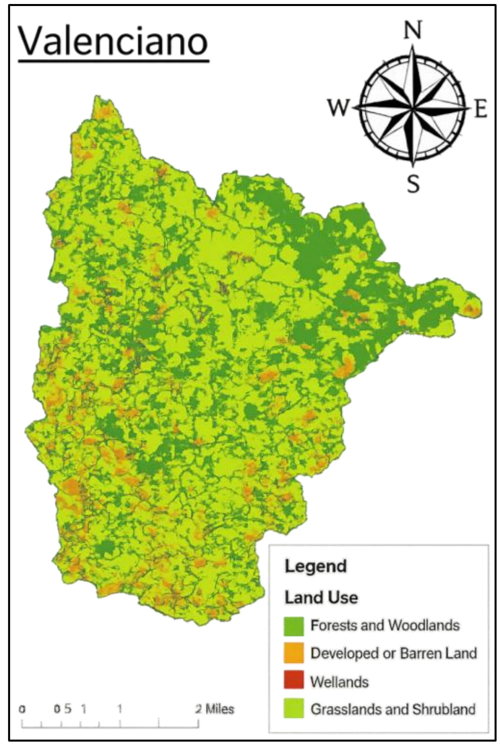

Figure 4
Valenciano Watershed Land Use

Soil Types

The watershed is characterized mainly by soils with low to moderate infiltration capacity. For modeling purposes, Hydrologic Soil Group C was adopted as representative of the basin, reflecting conditions that tend to generate relatively high runoff when soils are wet. Surface-water features occupy a small portion of the watershed area, with most runoff originating from upland terrain and tributary drainage paths.

Basin Parameters

A weighted CN for the watershed was developed based on land use, HSG and AMC. As described in the previous section, HSG type C was used for the soil types found in the watershed. In the 1998 study (PREPA), an AMC II, which is an average moisture condition, was used for estimating rainfall runoff. AMC type II was also used as the average moisture condition for the watershed in the current study [5].

Table 2 presents the identified CN for each land use classification and the weighted CN estimated for the watershed.

Table 2
Calculated Weighted CN for the Valenciano Watershed

LU CLASSIFICATION	% OF WS	CN (AMC II; HSG C)
Forest, Evergreen Shrub Land and Woodland (Bosques y Arboledas (ByA))	55%	73
Moist Grasslands and Pasture (Pastos y Arbustos (PyA))	20%	74
Low Density Urban Development (Desarrollados o Baldi (DoB))	14%	77
Landuse not Indicated Assumed by A	6%	70
Freshwater (Humedales (H))	5%	100
WEIGHT CURVE NUMBER		**76.19 ≈ 77**

Rainfall

Four precipitation events were considered for this study; they included the 6 and 24-hour PMP and the 6 and 24-hour 100-year rainfall events.

Data Sources

PMP values were based on standard precipitation guidance for Puerto Rico, while frequency-based rainfall depths for the 100-year events were taken from NOAA Atlas 14 [6]. These sources provided the basis for the storm inputs used in the hydrologic model. Estimation of precipitation for frequency-based events, such as the 100-year rainfall event, are prepared by the National Oceanic Atmospheric Association's (NOAA) National Weather Service (NWS) [6]. NOAA Atlas 14, Volume 3, Version 4 (2006) is the most recent update to precipitation frequency estimates for Puerto Rico. NOAA Atlas 14 is intended as the official documentation of precipitation frequency estimates for the United States, Puerto Rico and U. S. territories and it supersedes precipitation frequency estimates contained in TP-42 (excluding PMPs). NOAA Atlas 14 is based on more recent and extended data sets, currently accepted statistical approaches, and improved spatial interpolation and mapping techniques [6]. Rainfall event distribution is based on SCS Type II, which is typical and appropriate for Puerto Rico.

Precipitation Estimates

The rainfall estimates for the precipitation events modeled under this study are presented in Table 3.

Table 3
Rainfall Estimates for Precipitation Events

Precipitation Event	Total Rainfall (inches)
6-Hour, 100-Year	12.1
24-Hour, 100-Year	19.9
24-Hour PMP	52.8

Flood Hydrographs and Peak Discharges

The peak inflows into Valenciano, peak WSEs and peak discharges from the spillway as modeled by the HEC-HMS model are presented in Table 4. Figure 5 illustrates the inflow hydrographs for each of the four events modeled.

Table 4
Calculated Peak Inflows, WSEs and Outflows for Valenciano

Precipitation Event	Peak Inflow	Peak WSE	Peak Outflow
6-hour, 100-yr	34,100	224.35	19,167
24-hour, 100-yr	40,862	225.1	27,815
24-hour, PMP	136,018	238.1	105,146

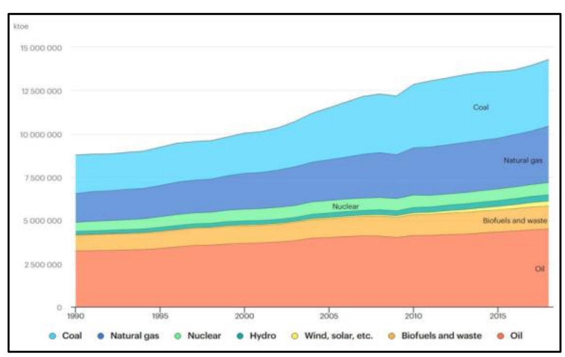

Figure 5
Types Energy Production Worldwide

Floating Photovoltaic (FPV) Solar System

Puerto Rico's energy system remains vulnerable to outages, fuel-price volatility, and infrastructure constraints. FPV offers a practical alternative by placing solar generation on reservoir surfaces, thereby avoiding land-use conflicts while supporting cleaner and more resilient energy supply.

In addition to energy production, FPV systems can reduce evaporation, limit algae-promoting sunlight penetration, and improve panel performance through cooling from the water surface.

A typical FPV plant includes PV modules mounted on floating structures, electrical equipment, and anchoring or mooring systems that maintain array stability under variable site conditions, see Figure 6 for better understanding of all the components in a FPV system [7].

Key advantages of FPV systems include:

- No land use required, preserving valuable terrestrial space.
- Increased energy efficiency due to natural cooling from water.
- Reduced evaporation and synergy with existing hydropower infrastructure.

Main disadvantages include:

- Higher capital costs (approximately 25% more than ground-mounted PV).
- Increased risk of corrosion and moisture-related electrical issues.
- Complex anchoring and installation requirements depending on water conditions.

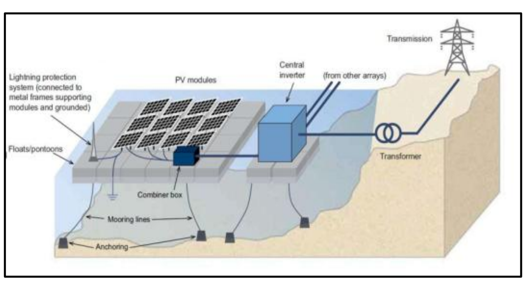

Figure 6
Typical Photovoltaic Plant

Globally, FPV deployment has grown rapidly, reaching over 2 GWp installed capacity by 2021, with more than 500 projects worldwide. Asia dominates the market, particularly China, followed by selected European countries. Most projects remain below 5 MWp, though large-scale plants above 100 MWp already exist. See the contrast in terms of power generation between the different types worldwide, including the FPV type on Figure 5.

The Hydrelio Air Optim

Figure 7 showed the Hydrelio Air Optim system, system selected as a representative FPV platform because its modular HDPE float configuration is widely used, adaptable to irregular reservoir geometry, and suitable for evaporation-reduction objectives [8].

Its characteristics align with current FPV practice by combining modularity, durability, and compatibility with large-scale reservoir applications.

- Uses HDPE floats consistent with industry standards.
- Demonstrates proven durability in global deployments.
- Provides environmental co-benefits validated by research.
- Offers modularity suitable for irregular reservoir shapes.
- Supports large-scale coverage for evaporation control.

Its selection is further supported by documented performance in international installations and by its suitability for long-term reservoir deployment.

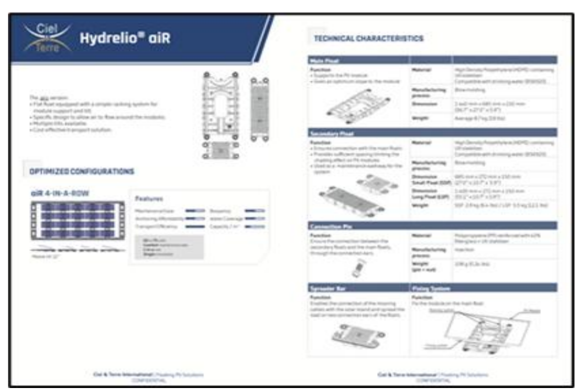

Figure 7
Hydrelio Air HDPE FPV System

960 kWp Floating Solar PV System – City of Altamonte Springs Water Reclamation Facility

The Altamonte Springs, Florida FPV project serves as a useful benchmark because it demonstrates the operational viability of a utility-scale floating solar installation at a water-treatment facility [9]. Reported benefits include on-site energy generation and reduced algae growth in the covered pond, supporting the broader environmental value of FPV systems.

On this project the benefits of this type of product were confirmed in terms of the quality and the water evaporation. The reservoir showed a drastic reduction in eutrophication and the amount of water evaporated.

Hydrelio Air Optim at Valenciano

Hydrologic modeling indicates that the reservoir can provide sufficient surface area for FPV deployment under normal operating conditions. Using representative water levels, the available surface is adequate to support a system sized to contribute meaningful renewable generation while preserving reservoir functionality.

At the planning level, the FPV concept was evaluated against the approximate electricity demand of 1,000 nearby homes to illustrate its potential community benefit.

Assuming the water elevation will be around 80 meters 90% of the time, equivalent to an 89,357 square meters water surface available to install the Floating Photovoltaic (FPV) Solar System. A 3.5 MWDC HYDRELIO floating PV system typically requires 17,500 - 23,300 m² of water surface, based on standard FPV power density values of 150 -200 W/m², which account for module spacing, walkways, and operational clearances. For planning purposes, feasibility studies generally adopt a conservative range of 20,000 - 25,000 m² (equivalent to 2.0 - 2.5 ha or 5 - 6 acres) to accommodate shoreline buffers, exclusion zones, and layout constraints. Consequently, early-stage reservoir assessments often use a broader planning allowance of 2 - 3 ha to ensure sufficient usable surface area for system design and optimization.

A planning-level comparison between conventional grid supply and an FPV alternative suggests that the floating solar option can provide long-term value through stable operating costs, reduced dependence on imported fuels, and added resilience benefits, Figure 8 shows how the FPV system capital cost are higher but in a term of 20 years becomes a cheapest system in comparison with the conventional grid supply fossil fuel combustion.

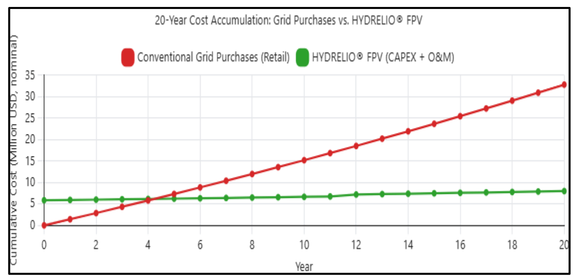

Figure 8
20-Years Cost Accumulation

Evaporation Benefits

FPV coverage can substantially reduce evaporation from the shaded portion of the reservoir while also supporting improved water-quality conditions. The magnitude of the benefit depends on local climate, coverage ratio, wind conditions, and array configuration. In some cases, a reduction in evaporation between 30% - 70% of water can be experienced.

Evaporation assessment for Puerto Rico should be based on local climatic conditions and reservoir characteristics; for this study, the reduction benefit is considered as an added sustainability advantage of FPV rather than the sole design driver.

Conclusion

This study evaluated the hydraulic behavior of the proposed Valenciano Reservoir to identify operating water levels and the available surface area for a floating photovoltaic system. The results indicate that integrating FPV with the reservoir is technically feasible and offers clear benefits, including renewable energy generation, reduced evaporation, and added value to the overall water infrastructure investment.

Overall, the project demonstrates a practical approach to combining reservoir design with sustainable energy generation in Puerto Rico. By linking hydrologic analysis with FPV implementation, it supports a resilient infrastructure strategy that can improve water reliability, expand renewable energy use, and serve as a model for future projects on the island.

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