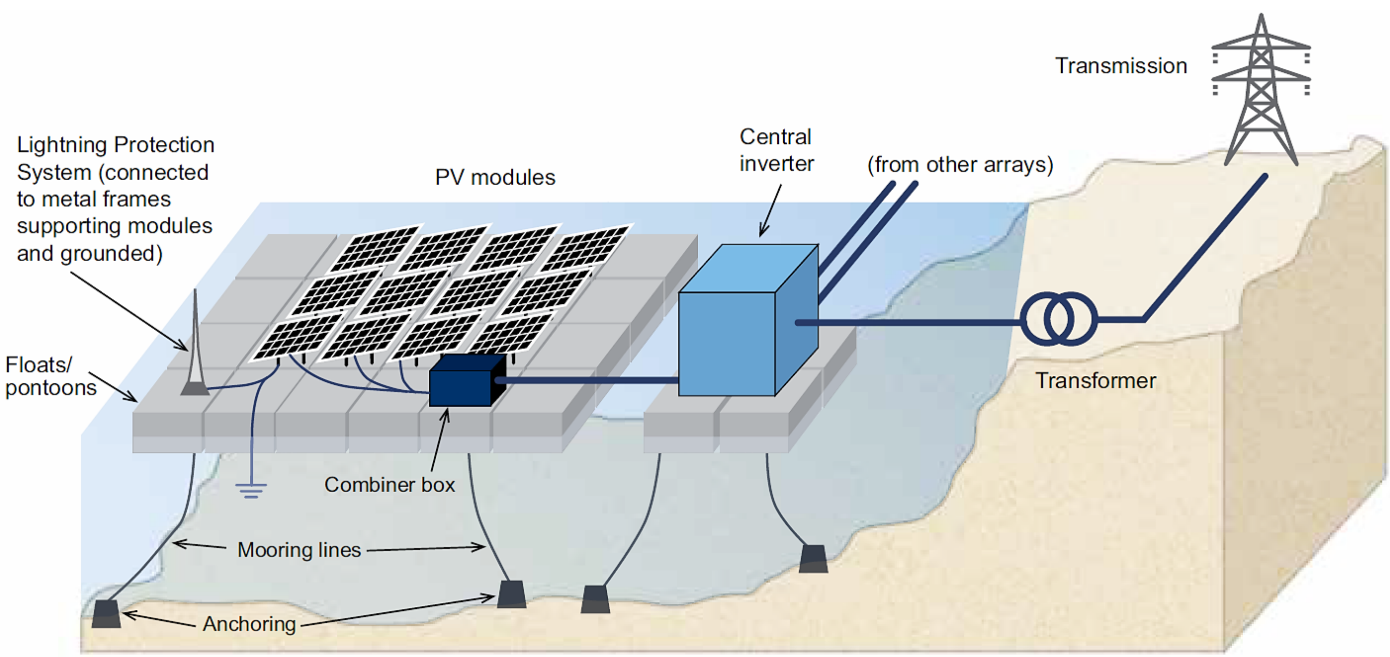
BUREAU OF RECLAMATION

Considerations for Floatovoltaics on Reclamation Reservoirs

Bureau of Reclamation
Power Resources Office
Upper Colorado Basin Region, Albuquerque Area Office

National Renewable Energy Laboratory



U.S. Department of the Interior

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Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Cover: Schematic representation of a typical large-scale floating PV system with its key components (World Bank Group et al. 2019/Used by permission)

Acronyms and Abbreviations

¢/kWh	cents per kilowatt hour
AAO	Albuquerque Area Office
ALK	alkalinity
CAISO	California Independent System Operator
CAP	Central Arizona Project
CCE	Community Choice Energy
CFR	Code of Federal Regulations
D&S	Directives and Standards
DOE	Department of Energy
DO	dissolved oxygen
DOI	U.S. Department of the Interior
DSRP	Decommissioning and Site Reclamation Plan
EAP	Emergency Action Plan
ESMAP	Energy Sector Management Assistance Program
FPV	Floating photovoltaics / floatovoltaics
Guidebook	*Guidebook—Use Authorizations for Non-Hydro Renewable Energy on Reclamation Lands*
GW	gigawatt
IREA	International Renewable Energy Agency
kV	kilovolt
kVA	kilovolt ampere
kW	kilowatt
kWh	kilowatt hour
LCB	Lower Colorado Basin Region 8
LCOE	levelized cost of electricity
LOPP	lease of power privilege
m	meter
m2	square meter
MW	megawatt
MWh	megawatt hour
NEPA	National Environmental Policy Act of 1969
NHD	National Hydrography Dataset
N-HRE	Non-Hydro Renewable Energy
NID	National Inventory of Dams
NREL	National Renewable Energy Laboratory
O&M	operation and maintenance
OM&R	Operation, Maintenance, and Replacement
OMB	Office of Management and Budget
pH	power of hydrogen – a measure of how acidic/basic water is

PL	Public Law
PMA	Power Marketing Administration
POD	plan of development
PPA	power purchase agreement
PXAO	Phoenix Area Office
PV	photovoltaics
Reclamation	Bureau of Reclamation
RMP	Resource Management Plan
SAM	System Advisor Model
SBOS	structural balance of system
Secretary	Secretary of the U.S. Department of the Interior
SEIA	Solar Energy Industries Association
SERIS	Solar Energy Research Institute of Singapore
SF	Standard Form
TIC	total inorganic carbon
TMY	typical meteorological year
TW	terawatt
TWh	terawatt hour
UCB	Upper Colorado Basin Region 7
U.S.C.	United States Code
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
W	watt

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Executive Summary

About this Report

Interest among non-Federal developers to deploy solar panels or "floating photovoltaic" (FPV) systems on Bureau of Reclamation (Reclamation) reservoirs has increased. Depending on site-specific situations, FPV projects may help address drought or climate change resiliency considerations.

As FPV is an emerging technology with limited deployments in the United States, few references exist to help inform Reclamation's decision-making and evaluation of non-Federal FPV proposals. This report summarizes the current state of FPV technology, explores considerations to be made by Reclamation when evaluating FPV proposals, and applies considerations to four theoretical "case study" deployments. Considerations are data-driven, informed by subject matter experts, and collectively designed to provide Reclamation an initial framework for a thorough evaluation.

This report is designed to inform Reclamation's evaluation of proposed non-Federal FPV development on Reclamation project reservoirs and does not take a position on the efficacy of the FPV technology or feasibility of FPV systems on Reclamation reservoirs.

FPV Opportunity and Authority

Non-Federal renewable energy development on Reclamation projects—hydropower or other sources, allows Reclamation and our stakeholders to derive additional value from existing Federal water resource projects. Non-Federal renewable energy development is an acceptable, discretionary use of Reclamation lands, facilities, and waterbodies—provided it is compatible with underlying, authorized Reclamation project purposes, is in the best interests of the public, and is consistent with appropriate resource management and environmental considerations for the area. As a discretionary authority, Reclamation is not obligated to process or execute a use authorization request for FPV or otherwise.

Reclamation's authority to develop utility-scale Non-Hydro Renewable Energy (N-HRE) on Reclamation lands, facilities, and waterbodies, including FPV would need to be further investigated. However, the potential to authorize non-Federal N-HRE development is possible through a use authorization as described in Reclamation Manual Directives and Standards (D&S), *Use Authorizations (LND 08-01)*.

Considerations

Due to the unique design and site-specific requirements for FPV systems, this report is not intended to provide a definitive answer regarding the feasibility of FPV systems on Reclamation reservoirs. However, the considerations laid out in this report provide Reclamation an initial framework for evaluating proposed, non-Federal FPV deployment.

Considerations made in this report relate to existing policy, economics, evaporation suppression, safety of dams, environmental, and recreation and public perception. The area for FPV on reservoirs would be limited to reservoir areas that are not already designated for reservoir purposes or dam safety considerations (Figure ES-1).

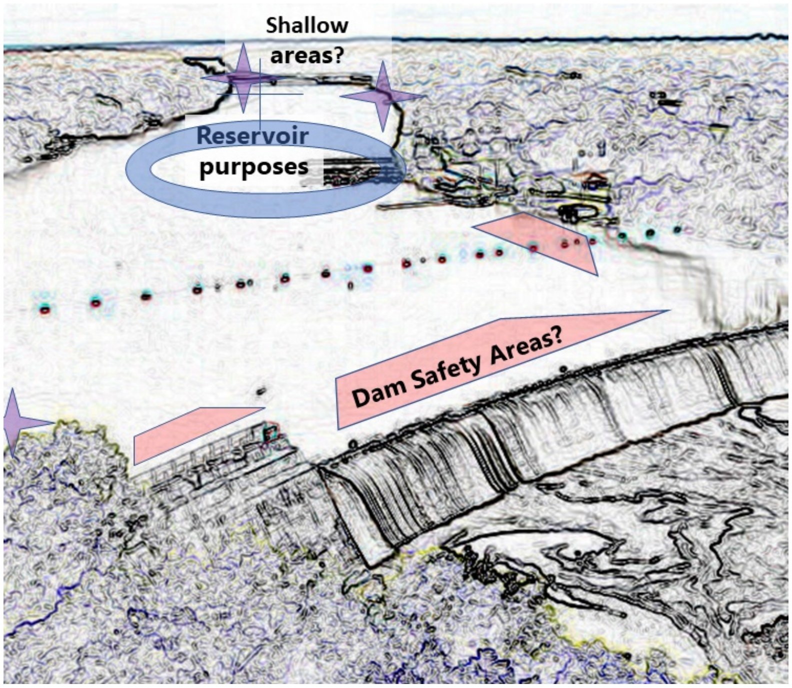

Figure ES-1. Potential considerations for placing FPV on Reclamation reservoirs.

Site and project specifics may (and likely will) warrant additional considerations not addressed in this report. While these considerations are presented separately, there is a clear inter-relation between them. Reclamation would work closely with all partners and operators at Reclamation projects. For example, working with site operators for transferred works and recreation managing partners for reservoirs with managed facilities.

Policy

43 Code of Federal Regulations (CFR) §429 *Use of Bureau of Reclamation Land, Facilities, and Waterbodies,* contains the regulations that Reclamation shall or may follow when considering use authorization requests. In addition, these regulations also provide the public, as well as entities requesting a use authorization on Reclamation land, with requirements associated with their use application.

Reclamation's *Guidebook—Use Authorizations for Non-Hydro Renewable Energy on Reclamation Lands* (Guidebook; Reclamation 2015) provides valuable guidance to assist Reclamation personnel in screening, processing, and administering use authorizations for N-HRE projects on Reclamation lands.

Reclamation Manual Directives and Standards (D&S), *Use Authorizations (LND 08-01)*, provides standard procedures for issuing authorization documents such as easements, leases, licenses, and permits to allow non-Federal entities to use Reclamation lands and interests in its lands, facilities, and water surfaces.

Use authorizations (for all proposed uses, including N-HRE) must be compatible with Reclamation project purposes and uses—e.g., a proposed N-HRE project may not impair the efficiency of Reclamation-generated hydropower or water deliveries, jeopardize public safety, or negatively affect any other Reclamation project purpose.

FPV project developers would have to submit an application to the Reclamation office with jurisdiction over the reservoir for a use authorization, per LND 08-01 requirements. The application would include a detailed plan of development (POD), allowing Reclamation to conduct an impact analysis on environmental resources, water operations, power generation and pumping operations, dam safety risks, and transmission resources. Issuance of a use authorization is at Reclamation's discretion. Reclamation is not obligated to process or execute a use authorization request. Reclamation may recover costs of environmental compliance and other planning from the FPV developer.

Economic

FPV costs vary widely, and the FPV market is less mature than the conventional, land-based PV market. However, FPV costs have been declining and are expected to continue their downward trend due to improvements in the cost of manufacturing the floating solar racking system, cabling, and anchoring, and increased competition on the supply side (Wood Mackenzie 2019). Despite the current cost differences, FPV capacity is expanding around the world.

Globally, motivations to install FPV over PV are primarily due to high land costs and limited land availability. While these drivers are not generally observed across the entire United States, there are populated areas where the premium on land along with other co-benefits are highly relevant to those interested in solar adoption. In the town of Walden, Colorado, an FPV array was a practical and efficient choice for the town's water treatment plant, which is surrounded by bodies of water and requires a good portion of the town's overall power (Kroschel 2018).

Project costs to be incurred by the non-Federal developer would include administrative, environmental and other analyses; installation; operation, maintenance, and replacements (OM&R); inspections; and life cycle costs (replacing approximately every 20 years) for the power system as well as transmission lines. Larger systems have a larger economy of scale (i.e., development costs for systems greater than 1 megawatt [MW] would be around $1 to $2 per watt (W) and systems above 10 MW would be closer to $1 per W). Note that system size may depend on other reservoir operations and dam safety considerations (e.g., distance needed from dams, spillways, and other infrastructure).

Benefits of FPV may include:

- **Energy yields.** Note that energy yield calculations will need to consider the positive cooling effects of placing solar panels above water and the potentially negative effects of fluctuating reservoir levels that may cause the system to slant or lay on a variegated reservoir bottom and produce less power.
- **Evaporation suppression.** Note that evaporation effects need to be studied further to be calculated. Smaller systems on larger reservoirs may not have an appreciable effect on evaporation losses.

Safety of Dams

FPV deployments may pose direct or indirect effects to the structural integrity or functionality of a dam, increasing the maintenance effort, inspection frequency, and risk of failure to the structure. Dam Safety risk analyses will be necessary for FPV installations to ensure that the installation of an FPV system will not result in an appreciable increase in risk to the dam or appurtenant structures. The results of the analyses must be documented in a Dam Safety Decision as required by Reclamation's D&S *Decisions Related to Dam Safety Issues (FAC P02)*. Concerns include:

- **Spillway operations.** Modifications at or near a dam, upstream or downstream, may alter a spillway's capacity and ability to function as designed.
- **Potential collisions.** As dams are specifically designed and constructed to safely operate under local conditions and objectives, each dam's infrastructure would respond differently to conditions and stresses if an FPV or any loose or broken parts collided with the infrastructure. Because of these differences, it is impossible to assign a consistent risk or hazard level posed by FPV arrays that applies across all Reclamation dams. A full feasibility design should include a full analysis and review by design professionals familiar with FPV technology, dam safety, and dam operations.
- **Embankment stability.** Installing a floating solar array requires an anchoring system, which must be designed to ensure that it does not compromise the dam embankment or structural integrity of any other infrastructure. Any penetration into an existing dam could affect the performance of an embankment or concrete dam and should be avoided.
- **Operations and inspections.** The system must be designed so that it does not impede any line of site or access needed for dam OM&R or inspections.

While areas near a spillway may benefit from restrictions on public access and increased existing surveillance, Reclamation would rarely approve this placement, and this may only be allowed after considerable analysis has proven that such an array will not alter the design capacity of the spillway. Spillways do not flow under normal conditions, but their operation is critical to preventing dam overtopping and failure in the event of large hydrologic and flood events.

Installing FPV arrays on a reservoir impounded by a Reclamation high hazard dam would require collaboration with Reclamation's Emergency Action Plan (EAP) Coordinator to keep the applicable dam's EAP updated with new risks and procedures associated with the FPV installation and operation.

Environmental

Regardless of the size and coverage, Federal environmental compliance staff would need to review any proposed FPV project for its potential effects to the physical environment; biological resources, including threatened, endangered, and sensitive species; visual resources; noxious weeds; cultural resources; socioeconomic effects; and other resources. Costs for environmental reviews (in addition to any required post-construction activities (e.g., surveying, monitoring, mitigation, and reporting) would be included as part of the administrative costs paid by the use authorization applicant (43 CFR Part 429).

Further research is needed in general to determine water quality effects (e.g., temperature, stratification, plant growth, toxic algae growth, dissolved organic carbon, and carbon sink potential).

Recreation, Public Safety, and Public Perception

Reclamation should take care to avoid authorizing arrays in key areas of recreational use, in order to avoid negative effects to swimming, boating, fishing, nearby roadways, etc. Careful planning by the developer, including robust public education and engagement, could help garner community support. Public comments received during the National Environmental Policy Act of 1969 (NEPA) scoping process or other public meetings may provide valuable information and alternatives on how to minimize conflicts between an FPV installation and the public.

Technical FPV Potential for Reclamation Reservoirs

The National Renewable Energy Laboratory (NREL) analyzed the technical potential for Reclamation reservoirs using the System Advisor Model (SAM). SAM is a techno-economic software model developed by NREL to facilitate decision-making in the renewable energy space.[1]

The estimate of total potential FPV generation for Reclamation reservoirs is at 1,500 terawatt hours (TWh) annually. The locations with highest potential are Wyoming (132 TWh), California (228 TWh), and Arizona (304 TWh). SAM-informed, technical potential may not translate to economic potential, given on-the-ground conditions and constraints. A more detailed analysis would be necessary to determine if technical potential is economically or market viable.

Theoretical FPV Deployment Case Studies

Considerations were applied to four theoretical "case study" deployments, as summarized in Table ES-1. Key insights from each of the case study reservoirs are:

- Elephant Butte Reservoir experiences significant evaporation losses. In 2020, a year that had below average evaporation losses due to low reservoir levels, the losses from Elephant Butte were still larger than a full year's municipal demand for the City of Albuquerque. Elephant Butte also sees significant recreational usage, with over one million visitors per year.
- While Caballo Reservoir is smaller than Elephant Butte, it has similarly high evaporation loss rates, and lost over 26,000-acre feet in 2020. Caballo is also a popular recreational site, though less so than Elephant Butte.

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[1] For additional information regarding SAM, see: *https://sam.nrel.gov*.

- Brock Reservoir is an artificially constructed reservoir with a liner and uniform depth and thus would eliminate variables for studying evaporation and water quality effects.
- Lauro Reservoir is a tiny reservoir that currently does not involve recreational use. The community strongly supports renewable energy, and the City of Santa Barbara has approached Reclamation about an FPV project. This reservoir could provide a study area for evaporation, water quality, etc. in a smaller, more controlled environment.

Table ES-1. Theoretical FPV Deployment Case Studies

	Elephant Butte	Caballo	Warren H. Brock	Lauro
Location	Truth or Consequences, NM	Hatch, NM	Imperial County, CA	Santa Barbara, CA
Reclamation Project	Rio Grande Project	Rio Grande Project	All American Canal Project	Cachuma Project
Surface Area	36,500 acres	10,000 acres	485 acres	21 acres
Reservoir Purpose	Water supply for irrigation, hydroelectric power generation, flood control and storm-water management, recreation (wakes allowed)	Water supply for irrigation, storm-water management, recreation (no wakes allowed)	Augment regulatory storage capacity in the Colorado River System for flows below Parker Dam	Water supply for irrigation, municipal, and industrial use

Conclusions and Recommendations

Given current information gaps and the site specific nature of FPV deployments, Reclamation is unable to determine the safety, efficacy, and utility of FPV installations on Reclamation's reservoirs. This report serves as a first step in informing that determination.

If Reclamation is approached by a non-Federal FPV developer, early coordination is key to best understand the FPV proposal and FPV effects to the applicable Reclamation project (both positive and negative). This early coordination will also facilitate the development of a detailed application that responds to Reclamation needs. Reclamation may use this report and Key Questions listed in Appendix A to inform coordination with developers.

In addition, this report recommends the following next steps for Reclamation:

- Use lessons learned from the non-Federal FPV community and a pilot case study to evaluate whether revisions may be necessary to support existing Reclamation use authorizations process requirements and/or guidance documents to best accommodate FPV development.
- Continue to coordinate internally and with transferred works operating partners, as well as recreation managing partners, to refine considerations and identify areas for further evaluation.

- Coordinate with the non-Federal FPV community to better understand the FPV technology, industry challenges and opportunities, and discuss report considerations and Key Questions listed in Appendix A. This coordination may help inform Reclamation's understanding of advertised reservoir evaporation mitigation benefits.
- Consider partnering with a non-Federal FPV developer(s) to conduct a pilot deployment case study to evaluate FPV system performance, benefits, and effects to Reclamation project operations—including water deliveries, hydropower generation, and recreation (as applicable), as well as any potential effects to environmental resources or Reclamation infrastructure.

These next steps align with past Reclamation efforts focused on hydrokinetics and may be pursued in coordination with Federal agencies interested in FPV systems (e.g., Department of Energy and National Labs, U.S. Army Corps of Engineers [USACE], and Power Marketing Administrations [PMA]).

1. Introduction

1.1. Report Objectives

This report serves to improve the Bureau of Reclamation's (Reclamation) understanding of floating photovoltaic (PV) panels, or "floatovoltaics" (FPV), on Reclamation project reservoirs. Reclamation's Albuquerque Area Office (AAO) with support from the National Renewable Energy Laboratory (NREL) developed this report. The Reclamation Power Resources Office provided report funding through its Fiscal Year 2019 Request for Proposals for Strategic Energy Initiatives internal funding opportunity.

Interest among non-Federal developers to deploy FPV systems on Reclamation reservoirs has increased over the past decade. Depending on site-specific situations, FPV projects may help address drought or climate change resiliency considerations. As FPV is an emerging technology with limited deployments, few references exist to help inform Reclamation's decision-making and evaluation of FPV proposals. This report summarizes the current state of FPV technology, explores considerations to be made by Reclamation when evaluating FPV proposals, and applies considerations to four theoretical "case study" deployments at Reclamation reservoirs. These sites were selected as examples to discuss Reclamation's particular considerations. Considerations are data-driven, informed by subject matter experts, and collectively designed to provide Reclamation a framework for thorough evaluation.

Non-Federal FPV development sited on Reclamation reservoirs would be evaluated and authorized (if approved) through Reclamation's use authorization process, defined in Reclamation Manual Directives and Standards (D&S), *Use Authorizations (LND 08-01)*.[2]

While this report is designed to inform Reclamation's evaluation of non-Federal FPV development, considerations may also apply to Federal development. Federal projects need to be authorized and supported by Reclamation and funding partners. At this time, report authors are not aware of any explicit authorization for Federal FPV development on Reclamation projects.

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[2] LND 08-01 serves, in part, to implement 43 CFR Part 429, *Use of Bureau of Reclamation Land, Facilities, and Waterbodies*. LND 08-01 does not establish standards and procedures authorizing non-Federal *hydropower* resource development on Reclamation projects. Standards and procedures authorizing non-Federal hydropower resource development on Reclamation projects through a lease of power privilege (LOPP) are defined in Reclamation Manual D&S, *Lease of Power Privilege Processes, Responsibilities, Timelines, and Charges* (FAC 04-08).

1.2. Background

Reclamation is the second largest hydropower producer in the United States. Each year, Reclamation's 53 reserved works hydropower plants generate approximately 40 million megawatt-hours (MWh) of clean, renewable energy. Reclamation's hydropower program supports Administration and the Department of the Interior (DOI) initiatives supporting clean energy, climate change, and domestic energy security by facilitating the development of untapped renewable energy potential on Federal water resource projects through a number of activities. These include collaborative regulatory reform; operational and technological innovation; energy resource assessments; and stakeholder outreach.[3]

Non-Federal renewable energy development on Reclamation projects—be it hydropower or otherwise—allows Reclamation and our stakeholders to derive additional value from existing Federal water resource projects. Non-Federal renewable energy development is an acceptable, discretionary use of Reclamation lands, facilities, and waterbodies—provided it is compatible with underlying, authorized Reclamation project purposes, is in the best interests of the public, and is consistent with appropriate resource management and environmental considerations for the area. Reclamation reserves the right of refusal to authorize any use which may be incompatible with authorized Reclamation project purposes or interfere with Reclamation rights or operations.[4]

1.3. Previous Reclamation Studies

1.3.1. Fundamental Considerations Associated with Placing Solar Generation Structures at Central Arizona Project Canal

In 2016, Reclamation's Phoenix Area Office (PXAO) published the *Fundamental Considerations Associated with Placing Solar Generation Structures at Central Arizona Project Canal*, a white paper evaluating placing solar panels over the Central Arizona Project (CAP) canal (Reclamation 2016). The PXAO studied operation and maintenance (O&M), structural, evaporation, costs, authorities, and stakeholder considerations specific to the CAP system. The PXAO white paper concluded:

> *From a cost perspective, the disadvantages outweigh the benefits of placing solar over the CAP canal. One main disadvantage is that a significant structure would be necessary to span the canal to support the panels. Concerns with such support structure include cost, access restriction to the CAP canal, interference of O&M, limited panel orientation due to the canal positioning, as well as the possibility of compromising the integrity of the CAP canal foundation. Covering the CAP canal with PV panels has the possible benefit of reducing evaporation because of cooling associated with shading. Assuming shading conserves 50%, 6 acre-feet may potentially be conserved per year from shading benefits.*

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[3] Initiatives are partly highlighted in the *DOI Strategic Plan for Fiscal Years 2018-2022*, and Executive Order 14008 of January 27, 2021, *Tackling the Climate Crisis at Home and Abroad*.

[4] e.g., Reclamation-generated power or water deliveries or any other Reclamation project purpose.

> *The results of this white paper show that the cost of placing PV panels over the CAP canal is approximately 24% more costly than placing PV panels near the canal on Reclamation rights-of-way, or on [Bureau of Land Management] land.*

The CAP canal was an interesting and illuminating case study for solar on a Reclamation *canal* system. This report complements the PXAO white paper by assessing solar deployments over Reclamation *reservoirs*—which present unique considerations distinct from the CAP canal system.

1.3.2. Guidebook—Use Authorizations for Non-Hydro Renewable Energy on Reclamation Lands

In 2015, Reclamation's Research and Development Office prepared a *Guidebook—Use Authorizations for Non-Hydro Renewable Energy on Reclamation Lands* to assist Reclamation personnel in screening, processing, and administering use authorizations for Non-Hydro Renewable Energy (N-HRE) projects on Reclamation project lands (Reclamation 2015).

The Guidebook details Reclamation's N-HRE approach and statutory authorities, as well as best management practices information for general administration of N-HRE projects, which would include FPV. As with the PXAO white paper, the Guidebook does not address specific considerations to be made when evaluating FPV proposals for reservoirs as studied in this report.

1.3.3. Guidelines for Collecting Data to Support Reservoir Water Quality and Hydrodynamic Simulation Models

Reclamation's Technical Service Center has provided some initial guidelines that could be used to help develop reservoir water quality monitoring standards for quantifying the effects of FPV on Reclamation reservoirs (*Guidelines for Collecting Data to Support Reservoir Water Quality and Hydrodynamic Simulation Models. Technical Service Center,* Reclamation 2009). "There are six important input data recommendations for modeling algal productivity, organic matter decomposition, and dissolved oxygen (DO) in thermally stratified reservoirs."

1. Choose a model and sampling protocol
2. Collect water samples for orthophosphorus (Soluble Reactive Phosphorus)
3. Collect profiles in early spring and late autumn
4. Collect organic decay data
5. Collect total inorganic carbon (TIC) and alkalinity (ALK) for pH calculations
6. Collect at the model layer centerline depth from surface

2. FPV Description and Status

Figure 1 represents an FPV system. In the system, PV modules are placed on floats anchored to the bottom of the reservoir by mooring lines. Alternatively, the flotation system can be anchored to the shore of the reservoir. From the FPV system, a cable runs to an inverter that collects the power from all FPV systems in the same reservoir and conditions the power to be connected to the grid system through a transformer.[5]

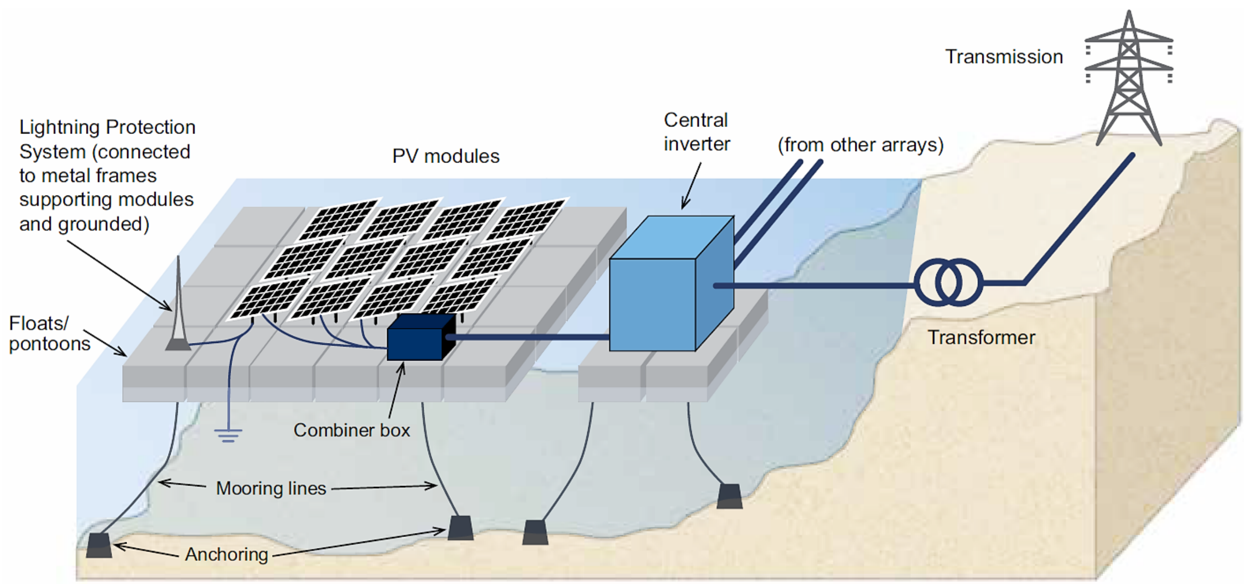

Figure 1. Schematic representation of a typical large-scale floating PV system with its key components (World Bank Group et al. 2019/Used by permission).

Configuration and placement of the PV panel array must consider site-specific reservoir operations—e.g., flood control and water deliveries (Figure 2). The array must be able to withstand a range of reservoir conditions: it must be flexible enough to withstand changing lake levels, potential biofouling, potential freeze-thaw cycles, hailstorms, and high-wind events, while simultaneously being secure enough to withstand any security threats, maintain a power connection and remain a safe distance from the shoreline, dam, intake(s), spillway, or other objects.

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[5] Permissions and authorizations to use Reclamation's transformers would be required.

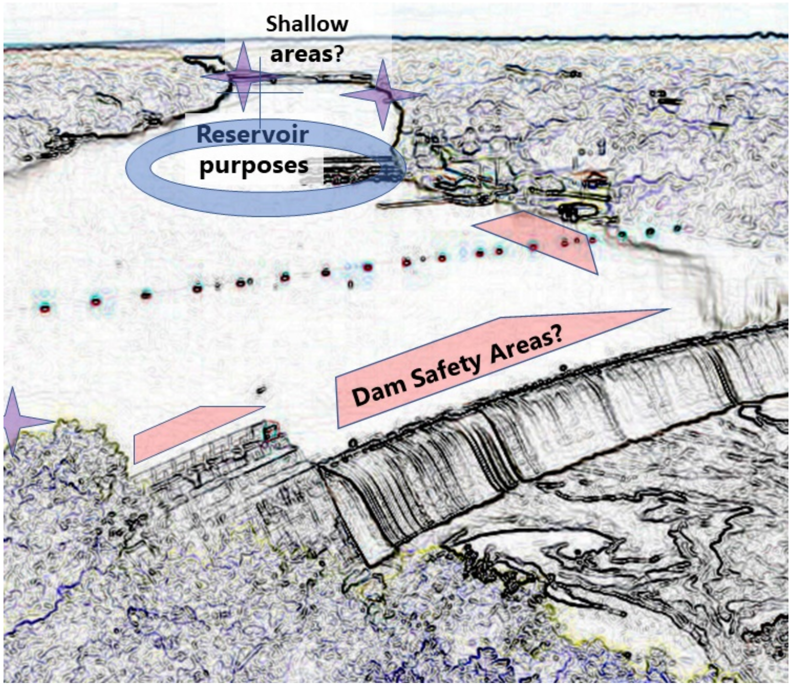

Figure 2. Potential considerations for placing FPV on Reclamation reservoirs.

Due to the unique design and site-specific requirements for FPV systems, the present study is not intended to provide a definitive answer regarding the technical and economic feasibility of installing FPV systems in any Reclamation reservoir. Instead, an interdisciplinary team of experts would be needed to determine the unique technical challenges and overall feasibility of installing FPV for each specific site.

2.1. State of the FPV Industry Globally and in the United States

The FPV industry has benefitted from the technological and cost-reduction experience from three decades of land-based PV deployment. Land-based PV has a cumulative installed capacity exceeding 580 gigawatts (GW) with thousands of projects built and more than 30 years of experience (Bellini 2020).

The first FPV systems were installed in California and Japan in 2007 (Wood Mackenzie 2019 and World Bank Group et al. 2018). Due to the structural differences necessary to install FPV systems over water bodies, FPV system costs remain higher than their land-based counterparts. However, the cost gap is decreasing at different rates around the world. The steepest decrease has occurred in Asia, where more than 70% of the existing FPV systems have been installed as of the end of 2019 (Wood Mackenzie 2019).

Figure 3 shows the rising global cumulative installed FPV capacity since the first installation in 2007 up to the end of 2020. However, in the United States, cumulative capacity remained relatively flat until 2019, when seven FPV projects came online (Figure 4). By the end of 2020, total installed capacity worldwide had reached 2,310 MW, with 92% of that capacity installed in Asia (Wood Mackenzie 2019).

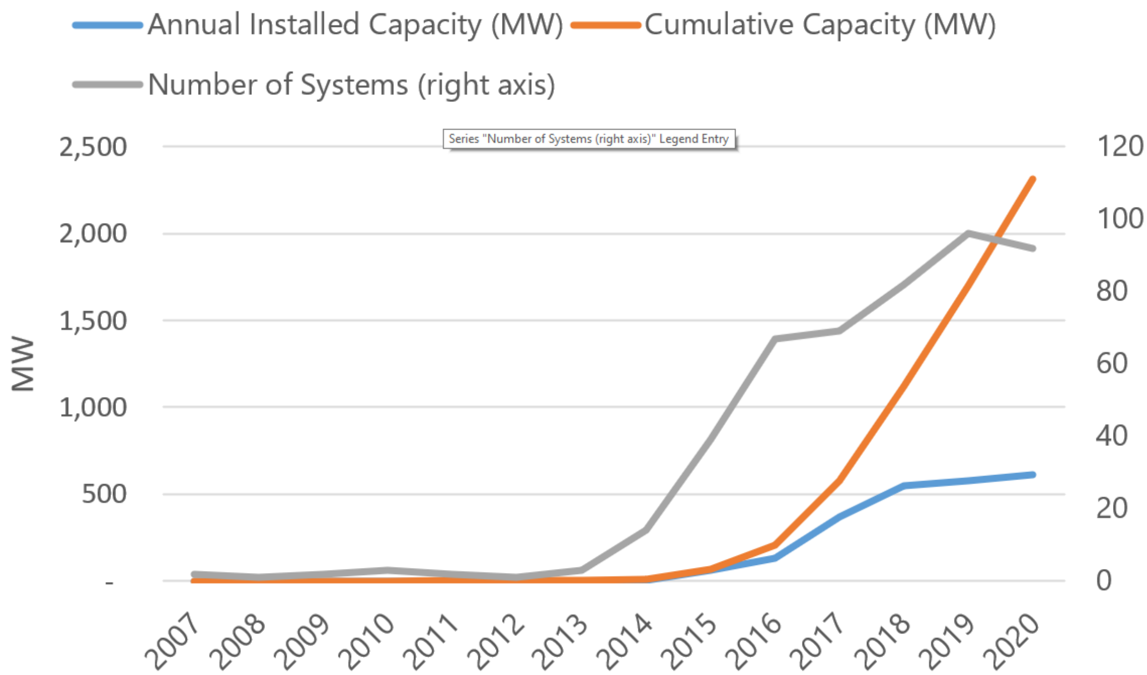

Figure 3. Global installed FPV capacity (NREL, with data from Wood Mackenzie 2021).

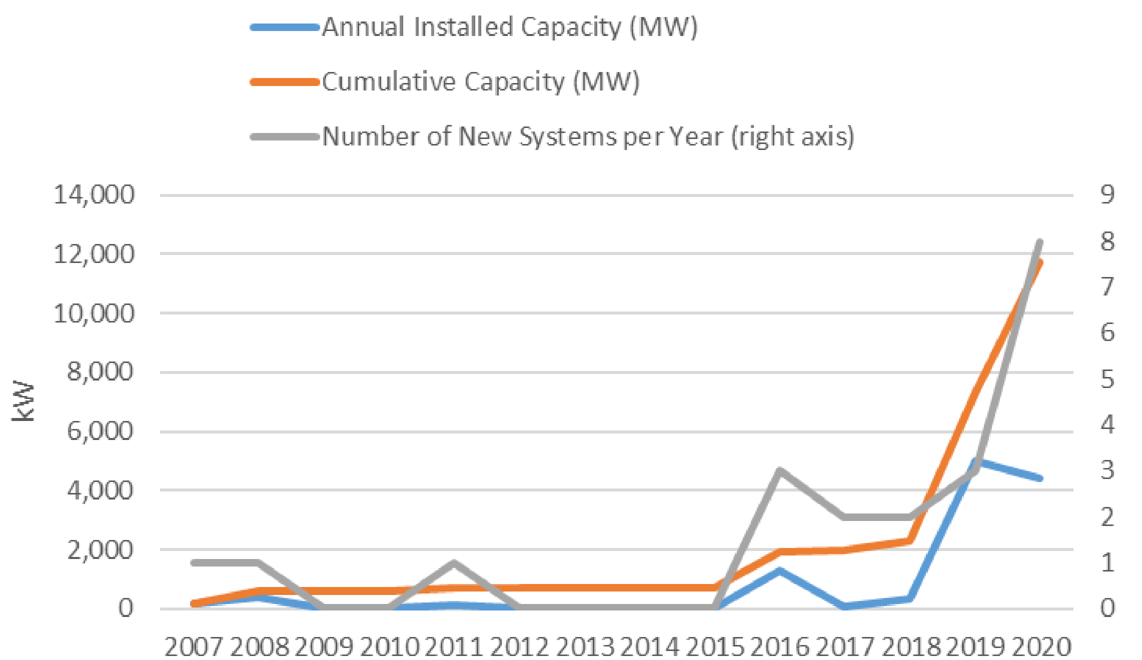

Figure 4. Floating PV capacity installed in the United States by the end of 2019 (NREL, with data from Wood Mackenzie 2021).

Even though one of the first installations of an FPV system took place in the United States, the industry in this country is still in the early stages of development with an 11.7 megawatt (MW) cumulative capacity, 80 percent of which was installed in 2019 and 2020. However, the five-fold increase in installed capacity experienced in 2019 may be an early indication that the industry is growing in the United States, with improved supply chains, costs, permitting, etc. In 2020, installations declined 12% compared to 2019, although 2020 was an atypical year in the energy industry due to the pandemic. Note that installations continue to grow in size; for example, in Healdsburg, California, a 4.78 MW array was installed across two wastewater treatment ponds (Hancock 2021).

Table 1 shows a partial list of FPV plants in the United States. As of the end of 2020, there were 21 FPV plants with capacities ranging from 0.005 to 4.4 MW. Most of the existing plants in the United States are located in California, Florida, and the Northeast—places where electricity costs are high (Spencer et al. 2018). For comparison purposes, a typical residential PV installation would be about 0.005 MW and the smallest Reclamation facility is 0.35 MW (Figure 5).

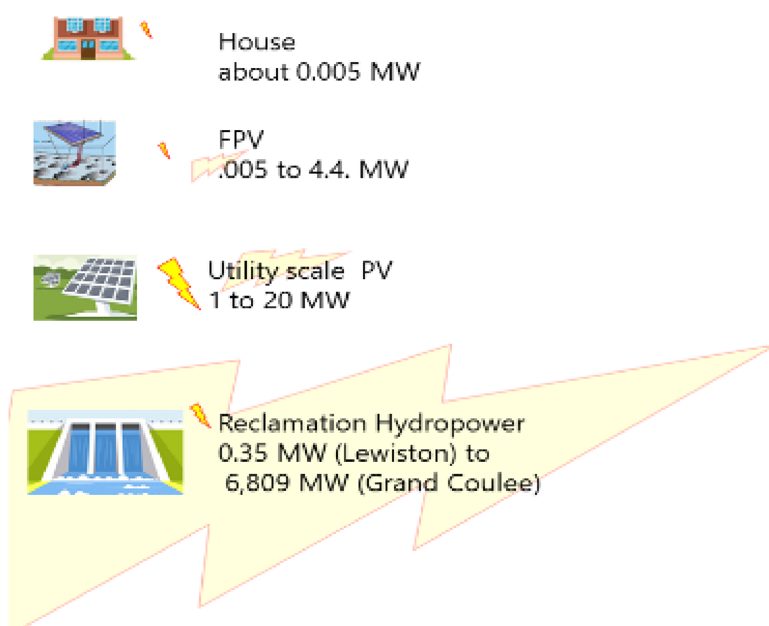

Figure 5. Conceptual idea of scale for FPV compared to typical utility scale PV and Reclamation hydropower plants.

Table 1. Partial list of FPV Installations in the United States as of 2020

Name of Plant/Region (a)	Capacity (MW)	State	Operational Year	Source
Napa Country Far Niente Winery	0.477	California	2007	Solar Plaza 2019
UFC Orlando	0.005	Florida	2016	Solar Plaza 2019
Kunde Winery	0.010	California	2016	Solar Plaza 2019
Orlando Utilities	0.032	Florida	2017	Solar Plaza 2019
Walden WTP	0.075	Colorado	2018	American Water Works Association 2018
Kelseyville County Waterworks, Dist.	0.250	California	2018	Solar Plaza 2019
SC Pond	0.607	California	2019	Solar Plaza 2019
Sayreville Water Treatment Plant	4.4	New Jersey	2019	Jaffe 2021
Windsor Wastewater Treatment Plant	1.8	California	2020	Bailey 2020

2.2. Floatovoltaics System Costs

Generally, installed FPV system costs are higher than land-based PV (based on the state of the industry in 2020). In the United States, FPV costs are 25% to 100% higher than land-based PV. The most recent development cost data shows a range from approximately $1.20/watt (W) to $1.80/W for FPV in 2020 (Wood Mackenzie 2020).[6] By comparison, Wood Mackenzie (2020) estimated utility-scale land-based PV system costs for 2019 at $1/W ± 10 cents, depending on the type and size of the installation. The International Renewable Energy Agency (2020) found that system costs for utility-scale, land-based PV worldwide averaged $0.99/W in 2019.

Two of the most important reasons for the higher capacity deployment of FPV systems are land availability in some countries (e.g., Japan), the small difference in price between floating and land-based systems (e.g., China), or a combination of both (e.g., South Korea). The availability of land and price differential between the two technologies in the United States may explain in part the difference in adoption rates between the United States and some countries in Asia. Figure 6 shows the variability of FPV system costs across countries and within each country for 2019. The figure includes the average costs of PV in each country for comparison.

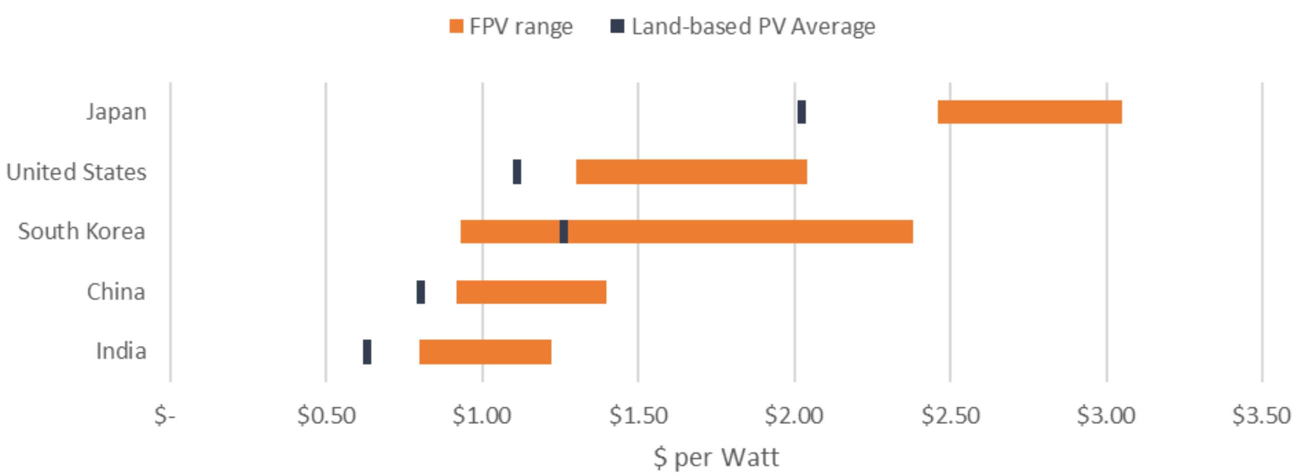

Figure 6. 2019 FPV cost ranges and average utility-scale PV system cost for selected countries (in U.S. dollars per watt) (International Renewable Energy Agency 2020 and Wood Mackenzie 2019).

Two of the main reasons for the cost difference between PV and FPV is the variability of the installation cost and the structural balance of system (SBOS) costs of FPV systems. FPV design and engineering is more complex than land-based PV and more dependent on project-specific factors, such as variation in water levels, extreme weather patterns, water depth, and project capacity. The symmetry and operation of each body of water will determine the design of the floating and anchoring system and change its cost. For example, a system that bottoms out due to the discharge of a particular reservoir must be designed to endure periods of sitting at the bottom of the body of water without being damaged (World Bank Group et al. 2019).

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[6] NREL agreements with data providers prohibit publishing precise cost information.

SBOS includes the floating solar racking system, cabling, and anchoring. The anchoring system design typically includes aluminum spreader bars to connect the mooring lines to the floating platform, cables to link the spreader bars to anchors, chains at the end of the cables to adjust length, secondary float rows that do not have PV panels to ensure buoyancy during harsh winds, and anchors to moor the floating platform on the bottom or shore to reduce movement of the floating platform (particularly during windy conditions). The cables that connect the floating platform to the anchors must be sized to consider water level variations (Ciel et Terre 2020).

FPV SBOS and installation labor are more expensive than PV (Trabish 2019). Anchoring and mooring can be more expensive in bodies of water with higher water level variations (Wood Mackenzie 2019). Future reductions in SBOS costs will have an important effect on the total cost of FPV systems because the costs of the floating platform as well as the anchoring and mooring system comprise between 30% and 37% of the total FPV cost (Figure 7). For comparison, SBOS for PV systems represent 10% or less of total system costs for utility-scale PV (Wood Mackenzie 2020).

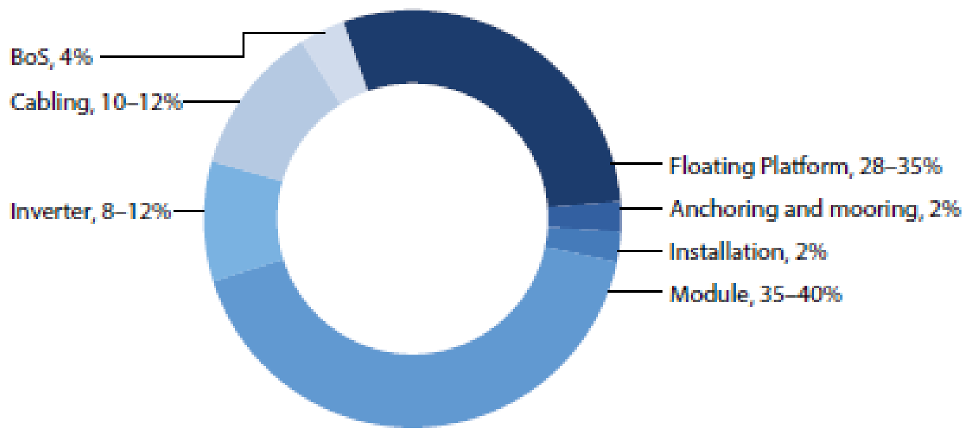

Figure 7. Cost break up for FPV plants (Acharya and Devraj 2019).

Another reason for the cost difference between PV and FPV worldwide is that the FPV market is less mature than the PV market. This means that the FPV supply chain is less established, with fewer developers, installers, and SBOS manufacturers; less experienced installers; and a smaller labor pool than the PV supply chain. Additionally, due to the relatively small pool of projects installed, particularly outside Asia, FPV project financing might be more difficult and expensive to obtain because of the lack of empirical FPV performance data (World Bank Group et al. 2019 and Wood Mackenzie 2019).

FPV costs have been declining and are expected to continue their downward trend due to improvements in SBOS manufacturing and increased competition on the supply side (Wood Mackenzie 2019). Despite the current cost differences, FPV capacity is expanding around the world. Globally, motivations to install FPV over PV are primarily due to high land costs and limited land availability. While these drivers are not generally observed within the United States, there are local cases where the premium on land along with other co-benefits are highly relevant to those interested in solar adoption. These considerations and other drivers were paramount for FPV projects in the United States:

- In the town of Walden, Colorado, a floating solar PV array was a practical and efficient choice for the water treatment plant, which is surrounded by bodies of water and requires a good portion of the town's overall power (Kroschel 2018).
- In Napa Valley, the Far Niente's installation saved valuable vineyard acreage from being sacrificed for land-mounted arrays (Renewable Energy Focus 2008).
- In New Jersey, the Sayreville Water Treatment Plant's installation provided more efficient energy production due to the cooling effect of the water, eliminated the need to use expensive real estate, minimized evaporation, and reduced water movement to minimize erosion (Ciel et Terre 2019).

These drivers may not exist on Federal lands, including Reclamation reservoirs. For Reclamation, FPV systems may offer more immediate benefits associated with current water management practices to protect water supplies' quantity and quality. Costs and resource benefits of hybridization with existing hydroelectric facilities may be another relevant driver for FPV on a Reclamation reservoir.

2.3. Hybrid FPV and Hydropower Systems

Lee et al. (2020) explains that the co-optimized operation and planning of hybrid FPV and hydropower systems may offer additional value beyond the benefits of stand-alone FPV systems. Additional benefits that could be derived from hybrid systems are detailed below. Note that individual cases will provide varying benefits.

1) Improved System Operation

- **Seasonal timescale:** Leverage asynchronous, seasonal resource availability by reducing reliance on hydropower resources during dry seasons, maximizing solar resources. Reduce reliance on solar resources during wet seasons, maximizing hydropower resources.
- **Daily and/or hourly timescale:** Compensate for the intermittent output of solar resources with hydropower, as solar resources are only available during certain hours of the day, conserving water resources until needed.
- **Sub-hourly timescale:** Compensate for the variableness in solar resource availability as well as changes in demand through ramping of hydropower generation.

2) Energy Storage Opportunities

- **Pumped storage hydropower:** Leverage excess solar generation to pump water into an upper storage reservoir for later hydropower generation.[7]

[7] For additional information regarding pumped storage hydropower, see: *Water Power Technologies Office 2021. Pumped Storage Hydropower*.

- **Virtual (full) hybrid system:** Conserve hydropower water resources during peak solar production hours, using the reservoir as storage for the non-dispatchable solar PV.

3) Transmission System Benefits

- **Improved transmission use:** Connecting FPV to existing transmission may increase the transmission lines' use rates where additional transfer capacity exists.

- **Reduced transmission system interconnection costs:** Co-locating FPV systems with hydropower (where Reclamation policy allows) may allow FPV to connect to existing transmission infrastructure—reducing transmission development costs.

4) Reduced FPV curtailment: Variableness and intermittency of FPV generation compensated by hydropower generation (where power contractual obligations and water availability allow).

5) Resource conservation: FPV coverage of hydropower reservoirs may help decrease water evaporation and conserve water resources for hydropower generation.

To be clear, these are *potential* additional benefits for Reclamation to be aware of. Within Reclamation projects, these additional benefits may be limited and/or prohibited due to statutory, contractual, and/or other requirements and/or commitments by Reclamation and/or Reclamation partners, e.g., Federal Power Marketing Administrations (PMA) and Reclamation project operating partners and recreation managing partners.

In all cases, the non-Federal FPV developer is responsible for securing any and all power purchase and wheeling agreements to transmit power over Federal and non-Federal transmission lines. Reclamation and Federal PMAs are not obligated to purchase or wheel (transmit) non-Federal FPV generated power over their transmission lines. In addition, Reclamation is not obligated to alter Reclamation project operations to accommodate a non-Federal energy project (FPV or otherwise).

3. Considerations Evaluated

The sections below address considerations to be made by Reclamation when reviewing a non-Federal FPV project proposal. Considerations relate, but are not limited, to project-specific authorization, existing policy, economics, evaporation suppression, safety of dams, environmental, and recreation and public perception. While these considerations are presented separately, there is a clear interrelation between them. Considerations addressed in this report are designed to provide an initial review framework for evaluating FPV projects. Site and project specifics may warrant additional considerations not addressed in this report.

Appendix A contains a list of key questions that may guide assessing the initial conceptual feasibility of FPV arrays on Reclamation reservoirs. These questions are intended to act as a planning aid and should not be construed as design guidance or a comprehensive list of issues to consider when installing an FPV system on a reservoir. A full feasibility design should include thorough analysis and review by design professionals familiar with FPV technology and dam operations.

3.1. Policy Considerations

Reclamation does not have the authority to develop utility-scale non-hydropower renewable energy (N-HRE) on Reclamation lands, facilities, and waterbodies, including FPV. However, the potential to authorize non-Federal development is possible through a use authorization. Use authorizations (for all proposed uses, including N-HRE) must be compatible with Reclamation project purposes and uses—i.e., a proposed N-HRE project may not impair the efficiency of Reclamation-generated hydropower or water deliveries, jeopardize public safety, or negatively affect any other Reclamation project purpose.[8]

Reclamation Manual D&S, *Use Authorizations (LND 08-01)*, provides standard procedures for issuing authorization documents such as easements, leases, licenses, and permits to allow non-Federal entities to use Reclamation lands, facilities, and water surfaces. Terms and conditions addressed in Appendix A in LND 08-01, may apply to any use authorization, including approved uses for pilot projects.

3.1.1. Reclamation Authorizations to Permit Development

Section 10 of the Reclamation Act of June 17, 1902 (43 United States Code [U.S.C.] §373), provides the DOI Secretary (Secretary) with the authority to "perform any and all acts and to make such rules and regulations as may be necessary and proper" for carrying out the provisions of the Act. Section 10 of the Reclamation Project Act of 1939 (43 U.S.C. §387) provides the Secretary the authority, in

[8] As noted, *Reclamation's Guidebook—Use Authorizations for Non-Hydro Renewable Energy on Reclamation Lands* provides valuable guidance to assist Reclamation personnel in screening, processing, and administering use authorizations for N-HRE projects on Reclamation lands (Reclamation 2015).

his or her discretion, to grant rights-of-way or use authorizations that include leases, licenses, permits, and easements—but must be compatible with project purposes and uses. These Acts provide Reclamation with the general statutory authority to issue rules on authorizing or prohibiting uses of Reclamation land, facilities, and water bodies. Non-Federal projects that are not compatible with Reclamation project purposes, or negatively affect Reclamation project operations, benefits, etc., would not receive a use authorization.

Authorizations for non-Federal entities to use Reclamation project lands, facilities, and waterbodies are guided primarily by the regulations of 43 CFR §429 *Use of Bureau of Reclamation Land, Facilities, and Waterbodies*. Renewable energy is not specifically mentioned in 43 CFR §429; however, utility infrastructure is noted in §429.3 as a typical use. Reclamation has clarified the regulations as they relate to renewable energy in the 2015 Guidebook (Reclamation 2015), which states:

> *N-HRE is an accepted use of Reclamation lands as long as it is compatible with hydroelectric and other project purposes. This is consistent with 43 CFR § 429.14 which indicates that compatibility with authorized project purposes, project operations, safety and security will be considered when reviewing land use authorizations. Accordingly, proposed land uses cannot interfere with project purposes, but such uses may or may not be water or power related. Examples of potentially compatible land uses include, but are not limited to row crops, roads, pipelines, fences, free-range cattle, solar panels, windmills, water pumps, and timber harvesting.*

Reclamation efforts to facilitate non-Federal N-HRE resource development are supported by a number of Federal statutes, including the Energy Policy Act of 2005 (Public Law [PL] 109-58); the Energy Independence and Security Act of 2007 (EISA) (PL 110-140); and the Omnibus Public Land Management Act of 2009 (PL 111-11, Title IX Bureau of Reclamation Authorizations, Subtitle F—Secure Water).

Additionally, N-HRE use authorizations, as detailed in LND 08-01, support Executive Order 14008 of January 27, 2021, *Tackling the Climate Crisis at Home and Abroad*, as well as domestic energy security objectives identified in the *DOI Strategic Plan for Fiscal Years 2018–2022* related to expanding the production of domestic energy resources on Federal lands through efficient permitting, appropriate standards, assessment, and oversight.

LND 08-01 provides standard Reclamation procedures for issuing authorization documents such as easements, leases, licenses, and permits to allow others to use Reclamation lands and interests in its lands, facilities, and water surfaces. LND 08-01 states that non-Federal N-HRE development "is an acceptable, discretionary use of Reclamation lands, facilities, and waterbodies provided it is compatible with authorized Reclamation project purposes, is in the best interests of the public, and is consistent with" the criteria in 43 CFR §429.14. As noted, issuance of a use authorization is at Reclamation's discretion. Reclamation is not obligated to process or execute a use authorization request.

3.1.2. Applicable Policy Requirements

3.1.2.1. Current Reclamation Requirements

FPV project developers must submit an application to the Reclamation office with jurisdiction over the reservoir for a use authorization. As outlined in 43 CFR §429.14, Reclamation will consider the following criteria when reviewing applications:

- compatibility with authorized project purposes, project operations, safety, and security;
- environmental compliance;
- compatibility with public interests;
- conflicts with Federal policies and initiatives;
- public health and safety;
- availability of other reasonable alternatives; and
- in the best interests of the United States.

The considerations proposed in this report are designed to facilitate a robust evaluation of proposed FPV projects, and in doing so, apply across the above criteria. For example, presented policy considerations address compatibility with authorized Project purposes, conflicts with Federal policies and initiatives, and interests of the United States. Likewise, presented Safety of Dams Considerations address project safety and security around Reclamation facilities. Other criteria are more directly aligned, e.g., environmental considerations and the environmental compliance criteria, and recreation and public involvement considerations and the criteria of compatibility with public interests.

Applications for use authorizations must include Standard Form 299 (SF-299) and a detailed—not conceptual—plan of development (POD). The POD must be of sufficient detail to provide the information necessary to perform analyses on effects to environmental resources, water operations, power generation and pumping operations, and transmission resources. Reclamation regional power managers must review the POD and advise the staff on the project's compatibility with Reclamation project purposes, technical feasibility, and appropriate stipulations to ensure public health and safety as well as non-interference with project power and pumping operations. Regional power managers must also consult with PMAs to ensure no negative effects to PMA obligations.

No application will be processed until an applicant has submitted a complete SF-299 and POD and the applicant has provided cost recovery fees as required by the regulations (43 CFR §429.17 and *Office of Management and Budget [OMB] Circular A-25*), including an annual fair market value rental, which includes both base rent and a MW capacity fee. In addition, Federal regulations authorize Reclamation to require a N-HRE use authorization holder to provide a bond to secure the obligations imposed by the use authorization (43 CFR §429.29), including environmental liabilities; decommissioning, removal, and proper disposal; and reclamation, revegetation, restoration, and soil stabilization.

3.1.2.2. Planning Suggestions

Development of a detailed project application and POD will likely require input from Reclamation, recognizing that Reclamation may be unable to provide any assurances until (if and when) the use authorization has been issued. To that end, it is recommended that Reclamation and the applicant meet at least once before the formal application is submitted to address the key questions listed in Appendix A and to provide a preliminary, high-level analysis. This analysis may help identify any red flag issues for the developer (e.g., type of use authorizations required by financial institutions and allowed under Reclamation authorizations, use fee negotiation), as well as inform Reclamation's efforts in reviewing the request. It is recommended that Reclamation share an example or executed use authorization in advance so that applicants can preview all of the terms and conditions (also found at 43 CFR §429.28) prior to submitting and going through the application process.

Topics that may be addressed in the pre-application meeting include:

- Identify necessary studies of environmental, wildlife, cultural, or other resources, permits, or other information that may be needed
- Identify other existing authorized uses within or near the project area
- Allow for possible consideration of potential alternative site locations and project configurations
- Identify lands with high conflict potential and identify potential conflicts with Reclamation project purposes or sensitive resource values
- Provide an opportunity for N-HRE projects to be directed toward other areas such as previously disturbed sites, areas adjacent to previously disturbed or developed sites, and locations that minimize construction of roads and/or transmission lines and avoid potential interference with hydroelectric or other project purposes
- Allow Reclamation to learn about the interests and objectives of the applicant, including any constraints or flexibilities with respect to the proposal (e.g., timing or location constraints based on loan guarantees, power purchase agreements, or transmission connections) and any consideration that has been given to siting on non-Federal lands.

Early coordination with transferred works operating partners (as applicable) as well as managing entities for recreational sites or grazing areas for permitting and environmental compliance is also advised.

It is also important to review the existing Reclamation Resource Management Plan (RMP) decisions (if any) that are used to guide management of the land at the desired location. In cases where N-HRE development proposals are not compatible with the RMP, it may be appropriate to amend the RMP concurrently with processing the application using the same environmental review process. Projects that would require major RMP revisions with potentially significant environmental effects should generally be rejected.

Based on discussions during the pre-application meeting and the recommendations of affected Federal, State, Tribal, and local government land managers, the appropriate Reclamation regional director or designee may recommend that an application not be filed for the proposed project or that a proposed project be modified prior to submission of an application. Applications with fewer resource conflicts are anticipated to be easier and thus less costly and time-consuming for Reclamation to process.

In accordance with Reclamation's use authorization regulations, the term or length of a N-HRE use authorization is limited to a reasonable period of time. The life of a renewable energy facility is typically 25 to 30 years. For context, the expected lifetime of a floating PV system ranges between 20 and 30 years (Cromratie Clemons et al. 2021 and World Bank Group et al. 2019). Consistent with 43 CFR §429.6, any use authorization for a term of 25 years or longer must have consent of any involved water user organization(s). If the term is to be 25 years or less, the water user organization(s) shall be notified, at a minimum, of the use authorization prior to its being granted.

3.2. Economic Considerations

Economic analyses should consider all benefits and costs of each alternative, regardless of who might benefit or pay. Reclamation follows the Principles and Requirements for Federal Investments in Water Resources. These guidelines define public benefits as encompassing "environmental, economic, and social goals, include monetary and nonmonetary effects and allow for the consideration of both quantified and unquantified measures" (Council on Environmental Quality [CEQ] 2013).

As this was a "desktop" study, NREL's analysis cannot take into account important site-specific considerations that may affect the technical and financial performance of the FPV systems analyzed in this report. As mentioned earlier, FPV systems are more complex to design because the local characteristics of each site have a bigger effect on the final design and cost of each system. Site specific factors may increase FPV project costs, decrease the financial performance of the FPV system, or both.

Economic considerations are provided to inform Reclamation's understanding of FPV project feasibility and competitiveness. This section discusses potential benefits that could be considered in a cost-benefit analysis.

3.2.1. Substitute Power

FPV or PV in general could be used to serve Reclamation project loads currently served by Reclamation hydropower generation. Reducing on project demand for Reclamation hydropower generation would allow for additional generation to be marketed by WAPA and BPA to preference power customers.

3.2.2. Cooling Effect on FPV Efficiency

FPV systems around the world have reported an increase in power production due to the cooling effect of the water—the evaporative cooling of the water around the PV panels keeps them cooler, which boosts their efficiency. The reported increase ranges from 1.5% to 22% annually (Spencer et al. 2018). A study from 2021 found that the gain in energy yield from the cooling effect was up to 3% in the Netherlands and up to 6% in Singapore (Dörenkämper 2021). However, currently there is no methodology to estimate what level of efficiency would be gained in other locations.

3.2.3. Water Levels and Bathymetry

Variable water levels require a specialized anchoring and mooring system that is likely to increase project costs—and therefore negatively affect the financial performance—of the system. Some Reclamation reservoirs are emptied with a certain frequency (e.g., yearly). Floatation systems designed to tolerate the wear caused by bottoming out may also increase the cost of the system.

Additionally, sitting on the bottom of a reservoir that is not flat and horizontal may cause the PV panels to lose their optimal orientation and, for that reason, produce less power, which would affect revenues and financial performance. Detailed information about the operation of each reservoir and bathymetry (topography of the reservoir bottom) would be needed to assess the effect of emptying reservoirs on annual energy yields from FPV systems. Furthermore, it is possible that the conditions of the terrain at a reservoir's bottom makes it unfeasible to deploy an FPV system.

3.2.4. Transmission Lines

Existing transmission lines may not be available to private developers or may need to be upgraded. Depending on the size of the system, the transmission line that connects the site to the utility's transmission line may require upgrading. Transmission upgrades to interconnect to the power grid could significantly increase the cost of FPV systems. Transmission upgrades may include rewiring the line and installing a new transformer with the capacity to carry the energy produced by the FPV system. If currently there is no such line, a new one would have to be built. The cost of a new high-voltage transmission line (230 kV) can be approximately $1 million per mile, not including additional upgrades such as a new substation, if required (Andrade and Baldick 2016). This approximate cost per mile may increase, depending on the characteristics and ownership of the tract of land over which transmission lines would be built. Mountainous land, thick vegetation, and wetlands are some of the factors that could increase the cost of building transmission lines above estimates or increase the length of the line required. Additionally, permitting costs may increase if protected land is traversed.

Transmission line footprints must also be considered. Ownership of the land plays an important role and may increase the cost of construction, necessitate longer transmission lines, or lengthen the permitting and construction processes depending on the number of different owners and their willingness to allow construction. For the theoretical case study analyses in this report, we have calculated the approximate cost of building a line from the closest point of the reservoir to the closest transmission line to approximate the minimum cost to interconnect the FPV system to the transmission system. We have not examined the permits or authorizations required to use these transmission lines.

3.2.5. Scale

The economies of scale for FPV systems are more pronounced than those of land-based PV systems, in addition to the price differential mentioned previously. In general, the cost of developing FPV systems in the United States does not come below $2/W for systems under 1 MW of capacity. Based on the analyses in 2020, the cost of developing systems above 1 MW are in the upper part of the $1/W to $2/W range. The cost nears the lower part of that range for systems 10 MW in size and above.

3.3. Technical Considerations

Technical considerations for FPV include footprints on Reclamation reservoirs as well as land. Determining potential areas for FPV installations include the usable surface area of the reservoir, which may be affected by the shape of the reservoir, slope of the edges, bathymetry, depth, as well as terrestrial infrastructure needed (e.g., transmission lines). Many reservoirs impounded by Reclamation-owned dams experience significant fluctuations in storage volume over the course of an average year. These fluctuations are a function of the season, local drought conditions, water user demands, power production, and legally binding contracts for water allocation and releases. In some cases, specific inspections, maintenance, or repairs also necessitate temporary lower reservoir elevations. Low or empty reservoirs may mean that the FPV rests on steep slopes or varied heights, thus losing its efficiency or posing O&M difficulties. Shallow shorelines that are frequently exposed with fluctuating reservoir levels may require placing an FPV system farther from shore, adding to the cost of the project. Further, the magnitude of effects, such as displacement of recreation users or navigational hazards, might increase along with a declining reservoir size, and these potential effects would need to be considered.

Technical potential may also be limited by conflicts with other reservoir uses, such as navigation or recreationists with prior claims to deep areas that would otherwise be suitable for FPV, or flood control and irrigation needs that result in fluctuating water levels.

3.4. Evaporation Suppression Considerations

If future studies show FPV is effective in reducing reservoir evaporation, this reduction would be a useful decision factor when determining whether to provide a use authorization for an FPV development on a Reclamation reservoir.

3.4.1. Potential Evaporation Effects

On some Reclamation reservoirs, it is estimated that tens and even hundreds of thousands of acre-feet of water—billions of gallons—are lost to evaporation every year. We know that evaporation loss rates depend on water temperature, wind speed, and incoming solar radiation (insolation), so evaporation can be reduced by providing shading from the sun's rays, especially by reducing water temperatures, or by reducing winds that reach the surface of the water. FPV proponents are hopeful that evaporation suppression will be shown to be a significant benefit of installing FPV on water bodies where evaporation loss rates are high, as the floating arrays would shade the water from incoming sunlight and also reduce wind across the surface of the water. However, the factors that drive open-water evaporation can be complex and are affected by local conditions like wind direction, humidity, water depth, and lake circulation. Therefore, without site-specific studies, it can be challenging to assess what effects an FPV installation would have on overall evaporation losses from a reservoir.

While one of the advantages of installing PV panels over water is that the water provides a cooling effect, which increases the electricity-generation efficiency of the panels, some heat from the panels is transferred to the water. This heating of the water would limit the decrease in evaporation losses to some degree, but it is not yet known how much. Heat transfer may not be complete, as converting some of the solar radiation to electricity would take energy away from the sun's rays that would otherwise hit the water and be absorbed.

The amount of evaporation reduction that could be achieved from an FPV installation would depend on the area of water covered by the panels, where on the reservoir it is installed, as well as some aspects of the installation type. Many proposed installations will have a small surface area relative to the overall size of the reservoirs. Therefore, even if they achieve a reduction in evaporation rates locally, the change in total evaporative losses from the reservoir might not be significant. Also, the reductions might be less if the installation is located over a deeper, cooler part of the reservoir rather than a warmer, shallower area. However, installation in the cooler, deeper areas should result in greater enhancement of efficiency of the panels. There are also aspects of the FPV installations that can affect how much reduction in evaporation losses can be achieved. These include the degree of shading of the water, how close the panels are to the water surface, how much excess heat from the panels is transferred to the water, and how much the panels block wind across the water surface. Many complicated factors affect the amount of evaporation reduction that can be achieved with an installation. Reclamation should be wary of contractors' claims of evaporation savings by a proposed installation.

3.4.2. Current State of the Science

Estimates of evaporation losses at reservoirs lack the overall accuracy and representativeness needed to validate and/or project the potential savings resulting from an FPV installation (Friedrich 2018). Albuquerque Area Office currently collaborates with researcher Dr. Jacob Collison at the University of New Mexico to improve evaporation measurements on Cochiti Reservoir and Elephant Butte Reservoir. To date, we have not found any research that provides a defendable evaporation suppression estimate for an FPV array of any size or set up.

3.4.3. Options to Develop Evaporation Suppression Estimates

A small, controlled site-specific FPV demonstration project would help answer some questions and provide a basis for site-specific analyses in view of the considerations evaluated in this document. In an initial conversation, Dr. Jacob Collison indicated that it would be feasible to install a solar panel above a floating evaporation pan in a reservoir and compare this with evaporation from a nearby uncovered floating evaporation pan to precisely quantify evaporation suppression at a small scale (<10 square meters [m^2]) (personal communication, 2021). Metrics to collect and analyze in an evaporation study (in addition to evaporation) to be able to scale-up evaporation suppression estimates would include:

- Solar radiation
- Energy generated
- Wind (speed and direction)
- Fetch (length of open water without wind obstruction)
- Relative humidity
- Water temperature
- Air temperature
- Reservoir bathymetry ("underwater topography")
- Remotely sensed reservoir surface temperature (full spatial coverage of reservoir).

FPV projects granted a use authorization may need to be monitored to better quantify environmental effects to aquatic species after installation. It may be useful to co-locate evaporation and environmental studies, if applicable, to maximize benefits and minimize costs. Additionally, further research could better quantify the efficiency improvements that location over water affords to photovoltaic panels.

Reclamation is involved in ongoing evaporation research and will continue to monitor progress in both estimating and reducing evaporation.

3.5. Safety of Dams Considerations

3.5.1. Description of Potential Effects

Any modifications that directly or indirectly affect the performance, structural integrity, or functionality of a dam or appurtenant facilities may increase the maintenance effort, inspection frequency, and risk of failure to the structure. In the most extreme cases, a dam failure can cause significant economic loss and loss of life for miles downstream of the dam. All phases of planning, design, installing, and operating FPV units on bodies of water impounded by Reclamation-owned facilities should be coordinated with the appropriate Reclamation Safety of Dams and Operation and Maintenance personnel at the Area, Regional, and Denver Office levels. For high-hazard dams and canals, the Reclamation Emergency Action Plan (EAP) Coordinator for the structure(s) involved should also be consulted. Dam Safety risk analyses will be necessary for FPV installations to ensure that the installation of an FPV system will not result in an appreciable increase in risk to the dam or appurtenant structures. The results of the analyses must be documented in a Dam Safety Decision as required by FAC P02 "*Decisions Related to Dam Safety Issues*."

Dams are specifically designed and constructed to safely operate under local conditions and objectives. The materials, geometries, and appurtenant structures of every dam are unique and respond differently to conditions and stresses produced by the potential collision of loose FPV arrays and components. Because of these differences, it is impossible to assign a consistent risk or hazard level posed by FPV arrays that applies across all Reclamation dams.

3.5.2. Structural Integrity of Dam

A floating solar array could affect the structural integrity of a dam in two primary ways:

1) **An FPV array might come loose from its anchoring system and collide with the dam embankment or associated works.** To reduce the risk of impact damage to the dam embankment and associated works, FPV arrays need to be securely anchored and placed at a sufficient distance from the structure(s) through a full range of normal and extreme reservoir operating conditions. The risks associated with the FPV colliding with the dam or associated structures from natural and man-made causes should be evaluated and appropriately mitigated. Existing floating debris curtains might need to be extended and fortified, and critical inlet works, and instrumentation might need additional protection added to reduce the risk of impact damage from loosed FPV components.
2) **The floating solar array requires an anchoring system that might be connected to the embankment which could compromise its integrity.** In no case should FPV arrays be installed on, immediately next to, or anchored to any portion of a dam's embankment (crest, upstream, or downstream), dike, outlet works, instrumentation, or any other appurtenant structure used for operation, maintenance, or inspection.

Furthermore, FPV units must not compromise visual lines-of-sight and access necessary for dam operation, inspection, and maintenance. Access to the FPV array for installation, operation, and maintenance should not include any Reclamation structure or restricted access points and should not impede Reclamation's ability to access any critical structures under normal or emergency conditions.

3.5.3. Spillways and Outlet Works

Areas near a spillway may be identified by developers as preferential locations for an FPV array as this area may benefit from restrictions to public access and increased existing surveillance. However, placing an FPV array near a spillway inlet will rarely be approved by Reclamation and may only be allowed after considerable analysis has proven that such an array will not alter the design capacity of the spillway.

The unimpeded functionality of all spillways is crucial for regular and flood control operations at Reclamation dams. All dam features, including inlet and outlet works, controlled service spillways, gated spillways, and uncontrolled emergency spillways have been designed and sized for specific operating conditions and design storms. Modifications at and near a dam, upstream or downstream, may alter a spillway's capacity and ability to function as designed. FPV arrays should not be placed in a spillway or immediately downstream of a spillway. An array should be placed far enough upstream of all spillway inlets so as not to impede or alter the hydraulic flow paths approaching the spillway. For large spillways, this upstream "area of influence" may extend thousands of feet or further into the reservoir and will vary based on reservoir elevation and gated spillway opening.

It should be noted that many uncontrolled emergency spillways are constructed physically apart from the primary dam embankment and may be miles away from the service spillway and dam embankment in large reservoirs. These spillways do not flow under normal conditions, but their operation is critical to preventing dam overtopping and failure in the event of large hydrologic and flood events.

High water velocities near spillways greatly increase the risk of FPV components breaking off and entering a spillway, where they could damage the spillway or block the flow of water. Such an instance could require repairs, and in certain circumstances, might compound or even cause an emergency response incident at the dam.

3.5.4. Standard Operations

Any effort to complete a feasibility study or design for FPV arrays on a body of water impounded by a Reclamation structure should include consulting with the Reclamation personnel involved in routine dam operations, water planning, maintenance, and security for that particular structure. Each dam and impounded reservoir have a unique combination of water supply, flood control, recreation, and other purposes that dictate how it is operated under normal conditions and emergency situations. These factors will be key in assessing the feasibility and placement of FPV units on reservoirs impounded by Reclamation dams.

In many cases, Reclamation-owned dams have transferred day-to-day operation and maintenance responsibilities to operating partners, and for some dams, USACE maintains jurisdiction over flood operations when reservoir water elevations reach specific levels. Where appropriate, USACE and operating partners will need to be involved in planning for FPV array placement and inspection, and specifics formalized in the use authorization.

3.5.4.1. Inspections

Reclamation and its operating partners perform multiple inspections at dam facilities on monthly, annual, and multi-year cycles. Many of these inspections involve visual inspection of the dam and appurtenant structures, but some include dive exams, instrumentation readings, and the occasional geotechnical investigation. FPV arrays should not occlude any of the line-of-sight or access required for any of these inspections.

3.5.4.2. Sediment Management

Sediment management occurs at most Reclamation dams via occasional sediment surveys and removal by dredging or excavation. Sediment surveys are performed approximately once every decade. At smaller diversion dams on high sediment-load rivers, sediment removal operations are performed regularly on a yearly basis—sometimes encompassing multiple months a year. These removal operations are quite rare at large dams, but critical to the function of the dam when needed. Wherever FPV arrays are located on a reservoir, they will likely need to be moved or temporarily removed during a sediment survey or removal operation. It is important that the use authorization detail any requirements for moving the FPV system for Reclamation actions for sediment removal or surveys.

3.5.4.3. Wireless Communications

Wireless communications and technologies at many Reclamation dams monitor critical instrumentation; inform water operations decisions; operate outlet works; and communicate during normal operations, inspections, and emergency response. These communications channels should not be compromised at any time. Any remote control or wireless communications used for FPV array monitoring and control shall not interfere with any existing or future communications channels and frequencies used by Reclamation, operating partners, and the U.S. Geological Survey (USGS).

3.5.5. Emergency Operations

Most Reclamation dams are classified as high hazard potential dams, meaning that failure of the dam or appurtenant structures would result in likely life loss or high operational release could cause loss of life or significant destruction downstream of the dam. Reclamation maintains an emergency management program for its high hazard structures that includes regularly scheduled exercises, communication drills, and facility-specific EAPs. Installing FPV arrays on a reservoir impounded by a Reclamation high-hazard dam would require collaboration with Reclamation's EAP Coordinator for that specific dam to keep the dam's EAP updated with new risks and procedures associated with the FPV installation and operation.

3.6. Environmental Considerations

Federal undertakings, such as permitting developments like FPV, are subject to numerous environmental laws, most of which are reviewed under the umbrella of complying with the National Environmental Policy Act of 1969 (NEPA). FPV systems may affect water temperature, stratification, light, oxygen, nutrients, algae, carbon dynamics, and fish—and those effects could be beneficial or harmful, depending on the location, size, and water quality of the water body, and the coverage and design of the FPV system (Jones et al. 2019). Effects of construction may include noise and vibration, disturbance of sediments, reduced water quality, aquatic habitat functionality, traffic effects, and the health and safety of construction workers (World Bank Group et al. 2019).

Federal environmental compliance staff would need to review any proposed FPV project, regardless of the size and coverage, for its potential effects to the physical environment; biological resources, including threatened, endangered, and sensitive species; visual resources; noxious weeds and other invasive species (e.g., quagga mussels); cultural resources; socioeconomic effects (including environmental justice related effects); and other resources. Anchoring systems and transmission lines would also need to be reviewed as part of the overall project. In addition, it is also important to review the existing Reclamation RMP decisions (if any) that are used to guide management of the land. If an FPV proposal is not compatible with the RMP, it may be appropriate to amend the RMP concurrently with processing the application using the same environmental review process.

Costs for environmental reviews (in addition to any required post-construction activities (e.g., surveying, monitoring, and reporting) would be included as part of the administrative costs paid by the use authorization applicant (43 CFR Part 429).

3.6.1. Known and Unknown Environmental Effects

Effects to local and migrating birds, cultural and visual resources, socioeconomic effects, and effects to other resources specific to the location would need to be addressed on a case-by-case basis as part of Reclamation's permitting and environmental compliance processes. Global FPV experts have identified environmental effects as one of the top four challenges for the development of FPV (World Bank Group et al. 2019). A Singapore study on an FPV test system found "no observable changes in the reservoir's water quality" and "no significant impact on the surrounding wildlife" (Singapore Economic Development Board 2018).

However, each proposed FPV location would have different resources that could be affected, so individual studies—and possibly post-implementation monitoring—would be necessary for each proposed project.

Long-term effects to water quality from FPV infrastructure (e.g., heavy metals and sealants) and changes in surface wind speeds and solar radiation could have resultant effects to fish and other aquatic species. Jones and Armstrong (2018) identified several water quality topics needing further research, including stratification, plant growth, phytoplankton, dissolved organic carbon, and whether FPV might affect how much carbon a waterbody stores and releases. Environmental studies could examine the potential for providing shading and other habitat benefits as well as the potential for disturbing fish during construction. Studies of water quality and biological resources should start by assessing baseline conditions. For resources of concern, post-deployment activities (e.g., monitoring) could be required as a condition of the use authorization. Monitoring reports from early FPV projects could inform subsequent project decisions.

Reclamation can develop robust monitoring standards and track the progress of international environmental studies on FPV to develop a safe and conservative approach for authorizing FPV projects that would allow the projects to maximize environmental benefits while providing additional information to the FPV community on environmental effects.

3.6.2. Evaluation and Permitting Requirements

Reclamation environmental compliance staff would determine the level of NEPA compliance required for a proposed project, specifically, whether a categorical exclusion, environmental assessment, or environmental impact statement is warranted. Permitting and consultations would also likely be required under the Section 10 of the Clean Water Act, Section 7 of the Endangered Species Act, and Section 106 of the National Historic Preservation Act (any effects, including aesthetics or location-specific requirements would need to be considered). For Reclamation reservoirs with surrounding recreational sites or grazing areas managed by other Federal, State, or local governments, coordination with those entities on permitting and environmental compliance would be necessary.

3.6.3. Climate Change

Exley et al. (2021) noted that "FPV have the potential to mitigate some of the impacts of climate change on water bodies and could be a useful tool for water body managers in dealing with changes to water quality, or, conversely, they could induce deleterious impacts on standing water ecosystems." They modeled FPV-induced changes in wind speed and solar radiation on lake temperatures in North West England. They found that FPV could be a useful tool to manage effects of climate change on lake systems, but that the FPV would need to be designed and deployed appropriately for each lake. As the conditions in the arid West differ from this study, considerable future research will be needed.

An FPV array would provide energy that could displace more fossil fuel resources. Generation from renewable energy resources (e.g., FPV) serves to displace carbon emissions that may have otherwise been generated by traditional fossil fuel energy resources. The U.S. Energy Information Administration found that in 2020, power plants that burned coal, natural gas, and petroleum fuels were the source of about 60% of total U.S. electricity generation, but they accounted for 99% of U.S. electricity-related CO_2 emissions (U.S. Energy Information Administration, 2021).

3.7. Recreation, Public Safety, and Public Perception Considerations

There is likely to be a diversity of public responses to floating solar arrays. Reclamation should take care to avoid authorizing arrays in key areas of recreational use to avoid negative effects to swimming, boating, fishing, etc. Careful planning by the developer, including robust public education and engagement, could help garner community support. Public comments received during the NEPA process or other public meetings, as applicable may provide valuable information and alternatives on how to minimize conflicts between an FPV installation and the public.

While any FPV use must be compatible with other existing leases, licenses, or easements, FPV would cover some portion of a reservoir that might otherwise have been open to recreationists. Conflicts could be minimized by developing reservoirs that either have less or no recreational value, or that are large enough to accommodate FPV without unduly interfering with recreational values. Developing portions of reservoirs from which recreationists are already restricted, such as near electrical facilities (dams), may also help to minimize conflicts. However, this may create other potential conflicts related to dam safety.

Reclamation must consider the health and safety of the community when reviewing applications for use authorizations. Potential safety hazards may include water navigation and public access. Most safety hazards can be minimized and mitigated with careful siting, signage, and effective barriers, both in the water and around onshore facilities (World Bank Group et al. 2019). Visual safety and/or aesthetic effects would also need to be considered. For example, reflections of glare from the sun could affect recreation (if seen from boats or shore) as well as public safety/transportation (if seen on nearby major roadways during certain times of the day). Buffers and barriers are necessary to keep people away from the equipment for their own safety and to protect the FPV installations. Barriers may also serve to protect the equipment from large floating debris or other natural hazards. While the developer should already have barriers in their design, Reclamation should consider explicitly requiring the developer to install barriers sufficient to protect public safety as a condition of the use authorization.

FPV installation could affect water temperatures, algal growth, or other factors which could have a resultant effect on fishing opportunities and fish survival—whether positive or negative. For example, if placed over shallow water, the FPVs could provide refugia for fish, but if too much of the reservoir is covered, FPVs could diminish opportunities for fish to capture bugs on the surface. Russo (2019) cites improvement in fishing yields and Shaw (2019) notes that FPVs have been called "fishpond installations—floating solar plants allowing enough sunlight between them for fish to survive below." Many news stories about FPV mention their potential to reduce harmful algal growth, further illustrating a widespread positive perception.

How the public perceives a project will affect whether they accept any restrictions to their recreational opportunities at a given reservoir. Public perception of the environmental effects of FPV has mostly been positive. Developers should begin community discussions early and openly. Once a use authorization request is received by Reclamation, a robust NEPA public involvement process, with earnest efforts to engage, listen to concerns, and educate recreational users and other community members about the project, can help improve public perceptions and acceptance.

4. Technical FPV Potential at Reclamation Reservoirs

Depending on the analysis and available data, real-world constraints such as proximity to the electric grid, reservoir usage restrictions, and environmental restrictions would preclude areas from FPV use. Different assumptions used for the technical potential estimate may result in more liberal estimates. In this case, NREL generally did not exclude dam safety areas and Reclamation-purpose (e.g., environmental and recreational) areas that may not typically be available for development at Reclamation reservoirs. While technical potential can be used to further determine market and adoption potential, it does not suggest the actual feasibility on a case-by-case basis. It does, however, provide a basis for understanding the magnitude and geospatial distribution of these opportunities across the landscape. Technical potential estimates can help inform owners (e.g., Reclamation), developers, planners, decision makers, etc. about the areas with higher potential that may warrant further study.

4.1. Analysis Methods

Technical potential is a theoretical limit to the amount of generation capacity that can be deployed in a certain area. As shown in the conceptual schematic in Figure 8, technical potential analysis takes into account the total amount of energy physically available (known as the resource potential). However, technical potential analysis may not consider all of the unique on-the-ground conditions. It does not take into account economic feasibility or market demand.

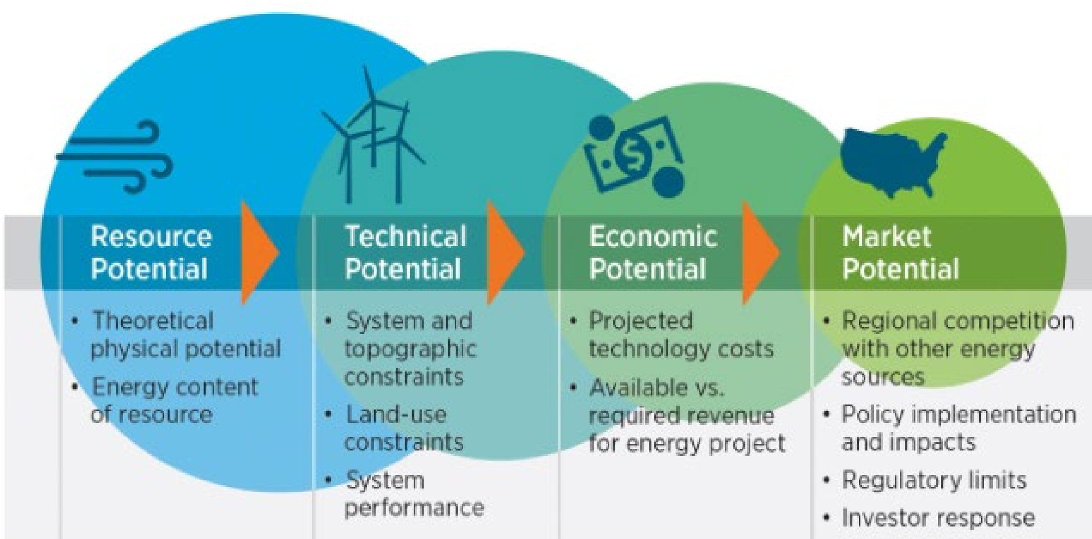

Figure 8. Technical potential within an analysis of overall potential for a power source.

NREL estimated over 2 terawatts (TW) of total technical potential of floating PV on man-made bodies of water throughout the United States (Spencer et al. 2019). This potential at a 27% surface area coverage would generate 9.6% of current electricity generation in the United States. The 27% is based on the median reservoir surface area covered by existing projects. 42% of the water bodies used in the study are owned by Federal agencies (Spencer et al. 2019) (Figure 9).

This section will take a deeper look at the Federal reservoirs owned by Reclamation that were introduced in this NREL estimate.

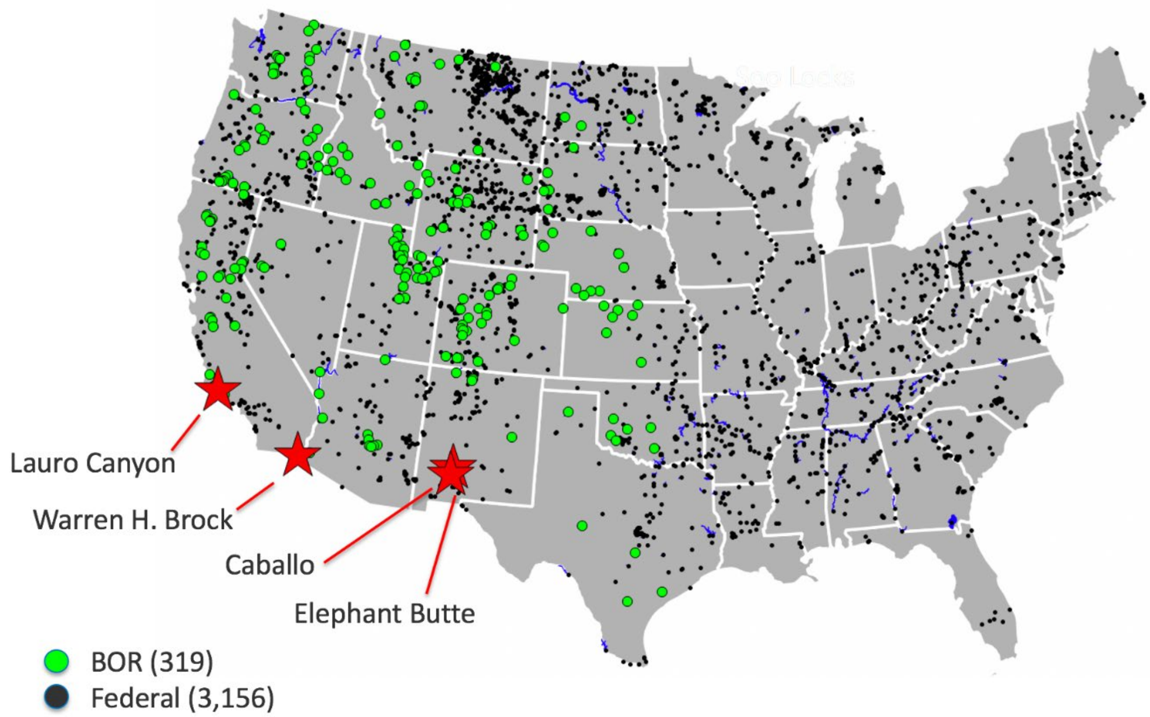

Figure 9. Locations of Reclamation reservoirs (green) and other reservoirs (brown and blue) considered in the overall analysis for FPV technical potential in the U.S. Red stars indicate the location of case studies for considerations for potential FPV deployment on a range of Reclamation reservoirs.

Like (Spencer et al. 2019), this analysis used similar assumptions to obtain a crude estimate of technical potential on a broad scale:

- Include all reservoir use types
- Feasible Area: between 4 m and 400 m from shoreline at 100% coverage
- Panel Packing Density: 2.5 acres/MW
- Panel Tilt Angle: 11 degrees
- System Advisor Model (SAM)

The data source of reservoirs was based on the National Inventory of Dams (NID) and updated with Reclamation's internal records. Surface area data was further supplemented by joining records with the National Hydrography Dataset (NHD) to provide the spatial geometries of each water body footprint.

Based on the spatial geometries of each water body, a buffer was applied to exclude surface areas that are within 4 meters (m) and beyond 400 m from shoreline. These thresholds were subjective assumptions that may vary widely by each use case. For instance, artificially shaped or naturally shaped reservoirs under different operating conditions may have drastically different implications for expanding and reducing surface area and shorelines with fluctuating reservoir levels. Likewise, a system exceeding 400 m from shoreline may not be necessarily infeasible, but we exclude this area to prevent very large bodies of water from contributing exceedingly unrealistic potential to our estimates. The remaining surface area, however, contributes to the overall estimate of technical potential.

SAM is a techno-economic tool developed by NREL to assess the cost of energy for decision makers considering renewable energy projects. SAM was used to estimate the technical potential at each of the reservoirs, by simulating output performance with local variable solar resource in a typical meteorological year (TMY). System configurations were set to a default south-facing system at a common floating PV tilt of 11 degrees. System sizes were based on each reservoir's feasible surface area using a 2.5 acres/MW packing density. This analysis yields results for the potential capacity, capacity factor, and annual generation.

4.2. Results of Analysis

As shown in Table 2, Reclamation owns or co-owns approximately 319 reservoirs with a total technical potential capacity of 1 TW. While NREL had previously estimated a total potential of 2 TW for all man-made reservoirs in the U.S. (Spencer et al. 2019).

While estimating the potential capacity is important, SAM only takes into account the surface area available. Therefore, we consider potential generation to capture the contributions of both the available surface area as well as the abundance of the local solar resources throughout the year. The total estimate of potential FPV generation for Reclamation reservoirs is approximately 1,500 terawatt hours (TWh) annually. The spatial distribution of this potential can be seen in Figure 10, with the highest potential in Wyoming (132 TWh), California (228 TWh), and Arizona (304 TWh). The technical potential for FPV varies across Reclamation regions, again according to the surface area of reservoirs within each region. Based on the Reclamation markers in Figure 10, it is evident that the Upper Colorado Basin (UCB) Region 7's potential is based on a larger number of reservoirs than within Lower Colorado Basin (LCB) Region 8. Since they both show potential on the highest end, this suggests that the sparser reservoirs within LCB are typically larger. Larger reservoirs tend to be multi-purpose, affecting deployment considerations.

Table 2. Summary of Technical Potential across Reclamation Reservoirs

	Bureau of Reclamation
Number of Reservoirs	319
Surface Area (million acres)	2.5
Technical Potential Capacity (TW)	1.0
Technical Potential Generation (TWh/year)	1,500

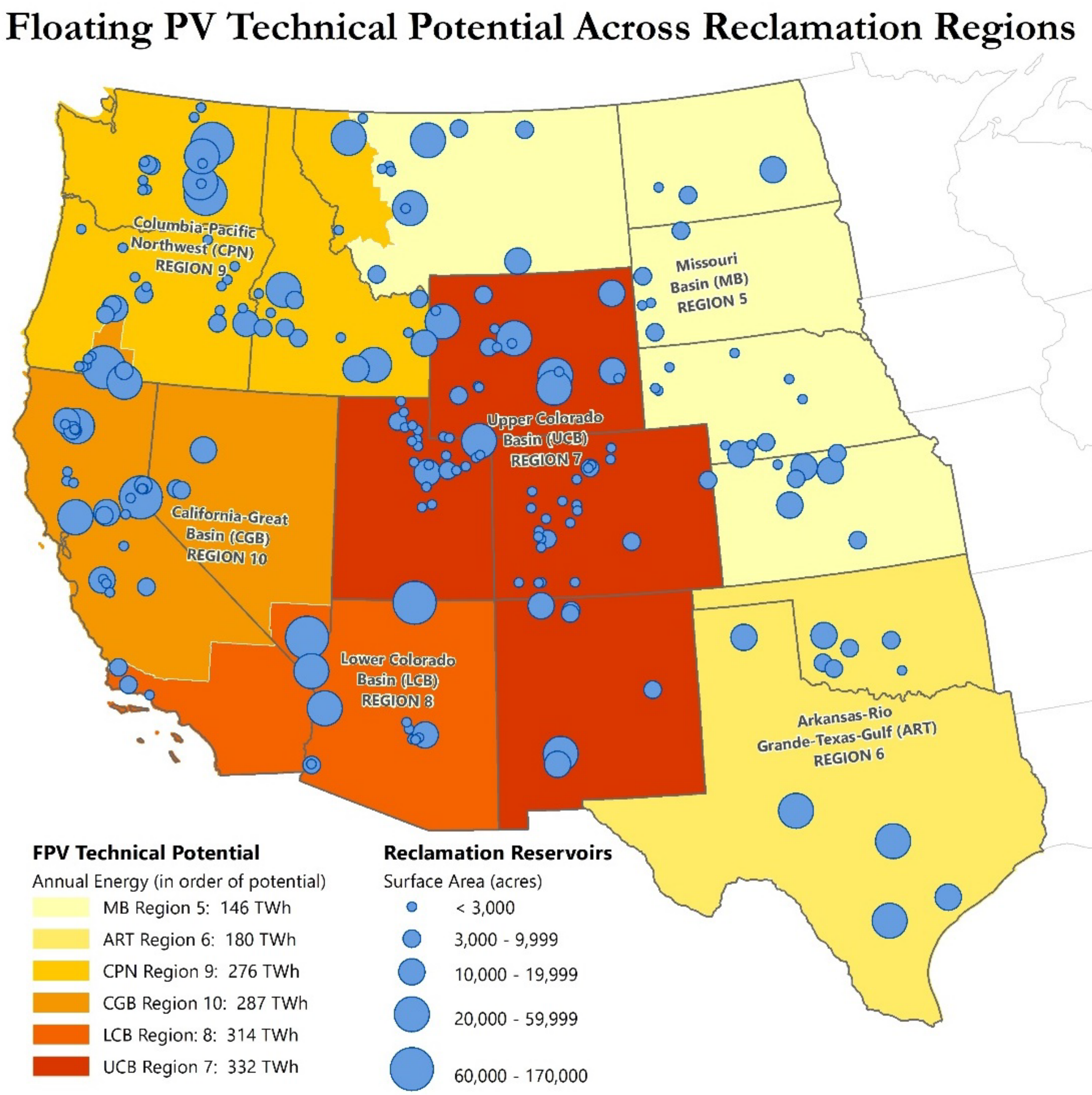

Figure 10. Spatial distribution of the floating PV technical potential across Reclamation reservoirs, by regions. Upper and Lower Colorado Basin regions show the greatest potential for deployment opportunities in terms of total estimated annual generation (in the range of 314 to 332 TWh).

In addition to the spatial distribution of reservoir potential, we can view the distribution of waterbody surface areas in Figure 11. Most reservoirs tend to fall below 25 acres with a small handful getting larger than 175 acres. Assuming a packing density of 2.5 acres/MW, this results in a large majority of 10 MW system sizes and the potential of over 70 MW system sizes, which is at the upper end of the current systems installed globally.

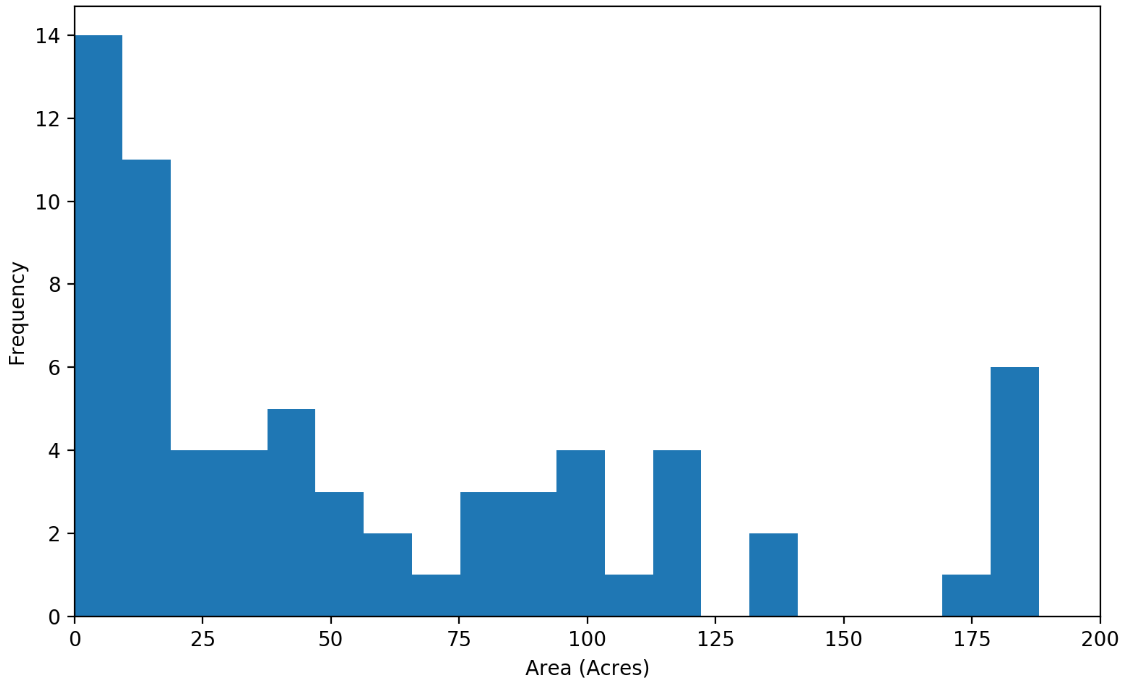

Figure 11 Surface area distribution of all Reclamation reservoirs.

Figure 12 provides the distribution of technical potential by total area and total number of reservoirs that fall within each reservoir purpose. Note that these categories are not mutually exclusive. For example, reservoirs that are used for hydroelectric power (column 2) will often have overlapping purposes with irrigation (column 1) and recreation (column 3).

Reclamation reservoirs are more often used for irrigation purposes (about 80% of the total area). With so much FPV potential occurring in the arid southwest and relatively low recreational use (40%), this may indicate better opportunities for evaporative loss mitigation of the water supply.

To get an idea of the overlap between reservoir purposes, Figure 13 illustrates the correlation between any two purposes. To understand the chart, look at any one row label along the left-hand side (the given purpose). Now find a corresponding purpose along the bottom to identify (from their intersection) how often that purpose is in occurrence given the original purpose on the left-hand side. The size of the square in the intersection of two purposes provides an indication of the percentage of time the purpose along the bottom corresponds with the purpose on the left-hand side. For example, if a reservoir is used for hydroelectric, then it is also used for irrigation most of the time. On the other hand, if a reservoir is used for irrigation, then it is only used for hydroelectric for roughly 65% of the time. No other uses occur for those reservoirs for tailings and grade stabilization.

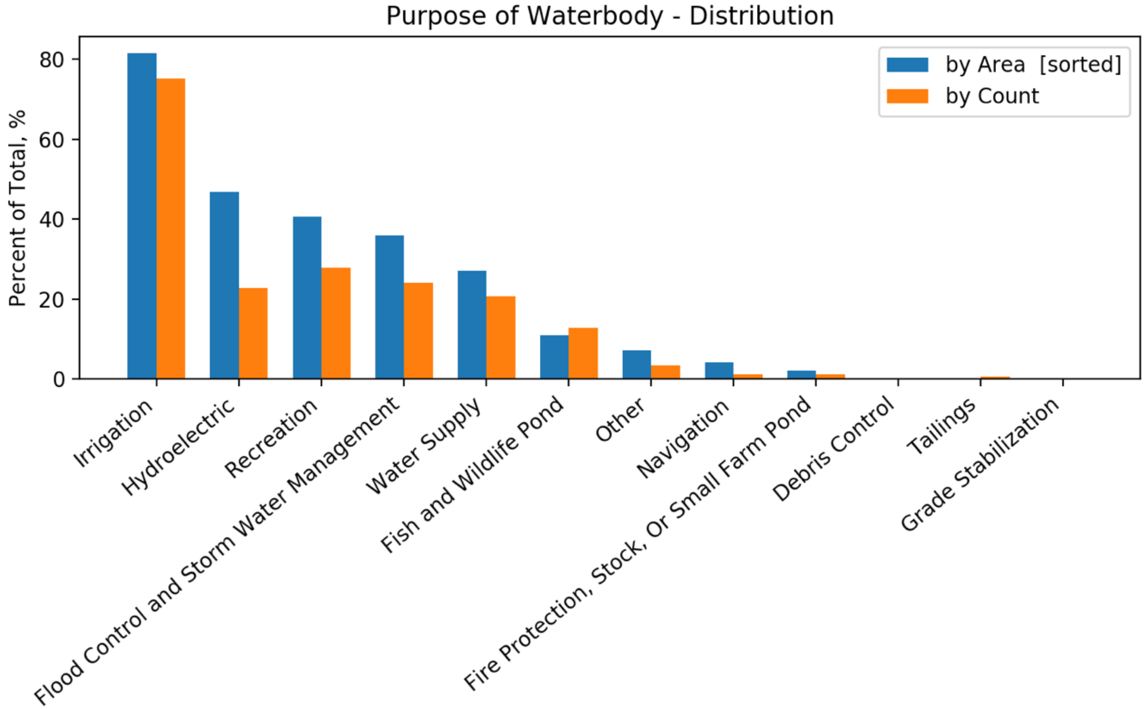

Figure 12. Reclamation distribution of the technical potential by both total surface area and total number of reservoirs across all reservoir purposes. Purposes are not mutually exclusive. Irrigation is the most common purpose within Reclamation reservoirs, at roughly 80% by surface area and 77% by total number of occurrences.

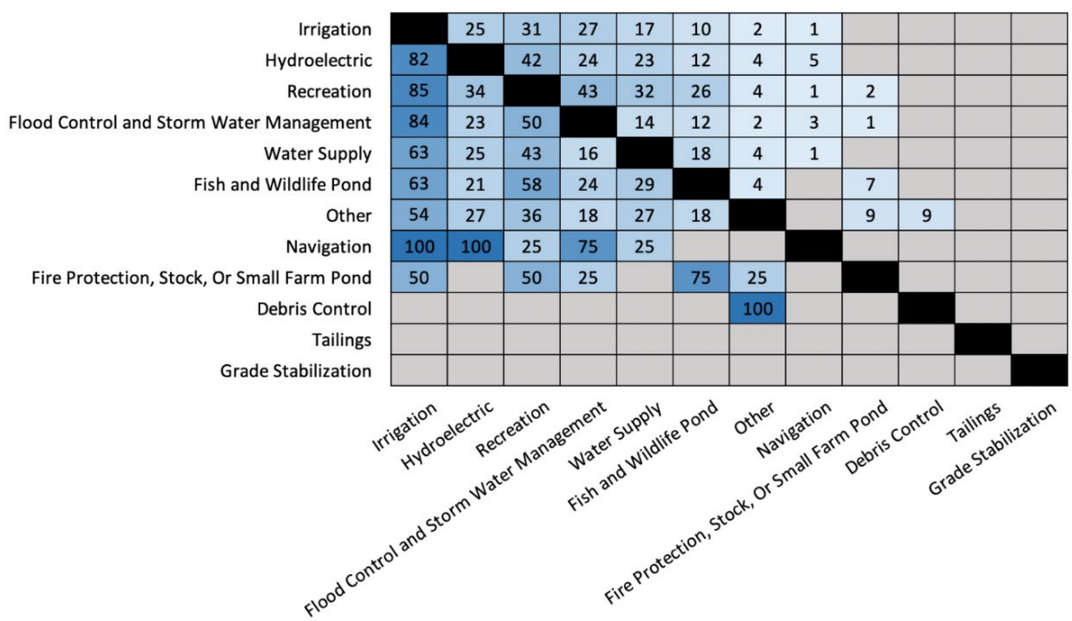

Figure 13. Correlation (%) of Reclamation reservoir purposes – Many reservoirs serve multiple purposes. The likelihood of occurrence (%) between two purposes can be determined by taking the left-hand side purpose as the given and finding the intersecting value of all other categories (across the bottom axis).

The key consideration regarding overlapping reservoir purposes is that there may be additional planning challenges at multi-purpose reservoirs. Recreation, fish and wildlife, and navigation uses may provide the greatest constraints on deploying an PV system. However, some of these combinations may also provide more ideal opportunities to owners and water managers. For example, there could be added benefits to locating an FPV system on a reservoir that serves hydroelectric and irrigation / water supply purposes. These benefits may include a readily accessible power interconnection (substations and powerline proximity) with hybridization opportunities as well as evaporative loss mitigation on a precious water resource (see Section 3.4. *Evaporation Suppression Considerations*).

5. Theoretical FPV Deployment Case Studies

Reclamation reservoirs vary widely in characteristics and considerations. FPV potential will depend on site-specific characteristics. The following section applies the considerations presented in this report to four theoretical, FPV deployment case study reservoir sites: Elephant Butte, Caballo, Warren H. Brock, and Lauro Reservoirs (Table 3). These four examples show a range of potential considerations for FPV.

Table 3. Summary Description of the 4 Case Study Reservoirs

	Elephant Butte	Caballo	Warren H. Brock	Lauro
Location	Truth or Consequences	Hatch	N/A	Santa Barbara
County	Sierra	Sierra	Imperial	Santa Barbara
State	New Mexico	New Mexico	California	California
Reservoir Purpose	Water supply for irrigation, hydroelectric power generation, flood control and stormwater management, recreation (wakes allowed)	Water supply for irrigation, flood control and stormwater management, recreation (no wakes allowed)	Water supply for irrigation	Water supply for irrigation, municipal, and industrial use
Surface Area	36,500 acres	10,000 acres	485 acres	21 acres
Maximum Storage	2,000,000 acre-feet	380,000 acre-feet	8,000 acre-feet	855 acre-feet
Annual Evaporation Rate	80 inches	75 inches	75 inches	65 inches

5.1. Elephant Butte Reservoir, New Mexico

Elephant Butte Reservoir was selected as a case study for this report because it's a key storage component (in combination with Caballo Reservoir) for Reclamation's Rio Grande Project. Additionally, hydropower is generated from Elephant Butte.

5.1.1. Location, Overview, and Authorization

Elephant Butte Dam and Reservoir is on the Rio Grande, 125 miles north of El Paso, Texas, and 145 miles south of Albuquerque, New Mexico. A volcanic cone in the reservoir which resembles the head and back of an elephant gives the reservoir its name. The dam is owned and operated by Reclamation for irrigation storage, flood control, and hydropower. Reclamation manages the water storage and releases, and USACE manages flood control operations. The New Mexico Interstate Stream Commission manages inflows. Outflows are requested by Elephant Butte Irrigation District, El Paso County Water Improvement District #1, and the Republic of Mexico.

Construction of the dam began in 1912 and was completed in 1916, with storage operations beginning in 1915. Elephant Butte Reservoir has a total capacity of over 2 million acre-feet of water to provide irrigation and power generation. When full, the reservoir has a surface area of 36,897 acres at the conservation pool water surface elevation of 4,407 feet. The dam is a concrete gravity dam 301 feet high and 1,674 feet long, including the spillway.

Construction of the Elephant Butte hydroelectric powerplant started in 1938. The power system consists of a 24,300-kilowatt hydroelectric powerplant. The plant contains three identical generating units, each rated 10,350 kilovolt amperes (kVA) at 0.9 power factor. A system consisting of 490 miles of 115-kV transmission line and 11 substations totaling 81,750 kVA is operated by a private electric company.

During the early years of powerplant operation, electricity was generated year-round. However, in 1964, new power contracts provided for operation only during the summer season (April through September). Presently, water is discharged through the powerplant whenever possible to generate hydroelectric power and concurrently satisfy irrigation demand on the Rio Grande Project downstream of Caballo Dam. The estimated annual saleable output of energy is approximately 60.7 GWh during years of normal water supply.

Located in scenic semidesert mountainous terrain, Elephant Butte Reservoir is popular throughout the entire Southwest for boating, fishing, and swimming, with approximately one million visitors each year. Cabin sites, boat rental, and fishing tackle are available.

5.1.2. Power Infrastructure

The power plant and transmission infrastructure at Elephant Butte Reservoir could reduce the time and expense to build a line to connect the floatovoltaic array to the nearest transmission line. Reclamation does not own the transmission lines at Elephant Butte Reservoir. Note that agreements with transmission line owners would need to be obtained and are not guaranteed. If using the existing power line is not possible, it might be possible to add a new line to the existing poles, or new poles could be added to the current right-of-way and the permitting process may be shortened due to the limited additional environmental effects.

5.1.3. Potential FPV Area

It is impossible to know with certainty the maximum capacity that this reservoir could host without an engineering study. Even though Elephant Butte has a very extensive reservoir, the feasible FPV system area could be limited by the shallowness of the reservoir upstream. Shallow depths increase the possibility for the array to hit the bottom of the reservoir. A system designed to rest on the bottom could increase costs because the floating devices would have to be built to withstand the conditions of the bottom of the reservoir. Additionally, the system could lose its optimal alignment with the sun, thus reducing its output while on the bottom of the reservoir.

Recreation is another limitation to the size and overall feasibility of installing an FPV system. Boating around an FPV array could represent a hazard for both the boat users and the array. Additionally, there are shallow marinas within the areas that may be most suitable for the array location, further reducing the potential size of the array. Figure 14 shows the scale for potential FPV in one portion of Elephant Butte Reservoir.

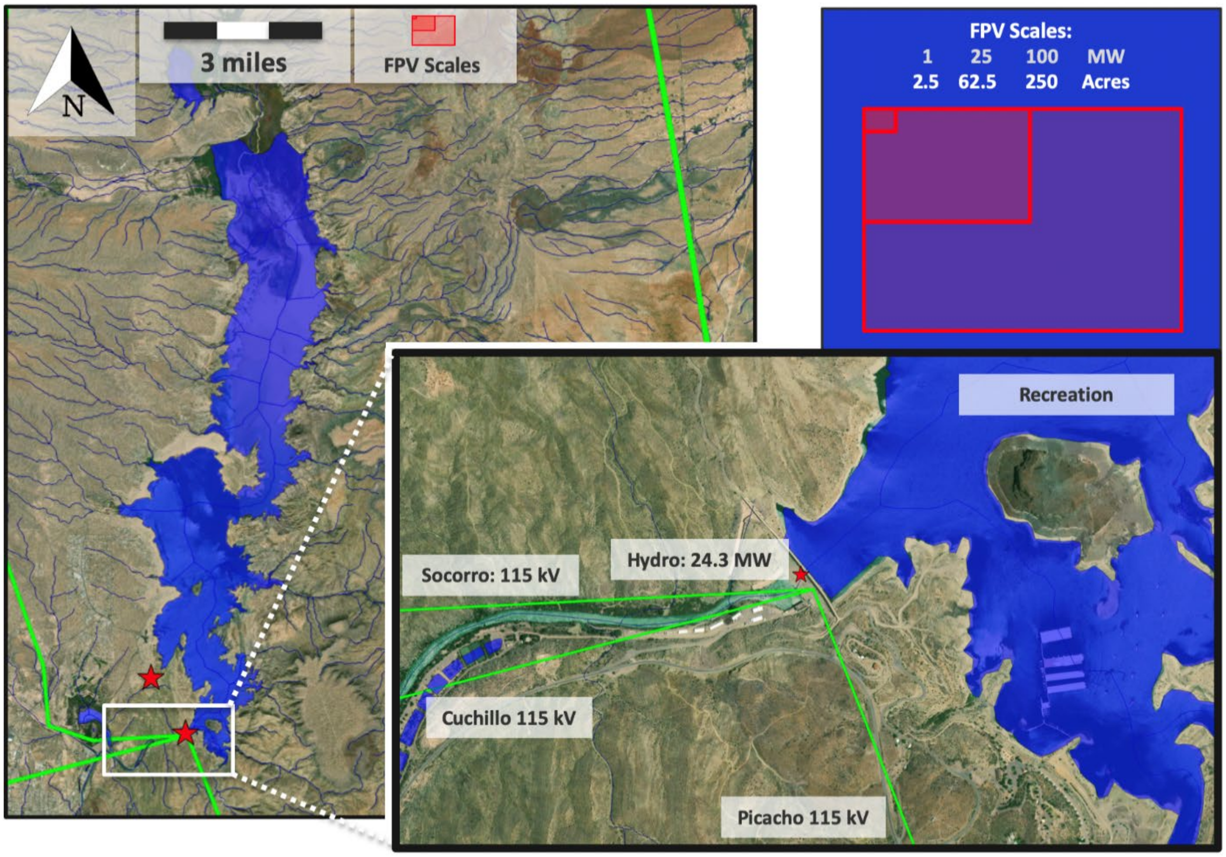

Figure 14. Site diagram that shows the nearby bulk transmission infrastructure (left, green lines) and relative scale (right). The FPV scale shows the areal extent (acres) needed for three different sizes (1, 25, and 100 MW) at the head of Elephant Butte Reservoir.

5.1.4. Unique Economic Considerations

A water market analysis would help determine the value of any water saved from evaporation suppression.

5.1.5. Unique Technical Considerations

Water elevations at Elephant Butte fluctuate widely. In any water year, the elevation rises and falls over the course of the irrigation season. In 2020, the elevation fell over 50 feet during the course of the irrigation season (Figure 15). Storm inflow from heavy snow-melt-runoff and monsoon rain events can also result in rapid elevation rise. Rapid changes in water levels do not preclude installing a floating PV array, but it may raise the costs of engineering and installation.

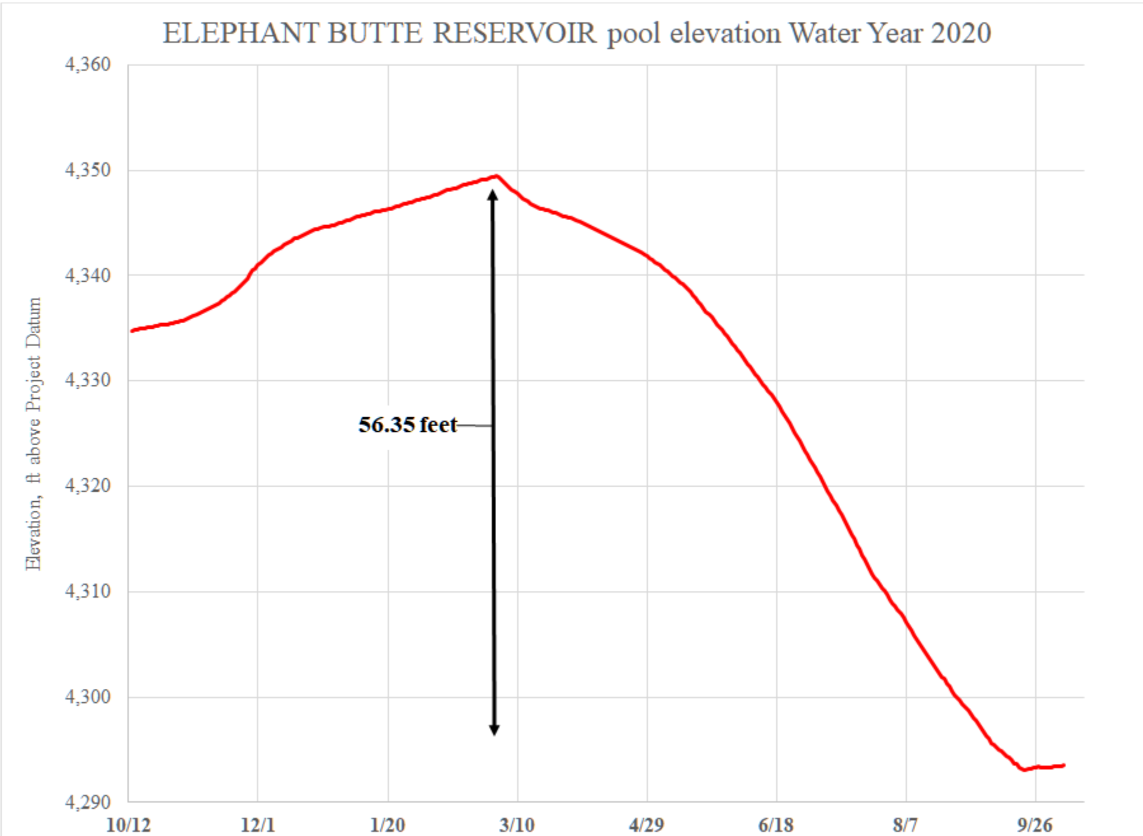

Figure 15. Elephant Butte Reservoir levels in water year 2020.

5.1.6. Unique Evaporation Suppression Considerations

General evaporation considerations are described in Section 3.4. Elephant Butte Reservoir sits in the high desert of central New Mexico and is subject to evaporation rates of almost 10 feet per year. In 2020, a year that had below-average evaporation losses due to low reservoir levels, the losses from Elephant Butte Reservoir were still larger than a full year's municipal demand for the City of Albuquerque. AAO is currently involved in several research studies to better characterize evaporation losses from Elephant Butte and Caballo Reservoirs. Methods being employed at Elephant Butte Reservoir include Collison Floating Evaporation Pans, eddy covariance towers, climate stations, satellite monitoring, and weather modeling.

5.1.7. Unique Dam Safety Considerations

All the limitations discussed in the Safety of Dams Considerations section above apply to Elephant Butte Dam and Reservoir.

The public prominence of Elephant Butte Dam and Reservoir along with the multiple public recreation access points from Federal and State land mandates securing an FPV array a safe distance away from the dam and away from recreational boating, which limits the size and location of an array. Any deployment that would increase structural and operational risk that would be unacceptable without a comprehensive risk analysis and approval by Reclamation's Dam Safety Office and concurrence by the Technical Service Center.

5.1.8. Unique Policy Considerations

Recreation is one of the specific authorized uses for Elephant Butte Reservoir, and the reservoir is very popular with recreationists, including boaters. FPV installations may have to compete with boaters and marina facilities that also seek water that remains deep enough throughout the hydrological year. Placing and operating an FPV array on Elephant Butte Reservoir would most likely require significant coordination with New Mexico State Parks, who manage the majority of recreation and access points to the reservoir.

5.1.9. Unique Environmental Considerations

The northern end of Elephant Butte Reservoir supports habitat for the threatened, yellow-billed cuckoo and the endangered southwestern willow flycatcher, as well as the endangered Rio Grande silvery minnow. The endangered New Mexico meadow jumping mouse is also in the area.

The Elephant Butte Historic District is at the southern end of the reservoir, and visitors flock to the site each year to stay in the historic lodgings, hike, picnic, fish, and camp. There are several marinas for boaters, which are occasionally moved to deeper water as reservoir elevations change. Potential effects to the Historic District, as well as visual effects and potential conflicts with recreationists, would all need to be considered by environmental compliance specialists as part of evaluating a use authorization request.

5.1.10. Unique Recreation and Public Involvement Considerations

Elephant Butte Reservoir is the largest lake in New Mexico and is popular throughout the entire Southwest for boating, jet skiing, fishing, and swimming, and camping with over 1 million visitors each year. Therefore, any FPV installation on this reservoir would be highly visible to the public and may be at risk of damage from boaters or curious visitors.

5.1.11. Potential Future Actions

- Because Elephant Butte Reservoir is so large, and evaporation is such a concern, it could be a good place to study evaporation effects of FPV.
- If an FPV installation were placed on Elephant Butte Reservoir, it would be a good case study for public perceptions as there are over 1 million visitors to the reservoir each year.

5.2. Caballo Reservoir, New Mexico

Caballo Reservoir was selected as a case study for this report because it is a key component of the Rio Grande Project, along with Elephant Butte Reservoir. Preliminary discussions with the staff at the Elephant Butte Reservoir have suggested that Caballo may be a better candidate for investigating an FPV pilot project than Elephant Butte.

5.2.1. Location, Overview, and Authorization

Caballo Dam, approximately 25 miles downstream of Elephant Butte Dam in south-central New Mexico, is a key feature of the Rio Grande Project. Caballo Dam was constructed in 1938 as a multi-purpose structure, providing at least 100,000 acre-feet of storage capacity for flood control. It also permitted year-round generation at Elephant Butte Dam, and part of the cost was allocated to power generation. Water used for wintertime generation of power at Elephant Butte Reservoir was held in Caballo Reservoir for irrigation use during the summer; however, because of recent litigation, winter generation is no longer permitted. Caballo Reservoir provides replacement storage for the storage lost at Elephant Butte Reservoir due to sediment deposition, and also provides fish and wildlife benefits.

As part of the Rio Grande Rectification Program, Caballo Reservoir management includes the United States International Boundary Water Commission, as well as the New Mexico Interstate Stream Commission, Elephant Butte Irrigation District, El Paso County Water Improvement District #1, and Mexico, in addition to Reclamation.

Caballo Reservoir has a total capacity of approximately 325,000 acre-feet and an active conservation pool of 225,450 acre-feet at elevation 4172.5 feet. At this elevation, there is a surface area of about 11,500 acres. In accordance with a court order, the reservoir storage is not to exceed 50,000 acre-feet (which corresponds approximately to a reservoir elevation of 4144.95 feet) between October 1 and January 31. Sediment deposition will gradually deplete the active conservation pool.

In rough desert terrain 17 miles south of Truth or Consequences, New Mexico, Caballo provides an all-year recreation program of picnicking, boating, and fishing, with over 350,000 visitors per year.

5.2.2. Power Infrastructure

Caballo Reservoir does not have existing power generation facilities. However, there is a transmission line nearby as well as local power infrastructure (e.g., distribution lines to the State Park which might be able to use power generated from the local FPV).

5.2.3. Potential FPV Area

Like Elephant Butte, Caballo is a large, elongated reservoir. The area that seems most suitable for floating PV development is the area about 5,000 feet from the dam. Closer to the dam, the water levels are shallow, in part due to a sand bar. Similarly, the rest of the reservoir features shallow waters. The area about 5,000 feet from the dam is approximately 4,500 feet wide and features a relatively flat, sandy bottom. This feature could be beneficial in cases where the water level drops, and the system has to sit in the bottom.

In general, Caballo's reservoir is relatively shallow, with typical depths of 10 to 20 feet. However, the depth of the reservoir can drop to 5 to 7 feet. Once or twice per decade, the reservoir's water levels drop to dead-pool levels. Figure 16 shows the scale for potential FPV in one portion of Caballo Reservoir.

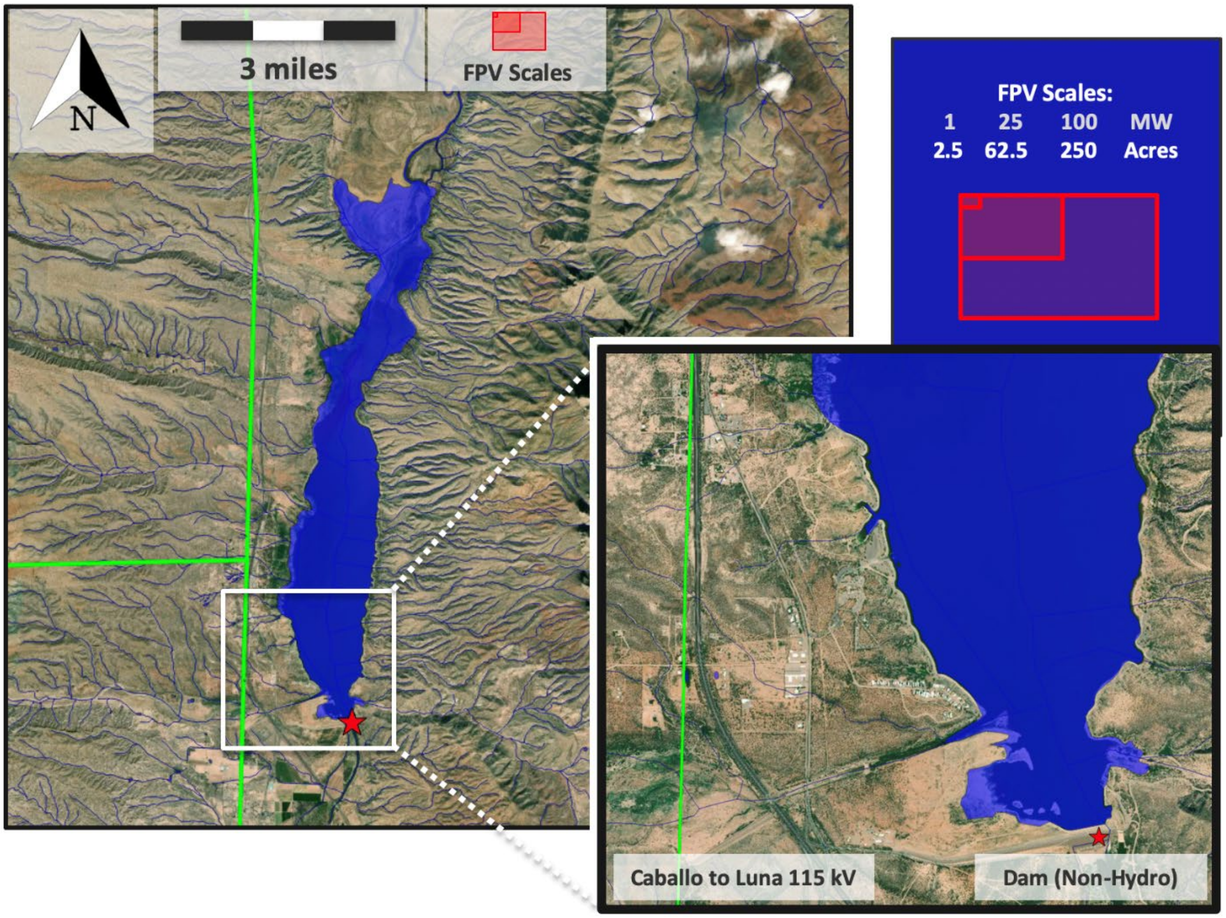

Figure 16. Site diagram that shows the nearby bulk transmission infrastructure (left, green lines) and relative scale (right). The FPV scale shows the areal extent (acres) needed for three different sizes (1, 25, and 100 MW) near the head of Caballo Reservoir.

5.2.4. Unique Economic Considerations

There is an adjacent state park, Caballo Lake State Park, which could benefit from the electricity produced from a floating solar array, either at a pilot scale or an operational scale.

5.2.5. Unique Technical Considerations

The rate of change of the water elevation at Caballo Reservoir could provide unique technical challenges for a floating solar installation. In any water year, the elevation rises and falls over the course of the irrigation season. In water year 2020, the Caballo Reservoir elevation dropped over 13 feet during the irrigation season (Figure 17). Storm inflow from monsoon rain events can also result in rapid elevation rise. Rapid changes in water levels do not preclude installing a floating PV array, but these fluctuations may raise the costs of engineering and installation.

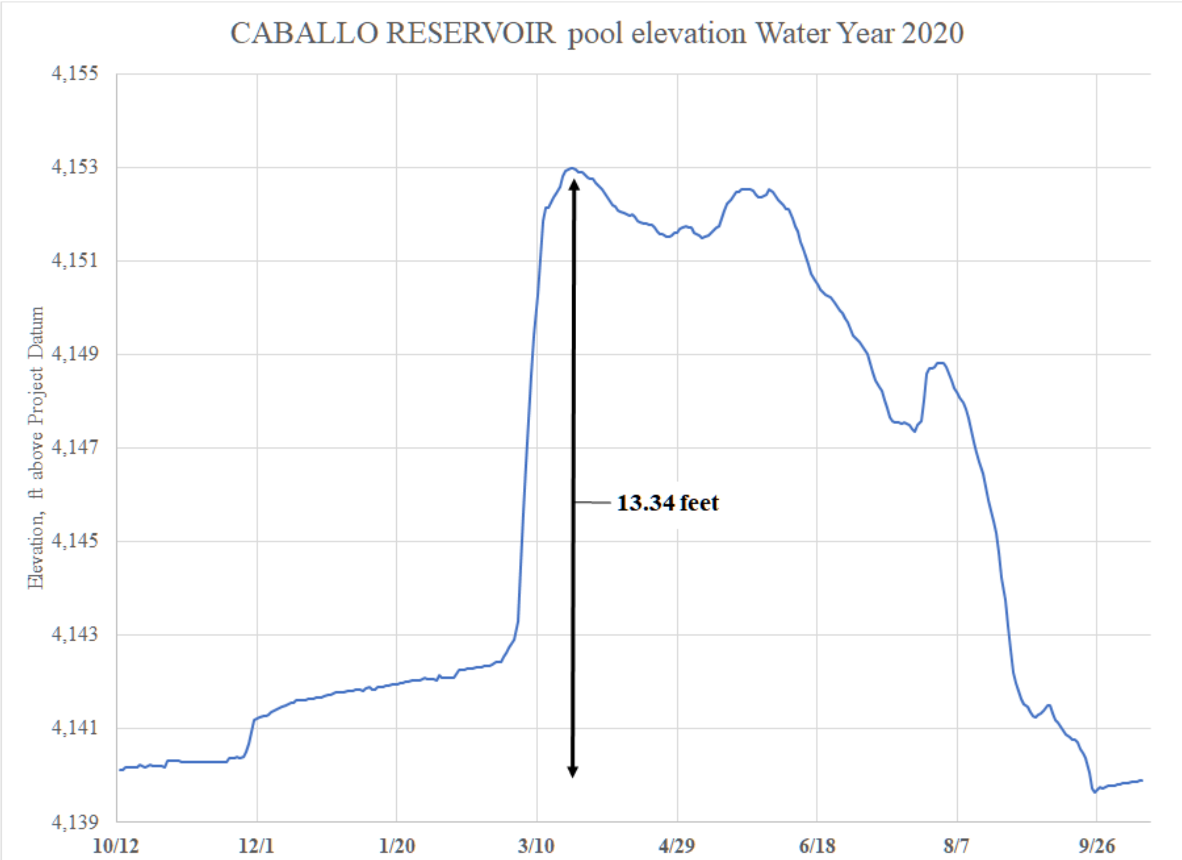

Figure 17. Caballo Reservoir levels in water year 2020.

5.2.6. Unique Evaporation Suppression Considerations

Like Elephant Butte, Caballo Reservoir sits in the high desert of central New Mexico and is subject to evaporation rates of almost 10 feet per year. AAO is currently involved in several research studies to better characterize evaporation losses from Elephant Butte and Caballo reservoirs. Methods being employed at Caballo Reservoir include Collison Floating Evaporation Pans, eddy covariance towers, climate stations, and satellite monitoring.

5.2.7. Unique Dam Safety Considerations

All the limitations discussed in the Safety of Dams Considerations section above apply to Caballo Dam.

5.2.8. Unique Policy Considerations

Disputes and past litigation may limit flexibility if changes in water levels are needed to support floating solar installations.

5.2.9. Unique Environmental Considerations

The northern end of Caballo Reservoir is very shallow and is referred to as "the mud flats." This area of the reservoir attracts abundant birdlife and would be inappropriate for an FPV installation. Areas surrounding the reservoir support habitat for the endangered southwestern willow flycatcher.

Any FPV array on Caballo Reservoir must be located to avoid damaging the Puskas Cultural Site in the event of extreme low-pool operations.

Potential effects to recreation uses, including visual effects, as well as effects to migrating birds and the southwestern willow flycatcher, would need to be taken into consideration by environmental compliance specialists as part of evaluating a use authorization request at Caballo Reservoir.

5.2.10. Unique Recreation and Public Involvement Considerations

Like Elephant Butte Reservoir, recreation is one of the specific authorized uses for Caballo Reservoir—and the reservoir is also very popular with recreationists, including boaters, though less so than Elephant Butte. FPV installations may have to compete with recreationists for the smaller area of water that is consistently wet at 5 to 7 feet in the dry season. Placing and operating an FPV array on Caballo Reservoir would most likely require significant coordination with New Mexico State Parks, who manages the majority of recreation and access points to the reservoir.

Caballo Reservoir has fewer visitors than Elephant Butte Reservoir, but is still is a popular destination for boating, swimming, fishing, and camping, with nearly a half-million visitors each year. Boating in the reservoir presents the same potential safety issues as with Elephant Butte. However, boating consists more of fishing than higher-speed boating. Floating solar arrays may be perceived positively if they provide shading and habitat for fish.

5.2.11. Potential Future Actions

Caballo Reservoir could be a good place to study public perceptions of FPV as it is a popular—but not too popular—location for recreationists.

5.3. Warren H. Brock Reservoir, California

Warren H. Brock Reservoir was included because it's an off-channel reservoir and relatively small. It is also a unique case study due to its uniformity in depth and dimensions. It is entirely artificially constructed and lined to eliminate seepage. No recreation is allowed.

5.3.1. Location, Overview, and Authorization

The Warren H. Brock Storage Reservoir is in California, 25 miles west of Yuma, Arizona, near the All-American Canal. Brock Reservoir provides additional storage capacity to store unused flows that would otherwise go to Mexico in excess of the United States' annual allocation to Mexico. Brock Reservoir allows Reclamation to capture water when supply is excess of demand, and conserve water in Lake Mead as orders for subsequent days are fulfilled from reservoir storage. These flows are diverted at a turnout structure on the All-American Canal and through a 6 ½-mile-long inlet canal into the reservoir. The Imperial Irrigation District then releases the water to users through a ¼ mile-long canal and siphon system.

Construction began in October 2008 and was completed in September 2010. The reservoir pool and sides were covered with 1,800 rolls of geomembrane lining to prevent seepage. Following installation of the membrane, the bottom of the reservoir and sides were then covered with nine inches of soil cement. The reservoir is comprised of two storage cells of equal size covering 410 acres. It is capable of storing 8,400 acre-feet of water and can be filled in about three days.

5.3.2. Power Infrastructure

There is no power infrastructure at Brock Reservoir. There is a 500 kilovolt (kV) transmission line about 0.5 miles from the reservoir.

5.3.3. Potential FPV Area

Brock Reservoir has several advantages over the other reservoirs in this study in regard to its suitability for floating PV development. Its size and regular shape could allow for a 112 MW system or possibly larger. At this size, the economies of scale would be fully achieved, and the installed cost would get closer to the range of utility-scale land-based PV systems. The lack of recreational activities means that the available area can be used for FPV and the safety concerns are avoided. Figure 18 shows the scale for potential FPV in one portion of Brock Reservoir.

5.3.4. Unique Economic Considerations

Some hydropower within the Imperial Irrigation District's canal system was removed when Brock Reservoir was constructed. Power generated by FPV could be used locally to pump water, as a replacement for the hydropower that was lost.

If the floating PV system cannot be connected to the closest transmission line, the capacity of the system would have to be limited to match the needs of the irrigation district, and batteries would need to be added to the system. Reducing the capacity of the system and adding batteries would increase the price per unit of energy produced.

Construction costs were shared among Southern Nevada Water Authority, Metropolitan Water District of Southern California, and the Central Arizona Project, in exchange for shares of water from Lake Mead. The cost of the reservoir was estimated at $172 million, and it was unlikely that the government would receive Federal appropriations to that amount without being able to demonstrate return on investment of the water. The municipal water agencies who received a portion of the water conserved by the reservoir funded this construction and will fund O&M through December 31, 2025. The budget cost of $172 million was funded by the Southern Nevada Water Authority in the amount $115 million for the Metropolitan Water District of Southern California and $28.6 million for CAP. After 2025, Reclamation will be fully responsible for the O&M.

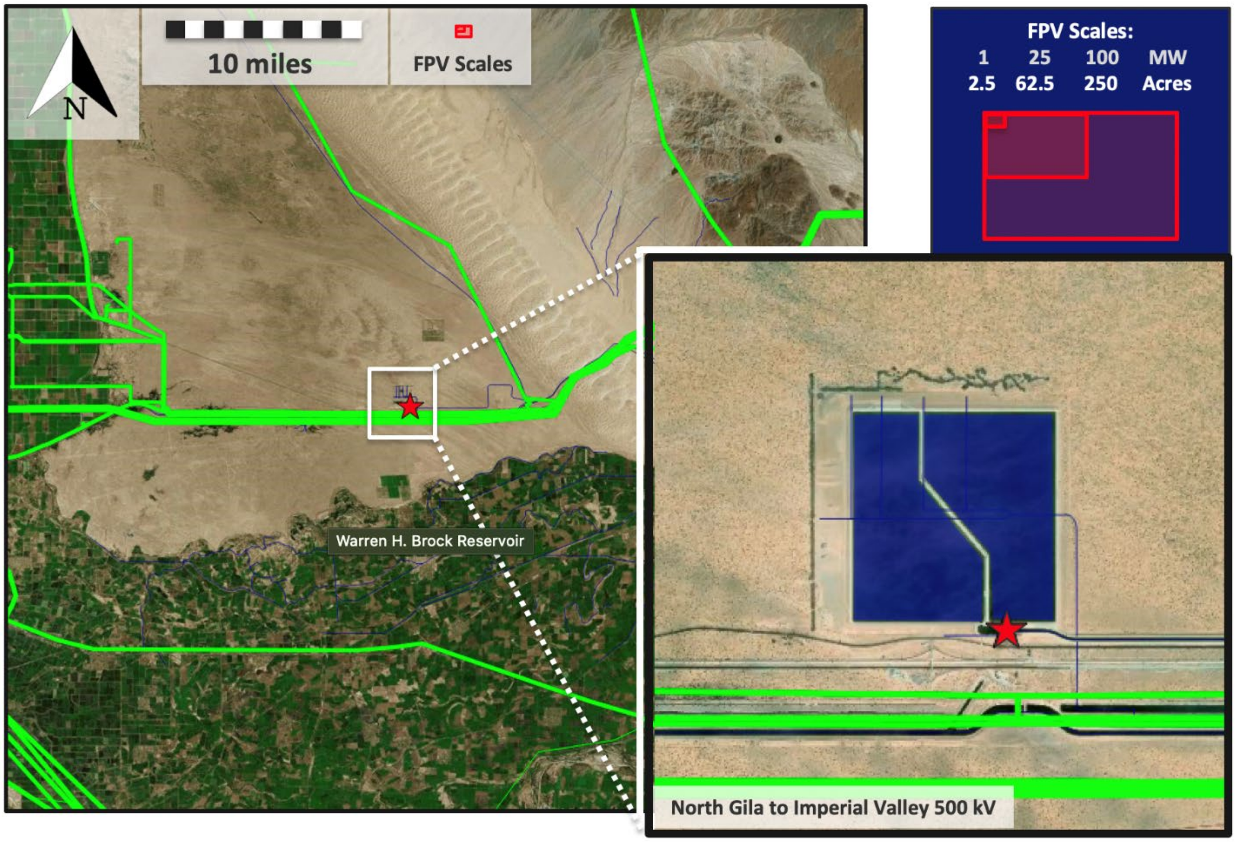

Figure 18. Site diagram that shows the nearby bulk transmission infrastructure (left, green lines) and relative scale (right). The FPV scale shows the areal extent (acres) needed for three different sizes (1, 25, and 100 MW) in Brock Reservoir.

5.3.5. Unique Technical Considerations

The reservoir has a flat bottom, which would reduce any alignment concerns in case the water level drops.

5.3.6. Unique Evaporation Suppression Considerations

Brock Reservoir sits in a hot desert environment, with no surrounding shading. This site could be used as a pilot location for further scientific studies evaluating the reduction in evaporation from the deployment of FPV. Since inflows and outflows are precisely measured, mass balance calculations could be used to corroborate measurements of changes in evaporation loss rates.

5.3.7. Unique Dam Safety Considerations

The construction and function of Brock Reservoir would allow FPV arrays to cover most of the surface area with minimal effects to safe operations. The arrays would need to be anchored and designed to rest during non-storage seasons so as not to damage the geomembrane liner. A safety and operational analysis would still be required to confirm this suitability at Brock Reservoir.

5.3.8. Unique Policy Considerations

This reservoir could be emptied if all of the water in the reservoir was needed to fill orders downstream. If the FPV required a minimum pool, then maintaining that pool would need to be coordinated with Reclamation and local irrigation districts.

5.3.9. Unique Environmental Considerations

Brock Reservoir is entirely man-made and off-channel. While the reservoir was not intended to provide habitat for flora and fauna, several fish species have come through the All-American Canal, and birds come to eat the fish. Coyotes, horned frog, ducks, vultures, and snakes have all be spotted at the reservoir, and there are breaks in the fence to allow animals to cross the site.

5.3.10. Unique Recreation and Public Involvement Considerations

Brock Reservoir is closed to the public and recreation is not an authorized use of the reservoir; however, there has been a rare occasion involving an unidentified/unauthorized individual who may have been using the reservoir for recreational fishing for carp, bass, striper, and catfish. There is an RV camp a few miles east of the reservoir and off-highway vehicles roam the nearby dunes.

5.3.11. Potential Future Actions

- Brock would be an ideal place to study FPV effects on evaporation due to its uniformity of depth and lack of groundwater seepage to factor into inflow and outflow calculations.
- Similarly, because Brock is a controlled environment, it would be a good place to study FPV effects on water temperature, though at a depth of 21 feet, it may not be deep enough to study stratification effects.

5.4. Lauro Reservoir, California

Lauro Reservoir was selected as a case study for this report as Reclamation has been approached by a non-Federal developer about placing an FPV project on the reservoir. Also, its small size and close proximity to power loads makes it an attractive site for FPV deployment. In addition, the reservoir currently does not provide for recreational use and is closed to the public.

5.4.1. Location, Overview, and Authorization

Lauro Dam and Reservoir are on Diablo Creek in the foothills near Santa Barbara, California. The dam was constructed in 1951 as part of the Cachuma Project to store water from the Santa Ynez River and its tributaries for irrigation, municipal, industrial, domestic, and other beneficial uses. The dam is an earthfill structure with a crest length of 540 feet and a height of 137 feet. The reservoir has a normal capacity of 640 acre-feet with a surface area of approximately 21 acres.

Lauro Dam and Reservoir O&M is provided under a long-term contract with the Cachuma Operation and Maintenance Board (a California Joint Powers Authority agreement among the Carpinteria Valley Water District, the Montecito Water District, the Goleta Water District, and the City of Santa Barbara.

5.4.2. Power Infrastructure

The City of Santa Barbara has an existing hydroelectric plant near the northern part of the reservoir. There might be opportunities to connect to this infrastructure. As areas around the reservoir are possibly suitable for land-based PV, this could be a combination FPV and PV system using the same transmission line.

5.4.3. Potential FPV Area

Placement of FPV on Lauro Reservoir would need to avoid being too close to the dam and an intake structure near the bottom of the V-shaped reservoir. In addition to dam safety concerns, space would need to be left at the bottom of the V for firefighters to fill helicopter buckets. The region historically has been susceptible to wildfires and as such, the areas around the transmission lines would need to be maintained for fuels reduction. Figure 19 shows the scale for potential FPV in one portion of Lauro Reservoir.

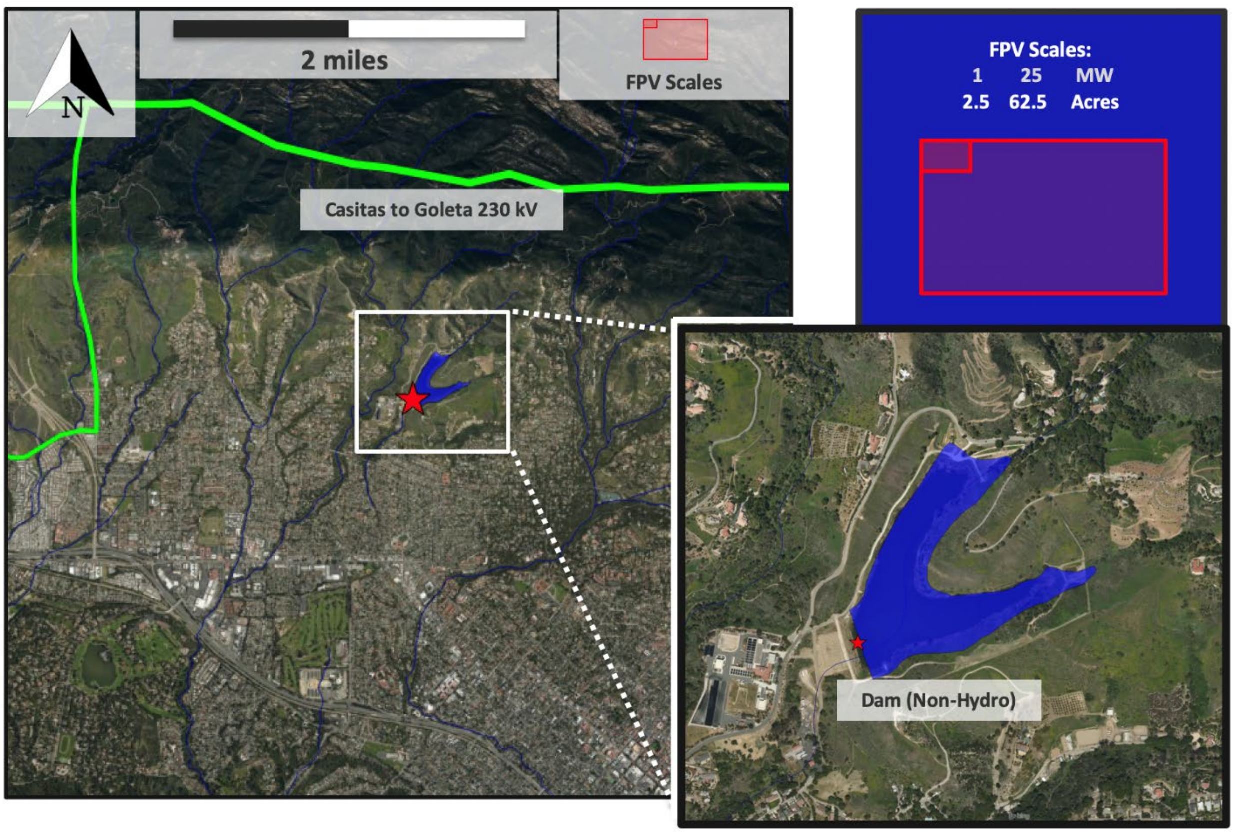

Figure 19. Site diagram that shows the nearby bulk transmission infrastructure (left) and relative scale (right). The FPV scale shows the areal extent (acres) needed for two different sizes (1 and 25 MW) in Lauro Reservoir.

5.4.4. Unique Economic Considerations

There is a nearby grid connection and a buyer for the generated electricity. However, the biggest issues for Lauro Reservoir could be its limited size and distance to a transmission line. The size of the reservoir may not allow for installing a system large enough to easily absorb the cost of transmission. While there is a small hydro plant at the north end of the reservoir, an FPV system may not be able to connect to its associated transmission. The high-level estimate to interconnect an FPV system in this reservoir to the nearest utility transmission line is $1.5 million. The total cost of a 1 MW system would be between $1.3 million and $2.04 million.

An alternative water source would cost about $2,000 an acre-foot, and thus if an FPV system saved 10 acre feet per year by reducing evaporation, savings could be about $20,000. These benefits would need to be estimated more accurately and added to the economic cost-benefit analysis.

New financing models for clean energy projects are providing increased incentive for PV systems in Santa Barbara. This includes the Santa Barbara County Energy Choice, a coalition of individuals, businesses, and organizations advocating for Community Choice Energy (CCE) in Santa Barbara County. This may provide a path for improved cost offsets, as power produced in excess could be sold back to the grid at competitive rates set by CCE in coordination with the existing utilities. The qualification requirements would need to be confirmed.

5.4.5. Unique Technical Considerations

Although the watershed around Lauro Reservoir may be subject to periods of drought and is dependent on rainfall, the reservoir elevation experiences very little fluctuation (less than 8 feet), and there is always water in the reservoir.

5.4.6. Unique Evaporation Suppression Considerations

Evaporation losses are estimated to be around 50 acre-feet per year, compared to a delivery of 15,000 acre-feet through Lauro Reservoir to the William B. Cater Water Treatment Plant. Due to its relatively small surface area, there have been very preliminary and informal discussions about installing a cover on Lauro Reservoir to help with evaporation losses. Therefore, suppressing evaporation with FPV would be a benefit, but would not be a driving factor in a decision.

5.4.7. Unique Dam Safety Considerations

This placement requisites a thorough investigation to ensure that any FPV array placements do not alter the dam operations in a way that would increase risk of an uncontrolled water release or dam failure. All of the limitations discussed in the Safety of Dams Considerations section above apply to Lauro Dam.

5.4.8. Unique Policy Considerations

Liability and maintenance responsibility would be agreed upon by the Reclamation, Cachuma Operation and Maintenance Board, and the developer, formalized under a use authorization.

5.4.9. Unique Environmental Considerations

Lauro Reservoir attracts migratory birds and is sensitive to algal blooms. Although the area adjacent to Lauro Reservoir is densely populated with residential homes, there is vegetation within and around the reservoir that may be susceptible to wildfire as the region sometimes experiences periods of drought.

Visual/aesthetic effects may be of concern for several neighbors of the reservoir. At the nearby Ortega Reservoir, when the operators wanted to cover the reservoirs for water quality protection, they had to paint the cover an earth tone as mitigation for visual effects to the surrounding community (Degner 2021). Glare off the FPV from reflection of the sun at certain times of the day may also present an unwanted effect to nearby homeowners.

5.4.10. Unique Recreation and Public Involvement Considerations

Lauro Reservoir is closed to the public and is surrounded by chain-link fence topped with three strands of barbed wire. Christmas bird counts have occurred the last couple years.

The City of Santa Barbara's City Council has adopted a goal to reach carbon neutrality by 2035 that will build on the City's commitment to 100% renewable energy by 2030 (City of Santa Barbara 2020).

5.4.11. Potential Future Actions

The City of Santa Barbara has approached Reclamation for help with a plan to publish a request for proposals for a private company to develop an FPV project on Lauro Reservoir. This presents an excellent opportunity for Reclamation to work with a local community on a pilot project that could be used to study water quality effects, evaporation, and other technical and economic considerations.

5.5. Case Study Technical Potential and Financial Performance

NREL analyzed the potential technical and financial performance of FPV systems at four sites selected by Reclamation as theoretical case studies. Table 4 shows the estimated annual energy production at the four sites by a 500-kilowatt (kW) FPV system. This size was chosen as a representative example for comparison across the four reservoirs. The annual energy output of the systems varies across the sites because the solar resource is not the same in the four locations. The best resource is in Caballo and Elephant Butte. As shown in the following tables, a higher energy yield translates into higher revenues, which improves the economic performance of the systems in Caballo and Elephant Butte.

Table 4. Energy Output and Capacity Factor Comparison Across Four Cases of a 500-kW FPV System

Site	Annual Energy (kWh)	Capacity Factor
Caballo	870,712	19.88%
Elephant Butte	869,970	19.86%
Lauro	797,121	18.20%
Warren H Brock	870,979	19.89%

As mentioned earlier in the report, FPV systems may get a boost in efficiency from the cooling effect of the water. That extra efficiency is not considered in this analysis because it is weather dependent and there is not enough information to estimate the extra efficiency that would be gained in the locations analyzed.

Table 5 shows the total system cost, depending on the price per watt, with a range between $1.20/W and $1.80/W reported in 2020[9] (Wood Mackenzie 2021). This price range does not factor in the cost reductions from the investment tax credit, which is set to expire in 2024 (Solar Energy Industries Association [SEIA] 2021).

The economic analysis was performed using both the high and low ends of the cost range because the actual cost per watt for each system will depend greatly on factors that cannot be determined before a detailed engineering analysis. Actual system costs may even surpass the $1.80/W price. A system of 500 kW is more likely to have a cost closer to or above the high end of the range.

System costs before financing do not include the costs of financing the construction of the project. The parameters used to model the cost of financing are an 18-year term debt with an annual interest rate of 7%. Debt is used to cover 60% of the total cost and equity covers the rest. An internal rate of return of 11% at year 20 was selected as target for the economic analysis.

Table 5. Energy Output Comparison Across Four Cases of a 500-kW FPV System

Cost per Watt	System cost	System cost before financing
$1.20	$1,118,550	$600,000
$1.80	$1,440,200	$900,000

Table 6 and Table 7 show the levelized cost of electricity (LCOE) in cents per kWh for each of the sites using $1.20/W and $1.80/W as a system cost, respectively. This metric represents the cost of each unit of electricity produced throughout the life of the system. Systems that produce more energy have a lower LCOE. The same table also shows the minimum power purchase agreement (PPA) price that reaches the target internal rate of return of 11%. The PPA price is the minimum price that the buyer of the energy must be willing to pay for the project to have a zero or positive net present value. Systems in locations with better solar resources require a lower PPA price. Projects with lower required PPA prices are more likely to find financing and developers.

Table 6. Levelized Cost of Electricity and PPA Price in Cents Per kWh Using a $1.20/W System Cost

Site	Levelized cost of electricity (cents/kWh)	PPA price (cents/kWh)
Caballo	12.04	11.89
Elephant Butte	12.05	11.90
Lauro	13.15	12.99
Warren H Brock	12.03	11.89

[9] These numbers have been rounded to the closest tenth of a dollar. The actual numbers are proprietary information of Wood Mackenzie.

Table 7. Levelized Cost of Electricity and PPA Price in Cents Per kWh Using a $1.80/W system cost

Site	Levelized cost of electricity (cents/kWh)	PPA price (cents/kWh)
Caballo	14.75	14.61
Elephant Butte	14.76	14.62
Lauro	16.11	15.95
Warren H Brock	14.74	14.60

The required PPA prices for the four projects range between 11.89 cents per kilowatt hour (¢/kWh) and 12.99 ¢/kWh at the $1.20/W cost, and between 14.60 ¢/kWh and 15.95 ¢/kWh at the $1.80/W cost. For comparison, the average annual wholesale price of electricity (i.e., the price that a utility would pay for the electricity they sell to their customers) in California in 2019 was 4.1¢/kWh (California Independent System Operator [CAISO] 2019). The International Renewable Energy Agency (IREA 2019) estimates that it pays about 7.5¢/kWh for the energy they sell to their members. In the United States in the third quarter of 2020, solar PV PPA prices averaged 2.93¢/kWh (Sylvia 2020). These are the prices that the systems in the four case studies of this report would have to compete with to find a utility willing to purchase the energy.

Lower system costs, higher PV efficiency, better financing terms would help these projects to be competitive with current alternative sources of electricity. It is expected that system costs will continue to decline, but it is unknown at what pace. The cooling effect from placing the panels over water can increase system efficiency. A recent study found that systems in the Netherlands had an efficiency up to 3% higher than land-based systems, and up to 6% in Singapore (Dörenkämper et al. 2021).

Transmission costs were not added to the cost of the systems analyzed. Transmission costs are estimated to be $1.3 million for Caballo, $0.5 million for Warren H. Brock, and $1.5 million for Lauro.[10] The costs of building a transmission line at Elephant Butte were not estimated because the distance from a hypothetical FPV system to an existing transmission line was not available. These are high-level estimates based on available data (see *Section 3.2.4. Transmission Lines* for more information about transmission cost estimation methodology and assumptions). The magnitude of these costs would severely skew the results of the analysis, given the investment cost of $1.12 million or $1.44 million (depending on the cost per watt selected). These investment costs reflect the selected capacity of 500 MW. Due to the magnitude of the potential transmission costs, smaller systems would see their financial performance more severely affected by transmission costs than larger ones.

[10] These costs are estimated considering a straight line between the closest transmission line and the closest point of each reservoir to that transmission line and could be higher if the line needs to be longer and if a substation is needed as cost estimates do not include substations.

6. Conclusions, Recommendations, and Next Steps

6.1. Site-Specific Requests

We recommend that Reclamation work with applicants to learn about the interests and objectives of the applicant, including any constraints or flexibilities with respect to the proposal (e.g., timing or location constraints based on loan guarantees, power purchase agreements, or transmission connections) and any consideration that has been given to siting on non-Federal lands. The Key Questions listed in Appendix A should be answered with as much detail as possible before the application is considered for analysis—understanding that more detailed information will be available as the analysis and planning continue.

As noted in Reclamation 2015:

> *Applications in high conflict areas will be more difficult to process and require a greater level of consultation, analysis, and mitigation to resolve issues or may not be feasible to authorize. Such applications may be given a lower priority for action. Applications with fewer resource conflicts are anticipated to be easier and thus less costly and time-consuming for Reclamation to process.*

6.2. Further Areas of Study

FPV is a clean, renewable energy resource—and may provide evaporation mitigation benefits. However, given current information gaps and the site-specific nature of FPV deployments, Reclamation is unable to determine the safety, efficacy, and utility of FPV installations on Reclamation's reservoirs at this time. Accordingly, this report recommends the following next steps for Reclamation:

1. Continue to coordinate internally and with transferred works operating partners and recreation managing partners, if any, to refine considerations and identify areas for further evaluation.

2. Refine considerations through existing and/or ongoing related Reclamation studies, e.g., Reclamation is working on sedimentation study guidelines for all Reclamation reservoirs. These studies might be expanded to include information about the topology of the bottoms of reservoirs as it relates to FPV siting.

3. Coordinate with the non-Federal FPV community to better understand the FPV technology and industry challenges and opportunities and discuss report considerations and Key Questions listed in Appendix A. This coordination may help identify any red flag issues for developers (e.g., type of use authorizations required by financial institutions and allowed

under Reclamation authorizations, use fee negotiation), as well as inform Reclamation's efforts in reviewing requests. This coordination may also help inform Reclamation's understanding of claimed reservoir evaporation mitigation benefits.

4. Consider partnering with a non-Federal FPV developer(s) to conduct a pilot deployment case study to evaluate FPV system performance, benefits, and effects to Reclamation project operations – including water deliveries, hydropower generation, and recreation (as applicable), as well as any potential effects to environmental resources or Reclamation infrastructure. The pilot study should have:

- Low potential for conflict
- High community support (e.g., near a city like Santa Barbara with a commitment to be self-sustaining)
- Low technical issues (e.g., very little fluctuation)
- Opportunity for study (partner with a university)
    - Economic and market analyses
    - Environmental issues (water temperature, habitat, quagga mussels, riparian habitat, migration, water quality)
    - Environmental justice issues
    - Evaporation loss suppression (particularly in a desert environment)
    - Any potential water temperature changes from the FPV
    - Power study (peak power, transmission)
    - Public safety and effects to infrastructure
        - Water temperature and stratification effects
        - Effects on algae and cyanobacteria growth, nutrients, carbon dynamics
        - Effects on fish and other aquatic species
        - Effects on migrating and resident birds
        - Percentage of water surface that can be covered by FPV before harmful effects to the ecosystem occur
        - Information on the amount of public interactions with FPV installations and other public safety considerations
        - Power generation at various water level depths and slopes
    - Potential safety concerns
        - Would the FPV system affect or increase the risks to the dam and appurtenant structures?
        - How have anchor safety issues been addressed in design, construction, maintenance, and inspections?
        - Have different anchoring systems been stress-tested?

Proposed next steps align with past Reclamation studies on hydrokinetics and may be pursued in coordination with other Federal agencies interested in FPV systems (e.g., Department of Energy and National Labs, USACE, PMAs, etc.).

Reclamation may use lessons learned from the non-Federal FPV community and pilot case study to evaluate whether revisions may be necessary to existing Reclamation use authorizations process requirements and/or guidance documents to best accommodate FPV development. Revisions may include:

- Developing general criteria for FPV development that can be customized to each reservoir by Regional and/or Area Offices for use by developers or communities requesting proposals for development
- Developing procedures to receive and analyze potential FPV proposals
    - Pre-application meetings
    - Preplanning funding agreements
    - Developing detailed analyses

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Appendix A: Key Questions

These questions are intended to act as a preliminary planning aid and should not be construed as design guidance or a comprehensive list of issues to consider when installing an FPV system on a body of water impounded by a dam. A full feasibility design should include a full analysis and review by design professionals familiar with FPV technology and dam operations.

Policy and Contract Considerations

- **How will non-contract costs (e.g., planning and environmental compliance) be accounted for and allocated?** ***Note that costs for environmental reviews (in addition to any required post-construction activities, e.g., surveying, monitoring, and reporting) would be included as part of the administrative costs paid by the use authorization applicant (43 CFR Part 429).***

- **What is the financial and technical capability of the applicant to construct, operate, maintain, inspect, and decommission the project?** ***Note that use authorization applications are generally not assignable interests.***

    - What is the applicant's availability of sufficient capitalization to carry out development, including the preliminary study phase of the project and the environmental review and clearance process?

    - Are there any conditional commitments of Department of Energy (DOE) loan guarantees; confirmed power purchase agreements; engineering, procurement, and construction contracts; and supply contracts with credible third-party vendors for the manufacture and/or supply of key components for the FPV? ***Note that technical and financial capability will likely become a condition of any use authorization, and failure to sustain technical and financial capability for the development of an approved project could be grounds for termination of the authorization.***

- **What will Reclamation set the performance bond at and what language will be used?** Reclamation will require a Performance Bond for all renewable energy projects to ensure compliance with the terms and conditions of the use authorization and the requirements. Ultimately, the Performance Bond should be a single instrument to cover all potential liabilities.

    - Is this use compatible with Reclamation project purposes (e.g., hydroelectric power generation, water delivery)?

    - Will the use interfere with any project purposes?

    - What are the potential funding mechanisms (e.g., loan guarantees, power purchase agreements, or transmission connections)?

    - What are the potential liabilities?

- What is the planning horizon?
- What are the insurance requirements?

- **How long will the authorization be for?** Consistent with 43 CFR §429.7, any use authorization for a term exceeding 25 years must have consent of any involved water user organization. Concurrence in and approval of uses for 25 years or less may be requested of the water users' organization at the discretion of the appropriate Reclamation Regional Director.

Power Infrastructure

- **What is the existing power infrastructure?**
- **Where can FPV be placed to minimize construction of new power infrastructure, transmission, or roads?**

Potential FPV Area

- **How much potentially usable surface area is there?**
- **What are areas where FPV might be considered (avoiding areas that might interfere with project purposes or dam safety or that might be technically infeasible)**
    - What is the preliminary safety margin around these features?
    - What analysis process and review will Reclamation use to refine this estimate to determine if FPV can or cannot be located in a certain area?
- **Would the magnitude of effects, such as displacement of recreation users or navigational hazards, increase along with a declining reservoir size?**

Economics

- **What are the benefits to Reclamation and the Nation? If power generated from the FPV project can be made available to Reclamation for Project purposes.**
    - Where would the power be used? Is there a local load nearby? What is the power market? Would power be used as it is generated or would battery storage be needed?
    - What carbon reduction would the project provide by replacing other grid generation assets? (e.g., carbon reduction per MWh of FPV generation is greater in Wyoming than California).
    - How much does power cost in the area?
    - How much water is lost to evaporation and how much do alternative sources of water cost?

- What are the potential costs for infrastructure, O&M, and life cycle?
- What are the power transmission costs?

Technical

- **What model output would be needed to inform safe and effective FPV locations?**
  - Wind-wave model to determine potential FPV stability?
  - Operations model to determine potential reservoir level fluctuation?
  - Temperature model to determine potential cooling or heating effects?
  - How will FPV perform if the reservoir freezes?
- **What reservoir areas will be excluded from the potential FPV area due to technical considerations?** Consider: wind, waves, temperature, humidity, water level variations, and water currents, size, shape, and depth of water body and wind fetch distance.
- **Reservoir fluctuations.** Can the FPV array be designed to accommodate reservoir levels at minimum and maximum pool elevations, including flood operations and emergency response levels?
  - What are the reservoir levels over the course of a year?
- **Reservoir Bottoms.** How will the bottom of the reservoir affect the FPV safety, use, and design?
  - What is the topography of the bottom of the reservoir?
  - Is there a reservoir liner? What is it made of?
- **Removal.** If the FPV array is not designed to accommodate all reservoir pool elevations, can it be removed before elevations outside of standard operating conditions are reached?
  - What are the procedures for removal?
  - Could these procedures inhibit operational or emergency response activities?

Dam Safety

- **What reservoir areas will be excluded from potential FPV development due to dam safety considerations? Consider:**
  - All dam infrastructure locations (intake works, dam, access, spillways, etc.)
  - Frequency of spillway use
  - Embankment and any other potential area that could cause stability issues

- **How will Reclamation ensure that the structural integrity of the anchoring system is maintained to prevent damage to any Reclamation infrastructure?**
- **Sensitivity assessment**
    - Sensitivity of operations and sensitivity of dam safety
- **Safety precaution recommendations by dam type or FPV array setup**
    - What reasonable and prudent actions should be taken?
    - Are there unsafe reservoir pool elevations (e.g., when the reservoir is in flood operations)?
    - What additional safety features/precautions will Reclamation mandate or recommend?
    - What maintenance recommendations for safe operating procedures will Reclamation mandate or recommend?
    - How will Reclamation evaluate the applicant's statement explaining limitations of this analysis and perform risk analyses?
- **Could the FPV array obstruct normal dam operations?**
    - Are FPV units, transmission lines, and mooring clear of spillway approaches and inlets?
    - Are FPV arrays clear of all instrumentation, controls, and access paths?
    - Will the FPV arrays block visual line-of-site needed for inspections or cover any portion of the dam or appurtenant structures that are regularly inspected?
    - Will the FPV array affect dam operations at high or low reservoir levels?
- **Could the FPV array pose dam safety issues?**
    - Operations: What are the dam-specific effects or potential consequences if the FPV fails or does not operate as designed?
    - Electrical:
        - What are the FPV electrical design safeguards for interacting with water/weather?
        - How will cables and other electrical equipment be maintained to prevent electrical hazards?
    - Potential damage to dam infrastructure: Would damage occur if the FPV array or portion thereof collided with the dam or any appurtenant structure?
    - Are there any potential effects to hydraulics and the capacity of the spillway or outlet works?

- **Public Access:** What is the reservoir public access/activity level (potential for deliberate or accidental actions that could impair dam/FPV array safety?
- **Anchoring system structural integrity and safety**
  - What is the likelihood that the FPV array or component of an array could break loose from its anchoring system? Have different anchoring systems been stress-tested and the best option for the local risk factors been selected?
  - Are anchoring systems vulnerable to vandalism or unintentional damage by the public?
  - Are anchoring systems vulnerable to damage by wildlife or uncontrolled pets?
  - How has this issue been addressed at existing FPV installations?
  - Is there a backup mooring system or safety net in place if the primary anchoring system fails?
  - What is the procedure for a failure of the anchoring system resulting in a free-floating array or component of the array?
- **Operations**
  - What will the Standing Operating Procedures be?
  - How will the FPV arrays be monitored and by whom?
  - How will inspections be incorporated into other facility inspections?
- **Emergencies**
  - FPV-specific—would damage occur to Reclamation infrastructure if an FPV array collided with or otherwise compromised the dam structure?
  - Emergency operations—would the FPV interfere with any emergency operations under any emergency scenario involving Reclamation's infrastructure?
  - How will the Emergency Action Plan be updated?
  - Detection: How will a failure be recognized?
  - Response: Who will be contacted, who will respond, and in what timeline?
    - How will the FPV array be managed during emergency procedures?
    - Who has authority to make decisions to minimized damage to other structures?
    - Who will have the responsibility to monitor the FPV array during emergencies?
    - Who will have the authority to control the FPV array operations during emergencies?

        - What triggers and FPV-specific response actions are necessary during emergencies?

- **Removal:** Are there emergency conditions that would require the FPV array be removed?
    - How long would it take to remove the FPV array from the reservoir in case of emergency?

Environmental

- What are the existing Reclamation resource management plans (RMP), biological opinions, or any other documents used to guide management of the land?
    - Is the use compatible with Reclamation's RMP and other documents?
- Do sensitive aquatic habitats exist at the site that may be adversely affected by FPV installation and, if so, are there opportunities for mitigating these effects?
- Do lands adjacent to designated transmission corridors have any significant resource conflicts or potential adverse effects to special areas designated on subject or nearby lands?
- Identify necessary studies of environmental, wildlife, cultural, environmental justice, or other resources, permits, or other information that may be needed.
- Are there alternative site locations and project configurations with fewer negative effects?
- What is the Decommissioning and Site Reclamation Plan (DSRP)? What reclamation, re-vegetation, restoration, and soil stabilization requirements for the project area will be met during decommissioning?

Recreation and Public Involvement

- How will neighboring lands and uses be affected?
    - Who owns the surrounding lands?
    - What are the surrounding land uses?
    - Are there any concerns about FPV effects on owned lands and uses (e.g., visual)?
- What agencies and stakeholders need to be contacted?
- How will communities and stakeholders be informed and involved?