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GOVERNMENT OF PUERTO RICO
PUBLIC SERVICE REGULATORY BOARD
PUERTO RICO ENERGY BUREAU

IN RE: REVIEW OF THE PUERTO RICO ELECTRIC POWER AUTHORITY INTEGRATED RESOURCE PLAN	**CASE NO.:** CEPR-AP-2018-0001 **SUBJECT:** Hydroelectric Study; Memorandum for Confidentiality

MOTION TO SUBMIT FINAL HYDRO STUDY AND JUNE 2021 MONTHLY STATUS REPORT AND REQUEST FOR CONFIDENTIALITY DESIGNATION

TO THE HONORABLE PUERTO RICO ENERGY BUREAU:

COMES NOW, the Puerto Rico Electric Power Authority, through its counsel of record, and respectfully sets forth and prays:

I. INTRODUCTION

1. On August 24, 2020, the Puerto Rico Energy Bureau of the Public Service Regulatory Board (the "Energy Bureau") entered *Final Resolution and Order on the Puerto Rico Electric Power Authority's Integrated Resource Plan* (the "IRP Order") directing the Puerto Rico Electric Power Authority (the "Authority") to, among other things, complete and submit a feasibility study of refurbishing each of the Authority's hydroelectric facilities (the "Hydro Study" or "Final Hydro Study"). Pursuant to the IRP Order, the deadline to present the Final Hydro Study was February 22, 2021.

2. On February 22, 2021, the Authority submitted to the Energy Bureau a *Motion to Submit Status Report of Feasibility Study for Improvement of PREPA's Hydroelectric System and to Request Extension of Time to Submit Final Study* (the "Request for Extension") through which the Authority requested an extension of time until today, June 30, 2021, to submit the Final Hydro Study.

3. In the Request for Extension, the Authority informed the Energy Bureau that it had retained the services of Black and Veacth Puerto Rico, PSC ("Black and Veatch") to complete the Hydro Study. The Authority also offered to submit a monthly project status reports to the Energy Bureau.[1]

4. The Authority, in compliance with the Final IRP Order and following the deadline proposed in the Request for Extension, hereby submits the Final Hydro Study titled *Feasibility Study for Improvements to Hydroelectrical System- Task 700- Feasibility Study Summary Report* dated June 28, 2021. Exhibit A.

5. The Authority also presents the Black & Veatch *Project Status Report* (the "Monthly Status Report") for June 2021 titled *Feasibility Study for Improvements to the PREPA's Hydroelectric System-Status Report* dated June 29, 2021. Exhibit B. Furthermore, the Authority submits the feasibility studies of Tasks 500 and 600 completed by Black and Veatch as referenced in the June 2021 Monthly Status Report (the "Feasibility Studies"). Exhibits C and D.

6. The Feasibility Studies in Exhibits C and D include detailed descriptions of the hydroelectric assets, site visits, recommendations made by Black and Veatch for the improvements and economic impact of the Authority's hydroelectric facilities and generation units.

II. MEMORANDUM OF LAW

7. Article 6.15 of the *Puerto Rico Energy Transformation and RELIEF Act*[2] provides that "any person who is required to submit information to the Energy [Bureau] believes that the information to be submitted has any confidentiality privilege, such person may request the [Bureau] to treat such information as such[.]" "If the Energy [Bureau], after the appropriate evaluation, believes such information should be protected, it shall grant such protection in a

[1] The Energy Bureau has not entered any order in regards to the Request for Extension.
[2] *Puerto Rico Energy Transformation and RELIEF Act*, Act no. 57 of May 27, 2014, 22 L.P.R.A. §§ 1051-1056 ("Act 57").

manner that least affects the public interest, transparency, and the rights of the parties involved in the administrative procedure in which the allegedly confidential document is submitted." *Id.* at 6.15(a). If the Energy Bureau determines that the information is confidential, "the information shall be duly safeguarded and delivered exclusively to the personnel of the Energy [Bureau] who needs to know such information under nondisclosure agreements." *Id.* at 6.15(c). "The Energy [Bureau] shall swiftly act on any privilege and confidentiality claim made by a person subject to its jurisdiction by means of a resolution to such purposes before any allegedly confidential information is disclosed." *Id.* at 6.15(d).

8. Pursuant to its vested powers, the Energy Bureau approved the *Regulation on Adjudicative, Notices of Compliance, Rate Review and Investigations Proceedings* ("Regulation 8543").[3] Regarding the safeguards that the Energy Bureau must give to confidential information, Regulation 8543 provides that:

> [i]f in compliance with the provisions of [Regulation 8543] or any of the Energy Bureau's orders, a person has the duty to disclose to the Energy Bureau information considered to be privileged pursuant to the Rules of Evidence, said person shall identify the allegedly privileged information, request the Energy Bureau the protection of said information, and provide supportive arguments, in writing, for a claim of information of privileged nature. The Energy Bureau shall evaluate the petition and, if it understands the material merits protection, proceed according to what is set forth in Article 6.15 of Act No. 57-2014, as amended.[4]

a. Trade Secrets

9. Exhibits C and D to the Motion contain information that qualifies as proprietary and includes trade secrets *(i.e.,* confidential and other protected information) which is protected under

[3] Energy Bureau, *Regulation on Adjudicative, Notices of Compliance, Rate Review and Investigations Proceedings*, No. 8543 (December 16, 2015).
[4] Regulation 8543 at Sec. 1.15.

Puerto Rico law.[5] Regulation 8543 specifically provides for the designation of such information as confidential.[6]

10. The Act 80-2011, the *Industrial and Trade Secret Protection Act of Puerto Rico*, defines a trade secret as any information that

> has a present or a potential independent financial value or that provides a business advantage, insofar as such information is not common knowledge or readily accessible through proper means by persons who could make a monetary profit from the use or disclosure of such information; and [f]or which reasonable security y measures have been taken, as circumstances dictate, to maintain its confidentiality.

Act 80 at Art. 3.

11. Trade secrets may take a variety of forms, including a process to manufacture, treat or preserve materials, a formula or recipe, a project or pattern to develop machinery, or simply a list of specialized clients that constitute a specific market which provides the owner with an advantage over its competitors. Act 80 at Statement of Motives. These examples are not exhaustive, however, and the Legislative Assembly has acknowledged in Act 80-2011's Statement of Motives, the broad definition of a trade secret includes "any confidential information with trade or industrial value, which its owner reasonably protects to prevent its disclosure." *Id.* In Puerto Rico, moreover, trade secrets "do not require registration or compliance with any formalities in order to be protected." *Id.*

12. As the Legislative Assembly has noted, "failure to protect trade secrets could leave

[5] *Industrial and Trade Secret Protection Act of Puerto Rico*, Act No. 80 of June 3, 2011, 10 L.P.R.A. § 4131-4141 ("Act 80"); *see also* Act No. 57, Art. 6.15 (establishing that any person having the obligation to submit information to the Energy Bureau can request privileged or confidential treatment of any information which the submitting party believes to warrant such protection).

[6] Regulation 8543 at Sec. 1.15 (recognizing appropriateness of according to proprietary information and trade secrets Confidential treatment); *cf.*, Energy Bureau, *Regulation on Integrated Resource Plan for the Puerto Rico Electric Power Authority,* No. 9021 (May 23, 2018), Sec. 1.15 (providing for designation of information submitted in support of an integrated resource plan as confidential).

companies at the mercy of any competitor or former employee who gains knowledge of any such secret, whether directly from the owner or by other means." *Id.*

13. PREPA, as a public body whose costs are ultimately borne by citizens of Puerto Rico, has a strong interest in protecting its trade secrets. The information included in Exhibits C and D is proprietary, commercially sensitive and qualifies as trade secrets. The disclosure of this information could place PREPA in a competitively disadvantageous position in dealing with potential proponents, ultimately harming customers. Therefore, PREPA requests the Energy Bureau to grant confidential designation to Exhibits C and D.

b. Critical Energy Infrastructure Information

14. Federal and Puerto Rico law protect the confidentiality of critical energy infrastructure information (CEII), the public disclosure of which may pose a security threat in that the information could be useful to a person or group in planning an attack on critical infrastructure. *See, e.g.*, 18 C.F.R. § 388.113, as amended by Federal Energy Regulatory Commission (FERC) Order No. 683, *Critical Energy Infrastructure Information* (issued September 21, 2006); *USA Patriot Act of 2001*, § 1016, creating the *Critical Infrastructures Protection Act of 2001*, including 42 U.S.C. § 5195c(e) (defining Critical Infrastructure).

15. Under the *Critical Infrastructures Protection Act of 2001*, the term "critical infrastructure" means "systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters." 42 U.S.C. § 5195c(e).

16. In 2006, FERC Order no. 683 amended the regulations for gaining access to CEII and simplified procedures for obtaining access to CEII without increasing vulnerability of the energy

infrastructure and ensuring that access to CEII does not facilitate acts of terrorism. 18 C.F.R. § 388.113

17. A utility is not required to obtain FERC or other federal government approval in order to designate information as CEII. For example, information required by FERC's Annual Transmission Planning and Evaluation Report, Form No. 715, ("FERC No. 715"), is *de facto* considered CEII and is automatically afforded the heightened protections. FERC No. 715 requires that any transmitting utility that operates integrated (non-radial) transmission facilities at or above 100 kV must annually submit information including but not limited to: Power Flow Base Cases, Transmitting Utility Maps and Diagrams, Transmission Planning Reliability Criteria, Transmission Planning Assessment Practices, and Evaluation of Transmission System Performance. Any utility that submits the required transmission information pursuant to FERC No. 715 does so with the knowledge that, as stated in the Form's Instructions, FERC "considers the information collected by this report to be Critical Energy Infrastructure Information (CEII) and will treat it as such." *See also* 18 C.F.R. § 141.300(d) relating to the Form and CEII.

18. The Authority further states that mainland regulators typically do not require a utility that designates material as CEII to follow any process before the federal government in order to make or support such a designation, and, further, that the regulator, in its informed discretion, can establish limits on how information that it considers CEII can be accessed.

19. The Energy Bureau, on numerous occasions in prior dockets has accepted the Authority's designations of material as CEII, recognizing that both federal law and Puerto Rico law support such designations when applicable.

20. Exhibit C includes the infrastructure and technology identified in each of the hydro facilities during the site visits, to evaluate the frequency response and remote-control capabilities

from the Authority's Energy Control Center (ECC) with recommendations. This information is considered as CEII. Wherefore, it is respectfully requested that the Feasibility Reports included in Exhibit C be designated as confidential, and the Energy Bureau orders they remain under seal to protect the Authority's CEII.

WHEREFORE, the Authority herein requests the Energy Bureau to accept this Motion, find the Authority in compliance with the IRP Order and GRANT the confidentiality to the Feasibility Reports included in Exhibit C and D of this Motion.

RESPECTFULLY SUBMITTED.

In San Juan, Puerto Rico, this 30th day of June 2021.

s/ Katiuska Bolaños Lugo
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TSPR 18,888

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CERTIFICATE OF SERVICE

It is hereby certified that, on this same date I have filed the above motion using the Energy Bureau's Electronic Filing System, at the following address: http://radicacion.energia.pr.gov and that a courtesy copy of the filing was sent via e-mail to: sierra@arctas.com; tonytorres2366@gmail.com; cfl@mcvpr.com; gnr@mcvpr.com; info@liga.coop; amaneser2020@gmail.com; hrivera@oipc.pr.gov; jrivera@cnslpr.com; carlos.reyes@ecoelectrica.com; ccf@tcmrslaw.com; manuelgabrielfernandez@gmail.com; acarbo@edf.org; pedrosaade5@gmail.com; rmurthy@earthjustice.org; rstgo2@gmail.com; larroyo@earthjustice.org; jluebkemann@earthjustice.org; acasellas@amgprlaw.com; loliver@amgprlaw.com; epo@amgprlaw.com; robert.berezin@weil.com; marcia.goldstein@weil.com; jonathan.polkes@weil.com; gregory.silbert@weil.com; agraitfe@agraitlawpr.com; maortiz@lvprlaw.com; rnegron@dnlawpr.com; castrodieppalaw@gmail.com; voxpopulix@gmail.com; paul.demoudt@shell.com; javier.ruajovet@sunrun.com; escott@ferraiuoli.com; SProctor@huntonak.com; GiaCribbs@huntonak.com; mgrpcorp@gmail.com; aconer.pr@gmail.com; axel.colon@aes.com; rtorbert@rmi.org; apagan@mpmlawpr.com; sboxerman@sidley.com; bmundel@sidley.com.

In San Juan, Puerto Rico, this 30th day of June 2021.

s/ Katiuska Bolaños Lugo
Katiuska Bolaños Lugo

Exhibit A

FINAL

FEASIBILITY STUDY FOR IMPROVEMENTS TO HYDROELECTRICAL SYSTEM

TASK 700 – FEASIBILITY STUDY SUMMARY REPORT

BLACK &VEATCH PROJECT NO. 407635.47.0000

PREPARED FOR

Puerto Rico Electric Power Authority

JUNE 28, 2021

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This is report was prepared by the following Black & Veatch personnel:

Randy Boyce - Hydro Project Manager

Dianys Arocho - Engineering Manager

Aaron Lemke - Hydropower Technical Lead, Mechanical / Civil

Bruce Benson - Hydropower Technical Lead, Electrical / Control

1 Executive Summary

The Puerto Rico Electric Power Authority (PREPA) contracted Black & Veatch to assist in its efforts to evaluate the feasibility of refurbishing the ten hydroelectric facilities listed below:

1. Dos Bocas (Units 1, 2 & 3)
2. Caonillas 1 (Units 1-1 & 1-2)
3. Caonillas 2 (Unit 2-1)
4. Toro Negro 1 (Units 1-1, 1-2, 1-3, & 1-4)
5. Toro Negro 2 (Unit 2-1)
6. Garzas 1 (Units 1-1 & 1-2)
7. Garzas 2 (Unit 2-1)
8. Río Blanco (Units 1-1 & 1-2)
9. Yauco 1 (Unit 1-1)
10. Yauco 2 (Unit 2-1 & 2-2)

The objective of this study is to determine the feasibility of achieving the following primary goals with the refurbishments:

- Increase the generation production from its current capacity factor (approximately 0.06 over the last 3 years) to a goal capacity factor of 0.28. This includes improvements to the facilities and modifications to the reservoir operational curves through water availability forecasting.
- Evaluate the potential to increase the hydroelectric capacity at these facilities by means of improvements to their current capacities, or above their current capacities. Identify the estimated cost and time required to achieve this goal.
- Evaluate the units to determine their ability to automatically respond to frequency variation events on the electrical system. Identify recommendations for governor upgrades or other modifications to improve unit responsiveness.
- Evaluate the potential for control of all units from the PREPA Energy Control Center (ECC) at Monacillo, San Juan (currently only Yauco 1 and Yauco 2 have this capability). Identify requirements to provide remote operation for each facility.

To evaluate the feasibility of achieving these primary goals for the ten facilities listed, Black & Veatch visited each of the sites to assess the condition of the existing equipment and civil facilities. The results of the condition assessment were presented in a site visit memorandum (Task 200).

Black & Veatch developed several technical memorandums to evaluate improvement alternatives to increase hydroelectric capacity. The Task 201 memorandum identified potential opportunities for increased performance and provided various recommendations for modernizing and/or returning the plants to active service, improve civil, mechanical and electrical reliability and electrical safety. The Task 300 memorandum summarized Black & Veatch's review of the existing water availability models for each hydroelectric system. The Task 400 memorandum provided recommendations for operating the reservoir systems to maximize yield and hydroelectric generation. A Task 500 report was completed for evaluating the generation unit frequency response and potential for remote control from the ECC.

Black & Veatch performed an economic feasibility evaluation as part of Task 600 that analyzed two of the most promising portfolios for all the improvement alternatives considered. The first portfolio included rehabilitation of the hydroelectric plants with positive Net Present Value (NPV) to achieve the maximum NPV for the entire system. The second portfolio included rehabilitation of all projects including projects with a negative NPV. Caonillas 2 was included in both portfolios as it has a negative NPV, however including Caonillas 2 increases the NPV of Caonillas 1 by a greater amount therefore increasing the total NPV. Toro Negro 2 is only included in the Portfolio 2 as it has a negative NPV.

The portfolio of selected improvements generates a positive NPV in the amount of $687.5 million over the 30 year study period. Table 1-1 shows the projects by facility utilized in this Portfolio.

Table 1-1 Summary of Capital Costs and NPV

Facility	Improvements	Total Capital Cost ($)	Net Present Value ($)(1)
Dos Bocas	Reliability Improvements, and 1MW Caonillas 2 plant with bypass	$5,946,000	$95,293,000
Caonillas 1	Reliability Improvements, and 1MW Caonillas 2 plant with bypass	$2,795,000	$188,204,000
Caonillas 2	New 1 MW full auto, with bypass and sediment passage gates	$20,300,000	($9,843,000)
Toro Negro 1	Rehabilitate Small Diversions with full Automation, New Penstocks in Future	$42,133,000	$31,241,000
Toro Negro 2	Full Automation, and Rule Curve 1, New Penstocks in Future	$22,077,000	($2,510,000)
Garzas 1	Tyrolean Weirs on Small Diversions, Full Automation, and Rule Curve 1, New Penstock in Future	$26,347,000	$23,638,000
Garzas 2	Tyrolean Weirs on Small Diversions, Full Automation, and Rule Curve 1, New Penstock in Future	$25,246,000	$19,615,000
Yauco 1	Modify Yahuecas and Prieto to Pass Sediment, Refurbish Electrical and Mechanical, Full Automation	$17,500,000	$161,590,000
Yauco 2	Modify Yahuecas and Prieto to Pass Sediment, Reliability Improvements, Full Automation	$3,176,000	$92,008,000
Río Blanco	Restore All Small Diversions to Service, Full Automation	$1,200,000	$88,214,000
Total		**$166,700,000**	**$687,500,000**

(1) The final NPV for each project varies on each portfolio, due to the individual conditions for each scenario. The NPV's presented in subsequent sections assume that all the facilities will be brought to full functionality.

This portfolio mainly aims at investing first on hydroelectric facilities to increase energy generation and improve the capacity factor, most of which produce a positive NPV. The projects with a negative NPV are included because they supply water for downstream hydroelectric facilities and increase their NPV.

The results from this study show that it is feasible to increase generation and improve the capacity factor for the hydroelectric facilities. The objectives PREPA requested are achievable in an economically advantageous way and all projects are economically beneficial to maintain or upgrade to keep operational.

2 Introduction

2.1 FEASIBILITY STUDY EVALUATION

PREPA contracted Black & Veatch to assist in its efforts to evaluate the feasibility of refurbishing the ten hydroelectric facilities listed below:

1. Dos Bocas (Units 1, 2 & 3)
2. Caonillas 1 (Units 1-1 & 1-2)
3. Caonillas 2 (Unit 2-1)
4. Toro Negro 1 (Units 1-1, 1-2, 1-3, & 1-4)
5. Toro Negro 2 (Unit 2-1)
6. Garzas 1 (Units 1-1 & 1-2)
7. Garzas 2 (Unit 2-1)
8. Río Blanco (Units 1-1 & 1-2)
9. Yauco 1 (Unit 1-1)
10. Yauco 2 (Unit 2-1 & 2-2)

The purpose for evaluating rehabilitation and upgrades to PREPA's hydroelectric system is to comply with the Puerto Rico Energy Bureau (PREB) requirements to improve capacity and achieve a 0.28 capacity factor. The deliverables for the work by Black & Veatch were divided into tasks as defined below:

- Task 200: Assessment of Hydropower Facilities
- Task 201: Installed Capacity and Average Annual Generation
- Task 300: Review of Water Availability Models
- Task 400: Review Reservoir Operation Curves
- Task 500: Evaluation for Frequency Response and Remote Control
- Task 600: Economic Feasibility Evaluation
- Task 700: Summary Report

The Task 200 memorandum provided an assessment of the condition of each of the hydroelectric facilities based on visual inspections, review of site data and discussions with PREPA personnel. Black & Veatch personnel visited each of the ten sites in February 2021.

The Task 201 memorandum evaluated the existing and potential installed generation capacity and the existing and potential average annual generation. The Task 201 memorandum identified potential opportunities for increased performance and provided various recommendations for modernizing and/or returning the plants to active service, improve civil, mechanical and electrical reliability and electrical safety.

The Task 300 memorandum summarized review of the water availability models for each hydroelectric system.

A Task 400 memorandum which provided recommendations for operating the reservoir systems to maximize yield and hydroelectric generation were completed for each hydroelectric system.

A Task 500 report was completed for evaluating the generation unit frequency response and potential for remote control from the ECC.

The Task 600 economic feasibility evaluation analyzed two portfolios. The first portfolio included rehabilitation of the hydroelectric plants with positive NPV to achieve the maximum NPV for the entire system. The second portfolio included rehabilitation of all projects including projects with a negative NPV. Caonillas 2 was included in both portfolios as it has a negative NPV, however including Caonillas 2 increases the NPV of Caonillas 1 by a greater amount therefore increasing the total NPV. Toro Negro 2 is only included in the Portfolio 2 as it has a negative NPV.

One of the critical limitations on hydropower potential is the availability of water to operate the turbines. While visiting the sites in February 2021 and discussing operations and limitations with PREPA personnel, it was noted on nearly every facility that water availability was a major limitation on their ability to operate the facility at a higher capacity. The existing water availability and generation models developed in 2012 by CSA Architects and Engineers (CSA) and Black & Veatch were used in the net generation calculations to model the existing and potential capacity and energy generation for each facility as part of Task 201 and for review of the reservoir operation curves as part of Task 400. These water availability models confirmed PREPA personnel's statement that the available water was a limitation for almost all the hydropower plants.

2.2 OVERVIEW OF THE EVALUATED HYDROELECTRIC SYSTEMS

The ten hydroelectric facilities evaluated are part of the following five hydroelectrical systems:

1) Dos Bocas-Caonillas (Dos Bocas, Caonillas 1 & Caonillas 2)
2) Toro Negro (Toro Negro 1 & Toro Negro 2)
3) Garzas (Garzas 1 & Garzas 2)
4) Yauco (Yauco 1 & Yauco 2)
5) Río Blanco

See Figure 2-1 for the location of the plants in each of the five hydroelectric systems.

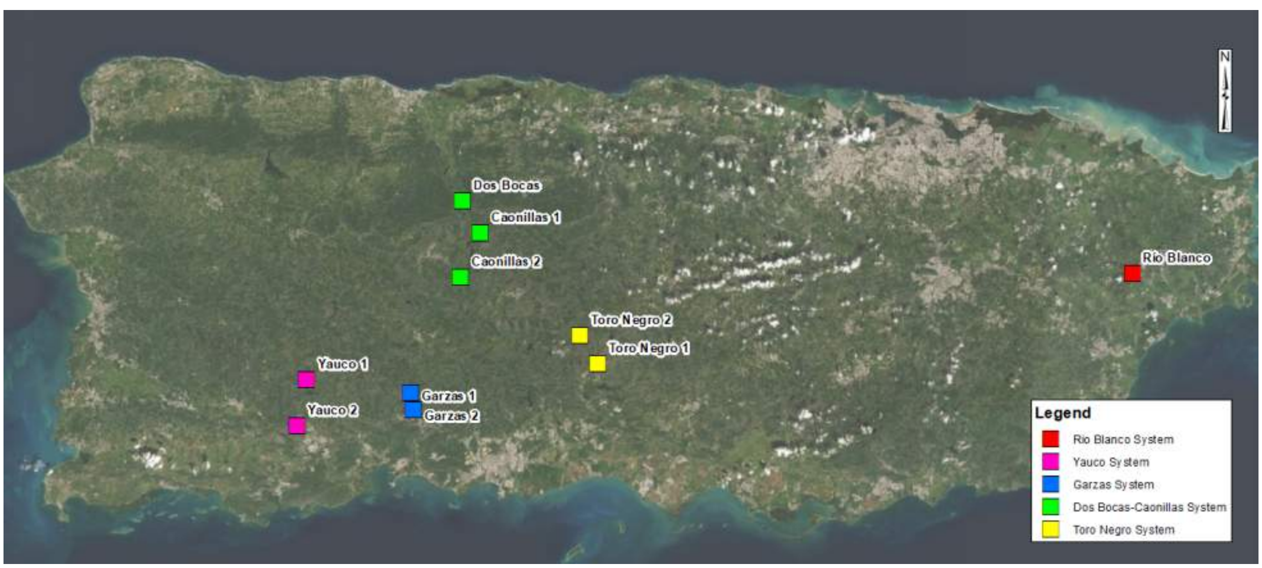


Figure 2-1 Overview Map of the Hydroelectric Facilities Investigated for this Study

The capacity for the ten facilities evaluated is approximately 94.3 MW. However, as shown in Table 2-1, only four of the ten hydropower plants are currently active and the total capacity from these facilities is approximately 38.8 MW. The remaining systems are currently inactive. The Toro Negro 2 plant is currently offline awaiting testing to be returned to service as the penstock has been repaired and is expected to return to service in the near future. Río Blanco is currently offline awaiting replacement of the penstock and work at the diversions as part of the FEMA work before it is returned to service. The Garzas 2 plant is currently offline because the transmission line (No. 1100) connecting it to the grid is out of service. The Garzas 2 plant cannot be returned to service until the transmission line is repaired and it should be a high priority to repair this transmission line as it is directly causing lost generation at the Garzas 2 plant. Caonillas 1 plant is currently offline due to damage from flooding during Hurricane Maria. Yauco 1 plant has been out of service for a significant period of time due to high turbine vibration issues. Caonillas 2 plant was flooded during Hurricane Georges in 1998 and has not been operational since.

Table 2-1 Summary of Existing Hydroelectric Capacity

Hydroelectric System	Facility	Existing Capacity (MW)	Status
Yauco	Yauco 1	20.0	Inactive
	Yauco 2	8.0	Active
Toro Negro	Toro Negro 1	8.6	Active
	Toro Negro 2	1.9	Inactive
Garzas	Garzas 1	7.2	Active
	Garzas 2	5.0	Inactive
Río Blanco	Río Blanco	5.0	Inactive
Dos Bocas-Caonillas	Dos Bocas	15.0	Active
	Caonillas 1	20.0	Inactive
	Caonillas 2	3.6	Inactive
Total		**94.3 (38.8 MW active)**	

2.2.1 Dos Bocas-Caonillas Hydroelectric System

The Dos Bocas-Caonillas Hydroelectric System consists of two major reservoirs (Dos Bocas and Caonillas), four small diversions, diversion tunnels and three plant developments (Dos Bocas, Caonillas 1 and Caonillas 2) that are in cascading order with Caonillas 2 being the upstream development. All flow for Caonillas 2 is diverted from the three diversion dams (Adjuntas, Pellejas, and Vivi), whose reservoirs are largely filled with sediment. See Figure 2-2 for a plan view of the system, including the system watersheds. Dos Bocas and Caonillas 1 are operational but the reservoirs are filling with sediment. The diversion system for Caonillas 2 is not operational.

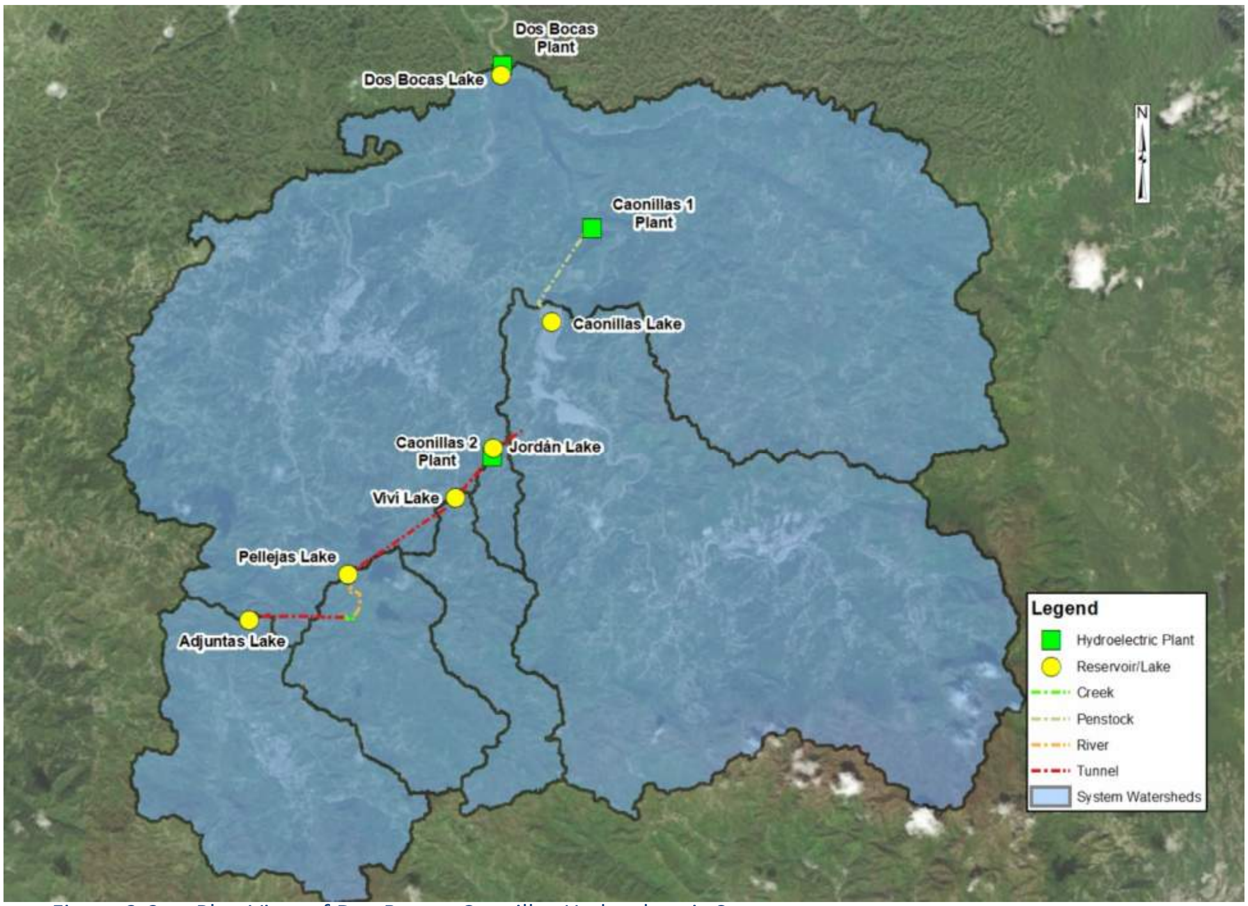


Figure 2-2 Plan View of Dos Bocas- Caonillas Hydroelectric System

2.2.2 Toro Negro Hydroelectric System

The Toro Negro Hydroelectric System consists of two plant developments (Toro Negro 1 and Toro Negro 2), two major reservoirs (El Guineo and Matrullas), ten diversion structures, a splitter box and a series of tunnels, penstocks and canals. Toro Negro 2 receives its flow from El Guineo via a penstock that varies from 24 to 36-inches in diameter. Flow from Toro Negro 2 and from the diversion structures is routed to a common splitter box via a series of canals, tunnels and pipelines. From the splitter box, the flow is routed through a tunnel crossing Puerto Rico's central divide to the Aceitunas forebay which then routes the flow to Toro Negro 1 via twin 30-inch diameter penstocks. See Figure 2-3 for plan view of the system, including the system watersheds.

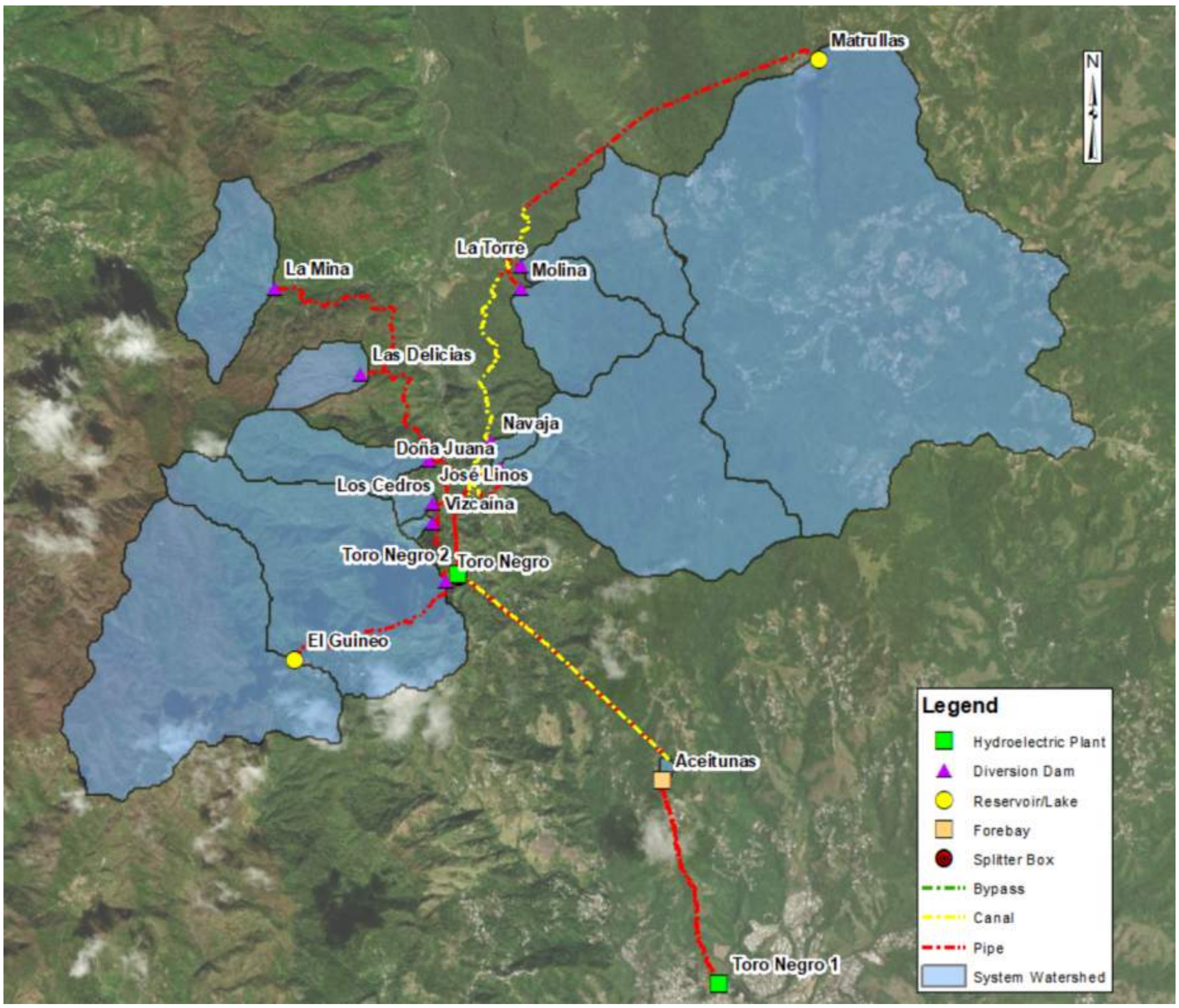


Figure 2-3 Toro Negro Hydroelectric System

2.2.3 Garzas Hydroelectric System

The Garzas Hydroelectric System consists of two plant developments (Garzas 1 and Garzas 2) one major reservoir (Garzas), and six diversion structures. Garzas 1 receives its flow from Garzas Reservoir and three diversion structures via a penstock that varies from 34 to 46 inches in diameter. Flow from Garzas 1 and from two diversion structures are routed to the Garza 2 forebay located next to Garzas 1. Flow from the forebay is routed to Garzas 2 via a 40 inch diameter penstock. See Figure 2-4 for plan view of the system, including the system watersheds.

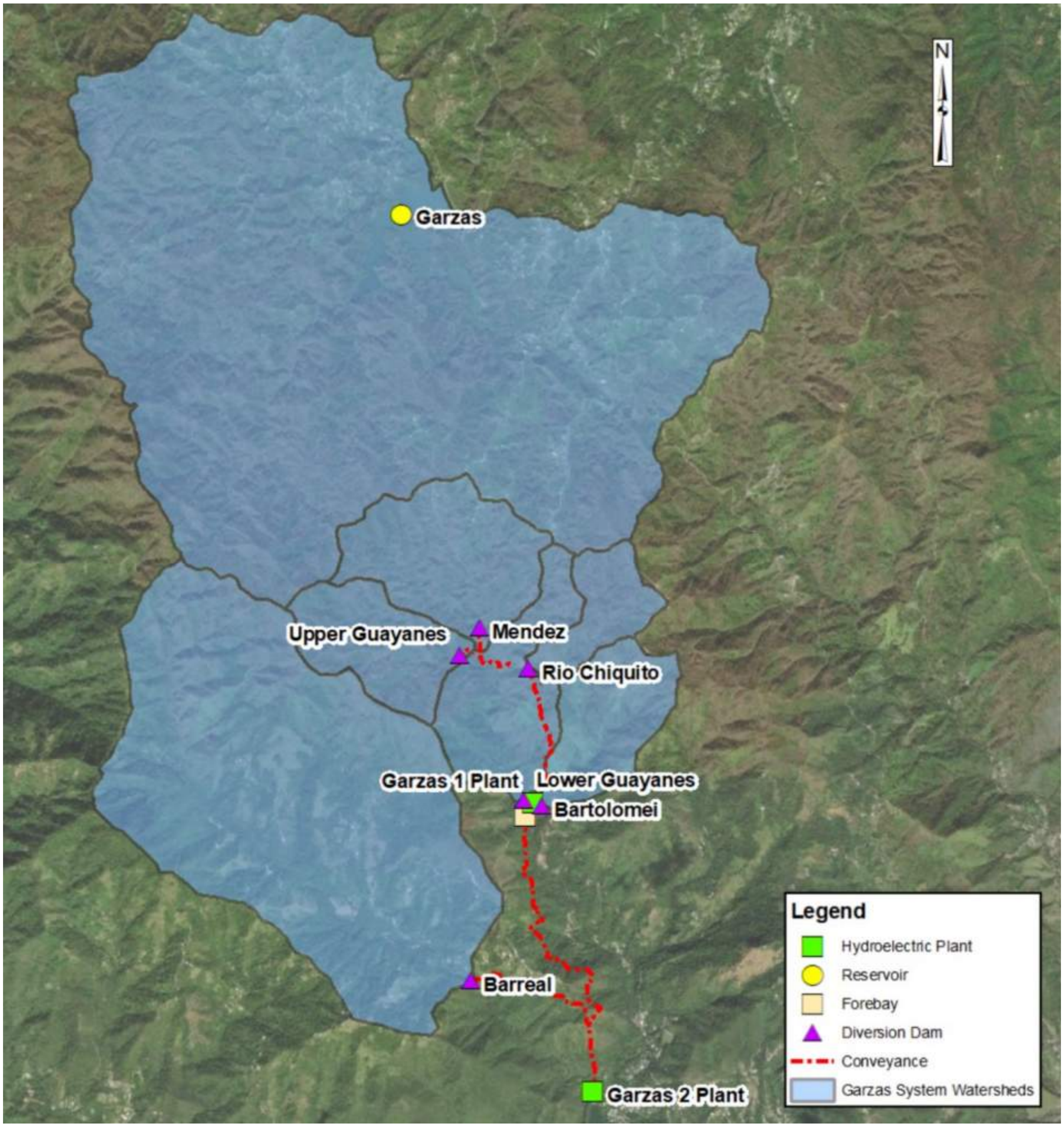


Figure 2-4 Garzas Hydroelectric System

2.2.4 Yauco Hydroelectric System

The Yauco Hydroelectric System consists of five reservoirs, diversion tunnels and two plant developments (Yauco 1 and Yauco 2) that are in cascading order with Yauco 1 being the upstream development. See Figure 2-5 for plan view of the system, including the system watersheds.

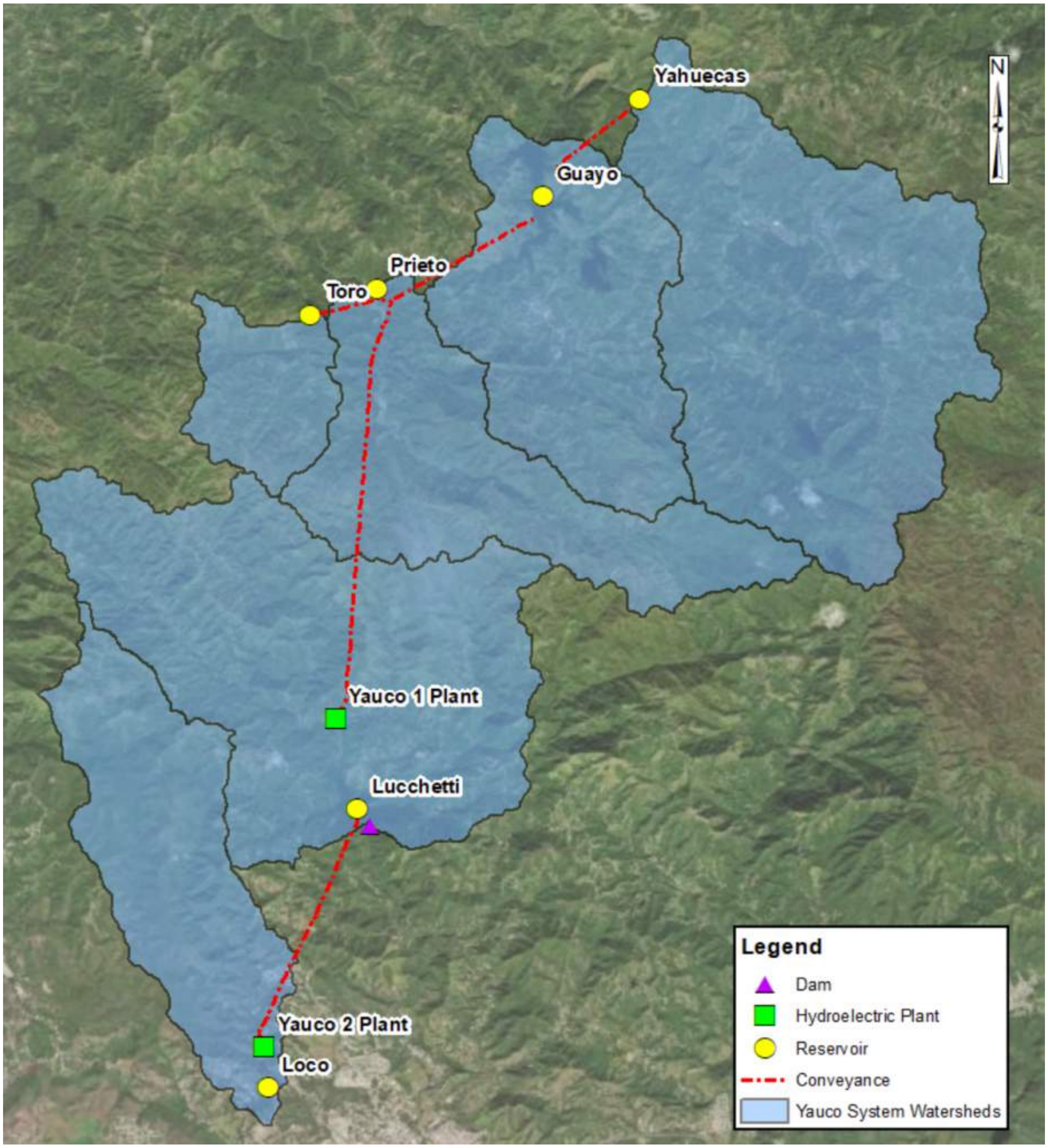


Figure 2-5 Yauco Hydroelectric System

2.2.5 Río Blanco Hydroelectric System

The Río Blanco Hydroelectric System consists of a series of diversion dams, flow conveyance, penstock and the powerhouse. The Cubuy dam diverts water from the Cubuy River into the flow conveyance system. The Sabana dam diverts water from the Sabana River into the flow conveyance system. The Icacos dam creates a small storage reservoir on the Icacos River and diverts flow into the conveyance system. The Prieto dam diverts water from the Prieto River into the flow conveyance system and to the penstock intake. See Figure 2-6 for plan view of the system, including the system watersheds.

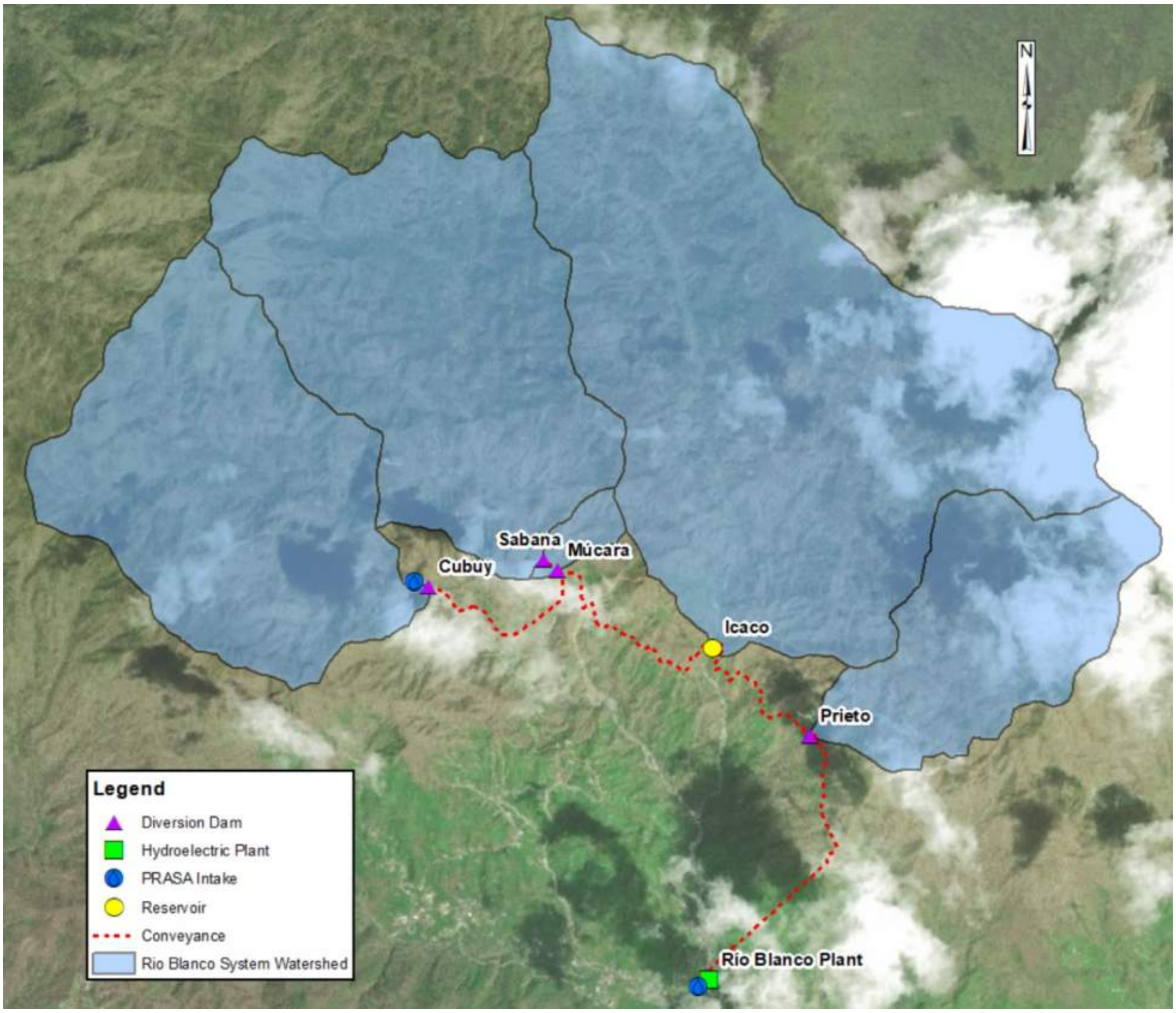


Figure 2-6 Río Blanco Hydroelectric System

2.3 WATER RESOURCES CONSIDERATIONS

Most of Puerto Rico's hydroelectric systems were constructed early in the 20th century and have been pivotal in the economic, cultural and social development in their regions. This is especially true for the Toro Negro, Yauco and Garzas Systems; which bring water from watersheds draining north or west to the much dryer southern region. Although the economic and social benefits of supplying water to municipal and agricultural users were not quantified as part of this study, the adverse impacts of curtailing water supply to those systems, in all likelihood, would be deemed unacceptable from a public policy standpoint by the government of Puerto Rico.

The Toro Negro 1, Toro Negro 2, Yauco 1 and Garzas 1 facilities provide a reliable raw water source for the Puerto Rico Aqueduct and Sewer Authority's (PRASA's) water treatment plants (WTP) by diverting water across the insular divide to the dry side of the island. While no economic benefits accrue to PREPA, continued reliable supply to the citizens of Puerto Rico which receive water from these projects is important, and maintaining an adequate minimum safe yield is a limitation on adjustments to the reservoir operating rule curves for these projects.

In the case of Toro Negro System, the effluent from Toro Negro 1 flows into the Guayabal Reservoir, which is the main source of water for the Juana Díaz Irrigation Canal. This canal was built as part of the Costa Sur Irrigation District and since the 1930s has been providing water to approximately 14,000 acres of agricultural land including the Santa Isabel Region; which is the Island's most productive agricultural land. The Toro Negro 1 penstocks will need to be replaced in order to continue supplying the required water to the canal. Rehabilitating the Toro Negro 1 water collection and conveyance system (small diversions) will also result in a more reliable raw water supply for the Aceitunas WTP. This WTP has a treatment capacity of 2.5 million gallons per day (MGD). This facility was constructed to alleviate the water deficit in the area and supplies potable water to approximately 18,000 inhabitants.

Water from the Garzas Reservoir in Lares is transferred via a tunnel to the Guayanés watershed in Peñuelas. Currently, two WTPs (Peñuelas Urbana and Guayanés) depend on this transfer for maintaining a reliable potable water supply. Overflows from Garzas 2 forebay (outflow from Garzas 1 Plant) spill into Río Guayanés which has two diversion dams. Likewise, outflows from Garzas 2 feed the Peñuelas Regulating Reservoir; which supplies raw water to the Peñuelas Urbana WTP. This WTP has treatment capacity of 1.0 MGD, but it is currently producing close to 1.3 MGD. This facility currently supplies potable water to approximately 12,000 inhabitants located along several wards in Peñuelas, including the Peñuelas Pueblo area. The Guayanés WTP has a design capacity of 1.2 MGD and supplies around 14,000 inhabitants.

Yauco System has both agricultural deliveries and PRASA's water supply deliveries. Water from Yahuecas, Guayo and Prieto reservoirs along with the Toro diversion, is diverted from the north side of the island through a series of tunnels. Yahuecas discharges into Guayo by means of an uncontrolled tunnel. Consequently, Guayo discharges into Luchetti through a second tunnel. The tunnel withdrawing water from Prieto Reservoir (and the Toro diversion which discharges into the Prieto Reservoir) connects to the tunnel between Guayo and Yauco 1. Water transfer to Luchetti is controlled by the operation of the Yauco 1 hydropower generation plant. Water from Luchetti is eventually transferred to Loco through another tunnel towards Loco when the Yauco 2 hydropower generation plant is operated. At Loco Dam, a sluice gate diverts water towards the Lajas Valley

Irrigation District, which delivers water to all its users. Water transfer from the major reservoirs (Guayo and Luchetti) (Black and Veatch, 2012). For the period of record, the average daily flow for agricultural deliveries with optimized operations was 42.3 acre-feet or 13.8 MGD. Currently PRASA's average withdraw from Luchetti is 4 MGD.Water released at Dos Bocas dam though the hydropower turbines is captured downstream by PRASA at the Superaqueduct intake and regulating reservoir. It delivers over 100 MGD, supplying water to approximately 1 million people. It is the largest source of municipal water supply in Puerto Rico.

Currently PRASA is withdrawing 2 MGD from the Vivi reservoir. Historically, PRASA was taking 2 MGD from the penstock just upstream from the Caonillas 2 hydroelectric power plant. PREPA is currently negotiating the water contract and the goal is to relocate the PRASA water supply to the tailwater of the Caonillas 2 hydroelectric power plant. This relocation will allow the hydroelectric plant to fully utilize the available water and will also eliminate a pressure connection to the penstock, which may pose a risk to uncontrolled release of water from the penstock if it fails.

Water withdrawals for municipal water supplies by PRASA were accounted for in modeling the available water for the hydropower plants. Several withdrawals from the water system were identified and used in the generation estimates by subtracting out the design withdrawal flows from the reservoirs or penstocks. The following table is a list of the withdrawals utilized in the generation models.

Table 2-2 Summary of Withdrawals from Modeled Flows for Water Availability

FACILITY	PRASA WITH-DRAWL (MGD)	PUBLIC IRRIGATION WATER (MGD)	SEEPAGE FROM RESERVOIR (AC-FT/DAY)	MINIMUM STREAMFLOW RELEASES (Q99) (AC-FT/DAY)	NOTES
Dos Bocas	0	0	0	0	PRASA takes water downstream of Dos Bocas
Caonillas 1	4	0	0	0	From Caonillas Reservoir (PREPA sent information that this may only be 3 MGD currently)
Caonillas 2	2	0	0	0	From the penstock
Garzas 1	0	0	0	0	No extractions Upstream of Hydroelectric Station
Garzas 2	0	0	0	0	No extractions Upstream of Hydroelectric Station
Toro Negro 1	2	0	0	0	From Aceitunas Forebay
Toro Negro 2	0	0	0	0	No extractions Upstream of Hydroelectric Station

FACILITY	PRASA WITH-DRAWL (MGD)	PUBLIC IRRIGATION WATER (MGD)	SEEPAGE FROM RESERVOIR (AC-FT/DAY)	MINIMUM STREAMFLOW RELEASES (Q99) (AC-FT/DAY)	NOTES
Río Blanco	0	0	0	0	No extractions Upstream of Hydroelectric Station
Yauco 1		0	4.4	9.3	From Guayo Reservoir
Yauco 2	8	0	0	16.8	From Luchetti Reservoir, PREPA has provided information that it may only be 4 MGD currently for PRASA withdrawal

Water firm yield was calculated for the proposed scenarios as shown on Table 2-3 to corroborate it will not significantly affect water supply described above.

Table 2-3 Summary of System Firm Yield

SYSTEM	SYSTEM FIRM YIELD (PREVIOUS STUDIES)	NEW SYSTEM FIRM YIELD
Dos Bocas	82.2 MGD (CSA, 2012)	81.6 MGD (No change in proposed Curve)
Garzas	7.1 MGD (B&V, 2012)	6.2 MGD (No change in proposed Curve)
Yauco	52 MGD (Scenario 2, B&V, 2012)	49.3 MGD (B&V Curve 1)

Reduction in firm yield are mostly related to sedimentation of the reservoirs decreasing active storage volumes.

2.4 POTENTIAL FOR AUTOMATED FREQUENCY RESPONSE SUMMARY

The governor controls the speed and power output of the turbine. In the event of a frequency deviation on the transmission line (system frequency), the governor can be configured to automatically respond in a direction to help restore the frequency. Most of the hydroelectrical facilities in this study have existing mechanical governors. Although this design is outdated, that alone does not justify the need for an upgrade. Over time, the governor may experience a change in responsiveness and frequency control stability due to wear in mechanical components. With proper maintenance and periodic tuning, mechanical governors can provide reliable operation and frequency response. Refer to Sections 4 through 13 for a summary of the automated frequency response evaluation at each facility.

2.5 POTENTIAL FOR REMOTE CONTROL SUMMARY

Remote control of the generating units from the ECC requires the following three major components:

- Reliable Communication Infrastructure between facilities.
- Supervisory Control and Data Acquisition (SCADA) system in the ECC and the facilities.
- Unit Control interface.

PREPA has a communication infrastructure around the island utilizing microwave radio with line-of-sight antennas and fiber optic cables run with the transmission lines. For hydro facilities with a working ECC to plant communication network, a Remote Terminal Unit (RTU) in the powerhouse provides the interface between the ECC and the local facility equipment. The RTU conveys the remote commands to the unit control system and monitors electrical generation and other facility data.

Remote hydro operation design is limited to ECC control of the voltage and power for Yauco 1 and 2 after they are locally started and put online manually. This level of semi-automation only requires an interface between the SCADA system and the governor and voltage regulator. If ECC needs to load the unit or adjust vars, it must first be put online (generator connected to the grid) by a local operator. Currently, Yauco 2 is the only facility in this study with the functioning ability for remote voltage and power control from the ECC.

For full automation, the control system should implement a remote start command and automatically step-through the startup sequence, synchronize the generator to the grid, and ramp up to a setpoint without additional operator action - all of the devices in the startup sequence will need the ability to be automatically controlled. Out of the ten facilities evaluated, only the Caonillas 1 plant is fully automated with the ability for remote start and load control from Dos Bocas, not the ECC.

Refer to Sections 4 through 13 for a summary of the communication and SCADA system condition and remote control potential evaluation at each facility.

3 Economic Feasibility Analysis Overview

The Task 600 economic feasibility analysis performed for each project rehabilitation and upgrade option considered the historical operating and financial performance of the hydroelectric facilities. Black & Veatch utilized the historical financial information to understand the current cost to operate these facilities and incorporated the costs and adjustments as a result of implementing specific hydro facility improvements. A 30 year cash flow analysis was developed to demonstrate each hydro facility's cost responsibility before and after the implementation of specific improvements.

The NPV was utilized as the preferred method for evaluating the proposed improvements. Annual cash flows are discounted at a selected discount rate, (Black & Veatch has utilized 6.15 percent to reflect PREPA's approximate cost of debt), to determine the value of the future cash flows over the 30 year forecast period.

In conducting our analyses and in forming an opinion related to the economic feasibility of the proposed hydro facility improvements, Black & Veatch has made certain assumptions with respect to conditions, events, and circumstances that may occur in the future. The methodology utilized by Black & Veatch in performing the aforementioned analyses follows generally accepted practices for such projections. Such assumptions and methodologies are summarized in this report and are believed to be appropriate for the purpose for which they are used.

Below is a summary of assumptions that apply to all facilities.

General Assumptions:

- Forecast Period – 30 Years (FY 2021 – FY 2050)
- Annual Hydroelectric System Generation Growth – 0%
- General Inflation – 2%
- Renewal and Replacement Rate – 1.33%
- Unit Revenue of Electricity Produced (unit rate, $/MWh) - $226.11
- Cost of PREPA's Aggregate Generation (All Resources) (unit rate, $/MWh) - $181.27
- Current Cost of Hydroelectric Generation (unit rate, $/MWh) – $67.26
- Net Present Value (NPV) Discount Rate – 6.15%

Financing Assumptions:

- Interest on long-term debt – 6.15%
- Term on long-term debt – 30 years
- Capital for improvements funded by debt – 100%
- Existing Maintenance Expenses
    - One Crew will be assigned to roam among the facilities or each of the five hydroelectric systems
    - Crew size will depend on the complexity of each operation
    - Maintenance crew hourly cost rate: $30.00

- Facility Operator Hourly Cost Rate: $50.00
    - Number of Operators depending on each facility and level of automation. An operator remains at the assigned facility for the duration of the shift.
- Roaming Facility Operator (Ranger) Hourly Cost Rate: $30.00
    - One Ranger assigned to each of the five hydroelectric systems. A ranger may visit multiple facilities during a shift and can operate the units.
- Security Guards Hourly Cost Rate: $25.00
    - One guard assigned to each hydroelectric facility (10 total), 8 hours per day, 260 workdays per year

Two portfolios were analyzed to determine which projects would be recommended. Table 3-1 shows the comparison of key parameters between the two portfolios.

Table 3-1 Comparison of Key Parameters

PORTFOLIO DESCRIPTION	CAPITAL COST	NPV	CAPACITY (MW)	GENERATION (MWH)
Portfolio 1: Highest NPV projects for each hydroelectric system	$163,300,000	$695,800,000	91.7	250,000
Portfolio 2: Best Implementable projects foreach hydroelectric plant	$166,700,000	$687,500,000	91.7	250,000

Since Portfolio 2 has an NPV that is relatively close to the highest NPV (Portfolio 1) and offers additional capacity, generation and water resources benefits, it is the recommended portfolio to implement. The projects included in this portfolio are:

- Toro Negro 1 – with new penstocks, small diversions rehabilitation, automation and reservoir optimization
- Toro Negro 2 – with new penstock, automation and reservoir optimization
- Garzas 1 - with new penstock, small diversions rehabilitation and Tyrolean weirs, automation and reservoir optimization
- Garzas 2 - with new penstock, small diversions rehabilitation and Tyrolean weirs, automation and reservoir optimization
- Caonillas 1 – with reliability improvements and reservoir optimization
- Caonillas 2 – with rehabilitation of the diversions and tunnels, and new electrical and mechanical equipment in the plant at 1 MW capacity, with a bypass
- Dos Bocas – with reliability improvements and reservoir optimization
- Yauco 1 – with reliability improvements and reservoir optimization
- Yauco 2 – with reliability improvements and reservoir optimization

- Río Blanco – with new penstock, conveyance system repairs and automation

This portfolio mainly aims at investing first in those hydroelectric facilities with short construction schedules, most of which produce a positive NPV. The Task 600 analysis shows that the Toro Negro 2 and Caonillas 2 facilities have a negative NPV but do increase generation in the downstream hydroelectric facilities.

The estimated engineering time and construction time used to establish the schedule from concept to startup of the recommended improvements for Portfolio 2 is shown below in Table 3-2.

Table 3-2 Portfolio 2 Engineering and Construction Schedule

SCHEDULE			
YEAR	**ENGINEERING (cost in $1,000)**	**CONSTRUCTION/ REFURBISH (cost in $1,000)**	**PENSTOCK REPLACEMENT (cost in $1,000)**
1	Dos Bocas ($425) Caonillas 1 ($195) Caonillas 2 ($1,420) Toro Negro 1 ($635) Toro Negro 2 ($120) Garzas 1 ($330) Garzas 2 ($220) Yauco 1 ($1,750) Yauco 2 ($320) Río Blanco ($120)	Dos Bocas ($5,630) Caonillas 1 ($2,600) Caonillas 2 ($10,875) Toro Negro 1 ($5,715) Toro Negro 2 ($1,080) Garzas 1 ($2,970) Garzas 2 ($1,980) Yauco 1 ($7,000) Yauco 2 ($2,856) Río Blanco ($1,080)	
2		Caonillas 2 ($8,000) Yauco 1 ($8,750)	
5	Toro Negro 1 ($1,650)		Toro Negro 1 ($14,920)
10	Toro Negro 1 ($1,900)		Toro Negro 1 ($17,300)
11	Garzas 1 ($2,300)		Garzas 1 ($20,750)
15	Toro Negro 2 ($2,100)		Toro Negro 2 ($18,775)
20	Garzas 2 ($2,300)		Garzas 2 ($20,745)

As penstock replacements do not increase energy production or capacity, their replacement is scheduled for the latest date estimated for their continued use. Actual date may vary from this estimated replacement date. Maximizing the life of these penstocks is recommended to delay their replacement as long as practical since the NPV for these projects is greatly reduced when the penstocks require replacement.

4 Dos Bocas

The Dos Bocas hydroelectric system consists of two major reservoirs (Dos Bocas and Caonillas), four small diversions, diversion tunnels and three plant developments (Dos Bocas, Caonillas 1 and Caonillas 2) that are in cascading order with Caonillas 2 being the most upstream development. All flow for Caonillas 2 is diverted from the three diversion dams (Adjuntas, Pellejas, and Vivi) whose reservoirs are largely filled with sediment. See Figure 2-2 for plan view of the system, including the system watersheds.

Dos Bocas was constructed in 1942 and contains three 5 MW vertical Francis turbine generating units. The powerhouse structure is in good condition with all the mechanical and electrical equipment functioning, but the reservoir is filling with sediment and the intake is beginning to draw sediment into the penstocks.

Figure 4-1 Dos Bocas Hydroelectric Plant Photo

4.1 EXISTING AND POTENTIAL INSTALLED CAPACITY

The existing capacity and potential installed nameplate capacity for the Dos Bocas system is 18 MW. Analysis of the generation indicate that the system is effectively limited to 5 MW per unit or 15 MW total as the maximum head is not sufficient to generate the nameplate rating of 6 MW. Therefore, the capacity is presented as the 5 MW which reflects the hydraulic limits for the units. It was determined from the models that water availability limits the potential capacity to no greater than what is currently installed.

4.2 EXISTING AND POTENTIAL AVERAGE ANNUAL GENERATION

The historic generation is compared to the modeled generation for the existing conditions (no small diversions in operation). Additional cases were analyzed including restoring the small diversions to service with various sized Caonillas 2 units. See Table 4-1 below for a summary of cases and annual average generation and capacity factors. Historical generation is based on output from 2016 through 2020.

Average annual generation was calculated using the existing capacities of the Dos Bocas plant and the following considerations in the model:

- Available flow into the Dos Bocas reservoir. Outflows are based on supplying a minimum of 125 MGD to the Rio Grande de Arecibo when the reservoir is at normal operating levels, and max flows for 24 hours per day when the reservoir is at high levels.
- Gross head based on reservoir operating levels. Net head based on gross head minus calculated headloss.
- Turbine efficiency of 90% is based on generic turbine efficiency curves for runners of the same time period.
- Turbines were modeled as operating from 50% power up to 100% rated power to maximize energy production.
- Estimated generator efficiency of 96% and estimated step up transformer efficiency of 98%.
- Estimated energy used at the station is 250 kWh per day and is subtracted from the generation to obtain net generation.

The calculated average annual net generation for Dos Bocas is 30,700 MWh. This generation is not evenly distributed throughout the year but has a noticeable increase in energy generation in the hurricane season from August through November.

Table 4-1 Dos Bocas Existing and Potential Average Annual Generation

	HISTORICAL	EXISTING, NO SMALL DIVERSIONS	RESTORED SMALL DIVERSIONS 3.6 MW CAONILLAS 2	RESTORED SMALL DIVERSIONS 1 MW CAONILLAS 2	RESTORED SMALL DIVERSIONS 1 MW CAONILLAS 2 WITH BYPASS	RESTORED SMALL DIVERSIONS 2 MW CAONILLAS 2	RESTORED SMALL DIVERSIONS 2 MW CAONILLAS 2 WITH BYPASS	SMALL DIV 1 MW CAONILLAS 2 WITH BYPASS – RULE CURVE 1	SMALL DIV 1 MW CAONILLAS 2 WITH BYPASS – RULE CURVE 2
Avg Annual MWh	28,838	30,700	30,000	30,650	30,650	30,500	30,500	29,500	29,500
Capacity Factor	0.18	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19

4.3 VARIATION OF HEAD AND FLOW CONDITIONS AT THE SITE

PREPA is required to maintain the head at a relatively constant level within a 4 foot operating band between elevation 288 and 292 based on an agreement between PREPA, PRASA and the Department of Transportation. PREPA's reservoir operating rule curve is to maintain the reservoir at elevation 288 whenever possible. The tailwater ranges from 145 feet to153 feet. This gives a head range from 135 feet to 147 feet of gross head.

The flow varies from a low of 193 cfs (125 MGD) minimum daily average to a maximum of 1,650 cfs when all three units are operating at full gate (maximum discharge varies with reservoir and tailwater levels).

4.4 RELIABILITY AND SUFFICIENCY OF AVAILABLE PROJECT DATA

The USGS performed a sedimentation study in 2009 which was used to update the stage storage curve based on the estimated long term rate of sedimentation. A previous study conducted by CSA provided water availability estimates (from a USGS Gage and ratios of the drainage basin areas) for the inflows to each of the six reservoirs (4 diversions plus Dos Bocas and Caonillas). The flow data covered the years 1995 through 2012 for a total of 17 years. This is a sufficient length of time to get an estimate of annual average net generation.

4.5 POTENTIAL OPPORTUNITIES FOR INCREASED PERFORMANCE

The biggest opportunity for improving performance at Dos Bocas is to increase the storage in the system. There are several methods of increasing the storage. The first is to raise the dam, which will not be evaluated as this reservoir has numerous structures built around the lake and flooding of property would eliminate the ability to permit a dam raise. The second is to dredge the reservoir which will restore some of the lost storage. There currently is a planned dredging operation for the Dos Bocas reservoir. The third is to divert water to the Caonillas 1 reservoir (Lago Caonillas) as this reservoir has a large storage volume available and could be used to fluctuate over a larger range with the increased inflow and peak inflows to the Dos Bocas reservoir. A fourth way to increase storage is to modify the reservoir operating rule curve. While this does not increase the total volume of reservoir storage, it does increase the active storage which is what is used for power generation. The original equipment design allowed for a much larger drawdown of the Dos Bocas reservoir which has recently been restricted by agreements with the Puerto Rico Department of Transportation to facilitate boat access to restaurants.

In addition to the improved storage, improving mechanical and civil reliability of the Dos Bocas hydropower plant will reduce outage time and ensure that the plant can utilize as much water as possible during wet periods to maximize generation.

4.6 RESERVOIR SEDIMENTATION STUDIES AND STAGE STORAGE CURVES

The most recent USGS sedimentation study for Lago Dos Bocas which we have found is a study from November 2009. This study concludes that the long term capacity loss is 247 ac-ft per year and a storage capacity of 13,570 ac-ft at the time of the study. The estimated remaining useful life (from 2012) was 55 years. Table 4-2 shows the stage storage curve for Dos Bocas Reservoir.

Table 4-2 Dos Bocas Stage Storage Curves

ELEVATION (FT)	DOS BOCAS 2009 STORAGE (AC-FT)	DOS BOCAS EST 2021 STORAGE (AC-FT)
295.0	13,571	10,607
291.7	12,331	9,637
288.5	11,180	8,738
285.2	10,101	7,895
281.9	9,080	7,096
278.6	8,115	6,342
275.3	7,207	5,633
272.0	6,364	4,974
268.8	5,586	4,365

4.7 RESERVOIR OPERATING RULE CURVES

The Dos Bocas reservoir is a large storage reservoir and has an operating rule curve. The following two trial operating rule curves were developed to take advantage of the typical rainfall patterns for Puerto Rico to determine if additional generation could be achieved. Note that for Dos Bocas in particular, it may be very difficult to obtain agreement to change the current operating rule curve as it was set for transportation reasons (min of 288, max of 292) and developed property around Lago Dos Bocas. The first trial rule curve stays within the established maximum and minimum values, while the second trial rule curve has a deeper drawdown.

Stage storage curves are taken from the data provided in the Task 300 Water Availability Model Review technical memorandum.

Table 4-3 below shows the Dos Bocas reservoir operating rule curves used in this study.

Table 4-3 Dos Bocas Reservoir Operating Rule Curves

RULE CURVE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Existing	288	288	288	288	288	288	288	288	288	288	288	288
Rule Curve 1	291	290	289	288	292	292	288	288	288	288	290	292
Rule Curve 2	288	284	280	276	288	288	276	276	276	288	292	292

The historic generation is compared to the modeled generation for the existing conditions (no small diversions in operation). Additional cases were analyzed including restoring the small diversions to service with various sized Caonillas 2 units. The existing and potential generation cases all use the existing rule curve except for the last two; which are based on Rule Curve 1 and 2, respectively.

As shown in the table, there is very little change in the Dos Bocas net generation with a change in operating rule curves. This likely indicates that there is not significant spilling except during large storm events. In the case of large tropical storm events, operating the reservoir at a lower level would be unlikely to stop the reservoir from spilling.

4.8 RECOMMENDATIONS TO IMPROVE CIVIL AND MECHANICAL RELIABILITY

The Dos Bocas reservoir has filled with sediment to the point that sediment is being drawn into the intakes for the turbines. The cooling water system takes water from the penstocks and runs the water through a set of duplex filters to prevent sediment in the water from damaging the mechanical equipment. It was noted by PREPA plant personnel that these filters have issues with clogging, and sometimes a unit needs to be taken off-line because cooling water is not available.

During the site visit, it was noted that Unit 2 was operating with more vibrations than it had in the past, and that there was a noticeable decrease in efficiency. This may be a consequence of premature wear of the runner with excessive sediment being passed through the turbine.

The following recommendations are provided as a means of improving plant reliability:

- Replace the existing water filters with new duplex strainers or automatic backflushing strainers to maintain cooling water flow and prevent the filters from plugging.
- Inspect Unit 2, and repair damage to the runner with weld overlays or epoxy as determined by the inspection.
- To modernize the facility, the mechanical governors can be converted to digital governors with electronic controllers and touchscreen graphic operator interface terminals (OITs).

4.9 RECOMMENDATIONS TO IMPROVE ELECTRICAL SAFETY AND RELIABILITY

Unit 3 generator has the original winding from 1942 which has exceeded its design life, it is due for a rewind with modern, less flammable and self-extinguishing insulation.

The Unit 1 original rotating exciter condition is being assessed as part of the current rewind project. It is assumed that the generator will be retrofitted with a solid state excitation system similar to Units 2 and 3.

The neutral breaker is an original manually operated breaker that is an obsolete technology and should be replaced due to age. Modern designs would replace the neutral breaker with low or high resistance grounding system to reduce damage to the generator from a line-to-ground fault.

There are exposed generator main bus leads and current transformers (CTs) at the turbine floor level that should be enclosed for personnel safety.

The generator step-up transformers are original equipment, over 70 years old and are at the end of their design life. Transformer oil and other testing will determine the condition, trending multiple tests over time will be useful in projecting useful life and schedule for replacement. Due to the spacing of the transformers, recommend upgrading to new transformers with less flammable fluid which will reduce the chance of catastrophic failure of multiple transformers.

The station service switchgear is 70 years old, is at the end of its useful life and not likely to operate as designed. This presents a hazard to personnel and equipment if the breaker will not open and may result in an arc-flash event. Recommend replacing the station service switchgear.

The control room is equipped with outdated electromechanical protective relays and solid-state frequency relays. The electromechanical relays are old and are at the end of their useful life. While single function electromechanical relays can be replaced individually, modern multifunction digital relays are available which do not drift and do not have to be tested as often and can be store historical data providing information to technicians in the event of a trip fault. To modernize the facility and reduce calibration time, recommend replacing the single function electromechanical protection relays with multi-function digital relays.

The existing manual control scheme using control switches and auxiliary relays is adequate for local, attended operation. To modernize the facility, an automated control system with graphic displays on an operator workstation can be provided for the Dos Bocas units, similar to the Caonillas 1 remote monitoring and control system. Modern control, digital protection and metering systems could replace the main control panel and benchboard devices.

4.10 RECOMMENDATIONS TO IMPROVE PLANT COMMUNICATIONS SYSTEM

The system to remotely operate the Caonillas 1 plant has been adversely impacted by unreliable communications using the microwave system. This should be upgraded to ensure reliable operations, particularly if the small diversions are placed back in service. Additionally, monitoring of the small diversion flows or automation of Caonillas 2 should be added so that Caonillas 1inflow can be monitored and balance the reservoir storage between Caonillas and Dos Bocas.

4.11 POTENTIAL FOR AUTOMATED FREQUENCY RESPONSE

The existing governors are original Woodward mechanical-hydraulic types. The governors were noted as having a good/fast response time and the units can be used for frequency control. To modernize the facility, the mechanical governors can be converted to digital as recommended above.

4.12 POTENTIAL FOR REMOTE CONTROL

There is a functional fiber optic network to the plant and functioning SCADA system allowing remote monitoring at the ECC. The ECC does not have any remote control of the generating units at Dos Bocas. The units are manually put online and controlled locally. In order to provide ECC remote startup, shutdown control of the units, the manual sequences including synchronization would need to be automated. Automating the speed matching would provide the required interface for remote load control. A SCADA interface to the modern excitation systems that have monitoring and control from the control room operator workstation can be added to provide remote voltage control. The SCADA system would need to be modified to add remote operation functionality

4.13 ECONOMIC ANALYSIS

Dos Bocas is currently an active hydroelectric facility. The improvements completed at this facility will directly impact the improvements made at Caonillas 2. The selection of improvements is directly linked with the Caonillas 2 selected improvements. The improvements recommended include implementing a bypass and replacing generators for smaller units; that will be more efficient given the existing water flow constraints. Line 4 of Table 4-4, Reliability Improvements, and 1 MW Caonillas 2 Plant with Bypass, provides an improvement that will produce an NPV of about $95.3 million over a 30 year forecast period. The NPV of improvements is impacted by the capacity factor improvements provided at Caonillas 2. The capital-related cost is about $5.9 million, and the adjusted payback period is about 1.3 years. Based on the daily model for the storage reservoir in the Dos Bocas-Caonillas hydroelectric system, the estimated average annual net generation for Dos Bocas is 30,650 MWh with a restored Caonillas 2 system with 1 MW turbine and bypass.

The major work recommended to maintain the reliability of Dos Bocas is to repair deficiencies in the structure, upgrade mechanical balance of plant systems, clean generating equipment and optimize reservoir operations.

Table 4-4 Dos Bocas Economic Feasibility Analysis Results

LINE	DOS BOCAS IMPROVEMENT	NET PRESENT VALUE ($)	ANNUAL AVERAGE COST	ADJUSTED PAYBACK PERIOD (YEARS)	TOTAL CAPITAL COST ($)	CAPACITY FACTOR (%)	FACILITY CAPACITY (MW)
1	Refurbished plant	95,479,000	1,567,000	1.3	5,946,000	23.4%	15.00
2	Refurb with 3.6 MW Caonillas 2	92,881,000	1,567,000	1.3	5,946,000	22.8%	15.00
3	Refurb with 1 MW Caonillas 2 no bypass	95,293,000	1,567,000	1.3	5,946,000	23.3%	15.00
4	Refurb with 1 MW Caonillas 2 with bypass	95,293,000	1,567,000	1.3	5,946,000	23.3%	15.00
5	Refurb with 2 MW Caonillas 2 no bypass	94,737,000	1,567,000	1.3	5,946,000	23.2%	15.00
6	Refurb with 2 MW Caonillas 2 with bypass	94,737,000	1,567,000	1.3	5,946,000	23.2%	15.00
7	Refurb with 1 MW Caonillas 2 with bypass with Rule Curve 1	91,025,000	1,567,000	1.3	5,946,000	22.5%	15.00
8	Refurb with 1 MW Caonillas 2 with bypass with Rule Curve 2	91,025,000	1,567,000	1.3	5,946,000	22.5%	15.00

5 Caonillas 1

The Caonillas 1 hydroelectric system consists of one major reservoir (Lago Caonillas), four small diversions, and diversion tunnels. Currently, Caonillas 2 is out of service and all flow that would normally be diverted from the three diversion dams (Adjuntas, Pellejas, and Vivi) whose reservoirs are largely filled with sediment is simply spilled and flows into Lago Dos Bocas. See Figure 2-2 for plan view of the system, including the system watersheds.

Caonillas 1 was constructed in 1948 and contains two 10 MW vertical Francis type generating units. The powerhouse structure is in good condition. Currently, the electrical and mechanical equipment is being refurbished to repair damage from flooding during Hurricane Maria. The reservoir is filling with sediment and the intake is beginning to draw sediment into the tunnel. The tunnel has not been inspected recently and the upstream diversion system which supplies water to the Caonillas reservoir via the Caonillas 2 plant is not functional.

Figure 5-1 Caonillas 1 Hydroelectric Plant Photo

5.1 EXISTING AND POTENTIAL INSTALLED CAPACITY

The existing capacity and potential installed capacity of the Caonillas 1 hydroelectric system is 20 MW. It was determined from the models that water availability limits the potential capacity to no greater than what is currently installed.

5.2 EXISTING AND POTENTIAL AVERAGE ANNUAL GENERATION

The historic generation is compared to the modeled generation for the existing conditions (no small diversions in operation). Additional cases were analyzed including restoring the small diversions to service with various sized Caonillas 2 units. See Table 5-1 below for a summary of cases and annual average generation and capacity factors. Historical generation is based on output from 2016 through 2020.

Average annual generation was calculated using the existing capacities of the Caonillas 1 plant and the following considerations in the model:

- Available flow into the Caonillas reservoir. Outflows are based on 8 hours a day when the reservoir is at normal operating levels, and 24 hours per day when the reservoir is at high levels.
- Small diversion flows were not included as the diversion system is not operable.
- Gross head based on reservoir operating levels. Net head based on gross head minus calculated headloss.
- Turbine efficiency of 90% is based on generic turbine efficiency curves for runners of the same time period.
- Turbines were modeled as operating from 50% power up to 100% rated power to maximize energy production.
- Estimated generator efficiency of 96% and estimated step up transformer efficiency of 98%.
- Estimated energy used at the station is 250 kWh per day and is subtracted from the generation to obtain net generation.

The calculated average annual net generation for Caonillas 1 is 38, 800 MWh. This generation is not evenly distributed throughout the year but has a noticeable increase in energy generation in the hurricane season from August through November.

The potential average annual net generation for Caonillas 1 is estimated using the same basic assumptions listed in for the existing capacity with the following exceptions:

- Return the diversion system to service.

The average annual generation with the improvements and automation is 54,400 MWh.

Based on the condition assessment, the following list summarizes the primary recommendations for upgrading the Caonillas system. These recommendations are used to determine capital costs for evaluating the economic viability or rehabilitating and upgrading the Caonillas 1 project.

Recommendations for Caonillas 1 include:

- Repair deficiencies in the structure
- Dredge the tailrace
- Inspect and upgrade balance of plant electrical systems
- Perform efficiency testing
- Return Caonillas 2 diversions to service

Table 5-1 Caonillas 1 Existing and Potential Average Annual Generation

	HISTORICAL	EXISTING, NO SMALL DIVERSION	RESTORED SMALL DIVERSIONS 3.6 MW CAONILLAS 2	RESTORED SMALL DIVERSIONS 1 MW CAONILLAS 2	RESTORED SMALL DIVERSIONS 1 MW CAONILLAS 2 WITH BYPASS	RESTORED SMALL DIVERSIONS 2 MW CAONILLAS 2	RESTORED SMALL DIVERSIONS 2 MW CAONILLAS 2 WITH BYPASS	RESTORED SMALL DIVERSIONS 1 MW CAONILLAS 2 WITH BYPASS RULE CURVE 1	RESTORED SMALL DIVERSIONS 1 MW CAONILLAS 2 WITH BYPASS RULE CURVE 2
Avg Annual MWh	5,711*	38,800	43,700	50,600	54,400	50,300	54,400	53,900	54,000
Capacity Factor	0.03	0.22	0.25	0.29	0.29	0.29	0.31	0.31	0.31
* The historical generation of Caonillas 1 has been far below historic generation for the years 2016 through 2020 because flooding during Hurricane Maria caused the Caonillas 1 plant to be offline the majority of this time period.									

5.3 VARIATION OF HEAD AND FLOW CONDITIONS AT THE SITE

The head is held relatively constant because the reservoir operating rule curve has a low water level of 788 in August and a high level of 826 in January and February. The tailwater is controlled by a small weir in the tailrace to maintain a minimum tailwater and is between 288 and 290. This gives a head range from 538 feet and 498 feet gross head.

The flow varies from a low of zero cfs minimum daily average to a maximum of 540 cfs when both units are operating at full gate (maximum discharge varies with reservoir and tailwater levels). A water withdrawal from the Caonillas Reservoir by PRASA of up to 4 MGD was accounted for in the water availability (PRASA withdrawal always present at 4 MGD).

5.4 RELIABILITY AND SUFFICIENCY OF AVAILABLE PROJECT DATA

The USGS performed a sedimentation study in 2012 which was used to update the stage storage curve based on the estimated long term rate of sedimentation. A previous study conducted by CSA provided water availability estimates (from a USGS Gage and ratios of the drainage basin areas) for the inflows to each of the six reservoirs (4 diversions plus Dos Bocas and Caonillas). The flow data covered the years 1995 through 2012 for a total of 17 years. This is a sufficient length of time to get an estimate of annual average net generation.

5.5 POTENTIAL OPPORTUNITIES FOR INCREASED PERFORMANCE

The biggest opportunity for improving performance at Caonillas 1 is to increase inflow to the reservoir by restoring the Caonillas 2 plant and diversions to service. A smaller increase in generation could be realized by dredging Lago Caonillas, particularly where sediment has been deposited above elevation 780.00 feet.

In addition to the increased inflow and storage, improving mechanical and civil reliability of the Caonillas 1 hydropower plant will reduce outage time and ensure that the plant can utilize as much water as possible during wet periods to maximize generation.

5.6 RESERVOIR SEDIMENTATION STUDIES AND STAGE STORAGE CURVES

The most recent USGS sedimentation study for Lago Caonillas which we have found is a study from November 2012. This study concludes that the long term capacity loss is 204 ac-ft per year and a storage capacity of 32,000 ac-ft at the time of the study. The estimated remaining useful life (from 2012) was 157 years. Table 5-2 shows the Caonillas Stage Storage Curve.

Table 5-2 Caonillas Stage Storage Curves

ELEVATION (FT)	CAONILLAS 2012 STORAGE (AC-FT)	CAONILLAS EST 2021 STORAGE (AC-FT)
826.0	32,064	30,228
819.4	28,359	26,735
812.9	25,051	23,617
806.3	22,092	20,827
799.7	19,506	18,389
793.2	17,122	16,142
786.6	14,893	14,040
780.0	12,898	12,160
773.5	11,091	10,456

5.7 RESERVOIR OPERATING RULE CURVES

The four small diversions are operated as run of river diversions and do not have specific operating rule curves. The Caonillas reservoir is a large storage reservoir and has an operating rule curve. The following two trial operating rule curves were developed from the typical rainfall patterns for Puerto Rico to determine if additional generation could be achieved. Note that for Caonillas 1, each rule curve utilized the restored small diversions using the 1 MW Caonillas 2 with a bypass.

Stage storage curves are taken from the data provided in the Task 300 Water Availability Model Review technical memorandum.

Table 5-3 below shows the Caonillas reservoir operating rule curves used in this study.

Table 5-3 Caonillas Reservoir Operating Rule Curves

RULE CURVE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
Existing	826.3	826.3	819.9	813.3	808.7	799.3	792.5	788.2	791.3	801.4	816.3	813.5
Rule Curve 1	825	815	800	785	800	815	785	785	785	785	805	825
Rule Curve 2	825	820	815	800	810	815	800	785	785	785	810	825

The historic generation is compared to the modeled generation for the existing conditions (no small diversions in operation). Additional cases were analyzed including restoring the small diversions to service with various sized Caonillas 2 units. The existing and potential generation cases all use the existing rule curve except for the last two; which are based on Rule Curve 1 and 2, respectively. As shown in the table, there is very little change in the Caonillas 1 net generation with a change in operating rule curves. This likely indicates that there is not significant spilling except during large storm events. In the case of large tropical storm events, operating the reservoir at a lower level would be unlikely to stop the reservoir from spilling.

5.8 RECOMMENDATIONS TO IMPROVE CIVIL AND MECHANICAL RELIABILITY

The existing diversions for Caonillas 2 have been filled with sediment, and a significant portion of inflows are no longer available to the Caonillas Plant. The tunnel from the Jordan diversion to Lago Caonillas is approximately 50% filled with sediment.

The governors are scheduled to be replaced as they were damaged during the flooding from Hurricane Maria. The electronic governor control panel with the GE Fanuc VersaMax programmable logic controller (PLC) was flooded and will have to be replaced. The new governor controllers will be configured into the unit control system. This would be a good opportunity to upgrade the unit and plant Atlas-II controllers and operator workstation located in the control area upstairs. Upgrading all of the unit and plant controls at the same time will avoid having to integrate new governors into the existing unit controllers. The new plant control system can include an operator workstation and local touchscreen OITs.

The following recommendations are provided as a means of improving plant reliability:

- Return the Adjuntas, Pellejas, Vivi, and Jordan diversions to service.
- Dredge the four small diversions to clean out the intake and provide a small pool for diverting the flow.
- Clean out and inspect the tunnels for the small diversions, repair any damage to the tunnels.
- Dredge the Caonillas reservoir to restore lost storage volume.
- Modify the drain adjacent to the plant to allow overflow without gratings to prevent future flooding.
- Install replacement sump pumps (project is ongoing) and piping.
- Replace turbine scroll case drain valves.
- Perform upgrades on the ventilation system, it was noted the battery room has issues with high humidity.

5.9 RECOMMENDATIONS TO IMPROVE ELECTRICAL SAFETY AND RELIABILITY

The switchgear breakers should be tested and if required, can be replaced individually while retaining the overall lineup.

There are three (3) single phase 4160 V : 115 KV, 8533 KVA generator step-up transformers that appear to be beyond their design life. Transformer oil and other testing will determine the condition, trending multiple tests over time will be useful in projecting useful life and schedule for replacement. When the transformers are replaced, they will need to be relocated farther away from the powerhouse to meet current standards. In addition, consideration should be made for replacement using a three-phase transformer.

Replace the water-damaged lighting panelboard.

5.10 RECOMMENDATIONS TO IMPROVE PLANT COMMUNICATIONS SYSTEM

The system to remotely operate the Caonillas 1 plant has been adversely impacted by unreliable communications using the microwave system. This should be upgraded to ensure reliable operations, particularly if the small diversions are placed back in service. Additionally, monitoring of the small diversion flows or automation of Caonillas 2 should be added so that Caonillas 1inflow can be monitored and balance the reservoir storage between Caonillas and Dos Bocas.

There is a functioning microwave communication system between the Caonillas 1 plant and the Dos Bocas plant. providing remote monitoring and control from Dos Bocas plant. The Caonillas 1 generating units are remotely monitored and controlled from the Dos Bocas hydroelectric facility.

5.11 POTENTIAL FOR AUTOMATED FREQUENCY RESPONSE

The new controller required to replace the flooded local panel will include an automatic frequency response as part of the governor control package.

5.12 POTENTIAL FOR REMOTE CONTROL

There is a functioning microwave communication to the plant providing remote monitoring and control from Dos Bocas.

The Caonillas 1 plant is fully automated with remote start, stop and load control from the Dos Bocas hydroelectric facility. Because the units are already remotely controlled from Dos Bocas, remote operation could also be extended to the ECC. If the ECC uses the network interface at Dos Bocas to monitor the Caonillas 1 units, this SCADA system could be modified to provide remote ECC control. If there is communication directly between the Caonillas 1 facility and the ECC, the SCADA system at Caonillas 1 could be modified to provide remote ECC control.

5.13 ECONOMIC ANALYSIS

Caonillas 1 is not an active hydroelectric facility. The recommended improvements at this facility will target the reliability and automation of the facility along with the improvements a Caonillas 2 to provide a more reliable source of water as Caonillas 1 receives its water source from Caonillas 2. Line 3 of Table 5-4, Refurbish with 1 MW Caonillas 2 Plant with Bypass, , provides an improvement that will produce an NPV of about $188.2 million. The capital-related cost is $2.8 million. The adjusted payback period calculated for this improvement is about 0.4 years. Based on the daily model for the storage reservoir in the Dos Bocas-Caonillas hydroelectric system, the estimated average annual net generation for Caonillas 1 is 54,400 MWh with a restored Caonillas 2 system with 1 MW turbine and bypass.

The major work recommended to maintain the reliability of Caonillas 1 is to repair deficiencies in the structure, upgrade mechanical balance of plant systems, upgrade electrical balance of plant systems and optimize reservoir operations. The capital costs do not include dredging which is part of a FEMA grant project, nor the ongoing repairs to flooding damage as these funding costs are outside of the project scope, or already approved and being spent.

Table 5-4 Caonillas 1 Economic Feasibility Analysis Results

LINE	CAONILLAS 1 IMPROVEMENT	NET PRESENT VALUE ($)	ANNUAL AVERAGE COST	ADJUSTED PAYBACK PERIOD (YEARS)	TOTAL CAPITAL COST ($)	CAPACITY FACTOR (%)	FACILITY CAPACITY (MW)
1	Refurbished plant	130,297,000	1,192,000	0.4	2,795,000	25.2%	20
2	Refurb with 3.6 MW Caonillas 2	148,486,000	1,192,000	0.4	2,795,000	28.3%	20
3	Refurb with 1 MW Caonillas 2 no bypass	174,099,000	1,192,000	0.3	2,795,000	32.8%	20
4	Refurb with 1 MW Caonillas 2 with bypass	188,204,000	1,192,000	0.3	2,795,000	35.3%	20
5	Refurb with 2 MW Caonillas 2 no bypass	172,985,000	1,192,000	0.3	2,795,000	32.6%	20
6	Refurb with 2 MW Caonillas 2 with bypass	188,204,000	1,192,000	0.3	2,795,000	35.3%	20
7	Refurb with 1 MW Caonillas 2 with bypass with Rule Curve 1	186,348,000	1,192,000	0.3	2,795,000	35.0%	20
8	Refurb with 1 MW Caonillas 2 with bypass with Rule Curve 2	186,719,000	1,192,000	0.3	2,795,000	35.0%	20

6 Caonillas 2

The Caonillas 2 Hydroelectric system consists of three small diversions, diversion tunnels and one hydroelectric plant. All flow for Caonillas 2 is diverted from the three diversion dams (Adjuntas, Pellejas, and Vivi) whose reservoirs are largely filled with sediment. See Figure 2-2 for plan view of the system, including the system watersheds.

Caonillas 2 was constructed in 1950 and contains one 4.0 MW vertical Francis type generating unit. The powerhouse has been inactive since Hurricane Georges damaged equipment in 1998. The powerhouse structure is in good condition with most of the mechanical and electrical equipment in poor condition and in need of replacement, the diversion tunnels and diversion dams are filled with sediment and not operational.

Figure 6-1 Caonillas 2 Hydroelectric Plant Photo

6.1 EXISTING AND POTENTIAL INSTALLED CAPACITY

The existing capacity of the Caonillas 2 hydropower plant is effectively zero MW as the currently installed turbine and generator likely need to be refurbished or replaced to be returned to service. The potential installed capacity of the Caonillas 2 hydropower plant is 3.6 MW assuming the existing runner would be refurbished. It was determined from the models that water availability in run of river operation limits the potential capacity and a decrease in size to either 1 MW or 2 MW may be more appropriate for the Caonillas 2 plant.

6.2 EXISTING AND POTENTIAL AVERAGE ANNUAL GENERATION

The historic generation is compared to the modeled generation for the existing conditions (no small diversions in operation). Additional cases were analyzed including restoring the small diversions to service with various sized Caonillas 2 units. See Table 6-1 below for a summary of cases and annual average generation and capacity factors.

Table 6-1 Caonillas 2 Existing and Potential Average Annual Generation

	HISTORICAL	EXISTING, NO REFURBISHMENT	RESTORED SMALL DIVERSIONS 3.6 MW CAONILLAS 2	RESTORED SMALL DIVERSIONS 1 MW CAONILLAS 2	RESTORED SMALL DIVERSIONS 1 MW CAONILLAS 2 WITH BYPASS	RESTORED SMALL DIVERSIONS 2 MW CAONILLAS 2	RESTORED SMALL DIVERSIONS 2 MW CAONILLAS 2 WITH BYPASS
Avg Annual MWh	0*	0	3,000	5,200	5,200	5,300	5,300
Capacity Factor	0	0.0	0.10	0.59	0.59	0.31	0.31

* The historical generation of Caonillas 2 is zero as the hydropower plant has been shut down since 1998.

6.3 VARIATION OF HEAD AND FLOW CONDITIONS AT THE SITE

The head of the small diversions is nearly constant with headwater at Vivi diversion of 1065 feet of elevation, and tailwater varying between 856 and 857 feet of elevation. The gross head is between 208 and 209 feet.

The flow varies considerably as the small diversions have a combined minimum flow of 5 cfs to a maximum of 700 cfs (pipe conveyance system limitation). The peaks occur during storms and are not used to size the turbine. As shown, there is very little increase in energy generation beyond the 1 MW size as flows large enough to operate the turbine become less common. A water withdrawal from the Caonillas 2 penstock (or Vivi diversion) by PRASA of up to 2 MGD was accounted for in the water availability (PRASA withdrawal always present at 2 MGD).

6.4 RELIABILITY AND SUFFICIENCY OF AVAILABLE PROJECT DATA

The small diversions do not have any storage considered for the Caonillas 2 system; therefore, the current sediment volumes are not critical to the energy generation as long as the system is cleaned out enough to restore full capacity to the intakes and tunnels. A previous study conducted by CSA provided water availability estimates (from a USGS Gage and ratios of the drainage basin areas) for the inflows to each of the six reservoirs (4 diversions plus Dos Bocas and Caonillas). The flow data covered the years 1995 through 2012 for a total of 17 years. This is a sufficient length of time to get an estimate of annual average net generation.

6.5 POTENTIAL OPPORTUNITIES FOR INCREASED PERFORMANCE

The biggest opportunity for improving performance at Caonillas 2 is to refurbish the existing turbine, or install a new turbine, and return the diversions and tunnels to operational condition. The size of the turbine should be matched to the available run of river flows in the combined diversions, and excess flow bypassed through a new fixed-cone (Howell-Bunger) valve to ensure as much flow as practical is diverted into Lago Caonillas (this is where most of the increase in generation occurs).

The return of the diversion system to service will require localized dredging in the area of the intake to the dam. Additionally, a sediment passing gate is recommended to be installed in the existing dam with an invert just below the intake level to allow passage of sediment and maintain an inlet which is not plugged with sediment. Without the addition of the sediment passage gate, the reservoirs would need regular maintenance dredging to prevent the intake from being filled with sediment.

The bypass would be added by cutting a new hole in the concrete of the powerhouse and connecting a pipe to the existing bypass line and extending it outside the powerhouse and installing a fixed-cone valve to dissipate the energy. This bypass allows the maximum amount of water to be diverted into the Caonillas 1 reservoir during high flow events (events which exceed the turbines full gate discharge capacity).

In addition to the returning the diversion system to operation, a complete replacement of the balance of plant mechanical systems and electrical systems is needed to return Caonillas 2 to operation.

6.6 RESERVOIR SEDIMENTATION STUDIES AND STAGE STORAGE CURVES

No sedimentation studies or stage storage rule curves were found for the small diversions for the Caonillas 2 system. Based on the sedimentation study for Dos Bocas, the sediment rate for the small diversions may be approximately 50 ac-ft per year if they were dredged (currently, they are filled with sediment, so the trapping efficiency is very low). This high sedimentation rate would require approximately $750,000 to $1,000,000 per year in average dredging to keep the storage available to operate a large unit. This total operation and maintenance cost would exceed the value of energy generated from the Caonillas 2 turbine, therefore it is recommended to do very limited dredging to open the intakes to the tunnels, and install a sediment passing gate so that future sediment during large storms can be passed downstream and minimize future cleanout to a localized area similar to what PREPA has recently performed at the Vivi diversion dam.

6.7 RESERVOIR OPERATING RULE CURVE

The Three small diversions currently have no method of controlling the water level within the reservoirs. As the proposed future operation is as run of river, no new rule curve is being proposed.

6.8 RECOMMENDATIONS TO IMPROVE CIVIL AND MECHANICAL RELIABILITY

The Caonillas 2 system has not been operated in over 20 years, and there was evidence of flooding and silt deposition in the lower level (turbine level) of the powerhouse. The following work is recommended to return Caonillas 2 to service:

- Dredge the four reservoirs (Adjuntas, Pellejas, Vivi, and Jordan).
- Clean out and inspect the tunnels.
- Clean out the tailrace from Caonillas 2 for better hydraulics. Excavate a channel for the stream past the Caonillas 2 tailrace.
- Install concrete wall to a higher elevation in the turbine level to protect against flooding.
- Replace all balance of plant mechanical systems including HVAC.
- Replace all balance of plant electrical systems and the generator (likely decrease in size to 1 or 2 MW).
- Implement remote control operations through Dos Bocas (or through Caonillas 1 to Dos Bocas).
- Install a fixed cone valve bypass around the turbine to operate in parallel during very high flows, or when turbine is shut down (low flows, or maintenance).
- Inspect penstock and repaint if in serviceable condition or replace if badly corroded.

6.9 RECOMMENDATIONS TO IMPROVE ELECTRICAL SAFETY AND RELIABILITY

The generator is rated 5000 KVA, 4160 V. It is assumed that the generator insulation has degraded over time while sitting idle, recommend rewinding the generator (or replace with a smaller 1 or 2 MW generator).

The three-phase generator step-up transformer is rated 5000/6250 KVA at 38 KV: 4160 V and is original equipment. There is a 38 KV outdoor circuit breaker located next to the step-up transformer. PREPA said to assume the transformer and breaker are not operational and should be replaced. When the transformer is replaced it will need to be relocated farther away from the powerhouse to meet current standards.

The existing switchgear lineup includes the generator and station service breakers, electrical protective relays and control switches. It is assumed that the breakers of this age are mechanical and will not operate having been setting for decades in humid conditions and should be replaced. The switchgear lineup can be replaced with a smaller lineup for breakers, modern control system and protective relay panels.

Modern digital governor controls can be incorporated into the new unit control system. A modern control system can include touchscreen OITs or an operator workstation with graphics for unit and balance-of-plant monitoring and control.

The balance-of-plant electrical equipment needs to be replaced, provide new dry type station service transformer, low voltage panelboard, station battery and battery charger.

6.10 RECOMMENDATIONS TO IMPROVE PLANT COMMUNICATIONS SYSTEM

Currently there is no remote communication operational to this facility. As part of a separate project, remote communication can be restored and the SCADA system upgraded to interface with the new control system.

6.11 POTENTIAL FOR AUTOMATED FREQUENCY RESPONSE

The original mechanical governor should be replaced with a modern digital governor which will include an automatic frequency response.

6.12 POTENTIAL FOR REMOTE CONTROL

There are no operational fiber optic or microwave communication links to this facility. The unit was manually operated using controls on the original switchgear lineup. New automated unit controls, a modern static excitation system and digital governor will provide the required interface for full remote control from the ECC. The SCADA system will need to be updated and communication re-established between the facility and the ECC to support remote control.

6.13 ECONOMIC ANALYSIS

Caonillas 2 is currently an inactive hydroelectric facility. Several improvements have been recommended to restore the facility to operating condition, and they are related to the rehabilitation or replacement of the existing facility turbine. However, the most important impact of restoring this facility is to provide a reliable water source for Caonillas 1 downstream. Line 3 of Table 6-2, New 1 MW Full Auto with Bypass, Sediment Passage Gates, provides an improvement that will produce a negative NPV of about ($9.8) million. This improvement produces a negative NPV, but the improvement aligns with the proposed approach to improve water flow at the Caonillas facility. The capital-related cost to rehabilitate this facility is $20.3 million, and there is no payback period.

Based on the daily model for the storage reservoir and diversions in the Dos Bocas-Caonillas hydroelectric system, the existing Caonillas 2 turbine is over-sized for the stream flow and is most economical when replaced with a smaller turbine. With a smaller 1 MW Francis type generating unit installed in Caonillas 2, the estimated average annual net generation is 5,200 MWh.

The major work recommended for Caonillas 2 is to clean out and repair any damage to the tunnels and replace the existing turbine with a smaller unit, install a bypass around the unit to increase maximum transfer to water to Caonillas 1 reservoir, dredge the area immediately around the intake, and install sediment passing gates to prevent buildup of sediments.

Table 6-2 Caonillas 2 Economic Feasibility Analysis Results

LINE	CAONILLAS 2 IMPROVEMENT	NET PRESENT VALUE ($)	ANNUAL AVERAGE COST	ADJUSTED PAYBACK PERIOD (YEARS)	TOTAL CAPITAL COST ($)	CAPACITY FACTOR (%)	FACILITY CAPACITY (MW)
1	Return to service 3.6 MW	(8,139,000)	1,486,000	NA	12,660,000	34.2%	3.6
2	New 1 MW full auto, no bypass	(7,071,000)	1,833,000	NA	36,360,000	59.4%	1.0
3	New 1 MW full auto, with bypass, sediment passage gates	(9,843,000)	2,203,000	NA	20,300,000	59.4%	1.0
4	New 2 MW full auto, no bypass	(16,667,000)	1,907,000	NA	37,150,000	30.3%	2.0
5	New 2 MW full auto, with bypass, sediment passage gates	(20,288,000)	2,350,000	NA	21,870,000	30.3%	2.0

7 Toro Negro 1

The Toro Negro 1 hydroelectric system consists of two major reservoirs (El Guineo and Matrullas), ten diversion structures, a splitter box and a series of tunnels, penstocks and canals. See Figure 2-3 for plan view of the system, including the system watersheds.

Toro Negro 1 was constructed in 1927 with the first three units (1-1 through 1-3) and expanded in 1937 by adding a fourth horizontal Pelton turbine generating unit. Units 1-1 through 1-3 are 1.44 MW each, and Unit 1-4 is 4.48 MW. The powerhouse structure is in good condition with all the mechanical and electrical equipment functioning. The penstock appears to be in poor condition and near the end of its useful life. The Matrullas Canal is in fair condition, but the tunnel has not been inspected recently.

Figure 7-1 Toro Negro 1 Hydroelectric Plant Photo

7.1 EXISTING AND POTENTIAL INSTALLED CAPACITY

The existing capacity of Toro Negro 1 is 8.64 MW. The system is currently water limited and there is no potential to increase the plant capacity. The potential installed capacity is 8.64 MW.

7.2 EXISTING AND POTENTIAL AVERAGE ANNUAL GENERATION

The historic generation is compared to the modeled generation for the existing conditions (some small diversions not in operation). Additional cases were analyzed including restoring the small diversions to service. See Table 7-1 below for a summary of cases and annual average generation and capacity factors. Historical generation is based on output from 2016 through 2020.

Average annual generation was calculated using the existing capacities of the Toro Negro 1 plant and the following considerations in the model:

- Available flow into the Matrullas reservoir. Outflows are based on sending water to the Toro Negro 1 facility at the Matrullas canal design flow for 8 hours a day five days per week when the reservoir is at normal operating levels, and 16 hours per day five days per week when the reservoir is at high levels.
- Small diversion flows were added to the flow from the Matrullas reservoir and outflow from Toro Negro 2. If the flows from the diversion were more than 5 cfs, one of the smaller units (1-1 through 1-3) was started.
- Gross head based on simulated forebay operating levels. Net head based on gross head minus calculated headloss.
- Turbine efficiency was 80% based on historical turbine performance tests.
- Turbines were modeled as operating from 35% power up to 100% rated power to maximize energy production.
- Estimated generator efficiency of 98% and estimated step-up transformer efficiency of 98%.
- Estimated energy used at the station was 100 kWh per day and is subtracted from the generation to obtain net generation.

The potential average annual net generation for Toro Negro 1 is estimated using the same basic assumptions with the following exceptions:

- Station service energy consumption was increased to 200 kWh per day.
- Plant operation was increased to 24 hours per day, 7 days per week.

The average annual generation with the improvements and automation is 26,700 MWh.

Based on the condition assessment, the following list summarizes the primary recommendations for returning the Toro Negro 1 system to full operation and upgrading the controls to automate the system. These recommendations were used to determine capital costs for evaluating the economic viability of rehabilitating and upgrading the Toro Negro 1 project.

Recommendations for Toro Negro 1 include:

- Replace existing penstocks
- Dredge diversion dams and Aceitunas forebay
- Refurbish small diversion dams and intakes
- Upgrade electrical equipment
- Replace ruptured conveyance pipe from the small diversions

- Automate the controls
- Optimize reservoir operations
- Perform miscellaneous plant upgrades such as replacing broken windows, ventilation fans, correcting alignment issue of crane rails to Unit 4 area, install pump for cooling water system, build wall/barrier between breakers and accessories and the manned portion of the control room, replace leaking seals/gaskets on the units
- Perform electrical upgrades including: converting the governors to digital governors, and adding control of needle valves to governor, rewind the generators for Units 1-3, replace voltage regulators & field breakers with modern static excitation systems, replace 37/2.3 KV, 1800 KVA at 55° C Transformer, replace oil circuit breakers with 3 PH vacuum breaker for indoor use, install modern control system with touchscreen OIT's or operator workstation, Upgrade remote operation specifically small diversion monitoring and automation.

Table 7-1 Toro Negro 1 Existing and Potential Average Annual Generation

	HISTORICAL	EXISTING, NO REFURBISHMENT	RESTORED SMALL DIVERSIONS, EXCEPT DONA JUANA, NO AUTOMATION	RESTORED SMALL DIVERSIONS, EXCEPT DONA JUANA, WITH AUTOMATION	RESTORED SMALL DIVERSIONS USING TYROLEAN WEIR, EXCEPT DONA JUANA, WITH AUTOMATION	RESTORED SMALL DIVERSIONS USING TYROLEAN WEIR, EXCEPT DONA JUANA, WITH AUTO RULE CURVE 1	RESTORED SMALL DIVERSIONS USING TYROLEAN WEIR, EXCEPT DONA JUANA, WITH AUTO RULE CURVE 2
Avg Annual MWh	5,123*	17,680	18,850	26,700	26,300	23,915	23,985
Capacity Factor	0.07	0.23	0.25	0.35	0.35	0.32	0.32

* Toro Negro 1 historical generation is lower than its capability. This is due in part to outages for the high number of repairs to the penstocks and issues with loss of communication to the control gates at Aceitunas forebay; which causes more spilling than typical.

7.3 VARIATION OF HEAD AND FLOW CONDITIONS AT THE SITE

The head of the small diversions is nearly constant with headwater at Aceitunas Forebay of 2178 ft of elevation, and free discharge from the Pelton Turbine at centerline elevation of 530 ft. The gross head is 1,648 feet.

The flow varies considerably as the small diversions have a combined minimum flow of 0 cfs to a maximum of 58 cfs (pipe conveyance system limitations). The peaks occur during storms and are not used to size the turbine. As shown, there is a significant increase by bringing the small diversions back into operation.

7.4 RELIABILITY AND SUFFICIENCY OF AVAILABLE PROJECT DATA

The USGS performed a sedimentation study in 2001 which was used to update the stage storage curve based on the estimated long-term rate of sedimentation. The small diversions do not have any storage considered for the Toro Negro 1 system. Therefore, the current sediment volumes are not critical to the energy generation as long as the system is cleaned out enough to restore full capacity to the intakes and tunnels. A previous study conducted by CSA provided water inflows, and flows diverted out of each of the small diversions. The flow data covered the years 1989 through 2009 for a total of 30 years. This is a sufficient length of time to get an estimate of annual average net generation.

7.5 POTENTIAL OPPORTUNITIES FOR INCREASED PERFORMANCE

The biggest opportunity for improving performance at Toro Negro 1 is to refurbish the existing small diversions and conveyance systems. Additional considerations of changing to a Tyrolean weir type intake (see Figure 7-2) to reduce clogging of the intake with sediment and cobbles should be considered to decrease the percent of time the intakes are operating at reduced capacity.

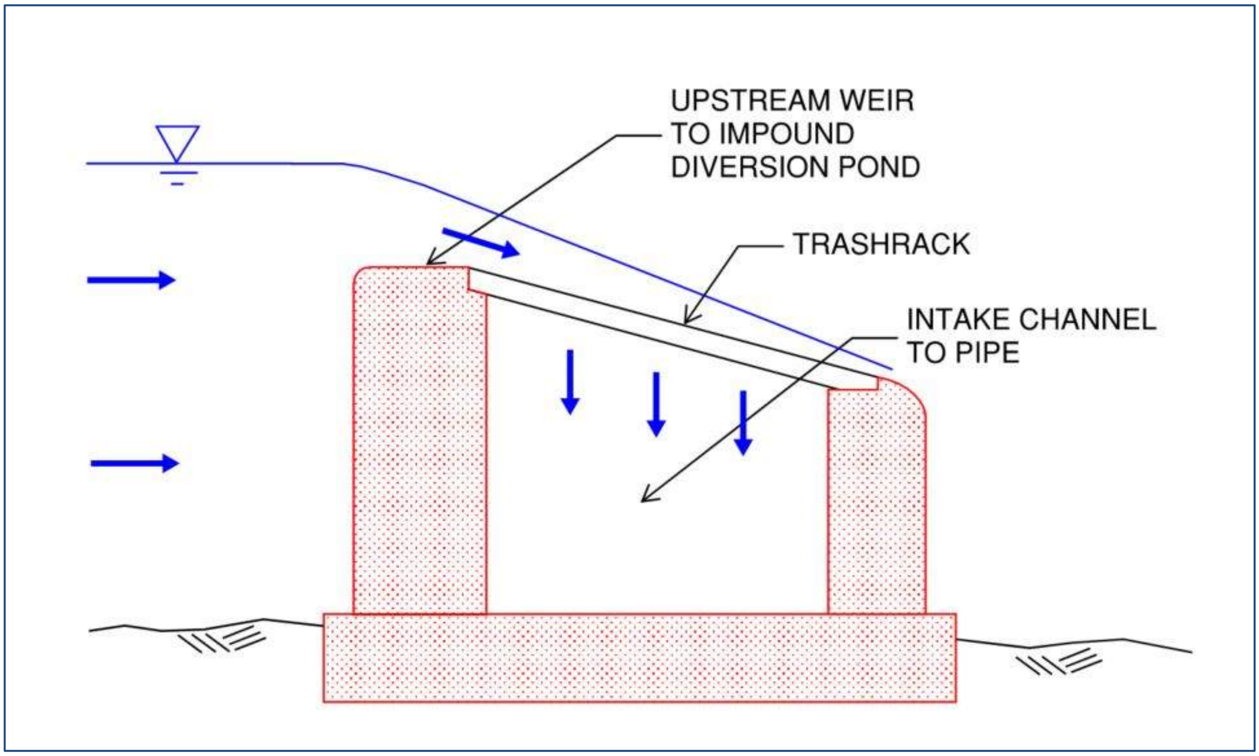


Figure 7-2 Tyrolean Weir – Simple Cross Section

7.6 RESERVOIR SEDIMENTATION STUDIES AND STAGE STORAGE CURVES

The most recent USGS sedimentation study for Lago Matrullas which we have found is a study from December 2001. This study concludes that the long term capacity loss is 7.6 ac-ft per year and a storage capacity of 2,497 ac-ft at the time of the study. The estimated remaining useful life (from 2012) was 327 years. Table 7-2 shows the stage storage curve for the Matrullas Reservoir.

Table 7-2 Matrullas Stage Storage Curves

ELEVATION (FT)	MATRULLAS 2001 STORAGE (AC-FT)	MATRULLAS EST 2021 STORAGE (AC-FT)
2415.0	2,497.0	2,354.0
2411.4	2,253.8	2,124.7
2408.4	2,026.8	1,910.7
2405.2	1,816.0	1,712.0
2401.9	1,613.3	1,520.9
2398.6	1,426.9	1,345.2
2395.3	1,248.5	1,177.0
2392.0	1,086.4	1,024.2
2388.7	924.2	871.3

7.7 RESERVOIR OPERATING RULE CURVES

The small diversions are operated as run of river diversions and do not have operating rule curves. The Matrullas reservoir is a large storage reservoir and has an operating rule curve. The following two trial operating rule curves were developed from the typical rainfall patterns for Puerto Rico to determine if additional generation could be achieved. Note that for the Toro Negro 1 net generation, the small diversions were modeled as being returned to service and fully automated.

Stage storage curves are taken from the data provided in the Task 300 Water Availability Model Review technical memorandum.

Table 7-3 below shows the Matrullas reservoir operating rule curves used in this study.

Table 7-3 Matrullas Reservoir Operating Rule Curves

RULE CURVE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Existing	2410.2	2408.3	2393.6	2405.8	2406.9	2410	2403.7	2385.9	2406.3	2406	2412	2409.2
Rule Curve 1	2410	2405	2395	2385	2395	2405	2380	2385	2390	2395	2400	2405
Rule Curve 2	2410	2410	2410	2405	2400	2390	2390	2390	2400	2405	2405	2410

The historic generation is compared to the modeled generation for the existing conditions (some small diversions not in operation). Additional cases were analyzed including restoring the small diversions to service. The existing and potential generation cases all use the existing rule curve except for the last two; which are based on Rule Curve 1 and 2, respectively. As shown in the table, there is very little change in the Toro Negro 1 net generation with a change in operating rule curves. This likely indicates that there is not significant spilling except during large storm events. In the case of large tropical storm events, operating the reservoir at a lower level would be unlikely to stop the reservoir from spilling. The model for the rule curve changes likely is slightly lower because of a difference in modeling higher flows at less regular intervals through the penstocks resulting in higher headloss and less net generation.

7.8 RECOMMENDATIONS TO IMPROVE CIVIL AND MECHANICAL RELIABILITY

The Toro Negro 1 system has been in operation for over 80 years and several components are beyond their normal design life and should be repaired as they deteriorate:

- Penstocks should be replaced in reasonable length sections of 500-1000 feet. The economics will be evaluated, but it is likely that with two parallel penstocks, it may be practical to run each penstock to failure and repair sections of them at a time until the entire penstock is replaced. (Utilizing the functioning penstock will limit lost generation costs).
- Replace leaking seals and gaskets, etc. on turbine and governor systems, see condition assessment for list of small items.
- Replace broken or worn out ventilation equipment. Replace broken glass in windows.
- Implement remote control operations to extend operating hours.
- Inspect penstock and repaint if in serviceable condition or replace if badly corroded and too thin to maintain the high pressures.
- Eliminate the cooling water tap from Unit 1-4 penstock and repump water from the tailrace. The water in the penstock is much higher pressure than needed and presents both a loss of generation, and a risk of equipment failure in the water system.

The Units 1-1, 1-2 and 1-3 needles are controlled manually using a handwheel at the unit to adjust unit speed, frequency and load. Speed sensing is via a belt riding over the turbine shaft. The manual positioners can be replaced with modern, digital governors providing local or remote control. The belt driven speed sensing should be replaced with modern speed instrumentation.

Unit 1-4 has a Woodward Type LR mechanical governor. If the other unit mechanical positioners are upgraded, it would be a good opportunity to modernize the Unit 1-4 governor with an upgrade to a digital governor.

7.9 RECOMMENDATIONS TO IMPROVE ELECTRICAL SAFETY AND RELIABILITY

The Units 1-2 and 1-3 generators have the original winding from 1929 and Unit 1-4 has the original winding from 1937. These generator windings have all exceeded their design life and are due for a rewind with modern, less flammable and self-extinguishing insulation.

The voltage regulators for all four units are original with manual control of the rheostats. The Units 1-1, 1-2 and 1-3 field breakers are lever action, manually controlled from panel sections next to the main control panel lineup. The back of the main control panel is exposed, access to the field breakers is protected by a plastic cover however this does not provide adequate protection during a fault. The Unit 1-4 field breaker is manually operated from a panel next to the switchboard. All the field breakers have exposed contacts on the front of panels that are hazardous to personnel and can emit sparks under normal operation. The obsolete field breakers need to be replaced to reduce hazards. The voltage regulators and field breakers can be replaced with modern static excitation systems.

The generator step-up transformers for Units 1-1, 1-2 and 1-3 are located outside next to the oil circuit breakers, are outdated and beyond their normal design life. Transformer oil and other testing will determine the condition, trending multiple tests over time will be useful in projecting useful life and schedule for replacement. Due to the spacing of the transformers, recommend upgrading to new transformers with less flammable fluid which will reduce the chance of catastrophic failure of multiple transformers. When the transformers are replaced, they will need to be relocated farther away from the powerhouse to meet current standards.

The oil circuit breakers for Units 1-1, 1-2 and 1-3 are Westinghouse Type ESM Recloser located outside in a fenced area next to the powerhouse. The breakers were manufactured in 1974 and have exceeded their design life. The Unit 1-4 generator breaker is located inside the powerhouse in the Truck Type Switchboard. Recommend replacing the Units 1-1 to 1-3 outdoor oil circuit breakers with non-oil type modern vacuum circuit breakers. Recommend replacing the outdated Unit 1-4 circuit breaker.

There is an outdated section of original station service bus with levers on the front main control panel lineup and exposed bus behind. Station service should be consolidated into a small motor control center to bring station service up to modern standards and eliminate hazards.

The 120 / 240 VAC distribution panel and 125 VDC distribution panel are at the end of their useful life and should be replaced to provide reliable protection.

The generator protective relaying consists mainly of discrete, single function GE electromechanical relays. There is a digital, SEL-587 current differential relay for Unit 1-1 and a few solid-state protection relays on the main control panel. To modernize the facility and reduce calibration time, recommend replacing the single function electromechanical, solid state and digital protection relays with multi-function digital relays.

The existing manual control scheme using control switches and auxiliary relays is adequate for local, attended operation. To modernize the facility, an automated control system with graphic displays on an operator workstation can be provided. A modern control, protection and metering system could replace most of the main control panel and benchboard devices.

7.10 RECOMMENDATIONS TO IMPROVE PLANT COMMUNICATIONS SYSTEM

The communication system to the Aceitunas Forebay, Toro Negro 2, and the El Guineo and Matrullas reservoirs should be restored. Currently, the gate at Matrullas reservoir is manually opened by sending an operator or Hydro Ranger to open and close the valve. Additionally, the loss of communication with the Aceitunas Forebay causes PREPA to regularly spill water from the Aceitunas Forebay, losing generation.

7.11 POTENTIAL FOR AUTOMATED FREQUENCY RESPONSE

Units 1-1, 1-2 and 1-3 turbines have manual needle operators and deflector control. The needles are controlled manually using a handwheel at the unit to adjust unit speed, frequency and load. Units 1-1, 1-2 and 1-3 do not have automatic frequency response capability. In order to get automatic frequency response, there would need to be a digital conversion of the mechanical equipment.

Unit 1-4 has a Woodward Type LR mechanical governor which will respond automatically to frequency deviation.

7.12 POTENTIAL FOR REMOTE CONTROL

There is a functioning microwave communication to the plant allowing ECC monitoring of this facility. There is no remote control of the generating units from the ECC.

In order to provide ECC remote startup, shutdown control of the units, the manual startup and shutdown sequences including synchronization would need to be automated. The manual needle and deflector operators would need to be replaced with digital governors for automatic sequencing and remote load control. The existing voltage regulators and field breakers would need to be replaced with modern static excitation equipment for automatic sequencing, automatic voltage regulation and remote voltage control. The existing Harris RTU would need to be modified to add remote control.

7.13 ECONOMIC ANALYSIS

Toro Negro 1 is currently an active hydroelectric facility. Several improvements have been recommended that vary around the rehabilitation or replacement of certain penstock and diversion structures, considering automation and some improvements. While physically in the same region and with some level of interconnection, the independent reservoirs for Toro Negro 1 and Toro Negro 2 allow for different criteria for selecting the best-case scenario for each facility. Line 3 of Table 7-4, Small Diversions with full Automation, provides an improvement that will produce the highest NPV of about $31.2 million. This improvement produces the highest energy output with a capacity factor of 34.6%. The capital-related cost is $42.1 million. The improvements recommended assumes the implementation of a new penstock structure. The adjusted payback period for this option is the shortest of all the options at 27 years. Based on the daily model for the storage reservoir and diversions in the Toro Negro hydroelectric system, the estimated average annual net generation for Toro Negro 1 is 26,300 MWh.

The major work recommended to maintain the reliability of Toro Negro 1 is to dredge, refurbish diversion intakes, install Tyrolean weirs, and provide regular maintenance to the small diversions; upgrade the electrical equipment, replace ruptured conveyance pipe, automate the controls and replace the penstock.

Table 7-4 Toro Negro 1 Economic Feasibility Analysis Results

LINE	TORO NEGRO 1 IMPROVEMENT	NET PRESENT VALUE ($)	ANNUAL AVERAGE COST	ADJUSTED PAYBACK PERIOD (YEARS)	TOTAL CAPITAL COST ($)	CAPACITY FACTOR (%)	FACILITY CAPACITY (MW)
1	Refurbish Powerhouse	2,378,000	5,203,000	490.3	38,863,000	22.9%	8.6
2	Restored Small Diversions	4,898,000	5,321,000	167.0	40,908,000	24.5%	8.6
3	Small Diversions with full Auto	31,241,000	5,433,000	27.0	42,133,000	34.6%	8.6
4	Small Diversions with Tyrolean weirs and full Auto	28,672,000	5,520,000	30.1	43,073,000	34.1%	8.6
5	Small Diversions with Tyrolean weirs and full Auto Rule Curve 1	20,213,000	5,520,000	42.6	43,073,000	31.0%	8.6
6	Small Diversions with Tyrolean weirs and full Auto Rule Curve 2	20,461,000	5,520,000	42.1	43,073,000	31.1%	8.6

8 Toro Negro 2

The Toro Negro 2 hydroelectric system consists of one major reservoir (El Guineo), a penstock and a powerhouse. Toro Negro 2 receives its flow from El Guineo via a penstock that varies from 24 to 36-inches in diameter. Toro Negro 2 is currently out of service due to issues with the penstock. The penstock is currently being repaired and Toro Negro 2 is expected to be back in operation withing the next month. Flow from Toro Negro 2 and from the diversion structures is routed to a common splitter box via a series of canals, tunnels and pipelines. See Figure 2-3 for plan view of the system, including the system watersheds. The discharge from Toro Negro 2 is required to provide adequate flow at Toro Negro 1 to operate all 4 units.

Toro Negro 2 was constructed in 1937 and contains one single-nozzle over-hung 1.9 MW horizontal Pelton type generating unit. The powerhouse structure is in good condition with all the mechanical and electrical equipment functioning. The penstock appears to be in poor condition and near the end of its useful life and was recently repaired to return the Toro Negro 2 powerhouse to operation.

Figure 8-1 Toro Negro 2 Hydroelectric Plant Photo

8.1 EXISTING AND POTENTIAL INSTALLED CAPACITY

The existing capacity of Toro Negro 2 is 1.92 MW. The system is currently water limited and there is no potential to increase the plant capacity. The potential installed capacity is 1.92 MW.

8.2 EXISTING AND POTENTIAL AVERAGE ANNUAL GENERATION

The historic generation is compared to the modeled generation for the existing conditions. The penstock was out of service until March 2021, but there are no other major facilities to consider modifying operation to increase generation. Automation may be used to allow more generation and avoid spills by operating 24 hours per day. See Table 8-1 below for a summary of cases and annual average generation and capacity factors. Historical generation is based on output from 2016 through 2020.

Table 8-1 Toro Negro 2 Existing and Potential Average Annual Generation

	HISTORICAL	EXISTING, REFURBISHED	AUTOMATED	AUTOMATED RULE CURVE 1	AUTOMATED RULE CURVE 2
Avg Annual MWh	85*	1,910	3,015	3,300	3,320
Capacity Factor	0.07	0.11	0.18	0.20	0.20
* Toro Negro 2 has been out of service, which reduces its historic output.					

8.3 VARIATION OF HEAD AND FLOW CONDITIONS AT THE SITE

The water elevation of the El Guineo varies from a minimum elevation of 2927 feet to a maximum elevation of 2959 feet, and free discharge from the Pelton Nozzle at centerline elevation of 2249 feet. The gross head is between 678 feet and 710 feet.

The flow varies considerably from a minimum flow of 0 cfs to a maximum of 28.7 cfs (turbine design flow). The discharge is coordinated with operations at Toro Negro 1 and the turbine is sized for providing flow to the Toro Negro 1 powerhouse rather than sized for the available water in the El Guineo reservoir.

8.4 RELIABILITY AND SUFFICIENCY OF AVAILABLE PROJECT DATA

The USGS performed a sedimentation study of the El Guineo Reservoir in 2001 which was used to update the stage storage curve based on the estimated long-term rate of sedimentation. A previous study conducted by CSA provided water inflows to El Guineo. The flow data covered the years 1989 through 2009 for a total of 30 years. This is a sufficient length of time to get an estimate of annual average net generation.

8.5 POTENTIAL OPPORTUNITIES FOR INCREASED PERFORMANCE

The Toro Negro 2 system with El Guineo as a large storage reservoir in a small watershed captures significant percentage of the available flow. The only opportunity for increased performance is to replace the unit with a new higher efficiency unit or modify reservoir operations to eliminate the small amount of spills. The replacement of functioning equipment is unlikely to be economical, and the study of modifying reservoir operations is part of an upcoming task of this study.

8.6 RESERVOIR SEDIMENTATION STUDIES AND STAGE STORAGE CURVES

The most recent USGS sedimentation study for Lago El Guineo which we have found is a study from October 2001. This study concludes that the long term capacity loss is 4.6 ac-ft per year and a storage capacity of 1,532 ac-ft at the time of the study. The estimated remaining useful life (from 2001) was 331 years. Table 8-2 shows the El Guineo stage storage curve.

Table 8-2 El Guineo Stage Storage Curves

ELEVATION (FT)	EL GUINEO 2001 STORAGE (AC-FT)	EL GUINEO EST 2021 STORAGE (AC-FT)
2960.0	1,532.3	1,444.5
2956.7	1,378.2	1,299.3
2953.4	1,240.4	1,169.4
2950.2	1,102.6	1,039.4
2946.9	972.9	917.1
2943.6	859.4	810.1
2940.3	737.7	695.5
2937.0	632.4	596.1
2933.8	535.1	504.4

8.7 RESERVOIR OPERATING RULE CURVES

The El Guineo reservoir is a large storage reservoir and has an operating rule curve. The following operating two trial rule curves were developed from the typical rainfall patterns for Puerto Rico to determine if additional generation could be achieved.

Stage storage curves are taken from the data provided in the Task 300 Water Availability Model Review technical memorandum.

Table 8-3 below shows the El Guineo reservoir operating rule curves used in this study.

Table 8-3 El Guineo Reservoir Operating Rule Curves

RULE CURVE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Existing	2949.3	2942.9	2939.4	2942	2952.4	2945.5	2939.9	2934.5	2949.4	2952.7	2955.3	2950.2
Rule Curve 1	2955	2955	2955	2945	2935	2950	2930	2930	2930	2940	2945	2950
Rule Curve 2	2955	2950	2945	2940	2935	2930	2930	2930	2935	2940	2945	2950

The historic generation is compared to the modeled generation for the existing conditions. The penstock is currently out of service until May 2021, but there are no other major facilities to consider modifying operation to increase generation. Automation may be used to allow more generation and avoid spills by operating 24 hours per day. As shown in the table, there is very little change in the Toro Negro 2 net generation with a change in operating rule curves. This likely indicates that there is not significant spilling except during large storm events. In the case of large tropical storm events, operating the reservoir at a lower level would be unlikely to stop the reservoir from spilling. Additionally, the unit is oversized for the available water, and can rapidly draw down the El Guineo reservoir immediately before, or after a storm and relatively little water is spilled.

8.8 RECOMMENDATIONS TO IMPROVE CIVIL AND MECHANICAL RELIABILITY

The outlet pipe from El Guineo, and penstock should be inspected and tested for pipe wall thickness and if it is too thin for the pressure, the weakest sections should be replaced. The leaking roof should be replaced with a new roof matching the existing clay tile roof.

To modernize the facility, the mechanical governor can be converted to a digital governor with an electronic controller and touchscreen graphic OIT.

8.9 RECOMMENDATIONS TO IMPROVE ELECTRICAL SAFETY AND RELIABILITY

The excitation system's original field rheostat is outdated and should be replaced. The field breakers/contactors are of the old exposed type, presenting a safety hazard due to arcing and should be replaced. The field rheostat and field breakers can be replaced with a modern static excitation system.

The generator breaker is an outdated oil circuit breaker located behind the main control panel. The circuit breaker is rated 600 amps, 15,000 V and has three individual oil-containing breaker chambers, presenting intrinsic fire safety and environmental risks and slow operating characteristics. There is additional exposed bus, CTs and PTs, all with inadequate clearances and safety hazard avoidance zones. The generator circuit breaker and associated bus, CT's and PT's should be replaced to provide safe, reliable operation.

The generator step-up transformer is beyond its design life. When the transformer is replaced it will need to be relocated farther away from the powerhouse to meet current standards.

There is a main control panel with single function, electromechanical protective relays of various ages. The 86 lockout relay is very old and should be replaced to ensure adequate unit protection. The control relays on the main control panel are very old and are the exposed coil and contact type, they should be replaced. The main control panel should be replaced with a modern control, protection and metering system.

8.10 RECOMMENDATIONS TO IMPROVE PLANT COMMUNICATIONS SYSTEM

There is a functioning microwave communication to the plant providing metering data to the ECC.

8.11 POTENTIAL FOR AUTOMATED FREQUENCY RESPONSE

The unit has the original mechanical Woodward governor which provides steady control of the unit. If the governor is tuned and working properly, it should provide automatic response to frequency changes. To modernize the facility, the mechanical governor can be converted to a digital governor as recommended above.

8.12 POTENTIAL FOR REMOTE CONTROL

The ECC does not have any remote control of the unit. The unit is manually controlled locally at the facility. In order to provide ECC remote startup, shutdown control of the units, the manual startup and shutdown sequences including synchronization would need to be automated. The mechanical governor would need to be replaced with a digital governor for automatic sequencing and remote load control. The manual rheostat controls would also need to be replaced with modern static excitation equipment for automatic sequencing, automatic voltage regulation, and remote voltage control. The existing SCADA RTU would need to be modified or replaced to add remote control.

8.13 ECONOMIC EVALUATION

Toro Negro 2 is currently an inactive hydroelectric facility. Several improvements have been recommended to improve the reliability and to maintain the facility properly. These improvements vary around the rehabilitation or replacement of the penstock structure with consideration for automation. While physically in the same region and with some level of interconnection, the independent reservoirs for Toro Negro 1 and Toro Negro 2 allow for different criteria for selecting the best-case scenario for each facility. Line 4 of Table 8-4, Fully Automated Rule Curve 2, provides an improvement that will produce the least negative NPV of about $(2.5) million. The capital cost is $22.1 million, and there is no payback period associated with this improvement. Based on the daily model for the storage reservoir and diversions in the Toro Negro hydroelectric system, the estimated average annual net generation for Toro Negro 2 is 3,300 MWh.

The major work recommended to maintain the reliability of Toro Negro 2 is to fix miscellaneous structural deficiencies, upgrade electrical systems, automate controls and replace the penstock.

Table 8-4 Toro Negro 2 Economic Feasibility Analysis Results

LINE	TORO NEGRO 2 IMPROVEMENT	NET PRESENT VALUE ($)	ANNUAL AVERAGE COST	ADJUSTED PAYBACK PERIOD (YEARS)	TOTAL CAPITAL COST ($)	CAPACITY FACTOR (%)	FACILITY CAPACITY (MW)
1	Refurbished plant	(8,212,000)	1,560,000	NA	21,827,000	10.9%	2.0
2	Fully Automated	(3,605,000)	1,509,000	NA	22,077,000	17.2%	2.0
3	Fully Automated Rule Curve 1	(2,582,000)	1,509,000	NA	22,077,000	18.8%	2.0
4	Fully Automated Rule Curve 2	(2,510,000)	1,509,000	NA	22,077,000	18.9%	2.0

9 Garzas 1

The Garzas 1 hydroelectric system consists of one major reservoir (Garzas), three small diversions, and diversion tunnels. See Figure 2-4 for plan view of the system, including the system watersheds.

Garzas 1 was constructed in 1941 and contains two 3.6 MW horizontal Pelton turbine generating units. The powerhouse structure is in good condition with all the mechanical and electrical equipment functioning. The penstock appears to be in poor condition and near the end of its useful life; the tunnel has not been inspected recently.

Figure 9-1 Garzas 1 Hydroelectric Plant Photo

9.1 EXISTING AND POTENTIAL INSTALLED CAPACITY

The existing capacity of Garzas 1 is 7.2 MW. The system is currently water limited and there is no potential to increase the plant capacity. The potential installed capacity is 7.2 MW.

9.2 EXISTING AND POTENTIAL AVERAGE ANNUAL GENERATION

The historic generation is compared to the modeled generation for the existing conditions. The three small diversions were out of service, but there are no other major facilities to consider modifying operation to increase generation. Automation may be used to allow more generation and avoid spills at the Garzas 2 Forebay, and by operating 24 hours per day. See Table 9-1 below for a summary of cases and annual average generation and capacity factors. Historical generation is based on output from 2016 through 2020.

Average annual generation was calculated using the existing capacities of the Garzas 1 plant and the following considerations in the model:

- Available flow into the Garzas reservoir. Outflows are based on sending water to the Garzas 1 facility at the design flow for 8 hours a day when the reservoir is at normal operating levels, and 16 hours per day when the reservoir is at high levels.
- Small diversion flows were added to the flow from the Garzas reservoir. If the flows from the diversion were more than 7 cfs, one of the units was started.
- Gross head based on simulated reservoir operating levels. Net head is based on gross head minus calculated headloss.
- Turbine efficiency of 85% is based on generic turbine efficiency curves for runners of the same time period.
- Turbines were modeled as operating from 35% power up to 100% rated power to maximize energy production.
- Estimated generator efficiency of 98% and estimated step up transformer efficiency of 98%.
- Estimated energy used at the station is 250 kWh per day and was subtracted from the generation to obtain net generation.

The potential average annual net generation for Garzas 1 with full automation is estimated using the same basic assumptions with the following exceptions:

- Station service energy consumption was decreased to 200 kWh per day.
- Plant operation was increased to 24 hours per day, 7 days per week.

The average annual generation with the improvements and automation is 10,906 MWh.

Based on the condition assessment, the following list summarizes the primary recommendations for rehabilitating, upgrading and automating the controls to automate the system. These recommendations are used to determine capital costs for evaluating the economic viability to rehabilitating and upgrading the Garzas 1 project.

Recommendations for Garzas 1 include:

- Upgrade mechanical balance of plant systems
- Install a penstock valve
- Refurbish small diversion dams and intakes
- Refurbish bearing on Unit 1
- Upgrade electrical equipment
- Perform testing for increasing generator ratings
- Automating the controls
- Optimize reservoir operations
- Replace penstock

Table 9-1 Garzas 1 Existing and Potential Average Annual Generation

	HISTORICAL	EXISTING, NO SMALL	RETURN SMALL DIVERSIONS TO SERVICE	INSTALL TYROLEAN WEIRS IN SMALL DIVERSIONS	TYROLEAN WEIRS AND AUTOMATION	TYROLEAN WEIRS, AUTOMATION AND INCREASED	TYROLEAN WEIRS AND AUTOMATION – RULE CURVE 1	TYROLEAN WEIRS AND AUTOMATION – RULE CURVE 2
Avg Annual MWh	2,829	9,000	9,300	9,300	10,580	10,580	12,500	12,500
Capacity Factor	0.05	0.14	0.15	0.15	0.17	0.17	0.20	0.20

9.3 VARIATION OF HEAD AND FLOW CONDITIONS AT THE SITE

The water elevation of the Garzas reservoir varies from a minimum elevation of 2390 feet to a maximum elevation of 2415 feet, and free discharge from the Pelton Nozzle at centerline elevation of 1153.33 ft. The gross head is between 1,236.7 feet and 1,261.7 feet.

The flow varies considerably from a minimum flow of 0 cfs to a maximum of 90 cfs (turbine design flow). The discharge is coordinated with operations at Garzas 2 (when it is operating).

9.4 RELIABILITY AND SUFFICIENCY OF AVAILABLE PROJECT DATA

The USGS performed a sedimentation study of the Garzas Reservoir in 2007 which was used to update the stage storage curve based on the estimated long-term rate of sedimentation. A previous study conducted by CSA provided water inflows to the Garzas Reservoir and all 6 diversions. The flow data covered the years 1964 through 2011 for a total of 47 full years. This is a sufficient length of time to get an estimate of annual average net generation.

9.5 POTENTIAL OPPORTUNITIES FOR INCREASED PERFORMANCE

The system shows very little spill from the Garzas reservoir, so increasing the inflow with small diversion being returned to operation is the greatest potential increase for generation. Additionally, improving communications and coordinating Garzas 1 outflow with the inflow from the small diversions for Garzas 2 will decrease any spilled water at the forebay and maximize generation from the available water.

9.6 RESERVOIR SEDIMENTATION STUDIES AND STAGE STORAGE CURVES

The most recent USGS sedimentation study for Lago Garzas which we have found is a study from July 2007. This study concludes that the long term capacity loss is 10.3 ac-ft per year and a storage capacity of 4,045 ac-ft at the time of the study. The estimated remaining useful life (from 2007) was 394 years. Table 9-2 shows the stage storage curve for Lago Garzas.

Table 9-2 Lago Garzas Stage Storage Curve

ELEVATION (FT)	GARZAS 2001 STORAGE (AC-FT)	GARZAS EST 2021 STORAGE (AC-FT)
2415.0	4,045.5	3,813.8
2411.4	3,696.9	3,485.2
2408.4	3,338.8	3,194.7
2405.2	3,096.9	2,919.6
2401.9	2,829.4	2,667.4
2398.6	2,594.3	2,445.7
2395.3	2,367.3	2,231.7
2392.0	2,156.5	2,033.0
2388.7	1,953.8	1,841.9

9.7 RESERVOIR OPERATING RULE CURVES

The Garzas reservoir is a large storage reservoir and has an operating rule curve. The following two trial operating rule curves were developed from the typical rainfall patterns for Puerto Rico to determine if additional generation could be achieved. Note that for the Garzas 1 net generation, the small diversions were modeled as being returned to service and fully automated.

Stage storage curves are taken from the data provided in the Task 300 Water Availability Model Review technical memorandum.

Table 9-3 below shows the Garzas reservoir operating rule curves used in this study.

Table 9-3 Garzas Reservoir Operating Rule Curves

RULE CURVE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Existing	2414	2414	2414	2414	2414	2414	2414	2414	2414	2414	2414	2414
Rule Curve 1	2410	2409	2408	2405	2400	2395	2390	2390	2390	2398	2404	2408
Rule Curve 2	2412	2412	2412	2412	2400	2390	2390	2390	2390	2390	2400	2412

The historic generation is compared to the modeled generation for the existing conditions. The three small diversions were out of service, but there are no other major facilities to consider modifying operation to increase generation. Automation may be used to allow more generation and avoid spills at the Garzas 2 Forebay, and by operating 24 hours per day. The existing and potential generation cases all use the existing rule curve except for the last two; which are based on Rule Curve 1 and 2, respectively. As shown in the table, there is very little change in the Garzas 1 net generation with a change in operating rule curves. This likely indicates that there is not significant spilling except during large storm events. In the case of large tropical storm events, operating the reservoir at a lower level would be unlikely to stop the reservoir from spilling.

Additionally, the units are oversized for the available water, and can rapidly draw down the Garzas reservoir immediately before, or after a storm and relatively little water is spilled. The proposed rule curves both show a small benefit in net generation but must be weighed against potential reduction in lost water storage for a drought as the outflow from Garzas is used as a water supply.

9.8 RECOMMENDATIONS TO IMPROVE CIVIL AND MECHANICAL RELIABILITY

The small diversions should be returned to service. Because of the extremely remote location of these diversions, a Tyrolean weir is recommended as this will reduce the maintenance. The following recommendations for improving the civil and mechanical reliability are:

- Penstock should be inspected to determine its condition. It was possibly leaking during the site visit but the source of the water near the penstock was not identified. The economics will be evaluated, but it is likely that with penstock cannot be economically replaced at one time.
- Replace leaking seals and gaskets etc. on turbine and governor systems, see condition assessment for list of small items.
- Replace broken or worn out ventilation equipment. Replace broken glass in windows.
- Implement remote control operations to extend operating hours and tie plant operations to Garzas 2 and small diversion flows.
- To modernize the facility, the mechanical governor can be converted to a digital governor with an electronic controller and touchscreen graphic OIT.

9.9 RECOMMENDATIONS TO IMPROVE ELECTRICAL SAFETY AND RELIABILITY

Generator 2 is rated at 4.5 MVA, 2.3 KV and has the original winding from 1941. The windings are well beyond their service life and are due for a rewind with modern, less flammable and self-extinguishing insulation.

The motorized voltage regulator rheostats are located in the control room and are not enclosed, having exposed moving parts accessible to personnel which is a safety issue. The rheostats are very dirty and the age and appearance suggest the presence of asbestos wiring in the resistor banks. The voltage regulators and rheostats should be replaced with a modern static excitation system.

There are not circuit breakers at the same voltage as the generators. There 46 kV, 600A high voltage oil circuit breakers in the switchyard for each generator, dated 1952. These generator oil circuit breakers are beyond their design life and should be replaced with modern breakers.

The generator step-up transformers are located outside next to the powerhouse and appear to be beyond their design life. When the transformers are replaced, they will need to be relocated farther away from the powerhouse to meet current standards.

There is an outdated 125 V DC panel with meters and breakers that is beyond the design life. The 125 VDC panelboard should be replaced.

There are control switches and indicating lights on the main control benchboard of various ages that are used for local manual operation of the units. There is a relay / metering panel in the control room with single function, electromechanical protective relays of various ages. To modernize the facility, an automated control system with graphic displays on an operator workstation can be provided. A modern control, protection and metering system could replace the main control benchboard and relay / metering panel.

9.10 RECOMMENDATIONS TO IMPROVE PLANT COMMUNICATIONS SYSTEM

Water from Garzas 1 powerhouse supplies Garzas 2 powerhouse. Formerly, the two powerhouses were linked with a communications and control system allowing coordinated operation of the two powerhouses – this communications link and functionality is no longer operational. Add additional automation to measure inflows from the three small diversions to Garzas 2 to coordinate outflow from Garzas 1 to total flow for Garzas 2.

Currently the microwave system is down and the SCADA RTU panel has been removed. To restore remote monitoring of this facility, the microwave system would need to be repaired and a new SCADA system installed – this would be done under a separate project and is not included in the cost analysis.

9.11 POTENTIAL FOR AUTOMATED FREQUENCY RESPONSE

The units have the original Woodward Type LR mechanical governors which have mechanical issues requiring annual maintenance. If the governor is tuned and working properly, it should provide automatic response to frequency changes. To modernize the facility, the mechanical governor can be converted to a digital governor as recommended above.

9.12 POTENTIAL FOR REMOTE CONTROL

When the microwave and RTU were functioning the ECC remotely monitored metering values, there was no remote control for the units.

There used to be a second transmission line in service to the Garzas 1 plant connecting power and communications over to the Garzas 2 plant. This line allowed the Garzas 2 unit to be controlled from the Garzas 1 powerhouse, improving coordination between the two facilities.

In order to provide ECC remote startup, shutdown control of the units, the manual startup and shutdown sequences including synchronization would need to be automated. The mechanical governors would need to be replaced with digital governors and the manual rheostat controls would also need to be replaced with modern static excitation equipment. The microwave system would need to be repaired and a new SCADA system installed at the plant to support remote ECC operation.

9.13 ECONOMIC ANALYSIS

Garzas 1 is currently an active hydroelectric facility. Several improvements have been recommended and vary around the rehabilitation or replacement of certain penstock and diversion structures considering automation. Line 5 of Table 9-4, Tyrolean Weirs on Small Diversions, Full Automation, Rule Curve 1, provides an improvement that will produce the highest NPV of $23.6 million and an adjusted payback of 22.3 years. This improvement produces the highest energy output with a capacity factor of 19.8% and has the least impact on reservoir levels. The capital-related cost is $26.3 million, which is not the lowest of all improvements. However, the higher Capacity Factor allows the plant to produce significantly more and reach a higher NPV. Based on the daily model for the storage reservoir and diversions in the Garzas hydroelectric system, the estimated average annual net generation for Garzas 1 is 12,500 MWh.

The major work recommended to maintain the reliability of Garzas 1 is to, rewind the generator, upgrade the controls for full automation, install Tyrolean weirs perform regular maintenance on small diversions and replace the penstock.

Table 9-4 Garzas 1 Economic Feasibility Analysis Results

LINE	IMPROVEMENT	NET PRESENT VALUE ($)	ANNUAL AVERAGE COST	ADJUSTED PAYBACK PERIOD (YEARS)	TOTAL CAPITAL COST ($)	CAPACITY FACTOR (%)	FACILITY CAPACITY (MW)
1	Electrical Refurbishment	11,969,000	2,722,000	40.5	24,247,000	14.3%	7.2
2	Small Diversions	12,464,000	2,766,000	39.7	24,717,000	14.7%	7.2
3	Tyrolean Weirs on small diversions	12,035,000	2,799,000	41.7	25,067,000	14.7%	7.2
4	Tyrolean Weirs on small diversions, full Auto	16,785,000	2,762,000	31.4	26,347,000	16.8%	7.2
5	Tyrolean Weirs on small diversions, full Auto Rule Curve 1	23,638,000	2,762,000	22.3	26,347,000	19.8%	7.2
6	Tyrolean Weirs on small diversions, full Auto Rule Curve 2	23,638,000	2,762,000	22.3	26,347,000	19.8%	7.2

10 Garzas 2

The Garzas 2 hydroelectric system consists of two plant developments (Garzas 1 and Garzas 2) one major reservoir (Garzas), and six diversion structures. Flow from Garzas 1 and from two diversion structures are routed to the Garza 2 forebay located next to Garzas 1. Flow from the forebay is routed to Garzas 2 via a 40 inch diameter penstock. One additional watershed (Barreal) adds flow to the Garzas 2 conveyance system. See Figure 2-4 or plan view of the system, including the system watersheds.

Garzas 2 was constructed in 1941 and contains one single-nozzle double over-hung 5.0 MW horizontal Pelton type generating unit. The powerhouse structure is in good condition with all the mechanical and electrical equipment functioning. The penstock appears to be in poor condition and near the end of its useful life. The Garzas 2 plant is currently offline because the transmission line (No. 1100) connecting it to the grid is out of service. The Garzas 2 plant cannot be returned to service until the transmission line is repaired and it should be a high priority to repair this transmission line as it is directly causing lost generation at the Garzas 2 plant.

Figure 10-1 Garzas 1 Hydroelectric Plant Photo

10.1 EXISTING AND POTENTIAL INSTALLED CAPACITY

The existing capacity of Garzas 2 is 5.04 MW. The system is currently water limited and there is no potential to increase the plant capacity. The potential installed capacity is 5.04 MW.

10.2 EXISTING AND POTENTIAL AVERAGE ANNUAL GENERATION

The historic generation is compared to the modeled generation for the existing conditions. The three small diversions were out of service, but there are no other major facilities to consider modifying operation to increase generation. Automation may be used to allow more generation and avoid spills at the Garzas 2 Forebay, and by operating 24 hours per day. See Table 10-1 below for a summary of cases and annual average generation and capacity factors.

Average annual generation was calculated using the existing capacities of the Garzas 2 plant and the following considerations in the model:

- Available flow into the Garzas reservoir and the small diversion. Flows are based on discharge from the Garzas 1 facility at the design discharge for 8 hours a day when the reservoir is at normal operating levels, and 16 hours per day when the reservoir is at high levels.
- Small diversion flows were added to the discharge from the Garzas 1 plant. If the flows from the diversions were more than 7 cfs, the unit was started.
- Gross head based on forebay operating levels. Net head based on gross head minus calculated headloss.
- Turbine efficiency of 85% is based on generic turbine efficiency curves for runners of the same time period.
- Turbines were modeled as operating from 10% power up to 100% rated power to maximize energy production.
- Estimated generator efficiency of 98% and estimated step up transformer efficiency of 98%.
- Estimated energy used at the station is 250 kWh per day and is subtracted from the generation to obtain net generation.

The historical average annual net generation for Garzas 2 is 1,890 MWh. This generation is not evenly distributed throughout the year but has a noticeable increase in energy generation in the hurricane season from September through November.

The potential average annual net generation for Garzas 2 with full automation is estimated using the same basic assumptions with the following exceptions:

- Station service energy consumption was decreased to 200 kWh per day.
- Plant operation was increased to 24 hours per day, 7 days per week.

The average annual generation with the improvements and automation is 7,978 MWh.

Based on the condition assessment, the following list summarizes the primary recommendations for upgrading and automating the Garzas 2 system. These recommendations are used to determine capital costs for evaluating the economic viability or rehabilitating and upgrading the Garzas 2 project.

Recommendations for Garzas 2 include:

- Upgrade mechanical balance of plant systems
- Repair deficiencies in the structure
- Refurbish small diversion dams and intakes
- Upgrade electrical equipment
- Automate the controls

- Optimize reservoir operations
- Replace penstock

Table 10-1 Garzas 2 Existing and Potential Average Annual Generation

	HISTORICAL	EXISTING, NO SMALL DIVERSIONS	RETURN SMALL DIVERSIONS TO SERVICE	INSTALL TYROLEAN WEIRS IN SMALL DIVERSIONS	TYROLEAN WEIRS AND AUTOMATION	TYROLEAN WEIRS, AUTOMATION AND INCREASED PIPE SIZE FROM BAREAL
Avg Annual MWh	0*	6,050	6,370	6,370	8,070	8,290
Capacity Factor	0.00	0.14	0.14	0.14	0.18	0.19

* The Garzas 2 plant has been offline since Hurricane Maria damaged the transmission lines and it has no connection to the grid.

10.3 VARIATION OF HEAD AND FLOW CONDITIONS AT THE SITE

The water elevation of the Garzas 2 Forebay is held basically constant at 1148 feet of elevation, and free discharge from the Pelton Nozzle at centerline elevation of 337.5 feet. The gross head is 810.5 feet.

The flow varies considerably from a minimum flow of 0 cfs to a maximum of 84 cfs (turbine design flow).

10.4 RELIABILITY AND SUFFICIENCY OF AVAILABLE PROJECT DATA

The USGS performed a sedimentation study of the Garzas Reservoir in 2007 which was used to update the stage storage curve based on the estimated long-term rate of sedimentation. A previous study conducted by CSA provided water inflows to the Garzas Reservoir and all 6 diversions. The flow data covered the years 1964 through 2011 for a total of 47 full years. This is a sufficient length of time to get an estimate of annual average net generation.

10.5 POTENTIAL OPPORTUNITIES FOR INCREASED PERFORMANCE

The system shows very little spill from the Garzas reservoir, so increasing the inflow with small diversion being returned to operation is the greatest potential increase for generation. Additionally, improving communications and coordinating Garzas 1 outflow with the inflow from the small diversions for Garzas 2 will decrease any spilled water at the forebay and maximize generation from the available water.

10.6 RESERVOIR SEDIMENTATION STUDIES AND STAGE STORAGE CURVES

The Garzas 2 system consists of three small diversions, and the forebay which receives water from the Garzas 1 plant. There have been no sedimentation studies, though the site visit did show the small diversions that were accessible were completely filled with sediment and had no storage. It was also noted that regardless of the presence of the sediment, these small diversions are run of river and have no storage capability.

10.7 RESERVOIR OPERATING RULE CURVES

The Garzas Hydroelectric System consists of two plant developments (Garzas 1 and Garzas 2) one major reservoir (Garzas), and six diversion structures. Flow from Garzas 1 and from two diversion structures are routed to the Garza 2 forebay located next to Garzas 1. Flow from the forebay is routed to Garzas 2 via a 40 inch diameter penstock. One additional watershed (Barreal) adds flow to the Garzas 2 conveyance system. See Figure 2-4 for plan view of the system, including the system watersheds. The three small diversions have very little storage, and no practical way to control outflow. Therefore, no operating rule curves are proposed for these and they should be operated as run of river diversion dams.

10.8 RECOMMENDATIONS TO IMPROVE CIVIL AND MECHANICAL RELIABILITY

The small diversions should be returned to service. Because of the high cobble and sediment loads, and inaccessibility of the Barreal diversion, a Tyrolean weir is recommended as this will reduce the maintenance. The following recommendations for improving the civil and mechanical reliability are:

- Penstock should be inspected to determine its condition. The economics will be evaluated, but it is likely that with penstock cannot be economically replaced at one time.
- Replace leaking seals and gaskets etc. on turbine and governor systems, see condition assessment for list of small items.
- Replace broken or worn out ventilation equipment. Replace broken glass in windows.
- Implement remote control operations to extend operating hours and tie plant operations to Garzas 2 and small diversion flows.
- To modernize the facility, the mechanical governor can be converted to a digital governor with electronic controller and touchscreen graphic OIT.

10.9 RECOMMENDATIONS TO IMPROVE ELECTRICAL SAFETY AND RELIABILITY

The Westinghouse generator is rated at 6.3 MVA, 2.3 KV and has the original 1941 winding. The windings are well beyond their service life and are due for a rewind with modern, less flammable and self-extinguishing insulation.

The voltage regulator has a motorized button type rheostat. The resistor bank has original wires, the age of which suggests the presence of asbestos. The regulator and resistor bank have exceeded their design life and should be replaced with a modern static excitation system.

There is a GE lineup of switchgear with the generator breaker and the station service transformer feeder breaker. Based on the age and the fact the breakers have been idle for so long, they may not operate. Recommend replacing the switchgear to ensure reliability.

There is a GE transformer for the generator and station service rated 38060 V : 2300 V, 6,300 KVA that appears to be at the end of its design life. Transformer oil and other testing will determine the condition, trending multiple tests over time will be useful in projecting useful life and schedule for replacement. When the transformer is replaced, it will be designed with less flammable fluid. The transformer will need to be relocated farther away from the powerhouse to meet current standards.

There is a main control panel on the generator floor with outdated control switches, indicating lights, single function electromechanical protective relays and auxiliary relays. The back of the main control panel has many wires which appear to have asbestos containing insulation. To modernize the facility, an automated control system with graphic displays on an operator workstation can be provided. The main control panel should be replaced with a modern control, digital protection and metering system.

10.10 RECOMMENDATIONS TO IMPROVE PLANT COMMUNICATIONS SYSTEM

The microwave system needs repaired, currently there is no communication to this facility from ECC. Water from Garzas 1 powerhouse supplies Garzas 2 powerhouse. Formerly, the two powerhouses were linked with a communications and control system allowing coordinated operation of the two powerhouses. Add additional automation to measure inflows from the three small diversions to Garzas 2 to coordinate outflow from Garzas 1 to total flow for Garzas 2.

The transmission line has failed so they can't run the unit. Consider running fiber with the transmission line when it is repaired.

10.11 POTENTIAL FOR AUTOMATED FREQUENCY RESPONSE

The Woodward Type LHR mechanical governor operates a common deflector shaft connected to both turbines and has steady control of the unit. If the governor is tuned and working properly, it should provide automatic response to frequency changes. To modernize the facility, the mechanical governor can be converted to a digital governor as recommended above.

10.12 POTENTIAL FOR REMOTE CONTROL

The ECC does not have any remote control of the unit. In order to provide ECC remote startup, shutdown control of the units, the manual startup and shutdown sequences including synchronization would need to be automated. Provide new digital governor and modern static excitation equipment. The microwave system would need to be repaired or consider running fiber with the transmission line when it is repaired to restore the remote communication link. The existing SCADA RTU would need to be modified or replaced to support remote ECC operation.

10.13 ECONOMIC ANALYSIS

Garzas 2 is currently an inactive hydroelectric facility. Several improvements have been recommended and vary around the rehabilitation or replacement of certain diversion structures to add Tyrolean weirs and reduce the maintenance required. Also, consideration for automation in some improvements will provide the ability to operate remotely. Line 6 of Table 10-2, Tyrolean Weirs on Small Diversions, Full Auto Rule Curve 1, provides an improvement that will produce the highest NPV of $19.6 million and an adjusted payback period of 25.7 years. This improvement produces the second highest energy output, which maximizes the energy savings potential. The capital-related cost is $25.2 million, which is not the lowest of all improvements but is significantly lower than the improvements that require the implementation of an increased pipe size from the small diversion structure. Based on the daily model for the storage reservoir and diversions in the Garzas hydroelectric system, the estimated average annual net generation for Garzas 2 is 8,800 MWh.

The major work recommended to maintain the reliability of Garzas 2 is to upgrade the mechanical balance of plant systems, repair deficiencies in the structure, refurbish small diversions, install Tyrolean weirs at small diversions, and replace the penstock.

Table 10-2 Garzas 2 Economic Feasibility Analysis Results

LINE	GARZAS 2 IMPROVEMENT	NET PRESENT VALUE ($)	ANNUAL AVERAGE COST	ADJUSTED PAYBACK PERIOD (YEARS)	TOTAL CAPITAL COST ($)	CAPACITY FACTOR (%)	FACILITY CAPACITY (MW)
1	Return to service	9,803,000	2,562,000	49.0	23,996,000	13.8%	5.0
2	Return Small Diversions to service	10,858,000	2,567,000	44.3	24,046,000	14.5%	5.0
3	Tyrolean Weirs at Small Diversions	10,491,000	2,595,000	46.4	24,346,000	14.5%	5.0
4	Tyrolean Weirs on small diversions, full Auto	17,068,000	2,522,000	29.6	25,246,000	18.4%	5.0
5	Tyrolean Weirs on small diversions, full Auto, increase Barreal Pipe	15,632,000	2,691,000	34.6	27,046,000	18.9%	5.0
6	Tyrolean Weirs on small diversions, full Auto Rule Curve 1	19,615,000	2,522,000	25.7	25,246,000	20.1%	5.0
7	Tyrolean Weirs on small diversions, full Auto Rule Curve 2	19,824,000	2,522,000	25.5	25,246,000	20.2%	5.0

11 Yauco 1

The Yauco 1 hydroelectric system consists of five reservoirs, diversion tunnels and two plant developments (Yauco 1 and 2) that are in cascading order with Yauco 1 being the upstream development. The system is operational but requires refurbishing the unit in Yauco 1 to return it to service. There is a dredging project which is being performed separately using FEMA funding to improve storage for irrigation purposes. This will improve the generation of the Yauco system but is not included in the economic evaluation as the funding is outside the scope of the work. See Figure 2-5 for plan view of the system, including the system watersheds.

Yauco 1 was constructed in 1956 and contains one 20 MW six jet vertical Pelton turbine generating unit. The powerhouse structure is in good condition with the electrical equipment functional, but the turbine needs a new runner. The penstock appears to be in good condition however the tunnel has not been inspected recently.

Figure 11-1 Yauco 1 Hydroelectric Plant Photo

11.1 EXISTING AND POTENTIAL INSTALLED CAPACITY

The existing capacity of Yauco 1 is effectively zero MW as the turbine needs either a replacement set of buckets, or a complete replacement as it has been out of service for a significant period of time due to high vibrations. The system is currently water limited if the turbine is installed and operational and therefore the potential capacity is the original capacity of 25 MW. There is no water available to expand beyond the original plant capacity.

11.2 EXISTING AND POTENTIAL AVERAGE ANNUAL GENERATION

The historic generation is compared to the modeled generation for the existing conditions. The three diversions are mostly filled with sediment, but the storage reservoir (Guayo) has significant storage remaining. The two sediment filled reservoirs could be dredged, or modified to pass sediment, and the intakes cleaned out and returned to full capacity. Automation may be used to allow more generation and avoid spills at the three reservoirs, and by operating 24 hours per day. See Table 11-1 below for a summary of cases and annual average generation and capacity factors.

Average annual generation was calculated using the existing capacities of the Yauco 1 plant and the following considerations in the model:

- Available flow into the Guayo reservoir based on USGS gage data with historical reservoir operational rules.
- Gross head based on reservoir operating levels. Net head based on gross head minus calculated headloss.
- Turbine efficiency of 89% is based on the turbine efficiency curves provided.
- Turbines were modeled as operating from 20% power up to 100% rated power to maximize energy production (automated needle selection).
- Estimated generator efficiency of 96% and estimated step up transformer efficiency of 98%.
- Estimated energy used at the station is 250 kWh per day and is subtracted from the generation to obtain net generation.

Recommendations for Yauco 1 include:

- Optimize reservoir operations
- Upgrade balance of plant mechanical systems
- Replace runner
- Automate needle selection
- Perform generator testing/inspection
- Overhaul and rewind the generator, up-rate the generator to 25 MW or 30 MVA at 0.85 PF
- Install a Howell-Bunger type turbine bypass valve

The potential average annual net generation for Yauco 1 is estimated using the same basic assumptions with the following exceptions:

- Available flow into the Guayo reservoir based on USGS gage data. Outflows are based on operating the reservoir at elevation 1459.7 during the dry season and 1456.8 during the wet season with turbine operation up to 24 hours per day when the reservoir is at higher than the target levels.

Table 11-1 Yauco 1 Existing and Potential Average Annual Generation

	HISTORICAL	EXISTING, NO DREDGING OR AUTOMATION	DREDGING AND AUTOMATION	DREDGING AND AUTOMATION – RULE CURVE 1	DREDGING AND AUTOMATION – RULE CURVE 2
Avg Annual MWh	45*	33,000	55,300	53,300	54,000
Capacity Factor	0.00	0.15	0.25	0.24	0.24
* The Yauco 1 plant has been offline since 2014 due to excessive vibrations in the runner.					

11.3 VARIATION OF HEAD AND FLOW CONDITIONS AT THE SITE

The water elevation of the Guayo reservoir is held basically constant at 1460 feet of elevation, and free discharge from the Pelton nozzle at centerline elevation of 587 feet. The gross head is 873 feet.

The flow varies considerably from a minimum flow of 0 cfs to a maximum of 420 cfs (turbine design flow).

11.4 RELIABILITY AND SUFFICIENCY OF AVAILABLE PROJECT DATA

The USGS performed sedimentation studies for Guayo, Yahuecas, and Prieto in 1997 and for Luchetti in 2014. A previous study conducted by Black & Veatch provided water inflows to the reservoirs. The flow data covered the years 1985 through 2005 for a total of 20 years. This is a sufficient length of time to get an estimate of annual average net generation.

11.5 POTENTIAL OPPORTUNITIES FOR INCREASED PERFORMANCE

The system shows significant spills from Prieto and Yahuecas diversions, so changing the operating rule curve for Guayo could allow more diversion flows into the main storage reservoir. Additionally, the Prieto and Yahuecas reservoirs are essentially filled with sediment and implementing methods to pass sediment and maintain diversion capacity, or dredging of the reservoirs is a good method of increasing power generation. The tunnels may also be partially blocked with sediment and should be inspected if possible and cleaned out to allow maximum capacity of diversion flows and transfer of water from Guayo to Yauco 1.

Reinstallation of the turbine for Yauco 1 will be necessary to allow power production to resume. Either new buckets, or a complete runner replacement is necessary.

11.6 RESERVOIR SEDIMENTATION STUDIES AND STAGE STORAGE CURVES

The most recent USGS sedimentation study for Lago Yahuecas which we have found is a study from March 2001. This study concludes that the long term capacity loss is 28.3 ac-ft per year and a storage capacity of 267 ac-ft at the time of the study. The estimated remaining useful life (from 1997) was 10 years. Note that this reservoir effectively has no storage at this time.

The most recent USGS sedimentation study for Lago Prieto which we have found is a study from October 1997. This study concludes that the long term capacity loss is 10.5 ac-ft per year and a storage capacity of 181 ac-ft at the time of the study. The estimated remaining useful life (from 1997) was 17 years. Note that this reservoir effectively has no storage at this time.

The most recent USGS sedimentation study for Lago Guayo which we have found is a study from October 1997. This study concludes that the long term capacity loss is 48.6 ac-ft per year and a storage capacity of 13,434 ac-ft at the time of the study. The estimated remaining useful life (from 1997) was 276 years. Table 11-2 shows the stage storage curve for Lago Guayo.

Table 11-2 Guayo Stage Storage Curves

ELEVATION (FT)	GUAYO 1997 STORAGE (AC-FT)	GUAYO EST 2021 STORAGE (AC-FT)
1460	13,782.1	12,992.9
1455	12,566.1	11,846.5
1450	11,106.8	10,470.8
1445	9,647.5	9,095.1
1440	8,755.7	8,254.3
1435	7,945.0	7,490.1
1430	7,134.3	6,725.8
1425	6,404.6	6,037.9
1420	5,431.8	5,120.7

11.7 RESERVOIR OPERATING RULE CURVES

The Guayo reservoir is a large storage reservoir and has an operating rule curve The Prieto, and Yahuecas reservoirs do have some nominal storage but are generally not used for storage purposes but operated as diversions structures. Based on the high sedimentation rates, it is recommended that a sediment passing gate be installed in both dams and they continue to operate as run of river diversion structures. The following two trial operating rule curves were developed from the typical rainfall patterns for Puerto Rico to determine if additional generation could be achieved. Note that for the Yauco 1 net generation, the Guayo reservoir was modeled as being dredged to remove approximately 1,065 acre feet of sediment.

Stage storage curves are taken from the data provided in the Task 300 Water Availability Model Review technical memorandum.

Table 11-3 below shows the Guayo reservoir operating rule curves used in this study.

Table 11-3 Guayo Reservoir Operating Rule Curves

RULE CURVE	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
Existing	1460	1460	1460	1460	1460	1460	1460	1460	1460	1460	1460	1460
Rule Curve 1	1460	1445	1430	1400	1425	1450	1430	1410	1400	1415	1430	1445
Rule Curve 2	1460	1455	1450	1440	1455	1460	1440	1440	1440	1450	1460	1460

The historic generation is compared to the modeled generation for the existing conditions. The three diversions are mostly filled with sediment, but the storage reservoir (Guayo) has significant storage remaining. The two sediment filled reservoirs could be dredged, or modified to pass sediment, and the intakes cleaned out and returned to full capacity. Automation may be used to allow more generation and avoid spills at the three reservoirs, and by operating 24 hours per day.

As shown in the table, there is very little change in the Yauco 1 net generation with a change in operating rule curves. This likely indicates that the water balance model (WBM) which previously optimized the rule curves is largely correct and only minor improvements can be made. The model is indicating little spill with the WBM or the new trial rule curves except during large storm events. In the case of large tropical storm events, operating the reservoir at a lower level would be unlikely to stop the reservoir from spilling. Additionally, the unit is oversized for the available water, and can rapidly draw down the Guayo reservoir immediately before, or after a storm and relatively little water is spilled.

11.8 RECOMMENDATIONS TO IMPROVE CIVIL AND MECHANICAL RELIABILITY

The powerhouse is in serviceable condition with some repairs necessary. The following recommendations for improving the civil and mechanical reliability are:

- Dredge the Yahuecas and Prieto Reservoirs or implement a gate system to allow passing sediment during high flow periods to avoid refilling the reservoirs with sediment.
- Clean out intakes and tunnels if filled with sediment.
- Replace broken or worn out ventilation equipment. Replace broken glass in windows, and window opening mechanisms which are broken or seized in place.
- Replace the cooling water filters with an automatic backflushing strainer to reduce the possibility of clogging the filters. Consider replacing cooling water system with a new system that is pumped from the tailwater.
- Fix the leaking oil seal on jet valve no. 6.
- Consider removing the penstock taps as this is a high pressure system and leaks could cause catastrophic flooding of the powerhouse.
- Replace the sump pumps and discharge piping.
- To modernize the facility and provide automatic two, four and six needle operation, the mechanical governor can be converted to a digital governor with an electronic controller and touchscreen graphic operator interface OITs.

11.9 RECOMMENDATIONS TO IMPROVE ELECTRICAL SAFETY AND RELIABILITY

The generator is rated 25 MVA, 13.8 KV and has the original 1953 winding. The windings are well beyond their service life and are due for a rewind with modern insulation.

To modernize the facility, replace the original excitation system, voltage regulator and field breaker with a more modern, static excitation system.

The neutral breaker is an original, now obsolete technology and should be replaced due to age. Modern designs would replace the neutral breaker with low or high resistance grounding system to reduce damage to the generator from a line-to-ground fault.

Based on the fact that this unit has had significant vibration issues, recommend adding a vibration monitoring instrumentation to the turbine and generator which can be input to the plant control system for trending and unit protection.

There is a 46 KV, 600 amp oil circuit breaker located on the roof of the powerhouse for the generator dated 1953 and is beyond its design life. Use of OCBs on the roof also presents an environmental and safety hazard. The breaker can be replaced with an SF6 or other non-oil type modern, fast-acting breaker to improve system reliability and asset protection.

The Westinghouse generator step-up transformer is rated 38 KV : 13.8 KV, 20 / 26.6 / 33.3 MVA OA, FOA, FOA @ 55 °C rise and appears to be beyond its design life. Transformer oil and other testing will determine the condition, trending multiple tests over time will be useful in projecting useful life and schedule for replacement. When the transformer is replaced, it will be designed with less flammable fluid need to be relocated farther away from the powerhouse to meet current standards.

The bus from the GSU up to the roof-located "switchyard" does not appear to have safe physical clearances from accessible locations. It appears that this could be revised at a nominal cost, due to the vertical orientation of the bus changing to horizontal.

There is a walk-in main control panel in the control room with protective relays on the front and back sections. There are a lot of single function, electromechanical protective relays of various ages and a few solid-state relays. The walk-in main control panel also has control switches, indicating lights, an outdated Westinghouse automatic synchronizer, synchscope and other devices, many of which are beyond their design life. The main control panel wiring has many wires which appear to have asbestos containing insulation. To modernize the facility, an automated control system with graphic displays on an operator workstation can be provided. The walk-in main control panel should be replaced with a modern control, digital protection and metering system.

11.10 RECOMMENDATIONS TO IMPROVE PLANT COMMUNICATIONS SYSTEM

Currently, the microwave at this plant is not in service and should be restored for remote ECC monitoring and control.

11.11 POTENTIAL FOR AUTOMATED FREQUENCY RESPONSE

The governor is a mechanical-hydraulic cabinet actuator type supplied by Woodward Governor Company. When Pelton turbines are required to operate over a wide load range, it is common for the governor to provide automatic change between one-needle up to six-needle operation to provide a higher efficiency over the load range compared to a constant six-needle operation. This operation is not provided by the existing governor. If the governor is tuned and working properly, it should provide automatic response to frequency changes. To modernize the facility, the mechanical governor can be converted to a digital governor as recommended above. Including needle sequencing as part of the governor control will improve the unit efficiency.

11.12 POTENTIAL FOR REMOTE CONTROL

There is an outdated HSQ Technology 2500 Series RTU with failed circuit boards resulting in some lost functionality for remote monitoring and control. The ECC had the ability to remotely adjust load and voltage, this functionality needs repaired. The ECC used to be able to remotely start and stop the unit, this capability is no longer working and needs to be repaired. The ECC used to be able to remotely start the emergency generator, this functionality is no longer working.

Communication between the plant and the ECC can be restored. The plant SCADA system can be repaired or upgraded restoring the previous remote control functionality.

11.13 ECONOMIC ANALYSIS

Yauco 1 is currently an inactive hydroelectric facility. Several improvements have been recommended and vary around implementing improvement to the existing Reservoir Operations. Line 2 of Table 11-4, Dredging, has the highest NPV of $166.5 million for this facility. However, Line 3 of Table 11-4, Dredging and Modify Yahuecas and Prieto to pass Sediment, Full Auto, provides an improvement that will produce the second-highest NPV of about $161.6 million and an adjusted payback period of 2.2 years. It has a much lower initial investment of $17.5 million. Yauco 1 is the largest hydroelectric facility operated by PREPA at 25.0 MW, and this improvement produces the highest energy output. Based on the water balance model for the diversion and storage dams in the Yauco hydroelectric system, the optimized model is estimating the average annual net generation for Yauco 1 is 55,300 MWh.

The major work recommended to return Yauco 1 to service is to refurbish the turbine, automate needle selection, overhaul generator, optimize reservoir operations and install a Howell Bunger turbine bypass valve.

Table 11-4 Yauco 1 Economic Feasibility Analysis Results

LINE	YAUCO 1 IMPROVEMENT	NET PRESENT VALUE ($)	ANNUAL AVERAGE COST	ADJUSTED PAYBACK PERIOD (YEARS)	TOTAL CAPITAL COST ($)	CAPACITY FACTOR (%)	FACILITY CAPACITY (MW)
1	Refurbished	90,159,000	1,606,000	8.1	36,600,000	15.1%	25
2	Dredging	166,491,000	1,527,000	4.4	36,600,000	25.3%	25
3	Dredging & modify Yahuecas & Prieto to pass sediment (full Auto)	161,590,000	2,080,000	2.2	17,500,000	25.3%	25
4	Dredging & modify Yahuecas & Prieto (full Auto) to pass sediment Rule Curve 1	154,823,000	2,080,000	2.3	17,500,000	24.3%	25
5	Dredging & modify Yahuecas & Prieto (full Auto) to pass sediment Rule Curve 2	157,192,000	2,080,000	2.2	17,500,000	24.7%	25

12 Yauco 2

The Yauco 2 hydroelectric system consists of five reservoirs, diversion tunnels and two plant developments (Yauco 1 and 2) that are in cascading order with Yauco 1 being the upstream development. The system is operational but requires refurbishing the unit in Yauco 1 to return it to service. There is a dredging project which is being performed separately using FEMA funding to improve storage for irrigation purposes. This will improve the generation of the Yauco system but is not included in the economic evaluation as the funding is outside the scope of the work. See Figure 2-5 for plan view of the system, including the system watersheds.

Yauco 2 was constructed in 1953 and contains two 4 MW vertical reaction generating units. The powerhouse structure is in good condition with all the mechanical and electrical equipment functioning. The penstock appears to be in good condition.

Figure 12-1 Yauco 2 Hydroelectric Plant Photo

12.1 EXISTING AND POTENTIAL INSTALLED CAPACITY

The existing capacity of Yauco 2 is 9 MW. The system is currently water limited; therefore, the potential capacity is the current capacity of 9 MW.

12.2 EXISTING AND POTENTIAL AVERAGE ANNUAL GENERATION

The historic generation is compared to the modeled generation for the existing conditions. The Luchetti reservoir has significant storage remaining. The primary means of increasing Yauco 2 generation is to increase the flow available for Yauco 1 which discharges into Lago Luchetti. The two sediment filled reservoirs could be dredged, or modified to pass sediment, and the intakes cleaned out and returned to full capacity. Automation may be used to allow more generation and avoid spills at the three reservoirs, and by operating 24 hours per day. See Table 12-1 below for a summary of cases and annual average generation and capacity factors. Historical generation is based on output from 2016 through 2020.

Average annual generation was calculated using the existing capacities of the Yauco 2 plant and the following considerations in the model:

- Available flow into the Luchetti reservoir based on USGS gage data with historical reservoir operational rules.
- Gross head based on reservoir operating levels. Net head based on gross head minus calculated headloss.
- Turbine efficiency of 85% is based on a typical turbine efficiency of the same time period.
- Turbines were modeled as operating from 50% power up to 100% rated power to maximize energy production.
- Estimated generator efficiency of 96% and estimated step up transformer efficiency of 98%.
- Estimated energy used at the station is 250 kWh per day and is subtracted from the generation to obtain net generation.

The potential average annual net generation for Yauco 2 is estimated using the same basic assumptions with the following exceptions:

- Available flow into the Luchetti reservoir based on USGS gage data. Outflows are based on operating the reservoir at elevation 569.8 during the dry season and 568.3 during the wet season with turbine operation up to 24 hours per day when the reservoir is at higher than the target levels.

The average annual generation with the improvements and automation is 19,800 MWh.

Based on the condition assessment, the following list summarizes the primary recommendations for upgrading the Yauco 2 system. These recommendations are used to determine capital costs for evaluating the economic viability or rehabilitating and upgrading the Yauco 2 project.

Recommendations for Yauco 2 include:

- Optimize reservoir operations
- Upgrade balance of plant mechanical systems
- Upgrade balance of plant electrical systems

Table 12-1 Yauco 2 Existing and Potential Average Annual Generation

CASE	HISTORICAL	EXISTING, NO DREDGING OR AUTOMATION	DREDGING AND AUTOMATION	DREDGING AND AUTOMATION – RULE CURVE 1	DREDGING AND AUTOMATION – RULE CURVE 2
Yauco 2 Avg Annual MWh	7,523	20,300	27,300	19,600	22,400
Capacity Factor	0.10	0.26	0.35	0.25	0.29

12.3 VARIATION OF HEAD AND FLOW CONDITIONS AT THE SITE

The water elevation of the Luchetti reservoir is between elevations 552 feet and 570 feet of elevation, and Lago Loco downstream is held between 228 and 235 feet. The gross head is between 342 feet and 317 feet.

The flow varies considerably from a minimum flow of 0 cfs to a maximum of 400 cfs (total turbine flow). A water withdrawal from the Luchetti Reservoir by PRASA of up to 8 MGD was accounted for in the water availability (PRASA withdrawal always present at 8 MGD).

12.4 RELIABILITY AND SUFFICIENCY OF AVAILABLE PROJECT DATA

The USGS performed sedimentation studies for Guayo, Yahuecas, and Prieto in 1997 and for Luchetti in 2014. A previous study conducted by Black & Veatch provided water inflows to the reservoirs. The flow data covered the years 1985 through 2005 for a total of 20 years. This is a sufficient length of time to get an estimate of annual average net generation.

12.5 POTENTIAL OPPORTUNITIES FOR INCREASED PERFORMANCE

The system shows significant spills from Prieto and Yahuecas diversions, so changing the operating rule curve for Guayo could allow more diversion flows into the main storage reservoir. Additionally, the Prieto and Yahuecas reservoirs are essentially filled with sediment and implementing methods to pass sediment and maintain diversion capacity or dredging of the reservoirs is a good method of increasing power generation. The tunnels may also be partially blocked with sediment and should be inspected if possible and cleaned out to allow maximum capacity of diversion flows and transfer of water from Guayo to Yauco 1 which increases water available to Yauco 2 through Lago Luchetti.

12.6 RESERVOIR SEDIMENTATION STUDIES AND STAGE STORAGE CURVES

The most recent USGS sedimentation study for Lago Luchetti which we have found is a study from 2014. This study concludes that the long term capacity loss is 129.7 ac-ft per year and a storage capacity of 8,277 ac-ft at the time of the study. The estimated remaining useful life (from 2014) was 62 years. Table 12-2 shows the stage storage curves for Lago Luchetti.

Table 12-2 Luchetti Stage Storage Curves

ELEVATION (FT)	LUCHETTI 2014 STORAGE (AC-FT)	LUCHETTI EST 2021 STORAGE (AC-FT)
570	8,277.4	7,803.4
566.7	7,531.5	7,100.3
563.5	6,842.4	6,450.6
560.2	6,201.9	5,846.6
556.9	5,610.1	5,288.9
553.6	5,050.7	4,761.5
550.3	4,531.9	4,272.4

12.7 RESERVOIR OPERATING RULE CURVES

The Luchetti reservoir is a large storage reservoir and has an operating rule curve. The following two trial operating rule curves were developed from the typical rainfall patterns for Puerto Rico to determine if additional generation could be achieved. Note that for the Yauco 2 net generation, the Luchetti reservoir was modeled as being dredged to remove approximately 1,820 acre feet of sediment.

Stage storage curves are taken from the data provided in the Task 300 Water Availability Model Review technical memorandum.

Table 12-3 below shows the Luchetti reservoir operating rule curves used in this study.

Table 12-3 Luchetti Reservoir Operating Rule Curves

RULE CURVE	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
Existing	552	552	552	552	552	552	552	552	552	552	552	552
Rule Curve 1	565	560	555	550	560	565	555	550	550	550	555	560
Rule Curve 2	565	555	545	535	545	560	545	530	530	540	550	560

The historic generation is compared to the modeled generation for the existing conditions. The Luchetti reservoir has significant storage remaining. The primary means of increasing Yauco 2 generation is to increase the flow available for Yauco 1, which discharges into Lago Luchetti. The two sediment filled reservoirs could be dredged, or modified to pass sediment, and the intakes cleaned out and returned to full capacity. Automation may be used to allow more generation and avoid spills at the three reservoirs, and by operating 24 hours per day.

As shown in the table, there is very little change in the Yauco 2 net generation with a change in operating rule curves. This likely indicates that the WBM which previously optimized the rule curves is largely correct and only minor improvements may be made. The model is indicating little spill with the WBM or the new trial rule curves except during large storm events. In the case of large tropical storm events, operating the reservoir at a lower level would be unlikely to stop the reservoir from spilling. Additionally, the units are oversized for the available water, and can rapidly draw down the Luchetti reservoir immediately before, or after a storm and relatively little water is spilled.

12.8 RECOMMENDATIONS TO IMPROVE CIVIL AND MECHANICAL RELIABILITY

The powerhouse is in serviceable condition with some repairs necessary. The following recommendations for improving the civil and mechanical reliability are:

- Inspect turbine runners to determine if excessive wear is present. The governor appeared to be at full gate but was significantly short of the rated power.
- Dredge the Yahuecas and Prieto Reservoirs or implement a gate system to allow passing sediment during high flow periods to avoid refilling the reservoirs with sediment.

- Dredge Lago Luchetti in the area around the intake for Yauco 2 as significant sediment is being passed through the turbines.
- Clean out intakes and tunnels if filled with sediment.
- Replace broken or worn out ventilation equipment.
- Replace the cooling water filters with an automatic backflushing strainer to reduce the possibility of clogging the filters.
- Fix the leaking cooling water pipe between U1 and U2.
- Consider removing the penstock taps as this is a high pressure system and leaks could cause catastrophic flooding of the powerhouse.
- Replace the sump pump seal which is leaking and discharge piping.
- The mechanical governor is a gate shaft Type HR manufactured by Woodward Governor Company. To modernize the facility, the mechanical governors can be converted to digital governors with electronic controllers and touchscreen graphic OITs.

12.9 RECOMMENDATIONS TO IMPROVE ELECTRICAL SAFETY AND RELIABILITY

There was a thermographic inspection of the main exciters in 2020 and the condition noted for one that the unit needs repair. Detailed inspection and assessment of the pilot exciter is necessary to determine if refurbishment or replacement is required. Each generator has the original motorized voltage regulator rheostat and field breaker which have exceeded their design life. Recommend either re-furbishing the exciters and replacing the voltage regulator and field breaker or replacing it all with a modern static excitation system. The voltage regulator and field breaker should either be re-furbished or be replaced with a modern static excitation system.

There are not circuit breakers at the same voltage as the generators at this facility. Each generator has a dedicated step-up transformer to 38 KV and high voltage circuit breaker located in the switchyard. The original breaker for Generator 1 was replaced with a 72.5 KV SF6 line breaker manufactured by Alstom in 2012. The Generator 2 step-up transformer is connected to the original high voltage oil circuit breaker which has exceeded its design life and should be replaced. The generator three-phase step-up transformers are beyond their design life. Transformer oil and other testing will determine the condition, trending multiple tests over time will be useful in projecting useful life and schedule for replacement.

The lightning arresters are in the switchyard, located further away from the powerhouse than current engineering practice advises. There is a section of overhead generator conductors, perhaps 100 feet in length, that provide a direct steep wave front exposure path should lightning strike. Recommend an engineering study be performed to evaluate the adequacy and location of lightning arresters for protection of the generators.

There are original DC and AC panelboards in the main control room that are beyond their design life and should be replaced to ensure the breakers function properly.

There is a walk-in main control panel in the control room with a lot of single function, electromechanical protective relays of various ages and a few solid-state relays. The walk-in main control panel has control switches, indicating lights and other devices, many of which are beyond their design life. To modernize the facility, an automated control system with graphic displays on an operator workstation can be provided. The walk-in main control panel can be replaced with a modern control, digital protection and metering system.

12.10 RECOMMENDATIONS TO IMPROVE PLANT COMMUNICATIONS SYSTEM

There is a functioning microwave communication to the plant allowing ECC remote monitoring and load / voltage control.

12.11 POTENTIAL FOR AUTOMATED FREQUENCY RESPONSE

Each unit has a gate shaft Type HR mechanical governor manufactured by Woodward Governor Company. It is reported that the governors respond well. The wicket gates can be controlled locally from the main control panel. Once online, the unit load can be controlled remotely from ECC. If the governor is tuned and working properly, it should provide automatic response to frequency changes. To modernize the facility, the mechanical governors can be converted to digital as recommended above.

12.12 POTENTIAL FOR REMOTE CONTROL

The plant has a modern Harris RTU panel and an outdated HSQ Technology 2500 Series RTU panel.

The units are run in synchronous condense mode allowing ECC load and voltage control. The units are manually put online and shut down locally. In order to expand ECC operation to include remote startup, shutdown control of the units, the manual startup / shutdown sequences including synchronization would need to be automated.

12.13 ECONOMIC ANALYSIS

Yauco 2 is currently an active hydroelectric facility. Several improvements have been recommended that vary around implementing improvements to the existing Reservoir Operations. Line 3 of Table 12-4, Dredging and modify Yahuecas and Prieto to pass sediment (full Auto), provides an improvement that will produce the highest NPV of about $92.0 million and the lowest adjusted payback period of 0.7 years. The capital-related cost is $3.2 million. Based on the water balance model for the diversion and storage dams in the Yauco hydroelectric system, the optimized model is estimating the average annual net generation for Yauco 2 is 27,300 MWh.

The major work recommended to maintain the reliability of Yauco 2 is to upgrade the balance of plant mechanical systems, upgrade the balance of plant electrical systems, optimize reservoir operations and install a turbine bypass.

Table 12-4 Yauco 2 Economic Feasibility Analysis Results

LINE	IMPROVEMENT	NET PRESENT VALUE ($)	ANNUAL AVERAGE COST	ADJUSTED PAYBACK PERIOD (YEARS)	TOTAL CAPITAL COST ($)	CAPACITY FACTOR (%)	FACILITY CAPACITY (MW)
1	Refurbished	67,481,000	666,000	0.8	2,700,000	23.2%	10
2	Dredging	92,591,000	744,000	0.6	2,700,000	31.2%	10
3	Dredging and modify Yahuecas and Prieto to pass sediment (full Auto)	92,008,000	789,000	0.7	3,176,000	31.2%	10
4	Dredging and modify Yahuecas and Prieto (full Auto) to pass sediment Rule Curve 1	63,426,000	789,000	1.0	3,176,000	22.4%	10
5	Dredging and modify Yahuecas and Prieto (full Auto) to pass sediment Rule Curve 2	73,820,000	789,000	0.9	3,176,000	25.6%	10

13 Río Blanco System

The Río Blanco Hydroelectric System consists of five small diversions, a conveyance pipe and one plant development. Refer to Figure 2-6 for a plan view of the Río Blanco hydroelectric system, including the system watersheds.

The powerhouse was constructed in 1930 and contains two 2.5 MW horizontal Pelton type generating units. The facility is in fair condition structurally with the turbines and generators in operational condition; however, the system has not been operated since May of 2011 due to penstock stability concerns. Part of the conveyance system from the upstream diversion dam (Cubuy diversion) to the second diversion (Sabana diversion) is ruptured and no longer in service. There is a FEMA funded project to replace the penstock and return the Río Blanco powerhouse to service.

Figure 13-1 Río Blanco Hydroelectric Plant Photo

13.1 EXISTING AND POTENTIAL INSTALLED CAPACITY

The existing capacity of Río Blanco is 5 MW. The system is currently water limited; therefore, the potential capacity is the current capacity of 5 MW.

13.2 EXISTING AND POTENTIAL AVERAGE ANNUAL GENERATION

The historic generation is compared to the modeled generation for the existing conditions. The five small diversions were out of service as there are various pipe issues and the penstock is out of service, but there are no other major facilities to consider modifying operation to increase generation. Automation may be used to allow more generation and avoid spills at the diversions, and by operating 24 hours per day. See Table 13-1 below for a summary of cases and annual average generation and capacity factors.

Average annual generation was calculated using the existing capacities of the Río Blanco plant and the following considerations in the model:

- Available flows from the small diversions without storage less spills at Icacos for minimum stream flow (USGS stream gauge data). Turbines are operated 24 hours per day 7 days per week. Flow from Cubuy diversion is not contributing as the pipeline is ruptured.
- Gross head based on diversion elevation. Net head based on gross head minus calculated headloss.
- Turbine efficiency of 85% is based on generic turbine efficiency curves for runners of the same time period.
- Turbines were modeled as operating from 20% power up to 100% rated power to maximize energy production.
- Estimated generator efficiency of 96% and estimated step up transformer efficiency of 98%.
- Estimated energy used at the station is 200 kWh per day and is subtracted from the generation to obtain net generation.

The potential average annual net generation for Río Blanco is estimated using the same basic assumptions with the following exceptions:

- Return the Cubuy diversion to service.

Based on the condition assessment, the following list summarizes the primary recommendations for upgrading the Río Blanco system. These recommendations are used to determine capital costs for evaluating the economic viability or rehabilitating and upgrading the Río Blanco project.

Recommendations for Río Blanco include:

- Repair deficiencies in the structure
- Replace damaged conveyance pipe from the Rio Cubuy diversion
- Upgrade balance of plant electrical systems
- Automate controls
- Clean and inspect conveyance pipelines
- Implement diversion maintenance program

Table 13-1 Río Blanco Existing and Potential Average Annual Generation

CASE	RÍO BLANCO AVG ANNUAL MWH	CAPACITY FACTOR
Historical	0*	0.00
Existing (No pipe from Cubuy to Sabana)	5,620	0.13
Restored to Original Condition (all conveyance in service)	6,680	0.15
Automation for 24 hour Operation (all conveyance in service)	28,890	0.66
Tyrolean weirs, increase capacity of Cubuy intake to 13 cfs	6,970	0.16
Tyrolean weirs, increase capacity of Cubuy intake to 15 cfs	7,150	0.16
Tyrolean weirs, increase capacity of Sabana intake to 35 cfs	8,050	0.18
Tyrolean weirs, increase capacity of Mucara intake to 5 cfs	8,050	0.18
Increase Penstock Diameter to 36 inches	7,270	0.17
Increase Penstock Diameter to 42 inches	7,380	0.17
* The Río Blanco Powerhouse has been out of service or at reduced service for a significant period of time due to penstock issues.		

13.3 VARIATION OF HEAD AND FLOW CONDITIONS AT THE SITE

The water elevation of the "Forebay" is held basically constant at 1405 feet of elevation, and free discharge from the Pelton nozzle at centerline elevation of 107 feet. The gross head is 1,298 feet.

The flow varies considerably from a minimum flow of 0 cfs to a maximum of 54 cfs (turbine design flow).

13.4 RELIABILITY AND SUFFICIENCY OF AVAILABLE PROJECT DATA

The USGS performed a sedimentation study for Icacos Reservoir in 2004. A previous study conducted by CSA provided water inflows to the small diversions. The flow data covered the years 1945 through 1980 for a total of 35 years. This is a sufficient length of time to get an estimate of annual average net generation.

13.5 POTENTIAL OPPORTUNITIES FOR INCREASED PERFORMANCE

The flows available in the small diversions can supply more flow than necessary to operate the turbines at full capacity. The conveyance system seems to be appropriately sized to convey the full Río Blanco turbine discharge from the small diversions to the Río Blanco powerhouse. The various calculations for increasing the size of the diversion intakes or conveyance pipes and penstock have relatively minor improvements in total energy generation. The largest improvement in energy generation is to automate the system and operate the Río Blanco turbines as many hours as possible and have full remote operation.

13.6 RESERVOIR SEDIMENTATION STUDIES AND STAGE STORAGE CURVES

The most recent USGS sedimentation study for Lago Icacos which we have found is a study from March 2004. This study concludes that the long term capacity loss is 0.06 ac-ft per year and a storage capacity of 6 ac-ft at the time of the study. The estimated remaining useful life (from 2004) was 105 years. Note that this reservoir effectively has no storage at this time. Table 13-2 shows the stage storage curve for the Icacos reservoir.

Table 13-2 Icacos Stage Storage Curves

ELEVATION (FT)	ICACOS 2004 STORAGE (AC-FT)	ICACOS EST 2021 STORAGE (AC-FT)
1860	6.0	5.7
1859	5.2	4.9
1858	4.4	4.1
1857	3.7	3.5
1856	3.1	2.9
1855	2.5	2.4
1854	1.9	1.8
1853	1.5	1.4

Based on the latest USGS sedimentation survey and extrapolating the accumulated sediment, it is estimated that the Icacos reservoir has only about 5 acre feet of storage, and any reservoir operating rule curve is unlikely to make a noticeable change in net generation. It is recommended that this reservoir continue to be operated as a run of river small diversion.

13.7 RECOMMENDATIONS TO IMPROVE CIVIL AND MECHANICAL RELIABILITY

The powerhouse is in good condition with some repairs necessary. The following recommendations for improving the civil and mechanical reliability are:

- Dredge the small diversions and construct a means of sediment passage to reduce future maintenance, possibly a Tyrolean weir.
- Replace damaged conveyance pipe between Cubuy and Sabana (currently a project is in the planning stage to complete this).
- Inspect penstock and repair any stability issues or replace pipe which has corroded and can no longer handle the pressures.
- The governor is a mechanical type deriving its operating power from a leather belt on the turbine/generator shaft. Speed sensing is via another leather belt on the shaft. To modernize the facility and remove personnel exposure to the moving leather belts, the mechanical governors can be converted to digital governors with electronic controllers and touchscreen graphic OITs.

13.8 RECOMMENDATIONS TO IMPROVE ELECTRICAL SAFETY AND RELIABILITY

The original field breakers are mounted on the wall in the control room. The voltage regulation is original, manual rheostat type that is exposed behind the main control panel. The voltage regulator and field breaker should be replaced with a modern static excitation system.

There are mechanical linkages from large levers through the front of the main control panel to the 4400 V oil circuit breakers located behind the panel. The breakers are manually closed from the front of the main control panel. There is an oil circuit breaker for each generator and for station service. These oil circuit breakers are outdated and pose a safety threat to operating personnel and the facility. There is also exposed bus, CT's and PT's behind the main control panel. The oil circuit breakers, exposed bus, CT's and PT's should be replaced.

One generator step-up transformer serves both generators, rated 38 KV : 4,160 KV and 5000 KVA @ 55° C/ 5600 @ 65° C / 7500 @ 65° C FA. Transformer oil and other testing will determine the condition, trending multiple tests over time will be useful in projecting useful life and schedule for replacement.

Recommend replacing the 120 / 208 V distribution panel in the outdoor station service lineup to ensure reliability.

There is a main control panel in the control room with protective relays that are single function, electromechanical type of various ages and a few solid-state relays. The main control panel has outdated control switches, indicating lights, auxiliary relays and mechanical flag type annunciators. The main control panel has many wires which appear to have asbestos containing insulation. The back of the main control panel is a safety hazard due to the exposed conductors and it lacks sufficient clearances, guarding and enclosures. To modernize the facility, an automated control system with graphic displays on an operator workstation can be provided. The main control panel should be replaced with a modern control, digital protection and metering system

13.9 RECOMMENDATIONS TO IMPROVE PLANT COMMUNICATIONS SYSTEM

There is a functioning fiber optic network to the plant allowing remote monitoring at the ECC.

13.10 POTENTIAL FOR AUTOMATED FREQUENCY RESPONSE

The governors are a mechanical type deriving its operating power from a leather belt on the turbine/generator shaft. The units are equipped with flywheels to increase momentum ride through and improve governing stability. If the governor is tuned and working properly, it should provide automatic response to frequency changes. To modernize the facility and remove exposure to the moving leather belts, the mechanical governors can be converted to digital as recommended above.

13.11 POTENTIAL FOR REMOTE CONTROL

The facility has an older Harris RTU providing the ECC data for remote monitoring. The ECC does not have remote control at this facility.

In order to provide ECC remote startup, shutdown control of the units, the manual startup and shutdown sequences including synchronization would need to be automated. The mechanical governors, voltage regulator rheostats, and manually operated, oil type generator circuit breakers would need to be replaced. The existing SCADA RTU would need to be modified or replaced to support remote ECC operation.

Previously the inlet valve located above the powerhouse was hardwire controlled from the powerhouse, this is no longer functional. There are plans to add a microwave between the inlet valve and the powerhouse to allow valve control from the powerhouse.

13.12 ECONOMIC ANALYSIS

Río Blanco is currently an inactive hydroelectric facility. Several improvements have been recommended and vary around rehabilitating or replacing the existing penstock and other piping and turbine repair. Line 3 of Table 13-3, full Auto, provides an improvement that has produced an NPV of $88.2 million and an adjusted payback period of only 0.3 years. This improvement is one of the two that produces the highest energy output, and the capital-related cost is $1.2 million. Based on the daily model for run-of-river operation of the Río Blanco hydroelectric system, the estimated average annual net generation for Río Blanco is 28,890 MWh.

The major work recommended to return Río Blanco to service is to install a new penstock (under a separate FEMA project), replace ruptured conveyance pipe, install new electrical controls and automate the plant.

Table 13-3 Río Blanco Economic Feasibility Analysis Results

LINE	RÍO BLANCO IMPROVEMENT	NET PRESENT VALUE ($)	ANNUAL AVERAGE COST	ADJUSTED PAYBACK PERIOD (YEARS)	TOTAL CAPITAL COST ($)	CAPACITY FACTOR (%)	FACILITY CAPACITY (MW)
1	Refurbished	2,317,000	1,598,000	6.0	700,000	12.8%	5.0
2	Restore all diversions (FEMA Grant)	9,127,000	1,327,000	1.5	700,000	15.3%	5.0
3	All Diversions, Full Auto	88,214,000	1,374,000	0.3	1,200,000	66.0%	5.0
4	Tyrolean weirs all diversions, full Auto	87,761,000	1,409,000	0.4	1,570,000	66.0%	5.0

14 Summary

The portfolio suggested herein outlines the improvements that would produce a very positive NPV with a capital spending of $166.7 million and taking into consideration water resources management criteria that support rehabilitating certain systems even if they produce a negative NPV. The estimated energy generation potential from this portfolio is contingent upon implementing the recommended system rehabilitation and modernization works from Task 200 and operating the reservoirs in accordance with the recommended reservoir operating rule curves. A comparison of the increase in capacity and generation resulting from the recommended improvements are included in Table 14-1 below. While the recommended improvements result in a small decrease in capacity, the average annual generation will increase by approximately 500%. The capacity factor for the portfolio 2 is increased from just below 0.06 to 0.28 which meets the target capacity factor. As the capital investments to return facilities to active status or maintain and upgrade currently active facilities results in a highly positive NPV, it is recommended that the upgrades and refurbishment work be completed as it represents a good value for PREPA and its customers.

The listed improvements allow for automatic control of the units in each hydroelectric facility. The communication improvements allow for the control of the units from the ECC. These improvements will allow for greater flexibility in dispatching the units to meet generating needs and allow more economical operation over a wider time period to maximize energy generation when water is available.

Table 14-1 Generation Potential with Recommended Improvements

Facility	Existing Capacity (MW)	Average Annual Generation w/o Recommended Improvements [b] (MWh)	Potential Capacity with Recommended Improvements (MW)	Average Annual Generation with Recommended Improvements (MWh)	Percent Increase in Annual Generation
Dos Bocas	15.0	28,838	15.0	30,650	6%
Caonillas 1	20.0	5,711	20.0	54,400	852%
Caonillas 2	3.6	0	1.0	5,200	-
Toro Negro 1	8.6	5,123	8.6	26,700	420%
Toro Negro 2	1.9	85	1.9	3,300	3782%
Garzas 1	7.2	2,829	7.2	12,500	341%
Garzas 2	5.0	0	5.0	8,800	-
Yauco 1	20.0	45	20.0	55,300	122,789%
Yauco 2	8.0	7,523	8.0	27,300	263%
Río Blanco [a]	5.0[a]	0	5.0	28.890	-
Total	**94.3 (38.8 active)**	**50,154**	**91.7**	**253,040**	**504%**

a. Inactive since May 2011
b Average annual generation from the past 3 years

The portfolio of selected improvements generates a positive NPV in the amount of $687.5 million over the 30 year study period. Table 14-2 shows the projects by facility utilized in this portfolio.

Table 14-2 Summary of Capital Costs and NPV

Facility	Improvements	Total Capital Cost ($)	Net Present Value ($)(1)
Dos Bocas	Reliability Improvements	$5,946,000	$95,293,000
Caonillas 1	Reliability Improvements, and 1MW Caonillas 2 plant with bypass	$2,795,000	$188,204,000
Caonillas 2	New 1 MW full auto, with bypass and sediment passage gates	$20,300,000	($9,843,000)
Toro Negro 1	Rehabilitate Small Diversions with full Automation, New Penstocks in Future	$42,133,000	$31,241,000
Toro Negro 2	Full Automation, and Rule Curve 1, New Penstocks in Future	$22,077,000	($2,510,000)
Garzas 1	Tyrolean Weirs on Small Diversions, Full Automation, and Rule Curve 1, New Penstock in Future	$26,347,000	$23,638,000
Garzas 2	Tyrolean Weirs on Small Diversions, Full Automation, and Rule Curve 1, New Penstock in Future	$25,246,000	$19,615,000
Yauco 1	Modify Yahuecas and Prieto to Pass Sediment, Refurbish Electrical and Mechanical, Full Automation	$17,500,000	$161,590,000
Yauco 2	Modify Yahuecas and Prieto to Pass Sediment, Reliability Improvements, Full Automation	$3,176,000	$92,008,000
Río Blanco	Restore All Small Diversions to Service, Full Automation	$1,200,000	$88,214,000
Total		**$166,700,000**	**$687,500,000**

Exhibit B

Puerto Rico Electric Power Authority

Feasibility Study for Improvements to the PREPA's
Hydroelectric System - Status Report
June 29, 2021

- Status on Study Execution
  - PREPA and the Consultant have held 16 weekly progress meetings since the Notice to Proceed, in which the project action list is discussed and how to address and solve any situation that arises during the study.
  - The Consultant has submitted 5 progress reports. The study is at 90% completion and is on schedule to be completed as per the contract term requirement.
  - On March 27, 2021, as part of the assessment of the hydropower facilities, the Consultant prepared and submitted the draft of the Generation Capacity Report.
  - On April 27, 2021, as part of the assessment of the hydropower facilities, the Consultant prepared and submitted the final Generation Capacity Report.

- Status on Study Execution (Cont.)
  - On April 9, 2021, the Consultant prepared and submitted the draft of the Frequency Response and Remote Control Report.
  - On April 23, 2021, the Consultant prepared and submitted the draft of the Reservoir Rule Curve Optimization Report.
  - On April 27, 2021 the Consultant prepared and submitted the Reservoir Rule Curve Optimization Final Report.
  - On May 10, 2021, the Consultant prepared and submitted the draft of the Economic Feasibility technical memorandum.
  - On May 13, 2021, the Consultant prepared and submitted the final Frequency Response and Remote-Control technical memorandum.

- Status on Study Execution (Cont.)
  - On June 3, 2021, the Consultant prepared and submitted the final of the Economic Feasibility technical memorandum.
  - On June 5, 2021, the Consultant prepared and submitted the draft of the Final Summary Report.
  - On June 28, 2021, the Consultant prepared and submitted the Final Summary Report.

Feasibility Study for Improvements to the PREPA's Hydroelectric System - Status Report – June 2021

- **Project Timeline Status:**

Milestone	Schedule - Date	Status
Procurement Process for Services (Scope of Work Evaluation, Cost, Deliverables and Timeline)	September 15, 2020 – November 19, 2020	Completed
Contract Negotiation & Signature	January 5, 2021	Completed
Submittal & Approval of Project Work Plan	January 27, 2021	Completed
Task 202 – Site Visit	Feb 8-12, 2021	Completed
Task 201 – Draft Site Visit Memorandum	March 5, 2021	Completed
Task 201 – Draft Generation Capacity TM	March 26, 2021	Completed
Task 300 – Complete Review Water Availability Models	March 19, 2021	Completed
Task 400 – Draft Operating Scenarios TM	April 23, 2021	Completed
Task 400 – Final Operating Scenarios TM	April 27, 2021	Completed
Task 500 – Draft Evaluation for Frequency Response and Remote-Control TM	April 9, 2021	Completed
Task 500 – Final Report Frequency Resp and Remote Control	May 6, 2021	Completed
Task 600 – Draft Economic Feasibility Evaluation Report	May 10, 2021	Completed
Task 600 – Economic Feasibility Evaluation Final Report	June 3, 2021	Completed
Task 700 – Submit Final Summary Report Project Complete, 160 days after NTP	June 28, 2021	Completed

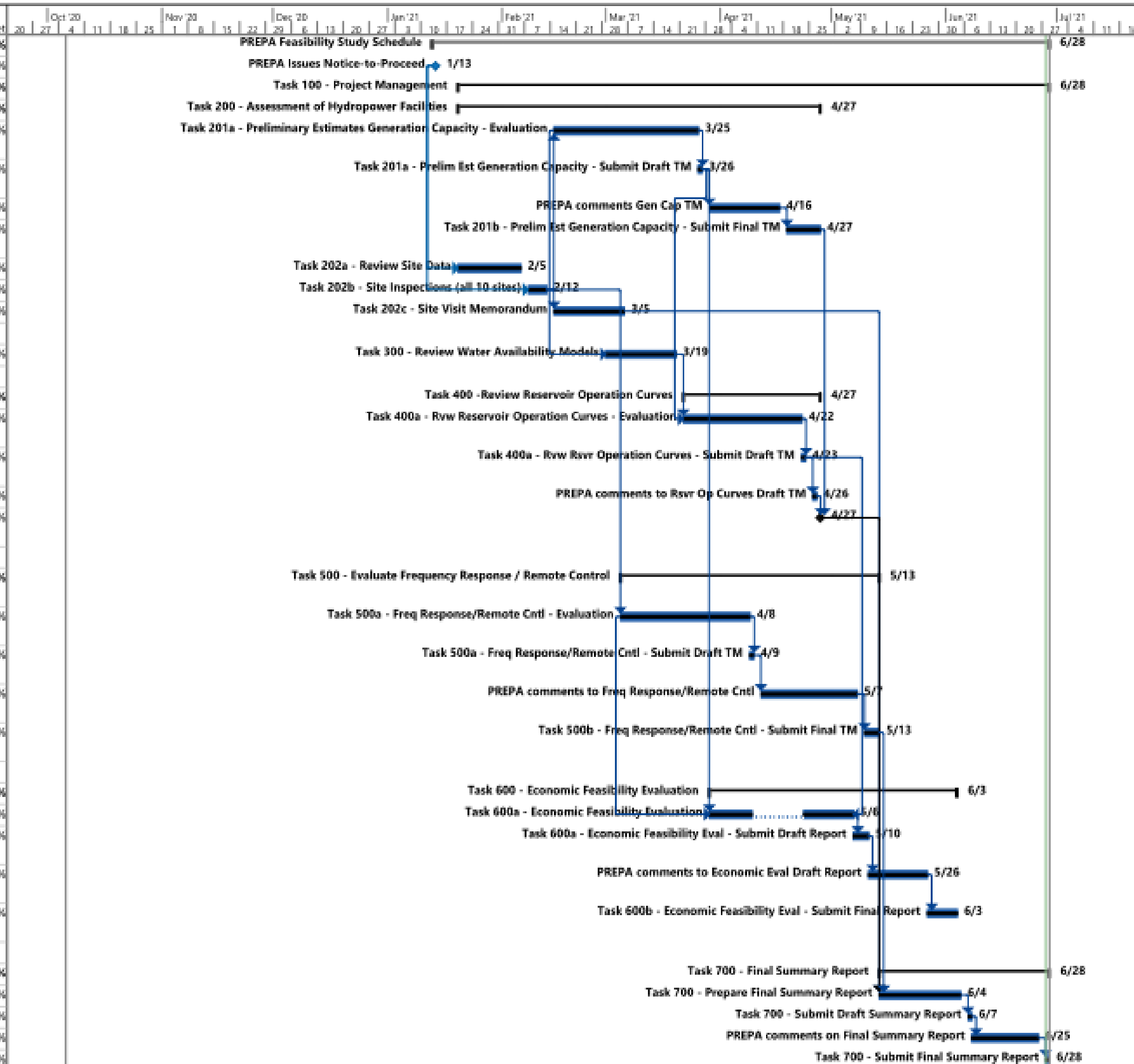
Feasibility Study for Improvements to the PREPA's Hydroelectric System - Status Report, June 2021

- **Project Milestones Payments Breakdown & Status:**

Milestone	Payment Amount	Payment Approval Date
Task 200 - Kick-Off Meeting, Document Review, Project Planning, Mobilization	$70,485	February 17, 2021
Task 200 - Site Visits Memorandum	$60,660	March 18, 2021
Task 200 - Draft Technical Memorandum – Generation Capacity	$30,206	April 14, 2021
Task 200 - Final Technical Memorandum – Generation Capacity	$5,849	April 27, 2021
Task 400 - Draft Technical Memorandum – Operating Scenarios	$83,330	April 23, 2021
Task 400 - Draft Technical Memorandum – Operating Scenarios	$10,130	April 27, 2021
Task 500 - Draft Technical Memorandum – Frequency Response/RC	$35,530	April 28, 2021
Task 500 - Final Technical Memorandum – Frequency Response/RC	$5,310	May 13, 2021
Task 600 - Economic Feasibility Criteria	$56,117	May 10, 2021
Task 600 - Draft Economic Feasibility Report	$56,117	May 10, 2021
Task 600 - Final Economic Feasibility Report	$4,676	June 13, 2021
Task 700 - Draft Feasibility Study Summary Report	$38,617	June 13, 2021
Task 700 - Final Feasibility Study Summary Report	$12,873	June 29, 2021

Feasibility Study for Improvements to the PREPA's Hydroelectric System Update Schedule – June 2021

ID		Task Mode	Task Name	Duration	Start	Finish	% Complete
0	✓		**PREPA Feasibility Study Schedule**	**119 days**	**Wed 1/13/21**	**Mon 6/28/2**	**100%**
1	✓		**PREPA Issues Notice-to-Proceed**	1 day	Wed 1/13/21	Wed 1/13/21	100%
2	✓		**Task 100 - Project Management**	**114 days**	**Wed 1/20/21**	**Mon 6/28/21**	**100%**
3	✓		**Task 200 - Assessment of Hydropower Facili**	**70 days**	**Wed 1/20/21**	**Tue 4/27/21**	**100%**
4	✓		Task 201a - Preliminary Estimates Generation Capacity - Evaluation	29 days	Mon 2/15/21	Thu 3/25/21	100%
5	✓		Task 201a - Prelim Est Generation Capacity - Submit Draft TM	1 day	Fri 3/26/21	Fri 3/26/21	100%
6	✓		PREPA comments Gen Cap TM	15 days	Mon 3/29/21	Fri 4/16/21	100%
7	✓		Task 201b - Prelim Est Generation Capacity - Submit Final TM	7 days	Mon 4/19/21	Tue 4/27/21	100%
8	✓		Task 202a - Review Site Data	13 days	Wed 1/20/21	Fri 2/5/21	100%
9	✓		Task 202b - Site Inspections (all 10 sites)	5 days	Mon 2/8/21	Fri 2/12/21	100%
10	✓		Task 202c - Site Visit Memorandum	15 days	Mon 2/15/21	Fri 3/5/21	100%
11							
12	✓		**Task 300 - Review Water Availability Model**	15 days	Mon 3/1/21	Fri 3/19/21	100%
13							
14	✓		**Task 400 -Review Reservoir Operation Curve**	**27 days**	**Mon 3/22/21**	**Tue 4/27/21**	**100%**
15	✓		Task 400a - Rvw Reservoir Operation Curves - Evaluation	24 days	Mon 3/22/21	Thu 4/22/21	100%
16	✓		Task 400a - Rvw Rsvr Operation Curves - Submit Draft TM	1 day	Fri 4/23/21	Fri 4/23/21	100%
17	✓		PREPA comments to Rsvr Op Curves Draft	1 day	Mon 4/26/21	Mon 4/26/21	100%
18	✓		Task 400b - Rvw Rsvr Operation Curves - Submit Final TM	0 days	Tue 4/27/21	Tue 4/27/21	100%
19							
20	✓		**Task 500 - Evaluate Frequency Response / Remote Control**	**50 days**	**Fri 3/5/21**	**Thu 5/13/21**	**100%**
21	✓		Task 500a - Freq Response/Remote Cntl - Evaluation	25 days	Fri 3/5/21	Thu 4/8/21	100%
22	✓		Task 500a - Freq Response/Remote Cntl - Submit Draft TM	1 day	Fri 4/9/21	Fri 4/9/21	100%
23	✓		PREPA comments to Freq Response/Remote Cntl	20 days	Mon 4/12/21	Fri 5/7/21	100%
24	✓		Task 500b - Freq Response/Remote Cntl - Submit Final TM	4 days	Mon 5/10/21	Thu 5/13/21	100%
25							
26	✓		**Task 600 - Economic Feasibility Evaluation**	**49 days**	**Mon 3/29/21**	**Thu 6/3/21**	**100%**
27	✓		Task 600a - Economic Feasibility Evaluatio	19 days	Mon 3/29/21	Thu 5/6/21	100%
28	✓		Task 600a - Economic Feasibility Eval - Submit Draft Report	2 days	Fri 5/7/21	Mon 5/10/21	100%
29	✓		PREPA comments to Economic Eval Draft Report	12 days	Tue 5/11/21	Wed 5/26/21	100%
30	✓		Task 600b - Economic Feasibility Eval - Submit Final Report	6 days	Thu 5/27/21	Thu 6/3/21	100%
31							
32	✓		**Task 700 - Final Summary Report**	**32 days**	**Fri 5/14/21**	**Mon 6/28/21**	**100%**
33	✓		Task 700 - Prepare Final Summary Report	16 days	Fri 5/14/21	Fri 6/4/21	100%
34	✓		Task 700 - Submit Draft Summary Report	1 day	Mon 6/7/21	Mon 6/7/21	100%
35	✓		PREPA comments on Final Summary Repor	14 days	Tue 6/8/21	Fri 6/25/21	100%
36	✓		Task 700 - Submit Final Summary Report	1 day	Mon 6/28/21	Mon 6/28/21	100%



Project: PREPA Feasibility Study
Date: Mon 6/28/21

Task | Split | Milestone | Summary | Project Summary | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | External Tasks | External Milestone | Deadline | Progress | Manual Progress

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Project Progress Report

June 28, 2021

To:	Carlos A. Negron Alfonso, PE, MECE, MEM
From:	Randy Boyce, PE, Project Manager

Client:	Puerto Rico Electric Power Authority (PREPA)	**B&V Project No: 407635**
Project:	Feasibility Study for Improvements to Hydroelectrical System	**B&V File No: 28.0000**
Report	May 26, 2021 – June 28, 2021	
Report	5	

This report summarizes the project schedule and budget status to date, identifies milestones completed, lists major activities performed and provides a look ahead for those activities planned for the next month.

SUMMARY OF MAJOR ACTIVITIES PERFORMED TO DATE

- Task 100 – Conducted weekly project meetings with PREPA.
- Task 100 – Updated Project Action Item List weekly and reviewed in project meetings.
- Task 100 – Submitted monthly progress reports and schedule updates.
- Task 201 – Submitted final Installed Capacity & Average Annual Generation technical memorandum (April 27,2021).
- Task 202 – Submitted final Site Visit technical memorandum (March 11, 2021).
- Task 300 – Submitted Water Availability Model Review technical memorandum (March 19, 2021).
- Task 400 – Submitted final Reservoir Rule Curve Optimization technical memorandum (April 27, 2021).
- Task 500 – Submitted final Frequency Response and Remote-Control technical memorandum (May 13, 2021).
- Task 600a – Submitted Final Economic Feasibility technical memorandum (May 10, 2021).
- Task 600b - Submitted Final Economic Feasibility technical memorandum (June 03, 2021).
- Task 700a - Submitted Draft Final Summary report (June 05, 2021).
- Task 700b - Submitted Final Summary report (June 28, 2021).

ACHIEVED MILESTONES THIS REPORTING PERIOD

- Task 600b - Submitted Final Economic Feasibility technical memorandum (June 03, 2021).
- Task 700a - Submitted Draft Final Summary report (June 05, 2021).
- Task 700b - Submitted Final Summary report (June 28, 2021).

TRACKING THE SCHEDULE

The official start date was January 13, 2021 and the project is currently on schedule to be completed by June 28, 2021 (166 calendar days). See the attached Gantt chart at the end of this report for the overall schedule and estimated percent completion for each task. The table below summarizes the status of the milestones in the current schedule.

PREPA Feasibility Study for Improvements to Hydroelectrical System – Task	Major Milestone Scheduled Date	Major Milestone Actual Date
Task 200 - Assessment of Hydropower Facilities	Mon 4/26/21	Tue 4/27/21
• Task 201a – Draft Generation Capacity Report	Fri 3/26/21	Sat 3/27/21
• Task 201b – Final Generation Capacity Report	Mon 4/26/21	Tue 4/27/21
• Task 202c – Draft Site Visit Memorandum	Fri 3/05/21	Fri 3/05/21
• Task 202d – Final Site Visit Memorandum	Thu 3/11/21	Thu 3/11/21
Task 300 - Review Water Availability Models	Fri 03/19/21	Fri 03/19/21
Task 400 - Reservoir Rule Curve Optimization Report	Mon 05/17/21	Tue 04/27/21
• Task 400a – Draft Report	Fri 04/23/21	Fri 04/23/21
• Task 400b – Final Report	Mon 05/17/21	Tue 04/27/21
Task 500 - Evaluate Local Automation / Remote Control	Thu 05/06/21	Thu 05/13/21
• Task 500a – Draft Report	Fri 04/09/21	Fri 04/09/21
• Task 500b – Final Report	Thu 05/06/21	Thu 05/13/21
Task 600 - Economic Feasibility Evaluation	Wed 05/26/21	Thu 06/03/2021
• Task 600a – Draft Report	Fri 05/07/21	Mon 05/10/21
• Task 600b – Final Report	Wed 06/02/21	Thu 06/03/2021
Task 700 - Final Summary Report	Fri 06/18/21	Fri 06/18/2021
• Task 700a – Draft Report	Fri 06/04/21	Sat 06/05/2021
• Task 700b – Final Report	Fri 06/18/21	Mon 06/28/2021

SCHEDULED ACTIVITIES FOR NEXT MONTH

- Summary presentation to PREPA Planning Team in Puerto Rico.

EXPENDITURES AND BUDGET BALANCE

Project Total Cost	$469,900.00
Cost of Last Invoice	$12,873.00
Previously Billed	$43,293.00
Total Earned to Date	$469,900.00
Budget Balance	$0.00*

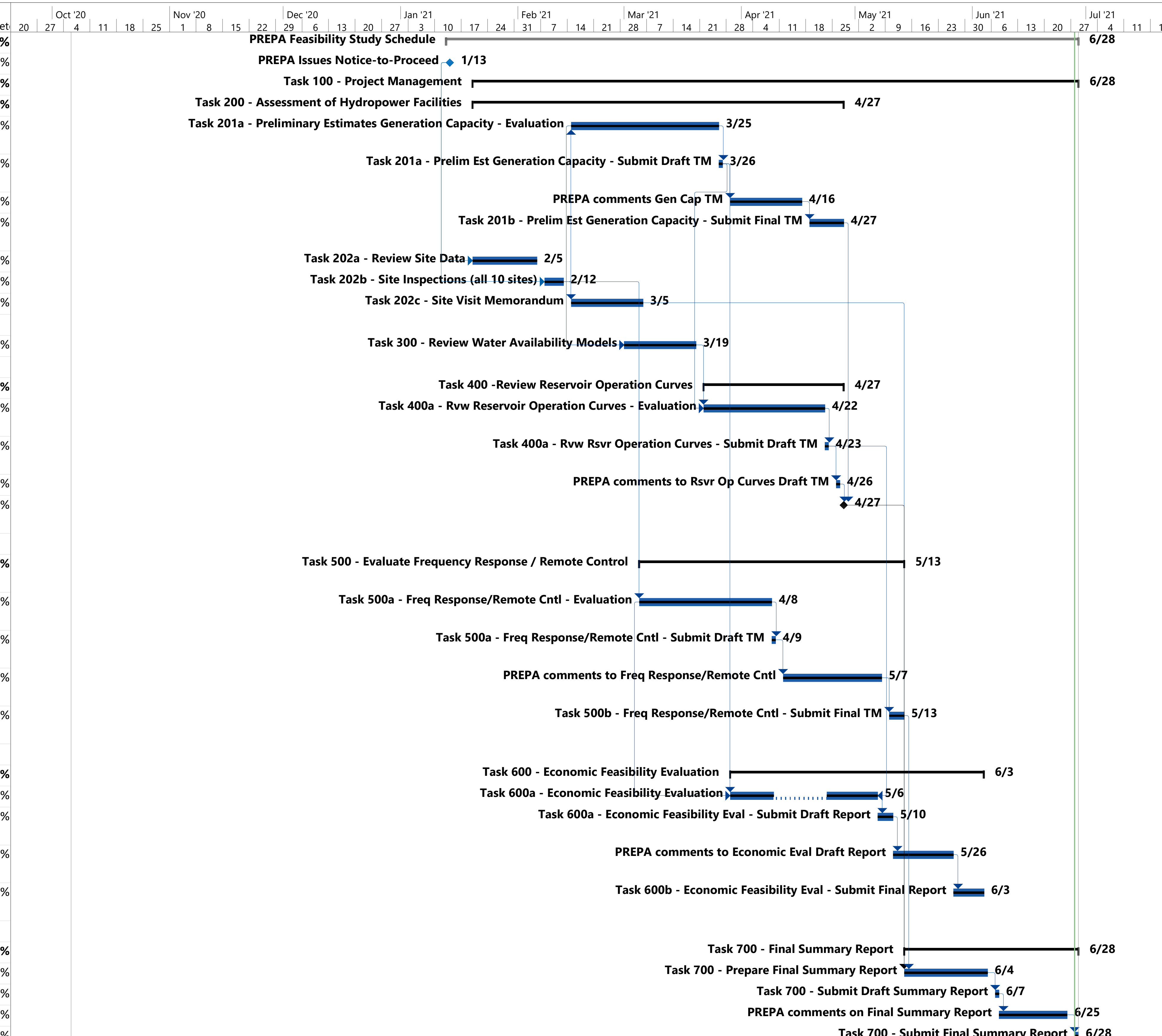
*Additional services will be invoiced on time and material based on contract rates.

This is report was prepared by the following Black & Veatch personnel:

Randy Boyce - Hydro Project Manager

Dianys Arocho - Engineering Manager

ID	Indicators	Task Mode	Task Name	Duration	Start	Finish	% Complet
0	✓		**PREPA Feasibility Study Schedule**	**119 days**	**Wed 1/13/21**	**Mon 6/28/2**	**100%**
1	✓		**PREPA Issues Notice-to-Proceed**	1 day	Wed 1/13/21	Wed 1/13/21	100%
2	✓		**Task 100 - Project Management**	**114 days**	**Wed 1/20/21**	**Mon 6/28/21**	**100%**
3	✓		**Task 200 - Assessment of Hydropower Facili**	**70 days**	**Wed 1/20/21**	**Tue 4/27/21**	**100%**
4	✓		Task 201a - Preliminary Estimates Generation Capacity - Evaluation	29 days	Mon 2/15/21	Thu 3/25/21	100%
5	✓		Task 201a - Prelim Est Generation Capacity - Submit Draft TM	1 day	Fri 3/26/21	Fri 3/26/21	100%
6	✓		PREPA comments Gen Cap TM	15 days	Mon 3/29/21	Fri 4/16/21	100%
7	✓		Task 201b - Prelim Est Generation Capacity - Submit Final TM	7 days	Mon 4/19/21	Tue 4/27/21	100%
8	✓		Task 202a - Review Site Data	13 days	Wed 1/20/21	Fri 2/5/21	100%
9	✓		Task 202b - Site Inspections (all 10 sites)	5 days	Mon 2/8/21	Fri 2/12/21	100%
10	✓		Task 202c - Site Visit Memorandum	15 days	Mon 2/15/21	Fri 3/5/21	100%
11							
12	✓		**Task 300 - Review Water Availability Model:**	15 days	Mon 3/1/21	Fri 3/19/21	100%
13							
14	✓		**Task 400 -Review Reservoir Operation Curv€**	**27 days**	**Mon 3/22/21**	**Tue 4/27/21**	**100%**
15	✓		Task 400a - Rvw Reservoir Operation Curves - Evaluation	24 days	Mon 3/22/21	Thu 4/22/21	100%
16	✓		Task 400a - Rvw Rsvr Operation Curves - Submit Draft TM	1 day	Fri 4/23/21	Fri 4/23/21	100%
17	✓		PREPA comments to Rsvr Op Curves Draft	1 day	Mon 4/26/21	Mon 4/26/21	100%
18	✓		Task 400b - Rvw Rsvr Operation Curves - Submit Final TM	0 days	Tue 4/27/21	Tue 4/27/21	100%
19							
20	✓		**Task 500 - Evaluate Frequency Response / Remote Control**	**50 days**	**Fri 3/5/21**	**Thu 5/13/21**	**100%**
21	✓		Task 500a - Freq Response/Remote Cntl - Evaluation	25 days	Fri 3/5/21	Thu 4/8/21	100%
22	✓		Task 500a - Freq Response/Remote Cntl - Submit Draft TM	1 day	Fri 4/9/21	Fri 4/9/21	100%
23	✓		PREPA comments to Freq Response/Remote Cntl	20 days	Mon 4/12/21	Fri 5/7/21	100%
24	✓		Task 500b - Freq Response/Remote Cntl - Submit Final TM	4 days	Mon 5/10/21	Thu 5/13/21	100%
25							
26	✓		**Task 600 - Economic Feasibility Evaluation**	**49 days**	**Mon 3/29/21**	**Thu 6/3/21**	**100%**
27	✓		Task 600a - Economic Feasibility Evaluatio	19 days	Mon 3/29/21	Thu 5/6/21	100%
28	✓		Task 600a - Economic Feasibility Eval - Submit Draft Report	2 days	Fri 5/7/21	Mon 5/10/21	100%
29	✓		PREPA comments to Economic Eval Draft Report	12 days	Tue 5/11/21	Wed 5/26/21	100%
30	✓		Task 600b - Economic Feasibility Eval - Submit Final Report	6 days	Thu 5/27/21	Thu 6/3/21	100%
31							
32	✓		**Task 700 - Final Summary Report**	**32 days**	**Fri 5/14/21**	**Mon 6/28/21**	**100%**
33	✓		Task 700 - Prepare Final Summary Report	16 days	Fri 5/14/21	Fri 6/4/21	100%
34	✓		Task 700 - Submit Draft Summary Report	1 day	Mon 6/7/21	Mon 6/7/21	100%
35	✓		PREPA comments on Final Summary Repo	14 days	Tue 6/8/21	Fri 6/25/21	100%
36	✓		Task 700 - Submit Final Summary Report	1 day	Mon 6/28/21	Mon 6/28/21	100%



Project: PREPA Feasibility Study
Date: Mon 6/28/21

Task	Summary	Inactive Milestone	Duration-only	Start-only	External Milestone	Manual Progress	
Split	Project Summary	Inactive Summary	Manual Summary Rollup	Finish-only	Deadline		
Milestone	Inactive Task	Manual Task	Manual Summary	External Tasks	Progress		

Exhibits C & D

Feasibility Reports

EXHIBIT	TASK	TITLE	DATE	DESCRIPTION	CONFIDENTIALITY
C	500	Feasibility Study for Improvements to Hydro Electrical System- Task 500 Frequency Response and Remote Control Memorandum	May 13, 2021	Report to evaluate and determine the existing potential for startup, shut down, voltage and power control from the Authority's Energy Control Center (ECC). Evaluates the communication between the facilities and the ECC.	Trade Secret, CEII
D	600	Economic Feasibility Analysis Report Task 600	June 3, 2021	Report evaluates the economic feasibility of rehabilitating the hydroelectrical facilities.	Trade Secret

[*These exhibits have been submitted under seal.*]