ANL-22/47

Financial Analysis of the 2020 Macroinvertebrate Production Flow Experiment at Glen Canyon Dam

Energy Systems Division

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Financial Analysis of the 2020 Macroinvertebrate Production Flow Experiment at Glen Canyon Dam

by
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Prepared for
United States Department of Energy
Western Area Power Administration

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Foreword

This report was prepared by Argonne National Laboratory (Argonne) in support of a financial analysis of the Glen Canyon Dam (GCD) flow experiment that was intended to support downstream macroinvertebrate production that are a primary food supply for fishes in the Colorado River. Also known as "bug flow" experiments, these experimental water releases were conducted on the weekends and holidays from the beginnings of May 2020 through the end of August 2020. This analysis was funded by and prepared for the Colorado River Storage Project (CRSP) Office of the U.S. Department of Energy's Western Area Power Administration (WAPA). CRSP markets electricity produced by hydroelectric facilities collectively known as the Salt Lake City Area Integrated Projects including dams equipped for power generation on the Colorado, Green, Gunnison, and Rio Grande Rivers and on Plateau Creek in the states of Arizona, Colorado, New Mexico, Utah, and Wyoming.

Staff members in Argonne's Energy Systems Division prepared this technical memorandum with assistance from WAPA's CRSP and Energy Marketing and Management Offices (EMMO).

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Acronyms and Abbreviations

The following is a list of the acronyms and abbreviations (including units of measure) used in this document.

AHP	available hydropower
Argonne	Argonne National Laboratory
CRSP	Colorado River Storage Project
CY	calendar year
EIS	Environmental Impact Statement
EMMO	Energy Management and Marketing Office (WAPA)
FES	firm electric service
GCD	Glen Canyon Dam
GTMax SL Exp	Generation and Transmission Maximization Superlite Experiments
LTEMP	Long-Term Experimental and Management Plan
MPF	Macroinvertebrate Production Flow
MSR	Minimum Schedule Requirement
PCF	Power conversion factor
PO&M-59	Power Operations and Maintenance, Form 59 (a Bureau of Reclamation form entitled, *Monthly Report of Power Operations – Powerplants*)
Reclamation	Bureau of Reclamation
ROD	Record of Decision
SHP	sustainable hydropower
SLCA/IP	Salt Lake City Area Integrated Projects
WAPA	Western Area Power Administration
WECC	Western Electricity Coordinating Council
WI	Western Interconnection
WY	water year

Units of Measure

cfs	cubic feet per second
ft	feet
hr	hour
MW	megawatt(s)
MWh	megawatt-hour(s)
pf	power factor
TAF	thousand acre-feet

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Abstract

This report examines the financial implications of macroinvertebrate production flows (MPF) conducted at the Glen Canyon Dam (GCD) from the beginning of May 2020 through the end of August 2020. It is the third report examining the financial implications of MPF, since the 2016 Record of Decision (ROD) was adopted in December 2016 (Reclamation 2016). The 2016 ROD implemented the Long-Term Experimental and Management Plan (LTEMP) regime.

Experimental releases may have either a positive or negative impact on the financial value of energy production. For these experimental releases, financial costs of approximately $941,000 were incurred, mainly driven by the flat and low releases during weekends and holidays.

This study identifies the main factors that contribute to MPF costs and examines the interdependencies among these factors. It applies an integrated set of tools to estimate financial impacts by simulating the GCD operations under two scenarios: (1) a "Baseline" scenario that mimics MPF operations during the period of the experiment when it complies with the 2016 ROD operating criteria, and (2) a counterfactual "Without Experiments" scenario that is identical to the Baseline except it assumes that the MPF did not occur.

The Generation and Transmission Maximization Superlite Experiments (GTMax SL Exp) model was the main tool used to simulate the dispatch of the GCD hydropower plant and associated water releases from Lake Powell. GCD is a Colorado River Storage Project (CRSP) power resource that is a component of the Salt Lake City Area Integrated Projects (SLCA/IP). The research team used extensive data sets and historical information on SLCA/IP hydropower plant characteristics, hydrologic conditions, and Western Area Power Administration's (WAPA's) energy prices in the modeling process. In addition to estimating the financial impact of the MPF, the team used the GTMax SL Exp model to gain insights into the interplay among ROD operating criteria, exceptions that were made to criteria to accommodate the experimental releases, and WAPA operating practices.

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1 Introduction

The Glen Canyon Dam (GCD) hydropower plant (referred to as the Powerplant in this report) consists of eight generating units with a continuous operating capacity of 1,320 megawatts (MW) at unity power factor (pf). It is one component of a larger system known as the Salt Lake City Area Integrated Projects (SLCA/IP). Electricity produced by the Powerplant serves the demand of 5.8 million consumers in 10 western states that are located in the Western Interconnection (WI). Before 1990, the Powerplant had few operating restrictions. Except for a minimum water release requirement, the daily and hourly operations of the Powerplant were initially constrained only by the physical limitations of the dam structures, the Powerplant, and its storage reservoir, Lake Powell. CRSP loads and market price signals were the principal dispatch drivers, often resulting in large fluctuations of the plant's power output and associated water releases.

Concerns about the impact of GCD operations on downstream ecosystems and endangered species, including those in Grand Canyon National Park, prompted the Bureau of Reclamation (Reclamation) to conduct a series of research releases from June 1990 to July 1991 as part of an environmental studies program. Based on an analysis of these releases, Reclamation imposed operational flow constraints on August 1, 1991 (WAPA 2010). These constraints were in effect until February 1997, when new operational rules and management goals specified in the Glen Canyon Dam Environmental Impact Statement (GCDEIS) Record of Decision (ROD) were adopted (Reclamation 1996). More recently in January 2017 a new ROD mandating the preferred alternative prescribed by the LTEMP Environmental Impact Statement (EIS) has been adopted. The 2016 ROD operating criteria limits hourly maximum and minimum water release volumes from the dam. The 2016 ROD criteria also constrain the change in the water release between consecutive hours, restricts the range of hourly releases on a rolling 24-hour basis, and limits the monthly water release from Lake Powell.

The Glen Canyon Dam Adaptive Management Program, established by the GCDEIS ROD (Reclamation 1996), conducts scientific studies on the relationship between Powerplant operations and downstream resources. Experimental water releases are performed periodically to monitor river conditions, conduct specific studies, enhance native fish habitat, and conserve fine sediment in the Colorado River corridor in Grand Canyon National Park.

This report follows several other financial analyses of GCD experiments that began in 1997. These experiments and associated financial analyses listed in chronological order below include:

- Calendar year (CY) 1997 through 2005 experiments reported in *Revised Financial Analysis of Experimental Releases Conducted at Glen Canyon Dam during Water Years 1997 through 2005* (Veselka et al. 2011);
- CY 2006 through 2010 experiments were reported in *Financial Analysis of Experimental Releases Conducted at Glen Canyon Dam during Water Years 2006 through 2010* (Poch et al. 2011);
- Water year (WY) 2011 were reported in *Financial Analysis of Experimental Releases Conducted at Glen Canyon Dam during Water Year 2011* (Poch et al. 2012);
- WY 2012 were reported in *Financial Analysis of Experimental Releases Conducted at Glen Canyon Dam during Water Year 2012* (Poch et al. 2013);

- WY 2013 experiments were reported in *Financial Analysis of Experimental Releases Conducted at Glen Canyon Dam during Water Year 2013* (Graziano et al. 2014);
- WY 2014 experiments were reported in *Financial Analysis of Experimental Releases Conducted at Glen Canyon Dam during Water Year 2014* (Graziano et al. 2015);
- WY 2015 experiments were reported in *Financial Analysis of Experimental Releases Conducted at Glen Canyon Dam during Water Year 2015* (Graziano et al. 2016);
- WY 2017 experiments reported in *Financial Analysis of Experimental Releases Conducted at Glen Canyon Dam during Water Year 2017* (Ploussard et al. 2019a);
- WY 2018 experiments reported in *Financial Analysis of the 2018 Glen Canyon Dam Bug Flow Experiment* (Ploussard et al. 2019b);
- WY 2019 experiments reported in *Financial Analysis of Experimental Releases Conducted at Glen Canyon Dam during Water Year 2019* (Ploussard et al. 2020a) and *Financial Analysis of the 2019 Glen Canyon Dam Bug Flow Experiment* (Ploussard et al. 2020b).

One experiment, referred to as a Macroinvertebrate Production Flow experiment (MPF), was conducted from the beginning of May 2020 through the end of August 2020. Two previous MPF experiments were conducted in 2018 and 2019 during the same months of the year. These MPF, also known as “bug flows”, maintained constant release rates on the weekends and holidays. During the 2020 MPF experiment, these constant weekend release rates were maintained at a level equal to the minimum weekday release plus 750 cfs. These low water releases during the weekends and holidays generally produce less energy with less operational flexibility than under normal operations, resulting in a financial cost to the Western Area Power Administration (WAPA) during those days. On the other hand, higher weekday releases under MPF in combination with a lifted minimum water release during weekends generally leads to relatively higher financial value of Powerplant operations during weekdays. Net costs of conducting the MPF is therefore a tradeoff between generally higher financial outcomes during weekdays versus lower financial outcomes during weekends. This report describes the method that was used to model the SLCA/IP, which includes GCD, and discusses Argonne’s estimates of financial costs of conducting this experiment.

During normal operations, GCD is governed by stringent operating rules as specified in the 2016 ROD. Although these rules yield environmental benefits, they also incur financial costs to WAPA and have economic implications over the Western Interconnection (WI) footprint. These criteria reduce the flexibility of operations, diminish dispatchers’ ability to respond to market price signals, and lower the economic and financial benefits of power production. Power benefits are affected by the ROD in two ways. First, the loss of operable capability must eventually be replaced by other power generation resources. Second, the hydropower energy cannot be used to its fullest extent when the market price and economic benefits are relatively high.

During the 2020 MPF, operational flexibility was further reduced to comply with the low steady flow requirement during weekends and holidays. An integrated set of tools was used to estimate the financial impacts of the MPF by simulating GCD operations under two scenarios, namely, (1) a “Baseline” scenario that mimics both MPF operations during the experiment and that complies with 2016 ROD operating criteria by optimizing the Powerplant operations under these conditions, and (2) a counterfactual “Without Experiments” scenario that is identical to the Baseline except that it assumes that the MPF experiment did not occur.

The Generation and Transmission Maximization Super Lite Experiments (GTMax SL Exp) model simulates the SLCA/IP powerplant dispatch from which WAPA's financial revenues are computed. This tool uses an integrated system modeling approach to dispatch hydropower plants in the system, while recognizing interactions among supply resources over time. Retrospective simulation for the study period made use of extensive sets of data and historical information on SLCA/IP hydropower plants' characteristics and hydrologic conditions and WAPA's power sale prices. The GTMax SL Exp model simulated two scenarios. Under the Baseline scenario, GTMax SL Exp mimics the MPF as documented by WAPA and simulates operations that comply with 2016 ROD operating criteria. The second scenario, Without Experiments, is identical to the first one, except it assumes that the experimental release did not occur. Differences in the net financial position between the two scenarios represent the change in the financial value of power attributed to experimental releases. To measure MPF costs, GTMax SL Exp runs were only made for May 2020 through the end of August 2020 period. It was not necessary to run other months of the year because monthly water release volumes in WY 2020 under the with and without Bug Flow scenarios are identical; therefore, the comparative financial cost of the MPF during non-experimental months is assumed to be zero. In addition to estimating the financial impact of experimental releases, the GTMax SL Exp model was also used to gain insights into the interplay among ROD operating criteria, exceptions that are made to criteria to accommodate bug flow releases, and WAPA operating practices. Details on the methodology and data sources are more thoroughly described in Section 4 of *Revised Financial Analysis of Experimental Releases Conducted at Glen Canyon Dam during Water Years 1997 through 2005* (Veselka et al. 2011).

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2 ROD Criteria and WAPA's Operating Practices

Important factors that contribute to the financial impacts of experimental releases include the following:

(1) Hourly and daily operating criteria – the 2016 Record of Decision (ROD),
(2) Exceptions to the 2016 ROD made to accommodate the experimental releases,
(3) Monthly water release (2016 ROD), and
(4) WAPA's scheduling guidelines.

This section provides background information on each of these factors.

2.1 Hourly and Daily Operating Criteria and Exceptions

Operating criteria specified in the 2016 ROD are intended to temper the rate of change in hourly and daily water releases. The criteria selected were based on the LTEMP preferred alternative as described in (Reclamation 2016). These criteria were put into practice by WAPA beginning in October 2017.

Flow restrictions under the 2016 ROD are shown in Table 2.1, along with operational limits in effect prior to October 1, 2016, for comparison. The 2016 ROD criteria require water release rates to be 8,000 cfs or greater between the hours of 7:00 a.m. and 7:00 p.m., and at least 5,000 cfs during the night. The criteria also limit how quickly the release rate can increase and decrease between consecutive hours. The maximum hourly increase (i.e., the up-ramp rate) is 4,000 cfs/hour (hr), and the maximum hourly decrease (i.e., the down-ramp rate) is 2,500 cfs/hr. 2016 ROD operating criteria also restrict how much the releases can fluctuate during rolling 24-hour periods. This change constraint varies depending on the monthly volume of water release. Daily fluctuation (in cfs) is equal to 10 times the monthly volume (in TAF) from June to August, and 9 times the monthly volume (in TAF) in other months, and it never exceeds 8,000 cfs/day.

The maximum flow rate is limited to 25,000 cfs under the 2016 ROD operating criteria. Maximum flow rate exceptions are allowed to avoid spills or flood releases during high runoff periods. Under very wet hydrological conditions, defined as when the average monthly release rate is greater than 25,000 cfs, the flow rate may be exceeded; however, water must be released at a constant rate. Exceptions to the operating criteria are also made to accommodate experimental releases.

Table 2.1: Operating constraints prior to 2017 and under the 2016 ROD (from October 2017)

Operational Constraint	1996 ROD Flows (Before October 2017)	2016 ROD Flows (From October 2017)
Minimum release (cfs)	8,000 from 7:00 a.m.–7:00 p.m. 5,000 at night	8,000 from 7:00 a.m.–7:00 p.m. 5,000 at night
Maximum release (cfs)	25,000	25,000
Daily fluctuations (cfs/24 hr)	5,000; 6,000; or 8,000 depending on monthly release volume[a]	**depending on monthly release volume**[b]
Ramp rate (cfs/hr)	4,000 up 1,500 down	4,000 up **2,500** down

[a] Limited to 5,000 cfs/day when monthly water release is less than 600 TAF; 6,000 cfs/day when monthly water release is 600 TAF to 800 TAF; and 8,000 cfs/day when monthly water release is greater than 800 TAF.

[b] Equal to 10 times the monthly volume (in TAF) in Jun.–Aug., and 9 times the monthly volume (in TAF) in other months; daily range not to exceed 8,000 cfs/day.

Source: (Reclamation 1996) and (Reclamation 2016).

2.2 Monthly Water Release Volumes

Reclamation sets the monthly water releases in the Upper and Lower Colorado River Basin to be consistent with various operating rules and guidelines, acts, international water treaties, consumption use requirements, State agreements, and the "Law of the River" (Reclamation 2008). In addition to power production, monthly release volumes are set considering other uses of the reservoirs, such as for flood control, river regulation, consumptive uses, water quality control, recreation, and fish and wildlife enhancement, and to address other environmental factors (Reclamation 2013). Since January 2017, monthly water release at GCD complied with the 2016 LTEMP ROD operating criteria (Reclamation 2016).

Release decisions are made by using current runoff projections provided by the National Weather Service's Colorado Basin River Forecast Center. Because future hydrologic conditions in the Colorado River Basin are not known with certainty and because events do not unfold as previously projected, Reclamation periodically adjusts its annual operating plan. Its release decisions are adjusted on a monthly basis to reflect projections made by rolling 24-month studies that are updated monthly.

For both the Baseline and Without Experiment scenarios, actual SLCA/IP monthly water releases, as recorded in Reclamation's Power Operation and Maintenance Form (PO&M-59) (Reclamation undated) and available on Reclamation website (Reclamation 2020), were used for all hydropower plants.

Table 2.2 shows the monthly water release volumes and the end-of-month elevations of the Lake Powell reservoir during the study period under both the with (actual) and without experiment (counter-factual) scenarios. The maximum daily fluctuations, based on the 2016 ROD rules described in Table 2.1, have also been included. Monthly water release volumes and elevations are also depicted in Figure 2.1 below.

Table 2.2: Water releases, Lake Powell elevations, and maximum daily fluctuations

Calendar Year	Month	Water Release (TAF)	Lake Powell Elevation (feet [ft])	Maximum daily fluctuations (cfs/day)
2020	May	629	3,605.1	5,660
2020	June	650	3,610.6	6,500
2020	July	750	3,606.3	7,500
2020	August	833	3,599.7	8,000

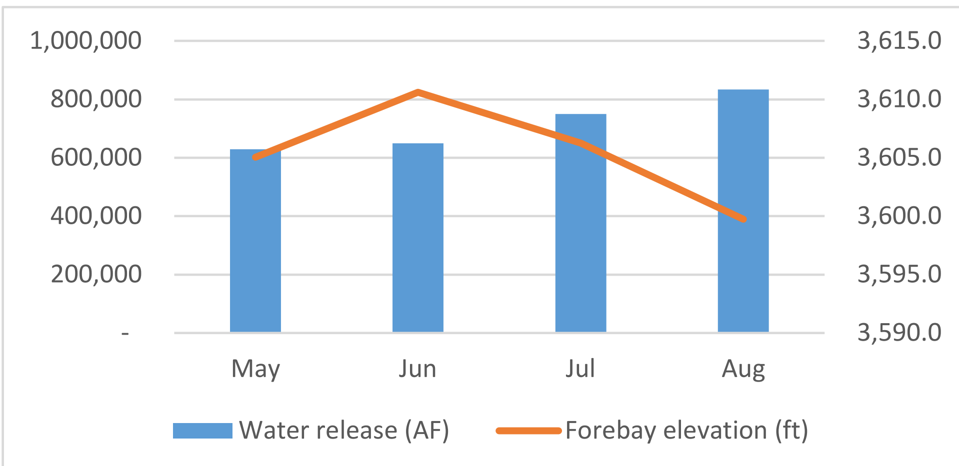

Figure 2.1: Monthly hydrologic conditions at GCD during the 2020 MPF Experiment

2.3 Montrose Scheduling Guidelines

The hourly scheduling of SLCA/IP hydropower plant operations is performed by WAPA's Energy Management and Marketing Office (EMMO) located in Montrose, Colorado. Schedulers make decisions based on a set of scheduling priorities and guidelines, including a directive to comply with environmental operating criteria. The GCD restrictions shown in Table 2.1 describe operational boundaries; however, within these limitations are innumerable hourly release patterns and dispatch drivers that comply with a given set of operating criteria. Thus, the operational range was significantly wider prior to the 1996 ROD and was further restricted under the 2016 ROD. Other SLCA/IP powerplants must also comply with various operational limitations. For example, Flaming Gorge releases are patterned such that downstream flow rates are within Jensen Gage flow limits (Reclamation 2006). In addition, releases from the Wayne N. Aspinall Dams cannot result in reservoir elevations that are outside of (1) a specified range of forebay elevation levels, and (2) limits on the Crystal reservoir has limits on decreases in reservoir elevations over time (Reclamation 2012).

As operational constraints were imposed on SLCA/IP resources, including those at the GCD, scheduling guidelines and goals shifted from objectives driven primarily by market prices to objectives driven by customer loads. Within the boundaries of these operating constraints, SLCA/IP power resources are used to serve firm load. WAPA also places a high priority on purchasing and selling power in 16-hour, on-peak blocks, and 8-hour, off-peak blocks in the day-ahead market.

As illustrated in Figure 2.2, when hydropower resources are short of load, SLCA/IP generation resources are typically “stacked” on top of the block purchases as a means of following firm customer load. Because of operational limitations, WAPA staff may need either to purchase or sell varying amounts of energy on an hourly basis in the day-ahead and/or real-time market. The volumes of these variable market purchases and sales are relatively small under normal hydropower conditions. The GTMax SL model topology and inputs are designed to mimic these guidelines.

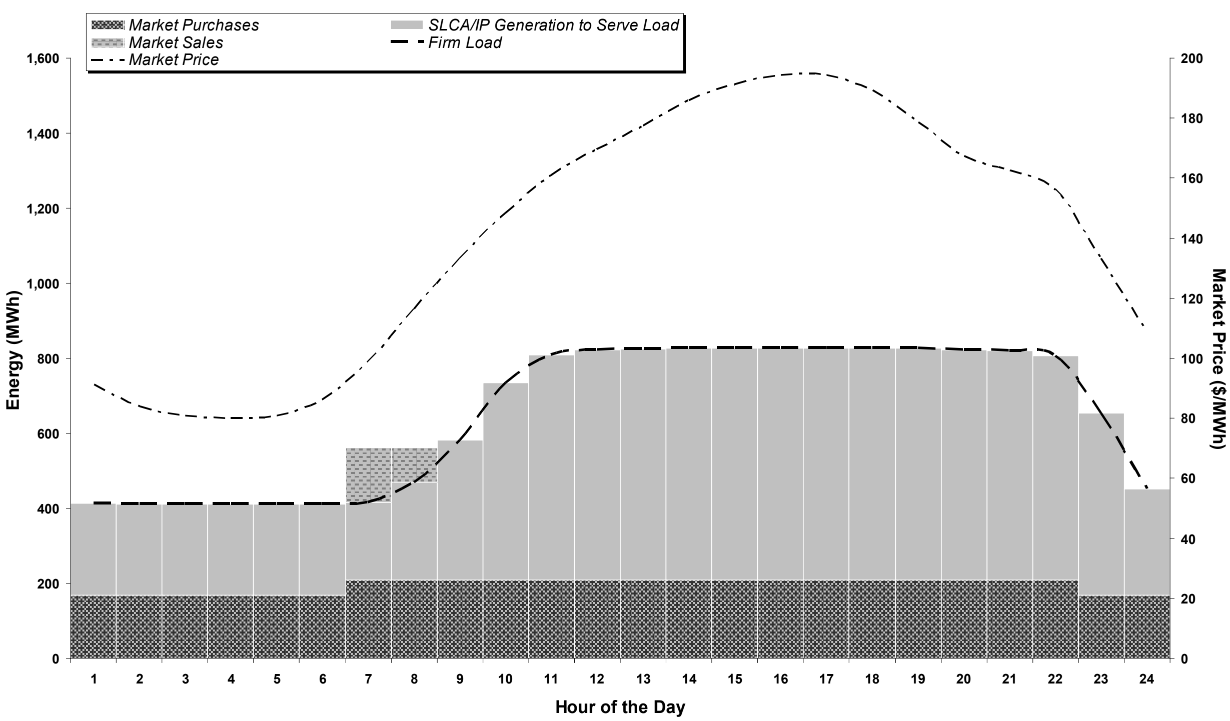

Figure 2.2: Illustration of the firm-load-driven dispatch guideline under the 1996 ROD operating criteria when SLCA/IP resources are short of load

The load-following objective creates a strong link between WAPA’s contractual obligations and among SLCA/IP hydropower plant operations, requiring dispatch among the hydropower plants to be closely coordinated. This interdependency exists because loads and hydropower resources are balanced whenever feasible. WAPA is able to affect the shape of its Firm Electric Service (FES) customer load requests indirectly through specifications in its contract amendments. In turn, these customer loads affect both SCLA/IP powerplant operations and hourly reservoir releases. Contract terms that indirectly affect load and powerplant operations include sustainable hydropower (SHP) and available hydropower (AHP) capacity and energy sales, as well as Minimum Schedule Requirement (MSR) specifications. The MSR is the smallest amount of energy that a customer must schedule from WAPA in each hour. The load-following dispatch directive minimizes scheduling problems and helps WAPA avoid noncompliant water releases.

In addition to load following, dispatchers follow other practices that are specific to GCD Powerplant operations. These practices fall within ROD operational boundaries but are not ROD requirements. Therefore, WAPA may alter or abandon these institutional practices at any time. One practice involves reducing generation at GCD to the same minimum level every day during low-price, off-peak hours. WAPA also avoids drastic changes to total water release volumes over successive days. Therefore, it is assumed that the same volume of water is released each weekday, and that, under the without experiment, weekend daily water release volumes were at least 85 percent of weekday releases. Under the MPF experiment, because of the low release requirement in Saturdays and Sundays, weekend daily release volumes were allowed to dip below the 85 percent threshold.

In addition, from June through August 2020, operations allowed one cycle of raising and lowering GCD Powerplant output per day. In May 2020, operations allowed a maximum of two cycles as dictated by the hourly load pattern.

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3 Description of Experimental Releases

The MPF experimental release was conducted from the beginning of May through the end of August 2020. This section describes this experimental release and its characteristics.

3.1 Macroinvertebrate Production Flow

The MPF experiment is requested and described in the 2016 ROD (Reclamation 2016). These "macroinvertebrate production flows" maintain flat releases on the weekends and holidays to a level equal to the minimum hourly release rate made during weekdays plus an additional level. This additional level, called "flat flow adder", was set to 750 cfs during the 2020 MPF experiment. The same flat flow adder value was used in the previous MPF experiment in 2019. This experiment is conducted two days a week to allow aquatic insects throughout the river corridor to be able to lay their eggs at a stage where they would not be at risk of being dewatered or desiccated. The experiment includes monitoring to evaluate if the flows increase the diversity and production of aquatic insects. The experiment was designed to test the hypothesis put forward in (Kennedy et al. 2016) while minimizing impacts to the hydropower resource at GCD by mandating steady flows on the weekend.

The 2020 MPF was conducted from May 1 to August 31, 2020. Day-ahead scheduled flow pattern for the 2020 MPF experiment is shown graphically in Figure 3.1. For the sake of clarity, only one week (May 4-10, 2020) is represented.

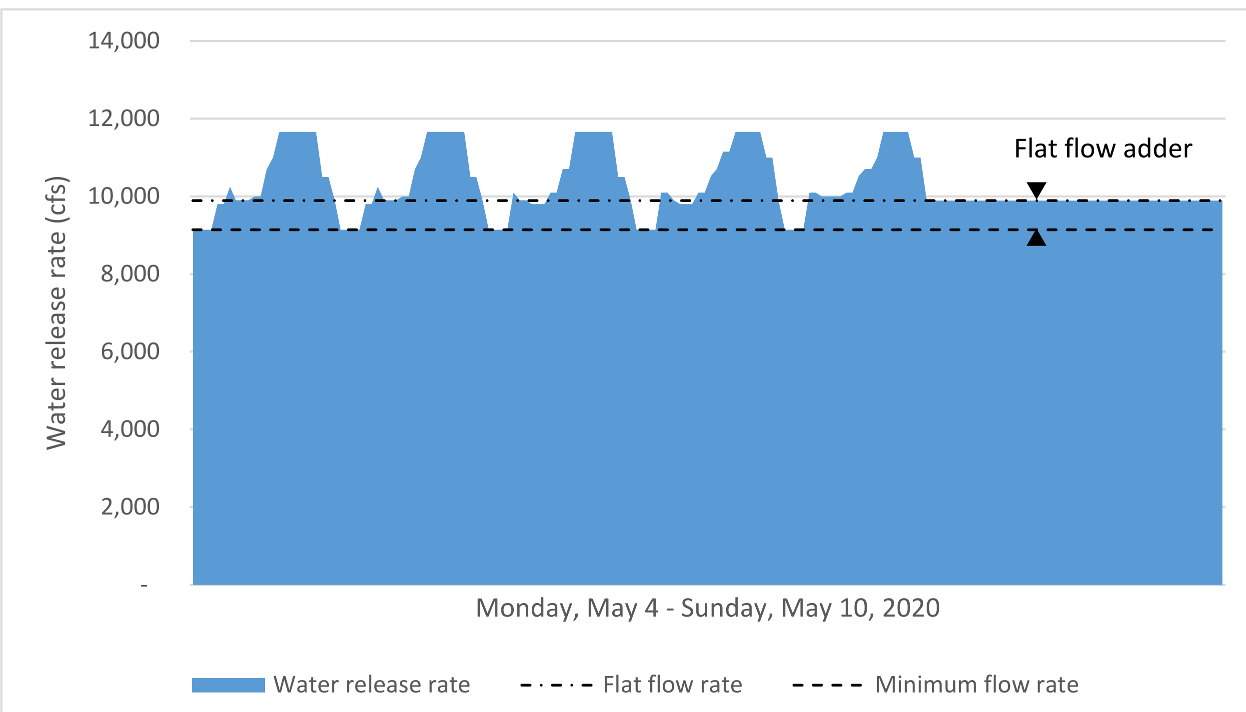

Figure 3.1: Release pattern of the MPF at GCD during a week in May 2020 according to day-ahead schedule

From an operating perspective, Western Electricity Coordinating Council (WECC) holidays are considered by WAPA to follow the same operating parameters as a Sunday and, thus, flat flows were applied during May 25^{th}, 2020. The flat flows were maintained at a constant level from Saturday, May 23^{rd} to Monday, May 25^{th}. Flat flows were also applied July 4^{th}, 2020, which occurred on a Saturday.

4 Methods and Models

For the 2020 MPF analysis, financial impacts were computed by comparing simulated results between two operating scenarios:

(1) The Baseline scenario**,** that assumes 2016 ROD operating criteria and the occurrence of the 2020 MPF; and

(2) The counterfactual Without Experiments scenario**,** which assumes 2016 ROD operating criteria and the absence of any experimental releases.

The financial impact was assessed as the difference in financial position between the two scenarios. Monthly water releases, daily fluctuations, power conversion factors (PCF), and turbine availability are assumed to be identical under both scenarios. MPF financial outcomes are therefore a function of (1) the allocation of water release volumes between weekend and weekdays, (2) the MPF weekend flat flow requirement, and (3) energy price profiles.

The GTMax SL Exp model is the main simulation tool used to simulate the operation of SLCA/IP hydropower plants, including GCD. It not only simulates GCD operations, but it also provides insights into the interplay among the 2016 ROD operating criteria, exceptions to the criteria to accommodate experimental releases, modifications to monthly water volumes, and WAPA's scheduling guidelines and goals. The GTMax SL Exp model is supported by several other tools and databases. These supporting tools include the SLCA/IP Contracts spreadsheet, Customer Scheduling algorithm, Market Price spreadsheet, Experimental Release spreadsheet, Price Shaping Algorithm spreadsheet, and a Financial Value Calculation spreadsheet.

The GTMax SL Exp model is a new, advanced, version of the original GTMax SL model that was used in previous MPF reports (Ploussard et al. 2019b, Ploussard et al. 2020b). This new version uses a more accurate representation of hourly hydropower operations because it models all days of a month instead of extrapolating modeling results for a single representative week to all days of a month. Similar to the GTMax SL model, the GTMax SL Exp model is supported by several spreadsheets that contain ROD operating criteria and parameters for WAPA scheduling guidelines, perform various preliminary computations, prepare input data, summarize simulation results, perform cost calculations, and produce a variety of tables and graphs.

4.1 Model Input Data for GCD Reservoir and Powerplant

Data for GCD reservoir and power plant input into the GTMax SL Exp model are based on historical monthly data from the Reclamation website (Reclamation 2022) and from pre-scheduled operations from the WAPA EMMO (Wilhite 2021). This information is used to calculate, for each month of the MPF period, water release volume, PCF, maximum 24-hr fluctuation (daily change constraint), and flat-flow adder.

Monthly water release volumes, PCFs, maximum output capacities, and daily constraint at GCD are assumed identical under both scenarios, and equal to the values calculated from Reclamation and EMMO data. The PCF is calculated monthly by the model using forebay elevation-to-PCF equations based on empirical data. The maximum output capability (output) at GCD is computed for each month. It is the minimum of (1) the physical capacity of the power plant turbines and (2) the maximum production level based on the monthly forebay elevation. Further details about the way the maximum output capability is computed can be found in the section 4.5.1 of (Veselka et al. 2011). The level of outage during the 2020 MPF experiment was sufficiently low to not have any impact on the maximum generation level at the Powerplant. Because of this, outages at the Powerplant were not modeled for this analysis, either in the Baseline or in the Counterfactual scenarios.

The main differences in terms of operations between the Baseline scenario and the Counterfactual scenario are the flat flow constraints and the ratio of daily release volumes between a weekend day and a weekday. Under the Without Experiment scenario (Counterfactual scenario), it is assumed that the total water release on Saturday and Sunday is at least 85 percent of the average daily water release volume during weekdays (i.e., Monday through Friday inclusive). In contrast, for each week during the MPF experiment, water flows during weekends and holidays are required to be flat (i.e. constant) and 750 cfs higher than minimum flows during weekdays. Under the Baseline scenario, this flat flow requirement generally conflicts with the 85 percent rule, and it is therefore not applied.

The operating rules in both scenarios are summarized in Table 4.1 below. Note that only the last two table entries in bold differ between the two scenarios.

Table 4.1: Summary of the operating rules used in each scenario

Operating rule	Baseline scenario	Counterfactual scenario
Operating mode	Load-following	Load-following
Monthly water releases	Based on Reclamation data	Based on Reclamation data
Monthly PCFs	Derived from Reclamation data	Derived from Reclamation data
Largest daily change	Derived from Reclamation data	Derived from Reclamation data
Flat flow during weekend	**Required, at a level equal to the minimum flow rate during weekdays plus 750 cfs**	**Not required**
Ratio between Saturday/Sunday and Weekday daily release	**Not constrained**	**Required to be greater or equal to 85 percent**

4.2 Model Input Data for Other SLCA/IP Hydropower Plants

Because we want to isolate the financial impact of the Bug Flow Experiment on GCD only, the generation from all the hydropower plants except GCD are required to be identical under both the Baseline and the Counterfactual scenarios. To achieve this, we allow the model to optimize the hourly operations of all large hydropower plants (including GCD) under the Counterfactual scenario (Without Experiment scenario). More specifically, the power plants for which the hydropower operations are being optimized are:

- Glen Canyon
- Flaming Gorge
- Blue Mesa
- Morrow Point
- Crystal
- Fontenelle

However, under the Baseline scenario, only GCD operations are optimized by the model while setting generation levels from all other hydropower plants to the hourly profiles determined by the Counterfactual scenario run.

Apart from the six large power plants mentioned above, the SLCA/IP system is composed of other relatively small hydropower generating resources that are not being optimized by the GTMax SL Exp model for sake of simplicity. Instead, their generation profiles is considered fixed under both scenarios, and based on historical generation profiles from EMMO (Wilhite 2021). These sources include:

- Upper and Lower Molina
- Deer Creek- Energy interchange into the SLCA/IP system

4.3 Model Input Data for Loads and Market Prices

Data for load input into the GTMax SL Exp model are based on pre-scheduled operations from EMMO (Wilhite 2021). For the sake of simplicity, customer load is aggregated with other types of loads to represent the total amount of energy withdrawn from the system. More specifically, this equivalent load is composed of:

- Customer Available Hydropower (AHP) load,
- Miscellaneous load,
- Pump operations at Deer Creek,
- Transmission losses, and
- SLCA/IP system energy exchanges into and out of the system.

The energy price profile used by the model is based on monthly hydropower sale prices provided by EMMO. The price data consists of monthly on-peak and off-peak prices which are shown in Table 4.2 below. Detailed hourly price profiles are shown in Appendix A, Figure A.1.

Table 4.2: Actual average on-peak and off-peak prices by month during the 2020 MPF experiment

Calendar Year	Month	Average off-peak price ($/MWh)	Average on-peak price ($/MWh)
2020	May	10.89	16.21
2020	June	17.35	24.85
2020	July	23.05	49.40
2020	August	42.40	100.45

5 Net Financial Cost of the MPF Experiment

The financial impact of the MPF experiment was assessed as the difference in financial position between the Baseline and Counterfactual scenarios. Both scenarios release identical amounts of water each month. However, modeled daily water release volumes during each day of the month differ. The flat flow constraint in the Baseline scenario generally leads to significantly smaller water releases, less than 85 percent, during weekends than during weekdays.

The differences of modeled flow patterns during a typical week between the With (i.e. Baseline) and Without Experiment scenarios are illustrated in the hydrograph in Figure 5.1, from (GCDAM 2020). Note that the MPF (labeled "Bug Flow") weekend flat flow requirement under the Baseline scenario (With Experiment scenario) leads to maximum flows during weekdays that are significantly higher than under the Without Experiment scenario. This occurs because both scenarios are bound by identical daily change restrictions and identical monthly release volumes.

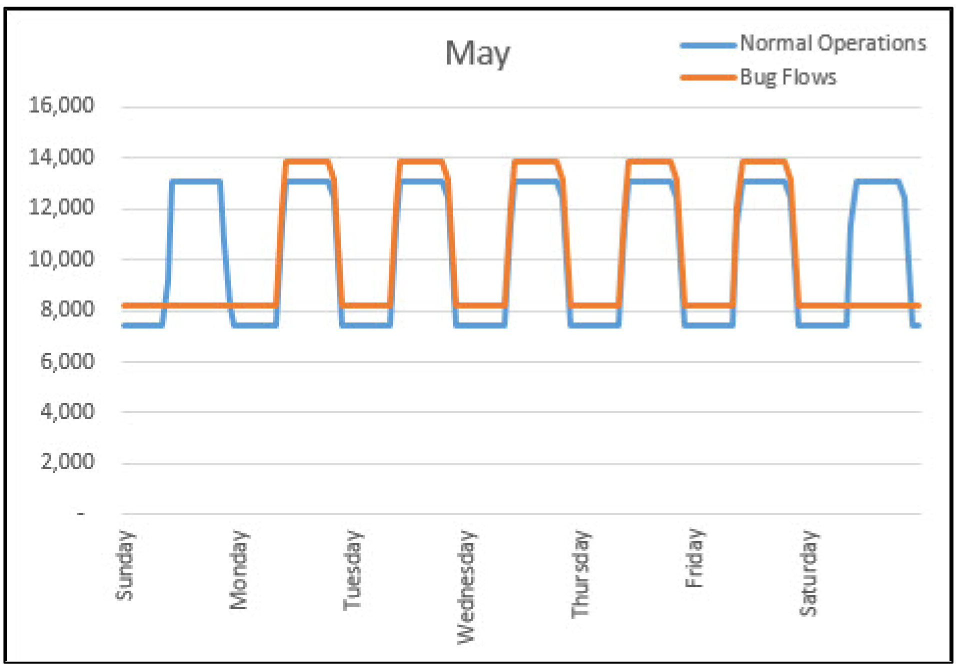

Figure 5.1: Modeled hydrograph in cfs at GCD under the With and Without MPF experiment scenarios (GCDAM 2022)

5.1 Hourly Water Release and Generation Results

The optimal water release and generation profiles at GCD are computed by the GTMax SL Exp model under the With and Without experiment scenarios based on the operating rules summarized in Table 4.1. A figure of the detailed generation results under both scenarios is provided in Appendix A, Figure A.1.

Water release ranges during weekends and weekdays, under both scenarios, are depicted in Figure 5.2. As can be seen in the figure, under the Baseline scenario (red rectangles), water release ranges during weekends are equal to zero cfs due to flat flow constraints. Moreover, because the flat flow level is required to be only 750 cfs greater than the minimum water release during weekdays, water release during weekends is relatively low. In July and August, when monthly release targets are relatively large, water releases during weekdays are significantly higher than under the Without Experiment scenario (blue rectangles) to compensate for the low water release volume during weekends. However, in May and June, when monthly release targets are low, weekday releases under both scenarios are similar. This is because, under low monthly release targets, daily fluctuations are also low (Table 2.2), which forces weekend and weekday release to be similar. Therefore, lifting the 85 percent minimum weekend-to-weekday release ratio described above under the Baseline scenario has no impact.

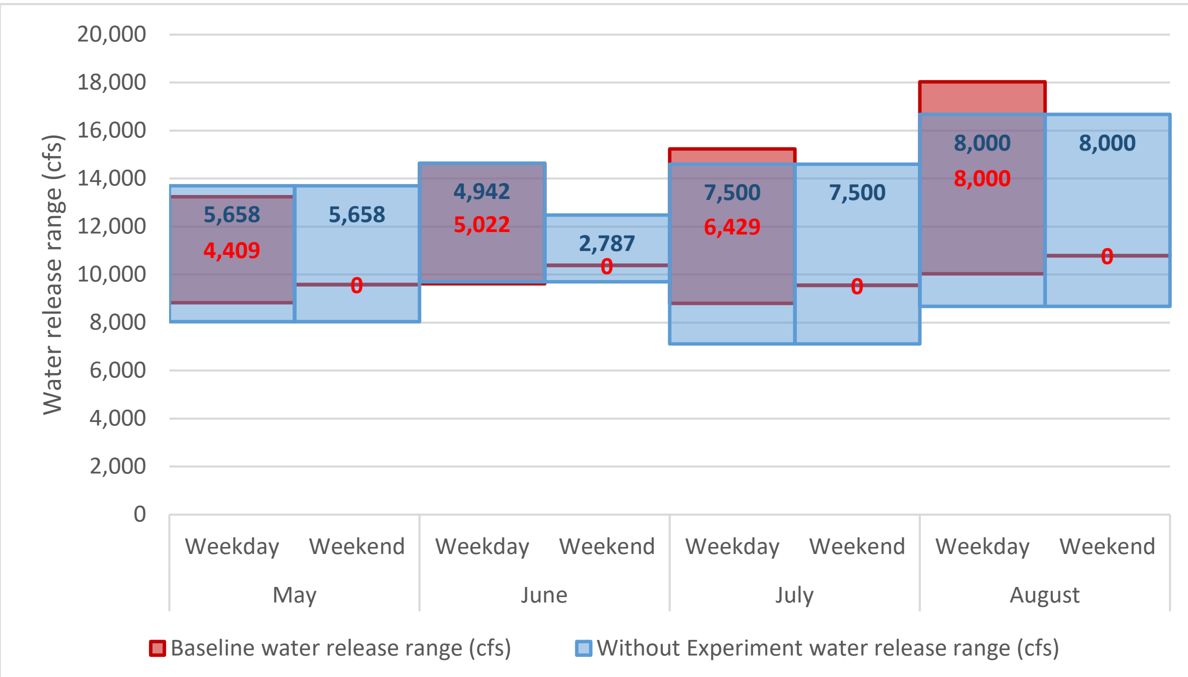

Figure 5.2: Model results of water release range in weekends and weekdays from May to August 2020 under the With and Without Experiment scenarios

In July and August, when monthly release targets are sufficiently high, bug flows shift water release volumes and therefore energy production from weekends to weekdays. From Figure 5.3, we can see that this generation shift is equal to 12 and 16 GWh in May and August, respectively. However, this shift of water is negligible in May and June.

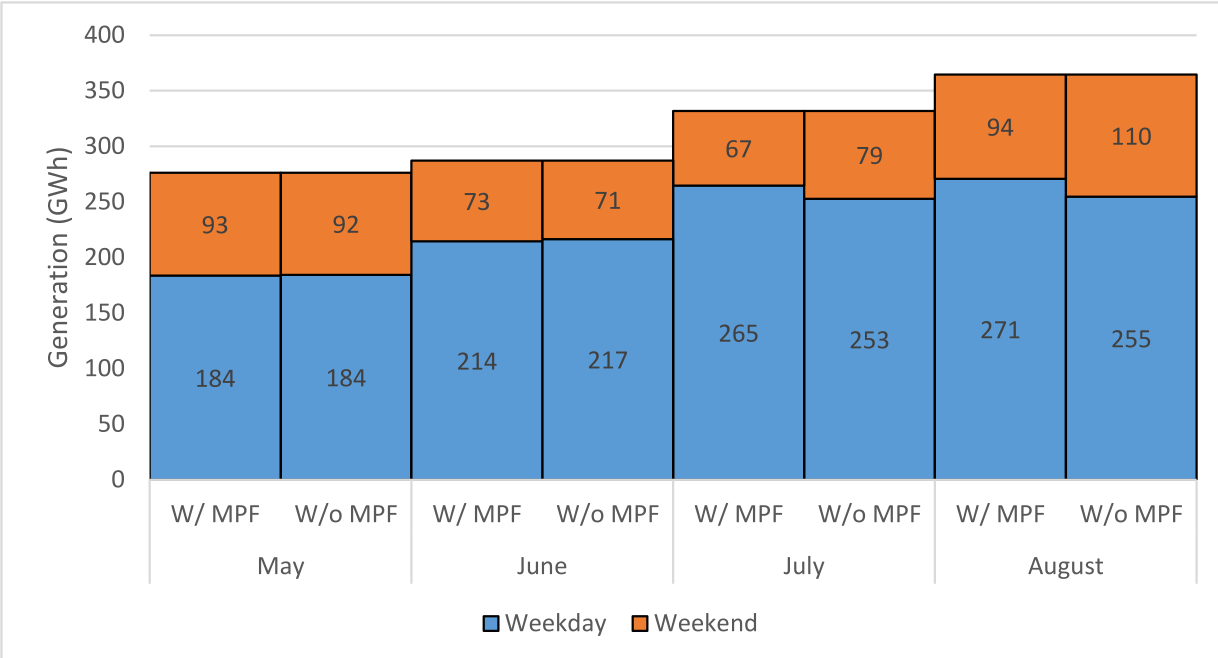

Figure 5.3: Comparison of With and Without Experiment GCD production for weekdays and weekends

5.2 Financial Results

The shifting in energy production in high release months results in lower net energy position during the weekends under the MPF experiment (Baseline scenario) compared to the Counterfactual scenario. In addition, the MPF flat flow requirement does not allow WAPA schedulers to follow/respond to market prices during the weekends. Lower releases and less power production therefore lower WAPA's net financial position during the weekend during an MPF experiment. On the other hand, in July and August, both net energy and financial positions are higher during weekdays under the Baseline (MPF) scenario because of higher water release volumes in combination with higher peak (cf. Figure 5.2).

Figure 5.4 shows that, apart from May and June where the MPF financial impact was relatively low, the accumulated MPF financial cost during weekdays is negative, whereas the accumulated MPF financial cost during weekends is always positive (it is a net cost). The MPF financial cost therefore tradeoffs weekday positive financial position against weekend negative financial position.

The results of this tradeoff are depicted in the waterfall chart shown in Figure 5.5 that depicts cumulative financial impacts at the end of each month. Conducting the MPF experiment resulted in an estimated WAPA financial losses in May, June, July, and August of $95,000, $31,000, $299,000, and $516,000, respectively, for a total MPF financial cost of $941,000.

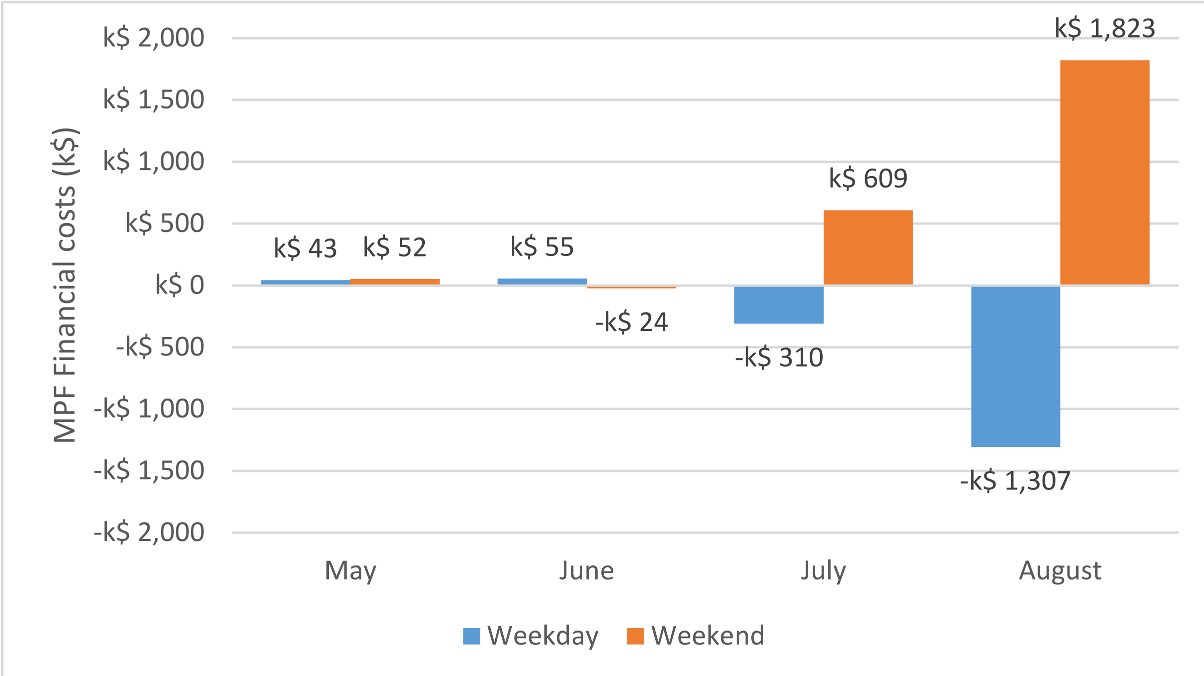

Figure 5.4: Cost of the MPF experiment conducted from May to August 2020: comparison of the MPF financial costs between weekdays and weekdends

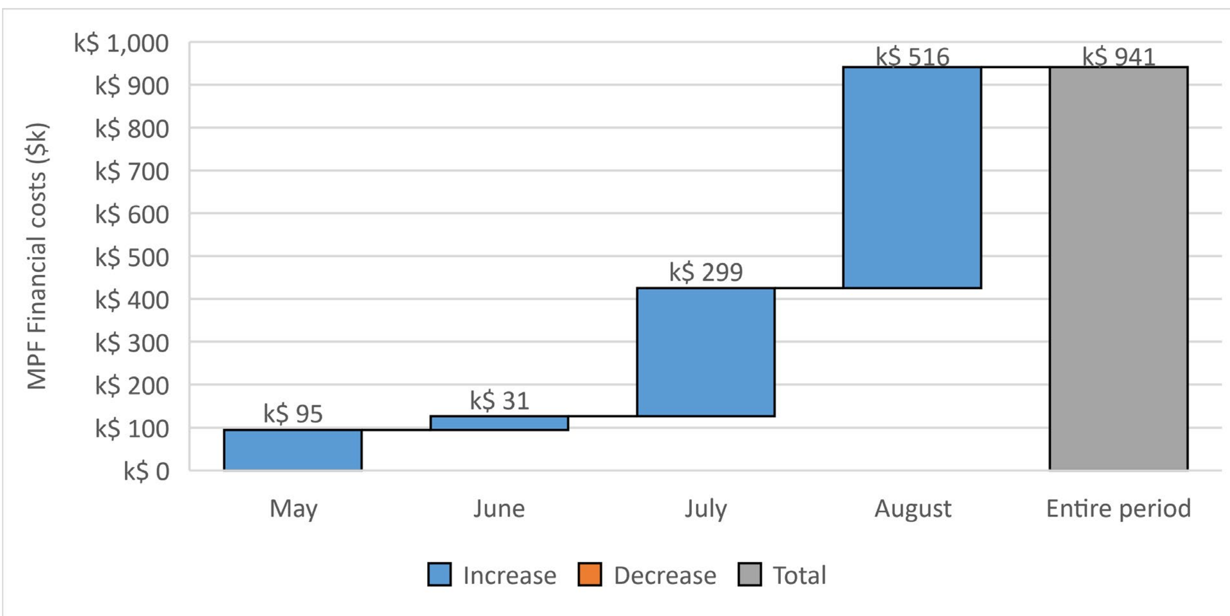

Figure 5.5: Waterfall chart illustrating the cumulative monthly cost of the MPF experiment conducted from May to August 2020

It should be noticed that the financial cost of the 2020 MPF experiment is significantly larger than the financial cost of the 2019 MPF experiment, which amount to $327,000 (Ploussard et al. 2020b).

This is essentially due to the much higher spread of energy prices in July and August that were two to three times larger in 2020 relative to 2019.

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6 Summary

In summary, the MPF experiment imposes flat flow operating constraints during weekends at GCD lowering WAPA's financial position during the weekend. On the other hand, under a MPF Experiment, the weekend constraint that requires minimum daily water release volume to be 85 percent the average weekday volume is lifted. Lifting this constraint generally increases WAPA's financial position during weekdays.

The tradeoff between a lower MPF financial position during the weekend and a higher position during weekdays is either positive or negative depending on hydrological conditions and energy market price profiles during the experiment. The positive financial impact of lifting the minimum weekend-to-weekday daily release ratio is, most of the time, not sufficient to counterbalance the financial costs of the weekend flat flow constraint imposed by the MPF experiment, especially during periods of large water release and high energy price variations.

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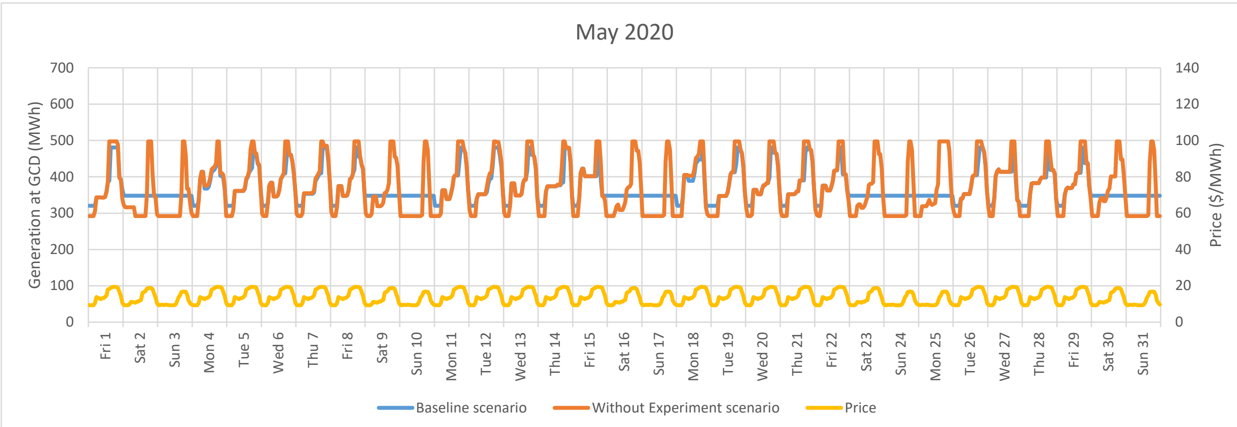
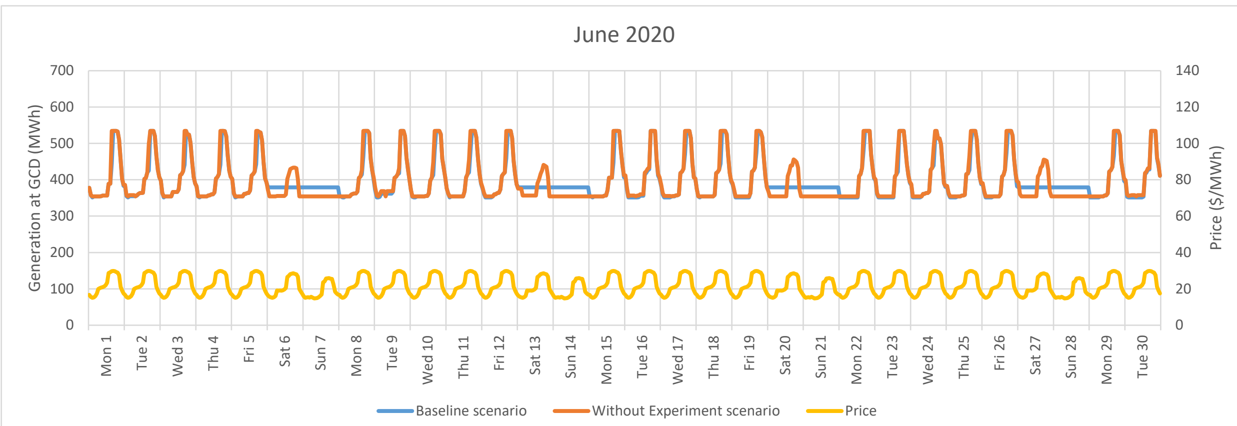
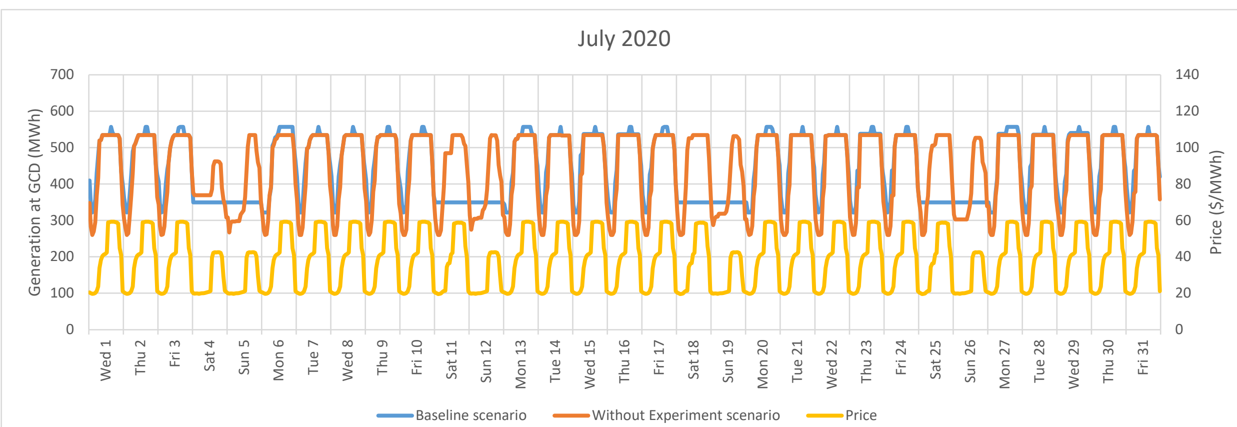
Appendix A: GTMax SL Exp Model Results for the 2020 MPF Experiment: Generation and price profiles







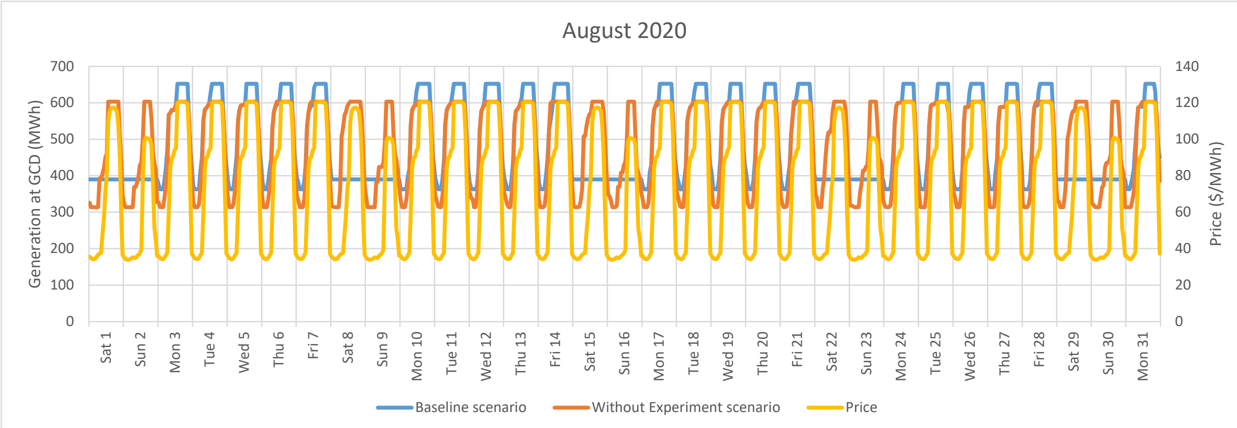


Figure A.1: Modeled hourly generation at GCD under the Baseline scenario and the Without Experiment scenario during May, June, July, and August 2020

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