Financial Analysis of Experimental Releases Conducted at Glen Canyon Dam during Water Year 2021

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Financial Analysis of Experimental Releases Conducted at Glen Canyon Dam during Water Year 2021

by
Q. Ploussard, and T.D. Veselka
Energy Systems Division, Argonne National Laboratory

Prepared for
United States Department of Energy
Western Area Power Administration

August 2022
Foreword

This report was prepared by Argonne National Laboratory (Argonne) in support of a financial analysis of two Glen Canyon Dam (GCD) flow experiments that were conducted in Water Year 2021. The first experiment, called “spring disturbance flow”, was conducted from March 15 to 26, 2021. This disturbance flow experiment is designed to simulate a spring-timed runoff event so scientists can study its effects on the Colorado River ecosystem. The second experiment was a reduced and steady discharge from May 29 to June 4, 2021. This reduced steady flow experiment was conducted for the United States Geological Survey (USGS) to collect high-resolution aerial imagery over Grand Canyon National Park. 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.

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<tr>
<th>Acronym</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>AHP</td>
<td>available hydropower</td>
</tr>
<tr>
<td>Argonne</td>
<td>Argonne National Laboratory</td>
</tr>
<tr>
<td>CRSP</td>
<td>Colorado River Storage Project</td>
</tr>
<tr>
<td>CY</td>
<td>calendar year</td>
</tr>
<tr>
<td>EIS</td>
<td>Environmental Impact Statement</td>
</tr>
<tr>
<td>EMMO</td>
<td>Energy Management and Marketing Office (WAPA)</td>
</tr>
<tr>
<td>FES</td>
<td>firm electric service</td>
</tr>
<tr>
<td>GCD</td>
<td>Glen Canyon Dam</td>
</tr>
<tr>
<td>GTMax SL Exp</td>
<td>Generation and Transmission Maximization Superlite Experiments</td>
</tr>
<tr>
<td>LTEMP</td>
<td>Long-Term Experimental and Management Plan</td>
</tr>
<tr>
<td>MPF</td>
<td>Macrinovertebrate Production Flow</td>
</tr>
<tr>
<td>MSR</td>
<td>Minimum Schedule Requirement</td>
</tr>
<tr>
<td>N/A</td>
<td>Not applicable</td>
</tr>
<tr>
<td>PCF</td>
<td>Power conversion factor</td>
</tr>
<tr>
<td>Reclamation</td>
<td>Bureau of Reclamation</td>
</tr>
<tr>
<td>ROD</td>
<td>Record of Decision</td>
</tr>
<tr>
<td>SHP</td>
<td>sustainable hydropower</td>
</tr>
<tr>
<td>SLCA/IP</td>
<td>Salt Lake City Area Integrated Projects</td>
</tr>
<tr>
<td>WAPA</td>
<td>Western Area Power Administration</td>
</tr>
<tr>
<td>WI</td>
<td>Western Interconnection</td>
</tr>
<tr>
<td>WY</td>
<td>water year</td>
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## Units of Measure

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>cfs</td>
<td>cubic feet per second</td>
</tr>
<tr>
<td>ft</td>
<td>feet</td>
</tr>
<tr>
<td>hr</td>
<td>hour</td>
</tr>
<tr>
<td>MW</td>
<td>megawatt(s)</td>
</tr>
<tr>
<td>MWh</td>
<td>megawatt-hour(s)</td>
</tr>
<tr>
<td>pf</td>
<td>power factor</td>
</tr>
<tr>
<td>TAF</td>
<td>thousand acre-feet</td>
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</table>
Financial Analysis of Experimental Releases Conducted at Glen Canyon Dam during Water Year 2021

by

Q. Ploussard, and T.D. Veselka

Abstract

This report examines the financial implications of two experimental releases conducted at the Glen Canyon Dam (GCD) during Water Year (WY) 2021: the “spring disturbance flow” (SDF) that was conducted from March 15 to March 26, 2021, and the “reduced steady flow” (RSF) that was conducted from May 29 to June 4, 2021. The SDF are designed to simulate a spring-timed runoff event so scientists can study its effects on the Colorado River ecosystem. The SDF was developed and evaluated within the adaptive management framework and provisions of the 2016 Record of Decision (ROD) for the Glen Canyon Dam Long Term Experimental and Management Plan (LTEMP) regime (Reclamation 2016). It is the first report examining the financial implications of a SDF, since the 2016 ROD was adopted in December 2016. The RSF was conducted to enable the United States Geological Survey (USGS) to collect high-resolution aerial imagery over Grand Canyon National Park in order to observe, document, and track long-term ecosystem changes in the Colorado River.

Experimental releases may have either a positive or negative impact on the financial value of energy production. For the 2021 SDF, a negative financial impact (i.e., financial costs) of approximately $39,000 was incurred, mainly driven by the inability for WAPA schedulers to follow/respond to hourly market prices during the SDF period. However, for the 2021 RSF, a positive financial impact of approximately $201,000 was incurred, primarily due to higher volumes of water available in the middle of June 2021, after the experimental release period, when market prices were exceptionally high.

This study identifies the main factors that contribute to SDF and RSF financial impacts 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 SDF and RSF operations during their respective periods of the experiment in compliance with the 2016 ROD operating criteria, and (2) a counterfactual “Without Experiments” scenario that is identical to the Baseline except it assumes that the SDF and RSF 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 powerplant characteristics, hydropower conditions, and Western Area Power Administration’s (WAPA’s) energy prices in the modeling process. In addition to estimating the financial impact of the SDF and RSF, 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.
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 (Reclamation 2016). 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);
Two experiments, referred to as Spring Disturbance Flow (SDF) and Reduced Steady Flow (RSF), were conducted during WY 2021. This is the first time these specific experiments have been conducted under the 2016 ROD criteria. For both experiments, the net financial impact is a tradeoff between lower financial outcomes during the experimental release period versus higher financial outcomes during the rest of the month(s).

During the SDF, Lake Powell water releases followed a prescribed pattern. The release rate was reduced to 4,000 cubic feet per second (cfs) beginning March 15 followed by a gradual increase between March 20 and March 22 when it peaked at 20,150 cfs (Reclamation 2021). It remained steady at that relatively high level until March 25. During the SDF experiment, the Western Area Power Administration (WAPA) was not allowed to deviate from the prescribed pattern in response to either its firm electricity service (FES) customer energy demands or market energy prices. This lack of operational flexibility in combination with the pattern of energy prices that occurred during March 2021 resulted in a WAPA financial loss.

In contrast to the SDF spike flow pattern, the RSF imposed a low steady flow of 8,000 cfs during the week of May 29 to June 4 (USGS 2021a). Similar to the SDF experiment, these prescribed releases also prevented WAPA from responding to both FES customer loads and energy market prices. This experiment financially benefited WAPA. This gain is primarily attributed to shifts in Lake Powell daily water release volumes that were required to conduct the RSF experiment. Lower daily water release volumes during the RSF experiment allowed WAPA to release more water during other days of May and June, specifically during mid-June when prices spiked to about $550/MWh.

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 these two experiments. During normal operations, GCD is governed by stringent operating rules as specified in the 2016 ROD. Although these rules yield environmental benefits, there are financial and economic implications. These criteria reduce the flexibility of operations, diminish dispatchers’ ability to respond to FES loads, market price signals, and lower the economic and financial value of power production. Hydropower value is 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 WY 2021, operational flexibility was expunged during the SDF and RSD experimental periods. An integrated set of tools was used to estimate the financial impacts of each experiment by simulating GCD operations under two scenarios, namely, (1) a “Baseline” scenario that mimics SDF and RSF operations during the experiment period 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 SDF and RSF experiments 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 powerplants 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 powerplants’ 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 SDF and RSF experiments 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 releases 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 the SDF and RSF financial impacts, GTMax SL Exp runs were only made for the months of March, May, and June 2021. It was not necessary to run other months of the WY 2021 because the SDF and RSF experiments did not affect the monthly or annual release volumes from Lake Powell (Reclamation 2021, USGS 2021a) and, therefore, the two experiments were not having any financial impacts outside of the months during which they occurred. 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 the experimental 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).
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 releases. 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)

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Minimum release (cfs)</td>
<td>8,000 from 7:00 a.m.–7:00 p.m.</td>
<td>8,000 from 7:00 a.m.–7:00 p.m.</td>
</tr>
<tr>
<td></td>
<td>5,000 at night</td>
<td>5,000 at night</td>
</tr>
<tr>
<td>Maximum release (cfs)</td>
<td>25,000</td>
<td>25,000</td>
</tr>
<tr>
<td>Daily fluctuations (cfs/24 hr)</td>
<td>5,000; 6,000; or 8,000 depending on monthly release volume</td>
<td>depending on monthly release volume</td>
</tr>
<tr>
<td>Ramp rate (cfs/hr)</td>
<td>4,000 up 1,500 down</td>
<td>4,000 up 2,500 down</td>
</tr>
</tbody>
</table>

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) Form PO&M-59 (Reclamation undated) were used for all hydropower plants. These data are also available on a Reclamation website (Reclamation 2020).
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, derived from the 2016 ROD rules (Table 2.1) have also been included.

<table>
<thead>
<tr>
<th>Calendar Year</th>
<th>Month</th>
<th>Experiment</th>
<th>Water Release (TAF)</th>
<th>Lake Powell Elevation (feet [ft])</th>
<th>Maximum daily fluctuations (cfs/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2021</td>
<td>March</td>
<td>SDF</td>
<td>700</td>
<td>3,566.7</td>
<td>6,300</td>
</tr>
<tr>
<td>2021</td>
<td>April</td>
<td>N/A</td>
<td>628</td>
<td>3,562.4</td>
<td>5,653</td>
</tr>
<tr>
<td>2021</td>
<td>May</td>
<td>RSF</td>
<td>624</td>
<td>3,560.6</td>
<td>5,616</td>
</tr>
<tr>
<td>2021</td>
<td>June</td>
<td>RSF</td>
<td>651</td>
<td>3,560.1</td>
<td>6,510</td>
</tr>
</tbody>
</table>

**Figure 2.1: Monthly hydrologic conditions at GCD during the 2021 SDF and RSF Experiments**

### 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, Powerplant 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](image_url)

The load-following objective creates a strong link between WAPA’s contractual obligations and SLCA/IP operations, requiring the 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 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. Another practice consists in imposing one or two cycles of raising and lowering GCD Powerplant output per day, consistently with the number of cycles of customers load profile. WAPA also avoids drastic changes to total water release volumes over successive days. Therefore, it is assumed that, for a given month, the same volume of water is released each weekday, and that weekend daily water release volumes are at least 85 percent of weekday releases. However, in order to conduct the SDF and RSF experiments, these daily water release restrictions had to be lifted during the experimental release periods. Additionally, for the SDF experiment, the minimum release constraint described in Table 2.1 was relaxed (lowered) by 1,000 during the nighttime and 4,000 cfs during the daytime to enable the 4,000 cfs flat flow from March 15 to March 20.
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3 Description of Experimental Releases

The 2021 experimental releases were conducted during the months of March (SDF), and May/June (RSF). This section describes these experimental releases and their characteristics.

3.1 Spring Disturbance Flows

The SDF experiment was developed and evaluated within the adaptive management framework and provisions of the 2016 ROD for the GCD LTEMP regime (Reclamation 2016). The experimental release period of the 2021 SDF was from March 15 to March 26, 2021. During the SDF, Lake Powell water releases followed a prescribed pattern. The release rate was reduced to 4,000 cfs beginning March 15 (Reclamation 2021) followed by a gradual increase between March 20 and March 22 when it peaked at 20,150 cfs. It remained steady at that relatively high level until March 25.

The SDF experiment is designed to simulate a spring-timed runoff event. This combination of low and high flows is expected to disturb river bottom habitats and may drive positive aquatic ecosystem responses like increased algae and insect production. One potential impact of these flows is to increase aquatic insect prey available for endangered humpback chub, non-native rainbow trout, and other wildlife. These flows may also disadvantage brown trout in Glen Canyon by reducing survival of emerging fry. The 2021 SDF experiment was the first SDF conducted at GCD since the 2016 ROD was implemented. Day-ahead scheduled flow pattern for the 2021 SDF experiment is shown graphically in Figure 3.1.

It should be noted that the initial reason water releases were reduced to 4,000 cfs between March 15 and March 20 was to repair the apron (underwater portion) of GCD following 50 years of operations (USGS 2021b). These reduced flows, required for maintenance purpose, represented a unique opportunity to conduct a SDF. This combination of low and high flow disturbance was
expected to enhance the natural processes that sustain the Colorado River ecosystem by mimicking springtime pre-dam flooding. Therefore, even though the reduced water release in March 15-20 can be considered part of the SDF experiment, these reduced flows would have been implemented for maintenance purpose even if the SDF was not conducted.

### 3.2 Reduced Steady Flow

The RSF experiment imposed a low steady (constant) flow of 8,000 cfs from May 29 to June 4, 2021. It was conducted to enable USGS to collect high-resolution aerial imagery over Grand Canyon National Park to observe, document, and track long-term ecosystem changes in the Colorado River (USGS 2021a). The collected data allow scientists to relate observations of landcover changes to physical, biological and hydrological processes, and to support resource management decisions in the Grand Canyon and Colorado River. The low and steady river discharge is required for remote sensing image analyses because data from the newly collected images are compared to historical image data collected at identical steady discharge (8,000 cfs). This is the 6th experiment of this kind conducted at GCD. Before 2021, other acquisitions of this type (high spatial resolution digital multispectral imagery and digital topography) occurred in 2002, 2004, 2005, 2009, and 2013. Day-ahead scheduled flow pattern for the 2021 RSF experiment is shown graphically in Figure 3.2.

![Figure 3.2: Release pattern of the RSF at GCD in May and June 2021 according to day-ahead schedule](image-url)
4 Methods and Models

For the analysis of the 2021 SDF and RSF experiments, financial impacts were computed by comparing simulated results between two operating scenarios:

(1) The Baseline scenario, which assumes 2016 ROD operating criteria and the occurrence of the 2021 SDF and RSF experiments; and

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

The financial impact of each experiment 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 identical under both scenarios. This is due to the fact that SDF and RSF experiments did not affect the monthly or annual release volumes from Lake Powell (Reclamation 2021, USGS 2021a). The financial outcomes of the two experiments are therefore a function of (1) changes in water release patterns due to the experiments, and (2) energy price profiles.

The GTMax SL Exp model is the main simulation tool used to dispatch 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 financial analyses of experimental releases (Ploussard et al. 2019a, Ploussard et al. 2019b, Ploussard et al. 2020a, Ploussard et al. 2020b). This new version uses a more accurate representation of hourly hydropower operations because it models all days of the month instead of extrapolating model 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. Compared to the previous versions of GTMax SL, the GTMax SL Exp model is tailored to simulate experimental water releases from SLCA/IP hydropower plants. In particular, this new version enables the user to specify fix water releases and/or generation schedules for hydropower plant operations during specific periods. This new feature makes it particularly suitable to simulate the SDF and RSF experiments.
### 4.1 Model Input Data for the GCD Reservoir and Powerplant

Data for GCD reservoir and hydropower 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 2022). This information is used to calculate, for each month of the experimental release period, water release volume, PCF, and maximum 24-hr fluctuation (daily change constraint).

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 2021 experimental release period was sufficiently low to not have any observable impact 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 fixed water release patterns during the SDF period (from March 15 to March 26, 2021) and during the RSF period (from May 29 to June 4, 2021). Under the Baseline scenario, the hourly water release patterns at GCD during the SDF and RSF experimental release periods are fixed and set equal to the historical day-ahead schedule as depicted in Figure 3.1 and Figure 3.2, respectively. Conversely, the hourly water release patterns outside the experimental periods are optimized by the GTMax SL Exp model in compliance with 2016 ROD operating criteria. Under the Without Experiment scenario (Counterfactual scenario), water release patterns are fixed only during the maintenance period (from March 15 to March 20, 2021) and set equal to their historical flat rate of 4,000 cfs. As explained in section 3.1, this maintenance was required regardless of whether the SDF was conducted, which is why they are included in the Without Experiment scenario. The hourly water release patterns outside the maintenance period are optimized by the GTMax SL Exp model in compliance with 2016 ROD operating criteria.

The operating rules in both scenarios are summarized in Table 4.1 below. Note that only one table entry in bold text differs between the two scenarios.

<table>
<thead>
<tr>
<th>Operating rule</th>
<th>Baseline scenario</th>
<th>Counterfactual scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating mode</td>
<td>Load-following</td>
<td>Load-following</td>
</tr>
<tr>
<td>Monthly water releases</td>
<td>Based on Reclamation data</td>
<td>Based on Reclamation data</td>
</tr>
<tr>
<td>Monthly PCFs</td>
<td>Derived from Reclamation data</td>
<td>Derived from Reclamation data</td>
</tr>
<tr>
<td>Largest daily change</td>
<td>Derived from Reclamation data</td>
<td>Derived from Reclamation data</td>
</tr>
</tbody>
</table>

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### Periods of Fixed Water Release Patterns

<table>
<thead>
<tr>
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<th></th>
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</thead>
<tbody>
<tr>
<td>2016 ROD Operating Criteria</td>
<td>2016 ROD Operating Criteria</td>
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</tr>
</tbody>
</table>

#### 4.2 Model Input Data for Other SLCA/IP Hydropower Plants

Because we want to isolate the financial impact of the experiments on GCD only, the generation from all the hydropower plants except GCD should 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 for all other power plants to the hourly profile 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 generation resources that, for sake of simplicity, are not optimized by the GTMax SL Exp model. Instead, their generation profile is considered fixed under both scenarios, and based on historical generation profiles from EMMO (Wilhite 2022). 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 2022). 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 historical hourly energy transactions provided by EMMO. For a given hour, the energy price profile is calculated as the energy-weighted average of prescheduled and real-time energy transaction prices. The hourly price profiles are depicted in Figure 5.1 and 5.3 in the following section.
5 Net Financial Cost of the SDF and RSF Experiments

The financial impact of the SDF and RSF experiments was assessed as the difference in financial position between the Baseline and Counterfactual scenarios. The volume of water released each month is identical under both scenarios and equal to the historical volume. However, the hourly water release pattern within each month differs between the two scenarios. The fixed water release patterns during the experiment periods in the Baseline scenario, and during the maintenance period in the Counterfactual scenario, allow no operational flexibility to follow either FES loads or energy prices.

5.1 Financial Results of the SDF Experiment

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 shown in Figure 5.1 below.

As can be seen in Figure 5.1, the water release patterns under the Baseline (blue line) and the Without Experiment scenario (orange line) are identical during the maintenance period (from 5am on March 15 until 6am on March 20) and equal to the historical 4,000 cfs. This is because repairs were scheduled for this period regardless of whether a SDF was conducted. Consequently, no financial costs were incurred during this period. However, the hourly generation profile during the rest of the SDF experiment period (from 7am on March 20 until 8pm on March 26) is fixed only under the Baseline scenario (blue line) and follows the high water release pattern described in 3.1. Even though SDF fixed patterns do not allow WAPA schedulers to follow/respond to market prices and optimize GCD financial position, the significantly higher average generation level during this period when compared to the Without Experiment scenario leads to a higher financial position. On the other hand, outside the experiment period (from March 1 to March 14, and from March 27 to March 31), GCD produces on average less power when compared to the Without Experiment scenario (orange line), and this shifting in energy production leads to a lower financial position.
outside the experiment period. The higher generation level during the SDF experiment, however, is insufficient to compensate for the loss of operational flexibility. Figure 5.2 below depicts the cumulative change in WAPA’s net financial position due to the SDF experiment in March 2021. These impacts are separated into 3 phases: before, during, and after the SDF experiment period.

![Figure 5.2: Waterfall chart illustrating the cumulative cost of the SDF experiment conducted in March 2021](image)

Conducting the SDF experiment resulted in an estimated positive financial outcome during the experiment period (from March 15 to March 26) of $541,000, and in a financial loss for the other days of the month (from March 1 to March 14, and from March 27 to March 31) of $580,000, for a total SDF net financial cost for WAPA of $39,000. Overall, the positive financial outcome resulting from the additional energy production during the experiment period was not sufficient to compensate the negative financial outcome (cost) resulting from the lack of flexibility during the experiment period and the lower amount of energy available outside the experiment period.

### 5.2 Financial Results of the RSF Experiment

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 Figure 5.3 below.

![Figure 5.3: Modeled hourly generation at GCD under the Baseline scenario and the Without Experiment scenario during May and June 2021](image)
As can be seen in Figure 5.3, under the Baseline scenario (blue line), the hourly generation profile during the RSF experiment period (from May 29 to June 4, 2021) is fixed and follows the water release pattern described in 3.2. During this period, the RSF low flat flow requirement forces GCD to release relatively small volumes of water and does not allow WAPA schedulers to respond to market prices. On the other hand, more water and, therefore, energy production is shifted from the RSF period to the other days of the month (between May 1 and May 28, and between June 5 to June 30). More specifically, in the Baseline scenario, GCD produces 1.5% more energy before the experiment (in May) and 4.6% more energy after the experiment (in June) when compared to the Without Experiment scenario.

Figure 5.4 below depicts the cumulative change in net financial position due to the RSF experiment during May and June 2021 before, during, and after the experiment. It shows that the daily shifting of water volumes under the experiment case more than compensated for the negative financial impacts of both a lower RSF water release volume and operating flexibility loss. This higher WAPA financial position is mainly attributed to higher generation levels when prices spiked to over $550/MWh a few days after the experiment ended (see Figure 5.3).

![Figure 5.4: Waterfall chart illustrating the cumulative cost of the RSF experiment conducted in May and June 2021](image)

Conducting the RSF experiment resulted in an estimated WAPA financial losses during the experiment period (from May 29 to June 4) of $692,000, and in a positive financial outcome during the other days of May and June of $893,000, for a total RSF net positive financial outcome of $201,000.
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6 Summary

In summary, the SDF and RSF experiments conducted in the year 2021 imposed fixed GCD operations during specific periods. The elimination of operational flexibility to follow FES loads and respond to market prices during these experiments diminishes the financial value of GCD. On the other hand, the shifting of water release volumes among days of the month when the experiment is conducted may either increase or decrease GCD financial value.

For the SDF experiment, the financial gain during non-experimental days did not fully compensate for financial losses that were incurred during the experiment, resulting in a net WAPA financial loss. On the other hand, under the RSF experiment, monetary gains resulting from higher GCD energy production during a period of exceptionally high energy prices that occurred after the experiment yielded a positive net WAPA financial position.
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7 References


Wilhite, J., 2022, personal communication from Wilhite (Western Area Power Administration, Littleton, Colo.) to Q. Ploussard (Argonne National Laboratory, Argonne, Ill.), March.