Eklutna Hydroelectric Project

Hydropower Operations Modeling

Study Report

DRAFT

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TABLE OF CONTENTS

List of Tables

List of Figures

Terms, Acronyms, and Abbreviations

1991 Agreement	1991 Fish and Wildlife Agreement
AF	acre-feet
AL&P	Anchorage Light & Power
AWWU	Anchorage Water and Wastewater Utility
cfs	cubic feet per second
Chugach	Chugach Electric Association, Inc.
ft	feet
Governor	Governor of Alaska
GPS	Global Positioning System
in.	inch
MEA	Matanuska Electric Association, Inc.
MJA	McMillen Jacobs Associates
MOA	Municipality of Anchorage
NMFS	National Marine Fisheries Service
NVE	Native Village of Eklutna
Parties	MOA, Chugach, MEA, NMFS, USFWS, and the State of Alaska
Project	Eklutna Hydroelectric Project
Project Owners	MOA, Chugach, and MEA
RM	river mile
State	State of Alaska
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

1 INTRODUCTION

The Hydropower Operations Modeling Study was conducted in accordance with Section 3.9 of the May 2021 Final Study Plans (FSP).

The Eklutna Hydroelectric Project (Project) is located in Southcentral Alaska approximately 30 miles northeast of downtown Anchorage near the Native Village of Eklutna (NVE). The Project was originally constructed by the Federal government in the 1950s but was later sold to, and is currently owned by, the Municipality of Anchorage (MOA), Chugach Electric Association, Inc. (Chugach), and the Matanuska Electric Association (MEA), collectively the "Project Owners". As part of the sale of the Project, the current Project Owners entered into the 1991 Fish and Wildlife Agreement (1991 Agreement) with the National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), and the State of Alaska (the Parties). The 1991 Agreement requires the Project Owners to develop and propose to the Governor of Alaska (Governor) a program to protect, mitigate damages to, and enhance fish and wildlife impacted by the development of the Project.

The primary interest of agencies and interested parties thus far has been the restoration of flows to the Eklutna River. Providing instream flows could require significant changes to current reservoir operations, and any variations to Project power plant flows, water surface elevations, or storage requirements would have an impact on the energy produced by Eklutna Power Plant. An operations model is needed to simulate alternative operational scenarios and quantify changes in flows through the power plant and impacts to generation. However, there is no existing operations model for the Project.

2 STUDY OBJECTIVES

The goal of this study was to develop a baseline operations model of the existing Eklutna Hydroelectric Project and associated reservoir in order to assess impacts to flows and energy generation as a result of potential operational changes. This model does not predict future basin hydrology; rather, it used historical reservoir inflow and available flow data along with operational criteria to develop various generation scenarios over the Project's period of operation. The objectives of this study are as follows:

- Develop a baseline reservoir and power plant operations model using historical data, to the extent that it is available.
- Determine baseline energy generation estimates through the power plant and compare to historical generation records to calibrate the model.

This study was finalized as part of the Year 1 study efforts but will be used significantly as part of the Hydro Valuation Study in Year 2. Decisions regarding what alternative operational scenarios to model as part of the Hydro Valuation Study in Year 2 will be made in collaboration with the agencies and other stakeholders.

3 STUDY AREA

The hydro operations modeling effort was a desktop exercise. The study area encompasses the Eklutna Lake watershed and extends to the Eklutna Power Plant location.

4 METHODS

This modeling effort used available water surface elevation data from the existing USGS Gage No. 15278000 located in Eklutna Lake near the Project intake, historical flow data for the Eklutna Power Plant from the Project Owners, and historical flow data for the Eklutna Water Treatment Plant from AWWU to develop an operations model of the reservoir. Historic spill events were also taken into account.

Energy modeling required a hydraulic model of the existing intake and hydraulic conveyance connecting Eklutna Lake with the Eklutna Power Plant. The generation equipment was modeled, such that flow is passed through one or both hydroelectric turbine generating units. Generating efficiencies were considered based on parameters of the equipment provided by Chugach Electric or representative data of homologous units. The baseline model considered all historical operating criteria to provide a working model that closely matches historical generation figures.

The following subsections provide the methodology pertaining to the development of the hydropower operations model.

4.1. Eklutna Lake

4.1.1. Technical Parameters

Eklutna Lake is a natural reservoir located within Chugach State Park, approximately 35 miles northeast of Anchorage near the village of Eklutna. The lake is fed primarily by the Eklutna Glacier and captures a watershed drainage area of approximately 123 square miles. The main technical parameters for the reservoir are provided in **Table 4.1-1**.

Table 4.1-1. Eklutna Lake Technical Parameters.

Description	Value
Max Regulated Water Surface Elevation	871.0 ft
Minimum Operating Water Surface Elevation	814.0 ft
Max Water Surface Area	3,500 Acres
Active Storage	174,800 Acre-Ft

4.1.2. Historic Operating Water Surface Elevation

The water surface elevation of Eklutna Lake is measured on a 15-minute basis at a gauging station located adjacent to the project intake, identified as USGS gauge no. 15278000. This gauge has an operating record from 06/22/1983 to Present (USGS, 2021). The data from this gauging station was utilized in the model to determine the water mass balance of the reservoir and to calculate the static head on the Eklutna Powerplant for determination of energy generation. The water surface elevations extracted from the gauge station for years 2017 – 2021 are presented in Figure 4.1-1. Note that the 2021 water surface elevations are incomplete, with data available to the date this report was written.

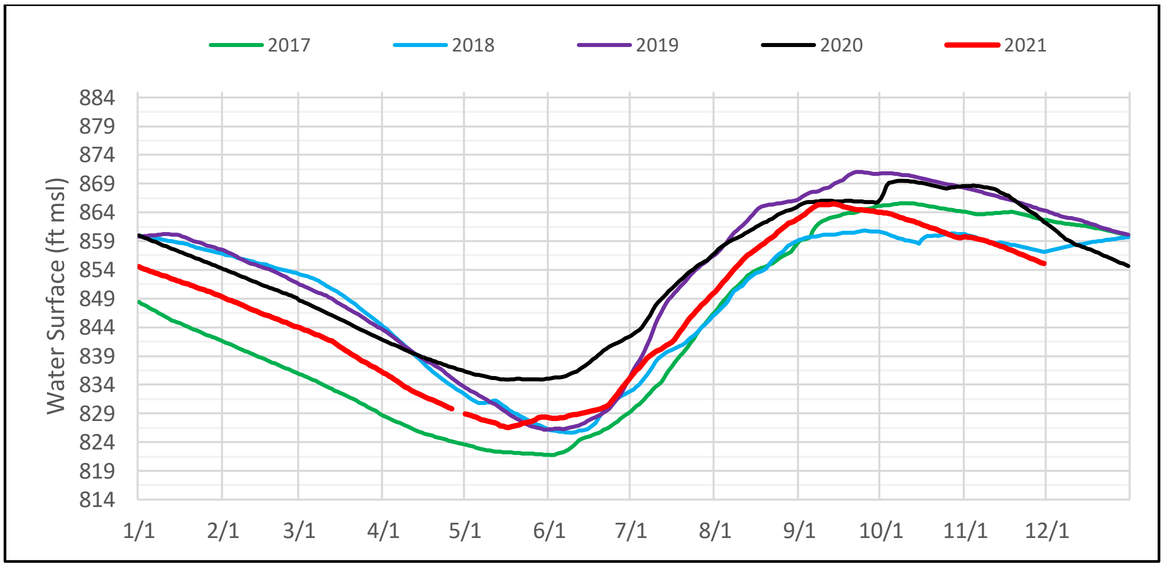

Figure 4.1-1. Water Surface Elevations - Eklutna Lake; 2017 - 2021.

4.1.3. Stage Storage

The operations model of the reservoir was based on a water mass balance, determining inflow to the reservoir and calculating changes in water surface elevations as a function of volumetric releases to the Eklutna Power Plant, AWWU's Eklutna Water Treatment Facility (EWTF), and spills over the dam. The stage storage curve, documenting the active storage of the reservoir as a function of the water surface elevation of Eklutna Lake is provided in **Figure 4.1-2**.

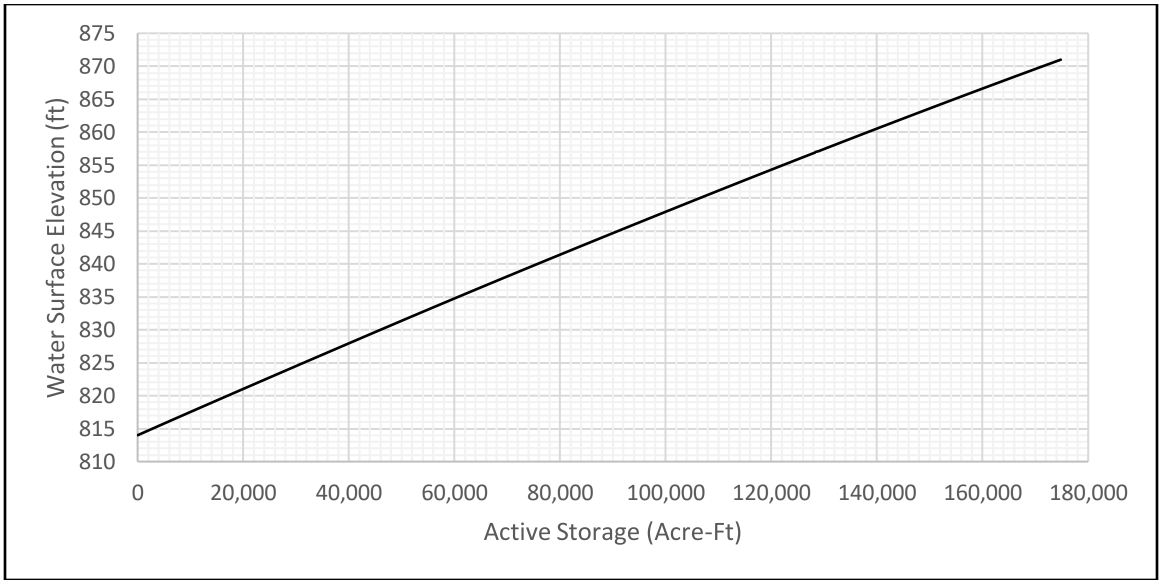

Figure 4.1-2. Stage Storage Curve; Eklutna Lake (USBR, 1964).

4.1.4. Average Reservoir Operation

In order to determine the operations of the Eklutna Project in an average year, and to better predict how any proposed operational changes of the reservoir may impact hydropower generation in future years, an average reservoir model was developed. The operating surface elevation of the prior decade was averaged to determine a baseline water surface elevation of the reservoir throughout a given year. This data is presented in **Figure 4.1-3**.

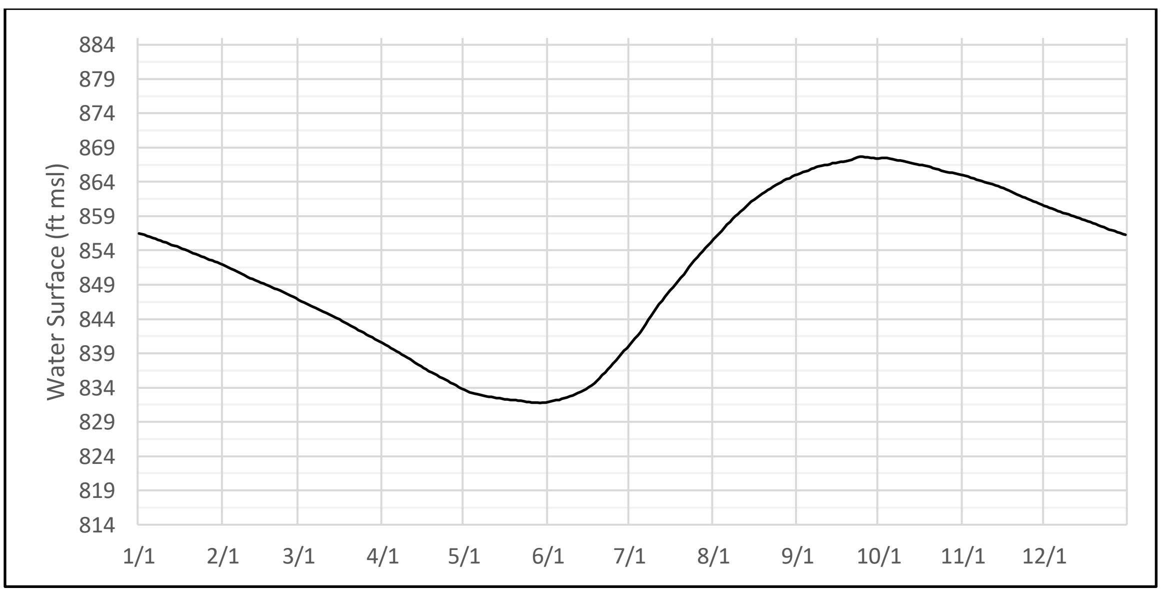

Figure 4.1-3. Average Operating Surface Elevation - Eklutna Lake; 2010 - 2021.

A reservoir water mass balance calculation was performed to determine inflows throughout the year over the period of record given for operating flows of the AWWU EWTF and the Eklutna Power Plant. Inflows for each day of the year from 2011 to 2021 were calculated using Equation 1 shown below. A graphical representation of the average inflows and outflows of Eklutna Lake are presented in **Figure 4.1-4**.

$$V_{in} = \Delta_{Storage} + V_{PP} + V_{AWWU} + V_{Spill} \qquad \text{(Equation 1)}$$

Where: V_{in} = Volumetric Inflow to Eklutna Lake (Acre-Ft)
$\Delta_{Storage}$ = Change in Storage of Eklutna Lake (Acre-Ft)
V_{PP} = Volumetric Outflow to Eklutna Power Plant (Acre-Ft)
V_{AWWU} = Volumetric Outflow to AWWU EWTF (Acre-Ft)
V_{Spill} = Volumetric Outflow through Spillway (Acre-Ft)

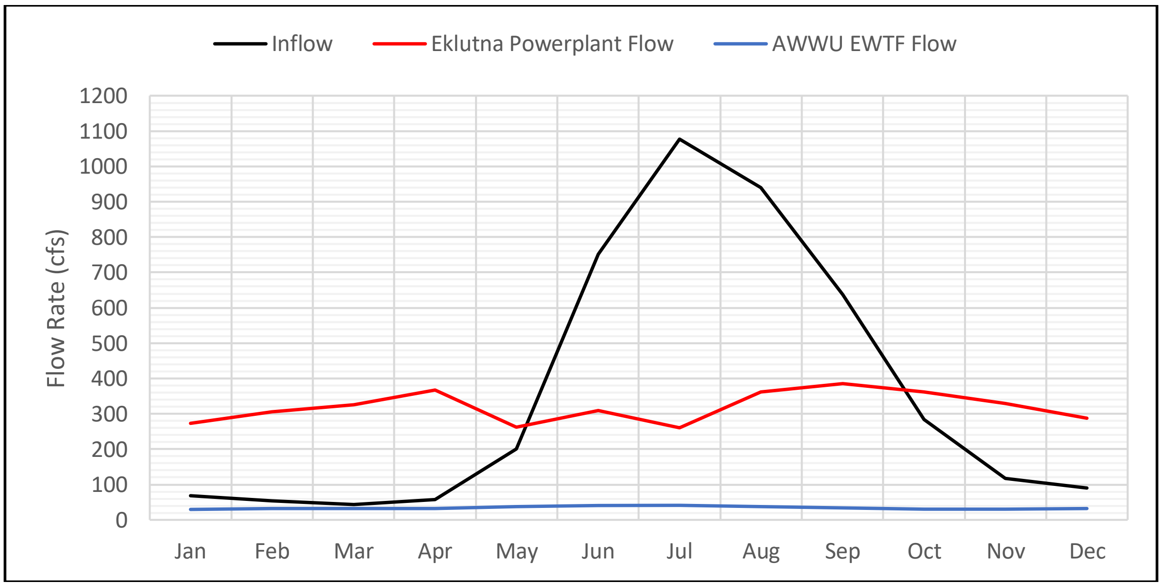

Figure 4.1-4. Eklutna Lake Average Inflows/Outflows; 2011 - 2021.

4.2. Power Conduit

4.2.1. Technical Parameters

Water is conveyed northward from Eklutna Lake to the Eklutna Power Plant through a power conduit approximately 4.5 miles long excavated through East Twin Peak Mountain (formerly identified as "Goat Mountain"). The conduit consists of a submerged intake structure excavated at the lake bottom at elevation 800 feet connected to an intake portal valve shaft, a 9-foot diameter concrete-lined tunnel spanning 23,550 feet to a surge tank and gate control house, and a power penstock connecting the tunnel to the power plant turbines, spanning 1,088 feet with a diameter varying from 91- to 75-inches.

4.2.2. Hydraulic Analysis

A hydraulic model was developed of the intake and power conduit to determine friction losses as a function of flow rate through the conveyance. Minor losses were included at the trashrack, each pipeline bend, each reduction in conveyance diameter, at the turbine bifurcation, valve, and turbine draft tube. Major friction losses were determined throughout the power tunnel and penstock. The following subsections describe how the minor and major losses were calculated and what coefficients were used in the analysis.

4.2.2.1. Major Friction Losses

An accurate estimate of the energy losses caused by the shear stress between the fluid and the boundary is essential to determining the major friction loss through the power tunnel and penstock. The shear stress or friction factor is a function of the viscosity and velocity gradient of the fluid near the boundary (Tullis, 1989). The Darcy-Weisbach equation (Equation 2) was used to determine the friction losses in the tunnel and pipeline. The Colebrook-White equation (Equation 3) was used to determine the friction factor, used in the Darcy-Weisbach equation, for the pipeline and the lined tunnel. The selected roughness (e) for different linings used in the analysis is presented in **Table 4.2-1**.

$$h_f = \frac{fL}{D}\frac{V^2}{2g} \qquad \text{Equation 2}$$

$$\frac{1}{\sqrt{f}} = 1.14 - 2\log\left(\frac{e}{D} + \frac{9.35}{R_e\sqrt{f}}\right) \qquad \text{Equation 3}$$

Where: h_f = friction losses (feet)
f = friction factor
D = Pipe or Tunnel Diameter (feet)
L = Pipe or Tunnel Length (feet)
V = Average Velocity (feet/second)
g = Gravitational Acceleration (feet/second^2)
e = roughness height (feet)
R_e = Reynolds Number, using Kinematic Viscosity at 60°F = 1.22E-05 ft^2/s

Table 4.2-1. Pipeline and Tunnel Roughness Values

Description	Value (mm)	Value (ft)	Range (mm)	Reference
Steel Pipe Roughness Height, *e* (feet) [1/]	0.045	0.00015	0.045 – 0.006	(Rennels, 2012)
Concrete-Lined Tunnel Roughness Height, *e* (feet) [2/]	0.3	0.0095	0.30 – 3.0	(Rennels, 2012)

4.2.2.2. Minor Friction Losses

Minor losses, or more appropriately called *local losses*, is a term referring to losses that occur at conveyance system appurtenances such as entrance, elbow, orifice, valve, etc. The head losses, as a result of a minor loss, are due primarily to the formation and decay of turbulent eddies (Tullis, 1989). The minor head loss is proportional to the velocity head, as presented in Equation 4. The minor loss coefficients used in the analysis are presented in **Table 4.2-2**.

$$h_l = K_l \frac{V^2}{2g} \qquad \text{Equation 4}$$

Where: h_l = Minor losses (feet)
K_l = Loss Coefficient
V = Average Pipe Velocity (feet/second)
g = Gravitational Acceleration (feet/second^2)

Table 4.2-2. Minor Loss Coefficients.

Description	Assumed Value	Reference
Entrance Loss, Sharp Corner	0.5	(Tullis, 1989)
Full Open Isolation Valve	0.20	(Tullis, 1989)
90° Bend Loss	0.24	(Tullis, 1989)
Exit Loss	1.0	(Tullis, 1989)

4.2.2.3. Combined Head Losses

Considering both major and minor friction losses in the proposed hydraulic conveyance, an overall system head loss function was developed for the power conduit. The head loss equation as a function of flow rate is provided below in Equation 5, with a site-specific head loss coefficient equal to $2.483*10^{-4}$. Head loss as a function of flow rate is graphically represented in **Figure 4.2-1**.

$$H_T = KQ^2 \qquad \text{Equation 5}$$

Where: H_T = Combined Head Losses (ft)
K = Head Loss Coefficient
Q = Flow Rate (cfs)

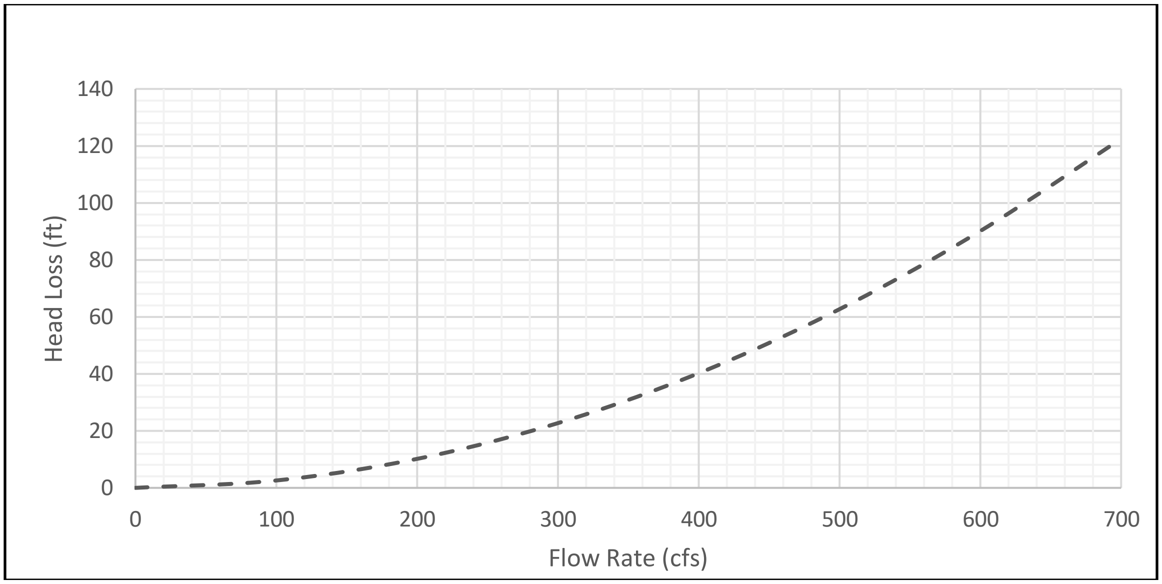

Figure 4.2-1. Eklutna Power Conduit Head Loss Curve.

The head loss equation was utilized within the hydraulic model to determine losses throughout the conveyance for calculating net head on the units during operation. The hydraulic grade line represented on the tunnel elevations throughout the power conduit are presented in **Figure 4.2-2**.

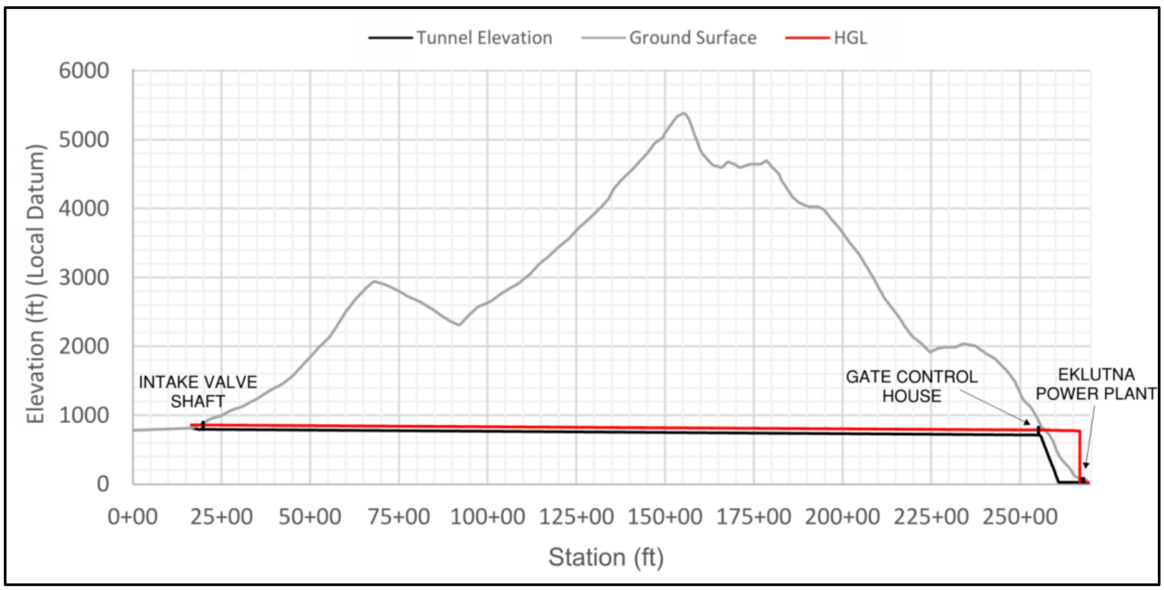

Figure 4.2-2. Eklutna Power Conduit Hydraulic Grade Line (HGL).

4.3. Eklutna Power Plant

4.3.1. Technical Parameters

The Eklutna Power Plant consists of two vertical Francis type hydroelectric turbines with a total rated capacity of 50,000 HP. The main technical parameters for the powerhouse and generating units are provided in **Table 4.3-1**.

Table 4.3-1. Eklutna Power Plant Turbine-Generator Technical Parameters.

Description	Value
Number of Generating Units	2
Turbine Type	Vertical-Shaft Francis
Rated Capacity (Per Unit)	25,000 HP (18.6 MW)
Rated Flow (Per Unit)	300 cfs
Gross Head	850 ft
Rated Head	800 ft

4.3.2. Turbine-Generator Efficiency

To calculate energy produced through each unit over the operating history analyzed in this study, the turbine efficiency as a function of the net head and flow rate is required. Typically in the form of a hill chart, the unit specific parameters for the Eklutna Power Plant turbines were not available for this analysis. To estimate unit efficiencies for each turbine over the operating range, the hydraulic parameters were compared to published efficiency data obtained through model testing of a homologous unit to produce an efficiency hill curve, presented in **Table 4.3-2**. To estimate the generator efficiency losses to determine daily energy output, a constant value of 97.5% generator efficiency is assumed for the purposes of this investigation.

Table 4.3-2. Eklutna Turbine Hill Curve.

		Net Head (ft)											
		650	668	686	705	723	741	759	777	795	814	832	850
Flow Rate (cfs)	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	40	35.8%	36.4%	36.7%	37.5%	38.0%	38.3%	38.5%	38.8%	38.8%	39.1%	39.4%	39.9%
	80	66.3%	66.5%	66.5%	66.6%	66.6%	66.5%	66.5%	66.4%	66.3%	66.2%	65.9%	65.7%
	120	78.5%	78.5%	78.6%	78.5%	78.5%	78.5%	78.3%	78.2%	78.0%	77.8%	77.6%	77.1%
	160	85.0%	85.2%	85.2%	85.3%	85.3%	85.2%	85.1%	85.0%	84.9%	84.7%	84.5%	84.0%
	200	88.5%	88.7%	88.8%	89.1%	89.1%	89.1%	89.1%	89.1%	89.0%	88.9%	88.7%	88.3%
	240	89.7%	90.1%	90.4%	90.9%	91.0%	91.1%	91.1%	91.1%	91.1%	91.0%	91.0%	90.7%
	280	89.4%	90.0%	90.5%	91.1%	91.4%	91.5%	91.6%	91.7%	91.8%	91.8%	91.7%	91.6%
	320	88.0%	88.4%	88.8%	89.7%	90.0%	90.4%	90.7%	91.0%	91.2%	91.4%	91.5%	91.5%
	360	88.0%	88.4%	88.8%	89.3%	89.5%	89.7%	89.9%	90.0%	90.1%	90.1%	90.1%	90.0%
	400	88.0%	88.4%	88.8%	89.3%	89.5%	89.7%	89.9%	90.0%	90.1%	90.1%	90.1%	90.0%

4.4. Hydropower Generation Model

4.4.1. Historic Operation

As discussed in Section 4.1, flow data was obtained from the Project owners to calibrate a baseline energy model. Hourly metered flow data was provided through each unit from 1/1/2011 to 12/31/2020 and is presented in **Figure 4.4-1**.

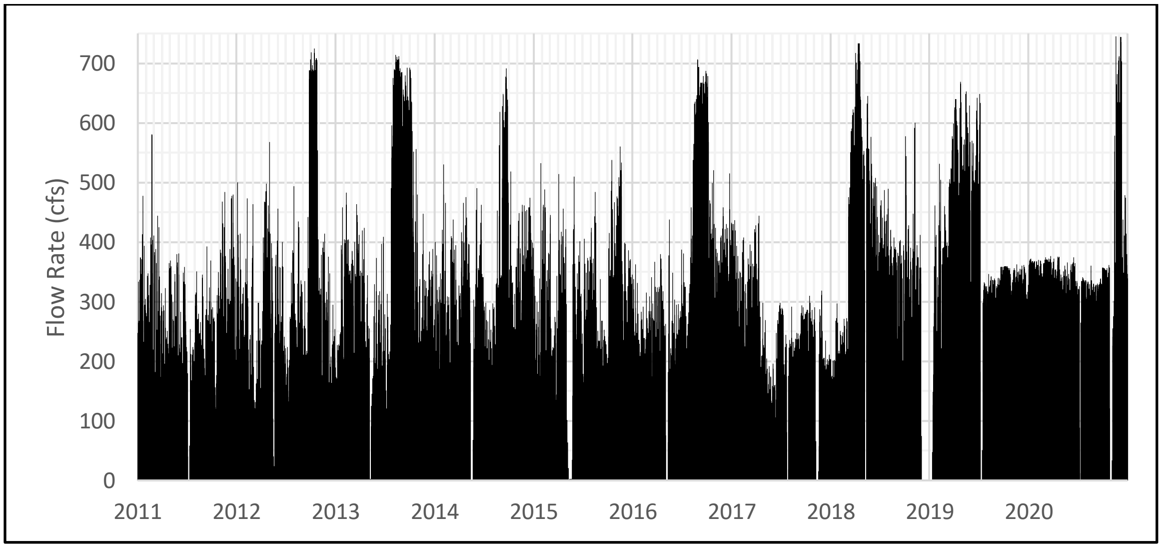

Figure 4.4-1. Daily Flow Rate (Total) to Eklutna Power Plant; 2011-2021.

In addition to flows, historic metered energy production from the Eklutna Power Plant was provided to determine the accuracy of the operations model for predicting generation estimates. A graphical representation of energy production by month is provided in Figure 4.4-2 and summarized in Table 4.4-1.

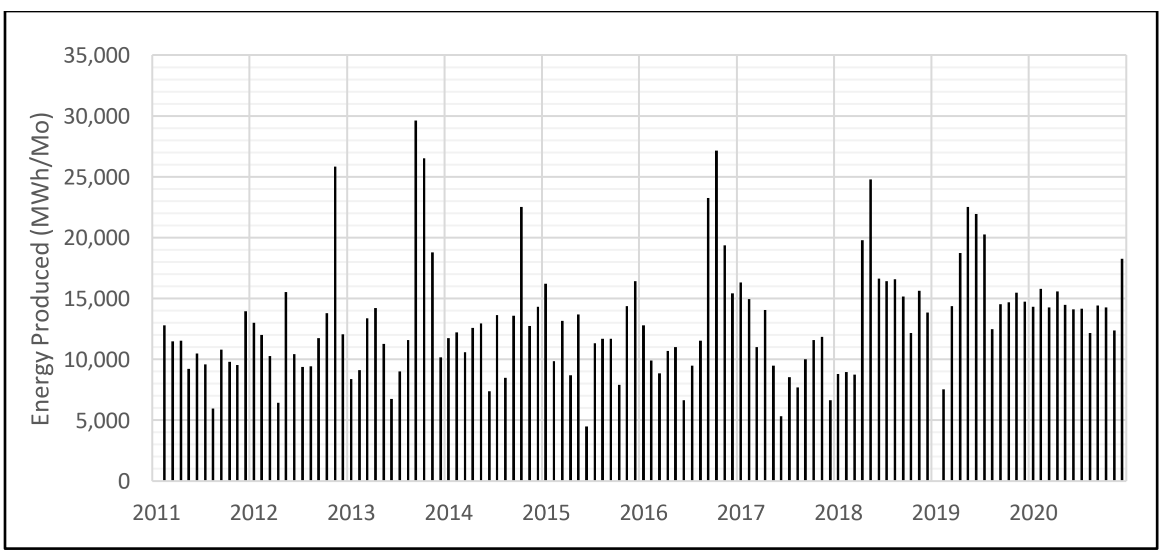

Figure 4.4-2. Monthly Energy Production - Eklutna Power Plant; 2011-2021.

Table 4.4-1. Annual Energy Production Summary; 2011 - 2021.

Year	Energy Production (GWh)
2011	128
2012	145
2013	172
2014	157
2015	136
2016	170
2017	120
2018	169
2019	192
2020	179

5 RESULTS

The operations modeling was performed to analyze calculated daily generation values over ten years of operation (2011 – 2021) to validate accuracy with known generation values described in Section 4.4.1. The output of the operations model compared with actual generation values is presented graphically in Figure 5-1 and summarized in **Table 5-2**.

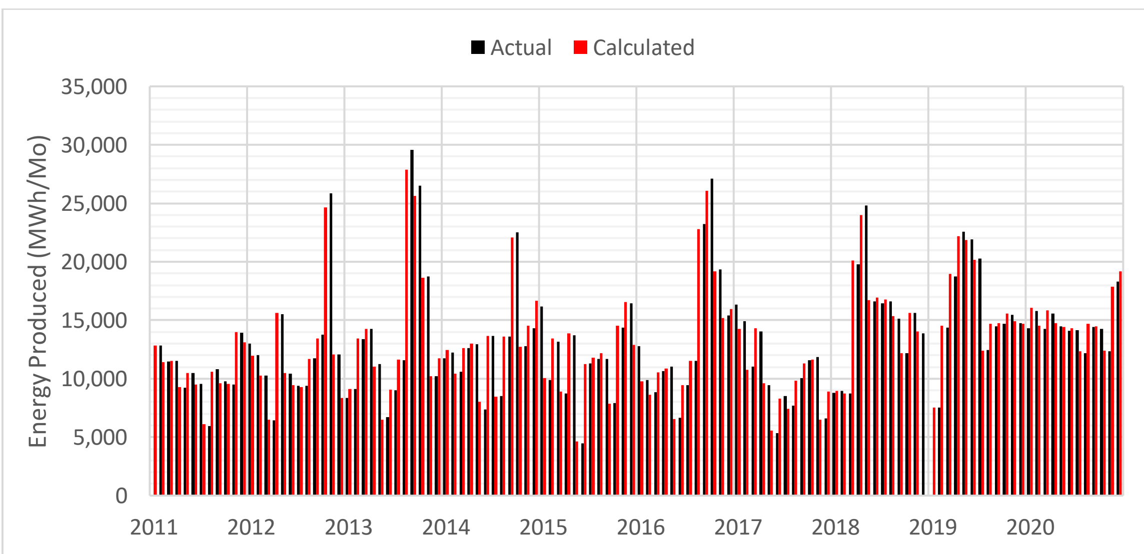

Figure 5-1. Monthly Energy Production Comparison – Actual vs. Calculated; 2011 – 2021.

Table 5-2. Annual Energy Comparison Summary - Actual vs Calculated; 2011-2021.

Year	Actual Energy Production (GWh)	Calculated Energy Production (GWh)	% Error
2011	128.1	128.0	-0.1%
2012	145.2	143.8	-1.0%
2013	172.1	169.1	-1.7%
2014	157.3	158.3	0.6%
2015	136.1	138.0	1.4%
2016	169.5	166.5	-1.8%
2017	119.9	118.4	-1.3%
2018	168.8	169.5	0.4%
2019	191.6	192.1	0.3%
2020	179.1	180.9	1.0%
Average	156.8	156.5	-0.2%

6 CONCLUSIONS

A hydropower operations model was developed to simulate the operation of Eklutna Lake, losses in the power conduit, and energy output of the hydroelectric units at the Eklutna Power Plant. The model is able to accurately predict the hydroelectric generation potential as a function of 10-year average Eklutna Lake water surface elevations and hourly power plant flows to within 0.2% of actual values. Future use of this model is intended to simulate proposed changes to reservoir or power plant operations in order to determine expected changes in energy production and revenue through the power plant. This model will be utilized as part of the Hydropower Valuation Study to be initiated in 2022.

7 VARIANCES FROM FINAL STUDY PLAN AND PROPOSED MODIFICATIONS

The work performed as part of this study plan was done in accordance with the approved final study plan, and no modifications were made to the scope or methodology.

8 REFERENCES

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