Modeling Complex Hydrodynamics in Washington Reservoirs

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Sponsor: Chelan County PUD

Chelan PUD plays a vital role in Washington's energy landscape, managing operations at Rocky Reach Dam and Rock Island Dam on the Columbia River.

The operation of these dams relies on controls that monitor inflow and outflow to optimize energy production efficiency and promote environmental sustainability.

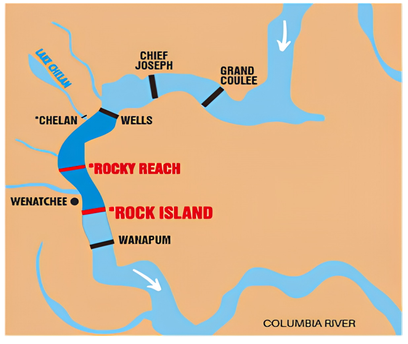

Figure 1: Map of Rocky Reach and Rock Island Dams

The Wells Dam Discharge, Chelan Flow, and Entiat Flow impacts the inflow at Rocky Reach.

The Rocky Reach Discharge and Wenatchee flow impacts the inflow at Rock Island.

Problem Statement

Current linear gradient models, based on averaging, used at Chelan PUD do not fully account for the real-time hydrodynamic conditions of the river, leading to inefficiencies in water distribution.

This project aims to enhance the accuracy of predicting inflow and headwater elevation levels, ensuring optimal water distribution across dams.

By improving prediction accuracy, we can avoid risks associated with overfilling and underfilling, and effectively meet electricity demand to maximize energy production efficiency and sustainability.

Proposed Solution

We will develop machine learning models using Principal Component Analysis and Time Series Analysis to improve the accuracy of water level predictions and generate the most efficient power generation for the dams.

Additionally, we will be analyzing external factors weather and electricity pricing data with the hydrological data from 2019-2023 for more insights and patterns.

Principal Component Analysis

Principal Component Analysis (PCA) is a statistical technique used to emphasize variation and bring out strong patterns in a dataset. It helps in reducing the dimensionality of large data sets, allowing for the simplification of complexity while retaining the most significant variances.

Feature Engineering Overview:

Lag variables represent historical data points that are predictors for future states.

Rocky Reach Dependencies:
- Wells Dam Discharge: Last 90-105 minutes
- Chelan Flow: Last 62-77 minutes
- Entiat Flow: Last 15-30 minutes
- Rocky Reach Headwater Level: Last 2 minutes
- Rocky Reach Discharge: Last 2 minutes

Rock Island Dependencies:
- Rocky Reach Discharge: Last 60-90 minutes
- Wenatchee Flow: Last 15-30 minutes
- Rock Island Headwater Level: Last 2 minutes
- Rock Island Discharge: Last 2 minutes

Feature Selection Using PCA:

Rocky Reach has a **99.5% variance** by the **selected 15 principal components** from the original 52 features.

Rock Island has a **99.6% variance** by the **selected 22 principal components** from the original 52 features.

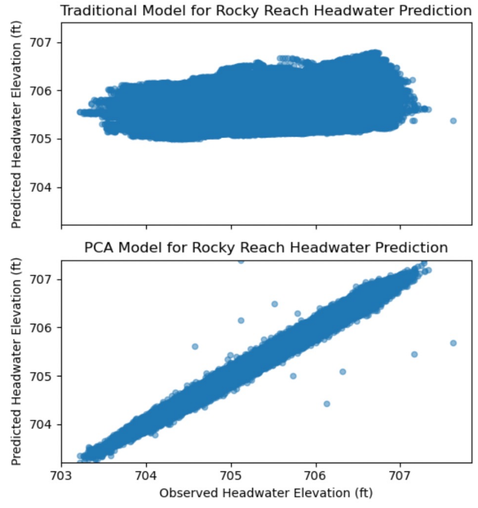

Figure 2: Model Comparison for Rocky Reach Headwater Elevation

What Do These Results Conclude?

The PCA analysis has identified key patterns and significant variances in the headwater elevation data for both dams. These results demonstrate that the principal components, rather than average values, are critical in understanding and predicting headwater levels. This insight allows for more precise modeling and operational decision-making.

External Data Influence on Water Levels

Weather Data

We analyzed hourly weather data from Wenatchee, focusing on Temperature (°C), Humidity (g/kg) and Wind Speed (m/s).

Rocky Reach: A **slight positive correlation** between weather conditions and headwater levels, although this impact is minimal compared to the influence of incoming water flows.

Rock Island: A **slight negative correlation** with weather variables, yet similarly, this influence is minor compared to actual water levels.

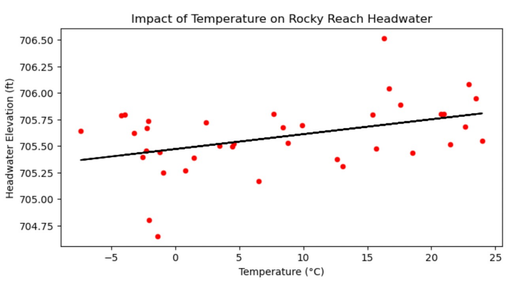

Figure 3: Temperature and Headwater Elevation Relationship

Pricing Data

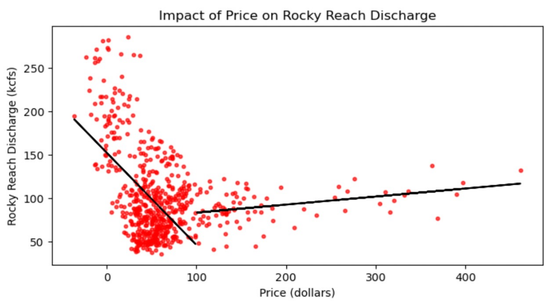

Figure 4: Price and Discharge Relationship

We utilized 5-minute interval pricing data from California ISO, representing marginal energy costs in dollars.

A **small correlation** exists between energy pricing and Rocky Reach's discharge rates.

The plot shows how high runoff season influences the dams discharge resulting in both **positive and negative trends with energy pricing.**

Time Series Analysis

Model Selection:
We ran multiple models including Autoregression (AR), Moving Average (MA), and Autoregressive Moving-Average (ARMA) for our analysis. We then compared these models looking at both daily and monthly average data.

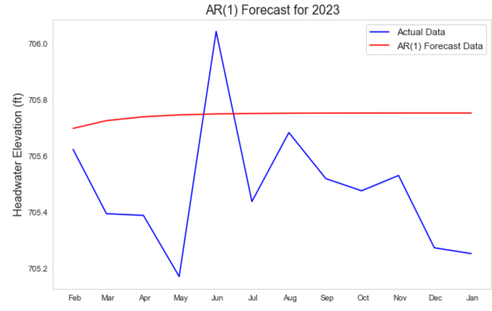

Figure 5: Monthly Average Forecasting for Rocky Reach Dam

The **AR(1) Model was the best fitting model** for monthly averaging of 2019-2022 data which predicted the 2023 data. We then compared the given 2023 data with the forecasted data and determined that it was not as insightful compared to our PCA and linear modeling analysis. However, the time series helped conclude that there is seasonal patterns in the data that make it difficult to predict headwater elevation overtime.

Conclusion

This poster shows our approach in addressing the complex hydrodynamic challenges faced by the Rocky Reach and Rock Island Dams through advanced machine learning techniques of Principal Component and Time Series Analysis. The anticipated outcomes promise environmental benefits through sustainable water management, improved dam operations, and potential cost reductions.

Acknowledgments

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