U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Small Business Vouchers
U.S. DEPARTMENT OF ENERGY

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

NATEL ENERGY

Modeling the Grid Value of Networked, Small Hydro Generators

2.3.0.402 / 32951

Hydropower Program

Tuesday, October 8, 2019

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National Renewable Energy Laboratory

Project Overview

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Project Summary

The focus of this project was on better understanding the potential grid value of a cascading network of Natel Energy's hydroEngine® turbines during dry, typical, and wet operating years. This project used operational optimization to quantifying net revenue and the ability of the system to meet grid needs for varying hydrologic conditions. NREL also assessed operations under multiple operating cost scenarios, storage volumes, market types, and plant locations.

Project Objective & Impact

- Assess the grid value of a network of small, cascading hydropower facilities.
- Evaluate the tradeoffs between downstream flow impacts and revenue streams.
- The project found that that the combined response of the co-optimized hydropower facilities was well matched to providing both energy and ancillary services.
- The project also found that the impact of the network on downstream flows could be reduced without significantly affecting net revenues, thereby eliminating one of the major environmental concerns associated with conventional hydropower.

Project Information

Project Principal Investigator(s)

Greg Stark

WPTO Lead

Marisol (Mari) Bonnet

Project Partners/Subs

Natel Energy

Project Duration

- Project Start Date: June 30, 2017
- Project End Date: September 30, 2018

Alignment with the Program

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Hydropower Program Strategic Priorities

Environmental R&D and Hydrologic Systems Science

Big-Data Access and Analysis

Technology R&D for Low-Impact Hydropower Growth

R&D to Support Modernization, Upgrades and Security for Existing Hydropower Fleet

Understand, Enable, and Improve Hydropower's Contributions to Grid Reliability, Resilience, and Integration

Alignment with the Hydro Program

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Understand, Enable, and Improve Hydropower's Contributions to Grid Reliability, Resilience, and Integration

- Invest in innovative technologies that improve hydropower capabilities to provide grid services

Environmental R&D and Hydrologic Systems Science

- Develop technologies and strategies that avoid, minimize, or mitigate ecological impacts
- Better identify opportunities and weigh potential trade-offs across multiple objectives at basin-scales

- This project demonstrates how multi-facility unit commitment and dispatch optimization can be used to respond to grid needs.
- One of the key outcomes of this project is that it demonstrated how a network of small, cascading hydropower facilities can be operated together to respect downstream flow constraints in a multiple tributary river basin without significantly impacting net revenues.

Project Budget

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Total Project Budget – Award Information		
DOE	Cost-share	Total
$145K	$40K	$185K

FY17	FY18	FY19 (Q1 & Q2 Only)	Total Actual Costs FY17–FY19 Q1 & Q2 (October 2016 – March 2019)
Costed	Costed	Costed	Total
$22K	$114K	$8K	$144K

This project was awarded through the U.S. Department of Energy's (DOE's) Small Business Voucher (SBV) program, which provides American small businesses access to DOE's national laboratories, helping them tap resources to overcome critical technology challenges for advanced energy products. Natel Energy were the recipient of this technical assistance and provided cost share.

Management Approach

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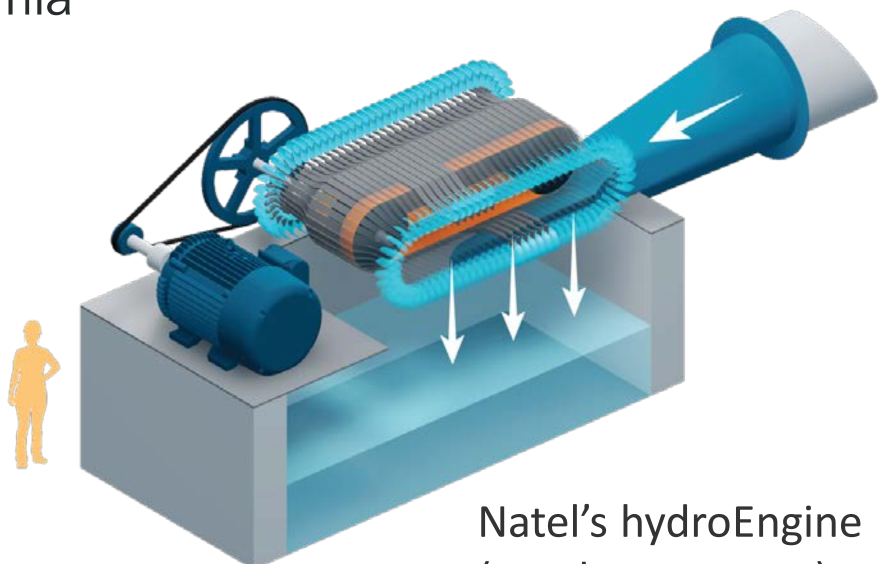
- The project team consisted of NREL and Natel staff members.
  - NREL provided the grid modeling expertise while Natel provided the equipment expertise and watershed flowrates and configurations.
- Natel Energy:
  - employs approximately 40 people in Alameda, CA
  - asked NREL to investigate deployment of 36 turbines in sequence along a river in Northeastern California
- Natel's hydroEnergy turbine:
  - uses a Linear Pelton designed to operate at high flows (8-10 m^3/s) and low heads (7-19 m)
  - couples with small reservoirs
  - offers power capacities that range from 0.5-1 MW



Natel's hydroEngine (natelenergy.com)

End-User Engagement and Dissemination Strategy

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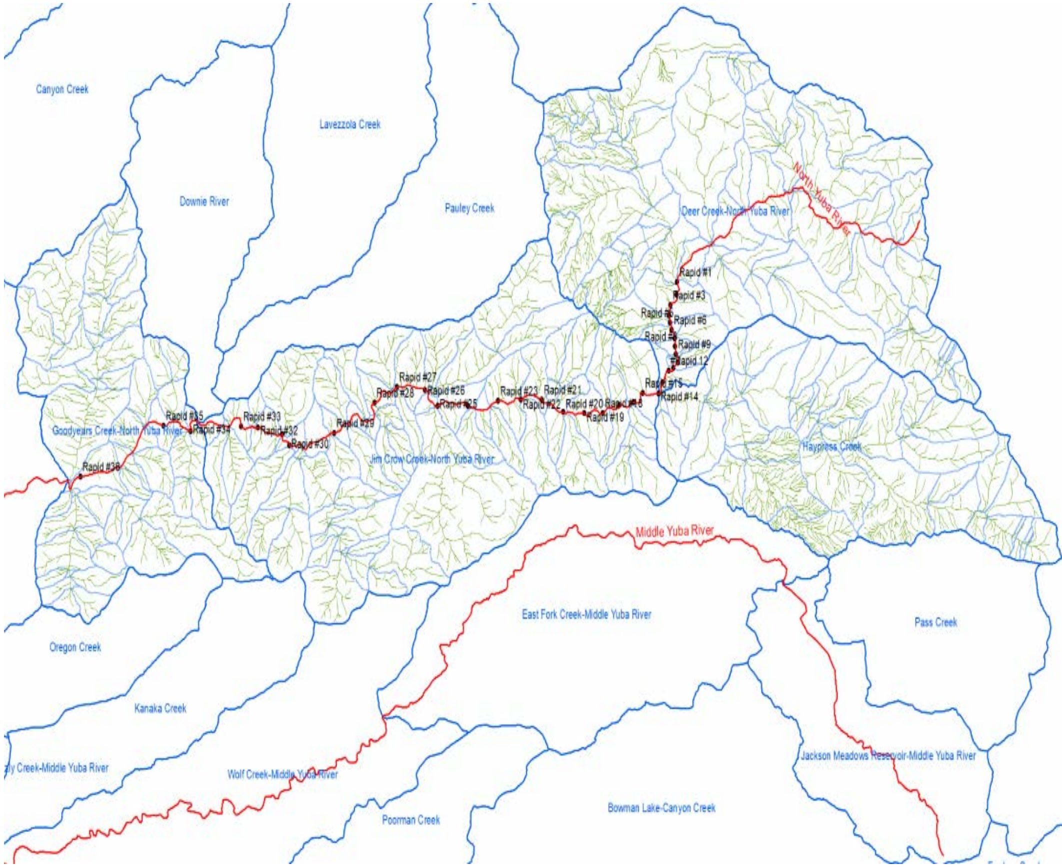
- **End Users:**
  - The immediate beneficiary of the work is Natel Energy. By leveraging NREL's capabilities, Natel now has a better understanding of the role that their products can play in the evolving grid.
  - Small hydropower owner/operators could also benefit from this work if interested in applying the methodology to their own facilities.
  - The model was designed to facilitate its use in other power systems, with forecasted prices, and with similar technologies. It has since been used in two other WPTO projects for pumped-storage hydropower applications.
- **Dissemination:**
  - NREL and Natel co-authored a journal article that highlighted how small hydropower could operate in a manner that reduces its environmental impact while not negatively impacting revenues.
  - In addition, a conference paper was presented at the 2019 HydroVision International Conference in Portland, Oregon.

Technical Approach

- The methodology consisted of the following tasks:
  1. Preliminary Portfolio Model
     - ➢ Identify hydroEngine operational attributes
     - ➢ Build an analytical model of a hydroEngine generator
     - ➢ Develop foundational scenarios
     - ➢ Model a fleet of hydroEngine generators to quantify expected value of Natel's turbines under different scenarios
  2. Expanded Portfolio Model, Including Additional Storage Capability/Operational Flexibility
     - ➢ Expand the portfolio model to include additional storage capability and operational flexibility
     - ➢ Conduct sensitivities, e.g., on operating practices, reservoir sizes, hybrid reservoir/battery storage, etc.
  3. Tradeoffs between Optimizing for Revenue vs. Optimizing for Downstream Flow Impacts

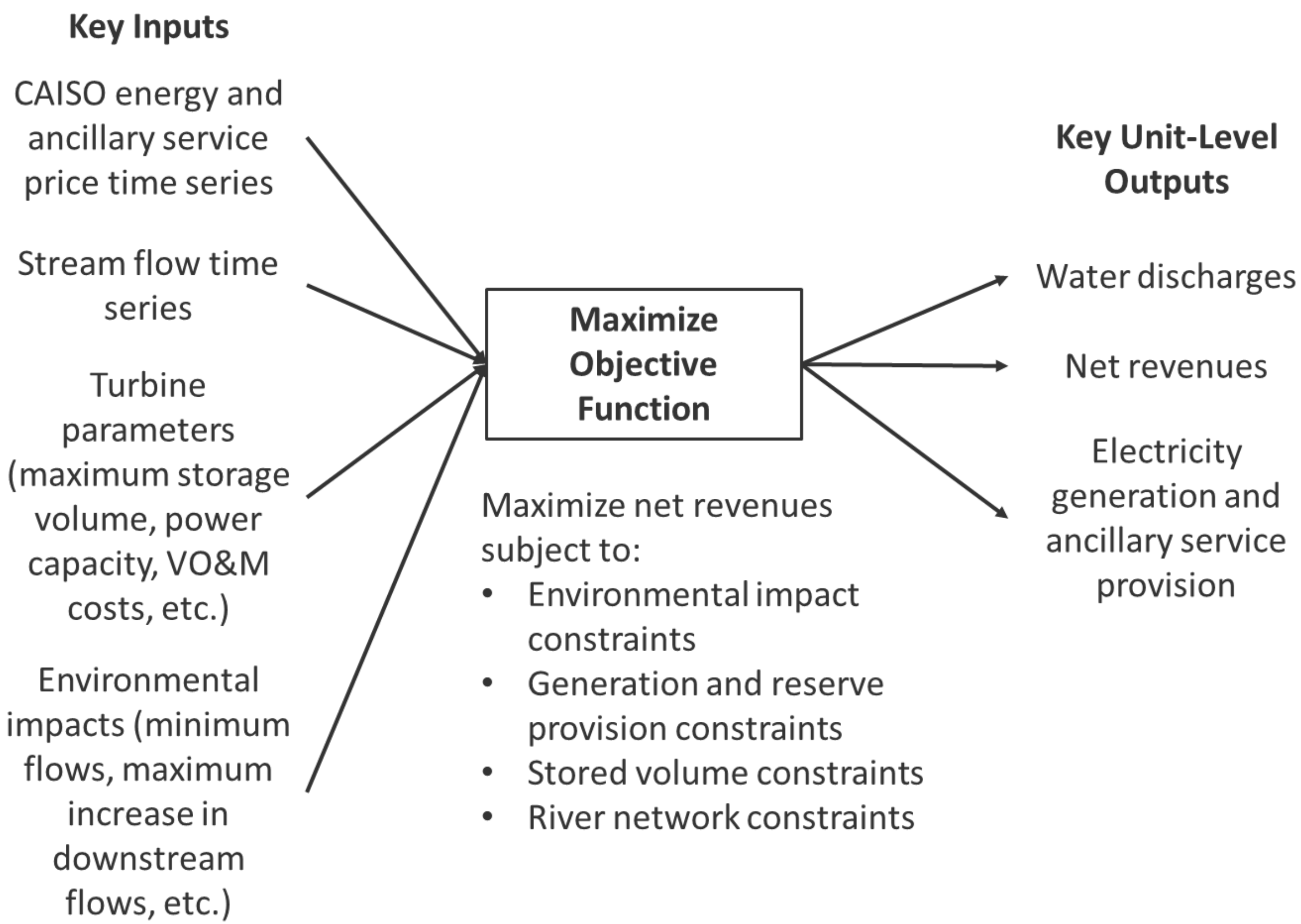
Test System

- Yuba River in California
  - ➢ 36 cascading plants
  - ➢ Total capacity: 33.5M
- Scenarios
  - ➢ Dry (2015), typical (2016), and wet (2017) flow years
  - ➢ Various flow and storage volume scenarios



Technical Approach

A profit-maximization model was developed using a price-taker approach:



Technical Accomplishments
Net Revenue

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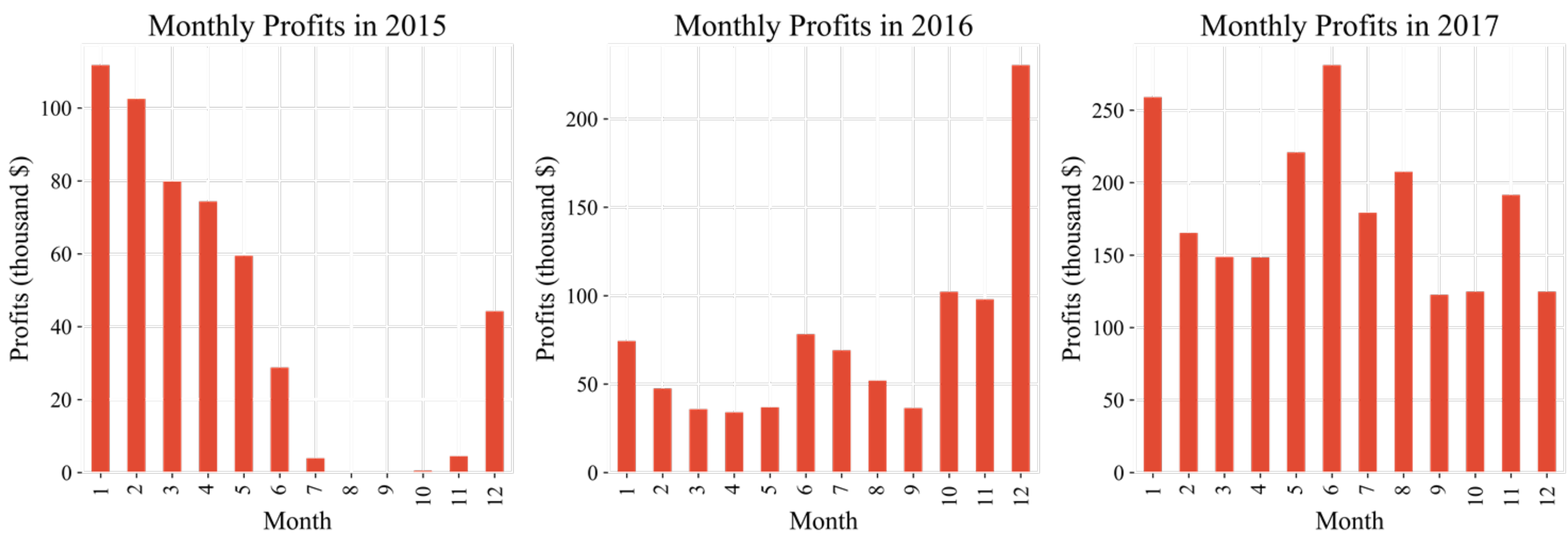
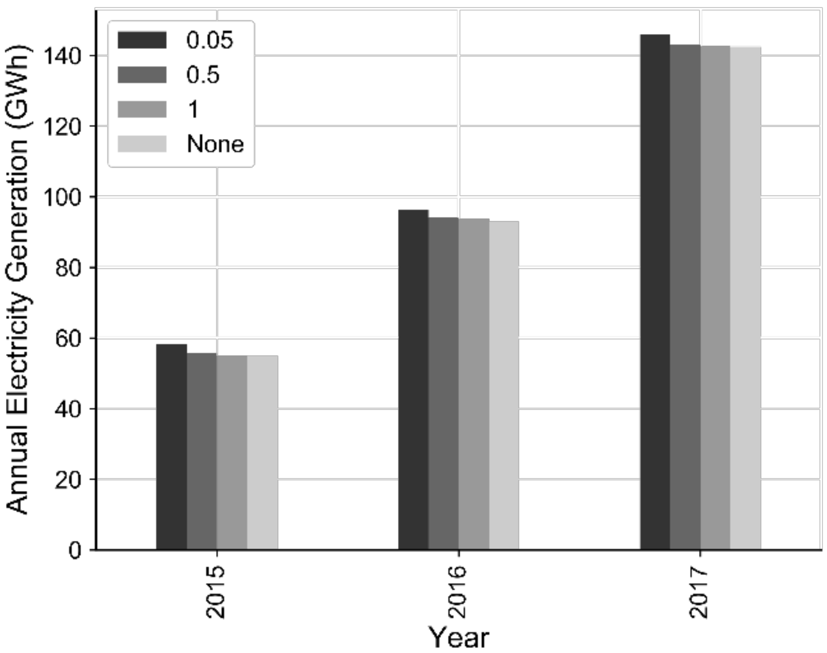
- Findings:
  - ➢ Net revenues varied from \$0.5 to \$2.2 million
  - ➢ Net revenues were between 16 and 25% greater in the real-time markets than in the day-ahead markets
  - ➢ Net revenues for a wet year were 4x those of the dry year
  - ➢ Doubling storage volumes increases net revenues by only 6%; quartering storage volumes reduces net revenues by 17%
  - ➢ Reducing VO&M costs by 25% is expected to increase net revenues by over 80% in a typical year (the system was found to be very sensitive to VO&M costs)

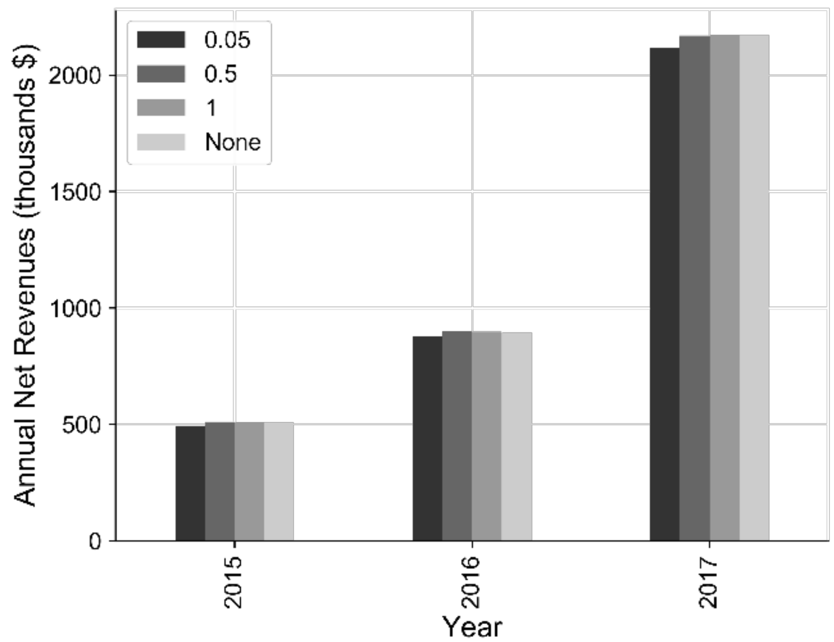
	Annual Net Revenue (million \$)	Total Electricity Generation (GWh)	Total Regulation Up Provision (GWh)
2015 (dry)	0.5	55	0.1
2016 (typical)	0.9	93	0.1
2017 (wet)	2.2	142	0.1



Technical Accomplishments
Tradeoffs

- Examined the trade-off between net revenues and downstream flow impacts and found that downstream flow impact constraints have little impact on total net revenues (less than 1% across years):





Legends: whether we impose no maximum flow constraints ("None") or limit operations to increasing downstream flows by 5% ("0.05"), 50% ("0.5"), or 100% ("1")

Future Work
Potential Extensions

- Model Natel operations in future systems or market conditions
  - Quantify impact of increasing renewable penetrations
    - 100% decarbonization law recently passed in California
  - CAISO market reforms ongoing (flexibility products, etc.)
- Modify model to co-optimize net revenues and environmental restoration
  - Rather than maximize revenues while limiting impacts, could maximize revenues as well as stream restoration metrics
- Extend model for use in investigating additional to grid effects:
  - Impacts on emissions
  - Value of flexibility
  - Integration of renewable energy
- Further develop the model to make it easier to use and customize, and then release it to industry and/or the public