RECLAMATION
Managing Water in the West

U.S. Department of the Interior
Bureau of Reclamation

# Research Update

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## Bottom Line

**This research project identified the physical and site factors that determine the economic value of a pump-generation plant, and estimated the independent contributions each attribute makes to this value.**

## Better, Faster, Cheaper

**Understanding the critical factors in determining economic values for generating hydropower will help inform engineers, planners, and decisionmakers as they explore potential locations for siting pump-generation plants.**

## Principal Investigator

**Todd Gaston**
**Economist**
**Economics and Technical Communications Group**
**Technical Service Center**
**303-445-2738**
**tgaston@usbr.gov**

## Research Office Contact

**Erin Foraker**
**Renewable Energy Research Coordinator**
**303-445-3635**
**eforaker@usbr.gov**

# Attributing Values to Pump-Generation Hydropower Plant Production Factors

*Developing detailed mathematical optimization models that simulate hourly production and sale of hydropower and ancillary services*

## Problem

Optimizing power systems can save millions of dollars and provide even more renewable energy for our Nation. Optimization includes identifying and eliminating losses, reducing energy consumption, and improving reliability and minimizing costs of ownership over the economic life of the pumping system. To do this, operators must be able to understand and forecast the complex interplay of many factors, such as unit design, gross head, forebay (upper reservoir) volume, and unit size and correlate them with economic benefits. Coordinating the operations of multiple pump-generation units could yield even more economic benefits than operating units independently. Yet modeling these complex interactions poses many challenges.

Pump-generation models simulate the hourly production and sale of ancillary services as well as energy requirements. Operators could use these models to explore various operating scenarios to determine the most effective operations for a given set of parameters. However, mathematical representations of pump-generation models require inherently nonlinear constrained optimization problems, which are notoriously difficult to solve.

## Solution

This Reclamation Science and Technology Program research project estimated the independent contribution of each of these factors to net economic benefits. The underlying nonlinear specifications were reformulated as more tractable piece-wise linear approximations, thus tracking individual factors and exploring how factors interacted. The resulting mixed integer linear programming models were then solved using the Special Ordered Sets of Type 2 (SOS2) approach.

This research built upon a number of recent studies by:

- Exploring the incremental contribution of economic value derived from providing four ancillary services:
  - ◊ Up-regulation
  - ◊ Down-regulation
  - ◊ Spinning reserve
  - ◊ Non-spinning reserve
- Estimating the additional economic value, which might be obtained by constructing a variable speed pump generator rather than a single or fixed speed pump generator
- Examining the independent value of selected site characteristics such as head and forebay (upper reservoir) storage, thereby contributing to informed design and site selection decisions

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For a typical week, several factors were systematically varied and the model resolved:

- Design of the pump-generation plant (fixed speed or variable speed pumps)
- Gross head
- Unit size
- Number of units
- Forebay storage volume

By comparing the results of each of these experiments to the reference case, the researchers estimated the independent contribution of each of these factors to the economic value of the plant.

## Application and Results

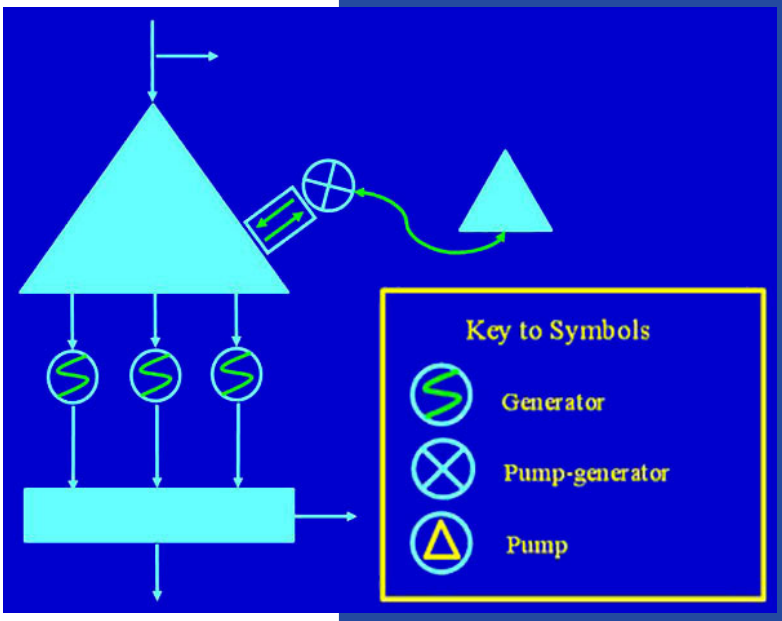
Publically available 2014 hourly price data were obtained from the California Independent System Operator and used to characterize hourly energy and ancillary service prices in this research.

Detailed mathematical optimization models of single speed (SS) and variable speed (VS) pump-generation units were crafted to represent Concept 5 pump-generation plants. These hourly models operate over a 1-week (168 hours) period. Granted research license was employed in developing these models to allow the size of the pump-generation unit, the forebay reservoir storage volume, and the gross head to be independently changed.

The SS and VS models were used to explore the potential differences in the economic benefits, which could be produced by two plant designs. Both models were used to simulate the behavior of pump-generation units. Conclusions included:

- Ninety-nine percent of the net economic storage benefits are captured in a range of 6.31 to 7.23 hours of storage. This level of forebay reservoir storage is considerably less than commonly used rules of thumb would suggest.
- If ancillary service prices are higher and the spread between the ancillary service and energy prices is greater, then net revenues increase and the share of gross revenues derived from ancillary services is much higher.
- Energy arbitrage (using energy when demand is low and producing energy when demand is high) is the predominant source of revenue for both SS and VS plant designs, regardless of the price set employed for analysis.

These abstractions from the real-world enable estimating the economic benefits of these determinants, independently from all other factors.




*Plant schematic for Concept 5.*

## Future Plans

Reclamation's Regional Offices have expressed interest in applying this research to existing and proposed pump-generation facilities to optimize economic benefits.

***"Producers can use these new models to more effectively model their operations. Planners can estimate the additional economic value from installing a variable speed pump generator, rather than a single or fixed speed pump generator, and calculate the independent value of selected site characteristics such as head and forebay (upper) reservoir storage, thereby contributing to informed design and site selection decisions."***

**Randy Christopherson**
**Manager, Economics and Technical Communications Group**
**Reclamation's Technical Service Center**

## More Information

**www.usbr.gov/research/projects/detail.cfm?id=9737**



For printable version see: www.usbr.gov/research/docs/updates/2016-22-value-attributes.pdf