C I T Y O F B O U L D E R
WATER RESOURCES ADVISORY BOARD
INFORMATION ITEM

MEETING DATE: July 15, 2013

AGENDA TITLE: Information Item – Hydroelectric Program Update

PRESENTERS:
Jeff Arthur, Director of Public Works for Utilities
Joe Taddeucci, Water Resources Manager
Jake Gesner, Hydroelectric Program Manager
Kevin Clark, Utilities Engineering Project Manager

EXECUTIVE SUMMARY:

Boulder began developing the hydroelectric power potential of its municipal water system in the 1980s. Between 1985 and 2004, the city built or acquired eight hydroelectric power plants with a present day capacity of roughly 16 megawatts (MW). Currently, the city has four hydroelectric facilities on its raw water delivery system and four facilities on the treated water system. Annually, the city produces an average of approximately 45,000 megawatt hours (MWh) of hydroelectricity, which results in annual revenue of about $2 million to the water utility. This revenue offsets capital and operating costs that would otherwise be borne by water utility customers through higher water rates.

Since the 1980s, it has been city policy to develop hydroelectric potential within the municipal water supply system where environmentally and economically feasible. Hydropower projects have been environmentally feasible since municipal water supply infrastructure is already in place. Economic feasibility has been defined as a hydroelectric facility's ability to pay for its construction, operation and maintenance costs over its lifetime. Seven of the city's facilities have met or are expected to meet this goal in significantly less than the assumed 50-year project lifetime. Boulder Canyon Hydro (BCH) underwent a major renovation completed in 2012 at a cost to the city of $4.75 million. It is expected that generation revenue will pay back this cost in under 20 years.

While much of the municipal water system hydroelectric potential has been developed, staff continues to monitor potential hydroelectric development options within the system. Future projects may rely upon additions to the water supply infrastructure, operational adjustments, future power sales markets and advancements in hydroelectric generation technology.

Staff is presenting the information to WRAB at this time as an overall status of the city's hydro program and to provide background in advance of upcoming projects, which will be coming to WRAB in the next several years as part of the capital improvement program.

BACKGROUND:

Although Boulder first recognized the hydroelectric power potential of its water system as far back as 1906, serious consideration of this potential began in the early 1980s, and Boulder's first hydroelectric power plant was completed in 1985. Today, the city's water utility enterprise operates eight hydroelectric power plants within its raw and treated water supply systems. Four facilities - Silver Lake, Lakewood, Betasso and Boulder Canyon – are located on the raw water transmission system. Orodell, Sunshine, Maxwell and Kohler Hydros are located on the treated water distribution system below the Betasso Water Treatment Facility. The eight facilities have a combined rated capacity of approximately 16 MW. Locations are shown on Attachment A, and facility descriptions are given in Attachment B.

The facilities on the raw water system use Pelton turbines to remove all pressure from the water prior to discharge. Silver Lake Hydro discharges water to Lakewood Reservoir. BCH discharges to Boulder Creek at the power plant. The Lakewood and Betasso facilities discharge water to the Betasso Water Treatment Facility. The Betasso and Lakewood Hydros can also discharge water back to Boulder Creek, just downstream of BCH.

The facilities on the treated water system use Francis turbines to reduce water pressure while maintaining the residual pressure needed in the downstream pipelines to deliver treated water to the end users. Maxwell and Kohler are pump/generator units designed to be reversed to pump water into pressure zone 3 of the distribution system under emergency conditions.

Hydropower generation is subordinate to water supply within the city's Water Utility. The city does not deplete its water storage reserves solely for hydropower generation. Seven of the city's eight hydroelectric facilities produce electricity as a byproduct of municipal water supply operations, and one (BCH) delivers water back to the stream using water from the city's hydropower water rights. Much of the system's hydro generation results from high water demand and water availability during the warmer summer months.

The city is not an electric utility and therefore sells all hydroelectricity it produces to electric utilities under the terms and conditions of power purchase agreements (PPAs). Seven of the eight existing PPAs are with Public Service Company of Colorado (PSCo)[1] and provide a set payment rate (adjusted annually) for kilowatt hours of electricity generated each month as well as a capacity payment for the capacity to generate electricity made available to PSCo by the city. The capacity payments are based on monthly capacity tests and provide considerable revenue to the city. The single PPA that applies to Betasso, Lakewood and Silver Lake Hydros is especially favorable to the city, with average summer capacity payments of about $126,000 per month and average winter monthly payments of about $85,000. These PPAs have a set term and expire based on the date they went into effect.

Since the city's hydroelectric generation relies on municipal water deliveries and downstream water demand, generation varies from year to year. System outages, planned maintenance and water source selection considerations all affect generation. On average[2], the city generates about 45,000 megawatt hours (MWh) of hydroelectricity annually, resulting in revenue of about $2 million per year. That averages out to roughly $44/MWh for all plants combined. Since 1985

[1] In June 2013, the city entered into a new PPA for Boulder Canyon Hydro with Tri-State Generation and Transmission Association, Inc. This PPA is discussed further under "Analysis."

[2] Averages are based on 2004-2011 generation and revenue. Revenue includes capacity payments.

when its first hydro plant went into service, the city has generated over 645,000 MWh of electricity which has produced over $31 million in revenue and displaced the need to burn more than 300,000 tons of coal to produce an equivalent amount of electricity at a traditional coal-fired generation plant.

The city operates all eight of its hydroelectric facilities under conduit exemptions from licensing from the Federal Energy Regulatory Commission (FERC)[3]. Advantages of this type of exemption include issuance in perpetuity (i.e., no periodic costly relicensing process), no annual charges by FERC, and limited federal jurisdiction over project facilities (usually just the power plant itself).

Operations and maintenance costs include payroll expenses as well materials, equipment and contractor costs for upkeep of the hydroelectric plants. While there is not a lot of variation in the annual hydro operating budget, the distribution of those funds between the eight facilities varies significantly from year to year depending on maintenance priorities. From 2007 through 2012, operations and maintenance costs averaged about $400,000 per year.

ANALYSIS:

Recent Accomplishments

The city completed its Boulder Canyon Hydro Modernization Project in 2012. A summary of this project is included as Attachment C. This effort replaced the one operable 10 MW turbine/generator with a state of the art 5 MW unit. The project was completed at a total cost of $5.9 million, of which $1.18 million was provided through a Department of Energy grant[4]. The city borrowed the estimated project cost ($5.155 million) from the Lakewood Pipeline Remediation Reserve, has repaid that fund $1.18 million from grant revenues and will repay the balance of the loan plus 3% interest from future plant revenues. Payback is expected to occur in less than 20 years subject to future power purchase agreement terms[5].

The modernization project presented an opportunity for the city and PSCo to separate previously co-mingled facilities at BCH. Prior to 2001 when the city purchased BCH, PSCo had been both power generator and transmission/distribution entity. It was not feasible to separate city and PSCo equipment and facilities at the time of city purchase of BCH in 2001. This separation has now been completed.

Concurrent with the modernization project, it was necessary to negotiate a new PPA for BCH. The city's previous agreement for BCH hydropower was with PSCo. It expired in 2009 but was extended to 2011 by mutual agreement. Once the modernization project was completed, a new

[3] The city has been issued a conduit exemption from licensing for BCH. The exemption will go into effect once a Special Use Permit authorizing occupancy of federal land is issued for portions of the Barker Gravity Pipeline by the U.S. Forest Service.

[4] WRAB approved (5-0) acceptance of the grant on Dec. 21, 2009, although it recommended use of CIP funds rather than the Lakewood Pipeline reserve to fund the city's share of the project. City Council unanimously approved acceptance of the grant and use of Lakewood Pipeline reserve funds on Jan. 5, 2010.

[5] The Lakewood Pipeline Remediation Reserve was established with the proceeds from a negotiated settlement of approximately $15 million concerning the potential for accelerated steel pipe corrosion. As of 2009, the city had conducted six internal inspections of the Lakewood Pipeline. Staff and consultants have concluded that corrosion of the steel pipe has stabilized, and extensive remediation measures in the next 10 years are not likely to be needed. Lakewood Pipeline will continue to be inspected at five-year intervals (standard industry recommendation for all high-pressure, welded steel pipelines) to monitor its condition.

agreement was needed before commercial operation could resume. In June 2013, the city entered into a new PPA for BCH with Tri-State Generation and Transmission Association, Inc. The Tri-State agreement is a five-year contract with varying monthly energy payments. The highest payment rates occur during the summer months when the city's generation potential is at its peak. Based on historical average water deliveries, staff estimates average annual revenue under the contract will be approximately $510,000. BCH resumed commercial operation on June 12, 2013.

The city completed the Betasso Area Pipelines Replacement Project in 2011, which had numerous benefits to the hydro program. The project reestablished the Betasso Hydrolectric plant capacity from 2.4 to 3.1 MW by alleviating pipeline capacity issues. The project also extended the useful life of the Orodell Pipeline (supplies Orodell Hydro) by replacing it with the old Betasso Penstock. Lastly, the project converted the original Orodell Pipeline to a raw water discharge line, which primarily is utilized when treatment plant inflows exceed municipal water needs during hydro capacity testing.

Significant maintenance was performed at Orodell and Silver Lake Hydros in 2011-2013. At Orodell Hydro, the generator received an internal rebuild to improve operating efficiency, and the generator mechanical bearing at the turbine was replaced. Silver Lake Hydro had a complete inspection, and the generator was sent to General Electric for complete cleaning, electrical testing and painting. The elevation of the generator pad in the power plant was also corrected to increase unit efficiency.

Upcoming Projects

The hydropower maintenance plan provides for a thorough inspection of each facility every five years. Every 10 years, the units undergo a total breakdown to determine, plan for and schedule specific maintenance needs. Lakewood Hydro is the next facility scheduled for major maintenance in 2014. While most routine maintenance is completed by the hydroelectric staff, major overhauls are generally completed by contractors specializing in this type of work.

The city also routinely inspects the pipelines that transport water to the hydro facilities to anticipate and plan for maintenance requirements. Over the next few years, inspections are planned for Sunshine Pipeline and the upper portion of the Boulder Canyon penstock.

BCH is a nationally significant historic site, and the city is careful to preserve and display significant aspects of the facility. Staff is currently seeking grant money to expand historical exhibits at the power plant.

Five of the existing PPAs will expire in 2015-2017. The city has the option to extend these agreements, most of which are for a 30-year term, provided it gives notice to PSCo at least two years prior to the expiration date. Staff will research other possible hydropower buyers as well to insure the city obtains the most favorable agreements in the future.

Long Range Planning

Much of the current environmentally and economically feasible hydro potential has been developed within the city's water system. However, feasible opportunities remain for additional hydropower generation within the system pending construction of other water supply infrastructure:

- Carter Lake Pipeline Hydro– This pipeline is considered the best long-term solution to water quality, operational and security vulnerability issues related to drawing water directly from either the Boulder Feeder Canal or Boulder Reservoir. The pipeline would provide an opportunity to develop a new hydroelectric facility, and funding for construction of this facility is allocated in 2019 in the proposed 2014-2019 Capital Improvement Program (CIP). During budget discussions in recent years, City Council has indicated that the hydroelectric potential of the Carter Lake Pipeline is a favorable component of the overall pipeline project.
- Hannah Barker Hydro - The Barker Dam outlet gates and related facilities are over 100 years old and are in need of significant rehabilitation or replacement. Funding for final design and construction of these important outlet works modifications is currently proposed for 2017 and 2018 in the projected 2014-2019 CIP. The outlet facilities would provide an opportunity to develop a new, year-round hydroelectric facility, and funding for construction of this facility is also proposed for 2018.

Prior to proceeding with design and construction, both the Carter Lake Pipeline Hydro and the Barker outlet works and hydro projects will be subject to review as part of the annual budget process and other applicable project approval processes.

There are also potential power development projects which, although not economically feasible at the current time, could become economically feasible depending on future power sales markets and advancements in hydroelectric generation technology. These potential future developments are:

- 101 Pearl Street Hydro – The 101 Pearl Street site currently has a pressure reducing valve much like Maxwell, Sunshine and Kohler Hydros had used. This facility is in operation for only six months of the year, and hydro development has not been economically feasible.
- At Sunshine Hydro, there is the potential to replace one of two pressure reducing valves with a micro turbine/generator for use during winter when pipeline flows are very low. The existing unit cannot operate at flows lower than 7 cubic feet per second. A new, micro unit would allow generation over a larger range of pipeline flows.

In addition to the potential projects listed above, staff also monitors industry conferences and trade information for emerging hydro technology. Attachment D includes information presented at the 2012 Colorado Small Hydro Association by Sonya Reiser of consulting firm Knight Peisold. Technology presented included in-pipe turbines, “turbinators” and Archimedes Screw type turbines.

Program Economics

The city’s policy is to develop hydropower within its water system where environmentally and economically feasible. Economic feasibility has been defined as the ability for a project to at least pay for itself within its life span (50 years is typically conservatively assumed for hydroelectric facilities), including construction, operation and maintenance. Current mid life modeling (combining actual and estimated information) of the city’s eight hydro-electric over a 50-year life cycle is provided in the following table:

Table 1 – City of Boulder Hydroelectric Program Economics Analysis Summary

Facility	Size (MW)	In Service Year	Benefit-Cost Ratio over 50 Year Project Life	Present Value of Net Revenue over Project Life*	Payback Period (Years)
Betasso	3.100	1987	2.9	$19,785,000	7
Orodell	0.225	1987	0.6**	$ (425,800)**	NA**
Sunshine	0.800	1987	1.8**	$ 3,696,000**	13**
Kohler	0.150	1986	1.8	$ 838,000	14
Maxwell	0.950	1985	1.7	$ 591,000	15
Silver Lake	3.200	1998	1.7	$ 9,318,000	14
Lakewood	3.400	2004	2.7	$14,052,000	7
Boulder Canyon	5.000	2013	1.3	$ 4,186,000	17
Total	**15.970**	**-**	**-**	**$51,449,000**	**-**

**Present Value of Net Revenue = Net Present Value (NPV - economic term) which takes into account gross revenues less gross costs and brings the future value back to present day (2013 dollars for analysis).*

***Orodell Hydro can be considered along with Sunshine Hydro as one integrated system due to present City water supply operation and water system flow connectivity.*

Seven of the eight hydro facilities more than pay for themselves (i.e. a positive net present value), and the total net present value (NPV) for the city's eight facilities is currently modeled at $51.4 million over 50 years. The one exception within the system is Orodell Hydo, which does not have a positive NPV and has a benefit-cost ratio (BCR) less than 1.0 when considered as an independent facility. Orodell Hydro is not generating as much power as initially modeled due to water delivery operational changes. The original Orodell Hydro economic analysis assumed year-round operation, but the city currently generates at Sunshine Hydro during winter (Orodell Hydro offline) because of favorable power generation terms and operational constraints on the downstream Orodell Pipeline system. Orodell Hydro and Sunshine Hydro, when viewed as a combined system, have a positive combined NPV of $3.27 million over the 50 year expected equipment life.

A pressure reducing valve (PRV) would be required at the Orodell Hydro location to reduce operational water pressure even if hydroelectric equipment had not been installed, and PRVs are included in all hydroelectric facilities to reduce water pressure when the turbine/generator is off-line. The PRV equipment and operation and maintenance costs are presently absorbed into the hydroelectric program costs, which reduces the net revenue attributed to each of the hydro facilities.

NEXT STEPS:

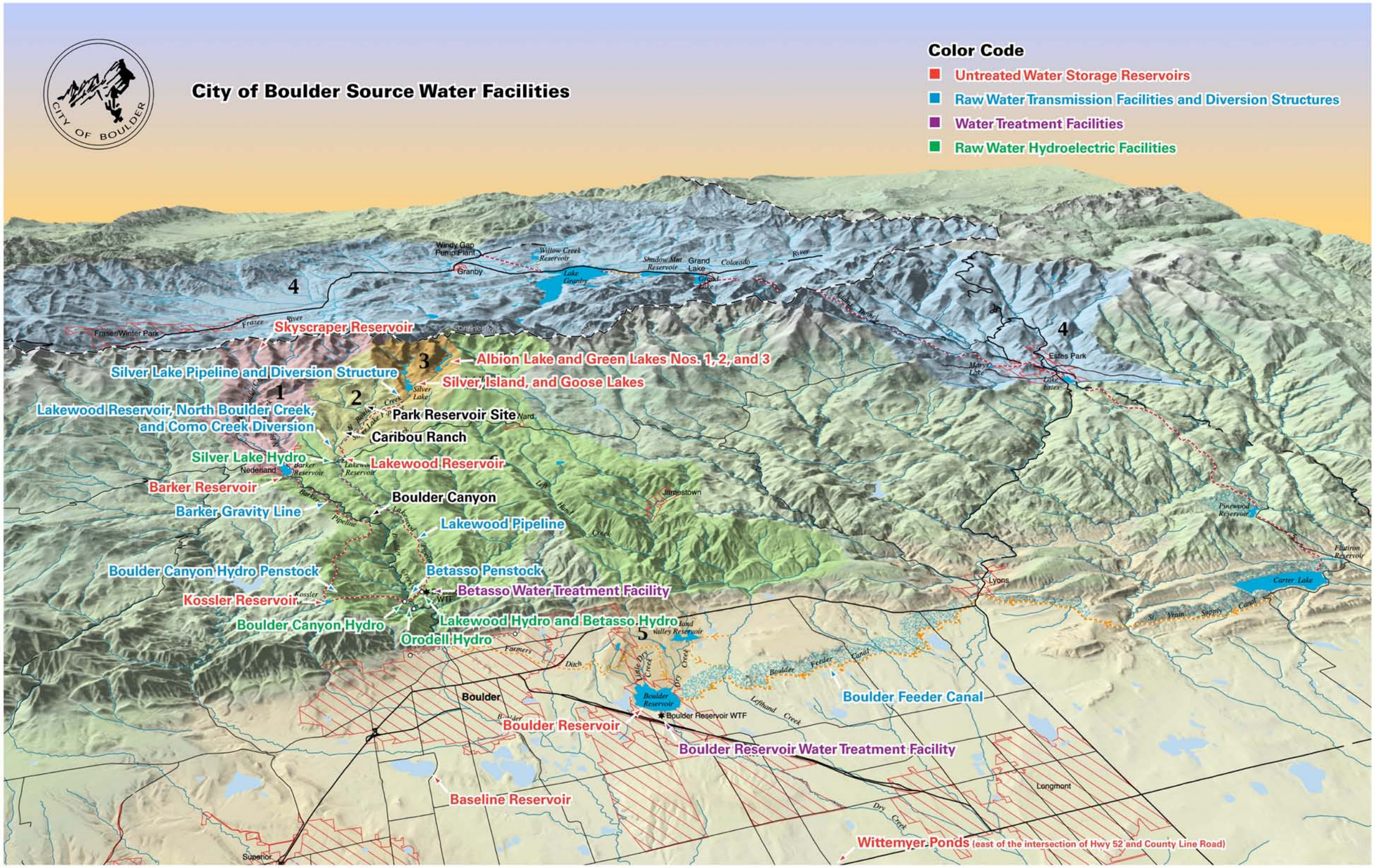
Staff will continue to operate and maintain the existing units, address PPA renewals, and look for new opportunities to develop hydroelectric potential within the city's water supply system. Staff will present additional information to WRAB as projects associated with the city's hydro system (new or enhancements to the existing system) come up for consideration during the capital improvement and budgeting process.

ATTACHMENTS:

Attachment A: City of Boulder Source Water Facilities
Attachment B: City of Boulder Hydroelectric Facility Summary
Attachment C: Boulder Canyon Hydroelectric Project Summary
Attachment D: 2012 Colorado Small Hydro Association Presentation Slides - Hydropower Technology Update by Sonya Reiser, P.E., Knight Peisold.

Attachment A

CITY OF BOULDER SOURCE WATER FACILITIES



Attachment B

City of Boulder Hydroelectric Facility Summary

Name	Pressure Source	Head on U/S Side Turbine (ft)	Type of Turbine	2013 Nameplate Capacity (kW)	Generator Make	Commercial Operation Date	2011 Generation (kWh)	2011 Revenue	Construction Cost
Maxwell (Pump/Generator)	Treated Water (Zone 3)	200	Reaction (Francis)	95	General Electric	March 1985	576,000	$25,400	$344,000
Kohler (Pump/Generator)	Treated Water (Zone 3)	140 -240	Reaction (2 Francis)	150	Marathon XRI	November 1986	754,000	$32,700	$431,000
Orodell.	Treated Water (Orodell Pipeline)	413	Reaction (Francis)	225	Primeline	September 1987	390,000	$13,000	$406,000
Sunshine	Treated Water (Sunshine Pipeline)	750	Reaction (Francis)	800	Unimega-Hitachi	September 1986	3,845,000	$165,700	$1,790,000
Betasso	Raw water (Betasso Penstock)	1,094	Impulse (Pelton)	3,100	Kumming Elec	December 1987	18,398,000 (combined with Lakewood)	$1,936,000 (includes Lakewood and Silver Lake)	$3,200,000
Silver Lake	Raw water (Silver Lake Pipeline)	1,406	Impulse (Pelton)	3,200	Alconza	March 1998	14,779,000	See Betasso	$7,224,000
Boulder Canyon	Raw water (Kossler/Barker)	1,847	Impulse (Pelton)	5,000	Hydudai-Ideal	Original August 1910 (COB Purchased March 2001) June 2013 after 5 MW replacement	11,525,000	$290,000	$5,900,000
Lakewood	Raw water (Lakewood Pipeline)	1,554	Impulse (Pelton)	3,400	Alconza	June 2004	Included with Betasso	See Betasso	$3,431,000
Total							***50,267,000***	***$2,463,000***	***$22,726,000***
Since beginning operation through 2011 these hydros have displaced 305,000 tons of burning coal and generated 609,879,000 kilowatt hours. Total revenue through 2011 was approximately $ 29,054,000.									

ATTACHMENT C

SUMMARY OF THE BOULDER CANYON HYDROELECTRIC PROJECT MODERNIZATION

The Boulder Canyon Hydroelectric Project (BCH) was purchased by the City of Boulder, CO (the city) in 2001. Project facilities were originally constructed in 1910 and upgraded in the 1930s and 1940s. By 2009, the two 10 MW turbine/generators had reached or were nearing the end of their useful lives. One generator had grounded out and was beyond repair, reducing plant capacity to 10 MW. The remaining 10 MW unit was expected to fail at any time.

When the BCH power plant was originally constructed, a sizeable water supply was available for the sole purpose of hydroelectric power generation. Between 1950 and 2001, that water supply had gradually been converted to municipal water supply by the city. By 2001, the water available for hydroelectric power generation at BCH could not support even one 10 MW unit. Boulder lacked the financial resources to modernize the facilities, and Boulder anticipated that when the single, operational historical unit failed, the project would cease operation.

In 2009, the City of Boulder applied for and received a U.S. Department of Energy (DOE) grant for $1.18 million toward a total estimated project cost of $5.155 million to modernize BCH. The federal funding allowed Boulder to move forward with plant modifications that would ensure BCH would continue operation. Federal funding was made available through the American Recovery and Reinvestment Act (ARRA) of 2009.

Boulder determined that a single 5 MW turbine/generator would be the most appropriate capacity, given the reduced water supply to the plant. Average annual BCH generation with the old 10 MW unit had been about 8,500 MW-hr, whereas annual generation with a new, efficient turbine could average 11,000 to 12,000 MW-hr. The incremental change in annual generation represents a 30% increase in generation over pre-project conditions.

The old turbine/generator was a single nozzle Pelton turbine with a 5-to-1 flow turndown and a maximum turbine/generator efficiency of 82%. The new unit is a double nozzle Pelton turbine with a 10-to-1 flow turndown and a maximum turbine/generator efficiency of 88%. This alone represents a 6% increase in overall efficiency. The old turbine operated at low efficiencies due to age and non-optimal sizing of the turbine for the water flow available to the unit. It was shut down whenever water flow dropped to less than 4-5 cfs, and at that flow, efficiency was 55 to 60%. The new turbine will operate in the range of 70 to 88% efficiency through a large portion of the existing flow range and would only have to be shut down at flow rates less than 3.7 cfs. Efficiency is expected to increase by 15-30%, depending on flow.

In addition to the installation of new equipment, other goals for the project included:

- Increasing safety at Boulder Canyon Hydro
- Increasing protection of the Boulder Creek environment
- Modernizing and integrating control equipment into Boulder's municipal water supply system, and
- Preserving significant historical engineering information prior to power plant modernization.

From January 1, 2010 through December 31, 2012, combined consultant and contractor personnel hours paid for by both the city and the federal government have totaled approximately 40,000. This equates roughly to seven people working full time on the project from January 2010 through December 2012.

This project also involved considerable material expense (steel pipe, a variety of valves, electrical equipment, and the various components of the turbine and generator), which were not accounted for in terms of hours spent on the project. However, the material expense related to this project did help to create or preserve manufacturing/industrial jobs throughout the United States. As required by ARRA, the various components of the hydroelectric project were manufactured or substantially transformed in the U.S.

BCH is eligible for nomination to the National Register of Historic Places due in part to its unique engineering features and innovative construction techniques. Special efforts were directed toward documenting the (largely original) interior of the plant and installing new equipment without modifying the power plant exterior in order to preserve the historical significance of the facility. In addition, a significant portion of the historical equipment within the power plant was preserved in place.

The modernization project began with DOE grant award on January 1, 2010, and the project was completed on December 31, 2012. In addition to city engineering and hydroelectric staff, major project participants included AECOM (design/engineering) Canyon Industries (turbine/generator manufacture), Gracon Corporation (general construction contractor), Exponential Engineering Company (electrical engineering) and URS Corporation (historical documentation), as well as numerous other subcontractors and consultants.

Attachment D

2012 Colorado Small Hydro Association Presentation Slides
Hydropower Technology Update by Sonya Reiser, P.E., Knight Peisold.

Knight Piésold
CONSULTING

Hydropower Technology Update

Sonya Reiser, P.E.

May 17, 2012

Overview

- Factors Driving Innovation
  - Demonstrated Need
  - Research Dollars
  - US Inventors
  - Repeatability
  - Water Supply Priorities
- Hydropower Equipment
  - In-pipe
  - Hydrokinetics
  - Other

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Innovation Factors

Factors Driving Innovation

- Demonstrated Need
  - Oakridge National Lab
  - Idaho National Lab
  - Bureau of Reclamation
  - Governor's Energy Office
- Research Dollars
  - National priority
  - Incentives - Grants, low interest loans, credits
- US Inventors

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Innovation Factors

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Factors Driving Innovation (continued)

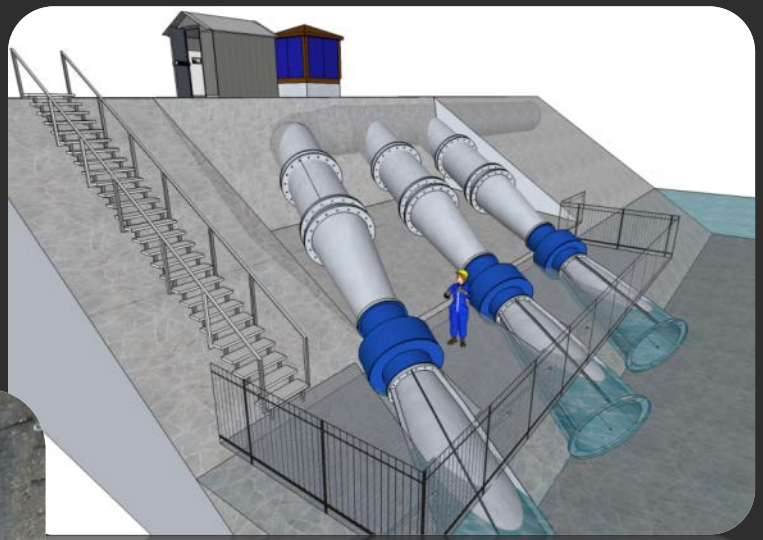
- Repeatability
  - Reduced capital cost
  - Reduced construction scope of work
  - Reduced complexity of permitting and licensing
- Water supply priorities - Adding hydropower to existing water infrastructure
  - Dams without hydro
  - Canal drops
  - Pipelines
  - Water wastewater facilities
  - Other

Hydropower Equipment

In-pipe Turbines

Clean Power

Turbinator

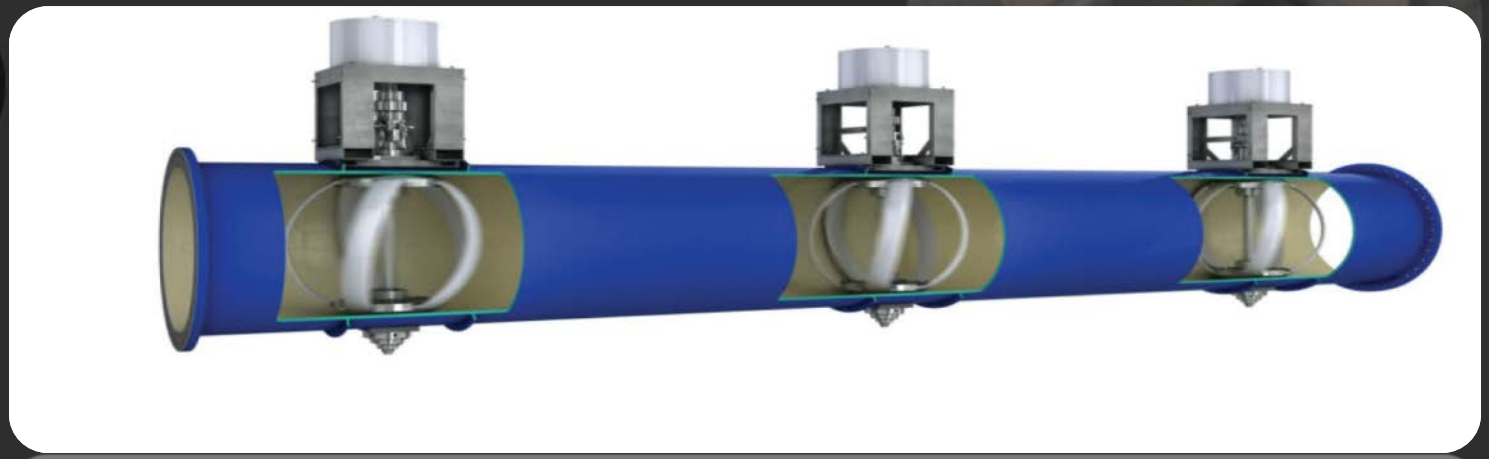


Hydropower Equipment

In-pipe Turbines

Lucid Energy

LucidPipe Power System



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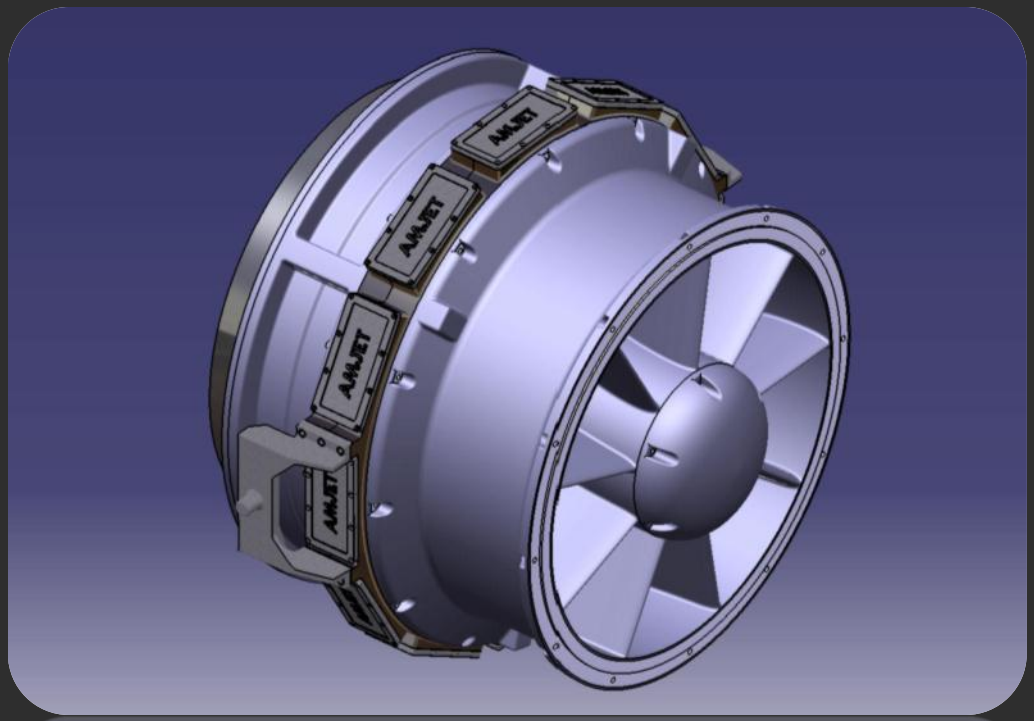
Hydropower Equipment

In-pipe Turbines

AMJET Turbine Systems

ATS 63 Series



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Hydropower Equipment

In-pipe Turbines

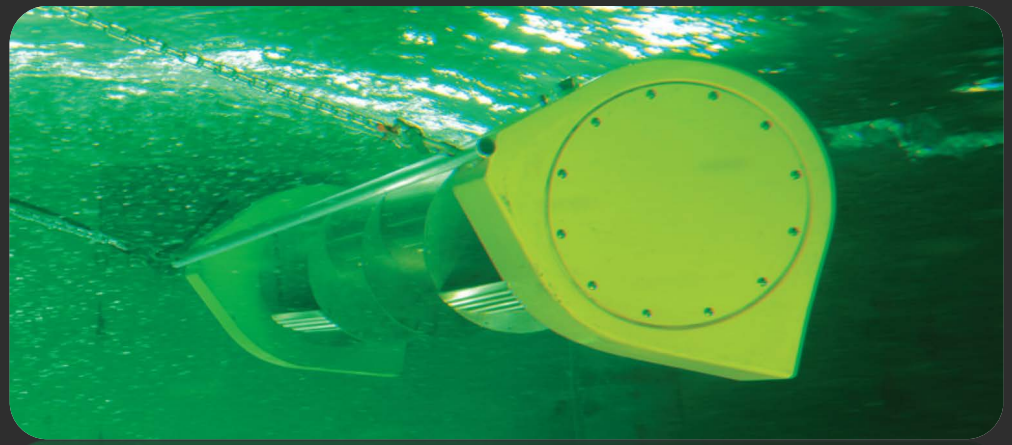
Hydro Green

Hydro Green Energy®

Hydropower Equipment

Hydrokinetics

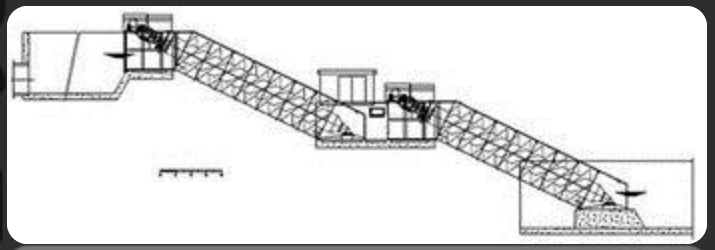
HydroVolts

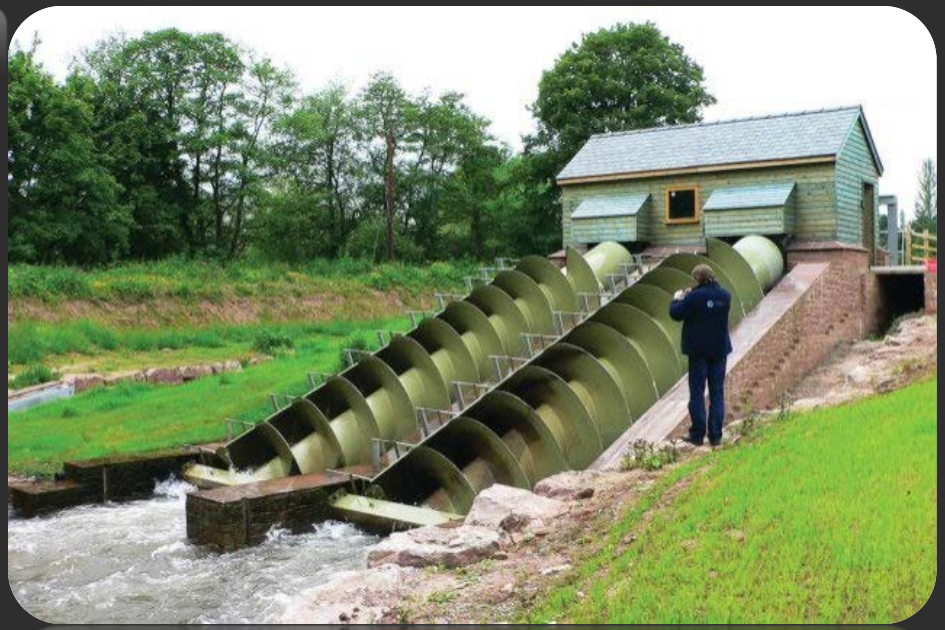


Hydropower Equipment

Hydrokinetics

Archimedes Screw





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Hydropower Equipment

Hydrokinetics

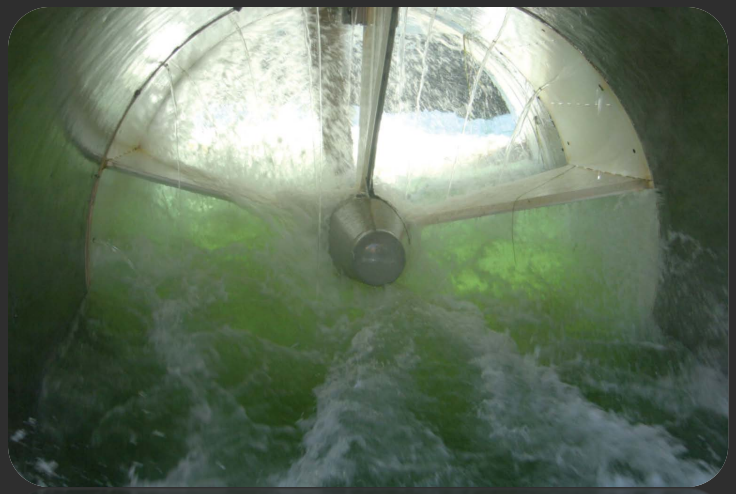
Verdant Power

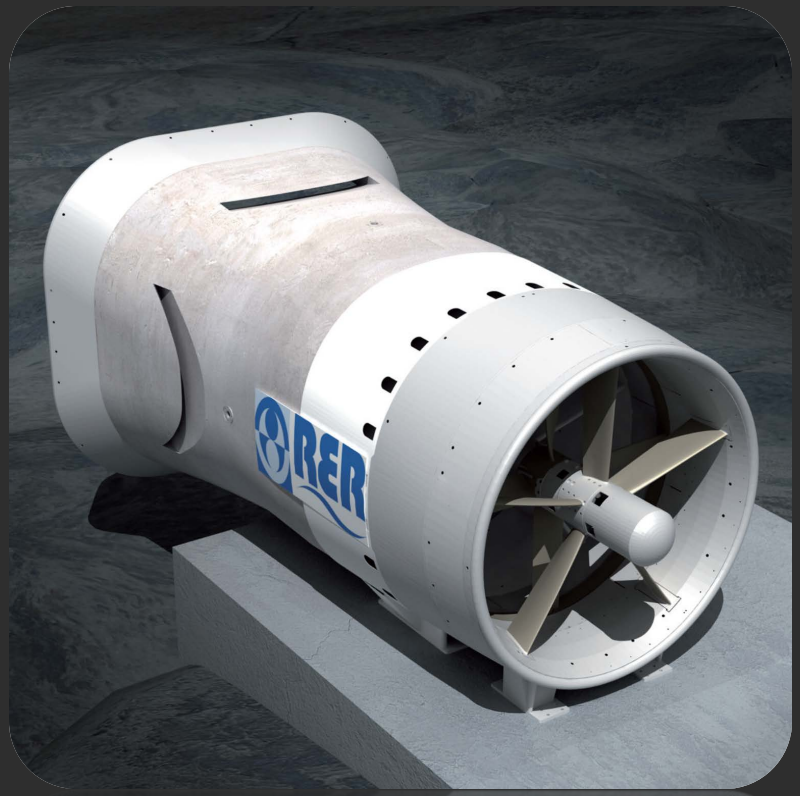
Hydropower Equipment

Hydrokinetics

RER Hydrokinetic

TREK Technologies





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Hydropower Equipment

Other Hydropower

- Natel – Drop structures
- Early development / prototypes
- Low cost international market

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Summary

How do we continue to motivate hydropower equipment innovation?

Developers and inventors are pursuing collaboration with Universities and hydraulic laboratories.

Innovation is reducing cost improving efficiency for a variety of applications from hydrokinetics to high head installations.

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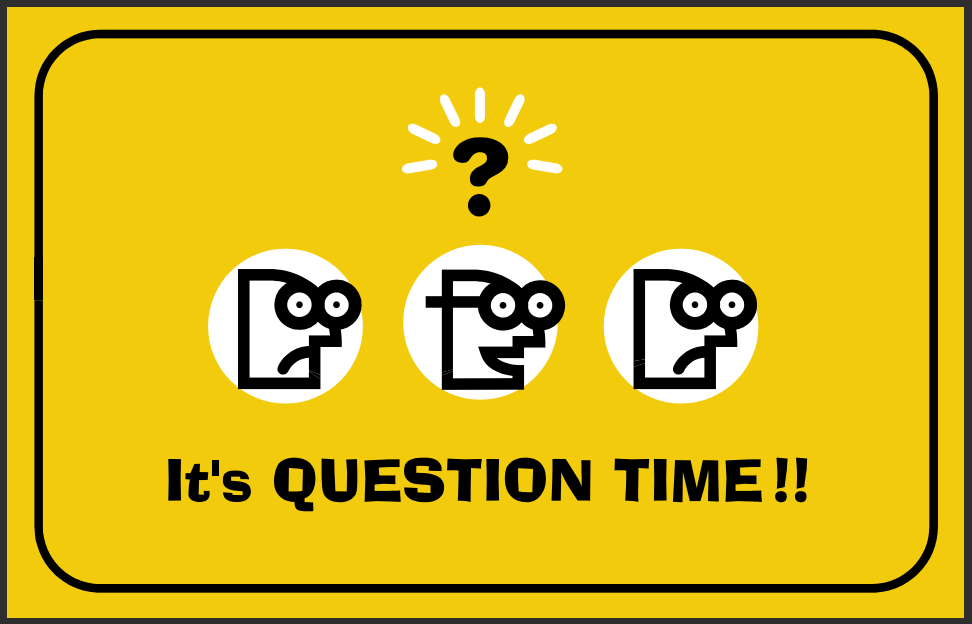
Questions



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