Recapturing Embedded Energy in Water Systems:
A White Paper on In-Conduit Generation Issues and Policies

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I. BACKGROUND

There is a significant amount of energy used in procuring, treating, and transporting water in California. In 2005, the California Energy Commission (CEC) found that water-related energy consumption and demand accounted for a significant portion of the state's energy use – nearly 20 percent of the electricity use[1] and that the water systems combined peak electrical demand exceeded 3,000 MW[2] . More than 12,000 GWhs annually was directly used by water and wastewater systems operations[3]. A more recent comprehensive study performed for the California Public Utilities Commission has found that that original estimate was too low, the actual consumption of electricity by water and wastewater systems was over 19,00 GWH annually, almost 8 percent of all the electricity used in the state[4].

There exists a relatively simple efficiency improvement that can be used to recapture some of this energy – replacing existing pressure reduction valves (PRV) with small hydroelectric turbines and generators. What has hampered the development of this resource in the past was the lack of opportunities for the sale of the power generated from these small generators, and the lack of appropriate generation technologies. There have been recent regulatory and technological changes that make the generation of renewable energy from small hydroelectric turbines and generators more feasible. There is a new water agency renewables Feed-in Tariff in California which customers can specify a contract term and start date and sign up for a pre-specified revenue stream. And there have been significant improvements in the small hydro turbine development, due to adaption of the technological advances in both turbines and generators from the wind industry. Yet despite these changes, there has been little response from the water industry in developing this resource. In the past several years under the new water agency Feed-in Tariff, only seven new small hydro units have been developed (providing slightly over 4 MW out of the 250 MW feed-in tariff allocation) and only one of these was less the 500 kW size (typical of an in-conduit generator replacement of a PRV).

The California Energy Commission found that in-conduit hydroelectric generation is the least expensive new renewable generation source available in the state (Table 1). The development of this market

[1] "California's Water-Energy Relationship", California Energy Commission, CEC-700-2005-011-SF, November 2005. Natural gas use in the water sector exceeded 13 billion therms, primarily for water heating. Water system use of natural gas was approximately 50 million therms annually.
[2] Lon W. House, *"Water Supply Related Electricity Demand in California",* Demand Response Research Center/California Energy Commission, Lawrence Berkeley National Laboratory, LBNL-62041, December 2006.
[3] The remainder coming from customers treatment of the water – heating, cooling, pressurizing, and transporting.
[4] "Embedded Energy in Water Studies" Presentation May 26, 2010, available at http://www.energydataweb.com/cpuc/.

segment requires additional information and policy changes, but has significant potential to dramatically improve the efficiency of the water systems in California, capturing previously wasted energy, and increase the amount of renewable electricity produced in the state. Additionally, most of these in-conduit generation sites are in urbanized areas, providing electricity directly into localized electric load centers, which has important utility distribution system benefits.

Table 1. Cost of Renewable Generation Types in California

Technology	Installed Cost ($/kW)	O&M Costs ($/kW)
Hydro (In-conduit)	$1,968	$276
Wind (Community)	$2,500	$319
Biomass (WWTP)	$3,000	$507
Biomass (Landfill Gas)	$3,800	$474
Biomass (Advanced Digester)	$4,769	$477
Solar PV (Grnd Based Track)	$7,340	$876
Solar PV(Commercial Fixed Tilt)	$7,860	$895

Source: KEMA, Inc. 2009 Cost of Generation Study, California Energy Commission, Staff Workshop, August 25, 2009

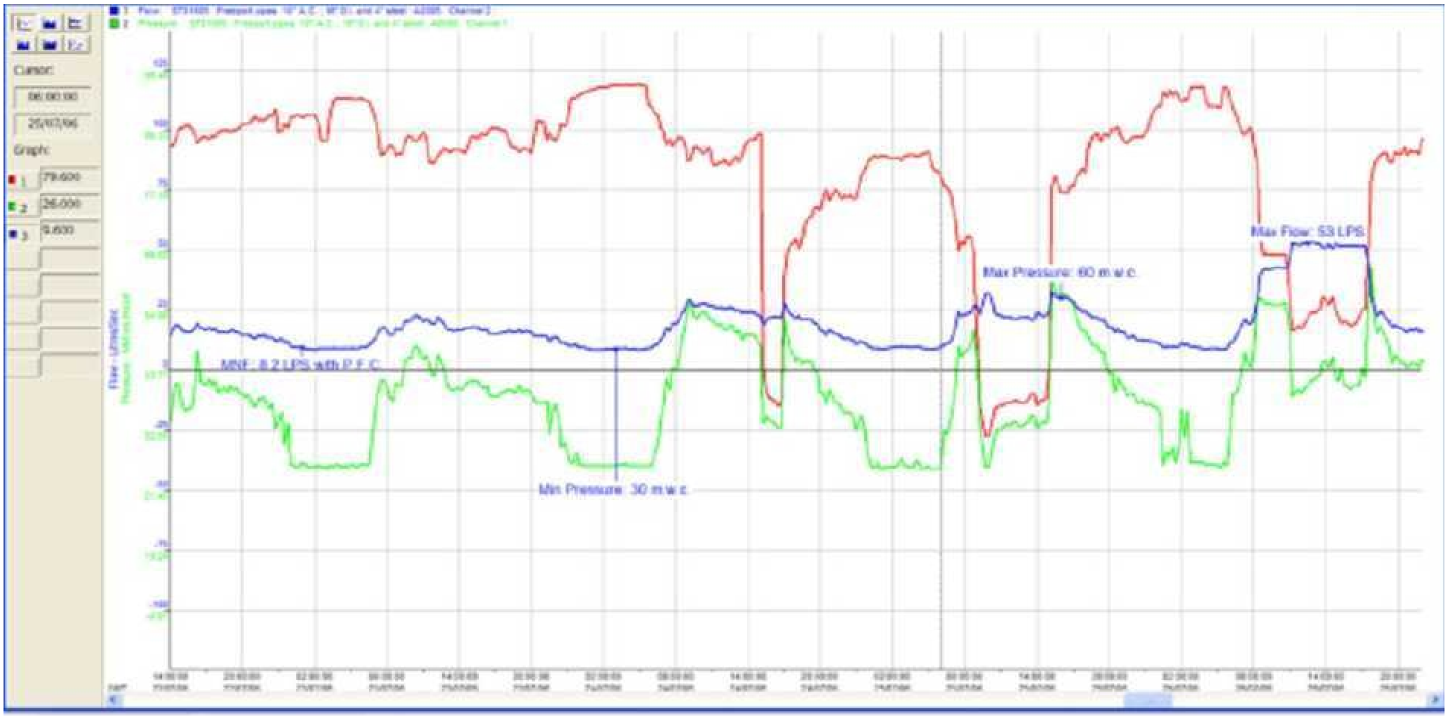
II. ENERGY RECAPTURE

Maintaining appropriate pressure is a critical design parameter in the development and operation of any water system. Excess pressure needs to be controlled to prevent damage to the system. A one-foot drop in elevation increases the water pressure by about 0.4 pounds per square inch, so any water system that has significant changes in elevation has to compensate for this pressure increase to keep the system water pressure within reasonable bounds. In the past there was no market for small hydroelectric generation and appropriate generation technologies didn't exist, so simple pressure reduction valves were installed to regulate pressure.

Figure 1 shows the operation of a pressure reduction valve. Figure 2 shows a typical water system that is one part of the City of Santa Rosa system. Note that two pressure-reducing stations are shown, one at Alpha Farms and one at Roberts Lake Road. Figure 1 shows how the pressure reduction valve is reducing the inlet pressure (red) to keep it within proper operating bounds (green line). This pressure reduction is wasted energy – the pressure is dissipated as heat and noise.

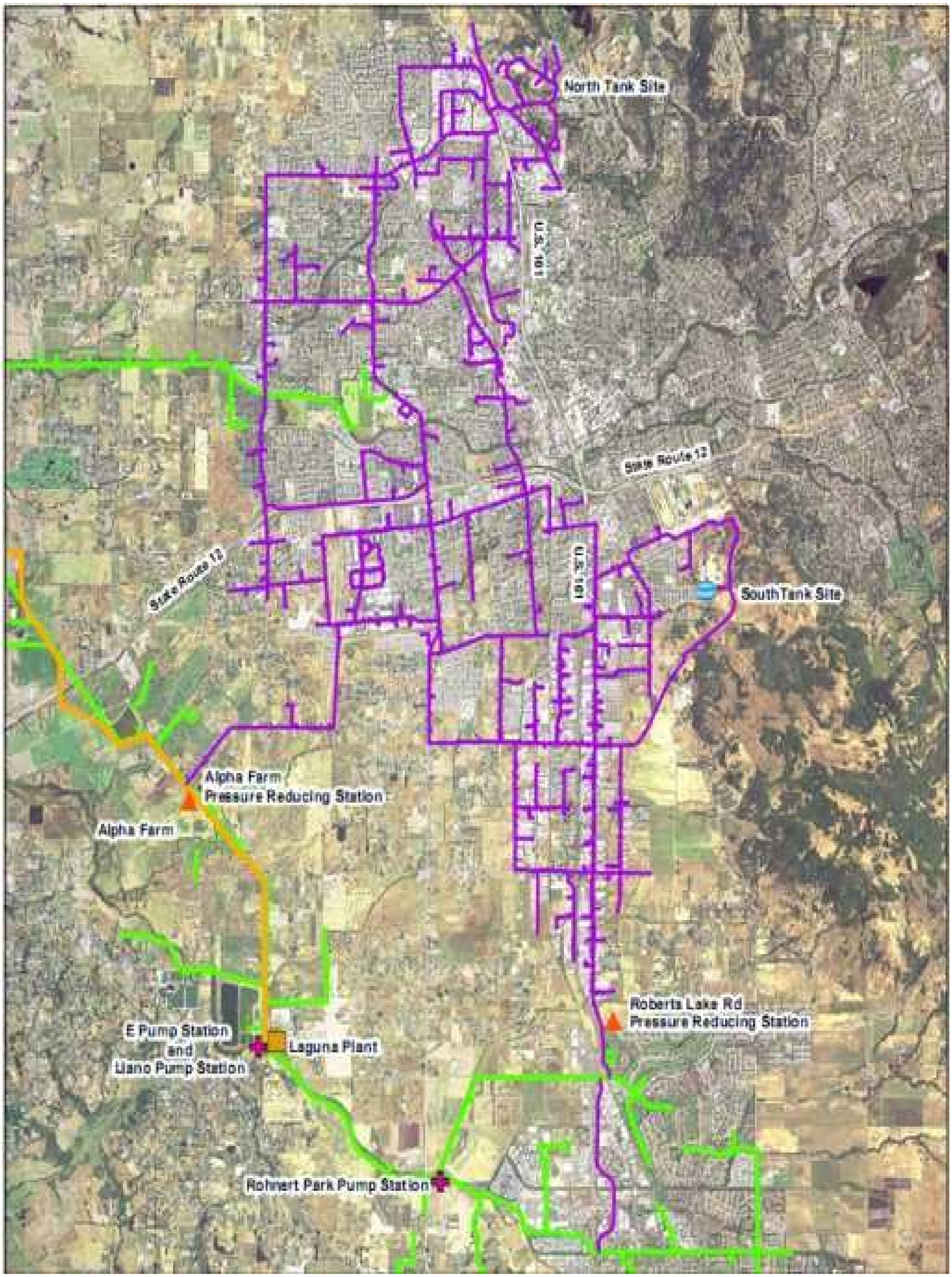
Instead of being wasted, the water could be run through a small hydroelectric turbine and the pressure used to turn a generator to produce electricity. With the developing market for additional renewable generation and the newly emerging generation technologies, the opportunity now exists for significant improvements in the efficiency of the water system in California – using the water pressure previously wasted to produce power. There are tens of thousands of pressure reduction stations operating throughout the state. Any water system with elevation differences within its system of over 100 ft will have pressure reduction valves to dissipate the excess pressure.

Figure 1. Pressure and flow traces for a pressure reduction valve.



Red = inlet pressure Blue = flow Green = outlet pressure

Figure 2. Santa Rosa municipal water supply system showing pressure reducing stations at Alpha Farm and Roberts Lake Road.



III. INFORMATION NEEDS

Despite improvements in this sector there remains poor understanding of both resources and technologies to fit this market, and a number of regulatory and economic impediments that need to be addressed.

III.A. RESOURCE ASSESSMENT: There has not been a statewide (or utility wide) assessment of the resource potential of in-conduit hydroelectric generation, primarily because this market until now has not been viable. The California Energy Commission commissioned the "Statewide Small Hydropower Resource Assessment"[5] which deals with open channel generation (primarily associated with irrigation supply). There is no comprehensive assessment of the resource potential from in-conduit hydroelectric generation throughout the state[6].

III.B. MARKET FOR THE PRODUCTION OF RENEWABLE ELECTRICITY: The potential for opportunities for using/selling the electrical power generation are often contradictory and confusing. Self generation, renewables Feed-in Tariffs, Net Energy Metering, Remote Net-Metering, utility procurement under the Renewable Portfolio Standards, and the Self Generation Incentive Program all provide potential avenues for the use/sale of the electricity generated .

III.C. TECHNOLOGY OVERVIEW: There are a multitude of small hydro turbines and generators, depending upon the characteristics of the water pressure (head) and flow, yet there exists no comprehensive inventory of available turbines or generators, nor their applicable applications.

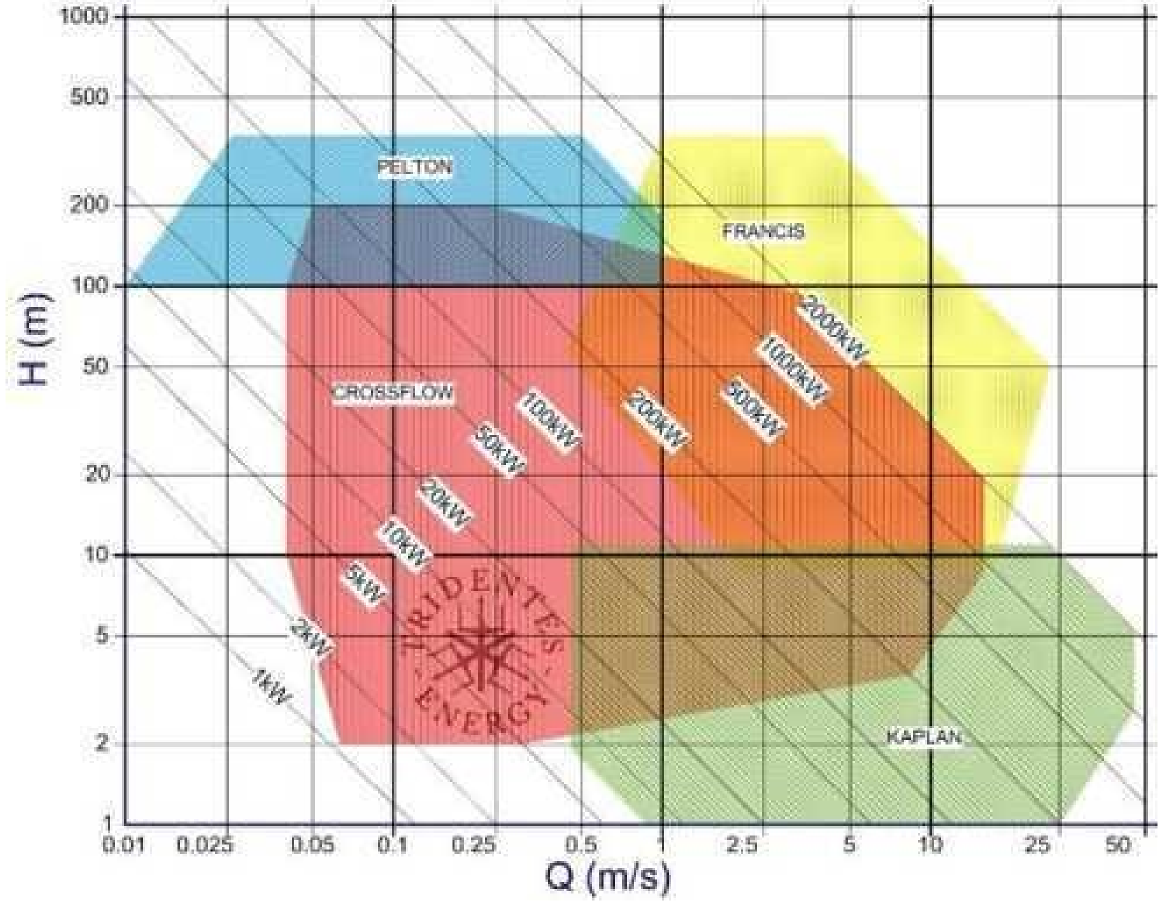
There are two major types of small hydroelectric turbines: impulse and reaction. Impulse turbines require high pressures to operate. The power produced by an impulse turbine comes from the force of the water impacting the generator blades. This water creates a direct push or 'impulse' on the blades, and thus such turbines are called 'impulse turbines'.

For low pressure (head) and high flow volume sites, a reaction (propeller) turbine is most often used. The reaction turbine is turned by reactive force rather than a direct push or impulse. The turbine blades turn in reaction to the flow of the water passing them.

The choice of the particular type turbine depends upon the relationship of the two variables of pressure (head) and flow, as the following figure shows (Figure 3).

[5] "Statewide Small Hydropower Resource Assessment", California Energy Commission, CEC-500-2006-065, June 2006.
[6] There have been estimates provided as to the potential of in-conduit generation within the water systems in California – 500 to 750 MW potential – Testimony of Lon W. House, "Water Storage as Energy Storage Opportunities in California", California Energy Commission, Docket 09IEP-1G, April 2, 2009.

Figure 3. Head-flow classification of different hydraulic turbines (source: Tridentes Energy).



In addition to traditional turbine types, there has been the recent development of hybrid turbines, able to operate under varying pressure and varying flow regimes, and turbines adapted from the wind industry that require very little pressure to operate.

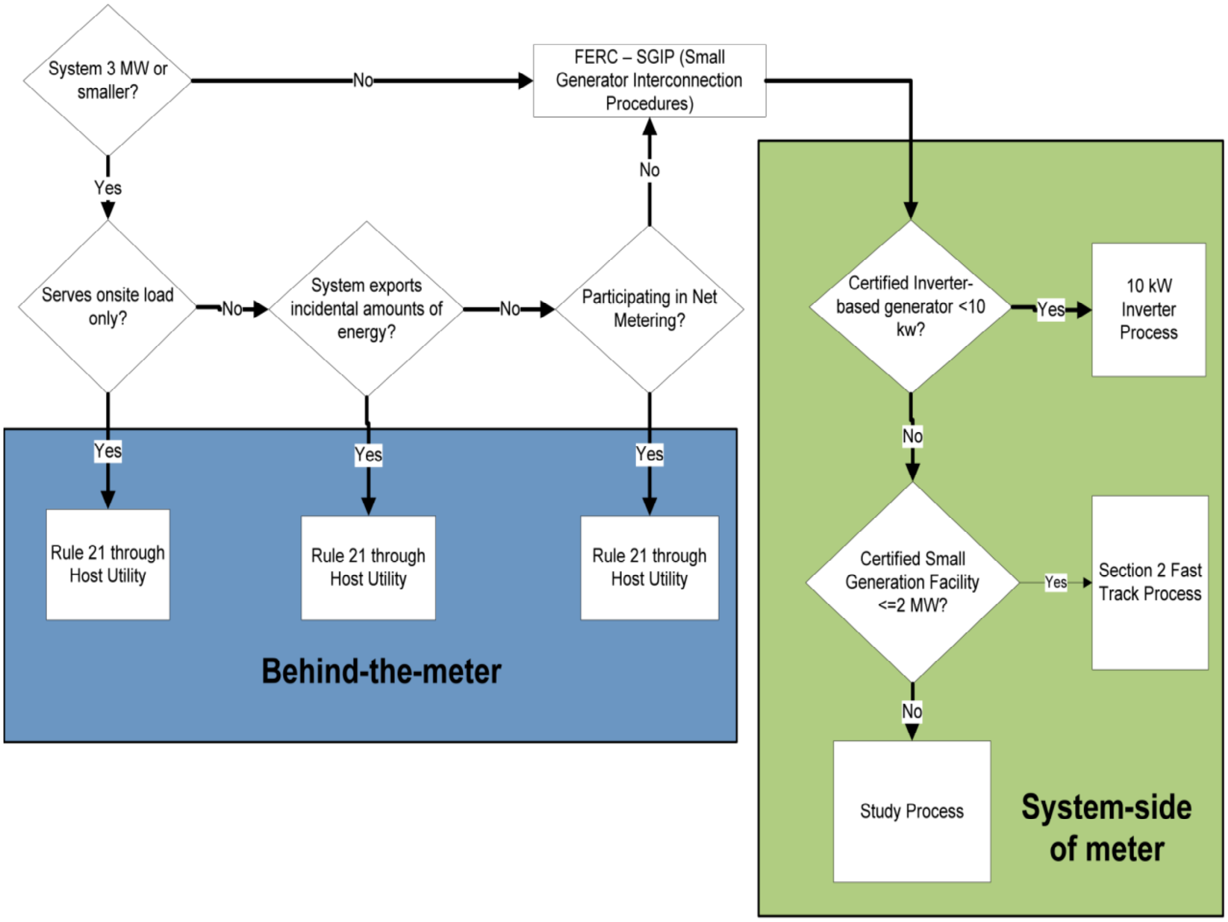
III.D. TESTING OF NEW TURBINES AND GENERATORS, EVALUATION PROTOCOLS AND PROCEDURES

A number of new small hydro turbine and generators have been developed in recent years. A common issue that many of them have is the lack of established testing protocol or procedures for evaluating this new technology. This results in the developers experiencing difficulty commercializing their product, and potential purchasers being at a loss to effectively evaluate the claims of these developers as to the performance of their new technology.

IV. POLICY NEEDS

IV.A INTERCONNECTION REQUIREMENTS: The electrical interconnection process can be quite involved for small generators, as the following figure shows (Figure 3). The California Public Utilities Commission (CPUC) has recognized this, and has initiated a Renewable Distributed Energy Collaborative (Re-DEC), but the emphasis of this project has been on solar installations and more specific information needs to be developed for in conduit generators. A complicated, and expensive, interconnection requirement discourages the development of this resource.

Figure 3. Flowchart of interconnection requirements for small power generators.



IV.B. PERMITTING REQUIREMENTS*:* Even though small hydroelectric generators are considered "categorically exempt" they still have to obtain a FERC license. The required FERC consultation takes approximately six months or more and tens of thousands of dollars, a significant barrier to the development of small hydro generation facilities[7]. The FERC process is set up for traditional hydroelectric generators, not in-conduit. In-conduit hydro generation is actually a system efficiency improvement since it aims at capturing energy that would otherwise be wasted. These systems are implemented on manmade conduits where a pressure reduction valve is already located. Fish or other aquatic organisms are not present in these systems. Hence, there are virtually none of the environmental impacts associated with traditional hydro generation, yet the extensive FERC consultation process adds time and a layer of complexity that dissuades many potential generation sites from even pursuing the option[8].

[7] A recent example for a water agency application for a 500 kW in-conduit turbine/generator has taken approximately nine months and cost between $50-$60,000. The application for a FERC exemption follows the same process as an application for a hydro generator on a dam: all the environmental review and analysis must be done (including required consultations), there has to be a notice public hearing followed by a 60 day comment period before the application is submitted to FERC. The FERC review of an application typically takes three to six months, even when there is no opposition to the project.

[8] There has been federal legislation introduced, the "Hydropower Improvement Act of 2010" (S.3570) that recognizes the onerous requirements of FERC licensing for small hydro, but it is concentrated on hydro generation at existing impoundment facilities, not in-conduit generation.

V. CONCLUSION AND RECOMMENDATIONS

There is large, relatively untapped potential within the water systems in California to significantly reduce their energy consumption by recapturing energy by replacing existing pressure reduction valves with in-conduit hydroelectric generation and increase the amount of renewable generation produced within the state, but the development of this resource requires additional information development and modification of existing regulations and policies.

APPENDIX A

LIST OF WATER SYSTEMS IN CALIFORNIA

* Alameda County Flood Control and Water Conservation, Zone 7
* Alameda County Water District
* Alhambra (City of) Utilities Department
* Alta Irrigation District
* Amador Water Agency
* American States Water Company
* Anderson-Cottonwood Irrigation District
* Antelope Valley District – see Cal Water
* Antelope Valley-East Kern Water Agency
* Antioch (City of) Public Works Department
* Bakersfield District – see Cal Water
* Bay Area Water Supply & Conservation Agency
* Bayshore District –
* Bear Gulch District –
* Bear Valley Community Services District
* Bella Vista Water District
* Berrenda Mesa Water District
* Big Bear Area Regional Wastewater Agency
* Big Bear City Community Services District
* Big Bear Lake (City of) Department of Water and Power
* Big Bear Municipal Water District
* Blue Ridge Oaks Public Water System –
* Bolinas Community Public Utility District
* Borrego Water District
* Brooktrails Township Community Services District
* Browns Valley Irrigation District
* Buellton (City of) Public Works Directory
* Cachuma Operation and Maintenance Board
* Calaveras County Water District
* Calaveras Public Utility District
* California American Water Company
* California Water Service Company (Cal Water) – Responsible for …
    o Antelope Valley District
    o Bakersfield District
    o Bayshore District
    o Bear Gulch District
    o Chico District
    o Dixon District
    o East Los Angeles District
    o Kern River Valley District
    o King City District
    o Livermore District
    o Los Altos District
    o Marysville District
    o Oroville District
    o Rancho Dominguez District
    o Redwood Valley District
    o Salinas District
    o Selma District
    o Stockton District
    o Visalia District
    o Westlake District
    o Willows District
* Calleguas Municipal Water District

* Cambria Community Services District
* Cameron Park Community Services District
* Camrosa Water District
* Carlsbad Metropolitan Water District
* Carmichael Water District
* Carpinteria Valley Water District
* Casitas Municipal Water District
* Castaic Lake Water Agency
* Central Coast Water Authority
* Central Marin Sanitation Agency
* Central Municipal Water District
* Chico District – see Cal Water
* Channel Islands Beach Community Services District
* Chino Basin Water Conservation District
* Chino Basin Watermaster
* Citrus Heights Water District
* Clear Creek Community Service District
* Coachella Valley Water District
* Coastside County Water District
* Contra Costa Water District
* Corona Department of Water and Power
* Cotati (City of) Water Division
* Crescenta Valley Water District
* Crestline Village Water District
* Cucamonga Valley Water District
* Desert Water Agency
* Dixon District –
* Dixon Solano Municipal Water Service –
* Downey (City of) Water Utilities
* Dublin San Ramon Services District
* East Bay Municipal Utility District
* East Los Angeles District – see Cal Water
* East Orange County Water District
* East Valley Water District
* Eastern Municipal Water District
* Eastside Water District
* El Dorado County Water Agency
* El Dorado Irrigation District
* El Toro Water District
* Elk Grove Water Service
* Elmira Public Water System –
* Elsinore Valley Municipal Water District
* Escondido (City of) Utilities Division
* Fair Oaks Water District
* Fairfield (City of)
* Fallbrook Public Utility District
* Fillmore (City of) Public Works Department
* Folsom (City of) Water Utilities
* Foothill Municipal Water District
* Forest Hill Public Utility District
* Frazier Park Public Utility District
* Fresno (City of) Department of Public Utilities
* Fresno Irrigation District
* Fresno Metropolitan Flood Control District
* Friant Water Authority
* Friant Water Users Authority (Includes contact info for member districts)
* Gibson Canyon Public Water System –

* Glendale (City of) Water and Power
* Glenn-Colusa Irrigation District
* Goleta Water District
* Grassland Water District
* Green Valley County Water District
* Groveland Community Services District
* Helix Water District
* Hesperia (City of) Water District
* Hi-Desert Water District
* Hidden Valley Lake Community Services District
* Hollister Water Dept.
* Humboldt Bay Municipal Water District
* Idyllwild Water District
* Inglewood Water Works
* Inland Empire Utilities Agency
* Imperial Irrigation District
* Indian Wells Valley Water District
* Inyo County Water Department
* Irvine Ranch Water District
* Walter Huber and friends: Huber Collection, no. 205 Joshua Basin Water District
* Jurupa Community Services District
* Kaweah Delta Water Conservation District
* Kern County Water Agency
* Kern River Valley District –
* King City District – see Cal Water
* Kings River Conservation District
* Kirkwood Meadows Public Utility District
* La Puente Valley County Water District
* Laguna Beach (City of) Water Quality Department
* Laguna Beach County Water District
* Lake Arrowhead Community Services District
* Lake County Water Resources Division
* Lake Don Pedro Community Services District
* Lake Elizabeth Mutual Water Co.
* Lake Hemet Municipal Water District
* Lakeside Water District
* Lakewood (City of) Water and Water Quality
* Las Virgenes Municipal Water District
* Livermore District – see Cal Water
* Long Beach (City of) Water Department
* Los Altos District –
* Los Angeles Department of Water and Power
* Lost Hills Water District
* Lower Tule Irrigation District
* Madera Irrigation District
* Main San Gabriel Basin Watermaster
* Malaga County Water District
* Mammoth Community Water District
* Marin Municipal Water District –
* Marina Coast Water District
* Marysville District –
* McKinleyville Community Services District
* Mendocino County Water Agency
* Merced Irrigation District
* Mesa Consolidated Water District
* Metropolitan Water District of Southern California
* Mid-Peninsula Water District

* Midway Heights County Water District
* Mission Springs Water District
* Modesto Irrigation District
* Mojave Water Agency
* Montara Water and Sanitary District
* Monte Vista Water District
* Montecito Sanitary District
* Montecito Water District
* Monterey County Water Resources Agency
* Monterey Peninsula Water Management District
* Moulton Niguel Water District
* Municipal Water District of Orange County
* Newhall County Water District
* Nevada Irrigation District
* North Coast County Water District
* North Marin Water District
* North of the River Municipal Water District
* Oakdale Irrigation District
* Oceanside (City of) Water Utilities Department
* Olivenhain Municipal Water District
* Orange County Water District
* Oroville District – see Cal Water
* Otay Water District
* Oxnard (City of) Public Works Department Water Section
* Padre Dam Municipal Water District
* Pajaro Valley Water Management Agency
* Palmdale Water District
* Paradise Irrigation District
* Pasadena Water and Power
* Peabody Public Water System –
* Pebble Beach Community Services District
* Petaluma (City of) Water Resources and Conservation
* Pico Water District
* Placer County Water Agency
* Pleasant Hills Public Water System –
* City of Poway
* Quail Canyon Public Water System –
* Quartz Hill Water District
* Rainbow Municipal Water District
* Ramona Municipal Water District
* Rancho California Water District
* Rancho Dominguez District – see Cal Water
* Reclamation District No. 1000
* Redding (City of) Water Utility
* Redwood Valley County Water District
* Redwood Valley District –
* Rincon del Diablo Municipal Water District
* Riverside (City of) Water Services
* Riverside County Flood Control and Water Conservation District
* Rio Linda-Elverta Community Water District
* Rohnert Park (City of) Water, Sewer & Garbage
* Rosamond Community Services District
* Roseville (City of) Water Utility
* Rowland Water District
* Sacramento (City of) Department of Utilities
* Sacramento County Water Agency
* Sacramento Suburban Water District

* Regional Water Authority – greater Sacramento
* Salinas District –
* San Benito County Water District
* San Bernardino (City of) Municipal Water District
* San Bernardino County Special Districts Department of Water & Sanitation Division
* San Bernardino Valley Municipal Water District
* San Bernardino Valley Water Conservation District
* San Diego (City of) Water Department
* San Diego County Water Authority
* San Dieguito Water District
* San Francisco Public Utilities Commission
* San Francisquito Creek Joint Powers Authority
* San Gabriel Basin Water Quality Authority
* San Gabriel Valley Municipal Water District
* San Gabriel Valley Water Association
* San Gorgonio Pass Water Agency
* San Joaquin County Public Works Department
* San Juan Bautista (City of) Water Department
* San Juan Capistrano (City of) Water Division
* San Juan Water District
* San Luis & Delta-Mendota Water Authority
* Santa Ana Watershed Project Authority
* Santa Barbara (City of) Public Works, Water Resources Division
* Santa Clara Valley Water District
* Santa Cruz City Water Department
* Santa Fe Irrigation District
* Santa Margarita Water District
* Scotts Valley Water District
* Selma District –
* Semitropic Water Storage District
* Serrano Water District
* Shafter-Wasco Irrigation District
* Sierra Lakes County Water District
* Solano County Water Agency
* Solano Irrigation District – Responsible for …
    o Blue Ridge Oaks Public Water System
    o Dixon Solano Municipal Water Service
    o Elmira Public Water System
    o Gibson Canyon Public Water System
    o Peabody Public Water System
    o Pleasant Hills Public Water System
    o Quail Canyon Public Water System
    o Stocking Ranch Public Water System
    o Suisun-Solano Water Authority
* Sonoma (City of) Water Division
* Sonoma County Water Agency
* Soquel Creek Water District
* South Coast Water District
* South San Joaquin Irrigation District
* South Tahoe Public Utility District
* Stinson Beach County Water District
* Stocking Ranch Public Water System –
* Stockton (City of) Municipal Utilities Department
* Stockton District – see Cal Water
* Stockton East Water District
* Suisun-Solano Water Authority –
* Sunnyslope County Water District

* Sweetwater Authority
* Sweetwater Springs Water District
* Tahoe City Public Utility District
* Tehachapi (City of) Public Works Department
* Tehachapi-Cummings County Water District
* Three Valleys Municipal Water District
* Torrance (City of) Municipal Water District
* Trabuco Canyon Water District
* Tulare Irrigation District
* Tuolumne Utilities District
* Turlock Irrigation District
* Twentynine Palms Water District
* United Water Conservation District
* Upper San Gabriel Valley Municipal Water District
* Vacaville (City of) Public Works Department
* Vallecitos Water District
* Valley Center Municipal Water District
* Valley County Water District
* Valley of the Moon Water District
* Vandenberg Village Community Services District
* Victor Valley Water District
* Visalia District – see Cal Water
* Vista Irrigation District
* Walnut Valley Water District
* Water Replenishment District of Southern California
* Weaverville Community Services District
* Westlake District – see Cal Water
* West Basin Municipal Water District
* West Kern Water District
* West Stanislaus Irrigation District
* Westborough Water District
* Westlands Water District
* Western Municipal Water District
* Wheeler Ridge-Maricopa Water Storage District
* Willows District – see Cal Water
* Yolo County Flood Control & Water Conservation District
* Yorba Linda Water District
* Yuba City Public Works Department
* Yuba County Water Agency
* Yucaipa Valley Water District
* Yuima Municipal Water District