In-Conduit Hydropower Project

– Phase II Report

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1 BACKGROUND

Massachusetts has many public water systems (PWS) and publically-owned treatment works (POTW) (wastewater) facilities that could potentially benefit from the installation of an in-line hydropower system. As the energy costs for operating these types of facilities can be high, the ability to offset some or all of that cost by harnessing available “excess” energy in a system may provide substantial economic benefits. These projects can also provide non-tangible benefits through the generation of green, renewable energy (production of electricity without the any emission of greenhouse gasses). In-conduit hydro projects can also help to meet the State of Massachusetts’ Renewable Portfolio Standard (RPS) goal and reduce dependency on foreign energy sources. Currently, there are some challenges associated with project development; primarily, developing a project such that it is financially viable.

2 OBJECTIVE

The objective of the Phase II evaluation was to develop some baseline information which will assist PWS or POTW facility personnel to gain basic knowledge of in-conduit hydropower projects. This information is intended to provide some efficiency in evaluating a particular project by providing baseline case studies and payback criteria. The baseline case studies identify and discuss typical installation types providing guidance on where in a system generation resources may be located. The payback criteria and theoretical financial values provided show the relationship between the various factors which contribute to a project’s financial viability. Using theoretical layouts and financial information, PWS and POTW personnel will have baseline tools available to complete an initial review of their site and gain a better understanding of whether or not additional studies should be pursued. It is important to understand that the characteristics of every site vary both in their physical layout and financial situation. Therefore, the feasibility of an installation can only be known through a site-specific evaluation. Baseline case studies and payback criteria have been developed separately for PWS and POTW facilities due to the differences in development.

A state-wide market analysis has been completed to gain a better understanding of the development potential in the Commonwealth. This information can be used to gain some perspective on how in-conduit hydropower generation may contribute to the Commonwealth’s RPS goal and provide guidance for resource planning. Information available for evaluation of state-wide market potential varied and assumptions used in the development of these estimates vary.

3 BASELINE CASE STUDY

Phase I of this project focused on identification of suitable generation technologies as well as investigation of existing installations. Based on this information, two typical development types for PWS facilities have been developed. Insufficient information was available to develop baseline case studies for POTW sites utilizing existing project data; therefore, an evaluation of these sites was completed based on professional judgment. In addition to physically defining the scenarios, typical approaches to development and generation equipment have been evaluated and are discussed.

3.1 PWS

Based on the information developed during Phase I and on professional experience, two installation scenarios have been defined as typical for PWS facilities:

- Replacement of an energy reducing component with a turbine and
- Installation of a turbine to harness the energy potential between two bodies of water at varying elevations such as reservoirs or storage basins.

Typically PWS facilities have relatively high head and low flow conditions. The presence of any energy dissipating component in the PWS system is an indicator that excess energy, beyond that required for PWS operations, is available in the system. This energy may be available consistently or vary; however, through the use of a supervisory control and data acquisition (SCADA) system and valves, a turbine can adjust itself to match the available resources.

The Phase I investigation found that the most common development type is the installation of a turbine in parallel with an existing energy dissipating component, as shown on Figure 1. Typically, the turbine is installed in parallel with a pressure reducing valve (RPV); however, a project which incorporated a turbine adjacent to an aeration block was investigated in Phase I. Transfer of water from one location to another may provide an opportunity for generation due to the elevation differential. It is important to only consider sites in which the transfer is made via gravity and that no additional energy will need to be put into the system for turbine operations.

Scenario 1 harnesses the energy which would otherwise be wasted at an energy dissipating component such as a PRV as shown in Figure 1. Depending on a system's particular hydraulics, a PWS may have excess pressure that requires dissipation prior to flow entering the treatment facility to prevent damage to downstream components. Typically, some pressure is required downstream of a PRV for plant operations and not all pressure can be dissipated. The safe and reliable operation of the existing PWS facility is critical to the success of the hydropower project and any impact to the PWS's normal operations are generally considered unacceptable. Generation equipment is typically installed on a bypass system parallel to the pressure reducing element with flow control achieved through a series of valves. This allows for isolation of the flow through either the turbine or bypass. In the event that that there is a turbine malfunction or outage, valves will redirect water to its original conveyance system and operation interruption will be minimal.

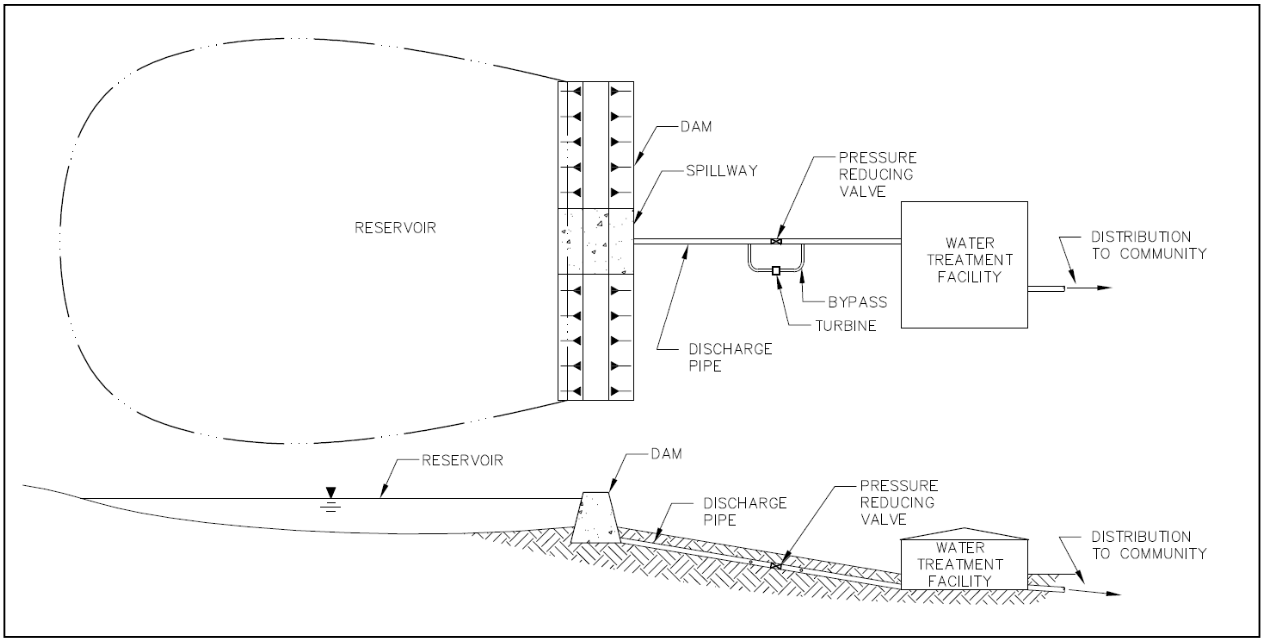

Figure 1. Scenario I – Relacement of a Pressure Reducing Feature at a PWS

As mentioned, some pressure is typically required downstream of the potential installation for PWS operations. Therefore, the turbine typically must be contained within a piping system and cannot discharge flow to atmosphere. Impulse turbines such as pelton wheels must discharge to atmosphere for operation and would not likely be technically feasible for this type of installation. Turbine types which should be considered include Francis, Kaplan and pump-as-turbine (PAT) units.

Scenario II focuses on harnessing the energy of water as it travels from one storage reservoir to another as shown in Figure 2. Systems which have multiple storage locations, such as a series of reservoirs, only need sufficient energy to overcome the hydraulic losses associated with water transfer. The difference in elevation between the water surface elevation of each reservoir, less the hydraulic losses associated with the system, provides the resultant head available to the turbine. Similar to Scenario I, a fail-safe bypass will be required to allow for continued operation of the PWS in the event of a planned or emergency outage of the hydroelectric system.

The system presented in Scenario II does not necessarily require pressure downstream of the turbine. Rather, sufficient energy must be present to convey the flow to its final location. Depending on the system characteristics, Scenario II could accommodate an impulse turbine which discharges to atmosphere as well as a reaction turbine which continues within the existing pipe. The impulse turbine could be accommodated by installing the turbine at a location adjacent to the lower reservoir or by utilizing the remaining gradient between the installation location and the lower reservoir for conveyance.

Pressure head is the pressure in the pipe line located upstream of the turbine while suction head is that located downstream of the turbine. Theoretically, the turbine can be installed at any location along the length of the pipeline; however, it is preferable that the ratio of pressure head to suction head is high meaning that the turbine is installed as far downstream in the pipe as possible. Low pressure/suction ratios can lead to equipment difficulties, including cavitation issues. In addition, for the turbine to actually utilize the suction pressure, a vacuum must be maintained in the pipe downstream of the turbine. Depending on the length of pipe downstream of the turbine, it may be difficult to maintain suction.

Turbines that may be technically suitable for Scenario II include both reaction and impulse turbines. This could include Kaplan, Francis, PAT, pelton, turgo and crossflow turbines.

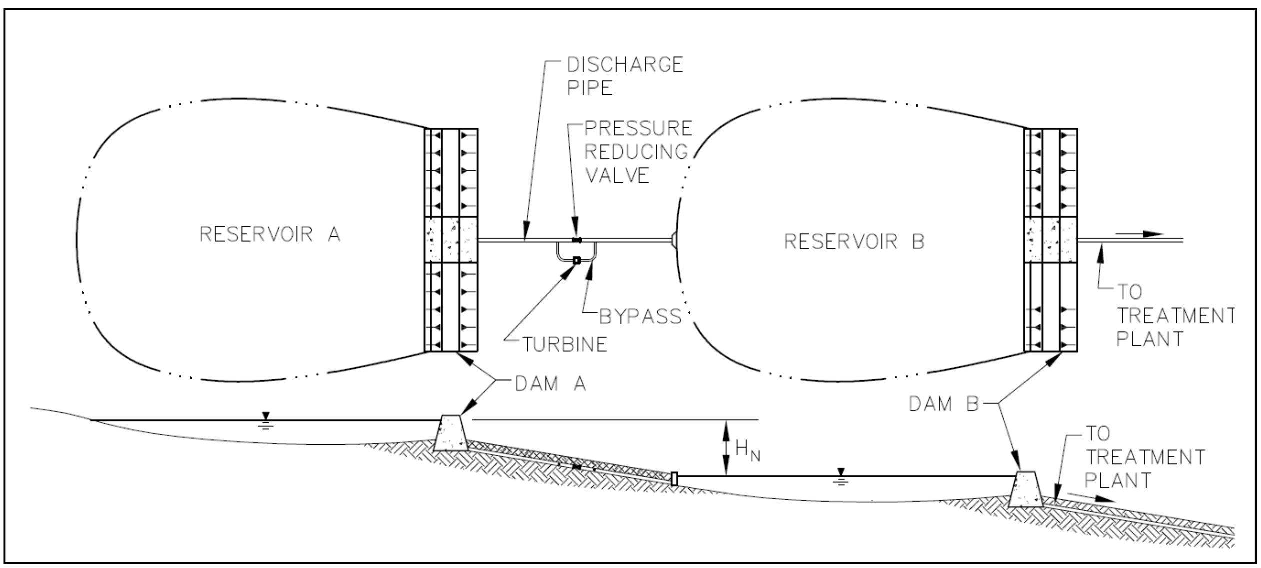

Figure 2. Scenario II - Inter-Reservoir Transfer at PWS

3.2 POTW

Limited information regarding POTW installations was found during Phase I. The limited Phase I information as well as professional judgment were utilized to define typical POTW facilities. Excess energy for generation will typically only be located at a POTW outfall structure which will likely consist of low head, high flow discharges. The two scenarios focusing on the energy available at a POTW outfall structure are detailed below. They include the installation of a conventional turbine at a closed conduit outfall (pressurized) and a hydrokinetic energy (HKE) turbine within an open channel (non-pressurized) outfall.

Scenario III and Scenario IV are similar in nature but utilize different means of discharging flow from the POTW to the receiving water body. Scenario III assumes that the treated effluent is discharged via a pressurized pipe, whereas Scenario IV assumes that the discharge is via open channel flow and that pressure is not developed. Both cases assume that following treatment, water must be discharged back to a river system at an outfall structure and that there must be some drop in elevation for discharge. In either case, careful evaluation will be required to ensure that:

- The POTW system is left with sufficient energy for water to discharge to the river; and
- That the generation system has minimal or no impact on the upstream system including the water surface elevation.

Figure 3 depicts a sewer line and outfall structure conveying flow from a POTW facility to the adjacent river through a pressurized system. This system is physically similar to Scenario II in that it is a simple transfer of water from one elevation to another with residual energy only required to convey flow out of the turbine-generating system to the receiving waters. A notable difference between the cases is that Scenario II is expected to be a high head, low flow development while Case III would likely be a low head, high flow development. This means that the turbine selection for each would be significantly different. Although Scenario III could accommodate a turbine that can discharge to atmosphere, such as a pelton wheel, these types of turbines typically require high head and would not be suitable for the characteristics anticipated at a POTW facility. Turbines suitable for Scenario III include reaction turbines, such as Kaplan and Francis turbines or mixed flow units (crossflow, banki) that have been specially designed for low head installations.

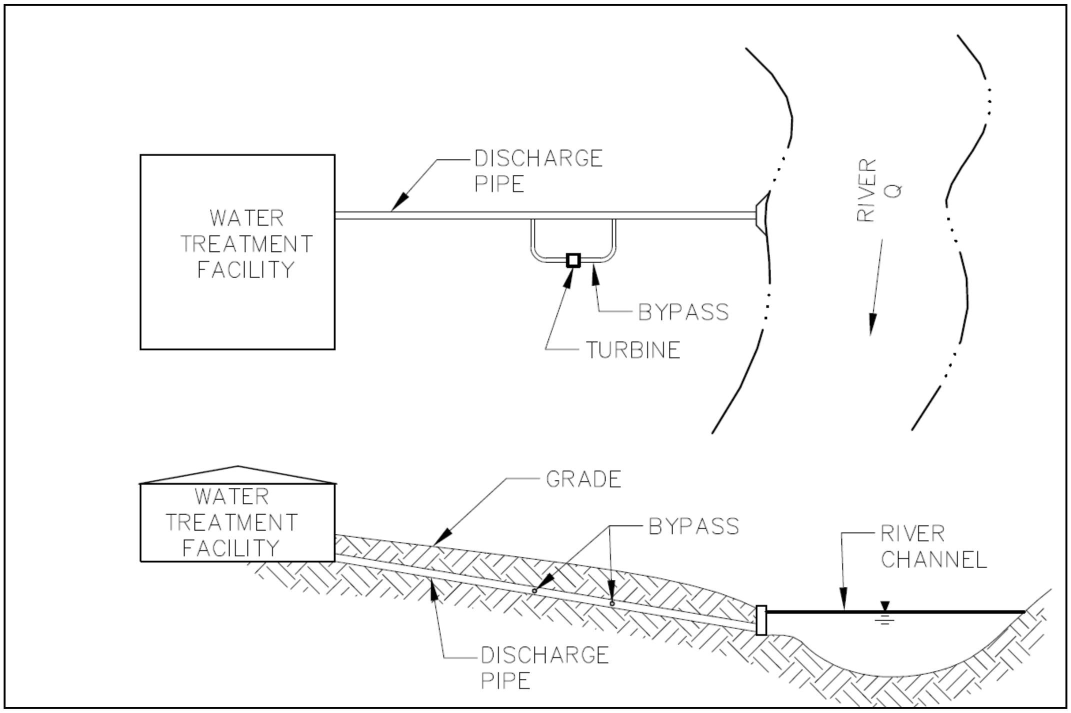

Figure 3. Scenario III - Pressurized Discharge at POTW

Scenario IV focuses on harnessing the energy in a free surface discharge. The discharge could be an open channel or a closed pipe which does not develop pressure. This scenario would be suitable for HKE units which generate power based on velocity rather than a pressure differential. As shown in Figure 4, an array of HKE turbines or a single turbine can be installed depending on the system configuration. Should the turbine cease operation, there is a potential to create a headloss that would back up the flow of water and impact upstream operations. Therefore, a bypass will be required to ensure uninterrupted operation of the upstream system. Conventional head-based turbines would not be suitable for this scenario, only HKE types would be technically feasible.

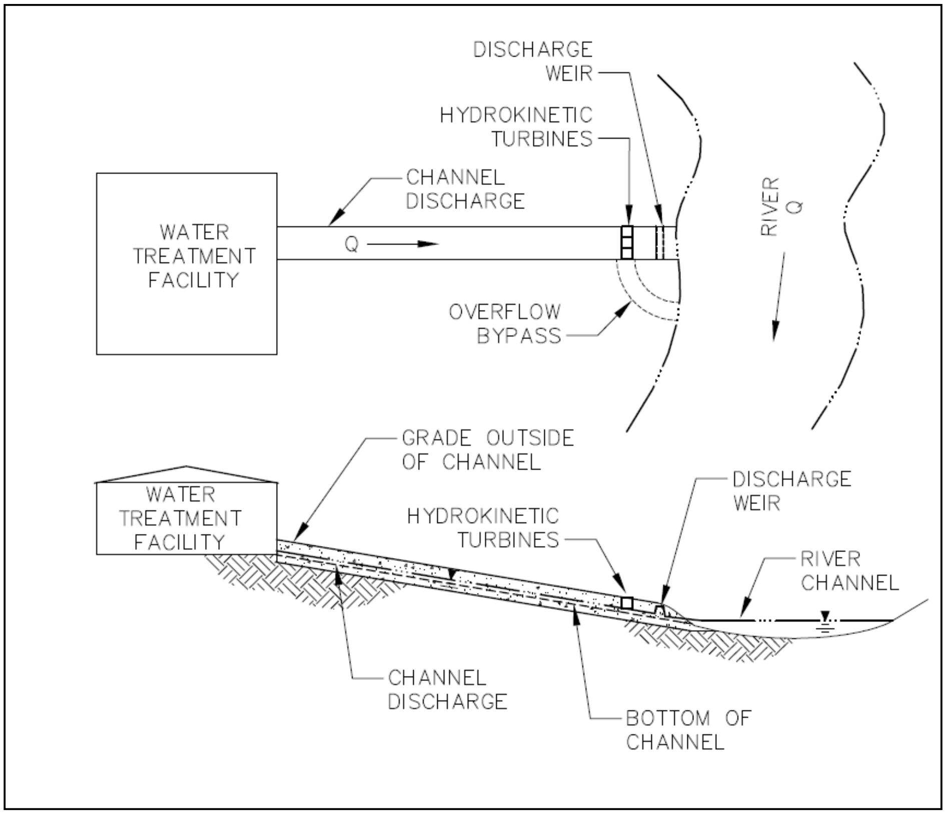

Figure 4. Scenario IV - Free Surface Discharge at POTW

3.3 Considerations

Every PWS and POTW facility is unique and the location for maximum energy extraction will vary. The four scenarios presented above are "typical" and provide initial guidance on identifying locations for consideration during initial investigations. Depending on the system there may be storage facilities or conveyance structures with sufficient head/flow resources for investigation. In addition, other facilities such as a reclaimed water treatment plant should be considered for in-conduit potential.

Regardless of the scenario, a variety of factors should be considered when evaluating a potential development including:

- Physical limitations;
- Equipment protection;
- Controls and integration into SCADA system;
- Potential impacts on primary system operations;
- Interconnection;

- Access; and
- Potential impacts of Federal Energy Regulatory Commission (FERC) regulation on existing PWS and POTW systems.

Regardless of the Scenario, an enclosure will be required to protect the generator and control system from weather. In New England, water pipes are typically buried at least four feet below grade to protect from freezing during the winter. Therefore, the hydroelectric system may be located below ground and a housing will be required. Often the most cost effective means of achieving this is through the installation of a concrete vault below ground to house the equipment.

Any system should have a SCADA system incorporated to control both the turbine operations and the flow control valves. Typically four flow control valves are required to isolate and direct flow through either the bypass or main line. This level of control is critical in maintaining consistent and reliable operation of the PWS or POTW system in that all turbine flows will be quickly re-directed through the main distribution line in the event of any turbine issues. Typically, a PWS or POTW system has an existing SCADA system which controls plant operations. The controls for the turbine system should be integrated into the existing SCADA system such that all project components will operate as a single system.

Depending on the installation location and the electrical characteristics of generation, there is potential that either the existing interconnection may be suitable or that a new interconnection may be required. Regardless, review by the electric service provider will be required to ensure that the installation will not have any effect on the surrounding electrical grid and is safe for linemen and other workers. In addition, electrical features, such as protective relays, will be required for grid protection.

Prior to moving forward with a project, it is recommended the project proponent complete some investigation to understand the FERC process and any potential effects of licensing in-conduit generation facilities on the PWS or POTW facility. In-conduit hydropower projects are typically eligible for a FERC conduit exemption which limits the extents of a project that will be jurisdictional. However, there are some agencies which may recommend changes to instream flows or other environmental protection measures as part of the permitting process. A project proponent will have a better understanding of any potential regulatory requirements following an initial project consultation.

4 PAYBACK CRITERIA

The financial viability of a development will depend on project costs and annual project benefits. The project costs will be comprise the initial capital investment and annual operations and maintenance expenditures. Annual benefits are a function of a project's average annual energy generation and the value of the energy generated. Energy generation is a function of the available head and flow resources and the system efficiency. These factors are discussed in more detail below along with a variety of theoretical financial scenarios that have been compiled based on case study information from Phase I.

Project Cost

Project costs include the initial capital investment as well as annual operations and maintenance costs. The initial capital investment can include the following:

- Turbine generator set;
- Electrical system;
- Controls;
- Civil modifications;
- Permitting;
- Engineering; and
- Interconnection.

A review of the project information during the Phase I case study investigation indicated project costs on the order of $3,200/kW to $10,500/kW for PWS hydropower installations. One plant included in the case studies had a cost of $16,000/kW; however, it was constructed outside of New England and it is unclear if the costs are representative of the Commonwealth. This data point has not been included in evaluations. The US Department of Energy estimates that the cost of conventional hydropower is on the order of $4,000/kW to $5,000/kW[1] for projects between 100 kW and 30 MW in size. There are some efficiencies of scale associated with hydropower development and the projects typical of PWS and POTW sites in New England will tend to be less than 100 kW. Based on the case studies, the average development cost for in-conduit hydro is on the order of $8,600/kW including any incentives. However, it should be noted that the capacity factor of in-conduit hydropower tends to be higher than conventional hydropower. This results in higher annual energy generation for an in-conduit system compared to a conventional project of the same power capacity and turbine type. Similar to the energy comparison the

[1] D. Olis. NREL, US Department of Energy. Introduction to Renewable Energy Technologies – Hydropower Addendum. Presentation.

annual revenue of the in-conduit system will be greater than a conventional system of the same energy value. This concept is discussed in more detail below.

A single project was identified with cost information available at a POTW facility. It resulted in an initial capital cost of about $16,000/kW which is approximately double the average of $8,600 for PWS facilities. It is estimated that this value is not necessarily unreasonable as equipment costs typically increase as head decreases for a given power output. This is because a turbine for a particular power output increases in size as the available head decreases. It is estimated that the typical head available at a POTW facility in the Commonwealth is on the order of 2 to 10 ft which is relatively low.

Operations and maintenance (O&M) costs can include personnel to inspect the site on a regular basis for items such as debris removal, oil levels, valve positioning and general system checks. Maintenance can include items such as changing belts, generator cleaning, and bearing replacement. The cost of operations and maintenance will vary by site as many PWS and POTW plants have existing personnel which can perform these tasks and a dedicated employee may not be required. The Phase I case studies indicated an average annual O&M cost of $5,000.

Annual Benefits

The annual benefits of an in-conduit project are a function of the average energy generation and the value of energy. An analysis of the Phase I case studies was completed to understand the range of development parameters and to define typical developments. Table 1 summarizes the information on head, flow, power, power factor and energy.

Table 1. Summary Phase I PWS Case Study Generation Data

Parameter	High	Low	Average
Head (ft)	384	52	163
Flow (cfs)	39	1.5	10
Power (kW)	200	17	64
Capacity Factor (%)	100	37	74
Energy (kWh)	1,210,000	140,000	389,000

Minimal information on POTW installations was available; therefore, site characteristics and professional judgment were used to complete this evaluation. A review of National Pollutant Discharge Elimination System (NPDES) permits indicated that the average discharge rates for POTW facilities in Massachusetts is 6.5 MGD (10 cfs). It is estimated that the average available head at POTW facilities is on the order of 2 to10 ft. It is likely that the average capacity factor for POTW facilities is similar to PWS facilities as the POTW facility is an un-natural system dependent partially upon PWS flow rates.

Annual Energy Generation

Understanding the difference between power and energy is important in evaluating a project finances. Power is the instantaneous rate at which work is done or energy is transmitted. Energy is power integrated over time. The amount of power that a plant can generate is the primary factor in annual energy generation; however, it is the energy itself that is the tangible asset with an associated monetary value. Equations 1, 2, and 3 provide information on the relation between site resources, energy generation and financial returns.

The power of a project is a function of the available generation resources and the efficiency of the system as shown in Equation (1).

$$P = \frac{QHe}{11.81} \tag{1}$$

Where:

P = Power (kW)
Q = Flow rate (cfs)
H = Head (ft)
e = efficiency (%)

As shown in Table 1, the Phase I case studies indicated an average power potential, system efficiency and capacity factor, of 64 kW, 67% and 74%, respectively for PWS systems. As head and flow are directly related, a variety of conditions can exist which would result in 64 kW of generation. A range of these conditions are summarized in Table 2.

Table 2. Summary of Resource Combinations Resulting in 64 kW at 74 % Efficiency

Head (ft)	Flow (cfs)
5	226
10	113
15	75
20	56
25	45
30	38
35	32
40	28
45	25

Head (ft)	Flow (cfs)
50	23
55	21
60	19
65	17
70	16
75	15
80	14

The typical power of POTW facilities in the New England area is unknown. This is because the only facilities identified are very large sites, such as Deer Island, which is not typical of POTW facilities throughout the Commonwealth. However, from the review of NPDES permits it has been determined that the average flow is about 10 cfs and it is estimated that the average head is between 2 and 10 ft. Assuming that the typical efficiency is on the order of 75% (similar to PWS facilities), the average power would be on the order of 1-to 10 kW.

The estimation of average annual energy can be complex because the instantaneous power generation of the system will vary as a function of the available head and flow and the efficiency associated with those conditions. A simple means of estimating the average annual energy can be completed as shown in equation (2).

$$E = P * Fc * t \qquad (2)$$

Where:

E = Average Annual Energy Generation (kWh) [2]
P = Power (kW)
F*c*=Capacity factor (%)
t=time, (hours/year)

Capacity factor is the ratio of a plant's actual annual energy generation to its potential output if it were possible to operate at peak power capacity indefinitely. As the head and flow available to a site may vary throughout the year, it is not possible to generate the peak power capacity 100% of the year. The average capacity factor for conventional hydropower projects is about 40%[3]; however, Table 1 indicates an average capacity factor of 74% for the PWS facilities in New England. A higher capacity factor for in-conduit projects is expected because the flow rates tend to be more consistent compared to conventional hydropower which is dependent upon the natural hydrological cycle of a river basin. Estimates of average annual energy generation have been developed by calculating the maximum theoretical energy generation (peak power*8,765 hr/yr)

[2] Unless otherwise noted, energy estimates discussed throughout this report refer to the average annual energy.
[3] US Energy Information Administration, DOE/EIA-0348 (2009), Electric Power Annual 2009. April 2011.

and then multiplying by the average capacity factor. It is estimated that a POTW development would have a capacity factor similar to that of the PWS facility and will be assumed as 74%.

Value of Energy

The value of the energy generated will include both the value of the energy itself as well as the value of the renewable energy certificates (RECs). The value of the tangible energy asset will depend on the end use of the energy. Energy can be used on-site to offset energy which would otherwise be purchased to power treatment facilities or other on-site demands. The value of energy used on-site will be equivalent to that which would otherwise be paid. Typically, this value is in the range of about $0.0.8/kWh to $0.15kWh and is referred to as retail rates. If there is not an on-site electrical demand available to utilize the energy, it will most likely be sold to the grid for wholesale prices. Wholesale prices are based on the ISO New England (ISO NE) Real Time Locational Marginal Pricing (RT LMP) which varies hourly depending on the supply and demand throughout a utility zone. Wholesale prices have been averaging about $0.04/kWh for several years in Massachusetts.

RECs represent the non-tangible asset associated with hydropower generation. A REC and its associated benefits are sold separately from the underlying physical electricity that is produced by a project. RECs are the property rights to the environmental, social and other non-power qualities of renewable electricity generation. It is likely that most new in-conduit hydropower projects at WTS and WTTP plants will be eligible for "Class I" RECs. The market value of RECs fluctuates. Recent MA Class I values have been in excess of $0.05/kWh, but for long range planning purposes a value such as $0.025/kWh is more appropriate.

Financial Evaluation

The simple payback period is a function of the initial capital investment and the annual project benefits as shown in Equation (3).

$$Simple\ Payback\ Period\ = \frac{Initial\ Capital\ Investment}{Average\ Annual\ Energy * Value\ Energy} \tag{3}$$

Where:

Simple Payback Period (years)
Initial Capital Investment ($)
Average Annual Energy (kWh)
Value Energy ($)

A series of theoretical scenarios were investigated to gain a better understanding of the relationship between financial parameters. Table 1 indicates an average peak power of 64 kW, an average power factor of 74% and an average project cost of $8,600/kW for PWS systems. In addition a total value of energy (energy and RECs) for wholesale and retail was assumed at $0.065/and $0.14/kWh, respectively. Using this information, an analysis was completed to estimate the maximum project capital investment allowable to return a set payback period for PWS facilities. Also, an associated maximum installed cost ($/kW) estimate was completed as shown in Table 3 and Table 4, such that the data can be applied to other projects with similar characteristics.

Table 3. Supportable Installed Costs at Wholesale Electric Rates PWS

Target Payback Period (year)	**15**
Peak Power (kW)	64
Power Factor	74%
Estimated Annual Energy (kWh)	415,000
Value Energy	$ 0.065
Annual Revenue	$ 27,000
Initial Capital Investment	$ 405,000
Calculated $/kW Required	$ 6,300

Table 4. Supportable Installed Costs at Retail Electric Rates PSW

Target Payback Period (year)	**15**
Peak Power (kW)	64
Power Factor	74%
Estimated Annual Energy (kWh)	415,000
Value Energy	$ 0.14
Annual Revenue	$ 58,000
Initial Capital Investment	$ 870,000
Calculated $/kW Required	$ 13,600

In addition estimates of the 30 year environmental life cycle benefit for each scenario were completed to understand the environmental attributes of the project. Based on the U.S. average fuel mix for all U.S. generation it has been assumed that 1.52 lb/kWh, 0.008 lb/kWh and 0.0049 lb/kWh is offset for carbon dioxide, sulfur dioxide and nitrogen oxides, respectively. It is estimated that for a 64 kW plant generating 415,000 kWh/year a offset of approximately 18,930,000 lbs of Co2, 99,000 lbs of So2 and 60,000 lbs of Nox will be provided by the project.

An average of power estimates for POTW facilities (including high and low head assumptions) resulted in approximately 5 kW. Theoretical scenarios were completed for POTW facilities assuming an average peak power of 5 kW, an average power factor of 74% and an average project cost of $16,000/kW. Using this information, an analysis was completed to estimate the maximum project capital investment allowable to return a set payback period. Similar to the PWS evaluation, an associated maximum installed $/kW estimate was completed for POTW facilities. This evaluation was completed for both wholesale and retail energy values as shown in Table 5 and Table 6.

Table 5. Supportable Capital Costs at Wholesale Electric Rates POTW

Target Payback Period (year)		15
Peak Power (kW)		5
Power Factor		74%
Estimated Annual Energy (kWh)		32,500
Value Energy	$	0.06
Annual Revenue	$	2,100
Initial Capital Investment	$	31,500
Calculated $/kW Required	$	6,300

Table 6. Supportable Capital Costs at Retail Electric Rates POTW

Target Payback Period (year)		15
Peak Power (kW)		5
Power Factor		74%
Estimated Annual Energy (kWh)		32,400
Value Energy	$	0.14
Annual Revenue	$	4,500
Initial Capital Investment	$	68,100
Calculated $/kW Required	$	13,600

An additional, more detailed financial evaluation using a proforma was completed based on retail rates at a PWS facility. This scenario was chosen as an example because it provides the most favorable development option of those identified in Table 3 through Table 6. Completing a proforma is important because it shows financial factors that may not be apparent in a simple payback evaluation. Private hydropower developers typically consider a project to be viable if it has a payback period of less than 10-15 years. Municipal entities often plan for their facilities in the long-term and will consider development of a project with a much longer payback period. Typically municipal project development will only be considered when the financial evaluation indicates positive cash flow starting in the first year and a payback period that does not exceed the project lifespan. To understand if a project meets these criteria, a proforma must be completed.

The proforma evaluation assumed similar values to those shown in Table 3 with an average annual energy generation of 415,000 kWh, retail energy rates at $0.14/kWh, and an initial capital investment of $550,000 based on a peak power generation of 64 kW. Additional input values and assumptions are detailed in Table 7. Based on this development scenario, the average annual project benefit over the finance period (10 years) is about $12,500 and the internal rate of return is about 5%. The internal rate has been assumed to be taken as a function of the total project benefits prior to loan and expense payments. Table 8 provides the results of an annual proforma evaluation for this scenario as well.

Table 7. Summary Proforma Inputs and Outputs; PWS with Onsite (Retail) Energy

Project Start-up Year		2014
Peak Capacity (kW)		64
Estimated Annual Energy Production (kWh)		415,000
Initial Avoided Cost of Energy ($/kWh)	$	0.14
Assumed Annual Power Rate Escalator (%)		2.5%
Initial REC Value ($/kWh)	$	0.03
REC Escalator (%)		0%
Operations Cost ($)		$5,000
Cost Escalator (%)		3.5%
Initial Capital Investment ($)	$	550,400
Total Finance ($)	$	550,400
Assumed Finance Rate (%)		1.5%
Financing Term (yr)		10
Average Annual Project Benefit Over Finance Period ($)	$	12,500
Simple Payback Period (yr)		43
Internal Rate of Return Over Investment Period (%)		5%

A second proforma was developed which includes all of the input values shown in Table 7 as well as additional grant funding similar to what is available through the Massachusetts Clean Energy Center (Mass CEC). The grant amount was chosen as the lesser of 50% of the total project cost or $1/kWh/yr which resulted in a grant of approximately $275,000. With a grant of about $275,000 incorporated into the project finances, the average annual project benefit over the project finance period (10 yr) is $42,400, the simple payback period is reduced to seven years and the internal rate of return is about 20%. The summary proforma for this scenario is shown in Table 9.

Table 8. Summary Proforma PWS with Onsite (Retail) Energy

Proforma										
Annual Income										
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Year	1	2	3	4	5	6	7	8	9	10
Avoided Cost of Energy	$0.140	$0.144	$0.147	$0.151	$0.155	$0.158	$0.162	$0.166	$0.171	$0.175
Power Sales Income	$58,100	$59,553	$61,041	$62,567	$64,132	$65,735	$67,378	$69,063	$70,789	$72,559
REC Value	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03
REC Income	$12,450	$12,450	$12,450	$12,450	$12,450	$12,450	$12,450	$12,450	$12,450	$12,450
Estimated Annual Income	$70,550	$72,003	$73,491	$75,017	$76,582	$78,185	$79,828	$81,513	$83,239	$85,009
Annual Expenses										
O&M	$ 5,000	$5,175	$5,356	$5,544	$5,738	$5,938	$6,146	$6,361	$6,584	$6,814
Estimated Total Expenses	$5,000	$5,175	$5,356	$5,544	$5,738	$5,938	$6,146	$6,361	$6,584	$6,814
Financing										
Income Before Loan and Interest Payment	$65,550	$66,828	$68,135	$69,474	$70,844	$72,246	$73,682	$75,151	$76,655	$78,194
Uniform Monthly BTFP LOC Payment	($59,682)	($59,682)	($59,682)	($59,682)	($59,682)	($59,682)	($59,682)	($59,682)	($59,682)	($59,682)
Annual Benefit	$5,868	$7,145	$8,453	$9,792	$11,162	$12,564	$14,000	$15,469	$16,973	$18,512

Table 9. Summary Proforma PWS with Onsite (Retail) Energy – Additional CEC Grant

Proforma										
Annual Income										
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Year	1	2	3	4	5	6	7	8	9	10
Avoided Cost of Energy	$0.140	$0.144	$0.147	$0.151	$0.155	$0.158	$0.162	$0.166	$0.171	$0.175
Power Sales Income	$58,100	$59,553	$61,041	$62,567	$64,132	$65,735	$67,378	$69,063	$70,789	$72,559
REC Value	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03
REC Income	$12,450	$12,450	$12,450	$12,450	$12,450	$12,450	$12,450	$12,450	$12,450	$12,450
Estimated Annual Income	$70,550	$72,003	$73,491	$75,017	$76,582	$78,185	$79,828	$81,513	$83,239	$85,009
Annual Expenses										
O&M	$ 5,000	$5,175	$5,356	$5,544	$5,738	$5,938	$6,146	$6,361	$6,584	$6,814
Estimated Total Expenses	$5,000	$5,175	$5,356	$5,544	$5,738	$5,938	$6,146	$6,361	$6,584	$6,814
Financing										
Income Before Loan and Interest Payment	$65,550	$66,828	$68,135	$69,474	$70,844	$72,246	$73,682	$75,151	$76,655	$78,194
Uniform Monthly BTFP LOC Payment	($30,015)	($30,015)	($30,015)	($30,015)	($30,015)	($30,015)	($30,015)	($30,015)	($30,015)	($30,015)
Annual Benefit	$35,535	$36,813	$38,121	$39,459	$40,829	$42,232	$43,667	$45,137	$46,641	$48,180

5 STATE WIDE MARKET ANALYSIS

5.1 Methodology

A statewide market analysis was completed to estimate the in-conduit energy potential within the Commonwealth. The market analysis evaluated PWS and POTW sites separately because the site conditions and resources available can vary significantly. The baseline case studies developed in Section 3.1 and Section 3.2 were utilized as guidance when evaluating a site's potential. Initially, a survey questionnaire was developed and sent to PWS and POTW sites in an effort to gain pertinent site information; however, minimal responses were received. Subsequent efforts focused on utilizing publically available information to identify sites which may have hydropower potential. Information regarding a particular project's flow rate and available head are difficult to estimate because the system is not based purely on hydrologic cycles and natural topography. Rather, in-depth knowledge of the design of a particular system is required for evaluation. As this information was not available, best estimates were made utilizing the information that was available.

To estimate the hydropower potential at PWSs throughout the Commonwealth, a list of all towns in the Commonwealth and their population numbers was developed based on State census data. Towns located within Bristol or Plymouth Counties were eliminated from consideration because the topography of the land has minimal elevation variations indicating that it is unlikely any suitable amount of excess head is available for generation. All cities and towns located within the MWRA water supply distribution system were eliminated from consideration as their potential resources are incorporated into the MWRA system. Finally, all cities and towns with a population less than 5,000 people were not considered because it is most likely that insufficient water resources are available for generation. Once these considerations were applied to the data set, an investigation into the type of PWS system was completed as not all systems are suitable for hydropower generation. In general, PWS systems in the Commonwealth include reservoir systems that utilize surface water for treatment and storage and well systems that extract groundwater for treatment. In many cases, the water supply system consists of a mixed supply system, meaning that a percentage of the system or portion of the population are supplied through wells while the remainder are supplied through surface water systems. In general, it was assumed that groundwater systems do not have excess head available for generation and were not considered for in-conduit hydropower development as they are typically pumped. Reservoir systems were assumed to have some potential for excess head and were considered for generation potential.

The type of system utilized for each town was determined based on the information described within the annual water quality reports issued for each public water system as required by the

Environmental Protection Agency (EPA). The brief description of the PWS in these reports details the source of each community's water. For those cities and towns which have both groundwater and surface water sources, it was assumed that half of the supply was obtained from each for the purposes of estimating available flow.

Once each city or town's water supply system had been classified and its population known, a factor of water use per population could be applied to those communities with systems appearing suitable for hydropower. Based on the Mass DEP's guideline #88-10, which details the uniform calculation for converting residential water use to persons served for daily water supply consumption, it was assumed that demand at a PWS is 100 gallons/day/person for the community's population. This value was applied to the city or town's population to estimate the average daily flow rate available for generation. Based on the Phase I case studies, the range of head was 52 ft to 384 ft of head with an average of 163 ft. It is unlikely that many or all facilities have several hundred feet of head; therefore, the range utilized for market estimates was 52 to 163 ft.

Similar to the PWS systems, limited data was available for the POTW systems and a similar approach was taken to estimating the power and energy potential. Analysis commenced with a list of all cities and towns in the Commonwealth that was sorted to eliminate all communities with less than 5,000 residents, towns in Bristol and Plymouth counties, and communities that utilize the MWRA system. For those cities and towns which remained, an investigation to understand the type of treatment facility and discharge rates was completed. In general, wastewater systems consist of a centralized treatment facility with a dedicated outfall system and septic systems. Research on the type of facility was completed utilizing publically available town and city documents and in some cases a call to the town to clarify the system type. In general, only facilities with an outfall are suitable for hydropower generation as there is a change in elevation between the treatment facility and the receiving water. Therefore, communities with septic systems were not further considered for hydropower potential. For facilities with an outfall and discharge, a NPDES permit would be required and information on average discharge rates were available. The average flow rate provided on the NPDES permit was utilized as the project flow rate in estimates of POTW potential. Similar to PWS facilities, head information for POTW facilities was not available and is specific to each facility. In general minimal or no excess head is available at POTW facilities and often pumping is used for system operations. Therefore, the treatment facility will be constructed at an elevation close to the discharge water body. Based on professional judgment, it was assumed that the head available at a particular POTW facility was on the order of 2 to 10 ft.

5.2 Findings

Based on the 61 sites identified, it is estimated that between 4,300,000 kWh and 39,500,000 kWh of energy per year can be generated through the installation of in-conduit turbines within existing PWS systems in the Commonwealth. It should be understood that these estimates represent a range of values associated with the range of estimated head values. In addition, the power values presented in Table 10 represent the average of the higher head and lower head estimates. For the higher head assumption, power estimates range from 20 kW to 750 kW whereas they ranged from 2 kW to 82 kW for the lower head assumption.

Table 10. Range of Estimated Power and Energy Potential at PWS Systems

	Surface Water		Mixed (Surface & Ground)		Total	
Evaluation Assumption	Power Range (kW)	Estimated Total Annual Energy (kWh)	Power Range (kW)	Estimated Total Annual Energy (kWh)	Power Range (kW)	Estimated Total Annual Energy (kWh)
High Head (163 ft)	20-750	30,000,000	95-230	9,500,000	--	39,500,000
Low Head (52 ft)	2-82	3,300,000	10-24	1,000,000	--	4,300,000

Based on the 70 sites identified, it is estimated that between 600,000 kWh and 3,000,000 kWh of energy per year can be generated through the installation of turbines within existing POTW systems. The estimates represent a range of values associated with the range of estimated head values. For the higher head assumption, power estimates range from less than 1 kW to 55 kW whereas they ranged from less than 1 kW to 11 kW for the lower head assumption. Table 11 summarizes the findings associated with the estimated POTW hydropower potential.

Table 11. Range of Estimated Power and Energy Potenital at POTW System

	Power Range (kW)	Estimated Total Annual Energy (kWh)
High Head Estimate (10 ft)	<1 - 55	3,000,000
Low Head Estimate (2 ft)	<1 - 11	600,000

6 DISCUSSION

The objective of this Phase II evaluation was to develop some baseline information which will assist a PWS or POTW facility gain basic knowledge of in-conduit hydropower projects. Four typical installation scenarios, two each for PWS and POTW facilities have been developed to provide project managers a starting place for identification of available resources. As mentioned, it is important not to limit an evaluation to the scenarios presented as each site is unique. Rather, these scenarios provide a project owner a starting place to complete initial level evaluations.

The financial evaluation is similar in nature to the four scenarios in that it is intended to provide conceptual level guidance. In this case, the information illustrates the relationship between the various variables involved in determining financial viability. Formulas have been included such that a PWS or POTW manager can re-calculate values more specific to their facility. Table 3 through Table 6 show the importance of the value of energy. Furthermore, they show that a project's financial viability is significantly higher when energy is used on-site as it is worth almost twice as much as when sold to the grid. Specific line items for financial incentives have not been included because the initial installed costs ($/kW) guidelines developed in Phase I included the various incentives. A variety of incentives at both the State and Federal level are available for the development of renewable energy. In addition, there may be some incentives at the local level. There is potential to enter into a power purchase agreement (PPA) with a third party to purchase the energy generated at a negotiated rate. This allows for a wide range of potential energy value. Additional calculations have been completed to estimate the value of energy which would be required to meet particular simple payback periods as well. For each of the financial cases evaluated, environmental life cycle estimates have been made via quantification of emission reduction. Over a thirty year period, it is estimated that millions of pounds of greenhouse gas emissions can be offset.

A state-wide market analysis has been completed to gain a better understanding of the development potential available in the Commonwealth. Ranges in estimated energy were provided for PWS and POTW facilities due to uncertainty and availability of data. It is estimated that about 4,000,000 kWh to 40,000,000 kWh of energy can be generated annually from WPS facilities and 600,000 kWh to 3,000,000 kWh can be generated from POTW facilities. Based on these estimates, more generation potential is available in WPS facilities which is primarily due to the higher head available as compared to POTW facilities. These estimates assume that all PWS systems with surface water have available head and that all POTW facilities with an outfall have available head. Based on these assumptions these estimates may be high. Although these conceptual estimates have been completed, many assumptions were made in developing them. To better understand and reduce the uncertainty of municipal in-conduit hydropower potential in

Massachusetts, Alden recommends a more detailed study that includes a thorough data gathering and site investigation phase.

The development of municipal in-conduit hydropower provides a wide spread benefit in that once in operation, it reduces the operational costs of the publically owned PWS or POTW facility and therefore the cost to the community. Where applicable, PWS and POTW facilities are encouraged to use this document as well as the Phase III screening tool to complete preliminary evaluations and understand if there is generation potential at their facilities.