Evaluation of Hydroelectric Potential
New York City Department of Environmental Protection

Final Report

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In Association with HANDS-ON! Hydro and O'Brien & Gere

November 2013

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LIST OF ACRONYMS

BAI	Brubaker Associates, Inc.
B/C	benefit/cost ratio
CAT/DEL UV Facility	Catskill Delaware Aqueduct Ultraviolet Light Disinfection Facility
cfs	cubic feet per second
City	New York City
CO_2e	carbon dioxide equivalents
DEP	New York City Department of Environmental Protection
EAML	EAML Engineering Company
ED	energy dissipation
eGrid2012	USEPA's eGrid2012 Version 1.0
FERC	Federal Energy Regulatory Commission
Gomez and Sullivan	Gomez and Sullivan Engineers, P.C.
INL	Idaho National Laboratory
kW	kilowatt
kWh	kilowatt-hour
MGD	million gallons per day
MW	megawatts
MWh	megawatt-hour
MWH	Montgomery Watson Harza
NA	not applicable
NO_x	oxides of nitrogen
NPV	net present value
NYC	New York City
NYS	New York State
O&M	operation & maintenance
OPCC	opinion of probable construction costs
PAT	pump-as-turbine
Plan	PlaNYC
PlaNYC Inventory 2012	PlaNYC Inventory of New York City Greenhouse Gas Emissions
PRV	pressure regulating valve
SO_2	sulfur dioxide
System	NYC Water and Wastewater System
USEPA	United States Environmental Protection Agency
VLH	Very Low Head (turbine)
WWTP	wastewater treatment plant

LIST OF CONVERSIONS

1 meter = 3.281 feet
1 foot = 0.3048 meters
1 MGD = 1.55 cfs
1 cfs = 0.646 MGD
1 MW = 1,000 kW

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1.0 INTRODUCTION

The City of New York ("City") is serviced by a vast water supply and wastewater system ("System"). The New York City Department of Environmental Protection ("DEP") manages the City's water supply, providing more than one billion gallons of water each day to more than nine million residents, including eight million within the City. The water is delivered from a watershed that extends more than 125 miles from the City, comprising 19 reservoirs and three controlled lakes. Approximately 7,000 miles of water mains, tunnels and aqueducts bring water to homes and businesses throughout the five boroughs, and 7,500 miles of sewer lines and 96 pump stations take wastewater to 14 treatment plants within the City. **Figures 1-1** and **1-2** provide maps of the City's water supply and wastewater systems, respectively.

In 2007, Mayor Bloomberg released "PlaNYC," a sustainability plan ("Plan") for a growing, livable city. One of the Plan's key points of focus is to combat climate change. To demonstrate leadership, the Plan established a goal for 30% reduction (from fiscal year 2006) of greenhouse gas (GHG) emissions from City government operations by 2017. This goal was later codified by the City Council in Local Law 22 (2008) – Climate Protection Act. To facilitate achievement of this goal, given the size of the City's water and wastewater system, the City Council added section 24-366, "Assessment of Electric Generation Viability," to the administrative code, requiring the DEP to evaluate the System for opportunities to produce emissions-free energy. The DEP already owns two hydroelectric facilities located in aqueducts that convey water from one reservoir to another. These two facilities have a total station capacity of 43 megawatts ("MW") and generate approximately 161,000 megawatt-hours (MWh) per year, or enough to power approximately 21,000 New York State ("NYS") homes per year. In addition, there are two other hydroelectric facilities on the water system; one is owned by the New York Power Authority and the other is privately held.

The purpose of this report is to identify additional sites in the water and wastewater system with the greatest hydroelectric potential, employing both traditional hydropower and innovative technologies such as in-conduit turbines and channel and weir hydrokinetic technologies. The overall scope of the study included the following phases:

- **Resource Assessment** – Identified 36 potential hydroelectric sites within the System, screened and ranked the sites based on criteria related to constructability, electrical demand, operability, and economic factors, and then selected 10 representative sites for further review

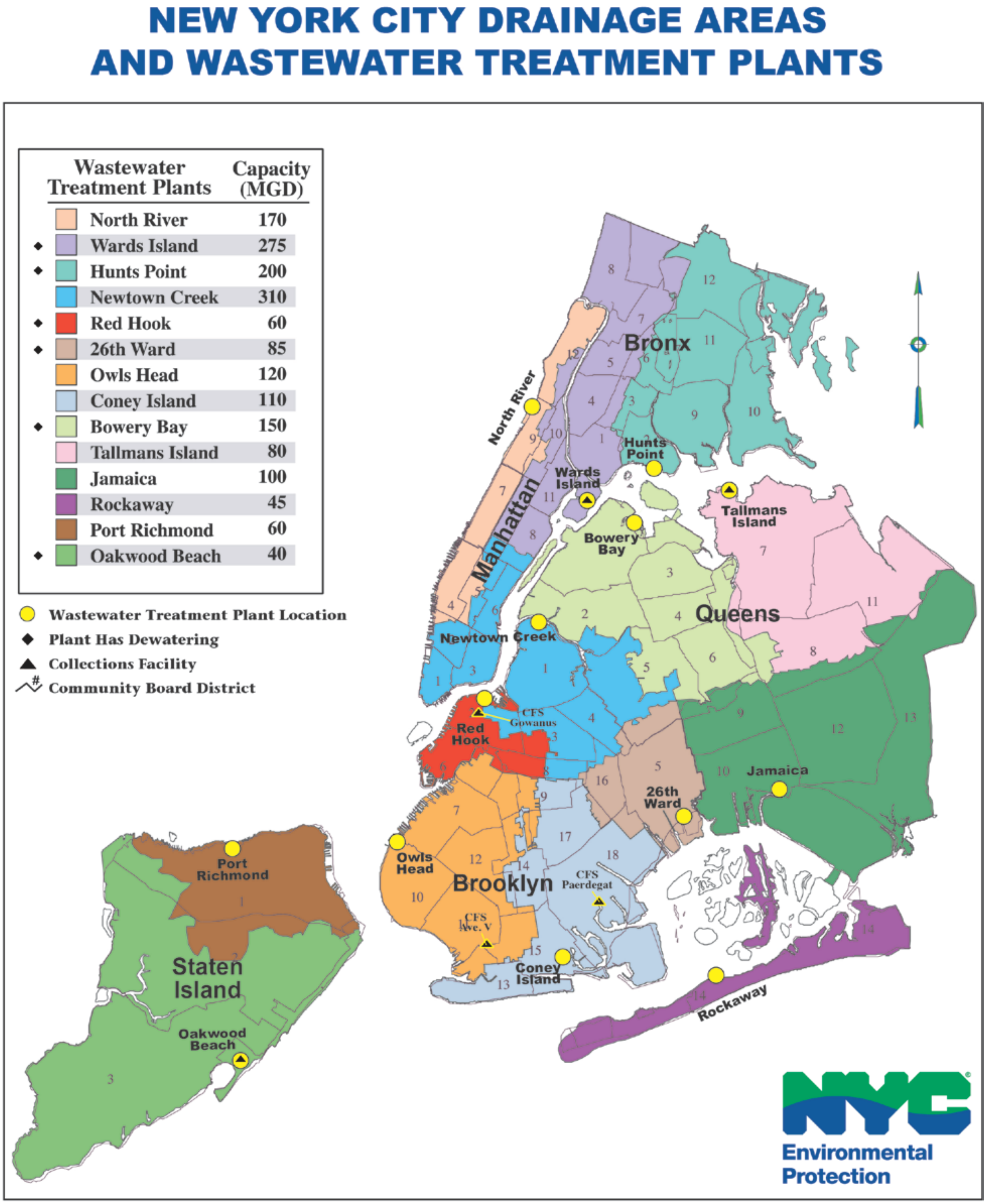
- **Technology Review Part A** – Reviewed the state of hydraulic turbine technology available

- **Technology Review Part B** – Summarized site visits to and selected the most appropriate turbine technology for the 10 selected representative sites, then ranked sites and advanced the top six

- **Economic Analysis** – Developed conceptual plans, opinions of probable construction costs ("OPCCs"), and several economic metrics for the top six sites

- **Environmental Benefits Analysis** – Determined GHG emissions avoided and pollutant reductions for the top six sites

Figure 1-1: Water Supply System Map
Source: DEP (2013)


NEW YORK CITY DRAINAGE AREAS AND WASTEWATER TREATMENT PLANTS

		Wastewater Treatment Plants	Capacity (MGD)
	■	North River	170
◆	■	Wards Island	275
◆	■	Hunts Point	200
	■	Newtown Creek	310
◆	■	Red Hook	60
◆	■	26th Ward	85
	■	Owls Head	120
	■	Coney Island	110
◆	■	Bowery Bay	150
	■	Tallmans Island	80
	■	Jamaica	100
	■	Rockaway	45
	■	Port Richmond	60
◆	■	Oakwood Beach	40

● Wastewater Treatment Plant Location
◆ Plant Has Dewatering
▲ Collections Facility
Community Board District

Figure 1-2: Wastewater Treatment Plant Map & Capacities
Source: DEP (2013)

2.0 RESOURCE ASSESSMENT

The purpose of this portion of the study was to identify sites in the System with the greatest hydroelectric potential, screen and rank the sites based on certain criteria, then select representative sites for further review. The full Resource Assessment report in **Appendix A** provides more detail; a summary is provided below.

System plans, reports, studies, and other data were collected and reviewed and key operational personnel were interviewed. Discussions were held with DEP staff, including West of Hudson, East of Hudson, Catskill Delaware Aqueduct Ultraviolet Light Disinfection Facility ("CAT/DEL UV Facility"), and City water and wastewater staff. The operations of each facility were explained, which aided in determining the location of potential hydroelectric equipment. The discussions also helped to identify any operating practices which might suggest that excess energy would be present in the water as it passed through the facilities and structures.

System maps contained in the construction contract documents were reviewed to gain an understanding of how the various facilities might interact. Facility drawings were reviewed to determine whether the physical features of the facilities and the water control features within them were conducive to known turbine styles and types identified in Part A of the Technology Review (**Section 3**), which was conducted concurrently with this Resource Assessment. In particular, it was determined whether sufficient existing physical space for turbines and generators was available in close proximity to water control features. Sites were evaluated regarding whether excess energy was likely to be present due to the design of the facilities. Qualitative judgments were made about whether installation of generating equipment would be relatively easily constructed or would require significant civil or structural modifications, which have historically been cost and schedule drivers in hydro plant construction. Qualitative assessments were made regarding whether generating equipment would be relatively expensive or inexpensive as compared to installed capacity and potential generation.

When physical features were identified to be conducive to known turbine styles and types, and excess energy was apparent in the water as it passed through the facilities, the likely capacity of generating equipment needed to capture all of the excess energy in the water was estimated using traditional equipment sizing rules of thumb and engineering judgment. Potential generation was also estimated, assuming the equipment was used to generate year-round at annual average flows and expected heads at those flows.

The City's water distribution system was also analyzed for hydropower potential. However, due to various reasons hydropower development within the water distribution system was not found to be feasible in this study. An overview of the major water distribution sites considered and their reasons for elimination are listed below (see Appendix A for more details):

- Hillview Reservoir is the primary balancing reservoir that provides the pressure head throughout the five boroughs of the City. It is not recommended to implement hydropower at Hillview Reservoir or on its main transmission system as it would have a major impact on the reliable delivery of water to higher elevations in the system and cause additional energy to be consumed in areas where pumps are needed to meet the requirement of the NYS Sanitary Code, which requires water be supplied to the curb at a minimum of 20 pounds per square inch ("psi") under all flow conditions.

- An analysis of eight representative, 20-inch-diameter, pressure regulating valves ("PRVs") indicated that potential power generation from the energy dissipated by each PRV ranges from 15 to 70 kW, with annual generation ranges from 135 to 600 MWh per year. However, due to space constraints in the PRV chambers and other issues including grid interconnection, worker safety, and continuous water service during power failure, it was determined that hydropower development at the PRV sites is not feasible.

- The construction of the Croton Water Filtration Plant was under construction during the time of this study. Hydropower was not considered under this study at this plant for the following reasons: a) the plant receives water from the Jerome Park Reservoir at a much lower pressure head than Hillview Reservoir; b) the plant requires significant pumping to elevate water to allow the water to travel through the treatment process; and, c) the water at the effluent of the plant can only be delivered to the lowest elevation of Manhattan and the Bronx without pumping.

An aggregate of 36 sites across the water and wastewater system were selected as having the highest hydroelectric potential. An initial screening analysis of the 36 sites was conducted to eliminate sites with fatal flaws. Based on the review of the facility operations and the above noted information, 10 sites were eliminated due to lack of hydroelectric opportunity or poor economics.

The remaining 26 sites were further evaluated using a risks and values matrix. The matrix was developed based on certain selection criteria and a point rating system. The selection criteria included:

- Constructability
- Behind-the-Meter Energy Needs
- Interconnection Issues
- Operability
- Environmental Health and Safety
- Other Systems Risks / Public Safety
- Economic Factors
- Generation

The sites were then assigned numerical values representing the relative amount of risk and value for each selection criteria being considered. The higher the number (5 being the highest), the greater the value; the lower the number (1 being the lowest), the greater the risk. The numerical values were summed to obtain a total value / risk number. The analysis did not indicate any sites with exceptional value.

Figure 2-1 presents a graph of the risks and values matrix and a list of the 26 sites. The graph indicates the amount of value and risk for each site. Ten representative sites were then selected by considering several factors, including a relatively high value / risk number, representativeness for a given type of site, and the various types of technology available.

The ten selected sites all fall within the middle block of **Figure 2-1**, which indicates medium risk and medium value. Of the ten selected sites, rankings No. 1 through 6 follow the order of total points, No. 6 is the Coney Island Wastewater Treatment Plant (“WWTP”), and Nos. 7, 8, 9, and 10 were included to provide a range of different types of sites. The total points for rankings No. 7, 8, 9, and 10 were close to the top, but were not necessarily in the order of the total points.

The following twelve representative sites, presented in order of decreasing priority, were recommended for more detailed analysis in Part B of the Technology Review (**Section 4**):

1. West Branch Reservoir Shaft #10 (outflow)
2. Catskill Delaware Aqueduct Interconnection at Shaft #4
3. CAT/DEL UV Facility
4. New Croton Dam
5. Kensico Reservoir Shaft #17 (inflow)
6. Coney Island WWTP
7. New Croton Lake Gatehouse
8. Rondout Effluent Chamber Releases
9. North River WWTP[1]
10. Ashokan Lower Gate Chamber Releases
11. Ashokan Release Channel
12. Newtown Creek WWTP[2]

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[1] North River WWTP was on the initial screening list, but was not included in the list of 10 representative sites. However, it was later added prior to the site visits based on discussions with DEP Bureau of Wastewater Treatment Staff.

[2] Newtown Creek WWTP was not on the initial screening list, but was similarly added prior to the site visits based on discussions with DEP Bureau of Wastewater Treatment Staff.

Figure 2-1: Risks and Values Matrix

Site Key

GROUP A
9 – Delaware Aqueduct Kensico Reservoir Shaft #18 (outflow)
21 – Croton - East Branch (Sodom Dam)
23 – Croton - Diverting

GROUP B
24 – Croton - Croton Falls
25 – Croton - Titicus
35 – Wastewater Plant - Oakwood Beach, Staten Island
36 – Wastewater Plant - 26th Ward

GROUP C
10 – Delaware - Cannonsville W. Delaware Intake Chamber
20 – Catskill Influent Chamber – Kensico

GROUP D
2 – Rondout Effluent Chamber Releases
33 – Wastewater Plant - Owls Head
34 – Wastewater Plant - North River

GROUP E
31 – Wastewater Plant - Wards Island
32 – Wastewater Plant -Coney Island

GROUP F
13 – CAT/DEL UV Facility
29 – Croton - New Croton Dam

INDIVIDUAL SITES
5 – Delaware – Catskill Aqueduct Interconnection at Shaft #4
7 – Delaware Aqueduct - West Branch Reservoir Shaft #10 (outflow)
8 – Delaware Aqueduct - Kensico Reservoir Shaft #17 (inflow)
11 – Delaware - Pepacton E. Delaware Intake Chamber
12 – Delaware - Neversink Intake Chamber - Tunnel Diversion
14 – Catskill - Shandaken Tunnel Outlet
15 – Catskill - Ashokan Lower Gate Chamber Releases
18 – Catskill - Ashokan Release Channel
19 – Catskill - Aqueduct
30 – Croton - New Croton Lake Gatehouse

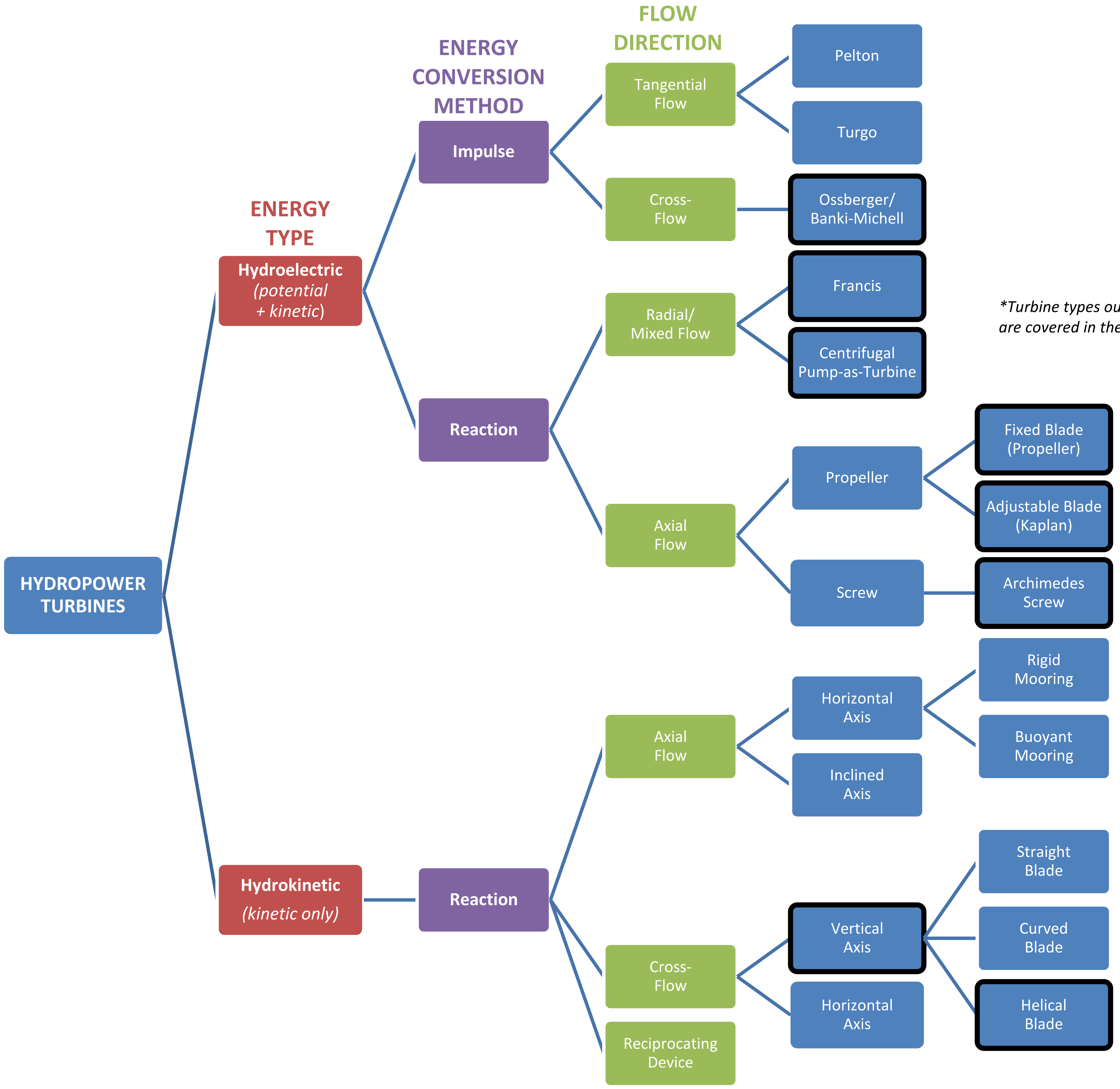
3.0 TECHNOLOGY REVIEW PART A

The purpose of this portion of the study was to conduct a literature search to collect data on state-of-technology hydroelectric equipment. The Technology Review report in **Appendix B** provides a general overview of hydraulic turbine types, profiles and case studies for selected turbine types that may be relevant to the City's System, and a comparative technology table illustrating the applicability of each technology and turbine type, the benefits and disadvantages of each, and qualitative and quantitative assessments based on selected criteria.

Overview of Turbine Types

A turbine unit consists of a runner connected to a shaft that converts the potential and/or kinetic energy in moving water into mechanical or shaft power. Hydraulic turbines may be classified according to several factors, including type of energy utilized (i.e., conventional hydroelectric or hydrokinetic), energy conversion method (e.g., impulse, reaction), direction of flow through the blades (e.g., radial, axial, cross, tangential), orientation of the shaft axis (vertical or horizontal), suitable range of head and flow (e.g., high, medium, low, very low), and/or their typical applications (e.g., at dams, between reservoirs, in conduits, or instream). Selection of the most appropriate type of turbine for a given site can be guided by charts comparing operating ranges or efficiency curves of different turbines.

A graphical overview of major turbine types is shown in **Figure 3-1**.



Turbine types outlined in a* ***black border* *are covered in the profiles in* ***Appendix B****.*

Figure 3-1: Overview of General Turbine Types

For a design flow and/or head, there may be several types of turbines capable of operating within the site requirements, although they will likely differ in efficiency or range. **Figure 3-2** below shows the recommended range of head and flow for several major types of turbines. Each turbine has certain advantages and disadvantages which may dictate selection. The design flow for smaller systems may also be dictated by standard turbine sizes.

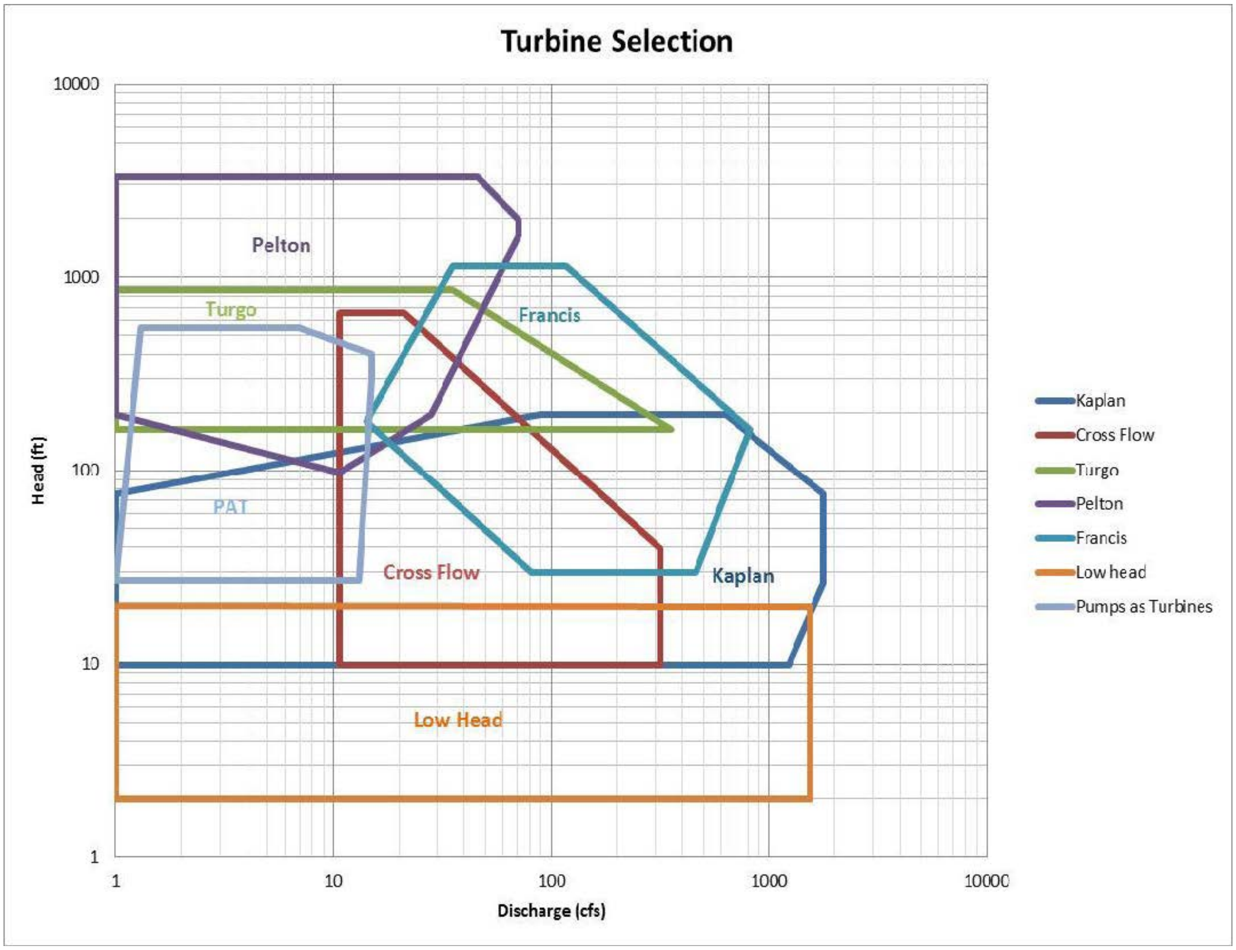


Figure 3-2: Turbine Selection Chart
Source: Colorado Small Hydropower Handbook (Colorado Energy Office, 2013)

Profiles of Selected Relevant Turbine Technologies

The general turbine types were reviewed and a selection of technologies that may be relevant to the City's System were chosen for further profiling of specific characteristics, manufacturers/models, and case studies. Profiles and case studies for the following turbine types are provided in **Appendix B**:

- **Cross-Flow** Turbines
- Natel Energy's **hydroEngine** – Fully Flooded, Two-Stage Impulse Turbine
- **Francis** Turbines
- **Pumps-as-Turbines** ("PATs")
- **Kaplan** Turbines
- EAML's Adjustable Blade Propeller **Submersible Hydroturbine-Generator**
- Mavel's **Microturbines** – Propeller-Type Siphon Turbines

- CleanPower's **Turbinator** –Tube-Type Propeller Turbine-Generator
- Andritz's **HYDROMATRIX** & **StrafloMatrix** – Propeller Turbine-Generator Arrays
- AMJET Turbine Systems' **ATS-63** Turbine – Rim-Type Propeller Turbine-Generator
- **Advanced Energy Conversion's Turbine** – Propeller Turbine-Generator
- **Archimedes Screw** Turbines
- Lucid Energy's **LucidPipe** – Hydrokinetic In-Conduit Gorlov Helical Turbine
- Hydrovolts' **Waterfall** Turbine – Hydrokinetic Cross-Flow Outfall Turbine

Appendix B also contains a table summarizing the following characteristics for each profiled turbine technology:

- Turbine Type
- Model/Manufacturer(s)
- Application
- Maturity of Technology
- Typical Range (head & flow)
- Generation Capacity
- Efficiency
- Equipment Dimensions
- Heat Rejection Rate
- Operational Complexity
- Maintenance Requirements & History
- Market Penetration (including geographic distribution)
- Cost per Kilowatt of Installed Capacity
- Other Pertinent Technological Information
- Benefits & Disadvantages

4.0 TECHNOLOGY REVIEW PART B

The purpose of this portion of the study was to select the most appropriate technology for the 12 sites with the highest hydroelectric potential identified during the Resource Assessment (**Section 2**). Twelve sites were visited between July 29-31, 2013 by Gomez and Sullivan and HANDS-ON! Hydro to gain a better understanding of facility operations via discussions with DEP staff, verify and collect site-specific data, and obtain photo documentation. O'Brien & Gere Engineers accompanied the Team for the WWTP site visits. The full Technology Review Part B report in **Appendix C** provides more detail; a summary is provided below.

At the start of this phase of the engineering evaluation, no turbine technology was eliminated from consideration or given an advantage due to factors such as cost, market penetration, or longevity. Proposed hydroelectric equipment was selected based purely on applicability and technical merit. However, characteristics of the sites that were chosen for further investigation during the Resource Assessment did eliminate some turbine technologies due to applicability. For example, none of the final hydro proposals favored the application of hydrokinetic turbines.

Turbine types which appeared to be technically applicable to the selected sites included Hydrovolts' Waterfall and Canal turbines, Mavel's modular siphon Microturbine, Andritz' StrafloMatrix turbine, various PATs, MJ2's Very Low Head ("VLH") turbine, compact Francis turbines, Archimedes Screw turbines, and LucidEnergy's LucidPipe hydrokinetic turbine. Most of these turbine types were discussed in more detail in Part A of the Technology Review (**Section 3**).

The following section provides the selected turbine technology type and size for each site, the potential energy generation for each selected hydropower proposal, and a discussion of other technologies that were considered.

Site Descriptions and Hydropower Proposals

Ashokan Lower Gate Chamber Releases

Turbine technologies considered for this site included LucidPipe and compact Francis turbines due to the combination of head and flow characteristics. Both technologies are suitable to act as energy dissipaters in closed pipes under pressure. Since the existing piping is embedded in concrete and forms a right angle within the relatively small turbine vault, there did not appear to be a practical means to employ the LucidPipe technology. The original Ashokan facility design was based on Francis turbines as the means to provide power for the house, thus the piping layout and embedded structures are easily adaptable to modern compact Francis turbines.

Therefore, the hydro proposal for this site is to replace both abandoned turbines with modern vertical-shaft Francis turbines, in-line speed increasers, and induction generators. Community[3] flow is 10 million gallons per day ("MGD"), or 15.5 cubic feet per second ("cfs"), from approximately October 1 to May 1 and 15 MGD (23.3 cfs) the remaining months of the year. Gross head across the facility is approximately 90 feet. Each turbine/generator unit would be approximately 180 kilowatts ("kW") so that its best efficiency flow would be at 15 MGD. Estimated generation would be approximately 1,100 MWh per year.

Ashokan Release Channel

Turbine technologies considered for this site included the VLH turbine, Hydrovolts' Canal turbine, and an Archimedes screw turbine. Other technologies are less adaptable to open channel flow or to ultra-low

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[3] Community flow is a term used by the plant operators, which refers to the minimum flow requirements.

head. The VLH turbine was eliminated since its minimum capacity is far above the community flows released through the Release Channel. The Canal turbine was rejected due to its very low comparative operating efficiency. The Archimedes screw turbine was selected since it offers a relatively consistent operating efficiency at both small and large flows and because it is suitable for deployment at very low heads.

Therefore, the hydro proposal for this site is to install an Archimedes screw turbine in the section of the Release Channel downstream of the bridge. Using the 10 MGD winter and 15 MGD summer community flows and a 12-foot head at the end of the Release Channel, an Archimedes screw turbine, could be installed. The installed capacity would vary between 12 kW and 18 kW. Corresponding annual generation would be 125 MWh.

Rondout Effluent Chamber Releases

Turbine technologies considered for this site included compact Francis turbines, LucidPipe turbines, and PATs. The LucidPipe technology was eliminated due to space constraints and due to the likelihood that the flow would need to be turned through 90 degrees. PATs were eliminated due to their lower operating efficiency compared to Francis turbines. In this situation, the 90-degree flow turn and head/flow conditions favor a compact Francis turbine.

Therefore, the hydro proposal for this site is to add a horizontal Francis turbine, speed increaser, induction generator, and control valve and discharge into the existing access to the blow-off tunnel. The community flow is 10 MGD (15.5 cfs) from October 1 to May 1 and 15 MGD (23.3 cfs) the remaining months of the year. The existing cone valve would continue to discharge through the existing community flow pipe opening through the valve chamber wall. The maximum gross head would be 139 feet. The installed capacity would be 275 kW so that the turbine can operate at its best efficiency at 15 MGD. Estimated annual generation would be approximately 1,700 MWh.

Catskill Delaware Aqueduct Interconnection at Shaft #4

Turbine technologies considered for this site included compact Francis turbines, PATs, and LucidPipe turbines, since all of these technologies are suitable for energy dissipation in pressurized conduits. The likely development flow path and available space seem to be able to accommodate the LucidPipe technology, but its operating efficiency is substantially lower than a Francis turbine. A PAT could also be adapted to this site, but again, its operating efficiency is lower than a Francis turbine. Due to the flow and head conditions and expected unit capacity, it is anticipated that the cost of a Francis turbine would be competitive and the relatively higher efficiency would offset the potential lower cost of the PAT.

There are currently four sets of valves which connect to Shaft #4. These valves will be modified to connect to four sleeve valves which will discharge from the pressurized Delaware Tunnel to a new stepped weir, which will discharge into the unpressured Catskill Aqueduct. The hydro proposal at this site is to install two sets of tees, isolation valves, and horizontal Francis turbines within the existing chamber, in piping which bypasses the two outboard new sleeve valves. Normal flow is expected to be 90 MGD (140 cfs) through the facility with 132 feet of head dissipated. Each turbine would be sized to pass 54 MGD (84 cfs), but best efficiency operation would be approximately 45 MGD (70 cfs). Each turbine/generator installed capacity would be 800 kW and annual generation would be approximately 11,600 MWh.

West Branch Reservoir Shaft #10

Turbine technologies considered for this site included PATs, submersible turbines within the piping, or VLH or StrafloMatrix turbines at the entrance. If the VLH or StrafloMatrix technology were employed at the inflow gates from the reservoir, they would likely have a very high cost per installed kilowatt due to the extremely low head available at the gate entrance. In addition, flow from the reservoir is not the common mode of facility operation, so annual production would be relatively low.

Therefore, the hydro proposal for this site is to install six PATs in the piping drops between the 48-inch gate valves and discharge nozzles. Each PAT would be sized to pass 100 MGD (155 cfs). Although there are 140 feet of available head, no PATs were identified with specifications meeting the available head. Therefore, a PAT from Sulzer Pumps that meets the flow rate with 65 feet of head is proposed. This reduces the originally proposed PAT installed capacity from 1.3 MW to 640 kW each. Annual generation would be reduced from 39,000 MWh to approximately 33,500 MWh.

As an alternative to the proposed PAT, EAML Engineering Company ("EAML"), a Japanese company, was also contacted for information on their submersible turbine, which they previously purchased from Flgyt Pump (a Swedish company). EAML is reviewing the request, but have not provided any size or cost information as of this date. Since EAML's product is considered a turbine and not a PAT, it would be a worthwhile alternative to pursue further.

New Croton Lake Gatehouse

Turbine technologies considered for this site included compact Francis turbines, PATs, and LucidPipe turbines since all of these technologies are suitable for energy dissipation in pressurized conduits. The likely development flow path and available space might be able to accommodate the LucidPipe technology, but its operating efficiency is substantially lower than a Francis turbine. A PAT could also be adapted to this site, but again, its operating efficiency is lower than a Francis turbine. Due to the flow and head conditions and expected unit capacity, it is anticipated that the cost of a Francis turbine would be competitive and the relatively higher efficiency would offset the potential lower cost of a PAT.

Therefore, the hydro proposal for this site is to install a single horizontal Francis turbine in the accessible chamber area, located in the basement floor of the Gatehouse, between the two bolted access flange connections. Normal flow is 130 MGD (201 cfs)[4] and normal head is 60 feet. The turbine would be selected for an installed capacity of 1.0 MW at 156 MGD (240 cfs) so that it would operate at its best efficiency at normal flow. Estimated generation would be approximately 7,600 MWh.

It should be noted the future flow through the New Croton Lake Gatehouse will be dependent on the operation of the Croton Filtration Plant which has not yet been determined. The above analysis will need to be revisited once the operation of the Croton Filtration Plant has been determined.

New Croton Dam

Montgomery Watson Harza ("MWH") completed a screening analysis of the hydroelectric potential at the New Croton Dam in a May 2011 study. Two alternatives were found to be feasible. One alternative proposed a 55-kW cross-flow minimum flow turbine within the lower valve chamber. The second alternative proposed a 2.1-MW horizontal Francis turbine and a 75-kW minimum flow turbine located in a new powerhouse adjacent to and downstream of the lower valve chamber.

An option that was not considered in the MWH study is to use the two discontinued pipelines located in the abandoned valve chamber located left (looking upstream) of the existing valve chamber. If it were possible to use this structure and piping, modification of the newly to-be-rehabilitated lower valve

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[4] Flow has not been directed through the New Croton Lake Gatehouse for distribution purposes since 2008 and future flows are dependent on how the Croton Filtration Plant will be operated in the future. At this time, such flow determinations have not been made.

chamber and gates could be avoided. The piping and chamber might be able to be modified to house one or two turbines capable of passing the 75 MGD (116 cfs) required instream flow and/or the 125-200 MGD (194-310 cfs) normally discharged to maintain reservoir level. If the turbine/generator were a cross-flow unit sized for 125 MGD (195 cfs) at 96 feet of head, its best efficiency range would also include 75 MGD (116 cfs) since cross-flow units have a broad best-efficiency curve. This turbine/generator could have a capacity of 1.25 MW with an annual generation of approximately 1,100 MWh based on 2 months of operation at 75 MGD. This abandoned valve chamber might also house the minimum flow horizontal Francis unit described in the MWH study. If so, it should produce more power than if sited in the active valve chamber since its discharge would be closer to the surface of the tailwater. Its estimated capacity in this location would be 66 kW and its estimated annual generation would be approximately 400 MWh based on 10 months of operation at 5.5 MGD (8.5 cfs). However, DEP has stated that the conduits in the abandoned valve chamber have been filled with concrete thereby complicating any efforts to install turbines in this location.

DEP noted recently that most of flow at New Croton Dam will be diverted to the new Croton water filtration plant when it comes online. Therefore, the most likely hydro proposal will be for the minimum (conservation) flow turbine.

Kensico Reservoir Shaft #17

Turbine technologies considered for this site included HydroMatrix, StrafloMatrix, Amjet, and VLH turbines. The HydroMatrix turbine may have compatible head/flow characteristics, but its upstream-to-downstream minimum dimension appears to be too large to allow economic modifications for this site. The VLH turbine appears to have compatible head/flow characteristics, but its minimum physical diameter is also too large to allow economic modifications for this site. The StrafloMatrix unit appears to have head/flow characteristics on the margin of the successful application envelope, so it would be a potential choice for the site. The Amjet turbine also would be a potential choice.

Therefore, the hydro proposal for this site is to add six StrafloMatrix or Amjet turbines in the upstream stop shutter openings of the sluice gates. The turbines would slide down the existing stop shutter slots. Typically, 1,200 to 1,500 MGD (1,850 to 2,320 cfs) move through the reservoir each day. Estimated turbine/generator capacity would be 80 kW per turbine when passing 200 MGD (310 cfs) at 4 feet of head. Estimated annual generation for all six turbine/generators would be approximately 4,300 MWh.

However, through discussions with both Andritz and Amjet, it was determined that neither company has a workable solution at this time. Andritz' StrafloMatrix turbine would fit into the stop shudder slots, but does not meet the low head requirements. Amjet does not have a small turbine that will fit into the existing stop shutter slots, but the company is planning to manufacture a smaller unit in the future. Andritz is a well-established company that has installed many turbines worldwide and Amjet is a small Iowa company that expects to have its first turbine operating in July 2014. It would be worthwhile to continue discussions with both companies to determine whether they would be willing to develop a turbine design to fit Shaft #17.

CAT/DEL UV Facility

Turbine technologies considered for this site included compact Francis turbines, PATs, and LucidPipe turbines since all of these technologies are suitable for energy dissipation in pressurized conduits. The likely development flow path and available space might be able to accommodate the LucidPipe technology, but its operating efficiency is substantially lower than a Francis turbine. A PAT could also be adapted to this site, but again, its operating efficiency is lower than a Francis turbine. Due to the flow and head conditions and expected unit capacity, it is anticipated that the cost of a Francis turbine would be competitive and the relatively higher efficiency would offset the potential lower cost of a PAT.

Therefore, the hydro proposal for this site is to install eight horizontal Francis turbines in parallel with a number of energy dissipation ("ED") valves. Each selected line would have two pipe tees installed—one upstream and one downstream of the ED valve. The branch of each tee would have isolation valves installed and a turbine between the isolation valves. It is expected that each set of isolation valves and turbine would be installed on the level above the ED valves. The turbines would be installed on every other pipe.

Design flow is approximately 125 MGD (194 cfs) per ED valve and normal head dissipated is 40 feet across each ED valve. The turbine would be selected for an installed capacity of 660 kW at 148 MGD (230 cfs) so that it would operate at its best efficiency at ED valve design flow. Estimated generation of eight turbines operating at today's average flow (1,000 MGD) would be approximately 39,000 MWh. It does not appear likely that a turbine would be installed to bypass every ED valve since design capacity appears to be well into the future and energy available for generation may well be utilized at a filtration plant before the UV facility reaches design capacity. It is anticipated that all generated power would be consumed within the facility so the value of the power would be the displaced energy and demand charges for this generation and dependable capacity.

Coney Island WWTP

Turbine technologies considered for this site included the Hydrovolts' Waterfall turbine, Mavel top-siphon propeller turbine, bottom-siphon PAT, and bottom-siphon submersible turbines across the final weir into the effluent channel. The Waterfall turbine and the bottom-siphon PAT would have lower operating efficiencies than either the top-siphon or bottom-siphon turbines, so these applications were eliminated. Since a bottom-siphon submersible turbine would contain more custom designed components than the modular off-the-shelf top-siphon propeller turbine, it is expected that the Mavel top-siphon propeller modular turbine would be more cost effective.

Therefore, the hydro proposal for this site is to install four Mavel top-siphon propeller turbines across the final weir into the effluent channel. The turbine and generator is located at the top of the unit. The siphon and draft tube extend over the weir into the channel at the base of the weir wall. The head drop at the final weir is about 9.4 feet from Idaho National Laboratory Study ("INL") for 100 MGD with a mean high tide. For 100 MGD (155 cfs), the total installed capacity of the combined siphon turbines is 89 kW. Annual generation is estimated to be approximately 780 MWh. It is anticipated that all generated power would be consumed within the facility so the value of the power would be the displaced energy and demand charges for this generation.

A second alternative placing a single turbine at the tunnel entrances was considered but eliminated. Further discussion is contained in **Appendix C**.

North River WWTP

Turbine technologies considered for this site included the Hydrovolts' Waterfall turbine, a Mavel top-siphon propeller turbine, a bottom-siphon PAT, and a bottom-siphon submersible turbine across the weir into the effluent channel. The Waterfall turbine and the bottom-siphon PAT would have lower operating efficiencies than either the top-siphon or bottom-siphon turbines, so these applications were eliminated. Since a bottom-siphon submersible turbine would contain more custom designed components than the modular off-the-shelf top-siphon propeller turbine, it is expected that the Mavel top-siphon propeller modular turbine would be more cost effective.

Therefore, the hydro proposal for this site is to install five Mavel top-siphon propeller turbines on the concrete deck that would siphon flow over the weir from the effluent channel into the hypochlorite tanks. The head drop is about 11 feet. Using 125 MGD (194 cfs) and 11 feet of head, the total installed capacity of eight siphon turbines would be approximately 153 kW. Estimated annual generation would be approximately 1,300 MWh. It is anticipated that all generated power would be consumed within the facility so the value of the power would be the displaced energy and demand charges for this generation.

A second alternative placing a single turbine at the tunnel entrance was considered but eliminated. Further discussion is contained in **Appendix C**.

Newtown Creek WWTP

A hydropower turbine does not appear feasible at this site due to the complexity of the effluent flow split between Whale Creek and the East River. As an example, if a StrafloMatrix turbine was placed in the stoplog slots downstream of the flow split in the East River outlet, a flow barrier would be required in the Whale Creek outlet to replicate the existing flow split. It may be complicated to try to manage the flow split properly between the two channels, and it would most likely be expensive due to the difficult access to the Whale Creek Channel. Due to additional costs for the barrier, the complexity of flow regulation between the two outlet channels, and low generation potential at this site, this site does not appear to be ideal to pursue further for hydroelectric equipment installation.

Summary and Recommendations

Table 1 in **Appendix C** presents the summary of the suitable technology selected for each site and the criteria to be considered in the ranking of the sites. The criteria include:

- Maturity of Technology
- Efficiency
- Implementation History in Water and Wastewater Systems
- Equipment Size
- Heat Rejection Rate
- Maintenance Requirements
- Potential Generation
- Permitting Requirements, and
- Other Pertinent Technological Information

The site rankings were primarily ranked based on energy generation; the greater the generation, the higher the ranking. Based on the information in Table 1 in **Appendix C**, the following is the site rankings from highest to lowest hydroelectric potential:

1. CAT/DEL UV Facility
2. West Branch Reservoir Shaft #10 (outflow)
3. Delaware Catskill Aqueduct Interconnection at Shaft #4
4. New Croton Lake Gatehouse
5. Kensico Reservoir Shaft # 17 (inflow)
6. Rondout Effluent Chamber Releases
7. North River WWTP
8. Ashokan Lower Gate Chamber Releases
9. Coney Island WWTP
10. Ashokan Release Channel
11. New Croton Dam

The following six sites were selected to advance to the economic analysis phase of the study. The first five sites are in order of generation. Coney Island was selected so a WWTP could be included in the economic analysis. Coney Island was selected over the North River WWTP because the site characteristics and generation are fairly similar for each, but the installation of turbines at Coney Island would be simpler to construct.

1. CAT/DEL UV Facility
2. West Branch Reservoir Shaft #10 (outflow)
3. Delaware Catskill Aqueduct Interconnection at Shaft #4
4. New Croton Lake Gatehouse
5. Kensico Reservoir Shaft # 17 (inflow)
6. Coney Island WWTP

5.0 ECONOMIC ANALYSIS

The purpose of this portion of the study was to prepare an economic analysis for the six sites identified to have the highest hydroelectric potential during Part B of the Technology Review (**Section 4**):

1. West Branch Reservoir Shaft #10
2. CAT/DEL UV Facility
3. Catskill Delaware Aqueduct Interconnection Shaft #4
4. New Croton Lake Gatehouse
5. Kensico Reservoir Shaft #17
6. Coney Island WWTP

Conceptual plans, OPCCs, and several economic metrics were developed for the six sites. Refer to the full version of the Economic Analysis Report in **Appendix D** for more details. A summary of the report follows.

Opinions of Probable Construction Costs

OPCCs[5] were developed based on the conceptual plans and turbine vendor budgetary quotes, internal information maintained by Gomez and Sullivan, and generally accepted cost estimating manuals. The following assumptions were made in developing the OPCCs:

- Costs are referenced to September 1, 2013.
- Mobilization/demobilization costs were assumed to be 10% of the total.
- Contingency was assumed to be 40% of the total, based on the conceptual screening level of the plans.
- Engineering, administration, and part-time construction services were included.
- Full- or part-time construction management was included.
- Federal Energy Regulatory Commission ("FERC") licensing costs were not included.

The proposed turbine information and economic metrics, including OPCC totals, for each of the six sites are presented in **Table 5-1**.

Schedule for Hydroelectric Development

The following is a schedule for the development of the hydroelectric facilities under the jurisdiction of the FERC. The developments that are considered non-jurisdictional by the FERC could likely be completed in a shorter timeframe, but, for the purpose of the economic analysis, the same timeframe was assumed. It should be noted that DEP would be unable to undertake all of the projects at the same time due to both balancing the water throughout the system and the large capital outlay that would be required.

- 2014 – Additional feasibility studies
- 2015 – File preliminary permit application and obtain preliminary permit (valid for 3 years)
- 2018 – File final exemption application
- 2020 – Receive license exemption
- 2021 and 2022 – Design project and obtain permits
- 2023 – Construct project

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[5] Note that the OPCC estimates and level of feasibility assessment completed is equivalent to Class 5 of the Association for the Advancement of Cost Engineering (AACE) manual. This means that the expected accuracy range of the OPCC is between -20% to -50% to+30% to+100%. This level is for concept screening.

- 2024 – Begin generating power

The following sites are under FERC jurisdiction (per H.R. 267) for a Small Hydroelectric Project of 10 MW or less.

- West Branch Reservoir Shaft #10
- CAT/DEL UV Facility

The following sites are exempt from FERC jurisdiction (per H.R. 267) for an In-conduit Project of 5 MW or less.

- Catskill Delaware Aqueduct Interconnection at Shaft #4
- New Croton Lake Gatehouse
- Kensico Reservoir Shaft #17
- Coney Island WWTP

Net Present Value Analysis

A Net Present Value ("NPV") analysis was conducted for each of the six sites – including a baseline case and seven sensitivity alternatives at each site. The following inputs were used:

- **Estimated Average Annual Generation** – Assumed to be constant over the time horizon. This likely results in an over estimation of the actual potential.

- **Price of Power** – Most sites used prices developed by Brubaker Associates, Inc. ("BAI") in their 70-year marginal electricity price forecast for the NYISO Zone G (Hudson Valley) load zone as part of the West of Hudson Hydroelectric Project feasibility study. BAI's nominal (i.e., including inflation) electricity reference price forecast shows Zone G price levels increasing from a projected level of $90.35/MWh in 2024 to $560.32/MWh in 2073. The Zone G energy pricing data is presented in **Appendix D**. For the CAT/DEL UV Facility and the Coney Island WWTP, because it is anticipated that all generated power would be consumed within the facility so the value of the power would be the displaced energy, a blended rate of $0.10 per kilowatt-hour ("kWh") was used for the year 2013 and an escalation factor of 2.5% was applied to year 2073.

- **Time Horizon** – Used a 50-year time horizon to reflect the likely licensing term

- **Engineering and Capital Costs**

- **Maintenance Costs** – Included major maintenance items including turbine overhauls, generator rewinds, and/or unit replacement.

- **Operation & Maintenance ("O&M") Costs** – Assumed to be $20/MWh annually for the base case and $10/MWh for three of the sensitivity runs

- **Escalation Rate** – 4.0% for engineering and capital costs and future capital expenditures considered major maintenance

- **O&M Escalation Rate** – 3.0% for general annual O&M expenses

- **Discount Rate** – 6.75%

- **Bond Issuance Charges** – 1.0% of the total bond

- **Timeline** – It was assumed that design would occur from 2021 to 2022, with construction occurring in 2023.

The purpose of the sensitivity analysis was to determine which variables had the greatest impact on the NPV. The different alternatives are summarized below:

- **Baseline Case** – reference energy price, bond rate of 6.75%, & annual O&M costs of $20/MWh
- **Sensitivity Run 1** – used high energy price
- **Sensitivity Run 2** – used low energy price
- **Sensitivity Run 3** – used $10/MWh for annual O&M
- **Sensitivity Run 4** – used high energy price and $10/MWh for annual O&M
- **Sensitivity Run 5** – used low energy price and $10/MWh for annual O&M
- **Sensitivity Run 6** – used a bond rate that would results in a zero NPV
- **Sensitivity Run 7** – used $15/MWh for annual O&M

Table 5-2 provides the NPV results for the baseline case and sensitivity runs by site.

Table 5-1: Proposed Turbine Information and Economic Metrics

Site	**Proposed Turbines & Runner Diameter**	**Total Flow** (MGD (cfs))	**Normal Head** (feet)	**Total Capacity** (kW)	**Annual Generation** (MWh)	**Capital Cost** ($2013)	**Capital Cost per Installed Capacity** ($2013/ kW) [(a)]	**Capital Cost per kWh for Annual Generation** ($2013/ kWh) [(b)]	**Simple Payback** (years)	**Complex Payback** (years)	**Annual O&M Cost** ($2013)	**Benefit / Cost Ratio**	**Internal Rate of Return** (%)
West Branch Reservoir Shaft #10	6 (34.4-in) PATs	600 (928)	65	3,840	33,500	$8,900,000	$2,300	$0.30	6	7	$670,000	1.02	200
CAT/DEL UV Facility	8 (46.5-in) Horizontal Francis turbines	1000 (1547)	40	5,280	39,000	$66,475,000	$12,600	$1.70	18	18	$780,000	0.49	NA
Catskill Delaware Aqueduct Inter-connection at Shaft #4	2 (22.5-in) Horizontal Francis turbines	90 (140)	132	1,600	11,600	$12,962,000	$8,100	$1.10	25	26	$232,000	0.58	7.4
New Croton Lake Gatehouse	1 (43-in) Horizontal Francis turbine	130 (201)	60	1,000	7,600	$7,599,000	$7,600	$1.00	23	23	$152,000	0.62	9.0
Kensico Reservoir Shaft #17	6 (63-in) Amjet turbines	1200 (1856)	4	480	4,300	$2,865,000	$6,000	$0.70	15	16	$86,000	0.59	17.0
Coney Island WWTP	4 (26.5-in) Mavel siphon MT5 turbines	100 (155)	9.4	89	780	$2,030,000	$22,800	$2.60	27	27	$15,600	0.37	NA

(a) Rounded to $100

(b) Rounded to $0.10

Table 5-2: NPV Results for Baseline Case and Sensitivity Runs

Site	Proposed Turbines & Runner Diameter	Net Present Value							
		Baseline Run Reference Energy Price & $20/MWh Annual O&M(a)	**Sensitivity Run 1** High Energy Price & $20/MHh Annual O&M(a)	**Sensitivity Run 2** Low Energy Price & $20/MWh Annual O&M(a)	**Sensitivity Run 3** Reference Energy Price & $10/MWh Annual O&M(b)	**Sensitivity Run 4** High Energy Price & $10/MWh Annual O&M(b)	**Sensitivity Run 5** Low Energy Price & $10/MWh Annual O&M(b)	**Sensitivity Run 6(c)** Baseline with Adjusted Bond Rate for NPV = 0	**Sensitivity Run 7** Reference Energy Price & $15/MWh Annual O&M
West Branch Reservoir Shaft #10	6 (34.4-in) PATs	$25,866,279	$45,833,434	$10,009,770	$31,224,721	$51,191,876	$15,368,212	NA(c)	$28,545,500
CAT/DEL UV Facility	8 (46.5-in) Horizontal Francis turbines	-$13,127,076	NA(d)	NA(d)	-$6,888,889	NA(d)	NA(d)	$0 bond rate = 3.33%	-$10,007,982
Catskill Delaware Aqueduct Interconnection at Shaft #4	2 (22.5-in) Horizontal Francis turbines	$618,914	$7,532,914	-$4,871,698	$2,474,374	$9,388,374	-$3,016,238	NA(c)	$1,546,644
New Croton Lake Gatehouse	1 (43-in) Horizontal Francis turbine	$1,204,881	$5,734,743	-$2,392,417	$2,420,527	$6,950,389	-$1,176,770	NA(c)	$1,812,704
Kensico Reservoir Shaft #17	6 (63-in) Amjet turbines	$1,132,442	$3,695,390	-$902,871	$1,820,242	$4,383,190	-$215,071	NA(c)	$1,476,342
Coney Island WWTP	4 (26.5-in) Mavel siphon MT5 turbines	-$807,086	NA(d)	NA(d)	-$682,322	NA(d)	NA(d)	$0 bond rate = 0.19%	-$744,704

(a) Average annual O&M cost of $20/MWh derived from averaging the O&M $/MWh for EDTO and NTO hydro facilities from a 3-yr average of generation data and the 2011 FY O&M budget.

(b) Average annual O&M cost of $10/MWh derived from the US Energy Information Administration Electric Power Annual 2011 escalated to 2013 dollars.

(c) Sensitivity Run 6 was determined only for the sites that have a negative baseline NPV; the others are shown as not applicable (“NA”).

(d) For the CAT/DEL UV facility and Coney Island Wastewater Treatment Plant, the value of power used in the NPV analysis is the displaced energy cost that the facilities pay for electricity, so there are no high and low power values like those used for the other sites; these are shown as not applicable.

Note: *All NPV runs conducted for a 50-year time horizon and a 30-year debt retirement period.*

Economic Analysis Conclusions

West Branch Reservoir Shaft #10

Based on the economic analysis, Shaft #10 has the best economics and the second highest energy generation of the six sites analyzed. The metrics in **Table 5-1** show a capital cost of $0.30 per kWh for annual generation, a complex payback of 7 years, a benefit/cost ("B/C") ratio of 1.02, and an internal rate of return of 200%—all very favorable. The results of the NPV analysis (see **Table 5-2**) show that the baseline run and all of the sensitivity runs have a significantly positive NPV for the 50-year analysis. At this screening level of study, the proposed alternative for Shaft #10 appears to be economically feasible.

CAT/DEL UV Facility

The results of the economic analysis for the CAT/DEL UV Facility show very poor economics. The metrics in **Table 5-1** show a cost of $1.70 per kWh of annual generation, a complex payback of 18 years, and a B/C ratio of 0.49—none of which are very favorable. The NPV analysis shows that both the baseline run and sensitivity run are significantly negative for the 50-year analysis. At this screening level of study, the proposed alternative for the CAT/DEL UV Facility does not appear to be economically feasible.

Catskill Delaware Aqueduct Interconnection at Shaft #4

For Shaft #4, the economic results are mixed. The metrics in **Table 5-1** show a cost of $1.10 per kWh of annual generation, a complex payback of 26 years, a B/C ratio of 0.58, and an internal rate of return of 7.4%—all of which are marginal. The NPV analysis shows that the baseline run is slightly positive and Sensitivity Run 3, with a lower O&M cost, is marginally better than the baseline case for the 50-year analysis. Both sensitivity runs with the lower energy values have negative NPVs, and both sensitivity runs with the higher energy runs have positive NPVs. At this screening level of study, the proposed alternative for Shaft #4 appears to be marginally economically feasible.

New Croton Lake Gatehouse

For the New Croton Lake Gatehouse, the economic results are mixed. The metrics in **Table 5-1** show a cost of $1.00 per kWh of annual generation, a complex payback of 23 years, a B/C ratio of 0.62, and an internal rate of return of 9.0%—all of which are marginal. The NPV analysis shows that the baseline run is slightly positive and Sensitivity Run 3, with a lower O&M cost, is marginally better than the baseline case for the 50-year analysis. Both sensitivity runs with the lower energy values have negative NPVs, and both sensitivity runs with the higher energy runs have positive NPVs. At this screening level of study, the proposed alternative for the New Croton Lake Gatehouse appears to be marginally economically feasible.

Kensico Reservoir Shaft #17

For Shaft #17, the economic results are favorable. The metrics in **Table 5-1** show a cost of $0.70 per kWh of annual generation, a complex payback of 16 years, a B/C ratio of 0.59, and an internal rate of return of 17.0%—, which is mostly favorable. The NPV analysis shows that the baseline run is slightly positive and Sensitivity Run 3, with a lower O&M cost, is marginally better than the baseline case for the 50 year analysis. Both sensitivity runs with the lower energy values have negative NPVs, and both sensitivity runs with the higher energy runs have positive NPVs. At this screening level of study, the proposed alternative at Shaft #17 appears to be marginally economically feasible. As noted earlier, discussions were held with both Andritz and Amjet, but at this time neither turbine company has a workable solution. Amjet is planning to build a smaller unit that may fit in this application, but no date has been established this time. Further discussions with the companies would be needed to determine whether either would be interested in developing a turbine to fit Shaft #17.

Coney Island WWTP

For the Coney Island WWTP, the results show poor economics. The metrics in **Table 5-1** show a cost of \$2.60 per kWh of annual generation, a complex payback of 27 years, and a B/C ratio of 0.37—none of which are favorable. The NPV analysis shows that the baseline run and Sensitivity Run 3 are negative for the 50-year analysis. At this screening level of study, the proposed alternative for Coney Island WWTP is not economically feasible. The construction cost would need to be cut in half for the NPV to turn positive.

North River WWTP

A detailed economic analysis was not performed for the North River WWTP, but a conclusion can be drawn by making a comparison to the Coney Island WWTP economic analysis. As described in **Section 4**, the North River WWTP hydro proposal was for five Mavel siphon turbines, which resulted in an annual energy generation of 1,300 MWh. Coney Island WWTP's hydro proposal was for four Mavel siphon turbines, which resulted in an annual energy generation of 780 MWh. This would make the North River WWTP's hydro proposal fairly similar to the Coney Island WWTP's proposal. Therefore, the economics for the North River WWTP's proposal would not be economically feasible.

Owls Head WWTP[6]

The Owls Head WWTP was not visited by the Gomez and Sullivan team, but the site generation was determined by using information from the INL Study. Based on the head of 8.4 feet at the outfall weir and flow of 98 MGD, the estimated turbine/generator capacity would be 78 kW and the annual generation would be 680 MWh. For this flow, four Mavel siphon turbines would be needed. This hydro proposal and generation results are the same as for the Coney Island WWTP. Therefore, the economics for the Owls Head WWTP's proposal would not be economically feasible.

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[6] Owls Head WWTP was on the initial screening list, but was not one of the sites visited. It was added based on discussions with DEP Bureau of Wastewater Treatment Staff.

6.0 ENVIRONMENTAL BENEFITS ANALYSIS

The purpose of this portion of the study was to quantify the environmental benefits due to replacing petroleum based fuel generation with hydropower generation for the six sites evaluated in the Economic Analysis (**Section 5**).

Installation of the proposed hydroelectric facilities would be expected to result in a reduction in the emissions of carbon dioxide equivalents (“CO_2e”), oxides of nitrogen (NO_x”), and sulfur dioxide (“SO_2”) emissions associated with the consumption of purchased electricity. These estimated CO_2e, NO_x, and SO_2 emissions reductions are provided in **Table 6-1**.

The emissions reductions were estimated by multiplying the projected purchased electricity savings for each proposed hydroelectric facility by the total output CO_2e, NO_x, and SO_2 emission factors provided in two sources: The US Environmental Protection Agency (“USEPA”) eGrid2012 Version 1.0 (“eGrid2012”) summary tables and the 2011 CO_2e emission coefficient for purchased electricity provided in Appendix I of the December 2012 *PlaNYC Inventory of New York City Greenhouse Gas Emissions* (“*PlaNYC Inventory 2012*”). The emission factors were obtained from the two sources as follows:

- **Coney Island WWTP, CAT/DEL UV Facility, New Croton Lake Gatehouse, & Kensico Reservoir Shaft #17:**
    - The *PlaNYC Inventory 2012* provides a CO_2e emission coefficient for purchased electricity that is specific to New York City. As the Coney Island WWTP is located within the boundaries of the City, this emission coefficient was used to estimate the CO_2e emissions reductions associated with the reduction in purchased electricity at the Coney Island site.
    - The *PlaNYC Inventory 2012* does not provide emissions coefficients for NO_x or SO_2. Therefore, the emission factors provided in eGrid2012 were used to estimate the NO_x and SO_2 emissions reductions for the Coney Island site.
    - The CAT/DEL UV Facility, the New Croton Lake Gatehouse, and the Kensico Reservoir Shaft #17 are located within Westchester County but the power to these sites is supplied through the New York Power Authority. Therefore, the emission factors provided in eGrid2012 for the NPCC NYC/Westchester subregion were used to estimate the expected CO_2e, NO_x, and SO_2 emissions reductions for these sites.
- **West Branch Reservoir Shaft #10 & Catskill Delaware Aqueduct Interconnection at Shaft #4:** eGrid2012 provides the CO_2e, NO_x, and SO_2 emission factors based on defined eGrid subregions.
    - The West Branch Reservoir Shaft #10 and the Catskill Delaware Aqueduct Interconnection at Shaft #4 are located north of Westchester County, in Upstate New York. Therefore, the emission factors provided in eGrid2012 for the NPCC Upstate NY subregion were used to estimate the expected CO_2e, NO_x, and SO_2 emissions reductions for these sites.

The CO_2e, NO_x, and SO_2 emissions reductions provided in **Table 6-1** are considered to be site reductions, which represent reductions at the point of use of the purchased electricity, rather than source reductions that reflect reductions at the generating sources of the purchased electricity. Table 6-1 also includes source reductions, which represent reductions at the point of generation of purchased electricity.

Table 6-1 also provides a comparison between the estimated CO_2e reductions expected to result from the installation of the six proposed hydroelectric sites and the total GHG emissions for DEP facilities located in the five boroughs and Upstate New York. As shown in **Table 6-1**, the total CO_2e reduction for the six sites combined was estimated to be approximately 12% of the total 2011 GHG emissions from purchased electricity for DEP facilities, as provided in DEP's draft 2012 GHG Strategic Mitigation Plan ("GHG Mitigation Plan"). It is assumed that the actual 2011 GHG emissions resulting from purchased electricity consumption for these six sites were included as part of the inventory provided in the GHG Mitigation Plan.

Also as shown in **Table 6-1**, the total CO_2e reduction for the Coney Island WWTP site, which is located within the boundaries of New York City, is approximately 0.004% of the total 2011 City-wide GHG emissions resulting from purchased electricity, as provided in the *PlaNYC Inventory 2012*. It is assumed that the actual 2011 GHG emissions resulting from purchased electricity consumption at the Coney Island WWTP site were included as part of the total City-wide GHG emissions provided in the *PlaNYC Inventory 2012.*

Table 6-1: Summary of Estimated GHG, NO_x and SO_2 Emissions Reductions

Site	**Location**	**Electricity Savings**(a)	**Emission Factor** (lb/MWh)			**Emissions Reduction** ($MTCO_2e$/yr)			
						Site			*Source*
			CO_2e (a)	NO_x (c)	SO_2 (c)	CO_2e (d)	NO_x (d)	SO_2 (d)	CO_2e (e)
West Branch Reservoir Shaft #10	Upstate NY, north of Westchester County	33,500	500.35	0.3954	0.9849	7,603	6.01	15.0	23,875
CAT/DEL UV Facility	Westchester County	39,000	658	0.2792	0.103	11,635	4.94	1.82	36,534
Catskill Delaware Interconnection at Shaft #4	Upstate NY, west of Hudson River	11,600	500.35	0.3954	0.9849	2,633	2.08	5.18	8,267
New Croton Lake Gatehouse	Westchester County	7,600	658	0.2792	0.103	2,267	0.96	0.355	7,120
Kensico Reservoir Shaft #17	Westchester County	4,300	658	0.2792	0.103	1,283	0.545	0.20	4,028
Coney Island WWTP	New York City (Brooklyn)	2,000	658	0.2792	0.103	597	0.253	0.093	1,874

Total CO_2e reduction, all Sites: 26,018
Total 2011 GHG Emissions, NYCDEP facilities(f)**:** 217,617
% of total 2011 GHG Emissions, NYCDEP facilities: 12.0%

Total CO_2e reduction, NYC Site: 597
Total 2011 GHG Emissions, NYC(g)**:** 15,300,000
% of total 2011 GHG Emissions, NYC: 0.004%

(a) *Estimated electricity savings from estimated annual generation in* ***Table 5-1****.*
(b) *GHG emission factors for Upstate NY and Westchester County obtained from eGrid2012 summary tables and represent total output emission rates. The GHG emission factor for NYC was obtained from Appendix I of* PlaNYC Inventory 2012. *The given factor of 82.867 kg CO2e/GJ was converted to units of lb/MWh using the given conversion factor of 1 lb/MWh per 0.125998 kg/GJ.*
(c) *The* NO_x *and* SO_2 *emission factors were obtained from eGrid2012 and represent total output emission rates.*
(d) *The* CO_2e, NO_x, *and* SO_2 *emissions reductions are considered to be site reductions.*
(e) *The CO2e reductions are considered to be source reductions. In accordance with the July 2013 Energy Star Portfolio Manager Source Energy Technical Reference, the quantity of purchased electricity generated by the source is estimated to be 3.14 times the quantity of purchased electricity used by the site.*
(f) *The total 2011 GHG emissions for DEP facilities was obtained from the draft 2012 GHG Strategic Mitigation Plan.*
(g) *The total 2011 GHG emissions for NYC was obtained from* PlaNYC Inventory 2012.

7.0 SUMMARY AND CONCLUSIONS

In summary, this report identified sites in the DEP's water and wastewater system with the greatest hydroelectric potential. In the Resource Assessment (**Section 2**), 36 potential hydroelectric sites were identified, screened to 26 sites, and ranked, and 10 representative sites were then selected for further review. In Part A of the Technology Review (**Section 3**), the state of available hydraulic turbine technology was reviewed. In Part B of the Technology Review (**Section 4**), site visits to the representative sites were summarized, the most appropriate turbine technology for each was selected, the sites were ranked based on generation, and the top six were selected for further study. In the Economic Analysis (**Section 5**), conceptual plans, OPCCs, and several economic metrics were developed for the top six sites. Lastly, in the Environmental Benefits Analysis (**Section 6**), GHG emissions avoided and pollutant reductions were estimated for the top six sites.

The following are the preliminary economic analysis results for the six representative sites with greatest hydroelectric potential:

- **West Branch Reservoir Shaft #10 (outflow)** – economically feasible
- **Kensico Reservoir Shaft # 17 (inflow)** – economically feasible
- **Delaware Catskill Aqueduct Interconnection at Shaft #4** – marginally economically feasible
- **New Croton Lake Gatehouse** – marginally economically feasible
- **CAT/DEL UV Facility** – not economically feasible
- **Coney Island WWTP** – not economically feasible

The following are the results of other WWTPs that were studied. The North River and Owls Head WWTPs were analyzed by comparison with Coney Island.

- **Newtown Creek WWTP** – no hydro solution found
- **North River WWTP** – not economically feasible
- **Owls Head WWTP** – not economically feasible

Due to the screening level of this study, only six sites were advanced through the full Economic Analysis phase (**Section 5**). However, additional sites in the larger group of 10 representative sites may warrant further study. For example:

- **New Croton Dam** – the minimum flow alternative this alternative prepared by MWH appears to be economically feasible.
- **Rondout Effluent Chamber Releases** – this site would be considered marginal based on the low generation expected
- **Ashokan Lower Gate Chamber Releases** – this site would be considered marginal based on the low generation expected

However, other sites within the group of 10 representative sites do not appear to have a high enough potential of hydropower feasibility to warrant additional studies:

- **Ashokan Release Channel** – the hydro proposal for this site would produce very little generation, so it not expected to be economically feasible

Looking further back in the study process, other sites within the initial screened group of 26 may have potential and should not be automatically ruled out of future studies. Some sites were not advanced to later phases because only a limited number of representative sites from a certain type of site (e.g., WWTPs) could be analyzed within the scope of this study. A few examples of other sites that may warrant further study include (in order of decreasing rank from Table 2 in **Appendix A**):

- **Croton Falls** – this site would be considered marginal based on the low generation expected
- **Titicus** – this site would be considered marginal based on the low generation expected
- **East Branch (Sodom Dam)** – this site would be considered marginal based on the low generation expected
- **Croton Diverting** – this site would be considered marginal based on the low generation expected

In conclusion, 36 sites representative of the greatest hydroelectric potential in the system were screened. After an initial screening analysis ten sites were dropped due to inadequate potential. The remaining 26 sites were evaluated based on criteria related to constructability, electrical demand, operability and economic factors and ranked in order of highest value/lowest risk. The top twelve sites were analyzed further to match up the best turbine technologies to site-specific characteristics. Appropriate technology that would result in uninterrupted operations was not identified for one location (Newtown Creek WWTP) and so was dropped from further analysis. Six sites that represented the best electric generation potential and different parts of the system were advanced through an economic analysis. Only two of the six sites appear to be economically feasible, while two others are of marginal economics.

Further analysis would be required before any investment decisions could be made with respect to the sites determined to be marginally feasible or better. It is recommended that the DEP continue to monitor the development of turbine technology and their costs along with market factors that may influence the price of electricity in conjunction with the environmental benefits that may be realized from any future development.