New York State Energy Research and Development Authority

Alden Turbine Market Analysis for New York State

Final Report

September 2012

Report Number 13-19

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Alden Turbine Market Analysis for New York State

Final Report

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Alden research laboratory, inc.

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Abstract

New York State Energy Research and Development Authority (NYSERDA) is interested in the development, demonstration, and commercialization of innovative hydropower technologies to increase the production of clean renewable energy while minimizing environmental impacts. The Alden fish-friendly turbine is a technology capable of contributing to meeting these objectives. The Alden turbine was developed by a research collaborative involving EPRI, the U.S. Department of Energy, NYSERDA, and industry. The turbine is predicted to allow high (≥98 percent) fish passage survival while maintaining high energy efficiency. The Alden turbine is available for deployment and testing. The objective of this project was to assess the scope of the potential market in New York State where the turbine could be deployed to support new renewable energy development. Project researchers used various state and federal databases to identify existing projects where unused capacity could be developed with this turbine. The project did not examine retrofit opportunities as that would not expand renewable energy development. Twenty-three powered projects were identified as having available capacity and sufficient head and flow resources to operate an Alden turbine, totaling approximately 90 MW if developed. Also identified were ten non-powered projects possibly capable of accepting the Alden turbine and would total approximately 31 MW if developed. Together, the powered and non-powered projects could expand New York State hydropower capacity by approximately two percent. The research reported on herein is screening level to support policy analysis. Actual project development would require a significantly more detailed analysis of head and flow data.

Keywords

Hydropower

Renewable Energy

Fish-friendly Hydro Turbine

Fish Passage

Table of Contents

NYSERDA Notice ii
EPRI Disclaimer of Warranties and Limitation of Liabilities iii
Acknowledgments v
Abstract vi
Keywords vi
List of Figures viii
List of Tables viii
1 Introduction 1
1.1 Background 1
1.2 Study Goal and Objectives 2
2 Project Background 3
3 Alden Turbine Development History 5
4 Market Potential Assessment Methods 8
4.1 Information Sources 8
4.2 Approach to Data Review 8
4.3 Site Suitability Evaluation 9
4.3.1 Evaluation of Dam Site Characteristics - Head and Flow 11
4.3.2 Evaluation of Turbine Characteristics- Diameter, Rotational Speed, and Power 14
4.3.3 Biology 16
5 Market Potential Analysis Results 17
6 Discussion 24
7 References 26

List of Figures

Figure 2-1. Electricity Generation Data for New York State (Tierney 2008) 3
Figure 2-2. Cutaway View of Alden Turbine 4
Figure 3-1. CFD Modeling of Alden Turbine Runner 6
Figure 4-1. Alden Turbine Application Chart (Murtha 2011) 10
Figure 4-2. Delineation of Major Drainage Basins in New York State (modified from http://www.dec.ny.gov/lands/56800.html) 12
Figure 4-3. Unit Flow Duration Curve for the Black River 13
Figure 5-1. Overview Map of Suitable Powered Project Locations 22
Figure 5-2. Overview Map of Suitable Non-Powered Project Locations 22

List of Tables

Table 5-1. Summary of Potential Powered Dams 18
Table 5-2. Summary of Potential Non-Powered Dams 21
Table 6-1. Potential Alden Turbine Installation Sites by River 24

1 Introduction

1.1 Background

New York State Energy Research and Development Authority (NYSERDA) is interested in the development, demonstration, and commercialization of innovative hydropower technologies to increase the production of clean renewable energy while minimizing environmental impacts. The Alden fish-friendly turbine is a technology capable of contributing to meeting these objectives.

Downstream fish passage and turbine entrainment reduction are key environmental issues associated with hydropower projects. Fish passage technology development to reduce turbine entrainment at many projects began in earnest in the 1990s (OTA 1995, EPRI 1998) and remains current. Overall, however, available technologies often have less than optimal effectiveness, can be expensive and their operation typically results in lost generation. In many cases, increased spillway flow for downstream fish passage is preferred over physical downstream passage technologies, but can also result in significant generation losses (Coutant et al. 2006). Sale et al. (2006) reviewed the costs of upstream and downstream fish protection and determined it to be greater than $700,000 per project (average in 1991) at non-federal projects. In addition, it was found that lost generation due to downstream passage flow discharges averaged above 6,000 MWhr/yr at non-federal project. This was the background for how the concept of developing “fish-friendly” hydropower turbines evolved.

The Alden turbine was developed to meet both the environmental and generation needs of project owners by allowing fish to pass through turbines with survival rates equal to or surpassing those associated with spillway passage or an engineered downstream bypass system. The turbine offers several benefits to hydro developers and project owners, primarily increased energy production and improved environmental performance. The innovative turbine design incorporates advanced engineering concepts resulting in a turbine which is expected to provide survival rates equal to or greater than 98 percent for 200-mm fish while achieving about 94 percent efficiency over a broad range of flows.

The potential market for the turbine in New York State may be considerable given the desire to supplement renewable energy production via incremental increases in generating capacity at existing hydro projects. The turbine is well-suited for projects that have the ability to add capacity in the form of new or retrofitted units, but that also need to address issues associated with the injury and mortality of downstream migrating fish. This technology is particularly attractive for sites with migratory species, declining fish populations, or threatened or endangered species where significant spill or bypass flows may need to meet fish passage requirements. The additional generating capacity resulting from the application of this turbine at existing and new hydro developments will also help offset greenhouse gas emissions.

Several types of installations can be considered for the application of the turbine at existing and new hydro projects in New York State. These include project expansions, the addition of power at existing non-powered dams, and the use of the turbine as a means to generate power from fish bypasses and minimum flow releases. Note that this project does not consider the potential for new dam construction. Project expansions and unit replacements can be accomplished without the need for new, modified, or additional downstream fish passage facilities. Since downstream fish passage issues are often the leading environmental concern at hydro projects, the ability of an Alden turbine to capture these flows for generation represents a significant opportunity to increase generation in New York State in an environmentally friendly manner.

There may be a number of potential sites in New York State that could benefit from the increased generation and improved fish survival provided by an Alden turbine. This analysis is focused on estimating the market potential, and applicability of the turbine for projects in New York State at existing dam sites.

1.2 Study Goal and Objectives

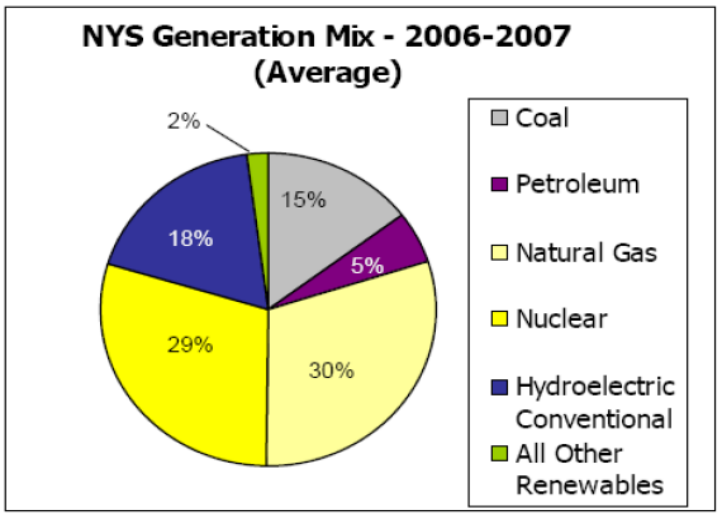
The overall goal of this study is to determine the market potential for the Alden Turbine in New York State. The specific study objectives developed in support of this goal were as follows:

- Review available engineering and operational information for existing non-powered dams and hydropower projects.
- Narrow the list of potential applications based on a detailed analysis of Alden turbine design and operational parameters that will influence feasibility at each site.
- Estimate potential power capacity for the sites that have the greatest possibility for successful application.

2 Project Background

New York State has adopted an aggressive Renewable Portfolio Standard (RPS) goal of obtaining 30 percent of its electricity from renewable sources (including hydropower) by 2015[1]. Hydropower generation comprised approximately 18 percent of the annual energy generation in New York State in 2006-2007 (Figure 2-1), demonstrating that it is a significant existing renewable resource with potential for expansion to help meet RPS goals.

Figure 2-1. Electricity Generation Data for New York State (Tierney 2008)



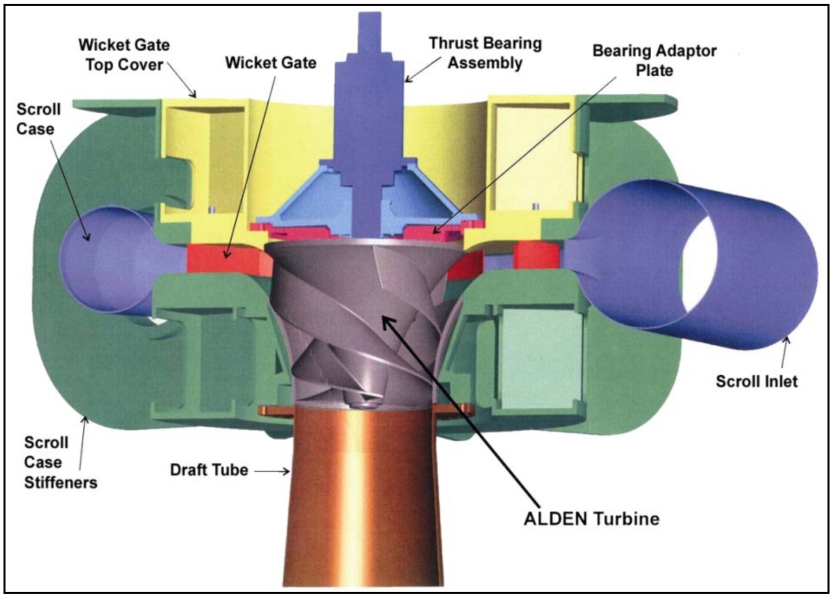
In addition to existing hydropower resources, the State has approximately 6,900 non-powered dams some of which offer potential generation capacity. As plans to meet the RPS goals are developed and potential dam sites are evaluated for hydropower, it is important to establish such energy sources in an environmentally sustainable manner.

Turbine fish entrainment and survival are two of the most important and controversial issues associated with hydropower projects (Amaral et al. 1997). Most often, the means for reducing turbine entrainment and increasing fish passage survival include the discharge of some river flow as spill or through a bypass system, resulting in a loss of water that could be used for hydropower generation. In conjunction with the loss of generation flows, a fish entrainment protection and downstream bypass systems may be required. In addition to the capital cost associated with constructing a downstream fish passage structure, the operation and maintenance as well as long term testing and monitoring are typically expensive. The need for downstream fish passage structures can potentially lead to reduced economic returns as well as uncertainty in project development.

[1] http://www.nyserda.ny.gov/BusinessAreas/Energy-Data-and-Prices-Planning-and-Policy/Program-Planning/Renewable-Portfolio-Standard.aspx

The Alden turbine is a recent and innovative technology that emerged from research funded by the hydropower industry, the Electric Power Research Institute (EPRI), the U.S. Department of Energy (DOE), and NYSERDA which addresses turbine entrainment and mortality without compromising power generation (EPRI 2011a). To reduce injury to fish, the turbine design minimizes the number of blades, eliminates gaps between the runner and runner housing and maintains pressure and velocity (shear) gradients that meet established biocriteria for safe fish passage. Injury and morality associated with blade strike during passage are also minimized through the use of thick leading blade edges with a semi-circular shape, and by maintaining low strike velocities.

Figure 2-2. Cutaway View of Alden Turbine



Consideration of the turbine for installation at either non-powered dams or FERC-authorized projects, has the potential to benefit New York State with respect to environmental impacts and RPS goals. The turbine has been designed to enable the safe passage of fish through an operating unit, which will offset the need for entrainment exclusion devices and downstream fish passage structures while increasing hydropower capacity through the use of otherwise bypassed water.

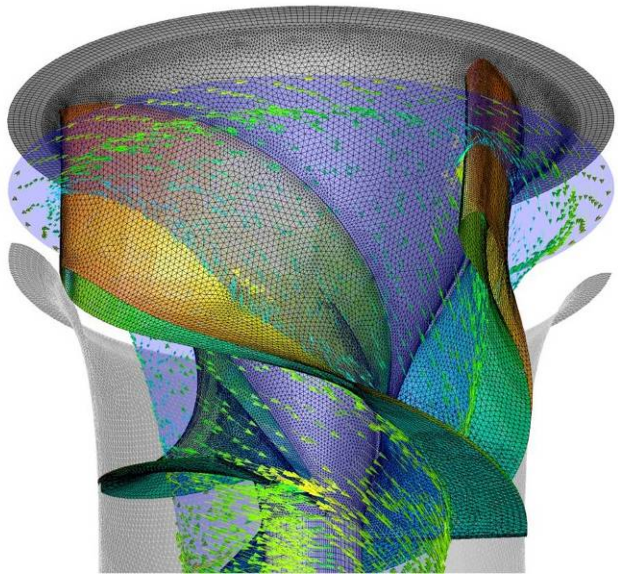
3 Alden Turbine Development History

By the late 1980s, environmental issues were emerging as a growing problem for the hydropower industry. This was a natural outgrowth of the environmental movement as well as a result of growing concerns about the severe population declines in high profile wild stocks of Pacific and Atlantic salmon and American shad. The extensive public and private hydropower system was viewed as contributing to their decline (OTA 1995). A 1991 DOE-sponsored survey (Sale et al. 1991) of non-federal projects documented the extent of the environmental concerns and found that fish passage and instream flow protection were two key issues requiring mitigation. As Sale et al. (1991) noted, determination of instream flow requirements was the most common issue, and fish passage was the most costly. Also, in addition to concerns for diadromous fishes, preventing or significantly reducing turbine entrainment of resident riverine species became a high priority for many state and federal agencies. Beginning in the early 1990s, turbine entrainment and survival studies were increasingly being required (FERC 1995; EPRI 1997). Turbine entrainment, while highly variable, could be as high as 2,500 fish/hr (FERC 1995) and mortality could range from zero to 100 percent (OTA 1995) depending on a number of site-specific factors.

In the early 1990s, a public-private collaboration known as Advanced Hydropower Turbine System (AHTS) program began. The program was supported by the Hydropower Research Foundation (HRF), EPRI and the Department of Energy (DOE) to develop “fish-friendly” turbines. The program consisted of a three-phase, multi-year effort: (1) Phase I – conceptual designs; (2) Phase II - detailed design and model testing; and (3) Phase III - construction and testing of full-sized prototypes.

In response to the Phase I competitive DOE solicitation, Alden Research Laboratory, Inc. submitted a proposal which focused on an innovative new turbine design. The design included a runner that was limited to three blades, had no clearances between the runner blades and the crown or housing and, with the exception of some small areas around the blade leading edges, had pressure and velocity (shear) gradients that met established bio-criteria for safe fish passage (Odeh 1999; Cook et al. 2003; Lin et al. 2004). Alden was successful in securing DOE funding and ultimately completed extensive computer modeling leading to a conceptual design (Figure 3-1). In addition, a pilot-scale test facility was constructed to evaluate the biological performance and complete preliminary engineering. A pilot-scale prototype was tested in 2001 and 2002 and the study results indicated that the Alden turbine would have substantially higher turbine passage survival rates than conventional turbine designs (e.g., Kaplan and Francis turbines) for comparable flow rates, heads, and fish species (Cook et al 2003).

Figure 3-1. CFD Modeling of Alden Turbine Runner



The results of the pilot-scale laboratory testing demonstrated that turbine passage survival was primarily dependent on fish length and operational turbine head (i.e., rotational speed and strike velocity) (Cook et al. 2003; Amaral et al. 2003). There were no statistical differences in survival rates among typical teleost species (trout, salmon, bass, alewife) of a similar size. However, white sturgeon (which has a cartilaginous skeleton and no true scales) and American eel (long flexible, sinuous, and lacking scales) had significantly greater survival rates than the other species (97 percent immediate survival for sturgeon and 100 percent for eels). Using the results of the pilot-scale survival tests, predicted survival rates for the prototype (full-scale) turbine indicated that fish less than 200 mm in length, which comprise more than 90 percent of fish entrained at hydro projects in the U.S. (Winchell et al. 2000), would be expected to have survival rates greater than about 95 percent for heads of 40 and 80 ft. These conclusions are based on pilot-scale laboratory tests measuring direct (96-hour) survival; results from tests under actual field conditions may differ. Direct fish survival rates are expected to be higher (97 percent to 100 percent) for the recently redesigned turbine, primarily due to thicker leading blade edges which minimize injury caused by blade strike (Amaral et al. 2008).

In recognition of the further potential of the Alden turbine, EPRI initiated continued conceptual development work after the DOE's AHTS program ended in 2005. EPRI focused on optimization of the scroll case, runner, and draft tube (EPRI 2007) as well as investigations of the relationship between turbine leading edge blade shape and fish injury and mortality (EPRI 2008). Investigation demonstrated that thick, rounded leading edge blade shapes reduce fish injury and increase survival (EPRI 2008, 2011b). Results of this research were incorporated into the design of the turbine to further improve biological performance.

In 2010, a scaled physical model of the Alden turbine was tested by Voith Hydro in York, PA, following preliminary design and engineering efforts to make the technology ready for a commercial deployment (EPRI 2011a). The physical model was used to assess the engineering and operational performance of the turbine before finalizing the design. Based on the model tests, the efficiency of the runner was determined to be approximately 94 percent at its best efficiency point (BEP) and maintains relatively high efficiency over a considerable range of turbine operating conditions, when scaled up to a full size runner. This indicates that the runner is competitive with existing conventional turbine designs. At this time, EPRI and the DOE are working with project owners and operators to find an installation site for the field demonstration of a full size unit.

4 Market Potential Assessment Methods

The goal of this study is to determine the market potential for the Alden Turbine in New York State. The general methodology for the project analysis was:

- Review the available data sources to find information on existing dam projects and compile the information into a single master data set.
- Based on available project information, estimate the available head and design flow (a 25 percent flow duration criteria was used).
- Sort projects based on head and flow estimates to summarize projects listed as having suitable characteristics for an Alden turbine installation.
- Based on a project's estimated head and flow, apply affinity equations to estimate the size and speed of an Alden turbine installation at a site; adjust as required.
- Estimate power associated with an installation at a particular site.

4.1 Information Sources

Several datasets were identified for use in evaluating the market potential of the Alden turbine in New York State. These datasets included:

- NY Department of Environmental Conservation Dam Safety (DEC) (Dominitz 2012);
- National Inventory of Dams (NID) (USACE 2012);
- National Hydropower Asset Assessment Program (NHAAP) (Hadjerioua 2012); and
- Available FERC datasets for FERC-authorized projects (FERC) (Spain 2012).

The NID dataset for New York State included information on a total of 1,982 dams, the DEC list included 6,995 dams, the NHAAP list (NY data) included 33 dams, and the FERC datasets for New York State included 206 projects. Many of the dams were listed in multiple datasets; therefore, a master dataset was developed which incorporated the data from all four sources. The master dataset included 7,107 individual dams.

4.2 Approach to Data Review

Each of the dams in the master dataset was parsed into FERC-authorized projects and non-powered dams. This separation is primarily due to some of the differences in available information, as well as evaluation considerations between powered and non-powered projects (e.g., need for powerhouse, transmission lines, tailrace at non-powered dams; availability of actual head values for FERC projects).

Initially, the review of FERC data was limited to a list of exemptions/licenses and what was available in the FERC e-library for New York State projects. However, the FERC e-library provided little useful information, so FERC was contacted directly. FERC staff provided a much more useful dataset than was available on-line. The dataset contained information on project head and authorized hydraulic capacity, turbine type, and river system where the dam is located.

The NID and DEC databases focus on dam related information such as height, storage capacity, and inspection requirements. Where possible, the more detailed information provided by FERC was utilized in evaluating potential projects. Data gaps that were identified in the available databases were noted. Additional research was conducted to locate missing information such as the project head/dam height, drainage area, major drainage basin, and the authorized hydraulic capacity of FERC projects. The data sources that were searched included alternative documents and publications obtained from the FERC e-library[2], information available through the Low Impact Hydropower Institute (LIHI), and individual project resources. If drainage area was not available, the U.S. Geological Survey (USGS) New York StreamStats program[3] was used for estimation where project coordinates were available. In general, the larger databases such as NID and DEC had significant data gaps; therefore, not all missing information was investigated. The FERC dataset, however, was a more complete source of information. If the data required to complete the analysis of a project were not available, the project was removed from further consideration.

4.3 Site Suitability Evaluation

The initial review of the available datasets determined if sites met the following general requirements necessary for considering the installation of an Alden turbine. Site applicability was determined based on the application chart provided by Voith Hydro (Figure 4-1):

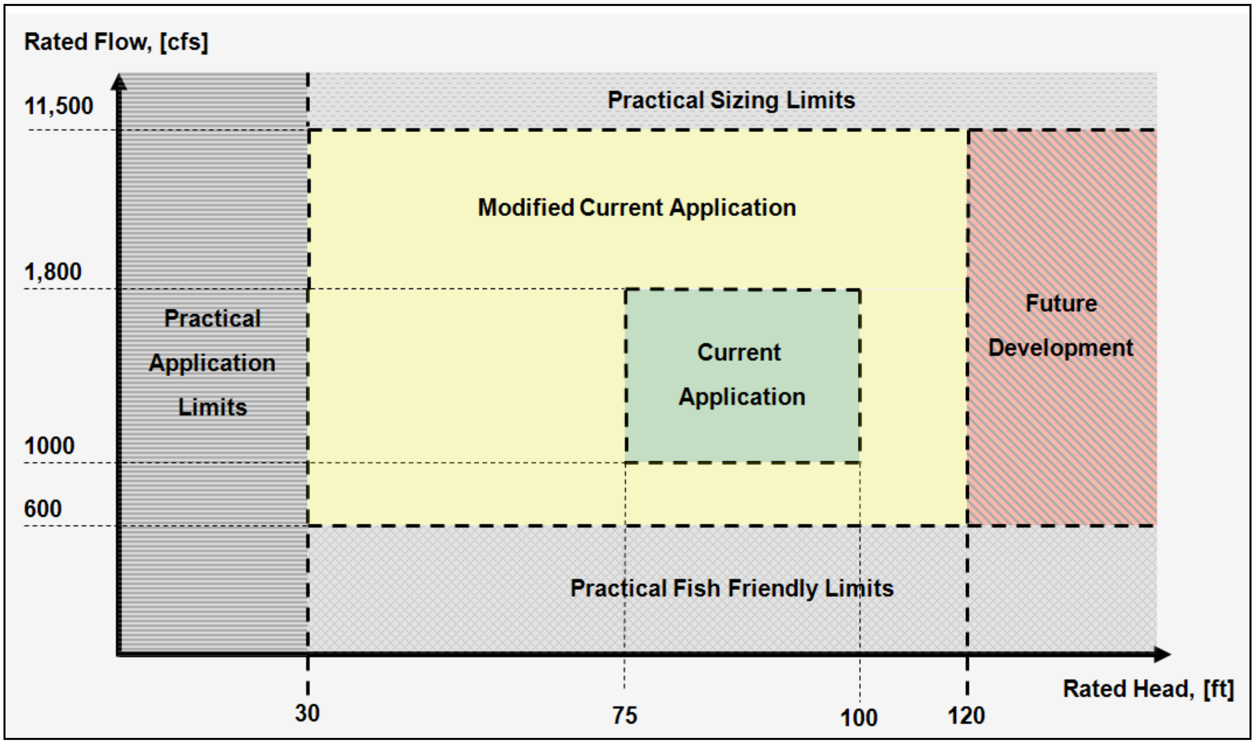
- Head range between 30 and 120 ft.
- Flow rate of at least 600 cubic foot per second (cfs).
- Downstream fish passage requirements.

Due to uncertainty in the data sets (e.g., using dam height to estimate head), the values listed above have been modified to provide an approximate 15 percent buffer in analysis. By extending the evaluation range for head and flow, the potential for excluding a site that may be appropriate is reduced. Therefore, for analysis purposes, the following were the expanded application criteria:

- Head range between 25 and 140 ft.
- Flow rate of at least 500 cfs (at 25 percent exceedance).

[2] http://www.ferc.gov/docs-filing/elibrary.asp
[3] http://streamstats.usgs.gov/new_york.html

Figure 4-1. Alden Turbine Application Chart (Murtha 2011)



As discussed previously, the quality of the available information and data needed to effectively assess the market potential of the Alden turbine in New York State varied. Therefore, assumptions were required to supplement and estimate missing data. A single dataset was generated for a preliminary project suitability analysis. Due to the hydraulic nature of a turbine, characteristics such as the design head, design flow rate, rotational speed, diameter, and power are all interrelated and will affect the generating and biological performance of the turbine. When evaluating a site's suitability and potential for an Alden turbine installation, the site characteristics, including the head and flow, were first evaluated based on the data provided in the available databases. Projects found to have suitable site characteristics were further evaluated to estimate the preliminary turbine design characteristics, including diameter and rotational speed, which would be associated with a turbine installation at a given site. Preliminary turbine design characteristics were estimated using affinity equations, which allow the design parameters of a turbine to be predicted based on the similitude between a test model and the full scale proto-type application. Following definition of the site and turbine characteristics, power estimates can be made.

The following sections discuss the general methodology and assumptions associated with evaluating the site and turbine characteristics that would lead to a potentially successful application.

4.3.1 Evaluation of Dam Site Characteristics - Head and Flow

The two primary parameters used to determine the applicability of an Alden turbine are the available head and flow. When estimating both the project head and flow, there were some differences in the approach used for powered and non-powered sites.

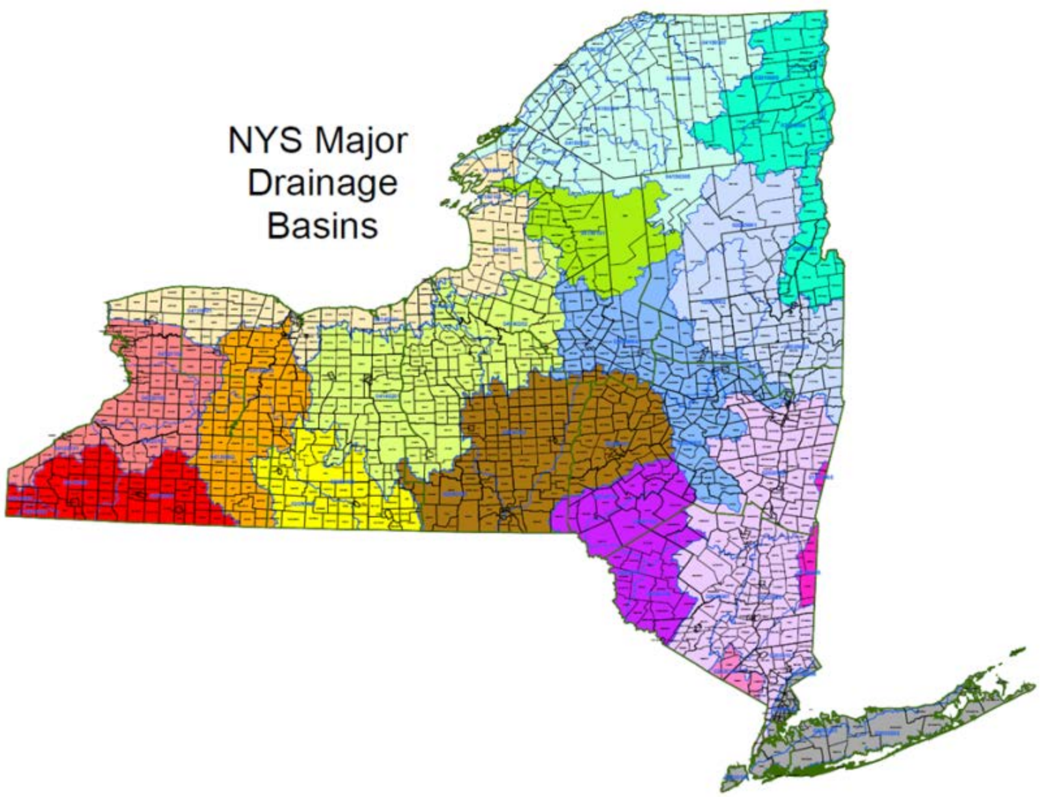
Based on biological and engineering constraints, suitable head for the Alden turbine has been determined to be between approximately 30 and 120 ft. However, to account for uncertainty in the datasets, the head range of 30 to 120 ft was increased by approximately 15 percent resulting in a 25 to 140 ft expansion. At heads below about 30 ft, fish survival through traditional turbine designs (i.e., propeller and Francis units) is typically high if the flow and diameter is adequate and, consequently, there are less biological benefits associated with the use of an Alden turbine. For projects exceeding 120 ft of head, strike may no longer be the primary mechanism for mortality, resulting in reduced biological effectiveness if other mechanisms (e.g., damaging pressure changes and shear levels) begin to cause injury to entrained fish. The turbine requires a minimum flow of approximately 600 cfs for operation to maintain good fish survival and the upper flow limit is defined by the practical size of the unit rather than any operational or biological constraints. However, to account for uncertainty in the datasets, the minimum operating turbine flow of 600 cfs was expanded by approximately 15 percent resulting in a minimum flow requirement of 500 cfs.

The gross head is typically measured from the upstream water surface elevation to the downstream, whereas the net head takes system losses into consideration. System losses include those incurred through penstocks, intake structures, trash racks, and tailrace channels. Due to the level of design required to estimate this information, system losses were not taken into consideration and gross head was used in the assessment of each site. Based on a review of the master dataset, some estimation of the actual gross head was required for non-powered dams. The NID and DEC datasets provided information on the dam height but not the available head. For the purposes of this study, gaining an increase in head through the installation of a penstock or canal system was not considered for non-powered dams. Therefore, it can be assumed that any new powerhouse structure would be constructed at or adjacent to the existing dam. Based on this assumption, gross head was estimated as 75 percent of the dam height provided in the database for non-powered dams. The FERC data included the head rather than the dam height and no modification to this data was required.

The available project flows vary throughout the year and, typically, the development of a flow duration curve will assist in choosing turbine design flows. For non-powered projects, flow duration curves estimated solely on hydrologic data were sufficient for the assessment of Alden turbine applicability. However, for powered projects, the hydraulic capacity of the existing turbines was accounted for and subtracted from the hydrologic estimates to determine available flow for a turbine.

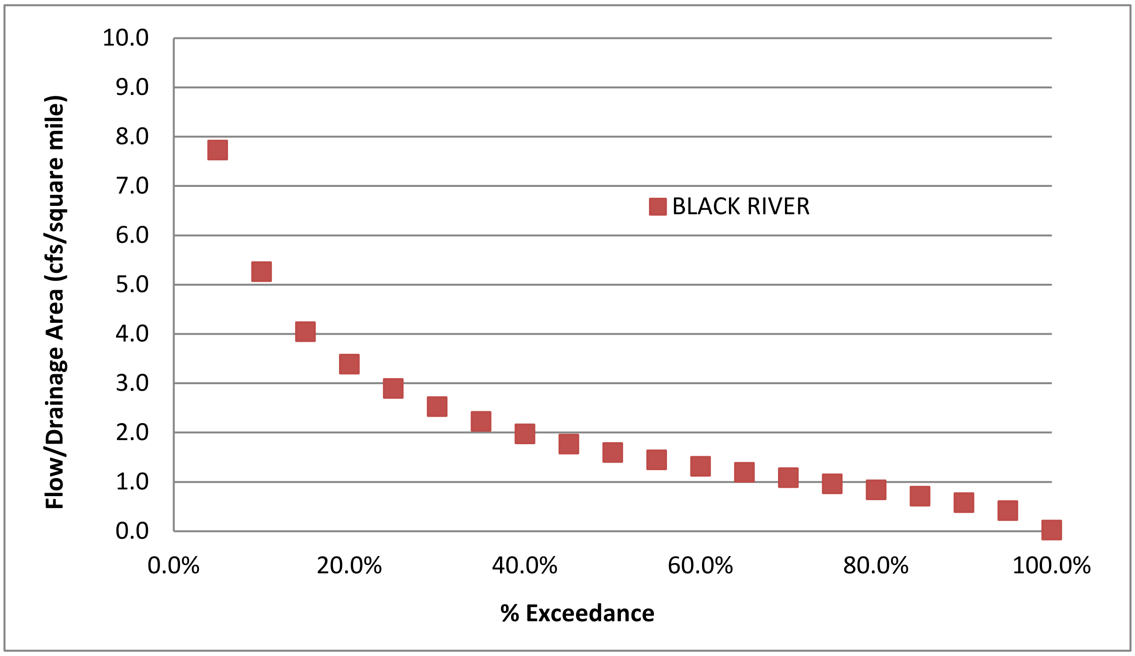
River flow data was not available from any of the datasets evaluated. The NID and DEC datasets provided information on the drainage area of a project, as well as the major drainage basin in which a project was located. To estimate the river flows at a project, USGS historic stream flow records for each of the 28 major drainage basins in New York State were evaluated (Figure 4-2).

Figure 4-2. Delineation of Major Drainage Basins in New York State (modified from http://www.dec.ny.gov/lands/56800.html)



Representative streams were chosen based on a typical river size and the period of record for available data. Based on this representative stream flow data, unit flow duration curves (flow/square mile/percent duration) were developed for major drainage basin (Figure 4-3). For each project, the unit flow duration curve is multiplied by the project drainage area to estimate the full river duration curve. For both powered and non-powered dams, turbine design flows were assumed to be the 25 percent exceedance flow. However, as described below, additional steps to finalize the duration curve were required for powered dams.

Figure 4-3. Unit Flow Duration Curve for the Black River



For the evaluation of available flow at FERC-authorized hydroelectric projects, the hydraulic capacity of any existing turbines needed to be considered and factored into the flow analysis. Also, to operate as a fish bypass, the Alden turbine must be the first unit turned on and last one turned off as river flow changes to ensure a safe passage route is available for downstream migrants throughout specified migration periods for all species of interest. When estimating the suitability of the hydraulic turbine capacity it is assumed that a minimum of 500 cfs is exceeded 25 percent of the year. For existing powered dams, this flow value must consider the hydraulic capacity of any existing turbines. At powered dams, there is some potential that an owner will allocate some existing turbine flows to the Alden turbine to allow for operation. However, the use of existing turbine flows has not been considered in calculations as the lower allowable flow limit for turbine suitability has already been decreased by about 15 percent.

For sites where drainage area data were not available, some estimation attempts were made using the USGS StreamStats program. The focus for filling in missing information was on the FERC projects due to the relatively low number of these sites.

When evaluating projects for suitable characteristics, head was evaluated first. For each project listed in the Excel dataset, an additional column was added to generate the project head. The cell was programmed to review the head and dam height information provided in each database for an individual project and returned the FERC value if available. If no FERC value was available, it looked at any NID or DEC values and returned 75 percent of the higher height listed if the values differed. The reason for evaluating the higher value was due to the number of erroneous zero values scattered in the datasets which could produce false results. Following the development of a single head value within the master dataset, all projects were sorted based on this value. As mentioned, suitable head for the Alden turbine is between approximately 30 and 120 ft; however, to account for uncertainty in head data, projects with heads reported between 25 and 140 ft were considered. Therefore, all projects with head values estimated at less than 25 or greater than 140 ft were deleted from the master dataset.

Following the removal of projects due to insufficient head, the remaining projects were evaluated based on flow estimations. Similar to the head evaluation, an additional column was added to the master dataset. For each project, the cell looked up the calculated 25 percent unit flow value based on the major drainage basin and then searched for the greater of the NID or DEC recorded project drainage area. The cell multiplied the unit flow by the drainage area to estimate the 25 percent duration flow. For powered dams, the cell also adjusted the flow duration curve to account for the hydraulic capacity of any existing turbines. Suitable minimum flow for the Alden turbine is about 600 cfs; however to account for uncertainty in the data, a minimum cutoff of 500 cfs was used. Projects whose available 25 percent duration flow was less than 500 cfs were removed from the master dataset.

4.3.2 Evaluation of Turbine Characteristics- Diameter, Rotational Speed, and Power

Alden turbine design and operational characteristics associated with particular head and flow values that were included in this evaluation are the runner diameter, rotational speed, and power output. All projects, regardless of whether they are powered or non-powered dams, were evaluated for size and speed using the same methodology because it is a function of the turbine design rather than site characteristics.

Reasonable runner diameters for the Alden turbine are between approximately eight and 15 ft. At diameters below eight ft the physical spacing of turbine components (i.e., turbine blades and wicket gates) will decrease the biological effectiveness of the turbine (reduced spacing results in greater probabilities that a fish will be struck by a blade). Diameters of an excessive size will likely result in an uneconomical installation. Suitable rotational speeds for the Alden turbine are between 90 and 140 rpm. At speeds below 90 rpm, an Alden turbine will typically require large and costly generators, whereas units exceeding about 140 rpm will also reduce the unit's biological effectiveness (i.e., greater probability of blade strike).

Based on known properties of the turbine for operational conditions tested in the scaled model, the properties of the turbine under alternative head and flow conditions can be determined. Equations (1) and (2) describe the affinity laws as they relate to the flow and head of a turbine.

$$Q_r = n_r D_r^3 \quad (1)$$

$$H_r = n_r^2 D_r^2 \quad (2)$$

Where:

Q_r=Flow ratio
n_r= Speed ratio
D_r = Diameter ratio
H_r = Head ratio

Rearrangement of equations (1) and (2) yield equations (3) and (4).

$$D_r = \frac{D_2}{D_1} = \frac{(Q_2/Q_1)^{0.5}}{(H_2/H_1)^{0.25}} \quad (3)$$

$$n_r = \frac{n_2}{n_1} = \frac{Q_2/Q_1}{D_r^3} \quad (4)$$

Using equations (3) and (4) in conjunction with a known set of turbine parameters (Q_1, H_1, N_1, D_1) and a set of potential site parameters (Q_2, H_2), the remaining turbine (D_2, N_2) characteristics can be calculated.

Using this methodology, two additional columns were added to the master dataset for each of the remaining projects which were found to have suitable head and flow characteristics. Using equation (3), the head and flow characteristics of a particular site were related to those of the Voith Hydro turbine model testing (EPRI 2011a) to estimate the diameter associated with the site. Similarly, in the adjacent cell of the master datasheet, equation (4) was applied based on the calculated diameter and how the site flow characteristics relate to the Voith Hydro model testing to estimate the turbine rpm.

Following the estimation of project turbine diameter and speed, adjustments were made to the flow rates for those turbines whose characteristics were outside of the defined guidelines. As a result, some projects still remained outside the guidelines with respect to their operational speed. Due to the preliminary nature of this evaluation as well as the need to review these guidelines on project specific basis, these projects were retained in the dataset for further consideration.

Upon calculation of diameter and speed estimates, the power potential of a site was estimated. The power potential of a site is dependent on available river flows and available net head. The efficiency of an Alden turbine will vary depending on the operating point (i.e., as determined by head and flow), but will perform with a peak efficiency of about 94 percent based on model tests conducted by Voith Hydro. The power formula used to estimate output of hydro turbines is shown as equation 5.

$$P = \frac{QHe}{11.81} \qquad (5)$$

Where:

P= Power (kW)
Q= Flow (cfs)
H = Head (ft)
e= Efficiency

4.3.3 Biology

Biological considerations for sites where the turbine has potential for application are primarily related to species presence and abundance as well as the need to provide downstream passage in a safe, timely manner. Occurrence of state and/or federally-listed endangered or threatened species will also be important, but is not considered an issue that would prevent the installation of a turbine since survival rates for such species passing through the turbine could be higher than alternative routes (i.e., spillways, gates, and downstream bypasses). The greatest biological benefits achieved with the turbine may be at dams with anadromous (salmon or steelhead trout, American shad, river herring) or catadromous (American eel) species, or which have abundant resident riverine species that may encounter high turbine entrainment rates during seasonal migrations to spawning, rearing, or overwintering areas within a river basin.

5 Market Potential Analysis Results

Utilizing the methodology described in section 4, the majority of projects listed in the in the master dataset were eliminated from further consideration due to inadequate flow or head conditions. No projects were eliminated from consideration due to unit size or speed limitations. Figures 5-1 and 5-2 provide the location of powered and non-powered projects with potential to accommodate an Alden turbine. It is important to understand that these projects have been evaluated in a preliminary manner with respect to their technical characteristics (i.e., head, flow, diameter, rpm). Further assessment of the feasibility including an evaluation of the actual installation location and project economics will be required.

A total of 24 powered projects and ten non-powered projects were identified as potentially having sufficient head and flow resources to operate an Alden turbine. Although some effort was made to identify potential fatal flaws associated with the projects, additional investigations and design will be required to pursue an installation at these identified projects.

Tables 5-1 and 5-2 summarize pertinent data associated with the sites identified as having potential for an Alden turbine installation. It is important to conduct further investigations including reconnaissance of the identified projects to further understand the project flows, operational regime, and physical characteristics of the site as well as an owner interview.

The initial review of non-powered projects indicated that 29 sites had sufficient resources to support an Alden turbine installation. Upon further review of these projects, it was found that 19 of them are listed as hydroelectric facilities but do not have FERC project numbers. It has been assumed that these hydro facilities are non-jurisdictional and therefore, not subject to FERC's regulatory authority. These projects were subsequently removed from further consideration since a method to estimate the existing turbine flows was unavailable. Similarly, the remaining non-powered projects will require additional investigation to definitively determine site-specific suitability for the Alden turbine.

Table 5-1. Summary of Potential Powered Dams

Dam Name	FERC Project No.	NIDID	Head (ft)	River	Existing Turbine Capacity (cfs)	25% Duration Flow (cfs)	Available Flow (cfs)	Alden Turbine Flow (cfs)	Diameter (ft)	RPM	Power (kW)
South Glens Falls	02385	NY00140	46	Hudson River	4084	6344	2260	900	11.7	92	3000
Robert Moses - St. Lawrence	02000	NY00678	81	St. Lawrence River	150400	279116	128716	2000	15.1	94	11700
School Street	02539	NY00173	96	Mohawk River	4950	9013	4063	1500	12.7	120	10400
Glens Falls	02385	NY00140	44	Hudson River	4084	6344	2260	850	11.5	92	2700
Black River	02569	NY00635	33	Black River	3210	5373	2163	600	10.4	88	1400
Kosterville - Mill B	02548	---	30	Moose River	540	2507	1967	600	10.6	82	1300
Beebee Island	02538	NY00546	32	Black River	3600	5471	1871	600	10.5	86	1400
Deferiet	02569	NY00297	46	Black River	3441	5260	1819	900	11.7	92	3000

Table 5-1. (continued)

Dam Name	FERC Project No.	NIDID	Head (ft)	River	Existing Turbine Capacity (cfs)	25% Duration Flow (cfs)	Available Flow (cfs)	Alden Turbine Flow (cfs)	Diameter (ft)	RPM	Power (kW)
Station 2	02582	NY00690	85	Genesee River	2250	3690	1440	1440	12.7	115	8800
Lyons Falls - Mill 3	02548	NY01503	64	Black River	1170	2518	1348	1348	13.2	96	6200
Sugar Island	02320	NY00248	56	Raquette River	1190	2447	1257	1257	13.2	90	5100
Gouldtown - Mill 5 West Channel	02548	NY01539	44	Moose River	670	1389	719	719	10.6	100	2300
Crescent - Dam B	04678	NY00171	27.5	Mohawk River	6000	9011	3011	600	10.9	77	1200
Vischer Ferry	04679	NY00170	27.5	Mohawk River	6000	8828	2828	600	10.9	77	1200
Hannawa	02320	NY00250	78	Raquette River	---	2445	2445	2100	15.7	90	11800
Higley	02320	NY00252	43	Raquette River	---	2411	2411	850	11.6	90	2600

Table 5-1. (continued)

Dam Name	FERC Project No.	NIDID	Head (ft)	River	Existing Turbine Capacity (cfs)	25% Duration Flow (cfs)	Available Flow (cfs)	Alden Turbine Flow (cfs)	Diameter (ft)	RPM	Power (kW)
Kamargo	02569	NY00729	25	Black River	3300	5370	2070	600	11.1	71	1100
Station 26	02584	NY00683	25	Genesee River	2100	3680	1580	600	11.1	71	1100
Delano Island	02442	NY00684	25	Black River	4200	5425	1225	600	11.1	71	1100
Clark Mills Upper	04667	NY00120	27	Battenkill River	---	996	996	600	10.9	76	1200
Theresa	04486	NY00407	70	Indian River	---	675	675	1750	14.7	91	8800
Hailesboro No. 4 Mill - Dam No. 1	06058	NY12194	32	Oswegatchie River	855	1421	566	600	10.5	86	1400
East Norfolk	02330	NY00251	30.4	Raquette	2067	2617	550	600	10.6	83	1300

Table 5-2. Summary of Potential Non-Powered Dams

Dam Name	NIDID	Head (ft)	River	River Basin	25% duration flow (cfs)	Alden Turbine Flow (cfs)	Diameter (ft)	RPM	Power (kW)
Newtown Hoffman Site 5A	NY15054	44	Jackson Creek	Chemung	2209	900	11.8	89	2900
Carry Falls Spillway	NY00261	57	Raquette River	Raquette	2159	1300	13.3	90	5300
Cannonsville	NY00542	78	West Branch Delaware River	Delaware	869	869	10.1	139	4900
Gilboa	NY00176	75	Schoharie Creek	Mohawk	819	819	9.9	139	4400
Muscoot	NY00061	40	Croton River	Lower Hudson	679	679	10.5	95	2000
New Croton Reservoir	NY00046	75	Croton River	Lower Hudson	806	806	9.8	140	4400
Springville	NY00704	30	Cattaraugus Creek	Lake Erie	627	627	10.9	80	1400
Camp Lakeland Pond	NY00589	35	Tr-Bear Creek	Black	5428	650	10.6	88	1600
Diamond Mills	NY00089	26	Esopus Creek	Lower Hudson	909	600	11.0	74	1100
Whitney Point	NY01055	71	Otselic River	Susquehanna	529	600	8.6	156	3100

Figure 5-1. Overview Map of Suitable Powered Project Locations

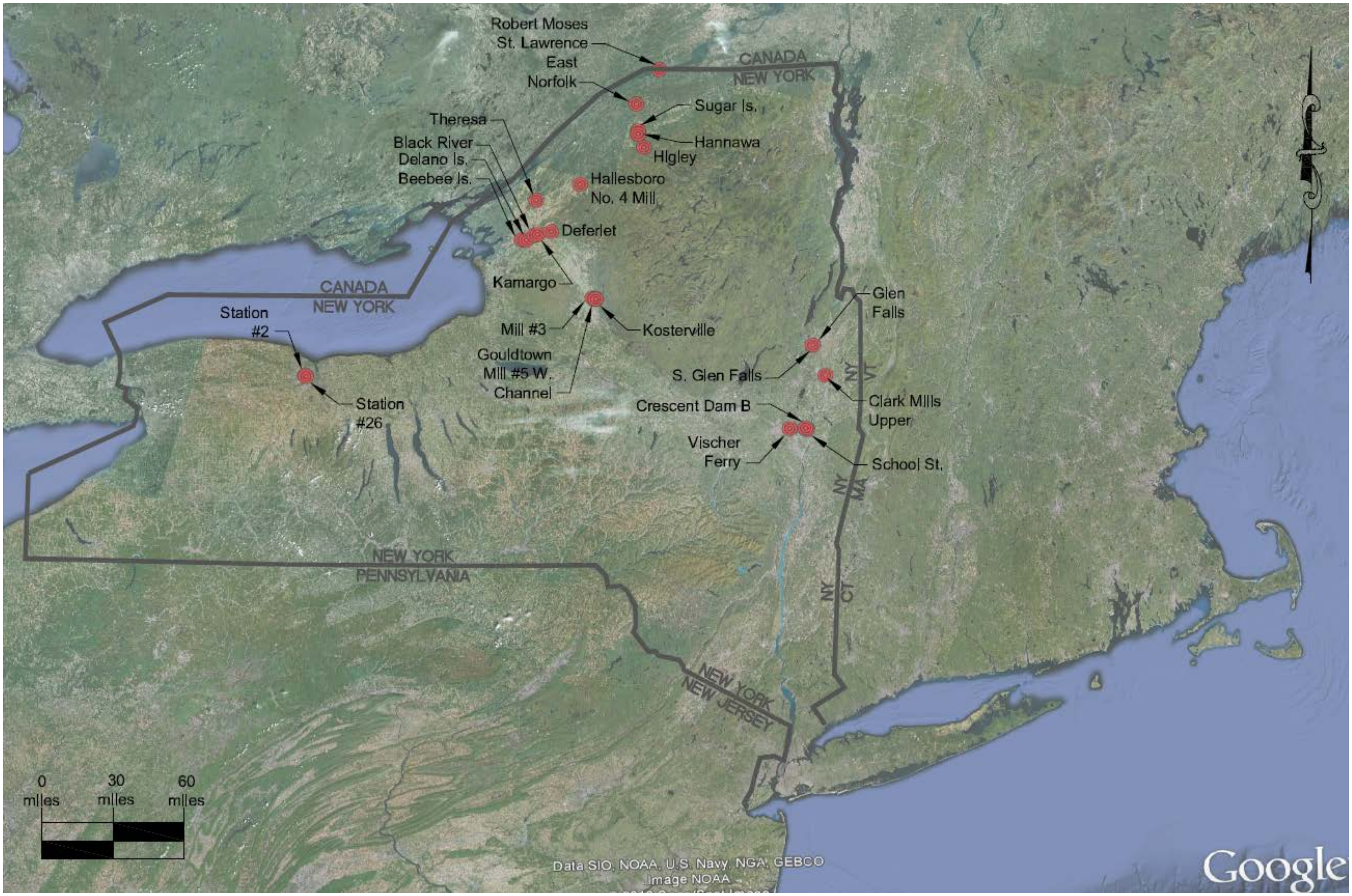
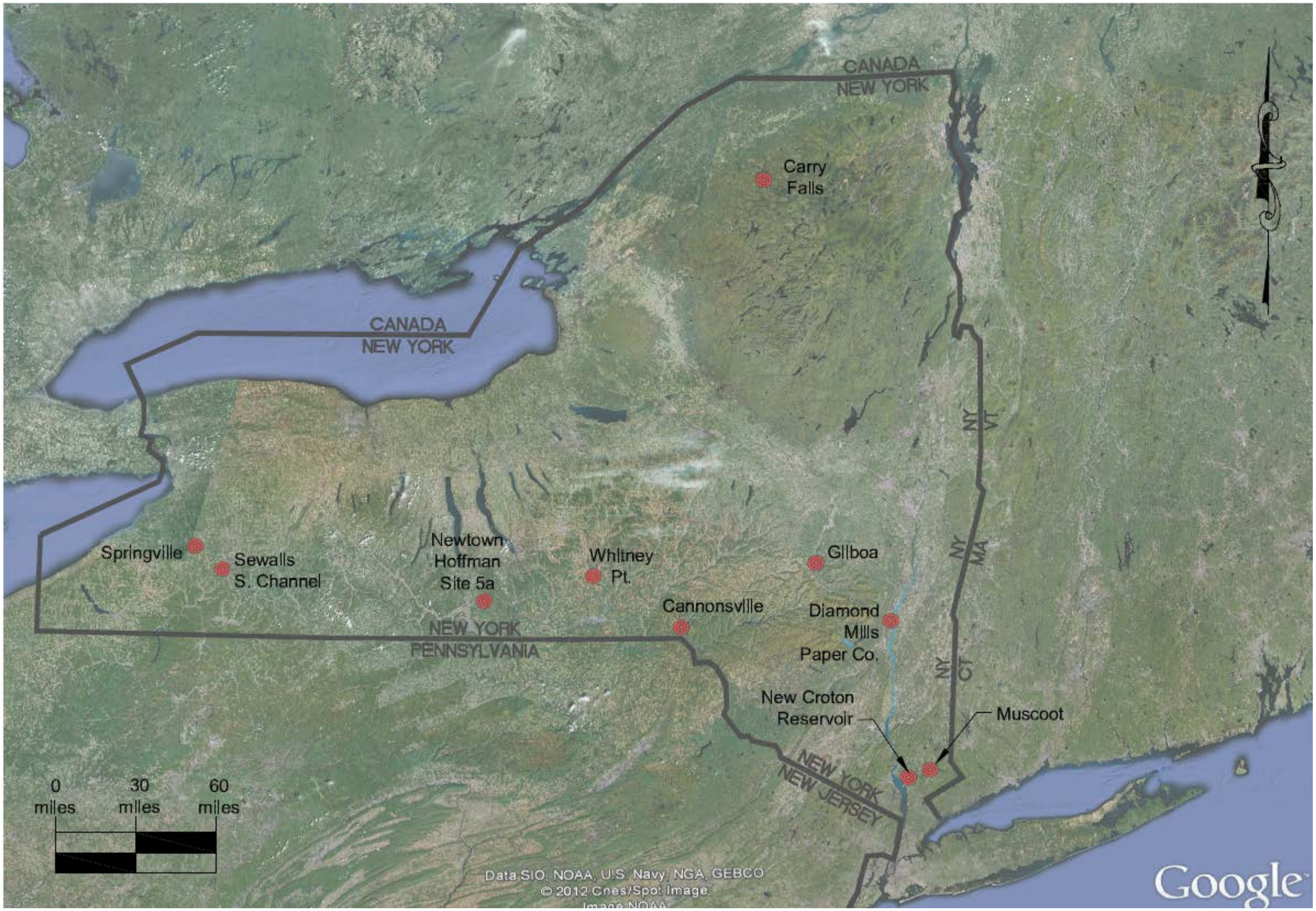


Figure 5-2. Overview Map of Suitable Non-Powered Project Locations



6 Discussion

This report reviewed dam sites within New York State in an effort to understand the market potential for the Alden turbine. The turbine may assist New York State in meeting its future RPS goal by increasing hydro generation in environmentally-friendly manner. Following analysis of the available data, a total of 33 sites were identified as having potential to support an Alden turbine installation.

As shown in Tables 5-1and 5-2, potential projects are located throughout New York State. Table 6-1 presents the number of potential sites on each of the 18 rivers identified.

Table 6-1. Potential Alden Turbine Installation Sites by River

River	Number of Projects Suitable for Alden Turbine	River	Number of Projects Suitable for Alden Turbine
Black	6	Battenkill	1
Raquette	5	Indian	1
Moose	2	Oswegatchie	1
Genesee	2	Jackson Creek	1
Hudson	2	Schoharie	1
St. Lawrence	1	Croton	2
Mohawk	3	Cattaraugus Creek	1
Ostelic	1	Tr-Bear Creek	1
Delaware	1	Esopus	1

Turbines sized for the projects identified as being suitable range in diameter from about eight to 15 ft and are estimated to produce between one and 12 MW per turbine. Assuming only one Alden turbine installation per dam site, the total power potential for the Alden turbine is estimated at about 120 MW. A review of the data provided by FERC indicated that the current existing authorized hydropower capacity in New York State is about 6,100 MW (FERC 2012); therefore, the addition of approximately 120 MW would result in an approximate two percent increase in capacity.

Results of this market potential analysis indicated that there are suitable dam sites in New York State for the installation of the turbine. However, further site specific investigations are required due to limitations associated with the head and flow data. In addition to further reviewing site characteristics, additional investigations should include owner questionnaires, site visits, and preliminary engineering evaluations that include cost estimates to better define the feasibility of an Alden turbine installation. Due to the assumptions made regarding flow head and flow characteristics as well as the limitations associated with the database information, there is a potential that some additional development may be available in New York State.

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Alden Turbine Market Analysis for New York State

Final Report
September 2012

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