

Masters Program in **Geospatial Technologies**



Multicriteria Suitability Modeling for In-river Hydrokinetic Turbines

Case of the Hudson River

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Dissertation submitted in partial fulfilment of the requirements
for the Degree of *Master of Science in Geospatial Technologies*

**Multicriteria Suitability Modeling for In-river Hydrokinetic
Turbines:
Case of the Hudson River**

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February de 2022

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ABSTRACT

The energy of water flowing through rivers 24/7 is one of the most reliable constant forms of clean energy available nowadays, and the potential of hydrokinetic power exploitation is rapidly growing. In this project we have set a framework that traces the hydrological network of the Hudson River, combine the available data on and around the region, considering the physical aspect of the stream; bathymetry and power density, the environmental aspect; protected and critical areas, and the socioeconomic aspect; accessibility and proximity to populated regions, and eventually pick the installation sites of the Hydrokinetic turbines over the stream. Moreover, we were able to explicate the parallels between the different approaches for this same purpose, bringing their differences into relief, while selecting the methodology that best fits the nature of our study. This project is a conceptual framework for articulating experimental guidelines to this state-of-the-art technology of river Hydrokinetic energy converters, to ultimately help decision makers consider more sustainable projects like In-stream-hydro systems as a practical support for the electrical grid, to aid secluded communities, and those surrounding old dammed structures recover. The ultimate goal is to obtain enough energy from clean power sources while making sure that the impact of these energy resources on the environment, economy and society is reduced methodically. The results revealed that: It is possible to effectively take in consideration different aspects

(physical, environmental, and socioeconomical) that affect the deployment strategy of the turbines' locations. Selecting the regions over the Hudson River, with the highest potential can be done with more than one method, (the weighted overlay method gave the best results). The picked-out sites of both methods designate regions where high-velocity streams were located, with over 5 meters depth, proximity to populated areas, access to the road network and electrical grid, while maintaining proper distance from the environmental sensitive and protected areas. The validation of these suitable locations however needs further on-site assessment. Although river flow is considerably slower than tides and ocean currents, when the river is perennial (continuous baseflow throughout the year), or have perennial tributaries (free flowing stream that discharges into the main river channel), it provides constant energy flow that can be harnessed using the power turbines, all year long. This project establishes the significance of incorporating different themes in pinpointing the suitable locations, using solely a GIS-based multi-Criteria analysis approach (MCA), without relying on any other equipment. And it is feasible as long as the necessary data is available.

KEYWORDS

Hydrokinetic power

Hudson River

Hydrokinetic turbine

In-stream-hydro system

Perennial tributaries

GIS

Multi-Criteria analysis

ACRONYMS

GIS – Geographic information System

MCA – Multi-Criteria Analysis

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1. INTRODUCTION

On December 7, 1972. the first image of our planet was taken from a distance of 29,000 kilometers from the surface, by the Apollo 17 crew, it was given the name "The Blue Marble". our earth has about 71% of its surface covered by water in constant movement according to statistics. This continuity of movement is what inspired this project, we believe that deploying a network of low-flow turbines throughout slow moving water like rivers and shores, harnessing this energy, alimentering the electrical grid, is the way to exploit this hydrokinetic energy properly, to give the Hydropower domain the push it needs, and build it up to the new "Go-To" renewable source of energy, especially that water is more powerful than wind at the same speed, and provides a 24/7 energy output, unlike solar energy, which further adds to the idea that there is a clear underestimation of the Hydro-energy potential.

When people talk about renewable energies, the mind quickly jumps to Photovoltaic- or Eolic-energy, and although these energies have grown as clean and sustainable power sources, the most frequently used clean energy source today is Hydropower, Moran, E. F., et al. (2018). This fact is partly due to the large number of dams worldwide that provide this type of energy. It is also often that we hear the term "Hydrokinetic", lately that this new technology is becoming more and more popular. Hydrokinetic energy is the conversion of kinetic energy of river and tidal currents, waves, or even man-made water channels into electricity, Güney, M. S., et al. (2010), by using in-river hydrokinetic turbines, placed systematically on the stream of water, to collect the largest possible amount of power. Thus, scholars and engineers are coming up with new measures to do that, and uncovering efficient low-head, low-flow turbines that can bypass the slow water movement issues. However, considering how case sensitive this matter is, there is multiple things to consider; like if the energy potential is high enough for the energy to be harnessed? what turbine to use for which case? How to locate the site of installation? also how to maintain efficiency of the system?

It is no surprise that most of the Hydro-energy today is generated by dams, Moran, E. F., et al. (2018). These dams also provide water to the surrounding communities, therefor, the economic and social benefits of dams are undeniable. However, more

evidence shows that the drawbacks of these massive structures, ultimately on the river ecosystem and their contribution to the global warming pollution are to be considered, Magilligan, F. J., et al (2016). These dams also have an expiration date, which leads to dam removals; a very costly process and nowadays very common. Old and out of use dams are being removed every day, in the US alone, according to the American government officials; there have been 69 dam removals, just in the year 2020. These removals are inevitable, expensive and have detrimental effect on the communities and ecosystems around the dam, often heavily dependent on irrigation and electricity that the dam produces, • Fox, C. A., et al (2016). But on the other hand, eventually, the stream flow picks up its pace and the rivers ecosystem recover over time, which only adds to the challenge in replacing this enormous power output of the removed facilities, generically with an even more eco-friendly process.

Nowadays, the global energy demand is exponentially rising, and with it the impact on the environment. With the increase of the projected demand, we can find good kinetic energy conversion systems considered as alternatives, such as; clean renewable. There are numerous projects worldwide dedicated to exploit this viable energy source, like converting stream power to electric power, by using what is referred to as In-stream Hydrokinetic systems, Niebuhr, C. M., et al (2019).

As a first step in this approach, resource mapping is regarded to be an essential point to begin with. Then comes investigating the potential of the stream power conversion systems over our study region the Hudson River estuary. Although, the tidal stream power conversion systems are overwhelming in this field of renewable hydropower conversion projects. The river based kinetic power conversion systems on the other hand are not falling behind, but due to river streams low speed and power potential, it has more challenges then the prior. But lately, we can witness a significant amplification of the projects worldwide. Thanks to all the new developments and technologies in this field, these kinetic systems are substantially affordable and more efficient.

The choice of the Hudson River location is mainly due to the wide variety of the hydrological and environmental data available for this area. And to do so, using methodologies from the literature to analyze the kinetic river power potential, incorporating the necessary physical, environmental and socioeconomical layers,

gathered and filtered using GIS tools and software, will help eventually conclude suitability maps for specific variables.

In this paper: First, we will discuss the constraints and factors of the river stream kinetic power conversion systems, and the literature review of this field of research. Then the use of multicriteria analysis in energy potential projects, data selection process, pre-processing, ranking of the suitable areas. Followed by a detailed presentation of the application of the procedure to the Hudson River estuary, to conclude the most suitable locations for the kinetic power conversion system devices on the stream, and eventually, a general conclusion, remarks and future potential of the study.

2. LITERATURE REVIEW

The growing demand on renewable energy due to pollution and climate change, is the main motive behind the advancement made in the research field of this subject in the last few decades, but considering the great progress made by the Hydrokinetic technologies, they are today compared to other sustainable energy resources like Photovoltaic and Eolic, although we still have a long way to go.

2.1. Hydro-power conversion systems

First of all, it is extremely important for the project to have an overall idea about the In-stream hydrokinetic turbines, and the state-of-the-art of these systems in sea and in river-based applications, the size, cut-in speed and efficiency of these devices is key for a proper selection of the suitable locations.

Unlike solar energy resources, that provide electricity only when sunlight is present. Harnessing energy from the ever-flowing streams of water around the world, is a 24/7 process, in addition to the fact that moving waters energy potential is far greater than winds, for the same speed. (Ibrahim et al., 2021) gave a full review of the state-of-the-art of these systems in sea- and river-based applications. The hydrokinetic systems can be classified into turbine and non-turbine systems, and although the ideal turbine is case relative, it was concluded that "the vertical axis turbine is preferable for river applications due to its small capacity, practicality, and cost-saving. Nevertheless, the non-turbine system is still a new research concept that requires further studies to test its reliability and practically for energy harnessing", on the other hand there is a number of pre-commercial tested prototypes in river settings on the market currently. Another interesting review by Elbatran, A. H. et al. (2021), it provides two ways of classifying turbines; "The first one consists of five technologies: dammed reservoir, run of river, pumped storage, in stream technology and new technology gravitational vortex. The other one is classified according to power scale is Large, Small, Mini, Micro and Pico Hydropower". A review with a more emphasis on applicability and potential worth mentioning is by Niebuhr, C. M. et al. (2019). Moreover, a detailed technology status

review, of the Hydrokinetic energy conversion systems and assessment of horizontal and vertical axis turbines for river and tidal applications, is discerned by Khan, M. J. et al. (2009). this paper gives a great deal of options for turbine sitting techniques considering channel cross-section (bottom, floating, or near-surface/fixed). As of a time perspective of the progression made by these systems back in 2009. Going about the literature, a remarkable skew is viewed towards the vertical axis current turbine class, Yain, N. M. et al. (2020) gives a more thorough experimental investigation of the matter. Results are presented in table-form for this class of turbines commonly used to function in low current speeds (0.32 m/s - 0.64 m/s).

The energy output of these systems in rivers is relatively low due to this low current speed, but also due to damming structures, free-flowing rivers systems produce considerably more energy output (about 0.5-5 kW), Sornes, K. (2010) discusses the application of these hydrokinetic turbine systems in free-flowing rivers, a review of the commercial market, and also existing turbine technologies are outlined, but this was back in 2010. However, in this era of rapidly changing technologies, we now have Hydrokinetic turbines for moderate sized rivers (Kirke, B., 2020) and even portable Hydrokinetic power generators (Alves, N., 2018). And the “Savonius” Rotor (DESAI, R. et al., 2019) which is THE state-of-the-art technology of the hydrokinetic conversion devices, it is called “Waterotor”, and it has a software-developed blade, that can handle namely; solid, liquid and viscous fluid without damaging any parts, and can efficiently harness energy from very low current streams (as low as 0,8 m/s =1,55 knots) without harming the fish and wildlife swimming by, as it has moderating and smoothing flow rates that reduces erosion, protects shorelines and provide slower moving pools behind each rotor. One unit of this device would cost approximately 5000 US dollars, more information about the cost of these devices and other turbines from different companies around the world is presented in the paper (Kirke, B., 2020).

Recently, there has been case studies around the world to optimize hydrokinetic usage and papers to support the future projects on the subject, although most of them accent the tidal hydro power conversion systems, rather than the river hydrokinetic conversion ones, but most of the methodologies used are equally relevant for both uses. Like in the case of the study for the Georgia state coastline USA by Defne, Z. et al. (2011), highlighting a structural data selection and classification methodology, that has a socioeconomic assessment of the site selection process, bearing the environmental

aspect in the picture, we will be using it as a guideline for our data collection and classification in the project. Also continuing in the United States coastline, Haas, K. (2011,2013). And similarly, around the world, like in Brazil by Van Els, R. H., & Junior, A. C. P. B. (2015). Spain by Fuentes-Bargues, J. L., & Ferrer-Gisbert, P. S. (2015). South Africa by Niebuhr, C. M. (2018). Congo by Bracco, G., & Dinglasan, J. E. (2018). the US's Californian coast by Leiker, S. S. (2018). Vietnam by Chien, F. et al. (2020). The Amazon basin by Chaudhari, S. et al. (2021). Egypt by Eshra, N. M. et al. (2021). Sarawak, Malaysia by Tan, K. W. (2021). Comparing the diverse methodologies used in different parts of the globe, helped conceptualize the site selection process in use in our own project.

2.2. Multicriteria analysis

According to Wang, J. J., et al. (2009), multi-criteria decision analysis (MCDA) is “a form of integrated sustainability evaluation. It is an operational evaluation and decision support approach that is suitable for addressing complex problems featuring high uncertainty, conflicting objectives, different forms of data and information, multi interests and perspectives, and the accounting for complex and evolving biophysical and socio-economic systems”, for our project it is key to facilitate the integration of different themes and criteria, in form of datasets, to decide eventually, the most suitable locations for Hydrokinetic turbines on the Hudson river. Accounting for physical, environmental and socioeconomical criteria.

The use of multicriteria analysis (MCA) lately have been widely associated with sustainable hydropower, particularly in the case of Europe and China, where Hydro power exploitation is already significant. The relation between the location where this type of energy exploitation is common and the location of the case studies is well-established; a meta-analysis by Vassoney, E. et al. (2017) aim was to review the state of the art of MCA applications to sustainable hydropower production by analyzing the most relevant scientific papers on the topic over the last 15 years, and concluded that the Analytic Hierarchy Process (AHP) is the most implemented MCA technique. It is flexible, user-friendly and its results can be clearly explained and justified (Supriyasilp et al., 2009). This meta-analysis had selected 45 relevant papers, almost all of them describe real case studies, although many have unspecified information like the criteria

and indicators used, making it hard to perform statistical analyses. The study has concluded “quality indexes” that should be implemented in future MCA applications to sustainable Hydro power planning and management problems, according to the authors. In addition to the fact that a more participatory attitude over the whole modelling process, via a simple and easily accessible pattern, is necessary to facilitate the procedure.

Moreover, going about this project and noting that the matter at hand is very case sensitive, Guitouni, A., & Martel, J. M. (1998) explicitly demonstrate MCDA methods. This paper gives a bigger perspective to what goes on, in the process of determining the ideal MCDA method to use and in which context as the paper’s title implies 'Tentative guidelines to help choosing an appropriate MCDA method'. The scope of the MCDA techniques use is endless, a case study of a large Hydropower project risk assessment, was using the fuzzy analytic hierarchy process (FAHP), to consider the imprecision of subjective judgment. Ribas, J. R. et al. (2019), case study was employed over the Santo Antonio Hydroelectric Plant under construction, to identify risk events using the multi-criteria analysis process. Although this risk assessment process is for a run-of-river hydroelectric plant, it is worth consideration in our project, as the limitations and issues are basically the same. The major pitfall to this research as well as many others is a technique that is called prone to bias (Boyce and Neale, 2006), where the members of the building committee want to prove that the project is running according to plan. Also here, the participatory attitude during the modeling process is required, as stakeholders are more likely to accept and adopt risk management of these elements, because they witnessed and participated in their generation. This involvement of stakeholder is increasingly recognized as an essential element of successful environmental decision making Kiker, G. A. et al. (2005).

On the other hand, there is many papers in the literature that discuss new generation sites, over huge study areas, adapting, a GIS-based multicriteria decision analysis approach. Omitaomu, O. A. et al. (2012) describes just that over the entire contiguous United States. the study induced the Oak Ridge Siting Analysis for power Generation Expansion (OR-SAGE) tool. This tool provides an in-depth analysis for siting options, and takes inputs such as population growth, water availability, environmental indicators, and tectonic and geological hazards for that matter.

In the light of the risk assessment studies done in the subject over the years, we can mention Linkov, I. et al. (2006), that suggests an integration of decision analysis methods with adaptive management, emphasizing the decision analysis portion, so that the adaptive management can only reduce the decisions calculations uncertainty, this is not the first study to propose this combined concept; previous researchers like : Pastorok et al. (1997), Nudds et al. (2003) have suggested that; but we note that it is a successful rigorous application of the process. Schweizer, P. E. et al. (2011) revokes an estimation of the risks of collision or strike to freshwater aquatic organisms resulting from operation of instream hydrokinetic turbines. Moreover, Morimoto, R. (2013) incorporates the social and environmental consideration into the assessment process. Whereas, Ji, Y. et al. (2015) uses an integrated fuzzy entropy-weight multiple criteria decision-making method.

2.3. From Hydropower to In-stream Hydrokinetic

The switch to clean energy power is a very hot topic nowadays, scientists and researchers have anticipated the depletion of fossil fuels decades ago. This switch will also diminish carbon dioxide emissions that come from burning these fuels like coal, oil, or natural gas. It is a known fact that change is scary, perhaps especially when it is good for us, but scientists need to make sure that this unavoidable switch is smooth, that is why most of our problems are thought of far ahead before they occur. Moreover, growing this collective consciousness of these problems in our communities is even harder to accomplish. In our case, we are rooting to make rivers' Hydrokinetic systems a practical substitute to dams' Hydropower.

A dam conserves large amounts of water and releases it through portals with turbines, to convert that kinetic energy into electric energy when needed, most of the big dams' hydropower energy is used by factories and communities around the facilities daily, it is a clean and viable source of energy. On the other hand, dams have expiration dates (50-100 years), especially when maintenance is no longer an option. Factories and industrial facilities can easily relocate after a dam is removed, but communities often reliable on the dam's Hydropower cannot. An interesting paper by Fox, C. A. Et al. (2016) that explores the powerful attachments of the communities to dammed landscapes, uncertainty associated with the ecological impacts of dam removal. And

this is a double-edged sword, as these impacts could be positive or negative; Shuman, J. R. (1995) is describing environmental research being conducted to assess both positive and negative impacts of dam removals, and comparing them to retaining and actively managing the reservoir for fish and wildlife. In the United States, dam removals have been a widely used approach to restore rivers, particularly large ones, thus a number of dams-removal studies have already been accumulating over the last few decades. Foley, M. M. et al. (2017) gives a critical review of the findings of these studies. Another important study in the same scope by Hart, D. D. et al. (2002) is discussing a risk assessment framework for understanding how potential responses to dam removal vary with dam and watershed characteristics.

Also, another concerning subject is how scale relates to these removals; Doyle, M. W. et al. (2005) answers to this question by exploring the impact of small dam removals on the fragile ecosystems surrounding them. Subsequently, to discover this scale's significance in a regional scope, we discern how large dam removals relate to multiple smaller dam removals for the same watershed, the paper by Magilligan, F. J. et al. (2016) describes a GIS database of all inventoried dams in New England irrespective of size and reservoir volume. And attempts to create a strategic removal approach, that has the opportunity to enhance the magnitude and rate of river re-connection. Further discussion about the variation of dams in the paper by Poff, N. L., & Hart, D. D. (2002). To address the problem in hand, it is essential to select an appropriate design of different operational techniques, to eventually have the finest solution for the decision makers, that evaluates various conflicting criteria of different natures, spatial (pluviometry, elevation, temperature...) and non-spatial (economic, environmental, social...). Multiple-criteria decision-making (MCDM) or multiple-criteria decision analysis (MCDA), is combined with the multi-representation GIS (MRGIS), to propose a structured design to accomplish this goal, which allows us to convey the information required to decide adequately. Associating geographical information systems (GIS) and the MCDA comes handy again in this process, this is proposed in the paper by Tikniouine, A. et al. (2006), it also considers spatial and non-spatial criteria in the design.

River Hydrokinetic systems are not going to replace the massive power output of the Hydroelectric power of dams, at least not in the near future, and especially for the industrial use. But it gives a reliable alternative for the communities that previously

depended on dams Hydropower in the past, and also to countless peoples that have no access to the power grid, particularly in third world countries. While reviewing the literature on Hydrokinetic systems, we note that: there is an abundant number of research about the subject, most research has focused on marine Hydrokinetic power conversion. there is an increasing interest in the Hydrokinetic power systems lately, but there is still a lack of robust research on river stream Hydrokinetic power systems, this is the gap that we will address in this project.

3. METHODOLOGY

Three major constraints were designated before data selection; physical, environmental and socioeconomic, Defne, Z. et al. (2011), and the collection of data was done according to these themes. Data incorporation and project constraints are both presented in detail in this section. First of all, we are going to compile the various data in hand in a GIS software database, pre-process the data selected respectively for the project and classifying it into conceptual layers. Secondly, different themes will be presented in a map form, these maps will incorporate the roles of each theme for the kinetic stream power conversion system. Finally, we will make up a suitability map for the relevant themes, the best locations for the power conversion devices will be illustrated.

This section will provide a detailed review of data selection process, contextual layers, their relative datasets components and the suitability mapping used in the relevant locations' selection.

3.1. Data Selection

For this specific region, there is a generous amount of GIS data available, explicitly hydrological data; most of it is open source, distributed between governmental offices, science centres and local agencies. However, the selection and compilation of the data took substantial time and work. GIS portals such as the New York State Department of Environmental Conservation (NYSDEC), and the New York State GIS Data Clearing House, supported facilitating state and country wide geographic data recovering. Nevertheless, data sources and origins differ, which leads to varying projections, datums and resolutions. Moreover, certain data has been converted into special formats in order to be used for specific platforms, thus it is crucial to check the compatibility between the datasets and the platforms in use.

After thorough research of online resources of diverse data sources in different platforms, in accordance with data accessibility, quality and coverage, major data sources for our study have been identified, credited under each dataset below respectively. GIS data collected have been structured and classified under three major

group layers, Defne, Z.et al. (2011); Environmental Restricted Layers, and it includes critical and protected areas, that have cultural, historical, recreational, educational, ecological or even aesthetic value. Socioeconomic Favourable Layers, and this group contains areas with social-economic value, like populated and urban regions, also conveyance coverage (transportation and electricity grid). And lastly and most importantly, Physical Crucial Layers; a bathymetry layer of the Hudson River estuary from Saugerties to Troy and a physical forces model of the river.

3.1.1. Environmental Restricted Layers

These layers contain two main group layers: critical areas layer, and protected areas layer. The first one was provided by New York State Department of Environmental Conservation (NYS DEC), and the second was sourced by both the Division of Environmental Remediation, New York State Department of Environmental Conservation, and the New York State Office of Parks, Recreation and Historic Preservation (OPRHP). A detailed selection of the features was made on the three datasets to extract the relevant data for the project, a more detailed explanation of the datasets from the official websites is provided below.

A visual representation of the combination of the critical and protected datasets is presented in the figure1.

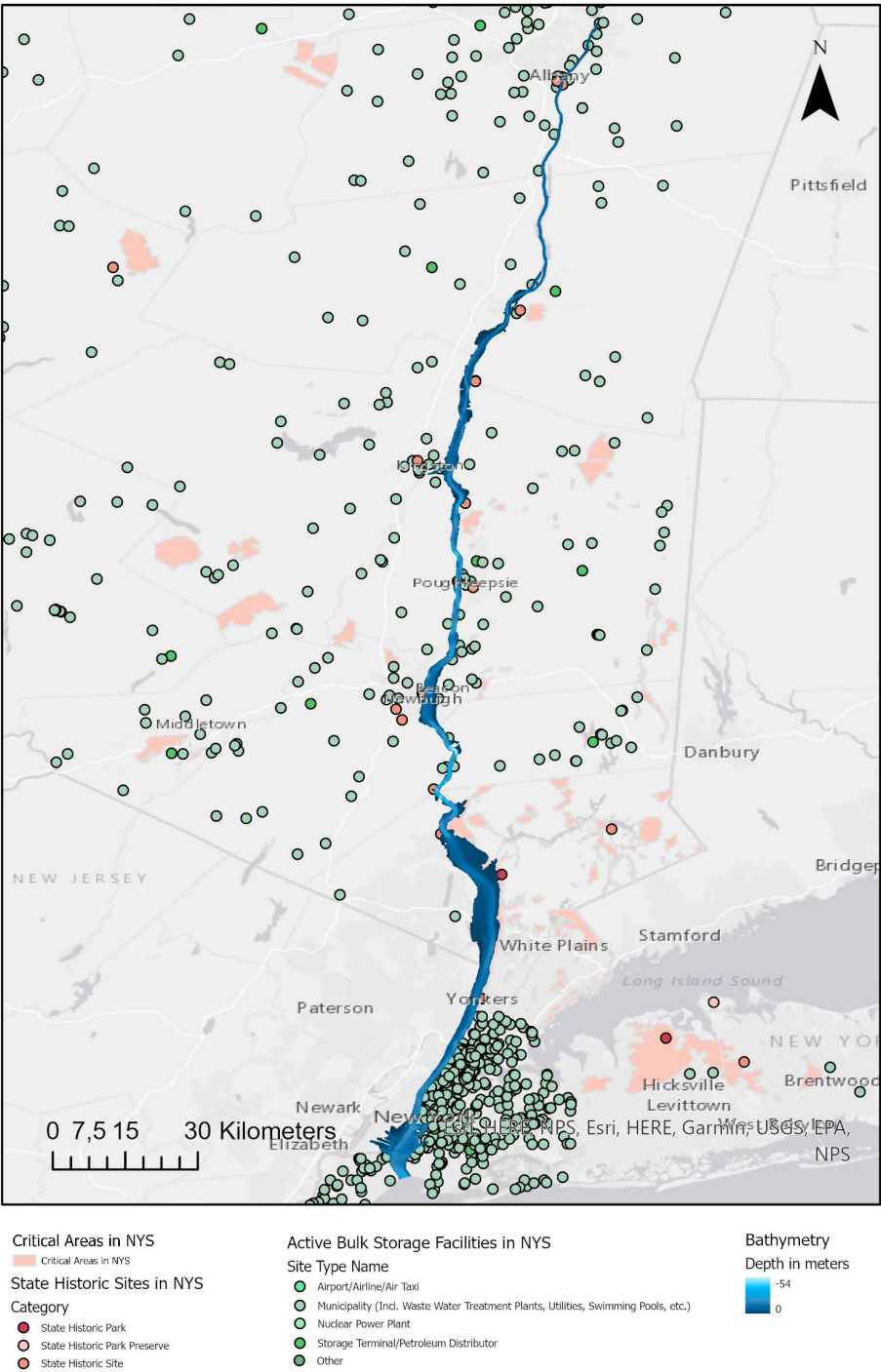


Figure 1 Distribution map of the environmental restricted areas around the Hudson River, New York State Department of Environmental Conservation (NYS DEC), New York State Office of Parks, Recreation and Historic Preservation (OPRHP).

3.1.1.1. Critical Areas dataset: Critical Environmental Areas - New York State (NYSDEC)

“The dataset is a representation of the areas, determined as Critical Environmental Areas (CEAs) under 6 NYCRR Part 617 - State Environmental Quality Review (SEQR). Explicit geographic areas are selected as a Critical Environmental Area (CEA), by local agencies if they fall within their boundaries. Besides, state agencies can designate as a CEA a geographic area which they possess, manage or monitor. To be titled as a CEA, an area must have a remarkable or unique character which has an advantage or threat to human health, a natural setting (e.g. fish and wildlife habitat, forest and vegetation, open space and areas of important aesthetic or scenic quality), agricultural, social, cultural, historic, archaeological, recreational, or educational values, or a deep-rooted ecological, geological or hydrological sensitivity that may be adversely impacted by any change. “

Originators: New York State Department of Environmental Conservation

Publisher: NYS DEC

Publication place: Albany, NY

Publication date: 2013/09/17

Data type: vector digital data

Data format: SDE Feature Class

Dataset credit: New York State Department of Environmental (NYS DEC), Division of Environmental Permits

3.1.1.2. Protected Areas datasets:

3.1.1.2.1. State Historic Sites dataset:

“The locations of the sites were provided by the New York State Office of Parks, Recreation and Historic Preservation (OPRHP), the agency manages more than 250 state parks, historic sites, recreational trails, golf courses, boat launches and more, including nearly 350,000 acres, that are accessed by 74 million people per year. For more information, visit the official website <http://nysparks.com/historic-sites/>.”

Originators: New York State Office of Parks, Recreation and Historic Preservation

Publisher: State of New York

Coverage: Statewide

Publication date: 2013/02/26

Data format: SDE Feature Class

Dataset credit: The New York State Office of Parks, Recreation and Historic Preservation (OPRHP).

3.1.1.2.2. Bulk Storage Facilities in New York State dataset:

“The dataset shows status information for:

- Chemical Bulk Storage (CBS) Facilities conforming to the Hazardous Substance Bulk Storage Law, Article 40 of ECL; and 6 NYCRR 596-599.
- Major Oil Storage Facilities (MOSF) conforming to Article 12 of the Navigation Law and 6 NYCRR Part 610
- Petroleum Bulk Storage (PBS) Facilities registered conforming to title 10 of Article 17 and 6 NYCRR Part 613.

Information may involve: Program Number; Program Type; Site Type Name; Program Facility Name; Address; Locality; County; NYSDEC Region; Tank Number; Tank Location; Tank Status; Install Date; Capacity in Gallons; Tank Type; Close Date; Material Name (of substance in tank); Percent (of material in tank - if hazardous substance - CBS tanks only); Expiration Date; (of license or registration); Site Status Name; UTMX and UTM Y location coordinates.”

Originators: Division of Environmental Remediation, New York State Department of Environmental Conservation

Publisher: NYS DEC

Coverage: Statewide

Publication date: 2016/12/16

Data format: SDE Feature Class

Dataset credit: Division of Environmental Remediation, New York State Department of Environmental Conservation (NYSDEC).

3.1.2. Socioeconomic Favorable Layers:

These layers are considered socioeconomically favorable areas, because they contain conveyance structures such as primary and secondary roads and trails, electric grid coverage and urban areas and regions where the population is concentrated. Close proximity to these areas is favorable and important for the study in hand. Details about each dataset from the official sources is thoroughly presented below.

3.1.2.1. Transmission and Transportation datasets:

3.1.2.1.1. Primary roads dataset: TIGER/Line Shapefile, 2019, nation, U.S., Primary Roads National Shapefile

“The TIGER / Line shapefiles and related database files (.dbf) are an extract of selected geographic and cartographic information from the U.S. Census Bureau's Master Address File (MAF), Topologically Integrated Geographic Encoding and Referencing (TIGER), Database (MTDB). The MTDB serve as a logical national file with no overlaps or gaps between parts, however, each TIGER / Line shapefile is intended to stand alone as an autonomous data set, or they can be joined to cover the entire nation. Primary roads are mostly divided, limited-access highways within the interstate highway system or under State management. These highways are distinguished by the presence of interchanges and accessible by ramps. They also may involve some toll highways. The MAF / TIGER Feature Classification Code (MTFCC) is S1100 for primary roads.”

Originators: US Census Bureau, Department of Commerce

Publisher: US Census Bureau

Coverage: Nationwide / Statewide

Publication date: 2019/06/01

Data format: SDE feature class

Data type: vector digital data

Dataset credit: US Census Bureau, Department of Commerce.

A visual representation of the combination of the transportation and transport datasets is presented in the figure2.

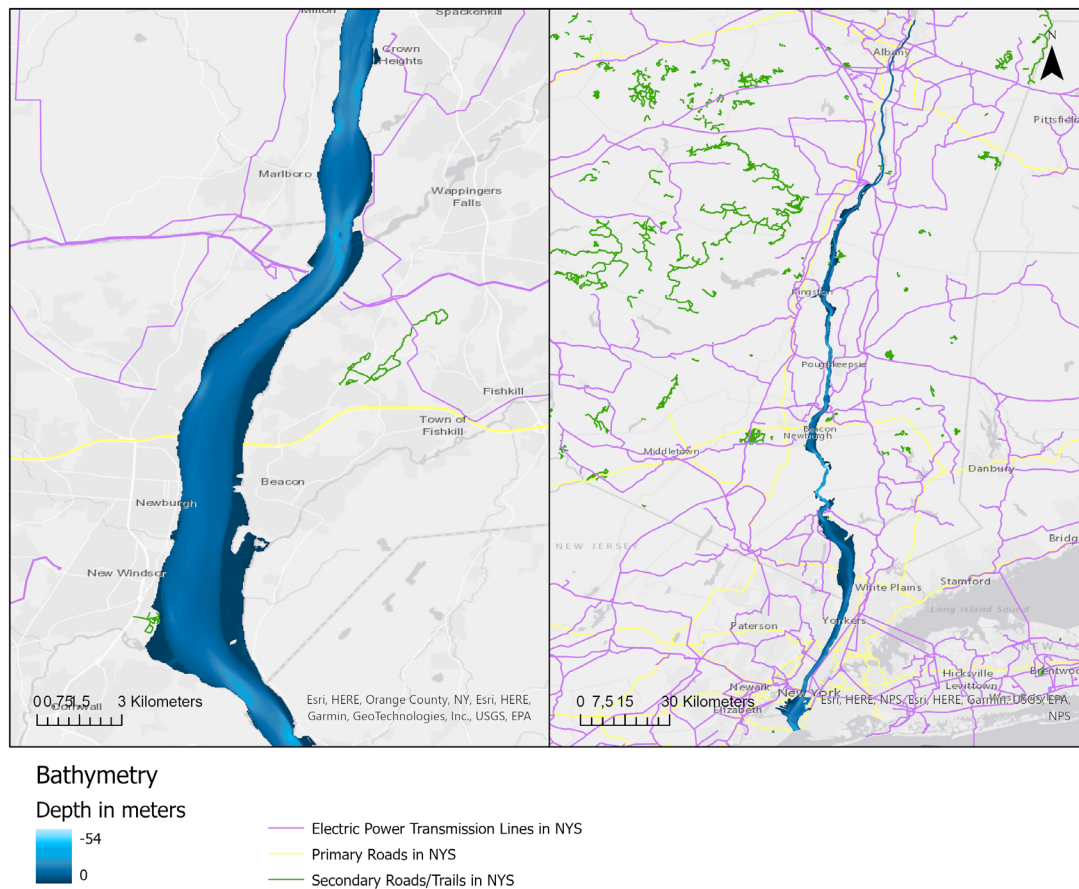


Figure 2 Map of the conveyance coverage over the Hudson River

3.1.2.1.2. Transportation corridors dataset: state Dept. of Environmental Conservation lands

“The dataset is a Line dataset that locates different transportation corridors on state Department of Environmental Conservation lands. The main purpose is to supply with a digital representation of transportation corridors on New York State Department of Environmental Conservation land. It is noted that this coverage is a work in progress. As supplementary roads and trails become digital, they are gathered into a single instance master copy for distribution.”

Originators: New York State Department of Environmental Conservation (NYS DEC)

Publisher: NYS DEC

Coverage: Nationwide / Statewide

Publication Place: Albany, NY

Publication date: 2021/08/27

Data format: SDE feature class

Data type: vector digital data

Dataset credit: New York State Land Transportation, New York State Department of Environmental Conservation (NYSDEC).

3.1.2.1.3. Electric power transmission lines dataset:

“This is a feature class/shapefile dataset, it is by the Homeland Infrastructure Foundation Level Database (HIFLD) (<https://gii.dhs.gov/HIFLD>) for the Energy modelling and simulation community. This feature class/shapefile symbolizes electric power transmission lines. In an electric power system, these transmission lines are the system of structures, wires, insulators and associated hardware that carry electric energy from one point to another.

Lines are operated at relatively high voltages that vary from 69 kV up to 765 kV, and are capable of performing large quantities of electricity over long distances. Underground transmission lines are included where sources were accessible.”

Originators: Homeland Infrastructure Foundation Level Database (HIFLD)

Publisher: HIFLD

Coverage: Nationwide / Statewide

Publication date: 2021/12/23

Data format: SDE Feature Class

Dataset credit: The Homeland Infrastructure Foundation Level Database (HIFLD).

3.1.2.2. Urban and Populated Areas dataset: TIGER/Line Shapefile, 2019, 2010

nation, U.S., 2010 Census Urban Area National

“The TIGER / Line shapefiles and related database files (.dbf) are an extract of selected geographic and cartographic information from the U.S. Census Bureau's Master Address File (MAF), Topologically Integrated Geographic Encoding and Referencing (TIGER), Database (MTDB). The MTDB database represents a nationwide file with no overlaps or gaps between parts, although, each TIGER / Line shapefile can be considered an independent dataset, or they can be combined to cover the entire nation.

After each decennial census, the Census Bureau delineates urban areas that represent densely developed territory, encompassing residential, commercial, and other non-residential urban land uses.

Generally, the "urban footprint" represents areas of high population density and urban land use. Urban areas are: urbanized areas (UAs) that contain more than 50,000 people and urban clusters (UCs) that contain at least 2,500 people, but less than 50,000 people (except in the U.S. Virgin Islands and Guam which each contain urban clusters with populations greater than 50,000)."

Originators: US Census Bureau, Department of Commerce

Publisher: US Census Bureau

Coverage: Nationwide / Statewide

Publication date: 2019/10/04

Data format: SDE Feature Class

Dataset credit: The United States Census Bureau, Department of Commerce.

A visual representation of the combination of the population datasets is presented in the figure3.

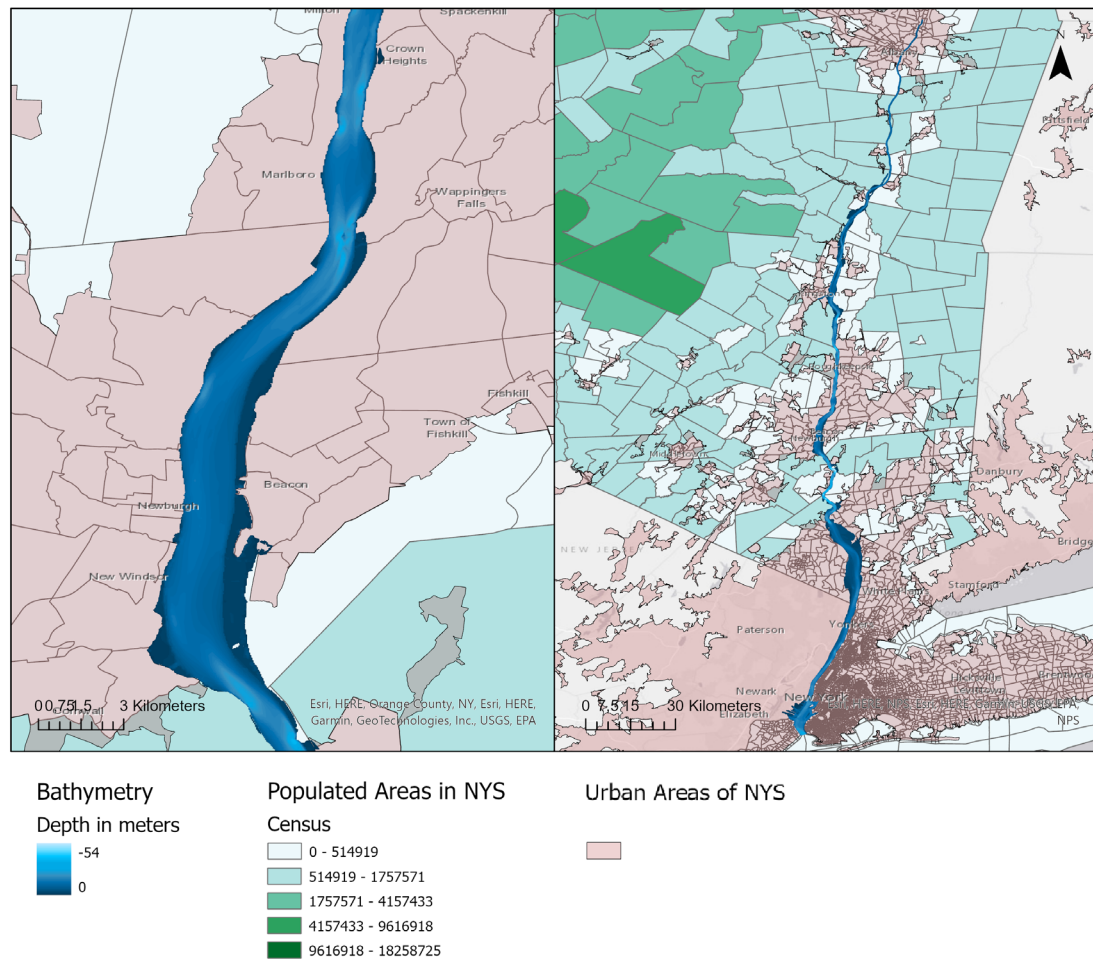


Figure 3 Distribution map of the socioeconomic favourable areas around the Hudson River

3.1.3. Physical Crucial Layers

This group layer represents the filtered set, where the Hydrokinetic turbines are going to be installed, it is intitled “crucial” because every selection needs be inside the premises of the overlay of these layers, it contains a bathymetry layer and a physical forces model layer. The datasets from which these layers where extracted are presented below.

A visual representation of the combination of the physical datasets is presented in the figure 4, bathymetry on the left and the physical forces model on the right.

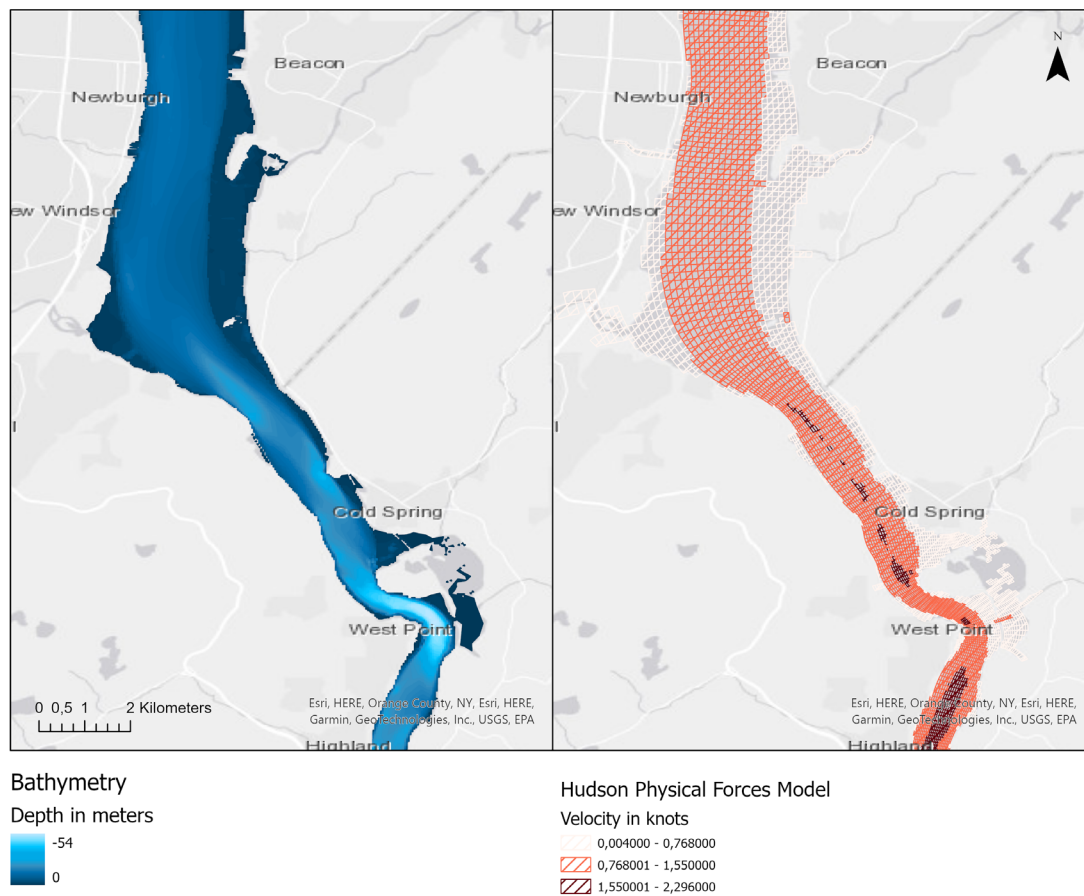


Figure 4 Distribution map of the physical crucial areas in the Hudson River, numerical model by Stevens Institute of Technology

3.1.3.1. Bathymetry dataset: Hudson River Estuary Bathymetry (Saugerties to Troy)

“This composite dataset displays 1-m closed polygon contours for the Hudson River relative to MLLW (Mean Lower Low Water) derived by merging a 10-m gridded dataset originating from SUNY Stony Brook, with the 10-m dataset originating from Fugro. SUNY data was collected during the time period 1998-2003. And from November 6 to December 15, 2009, Fugro data were collected in the estuary north from Saugerties to Troy.

This dataset was built in response to the Hudson River Estuary Action Plan, promulgated by the New York State Department of Environmental Conservation (NYSDEC) and approved by the Governor in 1996.

A mentionable detail is that the third of the estuary was not surveyed before 2009 due to submerged aquatic vegetation beds, thus a detailed bathymetry was not acquired, due to financial constraints, in areas of the river shallower than about 4 meters.”

Originators: Fugro, Roger Flood, Marine Sciences Research Center, State University of New York at Stony Brook

Series name: Hudson River Estuary Program

Series identification: Shallow Water Surveys

Publisher: NYS DEC

Publication place: Albany, NY

Publication date: 2010

Data type: vector digital data

Data format: SDE Feature Class

Dataset credit: Patrick Nissen, Robbie Dame, Jeff Carothers, Gilbert Suarez, Cindy Pratt, Kyle Spencer, Fugro and the New York State Department of Environmental Conservation (NYSDEC)

3.1.3.2. Water Power Density dataset: Hudson Physical Forces Model

“This physical model represents a compilation of simulated riverside water circulation statistics (2010), from a tidal Hudson River’ high resolution numerical model. The main purpose is to provide a characterization of the physical environment affecting the Hudson River shoreline, such as water levels, currents, vertical current stresses and mixing, and surface wind waves.

The Project is led by the New York State Department of Environmental Conservation (NYSDEC) Hudson River National Estuarine Research Reserve (<http://www.hrnerr.org>), in cooperation with the Greenway Conservancy for the Hudson River Valley. Partners in the Project involve the New York State Department of Environmental Conservation (NYSDEC) Hudson River Estuary Program, Stevens Institute of Technology and Cary Institute for Ecosystem Studies.

A partnership between the University of New Hampshire and the National Oceanic and Atmospheric Administration by the name of the National Estuarine Research Reserve System Science Collaborative, supports this project.”

Originators: Nickitas Georgas, John Miller, Stevens Institute of Technology

Series name: Physical Forces Impacting the Hudson River Shoreline

Publisher: Stevens Institute of Technology

Publication place: Hoboken, NJ

Publication date: 2013/05/20

Data type: vector digital data

Dataset credit: At Stevens Institute of Technology, the numerical model was constructed, run, and its output analyzed.

Numerical model bathymetry was based on a combination of latest and newest bathymetric and topographic surveys of the Hudson available in 2011, using geodetic NAVD88 as the bathymetric datum. Bathymetric and topographic datasets from FEMA and bathymetric datasets from the New York State Department of Environmental Conservation (NYSDEC) were merged and used.

Observed 6-minute total water levels at the river's southern mouth in New York Harbor were based on NOS (National Ocean Service) data.

Observed watershed-area-adjusted 15-minute locally distributed river inflows from the Hudson and its tributaries north of the Troy Dam and at tributary heads-of-tide along its tidal coastline were based on USGS (United States Geological Survey) data.

Monthly estimates of distributed water treatment plant effluents at main outfall locations and monthly estimates of distributed power plant inflow and outflow at locations of intakes and outfalls were based on US EPA (United States Environmental Protection Agency) Clearinghouse data.

Wind and barometric pressure forcing acting on the Hudson River's water surface was based on NCEP (National Centre for Environmental Prediction) analysis blending numerical meteorological models and observations.

3.2 Selection of Map regions

The selection methodology is going to be according to the three theme layers previously mentioned, first and most importantly the physical factors, bathymetry and power density, secondly the accessibility facilities and third, the environmental aspect of the regions around the study area. Table 2 features the layers of each theme the content of each layer and the source of each dataset used. The group layer highlighted in red contains critical and protected sensible environmental regions and spots to be avoided during the location selection around the river, and it is tagged "restricted", the socioeconomical layer group marked as "favorable" and highlighted in yellow contains conveyance networks and populated areas, where it is more beneficial to have the power conversion systems in close proximity. And lastly, the physical group layer labeled as

“crucial” and highlighted in green that presents the physical constrains of the stream. Examples of data visualization of each data layer is presented in the figures above, and further explanation of the theme components and their classification will follow below.



Figure 5 Flow chart of the methodology employed in the suitability location mapping (rectangles objects, ovals = actions), Defne, Z.et al. (2011)

The environmental restricted layers, figure 1, contain areas where human industrial activities should be limited, areas that benefit or threaten human health, areas that have

a unique natural setting and value, or ecologically sensitive areas like where endangered species of birds, fish and wildlife are concentrated, area that have social cultural, agricultural, historical, archeological or even recreational and educational value the list of the selected sensitive biological species is sat by the Department of Environmental Conservation of the New York State (NYS DEC), also natural resources extents, historical spots listed by the New York State Office of Parks, Recreation and Historic Preservation (OPRHP). Moreover, sensitive industrial facilities are taken into consideration like bulk storage facilities, petroleum terminals and nuclear power plants, and are avoided and classed as protected areas.

Our second theme of socioeconomic favorable set of layers is given attention because of the promising future local activities expected after the placement of the power conversion systems on the selected locations to meet the demand of the local communities already in place in the socially developed areas, also conveyance network proximity will help in the deployment of the devices in the case of the transportation, this has an environmental aspect to it in addition to the economical one, while close proximity to any trail or road will help avoid the making of any other transportation infrastructures that will certainly disturb the nature and habitat on the way. And on the other hand, transmission, to facilitate the distribution of the electrical power harnessed. The coverage network is explicitly presented in figure 2. Moreover, the urban areas shown in red in figure 3 are already built up and urbanized areas, where as the concentration of population shown in green reflects the non-urban but populated areas to give balance to the selection process. The population dissemination was built on the 2010-2019 US Census data. While the conveyance network was made using the collection of data from the NYS State Land Transportation of the NYS DEC, the Homeland Infrastructure Foundation Level Database (HIFLD) and the US Census bureau.

Before the deployment of the power conversion systems, restricted themes need to be excluded from the selection. Area credited “critical” by the New York State Department of Environmental Conservation (NYS DEC) on and around the Hudson river estuary, as well as industrial bulk storage facilities, in addition to the listed historical sites by the New York State Office of Parks, Recreation and Historic Preservation (OPRHP), have different rules and restrictions when it comes to locating a project site, most of these areas are already buffered and often have varying premises, sometimes for different times of the year, to assess if a certain project is

located or adjoins a state listed critical environmental area, the Department of Environmental Conservation have developed a mapping tool called the EAF Mapper that helps answer these kind of questions, so if the proposed project site is within the borders of a Conserved Environmental Area or is approximate to it, the EAF Mapper will check "yes" on a PDF that can be downloaded. Since the size of the buffers is based on the related regulations when information is available, we cannot strictly determine each buffer size accordingly. In the case of the US, the buffer size for industrial hazardous location, historical sites and environmental restricted areas range between 100 and 800 meters, Defne, Z.et al. (2011). Thus, for the sake of the study we gave each of the critical and protected areas a generous buffer of 5 km and 1 km respectively to avoid falling within the boundaries of any restricted areas. A more detailed presentation of the content of these restricted areas is provided in table 2, and the visualization of the data dissemination is presented in the maps in the figures above.

Stream power conversion devices do not have a regular design. Engineers come with new designs that convert the kinetic energy of the stream more efficiently every day, and for different regions accordingly, but regardless of the design, and considering the in-river stream usage the dimension of the device should fit in a minimum depth of 5 meters, Defne, Z.et al. (2011), and a minimum cut-in speed of at least 0,8 m/s or 1,55 knots ("Waterotor" cut-in speed) to start harnessing energy from the stream flow. Moreover, the devices will be placed in the bottom of the river, so the SDMAX values of the physical forces model were used for the interpretation of the velocity.

We have conducted a Univariate analysis on the SDMAX, which is the Maximum Simulated Value of the Depth-Averaged Current Speed (Magnitude, in knots) , and we can deduct from the descriptive statistics that; SDMAX was produced for 58452 cells over the Hudson River stream, and that the distribution of the SDMAX is positively asymmetric, because the mean is slightly bigger than the median. The results of the analysis are presented in table 1.

<i>SDMAX (knots)</i>	
Mean	1,1998
Standard Error	0,0028
Median	1,153
Standard Deviation	0,6871
Sample Variance	0,4722
Kurtosis	2,1632
Skewness	1,0351
Range	4,613
Minimum	0
Maximum	4,613
Sum	70128,561
Count	58452

Table 1 Summary statistics of the SDMAX

Water power density and bathymetry layers are filtered by the previously mentioned minimum values to extract respectively, the water power filtered set and the bathymetry filtered set, and the two sets are merged into the crucial themes set depicted on the flow chart figure 5.

A visual representation of a suitability map of the stream is embodied in figure 6, where weights descend from 1 unsuitable to 10 most suitable for each of the bathymetry raster on the lower right, where depths of more than 5 meters were given a 10 for the suitability score and lower than 5 meters a score of 1. And a water power density raster on the upper right, where velocity under 1,75 knots (0,9 m/s) was given a 1 score and velocity above that threshold increasing from a 4 to a 10 score. A suitability map ranging from 1 unsuitable to 10 most suitable was given as a result on the left (both rasters were given equal weights given the equal importance), figure 6 represents a visual representation of the suitability prior to the application of the methodology, to see the potential of the suitability before integrating the other layers.

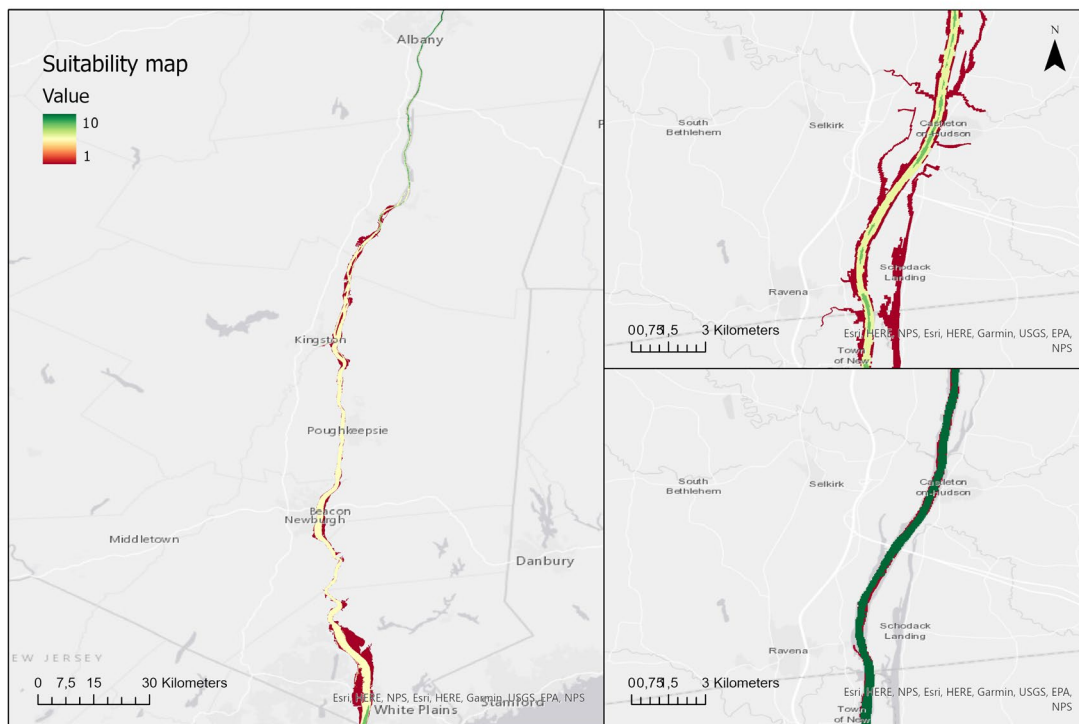


Figure 6 Suitability map of the Hudson River, bathymetry (bottom right), water power density (top right)

For the environmental restricted layers, the critical areas were merged with the protected areas into one set called restricted themes, the features of this set were given a buffer of 5 km for the critical set and 1 km for the protected set, and it is excluded from the previously mentioned crucial themes set, to make the selected set shown in figure 7.

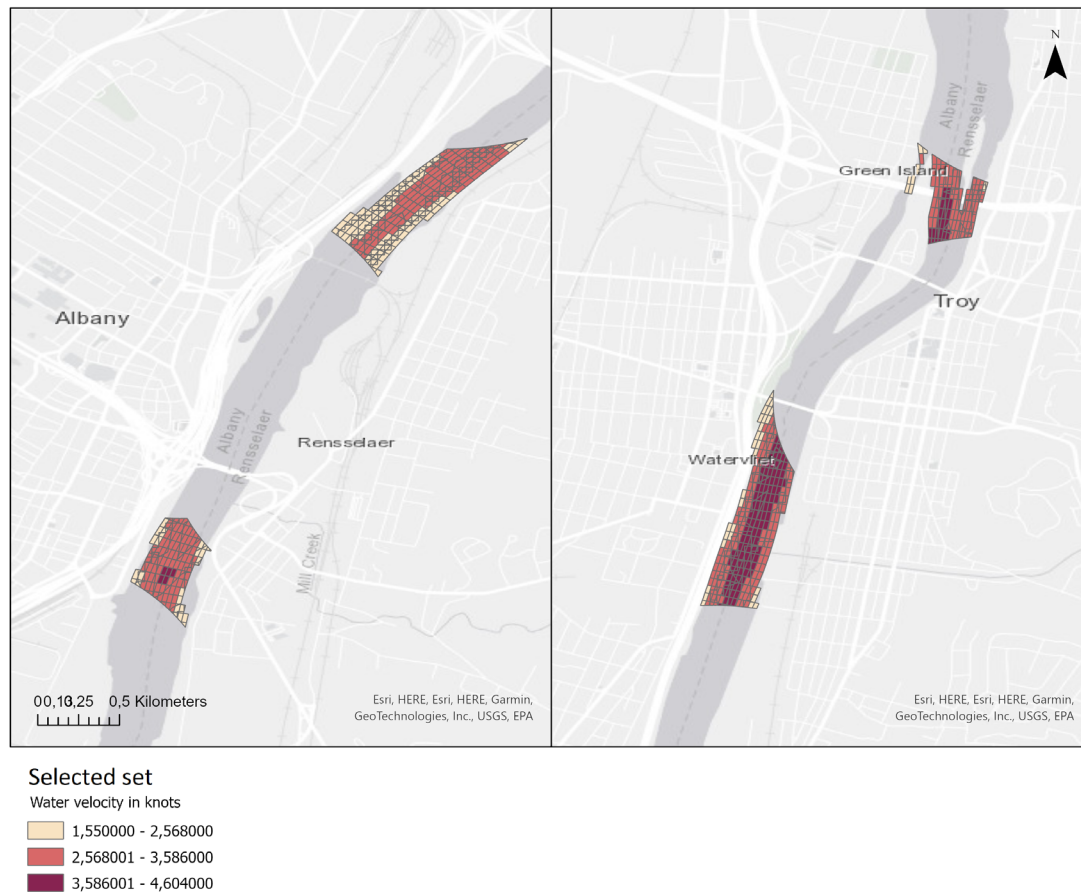


Figure 7 Distribution map of the selected set over the Hudson River

Likewise, the transmission and transportation layers are merged into the conveyance set, the populated set is filtered to select areas of at least 5000 people and merged with urban areas to make the filtered populated set presented in the flow chart. The Euclidean distance is applied to both sets accordingly, and the two sets were reclassified and overlayed using the weighted overlay action, to make the object “Distance to Favorable Set”. Afterwards, we used the suitable set previously stated and selected the areas with more than 0.8 m/s (1,55 knots) depth velocity, and used the resulted object to mask the “Distance to Favorable Set” object, to finally complete the Suitability Map.

Theme	Layer	Content	Source
Environmental Restricted Layers	Critical Areas	Benefit to human health	New York State Department of Environmental Conservation (NYS DEC)
		Benefit to human health & protect drinking water	
		Benefit to human health, natural setting	
		Conserve, improve, protect natural resources	
		Cultural, historical, recreational, educational value	
		Development threat to public health	
		Difficulties w/ portable water source	
		Diverse ecological habitat	
		Drainage and open space resource	
		Environmental sensitivity and unique environmental characteristics	
		Environmentally sensitive	
		Exceptional or unique character	
		Exceptional or unique character as an aesthetically important area	
		Exceptional or unique character	
		Important coastal fish & wildlife habitat	
		Inactive landfill, toxic pollutants present	
		Karst topography, inherent hydrological, geological, ecological, and unique scenic qualities	
		Natural setting	
		Preserve farmland, wetland, & mountain habitat	
		Preserve open space	
		Preserve pure water quality	
		Preserve ridgelines to reduce erosion	
		Preserve wildlife and green areas	
		Primary recharge for well fields	
		Primary source of drinking water	
		Protect Cortland's sole source aquifer	
		Protect Loughberry Lake water supply	
		Protect a red maple swamp	
		Protect barrier dunes, wetlands, resources	
		Protect creek bed & wildlife habitat	
		Protect cultural, historic, archaeological	
		Protect drinking water supply	
		Protect ecosystem & large number of wildlife	
		Protect freshwater wetland floodplain	
		Protect former & remaining wetland	

Protect freshwater wetland
Protect geologic and hydrologic sensitivity
Protect groundwater
Protect groundwater & drinking water
Protect groundwater aquifers
Protect hydrology and water quality, biological and geological uniqueness, and scenic views
Protect migratory & nesting birds
Protect natural setting, open space aesthetic quality, wetlands vegetation, and wildlife habitat
Protect open space & aesthetic beauty
Protect public health, open space and wetlands
Protect public health, water, vegetation, & scenic beauty
Protect public water supply
Protect rare plants and animal communities
Protect river bed, fish and wildlife habitat, and aesthetic beauty
Protect the quality of the ground water
Protect the resources of the park
Protect wetlands
Protect tidal wetland
Protect water & natural area
Protect water quality
Protect water resources
Protect water source & natural area
Protect water supply
Protection of Unique Natural Resources - Aquifer
Protection of Unique Natural Resources - Creek
Protection of Unique Natural Resources - Lake
Protection of environment and river bed prone to erosion
Protection of natural resource
Protection of waterfowl
Protection plant and wildlife
Provide groundwater protection
Public Water Supply Protection
Sensitivity to change & habitat and species protection
Significant & sensitive recharge area
Significant & sensitive water recharge area
Significant coastal fish & wildlife habitat
Significant historical features
Soil type, slope, wildlife habitat
To protect the municipal water supply

Socioeconomic Favourable Layers	Protected Areas	Trout habitat & may be spawning ground	Division of Environmental Remediation, New York State Department of Environmental Conservation
		Unique character of resources	
		Unique pond & wetland of undisturbed beauty	
		Unique, glacial kettle pond	
		Unpolluted drinking water source	
		Wide variety of botanical species	
		benefit to human health & protect drinking water	
		Protected area for other reasons	
		Airport	
		Chemical Distributor	
		Municipality (Incl. Waste Water Treatment Plants, Utilities, Swimming Pools, etc.)	The New York State Office of Parks, Recreation and Historic Preservation (OPRHP)
		Nuclear Power Plant	
		Storage Terminal/Petroleum Distributor	
		State Historic Sites	
		State Historic Park	
		State Historic Park Preserve	
	Transmission and Transportation	The United States primary roads (2016)	US Census Bureau, Department of Commerce NYS State Land Transportation - New York State (NYSDEC)
		ACCESSIBLE TRAIL	
		BIKE TRAIL	
		BOARDWALK	
		FOOT TRAIL	
		Foot Trail on Private Land	
		HORSE TRAIL	
		MAPPWD ROUTE	
		MULTIPURPOSE TRAIL	
		PAVED ROAD	
		PRIVATE ACCESS ROW	
		PRIVATE TRAIL/ROAD	
		PUBLIC ACCESS ROW	
		RAILROAD BED	
		ROAD	
		SKI TRAIL	

		SNOWMOBILE TRAIL	
		UNMARKED TRAIL	
		UNPAVED ROAD	
		Electric Power Transmission Lines	The Homeland Infrastructure Foundation Level Database (HIFLD)
	Urban and Populated Areas	Population census	The United States Census Bureau
		Urban Areas	The United States Census Bureau, Department of Commerce
Physical Crucial Layers	Bathymetry	Hudson River Estuary Bathymetry- Saugerties to Troy	New York State Department of Environmental Conservation (NYS DEC)
	Water Power	Hudson Physical Forces Model	Stevens Institute of Technology

Table 2 List of themes, their layers and respective content and sources

4. RESULTS

The Hudson River estuary primarily stretches 85 kilometres, all the way from Troy to New York Harbour, however, the physical forces model that we have extends till Yonkers. Figure 8 represents the merged restricted areas including the respective buffers is highlighted in red in the map, the merged favourable areas are represented in yellow/orange and the critical filtered physical areas over the stream are embodied in the green zones. The regulated buffers around industrial and historic sites normally range from 400 m to 800 m, a generous buffer of 1 km was dedicated for these areas combined in the protected set in our model, even though some of these spots and polygons require no buffer to biggen with. Likewise, several sensitive ecological regions home to endangered wildlife habitats require no buffer as it is already taking into consideration beforehand, spatial distribution of specific location with ecological, social, cultural or recreational value like national and historical parks, as well as spots with unique natural settings like fishing spots forests and vegetation areas. These areas have different environmental regulations. We combined them in the critical dataset, and given them a lavish buffer of 5 km.

A visual representation of the combination of each one of the themes; critical in green, restricted in red and favorable in yellow/orange, is presented in the figure8.

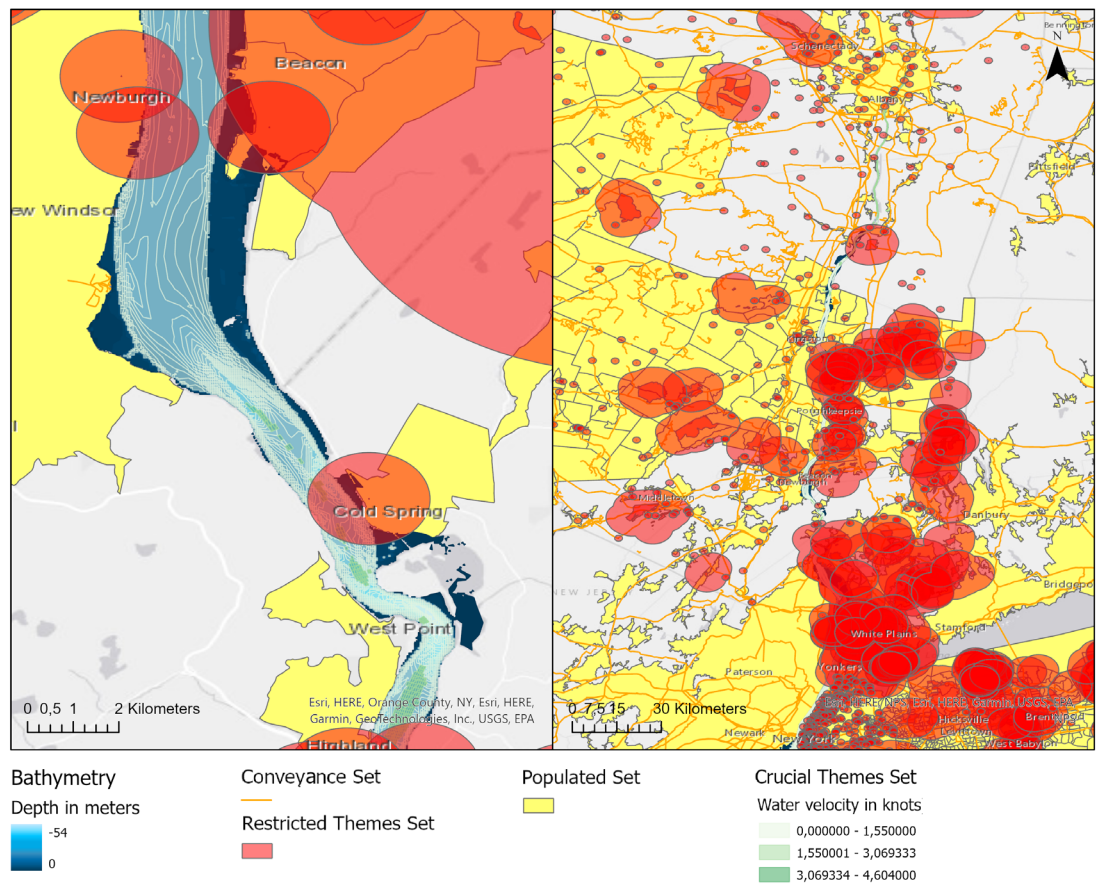


Figure 8 Distribution map of the critical, restricted and favorable themes over the Hudson River

Hydrokinetic power conversion devices have no standard size or design, as they are built for specific projects and the design usually reflects the requirements and explicit usage, and this varies with the nature and physical capabilities of the stream flow energy intended to harness. And considering that we are installing an In-stream river system and not a tidal/ocean conversion system, a minimum depth of 5 m was considered enough for this project especially that we are not intituled to consider any specific kind of conversion devices. A depth Big enough to lodge most of the medium and small devices on the market. The selection of the minimum depth has already detached considerable extent of the available stream area for the selection process.

After doing the literature review of many papers discussing different power conversion devices, it turns out that the range of the cut-in speed of these devices also varies and it is highly dependable on specific circumstances. For our In-river stream systems the scope is even smaller, as we only consider the medium and small conversion power devices. Many of the studies reviewed have simulated power extraction of up to 0.5 m/s. However, we considered only actual experimental power extraction projects, and avoid the theoretical aspect of these studies. And so on, a specific device called “Waterotor” developed by a Canadian renewable energy systems management company have shown great promising experimental results, the design of the blades and its small size enables the harnessing of namely two thirds of the available energy of the stream, with a cut-in speed of 0,8 m/s, which corresponds to a power density of 250 w/m². Consequently, the cut-in speed was filtered at a threshold of 0,8 m/s that corresponds to 1,55 knots for our physical forces model.

The minimum depth and the power density threshold was added to the restricted areas and their buffers, and the whole was extracted from our subset, which reduces our potential areas for the suitable locations considerably.

In the case of our conveyance layer, the normalised Euclidean distance to transmission and transportation, was to ensure the accessibility of the locations selected for the power conversion sites, which will reduce the cost of the project drastically. Similarly, the Euclidean distance for the populated set, will also have a great socioeconomical value for our study. Both objects were overlaid and masked by the suitable selected set. And the sites most suitable for our power conversion In-stream river system were located.

Nine main locations are selected by the end of our process in the figure 9 (a-i), demonstrating the practicality of the methodology for Hydrokinetic power conversion turbines suitability mapping, from north to south: (a) Troy, Watervliet and Menands, (b) Glenmont to Campbell Island, (c) Castleton on Hudson, Town of New Baltimore, (d) Coxsackie, (e) Germantown, (f) from Tivoli to East Kingston, (g) Port Ewen, (h) Milton, (i) Newburgh, New Windsor. These selected locations have general conditions for the deployment of hydrokinetic turbines, further validation procedures and on-site measurements are needed to confirm the results. Moreover, we think that this methodology was successful, and the results are accurate and each location conforms to the previously set conditions. Unfortunately, we found no prior such projects over

the study region, except for tidal turbines over East River, Gunawan, B. et al (2014), which is out of the scope of our study.

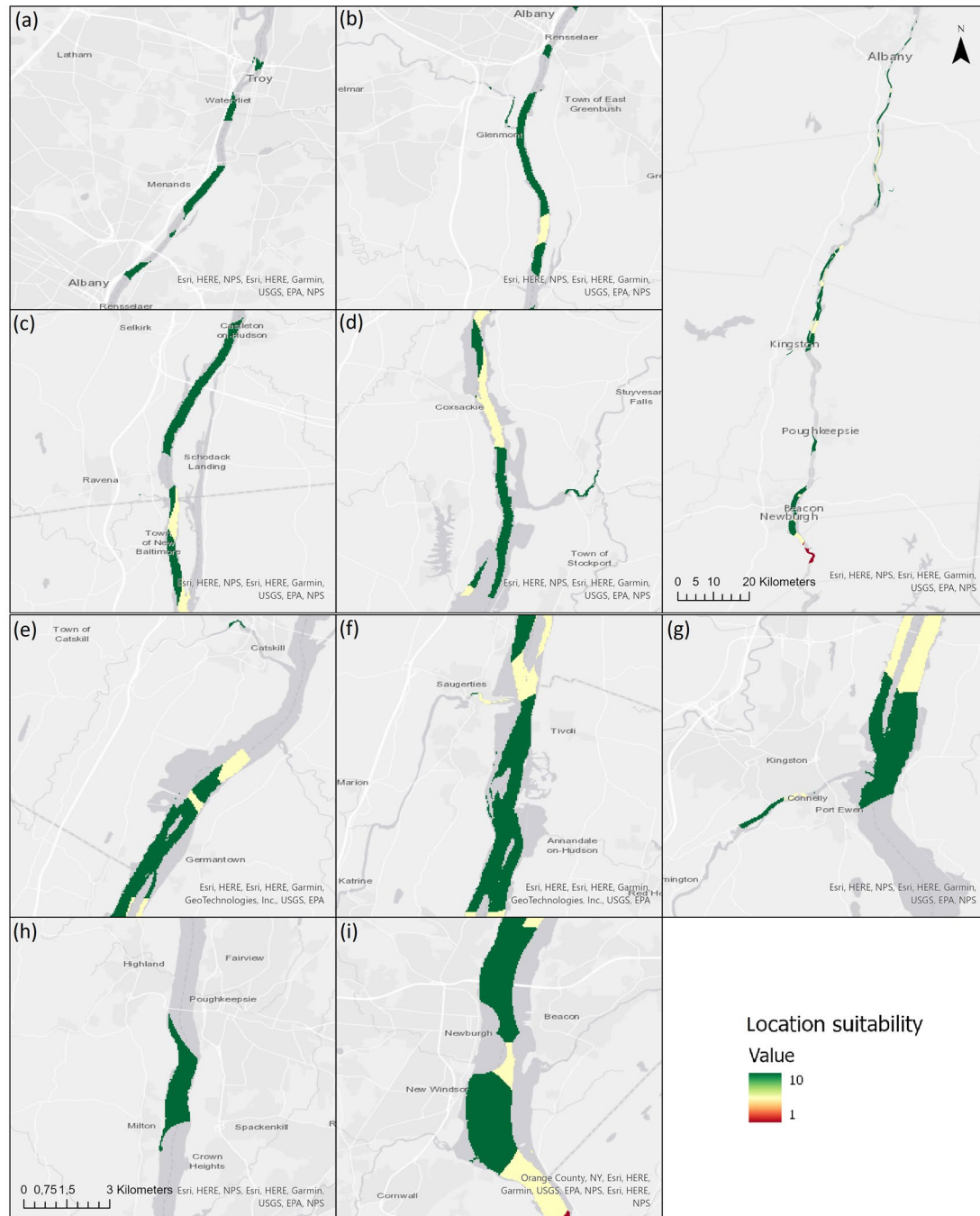


Figure 9 Distribution map of suitable locations for the In-stream Hydrokinetic turbines over the Hudson River, from north to south: (a) Troy, Watervliet and Menands, (b) Glenmont to Campbell Island, (c) Castleton on Hudson, Town of New Baltimore, (d) Coxsackie, (e) Germantown, (f) from Tivoli to East Kingston, (g) Port Ewen, (h) Milton, (i) Newburgh, New Windsor.

5. CONCLUSIONS

Given the abundance of geospatial data available for the Hudson River estuary, and the accessible GIS software and tools in hand, as well as the large number of papers in the literature on the subject, the development of this methodology for In-stream power conversion systems suitability mapping was made possible. Locating potential sites for the deployment of conversion devices over the Hudson River, via a multi-criteria analysis approach, that takes in consideration three major themes: physical, environmental, and socioeconomical. It is known that rivers have tremendous hydrokinetic potential, this potential is limited by physical constraints like depth and devices cut-in speeds, environmental constraints like wildlife and human activities, socioeconomic constraints like accessibility. According to our findings, and despite the constraints, it is possible to locate suitable sites for the placement of our turbines.

Further validation procedures are needed to endorse our selection of the locations, as the Hydrokinetic devices are an emerging field of research nowadays. Moreover, the design of these conversion devices needs to be refined to fit the unique environments of river bottoms rather than sea depths, and their slow-moving streams.

For future development each theme of the methodology should be thoroughly examined, the energy output can be calculated and compared between different study regions, as well as the economic cost of such a system can be further investigated.

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