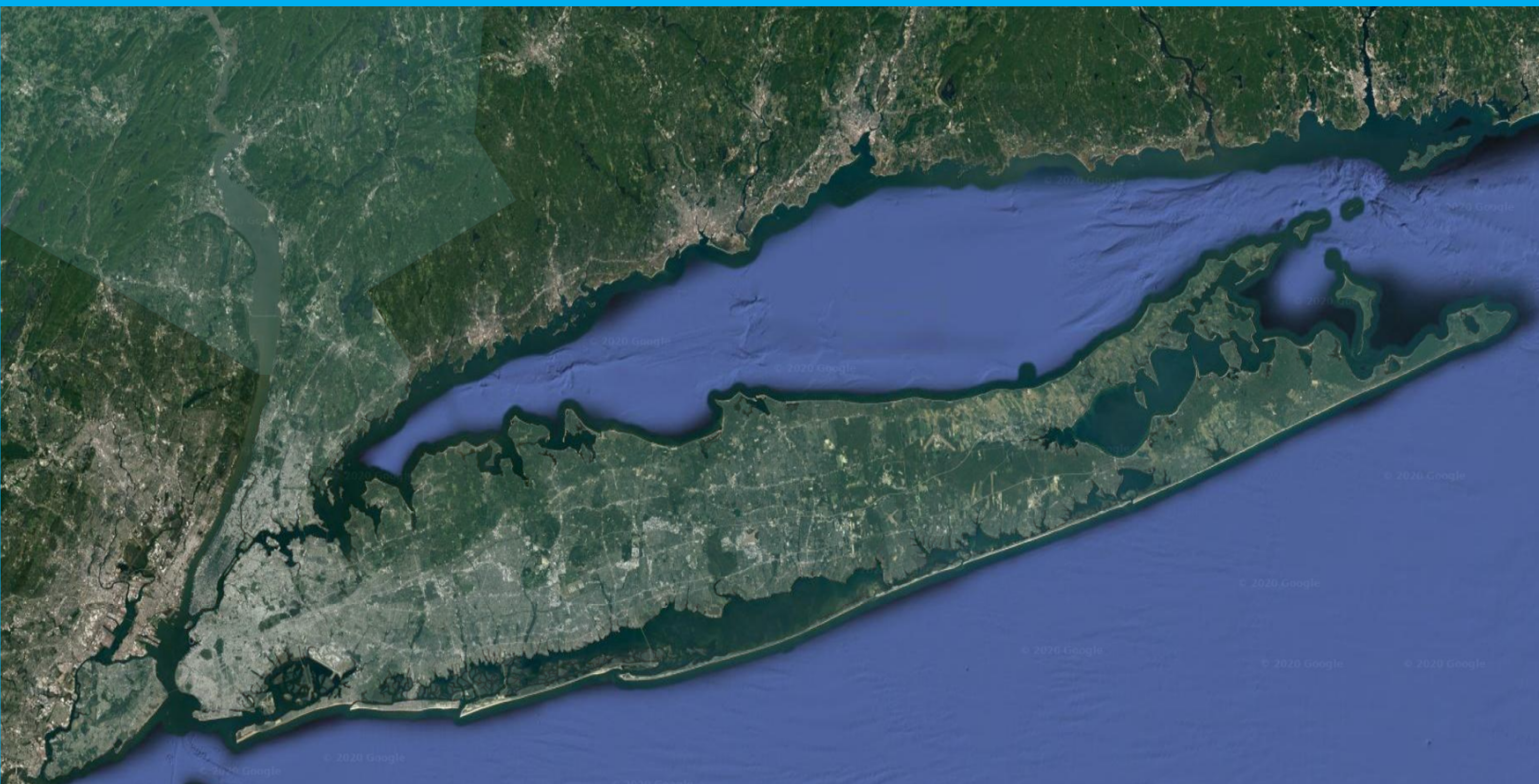
Advancing Adoption of Aquifer Thermal Energy Storage: a New Evaluation Method to Support Local Decision-Makers

N.J. Maltha

Evaluating the Technical and Commercial Potential of Aquifer Thermal Energy Storage in New York State Considering the Requirements and Interests of Key Stakeholders



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Advancing Adoption of Aquifer Thermal Energy Storage: a New Evaluation Method to Support Local Decision-Makers

Assessment of the Technical and Commercial Potential of Aquifer Thermal Energy Storage in New York State Considering the Requirements and Interests of Key Stakeholders

by

N.J. Maltha

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Company Supervisors	
Responsible supervisor:	Robertjan Spaans
E-mail:	robertjan.spaans@overmorgen.nl
Daily supervisor:	Tjakko Dijk
E-mail:	tjakko.dijk@overmorgen.nl
Thesis Exam Committee	
Chair:	Dr. E. Mostert
Daily Supervisor:	Dr. Ir. M. Bloemendal
Committee Member:	Dr. Ir. P. J. Vardon
Author Details	
Student number:	4329058
Author contact email:	nmaltha@gmail.com

An electronic version of this thesis is available at `http://repository.tudelft.nl/`.

Summary

Aquifer Thermal Energy Storage (ATES) is a geothermal technique that is an important component in the transition towards renewable energy in the heating and cooling industry, which accounts for half of the world's energy consumption. However, the technology has not yet been implemented in many countries. The main reason is that extensive preparation and site-specific analysis are required for the implementation of ATES systems and many stakeholders need to be involved. These stakeholders are typically unfamiliar with the technology and unaware of the potential applicability. To stimulate stakeholders and the decision-making process within the ATES sector, several studies emphasise the necessity of examining the potential of ATES technology on a local level. Such potential studies support ATES decision-makers as they evaluate the technology, potential scale and its commercial viability.

The objective of this research is therefore to develop a methodology to determine the technical and commercial potential of ATES while incorporating local characteristics. Until now, ATES feasibility studies have mainly been focused on large-scale ATES suitability. For generating more representative results, however, this new methodology also incorporates local geohydrological conditions and the interests of and restrictions imposed by its local ATES stakeholders. The methodology can be applied globally to every region that has available aquifers and moderate climate conditions. The developed methodology in this study is applied to the region of New York State (NYS). High expected energy savings and promising geothermal trends are among the main reasons for this geographic selection. Moreover, no commercial ATES project is yet in operation in the US, a country of which the potential energy savings are expected to be highest in the world. A successful introduction of the technology in NYS could therefore function as a valuable use-case for many other states in the US and also for other countries.

Firstly, the stakeholders in NYS are identified and analysed in this study. They are assessed based on their level of influence, attitude and their ability to solve current barriers that are preventing ATES from being adopted. This analysis indicated that geothermal architects are the most influential stakeholders and are therefore essential to engage for the successful implementation of ATES in NYS.

Secondly, the technical and commercial ATES potential are examined by analysing local geohydrological conditions, building characteristics and the identified requirements from geothermal architects. It is concluded that over 99% of all buildings in Nassau County (around 400,000) could technically receive the required amount of heat and cold if an ATES system was installed for those buildings. Moreover, it is found that for buildings with ATES systems, heating is twice as efficient as conventional methods in Nassau County and cooling is even 10-30 times more efficient, depending on ATES design parameters. Furthermore, it is concluded that ATES is already a commercially attractive solution for 385 separate buildings in Nassau County, accounting for an estimated 10% of the total heating and cooling demand of buildings in the county. This number is expected to increase significantly when multiple buildings are connected to a single ATES system.

This research shows that ATES is a technically and commercially viable geothermal solution for buildings in NYS. Therefore, it is critical that ATES is included in the existing evaluation tools developed and currently used by the city and state authorities of New York. The methodology developed in this study is characterised by the inclusion of local characteristics such as the interests and requirements of a region's key stakeholders and local geohydrological conditions, which are found to be essential to generate realistic and accurate insights into the technical and commercial potential of ATES. The model that has been developed is scalable and can be applied to other regions and the accuracy of the model can be increased further by also incorporating groundwater models in the analysis. All in all, the methodology developed in this study offers valuable support for local decision-makers and is an effective resource to increase the adoption of ATES technology worldwide.

Preface

This research is the result of my graduation work for the Master of Science Water Management at the Delft University of Technology and is performed in collaboration with the company Over Morgen.

First of all, I would like to thank the members of my thesis committee. Without their feedback and help, I would not have achieved the same result. A special thanks to my daily supervisors Martin Bloemendal and Robertjan Spaans from whom I have learned a lot about Aquifer Thermal Energy Storage and who connected me to many experts in this field. I am grateful that I was able to learn many new things about both the technical and commercial aspects of this sustainable technology and I am certain that this is helpful in my future career.

Moreover, this research would not have been possible without the help of the several ATES experts interviewed and approached in this research. Their time, effort and knowledge sharing is much appreciated and added significant value to this research.

Last but not least, I want to thank my parents, Hans and Lianne, for their incredible assistance throughout my study and Pieternel for all her support.

I hope you enjoy reading this report.

Niels Maltha
Delft, January 2021

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Introduction and ATES Applicability

1
Introduction

1.1. Problem Statement

1.1.1. Situation

To combat climate change and achieve global greenhouse gas mitigation targets, increasing attention must be paid to the decarbonisation of the heating and cooling industry (Fleuchaus et al., 2018). In 2015, heating and cooling accounted for half of the world's energy consumption, with three-quarters produced from fossil fuels. From this consumption, the share of modern renewable technologies is currently estimated at only 8% (REN21, 2017). Due to rising prosperity, population growth and climate change, the demand for thermal energy (both heat and cold) is only expected to increase further (Fleuchaus et al., 2018). According to the Intergovernmental Panel on Climate Change (IPCC), power consumption for air conditioning alone is expected to rise by a factor 33 by 2100 (IPCC, 2014).

The key challenge of increasing the share of renewables in the heating and cooling sector is attributed to the seasonal offset between thermal energy demand and supply. The idea of Thermal Energy Storage (TES) has attracted increasing attention, especially Underground Thermal Energy Storage (UTES), which is characterised by high storage capacities and efficiencies, to counter this mismatch (Dincer, 2002). Two types of UTES systems exist, namely closed-loop systems and open-loop systems (Fleuchaus et al., 2018). A closed-loop system or Borehole Thermal Energy System (BTES), stores or extracts thermal energy in the subsurface through conduction and consists of closed tubes which contain a transport medium such as water and/or glycol (Bloemendal et al., 2014). Open-loop systems are also referred to as Aquifer Thermal Energy Storage (ATES) and store sensible heat and cold temporarily in the subsurface through injection and withdrawal of groundwater. Figure 1.1 illustrates the basic principles of an ATES system. It shows that depending on the type of season, either warm or cold water is extracted from the aquifer to respectively heat or cool the building before reinjection in the opposing well. The integrated heat exchanger (indicated as 'HE' in Figure 1.1) facilitates the transfer of heat or cold from the groundwater circuit to the building circuit. An additional heat pump (indicated as 'HP' in Figure 1.1) is required for ATES systems in heating mode to increase the temperature to a sufficient level (Bloemendal et al., 2015). This technique allows buildings to overcome heat deficiencies in winter by using the heat surplus stored in the summer. Similarly, cooling deficiencies in the summer are reduced by using the cooling surplus stored in the winter season (Bloemendal et al., 2015). In moderate climates, this technique leads to significant carbon dioxide savings (approximately 60%) for heating and cooling of buildings (Bloemendal et al., 2015). Particularly when applied to large utility buildings, various studies report the competitiveness and preference of ATES compared to other geothermal and conventional heat and cooling systems in terms of financial, energy and subsequent carbon dioxide savings (Agterberg, 2016; Fleuchaus et al., 2018).

1.1.2. Complication

ATES is applied worldwide and literature shows that its application is growing, even exponentially in some countries (Bloemendal et al., 2015). It is a proven sustainable technology, especially for relatively large utility buildings (Agterberg, 2016). Despite these facts, the technology has still not been implemented in many countries. A key reason for this is that the implementation of ATES systems requires extensive preparation

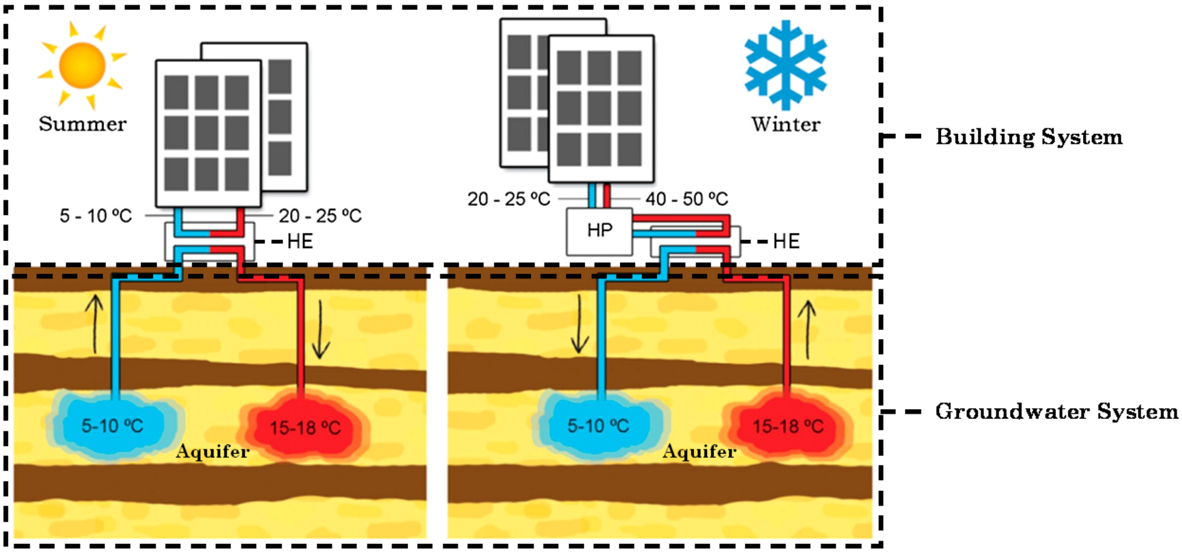

Figure 1.1: Illustration of the basic working principles of an ATES system in both a heating and cooling season (Bloemendal et al., 2018).

and analyses and many stakeholders need to be involved (Aalten et al., 2018). The ATES sector is therefore all about mobilising ATES stakeholders to take conducive measures or to at least refrain from opposition (Agterberg, 2016). Their interests, level of influence and attitude are therefore of importance (Agterberg, 2016). What is more, to stimulate stakeholders and the decision-making process within the ATES sector, several studies emphasise the importance of developing ATES potential maps in regions (Bloemendal et al., 2015; Fleuchaus and Blum, 2017). This is mainly due to the fact that even in markets with relatively high market-penetration, knowledge regarding ATES potential and applicability is inadequate (Fleuchaus et al., 2018; Bloemendal et al., 2015). Additionally, researchers confirm that local characteristics should also be considered when assessing a region's ATES potential. This especially relates to geographical, regulatory, geo-hydrological and climatic factors.

1.2. Goal of this Research

1.2.1. Objective of Research

To advance ATES implementation globally, the objective of this research is to develop a new evaluation methodology for examining a region's technical and commercial ATES potential. To allow for representative assessments, a region's local characteristics and the requirements and interests of key local stakeholders are included.

1.2.2. Geographical Scope

The evaluation methodology developed in this study is intended for world-wide application, but the focus of this study is on the New York State (NYS) region. Several reasons exist for this selection. First of all, this is a region with the required ATES preconditions of which a moderate climate and the availability of aquifers are the most important. Moreover, focusing on NYS for improving ATES adoption could result in the introduction of the technique in the United States. No commercial ATES project is yet in operation in the US, while the potential energy saving from ATES in the country is estimated to be among the highest in the world (Fleuchaus et al., 2018; Jaxa-rozen et al., 2018).

Scientific researchers agree that the most promising way to promote ATES technology to a region is the successful realization of projects (Fleuchaus et al., 2018; Hattrup and Weijo, 1989; Hicks and Stewart, 1988; Pellegrini et al., 2019). This draws public attention and proves technical and often economic feasibility. A successful introduction of the technology in NYS could therefore function as a valuable use-case for many other states in the US and also for other countries.

NYS not only has the required physical preconditions for ATES installation but also shows promising geothermal trends that improve the opportunities for ATES. Increasing energy demand and an insufficient network capacity, which is fixed by law, are the main reasons for the rising popularity of geothermal systems in NYS. Moreover, NYS decided to invest 26.5 million USD for financing geothermal systems and passed a law in 2015 which made it mandatory to install them in city-owned buildings if it proves to be commercially feasible. For these reasons, NYS is an attractive entrance region for introducing ATES technology. Finally, this study is performed in cooperation with Over Morgen, which has established an extensive network in New York State while leading the Dutch-ATES consortium in previous years. Through this network, it is possible to reach out to numerous experts within the geothermal industry in NYS, adding significant value to this research.

1.2.3. Research Questions to be Answered

To achieve the objective of this research, the following research questions are answered in this report:

- How does ATES work, what is needed for a successful implementation of this technique and what complications often occur?
- Which barriers are currently preventing the realisation of ATES projects in NYS?
- Who are the ATES-stakeholders in NYS and what are their roles, levels of influence and attitude towards ATES projects?
- Who are the key stakeholders and what are their interests?
- What are the technical possibilities of ATES and can ATES satisfy the energy demand in NYS?
- What is the potential of ATES in NYS when the requirements and interests of key stakeholders are included and what are the main benefits for these stakeholders?

1.3. Approach and Report Structure

Three subsequent parts in this research lead to meeting the objective by answering the related sub-questions. Part I describes the components of ATES systems and its boundary and favourable conditions. Also, the necessity of conducting a sector analysis and ATES-potential analysis for improving ATES adoption is explained in more detail. Subsequently, in Part II the ATES sector in NYS is examined. Here, the stakeholders, their roles, influence and ability to solve current ATES barriers are examined to eventually identify the key stakeholder group. The key stakeholder group in this context is the group of stakeholders with the highest influence on realising the implementation of ATES systems. In part III, the technical and commercial potential of ATES in NYS is examined as this is an important part of the decision-making process within the ATES sector. The requirements and interests of this key stakeholder group are considered when calculating both the technical and commercial ATES potential. The overview of the structure of this study is provided in Table 1.1, which also shows in which part and chapter the research questions listed above are covered.

Table 1.1: Overview of methods and chapters.

Research Questions	Methods	Chapter
Part I Introduction and Description of ATES		
• How does ATES work, what is needed for a successful implementation of this technique and what complications often occur?	Literature Study	2
Part II Identification of Key Stakeholder Group		
• Which barriers are currently preventing the realisation of ATES projects in NYS?	Interviews	3 & 4
• Who are the ATES-stakeholders in NYS and what are their roles, levels of influence and attitude towards ATES projects?	Interviews and surveys	3 & 4
• Who are the key stakeholders and what are their interests?	Selection based on influence, attitude and ability to overcome barriers	3 & 4
Part III Geospatial Analysis of the technical and commercial ATES-potential		
• What are the technical possibilities of ATES and can ATES satisfy the energy demand in NYS?	Technical Analysis using Geographic Information Systems (GIS)	5 & 6
• What is the potential of ATES in NYS when the requirements and interests of key stakeholders are included and what are the main benefits for these stakeholders?	Technical Analysis using GIS and results from Chapter 4	5 & 6
Discussion & Conclusions		
• All	Discussion: addressing limitations concerning all research questions	7
• All	Conclusions: overview of answers to all research questions	8

As shown in Table 1.1, the first part of this study describes the ATES technology, its boundary and favourable conditions and related terminology in Chapter 2. It also discusses the necessity of ATES potential maps and explains that the requirements and interests of key stakeholders must be included in the analysis. Part II of this report consists of Chapters 3 and 4. Chapter 3 explains the methods and materials used to identify the key stakeholder group and their interests. Chapter 4 subsequently describes its results. Part III consists of two chapters. Chapter 5 describes the methods and materials used to calculate the technical and commercial potential of ATES in the geospatial analysis while including the requirements and interests of the key stakeholders. Furthermore, methods are described to convert the information on ATES potential to information of use and interest to the key stakeholders. This is followed by the results in Chapter 6. Finally, in the Discussion in Chapter 7 the limitations of this research and the recommendations for future research are described followed by the conclusions in Chapter 8.

1.4. Previous Work

In previous years, much effort has been done to introduce ATES technology into the building environment in the US and particularly in the Northeast US. To this end, in 2015, a Dutch-ATES consortium was formed consisting of partners from knowledge institutes, governmental entities and private companies. With currently more than 2500 operating systems, the Netherlands is the global front runner in developing and installing this technique (Fleuchaus et al., 2018; Van Heekeren and Bakema, 2015) and subsidised by the Dutch government, this initiative bundled knowledge and expertise together to help promote and introduce ATES technology into the US East Coast building sector. And even though many intended results were achieved (such as two promising feasibility studies), the goal of one or more operating ATES systems is not realised. Harold Maasen, part of the consortium and actively involved in ATES developments in the Northeast US explained in an interview that within the ATES sector various stakeholders with different authorisations and interests are involved compared to the Netherlands. Dutch ATES experts must deal with different routines and decision-making processes for ATES installation. For example, where subsidies in the Netherlands are granted by the government, US energy and network operators do so in the US (interview Harold Maasen). A complete stakeholder overview today is still missing for regions in the Northeast US such as NYS, but are essential to successfully increase the region's ATES adoption.

To increase ATES adoption both the stakeholders and the related barriers they face must be identified and addressed (Pellegrini et al., 2019). On a global scale, barriers based on the level of market maturity were identified by Fleuchaus et al. (2018). In Europe too, barriers were identified by Pellegrini et al. (2019). However, such research and analyses are not yet conducted in the US but are a necessity for successfully applying market-entry strategies. This necessity stems from the fact that legislation, geohydrological conditions, societal perseverance and building systems vary strongly per country (Pellegrini et al., 2019). To this end, the selection of ATES key stakeholders is not solely based on the level of power they can wield regarding ATES projects, but also on their ability to help solve the barriers currently preventing ATES systems from being installed in NYS.

Finally, several researchers have analysed the feasibility of ATES on a large-scale (Bloemendal et al., 2015; Fleuchaus et al., 2018). However, these studies only allow a first estimation of ATES potential because local factors are not considered. Even though Bloemendal et al. (2015) indicated that ATES suitability is high in almost all developed economies, there is an urgent need for quantification of the ATES potential (Bloemendal et al., 2015; Jaxa-rozen et al., 2018). With an emphasis on local conditions and stakeholders, the methodology developed in this study differentiates from previous ATES feasibility studies. The new methodology consists of both a local stakeholder and geospatial analysis and is applied in this study to New York State (NYS).

2

ATES Components, Applicability and General Complications

Before examining the ATES sector in NYS, a thorough understanding is required of how the technology works and what is required for successful implementation. This chapter examines the components of the system itself, necessary boundary conditions for installation, the ingredients required for establishing a strong position in the heating and cooling industry and related terminology. Altogether this chapter is meant to get familiar with the technology, both in what it does and needs and is required for answering the sub-questions of this research.

2.1. The Components of ATES Systems

Many different ATES configurations exist, but the working principle remains similar. Depending on the type of season, warm or cold water is pumped up to respectively heat or cool its connected building and is then reinjected in the opposing well (see Figure 1.1). ATES systems have at least one cold and one warm well (called a doublet system), but multiple warm or cold wells could be necessary depending on the geohydrological characteristics of the soil and the thermal energy demand of the buildings (thermal energy refers to both heating and cooling). Due to the high heat capacity of water (4.2 MJ/kg/K), a large amount of thermal energy is stored, even for relatively small temperature differences between the warm and cold wells. ATES systems with groundwater temperatures below 25 °C or 25K are called low-temperature systems (LT-ATES) and represent more than 99% of the globally installed ATES systems. Globally, only one high-temperature (HT-ATES) system is in operation since the technique is more complicated than LT-ATES and requires more confidence before its wide-scale application (Drijver et al., 2012; Fleuchaus et al., 2018). Therefore, in the remaining of this study, ATES systems refer to LT-ATES systems whereas HT-ATES systems are excluded from the analyses. Regardless of the type, however, the components of ATES systems generally can be subdivided into two groups: the subsoil circuit and the building circuit. Both are explained in more detail below.

2.1.1. Building Circuit of ATES Sytems

The most essential components of the building circuit regarding LT-ATES systems are the heat exchangers and the heat pumps and are illustrated schematically in Figure 1.1. The figure illustrates that the building-circuit of the system is separated from the groundwater-circuit through the heat exchanger, which transfers thermal energy between the two piped water systems without the need for physical interaction. Only in heating-mode (as shown in the right part of Figure 1.1), the heat pump attached to the building-circuit raises the temperature of the water coming from the heat exchanger to temperatures suitable for heating its building. The (thermal) energy efficiency of the heat pump, also referred to as the Coefficient of Performance (COP), ranges typically between 3-5 (Self et al., 2013). Finally, in order to reduce the relatively high installation costs of ATES, often the building-circuit is equipped with additional heating (and less often) cooling devices for meeting its building's thermal energy demand during the coldest and hottest days of the year.

2.1.2. Subsoil Circuit of ATES Systems: Groundwater Well Components and Hydraulics

The components of ATES systems in the subsoil-circuit consist of the separated cold and warm groundwater wells. A well is a hydraulic structure which, when properly designed and constructed, permits the economic withdrawal of water from an aquifer, a water-bearing formation in the subsoil (e.g., a sand layer) (Driscoll, 1987). Wells are an important part of the design of ATES systems, especially since they substantially determine the quality and costs. Successful wells are designed and built in such a way that (I) the materials used will provide an efficient well with a long life-cycle, (II) the techniques in drilling and well construction take optimal advantage of the geohydrological conditions, and (III) the principles of hydraulics are applied in a practical way to the analysis of wells and aquifer performance (Driscoll, 1987). It is important to understand the meaning of common terms related to groundwater wells, which are described below and shown in Figure 2.1.

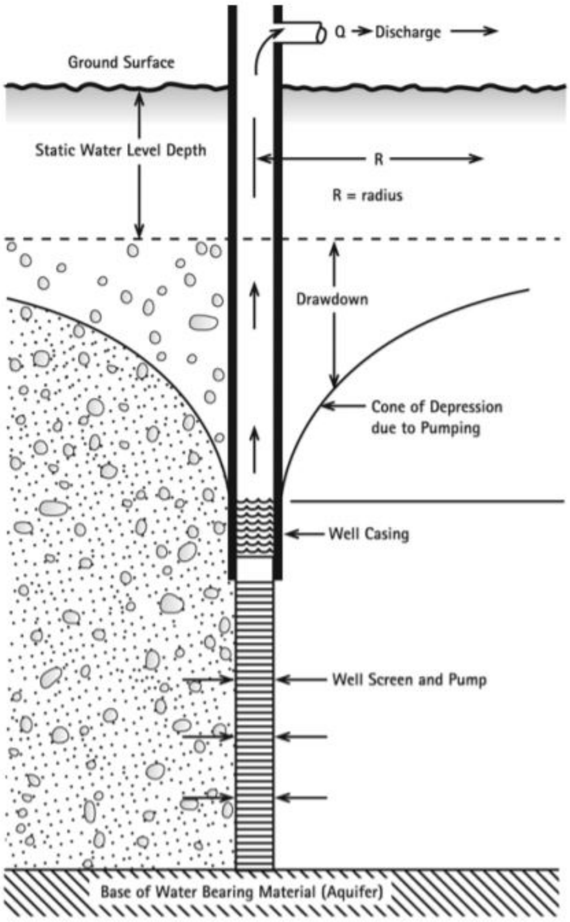

Figure 2.1: Drawdown and definition of well terms (Davidson and Wilson, 2011).

Well Components

The groundwater well has two main elements, the intake portion and the casing. The latter serves as a vertical conduit for water originating from the aquifer flowing upward to the pump intake and as a housing for the pumping equipment. Choosing the proper casing diameter for the well is important because it may significantly affect the cost of the structure (Driscoll, 1987). The diameter must be chosen to satisfy two requirements: (I) the well pump must fit in the casing, and (II) it must be sufficient to assure that maximum uphole groundwater velocities are not exceeded (1.5 m/sec or less) (Driscoll, 1987). The intake portion of groundwater wells allows water to enter the well and consists of the pump, screen and the plate bottom, which are discussed next.

Water Well Pumps

The primary function of a pump is to add hydraulic energy to certain volumes of fluid. This is fulfilled when the mechanical energy powered by the electrical grid is transferred to the fluid, increasing the pressure on the fluid. This increased pressure, or hydraulic energy, causes water to flow in the well. To this end, pumps are installed to lift the water to the ground surface and deliver it to the point of use (Driscoll, 1987). Pumps are generally classified into two groups: shallow-well pumps and deep-well pumps. This classification refers to the position of the pump in the well, not to the depth of the well. A shallow-well pump is mounted at ground level and removes water from the well by suction lift. The deep-well pump must be used for any well where the pumping level is below the limit of suction lift (approximately 6.1 - 7.6 meter). Commonly used in ATES systems, a deep-well pump is installed within the well casing, with the pump inlet submerged below the pumping level. Therefore, the inlet is under a positive pressure head.

Well Screen

A well screen is a filtering component that permits water to enter the well from the saturated aquifer, serves structurally to support the aquifer material and prevents sediment from entering the well. Well screens are a critical part of the well when considering the hydraulic efficiency of it and the long-term cost to its owner (Driscoll, 1987). The particles from the aquifer are collected at the bottom part of the well screen in a plate bottom, functioning as a sediment component (Driscoll, 1987).

Well Hydraulics

Next to the physical components of pumping wells described in the previous section, it is important to understand the meaning of common (hydraulic) terms related to pumping wells. The definition of the terms frequently used in the remaining of this study are described below, some of which are illustrated in Figure 2.1.

Static Water Level

The Static Water Level (SWL) is the level at which water stands in a well or unconfined aquifer when no water is being removed from the aquifer either free-flow or pumping. It is expressed as the distance from the ground surface to the water level in the well (Driscoll, 1987). For example, when the static water level in a well is 5 meters, it means that water stands 5 meters below the measuring point (often the surface) when the pump is not in operation.

Pumping Water Level

This Pumping Water Level (PWL), also called the dynamic water level, is the level at which water stands in a well when the pump is in operation (Driscoll, 1987).

Drawdown

The drawdown of a pump is the difference between the static water level and the pumping water level in meters or feet (Driscoll, 1987). Pumping a well lowers the water level around the well which causes a cone of depression as shown in Figure 2.1 and of which the shape is dependent on the level of drawdown. As the distance from the well increases, the influence of the pump on the static water level becomes less until it becomes zero. The extent of the cone of depression for a given rate of withdrawal of a pump depends on the local geohydrological conditions. When multiple pumps are installed within each other's area of influence, the drawdown of each pump is amplified which must be accounted for if the pumping level or cone of depression should be maintained at a certain level.

Well Yield and Specific Capacity

Well yield refers to the volume of water per unit of time extracted from a well by pumping, also referred to as pumping discharge. It is measured commonly as a pumping rate in cubic meters per day or gallons per minute (gpm) (Driscoll, 1987). Maximum achievable well yields can be derived from the specific capacity of a well. The specific capacity of a well is its yield per unit length of drawdown, usually expressed as cubic meters per day per meter (m^3/day/m of drawdown). This is derived after a given time of pumping has elapsed, typically 24 hours (Driscoll, 1987). Dividing the yield of a well by the drawdown (see Figure 2.1), when each is measured at the same time, gives the specific capacity. For instance, if the pumping rate is 5000 m^3/day and the drawdown is 10 meter, the specific capacity of the well is 500 m^3/day/m of drawdown.

2.2. Determining ATES Suitability: Required Psychical and Non-physical Conditions

Many factors determine the suitability of ATES and are of physical and non-physical nature. From a technical perspective, required geohydrological and climatic conditions must be present. From a market aspect, there must be a certain demand for ATES systems and finally, from a regulatory point of view, supportive (or at least non-opposing) legislation must exist for successful ATES installation in a region. These factors are illustrated in Figure 2.2 and in the following sections, both the physical and non-physical conditions are discussed in more detail followed by a preliminary assessment of these factors for the region of NYS.

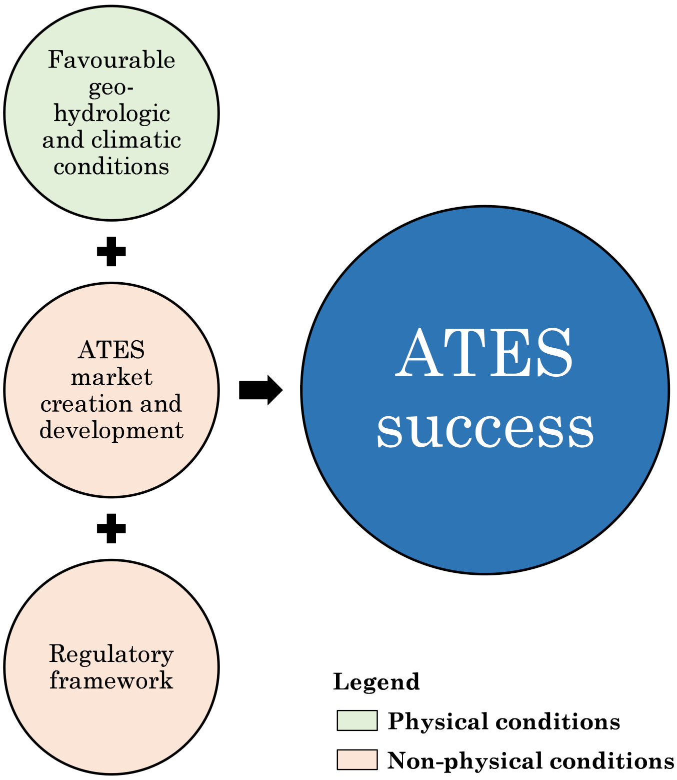

Figure 2.2: Factors determining the success of ATES in a region (compiled by author).

2.2.1. Geohydrological and Climate Conditions Determining ATES Suitability

ATES systems require suitable geohydrological and climatic preconditions (Bloemendal et al., 2015). The availability of suitable aquifers and favourable climatic circumstances are considered as the most important preconditions for applying ATES techniques (Bloemendal et al., 2015). The specific geohydrological properties on which efficient operation and design of ATES systems depend are as follows (Bloemendal et al. (2015)):

- **Ambient groundwater flow**
  Aquifers with groundwater velocities are poorly suited to store thermal energy since as its thermal energy floats away from the ATES wells
- **Groundwater quality**
  The quality of groundwater is an indication of both the life expectancy and required maintenance of ATES installation. The clogging of well screens and corrosion is likely to occur in aquifers with polluted groundwater.
- **Depth of aquifer**
  The quality of groundwater usually increases with the depth of an aquifer. This is mainly due to the swift from aerobic groundwater conditions (oxygen concentrations are present) to anaerobic conditions (no oxygen present) with increasing depth. However, it affects the commercial feasibility as it induces higher costs for drilling and installation. An optimal depth is therefore a trade-off between the two.

- **Redox conditions**
  Related to the depth of the aquifer, special attention must be paid to prevent the mixing of anaerobic water with aerobic water in ATES systems. Mixing of the two results in severe well clogging through the formation of iron and manganese hydroxide. This phenomenon is induced by reactions with dissolved iron and manganese in the anaerobic groundwater with oxygen from the aerobic groundwater. To prevent this, complete aerobic or anaerobic conditions are preferred.
- **Salinity in groundwater**
  ATES is suitable for installation in saline groundwater as long as it is secured with additional equipment to prevent corrosion of the system. However, this negatively affects the economic benefits of the system due to the extra measures necessary.
- **Composition of the aquifer**
  The thermal efficiency of ATES is sensitive to any discrepancies in the aquifer caused by the occurrence of layering, heterogeneous characteristics, fractures, fissures and faults.
- **Balancing seasonal heat storage and extraction**
  Climate conditions are among the main factors which determine a building's thermal energy demand and is an essential factor to consider for assessing a region on ATES suitability (thermal energy indicates both heating and cooling). To allow for sustainable ATES practices, a balanced heating and cooling demand of the connected building are preferred. This prevents uncontrollable growth of either the warm or cold zone in the subsurface, which ultimately affects the extraction temperature of the other well jeopardising its thermal system efficiency. However, if it concerns relatively minor deviations, additional measures and heating and cooling devices are able to compensate for expected imbalances.

2.2.2. Non-Physical Conditions Determining ATES Suitability

The literature on strategic management demonstrates that the chances of successful adoption of innovative and sustainable technologies like ATES are increased if the stakeholders willing to introduce the technology and collaborate in networks or industry clusters to build a favourable (non-physical) environment for the technology (Planko et al., 2016). The success factors determining a region's degree of ATES implementation therefore do not only consist of favourable physical geohydrological and climate conditions but also include conditions that enable market creation and development of a supportive regulatory framework. These are achieved by joint efforts between ATES stakeholders who are aware of the technology and its applicability.

Looking at NYS, no critical regulatory challenges are expected for ATES implementation, since the use of conventional geothermal open-loop systems is allowed for many years already. Compared to ATES systems, the main difference of these systems is that it functions as a one-way system for only space heating or cooling. However, the regulatory boundaries between both systems are similar, as it concerns the withdrawal from and reinjection of groundwater in aquifers. This creates opportunities for ATES adoption. However, lack of regulations or transparent policies specified for the ATES sector can also inhibit market development eventually, as uncertainty in this area can result in a reluctance to invest in the technology. The regulatory framework, therefore, needs to be adapted to enable and support ATES development and to allow market forces to emerge (Planko et al., 2016). Moreover, it is proven that efforts from governmental authorities to create a proper legislative framework are indispensable for enabling ATES development in a region (Fleuchaus et al., 2018). Collaborative networks of stakeholders can lobby to convince governmental actors to put the support of the new technology on the political agenda (Hekkert et al., 2007). Therefore, market development is positively affected by a solid and transparent regulatory framework, which again can be supported and co-developed by its market. These positive feedback loops, however, require at least one or more influential stakeholders who are willing to adopt the technology. This currently is found to be most challenging in the NYS ATES sector.

ATES is not regarded as an established technology in the NYS heating, cooling and air condition (HVAC) industry. Until today, not one commercial ATES installation is yet realised, even though preliminary studies in the region indicate highly suitable physical conditions. Planko et al. (2016) explains that one of the core drivers for increasing market demand for technologies like ATES is that general awareness and understanding of the technology has to be generated in the first market phase (Planko et al., 2016). For many emerging ATES markets in the world, however, this is found to be one of the major barriers preventing ATES from being implemented. The next section further discusses this barrier as well as the solution strategy to overcome it in more detail.

2.3. ATES Complications and Solutions to Advance ATES Implementation Emphasised in Literature

Despite experiences and developments in recent decades regarding ATES technology, many countries still experience many market barriers preventing ATES from establishing a strong position into its heating and cooling industry (Fleuchaus et al., 2018; Pellegrini et al., 2019). ATES markets are often rather immature, as is the case for the US and NYS. Corresponding barriers and solution strategies derived from practice and literature are therefore discussed in this section.

2.3.1. Complications and Corresponding Solution Strategies

Figure 2.3 shows the global distribution of ATES systems. It is concluded from this figure that most of the global ATES systems are installed in Europe. In attempts to increase adoption in Europe, several studies identified and addressed barriers and potential strategies to overcome them. First of all, it is concluded that many barriers are not geographically bounded and mainly depend on the size of the region's ATES market (see Figure 2.4). Secondly, substantial preparation and site-specific analysis are required for the implementation of ATES systems and many stakeholders need to be involved (Aalten et al., 2018). These stakeholders are typically unfamiliar with the technology and unaware of the potential applicability (Fleuchaus et al., 2018). Even in several countries in Europe with a relatively high ATES market-penetration, lack of knowledge regarding potential and (future) applicability of ATES is one of the main barriers for its application (Bloemendal et al., 2016; Bloemendal et al., 2015; Monti et al., 2012; Forsén et al., 2008). Therefore, in order to stimulate the decision-making process within the ATES sector, several studies emphasise the necessity of examining a region's ATES potential (Pellegrini et al., 2019; Fleuchaus et al., 2018).

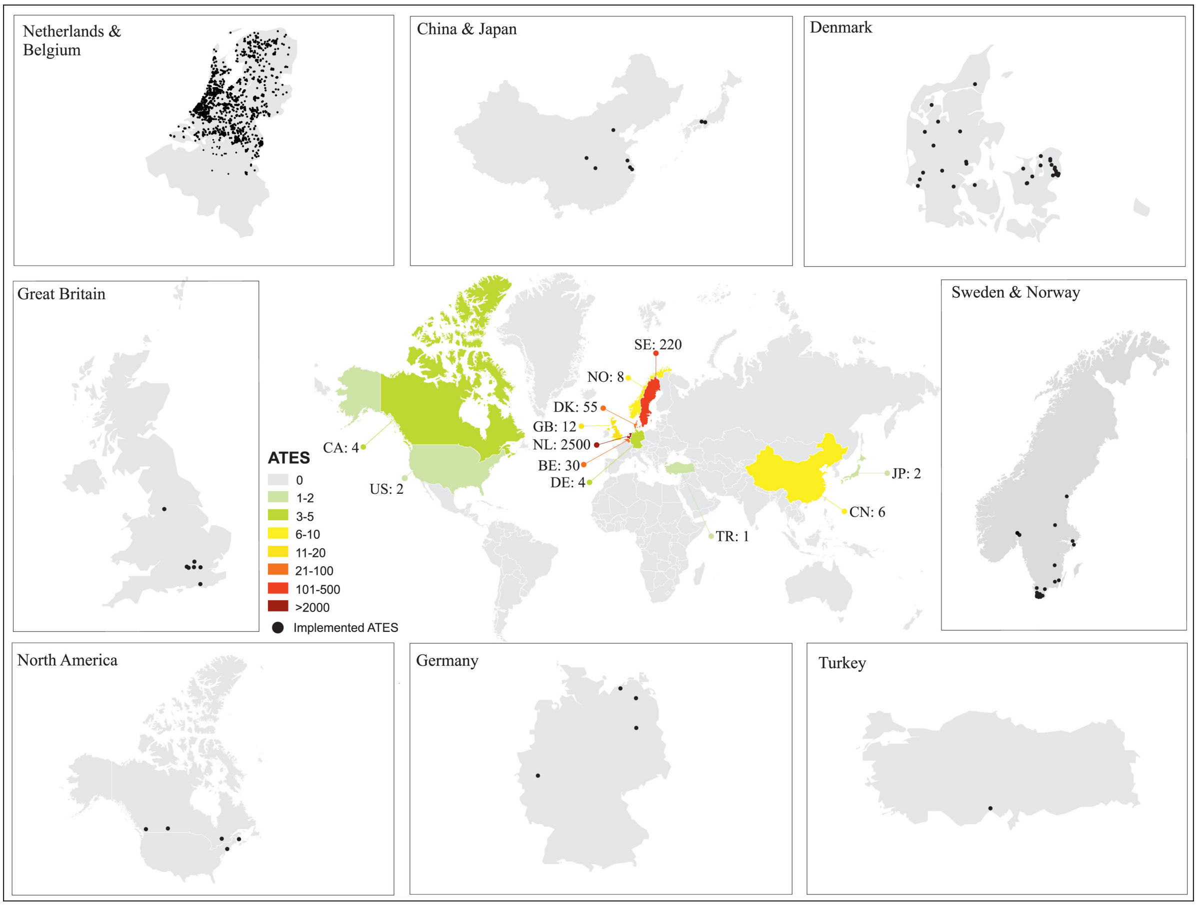

Figure 2.3: Global spatial distribution of ATES (Fleuchaus et al., 2018).

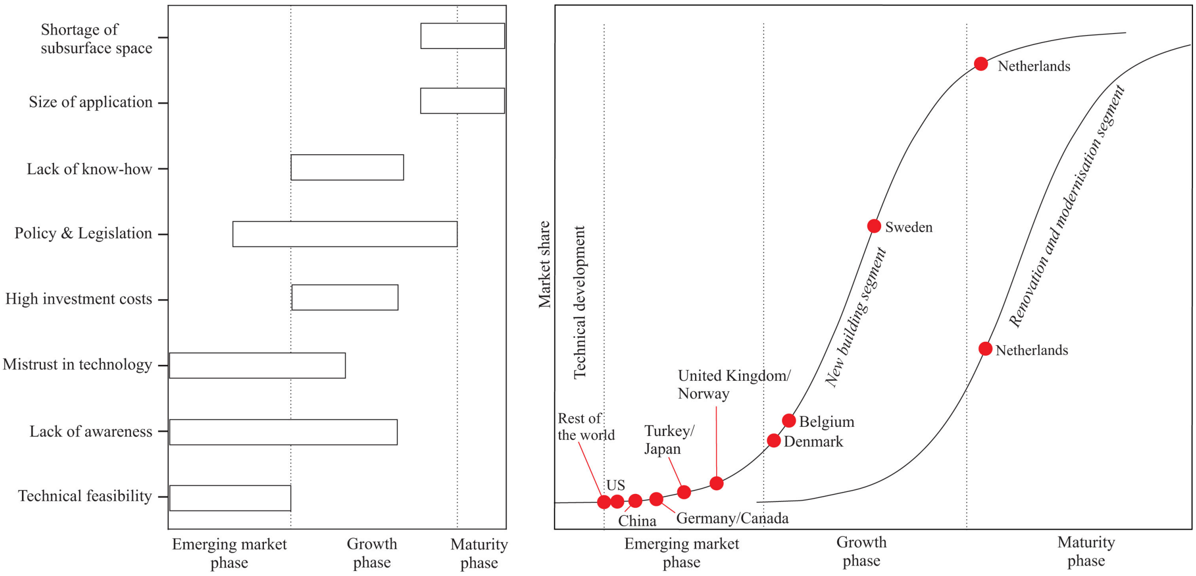

Figure 2.4: Left: market barriers limiting ATES development as a function of the market development level (subsurface and climatic conditions are assumed). Right: market development of ATES in all relevant countries considering new building and renovation segments (Fleuchaus et al., 2018).

2.3.2. Determining the Potential for ATES adoption in New York State

The ATES complications and corresponding solutions for improving ATES-implementation in a region emphasised in the literature are considered a foundation for the objective of this research. The objective of this research is, as mentioned in Chapter 1, to advance ATES adoption in New York State by examining the potential of ATES while considering the requirements and interests of the key stakeholders. One of the main reasons to consider the key stakeholder's interests and requirements when examining the NYS's ATES potential is, first of all, to generate more accurate results. Secondly, successful ATES-implementation strategies must be built upon the interests and requirements of those stakeholders that have the highest impact on the successful implementation of it.

2.3.3. Levels of ATES-Potential

The renewable energy potential of a technology such as ATES can be analysed at different levels, consisting of the resource, technical, commercial, and market potential. The key components for each level are presented in Figure 2.5. Indicated at the top part of the funnel in Figure 2.5, the resource potential represents the theoretically achievable energy generation, considering the renewable source availability (Okioga et al., 2018). In this context, the theoretical potential is based solely on physical boundaries for ATES adoption such as the presence of aquifers and suitable climatic conditions. A subdivision of this resource potential is the technical potential. The technical potential is lower than the resource potential since it represents the achievable energy generation of ATES given the system performance, topographic limitations, environmental constraints. Furthermore, key stakeholders may impose additional technical constraints such as limitations on certain ATES design parameters or suitable locations for installation. The primary benefit of assessing technical potential is that it estimates an upper boundary estimate for the total development potential.

Moving one level further down from the technical potential, the commercial potential incorporates the additional restrictions caused by the fact that ATES should be a commercially attractive solution for the stakeholders. Since buildings exist in many different types and sizes, the required investment and achievable profits also vary significantly (Agterberg, 2016).

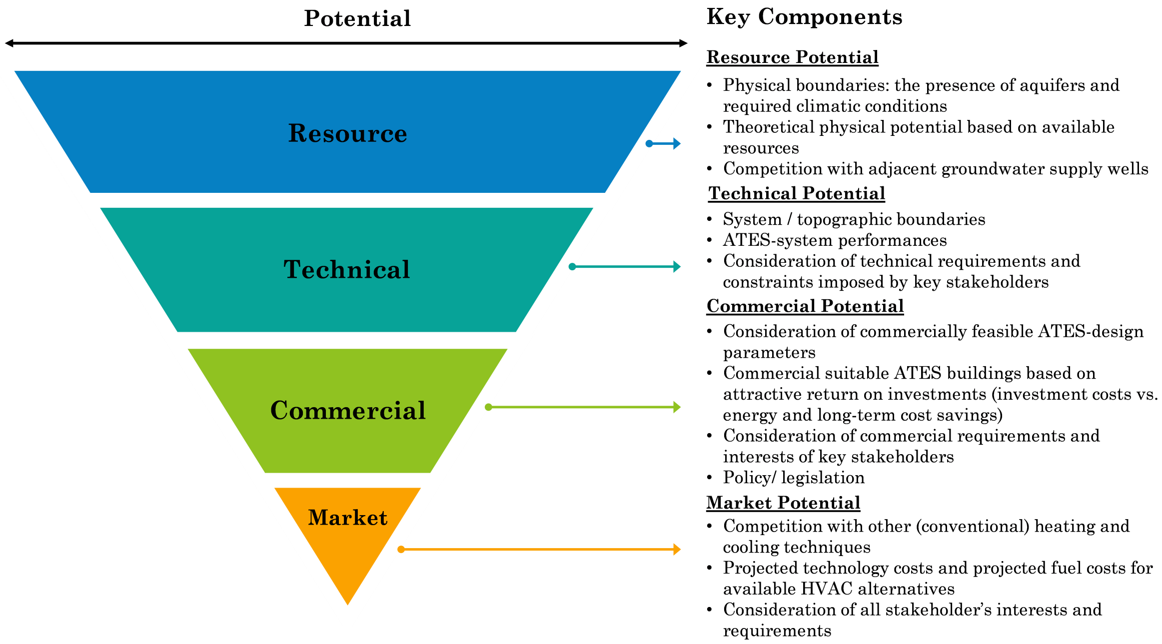

Figure 2.5: Funnel of levels of ATES-potential and corresponding key considerations (compiled by author).

The aim of examining the potential in this research is to support decision-makers in NYS as they evaluate ATES technology, the potential scale of ATES development and its commercial viability. The analysis of market potential would typically involve detailed analyses of the costs for installation, operation and return on investments of all available heating and cooling alternatives, but is out of scope in this study. By considering in Figure 2.5 the requirements and interests of the key stakeholders in NYS, the calculations of the technical and commercial ATES potential become more accurate and realistic. The more accurate the potential maps, the higher the possibility to effectively stimulate and mobilise important stakeholders in NYS to undertake essential measures to increase the implementation and acceptance of ATES.

II

Identification of Key ATES Stakeholders within the New York State ATES Sector

3

Methods and Materials Used for Identifying Key Stakeholders

Four types of analysis are used in this study for the selection of the most influential ATES stakeholders in NYS. These analyses are (I) the identification of stakeholders and barriers, (II) the assessment of a stakeholder's influence and attitude, (III) the selection of key stakeholders (for which I and II are required) and the determination of the requirements and interests of this group (IV). The necessity of selecting this group is already touched upon in previous chapters. Influential stakeholders in NYS are essential for their contribution to ATES implementation and ability to enhance the position of the technology in the heating and cooling industry. So to improve ATES adoption in NYS, successful market-entry strategies need to focus on the most influential stakeholders. This group of key stakeholders is selected based on their level of power, attitude and their ability to overcome existing barriers for ATES implementation in NYS. All methods for selecting the key stakeholder group for ATES projects in NYS and its interests are described in this chapter.

3.1. Stakeholder Analysis

ATES experts and local stakeholders are involved in this stakeholder analysis to obtain qualitative and accurate results. For analysing the stakeholders, interviews and questionnaires were used. This section describes the available methods for stakeholder analyses and substantiates why specific methods applied in this research were selected. Subsequently, the selected methods are further detailed for application in this study.

3.1.1. Stakeholder Analysis Methods

Several stakeholder analysis methods were derived from literature, these are listed in Table 3.1. A selection of the methods listed in this table is used in this study to identify stakeholders and corresponding interests and for the prioritization of stakeholders. Stakeholder identification refers to the development of a list of all stakeholders involved in ATES projects in NYS; stakeholder prioritisation refers to analysing stakeholders' influence on the project and decisions about which stakeholders' interests should be addressed preferentially. To retrieve comprehensive information on these aspects, a total of three approaches are chosen from Table 3.1: interviews for identifying stakeholders, components of the Stakeholder Circle Methodology for prioritising the stakeholders and finally questionnaires for retrieving information required for conducting part of the Stakeholder Circle Methodology. An overview of the selected methods is provided in Table 3.2.

The stakeholder analysis in this study is mainly built upon the methods of the Stakeholder Circle Methodology and the required data and information to do so is retrieved from the interviews and questionnaires. The main reason for using the methodologies in the Stakeholder Circle Methodology is because it is proven to be an effective method for obtaining the desired stakeholder information in development projects (which includes ATES projects) without the need of approaching every single stakeholder (Yang, 2014). The methods used in this study (see Table 3.2) are based on empirical methods, implying that knowledge can only be gained by experience (Markie, 2017). In this context, the stakeholder analysis relies on the experience of a (small) group of ATES stakeholders in NYS, called key informants, who occupy a central position, have direct connections to all stakeholders and have a broad understanding of the ATES sector in NYS. These methods

Table 3.1: Practical methods for stakeholder analysis used in previous studies (Yang, 2014).

Approaches	Description	Steps		Scholars
		Stakeholder identification	Stakeholder prioritisation	
Focus groups	A small group brainstorm stakeholders, their interests, influence and other attributes, and categorise them.	√	√	Reed et al. (2009), Lawson and Kearns (2010), Larson et al. (2010)
Interviews	Interviews with stakeholders to identify their interests.	√		Mushove and Vogel (2005), Oakely (2007)
Power/interest matrix (power/interest matrix; power/predictability matrix; stakeholder interest intensity index; the stakeholder impact index)	Despite various transformations, basically, stakeholders are categorised according to the levels of their power and interests.		√	De Lopez (2001), Winch and Bonke (2002), Young (2006), Olander and Landin (2008), Chinyio and Akintoye (2008), Walker et al. (2008), Reed et al. (2009)
Snow-ball sampling	Based on identified stakeholders, a series of interviews and questionnaire surveys are conducted to identify more stakeholders.	√		Prell et al. (2009), Reed et al. (2009)
Social Network Analysis	Through the use of structured interview/ questionnaire surveys, stakeholders' interrelationships are mapped, and stakeholders' influence are analysed.	√	√	Rowley (1997), Prell et al. (2009)
Stakeholder Circle methodology	An integrated process for classifying stakeholders, prioritising stakeholders, visualising stakeholders; and developing strategies.	√	√	Bourne (2005), Walker et al. (2008)
Surveys	Relatively large numbers of stakeholders are asked to express their opinions.	√		Timur and Getz (2008), Prell et al. (2009)
Workshops	Stakeholder representatives discuss specific issues and provide feedback.	√		Department of Planning (2005); Amado et al. (2009)

Table 3.2: Approaches used for the stakeholder analysis in this study.

Steps	Approaches Used		
	Interviews	Stakeholder Circle Methodology	Questionnaires
Stakeholder Identification	✓	✓	✓
Stakeholder Prioritisation		✓	✓

assume that the key informants have exhaustive information about the other ATES stakeholders. Below, the three methodologies used in this study are discussed.

3.1.2. Stakeholder and Barrier Identification

Several interviews were conducted with ATES experts to identify the stakeholders involved in ATES projects and the barriers these stakeholders face. The experts were selected for their ATES expertise and regional (US) knowledge and are listed in Table 3.3. The set up of the interviews was semi-structured and they took on average around an hour. The key topics to discuss (ATES suitability, incentives, barriers, competition and stakeholder roles) were shared prior to the interview and were used as guidelines during the conversation. Through this methodology, the interview could be steered in the intended direction when necessary without limiting other topics the expert deemed relevant to discuss. The insights from these interviews were reported and subsequently used in the remaining of the stakeholder analysis.

Table 3.3: List of experts interviewed for the barrier and stakeholder identification.

Name	**Company**	**Details**
Craig Wilson	M3 Energy	Partner at a Local Energy Consultancy Agency
Bas Godschalk	IF Technology	Published many reports on ATES and is an advisor and designer of ATES systems globally
Frank Agterberg	BodemenergieNL	Chairman BodemenergieNL and Chairman of the branch association heat pumps in NL
Gerwin Hop	Over Morgen	Founder Over Morgen and Coordinator of the Dutch-ATES consortium
Harold Maasen	Engie	Manager ENGIE Energy Solutions (part of Dutch-ATES consortium)
John Rhyner	Self-employed	Geohydrologist in New York and surroundings (did much research on ATES suitability for Dutch-ATES)
Robertjan Spaans	Over Morgen	Consultant and active in geothermal projects in Northeast US
Sanne de Boer	Over Morgen	Involved in realising the Dutch Geothermal WKO Tool initiated by IF technology and later launched by RVO (used for promotion, information management, registration and permits regarding ATES)
Wil van den Heuvel	Installect (Engie)	ATES engineer with 30 years of experience (also part of Dutch-ATES)

3.1.3. Rating of Stakeholder Attributes

A method to identify and prioritise the key stakeholders and subsequently develop appropriate stakeholder engagement strategies is the Stakeholder Circle methodology developed by Bourne and Walker (2008). This model is built on the stakeholder science model from Mitchell et al. (1997) and identifies three attributes which should be assessed to highlight stakeholder's relative level of influence:

- Power: is the stakeholder's power to influence the work or the outcomes of the project significant or limited?
- Proximity: is the stakeholder closely associated or remote from the work of the project?
- Urgency: what is the anticipated response of the team managing an ATES project to a request from a particular stakeholder?

Building on the research by Bourne and Walker (2008), a scoring system is developed to assess the attributes for stakeholders. The different scores for power proximity and urgency are presented in Table 3.4. The scoring system in Table 3.4 is subsequently integrated into the questionnaire which is discussed next.

Table 3.4: Scoring system for assessing a stakeholder's level of influence.

Power: Is the stakeholder's power to influence the work or the outcomes of the project significant or limited?	
1	Relatively low levels of power (cannot generally cause much change)
2	Some capacity to instruct change (e.g., must be consulted or has to approve...)
3	High capacity to cause change (e.g., a supplier with input to design)
4	Very high capacity to instruct change (i.e., can have the work stopped)
Proximity: Is the stakeholder closely associated or remote from the work of the project?	
1	Very remote from the work (does not have direct involvement with the work)
2	Relatively remote from the work but has regular contact with, or input to, various processes (e.g., some clients)
3	Routinely involved in the work (e.g., part-time members of the project team, external suppliers and active sponsors
4	Directly involved in the work (e.g, team members and contractors working most of the time)
Urgency: What is the anticipated response of the team managing an ATES project to a request from a particular stakeholder?	
1	There is no need for action outside of routine communications
2	Planned action is warranted which must be completed in a relatively long-term time-frame
3	Planned action is warranted which must be completed in a relatively medium-term time-frame
4	Planned action is warranted which must be completed as soon as possible (no need to put other commitments on hold immediately)
5	Immediate action is warranted, irrespective of other work commitments

3.1.4. Stakeholder Questionnaire and Processing of Responses

A questionnaire was sent to the selected stakeholder informants (with knowledge on ATES stakeholders in NYS) who were asked to allocate attribute and attitude scores to each stakeholder identified in the questionnaire. The respondents had the opportunity to provide notes where necessary and could also list other stakeholders. The questionnaire is provided in Appendix A and below the two requested input entries are discussed.

Stakeholder Attribute Scores

The respondents were asked to allocate attribute scores to each listed stakeholder according to the scoring system as shown in 3.4. Besides, the respondents were also asked to identify the importance of power, proximity and urgency in general. This was done by allocating a weighting score to each attribute as part of the questionnaire. The options for weighting scores per attribute varied from 1-9, depending on the respondents perspective. Since the weightings could vary per respondent, a normalization of the results is required. The total influence score of each stakeholder was determined according to Equation 3.1.

$$S_{ix;norm} = \frac{(f_p * S_p) + (f_{prox} * S_{prox}) + (f_u * S_u)}{(f_p * S_{p;max}) + (f_{prox} * S_{prox;max}) + (f_u * S_{u;max})} \tag{3.1}$$

Where:

$S_{ix;norm}$	= Normalised influence score from respondent i for stakeholder x	(value between 0-1)
f_p	= Weighting score of power allocated by respondent i	(value between 1-9)
S_p	= Power score of stakeholder x provided by respondent i	(value between 1-4)
f_{prox}	= Weighting score of proximity allocated by respondent i	(value between 1-9)
S_{prox}	= Proximity score of stakeholder x provided by respondent i	(value between 1-4)
f_u	= Weighting score of urgency allocated by respondent i	(value between 1-9)

S_u	= Urgency score of stakeholder x provided by respondent i	(value between 1-5)
$S_{p:max}$	= Maximum power score	(value = 4)
$S_{prox:max}$	= Maximum power score	(value = 4)
$S_{u:max}$	= Maximum power score	(value = 5)

As shown in Equation 3.1, $S_{ix;norm}$ represents the normalised influence score that is given to stakeholder x by respondent i. This normalization was done by dividing the stakeholder's influence score by the highest possible score that could be assigned, given the respondent's attribute weightings (see Table 3.4 for the highest score per attribute). This normalization enables the comparison of the scores given by the various respondents. Finally, the average influence score per stakeholder was calculated with Equation 3.2.

$$S_{x;avg;norm} = \frac{(\sum_{n=1}^{n} S_{ix;norm})}{n} \tag{3.2}$$

Where:
$S_{x;avg;norm}$ = The average standardised influence score of stakeholder x retrieved from all respondents
n = Total number of respondents filling in the stakeholder survey

The resulting average scores, $S_{x;avg;norm}$, provide insights in the relative influence of a stakeholder, contributing to the identification of the key stakeholder group.

Stakeholder Attitude Scores
The attitude of each stakeholder listed could be allocated by the respondents as 'positive', 'neutral' and 'negative' and therefore range from actively supportive in ATES projects through to its active opposition. This information is of importance for building ATES market-entry strategies as it provides insights on which stakeholders, with the related level of influence, should be approached and engaged more attentively than others for successful implementation. Prior to calculating average attitude scores of each stakeholder, a positive attitude is assigned a score of '+1', a neutral attitude is assigned a score of '0' and finally, a negative attitude is assigned a score of '-1'. Subsequently, the scores of each stakeholder are averaged according to Equation 3.3.

$$A_{x;avg} = \frac{(\sum_{n=1}^{n} A_{ix;avg})}{n} \tag{3.3}$$

Where:
$A_{x;avg}$ = The average attitude score of stakeholder x retrieved from all respondents
$A_{ix;avg}$ = Attitude score of stakeholder x provided by respondent i
n = Total number of respondents filling in the stakeholder survey

3.2. Selecting the Key Stakeholder Group

The results of the interviews and questionnaires are compiled in a Stakeholder Barrier Matrix (SBM). In here, the stakeholders and their accompanying influence and attitude scores are presented against the identified ATES barriers in NYS. The relationship between stakeholders and barriers within this matrix is based on the roles and responsibilities of the stakeholders which are gathered from the stakeholder analysis. The SBM provides insights in both the influence and attitude of stakeholders for ATES projects as well as to their ability to solve current barriers within the sector. From this overview, the key stakeholders are selected. The relation between a stakeholder and barrier is scored on a scale of 1-4 as shown below:

1. There is no relationship between the stakeholder and barrier
2. The stakeholder can contribute to overcoming the barrier
3. The stakeholder is affected by the barrier
4. The stakeholder is affected by the barrier but also can contribute to solving it

A stakeholder is affected when a stakeholder's attitude regarding an ATES project is affected negatively, i.e. the willingness to cooperate in ATES projects becomes less. Two subsequent questions must be answered to determine the relationship between a stakeholder and barrier as listed above:

1. Does the stakeholder get a more negative attitude towards ATES projects due to the barrier?
2. Is the stakeholder able to contribute to the solution of the barrier?

Four sets of answers to these subsequent questions are possible and shown in Table 3.5. The numbers assigned to a set refers to the relationship between the stakeholder and barrier as listed above.

Table 3.5: Four possibilities of answering the two questions leading to a number between 1-4.

	Answer	Answer	Answer	Answer
1. Does the stakeholder get a more negative attitude towards ATES projects due to the barrier?	YES	YES	NO	NO
2. Is the stakeholder able to contribute to the solution of the barrier?	YES	NO	YES	NO
Number Assigned	4	3	2	1

3.3. Method for Determining the Interests and Requirements of Key ATES Stakeholders in New York State

Once the key stakeholders have been identified, it is essential that ATES systems fulfil their expectations for successful adoption in NYS. Therefore, the requirements and interests of stakeholders of ATES projects in NYS have been formulated. This was done based on manuals and design and installation guides released by authorities in NYS. Although these documents do not include information on ATES systems, they do include alternative geothermal systems such as Borehole Thermal Energy Storage (BTES), standing column wells and conventional open-loop systems. The design and installation guide 'Geothermal Heat Pump Systems Manual' (NYCDDC, 2012) and the report 'Geothermal Systems and their Application in New York City' (New York City Mayor's Office of Sustainability (MOS), 2015) are mainly consulted to identify the interests and requirements of key stakeholders and the constraints they impose on geothermal projects in NYS. These are included in the calculations of the technical and commercial ATES potential in the geospatial analysis in Chapter 5 and 6.

4

Results of the Identification of Key ATES Stakeholders and their Requirements and Interests in New York State

Geothermal architects are identified as the key stakeholders of ATES projects in NYS. This is the result of the analysis of the stakeholders' influence, attitude and ability to solve existing barriers, which is presented in this chapter. These results follow from the methodology discussed in Chapter 3. In Section 4.1 the ATES stakeholders in NYS are identified and the barriers are analysed. In Section 4.2 the level of influence per identified stakeholder is assessed. Subsequently, for the final selection of the key stakeholder group, results from Section 4.1 and Section 4.2 are combined in the Stakeholder Barrier Matrix in Section 4.3. Finally, in Section 4.4, the interests and requirements of the geothermal architects are provided, which are used in the geospatial analysis in Chapter 5 and 6 to allow for representative and accurate ATES potential calculations.

4.1. Stakeholder Identification and Barrier Analysis

Through the nine conducted interviews and the questionnaires which were sent to five stakeholder informants, a complete list of the ATES stakeholders in NYS including their roles is created and presented in Table 4.1. In this table, the stakeholders are categorised into six groups: clients, permitting authorities, consultants and designers, construction companies, related sectors and finally, utilities and municipal infrastructure.

Furthermore, from the conducted interviews, a list of barriers currently preventing ATES adoption in NYS is provided in Table 4.2. For comparison reasons, the same table also includes typical barriers found in the literature for similar market phases. From the interviews, it is concluded that the main ATES barriers are market-related. The few interested project developers regarding ATES technology expect fully redundant systems in NYS, which illustrates the low market demand and mistrust in the technology. As, to the policy environment, there are some uncertainties regarding regulations (reinjection related), but, these are not considered as the main bottlenecks by the experts. Since one ATES demonstration system is already in operation in New Jersey (adjacent to NYS) and the fact that conventional open-loop systems are already allowed to reinject groundwater, no major issues in this field are anticipated (as mentioned in Section 2.2). The results from the interviews provide qualitative insights into the severeness of the barriers identified. Even though many experts recognise the potential of ATES technology in NYS, the results from the interviews show that the market demand is still significantly low. Explained in more detail in the following paragraphs, the majority of the nine ATES experts agree that the following ATES barriers in NYS are critical:

1. Negative image/ bad reputation of ATES
2. Mistrust in technology
3. Concerns on environmental impact (groundwater quality)
4. Unfamiliarity of technology
5. Improper drilling techniques: low quality and very expensive
6. Lack of local ATES design, installation and maintenance organizations (preferred all-in-one)

Table 4.1: ATES stakeholder list and the role description in New York State.

#	List of Stakeholders	Stakeholder Role
Clients		
S01	Non-Residential Building Owners (e.g. Universities, Hospitals, Commercial Buildings)	Customer and ATES end-user
S02	Individual Homeowners or Condo/Coop Developments (HOAs)	Customer and ATES end-user
S03	Commercial Property Management Companies	Customer but no ATES end-user
S04	Non-Residential Developer Selling the Property	Customer but no ATES end-user
S05	Residential Development Owners (Apartment Buildings, Affordable Housing)	Customer but no ATES end-user
Permitting Authorities		
S06	NYC and Local Long Island Government	Provide work/building permits on a city & local level
S07	State Government (NYSDEC)	Provide ATES well drilling permits on Long Island
S08	Federal Government (USEPA)	UIC notification on a national level
S09	Local Water Districts	Provide input to NYSDEC on effects of ATES on drinking water supply/wells
Consultants and Designers		
S10	NYS Registered Architects	Serve as Owner's representative/coordinates engineers & consultants on ATES projects
S11	NYS Registered Engineers (Mechanical/HVAC, Civil, Geotechnical)	Design & prepare bid documents for building side of ATES systems
S12	Energy/Sustainability Consultants	Assess energy efficiency & sustainability of ATES systems, e.g., LEED
S13	Building-Climate Advisors (Heating, Ventilation and Air Conditioning (HVAC) experts)	Involved in designing the internal building climate
S14	Geothermal System Designers	Recommend/design ATES well systems & prepare bid documents
S15	Geohydrologists	Assess suitability of site geohydrological conditions for use of ATES systems
S16	3rd-Party/Utility-Scale Energy Companies	Turnkey ATES system finance-design-build-own-operate option
Construction Companies		
S17	Construction Management Firms	Serve as Owner's rep/coordinates contractors on ATES projects
S18	Drilling Companies	Responsible for drilling ATES wells
S19	General Contractor	Prime contractor coordinating all trades for construction of ATES systems
S20	Mechanical & Electrical Contractors	Responsible for installation of piping & electrical parts of ATES systems
S21	Design-Build Firms	Turnkey ATES system design and installation option
S22	Labor Unions	Represent workers in the various trades on ATES projects
Related Sectors		
S23	Conventional Fossil Fuel Providers	Supply homes and businesses with heating oil, propane etc.
S24	Industrial Water Sector	Sector that uses groundwater for industrial purposes
S25	Sustainable Energy Sectors (other than geothermal)	For example solar, wind, thermal storage, wastewater heat exchange
S26	Agricultural Water Sector	Sector that uses groundwater for agricultural irrigation purposes
S27	Environmental Organisations	NGOs monitoring & protecting environmental/ecological resources
Utilities and Municipal Infrastructure		
S28	PSEG	Electric utility (Nassau/Suffolk Counties) that provides rebates for ATES projects
S29	National Grid	Natural gas utility (Nassau/Suffolk Counties)
S30	Con Edison	Electric & natural gas utility in NYC (Brooklyn and Queens on Long Island)
S31	Public Transport Agencies	Provide approvals to drill wells near public infrastructure (rail, subway, tunnels)

Reputation and Concerns (Barriers 1,2,3 and 4)

From the interviews, it is concluded that the unjustified bad reputation associated with ATES systems is the result of the already installed and so-called conventional open-loop systems. For a century already, groundwater is pumped up in multiple regions within NYS for building cooling purposes. In contrast with ATES, however, this is a one-way use of groundwater and does not function as a self-sustaining thermal battery.

Table 4.2: New York State ATES barrier overview ([1]: Fleuchaus et al., 2018; [2]:Agterberg, 2016; [3]: Pellegrini et al., 2019).

Expert Interviews	Literature Review
Technical Barriers	
1 Groundwater pollution affecting quality of ATES systems (perception that ATES therefore cannot be implemented) **2** Groundwater velocities affecting quality of ATES systems (perception that ATES therefore cannot be implemented) **3** Relative high energy demand and bad insulation **4** Improper use of drilling techniques for ATES wells resulting in high costs and low quality of the wells **5** ATES temperatures not optimally compatible with climate regulating equipment in buildings	• Complexity regarding High-Temperature ATES systems (>40 °C) [1] • Lack of experience [1,3] • Design, construction and operation by unqualified parties [3] • Low operational performances due to inadequate cooperation or lack of a unique market player taking full responsibility [3]
Economic Barriers	
6 Exceptional high drilling costs **7** Imbalance in demand for heat and cold (site-specific) **8** Competition with cheap and 'unlimited' natural gas/oil **9** No company exist that is able to provide full ATES installation and operation services **10** Low priority regarding the environmental aspect in decision-making **11** Uncertainty on who is taking the risk of ATES installation	• Decisions for HVAC systems often made based on capital costs [2] • Split incentives (customer is not end-user) [2] • High capital costs, especially for drilling [1] • Decision-makers are often not aware of typical low payback times [1] • Uncertainty on who is carrying the exploration and investment risks [1]
Regulatory/Policy Barriers	
12Responsibility of cooling lies with tenants **13** Involvement of many stakeholders/decision-makers **14** Expected difficulties with regulators due to the crossing of property boundaries **15** Expected difficulties with reinjecting ground water	• Restructuring of regulatory infrastructure is time-consuming [2] • Lack of adequate legislation [3]
Social Barriers	
16 Unfamiliarity of technology **17** General negative image/bad reputation of ATES systems due to mismanagement of conventional open-loop systems **18** Mistrust in technology on various aspects **19** New technology >no one wants to be first	• Lack of knowledge [1,3] • Lack of public awareness [1,3] • Mistrust in technology [1]

This system is also referred to as 'pump and dump' and caused two major problems in the past. First, due to the inadequate separation between the building and groundwater circuit, in some cases chemical refrigerants originating from the building circuit leaked into the aquifers, which led to severe groundwater pollution. Second, because this is a one-way cooling system, heated groundwater is constantly dumped into the aquifers, resulting in net heating of the subsurface. In some installations, therefore, the heated groundwater reached the extraction wells after some time, heavily affecting the efficiency of the systems until it no longer could be used. Both events led to the perception that cooling with groundwater cannot be done sustainably. ATES, on the other hand, is a balanced two-way system, where depending on the type of season, either warm or cold water is pumped and reinjected again (See Figure 1.1). So, although inaccurate, ATES systems are nowadays associated with these unsustainable conventional open-loop systems. Literature shows that in more cases a negative reputation of ATES is caused by other types of geothermal systems (Fleuchaus and Blum (2017); Grimm et al. (2014); Pellegrini et al. (2019)). All in all, before ATES had the chance to enter the market in the US, it already got a bad reputation. A perception (first critical barrier) exists that ATES is not functioning properly (second critical barrier) and easily could pollute the surrounding groundwater (third critical barrier). Concerns on the latter point are even amplified by the fact that the New York metropolitan area fully relies on drinking water from the underground (interview John Rhyner). These three barriers are strongly related to the fact that ATES is associated incorrectly with conventional and unsustainable open-loop systems (fourth critical barrier).

Unfamiliarity of Technology (Barriers 4,5,6)

As to unfamiliarity of technology, the few stakeholders that can distinguish ATES systems from conventional open-loop systems use suboptimal techniques for installation. This negatively affects both the quality and costs of ATES systems. Groundwater wells in the US are mainly drilled using drinking-water well techniques, such as flush drilling. Although not compliant with the installation of ATES wells, these techniques are used in the few ATES pilot projects (interviews with ATES experts Bas Godschalk, Wil van den Heuvel and Gerwin Hop). A demonstration project of IF technology on a US military base in Florida confirms these perspectives. In terms of quality and costs, however, the significantly better and more preferable option is the use of reversed rotary drilling with airlifts. Unfortunately, this technique is much less well-known and not applied in the US (interview Bas Godschalk). Adequate drilling methods are critical for ATES systems since, in contrast to drinking-water wells, groundwater is reinjected in the subsurface. Improper drilling techniques can lead to major problems which translate into the infiltration of particles from one to the other poorly developed ATES well, thereby compressing the filter gaps and the space between the grains. This is what Bas Godschalk run into when assisting in the demonstration project in Florida, namely that an inaccurate drilling method was carried out which resulted in low-quality and high costs of the ATES system. Where in the Netherlands an ATES well usually is cleaned and ready for use in one week, it took six months to properly clean the well in this pilot project (interview Bas Godschalk). Wil van den Heuvel and Bas Godschalk both indicate that the Dutch drilling techniques (reversed rotary drilling with airlifts) for the realisation of ATES systems result in a longer life span and lower installation costs. All in all, the unfamiliarity of the technology in the US (fourth critical barrier) results in the use of improper installation techniques (fifth critical barrier) and causes the strong need for the currently lacking local expertise in designing, installing and maintaining the systems (sixth critical barrier).

4.2. Influence and Attitude of ATES Stakeholders in New York State

The stakeholders listed in Table 4.1 were examined according to their level of influence and attitude by sending surveys to five ATES stakeholder informants. Except for the person who requested to remain anonymous, the respondents and their role within the ATES sector in NYS are provided in Table 4.3.

Table 4.3: Stakeholder informants who assessed the NYS ATES stakeholders.

	Name	Organisation	Stakeholder Role
Respondent 1	Harold Maasen	Engie	Leading role in introducing ATES in NYS
Respondent 2	Robert Carver	NYSERDA	State agency providing subsidies and permits to ATES projects
Respondent 3	John Rhyner	Self-employed	Geohydrologist and involved in ATES suitability assessment in the region
Respondent 4	Tyrand Fuller	Suffolk County Water-Authority	Lead Hydrogeologist for Long Island's Local Water Authority providing input to NYSDEC on effects of ATES on drinking water supply/wells
Respondent 5	Anonymous	Anonymous	Anonymous

The results of the stakeholders' influence and attribute scores are presented in Table 4.4. The second column of Table 4.4 represents the relative influence of the stakeholders and are sorted from highest to lowest. The maximum score that can be achieved is 1.0 and the minimum score is 0.23. The rightmost column represents the attitude scores of the stakeholders regarding ATES projects. Values of this column can range from -1 to 1, of which -1 represents the lowest possible score and 1 representing the highest possible score. In the subsequent sections, the influence and attitude scores from Table 4.4 are analysed.

Analysis of Influence Scores of ATES Stakeholders in NYS

In general, the relative influence scores developed in the stakeholder analysis is in accordance with the influences which are expected from stakeholders in geothermal projects in NYS. This is illustrated in Figure 4.1. Displayed by this figure, clients, architects, engineers, consultants and contractors are all involved in the project team, but their footprint and ability to instruct change in ATES projects varies. Clients, architects and engineers are involved in ATES projects for the bigger part, the consultants less so and the contractors the least. These gradations are found in the influence scores in Table 4.4 as well. Clients, architects and engineers score relatively high, the consultants somewhat lower and the contractors are found almost at the bottom. Relating these results to the ATES sector in the Netherlands, however, unexpected results can be found in Table4.4. Especially the level of influence and the responsibility of geothermal system designers is very dif-

Table 4.4: Normalised influence and attitude scores of ATES stakeholders in New York State.

No.	Stakeholders	Influence Score (Normalized)	Attitude Score (Normalized)
S01	Non-residential building owners	0.867	0.20
S14	Geothermal system designers	0.849	0.40
S11	NYS Registered Engineers	0.836	0.00
S04	Non-residential developer selling the property	0.832	0.00
S05	Residential development owners	0.823	0.00
S07	State Government (NYSDEC)	0.822	0.20
S10	NYS Registered Architects	0.797	0.00
S06	NYC and Local Long Island Government	0.795	0.20
S09	Local water districts	0.789	0.00
S17	Construction Management Firms	0.734	0.40
S13	Building-climate Advisors (HVAC experts)	0.733	0.00
S15	Geohydrologists	0.719	0.40
S21	Design-Build Firms	0.691	0.50
S28	PSEG	0.682	0.80
S18	Drilling Companies	0.667	0.40
S27	Environmental organizations	0.667	0.20
S31	Public Transport Agencies	0.665	-0.40
S16	3rd-Party/Utility-Scale Energy companies	0.651	0.50
S12	Energy/Sustainability Consultants	0.649	0.60
S02	Individual homeowners or condo/coop developments	0.642	0.20
S03	Commercial property management companies	0.606	0.00
S30	Con Edison	0.589	0.20
S08	Federal Government (USEPA)	0.583	0.40
S19	General Contractor	0.571	-0.20
S23	Conventional fossil fuel providers	0.569	-0.40
S20	Mechanical & Electrical Contractors	0.550	-0.20
S22	Labor Unions	0.525	0.00
S29	National Grid	0.519	0.20
S25	Sustainable energy sectors (other than geothermal)	0.510	0.40
S26	Agricultural water sector	0.498	-0.50
S27	Industrial water sector	0.431	-0.20

ferent compared to designers within ATES projects in the Netherlands (Interview Harold Maasen). In NYS, the architect serves as the lead consultant who coordinates with various professionals, from initial project screening through design development and construction administration (NYCDDC, 2012). The high scores for architects are therefore representative for the ATES sector in NYS but are different from ATES projects in the Netherlands. Finally, from Table 4.4 it is concluded that labour unions have a relatively low influence on the outcomes of ATES projects in NYS. This is unexpected since in recent ATES projects lead by Dutch companies the unions were considered the main bottlenecks due to unexpected imposed price increases for well drilling, jeopardising the ATES business case.

Analysis of Attitude Scores of ATES Stakeholders in NYS

It is concluded from the attitude values in Table 4.4 that most ATES stakeholders have a neutral attitude towards ATES projects. Furthermore, PSEG and sustainability consultants are the only stakeholders who come close to an attitude score of 1 and have a positive attitude towards ATES development. Also, only a few stakeholders appear to have a substantial negative attitude towards ATES projects. This is unexpected since no ATES projects are yet realised in NYS, even after recent ATES-implementation attempts (two projects with Over Morgen and Engie). In line with the literature study in Chapter 2 and the interviews with ATES experts, attitudes of stakeholders in NYS were expected to score lower.

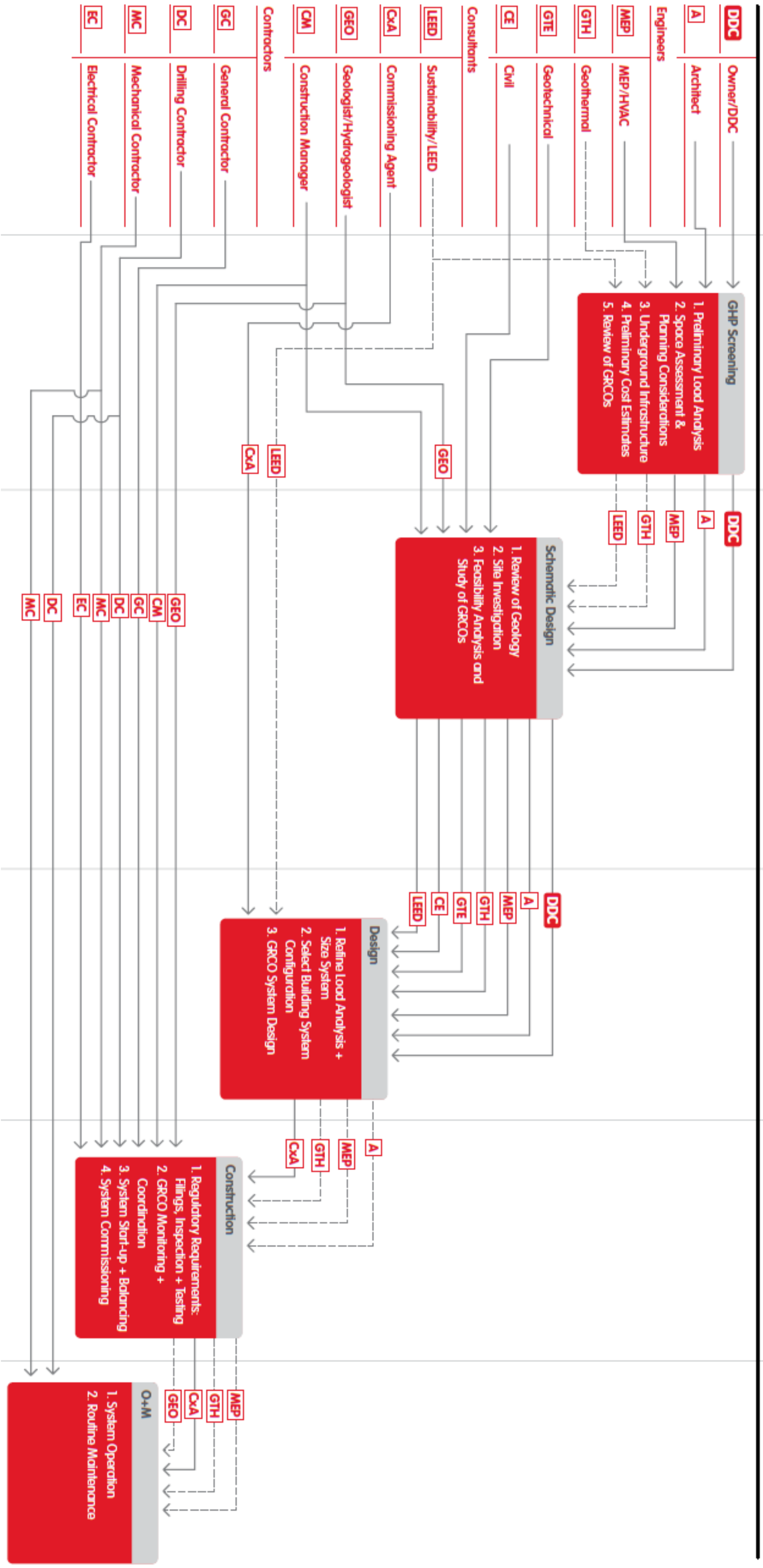

Figure 4.1: The typical workflow of the realisation of geothermal systems in NYC (NYCDDC, 2012).

4.3. Combining Stakeholders and Barriers: Selection of the Key Stakeholder Group

The degree in which stakeholders can exercise influence on the outcome of ATES projects is not solely based on the influential scores provided in Table 4.4, but also on their current attitude towards ATES projects and their ability to contribute to solving current barriers within the NYS ATES-sector. If for example a certain stakeholder has a high influence score but appears to have little control on overcoming current barriers, it is not necessarily strategic to build implementation strategies for that particular stakeholder alone. The same holds for powerful stakeholders which are already in favour of implementing ATES systems. To this end and as mentioned in Chapter 4.3, the stakeholders with their accompanying influence and attitude scores from Table 4.4 are related to the barriers identified in Table 4.2 in a so-called Stakeholder Barrier Matrix (SBM). From this SBM, a key stakeholder group is selected based on their influence scores, attitude scores and their ability to overcome current ATES barriers. Stimulating and mobilising this key stakeholder group to take conducive steps regarding ATES adoption is an effective manner to advance the implementation of the technology is NYS.

Four possible relationships exist between a particular stakeholder and a barrier in this context, of which the descriptions and methodologies are discussed in Chapter 3. The results are provided in Table 4.5 and for readability reasons, the four possible relationships are provided in the table once more. On the horizontal axis in Table 4.5, the barriers are displayed (descriptions of the numbers are provided in Table 4.2) and on the vertical axis, the stakeholders are placed and are sorted from top to down from highest to least influence regarding ATES projects. The description of the roles and responsibilities of concerning stakeholders is listed in Table 4.1.

Table 4.5: ATES Stakeholder Barrier Matrix in NYC (compiled by author).

			Barriers																		
No.	**Stakeholders**	**Attitude**	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17	B18	B19
S01	Non-residential building owners	Neutral	3	3	4	3	4	3	3	3	3	4	4	1	3	3	3	4	4	4	4
S14	Geothermal system designers	Neutral	4	4	4	3	4	3	4	3	3	4	4	3	3	3	3	4	4	4	4
S11	NYS Registered Engineers	Neutral	4	4	4	3	4	3	4	3	3	4	4	3	3	3	3	4	4	4	4
S04	Non-residential developer selling the property	Neutral	3	3	4	3	4	3	3	3	3	4	4	4	3	3	3	4	4	4	4
S05	Residential development owners	Neutral	3	3	4	3	4	3	3	3	3	4	4	4	3	3	3	4	4	4	4
S07	State Government (NYSDEC)	Neutral	3	3	2	1	1	1	1	2	1	2	2	2	1	4	4	4	4	4	4
S10	NYS Registered Architects	Neutral	4	4	4	3	4	3	4	3	3	4	4	3	3	3	3	4	4	4	4
S06	NYC and Local Long Island Government	Neutral	3	3	2	1	1	1	1	2	1	2	2	2	1	4	4	4	4	4	4
S09	Local water districts	Neutral	4	4	1	1	1	1	1	1	1	2	1	1	1	4	4	4	4	4	4
S17	Construction Management Firms	Neutral	3	3	4	3	4	3	4	3	3	2	1	1	3	3	3	4	4	4	4
S13	Building-climate Advisors (HVAC experts)	Neutral	3	3	4	3	4	3	4	3	3	2	3	3	3	3	3	4	4	4	4
S15	Geohydrologists	Neutral	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
S21	Design-Build Firms	Positive	2	2	1	1	3	1	2	3	2	2	2	1	1	3	3	2	2	2	2
S28	PSEG	Positive	1	1	1	1	1	1	1	2	1	2	2	1	1	1	1	4	4	4	4
S18	Drilling Companies	Neutral	1	1	1	2	1	2	1	1	1	1	1	1	1	1	1	4	4	4	4
S27	Environmental organizations	Neutral	2	2	1	1	1	1	1	2	1	2	1	1	1	1	1	2	2	2	2
S31	Public Transport Agencies	Neutral	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	3	3	3	3
S16	3rd-Party/Utility-Scale Energy companies	Positive	3	3	1	1	1	1	1	2	2	2	2	1	1	1	1	4	4	4	4
S12	Energy/Sustainability Consultants	Positive	3	3	4	3	4	3	4	3	3	2	2	3	1	3	3	4	4	4	4
S02	Individual homeowners or condo/coop developments	Neutral	3	3	4	3	4	3	3	3	3	4	4	3	3	3	3	4	4	4	4
S03	Commercial property management companies	Neutral	3	3	4	3	4	3	4	3	3	4	4	4	3	3	3	4	4	4	4
S30	Con Edison	Neutral	1	1	1	1	1	1	1	2	1	2	2	1	1	1	1	4	4	4	4
S08	Federal Government (USEPA)	Neutral	3	3	2	1	1	1	1	2	1	2	2	2	1	2	2	4	4	4	4
S19	General Contractor	Neutral	3	3	4	3	4	3	4	3	3	2	1	1	3	3	3	4	4	4	4
S23	Conventional fossil fuel providers	Neutral	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	4	4	4	4
S20	Mechanical & Electrical Contractors	Neutral	1	1	1	1	1	1	2	1	4	1	1	1	3	1	1	4	4	4	4
S22	Labor Unions	Neutral	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1
S29	National Grid	Neutral	1	1	1	1	1	1	1	2	1	2	1	1	1	1	1	4	4	4	4
S25	Sustainable energy sectors (other than geothermal)	Neutral	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	2	2	2	2
S26	Agricultural water sector	Positive	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	4	4	4	4
S27	Industrial water sector	Neutral	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	4	4	4

Legend

1	There is no relationship between the stakeholder and the barrier
2	The stakeholder can contribute to solving the barrier
3	The stakeholder is negatively affected by the barrier
4	The stakeholder is negatively affected by the barrier but can also contribute to solving it

Analysis of the Results from the Stakeholder Barrier Matrix

Table 4.5 provides information on the ATES sector in NYS in a nutshell and in the context of this study, this is used to select a key stakeholder. To this end, Table 4.5 is analysed below followed by a definitive selection of key stakeholders.

Generally, as is concluded from Table 4.5, the higher the influence of the stakeholder, the higher the ability to help solve the barriers (green and purple cells indicate that the stakeholder can contribute to a solution of a barrier). This is generally true except for the energy consultants, individual homeowners and the construction property management companies: stakeholders with relative high ability to solve barriers but relative low influence.

Considering the stakeholder's influence score, attitude and ability to help solve barriers, it would make sense to focus on non-residential building owners in order to develop a willingness to implement ATES systems in their buildings. Since the project team (engineers, architects and consultants) has to incorporate the demands of the client, this can be an effective way of increasing ATES implementation in NYS. However, assuming that clients such as the non-residential building owners are not always fully informed about the geothermal techniques (read ATES) available, it is more effective to focus on the architects. If architects are fully aware of the possibilities and benefits of ATES and if they have a positive attitude towards ATES projects, they can advise their clients to implement ATES systems rather than other heating and cooling systems. This is emphasised by the fact that architects serve as the lead consultants who coordinates with various professionals, from initial project screening through design development, construction administration and client reporting. Therefore, it would be strategic to focus on the interests of the (geothermal design) architects for advancing ATES adoption in the region.
Many stakeholders are affected by the social barriers identified in this study (barriers 16-19) but simultaneously have the opportunity to help solve these barriers too. Obtaining a clear understanding of ATES technology, its applicability and benefits stimulate stakeholders to advocate the technique among other stakeholders, positively affecting its reputation. From Chapter 4 it is concluded that unfamiliarity of the technology is the main barrier for low market penetration. The (geothermal) designers can exercise the biggest influence on overcoming this barrier since, as mentioned earlier, the architects are the lead consultants who oversee and coordinate heating and cooling projects while serving as the clients' representatives. This group, therefore, can be seen as a crucial stakeholder which must be considered in ATES-implementation strategies.

Finally, (geothermal) architects must fulfil the needs and interests of the local authorities (regulatory playing field) and there clients (market demand) for realising geothermal projects. So focusing on the needs and interests of the designers automatically means that the interests of clients (project developers and individual home-owners) and authorities (NYSDEC and water authorities) are taken into account as well. Since NYSDEC, individual home-owners and project developers are all part of the top-influential stakeholders (see Table 4.5), it is therefore strategic to focus on the interests of (geothermal) designers since it covers the interests of the most influential stockholders all at once.

Concluding, for advancing ATES adoption in New York State, special attention must be paid to the architects, or geothermal system designers, who have a significant influence in the outcome of successful ATES projects. This identified and key stakeholder is considered in the final part of this research in which the potential of ATES is examined while considering the requirements and interest of the (geothermal) designers. To do so, the interests of this key stakeholder group is examined in the next and final section of this chapter.

4.4. Overview of the Interests and Requirements of the Geothermal Architects

The (geothermal) architects are identified in the context of this study as the key stakeholders. As mentioned in Chapter 3, their interests and requirements are retrieved from consulting geothermal heat pump reports and manuals released by the City of New York for stimulating and guiding geothermal projects in the area. Below, these interests and requirements are provided. The requirements and constraints imposed by the (geothermal) architects are considered when calculating the technical and commercial ATES potential in the next chapters as shown in Figure 2.5.

At a minimum, the architects evaluate the following prior to selecting and designing geothermal heating and cooling systems: (I) installation costs, (II) filings and permit requirements, (III) system reliability and (IV) operation and maintenance. These are translated to more concrete requirements and interests below.

Spatial Assessment and Planning Considerations
Drilling and installing ATES wells with related piping require considerable area and must be accessible for drill rigs. Moreover, to avoid interference and thermal energy losses between warm and cold wells of ATES systems, adequate spacing is required between the two. As shown in Figure 4.2, groundwater is pumped from the aquifer inducing a drop in the water level surrounding the well, similar to an inverted cone called drawdown (explained in more detail in Chapter 2). When water is reinjected as shown in Figure 4.2, there is usually a groundwater level-raise around each of the infiltration wells. When multiple pumps are installed within each others' area of influence, interference can occur. Although a minimum of 150 to 250 feet between extraction and infiltration wells is recommended to avoid potential overlap in areas of influence, the actual spacing will be determined by the aquifer's hydraulic properties, specified flow rates, pumping schedule, and annual pump run times (NYCDDC, 2012).

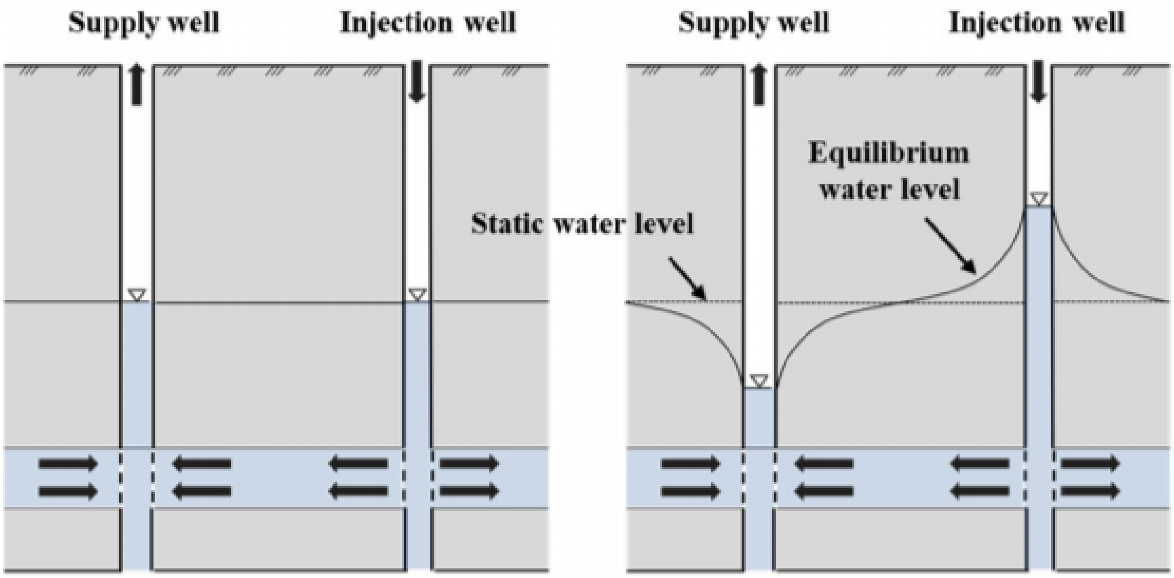

Figure 4.2: Left: groundwater level change around ATES wells before operation. Right: groundwater level in equilibrium state during operation (Kim et al., 2018).

Meeting a building's peak thermal energy demand
The thermal capacity of an ATES system is dependent on the pumping rate and groundwater temperature. The aquifer beneath a site must therefore be able to supply and accept the required flow rate to meet peak demand. Moreover, for optimal system operation, balanced annual energy loads of buildings are preferred for installation to limit unsustainable growth of either the warm or cold well which eventually could lead to interference and thermal energy losses.

Installations in highly permeable aquifers
ATES systems require a highly permeable aquifer such as sand and gravel deposits to limit the drawdown of the wells and realising high well yields. Aquifers containing a lot of clay and silt can restrict the flow of groundwater and should be avoided (NYCDDC, 2012). What is more, geohydrological studies of a particular area from a reliable source such as the USGS are essential in evaluating the viability of an aquifer (NYCDDC, 2012).

Minimising the potential of well clogging
Well screens must be designed to minimise the number of particles such as sand, silt, and clay that can enter the well from the aquifer. A high particular load in the infiltration well can clog screen slots, reduce flow rates back to the aquifer, and cause excessive back pressure and submersible pump damages. Slot sizes should also be designed to better match the different aquifer conditions throughout the depth of the well.

Design Temperature Difference
The thermal capacity of ATES systems is dependent on the temperature difference between the groundwater on the source side and the building circulation loop on the load side. This difference is known as the design temperature or ΔT. A geothermal system designer determines ΔT, which typically varies from 10 °F to 25 °F.

Limit groundwater level-raise to prevent soil cracks
Infiltration wells should be properly spaced to avoid groundwater level-raise in the area, particularly at project sites where the depth to water is shallow. Moreover, excessive raise may create higher back pressures on system pumps, which can lower pumping rates, increase the temperature difference and reduce overall efficiency (NYCDDC, 2012). Moreover, when groundwater level-raise to a critical level, soil cracks can occur resulting in complete malfunctioning of the ATES system (this phenomenon is explained in more detail in Chapter 5).

Groundwater quality
Groundwater quality is another critical factor for ATES design. Urban groundwater contains dissolved metals such as iron, organic pollutants, high salinity (only present in coastal areas), and bacteria which can lead to bio-fouling or corrosion of metallic piping, mechanical equipment and valves (NYCDDC, 2012). These compounds can lead to scaling, bio-fouling or corrosion of metallic piping, valves and mechanical equipment. Excessive bio-fouling and scaling can lead to loss of system efficiency by clogging well screens. Groundwater analysis is recommended during the schematic design phase to determine chemical compound levels that can affect system operation and to evaluate measures to address problems regarding water quality. High maintenance costs and even complete system failure are possible if water quality is not addressed in the design.

Reducing Initial Costs by using Bivalent Systems
Initial costs of the installation of ATES systems should be reduced by including bivalent and district-scale solutions, as well as procuring renewable federal, state, and local incentives that may be available. Bivalent solutions, or hybrid systems, refer to ATES systems which only cover part of the peak heating demand of its building, avoiding substantial installation costs that are not necessarily recovered during operation (New York City Mayor's Office of Sustainability (MOS), 2015). Addition heating devices, such as (electric) boilers, are then used during the coldest days to meet the peak heating demand of a building. Creative solutions that strive to reduce a portion of a building's load profile also can significantly reduce capital costs (New York City Mayor's Office of Sustainability (MOS), 2015). Additional benefits of bivalent systems are the increase in reliability and viability of the system by reducing the land area required, providing a buffer against possible imbalances between design building load and thermal capacity estimates of the ground and finally allow for redundancy of the system.

Interference with other adjacent systems
Hypothetically, it is possible that an ATES system on one property can impact systems on adjacent properties. In particular, if wells or loops are installed close to the site boundary, the potential of interference with adjacent properties increase. System size and building load profile will determine the extent of thermal effects. Factors such as pumping, well spacing, and hydraulic properties of the aquifer are also necessary to determine the possible effect. Drawdown and groundwater level-raise around wells can also influence water levels on adjacent property. The presence of any nearby existing geothermal system or groundwater supply well should be investigated prior to selecting geothermal systems.

Satisfying the needs of clients and permitting authorities
By focusing on the interests of architects, the interest of clients and authorities are covered as well. The architects serve as the representatives of the clients and are responsible for obtaining installation-permits from

the authorities. To this end, the interests of the ATES clients and authorities are discussed. As to the ATES clients, there are various types of ATES clients in NYS as shown in Table 4.1. Derived from Agterberg (2016), the ATES clients are divided into market segments similar to to the ATES market in the Netherlands. From the experiences developed in the Netherlands (with 2500 ATES systems in operation), four NYS ATES-market segments are built up and separated based on the criteria on which the clients within that particular segment make purchasing decisions. Agterberg (2016) concluded that the function and type of ownership of the buildings are the main factors determining these separating criteria. The type of the building is directly related to the amount of energy, hence the required capacity that the building requires and the type of ownership determines the willingness to invest in long-term solutions. This is applied to the ATES-client stakeholders in NYS as shown in Figure 4.3.

	Residential	Non - Residential
Self-exploitation	**Segment 1** • Individual Homeowners • Condo/Coop Developments (Homeowners Associations) **Criteria:** • Low installed HVAC capacity • Energy efficiency • Long-term cost savings • *(Sustainability)*	**Segment 2** • Non-Residential Building Owners (e.g. Universities, Hospitals, Commercial Buildings) **Criteria:** • High installed HVAC capacity • Energy efficiency • Long-term cost savings • *(Sustainability)*
Third party exploitation and use	**Segment 3** • Residential Development Owners (Apartment Buildings, Affordable Housing) **Criteria:** • Low installed HVAC capacity • Low capital costs • Short-term cost savings • *(Sustainability)*	**Segment 4** • Non-Residential Developer Selling the Property • Commercial Property Management Companies **Criteria:** • High installed HVAC capacity • Low capital costs • Short-term cost savings • *(Sustainability)*

Figure 4.3: ATES market segments based on purchasing decisions.

From Table 4.3 it is concluded that long-term cost savings, capital costs and possibly sustainability in terms of CO2-reduction are important and quantifiable criteria imposed by ATES clients. Other but less quantifiable interests of building owners are (from Agterberg (2016) and NYCDDC (2012)) :

- Level of comfort
- Compliance with building and exploitation regulations (e.g., since the entry of the current gas moratorium it is prohibited for new gas connections to be installed)
- Higher imposed charging rates by utilities during peak grid demand
- Reliability and redundancy
- Cost volatility (offset of fuel cost)

Finally permits are necessary for maintaining environmental perseverance and for installations in contaminated areas. Moreover, interference with existing groundwater supply wells must be avoided (questionnaire respondent: Lead hydrologist Suffolk Water Authority).

III

ATES Potential Considering the Interests and Requirements of Key Stakeholders

5

Methods and Materials Used in the Geospatial Analysis for Examining ATES Potential while Considering the Interests of Key Stakeholders in New York State

Now that the key stakeholders have been identified and their interests and requirements are known, the region's technical and commercial potential are subsequently derived through geospatial analysis. First of all, this chapter describes the methodology framework for this analysis in Section 5.1, including a more detailed scope and software, data and resources used. After that, Section 5.2 and 5.3 respectively cover the methodologies for assessing the region's technical and commercial potential. Finally, since energy efficiency is proven an important criterion for (geothermal) architects and ATES clients (discussed in Section 4.4), methodologies to derive the Coefficient of Performance (COP) levels of ATES systems are provided in Section 5.4. This information is eventually used in Chapter 6 to compare energy performances of ATES systems with those of the conventional heating and cooling techniques.

5.1. Methodology Framework

This section provides an overview of the (geographic) boundaries, tools and data used for the geospatial analysis in this study. First, the scope of the analysis is discussed, subsequently, an overview of the key steps is provided for examining the technical and commercial ATES potential. Finally, the software and data that are used are described followed by an overview of the included requirements from the (geothermal) architects in this analysis.

5.1.1. Geographic Extent of the Geospatial Analysis: Nassau County

Although the stakeholder analysis is focused on NYS, the scope of the geospatial analysis is confined to Nassau County for data processing purposes. Preliminary ATES-feasibility studies in NYS show that particularly beneath Long Island suitable ATES aquifers are present (Grosser, 2018). The geohydrological characteristics of Long-Island are extensively studied and mapped by the United States Geological Survey (USGS) and local municipal governments. The reason for these extensive studies is because Long Island's aquifer system has been designated by a 'sole source' aquifer by the U.S. Environmental Protection Agency (USEPA), which implies that it is the only source of drinking water for its residents.

Because of these extensive previous studies, limiting the scope to Nassau County still leaves a sufficiently large data set for analysis. Nassau County is a region located on Long Island, of which the geographic boundaries are shown in Figure 5.1. It occupies a portion of Long Island immediately east of the New York City borough of Queens and west of Suffolk County and is divided into two cities and three towns.

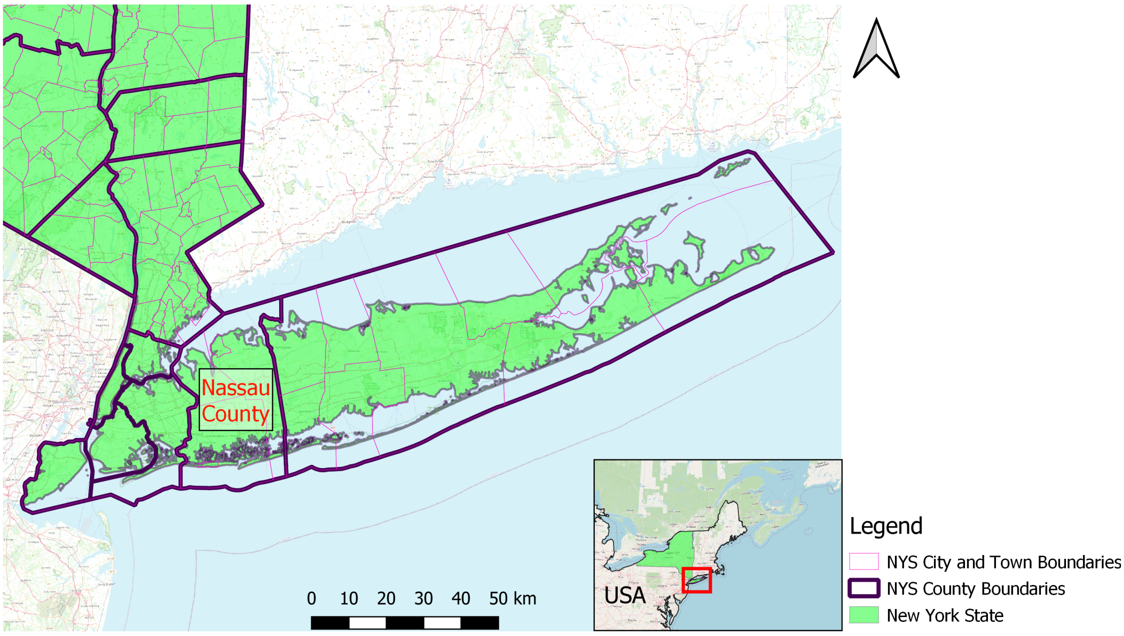

Figure 5.1: New York State, county and city boundaries. The geographical scope of the geospatial analysis, Nassau County, is indicated in red text (compiled by author).

5.1.2. Methodology Overview

The potential of ATES within Nassau County is examined in a geospatial analysis consisting of a technical geohydrological analysis and an ATES building-applicability analysis to determine the technical and commercial potential respectively. Figure 5.2 displays the building blocks for the geospatial analysis conducted in this study.

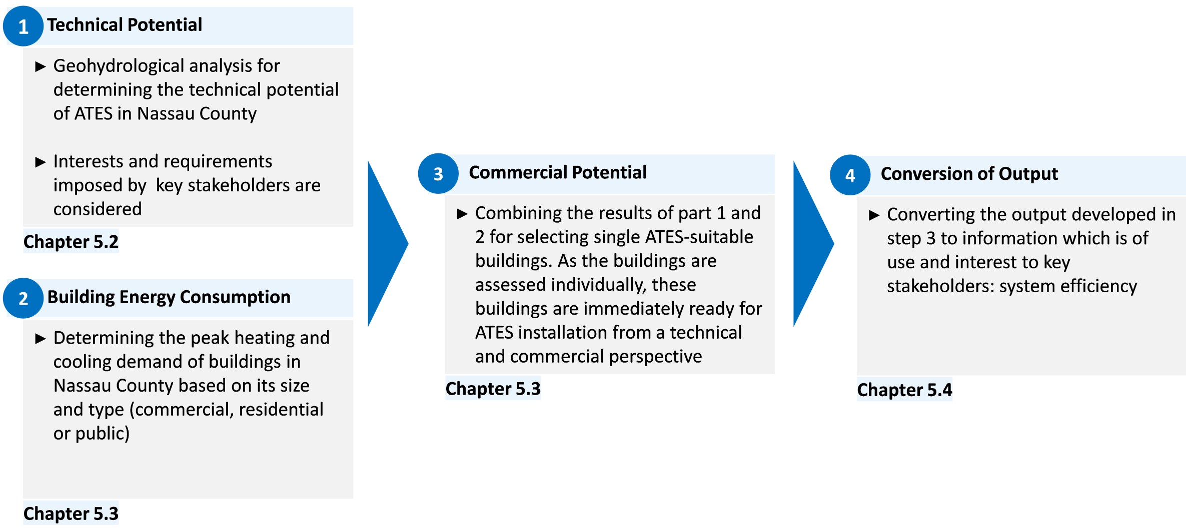

Figure 5.2: Steps for determining the technical and commercial potential in the geospatial analysis.

In the first part of Figure 5.2, the potential power supply of ATES wells is calculated based on local geohydrological conditions. In the second part, the power demand for buildings located in Nassau County is examined. The two analyses are then combined in the third part to determine the commercial ATES-potential and whether or not ATES can produce sufficient energy to meet the energy demand of buildings in Nassau County. In this study, the buildings are examined individually for ATES suitability, implying that these identified buildings are immediately ready for ATES installation from a technical and commercial perspective. This does imply however that the commercial potential calculated in this study is only a part of what is actually possible when building-owners would engage in joint efforts. Such partnerships provide attractive solutions for the installation of commercially viable ATES systems since the relatively high initial costs are shared among the building-owners resulting in lower payback years for the individuals. Finally, in the fourth part of Figure 5.2, the results from the previous part are converted to information which is of interests to the (design) architects, being system efficiency performances. The sections covering the methodologies of the four subsequent parts are shown in Figure 5.2 as well.

5.1.3. Software, Data and Resources

To calculate ATES potential in Nassau County, spatial data is used. Spatial data, also known as geospatial data, is a term used to describe any data related to or containing information about a specific location on the Earth's surface. Spatial data can be gathered, managed and analysed using a so-called Geographic Information System (GIS). Various GIS platforms are available and for the purpose of this study mainly two platforms are used, QGIS and PostGIS. QGIS is used for calculating the technical ATES potential and for visualising the results of both the technical and commercial ATES potential. For the identification of ATES-suitable buildings and for determining the commercial potential, the modification and combination of large geospatial datasets are required. To illustrate this, a building dataset of 420 000 rows and 220 columns are analysed and processed in the geospatial analysis. Performing operations on such datasets in QGIS is laborious and to prevent time and computational issues a relational database management system called PostgreSQL is used with its spatial extension PostGIS. This allows for more efficient operations when the spatial extent or resolution of the database is high. As to the data used for conducting the geospatial analysis, various data are collected from various resources. Moreover, hydraulic parameters are derived from literature and design parameters are derived from Dutch ATES design standards or from geothermal manuals in NYS. Finally, the requirements and constraints imposed by the design architects are considered in the geospatial analysis which is discussed in more detail in the next section. An overview of the data, the sources and the processing software used is provided in Table 5.1.

Table 5.1: Data, data sources and software used for determining the technical and commercial ATES potential.

	Data Used	Data Source	Data Processing Software
Technical Potential (Chapter 5.2)			
	• Elevation data of soil layers of Nassau County on a grid of 800x800m	• US Geological Survey (USGS)	• QGIS
	• Digital Elevation Model (DEM) of Nassau County	• Cornell University	• QGIS
	• Data on geohydraulic properties of aquifers in Nassau County	• Various local geohydrological reports	• QGIS
	• ATES design guidelines and restrictions imposed by (geothermal) architects	• NVOE (2006) • Requirements listed in Chapter 4.4	• QGIS
Commercial Potential (Chapter 5.3)			
	• Building-property and taxlot information of Nassau County	• Pitney Bowes • NYS GIS Clearinghouse	• PostgreSQL with PostGIS • QGIS
	• Data on building heating and cooling demands based on the building type	• Goldman Copeland	• PostgreSQL with PostGIS • QGIS
	• Restrictions imposed by (geothermal) architects	• Requirements listed in Chapter 4.4	• PostgreSQL with PostGIS • QGIS
	• Building footprints	• NYS GIS Clearinghouse	• QGIS

5.1.4. Inclusion of the Interests and Constraints Imposed by Key ATES Stakeholders for Determining ATES potential in Nassau County

Considerations, decisions and assumptions made for the methodologies used in this chapter are predominantly based on the interests and requirements of the (geothermal) architects. An overview of these interests and constraints is presented in Table 5.2 and are explained in more detail in Section 4.4. The same table also indicates whether or not these factors are included in both the technical and commercial ATES potential analysis.

Table 5.2: Overview of the interests of and constraints imposed
by (geothermal) architects and whether these are included in the technical and commercial ATES potential analysis for Nassau County.

Requirements / Constraints	Included in Technical Potential	Included in Commercial Potential
Spatial assessment and planning Considerations	x	x
Meeting a building's peak thermal energy demand	x	✓
Installation in highly permeable aquifers	✓	✓
Minimising the potential of well clogging	✓	✓
Design temperature differences	✓	✓
Limiting groundwater level-raise to prevent soil cracks	✓	✓
Groundwater quality	✓	✓
Reducing capital costs through bivalent systems	x	✓
Preventing interference with adjacent well systems	✓	✓
Satisfying the needs of clients regarding costs	x	✓
Satisfying the needs of clients regarding energy efficiency	✓	✓
Satisfying the needs of permitting authorities	✓	✓

5.2. Methods for Determining the Technical ATES Potential

The objective of the technical ATES potential analysis is to indicate ATES suitable regions and to calculate the maximum potential power of ATES systems in terms of heating and cooling in Nassau County. First, the aquifers underneath Nassau County are analysed for ATES-suitability and from this analysis, it is decided to solely consider the Magothy aquifer in Nassau County for ATES potential calculations. Afterwards, methods for determining the maximum allowable well yields, or pumping rates, are provided which are dependent on the geohydrological parameters of the Magothy aquifer. The maximum allowable well yields are an indication of the power that an ATES system can deliver. All in all, this section provides the methodologies used to define the technical boundaries of ATES systems and the accompanying potential power in Nassau County.

5.2.1. Geohydrological Analysis of Nassau County

According to the U.S. Census Bureau, Nassau County has a total area of 1,174 km^2, of which 737 km^2 consists of land and 436 km^2 (37%) is water. The elevation in the county ranges from sea level to about 104 meters above the sea near the center of Nassau County. Nassau County is part of Long Island, from which the topographic features are largely the result of glacial activity during the Pleistocene Epoch (McClymonds and Franke, 1972). The foundation of Long Island is the consolidated bedrock and consists almost entirely of igneous and metamorphic rock. The bedrock surface is nearly planar and slopes generally southeastward with a gradient of 65 to 100 ft/mi and slopes southeastward from 150 to 600 ft below sea level (McClymonds and Franke, 1972; Stumm, 2006). The top of the bedrock, which is relatively impermeable, generally forms the base of the ground-water reservoir (Stumm, 2006). On top of the bedrock foundation, several other geologic deposits and formations exist and are illustrated in Figure 5.3. Additionally, detailed descriptions of the hydrogeologic and geologic units shown in this figure are provided from top to down in Table 5.3.

Selection of Suitable Aquifers in Nassau County

As shown in Table 5.3, four aquifers are located underneath the surface of Nassau County. In this research, only one of them is further examined for ATES suitability, the Magothy Aquifer. The main reasons for this selection are to comply with the constraints and requirements imposed by the design architects on three aspects: minimising the potential of well clogging, installations in aquifers with proper groundwater quality (discussed in Chapter 2) and satisfying the needs of permitting authorities. The Upper Glacial Aquifer (UGA) is mainly excluded to minimise the possibility of well clogging due to redox conditions since this aquifer contains oxygen. Furthermore, the highest groundwater velocities are present in this aquifer (as shown in Figure 5.4). Both factors indicate less suitable ATES conditions due to respectively system failure and low energy recovery rates. The North Shore Aquifer is excluded since it only covers a significantly small part of the study area (see Figure 5.5). Besides its small size, previous USGC studies indicate that the northern part of Nassau County has a complex hydrogeologic framework (Stumm et al., 2004). Also, this aquifer is hydraulically connected with the Lloyd aquifer, in which well installations are not allowed by law. For over 30 years, a moratorium has been in place to prevent the installation of new Lloyd Aquifer wells in non-coastal communities, helping to preserve the aquifer for those communities that have no other cost-effective source of public water supply. To satisfy the needs of the permitting authorities (constraint), the Lloyd aquifer is excluded from the ATES potential analysis. All in all, in this research, the Magothy aquifer in Nassau County

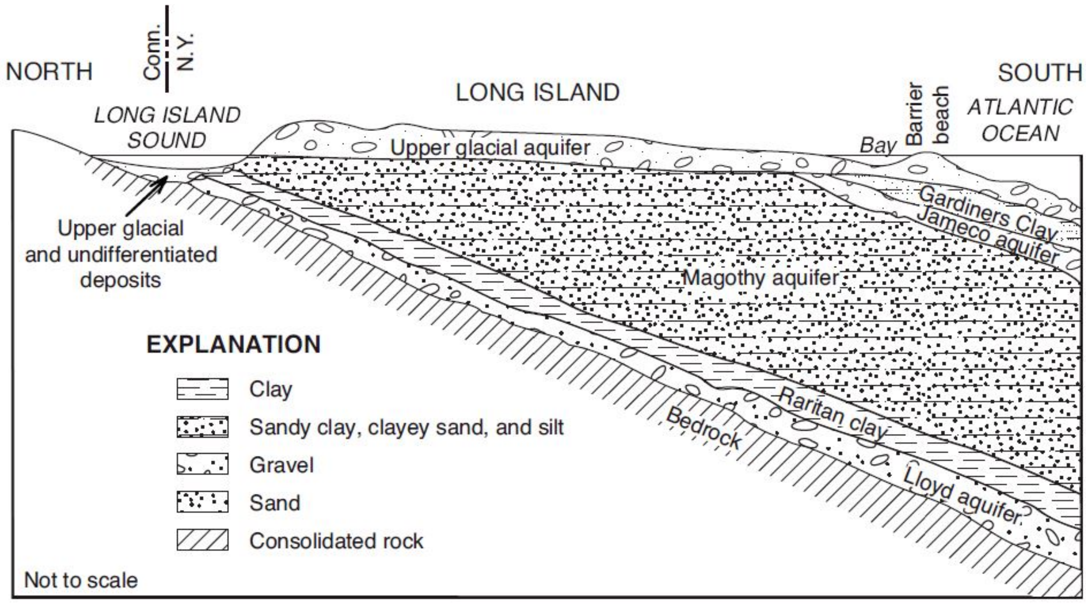

Figure 5.3: Generalised geologic section of Long Island showing relative positions of major aquifers (Lindner and Reilly, 1983).

is further examined for assessing the technical and commercial ATES potential of the region.

Table 5.3: Generalised description of hydrogeologic units underlying Nassau County, NYS (Stumm et al., 2004).

Hydrogeologic unit	Geologic unit	Description and hydraulic characteristics
Upper glacial aquifer	Upper Pleistocene deposits	Till and outwash deposits of sand, silt, and clay and boulders. Varied permeability with an average horizontal hydraulic conductivity of 270 feet per day and an anisotropy of 10:1. Outwash has the highest hydraulic conductivity.
North Shore confining unit	Pleistocene deposits	Marine and postglacial lake deposits. Clay and silt deposits with minor lenses containing shells. The clay is olive brown and olive gray and poorly permeable. Unit contains a minor sand unit that is moderately permeable.
North Shore aquifer	Pleistocene deposits	Sand, silt, and gravel; brown and olive gray, poor to moderate sorting. Moderately permeable.
Magothy aquifer	Matawan Group-Magothy Formation, undifferentiated	Fine sand with silt and interbedded clay. Gray and pale yellow quartz sand. Lignite and iron-oxide concretions common. Moderately permeable with an average horizontal hydraulic conductivity of 50 feet per day and an anisotropy of 100:1.
Raritan confining unit (Raritan clay)	Unnamed clay member of the Raritan Formation	Clay; solid with multicolors such as gray, white, red, or tan. Very poorly permeable. Confines water in underlying unit. Average vertical hydraulic conductivity of 0.001 foot per day.
Lloyd aquifer	Lloyd Sand Member of the Raritan Formation	Fine to coarse sand and gravel with clay lenses. White and pale-yellow sand is well sorted. Moderately permeable with an average horizontal hydraulic conductivity of 40 feet per day, and an anisotropy of 10:1.
Bedrock	Hartland Formation; crystalline bedrock	Highly weathered biotite-garnet-schist with low hydraulic conductivity. A thick saprolitic zone 50 to 100 feet thick, consisting of white, yellow, and gray clay, underlies most of the peninsula except in the northernmost part. Impermeable to poorly permeable.

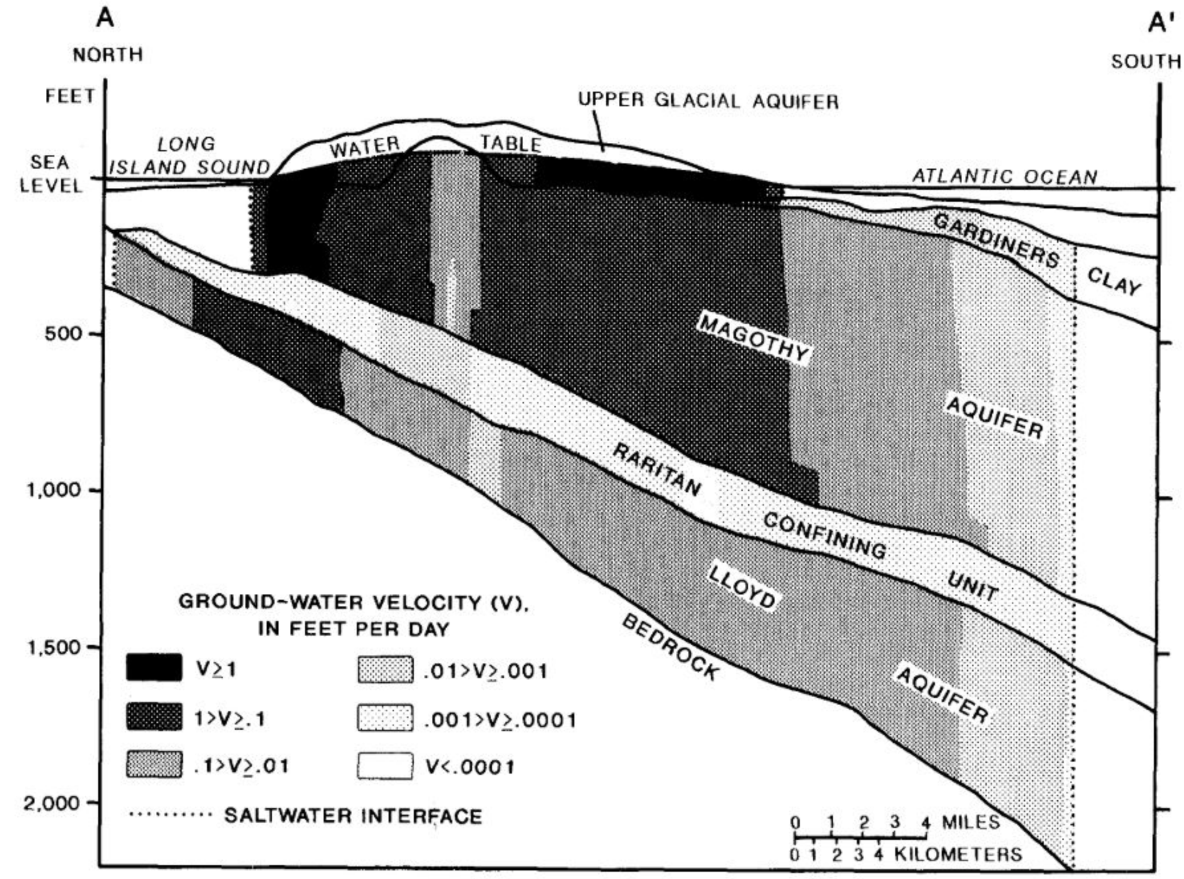

Figure 5.4: Ground water velocities of aquifers in Nassau County (Buxton and Modica, 1992).

5.2.2. Energy and Power Delivered by ATES Wells

Whether or not an ATES system can satisfy a building's thermal energy demand depends on the capacity (P_{ATES}) and the total energy (E_{ATES}) of the installed systems and are calculated with two basic equations:

$$P_{ATES} = c_w \cdot Q \cdot \Delta T \tag{5.1}$$

$$E_{ATES} = c_w \cdot V \cdot \Delta T \tag{5.2}$$

Where:
P_{ATES} = the capacity of the well (or Power) $[MWh]$
E_{ATES} = energy of the well $[m^3]$
c_W = volumetric heat of water (4,2 MJ / m^3 / K)
ΔT = difference in temperature between warm and cold well [K]

Equation 5.1 indicates that the well yield Q (or discharge) of the pump is related to the power of the system and Equation 5.2 indicates that the total stored volume of groundwater near the well is related to the total supply of energy. Equations 5.1 and 5.2 show that the thermal capacity and energy of an ATES system are dependent on the difference in temperature between the incoming and outgoing temperature of the groundwater through the heat exchanger (ΔT). This difference in temperature is set by the preferences of the geothermal architect and typically ranges between 10°F and 25°F, or 5.5 - 14 °Celcius or Kelvin (discussed in Section 4.4). Therefore, between times t and t_0, the total capacity and energy of warm and cold wells are calculated as follows (Bloemendal et al., 2018):

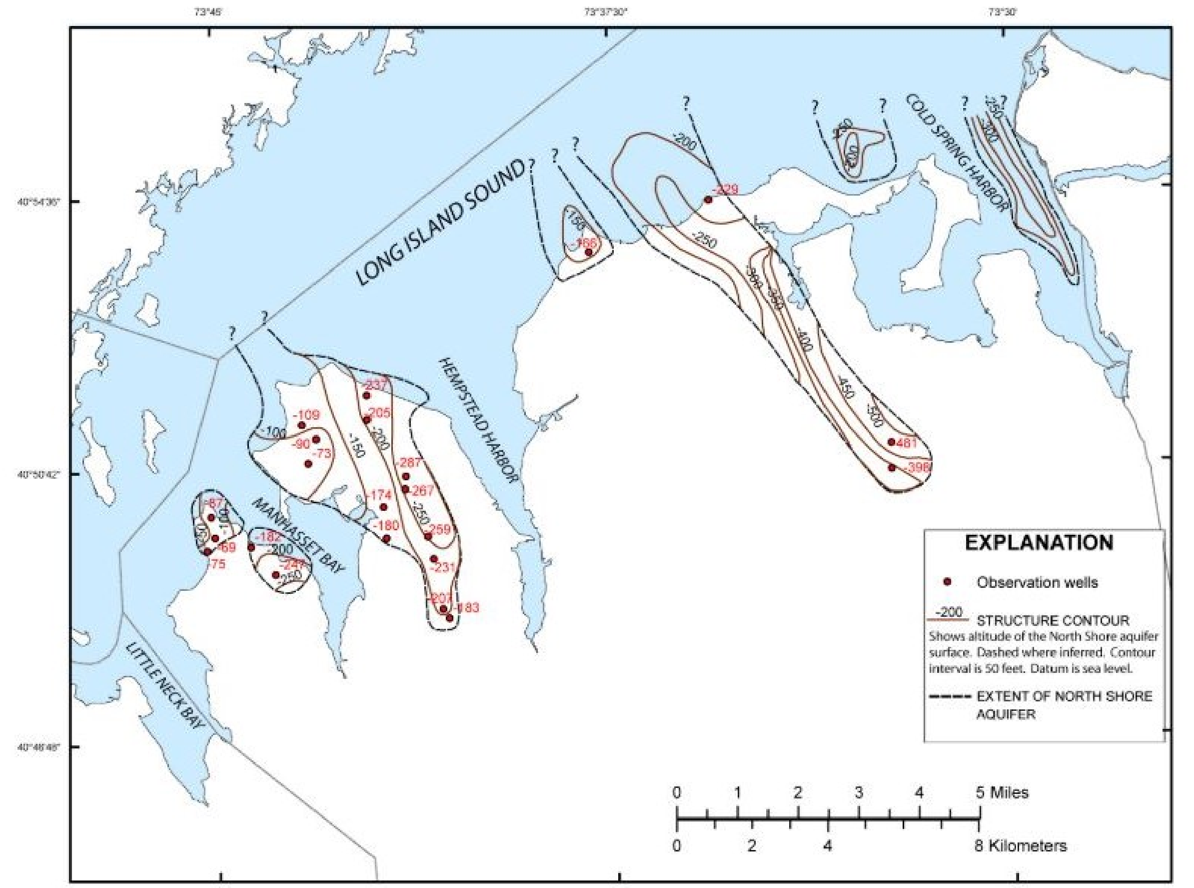

Figure 5.5: Extent and upper surface attitude of the North Shore Aquifer in Northern Nassau County, NYS (Stumm et al., 2004).

$$E_{h,ATES}(t_0 \to t) = \int_{t_0}^{t} P_{h,ATES} dt = c_w \Delta \bar{T}_h \int_{t_0}^{t} Q_w dt = c_w V_h \Delta \bar{T}_h \tag{5.3}$$

$$E_{c,ATES}(t_0 \to t) = \int_{t_0}^{t} P_{c,ATES} dt = c_w \Delta \bar{T}_c \int_{t_0}^{t} Q_c dt = c_w V_c \Delta \bar{T}_c \tag{5.4}$$

With

$$P_{h,ATES} = c_w Q_h (T_w - T_c) = c_w Q \Delta T \tag{5.5}$$

$$P_{c,ATES} = c_w Q_c (T_w - T_c) = c_w Q \Delta T \tag{5.6}$$

The integration between $(t_0 \to t)$ is done for both the duration of the heating and the cooling season (Bloemendal et al., 2018). $V_h[m^3]$ is the given seasonal volume of groundwater required for heating and $V_h[m^3]$ for cooling. ΔT[K] is the instantaneous temperature difference between the warm (T_w) and cold (T_c) well, $\Delta \bar{T}_h$ is the average temperature difference during the heating season and $\Delta \bar{T}_c$ during the cooling season, Q_w [m^3/h] is the groundwater flow from the warm well to the cold well (or the well yield of the warm well) and Q_c [m^3/h] is the groundwater flow from the cold well to the warm well (or the well yield of the cold well). Finally, c_w is the volumetric heat capacity of the water and is equal in both the heating and cooling season (4,2 MJ / m^3 / K) (Bloemendal et al., 2018). From Equation 5.5 and 5.6 it follows that if the maximum well yield of the cold and warm well is known, the maximum power delivered by the wells can be derived. To this end, methods to determine the maximum well yields are discussed in the next section.

5.2.3. Estimating Maximum Well Yields

The maximum well yields in Nassau County are estimated with the two empirical equations shown in Equation 5.7 and Equation 5.8. In the first equation, the specific capacity of the well is related to the transmissivity of confined aquifers like the Magothy aquifer (Chapter 2 provides descriptions of these hydraulic terms), the second equation is based on the empirically derived standard for flow to wells.

$$\frac{Q}{s} = \frac{T}{264 \log \frac{0.3\,T\,t}{r_w^2 S}} \tag{5.7}$$

$$Q = v_{\max} \cdot A_{\text{wellscreen}} \tag{5.8}$$

with

$$v_{\max} = 4 \cdot \left(\frac{k}{150}\right)^{0.6} \tag{5.9}$$

$$A_{\text{wellscreen}} = L_{\text{wellscreen}} \cdot 2\pi r_w \tag{5.10}$$

Where:
Q = the well pumping rate [gpm in Eq. 5.7; m^3/h in Eq. 5.8]
s = the observed "equilibrium" drawdown in the pumping well [ft]
T = transmissivity [gal/day/feet]
t = time of pumping required for reaching the equilibrium state [days]
r_w = radius of the well [ft in Eq. 5.7; m in Eq. 5.10]
S = storativity coefficient [dimensionless]
$v_{\max}$ = max flow velocity outside borehole [m/hr]
k = hydraulic conductivity [m/d]
$A_{\text{wellscreen}}$ = surface of the screen of the well [m^2]
$L_{\text{wellscreen}}$ = length of the screen of the well [m]

Equation 5.7 and Equation 5.8 provide the bases for two distinct methods for determining maximum allowable well yields. This is illustrated by rearranging the two equations:

$$Q_{max;s} = \frac{T \cdot s_{max}}{264 \log \frac{0.3\,T\,t}{r_w^2 S}} \tag{5.11}$$

$$Q_{max;v} = 4 \cdot \left(\frac{k}{150}\right)^{0.6} \cdot L_{\text{wellscreen}} \cdot 2\pi r_w \tag{5.12}$$

$$Q_{well;max} = \text{MIN}[Q_{v;max}; Q_{s;max}] \tag{5.13}$$

Where:
$Q_{max;v}$ = the maximum well yield based on the maximum allowable borehole velocity near the well
$Q_{max;s}$ = the maximum well yield based on the maximum allowable head raise near the well
$Q_{well;max}$ = the minimum value of $Q_{v;max}$ and $Q_{s;max}$

Equation 5.13 for determining the maximum well yields takes into account two requirements imposed by the geothermal architects: minimising the potential of well clogging by limiting the allowable borehole velocity (Equation 5.12); preventing soil cracks at the location of the well (Equation 5.11). This is further clarified in the subsequent sections in which the foundation of Equation 5.12 and Equation 5.11 are analysed respectively.

Maximum well yields and the Prevention of Well Clogging

When the borehole groundwater velocity of a well exceeds a certain threshold, which depends on local geohydrological conditions, clogging of the well screens occur. In many cases, due to the presence of particles in the aquifers, this type of clogging is most troublesome compared to other types of clogging (clogging caused by gas bubbles; clogging caused by bacteria; clogging caused by suspended matter) (Olsthoorn, 1982; Buik and Willemsen, 2002; NVOE, 2006). Olsthoorn (1982) has proved that there is a relation between the clogging rate of the well and the so-called Membrane Filter Index (MFI). The MFI is a standard test of the rate at which water clogs a membrane filter and according to Buik and Willemsen (2002), the best parameter to predict the clogging potential of water that has to be infiltrated. Buik and Willemsen (2002) described a quantitative and theoretically relation between the MFI and the clogging rate of wells to prevent the need for costly field tests:

$$v_{\max} = \left(\frac{k}{150}\right)^{06} \cdot 1000 \cdot \sqrt{\frac{v_v}{2 \cdot MFI \cdot hr_{eq}}} \tag{5.14}$$

Where:
hr_{eq} = amount of equivalent full load hours per year [h] (m^3 infiltrated per year divided by max. flow rate in [m^3/h])
v_v = clogging rate [m/yr]
v_{max} = infiltration rate on the borehole wall [m/h]
k = hydraulic conductivity [m/d]
MFI = Membrane Filter Index, the rate at which water clogs a membrane filter [m/h]

Rearranging Equation 5.14 and considering empirically derived standards for flow to wells gathered from NVOE (2006) (MFI = 2 m/h and v_v = 0.1 m/yr) results in Equation 5.9.

Maximum Well Yields and the Prevention of Soil Cracks

In 1935, Theis developed the non-equilibrium well equation that predicts the drawdown near a pump at any time after pumping starts (Driscoll, 1987). This equation is used in this study to determine maximum allowable well yields as shown in Equation 5.11 to ensure the prevention of soil cracks near the ATES wells. This is discussed in more detail in this section. In the simplest form, the Theis equation is:

$$s = \frac{114.6QW(u)}{T} \quad \text{and} \quad u = \frac{1.87r^2S}{Tt} \tag{5.15}$$

Where:
s = drawdown [ft] at any point in the vicinity of a well discharging at a constant rate
Q = well yield [gpm]
T = transmissivity of the aquifer [gpd/ft]
$W(u)$ = the "well function of u" and represents an exponential integral
r = distance from the center of a pumped well to a point where the drawdown is measured [ft]
S = coefficient of storage [dimensionless]
t = number of days since pumping started [days]

The Theis equation is based on the following assumptions (Driscoll, 1987):

1. The water-bearing formation, the Magothy aquifer in this context, is uniform in character and the hydraulic conductivity is the same in all directions;
2. The formation is uniform in thickness and infinite in areal extent;
3. The formation receives no recharge from any source;
4. The pumped well penetrates and receives water from, the full thickness of the water-bearing formation. This implies that for calculating maximum well yields and subsequent ATES potential in this study, the length of the screen of the well is considered similar to the full depth of the Magothy aquifer;
5. The water removed from storage is discharged instantaneously when the head is lowered;
6. The pumping well is 100% efficient;
7. All water removed from the well comes from aquifer storage;
8. Laminar flow exists throughout the well and aquifer;
9. The water table or potentiometric surface has no slope.

In working with the Theis equation, Cooper Jr. and Jacob (1946) pointed out that when u is sufficiently small (less than 0.05), the nonequilibrium equation is modified to the following form without significant error:

$$s = \frac{264Q}{T} \log \frac{0.3Tt}{r^2S} \tag{5.16}$$

Equation 5.15 illustrates that the value of u becomes smaller as t increases and r decreases. Therefore Equation 5.16 is valid when t is sufficiently large and r is sufficiently small. Equation 5.16 is similar in form to Theis' formula shown in Equation 5.15, except that the exponential integral $W(u)$, has been replaced by a logarithmic term. The logarithmic term is easier to work with regarding practical applications of well hydraulics (Driscoll, 1987). In actual practice, the Theis method is often avoided because it requires curve-matching interpretation and is laborious (Driscoll, 1987). By rearranging terms, the specific capacity according to Jacob is:

$$\frac{Q}{s} = \frac{T}{264 \log \frac{0.3Tt}{r^2 S}} \tag{5.17}$$

Equation 5.17 is rearranged to the form shown in Equation 5.11. The required parameters for using the latter equation are the transmissivity (T), the maximum allowable drawdown of the wells (s_{max}), the radius of the wells (r_w), the time of pumping (t) and the Storativity (S). Methods for deriving these parameters for the Magothy aquifer in Nassau County are discussed respectively in the following sections.

Tranmissivity of the Magothy Aquifer

Transmissivity is an important factor for determining the suitability of ATES installations in aquifers. Transmissivity is the rate in which water is transmitted through an aquifer under a unit width and a unit hydraulic gradient (Driscoll, 1987). It equals the aquifer's hydraulic conductivity (k) times the aquifer thickness (B). The higher the transmissivity, the greater the capability of the aquifer to move water and the lower the drawdown in the well (see Figure 2.1). Through the following formula, the transmissivity is calculated:

$$T_M = k_M * B_M \tag{5.18}$$

Where:
T_M = transmissivity of the Magothy aquifer [m^2/day]
k_M = hydraulic conductivity of the Magothy aquifer [m/day]
B_M = thickness of the Magothy aquifer [m]

It is assumed in this study that the Magothy aquifer is uniform in character, implying that the hydraulic conductivity of the aquifer is a constant. Information on the hydraulic conductivity is retrieved from previous geohydrological studies conducted within Nassau County. Particular an extensive study conducted by McClymonds and Franke (1972) is consulted in which 2500 wells were recorded to determine hydraulic conductivity levels of the aquifers in Long Island. From the well records and lithologic logs, it is concluded that the average hydraulic conductivity for the Magothy aquifer in Nassau County is 58 gpd/ft^2. These values are in close range compared to the hydraulic conductivity levels found by other researchers (Misnut and Busciolano, 2009; Lindner and Reilly, 1983; McClymonds and Franke, 1972). In contrast to the assumed constant hydraulic conductivity of the Magothy aquifer and as shown in Figure 5.3, the thickness of the aquifer beneath Nassau County does vary significantly along the width of Long Island and is therefore not considered as a constant. Concluded from the same figure, the Magothy aquifer is relatively shallow in the Nothern part of Long Island and becomes relatively thick towards the south of the island. The thickness of the Magothy aquifer is calculated using data from the USGS in which elevation data from hydrogeologic units (see Table 5.3) on a grid of 800x800 meter are provided. With the stratigraphic elevation data from the USGS and the geohydrological reports on hydraulic conductivity, the transmissivity of the Magothy aquifer in Nassau County is derived on a grid of 800x800 meter using QGIS as the data processing software.

Maximum Allowable Drawdown Levels in the Magothy Aquifer

Depending on the type of season, ATES wells can either function as extraction wells or infiltrating wells (see Figure 1.1). In both modes, the hydraulic head (or water level) near the pump changes depending on the discharge level of the pump (illustrated in Figure 4.2). During injection of water through a well (water directed from the building to the aquifer), the water level increases around the well and the difference between the new equilibrium and static water level is called 'head raise'. In case the well is in supply mode, however, in which water is pumped from the aquifer to the building, the water level around the well decreases and the difference between the new equilibrium and static water level is called 'drawdown'. When the head raise around a well becomes too high and exceeds a critical level, it causes the splitting of the soil around the wells inducing malfunctioning of ATES system. To prevent this and in accordance with the requirements of the geothermal architects, calculations are made to determine maximum allowable head raise levels near the pump and are derived from Olsthoorn (1982). Due to assumed symmetric geohydrological conditions between a connected extraction and infiltration well and the fact that for both wells the discharge is similar (see Figure 1.1), the maximum drawdown of an extraction well is restricted to the maximum allowable head raise at the connected infiltration well. So by calculating the maximum allowable head raises, the maximum allowable drawdown levels (s_{max}) are known too and subsequently used to calculate the maximum allowable discharge levels in Equation 5.11. To this end, using Equation 5.11 allows for maximum discharge calculations for ATES wells whereby soil cracks are prevented. From Olsthoorn (1982) it is concluded that the critical point regarding soil cracks around ATES wells is at the edge of the borehole and at the top of the screen of the well. The design ATES well screen covers the full thickness of the Magothy aquifer, hence the fact that the top of the filter is similar to the top of the Magothy aquifer. In unconsolidated sediment with negligible tectonics (sand, clay and peat) like the Magothy aquifer, cracks are prevented at this critical point if the following condition is satisfied (Olsthoorn, 1982; NVOE, 2006):

$$\Delta \mathrm{h} < 0,2\mathrm{h} \tag{5.19}$$

Where:
h = height between Maqothy aquifer and surface elevation [ft]
Δh = maximum increase in piezometric head, hence the maximum allowable drawdown level [ft]

The condition shown in Equation 5.19 is used in this study for calculating maximum allowable head raises at the location of infiltration wells. h is the height between the top of the Magothy aquifer and the surface elevation of Nassau County. Furthermore, the following assumptions are made for using this condition (NVOE, 2006; Olsthoorn, 1982):

- The groundwater level reaches the surface of Nassau County
- Above the top of the Magothy aquifer, a constant bulk density value is assumed, characterised by the bulk density of sandy soils ($\gamma_g = 20000\ N/m^3$)

For determining parameter h in Equation 5.19, a digital elevation model (DEM) of Nassau County is used to determine the height between the surface of Nassau County and the top of the Magothy aquifer which is progressed in QGIS software. The following equation is used:

$$h = h_{\text{surface}} - h_{\text{mag;top}} \tag{5.20}$$

Where:
h_{surface} = the elevation height of the surface of Nassau County [ft]
$h_{\text{mag;top}}$ = the height of the top of the Magothy aquifer [ft]

The newly derived dataset with information on the height differences h by using Equation 5.20 is, similar as the elevation dataset of the Magothy aquifer, a grid of 800x800m.

Determining the Radius of Wells, Time of Pumping and the Aquifer's Storativity
For estimating the maximum allowable well yields in Equation 5.11, empirical values for parameters t (time of pumping) and S (storativity) are used and equal respectively *1 day* and *0.001*. These empirical values are typical for confined aquifers like the Magothy aquifer (Driscoll, 1987). As to the radius r_w of the well, increasing the diameter of a well induces an increase in the maximum well yield according to Equation 5.11, Equation 5.12 and subsequently Equation 5.13. However, well diameters are restricted to the well construction capacities of the industry. What is more, determining optimal well design diameters is important because it may significantly affect the cost of the structure (Driscoll, 1987). This is particularly of importance since r_w is in the logarithmic function of Equation 5.11, implying that the well yield does not increase significantly with respect to an increase in well diameter. To identify proper ATES diameters, ATES standards in the Netherlands are consulted. Currently, between 6,000 and 8,000 wells have been drilled in the Netherlands for ATES applications and the diameters of these installed wells vary between 400 and 800 mm and are used as respectively the minimum and maximum design diameters of wells in this study (Buik and Bakema, 2019).

5.2.4. Overview of Key Assumptions and Design Parameters for Assessing the Technical Potential of ATES in Nassau County

To summarise, below an overview of the key assumptions and design parameters used to calculate the maximum technical ATES potential in Nassau County is provided. These assumptions are used to determine both the maximum well yields in Equation 5.13 and subsequently the maximum ATES capacity in Equation 5.1:

- The Magothy aquifer is chosen as a suitable ATES aquifer and based on the preferences of the geothermal architects, the only aquifer examined in this analysis for calculating the technical ATES potential of Nassau County;
- The maximum temperature difference (ΔT) between a warm and cold well is considered and is 13.88 K (similar to 13.88 °C and 25 °F);
- The hydraulic conductivity of the Magothy aquifer beneath Nassau County is considered constant and is 58 gpd/ft^2;
- Transmissivity levels are calculated by multiplying the Magothy aquifer thickness with the constant hydraulic conductivity;
- The empirical value for the storativity of a confined aquifer like the Magothy aquifer is used and is equal to 0.001;
- A minimum ATES well diameter of 400 mm and a maximum diameter of 800 mm is assumed for ATES installations. The latter one is used for determining the technical potential in this study;
- The design well screen length is considered similar to the full thickness of the Magothy aquifer and therefore varies throughout Nassau County on a grid layer of 800x800 meter (due to the resolution of the Magothy aquifer thickness).

5.3. Methods for Determining the Commercial Potential: Identification of ATES-Suitable Buildings in Nassau County

In the previous section, methods for determining the technical ATES potential in Nassau County are described. The technical potential provides insights into the potential scale of ATES development in Nassau County. Although this is a first indication of the possibilities of the technology, for more realistic results, commercial factors must be considered too. Eventually for ATES systems to become a valid option for the heating and cooling of buildings, the investment in ATES must result in positive commercial effects compared to other heating and cooling techniques (Schüppler et al., 2019). To this end, in this section, methods are discussed to determine the commercial ATES potential, following the general approach outlined in Figure 5.2. As shown in this figure, this section covers the methods and materials used for conducting steps 2 and 3 and are discussed respectively.

5.3.1. Building Analysis: Examining the Heating and Cooling Demands of Buildings in Nassau County

Previous studies indicate that ATES is most efficient for buildings with high and constant energy demand over the year, such as offices, airports, universities, shopping malls and in particular hospitals (Bonte, 2013; Fleuchaus et al., 2018; Snijders, 2005; Sommer et al., 2013; Eggen and Vangsnes, 2005; Schüppler et al., 2019). For determining the required installed ATES capacity for buildings in Nassau County, the peak heating and cooling demand of the buildings are examined. Methods for accurately calculating the heating and cooling demands of buildings are complex and depend on many factors such as the degree of insulation, year of construction, number of windows, number of floors and many more. It is not the purpose of this study to perform complex and comprehensive analyses regarding energy consumption in Nassau County. Even by including complex analyses, the accuracy is still uncertain, especially since data on building characteristics in NYS is scarce. To this end, in this study mainly two building factors are examined for estimating a buildings heating and cooling demand: the type of the building and the size of the building. Through combining these building characteristics retrieved from Pitney Bowes with data on energy consumption per type of building per square feet (SF) from Goldman Copeland, the heating and cooling demand of buildings in Nassau County are estimated. The following energy consumption data is considered for buildings located in Nassau County:

Table 5.4: Type and distribution of buildings in Nassau County and accompanying estimated peak heating and cooling demands.

Building Type	Number of Buildings in Nassau County	Peak Cooling Demand [kW / 1000 SF]	Peak Heating Demand [kW / 1000 SF]
Residential	381438	7.03	5.25
Commercial	14193	11.05	10.55
Public	2717	9.32	10.87
Other	4426	Out of Scope	Out of Scope

The category 'other' in Table 5.4 refers to buildings located on industrial, agricultural, recreational, transport or vacant lots and are excluded from the commercial ATES potential analysis. Except for the industrial one, these categories are generally not suitable for ATES implementation. However, since the energy consumption of the industrial sector can vary significantly per building (from chemical laboratories to breweries to heavy industrial activities to shipyards) and since required energy data is lacking, these buildings are excluded from the commercial ATES potential in this study. Finally, another important reason to exclude this group is the fact that this category includes areas used for groundwater supply installations. Excluding the concerning plots from the commercial ATES-potential calculation takes into account the constraints imposed by the geothermal architects (see Section 4.4. For the remaining buildings in the residential, commercial and public category, the peak heating and cooling demands are estimated through the following equation:

$$C_{P,ix} = \frac{C_{P,i} \cdot A_{B,x}}{1000} \tag{5.21}$$

and

$$H_{P,ix} = \frac{H_{P,i} \cdot A_{B,x}}{1000} \tag{5.22}$$

Where:
$C_{P,ix}$ = peak cooling demand of building x and type i (residential, commercial or public) [kW]
$C_{P,i}$ = peak cooling demand typical for a building of type i as illustrated in Table 5.4 [kW/1000 SF]
$A_{B,x}$ = gross building area of building x [SF]
$H_{P,ix}$ = peak heating demand of building x and type i (residential, commercial or public) [kW]
$H_{P,i}$ = peak heating demand typical for a building of type i as illustrated in Table 5.4 [kW/1000 SF]

Equations 5.21 and 5.22 are applied to a total of 419 999 buildings in Nassau County through using PostGIS software and the required building-characteristics data are retrieved from Pitney Bowes and Goldman Copeland (see Table 5.1).

5.3.2. Combining the Technical Potential and Energy Demand of Buildings to Determine the Commercial ATES Potential in Nassau County

For examining the commercial ATES potential as illustrated in step 3 of Figure 5.2, this section includes methods for selecting suitable ATES buildings. As mentioned, ATES is mainly applied to buildings with high and constant energy demand over the year. Therefore the identification of an ATES suitable building in this study is based on a certain minimum required energy demand. Looking at the Netherlands with the highest number of installations globally, most ATES doublet systems have storage volumes of 500,000 m^3/year and reaches up to 5,000,000 m^3/year in some cases (Bloemendal and Hartog, 2018). These numbers show that for buildings in the Netherlands which require ATES storage volumes of at least 500,000 m^3/year, the ATES business case is likely to be valid and can therefore be used as a proxy to determine commercially suitable buildings. However, since the business case is dependent on Dutch economic and market conditions, this threshold is not necessarily applicable in Nassau County. In this context, the minimum power capacity threshold is determined based on the optimal use of the groundwater resources underneath a building while minimising ATES design parameters. This implies that hypothetical ATES wells are designed to operate at maximum allowable well yields while using the full thickness of the Magothy aquifer and minimum design parameters. The latter condition concerns the use of minimum radii of the wells and minimum design temperature differences between warm and cold wells, 400 mm and 5.55 K (or °C) respectively. If a building's thermal peak demand is higher than this minimum required installation capacity calculated by considering these design conditions, the building is considered a commercially viable option for ATES installation.

Suitability Criteria and Ranking Analysis

In this study, the buildings in Nassau County are ranked according to their level of ATES-suitability as shown in Table 5.5. As illustrated in this table, a distinction is made based on the required heating and cooling capacity of the building as well as the balance between the annual heating and cooling consumption of the building and whether or not ATES systems can technically satisfy the peak loads of the building.

Table 5.5: The ranking of ATES suitable buildings.

Degree of Building-Suitability Regarding ATES Systems	Building Cooling Demand Exceeds Cooling Capacity Threshold	Building Heating Demand Exceeds Heating Capacity Threshold	Balanced Heating and Cooling Demand of Building
Highest	✓	✓	✓
Very High	✓	✓	X
High-heating	X	✓	X/✓
High-cooling	✓	X	X/✓
low	X	X	X/✓

5.4. Conversion of the Commercial ATES Potential to Overall System Efficiency

Energy efficiency rates of heating and cooling systems are important criteria for building owners when deciding on new installations and are therefore among the important factors to consider for geothermal architects too (see Figure 4.3). What is more, insights on a system's energy efficiency performance is a foundation for extensive cost analyses that determine the market competitiveness of ATES against alternative systems available on the market. Although the market potential of ATES (see Figure 2.5) is not examined in this study, retrieving information on energy efficiency is valuable for supporting decision-making amongst ATES stakeholders. To this end, the results of the commercial ATES potential are converted to values of the system's total energy efficiency, also referred to as the Coefficient of Performance (COP). The COP of an ATES system is based on the power it delivers to a particular building and the required power consumption. The well and heat pumps of ATES systems require electricity. Only in heating mode, an ATES system needs a heat pump for increasing the temperature to a sufficient level. A schematic overview of the total thermal energy delivered by an ATES system and the energy it requires is provided in Figure 5.6.

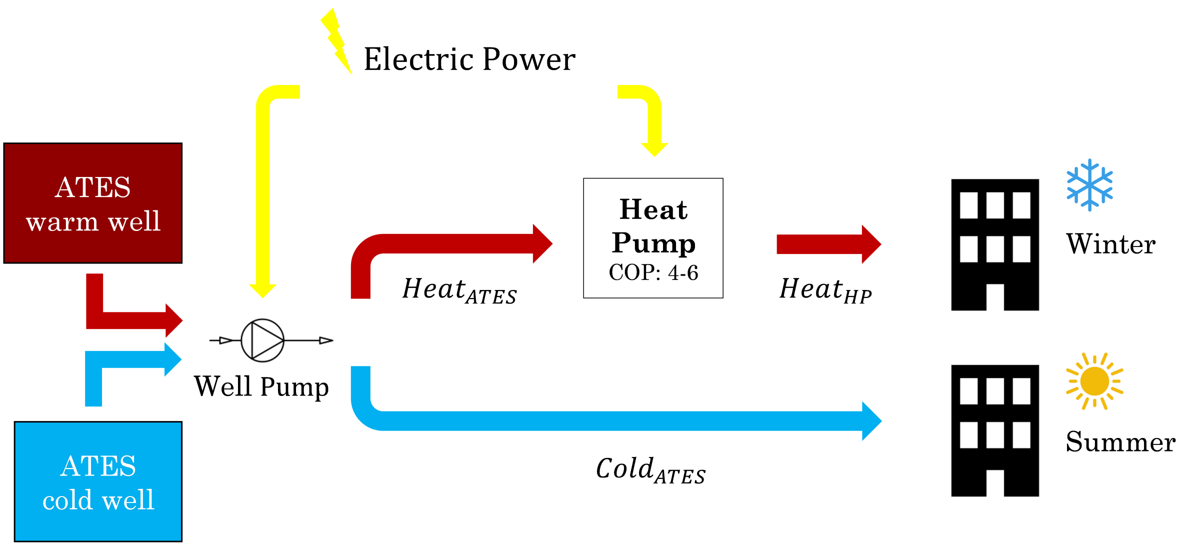

Figure 5.6: Schematic overview of (thermal) energy flows of an ATES system in heating and cooling mode (compiled by author).

From Figure 5.6 and based on Bloemendal et al. (2018) and NVOE (2006), the following equations are derived for calculating COP values for hypothetic ATES systems attached to suitable buildings in Nassau County in both heating and cooling mode:

$$\mathrm{COP_{cooling}} = \frac{\mathrm{P_{c,\,design}}}{\mathrm{P_{c,\,pump}}} \tag{5.23}$$

$$\mathrm{COP_{heating}} = \frac{\mathrm{P_{h,\,design}}}{\mathrm{P_{h,pump}} + \mathrm{P_{HP}}} \quad \text{and} \quad \mathrm{P_{HP}} = \frac{\mathrm{P_{h,\,design}}}{\mathrm{COP_{HP}}} \tag{5.24}$$

With

$$\mathrm{P}_{\mathrm{c,\,pump}} = \frac{Q_c \cdot H_{man}}{\eta_p} \quad \text{and} \quad Q_c = \frac{P_{\mathrm{c,\,design}}}{\Delta T \cdot c_w} \tag{5.25}$$

$$\mathrm{P}_{\mathrm{h,\,pump}} = \frac{Q_h \cdot H_{man}}{\eta_p} \quad \text{and} \quad \text{and} \quad Q_h = \frac{P_{\mathrm{h,\,design}}}{\Delta T \cdot c_w} \tag{5.26}$$

Where:

$\mathrm{COP}_{\mathrm{cooling}}$	= Coefficient of Performance (COP) of ATES system in cooling mode [-]
$\mathrm{P}_{\mathrm{c,\,design}}$	= design cooling power delivered to building [W]
$\mathrm{P}_{\mathrm{c,\,pump}}$	= electrical power consumed by the pump in the cold well [W]
$\mathrm{COP}_{\mathrm{heating}}$	= COP of ATES system in heating mode [-]
$\mathrm{P}_{\mathrm{h,\,design}}$	= design heating power delivered to building [W]
$\mathrm{P}_{\mathrm{h,\,pump}}$	= electrical power consumed by the pump in the warm well [W]
P_{HP}	= electrical power consumed by the heat pump [W]
$\mathrm{COP}_{\mathrm{HP}}$	= COP of the heat pump with values between 4-6 [-]
Q_c	= required well yield for meeting the design cooling power delivered to the building $[m^3/s]$
H_{man}	= maximum manometric delivery head [Pa]
η_p	= total pump efficiency (consisting of the engine efficiency and hydraulic efficiency [-]
Q_h	= required well yield for meeting the design heating power delivered to the building $[m^3/s]$
c_w	= volumetric heat of water (4,2 MJ/ m^3/ K)

Through using Equation 5.23 - 5.26, the COP values of ATES systems in both heating and cooling mode are determined. The following values are used for these equations:

- $\Delta T = 13.88K$ (maximum design temperature between the warm and cold well);
- The total pump efficiency, η_p, is assumed 0.45 (45%) based on typical values in the Netherlands;
- H_{man} is assumed at 15 meter or 146,71 kPa, a common value in the Netherlands where 6,000-8,000 ATES wells are installed (Buik and Bakema, 2019);
- Typical equivalent COPs for ground source heat pumps (used for ATES sytems) are between 3-5 and considers as 4 in this study (Self et al., 2013).

The only remaining and unknown parameters from Equation 5.23 - 5.26, $P_{h,\,design}$ and $P_{c,\,design}$, are derived based on the thermal peak load of the concerning buildings in Nassau County. These parameters are derived from the analysis of the buildings discussed in Section 5.3.1. However, ATES wells are usually not designed to deal with a building's peak heating demand since most ATES systems operate below the peak load for most of the year. This is explained in the next section.

Using the Load-Duration Curve for Determining the Design Heating Capacity

Most ATES systems are supplemented with additional heating devices required during the coldest days to meet the peak heating demand of a building (referred to as bivalent systems). This illustrated in the left part of Figure 5.7, which concludes that heat pump installations with a capacity of 35-50% of the building's peak heating demand, can deliver around 80% of the total energy (the surface area underneath the cross-section between the blue and red line is around 80% of the total surface area beneath the red line).

A bivalent system significantly increases the COP of an ATES system and it avoids substantial installation costs that are not necessarily recovered during operation (New York City Mayor's Office of Sustainability (MOS), 2015). Integrating supplementary heating equipment such as a (electric) boiler can help reduce the size of ATES installations while maintaining the energy benefits of the system. As a result of reduced construction costs and improved operating efficiency, design ATES capacities ($\mathrm{P}_{\mathrm{h,design}}$) for heating as illustrated in Figure 5.6) in this study are determined based on the load duration curve. Although the left curve in Figure 5.7 is based on conditions in the Netherlands, capacity loads in New York State show similar behaviour shown in the right part of the figure. The latter curve contains data from Con Edison, the energy company that provides electricity to, amongst other areas, Nassau County. From the curve, it is concluded that peak loading (above 13 000 MW) on their electrical grid only occurs for 7 hours per year, while the majority of the hours show the grid's peak demand between 5,800 and 7,600 MW. Due to the clear similarity between the left and right load-duration curves in Figure 5.7, it is assumed that 80% of the building's heating consumption can be generated with around two-third (66.86%) of the maximum required peak heating demand. To this end,

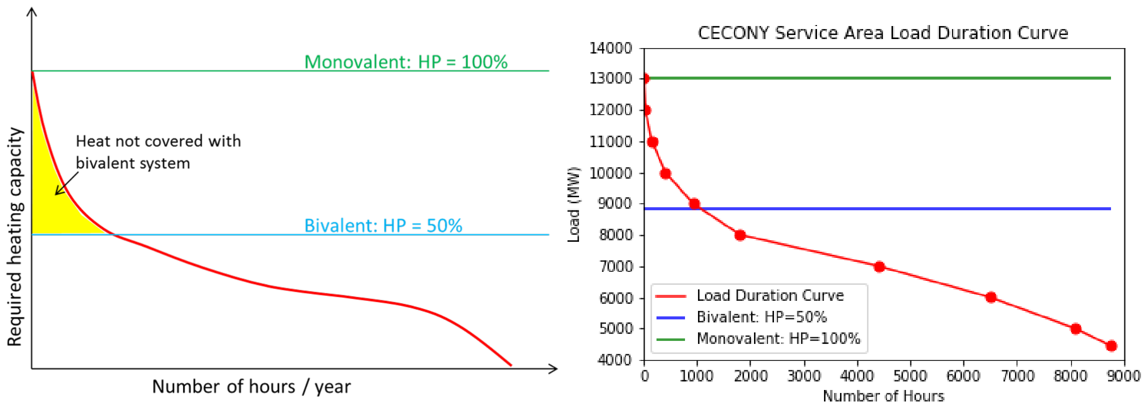

Figure 5.7: Left: The load duration curve typical for the Netherlands. Right: Load duration curve of Con Edison for NYS (CECONY) (compiled by author with data from Zhang and Augenbroe (2018)).

the next equation is used to determine the design heating power, $P_{h,design}$, required for buildings in Nassau County:

$$\mathrm{P_{h,design}} = \frac{2 \cdot H_{P,ix}}{3} \tag{5.27}$$

$H_{P,ix}$ is derived from Equation 5.22. With this final equation, the COP values of hypothetical ATES systems in Nassau County are calculated of which the results are shown in the next chapter.

6

Results of the Geospatial Analysis: ATES Potential in Nassau County

Based on the equations, assumptions, data and processing software discussed in Chapter 5, the results of the geospatial analysis are provided in this chapter. First, the results of the technical ATES potential are discussed followed by the results of the commercial ATES potential in Nassau County. In the final part of this chapter, the Coefficient of Performance (COP) values of hypothetical ATES systems in Nassau County are compared to conventional heating and cooling methods in the region.

6.1. The Technical Potential of ATES in Nassau County

For determining the technical potential of ATES in Nassau County, the required intermediate results are first discussed. These results consist of the transmissivity levels of the Magothy aquifer in Nassau County followed by its maximum allowable well yields. Subsequently, these insights are used to derive the technical power potential of hypothetical ATES systems in Nassau County. The technical ATES potential is evaluated for doublet systems, implying that the power potential is based on one extraction well and one infiltration well.

6.1.1. Transmissivity of Magothy Aquifer in Nassau County

Transmissivity is an important factor for determining the suitability of ATES installations in aquifers. The higher the transmissivity, the greater the capability of the aquifer to transport water in the aquifer, inducing higher possible well yields and thus higher power capacities of ATES systems. From data retrieved from USGS, the thickness of the Magothy aquifer is known on a grid of 800x800 meters. Multiplying the thickness values within this grid with the hydraulic conductivity of the Magothy aquifer of 58 gpd/ft^2 generates the transmissivity levels and are displayed in Figure 6.1. In Appendix B, the same results are provided in metric units.

6.1.2. Maximum Allowable Well Yields of the Magothy Aquifer in Nassau County

Maximum allowable well yields (or pumping discharges) of the Magothy aquifer in Nassau County are derived by considering two constraints: the maximum allowable drawdown levels to prevent soil cracks and the maximum borehole velocities to prevent the clogging of the wells. Following the equations and assumptions provided in Section 5.2, the results are provided in Figure 6.2.

6.1.3. Maximum Power Potential of ATES Doublet Systems in Nassau County

With the information on the maximum allowable well yields of the Magothy aquifer in Nassau County as shown in Figure 6.2, the maximum power potential is derived and illustrated in Figure 6.3. This Figure shows that in the Northern part of Nassau County, where the Magothy aquifer is relatively shallow, the borehole velocity constraint is mainly determining the maximum well yields and power potential. In these areas, the maximum ATES power potential is therefore strongly dependent on Equation 5.12. On the other hand, when the aquifer thickness increases towards the southeast of Nassau County, the maximum drawdown constraint near the wells becomes more dominant. This implies that in these locations, the maximum ATES power potential is mainly determined by Equation 5.11. The same observation is made for the design radius of

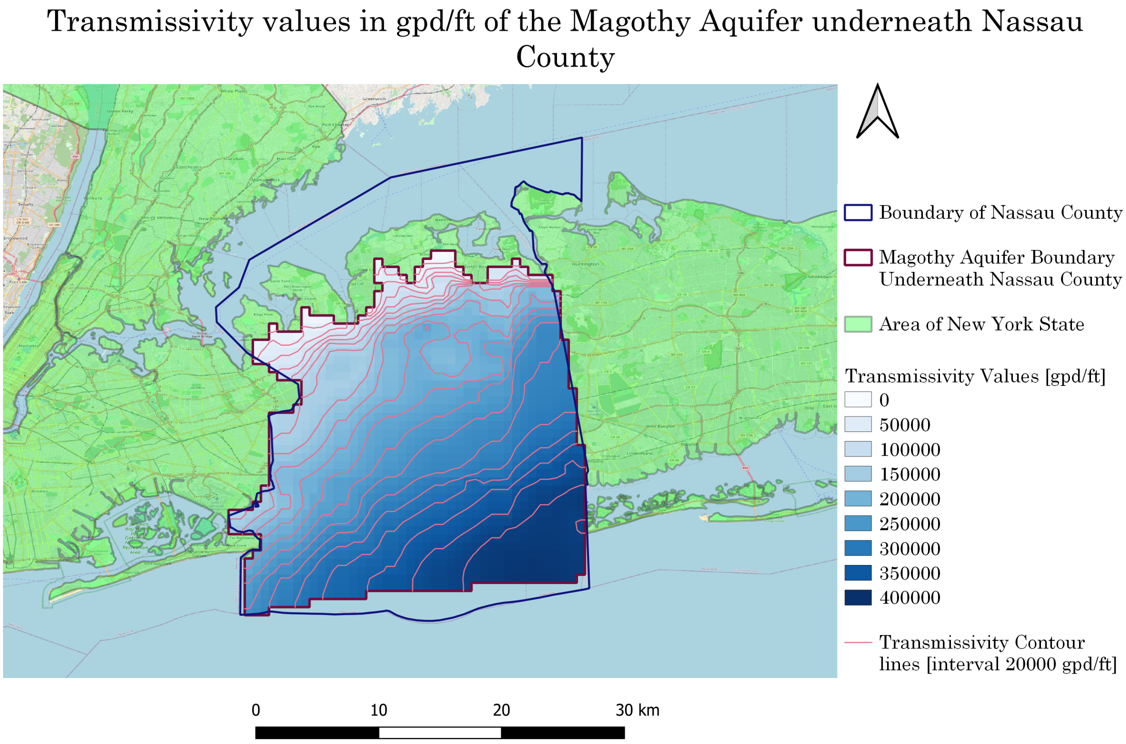

Figure 6.1: Transmissivity values in gdp/ft of the Magothy Aquifer underneath Nassau County (compiled by author).

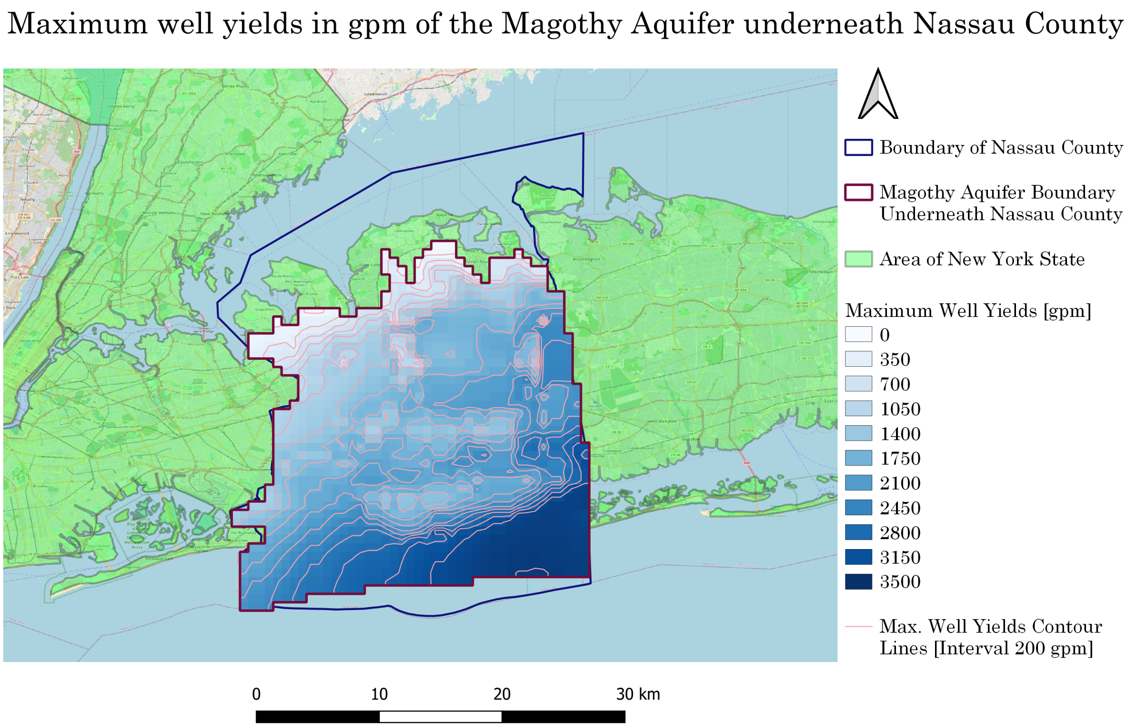

Figure 6.2: Maximum well yields in gpm of the Magothy Aquifer underneath Nassau County (compiled by author).

the wells. For applying minimum well design radii of 400 mm, the maximum borehole velocity constraint is dominant, whereas when the radius increases to its maximum of 800 mm, the maximum allowable drawdown constraint is dominant for determining the maximum well yields. This is expected since $Q_{max;v}$ in Equation 5.12 increases more as $Q_{max;s}$ does in Equation 5.11 when the radius of the well, r_w, increases.

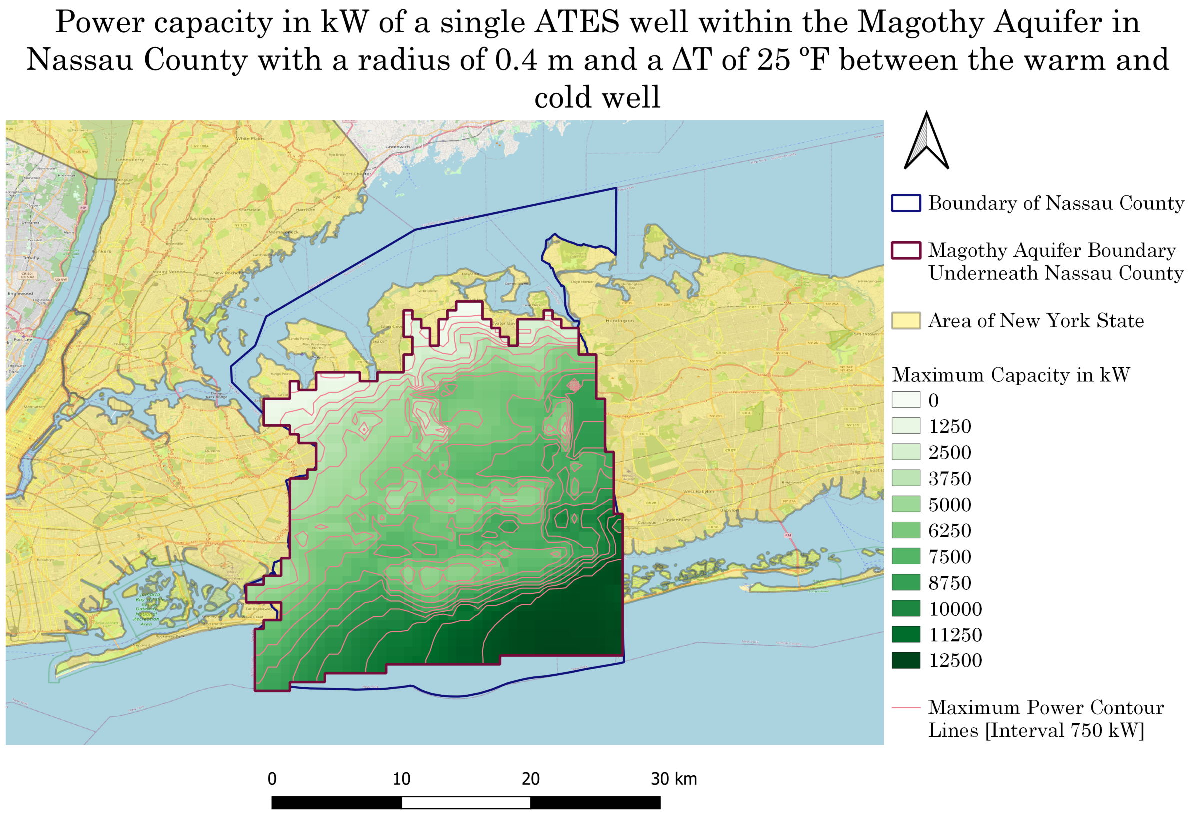

Figure 6.3: Power capacity in kW of a single ATES doublet system within the Magothy Aquifer in Nassau County with a radius of 0.4 m and a ΔT of 25 $^\circ F$ between the warm and cold well (compiled by author).

6.2. The Commercial Potential of ATES in Nassau County

Nassau County contains around 420 000 buildings which are examined in this study for determining the commercial potential of ATES in the region. This section provides insights on the heating and cooling consumption of these buildings followed by a selection of buildings identified as commercially suitable for ATES installation. Finally, for these commercial suitable buildings, the accompanying ATES COP values are calculated and compared to COP values of conventional heating and cooling systems in Nassau County.

6.2.1. Peak Thermal Energy Demand of Buildings in Nassau County

The peak cooling and peak heating demand of buildings in Nassau County are estimated according to the methods described in Chapter 5.3.1. The thermal peak loading demand is calculated for both heating and cooling and its distribution is shown in Figure 6.4. Some buildings have a significantly higher thermal energy demand (both heating and cooling) and are not observable in Figure 6.4. To this end, a boxplot is provided in Figure 6.5 which allows for an overall understanding of the results of the building energy demand in Nassau County. On the y-axis, the peak thermal energy demand is displayed on a logarithmic scale and the green lines in the same figure indicate de median values. As can be seen from Figure 6.4 and 6.5, the peak cooling demand is slightly more dominant than the peak heating demand. Since only for public buildings, as illustrated in Table 5.4, the peak heating demand surpasses the peak cooling demand and since only a small portion of the examined buildings is indicated as public (0.68%), this is an expected result.

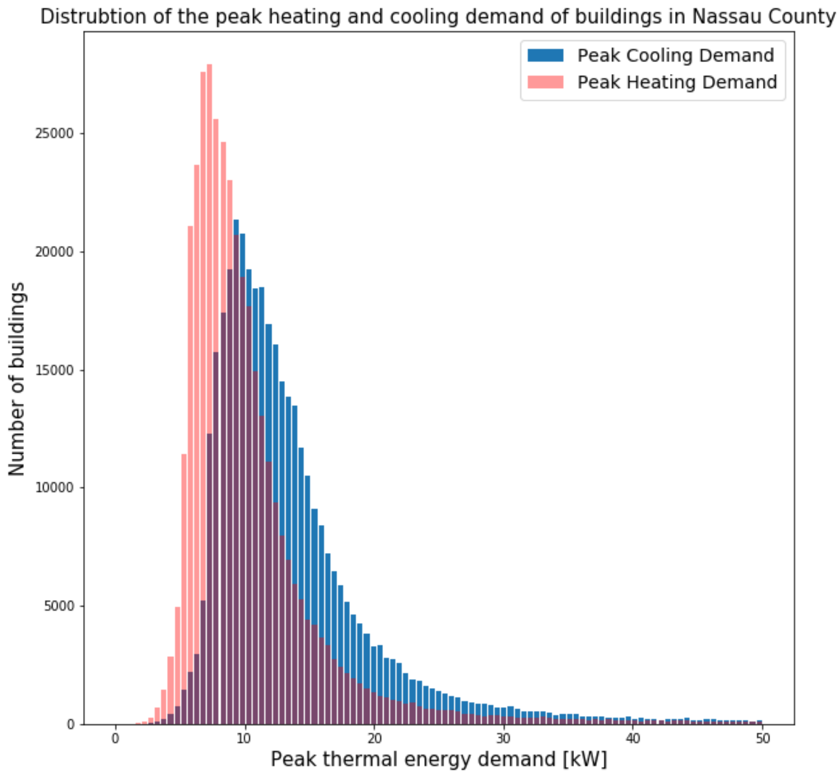

Figure 6.4: The distribution of the estimated peak cooling and heating demand of buildings in Nassau County (compiled by author).

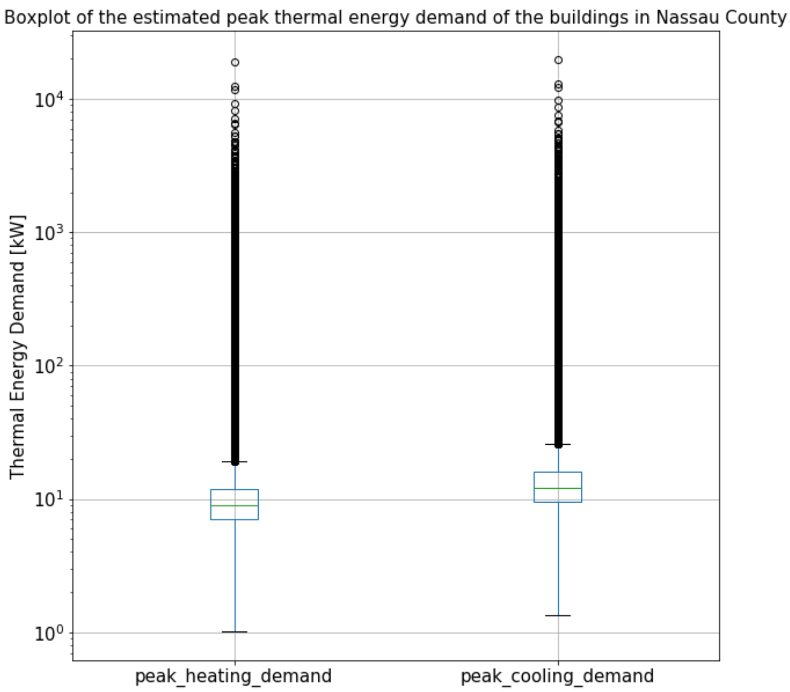

Figure 6.5: Boxplot of the estimated peak thermal energy demand of buildings in Nassau County (compiled by author).

6.2.2. The Categorisation of Buildings in Nassau County According to their Degree of ATES Suitability

Table 5.5 demonstrates the classification method to rank buildings according to their degree of ATES suitability. With information on the building type and peak thermal energy demands of the buildings in Nassau County, the gradation according to their level of ATES suitability is shown in Table 6.1.

Table 6.1: Degree of ATES suitability of buildings in Nassau County.

Building-Suitability Gradation	**Number of buildings [-]**	**Total peak heating demand [MW]**	**Total peak cooling demand [MW]**	**Total thermal power demand [MW]**	**Ratio of thermal energy demand to total demand [%]**
Highest (non-residential)	265	508.26	525.34	1033.60	8.72
Very high (residential)	61	46.25	61.99	108.24	0.91
high - cooling	49	26.57	33.29	59.86	0.50
high - heating	10	8.31	7.12	15.43	0.13
Low	373039	4701.17	5940.78	10641.95	89.74

Table 6.1 shows that a total number of 385 buildings are classified as at least highly suitable for ATES installation. This implies that, with the methodology developed in this study, 385 buildings in Nassau County are indicated as commercially suitable for ATES installation. As a first observation, this number may seem insignificant. However, looking at the outmost right column of Table 6.1, this perspective changes due to the that these buildings account for around 10% of the total thermal energy demand of buildings in Nassau County. Additionally, the buildings in this study are examined individually on commercial ATES suitability and is expected to increase significantly when multiple buildings are attached to the same ATES systems. This is explained in more detail in Chapter 7. Finally, in the categories 'highest' and 'very high' in Table 6.1, a total of 29 buildings (of which two are residential), exceed the required capacity that can be provided by a single ATES doublet system. This implies that for these 29 buildings, one doublet system (one extraction and one infiltration well) is not sufficient to meet the building's energy demand. Below, an overview is provided that indicates the number of doublet systems required for this group of buildings. For all other buildings in Nassau County, one ATES doublet system is concluded to be sufficient to meet the building's (peak) thermal energy demand.

Table 6.2: Number of ATES doublet systems required for buildings in the highest and very-high ATES suitability category.

	Number of ATES doublet systems required				
	1	**2**	**3**	**4**	**5**
Highest suitability	238	19	3	4	1
Very high suitability	59	2	0	0	0

From Figure 6.6 and indicated in yellow dots, it can be concluded that most of the multiple ATES doublet systems are required for buildings located in the northern part of Nassau County. Since the thickness of the Magothy aquifer is relatively small in this area, it experiences relatively low transmissivity levels, which is an important indicator for the potential ATES power (see Figure 6.1 and Figure 6.3). This implies that for buildings located in this area with high thermal energy demands, more ATES wells are likely required to be installed. Another observation is the relatively large number of ATES-suitable buildings that are centred in the northwestern part of Nassau County (see Figure 6.6). The reason for this is two-folded. First, the minimum threshold of required installed capacity for buildings is less as, again, the aquifer thickness is relatively small. This implies that the underground resources available are used optimally relatively soon, meaning that lower thermal energy demands of buildings are required for buildings to be labelled as suitable for ATES installation from a commercial perspective. Second, this observation is caused by the fact that it concerns the Greatneck County Village, a place with a relatively high density of large-sized buildings, which are more suitable for ATES implementation from a commercial aspect. Whereas Figure 6.6 shows the location of buildings that

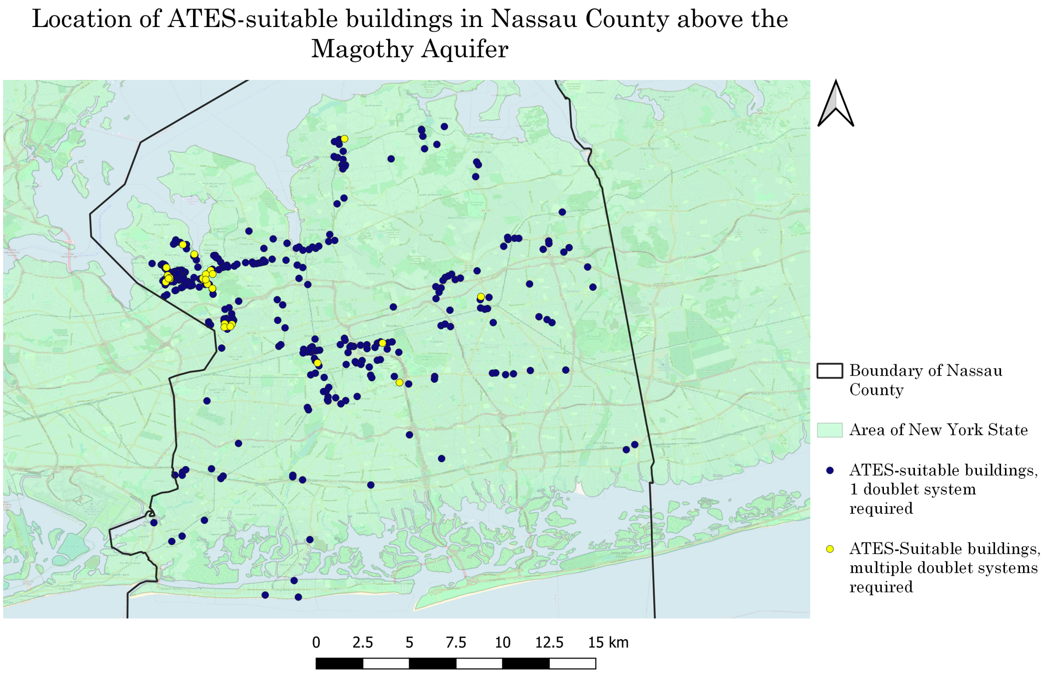

Figure 6.6: Location of ATES-suitable buildings in the categories 'high', 'very high' and 'highest' (compiled by author).

are technically and commercially suitable for ATES installation, Table 6.3 describes the type of buildings per ATES-suitability category. Since the category 'low' includes buildings labelled as not suitable for installation, it is excluded from this table. The numbers between brackets visible in Table 6.3 indicate the number of buildings that require multiple ATES doublet installations. As mentioned, this concerns a total of 29 buildings.

Table 6.3: Type of buildings per ATES building suitability category.

Type of Building	Level of ATES-Suitability				Total
	Highest	**Very High**	**High-Heating**	**High-Cooling**	**Count**
Residential					
Apartment	-	21	-	10	31
Cooperative	-	30 [2]	-	14	44
High-rise condo	-	3	-	1	4
Nursing home	-	4	-	5	9
Single family residential	-	3	-	9	12
Commercial					
Multiple uses	7	-	-	2	9
Auto sales	6	-	-	-	6
Commercial Condominium	1	-	-	-	1
Department store	27 [2]	-	-	1	28
Financial building	1	-	-	-	1
Hospital	12 [1]	-	-	-	12
Office building	119 [17]	-	-	3	122
Converted residence	1	-	-	-	1
Parking structure	10 [3]	-	-	-	10
Restaurant building	1	-	-	-	1
Service station	1	-	-	-	1
Service station/market	1	-	-	-	1
Shopping center	38 [3]	-	-	3	41
Store building	10	-	-	1	11
Food stores	3	-	-	-	3
Public					
PUBLIC (NEC)	2	-	1	-	3
County property	1	-	-	-	1
Municipal property	1	-	1	-	2
Police/fire/civil defense	1	-	-	-	1
US postal service	-	-	1	-	1
School	2	-	-	-	2
Public school	15	-	5	-	20
Religious	5 [1]	-	2	-	7
TOTAL	**265**	**61**	**10**	**49**	**385**

6.2.3. Coefficient of Performance of ATES and Conventional Heating and Cooling Methods in Nassau County

For the 385 identified commercially suitable buildings in Nassau County, COP values are provided in Table 6.4 following the equations shown in Chapter 5.4. Deriving COP values of hypothetically installed ATES systems in these buildings provide valuable insights on system performances. To allow for system comparisons, the COP values of conventional heating and cooling systems mainly used in buildings in Nassau County are also provided in Table 6.4. Since, next to pump characteristics, the COP values of ATES systems are predominantly dependent on the temperature differences between the warm and cold wells, a separation is made between the two outer design temperature differences, ΔT. This generates lower and upper boundaries of ATES system performances. Furthermore, the rightmost column of Table 6.4 displays the energy required for operating the various configurations. This is based on the sum of the peak thermal energy demand (both heating and cooling) of the 385 buildings divided by the COP-value of the overall system (provided in the third column). The COP value of the overall system takes into account the energy losses occurring in electric power plants. The typical energy efficiency of power plants is 43.6 % in the US and used for calculating the values in the third column of Table 6.4.

Table 6.4: COP values and energy required for ATES and conventional HVAC systems.

Configuration	**COP-value of single device [-]**	**COP-value of overall system [-]**	**Peak thermal energy demand [MW]**	**Power required during peak loading [MW]**
Cooling of Buildings				
ATES - 13.88 degrees	77.78	33.91	627.74	18.51
ATES - 5.55 degrees	31.11	13.56	627.74	46.29
Conventional Cooling	3	1.31	627.74	479.19
Heating of Buildings				
ATES - 13.88 degrees	3.80	1.66	392.93	236.70
ATES - 5.55 degrees	3.54	1.54	392.93	255.15
Gas Boiler	0.8	0.8	392.93	491.16

As concluded from Table 6.4, especially in cooling mode ATES provide significant COP values. The electricity required for operating the additional heat pump for ATES in heating-mode induces the lower COP levels in this configuration compared to ATES in cooling-mode. Still, this is around twice as much as the conventional heating methods in Nassau County.

IV

Discussion and Conclusions

7 Discussion

The objective of this research is to develop a methodology to determine the technical and commercial potential of ATES while incorporating local characteristics. Until now, ATES feasibility studies have mainly been focusing on large-scale ATES suitability. For generating more representative results, however, this new methodology also incorporates local geohydrological conditions and the interests of and restrictions imposed by its local ATES stakeholders. The literature describes the importance of ATES potential maps for effectively engaging stakeholders to increase ATES adoption in a region. Application of this methodology to Nassau County has shown that this methodology is especially useful for indicating the significant opportunities for ATES development in the region. Local (influential) decision-makers can use the results as they evaluate the technology, the potential scale of development and its commercial viability. However, several aspects of this study must be considered in order to apply the methodology and results in practice. The considerations and limitations regarding the methodologies and data used are discussed below followed by the recommendations for future research.

Applied Methods

Applying the GIS model to Nassau county is the first step in increasing ATES adoption in NYS and beyond. This is supported by the fact that the geographic extent of the model can easily be scaled up to other counties, states and countries. The main reason is that the methods, software and data used are applicable and available on a large-scale. To illustrate this, digital elevations and extents of the hydrogeologic units in the Northern Atlantic Coastal Plain aquifer system are publicly available. This also includes the elevation data of the Magothy aquifer underneath Nassau County used in this study. Five states are part of the Northern Atlantic Coastal Plain aquifer systems, which reaches from North Carolina to Long Island in New York State. With the methods used in this study, the technical ATES potential of all these aquifers can be determined relatively easily. The accompanying commercial potential of ATES may be somewhat more challenging as it depends on available information about the thermal energy consumption or characteristics of buildings. Nonetheless, obtaining the required (commercial) data does not have to be a problem for ATES stakeholders willing to introduce the technology. Furthermore, the stakeholders and barriers identified in this research are similar to other counties in NYS. This also provides a solid foundation for other states as well, but local policies can vary and must be investigated.

In this study, a questionnaire is used for analysing the influence and attitude of all ATES stakeholders in NYS. The questions in the questionnaires were optimised based on the feedback of the first respondents. This allowed for better results from respondents who filled it in after the adjustments, but as to the consistency it would have been better to have the questionnaire finalised and validated before the first respondents were approached. However, since the changes were minor and mostly requested additional information, the input from the first respondents could still be used.

Furthermore, this study has shown that the newly developed methodology provides a foundation for a region's ATES development potential. This has been demonstrated for Nassau County in this research. For the actual design and construction of ATES systems in any part of the world, however, additional research and site-investigations will be necessary to confirm hydraulic soil properties. Although available published data and reports can provide an overall understanding of a region's soil properties, site-specific soil characteristics must be verified before the realisation of ATES systems. System design based on insufficient site investigation may develop into significant problems later in the project such as additional costs, sub-optimal system performances or even the complete malfunctioning of the system.

Another discussion topic is the Coefficient of Performance (COP) values used in this study. For deriving the COP values of ATES systems, pump characteristics are important to consider as it determines the amount of electricity required for operating the system. A constant and typical pumping efficiency rate usual for ATES systems in the Netherlands is considered to determine COP values for Nassau County in this study. However, dependent on the type of pump, optimum pump efficiencies exist only for certain pumping discharges. Since the pumping discharge of an ATES well fluctuates over time according to the requested thermal energy of a building, it, therefore, may appear improper to assume a constant pumping efficiency. Nonetheless, by using devices such as variable speed pumps or a frequency converters, the power that an electric motor receives can be manipulated to avoid unnecessary power consumption. So even when pumping discharges fluctuates, relatively high and constant pumping efficiencies can be maintained throughout the year. Another important note as to the COP values used in this study is that (thermal) energy losses over the years for the hypothetical ATES systems are not included. COP values of heat pumps can deteriorate when in operation and the overall system efficiency can be compromised due to thermal energy losses in the wells. The latter is typically the result of either conduction, displacement (through ambient groundwater flow), dispersion (related to injection) or a combination of the three (Bloemendal and Hartog, 2018). However, thermal energy losses are kept minimal in this study since groundwater velocities are lowest in Magothy aquifer compared to the other present aquifers. What is more, according to Bloemendal and Hartog (2018), the thermal recovery efficiency is high for large storage volumes (as is the case for the 385 ATES-suitable buildings in Nassau County).

Finally, since this research has shown that ATES is a technically and commercially viable geothermal solution for buildings in NYS, it is critical that ATES is included in the existing evaluation tools used by the city and state authorities of New York. Since 2015, it has become mandatory to install geothermal heat pumps in city-owned buildings if this proves to be cost-effective and these tools are used to evaluate the alternatives for this purpose. The inclusion of ATES allows a comprehensive comparison of available geothermal solutions and is thereby likely to contribute to ATES adoption in the region. During the development of the GIS model for ATES in this study, the developers of the authorities' tools were frequently consulted. As a result, the models are based on the same GIS software and use similar data sources, ensuring that the newly developed model can be connected to the existing geothermal tool with minimal adjustments.

Data Availability and Quality

It may appear to be presumptuous to assume the hydraulic conductivity and storativity to be constant for the Magothy aquifer underneath Nassau County in the geospatial analysis. Particularly the hydraulic conductivity has the most impact on the outcome of the results in the geospatial analysis. This parameter is however derived from a study performed by McClymonds and Franke (1972) in which 156 wells with available lithologic logs were analysed for the Magothy aquifer underneath Nassau County and is therefore expected to be a valid approximation. For the other concerning parameters, such as the storativity of the aquifer and time in days for a pump to reach an equilibrium state, the impact on the output is significantly less. Even when these values appear to be a factor 10 higher or lower (i.e., a 900% increase or decrease) in some locations in Nassau County, the maximum well yield and accompanying power capacity according to the formula of Driscoll changes with only 13.24%. Due to the fact that these values appear in the log term of the used equations in Chapter 5, its effect is minimal. Nonetheless, such outliers are not expected as the concerning parameters are empirically derived and typical for aquifers such as the Magothy aquifer. Even more so since the study conducted by McClymonds and Franke (1972) analysed 2500 wells in Long Island and concluded that the parameters assumed in this study are a valid approximation.

The datasets used in this study to assess buildings in Nassau County on ATES suitability includes some entries with missing data. For around 15,000 buildings, data on size or location is lacking and are therefore not included in the geospatial analysis. The commercial ATES potential in Nassau County can therefore be somewhat higher in practice, although this is expected to be minimal based on the number of buildings in question. What is more, the location of most of the drinking water supply wells is not publicly available for safety reasons. ATES wells cannot be installed close to drinking water supply wells as this would induce interference between the systems and are not allowed by local (water) authorities. So detailed geographic information of these drinking water supply systems would have been valuable since it affects the resource potential and hence the technical and commercial potential of ATES in Nassau County. Based on available geographic data, only a limited number of plots with installed drinking water supply wells are excluded from the geospatial analysis to avoid interference.

Furthermore, due to the lack of reference ATES use-cases and accompanying cost-benefits analyses in the US and NYS for that matter, the validity of the commercial ATES potential in Nassau County is limited in this study. However, based on literature and common practice, the derived list of suitable ATES buildings in this study shows promising results as it contains building categories which are common for ATES installation (such as hospitals, shopping malls, offices and schools). To this end, the results obtained in this study regarding the commercial ATES potential in Nassau County is considered a valid foundation. Even so, to accurately verify this list and to examine the market competitiveness of hypothetical ATES systems in these buildings compared to other conventional or geothermal heating and cooling methods, it is recommended to examine the market potential by including comprehensive business cases in future research. Next to this recommendation, below, three more recommendations for future research are formulated based on the findings in this study.

Recommendations for Future Research

In future research, it is recommended to repeat the assessment of a region's ATES stakeholders. In this study, the information obtained regarding the ATES stakeholders in NYS is considered valid since it is developed by a group of key informants who have relevant experience and knowledge of the NYS ATES sector. It must be noted however that the stakeholder community can change over time as the stakeholders' attitude, power or responsibilities can alter. To maintain up-to-date information regarding the ATES stakeholders, the stakeholder assessment process has therefore to be (partly) repeated and validated regularly. Not only allows this for accurate and up-to-date sector information, but the review and re-assessment of a region's ATES stakeholders also provide a means for monitoring the effectiveness of newly developed engagement strategies.

A second recommendation for future research is to examine the commercial a region's ATES potential by aggregating the thermal energy demand of buildings in the same neighbourhood. In this research, buildings located in Nassau County are assessed individually for ATES suitability. However, ATES can be installed for the heating and cooling of multiple buildings. In this way, building-owners can benefit from economies of scale, making ATES systems commercially more viable options. The latter implies that individual buildings currently labelled as non-suitable for commercial ATES coupling can in fact become suitable. So the commercial ATES potential derived in this study for Nassau County, which is solely based on the assessment of individual buildings, is expected to increase significantly when two or more buildings are attached to a similar ATES system.

Finally, it is recommended in future research to include groundwater models when evaluating the potential of ATES within a region. This allows analysis of flow directions, velocities and (piezometric) water levels for more accurate calculations of well yields and accurate insights on thermal recovery efficiencies in ATES wells. Besides, uncertainty regarding drinking water wells is not sufficiently addressed in this study, which can be a showstopper for potential projects. By including groundwater models, the required distance between potential ATES wells and drinking water wells can be determined accurately and used to justify the installation of ATES systems, even with nearby drinking water installations.

8
Conclusions

Aquifer Thermal Energy Storage (ATES) is a geothermal technique that is an important factor in the transition towards renewable energy in the heating and cooling industry. Particularly for buildings with high and constant energy demand, the seasonal storage of heat and cold in aquifers through the use of ATES-installations allows for high energy efficiencies. Unfortunately, in many countries, the technology is not adopted. The key reason is that the implementation of ATES systems requires extensive preparation and site-specific analyses and many stakeholders need to be involved to successfully implement the technology. These stakeholders are often unfamiliar with the technology and unaware of the potential applicability. To increase a region's ATES adoption, many researchers emphasise the importance of ATES potential studies. To support a region's decision-makers as they evaluate ATES technology, the objective of this research is therefore to develop a methodology to determine the technical and commercial potential of ATES while incorporating local characteristics. With an emphasis on local conditions and stakeholders, the methodology developed in this study differentiates from previous ATES feasibility studies, which have mainly been focused on large-scale ATES suitability. The new methodology consists of both a stakeholder and geospatial analysis and is applied in this study to the region of New York State (NYS).

The main success factors for a region's ATES implementation consist of favourable geohydrological and climate conditions but also include conditions that enable market creation and development of a supportive regulatory framework. Joint efforts between ATES stakeholders are required to create these conditions and therefore critical for ATES implementation. This cooperation between stakeholders is currently the main challenge in NYS. The most important reasons for this are the sector's mistrust and unfamiliarity of the technology, environmental concerns, the use of improper drilling techniques and lack of experience.

To establish collaboration between ATES stakeholders, it is important to increase familiarity and build trust. Informing the stakeholders of the ATES potential in their region is likely to contribute significantly to ATES adoption. Based on the stakeholder analysis, geothermal architects are concluded to be the most influential stakeholders and are therefore crucial to persuade and engage for successfully implementing ATES technology in NYS. This is mainly due to the fact that (geothermal) architects serve as the lead consultants in geothermal projects who coordinate with various other influential stakeholders such as project developers, building-owners and permitting authorities from initial project screening to installation and operation.

Key information for these stakeholders in ATES projects are the technical and commercial ATES potential. Based on analysis of geohydrological conditions and building characteristics in Nassau County (NYS) and the identified requirements from geothermal architects, it is concluded that over 99% of all buildings (around 400,000) could technically receive the required amount of heat and cold if an ATES system was installed for those buildings. Moreover, the cooling of buildings with ATES is 10 - 30 times more efficient and the heating of buildings with ATES is around twice as efficient compared to conventional heating and cooling methods in Nassau County, depending on ATES design parameters. The electricity required for operating the additional heat pump, necessary to increase the water temperature to a sufficient level, induces the lower efficiency levels when ATES is in heating-mode. Finally, it is concluded that ATES is already a commercially attractive solution for 385 individual buildings in the county, accounting for an estimated 10% of the total heating and cooling demand of buildings in Nassau County. This commercial potential is solely derived for analysing single buildings in Nassau County but is expected to increase significantly when two or more buildings are attached to a single ATES system and building owners can benefit from economies of scale.

Both the technical and the commercial potential are derived from the developed methodology and obtained using a Geographic Information System (GIS), which is a universally adopted software and can also be applied to other regions globally. The analysis of ATES potential in Nassau county is, therefore, the first step in increasing ATES adoption, both in NYS and beyond. Application of the methodology developed in this study to the many parts in the world that have moderate climate conditions and aquifers available will contribute significantly to develop ATES markets in those regions. As to the applicability of the model in practice, it must be noted that site-specific aquifer and borehole tests are required before the actual realisation of ATES systems on a specific location. Finally, it is recommended that future research also includes a comprehensive groundwater analysis, as this would allow calculation of the optimal distance between an ATES system and adjacent drinking water supply wells, to derive more accurate maximum allowable well yields and to obtain insights on potential thermal energy losses affecting the Coefficient of Performance (COP) values of ATES systems.

The application of the newly developed methodology to Nassau County in this study indicates the significant role ATES could play in the heating and cooling of its buildings. The inclusion of local characteristics such as the interests and requirements of a region's key stakeholders and local geohydrological conditions are essential to generate realistic and accurate insights into the technical and commercial potential of ATES. The methodology developed in this study is therefore valuable support for local decision-makers and an effective resource to increase the adoption of ATES technology worldwide.

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A
Stakeholder Questionnaire

Analysis of Stakeholders of ATES Projects in New York State

Aquifer Thermal Energy Storage (ATES) success in a region is all about mobilizing influential stakeholders to take conducive measures or to at least refrain from the opposition. An important element is understanding the types of stakeholders in the ATES sector, their attitude and influence. The focus of this survey is on stakeholders in Long Island, New York State.

This survey is estimated to take 30 minutes and in case of any questions, please reach out to niels.maltha@overmorgen.nl.

Your help will be much appreciated and I would be more than happy to share results afterwards.

Niels Maltha
*Vereist

Stakeholder Category 1: Client Segments

This survey consists of a total of 6 stakeholder categories. This is the first category: Client Segments. This category consists of a few stakeholders. You are asked to allocate influence and attitude scores to each stakeholder, which are explained in more detail below.

For each stakeholder, their role is described. If you have any comments about the role description or the scores you assigned, there is room for comments after every stakeholder.

Scoring System

SCORING SYSTEM	
Power: Is the stakeholder's power to influence the work or the outcomes of the project significant or limited?	
1	Relatively low levels of power (cannot generally cause much change)
2	Some capacity to instruct change (e.g., must be consulted or has to approve...)
3	High capacity to cause change (e.g., a supplier with input to design)
4	Very high capacity to instruct change (i.e., can have the work stopped)
Proximity: Is the stakeholder closely associated or remote from the work of the project?	
1	Very remote from the work (does not have direct involvement with the work)
2	Relatively remote from the work but has regular contact with, or input to, various processes (e.g., some clients)
3	Routinely involved in the work (e.g., part-time members of the project team, external suppliers and active sponsors
4	Directly involved in the work (e.g, team members and contractors working most of the time)
Urgency: What is the anticipated response of the team managing an ATES project to a request from a particular stakeholder?	
1	There is no need for action outside of routine communications
2	Planned action is warranted which must be completed in a relatively long-term timeframe
3	Planned action is warranted which must be completed in a relatively medium-term timeframe
4	Planned action is warranted which must be completed as soon as possible (no need to put other commitments on hold immediately)
5	Immediate action is warranted, irrespective of other work commitments

Stakeholder 1 = Non-residential building owners (e.g. universities, hospitals, commercial buildings)

Stakeholder's Role: Customer and ATES end-user

1. Stakeholder 1: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

2. Stakeholder 1: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

3. Stakeholder 1: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

4. Stakeholder 1: Attitude *
What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- Opposed
- Neutral
- Supportive

5. Comments on stakeholder 1?
Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 2 = Individual homeowners or condo/coop developments (HOA's)
Stakeholder's role: Customer and ATES end-user

6. Stakeholder 2: Power *
Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low					Very High

7. Stakeholder 2: Proximity *
Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote					Directly Involved

8. Stakeholder 2: Urgency *
What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action						Immediate Action

9. Stakeholder 2: Attitude *
What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- Opposed
- Neutral
- Supportive

10. Comments on stakeholder 2?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 3 = Commercial property management companies

Stakeholder's role: Customer but no ATES end-user

11. Stakeholder 3: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

12. Stakeholder 3: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

13. Stakeholder 3: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

14. Stakeholder 3: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

15. Comments on stakeholder 3?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 4 = Non-residential developer selling the property

Stakholder's role: Customer but no ATES end-user

16. Stakeholder 4: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

17. Stakeholder 4: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

18. Stakeholder 4: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

19. Stakeholder 4: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

◯ Opposed

◯ Neutral

◯ Supportive

20. Comments on stakeholder 4?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 5 = Residential development owners (apartment buildings, affordable housing)

Stakeholder's role: Customer but no ATES end-user

21. Stakeholder 5: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

22. Stakeholder 5: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

23. Stakeholder 5: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	○	○	○	○	○	Immediate Action

24. Stakeholder 5: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ○ Opposed
- ○ Neutral
- ○ Supportive

25. Comments on stakeholder 5?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Did I miss any stakeholders in this category?

If so, please describe them in the comment section below. Please describe their role, attitude and provide scores related to their power, proximity and urgency.

26.

Stakeholder Category 2: Permitting Authorities

This survey consists of a total of 6 stakeholder categories. This is the second category: Permitting Authorities. This category consists of a few stakeholders. You are asked to allocate influence and attitude scores to each stakeholder, which are explained in more detail below.

For each stakeholder, their role is described. If you have any comments about the role description or the scores you assigned, there is room for comments after every stakeholder.

Scoring System

SCORING SYSTEM

Power: Is the stakeholder's power to influence the work or the outcomes of the project significant or limited?

1 Relatively low levels of power (cannot generally cause much change)
2 Some capacity to instruct change (e.g., must be consulted or has to approve...)
3 High capacity to cause change (e.g., a supplier with input to design)
4 Very high capacity to instruct change (i.e., can have the work stopped)

Proximity: Is the stakeholder closely associated or remote from the work of the project?

1 Very remote from the work (does not have direct involvement with the work)
2 Relatively remote from the work but has regular contact with, or input to, various processes (e.g., some clients)
3 Routinely involved in the work (e.g., part-time members of the project team, external suppliers and active sponsors
4 Directly involved in the work (e.g, team members and contractors working most of the time)

Urgency: What is the anticipated response of the team managing an ATES project to a request from a particular stakeholder?

1 There is no need for action outside of routine communications
2 Planned action is warranted which must be completed in a relatively long-term timeframe
3 Planned action is warranted which must be completed in a relatively medium-term timeframe
4 Planned action is warranted which must be completed as soon as possible (no need to put other commitments on hold immediately)
5 Immediate action is warranted, irrespective of other work commitments

Stakeholder 6 = NYC and Local Long Island Government

Stakeholder's Role: Provide work and building permits on a city and local level

27. Stakeholder 6: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	⬭	⬭	⬭	⬭	Very High

28. Stakeholder 6: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	⬭	⬭	⬭	⬭	Directly Involved

29. Stakeholder 6: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	⬭	⬭	⬭	⬭	⬭	Immediate Action

30. Stakeholder 6: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ⬭ Opposed
- ⬭ Neutral
- ⬭ Supportive

31. Comments on stakeholder 6?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 7 = State Government (NYSDEC)

Stakeholder's role: Provide ATES well drilling permits on Long Island

32. Stakeholder 7: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	⬭	⬭	⬭	⬭	Very High

33. Stakeholder 7: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	⬭	⬭	⬭	⬭	Directly Involved

34. Stakeholder 7: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

35. Stakeholder 7: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

36. Comments on stakeholder 7?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 8 = Federal Government (USEPA)

Stakholder's role: Underground Injection (UIC) notification on a national level

37. Stakeholder 8: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

38. Stakeholder 8: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

39. Stakeholder 8: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

40. Stakeholder 8: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

41. Comments on stakeholder 8?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 9 = Local Water Districts

Stakeholder's role: Provide input to NYSDEC on effects of ATES on drinking water supply/wells

42. Stakeholder 9: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

43. Stakeholder 9: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

44. Stakeholder 9: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

45. Stakeholder 9: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

46. Comments on stakeholder 9?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Did I miss any stakeholders in this category?

If so, please describe them in the comment section below. Please describe their role, attitude and provide scores related to their power, proximity and urgency.

47.

Stakeholder Category 3: Consultants and Designers	This survey consists of a total of 6 stakeholder categories. This is the third category: Consultants and Designers. This category consists of a few stakeholders. You are asked to allocate influence and attitude scores to each stakeholder, which are explained in more detail below. For each stakeholder, their role is described. If you have any comments about the role description or the scores you assigned, there is room for comments after every stakeholder.

Scoring System

SCORING SYSTEM

Power: Is the stakeholder's power to influence the work or the outcomes of the project significant or limited?
- **1** Relatively low levels of power (cannot generally cause much change)
- **2** Some capacity to instruct change (e.g., must be consulted or has to approve...)
- **3** High capacity to cause change (e.g., a supplier with input to design)
- **4** Very high capacity to instruct change (i.e., can have the work stopped)

Proximity: Is the stakeholder closely associated or remote from the work of the project?
- **1** Very remote from the work (does not have direct involvement with the work)
- **2** Relatively remote from the work but has regular contact with, or input to, various processes (e.g., some clients)
- **3** Routinely involved in the work (e.g., part-time members of the project team, external suppliers and active sponsors
- **4** Directly involved in the work (e.g, team members and contractors working most of the time)

Urgency: What is the anticipated response of the team managing an ATES project to a request from a particular stakeholder?
- **1** There is no need for action outside of routine communications
- **2** Planned action is warranted which must be completed in a relatively long-term timeframe
- **3** Planned action is warranted which must be completed in a relatively medium-term timeframe
- **4** Planned action is warranted which must be completed as soon as possible (no need to put other commitments on hold immediately)
- **5** Immediate action is warranted, irrespective of other work commitments

Stakeholder 10 = NYS Registered Architects (RA)

Stakeholder's Role: Serve as the owner's representative and coordinates engineers & consultants on ATES projects

48. Stakeholder 10: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

49. Stakeholder 10: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

50. Stakeholder 10: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

51. Stakeholder 10: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

◯ Opposed
◯ Neutral
◯ Supportive

52. Comments on stakeholder 10?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 11 = NYS Registered Engineers (mechanical/HVAC, civil, geotechnical)

Stakeholder's role: Design & prepare bid documents for building side of ATES systems

53. Stakeholder 11: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	⬭	⬭	⬭	⬭	Very High

54. Stakeholder 11: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	⬭	⬭	⬭	⬭	Directly Involved

55. Stakeholder 11: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	⬭	⬭	⬭	⬭	⬭	Immediate Action

56. Stakeholder 11: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ⬭ Opposed
- ⬭ Neutral
- ⬭ Supportive

57. Comments on stakeholder 11?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 12 = Energy/Sustainability Consultants

Stakeholder's role: Assess energy efficiency & sustainability of ATES systems, e.g., LEED

58. Stakeholder 12: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

59. Stakeholder 12: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

60. Stakeholder 12: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

61. Stakeholder 12: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

62. Comments on stakeholder 12?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 13 = Building-climate Advisors (HVAC experts)

Stakeholder's role: Involved in designing the internal building climate

63. Stakeholder 13: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

64. Stakeholder 13: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

65. Stakeholder 13: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

66. Stakeholder 13: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

67. Comments on stakeholder 13?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 14 = Geothermal system designers

Stakeholder's role: Recommend/design ATES well systems & prepare bid documents

68. Stakeholder 14: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

69. Stakeholder 14: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

70. Stakeholder 14: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

71. Stakeholder 14: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

72. Comments on stakeholder 14?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 15 = Geohydrologists

Stakeholder's role: Assess suitability of site hydrogeological conditions for use of ATES systems

73. Stakeholder 15: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

74. Stakeholder 15: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

75. Stakeholder 15: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

76. Stakeholder 15: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

77. Comments on stakeholder 15?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 16 = 3rd-Party/Utility-Scale Energy companies

Stakeholder's role: Turnkey ATES system finance-design-build-own-operate option

78. Stakeholder 16: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

79. Stakeholder 16: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

80. Stakeholder 16: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

81. Stakeholder 16: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

82. Comments on stakeholder 16?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Did I miss any stakeholders in this category?

If so, please describe them in the comment section below. Please describe their role, attitude and provide scores related to their power, proximity and urgency.

83.

Stakeholder Category 4: Construction Companies

This survey consists of a total of 6 stakeholder categories. This is the fourth category: Construction Companies. This category consists of a few stakeholders. You are asked to allocate influence and attitude scores to each stakeholder, which are explained in more detail below.

For each stakeholder, their role is described. If you have any comments about the role description or the scores you assigned, there is room for comments after every stakeholder.

Scoring System

SCORING SYSTEM

Power: Is the stakeholder's power to influence the work or the outcomes of the project significant or limited?
- **1** Relatively low levels of power (cannot generally cause much change)
- **2** Some capacity to instruct change (e.g., must be consulted or has to approve...)
- **3** High capacity to cause change (e.g., a supplier with input to design)
- **4** Very high capacity to instruct change (i.e., can have the work stopped)

Proximity: Is the stakeholder closely associated or remote from the work of the project?
- **1** Very remote from the work (does not have direct involvement with the work)
- **2** Relatively remote from the work but has regular contact with, or input to, various processes (e.g., some clients)
- **3** Routinely involved in the work (e.g., part-time members of the project team, external suppliers and active sponsors
- **4** Directly involved in the work (e.g, team members and contractors working most of the time)

Urgency: What is the anticipated response of the team managing an ATES project to a request from a particular stakeholder?
- **1** There is no need for action outside of routine communications
- **2** Planned action is warranted which must be completed in a relatively long-term timeframe
- **3** Planned action is warranted which must be completed in a relatively medium-term timeframe
- **4** Planned action is warranted which must be completed as soon as possible (no need to put other commitments on hold immediately)
- **5** Immediate action is warranted, irrespective of other work commitments

Stakeholder 17 = Construction Management Firms

Stakeholder's Role: Serve as Owner's representative andcoordinates contractors on ATES projects

84. Stakeholder 17: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

85. Stakeholder 17: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

86. Stakeholder 17: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

87. Stakeholder 17: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

◯ Opposed
◯ Neutral
◯ Supportive

88. Comments on stakeholder 17?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 18 = Drilling Companies

Stakeholder's role: Responsible for drilling ATES wells

89. Stakeholder 18: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

90. Stakeholder 18: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

91. Stakeholder 18: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

92. Stakeholder 18: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

93. Comments on stakeholder 18?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 19 = General Contractor

Stakeholder's role: Prime contractor coordinating all trades for construction of ATES systems

94. Stakeholder 19: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

95. Stakeholder 19: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

96. Stakeholder 19: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	○	○	○	○	○	Immediate Action

97. Stakeholder 19: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ○ Opposed
- ○ Neutral
- ○ Supportive

98. Comments on stakeholder 19?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

____
____
____
____
____

Stakeholder 20 = Mechanical & Electrical Contractors

Stakeholder's role: Responsible for installation of piping & electrical parts of ATES systems

99. Stakeholder 20: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	○	○	○	○	Very High

100. Stakeholder 20: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	○	○	○	○	Directly Involved

101. Stakeholder 20: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	○	○	○	○	○	Immediate Action

102. Stakeholder 20: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ○ Opposed
- ○ Neutral
- ○ Supportive

103. Comments on stakeholder 20?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 21 = Design-Build Firms

Stakeholder's role: Turnkey ATES system design and installation option

104. Stakeholder 21: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

105. Stakeholder 21: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

106. Stakeholder 21: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

107. Stakeholder 21: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

108. Comments on stakeholder 21?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 22= Labor Unions

Stakeholder's role: Represent workers in the various trades on ATES projects

109. Stakeholder 22: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

110. Stakeholder 22: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

111. Stakeholder 22: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

112. Stakeholder 22: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

113. Comments on stakeholder 22?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Did I miss any stakeholders in this category?

If so, please describe them in the comment section below. Please describe their role, attitude and provide scores related to their power, proximity and urgency.

114.

Stakeholder Category 5: Related Sectors

This survey consists of a total of 6 stakeholder categories. This is the fifth category: Related Sectors. This category consists of a few stakeholders. You are asked to allocate influence and attitude scores to each stakeholder, which are explained in more detail below.

For each stakeholder, their role is described. If you have any comments about the role description or the scores you assigned, there is room for comments after every stakeholder.

Scoring System

SCORING SYSTEM
Power: Is the stakeholder's power to influence the work or the outcomes of the project significant or limited?
1 Relatively low levels of power (cannot generally cause much change)
2 Some capacity to instruct change (e.g., must be consulted or has to approve...)
3 High capacity to cause change (e.g., a supplier with input to design)
4 Very high capacity to instruct change (i.e., can have the work stopped)
Proximity: Is the stakeholder closely associated or remote from the work of the project?
1 Very remote from the work (does not have direct involvement with the work)
2 Relatively remote from the work but has regular contact with, or input to, various processes (e.g., some clients)
3 Routinely involved in the work (e.g., part-time members of the project team, external suppliers and active sponsors
4 Directly involved in the work (e.g, team members and contractors working most of the time)
Urgency: What is the anticipated response of the team managing an ATES project to a request from a particular stakeholder?
1 There is no need for action outside of routine communications
2 Planned action is warranted which must be completed in a relatively long-term timeframe
3 Planned action is warranted which must be completed in a relatively medium-term timeframe
4 Planned action is warranted which must be completed as soon as possible (no need to put other commitments on hold immediately)
5 Immediate action is warranted, irrespective of other work commitments

Stakeholder 23 = Conventional Fossil Fuel Providers

Stakeholder's Role: Supply homes and businesses with heating oil, propane etc

115. Stakeholder 23: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

116. Stakeholder 23: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

117. Stakeholder 23: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

118. Stakeholder 23: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

119. Comments on stakeholder 23?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 24 = Industrial water sector

Stakeholder's role: Sector that uses groundwater for industrial purposes

120. Stakeholder 24: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

121. Stakeholder 24: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

122. Stakeholder 24: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

123. Stakeholder 24: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

124. Comments on stakeholder 24?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

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Stakeholder 25 = Sustainable energy sectors (other than geothermal)

Stakeholder's role: For example solar, wind, thermal storage, wastewater heat exchange

125. Stakeholder 25: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

126. Stakeholder 25: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

127. Stakeholder 25: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

128. Stakeholder 25: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

129. Comments on stakeholder 25?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 26 = Agricultural Water Sector

Stakeholder's role: Sector that uses groundwater for agricultural irrigation purposes

130. Stakeholder 26: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

131. Stakeholder 26: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

132. Stakeholder 26: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

133. Stakeholder 26: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

134. Comments on stakeholder 26?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 27 = Environmental Organizations

Stakeholder's role: NGOs monitoring & protecting environmental/ecological resources

135. Stakeholder 27: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

136. Stakeholder 27: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

137. Stakeholder 27: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

138. Stakeholder 27: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

139. Comments on stakeholder 27?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Did I miss any stakeholders in this category?

If so, please describe them in the comment section below. Please describe their role, attitude and provide scores related to their power, proximity and urgency.

140.

Stakeholder Category 6: Utilities and Municipal Infrastructure

This survey consists of a total of 6 stakeholder categories. This is the sixth and final category: Utilities and Municipal Infrastructure. This category consists of a few stakeholders. You are asked to allocate influence and attitude scores to each stakeholder, which are explained in more detail below.

For each stakeholder, their role is described. If you have any comments about the role description or the scores you assigned, there is room for comments after every stakeholder.

Scoring System

SCORING SYSTEM

Power: Is the stakeholder's power to influence the work or the outcomes of the project significant or limited?
- **1** Relatively low levels of power (cannot generally cause much change)
- **2** Some capacity to instruct change (e.g., must be consulted or has to approve...)
- **3** High capacity to cause change (e.g., a supplier with input to design)
- **4** Very high capacity to instruct change (i.e., can have the work stopped)

Proximity: Is the stakeholder closely associated or remote from the work of the project?
- **1** Very remote from the work (does not have direct involvement with the work)
- **2** Relatively remote from the work but has regular contact with, or input to, various processes (e.g., some clients)
- **3** Routinely involved in the work (e.g., part-time members of the project team, external suppliers and active sponsors
- **4** Directly involved in the work (e.g, team members and contractors working most of the time)

Urgency: What is the anticipated response of the team managing an ATES project to a request from a particular stakeholder?
- **1** There is no need for action outside of routine communications
- **2** Planned action is warranted which must be completed in a relatively long-term timeframe
- **3** Planned action is warranted which must be completed in a relatively medium-term timeframe
- **4** Planned action is warranted which must be completed as soon as possible (no need to put other commitments on hold immediately)
- **5** Immediate action is warranted, irrespective of other work commitments

Stakeholder 28 = PSEG

Stakeholder's Role: Electric utility (Nassau/Suffolk Counties) that provides rebates for ATES projects

141. Stakeholder 28: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

142. Stakeholder 28: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

143. Stakeholder 28: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

144. Stakeholder 28: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

145. Comments on stakeholder 28?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 29 = National Grid

Stakeholder's role: Natural gas utility (Nassau/Suffolk Counties)

146. Stakeholder 29: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	◯	◯	◯	◯	Very High

147. Stakeholder 29: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	◯	◯	◯	◯	Directly Involved

148. Stakeholder 29: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

149. Stakeholder 29: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

150. Comments on stakeholder 29?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 30 = Con Edison

Stakeholder's role: Electric & natural gas utility in NYC (Brooklyn and Queens on Long Island)

151. Stakeholder 30: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	○	○	○	○	Very High

152. Stakeholder 30: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	○	○	○	○	Directly Involved

153. Stakeholder 30: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	○	○	○	○	○	Immediate Action

154. Stakeholder 30: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ○ Opposed
- ○ Neutral
- ○ Supportive

155. Comments on stakeholder 30?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Stakeholder 31 = Public Transport Agencies

Stakeholder's role: Provide approvals to drill wells near public infrastructure (rail, subway, tunnels)

156. Stakeholder 31: Power *

Is the stakeholder's power to influence the work or the outcomes of the project very high or limited?

Markeer slechts één ovaal.

	1	2	3	4	
Low	○	○	○	○	Very High

157. Stakeholder 31: Proximity *

Is the stakeholder closely associated or remote from the work of the project?

Markeer slechts één ovaal.

	1	2	3	4	
Very Remote	○	○	○	○	Directly Involved

158. Stakeholder 31: Urgency *

What is the anticipated response of the team managing an ATES project to a request from this particular stakeholder?

Markeer slechts één ovaal.

	1	2	3	4	5	
No Action	◯	◯	◯	◯	◯	Immediate Action

159. Stakeholder 31: Attitude *

What is the attitude of the stakeholder towards ATES projects?

Markeer slechts één ovaal.

- ◯ Opposed
- ◯ Neutral
- ◯ Supportive

160. Comments on stakeholder 31?

Do you, for example, have comments on their role (described directly under the name of the stakeholder), influence or attitude? Or do you have other comments?

Did I miss any stakeholders in this category?

If so, please describe them in the comment section below. Please describe their role, attitude and provide scores related to their power, proximity and urgency.

161.

What Is More Important: A Stakeholder's Power, Proximity or Urgency?

In order to be able to prioritize the stakeholders, relative weightings must be applied to the power, proximity and urgency scores of the stakeholders.

For example, when you allocate the scores below as "Power = 9; Proximity = 1; Urgency =1", it implies that in your understanding the power is 9 times as important compared to the proximity and urgency when prioritizing the stakeholders.

If in your opinion, however, the stakeholders' power, proximity and urgency are all equally important, then you can fill in the same scores for each factor. In that case, since the final scores are relative scores, it does not matter what number you fill in (as long as they are the same).

According to your understanding, are the stakeholder's Power, Proximity and Urgency equally important or not? Provide scores from 1-9 below.

DEFINITIONS	
Power:	Is the stakeholder's power to influence the work or the outcomes of the project significant or limited?
Proximity:	Is the stakeholder closely associated or remote from the work of the project?
Urgency:	The urgency describes the project team's anticipated reaction to a request from a particular stakeholder

162. POWER *

Markeer slechts één ovaal.

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

163. PROXIMITY *

Markeer slechts één ovaal.

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

164. URGENCY *

Markeer slechts één ovaal.

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

165. Please provide your name, email address and organisation below *

B

Results of the Geospatial Analysis in Metric Units

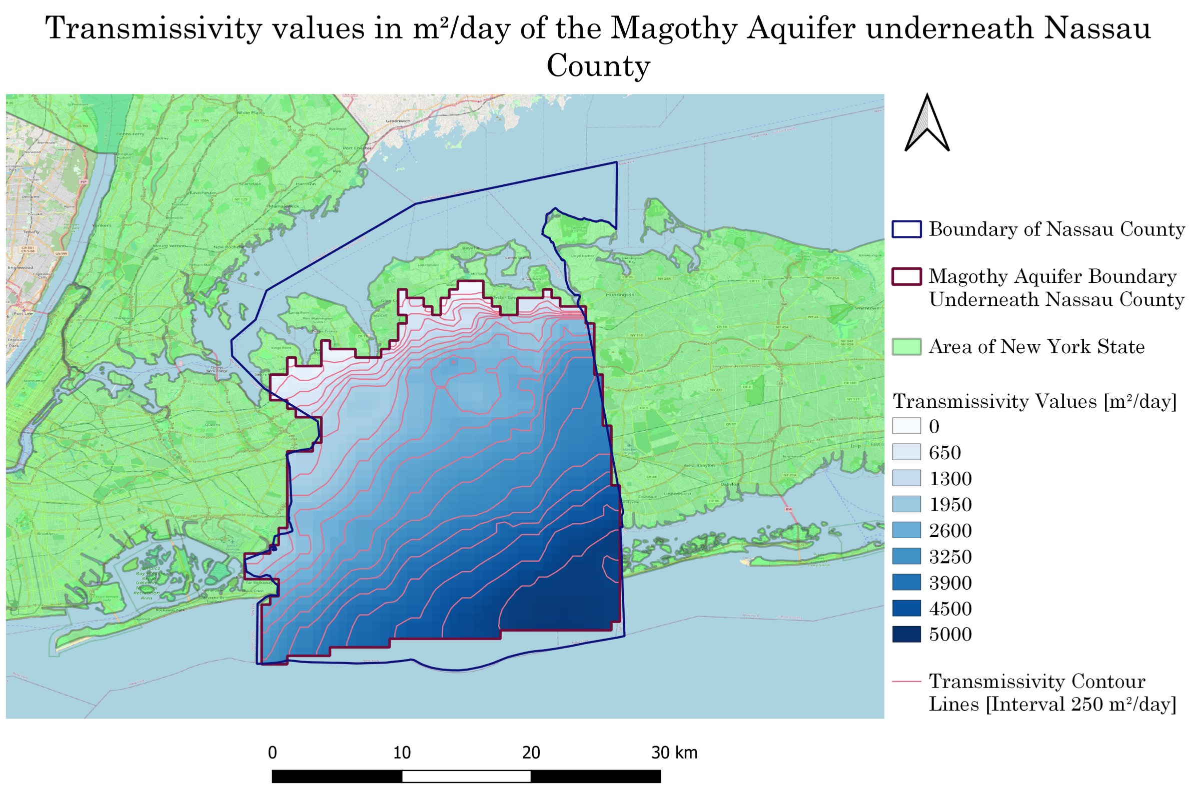

Figure B.1: Transmissivity values in m^2/day of the Magothy Aquifer underneath Nassau County (compiled by author).

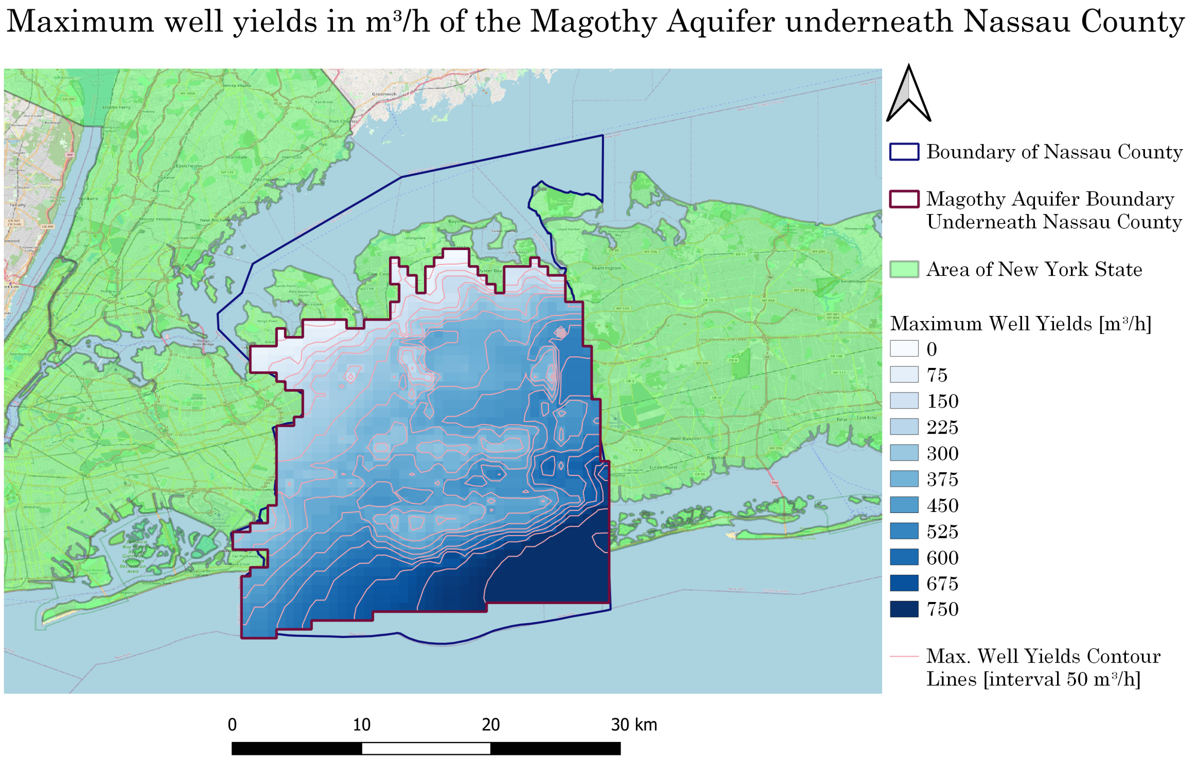

Figure B.2: Maximum well yields in m^3/h of the Magothy Aquifer underneath Nassau County (compiled by author).