Sudbury Renewable Renovations MQP

A Major Qualifying Project
Submitted to the Faculty of the
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Degree of Bachelor of Science

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Abstract

This project analyzed and reviewed the private residences at 42 & 50 Wolbach Road, Sudbury, MA with the purpose of designing sustainable renovations and homes closer to a goal of net-zero utility energy consumption. The Wolbach homes are in an environmentally sensitive area, limiting the available space and methods to perform the renovations. The property owner operates a dog daycare business out of on home, which new structures and site were designed.

For older or historical structures, renovating to fit modern sustainability goals presents specific challenges and constraints. To meet the goal of the project, the team designed a sustainable source of energy, up-to-date interiors, water sources, and new wastewater treatment system. The designs cover the sourcing and design of a solar arrays for each property, interior designs including windows, insulation, and layouts, and new alternative drinking and wastewater systems.

Capstone Design Statement

The Accreditation Board for Engineering and Technology (ABET) provides accreditations to university programs that satisfy the standards of quality necessary to prepare graduates in their profession. As part of the general criteria for baccalaureate-level programs, the curriculum must include a capstone experience, which develops the student's application of technical and non-technical skills acquired in the program.

To satisfy this requirement, Worcester Polytechnic Institute requires students to complete a capstone project, known as the Major Qualifying Project (MQP). This MQP developed a set of design recommendations of home structures and layouts, wastewater systems, and site layouts for new and existing properties based on results obtained through the team's application of engineering principles, environmental analyses, engineering software, and field assessments.

Data to complete architectural analyses was collected by the team through site visits, renovation documents and interviews with the owner. The team estimated energy consumption needs while demonstrating their ability to simulate energy usage through 3D modeling in Design Builder. Further proficiency of modeling software and architectural concepts were displayed through the creation of updated and new structures using Revit.

Using national soil surveys and other databases, the team was able to complete a 2D representation of the site by mapping the data in GIS. The team familiarized themselves with government regulations such as Massachusetts' Title 5, as well as provided recommendations for septic placements that follow state regulations. Knowledge of civil and environmental engineering concepts were demonstrated through calculation of water demands and distribution areas, as well as design recommendations that best fit the site's hydrogeological properties and water demand.

Licensure Statement

Becoming a licensed engineer provides engineers with a high level of responsibility and respect in the engineering community. The National Council of Examiners for Engineering and Surveying (NCEES) is a nonprofit organization that creates and administers professional licensure exams. State-level licenses are given to ensure all engineers are competent and credible to create engineering plans which protect the health and safety of those constructing and then using the final structures. Only professional, licensed engineers are legally authorized to sign and seal engineering plans, oversee work in the private sector, or qualify as expert witnesses. A PE license ensures greater job security and salaries and is a necessity to become an engineering consultant.

In order to receive a degree from an Accreditation Board Of Engineering and Technology (ABET) accredited engineering program, it is necessary for senior students to complete a capstone design project. A capstone design project gives engineering students the chance to use the knowledge and experience gained from their education and curriculum to create an engineering design considering real economic, environmental, and political constraints. After graduation, students desiring to become licensed architectural or civil engineers will study and partake in the NCEES Fundamentals of Engineering Exam to receive the title “Engineer in Training” (EIT). To receive the title “Professional Engineer” (PE) it is required to work under a licensed PE for four years and pass the Principles and Practice of Engineering Exam. Becoming a professional engineer is a valuable title and recognition which develops personal integrity and knowledge.

Table of Contents

Authorship

Location	Author/s
Abstract	Lana
1. Introduction	Lana
2. Background	
2.1	Lana
2.11	Keira, Derek
2.12	Danielle,
2.2	Sophia, Danielle, Lana, Keira, Derek
2.4	Danielle, Sophia, Lana
Methodology	
3.1	Danielle, Sophia,
3.2	Derek, Keira
3.3	Lana, Danielle, Sophia, Derek
4.0 Design Solution	
42. Existing & Proposed Solutions	Keira, Derek
42 Site Design	Lana, Danielle, Sophia
50 Existing & Proposed Solutions	Keira, Derek
50 Site Design	Lana, Danielle, Sophia
Dale End	Keira, Derek

Dale End Site design	Lana, Danielle, Sophia
5.0 Conclusion	Lana
6.0 Future recommendations	Lana

List of Figures

List of Tables

Chapter 1 Introduction

With the shift in design and construction practices toward more sustainable, energy-efficient, and renewable-powered buildings, many older homes and historic buildings have become outdated and face the question of renovation and retrofitting for these sustainability goals. Issues can arise from older buildings and the environmental effects they can have on the surrounding areas through their use of water and energy.

The project assessed 3 properties in Sudbury, Massachusetts which consist of two-family homes and a dog walking and daycare business, all accompanied with a primary ambition for long-term sustainability. Our main goals in this project are to create buildings that generate and store their own heat, electricity, and water; insulate and glaze the home efficiently, and require as little outside utility energy as possible. In addition to renovating the homes for energy efficiency, there is a dog daycare business currently based out of 42 Wolbach Road which must be relocated to a separate plot of land with new structures. In order to meet these goals, the issues of water usage and treatment, efficient interiors, and new energy sourcing were addressed. This project explores ways to upgrade existing structures in various ways to achieve either carbon neutrality or a sustainable footprint while leaving the character of the building intact.

This project provides methods to design renovations and update older homes while attempting to preserve both their historical character and meet the owner's wishes for the home's future. For this project, the team had 4 objectives:

- Objective 1: Analyze the existing site and its structures to address their functionality, utility system, and sustainability concerns.
- Objective 2: Simulate, design, and recommend new and efficient renewable energy

systems, HVAC systems, and thermal improvements.

- Objective 3: Design new structures for the proposed relocation of Dale End Dogs on 50 Wolbach.
- Objective 4: Research and inform owners about the zoning and conservation constraints of the proposed construction.

The main deliverables of the project are

- Deliverable 1: The creation of new 3D models featuring the interiors and exterior renovations of the homes.
- Deliverable 2: A layout featuring the placement of a renewable energy source, wastewater systems, and well systems for the sites.

Chapter 2 Background

In order to accomplish the project objectives, it is important to understand the elements required to become a more passive home, including but not limited to sourcing new sustainable energy, water usage, and treatment. Additionally, to work on maintaining the specific character of the existing properties, the history of the estate must be considered, as well as the constraints placed on the site both environmentally and legally.

2.1 Creating Sustainable Housing

In the past couple of years, the demand for sustainable green housing has increased greatly. With the trend beginning in the 1990s, green building has begun the shift from a special feature of buildings to a mainstream expectation. With the rise in concern over issues of climate change and environmental impacts, creating sustainable homes has become even more important. There are three main sourcing elements a self-sufficient home must address: water, wastewater management, and energy.

2.1.1 Solar & Wind Energy

Solar and wind energy are popular renewable energy sources for self-sufficient homeowners. While the upfront cost of a solar photovoltaic (PV) system is high, these can be offset by state incentives such as the Property and Sales Tax Exemption within Massachusetts (Massachusetts Clean Energy Center, 2019). Additionally, a solar PV system typically has a lifespan of 25 to 30 years or more, with a five to eight-year pay-back period. As for small wind electric systems, factors to consider include available wind, space, energy needs, and no existing restrictions for tall towers in the desired area (National Renewable Energy Laboratory, 2003). Just like the solar PV systems, Massachusetts grants similar tax incentives to those who opt for this energy source. When it comes to deciding what renewable energy source to use, the homeowner must consider their budget, energy demands, space, solar and wind availability, zoning restrictions, and more.

2.1.2 Water & Wastewater Systems

Well systems are widely used, as an estimated 20% of the New England population obtains water from their privately owned wells (US EPA, n.d.). Due to this, the Massachusetts Department of Environmental Protection (MassDEP) has created and published the Private Well Guideline to educate homeowners on regulation, procedures, design, construction, and maintenance among other topics for future or current private well owners (Massachusetts Department of Environmental Protection Northeast Regional Office, 1992). Despite initial regulations, the testing and maintenance responsibility falls on the homeowner. These shall be conducted at the suggested frequencies outlined by the EPA, as various odorless and flavorless contaminants can be introduced into the system through contamination of surrounding groundwater.

Regardless of the water-sourcing method, wastewater management is an essential component of water usage. A conventional septic system collects wastewater from housing plumbing into the buried septic tank. Settling of sludge and separation of grease and oils allows the now pre-treated effluent wastewater to exit into unsaturated soil, where natural treatment of coliforms, viruses, and nutrients occurs (US EPA, 2015). The construction of a septic system involves the installation of a septic tank and a series of drain fields. The land is excavated to the required depth and shape to accommodate the septic tank, which is then buried and connected to the drain field. The drain field is made up of perforated pipes that are laid out in the trench in a pattern to maximize the area for effluent dispersal. Gravel is placed over and under the pipes to allow for proper drainage and filtration of the wastewater. The trench is then backfilled with soil and grass to restore the landscape. *Figure 2.1* displays a conventional septic tank system showing the wastewater movement from the source to the tank, and then the leaching field. While there are a variety of conventional and alternative septic systems, they all vary in cost, removal efficiency, maintenance, and capacity, among other requirements that should be considered according to individual needs (US EPA, 2018). Most importantly, all septic system designs need to satisfy the requirements outlined in regulation 310 CMR §15.00, which is most commonly known as Title 5. This State Environmental Code outlines how septic systems need to be installed, used, and maintained.

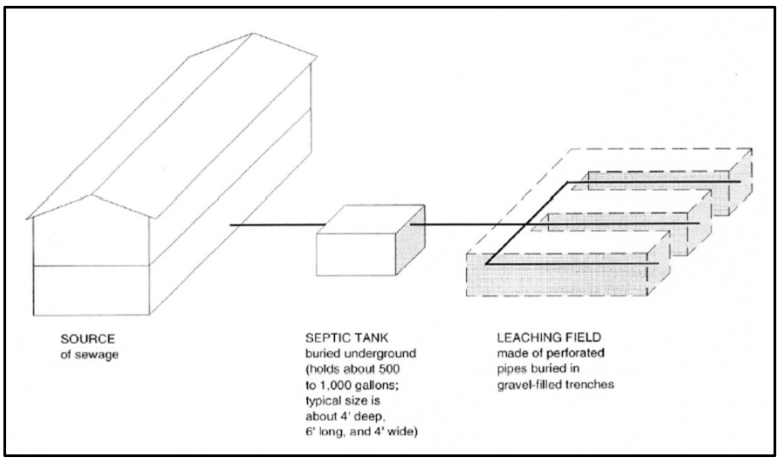


Figure 2.1 Schematic of a Conventional Septic System (T Larz, 2000)

2.2 Newton Estate Property, History, and Current Utilities

In the 1930s, Francis Newton, Mr. Newton's father, bought the land south of Wolbach Farm in Sudbury, Massachusetts. The parcel contained multiple lots, which were divided up later down the line. Mr. Newton is the current owner of the lots on 42 and 50 Wolbach Road, which make up the 7.4 acres of Newton Estate.

42 Wolbach Road holds a renovated 5150-square-foot barn home to Mr. Newton and his wife, Jane. The structure, originally built in the 1800s, was home to horses and hay, until the 30s when the barn was renovated into a one-family home. Due to the building's history, it is full of unique architectural details such as a cupola, high ceilings, large windows, and a timber frame. It has a steel-reinforced concrete foundation (Sudbury, MA, 2022a). It has balconies on both the first and second floors on the southeast-facing side (*Figure 2.2*). In 1997, Mr. Newton again renovated the 1800s four-bedroom home. Currently, the garage and loft are dedicated to the employees and clients of Mr. Newton and his son's dog-walking business, Dale End Dogs.

Figure 2.2 Wolbach Road, back (south-east); pictured - two back porches (balconies) to the right, many windows, a door on the basement level (center), a door on the first level (center, floating), door (top left, floating), many south facing windows

Continuing 700 feet up the wooded hill of Wolbach Road leads travelers to 50 Wolbach Road, which holds another 1910s cape-style single-family home. The home is located on 2.5 acres of wooded land (*Figure 2.3*). It has a masonry foundation and wooden frame. There are three bedrooms, 1 bathroom, and one additional toilet. As of 2021, Sudbury's assessor's office has marked the building as having a fair building grade, and very poor building condition (Sudbury, MA, 2022b).

Figure 2.3 50 Wolbach Road, side (southwest); pictured: two levels, open roof porch

Underground wells supply both homes with potable water. They are 500 feet deep, 6 inches in diameter, and utilize 2.5 horsepower pumps. 42 Wolbach Road's well is located just south of the northern property line, 158 feet north of the home. According to the 1996 assessment (Appendix A), the well has a drive shoe seal and 40 feet of 6-inch diameter protective steel. It yields 7 gallons per minute, pumping 242 feet below the ground's surface. 50 Wolbach Road's well is located 68 feet south of the building, next to the porch.

42 Wolbach has a 1500-gallon septic tank and a subsurface water infiltration system made of 3 leaching trenches, while 50 Wolbach has an incomplete system consisting of only a septic

tank to remove water and waste.

The homes are heated by forced hot water. 42 Wolbach has a boiler in the basement, and 50 Wolbach's boiler is located in the garage. The boilers use oil to heat up the water in the vessel which is circulated through the house by a pump through pipes. Radiators around the house emit the heat emanating from the hot water (Wilson Brothers, 2022). Eversource supplies the electricity.

2.3 Legal Restrictions

To complete this project by right, it is necessary to remain in accordance with state and local regulations. Environmental restrictions were defined by the Town of Sudbury's Conservation Commission. Sudbury's Zoning Bylaws define what uses of land are allowed in certain regions. It was necessary to review since Mr. Newton wants to run a business from a residential area.

2.3.1 Environmental Restrictions

Environmental restrictions affect the site, including wetlands and conservation areas. The Newton Estate is surrounded by the Wolbach Farm and the Great Meadows National Wildlife Refuge (NWR), owned by the Sudbury Valley Trustees (SVT) and the United States Fish and Wildlife Service respectively (U.S. Fish and Wildlife Service, n.d.). SVT abuts the estate to the north, protecting old Wolbach Farm and a stream. Southeast of 42 and 50 Wolbach Road is a 5.86-acre parcel of conservation land, and beyond that, there are marshes and ponds known for their wildlife. The marshes and ponds once owned by the Newton family were donated to the state with conservation efforts. The Natural Heritage and Endangered Species Program (NHESP) has since declared the land an estimated habitat of rare wildlife and is now protected by Great Meadows NWR. *Figure 2.4* shows conservation and wildlife areas around 42 and 50 Wolbach Road. With both conservation lands being managed under different ownership, they each have different but intersecting regulations and histories regarding their usage.

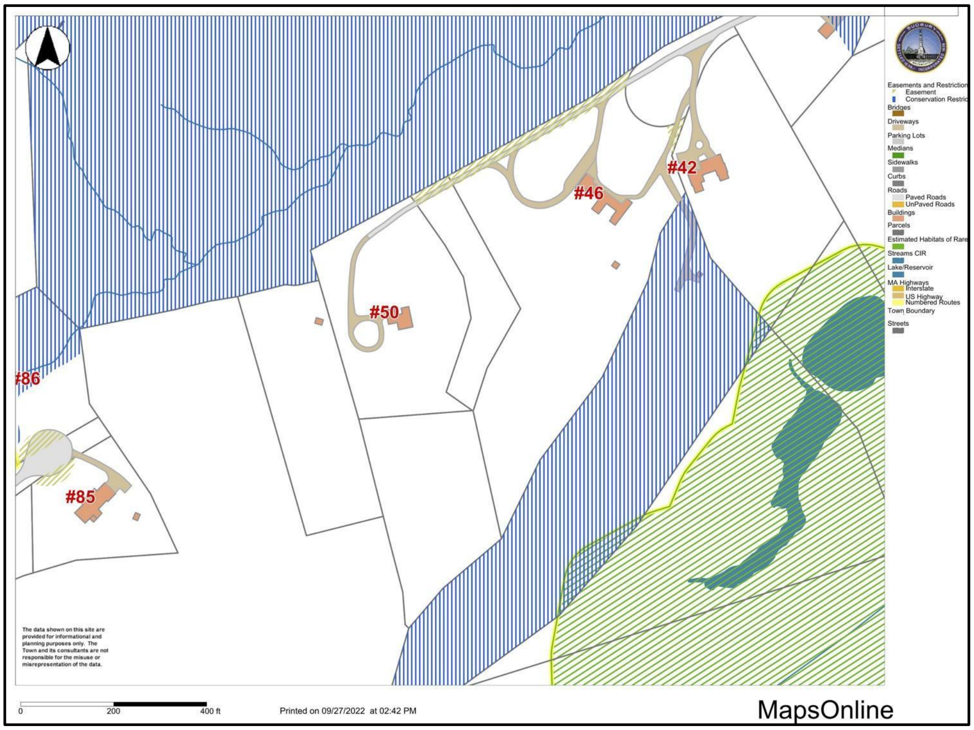


Figure 2.4 Map of known conservation restrictions (blue vertical stripes) and NHESP estimated habitats of rare wildlife (green diagonal stripes) around 42 and 50 Wolbach Road [MapsOnline]

2.3.2 Zoning Considerations

Constructing commercial or residential buildings requires applications, permitting, and review of the projects. The Town of Sudbury's Zoning ByLaw Article IX establishes the town's standards on how the land may be used and marketed and the regulations within those boundaries. Newton Estate is located in a residentially zoned area. In order to develop a business structure such as a kennel on the land, it is necessary to review article 6200 Special Permits, which describes the criteria for applying for a special permit from the zoning board of appeals. The Articles further establish general regulations regarding parking, signage, and frontage requirements. Article 4800 of the bylaw provides regulations on constructing and maintaining a solar farm, either ground or roof mounted, which must be considered when considering Mr. Newton's options for powering his estate. Single-family, roof-mounted solar energy systems do not require a site plan review, while ground-mounted systems require a site plan review by the town's planning board (Town of Sudbury, MA, 2021). Combining environmental and zoning considerations takes a careful review of legal provisions to plan the renovations legally and safely.

Chapter 3 Methodology

The methodology is ordered by the teams' objectives. First, the existing site including its structures and environment was analyzed using various resources and materials. Next, the team produced 3D models of the existing structures at 42 and 50 Wolbach Road, and energy modeling was done to understand the shortcomings of insulation which affect the efficiency of heating and thermal loss. 2D site layouts were made to have an overview of the properties. Using the original data, and new legal requirements the team developed solutions and further recommendations regarding various concerns and goals of Mr. Newton.

3.1 Analysis of Sites and Structures

In order to gain a better understanding of the site and its structures, the team visited Newton Estate to gather information about the project scope and the existing state of the properties. The team spoke with Mr. Newton about the history of the property, his current concerns, and his future goals for the property. Other sources of information include SketchUp files from Robert Karn, an architect friend of Mr. Newton's who had previously assessed the renovation of Newton Estate (Appendix B), and site and architectural plans from the 1990s provided by Mr. Newton (Appendix C). The resources from Robert Karn include existing site and floor plans and 3D models of both 42 and 50 Wolbach Road. Additionally, it provides case studies of the 42 and 50 Wolbach Road's drinking and wastewater systems. There is a concept design for Dale End Dogs and concept resource management. The plans from Mr. Newton himself contain lot subdivision plans, topographic maps of the area, and architectural plans of the 1990s renovation of 42 Wolbach Road.

3.1.1 Environmental Analysis

GIS data was used to determine the environmental constraints of Mr. Newton's property. MassGIS layers were downloaded to learn more about the site. To create a 2D representation of the site, tax parcels, roads, wetlands, contour lines, and existing buildings were added to the map. This created an existing site plan to understand existing conditions further. To analyze the site further, soil data, environmental protection sites, bedrock lithology, and drainage basin layers were added. Any construction, especially underground like installing septic tanks, requires a knowledge of the land to avoid harming the land or any existing or new structures. To determine the location and set up of wastewater treatment for 50 Wolbach Road, we employed the Soils data layer from MassGIS. The Soil layer provides the location and details of the soil's water permeability, composition and slope based on Natural Resources Conservation Center (NRCS) soil surveys (Appendix D). This data was used to calculate the size of the soil absorption system at 50 Wolbach Road. The Conservation Layers present the exact boundaries of the conservation land surrounding the north and south of Newton Estates, wetland layers provided locations of wetlands, etc.. *Figure 2.4* presents this data. Appendix E provides additional water delineation analysis, showing precipitations' path through the properties, and Appendix F shows the topographic map of the area. Tree placement is shown in Appendix G.

3.1.2 Water Testing

The team collected water samples from bathroom sink faucets in both 42 and 50 Wolbach with the goal of testing for total and fecal coliforms. Samples were diluted with distilled water in ranges between 10^0 and 10^{-6} and placed in tubes containing lauryl tryptose broth (LTB) according to procedures outlined in Standard Method 9221. LTB was used in Multiple Tube Fermentation as a preemptive test to determine the presence of any coliforms. These were left to incubate for 48 hours, and results were recorded at the 24- and 48-hour marks. A positive test represents possible presence of coliforms, while a negative result represents no coliforms found in the sample.

3.2 Simulation, Designs, and Modeling

Using the collected data from site visits, conversations, and renovation documents, we conducted an energy analysis of both properties using DesignBuilder, a 3D modeling software that allows the user to simulate detailed energy analyses while considering the many essential and adjustable parameters that make up a building energy analysis. Autodesk Revit was used to model and render the current properties as well as the proposed renovations, and to produce architectural drawings for renovation recommendations. AutoCAD|Civil3D was used to create 2D site layout drawings.

3.2.1 Energy and Thermal Modeling

A spreadsheet was used to estimate current energy consumption, using assumptions made based on the information provided to us as well as national and historical averages for all of the properties, as well as to calculate the impacts of possible changes, and groups of changes, to the overall energy consumption for each property. Additionally, a spreadsheet was used to calculate the number and square footage of solar panels required to meet these energy consumption needs.

A simple geometry for the buildings was created in Design Builder to simulate the energy usage for the buildings with specific temperature data for the area.

3.2.2 3D Building Design Modeling

Existing 3D models were provided to us by the sponsor for the houses at 42 and 50 Wolbach. These models had been created in SketchUp and were used as a general reference when creating our updated models of the properties. Updated models for 50 and 42, as well as a suggested layout for the Dale End Dogs business, were created using Revit. This allowed for 3D renderings to be made, as well as solar path studies.

3.3 Site Design

Combining public Massachusetts GIS Data, existing site plans and maps provided by Mr. Newton, satellite images, and pictures from site visits made it possible to create existing site plans of the property. AutoCAD|Civil 3D was used to create a 3D model of the topography of the land, and add relevant data like well locations, septic system layouts, and construction restrictions like wetlands or perennial streams to map out limitations. To create proposed site plans which include new house renovations, additional soil absorption systems, and wells, it was necessary to consult Title 5 which provides setback limits for drinking and wastewater systems to building foundations, surface water, and other environmental or built factors. Civil3D was also used to create a pipe network to create the soil absorption system for 50 Wolbach Road.

3.3.1 Solar

To model the use of Solar for the various parcels, a variety of methods was used. After obtaining the estimated energy usage following the renovations, it was possible to estimate the number of solar panels needed to meet the energy requirement.

Using Revit, we completed a solar study to determine the serviceable roof space for each property when considering solar panel installation. The allowable areas should face south and remain free of shadows throughout the year to maximize solar energy intake. Analysis of this revealed the amount of roof and square footage available for potential PV arrays to be mounted.

Alongside potential roof space, the density of the forested areas surrounding the parcels was calculated using images collected from site visits of the area and known distances to compare. By counting the number of trees in the area, and dividing by the total area in square feet, the density of trees/square footage was calculated. This number was used to indicate the minimum number of trees that may need to be removed if roof arrays do not provide adequate space. The estimations were supported through 3D model year-long solar analyses to ensure no shadows would be cast upon the recommended solar panel placement.

Various models of Solar Panels were researched. The efficiency, dimensions, and yearly energy output were calculated using the information provided on the design specification sheets. The yearly output was then divided by the estimated yearly energy usage to show the number of panels required from each model. With the known area of each panel and estimated roof area provided by Revit models, the required total square footage of each PV model was calculated.

3.3.2 Wastewater Management

To determine water treatment methods and requirements in each site, the team analyzed the condition and location of both existing septic systems and possible areas for a new system. Additionally, the team researched both traditional and alternative systems available in the market and analyzed which systems would comply with Title 5 requirements according to each site's properties and surrounding elements such as structures, roads, and wetlands.

The State Environmental Code, Title 5: Standard Requirements For The Siting, Construction, Inspection, Upgrade And Expansion Of On-Site Sewage Treatment And Disposal Systems And For The Transport And Disposal Of Septage (Title 5, 1995) lays out the testing, necessary permits, siting requirements, and maintenance of sewage systems in Massachusetts. These were followed including the §15.203 Design Criteria of 110 GPD per bedroom, §15.211 Minimum Setback Distances of 100 feet from wetlands, and 100 feet from a private well supply.

3.3.3 Environmental Protection

Construction of most varieties requires local or state permits to ensure the construction is performed safely. The Sudbury Conservation Commission "prohibits a person from 'removing, filling, dredging, or altering the land surface, water, or vegetation… within 100 feet of wetlands or 200 feet of a perennial stream, without obtaining a permit from the local Conservation Commission". GIS was used to create boundaries around the nearby streams, wetlands, and protected areas to ensure any new construction plans would not interfere with protected areas, or protective measures could be designed appropriately.

Chapter 4 Existing Conditions & Design Solutions

This chapter section provides an analysis of the existing conditions and design recommendations for 42 Wolbach and 50 Wolbach, organized into subsections by property. Through a combination of architectural plans and renderings, we examined the current layout and condition of building elements. This analysis includes an evaluation of the physical condition of the buildings, as well as an assessment of their functionality. Calculations for the current state of the houses were completed based on information provided by the owner, observations made during site visits, as well as assumptions made based on the age of the structures. Building on this analysis, we then present our renovation recommendations for each inspected building and site component. Design solutions that address the identified issues and improve the overall performance and functionality of the buildings are presented. Some of these recommendations include modifications to the site layouts, floor plans, and thermal systems.

The architectural plans created are being provided solely for educational purposes, recommendations, and visualizations of potential renovations. They are not intended for use in construction or any other practical application. Any attempt to use this plan for legal or practical purposes without appropriate licensing, approvals, and certifications is prohibited and may result in legal consequences. However, individuals who are certified or licensed in the field of architecture or engineering may use this plan as a reference or inspiration for their own designs, provided they meet all legal and regulatory requirements for their specific jurisdiction.

4.1 42 Wolbach Road

This section presents an analysis of various building elements of 42 Wolbach Road, along with proposed solutions to the outlined issues found during the analyses. Included are several building elements that were highlighted by the owner as areas needing improvement for their respective reasons, the basement, exterior stairwell, windows, cupola, and master bedroom. For each element, the section provides an overview of the existing conditions and issues, followed by proposed solutions and renovations to address these issues. The report aims to provide a comprehensive plan for the renovation and improvement of the building, taking into consideration factors such as structural integrity, energy efficiency, and aesthetic appeal. Where applicable, each recommendation is made with the overarching goal of sustainability and energy-efficiency.

4.1.1 42 Wolbach Architectural Recommendations

Basement

Existing: The basement of 42 Wolbach suffered extensive damage as a result of groundwater passing through the foundation. The water caused severe damage to the floor joists, necessitating their removal. In order to maintain the structural integrity of the building, the homeowner had to install a jack post to support a structural beam. The current state of the basement can be seen in *Figure 4.1.*

Figure 4.1 Basement floor flood damage in 42 Wolbach

Solution: The first step in refinishing the basement is to assess the damage caused by the flooding. This includes checking for any signs of mold, mildew, or structural damage. Any damaged items such as flooring, drywall, insulation, and other materials affected by the flood should be removed and disposed of and replaced properly. In case of any structural damage, it is advisable to hire a licensed professional to examine the space and recommend structural renovations. The groundwater flooding can be mitigated by the use of a french drain, which has been initiated by the owner already, and by grading the exterior ground to slope downhill, away from the home at one inch per foot for 10 feet.

Exterior Stairwell

Existing: The current focal point of egress within the home is the foyer. It connects the original renovated barn space with the garage addition, where Dale End Dogs currently operates. In addition to this interior connection, there is a front door in the foyer facing the driveway which is adjacent to a back door. The back door is currently inoperable as it has no platform to walk outside onto, and the ground surface elevation is roughly 4 feet below that of the door. *Figures 4.2* and *4.3* depict the existing floor plan and highlights the inoperable back door.

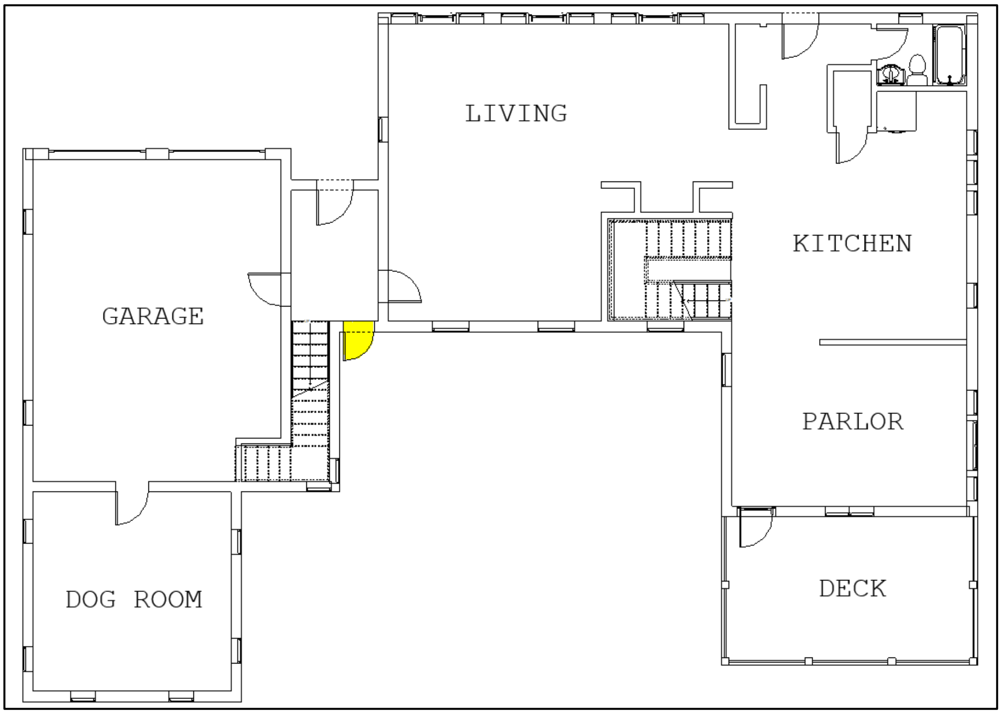


Figure 4.2 Existing first floor plan. The highlighted door is inoperable.

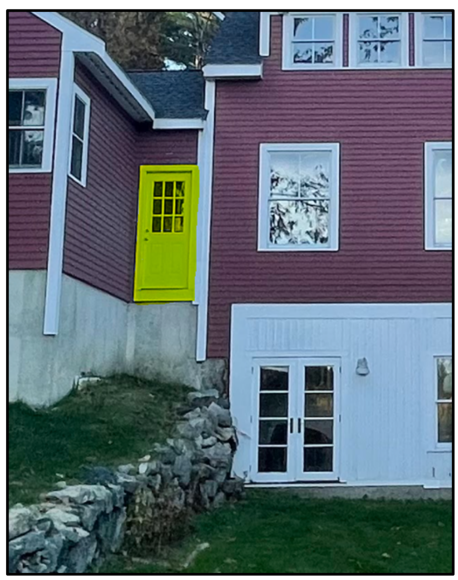


Figure 4.3 Inoperable back door

Solution: A quarter-turn stairwell descending from the back door to the exterior basement door would allow guests staying at the residence more privacy as they would not have to walk through the owner's current living space to use the interior stairwell. A new stairwell and patio addition plans are rendered in *Figure 4.4*.

Figure 4.4 Visualization of the new staircase and patio space in the backyard

4.1.2 42 Wolbach Thermal Recommendations

Windows

Existing: The current single-pane windows have not been replaced since the renovations that were completed over 25 years ago. They are outdated and drafty, allowing for a broader range of heat flux. To calculate the improvements that could be made by replacing the windows, the assumed insulation value for the existing windows was used to calculate heat loss, and then compared to the heat loss when using a high-efficiency window. All windows on the building appear similar to the window seen in *Figure 4.5*.

Figure 4.5 A deteriorated window is seen on the southern face of the basement-level facade at 42 Wolbach Road

Cupola

Existing: In the center of the roof over the renovated barn space is an uninsulated cupola covered in a sheet of plexiglass from the inside to mitigate heat loss. It is an important feature of the space as it adds a skylight-like effect that allows natural light into the second-floor hallway.

Solution: To minimize heat loss, the cupola should first be assessed for air-tightness. Through site visits, it is evident there are no large cracks or gaps in the structure, so tape and sealants may not be needed but could provide an additional air barrier to insulating the space. Spray foam insulation not only provides excellent thermal insulation, but it also acts as an effective air barrier. It can be sprayed directly onto the walls and roof of the cupola, filling any gaps and creating a seamless barrier against air leaks. A blown-in insulation such as *Greenfiber R-60 Cellulose Blown-In Insulation* or a similar alternative can easily be applied to the area in a few hours and at a relatively low cost at roughly $20 for 50 square ft of insulation. According to Oak Ridge National Lab, fiberglass loses up to 50% of its R-value in extreme cold, making cellulose-based insulation the more advantageous selection in this scenario. This would also allow for the plexiglass sheet to be removed, adding aesthetic appeal to the upstairs hallway. Since the cupola is difficult to reach, a spray foam insulation as such would allow for easier installation that other types of insulation. See an example of this blown-in insulation in the cupola in *Figure 4.6.*

Figure 4.6 Blown-in foam insulation used in a cupola (Sanders, 2017)

Master Bedroom

Existing: During site visits, the homeowner expressed concern about a large heat flux during the summer months in the master bedroom. We concluded this is due to the significant amount of south-facing glazing in the room. The southern wall faces direct sunlight for the majority of the day. However, the significant amount of natural light let into the space by this glazing is an important feature. The space does not currently have an air conditioning system.

Solution: There are several solutions for managing excessive heat gain in a room with a lot of south-facing glazing. Installing shading devices like awnings or shutters, using solar control window films, and replacing the existing glazing with high-performance windows are all effective options. The costs of these solutions can vary depending on several factors, such as the size of the window, the type of material used, and the installation method.

1. Install shading devices: The installation of shading devices, such as awnings, louvers, or

shutters, can be an effective way to reduce the amount of direct sunlight entering the room. Exterior shading devices are particularly effective as they block the sun's rays before they enter the window. A typical awning for a window can cost around $250-$750, depending on the size and the material used. Louvers or shutters can be more expensive, with costs ranging from $500 to $1,500 per window. The cost of installation may vary depending on the type of shading device selected.

2. Use solar control window films: Applying solar control window films can reduce the amount of heat gain by reflecting the sunlight back out. The cost of these films varies depending on the type and quality of the film, with a range of $7 to $15 per square foot. For a typical room with 150 square feet of glass, the cost of the film would be approximately $1,050 to $2,250. The installation cost can also vary, with an average cost of $5 to $10 per square foot.
3. Install high-performance glazing: Replacing the existing glazing with high-performance windows that are designed to block UV and infrared radiation can help reduce the amount of heat entering the room. The cost of high-performance windows depends on several factors, including the size of the window, the type of glass used, and the installation method. On average, the cost of replacing a window with high-performance glazing ranges from $500 to $1,000 per window.

4.1.3 42 Wolbach Total Energy Assessment and Recommendations

42 Wolbach currently uses an estimated 29,543 kWh of electricity per year, assuming year-round conditioning. The estimation is expected to be higher than the actual consumption as the homeowner likely mitigates energy use by turning off electronics and limiting heating and cooling

use through natural ventilation and wood stove heating, in addition to variations in estimated R-values for the given spaces. The proportion of energy use savings in renovation calculations remains applicable. Final energy estimations using the previously given recommendations were found to provide a 36% decrease in energy consumption, totaling 18,783 kWh. This decrease could become as much as 54% following the installation of a suitable GSHP.

Energy estimations for the existing conditions of 42 Wolbach as well as new recommendations and designs were calculated using Excel. Using the created Revit model for the building, the floor, ceiling, roof, foundation wall, exterior wall, window, and door areas were found which were then used to calculate respective monthly heat loss values for each element. Appliance energy use estimations were calculated using standard kWh consumption values for each given appliance in the home. The estimated heat losses were compiled to represent yearly heating and cooling energy requirements and were added to appliance electricity estimations in the total yearly kWh estimation. A summary of the calculations for 42 Wolbach and additional calculations are included in Appendix J. While improving the insulation at 42 Wolbach was not as much of a concern as 50 Wolbach, alternative thermal insulation levels were compared for this building as well. More details are found in the design solution section for 50 Wolbach. It is important to note that the estimations for the current R-values of the existing building components are conservative based on the discussions with the owner.

Month	average temp (c)	Current	Up to Code	Insulation A	Insulation B	Fenestrations	Recommendations
		Monthly, assuming 24/7 conditioning		kWh/year			
January	-4.0	5,087	4,322	4,717	4,798	3,594	3,234
February	-2.5	4,793	4,072	4,445	4,522	3,386	3,048
March	2.0	3,913	3,324	3,629	3,691	2,764	2,488
April	8.5	2,641	2,244	2,449	2,491	1,866	1,679
May	15.0	1,370	1,164	1,270	1,292	967	871
June	19.5	489	416	454	461	346	311
July	22.5	98	83	91	92	69	62
August	21.5	98	83	91	92	69	62
September	17.0	978	831	907	923	691	622
October	10.0	2,348	1,995	2,177	2,215	1,659	1,493
November	5.0	3,326	2,826	3,084	3,137	2,350	2,115
December	-0.5	4,402	3,740	4,082	4,152	3,110	2,799
Total Electric Use		29,543	20,027	27,396	27,868	20,870	**18,783**

Table 4.1 42 Wolbach: Total Energy Estimations

4.1.4 42 Wolbach HVAC System Recommendations

Existing: The current HVAC system in the home is comprised of a boiler in the basement that provides hot water throughout the home. The boiler is a natural gas-fueled unit that heats water, which is then circulated through the radiators via a series of pipes. The system is designed to provide heating during the winter months. The ventilation is natural and there is no central air cooling.

The HVAC system is powered by electricity, which is supplied by Eversource, a utility company that provides power to the Sudbury, MA area. The electrical panel is located in the basement, and it is connected to the various components of the HVAC system, as well as other electrical systems throughout the home. Electricity prices in Massachusetts have seen an 8.5% increase in the last month alone, giving the state the third most expensive electricity rate in the country *(Electricity Costs, 2023).* While the demand for electricity rises, homeowners should consider alternate heating systems prior to future increases in electric costs.

Solution: While there are no major issues with the HVAC system, improvements could be made to minimize cost and increase efficiency in the system. In this instance, a ground source heat pump would provide a multitude of advantages. The energy savings calculation for a ground source heat pump (GSHP) system is based on the efficiency of the system compared to a traditional oil boiler HVAC system. A GSHP system uses the constant temperature of the earth to extract and dissipate heat, making it more energy-efficient and sustainable. This is achieved through a closed-loop system of pipes that are buried underground, and a heat pump unit that extracts and dissipates heat between the ground and the home.

In the traditional boiler HVAC system, energy is used to burn oil and create heat, which is then distributed through a network of ducts and vents to different rooms in the house. This process is not very efficient, as energy is lost through the ducts and vents, and oil prices can be volatile, making it difficult to budget for heating expenses.

In contrast, a GSHP system is much more efficient, as it uses electricity to power the heat pump unit, which moves heat from the ground to the house. This process is much more energy-efficient, as it requires less energy to move heat than to create it. Additionally, the heat pump can be reversed in the summer to provide cooling, further reducing energy consumption and expenses.

To calculate the energy savings of a GSHP system compared to a traditional oil boiler HVAC system, we use a coefficient of performance (COP). The COP is a ratio of the amount of heat energy delivered by the GSHP system compared to the amount of electrical energy consumed by the system. For example, if a GSHP system has a COP of 4, it means that for every unit of electrical energy consumed by the system, it can deliver four units of heat energy.

Using the COP, we can calculate the total energy required by the GSHP system to deliver the same amount of heat energy as the traditional oil boiler HVAC system. In this case, assuming a COP of 4 for the GSHP system, we divide the total energy used by the traditional oil boiler HVAC system (29543 kWh) by the COP (4) to get the total energy required by the GSHP system

(7385.75 kWh).

Therefore, the estimated energy savings of a GSHP system compared to a traditional oil boiler HVAC system for a home using 29543 kWh of electricity per year would be 22157.25 kWh per year.

The cost calculation for a ground source heat pump (GSHP) system includes both the cost of the system itself and the installation cost. The cost of a GSHP system can vary depending on several factors, such as the size of the home, the type of GSHP system, and installation costs. Here's an estimate of the cost for a 3-ton GSHP system in Massachusetts, including installation costs:

Cost of the GSHP system: $12,000 - $20,000

Installation cost: $15,000 - $20,000

Therefore, the estimated total cost for a GSHP system would be between $27,000 and $40,000.

It's important to note that the initial cost of a GSHP system may be higher than a traditional boiler HVAC system, but it is important to consider the long-term energy savings and environmental benefits of a GSHP system.

To estimate the payback period for a GSHP system, we need to calculate the energy savings of the system and compare them to the additional cost of installation. Using the estimated energy savings of 22157.25 kWh per year and an estimated energy cost of $0.22 per kWh in Massachusetts, we can calculate the annual energy cost savings of a GSHP system compared to a traditional oil boiler HVAC system:

Annual energy cost savings = 22157.25 kWh * $0.22/kWh = $4,874.99

Assuming an installation cost of $30,000 and annual energy cost savings of $4,874.99, we can estimate the payback period for the GSHP system:

Payback period = $30,000 / $4,874.99 per year = 6.14 years

This means that it would take approximately 6.14 years for the energy cost savings to offset the additional cost of installing a GSHP system compared to a traditional oil boiler HVAC system. After the payback period, the homeowner would continue to save money on their energy costs, making a GSHP system a sound long-term investment.

It's worth noting that there may be government incentives and tax credits available that can help reduce the cost of installation and further reduce the payback period. Additionally, a GSHP system can increase the resale value of a home and provide additional benefits such as improved indoor air quality and comfort.

42 Wolbach Road Site Design

The following sections will go over the calculations and considerations when designing the site for 42 Wolbach Road, including the solar panel selection and placement, environmental considerations, and wastewater system design.

Solar Panels

The estimated roof space available and appropriate for PV array usage at 42 Wolbach Road is approximately 296 square feet. The minimal southern-facing roof space constrains PV arrays to be installed on the ground on this property. Based upon the calculated energy requirements (Appendix J) from all recommended renovations, the estimated number of panels were found in Table 4.1 below.

						42 Wolbach		
						Est. kWh/year	10812	
Panel Type	Efficiency	Size (ft^2)	Wattage	Solar Panel Output (kWh) / Day	Yearly Output per panel (kWh)	Number of Panels	Square footage of Panels	Estimated Tree Removal
BenQ Solar (AUO)	0.16	17.63	255.00	1.18	429.08	26	458.41	0.86
Amerisolar	0.15	20.89	325.00	1.50	546.86	20	417.78	0.65
Canadian Solar	0.22	27.81	570.00	2.63	959.11	12	333.72	0.20

Table 4.1 42 Wolbach Solar Panel Calculations

The most energy-efficient PV array, provided by Canadian Solar with the dimensions of 89.69" x 44.65", efficiency of 0.22, and wattage of 570W, was found to require 12 solar panels using roughly 333.72 square ft of ground area. This slope faces the south and would not be shaded by any trees following tree removal.

Environmental Analysis of Site

42 Wolbach Road is located north of a wetlands area that is overseen by the Sudbury Valley Trustees. Located downhill from the 42 Wolbach house, the wetlands are an environmentally protected area that is used as a flight zone for migrating wildfowl. The existing site plan shows the septic system located under the driveway area, to the front of the house. The North-East slope alongside the house features a densely wooded area (Appendix G). Use of the GIS Mapping software showed that the property of 42 Wolbach fell mainly into Type 104C soil classification or Hollis-Rock outcrop-Charlton complex with a slope up to 15% (Appendix D). *Figure 4.7* presents 42 Wolbach Road's existing site plan, including well placement, septic system, wetland locations, structure locations, roads, elevation levels, and parcel lines.

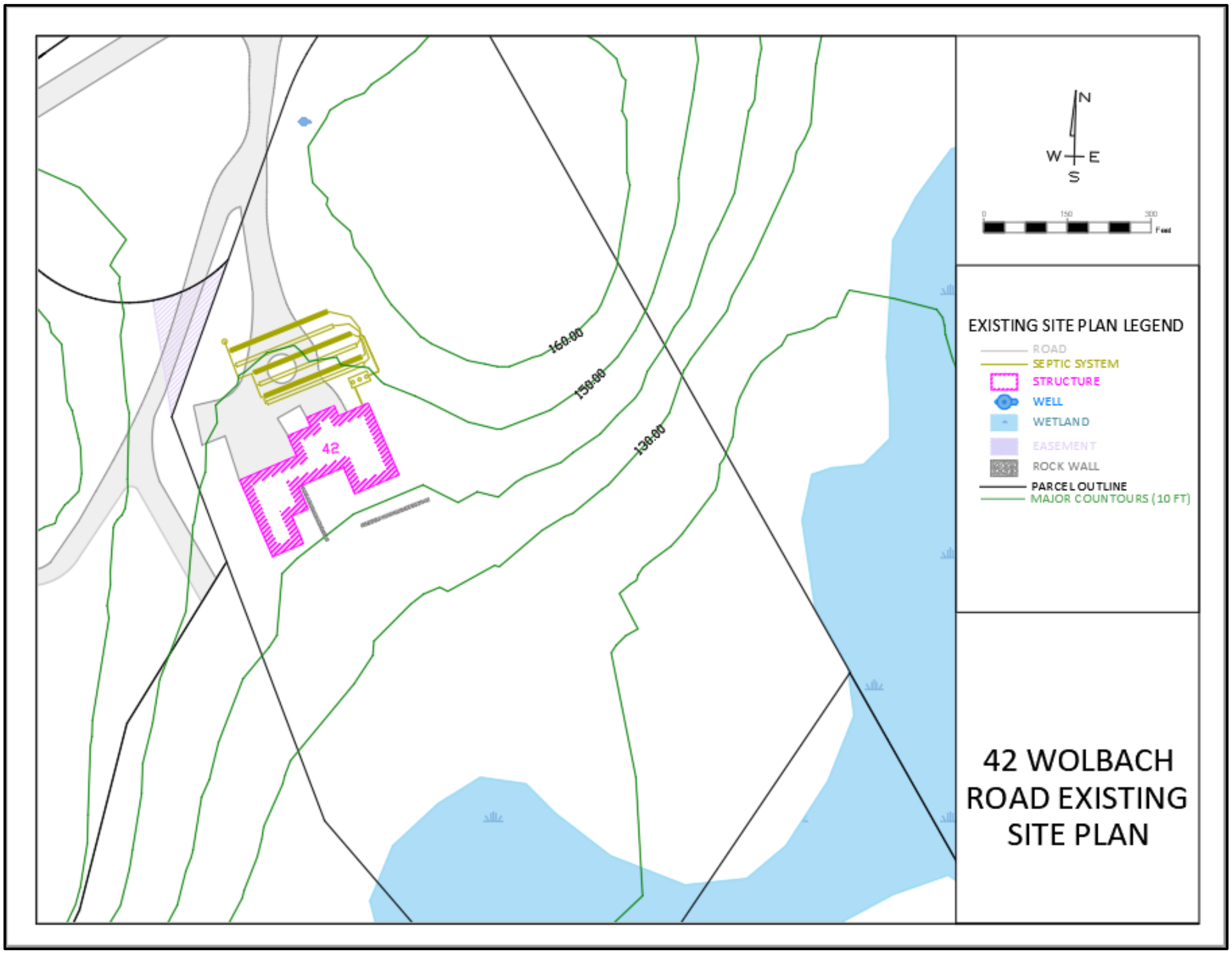


Figure 4.7 42 Wolbach Road Existing Site Plan

Regarding coliform testing, 42 Wolbach presented some positive results as seen in Appendix H, however this was a presumptive test and therefore not a confirmation of coliform presence. A presumptive test has a much higher sensitivity to a substance's presence when compared to a confirmation test. The results obtained are suspected to have inaccuracies, as positives were observed in higher dilutions, while undiluted samples showed no positives. Coliform presence is more easily detected in higher dilutions, and therefore the positive results may be attributed to contamination within the dilution bottles.

Regardless of possible errors in this presumptive test, the team highly recommends testing of coliforms and other parameters outlined by the MassDEP to ensure a safe source of potable water and perform necessary treatment (if any) as soon as possible.

Septic placement & Title 5

The existing septic system and placement were analyzed by the team through the Town of Sudbury Board of Health's well permit approval from 1996, along with the sewage disposal plan prepared by Stanki & McNary, Inc. from the same year (Appendix A). This complies with Title 5 requirements and standards, such as the minimum distance between system and well, a traditional 1500-gallon septic tank, and a leaching system consisting of three trenches and a reserved leaching area.

Proposed Final Full Site Layout

Figure 4.8 presents the proposed site layout for 42 Wolbach Road. With the above site renovations in mind, the final design of the site layout concerns the placement of the solar panels. The solar panels will be located on the east slope next to the house, necessitating the removal of some trees to be placed. The current septic system and leaching field currently meet Title 5 standards and do not need to be updated. Similarly, there are no issues with the existing well, so the current well will not be changed. Additionally, due to a flooding issue located on the basement level of the house, a french drain is proposed to direct water both away from the house to mitigate the issue before the flooding occurs, as well as having a drain leading from the interior of the house to the exterior. The house's main structure will not feature an extreme exterior renovation beyond the inclusion of an exterior stair.

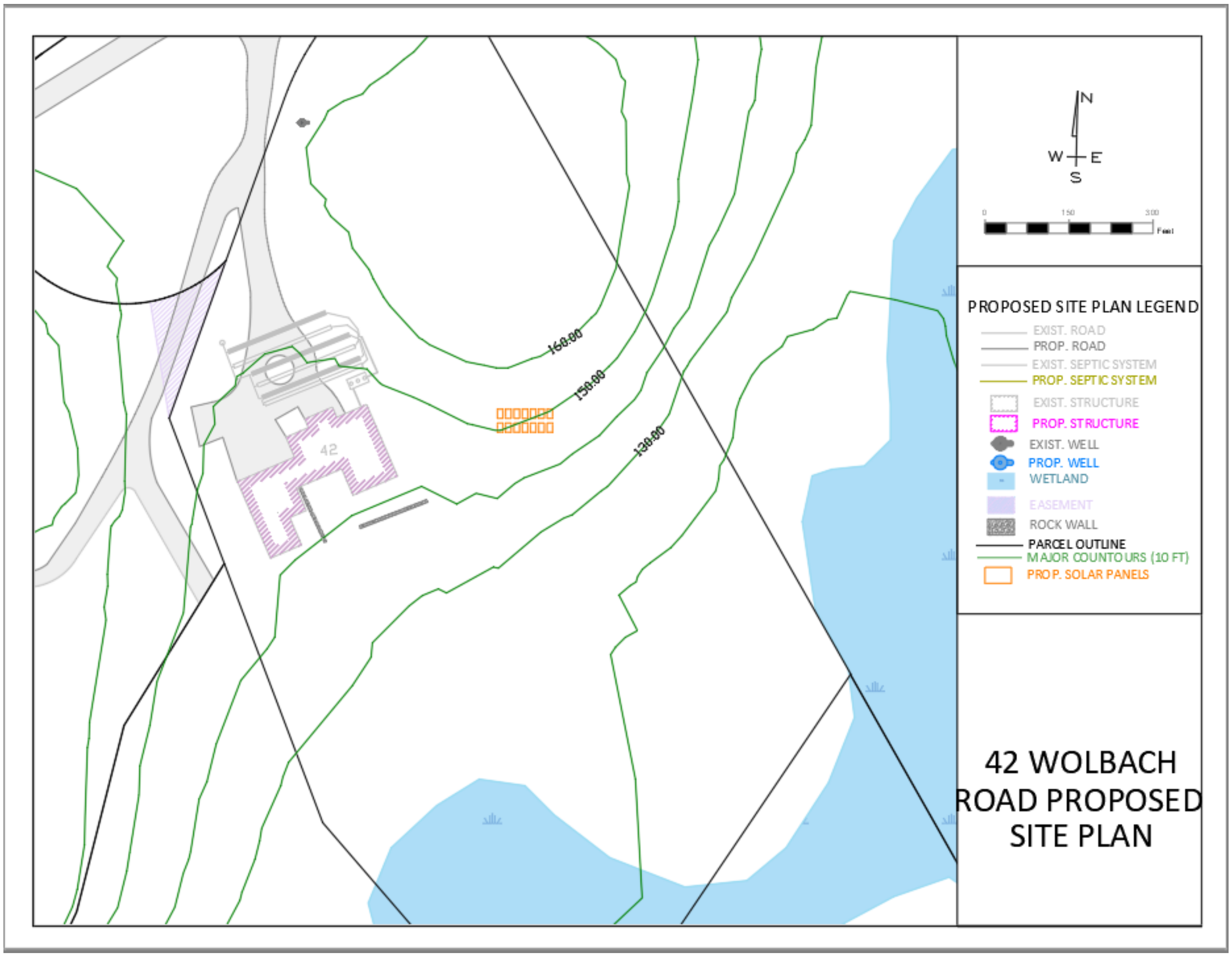


Figure 4.8 42 Wolbach Road Proposed Site Plan

4.2 50 Wolbach Road

This section includes analyses of the current condition of the property, as well as suggestions for future changes. The owner expressed interest in making changes to the current design of this house, enclosing the current porch to provide more indoor livable space, replacing the current bathroom situation with a full bath, and adding an additional livable space above the garage to convert the current bonus room into a master suite.

4.2.1 50 First Floor Redesign

Existing: 50 Wolbach Road currently has three bedrooms and a full bathroom on the upper floor. On the ground floor is the galley-style kitchen with the refrigerator located down several steps towards the laundry room, open concept living and dining space, and an additional room currently used as a second living room. The ground floor restroom is very small, containing just a toilet, and is located off of the kitchen.

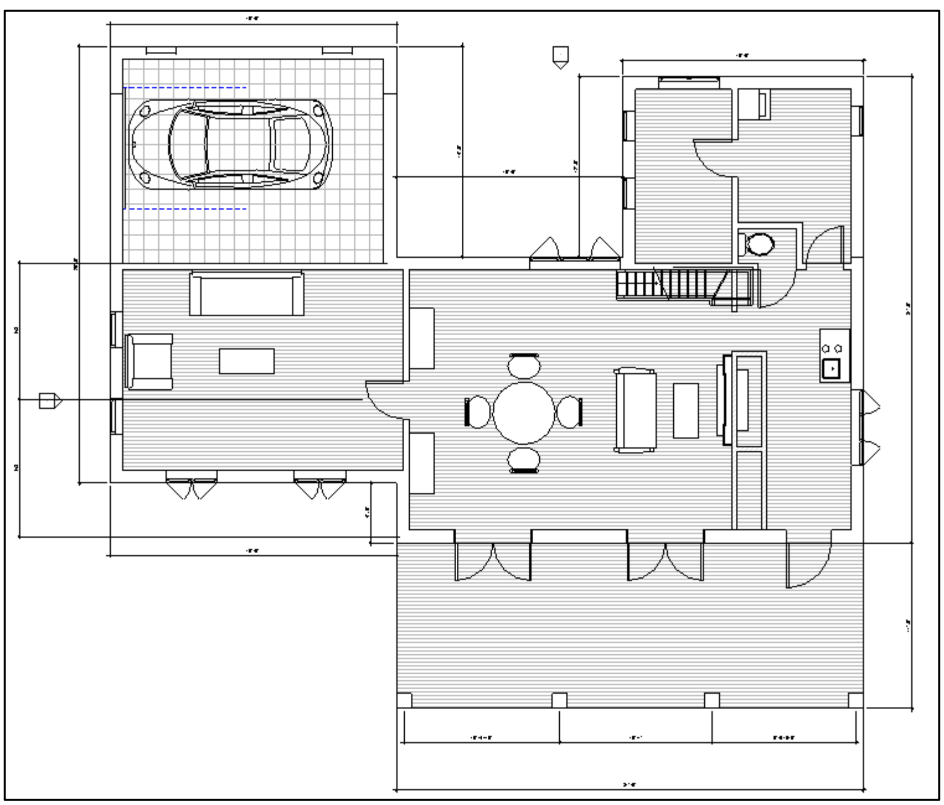


Figure 4.9 Existing 50 Wolbach Road Floor Plan

Solutions:

Enclosing current porch

Enclosing the porch would provide the home with more space on the first floor, allowing for an open floor plan living room, dining room, and kitchen, and could help with energy consumption by not having open air underneath a conditioned space, the upstairs bedrooms.

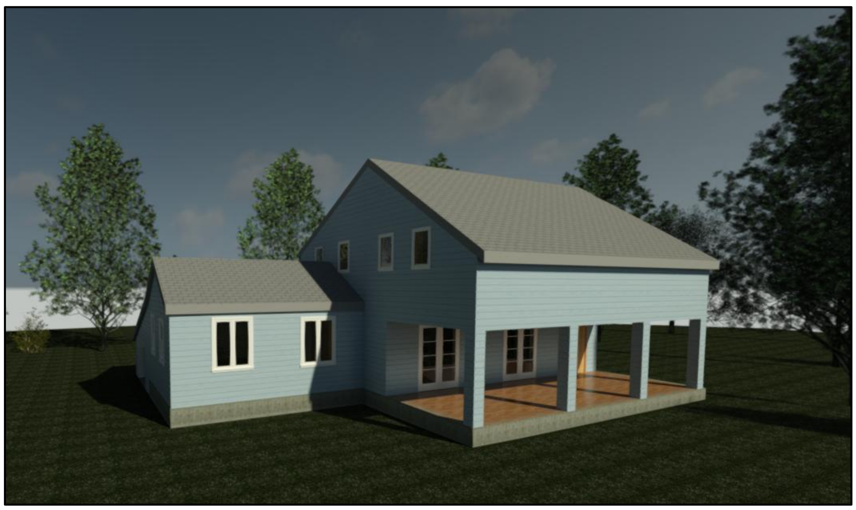


Figure 4.10 Existing 50 Wolbach Road Revit Model

Figure 4.11 Proposed 50 Wolbach Road Revit Model

Kitchen Remodel

The current kitchen does not meet Mr. Newton's needs, as it is long and narrow and lacks adequate space. Opening the floor plan would allow the fridge to be moved into a more accessible area, increase countertop space, and let more natural light throughout the area.

Master Bedroom Suite

To create a master bedroom space, the current additional room on the west side of the house would be converted. The existing room is significantly large enough to create a master bedroom suite, but a bathroom would need to be added to the downstairs and may not be entirely exclusive to the master bedroom.

Additional Bathroom

In the northeast corner of the living room, a bathroom would be added to provide a full bathroom on the first floor. Two doors would provide access to the bathroom from both the bedroom and the living room.

Stair Renovation

The existing stairs do not meet current code requirements, and though they may be grandfathered in, replacing them creates a safer and more enjoyable space. By utilizing the current footprint of the stairs as well as the area above the current laundry room area, a set of switchback stairs can be added, providing a wider and more easily maneuverable stairway.

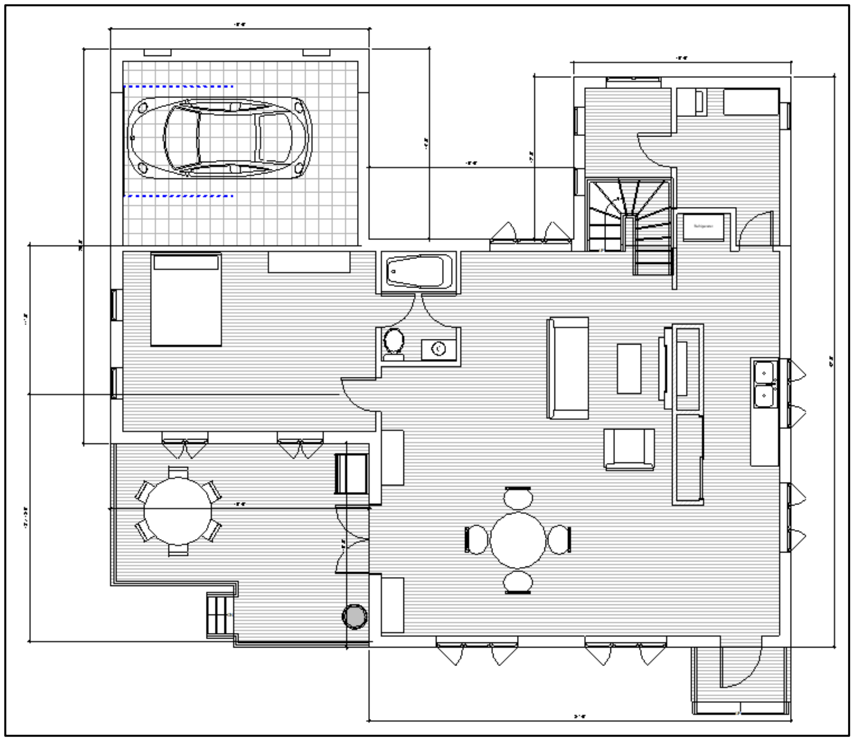


Figure 4.12 Proposed 50 Wolbach Road Ground Floor Plan

Above-Garage Bedroom

Upon reviewing the current space, it was decided that the renovations required to construct an additional room on top of the garage would be too extensive, and would not create a greatly beneficial layout due to the current multi-level layout of the home. A room above the garage would not be on the same level as the ground floor or the upstairs and would require stairs for access, a new roof on that section of the house, and new insulation in the walls because the garage is not currently a conditioned space, and an assessment of the structural integrity of the garage attic to determine if it would be fit for human occupation.

4.2.2 Insulation

Existing: Exact values for the insulation of the house are not known, assumptions were made based on information from the owner, observations made from site visits, and using historical data and referencing code based on the age of the house.

Solutions: Two options were considered to improve the insulation of the house. Insulation type A is blown-in insulation, and US Greenfiber Sanctuary was used as a reference for the R-value of possible new insulation. This method adds R 3.7 per inch of insulation in addition to the existing structure of the wall. For the home on 50 Wolbach, filling 3 inches of cavity space brings the total R-Value from 15.15 to 26.25. Calculations shown in Appendix J. Insulation type B is continuous board insulation, added to the exterior of the home, which would require re-siding the house and any insulation added would increase the total thickness of the wall. Using PolyShield Expanded Polystyrene Board Type I as a reference for R-value, this method adds R 4.35 per inch addition to the existing structure of the wall. Adding 1 inch of this type of insulation brings the total from 15.15 to 23.85. Calculations are shown in Appendix J.

4.2.3 Window Upgrades

Existing: To calculate the current heat loss through the windows, assumptions were made based on observations from site visits. The windows appeared to be older style, single pane glass windows.

Solution: When calculating for "fenestrations," a window with a U-Value of 0.2 Btu/(h·ft2·°F) was used. To create recommendations, the data for the Pella 150 series was used, with a U-Value of 0.3 Btu/(h·ft2·°F). While not as efficient as the other window calculated, it is more common, more accessible, and more cost-effective and therefore this window or something similar is recommended for the renovations. Calculations shown in Appendix J.

4.2.4 HVAC

Existing: The current HVAC system for the home is hot water radiant heating, fueled by oil, similar to the one in use at 42 Wolbach (Sudbury, MA, 2022). There is not a central air conditioning unit, therefore it is assumed that any cooling is provided by in-window or stand-alone units.

Solutions: Post renovations, the recommended heating system is an electric powered heating system. Though this would require investing in the unit up front, the heating would then be powered by the solar panels and would not require further electric, oil, or gas costs. An electrically powered central air conditioning system could be installed as well, however if the current in-window units are providing sufficient cooling to the home, the solar system would be able to power that as well without the need to invest in a new system.

4.2.5 Total Energy Calculations

Energy estimations for the current state of 50 Wolbach as well as recommendations and design changes were calculated using Excel. Below is a compiled summary of those calculations for 50 Wolbach, showing the energy use by month for the current state of the house, four possible design suggestions, and the recommendations for changes by our team. By adding blown-in insulation to the current walls, increasing the roof insulation, and updating doors and windows to a more energy-efficient version, the total electric use could be brought down from the current estimation of 20,335 kWh/year to an estimated 17,382 kWh/year. Additional calculations are included in appendix J.

		Monthly, assuming 24/7 conditioning		kWh/year			
Month	average temp (c)	Current	Up to Code	Insulation A	Insulation B	Fenestrations	**Recommendations**
January	-4.0	3,501	2,669	2,911	2,992	2,950	2,214
February	-2.5	3,299	2,515	2,743	2,819	2,780	2,086
March	2.0	2,693	2,053	2,239	2,301	2,269	1,703
April	8.5	1,818	1,386	1,511	1,553	1,532	1,150
May	15.0	943	719	784	805	794	596
June	19.5	337	257	280	288	284	213
July	22.5	67	51	56	58	57	43
August	21.5	67	51	56	58	57	43
September	17.0	673	513	560	575	567	426
October	10.0	1,616	1,232	1,343	1,381	1,362	1,022
November	5.0	2,289	1,745	1,903	1,956	1,929	1,448
December	-0.5	3,030	2,310	2,519	2,589	2,553	1,916
Total Electric Use		20,335	20,027	21,428	21,899	21,656	**17,382**
# of Solar Panels	Amerisolar	46	37	40	41	40	32
Square Footage	20.89 ft^2/panel	960.89	772.89	835.56	856.45	835.56	668.45

Table 4.2 50 Wolbach Road Monthly Energy Use by Design Suggestion

50 Wolbach Road Site Design

The following sections will go over the calculations and considerations when designing the site for 50 Wolbach Road, including the solar panel selection and placement, environmental considerations, and wastewater system design.

Solar Panels

With the estimated energy usage following the implementation of all recommended renovations calculated as 16,720 kWh/year (Appendix J) for 50 Wolbach road, the needed number of solar panels, and space required for the solar array were found in *Table 4.2* below.

						Recommendations	
						Estimated kWh/year	16720
Panel Type	Efficiency	Size (ft^2)	Wattage	Solar Panel Output (kWh) / Day	Yearly Output per panel (kWh)	Number of Panels	Square footage
BenQ Solar (AUO)	0.16	17.6	255.0	1.1	429.1	39	687.6
Amerisolar	0.15	20.8	325.0	1.5	546.9	31	647.5
Canadian Solar	0.22	27.8	570.0	2.6	959.1	18	500.6

Table 4.3 50 Wolbach Road Solar Panel Calculation

The number of solar panels required for the house to function entirely on solar energy would need approximately 500 to 690 square feet of space. Using the calculated available and appropriate roof space at 50 Wolbach as 823.78 sq ft, this shows that 50 Wolbach is able to entirely support solar utilizing roof space only, meaning there is no need for the removal of trees at this location.

Environmental Analysis

50 Wolbach is located in an area with hydrological group D soil, which consists mainly of

clay and has a poor percolation rate. The soil itself is made up of Rock outcrop-Hollis complex, (Appendix D). The property has a slope Categorization of E or above a 25% slope. There are no large water sources located on or nearby the property borders. The property is surrounded by woods on all sides by a wooded area (Appendix G). The current septic tank is located 15 feet north of the existing structure. Figure 4.13 presents 50 Wolbach Road's existing site layout.

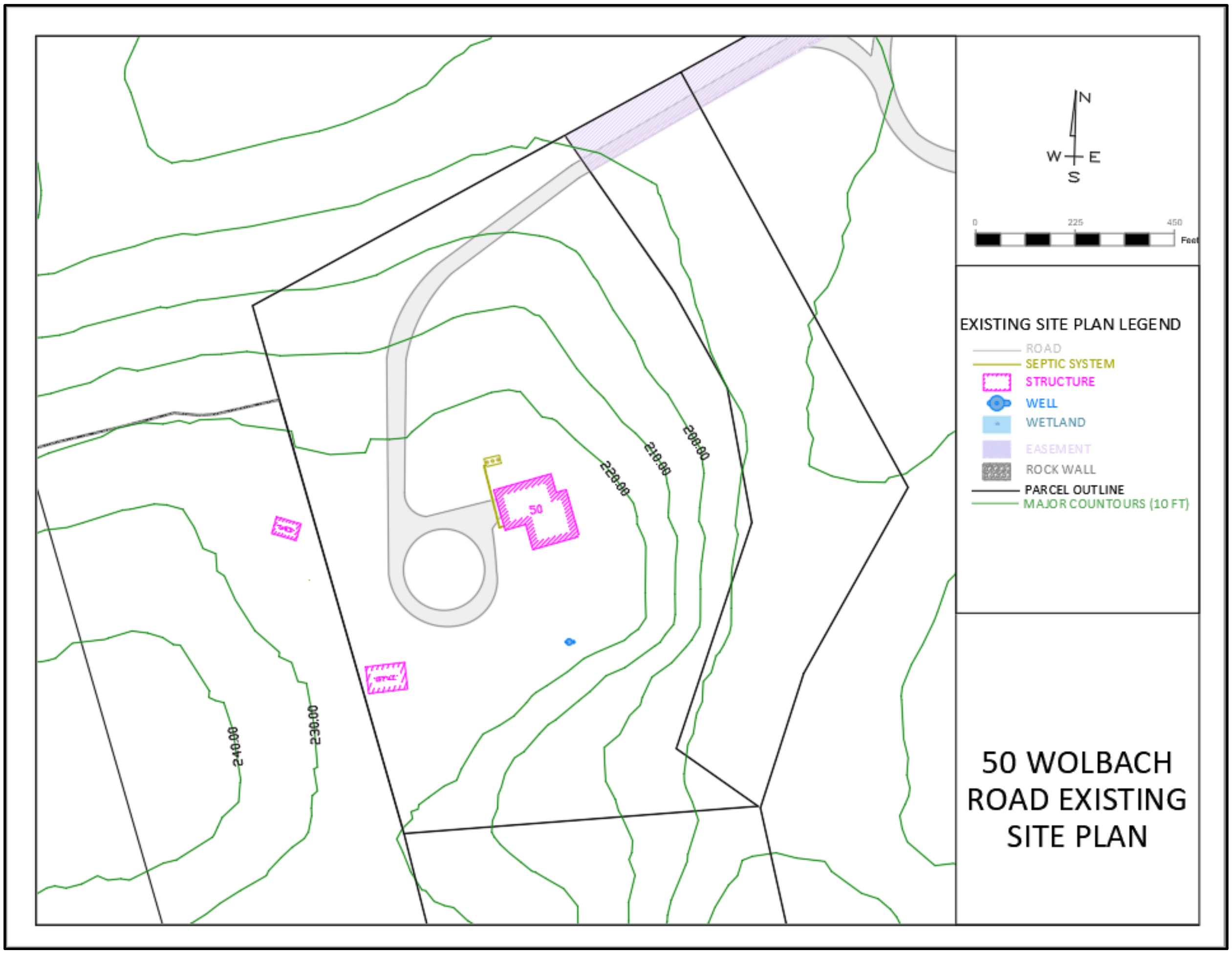


Figure 4.13 50 Wolbach Road Existing Site Plan

Regarding coliform testing, 50 Wolbach had no positive indicators of coliform presence after the 48-hour incubation test, as seen in Appendix H. However, testing of coliforms and other parameters as outlined by the MassDEP should be conducted to remain in compliance with state regulations, and to ensure safe standards of water consumption.

Septic Placement & Title 5

The development of the following solutions for 50 Wolbach includes a breakdown of options according to future testing, as well as suggested systems that are in compliance with Title 5. Title 5 provides a flow rate of 110 GPD per bedroom in a single-family dwelling unit, which results in a calculated flow rate of 440 GPD for this property. Due to unavailable soil log data, the team has prepared a set of solutions based on possible hydrogeologic properties provided by a Soil Evaluator's future examination, as outlined in 310 CMR §15.101. These possibilities were determined under the assumption that the site's soil is a Soil Class IV with an unknown percolation rate. Therefore, the suggestions based on percolation rates are as follows:

Percolation rate faster or equal to 60 min/inch

If soil testing data finds that the soil has a percolation rate of 60 min/inch or faster, this means that the site is in compliance with the SAS Siting requirements outlined in §15.245(1) of Title 5. In this case, a percolation rate of 60 min/inch on Class IV soil results in an effluent loading rate of 0.15 gpd/ft^2 according to §15.241(1)(a). Given the calculated flow rate of 440 GPD, the calculated trench area is 2933 ft^2.

While a traditional septic system would be considered functional, we highly recommend adopting one of the alternative systems we have suggested in the sections outlined below. The use of alternative systems can provide better treatment results, which will prevent the clogging of distribution systems in soil with poor percolation rates. However, maintenance of alternative systems is crucial to prevent the failing of these. Therefore, a traditional septic system with a mound system would be the best option if maintenance and operation is not feasible for the homeowner.

Percolation rate faster than 60 min/inch and slower than 90 min/inch

Under this condition, a complete construction infill can be avoided if this is treated as an upgrade to the existing system and not a placement of a new system. §15.245(4) allows for approval of a SAS under this condition, with designs being based on a maximum effluent rate of 0.15 gpd/ft^2. Since this is the same effluent loading rate as the previous case, the same design layout can be used.

To be able to implement an alternative septic system, approval for alternative system installation can be requested under remedial use under §15.284. This is granted if the existing system has failed, is failing, or is a nonconforming system.

Percolation rate slower than 90 min/inch

This percolation rate requires construction infill, as this will replace the unsuitable soil with soil that has a better percolation rate. Following §15.255(5), the excavation of the unsuitable soil will have an added five feet around the entire perimeter of the planned Soil Absorption System (SAS). The fill material shall consist of clean granular sand, without any material that exceeds two inches in diameter.

Through the research we conducted on both traditional and alternative systems, we've compiled a list of systems we do and do not recommend. Systems that we do not recommend were categorized as such due to incompatibility with the site, high installation costs, and/or extensive maintenance required. A summary of these systems is provided in Appendix F, which include the Cultec, Bioclere, jet aerobic and infiltrator systems.

While a traditional septic system would work in all previous scenarios by itself, our team is recommending the Singulair or Microfast system be used in conjunction with it, as well as a mound distribution system to improve the percolation rate.

Singulair System

The Singulair system is designed by Norweco through extended aeration and a tank in the series method. This system can be broken down into three main components: the pretreatment chamber, aeration chamber(s), and clarification system, as seen in *Figure 4.14.*

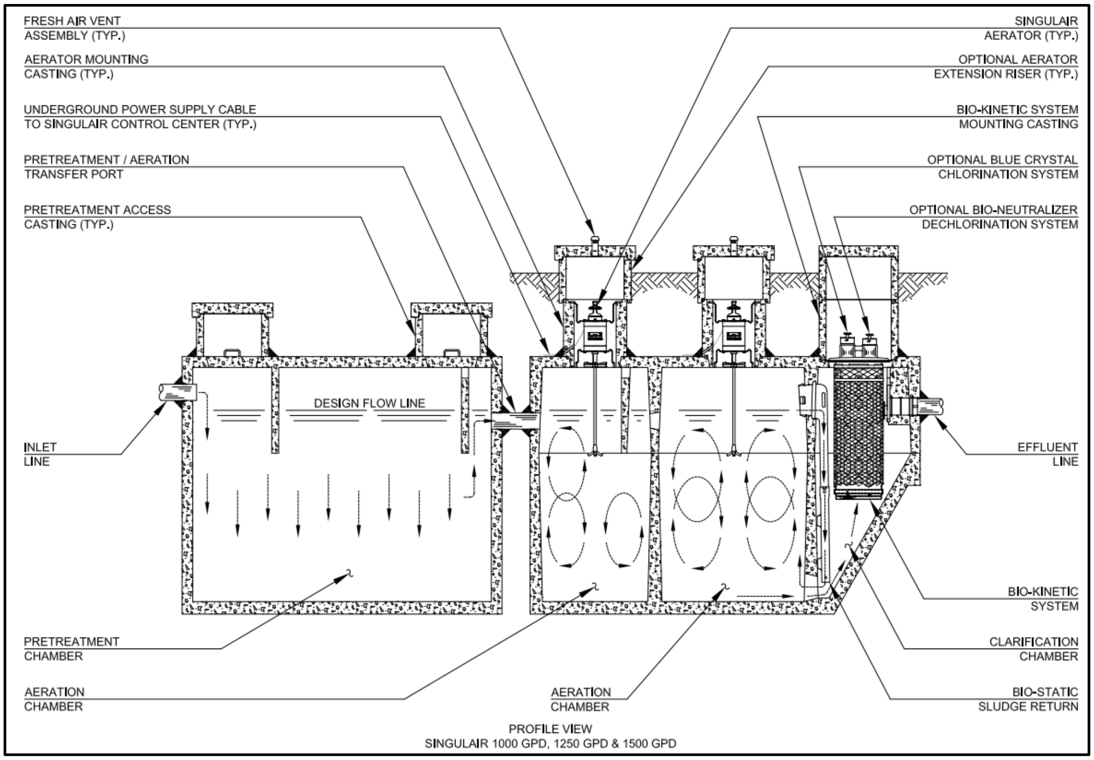


Figure 4.14 Profile view of a Norweco Singulair Treatment System for flows of 1000 GPD, 1250 GPD and 1500 GPD (Norweco, n.d.)

The pretreatment chamber serves the same function as a traditional primary settling tank, while the aeration chambers allow aerobic bacteria to convert waste into stable substances by using the organic matter in its environment. Both the aerated wastewater and newly formed sludge flow into the clarification chamber, where solids can settle and be returned to the aeration chamber (Norweco, n.d.). The final treatment in the clarification chamber filters, settles, and equalizes the flow of the final effluent. The Singulair 960 model has a cost of approximately $6,750, which does not include any installation and/or transportation fees (Cardinal, n.d.). Potential buyers should solicit a quote from providers to determine installation, inspection, and pumping costs.

This system's advantages are that the unit bought is complete, and therefore there is no need to outsource a settling tank. Additionally, all Norweco Singulair Systems include a two-year warranty period, during which distributors will provide service and maintenance twice a year for free (Commonwealth of Pennsylvania, 2015). After this warranty period, Norweco recommends an inspection of the pretreatment chamber every three years. Pumping is not required as often as in a traditional septic tank, since normal use will only require pumping of the pretreatment chamber every three to five years (Norweco, n.d.).

While we considered these to be major advantages, there are still disadvantages to be considered. As with other energy-dependent systems, if a power outage occurs further precautions shall be taken regarding water usage as to avoid backflow or improper treatment. If the user opts for the optional disinfecting and dechlorination tablets, these are an additional monetary investment not included in regular maintenance costs.

<u>MicroFast System</u>

The MicroFast system consists of a primary settling zone and a treatment zone, as outlined in *Figure 4.15* Within the treatment zone, the blower uses air to force water to move up through the media inside the tank. When this combination of air and liquid is cycled through, bacteria on the media feed on the waste. This process will result in a thick growth on the media surface, which will fall off and sink to the bottom of the tank (MASSTC, 2004). The now-treated water will be discharged to the leaching system. Accumulation of this waste results in a projected tank pumping once every 12 months.

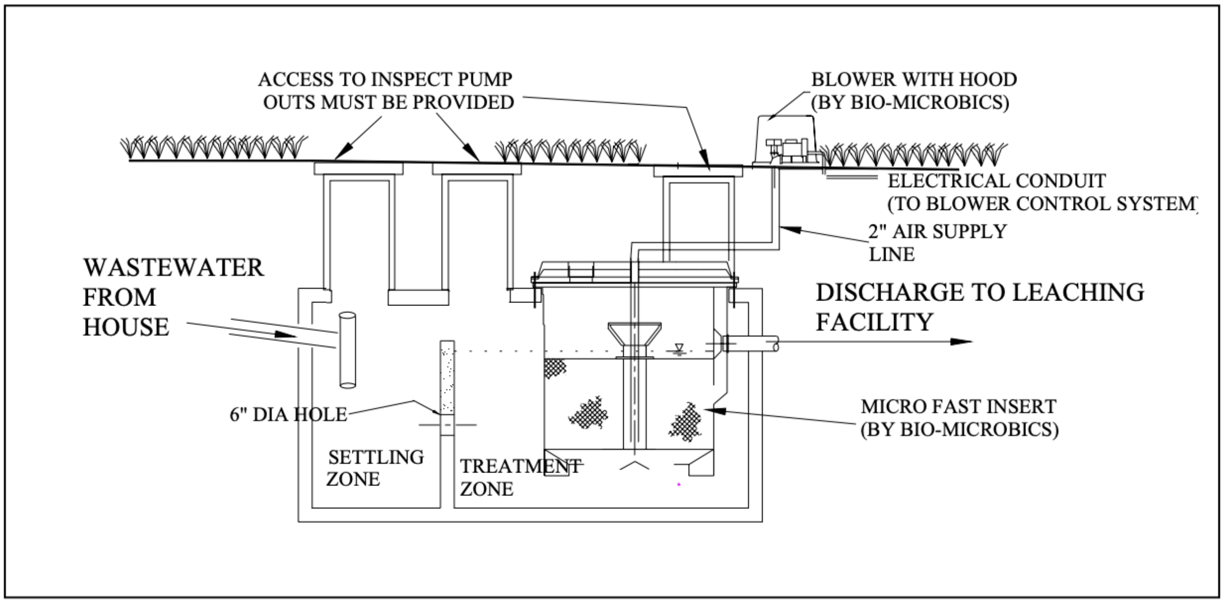


Figure 4.15 Profile view of a MicroFAST system (MASSTC, 2004)

The main advantages of this system consist of the ease of access for maintenance and its initial cost. It is estimated that the system's total cost for components and installation is $3,500. However, possible quarterly effluent monitoring and other maintenance costs can result in an additional $400 per year (MASSTC, 2004). Additionally, the blower feature means electricity use as well as an increase in noise levels.

<u>Mound System</u>

This system uses pressure-dosed sand filters placed above the soil surface that discharges effluent through the elevated mound directly into the natural soil beneath (U.S. EPA, 1999). The main components in this system include a pretreatment unit, such as a septic tank, a dosing chamber, and an elevated mound, as seen in *Figure 4.16*.

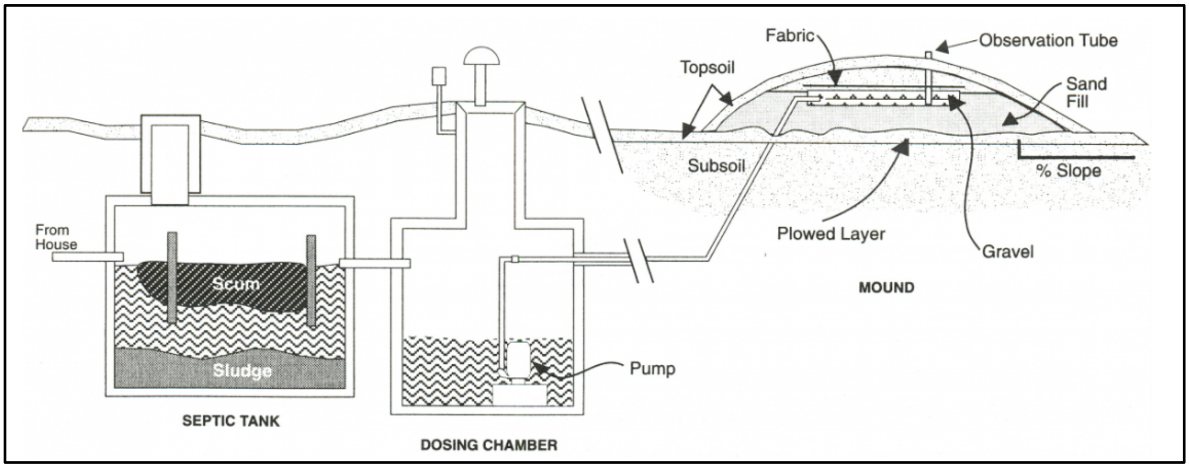


Figure 4.16 Schematic showing the components of a mound system (Mancl et al., 2019)

The effluent from the dosing chamber gets pumped into the mounds through distribution laterals, which slowly distribute the effluent under low pressure (Humboldt County, n.d.). These laterals are surrounded by gravel, as well as a fabric top layer to separate the topsoil from the gravel and sand fill (Tacoma-Pierce County Health Department, n.d.). Finally, one of the main components of these mounds is the sand fill, which further filters the effluent before reaching the subsoil. The depth and fill material will vary on the distribution specifications of the site, such as the water table depth and bedrock classification (U.S. EPA, 1999).

Both the septic tank and dosing chamber should be inspected once a year, as well as pumped and/or repaired according to the inspector's recommendations (U.S. EPA, 1999). Additionally, further precaution is needed when a power outage lasting more than 6 hours occurs. Without the pump working, water will continue to collect, which can cause the pump to dose more effluent than the mound is designed for (Humboldt County, n.d.). As for the mound, the user must be aware of the system placement, to avoid excessive pressures from traffic that can result in damage to the system. It is generally good practice to keep the mound covered in the grass since impermeable materials can reduce evaporation needed for the treatment (Humboldt County, n.d.).

Mounds offer the advantage of converting an unsuitable site under other systems' requirements and help overcome restrictions such as a high water table or soil with an undesirable permeability speed (U.S. EPA, 1999). While excavation depth in the mound area is minimum, the space required can be substantial, which may limit land use and appear unsightly. As with most systems, maintenance is crucial to avoid system failure and an added cost to a high-cost system.

According to the EPA's Mound Systems Fact Sheet, the estimated total cost for a single home unit in 1997 would be $9,750 with an annual $95 fee for operation and maintenance. Accounting for inflation, these values would translate to around $18,100 and $175 respectively. Modern sources show a total cost range between $10,500 and $21,000, and an annual operations and maintenance cost of around $550 (Pow, 2022).

<u>Absorption Trenches</u>

Regardless of the two previously mentioned treatment systems, we are recommending the use of absorption trenches for the effluent distribution method. These trenches will distribute effluent throughout a gravel bed to treat and infiltrate. The trenches are constructed with 4' diameter PVC sewer pipes, with infiltration holes throughout. The gravel surrounding the trenches is covered using geotextile fabric to avoid topsoil infiltrating the gravel layer (National Small Flows Clearinghouse, n.d.).

This distribution system is common and therefore has accessible maintenance when needed. Upfront costs range between $5,000 and $8,000, which includes installation costs if no other problems occur (National Small Flows Clearinghouse, n.d.). Ledge or bedrock found underground would need to be blasted and removed, increasing the cost. This system is recommended due to its compatibility with sloped land and low maintenance requirements, which consist of pumping every 4 to 5 years. *Figure 4.17* presents 50 Wolbach Road's proposed layout.

Proposed 50 Wolbach Road Layout

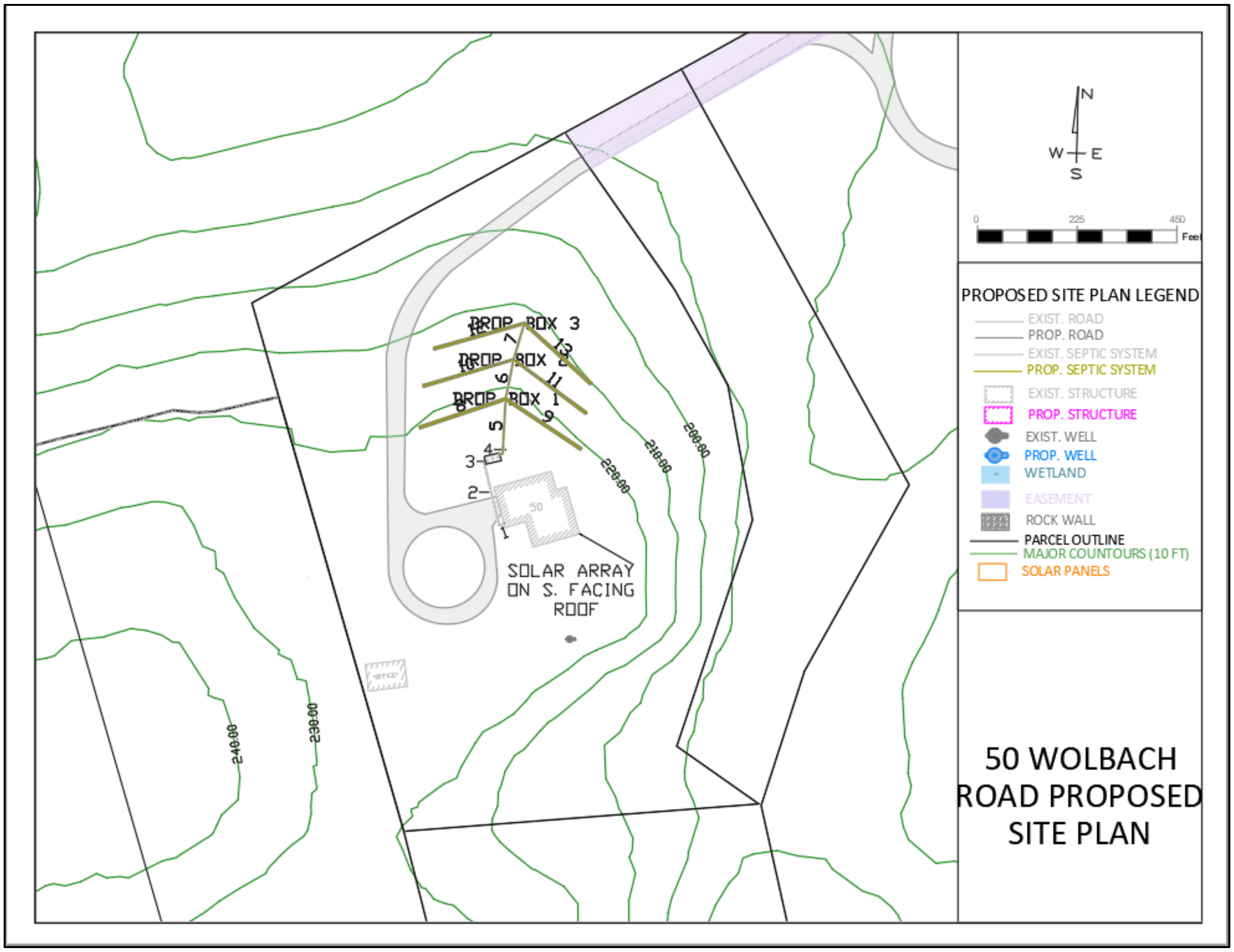
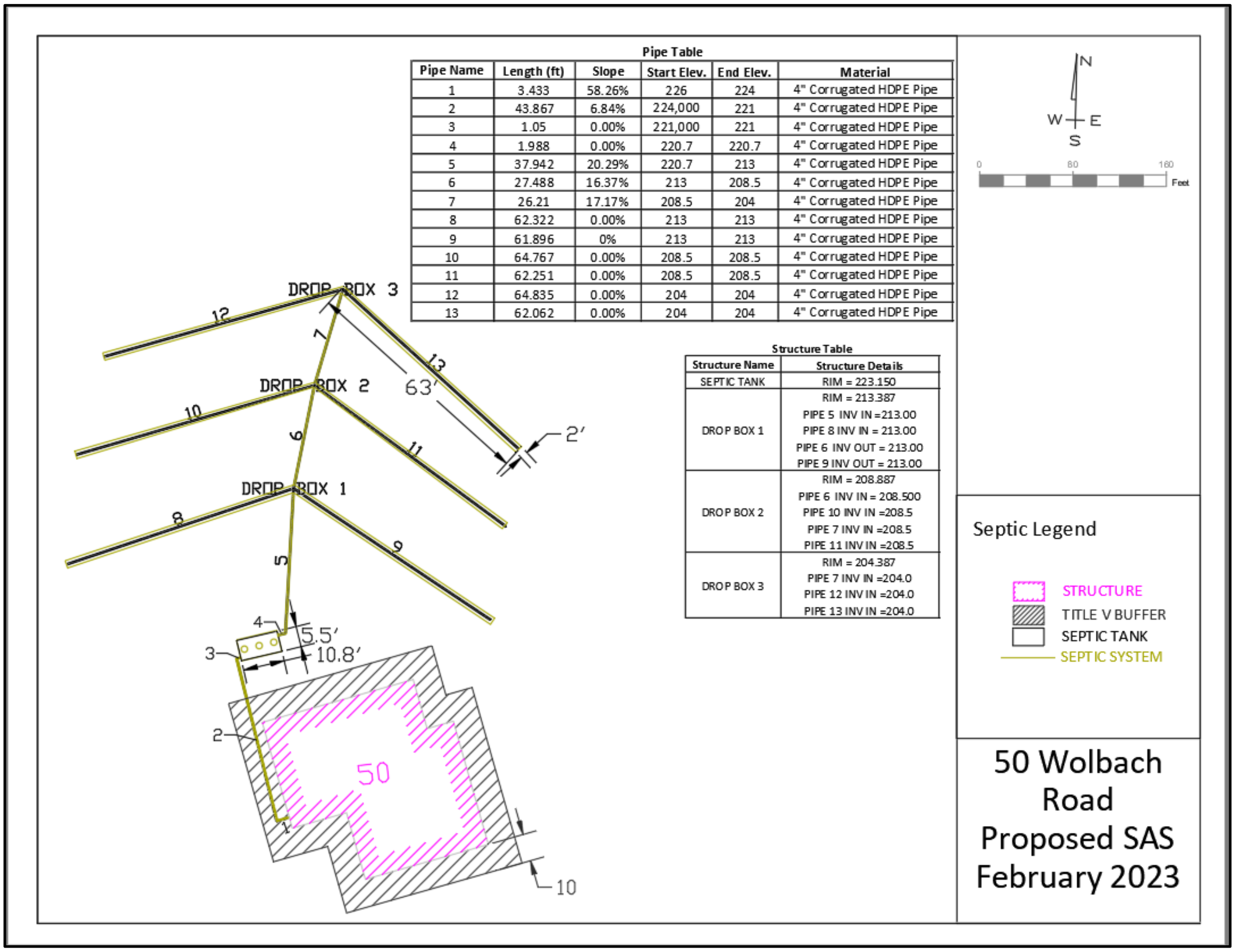


Figure 4.17 50 Wolbach Road Proposed Site Plan

Following the above recommendations, the layout for the final site design for 50 Wolbach Road features a new placement of solar panels, a new leaching field, a septic system, and a well. Due to the calculated size of the roof, the solar panels are able to be mounted on the roof of the 50 Wolbach house.

The placement of the well must be at least 100 feet from the waste water disposal system. Assuming that the soil absorption system (SAS) will be made up of an absorption trench system and a wastewater disposal system, it will be located upon the slope to the northwest of the house.

The proposed trenches for the absorption field have been designed to align with the slope contours of the current land (*Figure 4.18*). To calculate the size of the soil absorption field, we first determined the soil characteristics provided by NRCS. The soil surrounding the septic tank is hydrological group D, meaning a poor infiltration rate. While the soil characteristics provided by the NRCS are not designed to be used at this scale, we assume that this would be considered Soil Class IV under Title 5, Chapter §15.243. Though percolation tests are necessary to correctly evaluate soil percolation rate, due to our constraints, we have provided design solutions according to the possible results of the percolation tests. Using a flow rate of 440 GPD, the calculated trench area is 2933.3 square feet, with a minimum of 6" of gravel underneath per chapter's §15.251 requirements (T Larz, 2000)Environmental Protection, 2016). To accommodate the slope of the land, it was necessary to use contour trenches, which are built parallel to the contour lines of the land. Contour trenches are a series of pipes built with 16% slopes between each drop box, and 100 feet of 4" high-density polyethylene (HDPE) pipe on either side of the box (Sussman, n.d.).



Pipe Table

Pipe Name	Length (ft)	Slope	Start Elev.	End Elev.	Material
1	3.433	58.26%	226	224	4" Corrugated HDPE Pipe
2	43.867	6.84%	224,000	221	4" Corrugated HDPE Pipe
3	1.05	0.00%	221,000	221	4" Corrugated HDPE Pipe
4	1.988	0.00%	220.7	220.7	4" Corrugated HDPE Pipe
5	37.942	20.29%	220.7	213	4" Corrugated HDPE Pipe
6	27.488	16.37%	213	208.5	4" Corrugated HDPE Pipe
7	26.21	17.17%	208.5	204	4" Corrugated HDPE Pipe
8	62.322	0.00%	213	213	4" Corrugated HDPE Pipe
9	61.896	0%	213	213	4" Corrugated HDPE Pipe
10	64.767	0.00%	208.5	208.5	4" Corrugated HDPE Pipe
11	62.251	0.00%	208.5	208.5	4" Corrugated HDPE Pipe
12	64.835	0.00%	204	204	4" Corrugated HDPE Pipe
13	62.062	0.00%	204	204	4" Corrugated HDPE Pipe

Structure Table

Structure Name	Structure Details
SEPTIC TANK	RIM = 223.150
DROP BOX 1	RIM = 213.387 PIPE 5 INV IN =213.00 PIPE 8 INV IN = 213.00 PIPE 6 INV OUT = 213.00 PIPE 9 INV OUT = 213.00
DROP BOX 2	RIM = 208.887 PIPE 6 INV IN = 208.500 PIPE 10 INV IN =208.5 PIPE 7 INV IN =208.5 PIPE 11 INV IN =208.5
DROP BOX 3	RIM = 204.387 PIPE 7 INV IN =204.0 PIPE 12 INV IN =204.0 PIPE 13 INV IN =204.0

Figure 4.18 50 Wolbach Road Proposed SAS

4.3 Dale End Dogs

Dog Sheds

Three 17-foot by 17-foot prefabricated, insulated sheds would provide adequate space to the size of the business they expect to see post renovations. These spaces would be conditioned and have water access for use in clean-up. Electricity would be needed at each shed to provide interior and exterior lighting.

Office

The office building would serve as the space for employees' breaks and separate food storage for employees and the dogs. The space would be conditioned and have water access. Appliances such an employee refrigerator, microwave, and a refrigerator dedicated to dog food would be present.

Parking and EV Charging

Due to the energy load from Electric Vehicle charging, the current plans and calculations are assuming only one electric vehicle charger on the property to reach the goal of the property being net zero energy usage. Parking would be provided for four vehicles, with clear turnaround, loading, and unloading points.

Fencing

For the number of dogs expected, as well as the differing schedules, and temperaments, a large fenced section would allow for different time groups of dogs to be let out and called back without interrupting other schedules, and without extra hassle for the employees.

Total Energy Calculations

The total energy consumption was calculated in a similar manner to 42 and 50 Wolbach using the anticipated R-values for building components of the sheds and electricity usage of ammenities required in the dog sheds. The total yearly energy consumption of the new location for Dale End Dogs was estimated to be around 13,000 kWh. Sourcing for this energy was not analyzed or considered in this project. Calculations for the energy consumption estimation at the new site for Dale End Dogs is located in Appendix J.

Dale End Dogs Site Design

The following sections will go over the calculations and considerations when designing the site for Dale End Dogs, including the solar panel selection and placement, environmental considerations, and dog and employee housing ideas.

Solar Panels

Based upon the total energy requirements (Appendix J), Dale End Dogs necessitates somewhere between 306 to 441 square feet of solar panels to meet the estimated need of 10488 kWh/year (*Table 4.4*). The estimated power required was calculated from the need provided by the proposed appliances, heating load, and power necessitated by the electrical vehicle (EV) chargers proposed on site. Using the Most efficient solar panels, a total number of 11 solar panels are required to run the property. With the Canadian Solar panels, Dale End Dogs solar array will fit upon the roof space of the four new buildings which has an estimated space available of 553 square feet.

						Dale End Dogs	
						Est. kWh/year	10488
Panel Brand	Efficiency	Size (sq ft)	Wattage	Solar Panel Output (kWh) / Day	Yearly Output per panel (kWh)	Number of Panels	Square footage of Total Panels
BenQ Solar (AUO)	0.16	17.63	255.00	1.18	429.08	25	440.78
Amerisolar	0.15	20.89	325.00	1.50	546.86	20	417.78
Canadian Solar	0.22	27.81	570.00	2.63	959.11	11	305.91

Table 4.4 Dale End Dog's Solar Panel Calculations

Environmental Analysis

Dale End Dogs is in an area with hydrological group D soil, which consists mainly of clay and has a poor percolation rate. The soil itself is made up of Rock outcrop-Hollis complex with 3 to 35 percent slopes, Ridgebury fine sandy loam with 3 to 8 percent slopes, and an extremely stony Hollis-Rock outcrop-Charlton complex with 0 to 15 percent slopes (Appendix D). There are no large water sources located on or nearby the property borders. The property is surrounded by wooded areas (Appendix G) and currently has an older shed located on the property.

Septic placement & Title 5

The development of the following solutions for Dale End Dogs includes a breakdown of options according to future testing, as well as suggested systems that are in compliance with Title 5. Title 5 provides a flow rate of 50 GPD per kennel unit, which results in a calculated flow rate of 200 GPD for this unit. The soil data available for this site has the same status as the one for 50 Wolbach, where we must work under the assumption that the soil in the area is generally assumed to be Soil Class IV with an unknown percolation rate. Therefore, we have again prepared solutions dependent on what the Soil Evaluator's future assessment results in, with an emphasis on percolation rates.

<u>Percolation rate faster or equal to 60 min/inch</u>

If soil testing data finds that the soil has a percolation rate of 60 min/inch or faster, this means that the site is in compliance with the SAS Siting requirements outlined in Chapter §15.245(1) of Title 5. Just like in 50 Wolbach, a percolation rate of 60 min/inch on Class IV soil results in an effluent loading rate of 0.15 gpd/ft^2 according to chapter §15.241(1)(a). Given the calculated flow rate of 200 GPD, the calculated trench area is 1333.3 ft^2.

Since Dale End Dogs is not a single-family dwelling unit, a two-compartment tank or two tanks in series are required per chapter §15.223(1)(b). We highly recommend adopting one of the alternative systems we have suggested in the 50 Wolbach site design.

<u>Percolation rate slower than 60 min/inch</u>

Similar to 50 Wolbach, this percolation rate will require a construction infill. Unlike the other lot, Dale End Dogs must adopt this plan at a lower percolation rate, since there is no existing septic system that could allow for a remediation approval. Following chapter §15.255(5), the excavation of the unsuitable soil will have an added five feet around the entire perimeter of the planned SAS. The fill material shall consist of clean granular sand, without any material that exceeds two inches in diameter.

Alternative Systems Usage

The alternative systems provided for 42 Wolbach can also be applied for Dale End Dogs. Due to the existing soil, the best course of action that can be taken is installing a MicroFast or Singulair system in conjunction with a traditional septic system. This combination provides higher treatment levels before distribution into the soil. Our recommended distribution system is a mound system using an infill with a better permeability soil than the existing site's. Due to the site's soil classification, a mound system will allow for better filtration and less clogging of the distribution system. Taking these steps will ensure longevity and effectiveness of the system, ensuring compliance and less repair costs in the future.

Proposed Dale End Dogs Site Layout

The final layout for the new business structure has most structures located in the northern portion of the parcel where the original shed was located The property design shows the placement of the parking area for the EV charger and cars, a circular driveway allowing easy access to each individual dog kennel for efficient drop-offs and pick-ups. Three dog kennels are featured on the design in addition to the individual office for the employees of the business. The new well has been located to the south of the dog kennels, with the septic system located outside of the required buffer distance to the well, to the south of the employee's office. The Solar panels for this business are fully located upon the roof of the structures. Figure 4.15 presents Dale End Dog's proposed site plan, including a new road, parking lot, employee and dog sheds, well and septic tanks.

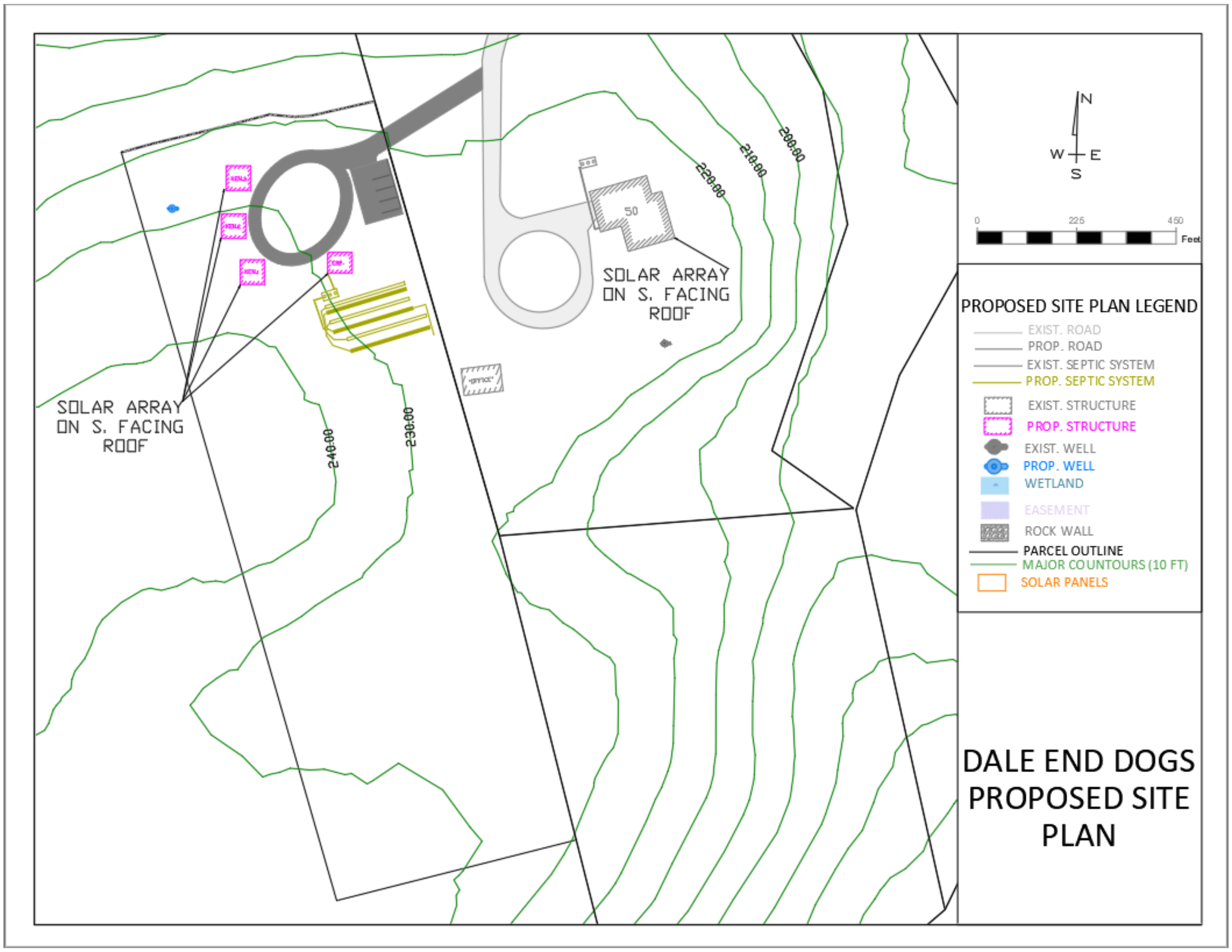


Figure 4.19 Dale End Dogs Proposed Site Plan

Chapter 5 Conclusion

The project team was able to implement and justify much of the owner's initial requests, and project objectives. In order to design renovations for a sustainable and green home that is as carbon-neutral as possible, the existing structures and property sites were analyzed to find environmental, architectural, and energy constraints that exist. From those analyses, simulations and then new designs were created to address new interior finishes to help make the build more efficient, as well as new sourcing of utilities that are renewable. The design of structural renovations and entirely new structures helped to make this vision a possibility.

The final products developed in this project include 3D and 2D model renderings of the existing and proposed structures that show all considered renovations, comprehensive energy analyses of each property, and site plans for all water treatment and sourcing, solar arrays, and property layouts.

The renovation of older structures often faces difficulties in renovations with modern constraints, especially with the goal of moving toward more carbon-neutral properties. The design of the properties of Wolbach Road in regard to more energy and environmentally friendly renovations is one step towards a more carbon-neutral world.

Chapter 6 Future Recommendations

Following the conclusion of this project, the team would recommend that Mr. Newton continue testing on the property before moving into any construction phase.

- Additional testing would be necessary upon the make-up of the soil to see if septic system designs are fully compatible in the region as the designs proposed in this report is based on
- Additional testing of the water for coliforms and PFAS by an Official agency.
- While 42 Wolbach road's septic system is functional, we recommend state testing and regular maintenance be conducted for the system to make sure it remains fully functional and meets state requirements.
- Before starting any renovations, the team also recommends a comprehensive structural analysis be completed due to potential issues arising from visual cracks and settling in the buildings, and to receive needed data regarding the structural integrity of the existing homes.

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Chapter 8 Appendices

Appendix A: 42 Wolbach Well Permit & Testing (1996)

#42

250

TOWN OF SUDBURY

BOARD OF HEALTH

DATE: 4/9/96

FROM: NEWTON, JAMES

ADDRESS: 42 Wolbach Rd

TELEPHONE: (2 Constitution Plaza Charlestown, MA 02129

OWNER:
(IF OTHER THAN APPLICANT
PERMISSION IN WRITING ATTACHED)

NEW

REPAIR #96-2965

REASON FOR CALL: 42 Wolbach Rd (Lot A)

DATE PLAN APPROVED 5/15/96 DISAPPROVED ________ ENGINEER* Stamski & McNary, Inc.

1500 GALLON SEPTIC TANK THREE 2'w x 2'd x 57'l leaching trenches

IN ACCORDANCE WITH PLAN SM-1774 SUBMITTED BY* DATED REV. 3/28/96

INSPECTIONS: EXCAVATION PRIOR TO STONE 10/96

FINAL ON SYSTEM 11/8/96

OTHER INSPECTIONS ________

AS BUILT RECEIVED 12/2/96 Approval Rec'd

NOTES: 5/10/96 Well results OK Well permit #96-728

42 Wolbach Rd
11/8/96
Calvin Blandford

...t/Division of Water...
...MPLETION REPORT

...ress LOT A
42 WOLBACH Rd
City/Town SUDBURY MA
Well owner MANGANIELLO Constr.
Address 171 WOBURN St
Wilmington, Ma 01887

Board of Health permit obtained: yes ☒ no ☐

GEOGRAPHIC DESCRIPTION

45 (feet) N S E W (circle) of
Wolbach (road)
2/10 (mi. in tenths) N S E W (circle) of
intersect. w/ RT 27 (road)

WELL USE
Domestic ☒ Public ☐ Industrial ☐
Monitoring ☐ Other ______

Method drilled air rotary
Date drilled 5/2/96

CASING
Type Steel
Length 40 ft. Dia(I.D.) 6 in.
Length into bedrock 32 ft.
Protective well seal: drive shoe
Grout ☐ Other ______

WELL DATA
Total well depth 500 ft.
Depth to bedrock 8 ft.
Water-bearing rock/unconsolidated material:
Description Granite
Water-bearing zones:
1) From 300 To 320
2) From ______ To ______
3) From ______ To ______
Gravel pack well: dia. ______
Screen: dia. ______
Slot # ______ length ______ from ______ to ______

...G WATER LEVEL (all wells)
...r level below land surface 53 ft. Date 5/6/96

...duction wells)
...after pumping 16 hr. ______ min. at 7 gpm
Recovery 350 ft. after 12 hr. ______ min.

...MENTS
...k 300-440 ... bear Hych. Fract.

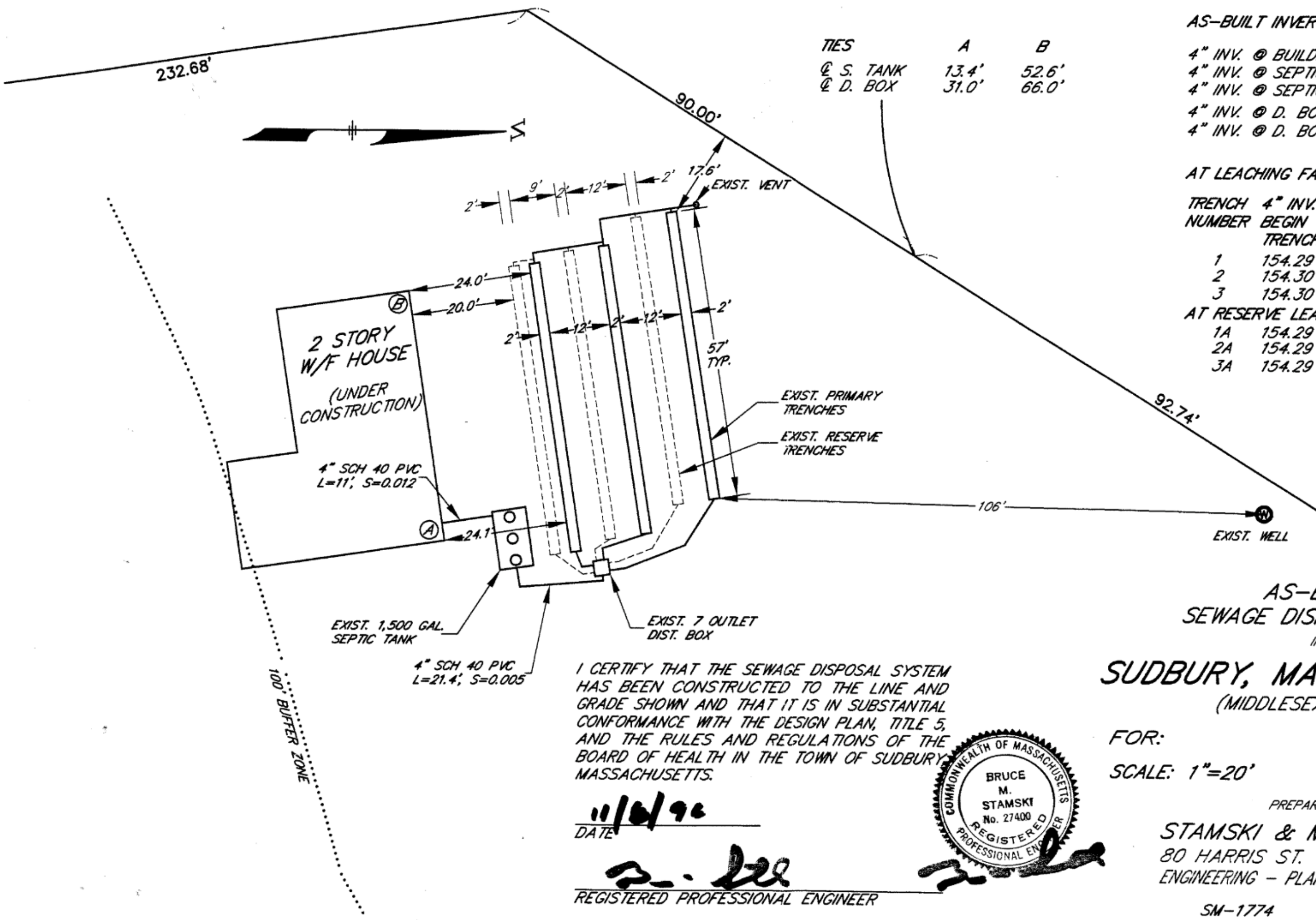
Office use only

...Pelletier
...Sons Inc
...ctor Hill Rd
...S, NH 03049
Reg.# 546

Signature of supervising registered well driller

...RD OF HEALTH COPY

AS...
NOT...



TIES	A	B
℄ S. TANK	13.4'	52.6'
℄ D. BOX	31.0'	66.0'

AS-BUILT INVERT ELEVATIONS:

4" INV. @ BUILDING	= 155.04
4" INV. @ SEPTIC TANK (IN)	= 154.91
4" INV. @ SEPTIC TANK (OUT)	= 154.71
4" INV. @ D. BOX (IN)	= 154.60
4" INV. @ D. BOX (OUT)	= 154.44

AT LEACHING FACILITY

TRENCH NUMBER	4" INV. BEGIN TRENCH	4" INV. END TRENCH	BOTTOM STONE
1	154.29	154.01	153.0±
2	154.30	154.00	153.0±
3	154.30	153.99	153.0±
AT RESERVE LEACHING FACILITY			
1A	154.29	154.01	153.0±
2A	154.29	154.02	153.0±
3A	154.29	154.01	153.0±

I CERTIFY THAT THE SEWAGE DISPOSAL SYSTEM HAS BEEN CONSTRUCTED TO THE LINE AND GRADE SHOWN AND THAT IT IS IN SUBSTANTIAL CONFORMANCE WITH THE DESIGN PLAN, TITLE 5, AND THE RULES AND REGULATIONS OF THE BOARD OF HEALTH IN THE TOWN OF SUDBURY, MASSACHUSETTS.

11/6/96
DATE

REGISTERED PROFESSIONAL ENGINEER

COMMONWEALTH OF MASSACHUSETTS
BRUCE M. STAMSKI
No. 27400
REGISTERED PROFESSIONAL ENGINEER

AS-BUILT SEWAGE DISPOSAL PLAN

IN

SUDBURY, MASSACHUSETTS

(MIDDLESEX COUNTY)

FOR: JIM NEWTON

SCALE: 1"=20' NOVEMBER 8, 1996

PREPARED BY:

STAMSKI & MCNARY, INC.
80 HARRIS ST. ACTON, MA
ENGINEERING - PLANNING - SURVEYING

SM-1774 (1774AB.DWG)

FROM: SKILLINGS & SONS, INC.   FAX: 603-465-3512   May-10-96 Fri 10:00   PAGE: 01

508 - 443 - 0756

Thorstensen Laboratory, Inc.

66 LITTLETON ROAD WESTFORD, MA 01886   (508) 692-8395 FAX (508) 692-0023 1-800-649-TEST

Report Number: C-sks-19507
Client:

Skillings and Sons
269 Proctor Hill Rd.
Hollis NH 03049

Report Date: May 9, 1996
Sample Taken At:

Manganullo Const.
Lot A Walbach Rd.
Sudbury, MA

Sample Taken By: SKS Staff   On: May 7, 1996

CERTIFICATE OF ANALYSIS

TEST PARAMETER:	EPA Max	RESULTS	UNITS
Total Coliform (P)	0	*0	Per 100ml
Arsenic (P)	0.05	<0.005	mg/L
Calcium	No Limit	29.5	mg/L
Copper (S)	1.3	0.02	mg/L
Iron (S)	0.3	0.09	mg/L
Lead (P)	0.015	0.001	mg/L
Magnesium	No Limit	9.0	mg/L
Manganese (S)	0.05	<0.01	mg/L
Sodium	"28	9.8	mg/L
Potassium (S)	Not Spec.	1.5	mg/L
Alkalinity (S)	Not Spec.	100	mg/L
Ammonia	Not Spec.	<0.03	mg/L
Chloride (S)	250	13.9	mg/L
Chlorine (total)	Not Spec.	<0.02	mg/L
Color (S)	15	0	CPU
Conductivity	Not Spec.	283	umhos/cm
Hardness	No Limit	111	mg/L
Nitrates(as N)(P)	10	0.16	mg/L
Nitrites(as N)	1	<0.01	mg/L
pH (S)	6.5-8.5	7.8	SU
Odor (S)	3	0	TON
Sulphates (S)	250	13.1	mg/L
Turbidity	5	1.2	NTU
Sediment	pos/neg	neg	

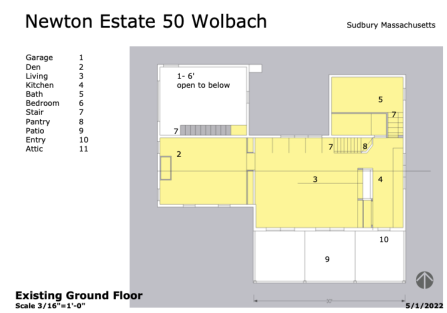
NT=Not Tested, #=Value Exceeds EPA STD, TNTC=Too Numerous to Count
*=Background Bacteria Noted, "=EPA Advisory Limit
'=Exceeds EPA Advisory Limit   Not Spec.= Not Specified
(P)-Primary EPA Standard, (S)=Secondary EPA Standard (may affect aesthetics of drinking water i.e. taste, color, etc.)

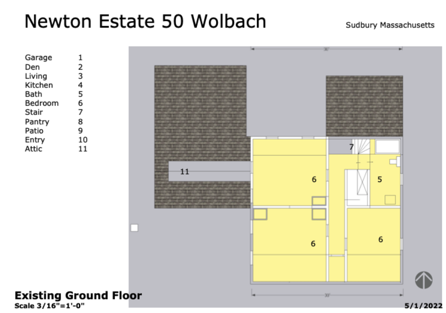
This water sample, as submitted, meets or exceeds EPA health standards for the parameters listed above. The quality of this water is accepted as POTABLE according to EPA Standards.

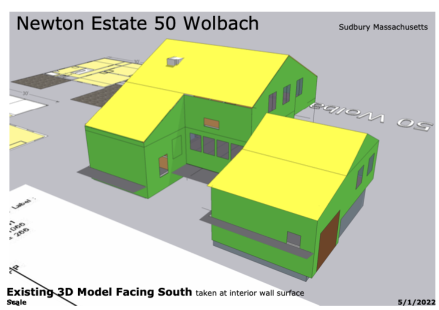
Massachusetts State Certified
Testing Laboratory #MA048

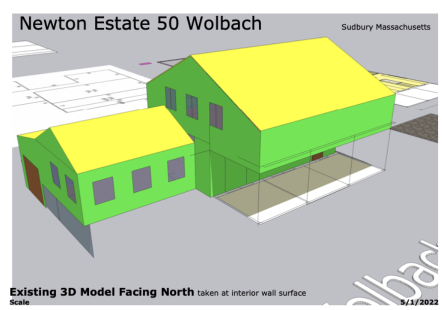
Michael P. Carlson
Michael P. Carlson, for   ebb
Thorstensen Laboratory Inc.

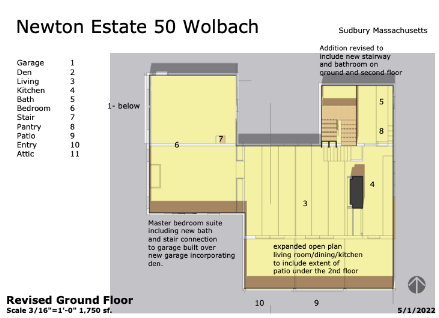
Appendix B: Rob Karn's Files

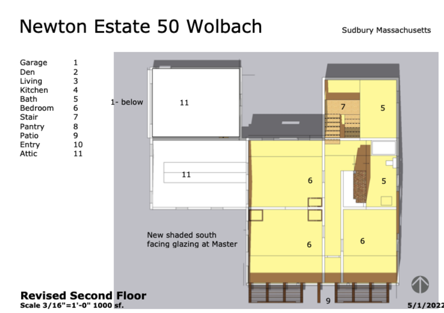






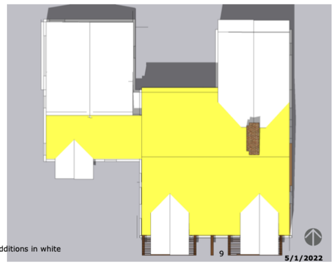






Newton Estate 50 Wolbach

Sudbury Massachusetts



Revised Roof additions in white
Scale 3/16"=1'-0"

5/1/2022

Newton Estate 50 Wolbach

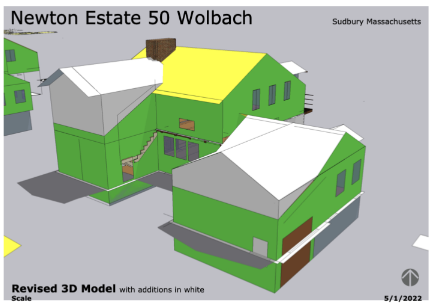
Sudbury Massachusetts

Revised 3D Model with additions in white
Scale

5/1/2022

Newton Estate 50 Wolbach

Sudbury Massachusetts



Revised 3D Model with additions in white
Scale

5/1/2022

Newton Estate 50 Wolbach

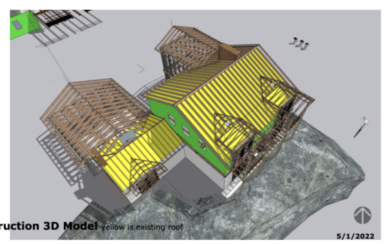
Sudbury Massachusetts

Construction 3D Model
Scale

5/1/2022

Newton Estate 50 Wolbach

Sudbury Massachusetts

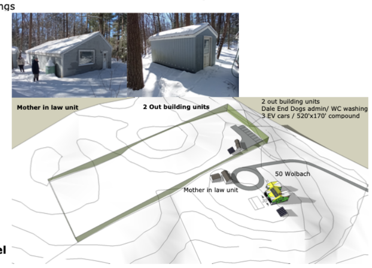


Construction 3D Model yellow is existing roof
Scale

5/1/2022

Newton Estate Dale End Dogs
Out buildings

Sudbury Massachusetts



3D Model
Scale

NEWTON ESTATE ENERGY SOURCES AND USES

Sources			yearly	Monthly	**Uses**		Unit type	Unit area breakdown in sq ft (including expansion of 50 Wolbach and enlarged south facing windows both huoses)							
					12000 BTU =1 ton										
					2 ton (refer)= 7 kW*h										
42 Wolbach	consumption/conservation-based on energy model							42 Wolbach	Use	Floor	Roof/ceiling	Ext Wall conc	Ext Wall wood	Int Wall	windows/doors
	2700 sf (house)		existing					Basement	mech	700	700c	584	324		18
	600 st (apt basement)							1st Floor	living	1325	1315c		1278	120	350
	715 sf (apt above garage)							2nd Floor	bedrooms	1315	1860r		1648		210
	4000 sf 6 bed 5 bath		proposed												
Electric															
	Photo voltaic	**PV**	**10,000kWh**	**900 kWh**	**Electric**			Basement Apt							
		5%	500kWh		lights/Power					600	600c	780	204		76
		3%	300kWh		Major Appliances			2nd Floor apt							
		21%	2100kWh		Mechanical systems					715	1030r		455		96
		17%	1700kWh		AC	643 deg days-c	Heat pump								
		?			EV -Elec auto										
	Battery Pack														
	Advanced metering	AMI													
	Ventilation	HRV													
Heating		46%	4600kWh		Heating	5822 deg days	heating								
	Geo thermal		4.5 ton		Underfloor heating		Heat pump								
	Solar thermal														
	Wood Burning/hybrid														
Domestic HW					2 msq- pp +.7 msq ea add pers		80-100 gallon storage								
	Solar thermal														
	Air thermal														
Water resource management															
	well														
	septic														

50 Wolbach	consumption/conservation-based on energy model							50 Wolbach							
	2100 sf (house)		existing					Basement	Garage /M	400	400 c	400			64
	450 x(2)=900 sf (mother inlaw)							1st Floor	living/ Mas	1750	1750 c/r		1565		200
	4000 sf 5 bed-4 bath		proposed					2nd Floor	bedrooms	1000	1000 r		1086		50
Electric															
	Photo voltaic	**PV**	**10,000kWh**	**900 kWh**	**Electric**										
		5%	500kWh		lights/Power										
		3%	300kWh												
		21%	2100kWh		Mechanical systems										
		17%	1700kWh		Heat/AC										
					EV -Elec auto (2)										
	Battery Pack														
	Advanced metering	AMI													
	Ventilation	HRV													
Heating		46%	4600kWh		Heating										
	Geo thermal		4.5 ton		Underfloor heating										
	Solar thermal														
	Wood Burning														
Domestic HW															
	Solar thermal														
	Air thermal														
Water resource management															
	well														
	septic														
Dale End Dogs	consumption/conservation-based on energy model														
	180 sf (office)		existing												
	300 sf (kennel)														
	500 sf 1 bath		proposed												
Electric															
	Photo voltaic	**PV**	**1,250 kWh**	**104 kWh**	**Electric**										
					lights/Power										
					Mechanical systems										
					EV -Elec auto (3)										
	Battery Pack														
Heating															
	Solar thermal														
Domestic HW															
	Solar thermal														
	Air thermal														
Water resource management															
	well														
	septic/composting toilet														

Appendix C: Newton's Plans

Packet 1:

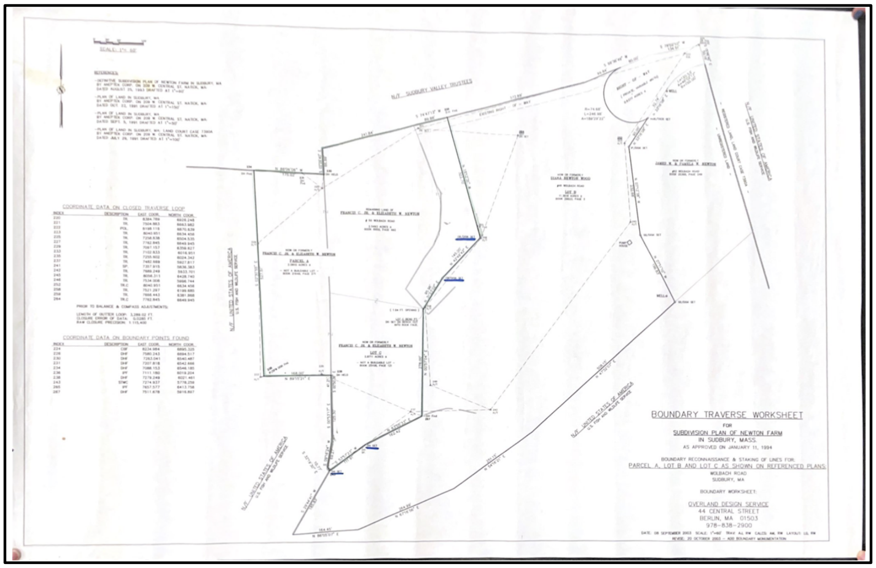


Figure A

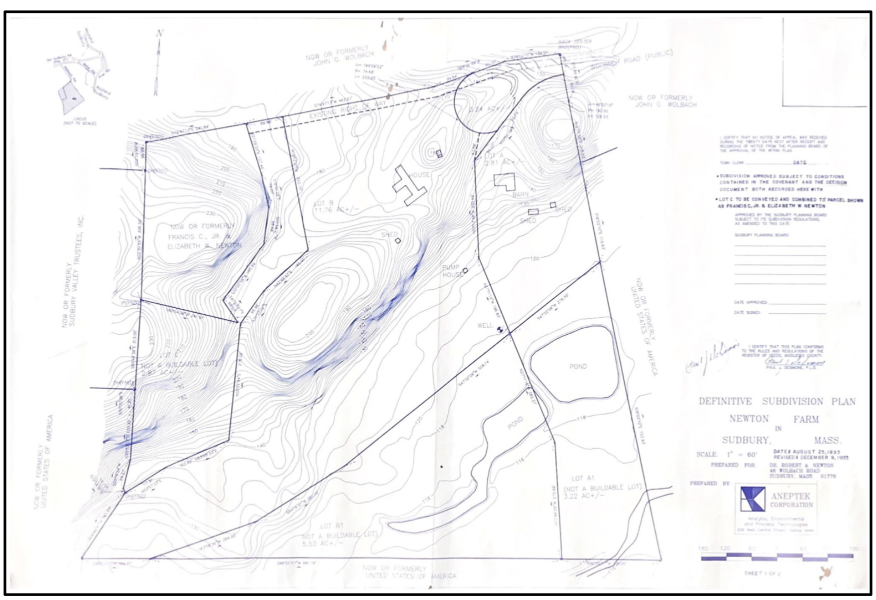


Figure B

Figure C

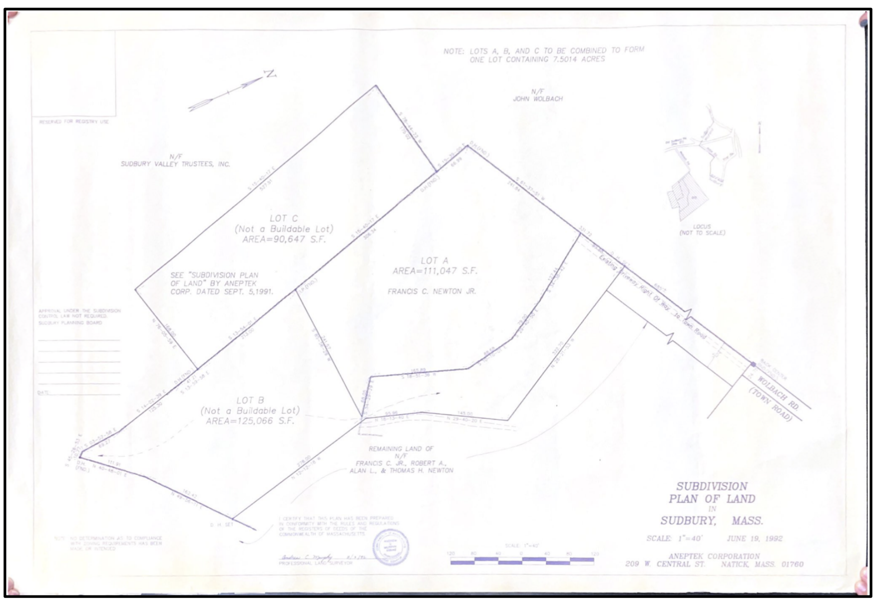


Figure D

Packet 2:

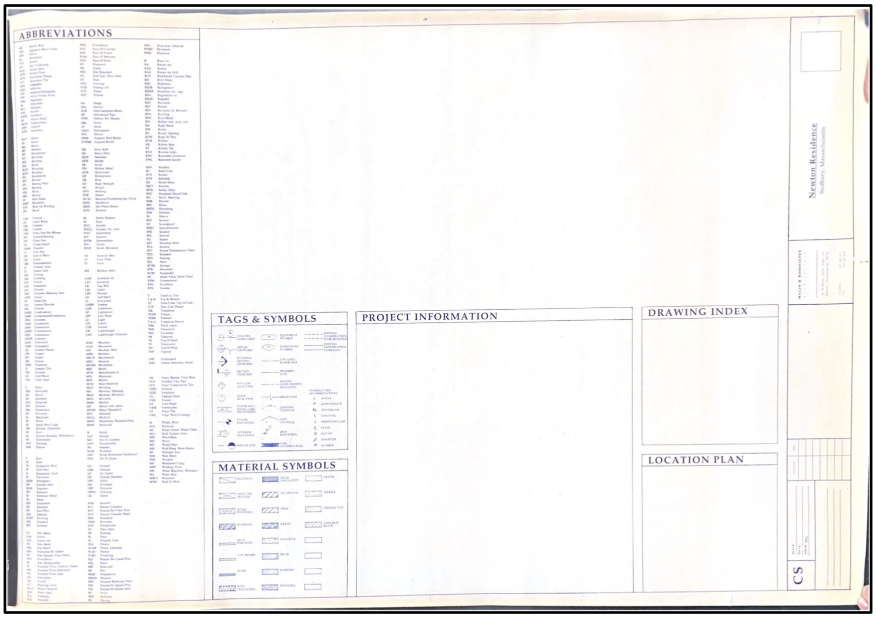


Figure A

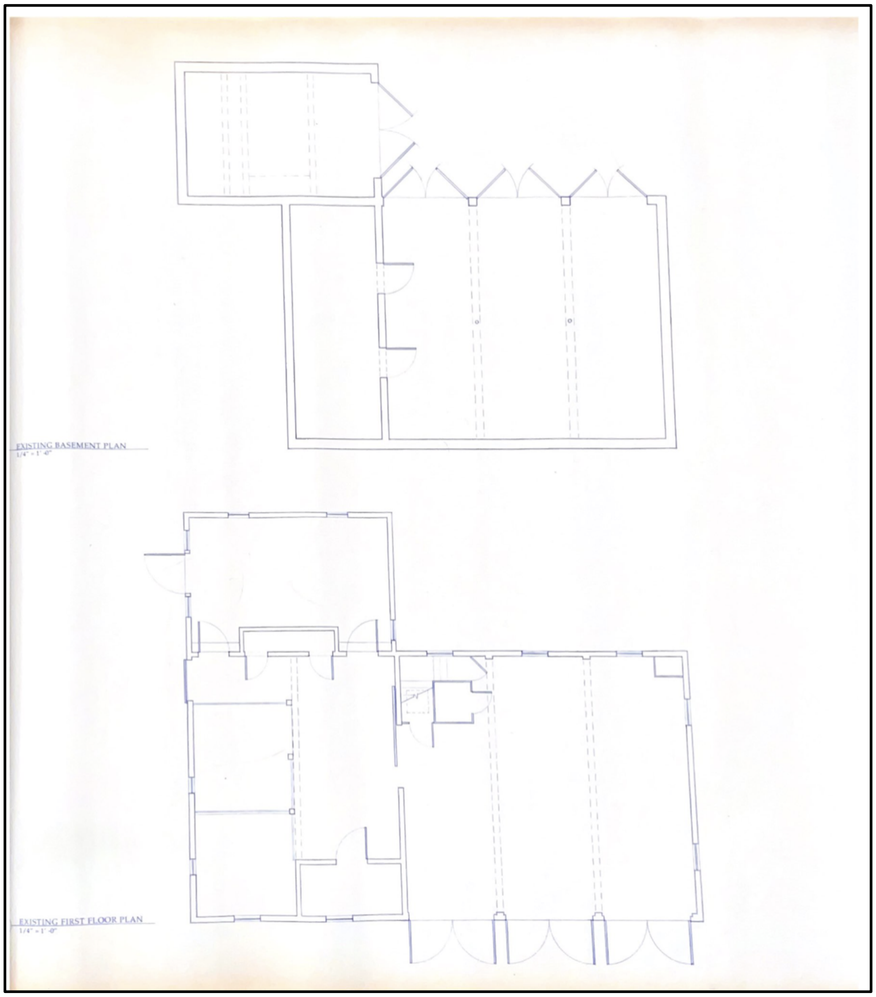

EXISTING BASEMENT PLAN
1/4" = 1' -0"
EXISTING FIRST FLOOR PLAN
1/4" = 1' -0"

Figure B

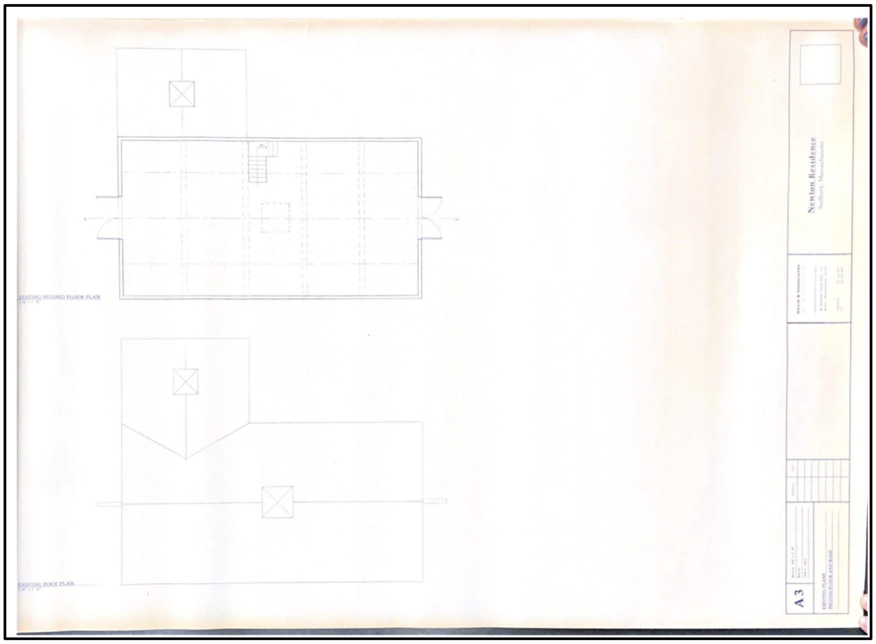


Figure C

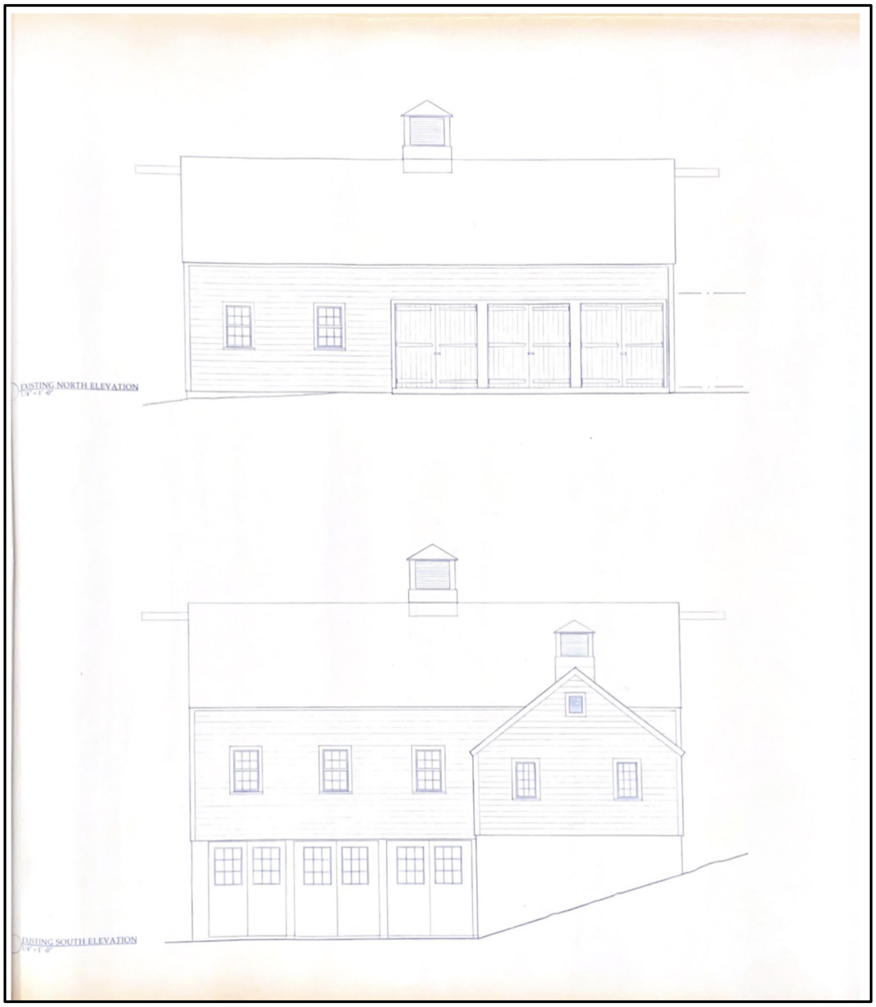

EXISTING NORTH ELEVATION
1/4" = 1'-0"
EXISTING SOUTH ELEVATION
1/4" = 1'-0"

Figure D

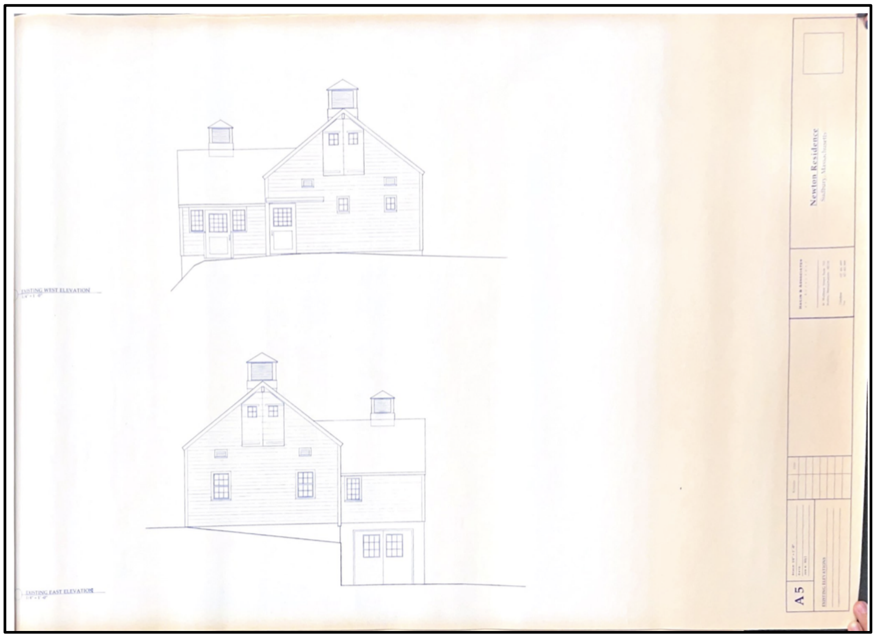


Figure E

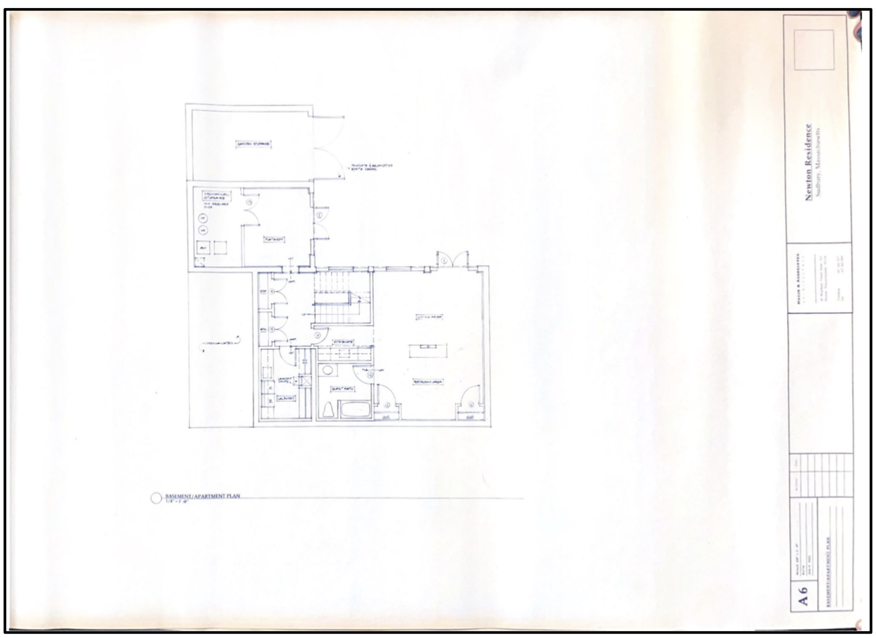


Figure F

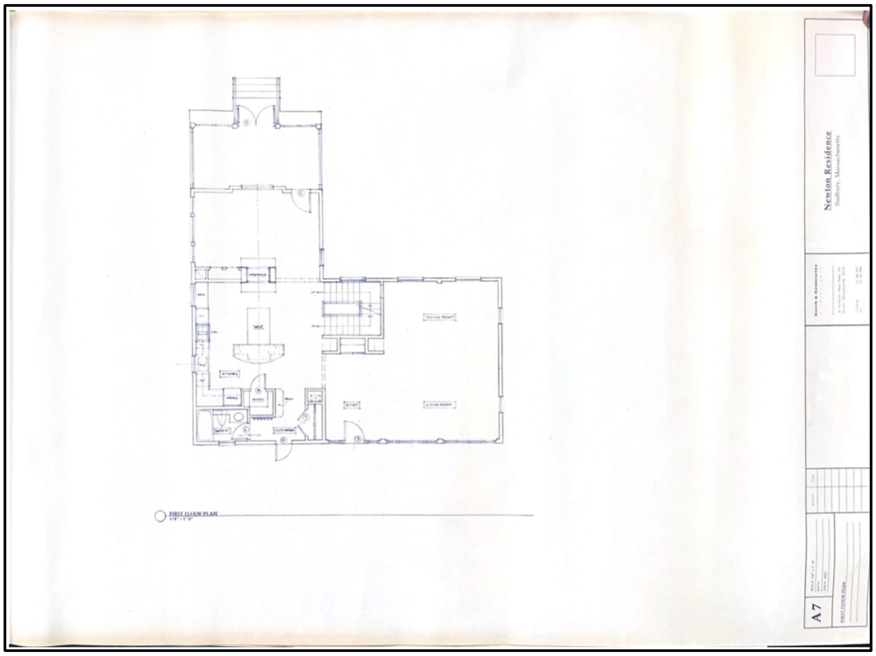


Figure G

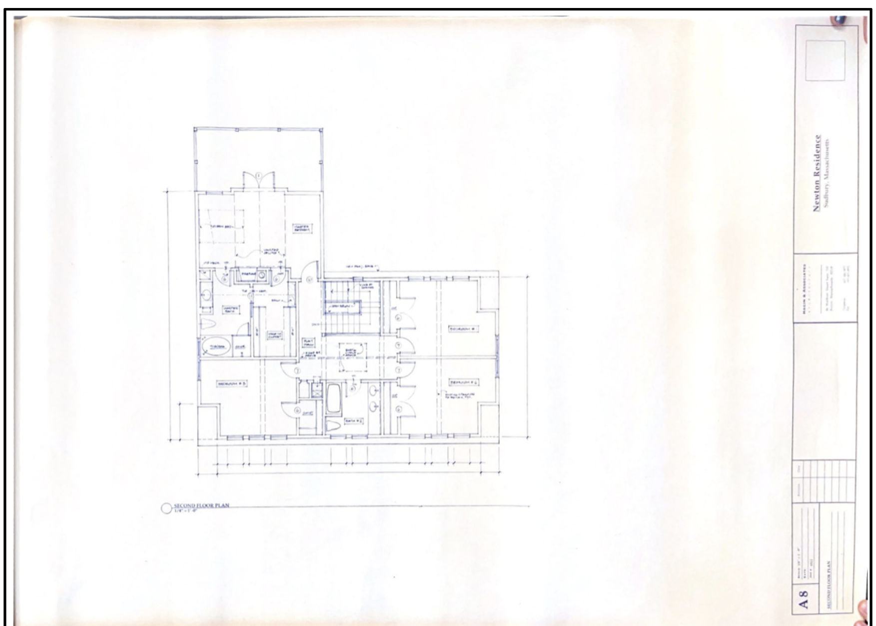


Figure H

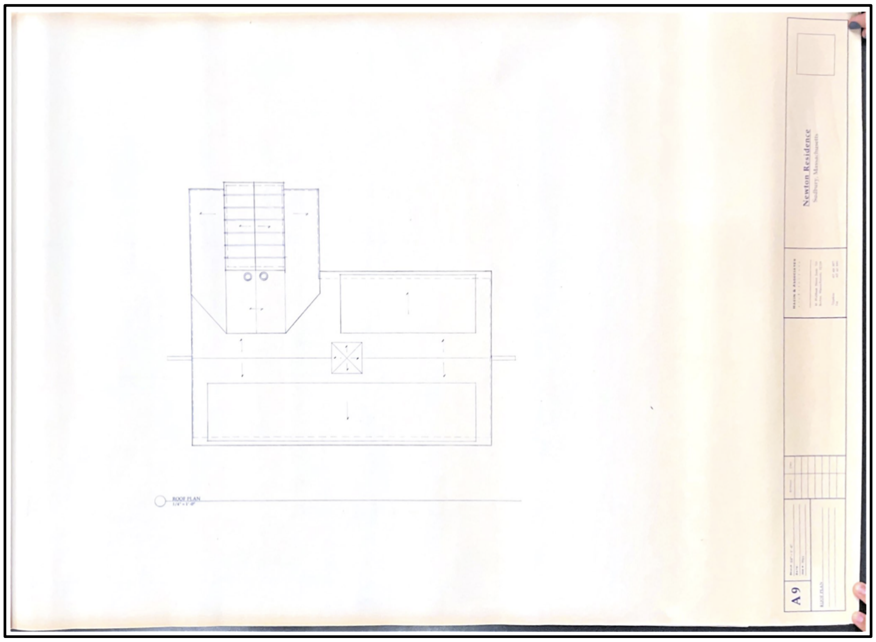


Figure I

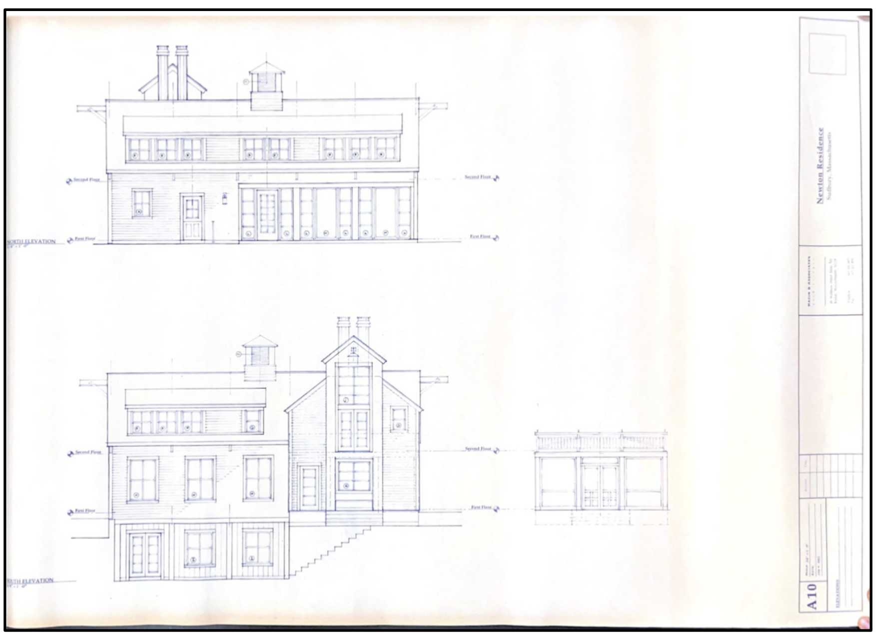


Figure J

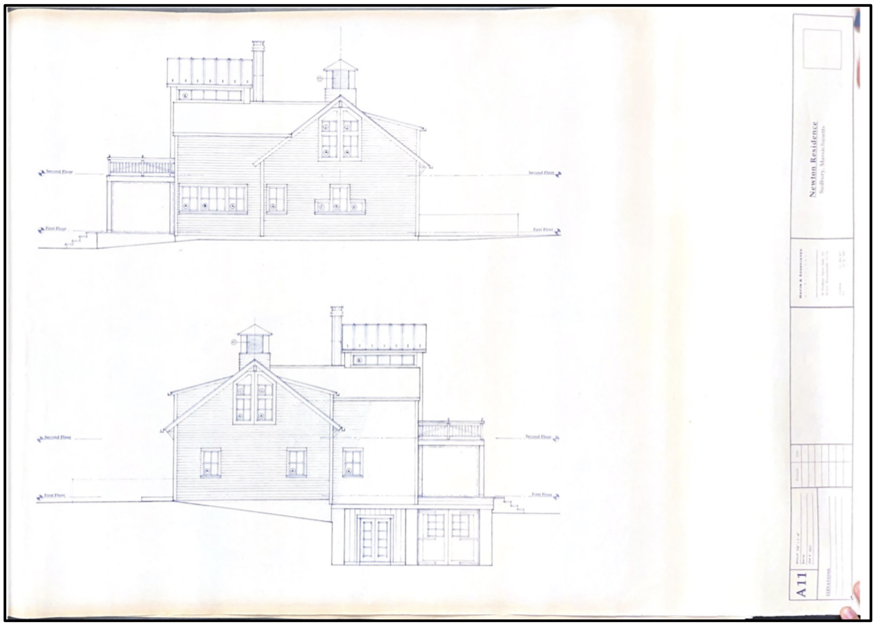
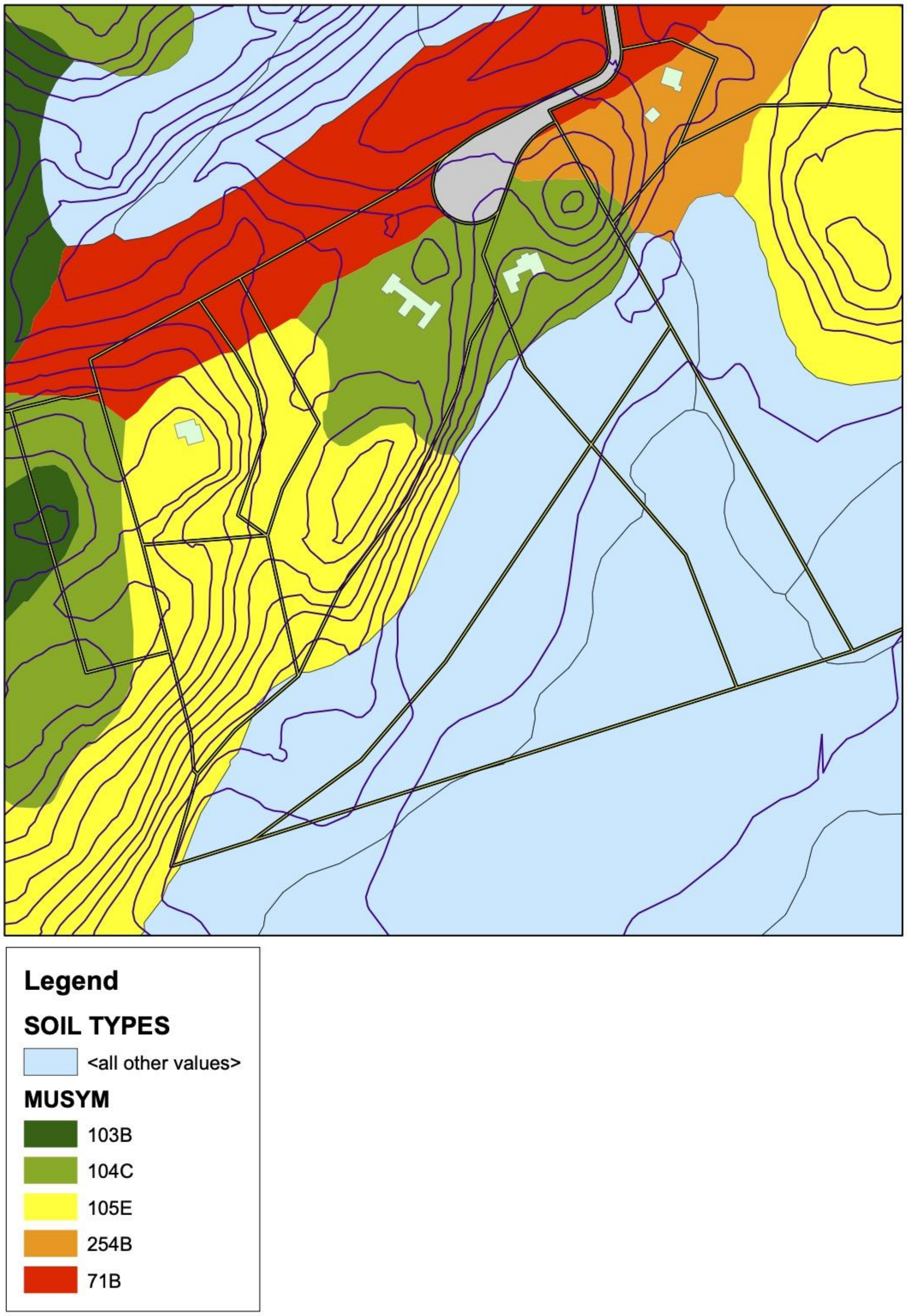
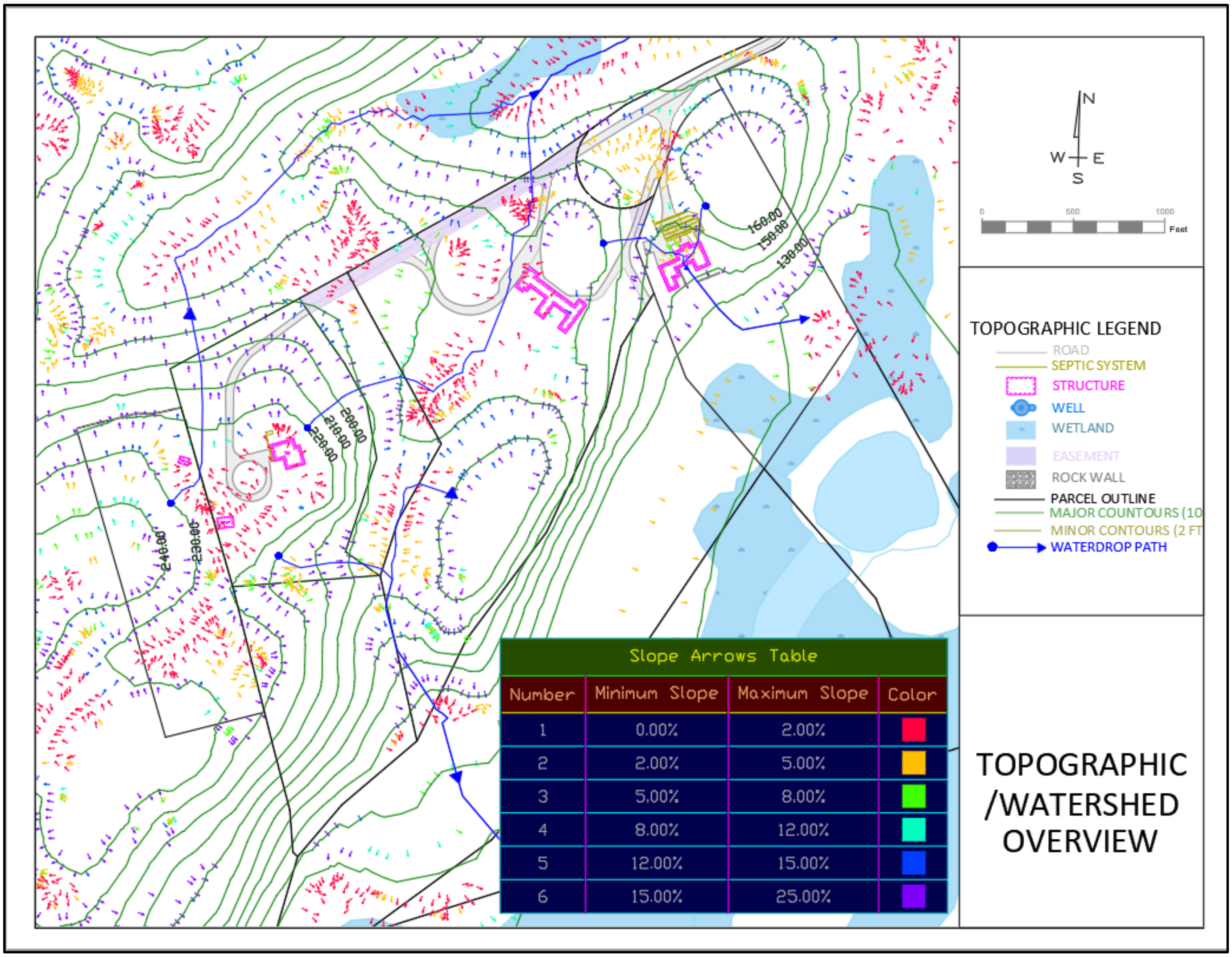


Figure K

Appendix D: Soil Data

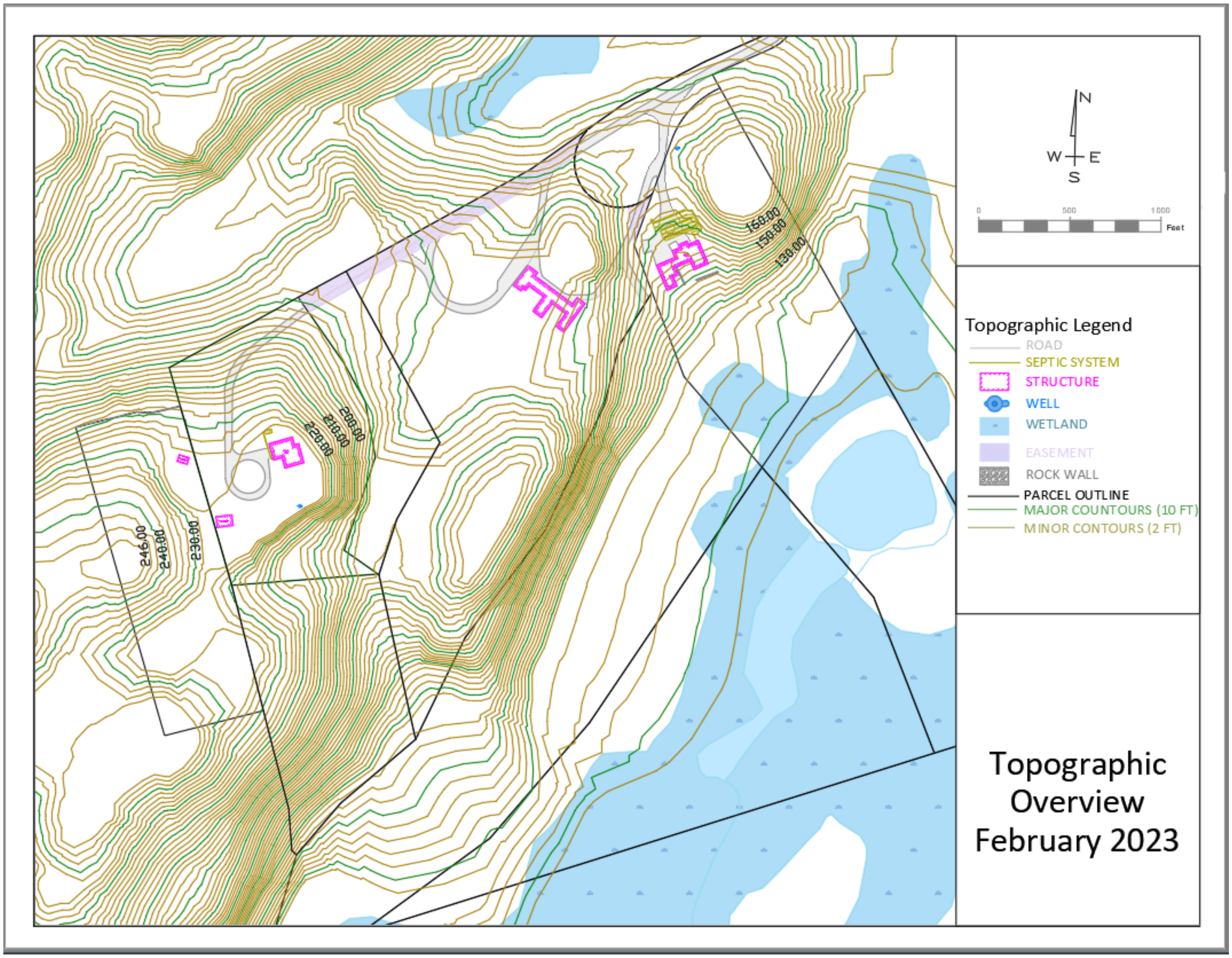


Appendix E: Watershed Delineation

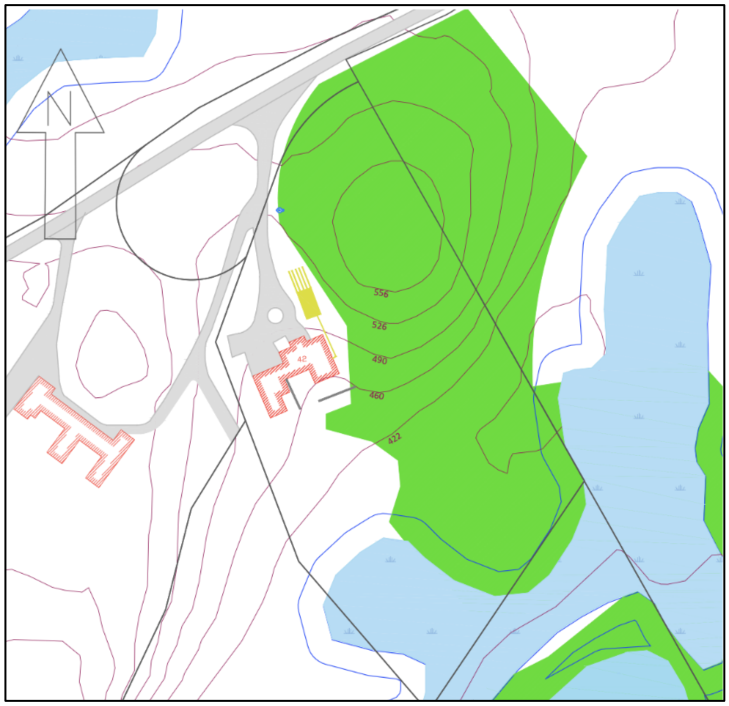


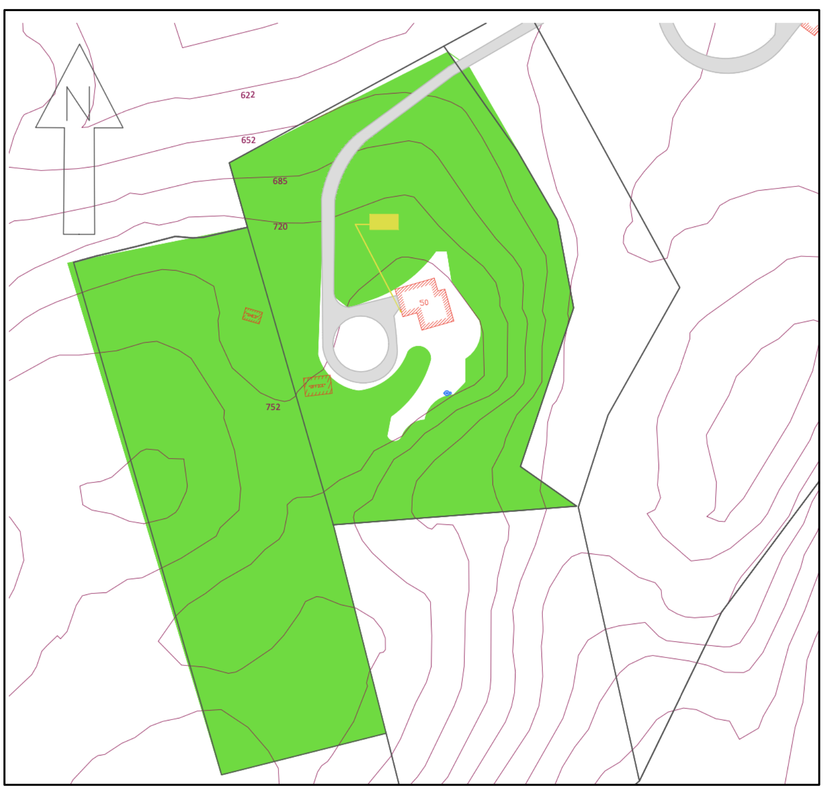
Number	Minimum Slope	Maximum Slope	Color
1	0.00%	2.00%	
2	2.00%	5.00%	
3	5.00%	8.00%	
4	8.00%	12.00%	
5	12.00%	15.00%	
6	15.00%	25.00%	

Appendix F: Topographic Overview



Appendix G: Tree Locations





Appendix H: Coliform Presumptive Testing Results

Results after 24 hours

50 Wolbach:

Test Tube	Dilution						
	0	-1	-2	-3	-4	-5	-6
A	-	-	-	-	+	+	-
B	-	-	+	+	-	+	-
C	-	-	+	-	-	-	+
D	X	-	-	-	+	+	-
E	X	-	+	-	-	-	-

- = Negative Result
+ = Positive Result
X = Missing Tube

42 Wolbach:

Test Tube	Dilution						
	0	-1	-2	-3	-4	-5	-6
A	-	-	-	-	-	-	-
B	-	-	-	-	-	-	-
C	-	-	-	-	-	-	-
D	-	-	-	-	-	-	-
E	-	-	-	-	-	-	-

- = Negative Result
+ = Positive Result
X = Missing Tube

Results after 48 hours

50 Wolbach:

Test Tube	Dilution						
	0	-1	-2	-3	-4	-5	-6
A	-	-	-	-	+	+	-
B	-	-	+	+	-	+	+
C	-	-	+	-	-	-	+
D	X	-	-	-	+	+	–
E	X	-	+	-	-	-	

- = Negative Result
+ = Positive Result
X = Missing Tube

42 Wolbach:

Test Tube	Dilution						
	0	-1	-2	-3	-4	-5	-6
A	-	-	-	-	-	-	-
B	-	-	-	-	-	-	-
C	-	-	-	-	-	-	-
D	-	-	-	-	-	-	-
E	-	-	-	-	-	-	-

- = Negative Result
+ = Positive Result
X = Missing Tube

Appendix I: Wastewater Treatment Alternative Options

System	How it Works	Design Components & Considerations	Advantages	Disadvantages	Maintenance	Cost
Cultec System -Plastic Leaching Chamber[1]	Is installed in conjunction with a septic tank and pumps. Chambers distribute effluent throughout a gravel bed to treat and infiltrate	· Polyethalyne chambers · Fabric interface	· Heavy duty or regular duty available. · Gravel-less, lighter installation · Greater contact area allows for a smaller field (up to 50% area) · Works for gravity or pressure systems · May be used for stormwater as well	· Not great for sloped ground	N/A	N/A
System	How it Works	Design Components &	Advantages	Disadvantages	Maintenance	Cost

		Considerations				
Bioclere System[2,3]	A modified trickling system which acts as a secondary treatment unit through the use of microorganisms in its biological film	· Primary settling tank · Bioclere dosing array · Requires 4-7 ft depth excavation	· Effective BOD and TSS reduction · Preassembled unit	· Reliable on electricity, therefore a prolonged outage or malfunction interrupts treatment · High initial cost	· Grease traps and primary settling tanks checked every 3 and 6 months respectively. · Follow repair and pumping according to inspection	Upfront: \$18,000-\$21,000 Plus primary settling tank and dispersal unit Electricity cost \$200 semi-annual maintenance
Jet Aerobic[4,5]	Water is cycled through three components, a tank where sludge settles, treatment where grey water mixed with oxygen through aerator, passed over bacteria media, and then is forced to flow into a settling tank where the treated water flows to the discharge.	· Air Pump · Pre-Treatment of influent · Treatment ·Settling tank · Discharge outlet · Works on high water tables	· Can treat 500 to 1,500 gallons/day · Operates five times longer than normal septic system · Aerator Exchange program past warranty	· High Maintenance · Noisy · High Cost · Potentially produce odors	· Inspection every 6 months	· \$25,000 to \$35,000 for components, installation, and field.

System	How it Works	Design Components & Considerations	Advantages	Disadvantages	Maintenance	Cost
Infiltrator[6]	In conjunction with a normal septic tank. Each field is made of chambers instead of PVC or crushed stone. Chambers are half dome, capped on the ends, and effluent is filtered downwards into the soil.	· Half Dome Plastic Dome · Roughly 48" long, 34"wide · 16" tall per component · Not designed for sloped areas	· Can run parallel to each other	· 70 gal/48"/day	· Low for the leaching field	$62 per 48" of pipe

Sources:

1. CULTEC. (n.d.). Pipe Distribution Systems—Pds. CULTEC, Inc. Retrieved February 9, 2023, from https://cultec.com/pipe-distribution-systems-pds/
2. AquaPoint. (2014). Bioclere Operation & Maintenance Manual. https://archives.lib.state.ma.us/bitstream/handle/2452/734515/ocn993441619-2015-09-17-man3.pdf?sequence=4&isAllowed=y

3. Peconic Green Growth. (2016). Tech Info Sheet Bioclere. http://peconicgreengrowth.org/wp-content/uploads/2016/10/FP_1_AquaPointBioclere2.pdf
4. GroundStone. (n.d.). Aerobic Septic System, a Rundown of How They Work and Cost. Septic System Services. Retrieved January 24, 2023, from https://groundstone.ca/aerobic-septic-system/
5. Jet Inc. (2022, January 19). Residential—Jet Wastewater Treatment SolutionsJet Wastewater Treatment Solutions. https://www.jetincorp.com/residential/
6. Loomis Tank Centers. (n.d.). Infiltrator Systems Leach Fields. Retrieved January 24, 2023, from https://www.loomistank.com/infiltrator-leach-field-system.shtm

Appendix J: Energy Calculations

	SI Units	Q=U*deltaT*A		comfort temp = 22C					
50 Wolbach		Floor Area (sq m)	Ceiling/Roof Area (sq m)	Concrete Wall Area (sq m)	Ext Wood Wall Area (sq m)	Window Area (sq m)	Door Area (sq m)		
Basement		22				1	4		
1st Floor		86	31			13	8		
2nd Floor		76	126			4			
Total Area (square meters)		184	187	3	193	18	12		
U-Value (W/m²K)			0	0	0	3	2		
Month	average temp (C)							Monthly Totals	24/7 conditioning
January	-4		920	38	1,878	1,271	599	4,706	3,501
February	-3		867	36	1,770	1,198	565	4,435	3,299
March	2		708	29	1,445	978	461	3,620	2,693
April	9		478	20	975	660	311	2,444	1,818
May	15		248	10	506	342	161	1,267	943
June	20		88	4	181	122	58	453	337
July	23		18	1	36	24	12	91	67
August	22		18	1	36	24	12	91	67
September	17		177	7	361	244	115	905	673
October	10		425	18	867	587	277	2,172	1,616
November	5		602	25	1,228	831	392	3,077	2,289
December	-1		796	33	1,625	1,100	519	4,073	3,030
Yearly Totals			5,343	221	10,906	7,382	3,481	27,332	20,335

50 Wolbach: Current

50 Wolbach	Floor Area (sq ft)	Ceiling/Roof Area (sq ft)	Concrete Wall Area (sq ft)	Ext Wood Wall Area (sq ft)	Window Area (sq ft)	Door Area (sq ft)
Basement	235	324			12	45
1st Floor	931	332			137	86
2nd Floor	817	1355			44	
Total Area	1983	2011	36	2073	193	131
R-vaule		30	13	26.25	2.084	3
		5.28	2.288	4.62	0.366784	0.528

Imperial units	
r value per inch	3.7
estimated inches	3
total r value	11.1

	SI Units		Q=U*deltaT*A	comfort temp = 22C					
50 Wolbach		Floor Area (sq m)	Ceiling/Roof Area (sq m)	Concrete Wall Area (sq m)	Ext Wood Wall Area (sq m)	Window Area (sq m)	Door Area (sq m)		
Basement		21.83				1.11	4.18		
1st Floor		86.49	30.84			12.73	7.99		
2nd Floor		75.90	125.88			4.09			
Total Area (square meters)		184.23	186.83	3.34	192.59	17.93	12.17		
U-Value (W/m²K)			0.19	0.44	0.22	2.73	1.89		
Month	average temp (c)							Monthly Totals	24/7
January	-4.0		919.99	38.01	1,083.83	1,271.01	599.29	3,912.13	2911
February	-2.5		866.91	35.81	1,021.30	1,197.69	564.72	3,686.43	2743
March	2.0		707.68	29.24	833.71	977.70	461.00	3,009.33	2239
April	8.5		477.69	19.73	562.76	659.95	311.17	2,031.30	1511
May	15.0		247.69	10.23	291.80	342.20	161.35	1,053.27	784
June	19.5		88.46	3.65	104.21	122.21	57.62	376.17	280
July	22.5		17.69	0.73	20.84	24.44	11.52	75.23	56
August	21.5		17.69	0.73	20.84	24.44	11.52	75.23	56
September	17.0		176.92	7.31	208.43	244.43	115.25	752.33	560
October	10.0		424.61	17.54	500.23	586.62	276.60	1,805.60	1343
November	5.0		601.53	24.85	708.66	831.05	391.85	2,557.93	1903
December	-0.5		796.14	32.89	937.93	1,099.92	518.62	3,385.50	2519
Yearly Totals			5,343.00	220.73	6,294.54	7,381.66	3,480.52	22,720.44	16904

50 Wolbach: Additional Blown-In Insulation

50 Wolbach	Floor Area (sq ft)	Ceiling/Roof Area (sq ft)	Concrete Wall Area (sq ft)	Ext Wood Wall Area (sq ft)	Window Area (sq ft)	Door Area (sq ft)
Basement	235	324			12	45
1st Floor	931	332			137	86
2nd Floor	817	1355			44	
Total Area	1983	2011	36	2073	193	131
R-vaule		30	13	23.85	2.084	3
		5.28	2.288	4.1976	0.366784	0.528

imperial units	
R per inch	4.35
inches	2
total	8.7

SI Units		Q=U*deltaT*A	comfort temp = 22C						
50 Wolbach		Floor Area (sq m)	Ceiling/Roof Area (sq m)	Concrete Wall Area (sq m)	Ext Wood Wall Area (sq m)	Window Area (sq m)	Door Area (sq m)		
Basement		21.83				1.11	4.18		
1st Floor		86.49	30.84			12.73	7.99		
2nd Floor		75.90	125.88			4.09			
Total Area (square meters)		184.23	186.83	3.34	192.59	17.93	12.17		
U-Value (W/m²K)			0.19	0.44	0.24	2.73	1.89		
Month	average temp (c)							Monthly Totals	24/7
January	-4.0		919.99	38.01	1,192.89	1,271.01	599.29	4,021.19	2992
February	-2.5		866.91	35.81	1,124.07	1,197.69	564.72	3,789.20	2819
March	2.0		707.68	29.24	917.61	977.70	461.00	3,093.23	2301
April	8.5		477.69	19.73	619.39	659.95	311.17	2,087.93	1553
May	15.0		247.69	10.23	321.16	342.20	161.35	1,082.63	805
June	19.5		88.46	3.65	114.70	122.21	57.62	386.65	288
July	22.5		17.69	0.73	22.94	24.44	11.52	77.33	58
August	21.5		17.69	0.73	22.94	24.44	11.52	77.33	58
September	17.0		176.92	7.31	229.40	244.43	115.25	773.31	575
October	10.0		424.61	17.54	550.57	586.62	276.60	1,855.94	1381
November	5.0		601.53	24.85	779.97	831.05	391.85	2,629.24	1956
December	-0.5		796.14	32.89	1,032.31	1,099.92	518.62	3,479.88	2589
Yearly Totals			5,343.00	220.73	6,927.96	7,381.66	3,480.52	23,353.86	17375

50 Wolbach: Additional Continuous Board Insulation

50 Wolbach	Floor Area (sq ft)	Ceiling/Roof Area (sq ft)	Concrete Wall Area (sq ft)	Ext Wood Wall Area (sq ft)	Window Area (sq ft)	Door Area (sq ft)
Basement	235	324			12	45
1st Floor	931	332			137	86
2nd Floor	817	1355			44	
Total Area	1983	2011	36	2073	193	131
R-vaule		30	13	15.15	5	3
		5.28	2.288	2.6664	0.88	0.528

SI Units		Q=U*deltaT*A	comfort temp = 22C						
50 Wolbach		Floor Area (sq m)	Ceiling/Roof Area (sq m)	Concrete Wall Area (sq m)	Ext Wood Wall Area (sq m)	Window Area (sq m)	Door Area (sq m)		
Basement		21.83				1.11	4.18		
1st Floor		86.49	30.84			12.73	7.99		
2nd Floor		75.90	125.88			4.09			
Total Area (square meters)		184.23	186.83	3.34	192.59	17.93	12.17		
U-Value (W/m²K)			0.19	0.44	0.38	1.14	1.89		
Month	average temp (c)							Monthly Totals	24/7
January	-4.0		919.99	38.01	1,877.92	529.76	599.29	3,964.97	2950
February	-2.5		866.91	35.81	1,769.58	499.20	564.72	3,736.22	2780
March	2.0		707.68	29.24	1,444.55	407.51	461.00	3,049.97	2269
April	8.5		477.69	19.73	975.07	275.07	311.17	2,058.73	1532
May	15.0		247.69	10.23	505.59	142.63	161.35	1,067.49	794
June	19.5		88.46	3.65	180.57	50.94	57.62	381.25	284
July	22.5		17.69	0.73	36.11	10.19	11.52	76.25	57
August	21.5		17.69	0.73	36.11	10.19	11.52	76.25	57
September	17.0		176.92	7.31	361.14	101.88	115.25	762.49	567
October	10.0		424.61	17.54	866.73	244.50	276.60	1,829.98	1362
November	5.0		601.53	24.85	1,227.87	346.38	391.85	2,592.48	1929
December	-0.5		796.14	32.89	1,625.12	458.44	518.62	3,431.22	2553
Yearly Totals			5,343.00	220.73	10,906.39	3,076.67	3,480.52	23,027.31	17132

50 Wolbach: Triple-Pane Low-E Windows

50 Wolbach	Floor Area (sq ft)	Ceiling/Roof Area (sq ft)	Concrete Wall Area (sq ft)	Ext Wood Wall Area (sq ft)	Window Area (sq ft)	Door Area (sq ft)
Basement	235	324			12	45
1st Floor	931	332			137	86
2nd Floor	817	1355			44	
Total Area	1983	2011	36	2073	193	131
R-value	30	60	13	26.25	3.3	3
		10.56	2.288	4.62	0.59	0.528
				Insulation A	Pella 150 Series	

SI Units			Q=U*deltaT*A	comfort temp = 22C					
50 Wolbach		Floor Area (sq m)	Ceiling/Roof Area (sq m)	Concrete Wall Area (sq m)	Ext Wood Wall Area (sq m)	Window Area (sq m)	Door Area (sq m)		
Basement		21.83				1.11	4.18		
1st Floor		86.49	30.84			12.73	7.99		
2nd Floor		75.90	125.88			4.09			
Total Area (square meters)		184.23	186.83	3.34	192.59	17.93	12.17		
U-Value (W/m²K)			0.09	0.44	0.22	1.70	1.89		
Month	average temp (c)							Monthly Totals	24/7
January	-4.0		459.99	38.01	1,083.83	794.64	599.29	2,975.76	2214
February	-2.5		433.46	35.81	1,021.30	748.79	564.72	2,804.08	2086
March	2.0		353.84	29.24	833.71	611.26	461.00	2,289.05	1703
April	8.5		238.84	19.73	562.76	412.60	311.17	1,545.11	1150
May	15.0		123.84	10.23	291.80	213.94	161.35	801.17	596
June	19.5		44.23	3.65	104.21	76.41	57.62	286.13	213
July	22.5		8.85	0.73	20.84	15.28	11.52	57.23	43
August	21.5		8.85	0.73	20.84	15.28	11.52	57.23	43
September	17.0		88.46	7.31	208.43	152.81	115.25	572.26	426
October	10.0		212.30	17.54	500.23	366.76	276.60	1,373.43	1022
November	5.0		300.76	24.85	708.66	519.57	391.85	1,945.69	1448
December	-0.5		398.07	32.89	937.93	687.67	518.62	2,575.18	1916
Yearly Totals			2,671.50	220.73	6,294.54	4,615.01	3,480.52	17,282.30	12858

50 Wolbach: Compiled with All Recommendations

								Current		Up to Code		Insulation A		Insulation B		Fenestrations		Recommendations	
								Est. kWh/year	24,859	Est. kWh/year	20027	Est. kWh/year	21428	Est. kWh/year	21899	Est. kWh/year	21656	**Est. kWh/year**	**17382**
Panel Type	Efficiency	Dimensions	size (sqaure m)	Size (square ft)	Wattage	Solar Panel Output (kWh) / Day	Yearly Output per panel (kWh)	Number of Panels	Square footage	Number of Panels	Square footage	Number of Panels	Square footage	Number of Panels	Square footage	Number of Panels	Square footage	Number of Panels	Square footage
BenQ Solar (AUO)	0.16	65.0" x 39.06"	1.64	17.63	255.00	1.18	429.08	58	1,022.61	47	828.67	50	881.56	52	916.83	51	899.19	41	722.88
Amerisolar	0.15	77.01" x 39.06"	1.94	20.89	325.00	1.50	546.86	46	960.89	37	772.89	40	835.56	41	856.45	40	835.56	32	668.45
Canadian Solar	0.22	89.69" x 44.65"	2.58	27.81	570.00	2.63	959.11	26	723.06	21	584.01	23	639.63	23	639.63	23	639.63	19	528.39

50 Wolbach: Solar Calculations for Update Scenarios

Appliance	energy per month (kWh)	amount-50	energy-50
fridge (17-20 cubic foot)	150	1	150
mini fridge		0	0
sump		0	0
oven	58	1	58
stove		1	0
lighting	50	1	50
televisions	27		0
EV charger	405		0
garage door		1	0
microwave	16	1	16
water pump	18	1	18
washer	9		0
dryer	85		0
computer		1	0
dishwasher	30		0
			0
			0
Summer			602

50 Wolbach: Estimations for Energy Use by Household Appliances

42 Wolbach	Floor Area (sq ft)	Ceiling/Roof Area (sq ft)	Concrete Wall Area (sq ft)	Ext Wood Wall Area (sq ft)	Window Area (sq ft)	Door Area (sq ft)
Basement	1457		1364	528	76	18
1st Floor	2228	107		1278	314	35
2nd Floor	2133	2133		1648	210	
Total Area	5818	2240	36	2073	600	53
R-value (IP)		30	13	18	2.084	3
R-value (SI)		5.28	2.288	3.168	0.366784	0.528

SI Units		Q=U*deltaT*A		comfort temp = 22C					
42 Wolbach		Floor Area (sq m)	Ceiling/Roof Area (sq m)	Concrete Wall Area (sq m)	Ext Wood Wall Area (sq m)	Window Area (sq m)	Door Area (sq m)		
Basement		135		127		7	2		
1st Floor		207	10		119	29	3		
2nd Floor		198	198		153	20			
Total Area (square meters)		541	208	3	193	56	5		
U-Value (W/m²K)			0	0	0	3	2		
Month	average temp (C)							Monthly Totals	24/7 conditioning
January	-4		1,025	38	1,581	3,951	242	6,837	5,087
February	-3		966	36	1,489	3,723	228	6,443	4,793
March	2		788	29	1,216	3,039	187	5,259	3,913
April	9		532	20	821	2,052	126	3,550	2,641
May	15		276	10	426	1,064	65	1,841	1,370
June	20		99	4	152	380	23	657	489
July	23		20	1	30	76	5	131	98
August	22		20	1	30	76	5	131	98
September	17		197	7	304	760	47	1,315	978
October	10		473	18	730	1,824	112	3,156	2,348
November	5		670	25	1,033	2,584	159	4,470	3,326
December	-1		887	33	1,368	3,419	210	5,917	4,402
Yearly Totals			5,951	221	9,180	22,948	1,408	39,708	29,543

42 Wolbach: Existing

42 Wolbach	Floor Area (sq ft)	Ceiling/Roof Area (sq ft)	Concrete Wall Area (sq ft)	Ext Wood Wall Area (sq ft)	Window Area (sq ft)	Door Area (sq ft)
Basement	1457		1364	528	76	18
1st Floor	2228	107		1278	314	35
2nd Floor	2133	2133		1648	210	
Total Area	5818	2240	36	2073	600	53
R-value	30	49	13	23.8	2.222222222	3
		8.624	2.288	4.1888	0.3911111111	0.528
			* 7.5 min	R20 + R3.8ci		

SI Units		Q=U*deltaT*A	comfort temp = 22C			
42 Wolbach	Floor Area (sq m)	Ceiling/Roof Area (sq m)	Concrete Wall Area (sq m)	Ext Wood Wall Area (sq m)	Window Area (sq m)	Door Area (sq m)
Basement	135.36		126.72		7.06	1.67
1st Floor	206.99	9.94		118.73	29.17	3.25
2nd Floor	198.16	198.16		153.10	19.51	
Total Area (square meters)	540.51	208.10	3.34	192.59	55.74	4.92
U-Value (W/m²K)		0.12	0.44	0.24	2.56	1.89

Month	average temp (c)							Monthly Totals	24/7
January	-4.0		627.40	38.01	1,195.40	3,705.56	242.46	5,808.83	4322
February	-2.5		591.20	35.81	1,126.43	3,491.78	228.47	5,473.70	4072
March	2.0		482.61	29.24	919.54	2,850.43	186.51	4,468.33	3324
April	8.5		325.76	19.73	620.69	1,924.04	125.89	3,016.12	2244
May	15.0		168.91	10.23	321.84	997.65	65.28	1,563.92	1164
June	19.5		60.33	3.65	114.94	356.30	23.31	558.54	416
July	22.5		12.07	0.73	22.99	71.26	4.66	111.71	83
August	21.5		12.07	0.73	22.99	71.26	4.66	111.71	83
September	17.0		120.65	7.31	229.88	712.61	46.63	1,117.08	831
October	10.0		289.57	17.54	551.72	1,710.26	111.91	2,681.00	1995
November	5.0		410.22	24.85	781.61	2,422.87	158.53	3,798.08	2826
December	-0.5		542.94	32.89	1,034.48	3,206.74	209.82	5,026.87	3740
Yearly Totals			3,643.73	220.73	6,942.51	21,520.78	1,408.15	33,735.89	25100

42 Wolbach: Renovated to meet current code

42 Wolbach	Floor Area (sq ft)	Ceiling/Roof Area (sq ft)	Concrete Wall Area (sq ft)	Ext Wood Wall Area (sq ft)	Window Area (sq ft)	Door Area (sq ft)
Basement	1457		1364	528	76	18
1st Floor	2228	107		1278	314	35
2nd Floor	2133	2133		1648	210	
Total Area	5818	2240	36	2073	600	53
R-value	30	60	13	26.25	3.3	3
		10.56	2.288	4.62	0.59	0.528
				Insulation A	Pella 150 Series	

	SI Units	Q=U*deltaT*A		comfort temp = 22C					
42 Wolbach		Floor Area (sq m)	Ceiling/Roof Area (sq m)	Concrete Wall Area (sq m)	Ext Wood Wall Area (sq m)	Window Area (sq m)	Door Area (sq m)		
Basement		135		127		7	2		
1st Floor		207	10		119	29	3		
2nd Floor		198	198		153	20			
Total Area (square meters)		541	208	3	193	56	5		
U-Value (W/m²K)			0	0	0	2	2		
Month	average temp (c)							Monthly Totals	24/7
January	-4		512	38	1,084	2,470	242	4,347	3,234
February	-3		483	36	1,021	2,328	228	4,096	3,048
March	2		394	29	834	1,900	187	3,344	2,488
April	9		266	20	563	1,283	126	2,257	1,679
May	15		138	10	292	665	65	1,170	871
June	20		49	4	104	238	23	418	311
July	23		10	1	21	48	5	84	62
August	22		10	1	21	48	5	84	62
September	17		99	7	208	475	47	836	622
October	10		236	18	500	1,140	112	2,006	1,493
November	5		335	25	709	1,615	159	2,842	2,115
December	-1		443	33	938	2,138	210	3,762	2,799
Yearly Totals			2,976	221	6,295	14,347	1,408	25,246	18,783

42 Wolbach: Recommended insulation

42 Wolbach	Floor Area (sq ft)	Ceiling/Roof Area (sq ft)	Concrete Wall Area (sq ft)	Ext Wood Wall Area (sq ft)	Window Area (sq ft)	Door Area (sq ft)
Basement	1457		1364	528	76	18
1st Floor	2228	107		1278	314	35
2nd Floor	2133	2133		1648	210	
Total Area	5818	2240	36	2073	600	53
R-vaule		30	13	26.25	2.084	3
		5.28	2.288	4.62	0.366784	0.528

Imperial units	
r value per inch	3.7
estimated inches	3
total r value	11.1

SI Units			Q=U*deltaT*A	comfort temp = 22C					
42 Wolbach		Floor Area (sq m)	Ceiling/Roof Area (sq m)	Concrete Wall Area (sq m)	Ext Wood Wall Area (sq m)	Window Area (sq m)	Door Area (sq m)		
Basement		135.36		126.72		7.06	1.67		
1st Floor		206.99	9.94		118.73	29.17	3.25		
2nd Floor		198.16	198.16		153.10	19.51			
Total Area (square meters)		540.51	208.10	3.34	192.59	55.74	4.92		
U-Value (W/m²K)			0.19	0.44	0.22	2.73	1.89		
Month	average temp (c)							Monthly Totals	24/7
January	-4.0		1,024.75	38.01	1,083.83	3,951.34	242.46	6,340.38	4717
February	-2.5		965.63	35.81	1,021.30	3,723.38	228.47	5,974.59	4445
March	2.0		788.27	29.24	833.71	3,039.49	186.51	4,877.22	3629
April	8.5		532.08	19.73	562.76	2,051.66	125.89	3,292.12	2449
May	15.0		275.89	10.23	291.80	1,063.82	65.28	1,707.03	1270
June	19.5		98.53	3.65	104.21	379.94	23.31	609.65	454
July	22.5		19.71	0.73	20.84	75.99	4.66	121.93	91
August	21.5		19.71	0.73	20.84	75.99	4.66	121.93	91
September	17.0		197.07	7.31	208.43	759.87	46.63	1,219.30	907
October	10.0		472.96	17.54	500.23	1,823.69	111.91	2,926.33	2177
November	5.0		670.03	24.85	708.66	2,583.57	158.53	4,145.64	3084
December	-0.5		886.80	32.89	937.93	3,419.43	209.82	5,486.87	4082
Yearly Totals			5,951.43	220.73	6,294.54	22,948.15	1,408.15	36,823.00	27396

42 Wolbach: Blown-in insulation (Type A)

42 Wolbach	Floor Area (sq ft)	Ceiling/Roof Area (sq ft)	Concrete Wall Area (sq ft)	Ext Wood Wall Area (sq ft)	Window Area (sq ft)	Door Area (sq ft)
Basement	1457		1364	528	76	18
1st Floor	2228	107		1278	314	35
2nd Floor	2133	2133		1648	210	
Total Area	5818	2240	36	2073	600	53
R-vaule		30	13	23.85	2.084	3
		5.28	2.288	4.1976	0.366784	0.528

imperial units	
R per inch	4.35
inches	2
total	8.7

SI Units			Q=U*deltaT*A	comfort temp = 22C					
42 Wolbach		Floor Area (sq m)	Ceiling/Roof Area (sq m)	Concrete Wall Area (sq m)	Ext Wood Wall Area (sq m)	Window Area (sq m)	Door Area (sq m)		
	Basement	135.36		126.72		7.06	1.67		
	1st Floor	206.99	9.94		118.73	29.17	3.25		
	2nd Floor	198.16	198.16		153.10	19.51			
	Total Area (square meters)	540.51	208.10	3.34	192.59	55.74	4.92		
	U-Value (W/m²K)		0.19	0.44	0.24	2.73	1.89		
Month	average temp (c)							Monthly Totals	24/7
January	-4.0		1,024.75	38.01	1,192.89	3,951.34	242.46	6,449.45	4798
February	-2.5		965.63	35.81	1,124.07	3,723.38	228.47	6,077.36	4522
March	2.0		788.27	29.24	917.61	3,039.49	186.51	4,961.11	3691
April	8.5		532.08	19.73	619.39	2,051.66	125.89	3,348.75	2491
May	15.0		275.89	10.23	321.16	1,063.82	65.28	1,736.39	1292
June	19.5		98.53	3.65	114.70	379.94	23.31	620.14	461
July	22.5		19.71	0.73	22.94	75.99	4.66	124.03	92
August	21.5		19.71	0.73	22.94	75.99	4.66	124.03	92
September	17.0		197.07	7.31	229.40	759.87	46.63	1,240.28	923
October	10.0		472.96	17.54	550.57	1,823.69	111.91	2,976.67	2215
November	5.0		670.03	24.85	779.97	2,583.57	158.53	4,216.95	3137
December	-0.5		886.80	32.89	1,032.31	3,419.43	209.82	5,581.25	4152
Yearly Totals			5,951.43	220.73	6,927.96	22,948.15	1,408.15	37,456.41	27868

42 Wolbach: Additional continuous board insulation

42 Wolbach	Floor Area (sq ft)	Ceiling/Roof Area (sq ft)	Concrete Wall Area (sq ft)	Ext Wood Wall Area (sq ft)	Window Area (sq ft)	Door Area (sq ft)
Basement	1457		1364	528	76	18
1st Floor	2228	107		1278	314	35
2nd Floor	2133	2133		1648	210	
Total Area	5818	2240	36	2073	600	53
R-vaule		30	13	15.15	5	3
		5.28	2.288	2.6664	0.88	0.528

	SI Units		Q=U*deltaT*A	comfort temp = 22C					
42 Wolbach		Floor Area (sq m)	Ceiling/Roof Area (sq m)	Concrete Wall Area (sq m)	Ext Wood Wall Area (sq m)	Window Area (sq m)	Door Area (sq m)		
Basement		135.36		126.72		7.06	1.67		
1st Floor		206.99	9.94		118.73	29.17	3.25		
2nd Floor		198.16	198.16		153.10	19.51			
Total Area (square meters)		540.51	208.10	3.34	192.59	55.74	4.92		
U-Value (W/m²K)			0.19	0.44	0.38	1.14	1.89		
Month	average temp (c)							Monthly Totals	24/7
January	-4.0		1,024.75	38.01	1,877.92	1,646.92	242.46	4,830.06	3594
February	-2.5		965.63	35.81	1,769.58	1,551.90	228.47	4,551.40	3386
March	2.0		788.27	29.24	1,444.55	1,266.86	186.51	3,715.43	2764
April	8.5		532.08	19.73	975.07	855.13	125.89	2,507.91	1866
May	15.0		275.89	10.23	505.59	443.40	65.28	1,300.40	967
June	19.5		98.53	3.65	180.57	158.36	23.31	464.43	346
July	22.5		19.71	0.73	36.11	31.67	4.66	92.89	69
August	21.5		19.71	0.73	36.11	31.67	4.66	92.89	69
September	17.0		197.07	7.31	361.14	316.71	46.63	928.86	691
October	10.0		472.96	17.54	866.73	760.12	111.91	2,229.26	1659
November	5.0		670.03	24.85	1,227.87	1,076.83	158.53	3,158.11	2350
December	-0.5		886.80	32.89	1,625.12	1,425.22	209.82	4,179.86	3110
Yearly Totals			5,951.43	220.73	10,906.39	9,564.79	1,408.15	28,051.48	20870

42 Wolbach: Triple pane glazing

	Dale End Dogs							
	Rough Estimates Based on Current Conditions and Assumptions							
	Dogs	Floor Area (sq ft)	Ceiling/Roof Area (sq ft)	Ext Wood Wall Area (sq ft)	Window Area (sq ft)	Door Area (sq ft)		
	Shed 1	289	306	405	18	36		
	Shed 2	289	306	405	18	36		
	Shed 3	289	306	405	18	36		
	Office	160	187	252	36	54		
	Total Area	1027	1,106	1467	90	162		
	R-Value		30	15.15	2.084	3		
US UNITS			5.28	2.6664	0.366784	0.528		
	SI Units		Q=U*deltaT*A	comfort temp = 22C				
	Dogs	Floor Area (sq m)	Ceiling/Roof Area (sq m)	Concrete Wall Area (sq m)	Window Area (sq m)	Door Area (sq m)		
	Shed 1	26.85	28.47	37.63	1.67	3.34		
	Shed 2	26.85	28.47	37.63	1.67	3.34		
	Shed 3	26.85	28.47	37.63	1.67	3.34		
	Office	14.86	17.33	23.41	3.34	5.02		
Total Area (square meters)		95.41	102.75	136.29	8.36	15.05		
	U-Value (W/m²K)		0.19	0.38	2.73	1.89		
Month	average temp (c)						Monthly Totals	
January	-4.0		505.97	1,328.95	592.70	741.11	3,168.73	2358
February	-2.5		476.78	1,252.28	558.51	698.36	2,985.92	2222
March	2.0		389.21	1,022.27	455.92	570.09	2,437.49	1813
April	8.5		262.72	690.03	307.75	384.81	1,645.30	1224
May	15.0		136.22	357.79	159.57	199.53	853.12	635
June	19.5		48.65	127.78	56.99	71.26	304.69	227
July	22.5		9.73	25.56	11.40	14.25	60.94	45
August	21.5		9.73	25.56	11.40	14.25	60.94	45
September	17.0		97.30	255.57	113.98	142.52	609.37	453
October	10.0		233.53	613.36	273.55	342.05	1,462.49	1088
November	5.0		330.83	868.93	387.54	484.57	2,071.86	1541
December	-0.5		437.86	1,150.05	512.91	641.35	2,742.17	2040
Yearly Totals			2,938.53	7,718.12	3,442.22	4,304.16	18,403.03	13692

Dale End Dogs: Energy consumption estimations