Spring 2021

Suburban Tiny Home Development

Colin Wood

Paul Carr

Chris Wang

SANTA CLARA UNIVERSITY

Department of Civil, Environmental, and Sustainable Engineering

I hereby recommend that the

SENIOR DESIGN PROJECT REPORT

Prepared under my supervision by

COLIN WOOD

&

PAUL CARR

&

CHRIS WANG

entitled

SUBURBAN TINY HOME DEVELOPMENT

be accepted in partial fulfillment of requirements for

the degree of

BACHELOR OF SCIENCE IN CIVIL, ENIRONMENTAL, AND SUSTAINABLE ENGINEERING

DocuSigned by:

Tonya Nilsson

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6/9/2021

Advisor Date

DocuSigned by:

Ed Maurer

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6/9/2021

Chairman of Department Date

SUBURBAN TINY HOME DEVELOPMENT

by

Colin Wood

&

Paul Carr

&

Chris Wang

SENIOR DESIGN PROJECT REPORT

submitted to

the Department of Civil, Environmental, and Sustainable Engineering

of

SANTA CLARA UNIVERSITY

in partial fulfillment of requirements for
the degree of
Bachelor of Science in Civil, Environmental, and Sustainable Engineering

Santa Clara, California
Spring 2021

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SUBURBAN TINY HOME DEVELOPMENT

Colin Wood, Paul Carr, and Chris Wang

Department of Civil, Environmental, and Sustainable Engineering

Santa Clara University, Spring 2021

Abstract

This project aimed to capitalize on a future trend in housing that allows for new sustainable housing solutions. Due to advancements in the virtual workplace catalyzed by COVID-19, virtual work and virtual work platforms have been normalized, allowing people who live in cities greater flexibility in where they choose to live. Many companies, including Facebook, Google, and Microsoft, have implied that they will likely keep remote work as an option indefinitely, allowing for increased flexibility in workers' living situations. This change allows for employees to venture outside of the city to suburbs or even rural areas. The goal of this project was to assess one possible sustainable living option given this likely trend: a suburban tiny home community. The scope of this project included the design of a model tiny home structure, the design of water resource systems to meet in-home community water demands, the municipal design of the development, and a construction cost estimation of a single tiny home. It did not deeply explore further details such as the electricity or agriculture, which may be expanded upon in future iterations of this project.

Table of Contents

Introduction

In the era of climate change, the consequences of 200 years of unregulated industrialization are becoming increasingly known and understood. It is widely accepted among scientists that climate change is a human issue and that it must be wholeheartedly addressed [1]. If climate change continues to accelerate, sea levels will rise, agricultural crops and drinking water will become sparser, and natural disasters will grow more common and extreme [2]. The effects of climate change call for a fundamental change in societal living norms. Carbon Dioxide emissions must be severely decreased and more sustainable habits must be widely adopted [3].

One roadblock in finding sustainable solutions to the problem of overuse is the unsustainable infrastructure of cities. In his paper about sustainability and urban infrastructure, Tomaz Dentinho, an expert in environmental economics, argues that cities that grow without centering sustainability suffer from the 'tragedy of the commons' [4]. There are two contributing factors to this: first, when people are separated from the source of their water and power and have no reason to regulate their use, they tend to use freely [4]. Second, when a large population is concentrated in a small area, the land cannot provide for everyone unless resources are renewed at the rate of use. The result, Dentinho says, is resources being used at a higher rate than the surrounding environment's ability to supply these resources [4]. Since so many people living in cities already rely on these unsustainable urban infrastructures, it is difficult to make significant shifts in city living standards. While there is great work being done in the field of green infrastructure to make cities more sustainable, there is also room to look outside the city to something that centers sustainability in its conception instead of attempting to reform deeply unsustainable practices.

The idea of a modern sustainable community has not yet been normalized to the point where it is seen as a viable alternative to city living. This is largely due to the fact that most economic activity takes place within the city, forcing most people who are aiming to work in a lucrative job sector to look towards the city [5]. However, since the COVID-19 pandemic, remote work has become much more common. In many cases, the option to work remotely will remain indefinitely, allowing many people who previously needed to live in cities for work to migrate elsewhere while experiencing the same job market [6]. This creates a potential market opportunity for suburban housing communities. Mixed with the problem of climate change, this potential market is also an opportunity to center sustainability.

An off-grid, suburban tiny home community tackles the intersection of climate change and the added living flexibility many are experiencing due to COVID-19. Designing self-sufficient communities of small, sustainable tiny homes in suburban areas combats climate change while capitalizing on the changes society is experiencing due to the global pandemic. Overall, the community's methods of obtaining their water, power, and food and how the community will be organized with respect to transportation and community living must all be addressed.

This project looked at creating an outline of a tiny home community that can be replicated in a variety of locations. The design for this project focused on the criteria and challenges of the area around the city of Seattle. Overall, the goal of this project was to determine what it would look like to design a tiny home development from the ground up. This report aimed to assess the design options for a community of this nature and the difficulties and limitations that a project like this might face in future iterations. It focuses on Seattle and its suburbs because the wet environment allows for more water resource options. By analyzing this situation, other engineers or groups continuing this project in the future may take the findings and create a set of solutions to meet a community's demands in different climates. If a group were to pick up where this project leaves off, they could apply its findings to a specific location they decide to develop. This means they will be able to look at the demands of the development and easily determine what methods of water collection, construction, etc. to use based on the restraints of the location's climate. The scope of this project looks specifically at shelter, in-home water use, and municipal design. The scope of the overall project is significant, so further aspects of the development such as food, electricity, and fire safety will be left for future iterations of the project to determine.

To begin designing a development, a variety of parcels near Seattle were considered. The goal was to find a large, relatively flat piece of land that could be effectively divided into equally sized smaller lots. Ultimately, a 68 acre parcel of land about 40 miles outside of Seattle was chosen (Figure 1 and Figure 2). The geography of this parcel was analyzed to determine the best methods of meeting the needs of community members. For in-home water use, rainwater catchment and well water proved to be capable of meeting water demands. For the structure of the tiny house, a 250 square foot (ft^2) single story tiny house was chosen to accommodate for the needs of having enough space to work remotely, as well as ensuring it to feel as home-welcoming as possible. The tiny house will be constructed out of timber because it is the most cost effective and most sustainable material for the scale of the full project.

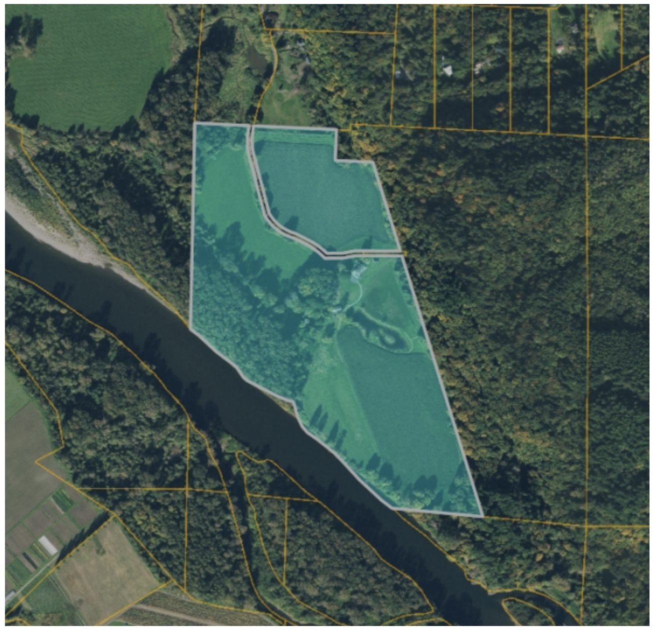


Figure 1: Outline of the Parcel.

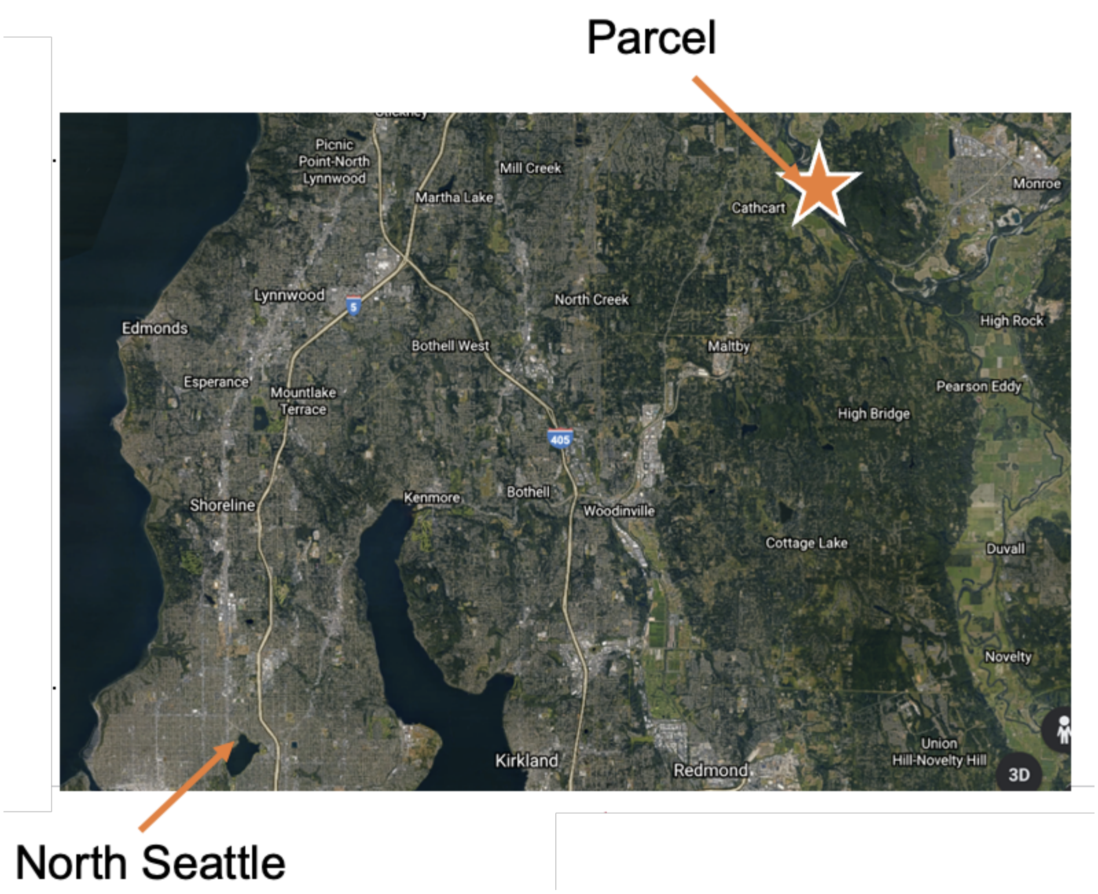


Figure 2: Location of the Parcel.

Comparative Alternative Analysis

In deciding on a location, the goal was to pick a region that matched the intentions of the project and allowed for as many design options as possible. To do this, three general locations were considered: Chicago, San Jose, and Seattle. Table 1 shows an alternative analysis of the three (3) locations. In this analysis, each option was ranked from best to worst, with the number 1 representing the best choice in that category and the number 3 representing the worst. Next, each criteria was given a weight of importance. Availability of water and potential for remote work were each given a weight of 2x because of their relevance to the goals of this project. Finally, the ranks for each alternative were summed, with the lowest total score representing the best option.

Table 1: Comparison of Potential Locations.

	Availability of Water (2x)	Potential for Remote Work (3x)	Cost	Hazard Possibility	Totals
Chicago	1	3	1	3	14
San Jose	3	1	3	2	14
Seattle	1	2	2	2	11

After adding the rows, the greater Seattle area was chosen as the most favorable location to design the desired community. Most importantly, Seattle experiences a significant amount of rainfall and is a hotspot for jobs in the tech industry [7]. San Jose has even more potential for remote work with Silicon Valley nearby, however the lack of options for water resources vastly decreases the feasibility of a self-sustaining community. Chicago's lesser potential for remote work made it a less favorable option despite its water availability [8].

With the location chosen, there were three main pieces within the scope of this project: the structural design of the homes, water resource systems, and the municipal layout of the development. Alternatives will be compared for each aspect of the project in the following sections.

Structural Alternative Analysis

The structural design of the homes were designed to meet the accommodations of someone who is working in tech related industries or any company that has allowed their employees to work remotely from home. This means that employees can live in tiny homes away from the city, but at the same time feel like the tiny house has everything that a normal house in the city would provide for them.

When designing the tiny houses, the primary material that was decided on was timber. Using timber would not only tackle the issue of civil engineers combating climate change, but also through research on price comparison between steel and concrete, timber was a more cost effective choice. Both the architectural and structural design of the house was pretty simple. Each tiny house was designed to be 250 square feet (ft^2). Each tiny house would include space for a living room, kitchen, full bathroom, and a bedroom.

As society increasingly progresses towards advanced technology, more and more carbon embodied materials are being used. The result of society progressing has caused a major issue in today's world. That issue is climate change. The design of the tiny homes in this project not only focuses on creating an opportunity for those that have been impacted by COVID-19 in relation to their work, but also more importantly, tackle the issue of climate change. There are currently very few mainstream sustainable living options. The infrastructure in cities is very outdated and unstainable. Furthermore, it is difficult to make significant changes in city infrastructures due to many people relying on these outdated infrastructure. Due to these reasons, the choice of designing the tiny house out of timber is a solution that will center sustainability from the start.

Timber has an advantage over other materials such as concrete and steel. By using timber to design the tiny houses, it allows for residents to reduce the amount of carbon footprint on society. This is due to the fact that timber naturally stores carbon but at the same time avoids any greenhouse gas emissions. In modern engineering, most skyscrapers are made of steel. This is an issue because steel produces about 8% of the global CO_2 emissions. A single story house built out of steel averages at about 40-45 tons of steel. However, since these homes are tiny houses and not regular sized houses, a rough estimation of about 15-20 tons of steel would be used. For each ton of steel being used, approximately 1.85 tons of CO_2 is being emitted into the atmosphere. For each tiny house, if it were to be built out of steel, it would generate up to 37 tons of CO_2. However, by designing and building these tiny houses out of timber, the timber, instead of emitting, essentially sequesters at a minimum of 37 tons of CO_2 per tiny house. Sustainability was not the only deciding factor in why timber was chosen to design the tiny homes. Table 2 below provides a comparison with a ranking system from 1-5, 1 being the best and 5 being the worst, between the different types of materials that were considered based on the following requirements.

Table 2: Comparison of Potential Building Materials.

	Sustainability	**Cost (low cost)**	**Difficulty(constructability)**	**Total**
Timber	2	2	1	5
Steel	5	5	4	14
Concrete	3	4	3	10

As seen in Table 2 above, timber exceeds in not only sustainability over steel and concrete, but also in being the most cost effective and being the material that requires the least amount of skill to build with. After comparing the three different alternatives, timber was chosen to design the tiny house.

Water Resources Alternative Analysis

For the water resource system, there were a few options for systems to meet the demand of the development. Given that the parcel is not located in a city water district, the collection system must be off the grid. This left the options of rain water, surface water, groundwater, snowmelt, and sourcing water from outside the development (trucks bringing water to the development). In terms of sustainability, self sufficiency is important, and it is unreasonable to bring water in from outside the development if demands can be met from within. For this reason, bringing water from outside was seen as a last resort for when there was no way to meet demands with the water that flows through the bounds of the parcel. Another option that was not explored deeply in this context was snowmelt. Monroe, the closest town to the parcel, experiences only three (3) inches of snow per year, meaning snowmelt is not a viable option in meeting water demands. This left rainwater, groundwater, and surface runoff. All of these were viable options in the context of the development, however surface runoff was not explored in this project because a pre-existing well, capable of meeting all demands, was found on the parcel. In the future, surface water may be considered in meeting other water demands, such as fire safety or irrigation. This project covers a rainwater collection and storage system and a well water system to meet in-home demands.

Another set of alternatives that were explored in order to understand the design criteria for the water resource systems of the development was sewage management. The three options were a septic system, composting toilets, and tying into the grid. Table 3 shows an alternative analysis between these three options. This analysis was done with the same scoring convention as Table 1, ranking each alternative from 1 to 3, assigning weights to the scoring criteria, and summing up totals to find the lowest score. Water use was given a 1.5x weight due to the emphasis this project places on sustainability. Cost, constructability, and lifespan were all given an even weight of 1x. Usability was given a weight of 3x as it proved extremely difficult to justify making a decision for users that greatly impacts their experience when compared to living outside development. In other words, the difficulty of use associated with composting toilets was too much to expect the average resident to accept.

Table 3: Toilet Alternative Analysis.

	Water use (1.5x)	Cost	Constructability	Usability (3x)	Lifespan	Totals
Septic	3	2	2	1	1	11.5
Composting	1	1	1	3	2	14.5
Tie-in	3	3	3	1	1	12.5

After adding each row, the septic, composting, and tie-in toilets received scores of 11.5, 14.5, and 12.5 respectively. Since the septic system had the lowest score, it was deemed the best option. As mentioned, while the composting toilet is extremely easy to implement and uses no water, its unfamiliarity and the general dislike of human waste made it unreasonable to expect the average person to use it. Since tying into the grid would require the construction of a new sewer line and the parcel is thousands of feet from the nearest line, it is by far the most expensive and difficult to implement option. Since the development is relatively small, septic toilets are a better option than tying into the grid. Given the sustainability benefits of composting toilets, residents should be given the option to use composting toilets. That is, it should not be a given that a septic system will be installed in constructing every house. In estimating the demand of each house and the community at large, however, a septic system was assumed to be installed at each house.

Municipal Alternative Analysis

The municipal portion of this project had many alterations during its design. Towards the very beginning of the project, there was a great deal of deliberation on the location of the community. The greater Seattle area was eventually chosen and potential parcels were ranked by their attributes. Initially there was one other parcel that a basic municipal layout was drawn for. However, this parcel was deemed less desirable due to price, existing foliage, and water availability. Once the team chose the final plot of land, there were two versions of the lot layouts, one with 100 lots and one with 70 lots. The 70 lot layout was chosen because the amount of water required to service 100 houses was not feasible given the rainwater runoff amounts and well drawdown times. An added benefit of the 70 lot layout was that it gave the residents two recreation and community areas that could also be developed in the future. These areas also house the well, well-water storage, and the pond which provide water for the community. Choosing the 100 lot layout would not only give the community no place to expand, but it would also mean more water consumption which would put strain on the water system. This would mean having to transport water at various times when the community was running low, which would create higher homeowners association fees as well as being a less sustainable design. The choice of the 70 lot design also allowed the team to have room for multiple bioretention ponds that service the property.

The drainage system for the community was a challenge due to the lack of a municipal storm drain system as well as a close proximity to the Snohomish River. The team looked into many filtration options including different types of sand filters and even having a small filtration system. However, these options were either not adequate in decontaminating the runoff or too expensive to be viable. In the end, a bioretention swale was chosen which combines 30 inches of engineered soil and aggregates in order to effectively filter the contaminated runoff from the community. Initially the bioretention swales were situated on the western and south western edges of the community. However, these locations were designated as being too close to the river, and the team decided to not risk any unforeseen pollution so the swales were then moved to the north eastern side of the property. The different iterations of the property layout was a struggle but ended up helping the final design become even better through trial and error.

Design Criteria & Standards

Structural Design Criteria & Standards

Each tiny house will be 250 square foot (ft^2), and will include a kitchen/living room, a bathroom, and a bedroom. The tiny houses will have a sloped roof to assist with the rainwater catchment that will be discussed later in this report. The interior of the tiny house was designed to provide a livable and workable home for tech employees that have chosen to work remotely and also want to reduce their carbon footprint on society. The design of the interior tiny house can be seen below in Figure 3.

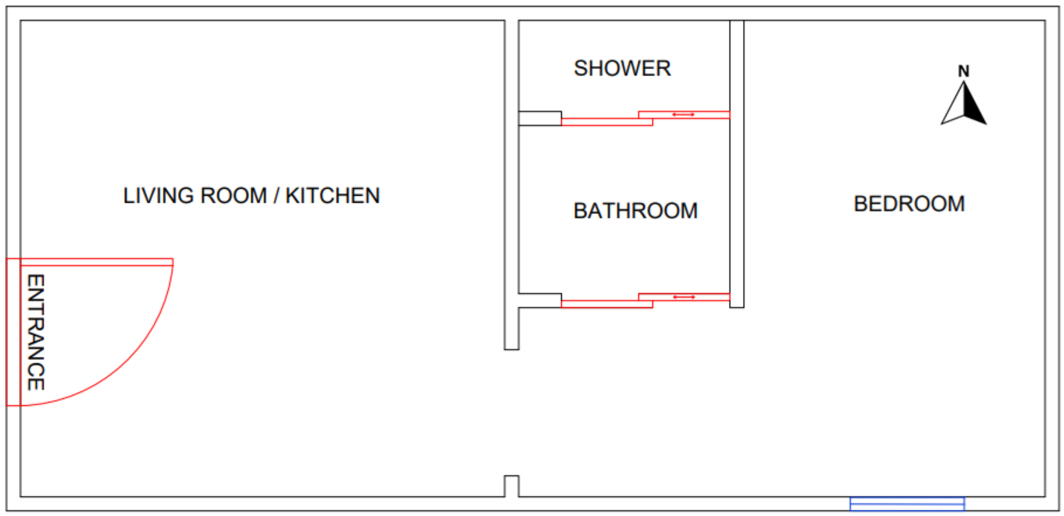


Figure 3: Floor plan of tiny house.

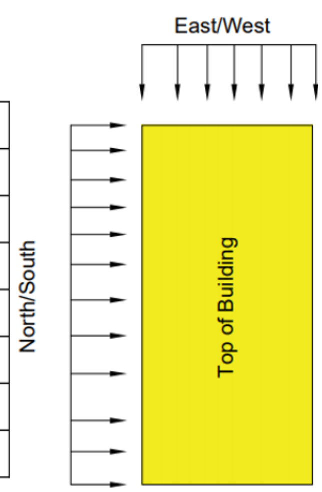
To assist the design for the tiny house, a list of resources were utilized. These sources include; 2018 National Design Specification for Wood Construction [9], California Building Code [10], Special Design Provisions for Wind & Seismic (SDPWS) [11], Seattle SDCI - Seattle Building Code [12], Design of Wood Structures ASD/LRFD - 6th Edition [13], and the ASCE 7-16 [14].

During the design phase of the house, the members chosen for the framework of the houses were all based on calculations as shown in Appendix E-M. In terms of design for gravity loads, dead load was calculated as shown in Appendix E by taking into consideration the weight of the roof rafters along with plywood over the roof rafters and a sheet metal on top of the plywood to assist with rainwater catchment. For the wind load, using the ATC Hazard by Location that is developed by the Applied Technology Council located in Redwood City, California [15], the maximum wind load of 98 miles per hour (mph) for a risk category 2 was chosen for the plot of land in Snohomish County. The exposure that was used for the calculation was exposure C due to the openness of the parcel that was chosen. Using these data, the maximum wind speed from both north-south and east-west directions were calculated to be 15.3

pounds per square foot (psf) per ASCE 7-16 [14]. The worst case total wind shear was calculated to be 6.24 kips at the roof as shown in Appendix I.

Figure 4: Wind load values for chosen parcel.

Building Risk Category	2	Internal Pressure Coefficient, GC_{pi}	+/- 0.18
Wind Speed, V	98 mph	External Pressure Coefficient	
Wind Directionality Factor, Kd	0.85	Roof Type	Sloped
Topographic Factor, Kzt	1.0	Exposure	C
Ground Elevation, Ke	1.0		
Gust Effector	0.85	Velocity Pressure Exposure Coefficient, K_z	0.85
Maximum NS Wind (PSF)	15.277	**Maximum EW Wind (PSF)**	15.277



In terms of the seismic load, after carefully looking through the PDS Map Portal provided by the Snohomish County Planning and Development Department [16], it was determined that the soil site class of the chosen parcel was soft clay soil. This meant that the classification of the soil type would be type E. This type of soil is difficult to work with and would not typically be recommended to build on because of how susceptible to moisture fluctuations. Clay will expand when it becomes wet and contract when it is dry. Building on type E soil will ultimately result in having deeper footings, use of drilled piers and even pre-tensioned slabs. However, because the class of the soil was determined midway through the project, choosing a different parcel was not possible. With the given information on the parcel, similar to the wind load calculations, the address and data collected was plugged into the ATC Hazardby Location provided by the Applied Technology Council [15] to determine the necessary values to determine the seismic spectrum parameters. However, due to the site classification, only the ground motion (S_s) and (S_1) values were provided. This meant that the other basic seismic parameters such as the site-modified spectral acceleration value (S_{MS}) and the numeric seismic design values (S_{DS} and S_{D1}) were determined by using ASCE 7-16 Chapter 11 & 12 [14]. To begin determining the missing seismic parameters, the site coefficient (F_a) was determined to be 0.9 by using Table 11.4-1 in the ASCE 7-16 Chapter 11 [14]. After determining the site coefficient, the site-modified spectral acceleration value (S_{MS}) and numeric seismic design value (S_{DS}) can be determined by referring to ASCE 7-16 11.4.3 and ASCE 7-16 11.4.4 [14] respectively. The site-modified spectral acceleration value (S_{MS}) was calculated to be 1.148 by multiplying the site coefficient (F_a) and ground motion (S_s). The numeric seismic design value (S_{DS}) was calculated to be 0.765 by multiplying the site-modified spectral acceleration value (S_{MS}) by two-thirds. These calculations can be seen in Appendix J. Using the seismic parameters from ATC Hazard by Location along with the calculated seismic parameters, the total seismic weight estimate that included the weight of the roof and walls was 1.455 kips.

Though the design of the tiny homes were fairly simple, all the calculations were calculated by hand so that going through the process would be considered a learning experience on how to design a house from scratch. During the process, no prescriptive models or residential code methods were used. Although the tiny home community is located in Snohomish County in Seattle, the California Building Code was referenced for a better understanding on design specifications required for design in California.

Water Resources Design Criteria & Standards

Seattle and the areas surrounding it are known for having a significant number of rainy days due to their windward orientation to the Cascade Mountains [17]. According to PRISM, a climate group that specializes in collecting climate data in the United States, the location of the parcel averaged 46.18 inches of rain per year between 1981 and 2010 [18]. The 300 square foot (ft^2) roofs of the tiny homes allow each home to catch up to 8,600 gallons of water per year without accounting for the runoff coefficient of the roofing material. The roof's runoff coefficient was determined according to the Storm Water Management Model 5 (SWMM5), a resource used to predict runoff quality and quantity [19].

In terms of water demand, the goal was to make this community sustainable but still attractive for those who wish to live comfortably. This means the per person demand accounted for a dishwasher, washing machine, and shower. According to Finish brand, a standard dishwasher uses about three (3) gallons of water per cycle and is more efficient than hand washing dishes with the exception of highly efficient handwashing techniques that cannot be expected of every resident [20]. There are no reputable statistics available on how frequently the average American household washes dishes, but it is largely dependent on the size of the household. For this project, it was estimated that each person will use the dishwasher an average of two times per week, yielding six (6) gallons of water per person per week. While it is unlikely that a two person household will use exactly twice as many dishes as a one person household, there was no better way to make this estimation and it is better to be conservative. This estimate was used for every person in the development, regardless of the size of household. Washing machines have become much more efficient in recent years [21]. It is possible to find washing machines that wash clothes adequately while only using seven (7) gallons of water per cycle, as opposed to the 40 gallons of the 20 year old washing machine. Washing machines can even use as little as two (2) gallons per cycle, but Consumer Reports states that the lowest use washing machines do not work well [21]. Their recommendation for the best washing machine that uses the lowest amount of water is a machine that uses seven (7) gallons per cycle [21]. This number, along with an estimate of two cycles of clothes per week per person yields an estimated 14 gallons of water per person per week for clothes washing. According to the EPA, the average shower is eight (8) minutes long [22]. Ideally, residents of a tiny home development would take shorter showers in the spirit of sustainability, but it is not reasonable to control this, so the eight (8) minute value was used. Shower water use varies heavily depending on the shower head, so it is important to use a low flow shower head in order to conserve water. For this project, a commercially available low flow shower head that uses 1.5 gallons per minute was used [23]. Assuming each person takes the average eight (8) minute shower once a day, each person will use 12 gallons of water per day to shower. According to MayoClinic, a healthy amount of water to drink per day is about 0.85 gallons [24]. For the total demand estimation, this was rounded up to one gallon per person per day. Sinks used for washing hands, brushing teeth, and other uses account for one gallon per person per day.

For toilets, the alternative analysis found that composting toilets have yet to gain social acceptance, making them unrealistic to require. For this reason, a septic system with normal flushing toilets was assumed for each tiny home in determining the demand design criteria. Toilets are another appliance that have improved in terms of their water use in recent years. It is reasonable to assume 0.8 gallons per flush based on toilets are available on the market [25]. With an average of five (5) flushes per person per day, four (4) gallons of water per person per day were added to the total demand [26]. Every appliance together yields an average daily demand of 20.85 gallons per person, but to account for the significant uncertainty in the frequency and intensity at which these appliances may be used, a value of 30 gallons per person per day was used as a starting point to design water resource systems for the development. ASCE's Field Guide to Environmental Engineering Development Workers was used to outline methods of storage design [27].

The 30 gallon per day demand was the basis for this project and only takes into account in-home water use. Fire suppression, a crucial component of any water system, was left out of the scope because the high instant water demand could not feasibly be drawn from the water source options examined in this project. Similarly, with limited foresight of the way food demands would be met in this community, irrigation was left out of the scope. There are options available, such as surface water and outside sources, to meet these needs, however their high demands and independent sourcing justifies focusing on systems of meeting in-home demands separately.

For the well water system, a well report was found for a pre-existing well located on the development [28]. The well report, Figure 5, included significant information that the well analysis and pump design stemmed from. The well is drilled 125 feet deep with a diameter of six

(6) inches. Water was found 40-50 feet deep in a layer of sandstone. In a well test, a pump rate of 33 gallons per minute yielded a 30 foot drawdown after two (2) hours of pumping. With uncertainty around the characteristics of the aquifer, critical assumptions were made in order to estimate the aquifer's storativity. To define the type of aquifer, the soil types above the water level specified in the well report, as well as the depth of water were examined. Most of the soils above the water level were permeable, though there was a nine-foot layer of brown clay mixed with gravel from six to 15 feet below the surface. Despite this low permeability layer, it was assumed that there is a chance for water to seep through the ground into the aquifer. Unconfined aquifers are characterized by surface water flowing through permeable layers of soil into the aquifer and they usually occur closer to the surface than confined aquifers, which have impermeable layers above and below. According to the well report, water is first found at 40 feet below the surface, a relatively shallow depth that strengthens the case for an assumption of an unconfined aquifer. Taking what was known about the aquifer into account, a storativity value of 0.1 was estimated. This value is on the lower range of values for unconfined aquifers because of the clay layer. In the future, this value should be more extensively researched with a full drawdown-recovery test to gain greater confidence in the results of this report.

These values were used to analyze the well's yield and drawdown and recovery and determine to what extent the well would be capable of meeting community water demands. This analysis was done according to the Freeze and Cherry Groundwater Hydrology Text [29]. The Cengel and Cimbala fluid mechanics text was used to define a pump to move water from the well into storage [30]. For the well water distribution system, a range of 30-90 psi supplied to each home was used to control design according to Snohomish standards [31].

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report

WATER WELL REPORT
Original & 1st copy – Ecology, 2nd copy – owner, 3rd copy – driller

DEPARTMENT OF ECOLOGY State of Washington

Construction/Decommission *("x" in circle)*
☒ Construction
☐ Decommission *ORIGINAL INSTALLATION Notice of Intent Number* ______

PROPOSED USE: ☒ Domestic ☐ Industrial ☐ Municipal ☐ DeWater ☐ Irrigation ☐ Test Well ☐ Other ______

TYPE OF WORK: Owner's number of well (if more than one) ______
☒ New well ☐ Reconditioned *Method:* ☐ Dug ☐ Bored ☐ Driven
☐ Deepened ☐ Cable ☒ Rotary ☐ Jetted

DIMENSIONS: Diameter of well **6** inches, drilled **125** ft.
Depth of completed well **125** ft.

CONSTRUCTION DETAILS
Casing Installed: ☒ Welded **6**" Diam. from **+3** ft. to **22** ft.
☒ Liner installed **4**" Diam. from **5** ft. to **125** ft.
☐ Threaded ______" Diam. From ______ ft. to ______ ft.

Perforations: ☒ Yes ☐ No
Type of perforator used **drill**
SIZE of perfs **1/2**in. by **1/2** in. and no. of perfs **20**from **85**ft. to **95**ft.

Screens: ☐ Yes ☒ No ☐ K-Pac Location ______
Manufacturer's Name ______
Type ______ Model No. ______
Diam. ______ Slot size ______ from ______ ft. to ______ ft.
Diam. ______ Slot size ______ from ______ ft. to ______ ft.

Gravel/Filter packed: ☐ Yes ☒ No Size of gravel/sand ______
Materials placed from ______ ft. to ______ ft.

Surface Seal: ☒ Yes ☐ No To what depth? **18**ft.
Material used in seal **BENTONITE**
Did any strata contain unusable water? ☐ Yes ☒ No
Type of water? ______ Depth of strata ______
Method of sealing strata off ______

PUMP: Manufacturer's Name ______
Type: ______ H.P. ______

WATER LEVELS: Land-surface elevation above mean sea level ______ ft.
Static level **40** ft. below top of well Date **10/12/17**
Artesian pressure ______ lbs. per square inch Date ______
Artesian water is controlled by ______ (cap, valve, etc.)

WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? ☒ Yes ☐ No If yes, by whom? ______
Yield: **33** gal./min. with **30** ft. drawdown after **2** hrs.
Yield: ______ gal./min. with ______ ft. drawdown after ______ hrs.
Yield: ______ gal./min. with ______ ft. drawdown after ______ hrs.
Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

Date of test **10/12/17**
Bailer test ______ gal./min. with ______ ft. drawdown after ______ hrs.
Airtest **30** gal./min. with stem set at **120** ft. for **2** hrs.
Artesian flow ______ g.p.m. Date ______
Temperature of water ______ Was a chemical analysis made? ☐ Yes ☒ No

CURRENT
Notice of Intent No. WE28813
Unique Ecology Well ID Tag No. **BJF105**
Water Right Permit No. ______
Property Owner Name **Paul Lund**
Well Street Address **15813 Shorts School Rd**
City Snohomish County Snohomish
Location SW1/4-1/4 SW1/4 Sec **05** Twn **27** R **06** **EWM** ☒ Or **WWM** ☐
(s, t, r Still REQUIRED)

Lat/Long
Lat Deg ______ Lat Min/Sec ______
Long Deg ______ Long Min/Sec ______

Tax parcel No. (Required) **27060500300200**

CONSTRUCTION OR DECOMMISSION PROCEDURE
Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information. (USE ADDITIONAL SHEETS IF NECESSARY.)

MATERIAL	FROM	TO
brown silt, sand, some gravel	**0**	**6**
brown clay, gravel	**6**	**15**
gray sandstone	**15**	**51**
brown sandstone, water	**51**	**52**
gray sandstone	**52**	**75**
brown sandstone, water	**75**	**76**
gray sandstone	**75**	

RECEIVED
DEPT OF ECOLOGY
MAY 18 2018
WATER RESOURCES PROGRAM
NORTHWEST REGIONAL OFFICE

Start Date **10/04/17** Completed Date **10/05/17**

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

☒ Driller ☐ Engineer ☐ Trainee Name (Print) **Brannon Hopke**
Driller/Engineer/Trainee Signature
Driller or trainee License No. **1825**
IF TRAINEE: Driller's ~~License~~ No:
Driller's Signature:

Drilling Company **Aquatech Well Drilling &Pumps Inc.**
Address **2675 Butler Crk. Rd.**
City, State, Zip **Sedro Woolley**, **WA, 98284**
Contractor's Registration No. **AQUATWDO4OK4** Date **10/20/17**

ECY 050-1-20 (Rev 02-2010) To request ADA accommodation including materials in a format for the visually impaired, call Ecology Water Resources Program at 360-407-6872. Persons with impaired hearing may call Washington Relay Service at 711. Persons with speech disability may call TTY at 877-833-6341.

Figure 5: Well Report for Pre-Existing Well on Parcel.

Municipal Design Criteria & Standards

First and foremost, the community has been designed with the homeowner in mind, beginning with each lot and expanding to the roads and community spaces. The desired acreage for each lot started as half of an acre in order to give residents ample space to have a large yard, garden, pond, or carport. Due to concerns about water availability, the design of the community was limited to a maximum of 75 lots. The ending design featured 70 lots with an average of 0.6 acres per lot, which exceeds the initial design criteria and allows for a slightly higher price point and profit. The largest lot is approximately one acre, while the smallest is 0.45 acre. Many of the lots along the left side of the property are uniform in design and have an acreage of 0.56.

In order to service up to 140 residents, 36 foot roads were needed to create a smooth traffic flow as well as room for streetside parking. The community spaces were designed with a total of 22.5 acres in order to fulfill the need for community amenities such as the well, water pump, and storage as well as room for future expansion.

Description of Designed Facilities

Structural Design

For the structural members of the house, since the design of the house was fairly simple, the members that were considered during the design process were the ceiling joists, roof rafters, exterior walls, and key headers that will be discussed more in detail. For both the roof rafters and the ceiling joists, No. 2 2x8 Douglas Fir Larch were chosen to structure the roof at 16 inches on center, with deflection controlling the design. The exterior walls were designed to be 2x6

Douglas Fir Larch at 16 inches on center as well. The typical connection from the roof rafter to the south wall can be seen below in Figure 6.

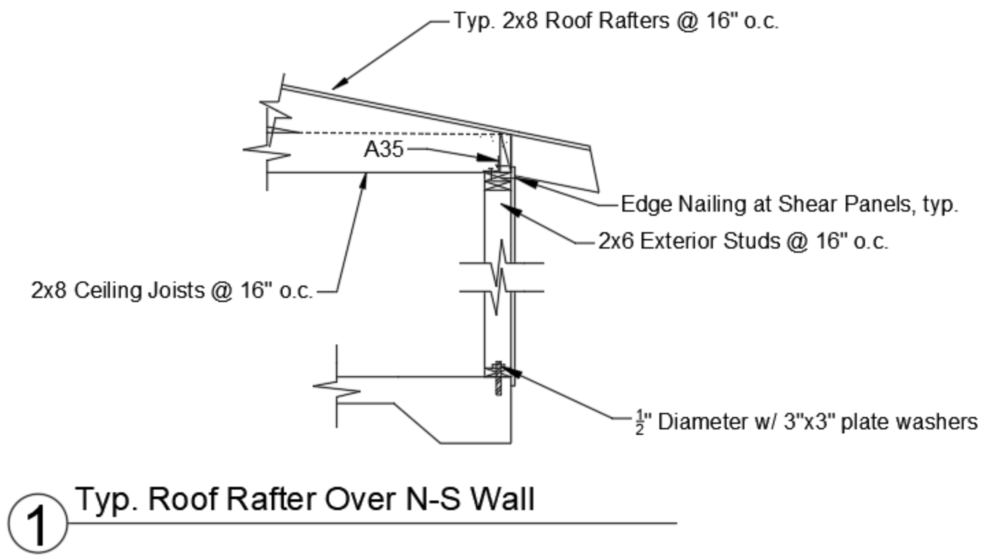


Figure 6: Typical Roof Rafter Over N-S Wall.

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The 2x8 roof rafter will be nailed into the ceiling joists. Blocking will be placed between each roof rafter to prevent any horizontal movement. An A-35 clip will then be placed to assist the nailing from the exterior plywood to the blocking to help transfer the load into the 2x6 exterior studs and into the foundation. A half (½) inch with 3x3 plate washers will be used to anchor the exterior studs concrete slab as shown in Figure 6 above.

When designing the architecture of the house, glass panels were incorporated into the design. Since there will be glass panels in the design of the house, having a post at the corner where the two glass panels meet will make the design aesthetically not pleasing. This design resulted in having to have two header beams on both the south wall and the west wall, where the south wall header is carried by the cantilever west wall header as shown below in Figure 7.

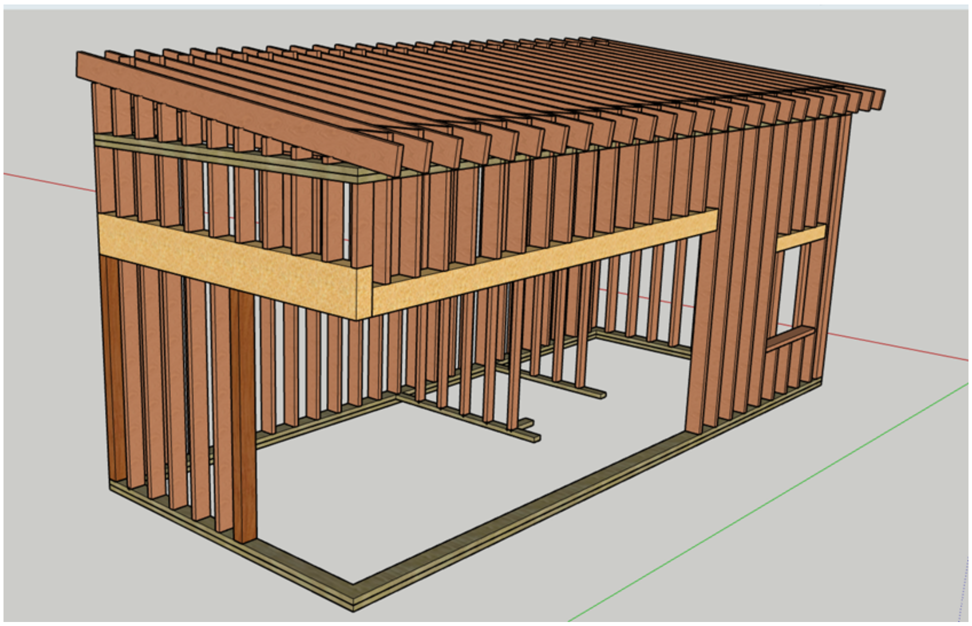

Figure 7: Structure Framing of Tiny House.

However, due to the length of the west and east wall being 10 feet long, the four (4) foot glass panel on the west wall turns the west wall from being ten (10) feet long to a six (6) feet long wall. The header on the west wall will sit on top of two 4x6 posts, one located at the north end of the beam and one located six (6) feet from the north end of the beam. On the south wall, there is also a 4x6 post that is located eight (8) feet away from where the west wall is connected to the south wall. A 6x8 No.2 Douglas Fir larch header for the south wall was sized to connect to the west wall header. Due to the design of the west wall, the standard rule of thumb to design for cantilever beams could not be utilized when designing for the header. Since the west wall header cantilever did not have a standard 2:1 back span cantilever ratio, in order to design and size for the proper header size, integration, as shown in Appendix M, was utilized to find that the best fit header would be a 6x14 parallam lumber to reduce the amount of deflection that would be caused by the southwall header. The controlling factor here is deflection caused by the shear force at the end of the south wall header being transferred over to the west wall header. This will result will cause more deflection on the west wall header. The south wall header will then be connected to the west wall header by using a Simpson Strong-tie HUC614. In Figure 8 and Figure 9 below, structural details are shown on how the headers will connect.

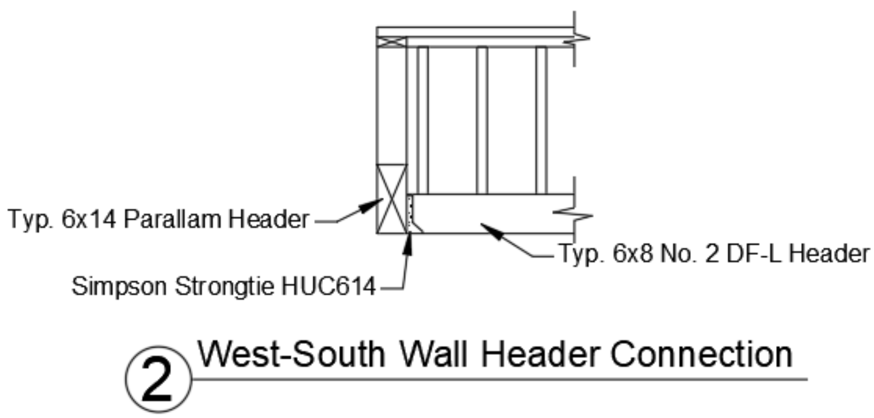

Figure 8: West-South Wall Header Connection.

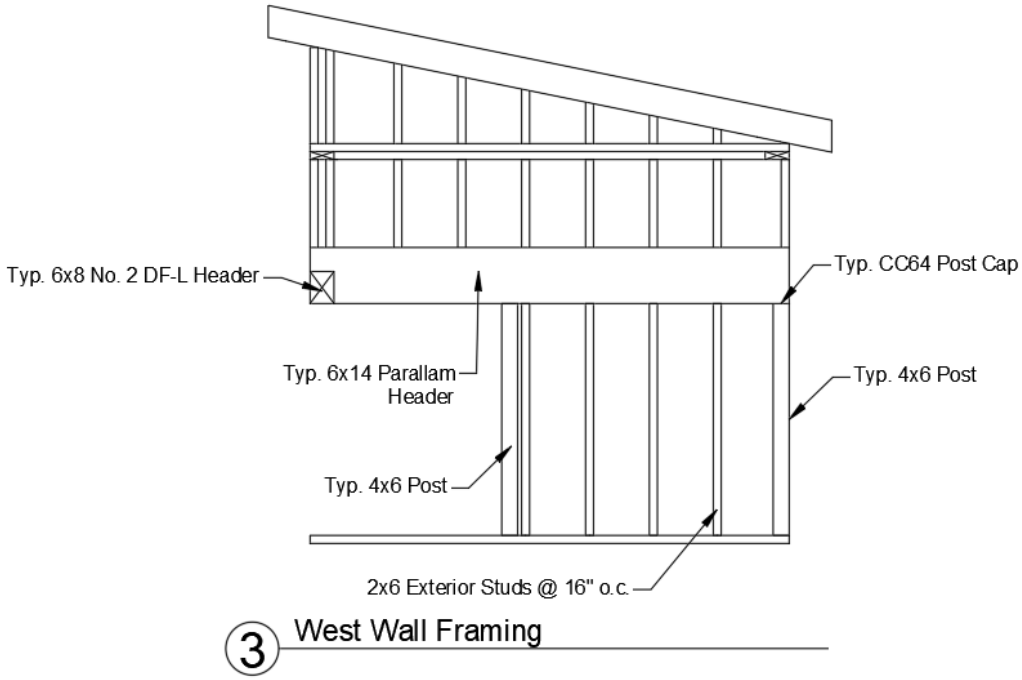

Figure 9: West Wall Framing.

In Figure 10 below, the shear wall plan is shown for the tiny house.There are four (4) shear walls that are applied to the tiny house. The most concerning is the west wall due to the short six (6) feet span. In order to prevent the west shear wall from tearing due to having too many nails on one side, shear panels were incorporated on both inside and outside of the wall. The 2018 National Design Specification [9] was utilized to help calculate the thickness of the shear panel and the nailing space, 15/32" plywood with 8d fasteners at four (4) inches on center was selected for the west wall. The three (3) remaining walls, in order to ensure that errors were minimized in applying the shear walls during the construction process, all shear panels were selected to have the same thickness and nailing spacing. In Figure 11, a detail shear wall schedule can be found.

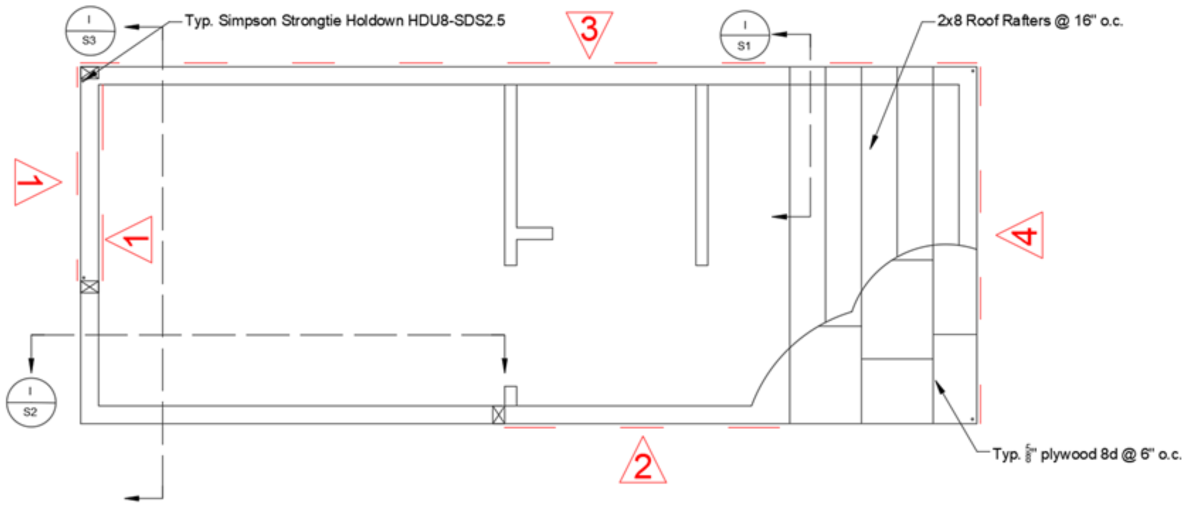

Figure 10: Shear Wall Plan.

Figure 11: Shear Wall Schedule.

Water Resources Design

There were five main design components in the scope of the water resources for this project:

1. A demand estimation to build the water resource systems according to.
2. An analysis of rainwater catchment as a way of meeting demand centering around the analysis of 40 years of daily rainfall data.
3. An analysis of a pre-existing well on the parcel's ability to meet demand.
4. The design of a pump and storage system for said well.
5. A distribution model in WaterGEMS to specify a distribution pump and pipe sizes.

The demand estimation was explained in depth in the Design Criteria section, as it creates the design criteria for the remainder of the water resource systems, which will be detailed in this section. To begin to understand the viability of rainwater catchment, an estimate of how much rainwater can be caught on the roofs of the tiny homes was made. As mentioned, given the 46.18 inch annual rainfall value and the roof area of 300 square feet, each house experiences an average of 8,600 gallons of runoff per year. The roof surface was chosen as corrugated sheet metal due to the material's zinc sealing, which reduces possible contaminants in runoff. With corrugated sheet metal, a runoff coefficient of 0.9 was chosen according to SWMM5 [19] and used in equation 1, from the ASCE manual [27], to calculate a total average yearly runoff of approximately 7,750 gallons per house.

$$V = P \times A \times C \qquad \text{(Eq. 1)}$$

Where P is the precipitation in inches, A is the catchment area, and c is the runoff coefficient.

With a yearly demand of 10,950 gallons per person, 7,750 gallons of rainwater catchment per house means up to nearly three fourths (¾) of the demand in a one (1) person household can be met with rainwater. Given the project's goal of sustainability, this rough preliminary viability test showed that though it does not fully reach demand, rainwater catchment is a promising method of supplementing other water sources in supplying water to the community.

The estimate of 7,750 gallons does not take into account the impossibility of storing all the rainfall in a year in a reasonably sized tank. Since rainfall dramatically fluctuates over the course of a year, picking a storage tank capable of catching all of the rainwater during the peak rainy season would result in an oversized tank that would sit nearly empty for the majority of the year. To find the right size storage tank, a storage analysis was performed according to methods based on those found in ASCE's Field Guide to Environmental Engineering Development Workers [27]. In this method, the amount of water in a storage tank at the end of any month, V_t , is calculated by adding runoff to the storage left in the tank at the end of the previous month, V_{t-1}, and subtracting demand: $V_t = V_{t-1} + \text{runoff} - \text{demand}$. When this method, using monthly data, is applied to the site of this project, it yields a maximum available storage capacity of 1,100 gallons (December) and minimum of zero gallons (July, August, September). A 1,100 gallon tank that sits completely empty for three months is not reasonable or realistic, pointing to an error in methodology. To provide more useful information about rainwater storage, the method found in ASCE's guide was expanded upon. A more complete picture of rainwater storage throughout the average year was found by analyzing 40 years of PRISM daily precipitation data in Microsoft Excel. In addition to the simple ASCE analysis, variables to account for a varying tank size, demand shortfall, overflow (spill), and percentage of demand met were added.

First flush was also taken into account. When it does not rain for a period of time, debris such as bird droppings, dust, trees, and anything else travelling through the air builds up on the roof surface. In a safe rainwater collection system, a first flush system diverts the early rainfall, which cleans the roof surface of debris, out of the system. To calculate the volume of water that should be diverted in a new rainfall event, a commercially available first flush diverter was found. In the details of the system, a specification of how to calculate the volume of first flush was given as 0.0125 gallons per square foot for minimal pollution and 0.05 gallons per square foot for substantial pollution. Substantial pollution is specified by the manufacturer as “Leaves and debris, bird droppings, various animal matter, e.g. dead insects, lizards, etc.” [32]. Given limited knowledge of the parcel and an assumption that all specified types of pollution are possible on the parcel, the substantial pollution value was used in this analysis, meaning 15 gallons of rainwater was subtracted from the total daily runoff when there was no rainfall on the previous day. This is not a perfect estimate since the first flush diverter will be most active after longer periods of no rainfall, and there will be little debris after a single day of debris accumulation. There are, however, few days where rain only ceases for a single day in a row and it is better to be conservative in these estimates [18].

Taking all of these variables into account, a summarization of data for both one and two person households was completed. There are two important variables to define in this summarization: (1) Days not reaching demand and (2) Overflow/Runoff. Days not reaching demand takes a storage tank size and counts the average number of days per year that the rainwater stored in the tank does *not* meet the 30 gallon per person requirement. This variable helps to measure the viability of rainwater collection in meeting demands and provides a measure of how well the given tank size utilizes the total runoff. With a small tank size, there will be very few days where demand is met because most of the runoff will spill out of the tank and as mentioned previously, a storage tank that is capable of catching all rainfall will sit nearly empty for most of the year. Overflow/Runoff is similarly given a tank size and returns the percentage of total runoff that spills out of the storage tank. Again, this variable provides an important measure of how much the tank size is able to utilize the total rainfall. In a particularly rainy part of the year, more rainwater will spill out. Together, these variables were used to find a tank size that optimizes the tank's utility, meaning it meets as much demand as possible and has less spill, but does not use an excessively large tank. Figures 12 and 13 show charts of these variables compared with tank size for the case of single person households. Figures 14 and 15 show the same graphs for the case of two person households.

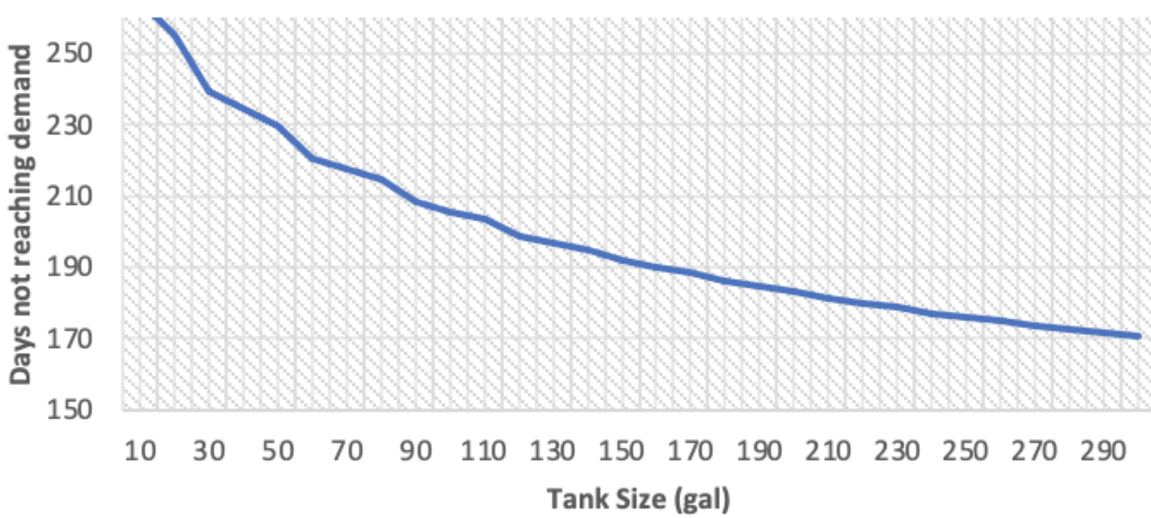

Figure 12: One Person Household Number of Days/Year Not Reaching Demand.

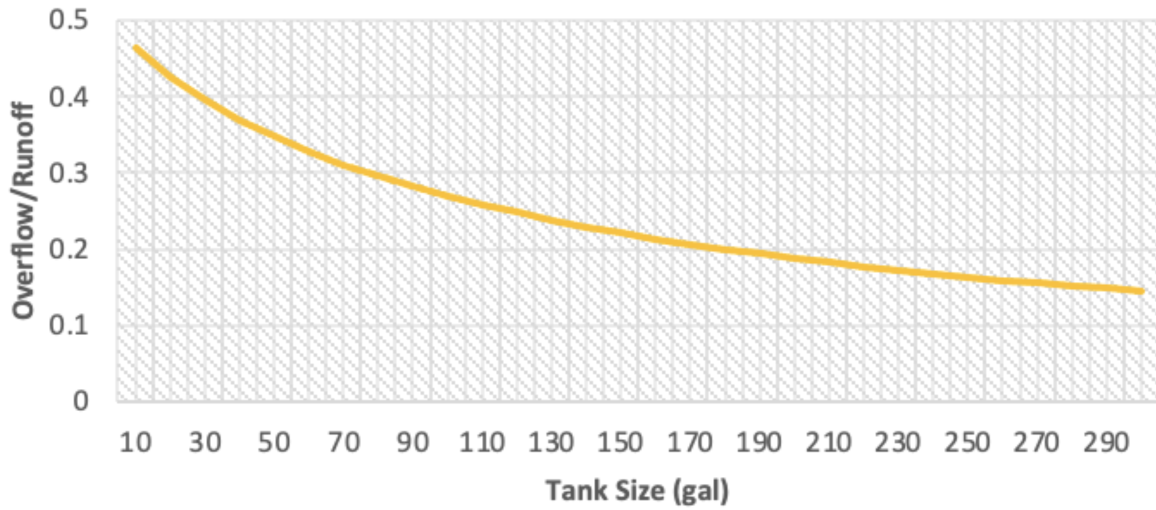

Figure 13: One Person Household Overflow/Runoff.

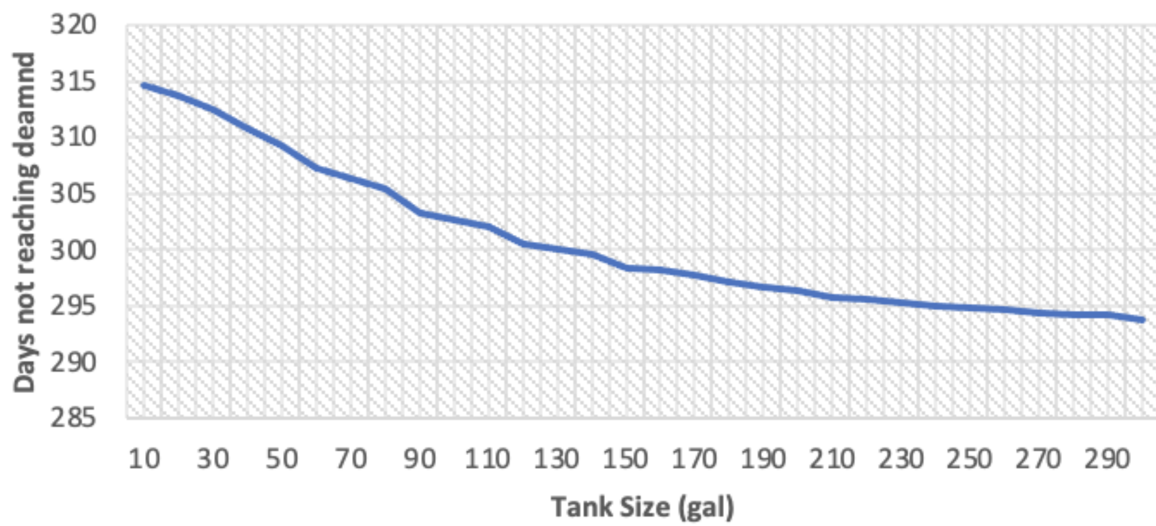

Figure 14: Two Person Household Number of Days/Year Not Reaching Demand.

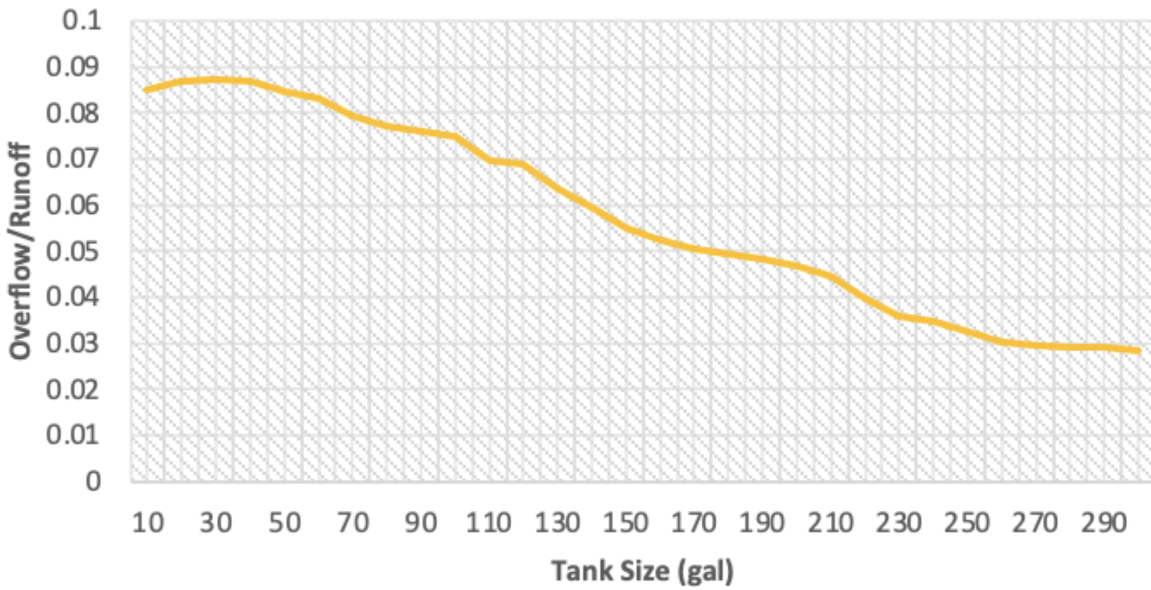

Figure 15: Two Person Household Overflow/Runoff.

In the graphs above, as the tank size increases, the unfavorable variable decreases but there is a diminishing return as tank size continues to increase. Looking at each figure, a tank size was chosen based on the slope and the curvature at that point. A smaller slope means the return has diminished and there is less reason to pick a larger tank. More favorable storage sizes also occur when the slope has recently decreased. For each size house, a 250 gallon storage tank was chosen as the best option given the results of the storage analysis. In a one person household, a 250 gallon tank will not meet demand for 175 days and 16% of runoff will spill out of the tank. For a two person household, there will be 292 days not reaching demand and only 3% of runoff will overflow. Overall, this means that rainwater is a viable and important way of reaching demand in this project, but other systems must be looked at in order to fully reach the demand.

Well water from the preexisting well on the parcel was considered as a supplemental method of meeting demands. To understand how much water could feasibly and sustainably be taken from the aquifer, an aquifer analysis based on the findings of the well report was performed. To simulate the aquifer's behavior under different pumping conditions, the variables required to calculate drawdown at different pump rates were first defined. To calculate unknown variables, the Cooper-Jacobs drawdown equation was used [29]. The Cooper-Jacob's equation outputs drawdown given pump rate, time of pumping, distance from the well at which drawdown is to be measured, transmissivity, and storativity. Out of these variables, transmissivity and storativity were unknown, but storativity was estimated as 0.1, as outlined in the design criteria section (Appendix B).

With a storativity estimate and the values of drawdown, time, and pump rate given in the well report, transmissivity was calculated as 0.0975 ft^2/min using the Cooper-Jacobs Equation. Next, a drawdown-recovery analysis was performed. In this analysis, the Thies equation was used to find drawdown with time as the dependent variable. This was carried out with multiple pump rates for $t = 0$ to $t = 120$ minutes. Recovery was simulated using a method found in the Freeze and Cherry text in which the Cooper-Jacobs equation is effectively reversed when pumping stops [29]. More details on this method can be found in Appendix B.

Before going into depth about the findings of the drawdown-recovery analysis, it is important to define the criteria for assessing the well's ability to supply the community with water. First, the maximum well water demand was determined by creating a scenario of a summer day with no rainwater left in the rain tanks, meaning all water throughout the development would need to be supplied by well water. To calculate a well water demand estimate for this scenario, an assumption was made that the 70 houses are made up of 35 single person households and 35 two person households, yielding a maximum daily well water requirement of 3090 gallons. The goal of the drawdown recovery analysis was to assess whether this amount of water could be pumped on a daily basis with full recovery before pumping resumes the next day. The analysis assumes that all of the well water pumping occurs in the same time period every day and the aquifer spends the remainder of the 24 hour period recovering. Figure 16 shows the number of hours of pumping required to yield 3090 gallons of water at different pump rates.

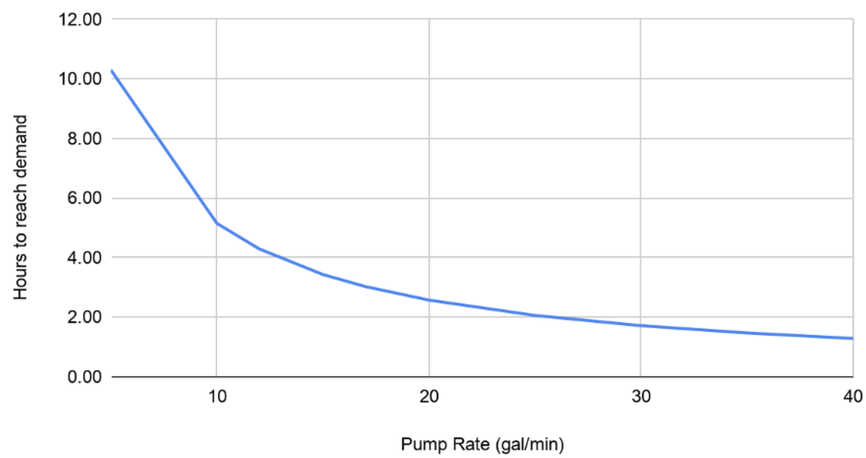

Figure 16: Hours of Well Pumping to Reach Demand with no Rainwater.

By examining the figure above and testing different pump rates on the drawdown recovery graph, a final pump rate recommendation was chosen as 30 gallons per minute. With this pump rate, 3090 gallons of water can be pumped out of the well in 1.7 hours, leaving 22.3 hours for the aquifer to recover. Figure 17 shows the drawdown-recovery graph for a single 24-hour period with the recommended pump rate.

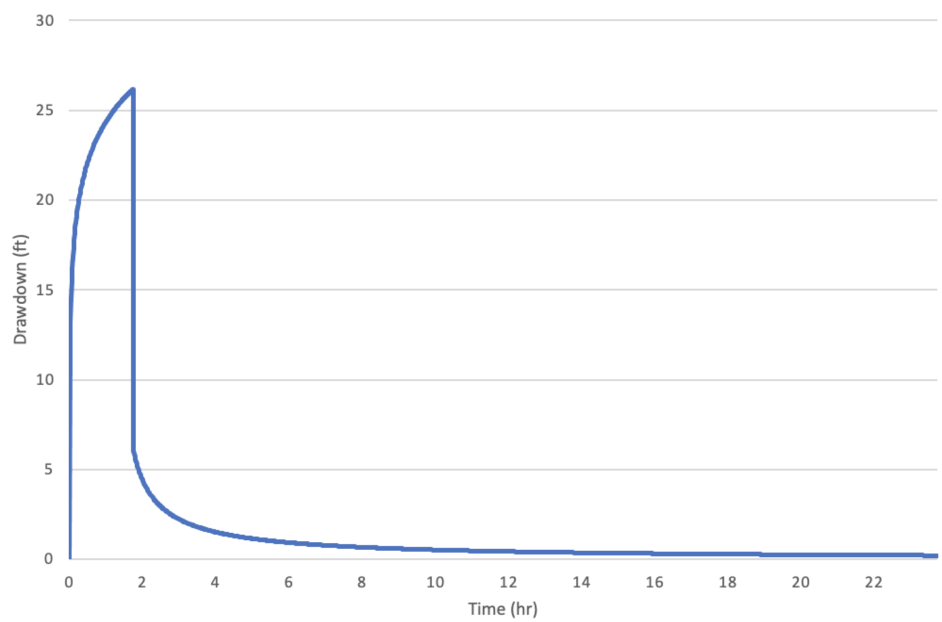

Figure 17: Drawdown-Recovery Over 24-Hour Period for 30 GPM Pump Rate.

In this graph, it is clear that the aquifer is able to make a full recovery by the time pumping begins the next day, meaning the well will not dry out in meeting its maximum yearly demand. In other words, it is sustainable to use well water to supply the community with water even when there are no other sources to supplement. The drawdown analysis was consistent with the well's reported drawdown values, and the fast recovery is likely due to the estimated storativity value. It is important to note that there was no recovery data reported and a well recovery test would be helpful in confirming these results.

Another important aspect of aquifer drawdown is how far reaching the drawdown is. In certain cases, pumping results in a drawdown that affects the nearby well's abilities to pump water. In the case of this well, it was important to assess whether or not the drawdown associated with meeting demand would affect nearby wells and properties. To achieve this, the same equation (Cooper-Jacobs) was used, this time varying distance instead of time with drawdown.

Figure 18 was created using R and shows drawdown varied with distance after 1.7 hours of pumping at 30 gallons per minute.

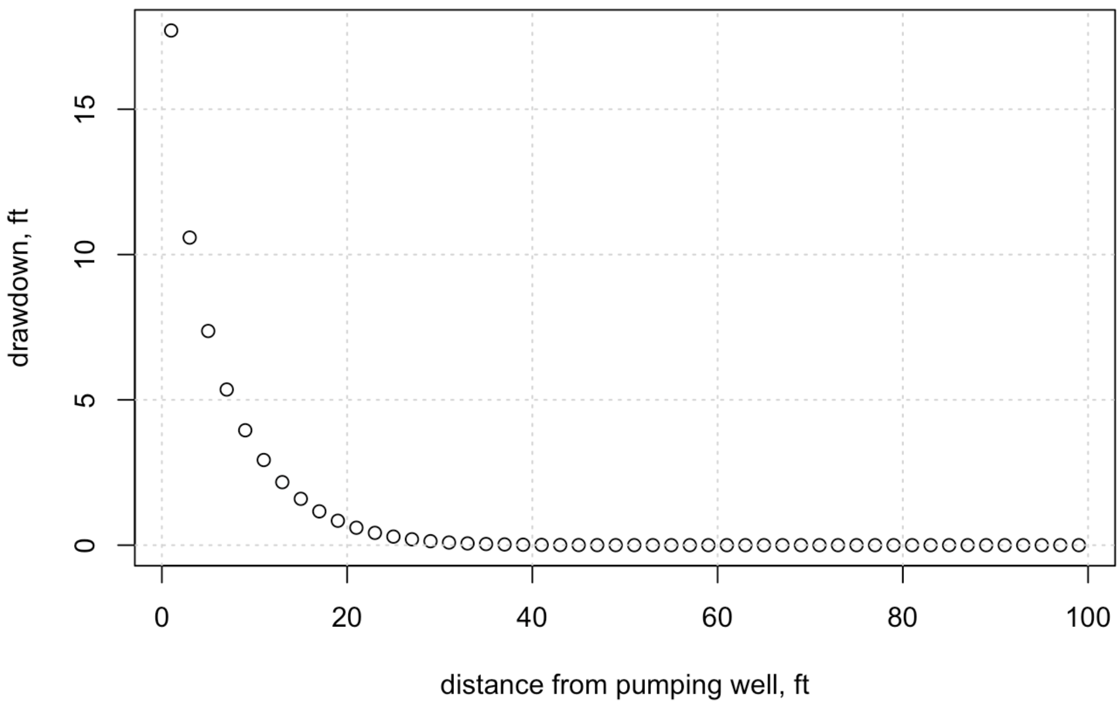

Figure 18: Distance-Drawdown After 1.7 Hours of Pumping at 30 GPM.

Figure 18 shows that the drawdown is consolidated to the immediate area around the well. Even 30 feet away from the well, there is virtually no drawdown. This is another positive result because it shows meeting demands with well water will not affect nearby wells or properties, as the property line is significantly further than 30 feet away from the well. In summary, a 30 gpm pump rate takes 1.7 hours of pumping to meet the community’s highest yearly demand, while allowing the aquifer to recover fully within 24 hours and without affecting nearby properties.

Next, the well water storage location was selected. To pick the best location on the parcel, the distribution of well water throughout the community was considered. After looking at the topography of the parcel and the location of the well, a hill approximately 430 feet away from the well was chosen (Figure 19). The hill's elevation is 80 feet and is the highest point on the parcel, allowing for the force of gravity to aid in the distribution of water.

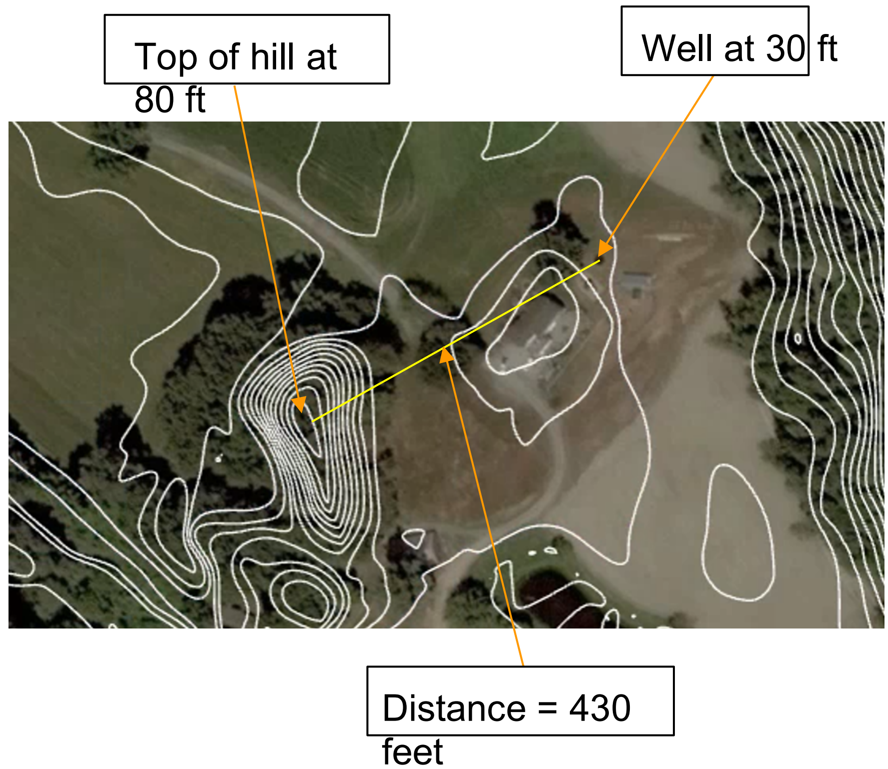

Figure 19: Elevations and Distance Between the Well and the Storage Location.

There are two pumps to define in this well water system. First, the water must be pumped from the well into the tank. Once the water is ready to be distributed out of the tank, it will flow down the other side of the hill, and a second pump will be used to distribute the water to each home. The pump used to move the water from the well into the storage tank was first chosen and analyzed. Given the previously recommended pump rate of 30 gallons per minute and the 90 foot static head between the well water level (40 feet below the ground) and the top of the hill, a Grundfos pump (30 GPM, 90' rated head) was chosen for analysis [33]. Seen in Appendix C, the pump is fully submersible, 0.75 horsepower, and fits within the six-inch (6") diameter well casing with a three-inch (3") diameter. To determine the operating point of this pump in this scenario, the total dynamic head was calculated at different pump rates and pipe sizes and plotted on the pump curve provided by the manufacturer. The friction factor was calculated using the Haaland equation and the friction head loss using Darcy-Weisbach with a distance of 450 feet to account for the slope of the hill (Appendix C) [27]. The total dynamic head values were tabled in Excel spreadsheets with pump rates ranging from zero (0) to 40 gallons per minute. This procedure was repeated for different pipe types and sizes until the plotted line intercepted the Grundfos pump curve at approximately 30 gallons per minute (Appendix C). As seen in Figure 20, The operating point of 30 gallons per minute with a 131 foot head was achieved with a 2.5 inch PVC pipe.

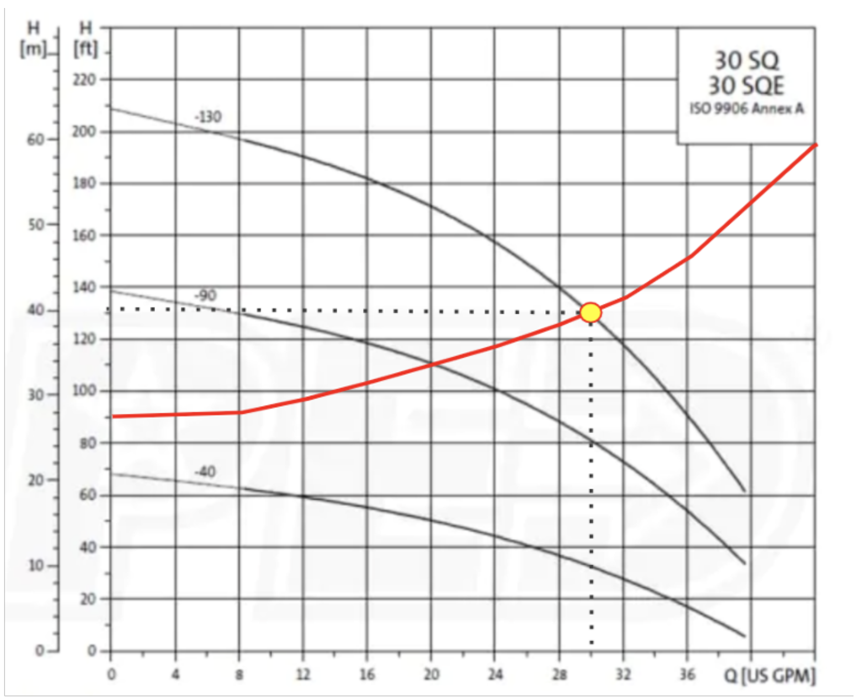

Figure 20: Determination of Pump Operating Point on Pump Curve.

Next, the distribution pump was defined by first creating a WaterGEMS distribution layout (Figure 21). In this layout, the lots were divided into 15 junctions with each junction supplying between four (4) and six (6) homes. The tank is seen as T-2 in Figure 21 and the pump PMP-2. According to Snohomish County standards, a pressure range was defined between 30 and 90 psi. A variety of commercially available booster pumps were considered in this system. A line of Grundfos booster pumps were ultimately compared for the final design. Each pump, ranging in power, was defined in WaterGEMS and run in the Darwin Designer feature to determine its resulting pipe pressures, sizes, and costs. The most efficient distribution system used a 15 horsepower booster pump to meet the range of pressures. The table of pressures, pump curve, pipe sizes, and pipe system cost can be seen in Appendix D.

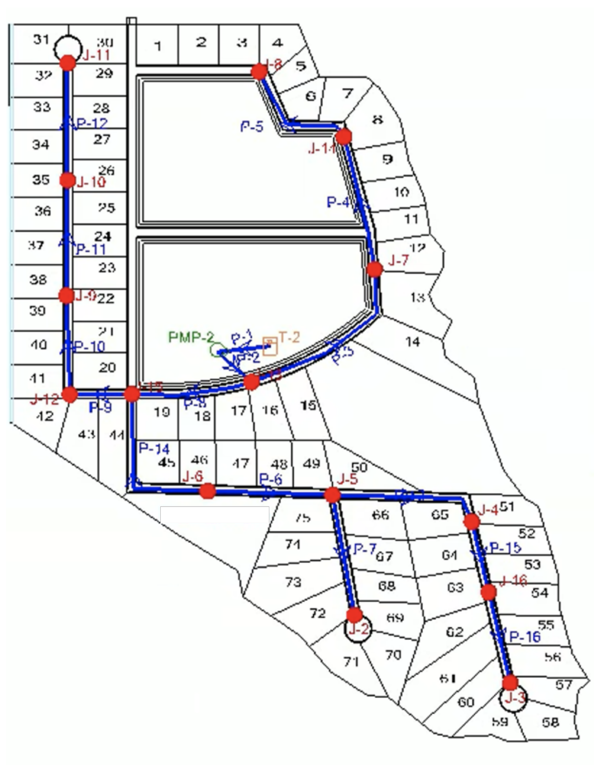

Figure 21: WaterGEMS Distribution Layout.

Municipal Design

The municipal design for the community consisted of three main work sections. The first was the initial research into the lot, housing requirements, and water demands as well as on the drawing of the community along with basic community design decisions. The second municipal design phase involved calculating the cut and fill of the area. Finally, the third municipal section was dedicated to the drainage system for the community.

The community layout design started with an image taken from Google Maps and loaded into AutoCAD to be outlined. Initially, the layouts were created randomly to get a feel for the layout of the property, as well as the property's topographic features. Using the preliminary design criteria of 36 foot roads, approximately 0.5 acres of land per lot, and the 75 lot limit due to water constraints, the most effective parts of each trial drawing were combined. What resulted was the first iteration of the team's final design that can be seen in Figure 23. This design featured exactly 75 lots with two large community spaces in the middle of the parcel as well as around the pond. The creation of the individual plots of land began as uniform 0.56 acre lots on the west side of the property. However, as the property line became non-linear, the property sizes also started to vary. The lots along the North-East border range anywhere from 0.35 acres at the smallest to about one (1) acre at the largest. Further research into the property showed that municipal storm drain, electrical, and sewage lines did not reach the property, which meant that an eco-friendly way of filtering the pollutants found in the runoff needed to be designed. Bioretention swales were found to be the best option, as they can reduce runoff by up to 90% and are becoming standard in communities across the United States.

Initially, cut and fill as well as elevations for top of curb and top of pad were to be calculated for the entire property. The topographic maps [34] that were found proved ineffective due to inaccuracy as well as the inability to export the information into the AutoCAD Civil 3D software. After talking with multiple advisors about this issue, it was determined that to complete this task, a professional survey of the property would need to be conducted. Since it would not be feasible to conduct a survey, the existing geographical topography would be used and accounted for when designing the bioretention swales. Except for a small hill in the middle of the property located towards the south end of community space 2, the land was already graded since it had been used as agricultural land in the past. Keeping this hill had the added benefit of also being the designated area for the well water storage and allowed for easier distribution of the water to the community. In future properties however, it is recommended that the entire parcel be graded to the desired design.

Since a traditional drainage system was unobtainable, the team had to look into other options for the community. Bioretention was the most logical source due its sustainability benefits, effectiveness, and its ease of design and implementation. The bioretention design was based on the Snohomish County Drainage Manual recommendations (Figure 22) for bioretention swales [35]. There is a bottom width minimum of one (1) foot, while the slope of the sides have a minimum 1:3 ratio. The maximum allowed ponding depth was set at 12 inches, and the freeboard for these swales have a six (6) inch minimum.

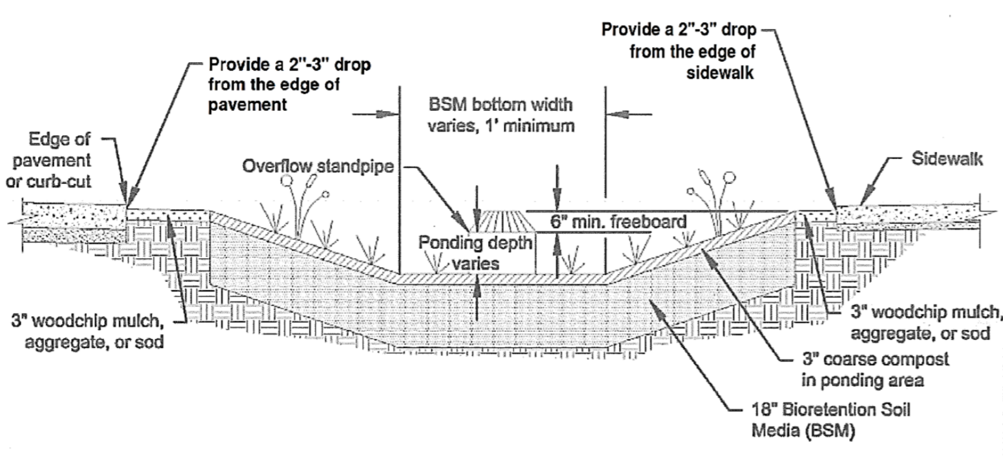

Figure 5.6 –Bioretention System Without Underdrain (Cross Section)

Figure 22: Snohomish County Bioretention Design.

Due to the lack of storm drain lines available to the property, a bioretention soil mix designed for maximum water filtration was necessary. This soil composition consisted of 85% sand by volume, 10% fines (Silt/Clay) by volume, and 5% organic matter (Grade 2 Compost) by volume. To find the final area of bioretention necessary for the property, the Western Washington Hydrology Model software was used [36]. This allowed the use of accurate rainfall and runoff measurements based on the existing topography to simulate how well the bioretention system would function. With the previously stated bioretention design and the runoff patterns of the property, it was determined that three (3) acres of land would need to be set aside for bioretention. At first many of the larger bioretention areas were located on the West side of the property (shown below in Figure 23), near the Snohomish River. As the project progressed, it was realized that although the design filtered most of the water, this could potentially lead to pollution seeping into the river and marshlands. The bioretention areas were then moved to the North-East area of the property in order to minimize the amount of pollution distributed to the river. This final design can be seen below in Figure 24.

Figure 23: Initial Bioretention Layout.

Figure 24: Final Bioretention Layout.

Cost Estimate

To begin the cost estimation portion of this project, a work breakdown structure (WBS) was created. The WBS lists the major components of the construction project so that all activities will be accounted for. The main sections for the WBS included site mobilization, excavation and grading, foundation, framing, interior finishes, and exterior finishes. These sections are further broken down into smaller pieces which can be seen below in Figures 25 and 26. This way of organization helps the contractor get a basic idea of the amount of work that will be required for the project.

Site Mobilization	office	supplies
		tech
	security	fencing
		signage
	storage	
Grading	Survey	
	Excavation	
	Fill	
Foundation	Excavation	
	Rebar Cage	
	Formwork	
	Concrete Pour	
Framing	Floor	Build frame
		secure to SOG
		Insulation/plywood
	Walls	Build Frame x4
		Raise
		secure to floor
	Roof	Build Frame
		secure frame to walls
	Stairs	Frame stair interior wall
		Frame stairs
		insulation
		plywood
	Loft	Frame
		install
		insullation
		plywood

Figure 25: Work Breakdown Structure Table 1.

		installation
		establish connections
	Solar	Wire to electrical
		Installation
	HVAC	Connection
		Wiring
		lighting
		outlets
	Electrical	appliance hookups
		Windows
		Doors
		insulation
		Drywall
		Painting
		Flooring
Internal	Finishes	Composting Toilet
		Plywood
	Sheathing	install Sheathing
		Plywood
		Sealant
		Install Shingles
	Roofing	allow for solar wiring
		Driveway
	Landscape	walkway
	Painting	
		excavation
External	Septic	installation

Figure 26: Work Breakdown Structure Table 2.

The second major section of the construction estimation focused on the activity list which provides more in depth information about specific activity durations, materials, and labor requirements. An example of this can be seen in Figure 27, below. and the full activity list can be found in the Appendix O. All activities are found through the RSmeans online cost data [37] and input with their respective descriptions, units, daily output (based on eight-hour workdays), and type of crew, as well as material, labor, and equipment costs per unit. Using the 3D model of the structural framing that team member Chris developed (Figure 6), quantity takeoffs of all the activities were performed. Dividing the total quantity of an activity by the daily output produces the estimated duration of the activity in eight-hour work days. These durations ranged anywhere from 0.1 days for items such as outlets, up to 1.88 days for the flooring installation.

ID	Activity	Quantity	unit	Daily	Duration	Material	**WTC**	Material	Crew	Labor	**Labor**	Labor	Equip.	**C**	Equip.	Total	Means Item
				Output	days	$/Unit		Cost		$/Unit	**FC**	Cost	$/Unit		Cost	Cost	
7	SOG - 3500 psi not incl. forms or reinforcing, 4" thick	250	S.F.	3425	0.07	1.39	1.191	$348	C14F	0.74	1.504	$185	0.01	1.138	$3	$695	0-33053404760
21	plywood sheathing on exterior	770	S.F.	1952	0.39	0.55	1.228	$424	2 Carp.	0.34	1.397	$262	0	1.086	$0	$886	0-61636100035
23	Flooring - floating floor, laminate, wood pattern strip, complete	250	S.F.	133	1.88	4	1.214	$1,000	1 Clab.	1.95	1.353	$488	0	1.062	$0	$1,874	0-96219108300

Figure 27: Example Activity List for the Cost Estimate.

The cost estimations for the activities are based on RSmeans 2017 data which meant that the values for material, labor, and equipment would have to be adjusted to the year 2021. The RSmeans 2021 cost indices were used in order to calculate the rising cost of construction due to Covid-19 manufacturing and shipping issues. These indices include adjustment factors for waste, taxes, and inflation factors of specific cities, which when put together is known as the WTC factor. An example of this can be found below in Figure 28. Also given by RSmeans are the factors for different types of material including woods, metals, and composites. The average cost factor for material was about 1.25x, while the average cost factor for labor was about 1.4x. After all the cost factors were input, the total cost of the line item was derived by multiplying the material, labor, and equipment costs by their respective cost adjustment factor and then adding them together.

	ADJUSTMENT FACTORS								
ID		Waste	Tax	Mat. City Index	Material WTC	Labor Overhead	Inst. City Index	Labor FC	Equip. C
7	SOG - 3500 psi not incl. forms or reinforcing, 4" thick	1.07	1.06	1.05	1.191	1.322	1.138	1.504	1.138
21	plywood sheathing on exterior	1.04	1.06	1.114	1.228	1.286	1.086	1.397	1.086
23	Flooring - floating floor, laminate, wood pattern strip, complete	1.05	1.06	1.091	1.214	1.274	1.062	1.353	1.062

Figure 28: Example Adjustment Factors for Cost Estimation.

Scheduling was the final part of the cost estimating process, and it utilized the data collected during the creation of the activity list. Putting the line item descriptions and the task durations into the Microsoft Project software allows for a simple but effective construction schedule. With a resource constraint of four carpenters on site at one time, the total duration of the project concluded at 22 work days. A total of nine different trades, including glazers, electricians, and plumbers will be working on the project as well at different times.

The total cost to develop a single lot equated to $58,000. With a half acre of land costing approximately $100,000 in the greater Seattle area, the total project cost per lot is $158,000. If the developer aims for a 20% profit, they would need to sell for $189,000. The net gain for a single lot would be $31,000 and the net gain for the entire project would come out to be $2,250,000 before the construction of the roads and bioretention swales. The scope of the cost estimation portion of the project only included the estimation for a single lot and in the future, a price for the total project would need to be calculated.

Future Work

There is potential for this project to be continued in the future. This section will outline the next steps based on the findings of this report. First, it is important to be clear about the shortcomings of the chosen parcel. The parcel was chosen without a full evaluation of the site. For this reason, many aspects of the parcel proved to be suboptimal late in the design process. In the future, new parcels should be examined extensively before design. Soil type, as well as water courses on the parcel, proved to be critical aspects that would have changed the choice of parcel if considered at the beginning. These may both be aided by the future ability to see the parcel in person before design, something that could not happen in this iteration of the project due to COVID-19.

If it is determined that the best option moving forward is to restart with a new parcel, most of the design must be redone. Many of the methods outlined in this report, however, may be applied to a new parcel, especially if said parcel is in a similar location. If the design outlined in this report is deemed worthy of expansion despite the parcel's faults, the following paragraphs may be used to outline possible directions for future design.

Future structural improvements that can be made to this tiny homes community is vast. Since the tiny home design is very simple, future projects can look to increase living spaces by combining two tiny homes together to provide for not just single use, but for family use. The possibility of stacking tiny homes to increase more living area within the small plot of land is also something that can be incorporated into the future development. Future structural improvements do not need to be focused strictly on the tiny homes, but can also be focused on designing a community center for the residents within the community. Providing a center for residents will draw more attention to people that are on the verge of deciding whether they want to move to a place that consists of nothing more than just a living space. The future for structural improvements is endless and will only continue to improve in compliance to the residents of the tiny home community.

The scope of the water resource systems in this iteration of the project can be described as estimating the community's in-home water demand and designing solutions to meet this demand. As mentioned, there are many important systems that were deliberately left out of the scope; water treatment, irrigation, and fire safety were not considered. Including water treatment would have changed the shape of the systems that have been described in this report, and it would be an important next step for those wishing to carry on with what has been found in this project. Given the limited supply of the two water sources that were considered in this project, fire safety and irrigation would likely need to be supplied using other water sources, but are extremely important in designing a safe and healthy community. Again, these community needs should be addressed in future iterations. Another way the water resource systems may be expanded upon is the inclusion of a system of recycling greywater. If the greywater was cleaned and used to fuel a hydroponics system, for example, the agricultural water demands may be reduced.

The future municipal improvements to this project, as well as the iterations that will come after, include the addition of other community buildings, electrical engineers that can design more of the electrical components for the community, and finally a full community cost estimate. In the future, new community centers or small stores could increase the desirability of the development. This would allow the developers to sell the houses for more profit and make the community more financially viable. Along with this, other engineering disciplines could add their specialties to the project. Electrical engineers will be needed to design the solar and electrical systems for the houses, streetlights and water distribution systems. Finally, a full community cost estimate would be necessary for the developer to determine the feasibility of the entire project versus only developing single lot tiny homes.

Conclusion

The goal of this project was to explore the early design, viability, and limitations of a suburban tiny home community that gives sustainable living options to those experiencing an increase in workplace flexibility after the COVID-19 pandemic. After choosing a parcel to work with, this project included the design of a model tiny home structure, the layout of the community, the bioretention drainage system, a rainwater catchment system, and a well water system. With all of its different design solutions, this project created a starting point for its greater scope. It also showed some significant limitations in the way it was carried out. Since the parcel was chosen as a starting point and design began immediately, the parcel was not fully vetted and many design issues emerged throughout the project. It was determined late in the process that there is a water course running through a significant portion of the parcel for a part of the year, rendering the current layout useless. Also, the class E soil and agricultural zoning of the parcel did not match up well with the intended use of this community. These issues are partly due to not being able to see the parcel in person and partly due to a lack of understanding of how a project like this should begin, but a great deal was learned because of this project. In future iterations of this project, the parcel should be fully vetted for the intended use of the land. Soil, zoning, and other possible design considerations like water courses, should be fully understood before any design is done.

It is also important to reiterate that this project only scratches the surface of what it can become in the future. In terms of engineering, designing and building a complete tiny home community, it will require an interdisciplinary approach, with electrical engineers to think about powering the community and other engineers to think about each and every need of the community. Also, this project focused on a specific location where water resources are abundant. In the future, other locations should be considered, requiring an entire new set of design solutions. While the work outlined in this report will not provide all of the answers, it provides a baseline of methods for the early design thinking of a suburban tiny home community. Outside of engineering, a community of this nature should be explored from a social scientific perspective to understand how the community will function. Ultimately, the social goals of the community must be defined along with a set of rules and regulations within the community to ensure its success.

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Appendices

Appendix A
Rainwater Storage Excel Sample

The following shows the first 17 days of precipitation data and analysis of data. Each column was performed for 40 year worth of daily data.

			1 person house					
Date	ppt (inches)	Runoff (gal)	Demand (gal)	Excess Water (gal)	Shortfall (gal)	Tank Storage (gal)	Overflow (gal)	% of demand
1/1/81	0	0	30	0	30	0	0	0
1/2/81	0.02	3.3662304	30	0	26.6337696	0	0	11.220768
1/3/81	0	0	30	0	30	0	0	0
1/4/81	0.01	1.6831152	30	0	28.3168848	0	0	5.610384
1/5/81	0	0	30	0	30	0	0	0
1/6/81	0.06	10.098691	30	0	19.9013088	0	0	33.662304
1/7/81	0.02	3.3662304	30	0	26.6337696	0	0	11.220768
1/8/81	0	0	30	0	30	0	0	0
1/9/81	0.05	8.415576	30	0	21.584424	0	0	28.05192
1/10/81	0	0	30	0	30	0	0	0
1/11/81	0	0	30	0	30	0	0	0
1/12/81	0	0	30	0	30	0	0	0
1/13/81	0	0	30	0	30	0	0	0
1/14/81	0	0	30	0	30	0	0	0
1/15/81	0	0	30	0	30	0	0	0
1/16/81	0	0	30	0	30	0	0	0
1/17/81	0	0	30	0	30	0	0	0

Runoff = Precipitation * Roof Area () * Runoff Coefficient * Conversion to gallons
Runoff = Precipitation * 43200 * 0.9 * 0.004329

Excess Water =Runoff - Demand (If Runoff > Demand)
Shortfall = Demand - Runoff (If Demand > Runoff)

Tank Storage = Maximum of (Tank Storage of previous day - Shortfall + Excess water) and Size of storage tank

Overflow:
If (Tank Storage of previous day - Shortfall + Excess water) > Size of storage tank,
Overflow = (Tank Storage of previous day - Shortfall + Excess water) - Storage tank

If Size of storage tank > (Tank Storage of previous day - Shortfall + Excess water),
Overflow = 0

% of demand = (Tank storage + runoff)/Demand

Days not reaching demand:
Count Cell if % of demand < 100, divide by the number of years (40)

Overflow/Runoff:
Sum of overflow/sum of runoff

	1 person		2 person	
Tank size	# of days not reaching demand	Overflow/Runoff	# of days not reaching demand	Overflow/Runoff
10	264.35	0.463994629	314.675	0.085163947
20	255.075	0.425544937	313.65	0.086732153
30	239.05	0.394926815	312.45	0.08728526
40	234.25	0.369488249	310.85	0.086813674
50	229.725	0.347519641	309.225	0.08475276
60	220.6	0.327973701	307.325	0.083258889
70	217.475	0.310983518	306.275	0.079
80	214.6	0.295773734	305.45	0.077
90	208.25	0.282009085	303.325	0.076
100	205.575	0.269756806	302.65	0.075
110	203.425	0.25849145	301.975	0.070
120	198.8	0.2479239	300.525	0.069
130	196.9	0.238158409	300	0.063
140	195.025	0.229162133	299.55	0.060
150	191.95	0.220993857	298.4	0.055
160	189.975	0.213522229	298.1	0.052
170	188.5	0.206532064	297.7	0.050
180	186.05	0.199811243	297.025	0.050
190	184.475	0.193602051	296.6	0.048
200	183.275	0.187852299	296.275	0.047
210	181.075	0.182307673	295.775	0.044
220	179.725	0.177140155	295.525	0.040
230	178.8	0.172341148	295.325	0.036
240	176.925	0.167777283	294.9	0.035
250	175.925	0.163414867	294.75	0.033
260	174.95	0.159201868	294.675	0.030
270	173.5	0.155226619	294.325	0.030
280	172.6	0.151595386	294.225	0.029
290	171.8	0.148149135	294.1	0.029
300	170.675	0.144809812	293.775	0.028

Appendix B
Well and Aquifer Calculations

Transmissivity Calculation (Eq. 8.42 from Freeze and Cherry):

$$\Delta h = \frac{2.3\,Q}{4\pi T}\log\frac{2.25\,Tt}{r^2 S} \qquad \text{(Eq. 8.42)}$$

$Q = 33$ gal/min $= 4.41$ ft^3/min

$t = 120$ minutes

$S = 0.1$

$r = 3$ inches $= 0.25$ ft

$\Delta h = 30$ ft

$$30\text{ ft} = \frac{2.3(4.41\text{ ft}^3/\text{min})}{4\pi T}\log\frac{2.25\,T(120\text{ min})}{(0.25^2)(0.1)}$$

$$37.1676\,T = \log(43200\,T)$$

$$T = \frac{\log(43200\,T)}{37.176} \Rightarrow$$

Use solver on excel $\rightarrow$ $\boxed{T \approx 0.0975\text{ ft}^2/\text{min} \approx 0.0016\text{ ft}^2/\text{sec}}$

$T = kb$

$T = 0.0016$ ft^2/sec

$b = 55$ ft

$$\boxed{K = \frac{T}{b} = 2.95 \times 10^{-5}\text{ ft/sec}}$$

within the lower range of k values for sandstone.

Sample of Drawdown Spreadsheet:

TIME	U	DRAWDOWN	U2	RECOVERY	ACTUAL DRAWDOWN
0	0	0	0	0	0
1	0.019778481	10.88482714	0	0	10.88482714
2	0.009889241	13.18579946	0	0	13.18579946
3	0.006592827	14.5235425	0	0	14.5235425
4	0.00494462	15.47041016	0	0	15.47041016
5	0.003955696	16.20390542	0	0	16.20390542
6	0.003296414	16.802726	0	0	16.802726
7	0.002825497	17.30873755	0	0	17.30873755
8	0.00247231	17.74688506	0	0	17.74688506
9	0.002197609	18.1332377	0	0	18.1332377
10	0.001977848	18.47875676	0	0	18.47875676
11	0.001798044	18.79125448	0	0	18.79125448
12	0.001648207	19.07649563	0	0	19.07649563
13	0.001521422	19.33885582	0	0	19.33885582
14	0.001412749	19.58173487	0	0	19.58173487
15	0.001318565	19.80782694	0	0	19.80782694

Freeze and Cherry Equations for U and Drawdown:

$$u = \frac{r^2 S}{4Tt} \tag{8.6}$$

$$h_0 - h = \frac{2.3Q}{4\pi T} \log \frac{2.25Tt}{r^2 S} \tag{8.42}$$

Where r = 3 inches = 0.25 ft, T = 0.0975 ft^2/min, S = 0.1, Q = 30 gpm = 4.01 ft^2/min

Sample of Recovery Method:

The following takes place when pumping stops (t = 1.7 hours)

TIME	U	DRAWDOWN	U2	RECOVERY	ACTUAL DRAWDOWN
105	0.000188366	26.17964415	0	0	26.17964415
106	0.000186589	26.21066977	0.0011634	-20.21794	5.992730348
107	0.000184846	26.24140401	0.0010988	-20.40521	5.83619833
108	0.000183134	26.27185229	0.001041	-20.58233	5.689518767
109	0.000181454	26.30201989	0.0009889	-20.75036	5.551655316
110	0.000179804	26.33191194	0.0009418	-20.91019	5.421724199
111	0.000178185	26.36153341	0.000899	-21.06257	5.298965741
112	0.000176594	26.39088917	0.0008599	-21.20817	5.182722252
113	0.000175031	26.41998394	0.0008241	-21.34756	5.072420618
114	0.000173495	26.44882233	0.0007911	-21.48126	4.967558455
115	0.000171987	26.4774088	0.0007607	-21.60972	4.867692982
116	0.000170504	26.50574772	0.0007325	-21.73332	4.772431998

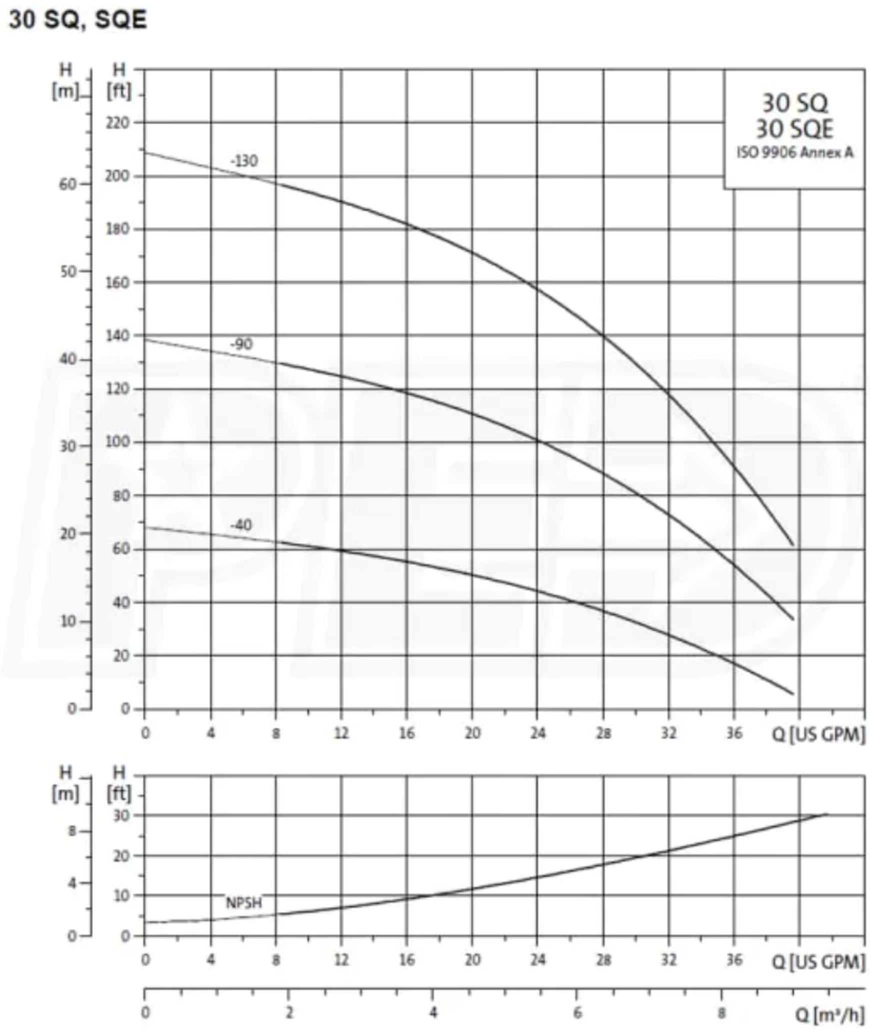
U2 is equal to U at the beginning of pumping, meaning the values of U2 starting at t = 106 minutes are the same as the values of U starting at t = 0. The Recovery variable uses the same Thies equation (8.42) as Drawdown, with using U2 instead of U and reversing the resulting solution, making it negative.

R-script for Distance-Drawdown Graph:

```r
Tr <- 0.0975 #units here are in f^2/min
St <- 0.1 #unitless
Q<- 4.01 #ft^3/min

rs <- 10   #distance from pumping well in meters
#a set of times in minutes
t <-c(0,1,1.5,2,2.5,3,4,5,6,8,10,12,14,18,24,30,40,50,60,80,100,120,150,180,210,240)

us <-(rs)^2*St/(4*Tr*t)
Wus <-expint::expint_E1(us)
dds <-Q/(4*pi*Tr)*Wus

plot(t, dds, log="xy", xlab="time, min", ylab="drawdown, ft", type="l")
grid()
title(main = paste0("Drawdown at distance = ",rs," ft"))



rs <-seq(from=1, to=100, by=2)          #distances in ft
t <-102                                #time in min

us <-(rs)^2*St/(4*Tr*t)
Wus <-expint::expint_E1(us)
dds <-Q/(4*pi*Tr)*Wus

plot(rs, dds, xlab="distance from pumping well, ft", ylab="drawdown, ft")
grid()
line(x=rs, y=dds)
title(main = paste0("Drawdown at time = ",t/60," hours"))

```

Appendix C
Well Pump Definition and Calculations

Grundfos 30SQE07-90 - 30 GPM 3/4 HP SQE-Series Deep Well Submersible Pump (90' Rated Head) (2W - 200-240V)



Friction Loss Calculations:

The following shows calculations for the first 10 rows of data. The same calculations were done for flow rates up to 40 gallons per minute.

D (in)	2.5					
Dynamic viscosity (lb*s/ft^2)	0.00002731					
Water Density (lb/ft3)	62.4			2.5" PVC pipe		
Roughness (PVC)	0					
Length (ft)	450				w/Re	
				Haaland	Darcy-Weisbach	
Flow Rate, Q (gpm)	Q (ft3/s)	Velocity (ft/s)	Reynold's Number	Friction Factor	Friction head loss (ft)	TDH (ft)
0	0	0	0	0	0	90
1	0.0022	0.1	31112.2	0.3899	0.05586781001	90.05586781
2	0.0045	0.1	62224.5	0.3748	0.2147985727	90.21479857
3	0.0067	0.2	93336.7	0.3667	0.4728844368	90.47288444
4	0.0089	0.3	124448.9	0.3613	0.8282524359	90.82825244
5	0.0111	0.3	155561.2	0.3572	1.279657877	91.27965788
6	0.0134	0.4	186673.4	0.3540	1.826173308	91.82617331
7	0.0156	0.5	217785.7	0.3514	2.467062702	92.4670627
8	0.0178	0.5	248897.9	0.3492	3.201717857	93.20171786
9	0.0201	0.6	280010.1	0.3472	4.029621786	94.02962179
10	0.0223	0.7	311122.4	0.3455	4.950325755	94.95032575

Velocity = $Q/A = \frac{Q}{\pi(d/2)^2}$

Reynold's Number = (Density * Velocity * Diameter)/Dynamic Viscosity

Friction Factor: Haaland Equation:

$$\frac{1}{\sqrt{f}} = -1.8 \log_{10}\left[\left(\frac{\varepsilon/D}{3.7}\right)^{1.11} + \frac{6.9}{\mathrm{Re}}\right]$$

Where $\varepsilon = 0$ and f = friction factor

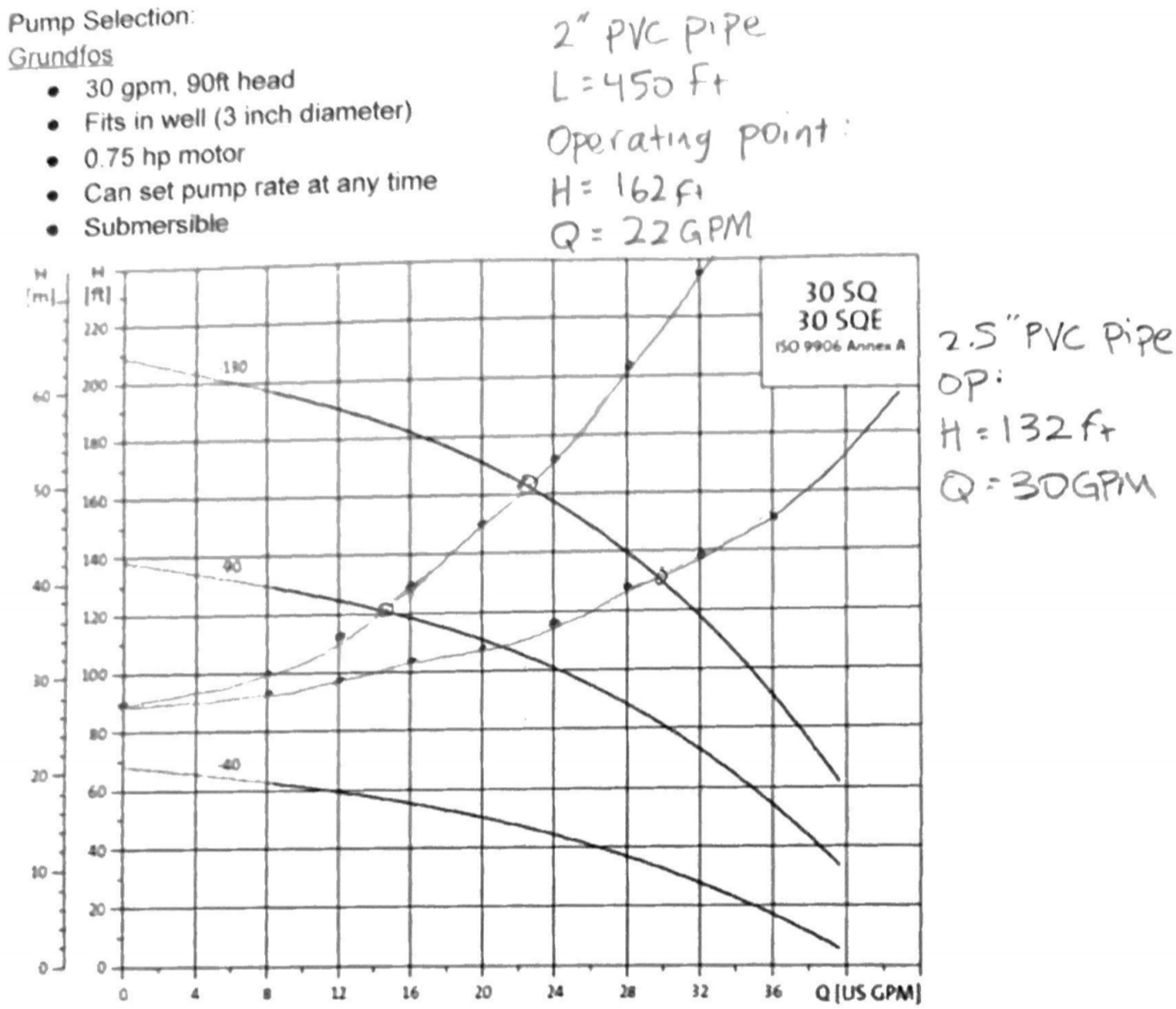
Friction head loss: Darcy-Weisbach

$$h_f = f\frac{L}{D}\frac{V^2}{2g}$$

f = friction factor, L = 450 ft, D = Diameter, V = velocity, g = 32.2 ft/sec^2

TDH = 90 (TSH) + Friction head loss

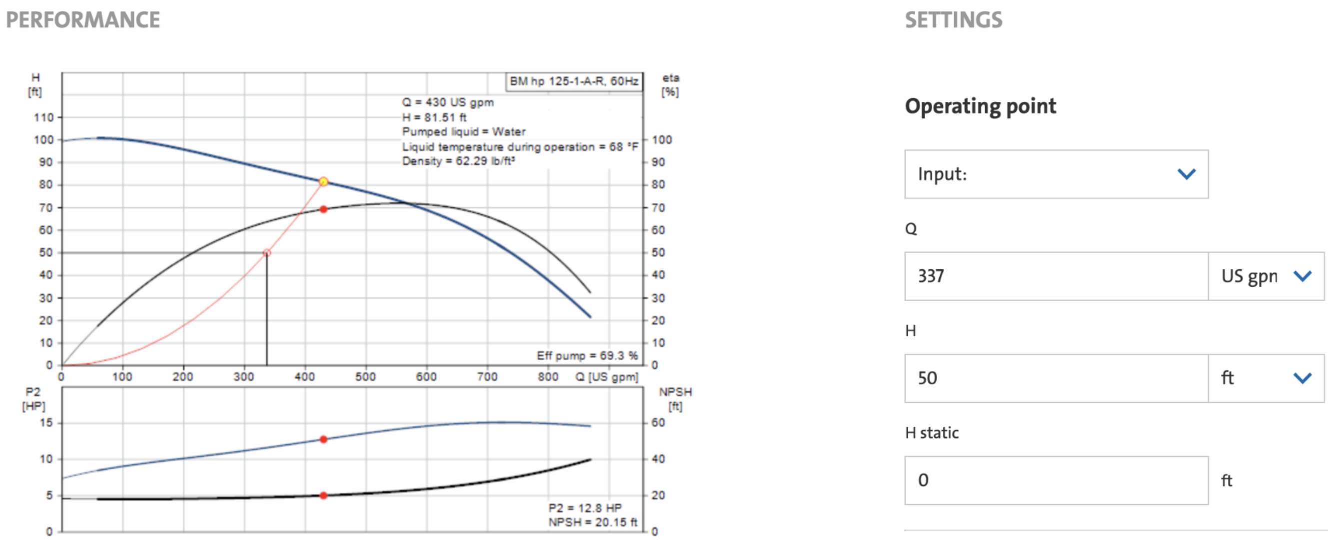
Hand Plots of different pipe sizes to find acceptable operating point:



Only one pipe size was tested before the ideal 30GPM operating point (given aquifer analysis) was found.

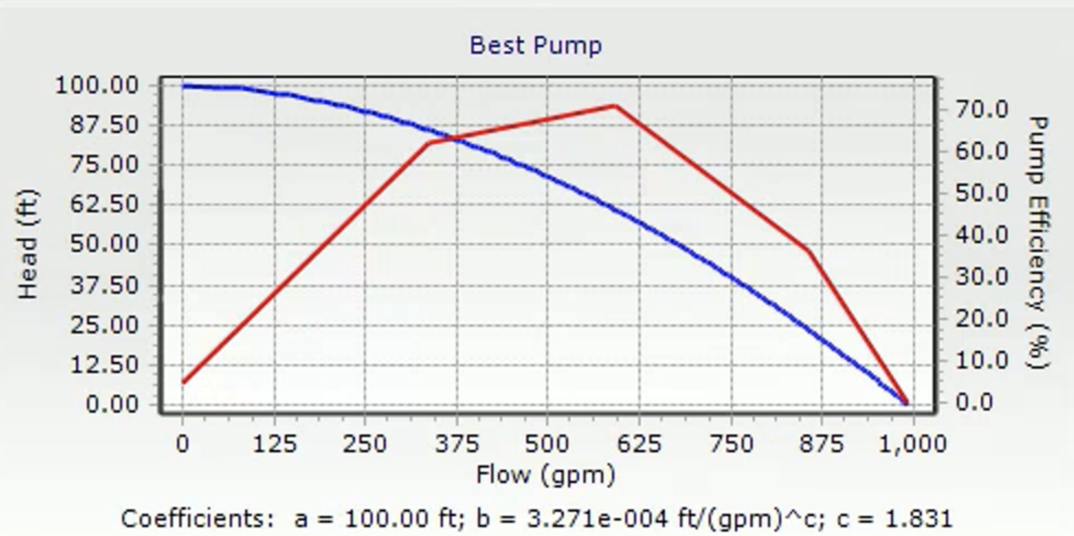
Appendix D
WaterGEMS Distribution Layout Details

Pump Curves on Grundfos Website:



3 Point Pump Definition in WaterGEMS:

	Flow (gpm)	Head (ft)
Shutoff:	0	100.00
Design:	337	86.14
Max. Operating:	866	22.00



Junction Simulated Pressures in Darwin Designer:

	Design Event	Element	Required Minimum Pressure (psi)	Required Maximum Pressure (psi)	Simulated Pressure (psi)	Violation (psi)
1	Pressures Required	J-2	30	90	54	0
2	Pressures Required	J-3	30	90	32	0
3	Pressures Required	J-4	30	90	37	0
4	Pressures Required	J-5	30	90	57	0
5	Pressures Required	J-6	30	90	57	0
6	Pressures Required	J-7	30	90	35	0
7	Pressures Required	J-8	30	90	30	0
8	Pressures Required	J-9	30	90	55	0
9	Pressures Required	J-10	30	90	43	0
10	Pressures Required	J-11	30	90	40	0
11	Pressures Required	J-12	30	90	55	0
12	Pressures Required	J-13	30	90	58	0
13	Pressures Required	J-14	30	90	31	0
14	Pressures Required	J-15	30	90	62	0
15	Pressures Required	J-16	30	90	33	0

Pipe Sizes and Costs for Darwin Designer Simulation:

	Design Group	Pipe	Material	Hazen-Williams C	Diameter (in)	Cost ($)
1	Design Group - P-1	P-1	PVC	150.0	6.0	1,135.37
2	Design Group - P-2	P-2	PVC	150.0	6.0	876.37
3	Design Group - P-3	P-3	PVC	150.0	2.0	1,514.93
4	Design Group - P-4	P-4	PVC	150.0	2.0	1,097.24
5	Design Group - P-5	P-5	PVC	150.0	2.5	1,640.84
6	Design Group - P-6	P-6	PVC	150.0	6.0	3,115.51
7	Design Group - P-7	P-7	PVC	150.0	2.0	980.96
8	Design Group - P-8	P-8	PVC	150.0	6.0	3,133.49
9	Design Group - P-9	P-9	PVC	150.0	3.0	830.13
10	Design Group - P-10	P-10	PVC	150.0	3.0	1,325.38
11	Design Group - P-11	P-11	PVC	150.0	2.0	929.87
12	Design Group - P-12	P-12	PVC	150.0	2.0	941.90
13	Design Group - P-13	P-13	PVC	150.0	2.0	1,241.23
14	Design Group - P-14	P-14	PVC	150.0	6.0	4,218.50
15	Design Group - P-15	P-15	PVC	150.0	2.0	583.91
16	Design Group - P-16	P-16	PVC	150.0	2.0	750.61

If pipe diameter variation is an issue for constructability, pipe diameters can be limited. To confirm this, a simulation with only 3 and 6 inch pipes was run, yielding a more expensive, but more constructable system:

Pipe	Diameter (in)	Cost ($)	Diameter (in)	Cost ($)
P-1	6.0	1,100.00	6.0	1,300.00
P-2	6.0	900.00	6.0	1,100.00
P-3	2.0	1,500.00	3.0	2,500.00
P-4	2.0	1,100.00	3.0	1,800.00
P-5	2.5	1,600.00	3.0	1,600.00
P-6	6.0	3,100.00	3.0	1,700.00
P-7	2.0	1,000.00	3.0	1,600.00
P-8	6.0	3,100.00	6.0	3,000.00
P-9	3.0	800.00	3.0	800.00
P-10	3.0	1,300.00	3.0	1,300.00
P-11	2.0	900.00	3.0	1,500.00
P-12	2.0	900.00	3.0	1,600.00
P-13	2.0	1,200.00	3.0	2,100.00
P-14	6.0	4,200.00	3.0	2,300.00
P-15	2.0	600.00	3.0	1,000.00
P-16	2.0	750.00	3.0	1,300.00
		$24,050.00		$26,500.00

Appendix E
Structural Analysis Gravity Loads

Roof: 2x8 in.

$$L := 12\ ft$$

$$w_{2x8.dougfir} := 3.28\ plf$$

$$w_{single.rafter} := 3.28 \cdot 12.165 = 39.901$$

$$39.901\ lb \cdot 19 = 758.119\ lb$$

$$\frac{(758.119)}{300} = 2.527 \quad psf$$

$$w_{roof} := 2.527\ psf \cdot \frac{12}{16} = 1.895\ psf$$

Weight of Plywood: 1/2" plywood

$$w_{roof.plywood} := 1.7\ psf$$

Standing Seam Metal Roof

$$w_{ssm} := 1.2\ psf \cdot \frac{16}{12} = 1.6\ psf$$

Total Roof Dead Load:

$$w_{roof.DL} := w_{roof.plywood} + w_{ssm} + w_{roof} = 5.195\ psf$$

$$L_{load} := 20\ psf = 20\ psf$$

Per: Seattle SDCI

$$w_{snow} := 25\ psf = 25\ psf$$

Appendix F
Structural Analysis Roof Rafter Member

Load Combination: 1.2D+1.6L+0.5S

$$w := 1.2 \cdot w_{roof.DL} + 1.6 \cdot L_{load} + 0.5 \cdot w_{snow} = 50.734\ \mathbf{psf}$$

$$w := w \cdot \frac{16}{12}\ \mathbf{ft} = 67.646\ \mathbf{plf}$$

Maximum Moment:

$$M_{max} := \frac{\left(w \cdot L^2\right)}{8} = 1.218\ \mathbf{kip \cdot ft}$$

Maximum Shear:

$$V_{max} := w \cdot \frac{12.165\ \mathbf{ft}}{2} = 0.411\ \mathbf{kip}$$

Maximum Deflection:

$$\Delta_{limit} := L \cdot \frac{\left(12\ \frac{\mathbf{in}}{(\mathbf{ft})}\right)}{180} = 0.8\ \mathbf{in}$$

Properties of No. 2 2x8 Doug Fir:

$$b := 1.5\ \textbf{in}$$
$$d := 7.25\ \textbf{in}$$
$$F_v := 180\ \textbf{psi}$$
$$F_b := 1.0 \cdot (900\ \textbf{psi}) = 900\ \textbf{psi}$$
$$F_{c.perpend} := 625\ \textbf{psi}$$
$$E := 1600000\ \textbf{psi}$$
$$E_{min} := 580000\ \textbf{psi}$$

$$S_{xx} := b \cdot \frac{d^2}{6} = 13.141\ \textbf{in}^3$$
$$I_{xx} := b \cdot \frac{d^3}{12} = 47.635\ \textbf{in}^4$$

$$\Delta_{max} := \frac{(5 \cdot w \cdot L^4)}{384 \cdot E \cdot I_{xx}} = 0.414\ \textbf{in}$$

Required Stress:

$$f_b := \frac{M_{max}}{S_{xx}} = 1112\ \textbf{psi}$$

$$f_v := 1.5 \cdot \frac{V_{max}}{b \cdot d} = 56.8\ \textbf{psi}$$

Available Strength Adjustment Factors

$C_D := 1.0$ ... NDS-2018, Table 2.3.2 live load (ten-year load)

$C_M := 1.0$ ... $MC \le 19\%$

$C_F := 1.2$ ... NDS-2018-SUPP, Table 4A Adjustment Factors

$C_L := 1.0$

$C_r := 1.15$

Available Strength

$$F'_b := F_b \cdot C_D \cdot C_M \cdot C_L \cdot C_F \cdot C_r = 1242 \ \boldsymbol{psi}$$

$$F'_v := F_v \cdot C_D \cdot C_M = 180 \ \boldsymbol{psi}$$

$$F'_{c.perpend} := F_{c.perpend} \cdot C_M = 625 \ \boldsymbol{psi}$$

$$E' := E \cdot C_M = 1600000 \ \boldsymbol{psi}$$

$$F'_b \cdot S_{xx} = 1.36 \ \boldsymbol{kip \cdot ft}$$

Demand-Available Strength Ratios

$$DCR_{Fb} := \frac{f_b}{F'_b} = 0.895$$

$$DCR_{Fv} := \frac{f_v}{F'_v} = 0.315$$

Appendix G
Structural Analysis Ceiling Joist Member

Cieling Joist: No. 2 2x8 Cieling Joist

$L:=12\ ft$

$D_L:=5\ psf$

$L_L:=10\ psf$

$b:=1.5\ in$

$d:=7.25\ in$

$S_{xx}:=b\cdot\frac{d^2}{6}=13.141\ in^3$

$F_v:=180\ psi$

$F_b:=900\ psi$

$E:=1600000\ psi$

$E_{min}:=580000\ psi$

$w_{selfweigh2x8}:=2.56\ plf\cdot\left(\frac{12}{16\ ft}\right)=1.92\ psf$

$w:=D_L+L_L+w_{selfweigh2x8}=16.92\ psf$

$w:=w\cdot\frac{16}{12}\ ft=22.56\ plf$

Not Supporting Cieling:

$\Delta_{Limit.Live}:=\frac{L\cdot\left(12\ \frac{in}{ft}\right)}{180}=0.8\ in$

$\Delta_{Limit.Snow}:=\frac{L\cdot\left(12\ \frac{in}{ft}\right)}{180}=0.8\ in$

Table 1604.3 2015 NDS

$\Delta_{Limit.dead.load}:=\frac{L\cdot\left(12\ \frac{in}{ft}\right)}{120}=1.2\ in$

Supporting Nonplaster Cieling:

$\Delta_{Limit.Live}:=\frac{L\cdot\left(12\ \frac{in}{ft}\right)}{240}=0.6\ in$

$\Delta_{Limit.Live}:=\frac{L\cdot\left(12\ \frac{in}{ft}\right)}{180}=0.8\ in$

Choose to do L+D so dont have to inspect wood member - table 1604.3 CBC

Maximum Moment:

$$M_{max} := \frac{\left(w \cdot L^2\right)}{8} = 0.406\ \boldsymbol{kip \cdot ft}$$

Max Shear:

$$V_{max} := w \cdot \frac{L}{2} = 0.135\ \boldsymbol{kip}$$

Max Deflection:

$$\Delta_{limit} := L \cdot \frac{\left(12\ \frac{\boldsymbol{in}}{(\boldsymbol{ft})}\right)}{240} = 0.6\ \boldsymbol{in}$$

Required Stress:

$$f_b := \frac{M_{max}}{S_{xx}} = 370.832\ \boldsymbol{psi}$$

$$f_v := 1.5 \cdot \frac{V_{max}}{b \cdot d} = 18.7\ \boldsymbol{psi}$$

Available Strength Adjustment Factors

$$C_D := 1.0$$

$$C_M := 1.0$$

$$C_t := 1.0$$

$$C_F := 1.0$$

$$C_r := 1.15$$

$$C_f := 1.2$$

$$C_L := 1.0$$

Available Strength

$$F'_b := F_b \cdot C_D \cdot C_M \cdot C_t \cdot C_L \cdot C_F = 900\ psi$$

$$F'_v := F_v \cdot C_D \cdot C_M \cdot C_t = 180\ psi$$

$$F'_{c.perpend} := F_{c.perpend} \cdot C_M \cdot C_t = 625\ psi$$

$$E' := E \cdot C_M \cdot C_t = 1600000\ psi$$

$$F'_b \cdot S_{xx} = 0.986\ kip \cdot ft$$

Appendix H
Structural Analysis Exterior Wall Member

$F_v := 180\ psi$

$F_b := 900\ psi$ NDS Supplement Table 4A

$E := 1600000\ psi$

$F_c := 1350\ psi$

$E_{min} := 580000\ psi$

$$w_{selfweigh2x6} := (1.94\ plf) \cdot \left(\frac{12}{16\ ft}\right) = 1.455\ psf$$

$$w := D_L + w_{selfweigh2x6} = 8.455\ psf$$

$$w := w \cdot 16\ \frac{ft}{12} = 11.273\ plf$$

Maximum Moment:

$$M_{max} := \frac{\left(w \cdot L^2\right)}{8} = 0.141\ kip \cdot ft$$

Max Shear:

$$V_{max} := w \cdot \frac{L}{2} = 0.056\ kip$$

Max Deflection:

$$\Delta_{limit} := L \cdot \frac{\left(12 \frac{in}{(ft)}\right)}{360} = 0.333\ in$$

Required Stress:

$$f_b := \frac{M_{max}}{S_{xx}} = 223.603\ psi$$

$$f_v := 1.5 \cdot \frac{V_{max}}{b \cdot d} = 10.2\ psi$$

Available Strength Adjustment Factors

$C_D := 1.0$

$C_M := 1.0$

$C_t := 1.0$

$C_F := 1.0$ NDS Supplement Pg 32

$C_r := 1.15$

$C_f := 1.2$

$C_L := 1.0$

Available Strength

$F'_v := F_v \cdot C_D \cdot C_M \cdot C_t = 180\ psi$
$F_c' := F_c \cdot C_D \cdot C_M \cdot C_t \cdot C_F = \left(1.35 \cdot 10^3\right)\ psi$
$F'_{c.perpend} := F_{c.perpend} \cdot C_M \cdot C_t = 625\ psi$

$l_u := 10 \cdot ft$

$\frac{l_u}{d} = 21.818$

$l_e := 1.37 \cdot l_u + 3 \cdot d = 15.075\ ft$

$$R_B := \sqrt{\frac{l_e \cdot d}{b^2}} = 21.029$$

$F_{b.star} := F_b \cdot C_D \cdot C_M \cdot C_t \cdot C_F = 900 \; psi$

$E'_{min} := E_{min} \cdot C_M \cdot C_t = 580000 \; psi$

$$F_{bE} := \frac{0.822 \cdot E'_{min}}{R_B^{\,2}} = \left(1.078 \cdot 10^3\right) \; psi$$

$$C_L := \frac{1 + \left(\frac{F_{bE}}{F_{b.star}}\right)}{1.9} - \sqrt{\left(\frac{1 + \left(\frac{F_{bE}}{F_{b.star}}\right)}{1.9}\right)^2 - \frac{\frac{F_{bE}}{F_{b.star}}}{0.95}} = 0.879$$

$F'_c := F_c \cdot C_L = \left(1.187 \cdot 10^3\right) \; psi$

$F'_b := F_b \cdot C_D \cdot C_M \cdot C_t \cdot C_L \cdot C_F = 791 \; psi$

$F'_v := F_v \cdot C_D \cdot C_M \cdot C_t = 180 \; psi$

$F'_{c.perpend} := F_{c.perpend} \cdot C_M \cdot C_t = 625 \; psi$

$E' := E \cdot C_M \cdot C_t = 1600000 \; psi$

$F'_b \cdot S_{xx} = 0.499 \; kip \cdot ft$

$P_{buckling} := b \cdot d \cdot F'_c = \left(9.789 \cdot 10^3\right) \; lbf$

$P_{bearing} := b \cdot d \cdot F'_{c.perpend} = \left(5.156 \cdot 10^3\right) \; lbf$

$P_{bearing2} := b \cdot d \cdot F_c{}' = \left(1.114 \cdot 10^4\right) \; lbf$

$C_b := 1.25$ Table 3.10.4 2015 NDS

$P_{increased.bearing} := b \cdot d \cdot F'_{c.perpend} \cdot C_b = \left(6.445 \cdot 10^3\right) \; lbf$

Appendix I
Structural Analysis Wind Load

Long Side Wind Design Calculation

15813 Shorts School Rd, Snohomish, WA 98290, USA | Search

Coordinates: 47.855481, -122.076269

Wind | Snow | Tornado | Seismic

Print these results | Save these results

ASCE 7-16 — *Select a dataset to view contours.*

MRI 10-Year	67 mph
MRI 25-Year	74 mph
MRI 50-Year	78 mph
MRI 100-Year	83 mph
Risk Category I	92 mph
Risk Category II	98 mph
Risk Category III	105 mph
Risk Category IV	109 mph

$V_{ult} := 98$ mph

$h_{mean} := 10\ ft + 1\ ft = 11\ ft$ wall height + half of roof height

Exposure: C

Wind Variables:

$k_d := 0.85$ [Per 26.6, Table 26.6-1]

$k_e := 1.0$ Elevation of site is below 1000 ft above sealevel. per table 26.9-1

$k_{zt} := 1.0$

Table 26.6-1 Wind Directionality Factor, K_d

Structure Type	Directionality Factor K_d
Buildings	
Main Wind Force Resisting System	0.85
Components and Cladding	0.85
Arched Roofs	0.85
Circular Domes	1.0[a]
Chimneys, Tanks, and Similar Structures	
Square	0.90
Hexagonal	0.95
Octagonal	1.0[a]
Round	1.0[a]
Solid Freestanding Walls, Roof Top Equipment, and Solid Freestanding and Attached Signs	0.85
Open Signs and Single-Plane Open Frames	0.85
Trussed Towers	
Triangular, square, or rectangular	0.85
All other cross sections	0.95

[a]Directionality factor $K_d = 0.95$ shall be permitted for round or octagonal structures with nonaxisymmetric structural systems.

Table 26.11-1 Terrain Exposure Constants

Customary Units										
Exposure	α	z_g (ft)	$\hat{\alpha}$	$\hat{b}$	$\bar{\alpha}$	$\bar{b}$	c	ℓ (ft)	$\bar{\epsilon}$	z_{min} (ft)[a]
B	7.0	1,200	1/7.0	0.84	1/4.0	0.45	0.30	320	1/3.0	30
C	9.5	900	1/9.5	1.00	1/6.5	0.65	0.20	500	1/5.0	15
D	11.5	700	1/11.5	1.07	1/9.0	0.80	0.15	650	1/8.0	7

Table 26.10-1 Velocity Pressure Exposure Coefficients, K_h and K_z

Height above Ground Level, z		Exposure		
ft	m	B	C	D
0–15	0–4.6	0.57 (0.70)[a]	0.85	1.03
20	6.1	0.62 (0.70)[a]	0.90	1.08
25	7.6	0.66 (0.70)[a]	0.94	1.12
30	9.1	0.70	0.98	1.16
40	12.2	0.76	1.04	1.22
50	15.2	0.81	1.09	1.27
60	18.0	0.85	1.13	1.31
70	21.3	0.89	1.17	1.34
80	24.4	0.93	1.21	1.38

Velocity Pressure:

$\alpha := 9.5$

$k_h := 0.85$

$k_z := k_h$

$G := 0.85$ [Rigid Building, Gust factor can be taken as 0.85 per 26.11.4]

$h\_L := \dfrac{h_{mean}}{25\ ft} = 0.44$ height to length ratio

$L\_B := \dfrac{(25\ ft)}{12\ ft} = 2.083$ Ratio of length of building to width of building

$C_{p\_windward} := 0.8$

$C_{p\_leeward} := -0.3$

Wall Pressure Coefficients, C_p

Surface	L/B	C_p	Use With
Windward wall	All values	0.8	q_z
Leeward wall	0–1	−0.5	q_h
	2	−0.3	q_h
	≥4	−0.2	q_h
Sidewall	All values	−0.7	q_h

Figure 27.3-1

Solving for Wind Pressure:

windforce north-south east-west depending on lot

$q_h := .00256 \cdot k_z \cdot k_{zt} \cdot k_d \cdot V_{ult}^{\ 2} = 17.764 \quad psf$

$GC_{pi} := -0.18$ +/- [Per Table 26.13-1]

$P_{windward} := q_h \cdot G \cdot C_{p\_windward} - q_h \cdot GC_{pi} = 15.277 \ psf$ windward wall wind pressure

$P_{leeward} := q_h \cdot G \cdot C_{p\_leeward} - q_h \cdot GC_{pi} = -1.332 \ psf$ leeward wall wind pressure

$P_{wall} := P_{windward} - P_{leeward} = 16.609 \ psf$ total wall wind pressure

Roof Wind Pressure:

$\theta := \sin\left(\frac{2}{12}\right) \cdot \frac{180}{\pi} = 9.505$

$\theta := 10 \ deg$ round up

$C_{p\_l1} := -0.9$ $C_{p\_l2} := -0.18$

$C_{p\_lr} := -0.5$

Roof Pressure Coefficients, C_p, for use with q_h

Wind Direction	h/L	Windward: Angle, θ (degrees) 10	15	20	25	30	35	45	≥60[c]	Leeward: Angle, θ (degrees) 10	15	≥20
Normal to Ridge for θ ≥ 10°	≤0.25	−0.7	−0.5	−0.3	−0.2	−0.2	0.0[a]			−0.3	−0.5	−0.6
		−0.18	0.0[a]	0.2	0.3	0.3	0.4	0.4	0.01 θ			
	0.5	−0.9	−0.7	−0.4	−0.3	−0.2	−0.2	0.0[a]		−0.5	−0.5	−0.6
		−0.18	−0.18	0.0[a]	0.2	0.2	0.3	0.4	0.01 θ			
	≥1.0	−1.3[b]	−1.0	−0.7	−0.5	−0.3	−0.2	0.0[a]		−0.7	−0.6	−0.6
		−0.18	−0.18	−0.18	0.0[a]	0.2	0.2	0.3	0.01 θ			

[Figure 27.3-1]

$GC_{pi} := -0.18$ +/- [Per Table 26.13-1]

$P_{l\_r} := q_h \cdot G \cdot C_{p\_lr} - q_h \cdot GC_{pi} = -4.352\ psf$

uplift pressure

$V_1 := 15.277\ psf \cdot 12\ ft \cdot 25\ ft = 4.583\ kip$

$V_2 := 4.352\ psf \cdot 12.165\ ft \cdot 25\ ft = 1.324\ kip$

$V_3 := 1.332\ psf \cdot 10\ ft \cdot 25\ ft = 0.333\ kip$

horizontal shear

$V_1 + V_2 + V_3 = 6.24\ kip$

Short Side Wind Design Calculations

Wind Variables:

$k_d := 0.85$ [Per 26.6, Table 26.6-1]

$k_e := 1.0$ Elevation of site is below 1000 ft above sealevel. per table 26.9-1

$k_{zt} := 1.0$

Table 26.6-1 Wind Directionality Factor, K_d

Structure Type	Directionality Factor K_d
Buildings	
Main Wind Force Resisting System	0.85
Components and Cladding	0.85
Arched Roofs	0.85
Circular Domes	1.0[a]
Chimneys, Tanks, and Similar Structures	
Square	0.90
Hexagonal	0.95
Octagonal	1.0[a]
Round	1.0[a]
Solid Freestanding Walls, Roof Top Equipment, and Solid Freestanding and Attached Signs	0.85
Open Signs and Single-Plane Open Frames	0.85
Trussed Towers	
Triangular, square, or rectangular	0.85
All other cross sections	0.95

[a]Directionality factor $K_d = 0.95$ shall be permitted for round or octagonal structures with nonaxisymmetric structural systems.

Table 26.11-1 Terrain Exposure Constants

Customary Units										
Exposure	α	z_g (ft)	$\hat{a}$	$\hat{b}$	$\bar{\alpha}$	$\bar{b}$	c	ℓ (ft)	$\bar{\epsilon}$	z_{min} (ft)[a]
B	7.0	1,200	1/7.0	0.84	1/4.0	0.45	0.30	320	1/3.0	30
C	9.5	900	1/9.5	1.00	1/6.5	0.65	0.20	500	1/5.0	15
D	11.5	700	1/11.5	1.07	1/9.0	0.80	0.15	650	1/8.0	7

Table 26.10-1 Velocity Pressure Exposure Coefficients, K_h and K_z

Height above Ground Level, z		Exposure		
ft	m	B	C	D
0–15	0–4.6	0.57 (0.70)[a]	0.85	1.03
20	6.1	0.62 (0.70)[a]	0.90	1.08
25	7.6	0.66 (0.70)[a]	0.94	1.12
30	9.1	0.70	0.98	1.16
40	12.2	0.76	1.04	1.22
50	15.2	0.81	1.09	1.27
60	18.0	0.85	1.13	1.31
70	21.3	0.89	1.17	1.34
80	24.4	0.93	1.21	1.38

Velocity Pressure:

$\alpha := 9.5$

$k_h := 0.85$

$k_z := k_h$

$G := 0.85$ [Rigid Building, Gust factor can be taken as 0.85 per 26.11.4]

$h\_L := \frac{12\ ft}{12\ ft} = 1$ height to length ratio

$L\_B := \frac{(12\ ft)}{25\ ft} = 0.48$ Ratio of length of building to width of building

$C_{p\_windward} := 0.8$

$C_{p\_leeward} := -0.5$

Wall Pressure Coefficients, C_p

Surface	L/B	C_p	Use With
Windward wall	All values	0.8	q_z
Leeward wall	0–1	−0.5	q_h
	2	−0.3	q_h
	≥4	−0.2	q_h
Sidewall	All values	−0.7	q_h

Figure 27.3-1

Solving for Wind Pressure:

windforce north-south east-west depending on lot

$q_h := .00256 \cdot k_z \cdot k_{zt} \cdot k_d \cdot V_{ult}^2 = 17.764\ psf$

$GC_{pi} := -0.18$ +/- [Per Table 26.13-1]

$P_{windward} := q_h \cdot G \cdot C_{p\_windward} - q_h \cdot GC_{pi} = 15.277\ psf$ windward wall wind pressure

$P_{leeward} := q_h \cdot G \cdot C_{p\_leeward} - q_h \cdot GC_{pi} = -4.352\ psf$ leeward wall wind pressure

$P_{wall} := P_{windward} - P_{leeward} = 19.629\ psf$ total wall wind pressure

Roof Wind Pressure:

$\theta := \sin\left(\frac{2}{12}\right) \cdot \frac{180}{\pi} = 9.505$

$\theta := 10\ deg$ round up

$C_{p\_l1} := -0.9$ $C_{p\_l2} := -0.18$

$C_{p\_lr} := -0.5$

Appendix J
Structural Analysis Seismic Design

Seismic Loading

S_{DS}

$S_s := 1.275$

$S_1 := 0.449$

$F_a := 0.9$

TABLE 11.4-1 SITE COEFFICIENT, F_a

Site Class	Mapped Maximum Considered Earthquake Spectral Response Acceleration Parameter at Short Period				
	$S_S \le 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1.0$	$S_S \ge 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.4.7				

NOTE: Use straight-line interpolation for intermediate values of S_S.

Search by Address Search by Coordinate

313 Short School Rd, Snohomish, WA 98290, USA Search

inates: 47.855481, -122.076269

Wind Snow Tornado Seismic

erence Document	ASCE7-16
Category	II
Class	E - Soft Clay Soil

Print these results Save these results

Basic Parameters

Name	Value	Description
S_S	1.275	MCE_R ground motion (period=0.2s)
S_1	0.449	MCE_R ground motion (period=1.0s)
S_{MS}	** null	Site-modified spectral acceleration value
S_{M1}	* null	Site-modified spectral acceleration value
S_{DS}	** null	Numeric seismic design value at 0.2s SA
S_{D1}	* null	Numeric seismic design value at 1.0s SA

* See Section 11.4.8
** See Section 11.4.8

$S_{MS} := F_a \cdot S_s = 1.148$

$S_{DS} := \frac{2}{3} \cdot S_{MS} = 0.765$

Approximate Period:

$h_n := 10\ ft + 1\ ft = 11\ ft$

TABLE 12.8-2 VALUES OF APPROXIMATE PERIOD PARAMETERS C_t AND x

Structure Type	C_t	x
Moment-resisting frame systems in which the frames resist 100% of the required seismic force and are not enclosed or adjoined by components that are more rigid and will prevent the frames from deflecting where subjected to seismic forces:		
Steel moment-resisting frames	0.028 (0.0724)[a]	0.8
Concrete moment-resisting frames	0.016 (0.0466)[a]	0.9
Eccentrically braced steel frames	0.03 (0.0731)[a]	0.75
All other structural systems	0.02 (0.0488)[a]	0.75

[a]Metric equivalents are shown in parentheses.

$C_t := 0.02$

$x := 0.75$

$T_a := C_t \cdot h_n^{\,x}$

$T_a := .1208$ seconds

Approximate Fundamental Period

Seismic Response Coefficient:

$I_e := 1.0$ Risk Category 2

Table 1.5-2 Importance Factors by Risk Category of Buildings and Other Structures for Snow, Ice, and Earthquake Loads[a]

Risk Category from Table 1.5-1	Snow Importance Factor, I_s	Ice Importance Factor—Thickness, I_i	Ice Importance Factor—Wind, I_w	Seismic Importance Factor, I_e
I	0.80	0.80	1.00	1.00
II	1.00	1.00	1.00	1.00
III	1.10	1.25	1.00	1.25
IV	1.20	1.25	1.00	1.50

[a]The component importance factor, I_p, applicable to earthquake loads, is not included in this table because it is dependent on the importance of the individual component rather than that of the building as a whole, or its occupancy. Refer to Section 13.1.3.

$$R := 6.5$$

$$C_s := \left(\frac{S_{DS}}{\frac{R}{I_e}} \right) = 0.118$$

ASCE 7-16 12.8-2

Table 12.2-1 Design Coefficients and Factors for Seismic Force-Resisting Systems

Seismic Force-Resisting System	ASCE 7 Section Where Detailing Requirements Are Specified	Response Modification Coefficient, R^a	Overstrength Factor, Ω_0^g	Deflection Amplification Factor, C_d^b	Structural System Limitations Including Structural Height, h_n (ft) Limits[c] — Seismic Design Category B	C	D^d	E^d	F^e
A. BEARING WALL SYSTEMS									
1. Special reinforced concrete shear walls[l,m]	14.2	5	2½	5	NL	NL	160	160	100
2. Ordinary reinforced concrete shear walls[l]	14.2	4	2½	4	NL	NL	NP	NP	NP
3. Detailed plain concrete shear walls[l]	14.2	2	2½	2	NL	NP	NP	NP	NP
4. Ordinary plain concrete shear walls[l]	14.2	1½	2½	1½	NL	NP	NP	NP	NP
5. Intermediate precast shear walls[l]	14.2	4	2½	4	NL	NL	40[k]	40[k]	40[k]
6. Ordinary precast shear walls[l]	14.2	3	2½	3	NL	NP	NP	NP	NP
7. Special reinforced masonry shear walls	14.4	5	2½	3½	NL	NL	160	160	100
8. Intermediate reinforced masonry shear walls	14.4	3½	2½	2¼	NL	NL	NP	NP	NP
9. Ordinary reinforced masonry shear walls	14.4	2	2½	1¾	NL	160	NP	NP	NP
10. Detailed plain masonry shear walls	14.4	2	2½	1¾	NL	NP	NP	NP	NP
11. Ordinary plain masonry shear walls	14.4	1½	2½	1¼	NL	NP	NP	NP	NP
12. Prestressed masonry shear walls	14.4	1½	2½	1¾	NL	NP	NP	NP	NP
13. Ordinary reinforced AAC masonry shear walls	14.4	2	2½	2	NL	35	NP	NP	NP
14. Ordinary plain AAC masonry shear walls	14.4	1½	2½	1½	NL	NP	NP	NP	NP
15. Light-frame (wood) walls sheathed with wood structural panels rated for shear resistance or steel sheets	14.1 and 14.5	6½	3	4	NL	NL	65	65	65
16. Light-frame (cold-formed steel) walls sheathed with wood structural panels rated for shear resistance or steel sheets	14.1	6½	3	4	NL	NL	65	65	65
17. Light-frame walls with shear panels of all other materials	14.1 and 14.5	2	2½	2	NL	NL	35	NP	NP
18. Light-frame (cold-formed steel) wall systems using flat strap bracing	14.1	4	2	3½	NL	NL	65	65	65

Seismic Weight Estimates:

$$W_{roof} := w_{roof} \cdot 12\ ft \cdot 25\ ft = 0.569\ kip$$

$$W_{wall\_1} := w_{ext.wall} \cdot 12\ ft \cdot 25\ ft = 0.332\ kip$$

$$W_{wall} := w_{ext.wall} \cdot 10\ ft \cdot (12 \cdot 2 + 25)\ ft = 0.542\ kip$$

triangular wall: wall wt*(bh/2)

$$W_{triangular\_wall} := w_{ext.wall} \cdot \left(12\ ft \cdot 2\ \frac{ft}{2} \right) = 0.013\ kip$$

$$W := W_{roof} + W_{wall} + W_{wall\_1} + W_{triangular\_wall} = 1.455\ kip$$

Appendix K
Structural Analysis Shear Wall Design

Shear Walls

Shear Wall Shortside Wall: West Wall w/ Header 1

$$h := 10\ ft$$
$$b := 6\ ft$$
$$\frac{h}{b} = 1.667$$
$$V_{ASD} := \left(\frac{6240}{2}\right)\ lbf = \left(3.12 \cdot 10^{3}\right)\ lbf$$

$\phi := 0.80$ ...Resistance Factor

$\Omega := 2.0$ ...Safety Factor

Required Unit Load

$$v_{nominal.req} := \frac{V_{ASD}}{b} = 520\ plf$$

Table 4.3A Nominal Unit Shear Capacities for Wood-Frame Shear Walls[1,3,6,7]

Wood-based Panels[4]

Sheathing Material	Minimum Nominal Panel Thickness (in.)	Minimun Fastener Penetration in Framing Member or Blocking (in.)	Fastener Type & Size	A SEISMIC — Panel Edge Fastener Spacing (in.) 6			4			3			2		
				v_s (plf)	G_a (kips/in.)		v_s (plf)	G_a (kips/in.)		v_s (plf)	G_a (kips/in.)		v_s (plf)	G_a (kips/in.)	
			Nail (common or galvanized box)		OSB	PLY		OSB	PLY		OSB	PLY		OSB	PLY
Wood Structural Panels – Sheathing[4,5]	5/16	1-1/4	6d	360	13	9.5	540	18	12	700	24	14	900	37	18
	3/8			400	11	8.5	600	15	11	780	20	13	1020	32	17
	3/8[2]	1-3/8	8d	440	17	12	640	25	15	820	31	17	1060	45	20
	7/16[2]			480	15	11	700	22	14	900	28	17	1170	42	21
	15/32			520	13	10	760	19	13	980	25	15	1280	39	20
	15/32	1-1/2	10d	620	22	14	920	30	17	1200	37	19	1540	52	23
	19/32			680	19	13	1020	26	16	1330	33	18	1740	48	22

1. Nominal unit shear capacities shall be adjusted in accordance with 4.3.3 to determine ASD allowable unit shear capacity and LRFD factored unit resistance. For general construction requirements see 4.3.6. For specific requirements, see 4.3.7.1 for wood structural panel shear walls, 4.3.7.2 for particleboard shear walls, and 4.3.7.3 for fiberboard shear walls. See Appendix A for common and box nail dimensions.
2. Shears are permitted to be increased to values shown for 15/32 inch (nominal) sheathing with same nailing provided (a) studs are spaced a maximum of 16 inches on center, or (b) panels are applied with long dimension across studs.
3. For species and grades of framing other than Douglas-Fir-Larch or Southern Pine, reduced nominal unit shear capacities shall be determined by multiplying the tabulated nominal unit shear capacity by the Specific Gravity Adjustment Factor = [1-(0.5-G)], where G = Specific Gravity of the framing lumber from the NDS (Table 12.3.3A). The Specific Gravity Adjustment Factor shall not be greater than 1.
4. Apparent shear stiffness values G_a, are based on nail slip in framing with moisture content less than or equal to 19% at time of fabrication and panel stiffness values for shear walls constructed with either OSB or 3-ply plywood panels. When 4-ply or 5-ply plywood panels or composite panels are used, G_a values shall be permitted to be multiplied by 1.2.
5. Where moisture content of the framing is greater than 19% at time of fabrication, G_a values shall be multiplied by 0.5.
6. Where panels are applied on both faces of a shear wall and nail spacing is less than 6" on center on either side, panel joints shall be offset to fall on different framing members as shown below. Alternatively, the width of the nailed face of framing members shall be 3" nominal or greater at adjoining panel edges and nails at all panel edges shall be staggered.
7. Galvanized nails shall be hot-dipped or tumbled.

$$\textit{Specific Gravity Adjustment Factor } (SGAF) = [1 - (0.5 - G)]$$

DOUGLAS FIR-LARCH										
Select Structural	2" & wider	1,500	1,000	180	625	1,700	1,900,000	690,000	0.50	WCLIB WWPA
No. 1 & Btr		1,200	800	180	625	1,550	1,800,000	660,000		
No. 1		1,000	675	180	625	1,500	1,700,000	620,000		
No. 2		900	575	180	625	1,350	1,600,000	580,000		
No. 3		525	325	180	625	775	1,400,000	510,000		
Stud	2" & wider	700	450	180	625	850	1,400,000	510,000		
Construction	2" - 4" wide	1,000	650	180	625	1,650	1,500,000	550,000		
Standard		575	375	180	625	1,400	1,400,000	510,000		
Utility		275	175	180	625	900	1,300,000	470,000		

$G := 0.5$

Use 19/32" Plywood Sheathing with 10d fasteners @ 4" o.c. at panel boundaries

$v_{nominal} := 1430\ plf$ SDPWS 2015 Table 4.3A

$$v_{allowable} := \frac{v_{nominal}}{2} = 715\ plf$$

$$DCR := \frac{v_{nominal.req}}{v_{allowable}} = 0.727$$

$$OTM := V_{ASD} \cdot h = 31200\ lbf \cdot ft$$

$$T_{chord} := \frac{OTM}{b} = 5200\ lbf$$

$$C_{chord} := T_{chord} = 5200\ lbf$$

$$T_{chord.ASD} := \frac{T_{chord}}{\phi} \cdot \left(\frac{1}{\Omega}\right) = \left(3.25 \cdot 10^3\right)\ lbf$$

Appendix L
Structural Analysis South-Wall Header Design

Header Size: 8'

$$L := 8\ ft$$

Loads:

$L_r := 20\ psf$ ... Per Seattle SDCI

$D := 5.195\ psf$ ... Per Total Live Load Calc.

$S := 25\ psf$ ... Per Seattle SDCI

Load:

$$w := (411\ lb + 135\ lb) \cdot \frac{12\ \frac{in}{ft}}{16\ in} = 409.5\ \frac{lb}{ft}$$ Roof Rafter Load ... SDSA pg.1

$$w := 409.5\ plf$$ Roof Rafter Load ... SDSA pg.4

Dimensions of 6x8 Doug-Fir L:

$$b := 5.25\ in$$

$$d := 7.25\ in$$

Geometric Values:

$$A_g := b \cdot d = 38.063\ in^2$$

$$S_{xx} := b \cdot \frac{d^2}{6} = 45.992\ in^3$$

$$I_{xx} := b \cdot \frac{d^3}{12} = 166.722\ in^4$$

Load Reactions:

$$M := w \cdot \frac{L^2}{8} = 3.276\ kip \cdot ft$$

$$V := w \cdot \frac{L}{2} = 1.638\ kip$$

Design Values ... Per NDS-2018-SUPP

DOUGLAS FIR-LARCH										
Select Structural	2" & wider	1,500	1,000	180	625	1,700	1,900,000	690,000	0.50	WCLIB WWPA
No. 1 & Btr		1,200	800	180	625	1,550	1,800,000	660,000		
No. 1		1,000	675	180	625	1,500	1,700,000	620,000		
No. 2		900	575	180	625	1,350	1,600,000	580,000		
No. 3		525	325	180	625	775	1,400,000	510,000		
Stud	2" & wider	700	450	180	625	850	1,400,000	510,000		
Construction	2" - 4" wide	1,000	650	180	625	1,650	1,500,000	550,000		
Standard		575	375	180	625	1,400	1,400,000	510,000		
Utility		275	175	180	625	900	1,300,000	470,000		

$F_b := 900\ psi$ $F_v := 180\ psi$ $E := 1.6 \cdot 10^6\ psi$ $E_{min} := 580000\ psi$

$F_{c.perp.} := 625\ psi$

Adjustment Factors:

$C_D := 1.0$ ... NDS-2018, Table 2.3.2 live load (ten-year load)

$C_M := 1.0$ ... $MC \le 19\%$

$C_F := 1.2$ ... NDS-2018-SUPP, Table 4A Adjustment Factors

$C_L := 1.0$

$C_r := 1.0$

$C_T := 1.0$

$C_{fu} := 1.15$ ... NDS SUPP Table 4A pg. 32

Adjusted E Values:

$E' := E \cdot C_M = \left(1.6 \cdot 10^6\right)\ psi$

$E'_{min} := E_{min} \cdot C_M \cdot C_T = \left(5.8 \cdot 10^5\right)\ psi$

Check Bending:

$$f_b := \frac{M}{S_{xx}} = 854.754\ psi$$

$$F'_b := F_b \cdot C_D \cdot C_M \cdot C_r \cdot C_L \cdot C_F = \left(1.08 \cdot 10^3\right)\ psi$$

Check Shear:

$$f_v := 1.5 \cdot \frac{V}{A_g} = 64.552\ psi$$

$$F'_V := F_v \cdot C_D \cdot C_M = 180\ psi$$

Check Deflection:

$$\Delta_L := \frac{\left(5 \cdot L_r \cdot L^4\right)}{384 \cdot E' \cdot I_{xx}} = 0.007 \, \frac{1}{ft} \cdot in$$

$$\Delta_{L.allow} := \frac{L}{480} = 0.2 \; in$$

$\Delta_{L.allow} > \Delta_L$ good

$$\Delta_w := \frac{\left(5 \cdot w \cdot L^4\right)}{384 \cdot E' \cdot I_{xx}} = 0.141 \; in$$

$\Delta_{w.allow} > \Delta_w$ good

$$\Delta_{w.allow} := \frac{L}{360} = 0.267 \; in$$

Appendix M
Structural Analysis West-Wall Header Design

Dimensions: Parallam 6x14

$b := 5.25\ in$

$d := 13.875\ in$

$P := V = 1.638\ kip$

$E := 1660000\ psi$

$I_{xx} := b \cdot \frac{d^3}{12} = \left(1.169 \cdot 10^3\right)\ in^4$

$R_B := 2.73\ kip$

$\Sigma F_y := 0$

$R_A := V - R_B = -1.092\ kip$

$L := 10\ ft$ (x-6)

$w := 22.6\ plf$

$$\Delta_C := \frac{1}{E \cdot I_{xx}} \cdot \left[\frac{\left(R_A \cdot L^3\right)}{6} + \left(\frac{R_B}{6} \cdot (L - 6\ ft)^3\right) + \left(w \cdot \frac{L^4}{24}\right) + 209.952\ kip \cdot ft^2 \cdot L + \left(98.28\ kip \cdot ft^3\right) \right] = [1.83]$$

... Deflection at L=10

$$\frac{-154.51\ kip \cdot ft^3}{E \cdot I_{xx}} = -0.138\ in$$

Appendix N
Lot Areas Table

	A	B	C
1	Lot Number	Area ft^2	acreage
2	1	21462	0.4926997245
3	2	21462	0.4926997245
4	3	21462	0.4926997245
5	4	21865	0.5019513315
6	5	15318	0.3516528926
7	6	18012	0.4134986226
8	7	21719	0.4985996327
9	8	31269	0.7178374656
10	9	22717	0.5215105601
11	10	22024	0.5056014692
12	11	20695	0.4750918274
13	12	27920	0.6409550046
14	13	40279	0.9246786042
15	14	53714	1.233103765
16	15	30728	0.7054178145
17	16	24226	0.5561524334
18	17	22896	0.5256198347
19	18	19994	0.4589990817
20	19	22161	0.5087465565
21	20	24496	0.5623507805
22	21	24496	0.5623507805
23	22	24496	0.5623507805
24	23	24496	0.5623507805
25	24	24496	0.5623507805
26	25	24496	0.5623507805
27	26	24496	0.5623507805
28	27	24496	0.5623507805
29	28	24496	0.5623507805
30	29	24496	0.5623507805

	A	B	C
32	31	25436	0.5839302112
33	32	22832	0.5241505969
34	33	22832	0.5241505969
35	34	22832	0.5241505969
36	35	22832	0.5241505969
37	36	22832	0.5241505969
38	37	22832	0.5241505969
39	38	22832	0.5241505969
40	39	22832	0.5241505969
41	40	22832	0.5241505969
42	41	22832	0.5241505969
43	42	27331	0.6274334252
44	43	32287	0.7412075298
45	44	32493	0.7459366391
46	45	22748	0.5222222222
47	46	20649	0.4740358127
48	47	23262	0.5340220386
49	48	21269	0.4882690542
50	49	21573	0.4952479339
51	50	29977	0.6881772268
52	51	24589	0.5644857668
53	52	25127	0.5768365473
54	53	24987	0.5736225895
55	54	26581	0.6102157943
56	55	24186	0.5552341598
57	56	27515	0.6316574839
58	57	21300	0.4889807163
59	58	24143	0.5542470156
60	59	21921	0.5032369146
61	60	32843	0.7539715335

	A	B	C	D	E
62	61	51839	1.190059688		
63	62	33738	0.7745179063		
64	63	31736	0.7285583104		
65	64	28804	0.6612488522		
66	65	26878	0.6170339761		
67	66	29204	0.6704315886		
68	67	27888	0.6402203857		
69	68	23004	0.5280991736		
70	69	24304	0.557943067		
71	70	29467	0.6764692378		
72	Community space 1	357686		8.211	22.521
73	community space 2	386704		8.87	
74	pond space	236977		5.44	
75			0.603 Acres	average	
76	Total Community Space		47.06 Acres	Total Lot Area	
77	981367				
78	22.52 acres				

Appendix O
Activity List and Cost Estimation

Self-Performed Work Cost Estimate

ID	Activity	Quantity	unit	Daily Output	Duration days	Material $/Unit	WTC	Material Cost	Crew	Labor $/Unit	**Labor FC**	Labor Cost	Equip. $/Unit	**C**	Equip. Cost	Total Cost
1	Clearing and Grubbing - Cut and chip medium, trees to 12" diam. - Grub stumps and remove	0.5	Acre	1	0.50	0	1.024	$0	B30	846.84	1.361	$423	2,567.25		$2,567	$3,143
2	Foundation Excavation - Structural Excavation for minor structures - 3/8' C.Y. excavator	82.5	B.C.Y	132	0.63	0	1.252	$0	1 Clab	28.73	1.418	$2,370	0.00		$0	$3,362
3	SOG - 3500 psi not incl. forms or reinforcing, 4" thick	250	S.F.	3425	0.07	1.39	1.191	$348	C14F	0.74	1.504	$185	0.01		$0	$692
4	SOG formwork - CIP concrete forms, bulkhead for slab on grade w/ keyway 4/5" high, erecting bracing stripping cleaning	70	L.F.	1200	0.06	0.91	1.233	$64	C1	0.97	1.499	$68	0			$180
5	Floor Framing (2x6) -Bolted to concrete 2"x6"	190	L.F.	160	1.19	4.82	1.252	$916	1 Carp	2.1	1.418	$399	0		$0	$1,712
6	Wall Framing (2x8) - 2"x8", pneumatic nailed	578	L.F.	870	0.66	0.99	1.216	$572	2 Carp	0.77	1.422	$445	0		$0	$1,329
7	Interior wall framing (2x4) - 2x4 studs, 10' high, 16" O.C., Pneumatic Nailed	100	L.F.	120	0.83	4.05	1.252	$405	2 Carp	5.59	1.400	$559	0			$1,290
8	Roof Framing (2x8) - 2"x8", 12' Ordinary	228	L.F.	950	0.24	0.81	1.240	$185	2 Carp	0.71	1.436	$162	0		$0	$461
9	Joist Framing (2x8) - 2"x8" pneumatic nailed	225	L.F.	1265	0.18	0.82	1.240	$185	2 Carp	0.53	1.422	$119	0			$398
10	Exterior Door - Doors, glass, swing, tempered, 1/2" thick, 3'x7' opening, incl. hardware	1	Opng.	2	0.50	2191.9	1.173	$2,192	2 Glaz.	278.63	1.466	$279				$2,979
11	Interior Sliding Door - Doors, aluminum sliding glass door system, 4' wide opening single side, 4'x7'	2	ea.	2	1.00	1512	1.151	$3,024	2 Carp.	162	1.466	$324	0			$3,955
12	sheetrock/drywall	770	S.F.			0.75	1.234	$578	1 carp	0.75	1.442	$833	1.5		$1,155	$3,068
13	Insulation in walls ceilings floor - Blanket Insulation, for walls and ceilings, foil faced fiberglass, 6" thick, R21, 15" wide	1320	S.F.	1350	0.98	0.65	1.301	$858	1 Carp.	0.23	1.481	$304	0		$0	$1,566
14	plywood sheathing on exterior	770	S.F.	1952	0.39	0.55	1.228	$424	2 Carp.	0.34	1.397	$262			$0	$886
15	subfloor plywood sheathing - 1/2" thick CDX plywood, pneumatic nailed	250	S.F. Fir	1860	0.13	0.59	1.240	$148	2 Carp.	0.36	1.384	$90	0			$307
16	Flooring - floating floor, laminate, wood pattern strip, complete	250	S.F.	133	1.88	4	1.214	$1,000	1 Clab.	1.95	1.353	$488				$1,874

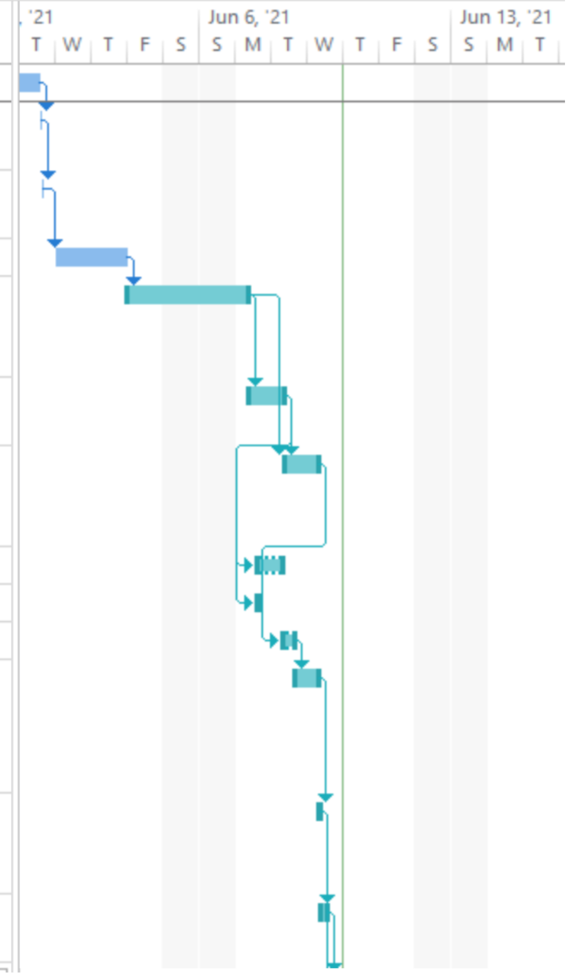
17	Plywood on Roof, CDX 5/16" thick, pneumatic nailed	300	S.F.	1952	0.15	0.55	1.240	$165	2 Carp.	0.34	1.436	$102	0			$351
18	Solar - subcontractor work						0.000	$0			1.560	$0	0		$0	$5,000
19	electrical wiring - 20' avg. runs, #14/2 wiring, socket, panel board, main bkr., ground rod, 100 amp, with 10 branch breakers with pvc conduit wire	1	ea.	0.92	1.09	516.75	1.203	$517	1 Elec.	398.48	1.430	$398	0		$0	$1,192
20	Air Conditioner outlet	1	ea.	10	0.10	60.45	1.227	$60	1 Elec.	36.74	1.401	$37	0		$0	$126
21	Dryer outlet	1	ea.	6.41	0.16	56.55	1.238	$57	1 Elec.	56.93	1.454	$57	0		$0	$153
22	Low voltage outlets	6	ea.	16	0.38	15.36	1.238	$92	1 Elec.	22.77	1.401	$137	0		$0	$306
23	Lighting Outlets	4	ea.	25	0.16	13.55	1.238	$54	1 Elec.	14.65	1.419	$59	0		$0	$150
24	Steel roofing panels, corrugated or ribbed, painted finish on steel frame, 22 gauge	300	S.F.	900	0.33	3.03	1.201	$909	G3	1.28	1.275	$384	0		$0	$1,581
25	Painting Exterior - siding, exterior,1 coat	3500	S.F.	2015	1.74	0.09	1.091	$315	2 Pord.	0.25	1.270	$875	0		$0	$1,455
26	Sink, Kitchen, counter top style, 24"x21"	1	ea.	5.6	0.18	300	1.091	$300	Q1	108.03	1.27	$108	0		$0	$464
27	Shower, Stall, with drain only, 32" square	1	ea.	5	0.20	1350	1.091	$1,350	Q1	120.46	1.386	$120	0		$0	$1,640
28	6x14 Header	1	L.F.					$0				$0			$0	$400
29	6x8 Header	1	L.F.					$0				$0			$0	$87
30	2x8 Joists	187.9	L.F.	200	0.94	0.81	1.228	$152	1 Carp	1.68	1.384	$316			$0	$624
31	Exterior Trim, band board, cedar, rough sawn 1"x10"	1163	L.F.	225	5.17	2.69		$3,128	1 Carp	1.49	1.384	$1,733			$0	$4,861
32	Plumbing/pipes/shower,sinks,toilet							$0				$0			$0	$3,500
33	septic							$0				$0			$0	$7,000
34	Windows, custom, 8' 6" x 5' double glazed, 3/16" thick, incl. glazing	2	ea.	4.3	0.47	561.44	1.173	$1,123	2 carp	180.79	1.301	$362			$0	$1,788
					20.30											
																$57,880

Appendix P
Cost Adjustment Factors

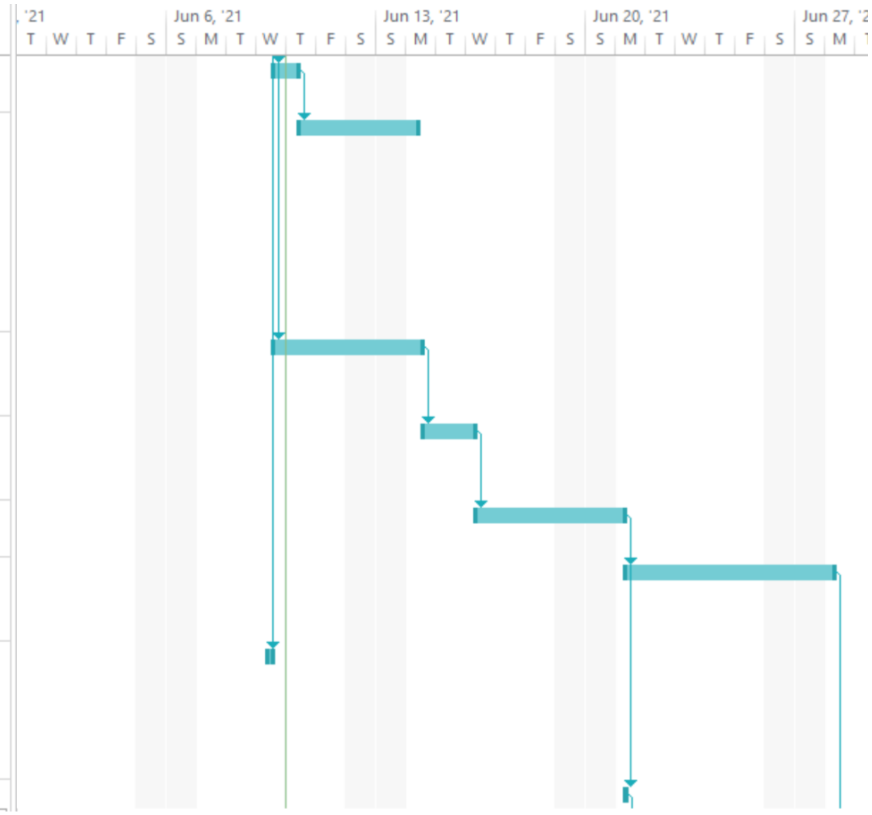
ID		Waste	Tax	Mat. City Index	Material WTC	Labor Overhead	Inst. City Index	Labor FC	Equip. C
1	Clearing and Grubbing - Cut and chip medium, trees to 12" diam. - Grub stumps and remove	1	1.06	0.966	1.024	1.294	1.052	1.361	1.052
2	Lot Grading (excavation) -	1.06	1.06	0.966	1.085	1.322	1.052	1.391	1.052
3	Lot Grading (fill)	1.03	1.06	0.966	1.055	1.306	1.052	1.374	1.052
4	Foundation Excavation - Structural Excavation for minor structures - hand, pits to 6' deep, heavy soil or clay	1.05	1.06	0.966	1.075	1.311	1.052	1.379	1.052
5	Foundation (rebar/formwork/concrete)	1.05	1.06	0.966	1.075	1.311	1.052	1.379	0
6	SOG - Fine Grade for slab on grade, machine	1.05	1.06	1.05	1.169	1.322	1.138	1.504	1.138
7	SOG - 3500 psi not incl. forms or reinforcing, 4" thick	1.07	1.06	1.05	1.191	1.322	1.138	1.504	1.138
8	SOG formwork - CIP concrete forms, bulkhead for slab on grade w/ keyway 4/5" high, erecting bracing stripping cleaning	1.06	1.06	1.097	1.233	1.306	1.148	1.499	1.148
9	Floor Framing (2x6) -Bolted to concrete 2"x6"	1.06	1.06	1.114	1.252	1.306	1.086	1.418	1.086
10	Wall Framing (2x8) - 2"x8", pneumatic nailed	1.03	1.06	1.114	1.216	1.310	1.086	1.422	1.086
11	Interior wall framing (2x4) - 2x4 studs, 10' high, 16" O.C., Pneumatic Nailed	1.06	1.06	1.114	1.252	1.289	1.086	1.400	1.086
12	Roof Framing (2x8) - 2"x8", 12' Ordinary	1.05	1.06	1.114	1.240	1.322	1.086	1.436	1.086
13	Joist Framing (2x8) - 2"x8" pneumatic nailed	1.05	1.06	1.114	1.240	1.310	1.086	1.422	1.086
14	Stair Framing (2x4) -prefab wood stairs, box stairs, pine treads for carpet 3' wide	1.07	1.06	1.114	1.263	1.322	1.086	1.436	1.086
15	Wood Stair Parts, Risers, pine 1"x8"x36" long	1.05	1.06	1.114	1.240	1.301	1.086	1.413	1.086
16	Exterior Door - Doors, glass, swing, tempered, 1/2" thick, 3'x7' opening, incl. hardware	1.07	1.06	1.034	1.173	1.322	1.109	1.466	1.109
17	Interior Sliding Door - Doors, aluminum sliding glass door system, 4' wide opening single side, 4'x7'	1.05	1.06	1.034	1.151	1.322	1.109	1.466	1.109
18	Loft (2x4) - Ceiling framing suspended 2"x4"	1.05	1.06	1.114	1.240	1.322	1.105	1.461	1.105
19	sheetrock/drywall	1.04	1.06	1.119	1.234	1.322	1.091	1.442	1.091
20	Insulation in walls ceilings floor - Blanket Insulation, for walls and ceilings, foil faced fiberglass, 6" thick, R21, 15" wide	1.04	1.06	1.18	1.301	1.322	1.12	1.481	1.12
21	plywood sheathing on exterior	1.04	1.06	1.114	1.228	1.286	1.086	1.397	1.086
22	subfloor plywood sheathing - 1/2" thick CDX plywood, pneumatic nailed	1.05	1.06	1.114	1.240	1.274	1.086	1.384	1.086
23	Flooring - floating floor, laminate, wood pattern strip, complete	1.05	1.06	1.091	1.214	1.274	1.062	1.353	1.062
24	Plywood on Roof, CDX 5/16" thick, pneumatic nailed	1.05	1.06	1.114	1.240	1.322	1.086	1.436	1.086
25	Solar - subcontractor work	1.07	1.06		0.000	1.322	1.18	1.560	1.18
26	electrical wiring - 20' avg. runs, #14/2 wiring, socket, panel board, main bkr., ground rod, 100 amp, with 10 branch brekers with pvc conduit wire	1.03	1.06	1.102	1.203	1.300	1.1	1.430	1.1
27	Air Conditioner outlet	1.05	1.06	1.102	1.227	1.274	1.1	1.401	1.1
28	Dryer outlet	1.06	1.06	1.102	1.238	1.322	1.1	1.454	1.1
29	Low voltage outlets	1.06	1.06	1.102	1.238	1.274	1.1	1.401	1.1
30	Lighting Outlets	1.06	1.06	1.102	1.238	1.290	1.1	1.419	1.1
31	Steel roofing panels, corrugated or ribbed, painted finish on steel frame, 22 gauge	1.06	1.06	1.069	1.201	1.290	0.988	1.275	0.988
32	Painting Exterior - siding, exterior,1 coat	1.06	1.06	0.971	1.091	1.306	0.972	1.270	0.972
33		1.06	1.06		0.000		1.054	0.000	1.054
34		1.06	1.06		0.000	1.315	1.054	1.386	1.054

Appendix Q
Construction Schedule

		Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1			Foundation Excavatic	0.63 days	Tue 6/1/21	Tue 6/1/21		
2			SOG Formwork - CIP concrete forms	0.2 days	Tue 6/1/21	Tue 6/1/21	1	
3			SOG - 3500 psi, 4" thick	0.15 days	Tue 6/1/21	Tue 6/1/21	2	
4			SOG Curing	2 days	Wed 6/2/21	Thu 6/3/21	3	
5			Floor Framing, 2"x6", bolted to concrete	1.19 days	Fri 6/4/21	Mon 6/7/21	4	
6			Wall framing, 2x8 - pneumatic nailed	1 day	Mon 6/7/21	Tue 6/8/21	5	
7			Interior Wall Framing, 2x4 studs, 10' high, 16" O.C.	0.83 days	Tue 6/8/21	Wed 6/9/21	5,6	
8			Header 6"x14"	0.2 days	Mon 6/7/21	Tue 6/8/21	6	
9			Header 6"x8"	0.1 days	Mon 6/7/21	Mon 6/7/21	6	
10			Joists 2"x8", 10' long	0.9 days	Tue 6/8/21	Tue 6/8/21	7	
11			Subfloor Plywood Sheathing, 1/2" thick CDX plywood, pneumatic nailed	0.13 days	Tue 6/8/21	Wed 6/9/21	10	
12			Plywood on Roof, CDX 5/16" thick, pneumatic nailed	0.15 days	Wed 6/9/21	Wed 6/9/21	11	
13			Plywood Sheathing Exterior	0.39 days	Wed 6/9/21	Wed 6/9/21	12	



		Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names
14			Outlets for lighting/appliances	0.8 days	Wed 6/9/21	Thu 6/10/21	13	
15			electrical wiring - 20' avg. runs, #14/2 wiring, socket, panel board, main bkr., ground rod, 100 amp, with 10 branch brekers with pvc conduit wire	2 days	Thu 6/10/21	Mon 6/14/21	14	
16			Plumbing, bathroom/kitchen pipes	3 days	Wed 6/9/21	Mon 6/14/21	13	
17			Insulation in walls and ceilings -6" thick, R21, 15" wide	1.5 days	Mon 6/14/21	Wed 6/16/21	16	
18			Drywall - Taping, Hanging, Mudding	3 days	Wed 6/16/21	Mon 6/21/21	17	
19			Exterior Trim, Band Board, cedar, rough sawn, 1"x10"	5 days	Mon 6/21/21	Mon 6/28/21	18	
20			Steel Roofing Panels, Corrugated or Ribbed, Painted finish on steel frame, 22 gauge	0.5 days	Wed 6/9/21	Wed 6/9/21	12	
21			Kitchen, sink,	0.18 days	Mon	Mon	18	



		Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names
21			Kitchen, sink, countertop style 24"x21"	0.18 days	Mon 6/21/21	Mon 6/21/21	18	
22			Shower, Stall, with drain, 32" square	0.2 days	Mon 6/21/21	Mon 6/21/21	21	
23			Painting, interior and exterior	1.74 days	Mon 6/28/21	Tue 6/29/21	19	
24			Sindows, custom, 8' 6"x5' double glaxed , 3/16" thick, incl. glazing	0.5 days	Tue 6/29/21	Wed 6/30/21	23	
25			Exterior Door - glass, swing, tempered, 3/16" thick, incl. Hardware	0.5 days	Wed 6/30/21	Wed 6/30/21	24	
26			Interior sliding door - aluminum sliding glass door system, 4' wide opening single side, 4'x7'	0.5 days	Tue 6/29/21	Wed 6/30/21	23	
27		?	Solar					
28		?	Septic