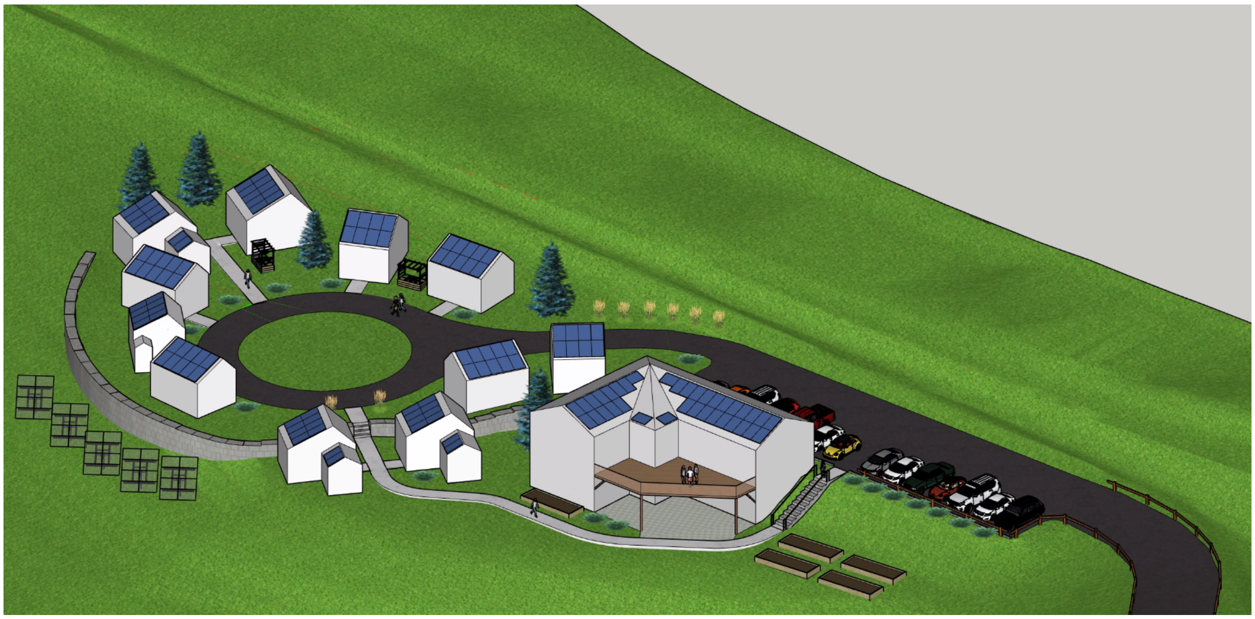
Cohousing Development Design for Lot in Bozeman, Montana



A Major Qualifying Project to be submitted to the faculty of
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Abstract

Cohousing is an intentional form of living that fosters affordable housing, sustainable practices, and tight-knit communities. With peer preferences as a guide, I designed a twenty-person cohousing development on a parcel of land located in Bozeman, Montana. The final product consisted of a full schematic site plan (developed in Civil 3D), a digital model (developed in SketchUp), and a cost estimate that included a mortgage schedule for all residents. Design elements included grading, stormwater management, wastewater treatment, electrical system sizing, layout development, and landscape architecture.

Design Statement

ABET (The Accreditation Board for Engineering and Technology) defines economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability as reasonable constraints for a capstone design project. Throughout the course of this Major Qualifying Project (MQP), all of these constraints (with the exceptions of political and manufacturability) were addressed.

The first constraint that influenced design was social structure. Being an intentional form of living, cohousing design is dependent on the preferences of the residents who make up the community. Since this project was hypothetical in nature, peer preferences on dwelling size, number of residents, and community layout all influenced the final design. The final proposed development was tailored to maximize the level of communitas (a measure of a community's closeness).

The next constraint addressed was ethics. With the many social benefits of cohousing, comes the opportunity to share resources with lower-income individuals. Of the eleven dwellings designed, one two-person dwelling was set to be fully subsidized by the community to provide an affordable housing option for a local family. This choice comes in conjunction with the intention to host public meals once a month where anyone from the surrounding area can come and share food while learning about life in a cohousing development.

The next constraint considered was environmental impacts. By referencing Bozeman design standards for stormwater conveyance, wastewater treatment, and well placement, the aforementioned site features were able to be specified and sized properly. Properly managing stormwater is integral in preventing increased pollutant runoff and ensuring adequate groundwater recharge. Similarly, proper wastewater treatment enables naturally occurring bacteria to breakdown human waste before it reaches groundwater, while monitored well pumping limits drawdown of the water table. Through the entire schematic stage of the project, environmental factors were some of the most significant influences on design.

The fourth constraint considered during design was safety. By following grading standards, driveway, walkway, and parking lot slopes were all kept at levels traversable by car or foot. Given an extremely steep existing site to begin with, it was key to find ways to level grades outside of dwellings to ensure residents could easily maneuver the site. In areas where steep slopes were unavoidable, guard rails were included to minimize the risk of driving off course.

The fifth constraint addressed was sustainability. With over-consumption being one of the largest detriments to the environment, ensuring low-impact development was an important consideration during this project. In an effort to limit raw materials, all dwellings were designed at under 400 SF. Additionally, the entire development was designed net-zero with a solar system supplying enough power to offset average energy consumption over the course of the year.

The final constraint considered was economics (or cost). This component came into play early on in the project when the parcel of land was being selected. Minimizing the cost of the land was an important starting place in ensuring a lower total cost by the end of development. Once the entire design was completed and a cost estimate had been conducted, it was necessary to determine the relevant costs to each resident living in the community. Utilizing current cost data and mortgage rates helped create a clear picture of the different possibilities for funding the development of the proposed design. As this project was designed on a real piece of land, the ultimate intention is to bring the concept into a reality sometime in the future. Knowing that construction would be economically viable was critical in assessing feasibility at the conclusion of the project.

Professional Licensure Statement

Professional licensure is an integral process in progressing a career as a Civil Engineer and should be sought after by anyone who wishes to develop their own firm and/or sign off on official design documents.

Civil Engineers design large-scale infrastructure projects, manage water quality, and ensure the structural integrity of buildings. All of these activities have major implications on public wellbeing and safety and, if done carelessly or negligently, could result in injury and death. Given the high stakes of the Civil Engineering projects, it is vital that the engineers signing off on the project designs are held to a high order of expertise and professionalism. For this reason, only design plans stamped and approved by a Professional Engineer (PE) are allowed to be constructed and brought to fruition.

Becoming a Professional Engineer is an involved process that typically starts with completing an ABET accredited Bachelor's Degree in the specific field of engineering interest. (While some can progress to Professional Engineers without an ABET accredited degree, the process is far more intensive). Following the completion of the Bachelor's degree, or during senior year, individuals can apply to take the Fundamentals of Engineering Exam (commonly referred to as the FE). This exam is offered in all states, is roughly six hours long, and includes 110 multiple choice questions. While passing grades differ from test to test, 70% correctness is often required to pass the FE. Once an individual has passed the FE they can receive their Engineer in Training certificate. At this point, if they wish to work towards becoming a Professional Engineer, they must work under the direct supervision of an existing PE for at least four years. Following the completion of this fellowship, individuals can apply to take the Professional Engineering Exam, and if they pass, they will receive a PE license in the state in which they took the test. This license certifies that they are allowed to sign off on official design documents and establishes their credibility as an engineer. Depending on the state in which the PE license was earned, the now Professional Engineer may be licensed to work in other states as well. If the Professional Engineer is not licensed to work in a particular state, but wants to be able to, they will likely have to complete an additional certification.

While the process to gain professional license as an engineer seems extensive, it is designed that way intentionally to ensure both public safety and project longevity. The oversight of design flaws can result in large change orders on projects, project failure, and, in the worst-case scenario, injury to civilians. Beyond the altruistic reasoning for acquiring a professional engineering license, the personal freedom that comes along with it is significant and motivation to become a PE sooner rather than later. Being able to set out and develop one's own firm is a huge career milestone and enables engineering autonomy and progression. As more engineers chart their own path in the industry, designs become better, processes become cheaper, and overall public wellbeing is improved. Obtaining a professional engineering license is better for the individual, better for their career, and better for the civilians they are serving with their work.

Executive Summary

During the course of this MQP, a 2.6-acre parcel of land in Bozeman, Montana was selected as the basis for a hypothetical cohousing development design. Through several conceptual design iterations, a full schematic site plan was developed, alongside a digital model and cost estimate for the proposed development. Physical, legal, economical, ethical, and environmental constraints all provided influence to the progression of the project and made it as realistic as possible.

Once a parcel of the land was selected, the design process could begin. The first step involved formally consulting peers on their preferences for such a community, given the available site. Through a group workshop and individual survey, data trends on preferred layout, dwelling size, community size, and social structure were all tabulated. Since cohousing communities are built around intentional living (where stakeholders have a direct influence on the design of their lived environment), the peer input provided a solid baseline to begin conceptual design iterations.

Drafting started by hand and quickly progressed to Civil 3D, where three defined site layout plans were developed on top of a base file that consisted of existing roadways, adjacent parcels, and topographic contours. These three designs were all influenced by both physical and legal constraints, such as slopes, land cover, and zoning ordinances. Following the completion of the conceptual layouts, a set of common metrics was established to rank the layouts and the one with the highest ranking moved forward into the schematic design phase.

The schematic design stage was the most time intensive portion of the project and involved stormwater management design, wastewater treatment design, site grading, well location selection, electric system specification, and progression of the layout. The first of these components addressed was the wastewater system, which was developed based on Bozeman design standards and the physical constraints of the site. Once the leach fields, septic tanks, and piping were located, grading design could begin. Common grading standards for drive aisle, parking lot, and planted slopes were all used as constraints when deciding how to manipulate the existing surface. Drainage was, of course, a significant influence during this portion of design and contributed to some of the higher-level grading decisions. With the entire site graded, stormwater best management practices (BMPs) were selected to offset the proposed runoff rates back to existing site conditions. Again, Bozeman design standards influenced the calculations involved in measuring runoff and in the selection of BMPs. At the completion of stormwater management design, a location for the well was chosen based on local design standards. Finally, the anticipated energy needs of all site structures—based on appliance type and number of residents—were calculated to inform the sizing of the electrical system for the community. Grid-connected solar ended up being the preferred system with panels both ground mounted and roof mounted.

Following finalization of the schematic design, the site was ready to be moved into model space. By combining and manipulating the existing and proposed site contours, the Civil 3D surfaces were able to be imported into SketchUp alongside two-dimensional layout linework.

With this base file setup in SketchUp, further modeling could be completed. All structures were extruded to their desired height and shapes, while major site features such as retaining walls, walkways, driveways, and stairways were added in. With significant site components set to their proper location, the more artistic phase of modeling was entered. Plantings, gardens, guardrails, vehicles, residents, and paint styles were all added to the model to produce final renderings of the site. These renders provided a clear view of what the property would look like, were it developed to the specifications outlined in the project.

With the model complete, the final stage of the project was conducting a cost estimate, and subsequent cost structure, for the proposed development. Localized construction costs for site work, houses, and site features were all referenced in compiling the cost estimate. Additionally, architectural and construction management fees were considered and applied to the subtotal for the estimate. With a total cost tabulated, several mortgage structures were laid out based on different payback schedules, interest rates, and type of dwelling. One of the two-person units on the property was set to be fully subsidized by the community, making it an affordable housing option for lower-income individuals.

At the completion of the cost estimation stage, all that was left to do was reflect on the project and consider potential future progressions. With more time, architectural design for the common house and dwellings could be carried out to provide a clearer picture of what the development would actually look like if constructed. Additionally, with better cost data, a more accurate estimate of project expenses could be calculated. Although there were some limitations to the stage the project could be taken to, the cost benefits of cohousing were very apparent and thanks to peer feedback, it seemed like many young adults were interested in this type of communal living.

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I. Introduction

With housing costs on the rise, over-consumption at its peak, and personal isolation higher than ever before, the need for innovative living arrangements is pressing. Cohousing, an intentional form of communal living, addresses all of the aforementioned hardships and provides a physically minimalist approach to housing while fostering strong interpersonal connections and a sense of belonging.

The goal of this Major Qualifying Project is to select an existing parcel of land and design a cohousing development based on input from peers and acquaintances. Through design iterations, influenced by physical and legal constraints, a conceptual site layout is taken through schematic development involving stormwater management, wastewater treatment, grading, and electrical system sizing. With a site plan developed in Civil 3D, the project transitions to a digital model where more artistic design can be conducted.

At the completion of the design stage, the feasibility of the project is assessed through a cost estimate. Once a final price-tag is known, a cost structure is developed to demonstrate several mortgage schedules that could potentially fund the proposed construction.

The framework of this capstone design project is built on a combination of technical engineering work, artistic design, and social considerations. Design of an actual cohousing community is critically dependent on input from future residents who plan on calling it home. As this project is conceptual in nature, basing design considerations on peer preferences creates a convincing mock-environment of an actual cohousing community.

II. Background

What is Cohousing

Cohousing, as defined by the Cohousing Association of America, is a type of intentional, collaborative housing in which residents actively participate in the design and operation of their neighborhood [1]. The concept took its beginnings in Denmark in the 1960s under the design leadership of architect Jan Gudmand Hoyer who established over forty cohousing developments during his career. Following Hoyer's first set of housing communities, two American architects, Kathryn McCamant and Charles Durrett, promoted the concept in the United States and today there are more than 160 cohousing developments in the country [2].

While the word "cohousing" may trigger thoughts of condominiums to some, and to others the visual of the ancient village commune, cohousing is actually an all-encompassing term that describes the spectrum of communal living. Cohousing practices can be as simple as sharing lawn-care tools with neighbors or as involved as cooking group meals seven days a week and sharing all common spaces outside of the bedroom [2]. Although there is a plethora of reasons individuals might seek out cohousing as their lifestyle of choice, some of the most readily accepted benefits are affordability, decrease in physical and carbon footprint, and increase in sense of belonging.

Existing under the umbrella term "cohousing," are many different types of communities that live together such as multigenerational, senior, urban, and rural groups. Additionally, there are mission-oriented communities that are invested in a specific cause beyond their shared values and work as a team to carry out activities like environmental restoration, homesteading, and community service [3]. Regardless of the type, arrangement, and cause, the key shared attribute of cohousing is that it is intentional living where the residents of the community support one another and are actively involved in the progression and future of the development.

When establishing a new cohousing development there are many preliminary decisions that need to be addressed. While the physical layout of the site and living structures is important, this step is often prefaced by deciding on the financial and social structure of the community that will ultimately dictate how the houses are organized. Some communities, like the Belfast Cohousing & Ecovillage (BCE) in Downeast Maine, are developed by a private contractor and architect and then sold or leased to residents who earn membership status simply by living in the houses. This financial and mortgage arrangement follows essentially the same logic as a condominium complex where the shared spaces are built into the price of the home or the monthly rental fee. The community is further governed internally by a set of bylaws that are democratically decided upon by both permanent owners and temporary lessees [4]. Other cohousing developments are built and established by individuals who jointly share a mortgage and cover other expenses through arrangements outlined in community charters. Beyond these two main types, are hybrid communities that are built and established by members who live on the property, but are designed to accommodate a capacity larger than their initial membership size. The Maitreya Mountain Village (located in the mountains of Northern California) for instance, was started in 2008 by a couple as a single home for their family and over the years they added more and more houses with the established precedent that they could be purchased, leased, or rented for short periods of time. Since then, they have taken in many full-time residents who share a community center and bath-house, but also many temporary guests who book nights or weeks on their property via AirBnB [5]. This organization structure allows for secure growth of the community and is a safer plan for individuals looking to establish their own cohousing development. Whether it be the first, second, or third option, deciding on the financial structure of the community is an integral early step in cohousing that will inevitably influence physical design.

Physical Site Constraints

Once an organizational and financial arrangement has been decided upon by either the developer or the group of future residents, the next major step is to select the parcel of land that the cohousing development is to be built on. Aviara Real Estate lists the three most significant factors to consider when buying land as location, natural hazards, and utility sources [6]. Location pertains to future land valuation and any other personal preferences of the potential residents, while natural hazards and utility sources pertain to site buildability.

Some of the most notable natural constraints to consider are soil composition, slope, obstructions (large rocks, trees etc…), wetlands, fire zones, and conservation land. Soil composition has a number of implications on the buildability of the site, but most significant is the cost of structure foundations and the longevity of the homes built on the land. Soil that is rich in clay and silt for instance absorbs water easily and can cause foundations to crack and heave as it expands [7]. Houses that are built on unstable soils of uniform particle size are also at risk, as faster erosion rates can quickly undermine a structure and render it unsafe [7]. In respect to sites with steep slopes, there are the obvious inhibiting factors such as the difficulty of building a level structure and driveways on the side of a hill, but there are also more subtle concerns such as increased stormwater runoff. Constructing a house, or houses, on a steep slope (usually defined as 20%+) is not only more difficult, but also more expensive as there is more excavation to be done and depending the location, blasting may be required [8]. Physical obstructions like large boulders bring about similar cost impacts as their removal or relocation is labor intensive and often mandates heavy machinery. In regards to wetlands and conservation land, there may be portions of the site that are simply unbuildable by law for both preservation and logistical reasons. Building a foundation in a swamp would cause great harm to the existing ecosystem and is undesirable to begin with because the foundation would be unstable and prone to flooding. While not currently regulated with land statutes like wetlands and conservation land, properties within frequent fire zones are problematic for apparent reasons and also bring about their own cost implications. While the price to build in these areas is likely not impacted by the fires, home insurance rates certainly are and any residents living in these zones can expect to pay premiums well beyond what it would cost to insure a home in a low-risk area [9].

In addition to natural factors, utility constraints also play a significant role in deciding on a parcel of land. Most notably, sewer, electric, and roadways are important utilities to consider, both for site selection and site design purposes. Although most sites have at least one edge of the property line adjacent to a roadway, connecting that roadway to the portion of the site that is buildable can become expensive if the distance is far and there are obstacles in the way. Other sites do not border an existing roadway altogether and require an easement on another piece of property to access the site at all. Such sites would incur significant costs to establish a drive all the way to the proposed structures and are less desirable for this reason. Another key utility component to consider is electricity. The three main options are to tie into the existing power grid and utilize the public supply from the given state, erect a wind or solar system on the site and still tie into the grid for supplementary support or sell back purposes, or erect an off-the-grid wind or solar system and bypass the need to tie into the public electric supply [10]. If an off-the-grid system is preferred then site location relative to existing power lines may not be an existing factor, however if individuals wish to still have access to the public electric grid, then location becomes a very important consideration. Similarly to electric, site relation to an existing sewer main is significant in terms of cost and site design. Any new structures need to have a plan to properly dispose of sewage and if there is a nearby main, the structures can be connected to it via a pipe called a lateral [11]. The further the buildable portion of the site is from the sewer main, the higher the cost. In some situations, the sewer main is so far away that it makes more sense to construct a leach field on site where sewage will naturally dissipate into the soil via an underground trench system [11]. All of these utilities, in addition to others like gas, water, and internet are all important factors that influence the favorability of a parcel of land.

Legal Site Constraints

Zoning is a land-use management process that divides a municipality's land into districts with the broadest groups being residential, commercial, and industrial. Some typical regulations included in zoning ordinances include maximum dwelling densities, maximum structure heights, minimum dwelling setbacks, and signage restrictions [12]. While zoning ordinances are designed to assist a city or town in its path towards goals outlined in its master plan, they are not set in stone and can be amended through various processes or bypassed in special cases. Almost all zoning ordinances have systems in place where residents or businesses can apply for exceptions to the rules and these granted exceptions are known as variances [12].

Cohousing communities typically require variances or the creation of new zoning districts to come to fruition as they often come into conflict with density maximums and setback requirements. Additionally, common houses (a staple in most cohousing developments) are rarely included as an allowable use so new definitions need to be created for those as well [13].

Another potential avenue for cohousing creation is specifying the community as a subdivision. Subdivisions are parcels of land purchased by developers that are divided into smaller lots (typically neighborhoods) and sold off to residents either as land or properties with houses on them. In some instances, if there are more relaxed subdivision regulations, communities can share resources and possibly common spaces which condominium complexes frequently allow. However, in most cases, subdivision regulations are too stringent to allow for cohousing given rules about sidewalks, separate utility systems, and spaced housing which directly conflict with many of the benefits of communal living [13].

Overall, zoning does not tend to accommodate groups of unrelated individuals sharing spaces or living structures. Beyond just the number of “units” on a parcel being constrained, zoning regulations also cap the number of occupants residing in a unit that are unrelated or not sharing finances. Many zoning ordinances use language like “single-family” to describe the types of groups they allow to live in certain zoning districts which provides roadblocks to individuals seeking cohousing and other intentional living situations. While some communal living developments in the U.S. were able to be grandfathered in, most new intentional living communities need to work with their local zoning boards to reach a compromise on what is and is not permitted.

General Site Design

Site design describes the entire process of development on a piece of land, from selecting the parcel to stamping the final 100% Construction Documents. Larger projects typically involve landscape architects, civil engineers, and general contractors, while smaller ones have the possibility to be completed absent one or more of these entities. Regardless of the scale of the design, consistent coordination with the town or city where the site resides is necessary to ensure the project meets codes, zoning, and other legal regulations. Projects adapt along the way as new roadblocks make themselves apparent, which is why the process of designing and building is so extensive and thorough.

The first step in site design is a feasibility study. During these studies, future owners can determine—or work with others to determine—if their project vision is viable and roughly within the budget they are hoping to maintain. Civil engineers are often involved in this process as they can foresee significant cost items in the design that the owner may not have anticipated before. This is also the stage where the project team assesses the various types of permitting that will be required to develop and build on a piece of land [14].

Assuming that the project seems feasible, the team moves into the conceptual design stage, where a rough layout of the site plan is established. This step often entails potential structure outlines, parking and drive location, and general plans for larger utilities. With many other design factors ultimately coming into play, it is important to keep the conceptual design broad so that it can be adjusted slightly as the project moves forward. The main goal of this step is to allow the team to visualize what the site could look like upon completion. At the commencement of the conceptual design phase, plans are typically sent to the local governing body to identify and address any legal concerns before the design is progressed further [14].

Following conceptual design, is the schematic design stage. At this point the team has an idea of what they want the site to look like, and have to dive into site constraints to make adjustments and modifications. During the schematic design portion, natural constraints like subsurface conditions, wetlands, and large existing objects are considered for their impact to the conceptual design. Additionally, zoning and permitting are dove into more thoroughly to assess environmental impact and additional strain on existing infrastructure. Considerations like the change in pervious surfaces and stormwater runoff are inspected during this stage to ensure the new site is in compliance with local standards.

Once a more in-depth understanding of project challenges and solutions is established and a preliminary review and approval from the local governing body has occurred, the project moves into design development where grading, drainage, erosion and sediment control, demolition (which can include tree and rock removal), and utility design are progressed further to prepare for construction. Grading and drainage, specifically, go hand in hand because they both pertain to stormwater management and together keep surface flow rates to a reasonable degree. Erosion and sediment control keeps the site particulate runoff to a minimum while construction is underway (since stormwater systems may not fully be in place yet) and demolition occurs before structures and roadways are built. Design development is usually one of the longer stages of site design because plans are bounced back and forth between engineers and contractors. While designs might look good on paper, this is really the point where the people who will end up managing the construction, scrutinize the plans and determine buildability [14].

After design development concludes, the final stage of site design begins which is the construction document phase. At this point, only small tweaks are made to the overall design, and more efforts are focused on compiling details and specifications for all of the systems that were designed earlier. Pipe sizes, roadway materials, and electrical conduits are all outlined by engineers and once the construction documents are completed for bid, subcontractors will submit their materials to the engineers for review. Site design is ostensibly over at this stage and construction is all that is left to follow.

Site Design Software Applications

Understanding the stages of design is important to anyone looking to develop on a piece of land, but putting the concept into practice requires a bit more knowledge and the assistance of multiple software packages.

Before doing any design work at all, it is imperative to know what exists on a site in regards to elevations, natural features, and any land that is under environmental protection or within a buffer zone. Mapping a site can be done two different ways: through a formal site survey and via existing online GIS (geographic information system) data. The former is almost always completed for medium to large projects while the latter may be sufficient for smaller jobs and feasibility studies [15].

For most parcels of land in the United States, GIS data is available in online banks to be downloaded and used within ArcGIS, which is a mapping program frequently utilized by engineers. In addition to showing property lines, roadways, and town boundaries, ArcGIS allows users to bring in elevation and soil data, which can be grouped by slope and type respectively and then displayed in color-coordinated units. Beyond this, layers like wetlands and endangered species habitats can be pulled into a map to show areas of a site that may not be developable.

Layers in ArcGIS can be expressed as points, lines, polygons, or surfaces depending on the data source that is being pulled from. Once all desired layers are pulled into an ArcGIS map for the parcel of interest, buffers can be added manually and watershed delineations can be conducted to develop a more complete picture of the existing site conditions [16].

Once a preliminary understanding of a site is gathered through ArcGIS, a more robust design application is required to begin drafting plans. Autodesk Civil 3D is by far the most utilized computer drafting program in the United States by site designers given the multitude of features it includes [17]. What differentiates Civil 3D from AutoCAD is its ability to map surfaces and structures in three dimensions which helps in determining buildability and in visualizing design more easily. In AutoCAD, a pipe is merely a polyline drawn on a flat surface, but in Civil 3D it is a tangible structure with inverts, a slope, and a diameter. One three-dimensional feature that is of particular interest when beginning a site design is the ability to pull in elevation points from an online data source (like GIS) and then tie the points together into a complex surface that emulates the parcel of interest. Through site design and grading, these points and elevations can be changed with the creation of new point elevations (called COGO points) or feature lines (think topographic maps). Following the establishment of a surface in Civil 3D, design work is often done from an aerial view of a two-dimensional site, although any points within the surface still have a real-world elevation and set of coordinates. Civil 3D is typically used for the majority of site design and takes a project all of the way to final construction documents.

Two other software applications that can be used throughout the site design process are Autodesk Revit and SketchUp. Compared to Civil 3D which is best tailored for horizontal design, Revit and SketchUp are primarily suited for vertical design and the modeling of structures that will populate a site. While SketchUp and Revit can theoretically be used for the same functions, the AEC (architecture, engineering and construction) industry tends to lean towards Revit for detailed architectural design and towards SketchUp for large-scale urban planning and preliminary conceptual designs [17]. Many users find SketchUp to be more intuitive and it is quicker to turn an idea into a model within the program, but in terms of drafting buildable structure plans that others will be able to follow, Revit is often the industry standard. Civil 3D has the ability to communicate with both SketchUp and Revit, but considering Revit and Civil 3D are both Autodesk applications, the link between the two is much more seamless. Fortunately for site designers looking to turn their site plans into conceptual models, SketchUp is now equipped to import a Civil 3D surface into a modeling space where building footprints can be turned into actual structures [17].

Cohousing Design

Compared to less intentional developments, cohousing design is a more involved process and often requires the inclusion of unique site features. The first main difference in the design process is in the planning of the community. While typical neighborhoods are often spearheaded by a developer driven design process, cohousing communities usually begin design through workshops with future residents and cohousing design professionals [18]. This process ensures that the design is representative of what the community wants and is inclusive for all of the residents. Rather than adjusting plans later when a new resident with special needs joins the community, the preparatory planning workshops help future residents foresee accommodations that might be needed and include them in the design from the beginning.

Beyond the process itself, there are a number of key design features that are indicative of cohousing communities and promote social interaction and ease of living. Three of the most significant components of design are the common house, pedestrian pathways and activity nodes, and shared outdoor spaces [18].

When determining the location of the common house, some factors to consider are accessibility from each dwelling, relation to the outdoor common area, and easy indoor and outdoor circulation. As is true with any public space, the main goal is to design an area that is not too tight that it is cramped and uninviting, but not too large that people are spread out and unable to interact comfortably. Many cohousing design teams will begin design with the placement of the common house and build out the dwellings and paths from there [18].

The pedestrian pathways portion of the design is the aspect that ties the entire community together. Where typical suburban neighborhoods have roadways, cohousing developments frequently have narrow walkways that go from dwelling to dwelling and from dwellings to the common house. The Cohousing Association of America recommends that these pathways be just around 4 feet if intended only for pedestrians and 10 feet wide if there is need for emergency vehicular access. Additionally, as they span the courtyard between the dwellings, this distance should be anywhere from 30 to 50 feet so that residents can communicate comfortably from porch to porch, while not feeling like their personal space is being impeded upon. When these pathways are combined with open front porches, they create a permeable membrane where people can circulate into conversations while on their way somewhere and easily exit because it is not a secluded space. Promoting interaction and connection are key in cohousing design and the organization of the site pathways plays a key role in this process.

The third main design feature of cohousing is the shared outdoor spaces. These spaces can take the form of a green open space, a patio, an outdoor dining or cooking area, and many other possibilities. Some important factors to consider when designing shared outdoor spaces are the climate, the needs/wants of the community, and the amount of area available. Large open spaces tend well to active communities where recreational games can be played, where smaller spaces tend to more stationary groups. If the community is looking to internally source some or all of their food, then the shared spaces may be devoted to farming and gardening. If the community is interested in sharing all meals and cooking together, then having an outdoor kitchen may make a lot of sense for that group. The paramount component of these design features is to assess how much space is available, learn what the group would like to see developed, and then work to coordinate the spaces within the given area.

On the whole, the mission of cohousing design is to create an intentional environment that lends itself to the people who are living in the development. The ever-ambiguous boundary between what is personal space, what is public space, and what is both will be sculpted by future residents during the design coordination and once the community is established. Integral to the entire process is ensuring that residents feel included and connected to both their cohousing community and to the larger community beyond [18]. An excellent cohousing design does not siphon off the group from other neighborhoods, but instead provides its own permeable membrane where members can stay or go as they please and feel comfortable doing both.

III. Methodology

Overview of Goals, Objectives, and Tasks

The overarching goal of this Major Qualifying Project (MQP) was to develop a design for a cohousing development on a real parcel of land in Bozeman, Montana. Within this goal, the four main objectives, and their respective tasks, are as follows:

- Select a site and perform a legal and physical constraints analysis
    - Choose an undeveloped parcel of land that is on the market
    - Consult zoning and subdivision requirements
    - Reference GIS data and online imagery to assess the site physically
- Develop a schematic site design plan in Autodesk Civil 3D
    - Consult peers for design preferences in a class workshop
    - Perform an existing conditions stormwater takeoff
    - Develop concept layout plans
    - Select a layout
    - Perform a proposed conditions stormwater takeoff
    - Design site grading
    - Design stormwater BMPs
    - Design a wastewater treatment plan
    - Locate a well on site
    - Specify an electric system
- Develop a 3D model in SketchUp
    - Transfer Civil 3D surfaces into SketchUp
    - Extrude structures into block form
    - Select site plantings
    - Further develop significant site features into appealing visuals
- Determine project expenses
    - Perform a cost estimate for the site
    - Develop a basic financing plan given the number of anticipated residents

Site Selection

The process of selecting a parcel of land for the conceptual cohousing design began by scanning realty sites that listed properties in the Bozeman, Montana area. Both mainstream sites, such as Zillow and VRBO, and local companies, such as PureWest Real Estate and High Mountain Real Estate, were used to find available parcels in the area. The rough parameters set for selecting a site were:

- Area: (2-20 acres),
- Location: (within 15 miles of Bozeman proper),
- Price: under $500,000,
- and Zoning District: Residential.

Developers and agents from PureWest Real Estate and High Mountain Real Estate were contacted during the search process in an effort to keep up with new listings and learn more about development feasibility in certain subdivision covenants and HOAs. One developer from PureWest Real Estate assisted in setting up a listing watch so that emails would automatically be sent when a new land listing was posted on their site that met the parcel parameters.

Beyond the overarching guidelines established for selecting a piece of land, other site nuances such as existing grade, relation to existing infrastructure, and land cover were considered during the search process. Flatter sites and those absent of large rocks were prioritized since development would be easier and more affordable on these pieces of land. Most properties in the Bozeman valley contained few large trees, so the concern of having to clear portions of the site was minimized. Since the creation of zoning variants, or a new zoning district altogether, is typically required for cohousing developments, existing allowable uses were not considered as a concrete constraint for selecting a site. However, only sites in residential districts such as Residential-Suburban (R-S) and Residential High-Density (R-4) were considered since the allowable uses in these zones were closest in alignment to a cohousing development.

Presentation and Workshop with Urban and Environmental Planning Class

Once a parcel of land was selected, a presentation and workshop were assembled and delivered to the Urban and Environmental Planning class, which is an upper-level undergraduate course in the Civil Engineering Department. This presentation consisted of a background on cohousing, a brief overview of site design and zoning ordinances, and an overview of several existing cohousing developments in the United States. During the presentation, attention was drawn to the main benefits of cohousing as well as the potential challenges that come with founding and development.

Following the presentation, there was a brief period of time allotted for questions before the workshop portion of the class began. The first portion of the activity was an online Google survey that polled individuals on their ideal cohousing community (see Appendix-B for detailed results). Several questions pertaining to community size, location, structure types, and structure amenities were included in a multiple-choice format while other questions about subsidized residents provided room for written responses. Following the completion of the individual survey, the class was split into break-out groups of 3-5 students. Each group was given a 11x17 inch piece of paper that included an aerial image of the site and the dimensions of the parcel. The teams were tasked with laying out a roughly-to-scale site layout for their ideal cohousing community. The groups were asked to include roadways, parking lots, pedestrian walkways, and structure footprints in addition to specifying the number of residents they accounted for in their design. Following a brief 15-minute design session, these concept layouts were collected and used to influence layout iterations later on in the project. The survey results were also compiled automatically in Google to display the cohousing preferences of the class.

Base File Setup in Civil 3D

With a parcel of land selected, a base CAD file was set up so that future design could be conducted to scale and with real coordinates and elevations. To begin, a search was done to locate topographic surface data for the Bozeman area. Several options were available, but the best data set was a 1-foot contour map for the entirety of Gallatin County located on Bozeman's open-data ArcGIS site [19]. Since this data could not be condensed prior to download, the full county file was downloaded as a shapefile and then imported into a template AutoCAD Civil 3D (Civil 3D) file set to UCS-WORLD to ensure the data came in with real z-values and coordinates. Once the topographic data was loaded into the Civil 3D file, geolocation was turned on to locate the parcel via coordinates. Since the file in its current state was much too large to be workable without significant lag, the contour surface was trimmed to a boundary just a bit larger than the parcel itself. The BREAK command was used to trim each contour line until a group of contour lines that covered the site could be selected as a group. Once these contour lines were selected, they were copied with a base point of 0,0,0 and pasted into another template Civil 3D file. The remaining topographic file was archived for potential use in the future.

Next, parcel and roadway data were located for download. The Gallatin County GIS website provided easy access to this information as well as the ability to download the data in shapefile format [20]. Both "parcels" and "roads" were downloaded for the entirety of Gallatin County and then imported into the Civil 3D file containing the trimmed topographic data for the site. After these files were loaded into Civil 3D, the majority of the data was deleted so that only the roadways and parcels adjacent to the site remained. Since the roadways came imported to Civil 3D as polylines, geolocation was again turned on to provide insight on the actual shape of the roadways. The DI command was used to measure the width of the roadways around the site and since the imported polylines represented the centerlines of these roadways, the OFFSET command was used to display the true width of each roadway. Radii existing at drive entrances and roadway intersections were measured on the geolocation map using the command MEASURE+ANGLE and then the measured radii were added to the Civil 3D file as arcs. The existing polylines that represented the edge of the roadways were then adjusted to match these arcs so that they could better represent the roadways as they exist in the real world. Following the completion of these roadway edges, the entirety of the roadways remaining in the Civil 3D file were traced with a closed polyline and then hatched to make them easier to view. The project site boundary was then placed on its own layer as the limit of work, while the other adjacent parcels were set to the layer: Parcel Boundary. Finally, the trimmed topographic contours were copied into the base CAD file and converted into polylines. Polylines were then selected individually and assigned an elevation consistent with the online GIS data [19]. Next, in the Civil 3D Toolspace a new surface was created and named EG1. All contour lines were then selected and added to the EG1 surface to create a three-dimensional representation of the site. Given these actions the file was set and ready for design work to occur.

Legal Site Evaluation

To begin informing proposed site layout design, zoning bylaws, neighborhood codes, and subdivision rules were researched and referenced consistently. Design components such as site access, setback requirements, and parking maximums were all considered for the initial stages of design. Additionally, stormwater management requirements were referenced during the existing conditions takeoff to determine the correct runoff coefficients and storms to model for design. The entire process of runoff calculations was conducted using formulas, definitions, and variables from the Bozeman Design Standards and Specifications manual [21]. In regards to allowable uses on the site, those outlined in the zoning district were considered when selecting the number of residents the design would account for, but were not followed absolutely. Considering Bozeman Cohousing needed to create their own zoning district island, the number of dwellings and the density of the dwellings was not tailored exactly to the parameters given in the zoning bylaws.

Physical Site Evaluation

To best understand potential obstacles of design, physical site information was gathered from several online sources. The first condition considered was site soils. A USDA.gov service called WebSoilSurvey was used to determine the various soil types that existed on the property [22]. To extract only data relevant to the site, the rough location of the property was entered into the search tab on the site and from there a polygon boundary was drawn to limit the data output. The soil results were then saved into a project folder for later reference. The next condition assessed was existing above-grade obstacles. Google Maps satellite and road level imagery was used to examine the parcel, adjacent roadways, and adjacent parcels and public land [23]. Notable existing features were inputted into the base Civil 3D model. The last and most important physical condition considered was site stormwater. To begin, parcel area delineations were conducted in Civil 3D to separate existing pervious and impervious conditions. Then, based on slopes, land cover, and soil types, runoff coefficients were determined for all areas of the site. Following this step, rainfall intensities were gathered from Bozeman IDF curves which allowed time of concentration and peak runoff rates to be calculated [21]. All data and calculations were compiled in an Excel spreadsheet to inform future drainage system design (see Appendix-C).

Layout Concept Iterations

Following research on legal design constraints and a physical evaluation of all existing site conditions, layout concepts were sketched by hand and then formally drafted in Civil 3D. These layouts started with drive aisles and parking areas and then progressed to include pedestrian walkways and building footprints. Building footprints were kept consistent for all design iterations and were used as placeholders for structures that would be further developed at later stages in the project. Seeing as these were only concept designs, exact locations of less significant site features, such as gardens and gravel paths, were not decided on as grading, drainage, and utility design in the schematic stage of the project would likely influence these components.

To begin layout design, the Civil 3D base file was copied three times to create a template from which linework could be added. Site setbacks, determined from Bozeman zoning ordinances, were added into the file to provide a visual guide for where certain design features were allowed to go. Next, based on sketches that considered existing site grades in a preliminary sense, parking areas and driveways were added to accommodate the decided-on number of residents. Following this step, the main pedestrian and emergency vehicular pathways were extended from the parking lot using, first, a center alignment and then an offset to give them widths. Once the main pathways were drawn, the common house and dwellings were positioned along the way. The building footprints were intentionally kept simple for this stage of design to focus on broader site planning concepts like general location and organization of larger site features. Three unique site layout concepts were developed in Civil 3D, each with their own pros and cons.

Selecting a Layout

Following the design and drafting of three alternative site layout concepts, a quantifiable ranking scale was applied to each design to assess a number of factors and determine which design would move forward into the schematic phase. Factors involved in this selection process included gradeability, ease of drainage design, accessibility, minimization of impervious surfaces, and a few other more subjective components like circulation and interconnection. These factors were all compiled in a table and then given a ranking. The layout concept with the highest overall score would move forward to the next stage of design where grading, drainage, utilities, and other site details would be added.

Designing a Wastewater Treatment System

Once a site layout was selected, the schematic design stage commenced. The first component of this stage was the wastewater treatment system, since its location and design would likely have the largest influence on grading and the location of other site features. The Montana Standards for Subsurface Wastewater Treatment System were followed closely during the design process to ensure that the system would meet the requirements of the anticipated number of residents given the existing site conditions [24]. Factors such as number of individuals, percolation rates, and available area were all influencers of the final system design. These factors had influence on the size of septic tanks as well as the leach fields.

Grading the Site

Grading the site was the most time-consuming task of the schematic design phase. It began by breaking the existing surface with a polygon so that a new proposed surface could be inserted in its replacement. To do this, the surface was selected in Toolspace and the boundary feature was used to “hide” a section of the surface internally using the drawn polygon. Once the selected section was removed from the existing surface, the process of grading with new contour polylines could begin.

When grading, several parameters had to be accounted for which included a maximum drive aisle slope of 10%, a maximum parking lot slope of 4%, and a maximum grass planting slope of 1:2.5. or 40%. Additionally, positive drainage needed to be accounted for on the site's entirety which assumes a minimum slope of 1%. Most importantly, dwellings needed to be close to level around their footprint for the foundation, and the grade needed to slope away from all dwellings so that there would be no ponding. While stormwater best management practices (BMPs) were not officially designed during this portion of the schematic process, their rough locations were still considered as drainage areas and pathways were worked into the proposed grading. All new grading, with the exception of the drive aisle entrance occurred within the parcel boundary and tied into existing grades.

Once all contours were drawn as polylines, elevations were manually added to them using the "properties" command. After all of the polylines had real z-values assigned to them, they were added to a new surface titled "PR." This was done by selecting "contours" under the surface in the Toolspace and adding all polylines to this data-input section. Areas on the site that had elevation value diverging from the contours, such as walls, were converted into feature lines and assigned elevations depending at various points along the feature. Once these feature lines had been given correct elevations, they were added to the "PR" surface as breaklines. Finally, all site features that would elevations differing from that of contours, were accounted for by making holes within the new surface. Walkways, walls, and dwelling footprints were all added as internal boundaries to the proposed surface in the Toolspace and set to "hide" so that no z-values would exist within their boundaries.

Designing and Sizing Stormwater Best Management Practices

Given the selected layout, a proposed stormwater conditions assessment was conducted for the site. The procedure followed the same sequence of calculations executed for the existing site conditions so that a new time of concentration, peak runoff rate, and peak runoff volume could be calculated. Once these values were determined, they were compared to the existing values to determine the net differential between the existing site conditions and the proposed site conditions. The Bozeman Design Standards and Specification Manual specifies that all new runoff generated from the development must be manipulated in a way that limits the peak runoff rate to a value equivalent to the existing conditions value. With this net change determined, stormwater management solutions were designed to accommodate.

The process began by determining locations on the proposed site that had the opportunity to accommodate stormwater BMPs. By referring to the grading, catchment areas were outlined and their areas were calculated. With these areas, the volume of runoff was calculated based as a percentage of the total site runoff (see Appendix-E). In calculating the runoff for each area, new weighted c-values had to be determined to account for the amount of pervious and impervious surfaces. With the site broken down into smaller areas, specific stormwater volumes offset by

BMPs were determined. To ensure that these BMPs were sized properly, further calculations were done and hardware feature specifications were referenced. Prinsco's pipe sizing tool was used specifically when selecting diameters for drainage pipes [25]. Once the entire net-volume of runoff was accounted for, drainage design was complete.

Selecting Well Location

Since no public utilities, other than electric, run adjacent to the property, an onsite well needed to be placed in order to supply the community with water. The Water Well Drilling for the Prospective Well Owner Manual was followed closely in determining the location of the well and the anticipated flows that would need to be pumped [26]. Some key parameters outlined in manual were as follows:

- The well must be at least 10 feet from the property line.
- The well must be at least 50 feet from any septic tank or sewer lines.
- The well must be at least 100 feet from the sewage drain field.
- The well should be located as close to the dwellings as possible to minimize the amount of ditching and piping required.
- 100 gallons of water should be pumped per person per day.
- The well should be located away from any paving or decking so that it can be easily maintained.

Given the criteria outlined in the manual, a location was selected for the well and a pump rate was calculated. Were this component of design to be taken further, a well tank would need to be sized and piping to all structures would need to be drafted. Additionally, a geotechnical team would need to visit the site and determine the level of drawdown acceptable on the site so that the well is not influencing water table levels too much. This could have an impact on the maximum rate of water that is able to be pumped by the well each day [26].

Sizing Solar Electric System

The last major utility system to specify was electric. Grid-connected solar was the preferred design for development, so determining anticipated power demand was the first step in sizing the system. An appliance energy-use chart from Silicon Valley Power was used as a reference for determining average kWh per day per appliance [27] while a Tiny House forum was used as a guide for selecting appliances [28]. For the common house, the heating system was selected based on square footage of the structure, and the hot water heater was sized based on the number of residents [29]. The number and type of lighting fixtures for each structure were determined based on the number of lumens required per square foot of various room types. Lumens per square foot could then be equated to watts per square foot which allowed for a count and type of lighting fixtures to be determined [30].

To start, anticipated appliances for each of the dwellings were compiled into a list. The same was done for the common house to follow. Then, regardless of the metric listed on Silicon Valley Power's energy-use chart, all appliances' energy needs were converted to kWh/day. For appliances such as personal computers which would only be used for a portion of the day, a daily time-of-usage was estimated. Once all structures and their appliances were accounted for, they were compiled into a table and summed to determine the daily needs of each individual dwelling and the common house. Next, the average power output of a single solar panel was determined so that a number of panels needed per structure could be calculated. Given the anticipated southern-facing roof area for all of the structures, a maximum number of panels per roof was determined. For all panels required beyond the number that fit onto the roofs of the structures, a ground-array was sized.

Moving Civil 3D Surface into SketchUp

Having previously finalized the proposed surface for the site and maintained a portion of the existing surface, the surfaces were ready to be transferred into SketchUp. A YouTube tutorial from Land FX was referenced throughout the entirety of this process [31], as well as an Autodesk Forum [32].

To begin, the Schematic Civil 3D file (where the existing and proposed surfaces lived) was copied and saved under a new name “Combined Surfaces.” Once in this file, all entities were selected using the ctrl-A command, the two surfaces were unselected, and then all remaining entities were deleted, leaving just the proposed surface and a portion of the existing surface. Next, in the Toolspace tab under “Surfaces,” a new surface was created and named “Combined.” To add real values to this surface, the edit tab within the surface in Toolspace was selected and the “add” button was selected. Within this component, the existing surface and proposed surface were able to be added to the new combined surface (maintaining all of the prior adjustments made such as internal boundaries). Following this step, the proposed and existing surface were deleted from the file, leaving only the combined surface.

At this point, the surface was modified in several ways within the Toolspace. To begin, the “Surface Style” toolbar was opened and the surface style was set to “Triangles”. Then, still in the “Surface Style” toolbar, the Display tab was opened and all components were deselected except for “Slopes”. Next, in the Analysis tab, slopes were selected and in the dropdown the scheme was set to “Green” and the display type was set to “3D Faces.” Finally, the remaining surface was exploded two times, to leave only 3D Face objects in the file. At this point, the file was exported as an AutoCAD 2013 file, with 3D values maintained in the export. Once exported, the file was able to be imported into a basic SketchUp Pro 2021 model template. Inside the SketchUp model space, the surface was selected and exploded, leaving it ready to be modified.

Developing the Model in SketchUp

With an exploded surface of 3D faces in the SketchUp file, the next step was to bring in two dimensional linework from the layout file. Layout 3 was opened in Civil 3D and then exported into a 2013 AutoCAD format so that it could be imported into SketchUp. Once imported into SketchUp, all of the linework populated at an elevation of 0, while the surface remained at its actual elevation (roughly 5,000 feet above). To make coordination between the linework and surface easier, the surface was moved 4,800 feet vertically so that it existed above the linework, but not too far away.

The first action taken here was massing the structures and bringing them to their proper location on the surface. Each two-dimensional structure outline was turned into a face by drawing a diagonal line from corner to corner. Once turned into a face, the diagonal line was hidden using the eraser/hide tool. At this point, using the push/pull tool, the face was extruded up to create a rough block for the dwellings and common house. Once all structures were extruded to their desired height, they needed to be moved to the correct locations on the site. The entire structure was selected so that it was all highlighted in blue. Then, the corner of the house, located at the lowest elevation on the surface, was selected with the move tool and dragged until it lined up with the correct corner of the hole in the surface. This process was done with all structures.

Next, the retaining wall and walkway linework were converted into faces. Since these two site features came imported into SketchUp as disconnected arc and line segments, all components were combined with the "weld edge" command before they could be converted into faces. Similarly to the structure, the faces of these two features were extruded with the push/pull tool to heights of roughly twenty feet. The lowest point on each feature was then moved into place within the surface to match the lowest elevation along the feature. Next, the wall and walkway were split into segments (roughly 5 feet long) and then lowered to be just above the elevation of the surface. The walkway sections were then smoothed with the eraser tool, while the retaining wall remained in distinct sections. At this point, all internal boundaries within the surface were filled with site features.

The next step was snapping the two-dimensional parking lot, driveway, and pedestrian way onto the three-dimensional surface. To do this, the remaining linework was welded and turned into faces. It was then extruded to a height of 40 feet. The highest corner of this block (the southeast corner of the driveway) was dragged to its proper location on the surface, leaving a distinct edge on both sides of the block where it intersected with the surface. Since the surface existed in triangle face tiles at this point, lines and arcs were traced across each surface face where the block intersected with the surface. Once the entire block was traced, it was deleted, leaving just an outline on the surface. At this point, all surface triangle faces within the driveway, parking lot, and pedestrian way were painted as asphalt to define the feature.

Following this, the remainder of the surface was smoothed with the eraser tool and holes that developed during the file transfer from Civil 3D were filled in. To fill the holes, line segments were drawn between each point at the corner of surface triangles along the hole to make new triangle faces. This was done repeatedly until the entire hole was filled in. Once the hole was filled, it could be smoothed like the remainder of the site. This left the entire property with a smooth finish that was painted with a grass fill.

Next, the rooflines of all structures were drawn in, with pitches and orientations that coincided with the zoning codes for the lots [33]. Once roof lines were determined, the southern facing roof section was dimensioned to determine how many solar panels could be mounted on the roof. Structure heights were then adjusted to reach their optimal size.

Finally, the finishing touches and more artistic portions of design were completed. A deck was added to the common house, stairways and railings were added where necessary, and guardrails were added adjacent to the drive. Native Montana plantings were then selected and placed onto the site (using 3D warehouse to import the plant blocks) [34]. Alongside this step, other 3D blocks were imported into the file such as raised planters, vertical gardens, cars, and humans. Once all site features were in the file and set to their desired location, final paint fills were done on all surfaces to complete the model.

Conducting Cut/Fill Analysis for Proposed Surface

Having earlier developed a proposed surface for the site, a cut/fill analysis could be completed to determine how much fill would be needed to execute the proposed development. The process of conducting a volumetric cut/fill analysis in Civil 3D, was outlined on the InfraTech Tutorial website [35].

To begin, a new CAD file was created and titled cut-fill. From the base file setup earlier, the existing site surface was copied and pasted in with the base coordinates 0,0,0. Next, the proposed surface was brought in from the schematic design file. Because this surface had been manipulated to have internal boundaries (for structures and site features) a non-broken version of this surface was necessary for the cut/fill analysis. Rather than manipulating the surface in the schematic file, the polyline contours were instead copied and pasted into the cut-fill file. Once in the file, a new proposed surface was created in Toolspace and the contours (still containing their assigned elevation values) were added to the surface to give it definitions. At this point, both the complete existing surface and the complete proposed surface were together in the same file.

Next, a new surface was created. Rather than creating a TIN surface, as was done for the other two, this surface type was set to “TIN-volume” and titled “EG1-volume.” The surface style was set to “No Display” since a visual representation would not be necessary. Within the surface properties, a base surface and a comparison surface were able to be selected. The existing surface, EG1, was set as the base surface and the proposed surface, PR, was set as the comparison surface. At this point, the cut/fill volumes could be observed by selecting “Surface Properties” in the Toolspace and then navigating to the Statistics tab and expanding the “Volume” drop down. Within this tab, the cut volume, fill volume, and net volume could be observed. This value would later assist in the cost estimating portion of the project

Cost Estimating the Project

Once the design phase of the project was completed, a cost estimate was carried out to determine the total project expense. The cost estimate was divided into five major sections: the cost of the land, the cost of the earth work, the cost of the structures, the cost of site features, and the cost of architecture and construction management fees.

With the cost of the undeveloped property determined from the appraised value on Zillow, the first item to address was the earth work expense. To begin, the total volume of fill required for the proposed development was recalled from the cut/fill analysis completed earlier.

Next, the average price per unit volume of fill was determined and multiplied by the amount required. To complete this component, the average labor cost per unit volume of earth work in Bozeman was determined and again multiplied by the volume calculated in the cut/fill analysis.

To assess structure costs, a per-square-foot estimate was conducted based on industry averages in Bozeman with the assumption of fully furnished dwellings. Considering appliances and furniture were not specified within the scope of the project, construction averages were more appropriate for the stage of design the development was in. The common house and the dwellings' price-per-square-foot values were determined separately as tiny homes (dwellings under 600 SF) typically cost more per unit area [36].

The next, and most time intensive, portion of the cost estimate was the pricing of site features and the labor costs associated with installation. Site features included both larger scale items, such as solar panels and retaining walls, and smaller items such as plantings and area drains. The material cost of each item was determined first followed by labor costs. Whenever possible, data specific to Montana was used for the estimate.

Finally, with all cost items compiled into a table, construction management and architecture fees were applied to the subtotal. With the fees determined as a percentage, the project subtotal was multiplied by both to calculate the total cost estimate of the project. The fee percentages were determined based on industry averages in Bozeman.

Developing a Cost Structure for Residents

With the total cost of construction determined, the final step of the project was to determine a cost structure to fund the development of the cohousing community. Before any calculations were done, it was established that one of the two-person dwellings would be fully subsidized by the community with the residents needing only to pay monthly dues that contribute to utilities, meals, and property maintenance. In this way, this dwelling could act as either a long-term home or a short-term rental that new people move into every so often.

The first step of developing the cost structure involved separating the individual dwelling costs from the costs of common house and all other site development. Next, the cost of each dwelling, and cost per person, were determined. (Of course, it is possible that a resident could be a dependent child, but for the sake of showing a fair price comparison between dwellings, it made the most sense to show a price per person). Once all of the dwellings were priced separately, the remainder of the costs were split 18 ways (accounting for the two subsidized residents) and added to the dwelling costs. This new number represented the principle that all residents would be responsible for. Finally, the rates for multiple mortgage timelines were tested to understand the potential monthly payments under a 15-, 20-, and 30-year mortgage. In addition to the cost of funding the new development, there would of course be monthly dues for most residents, but these were not included in the cost structure.

IV. Results

Site Selection

The site selected for this MQP was a 2.54-acre triangular corner parcel, bordered on the south and west by Bozeman Trail road, on the north by a right of way with overhead power lines, two other properties, and then Alpine Way, and on the East by Meadow Lane (outlined in white in Figure 1). This parcel was found on Zillow and as of October, 2021 it held a market value of $305,540 [37]. It is located in the R-1 zoning district of Bozeman and is a part of the Mountain Meadows Subdivision which contains 11 other lots. Within this subdivision the parcel is titled Lot 3 or Block 3 and is the largest lot of the twelve properties [38]. Across Bozeman Trail Road on the East, is a large piece of conservation land consisting of meadows and some small wetlands. Located roughly two miles to the south-east of downtown Bozeman, the site sits right on the Bozeman city border and is entirely undeveloped.

Figure 1: Selected site (Lot 3) shown with thick white border.

The main considerations involved in selecting this parcel were price, relative location, and size. In regards to land available for sale in the greater Bozeman area, there was a stark divide between larger parcels that were over 20 miles away from Bozeman proper, and smaller, expensive parcels located in Bozeman proper [37]. Proximity to the more developed part of Bozeman was an important factor, but a minimum lot size of at least two acres was a must. Lot 3 of the Mountain Meadows Subdivision proved to accommodate all major needs and came in at a price point under the target maximum and considerably lower than 0.25-1.00 acre lots located closer to downtown Bozeman. Some more subjective factors involved in the decision process were scenery, site cover, and major existing obstacles. With no nearby existing structures and a declining slope to the South of the site, there are clear views of the Gallatin Range from most places on the property. From aerial and street view imagery the site is shown to be covered entirely in mid-length prairie grass and there are no trees or large rocks on the site. All previously mentioned site components looked promising in allowing for many different design concepts on the land.

Presentation and Workshop with Urban and Environmental Planning Class

The presentation was delivered successfully to the Urban and Environmental Planning Class and garnered lots of questions, feedback, and engagement. The workshop portion of the class generated useful data on individual cohousing preferences and envisioned layout designs. The Cohousing Questionnaire that was sent out to students and a few other select individuals as a Google form received 38 total responses and the group design activity produced 10 different site layout concepts (Appendix B,1-10).

From the survey, several significant trends in preferences were discerned and used to influence the layout concepts for the project. The most notable, and useful, statistic that came from the survey was that nearly half of respondents preferred a community size of 11-20 residents when given the choices of 4-10, 11-20, 21-30, 31-40, and over 40. The second largest cohort was 21-30 individuals which 21.1% of respondents selected. When asked about the assortment of structures on the cohousing development, 47.4% preferred many small single-unit dwellings and a common house, 28.9% preferred several multi-unit dwellings and a common house, and 21.1% preferred a few larger structures with common spaces included. Another question in the survey asked which amenities they would want in single-dwelling structures assuming the common house is equipped with bathrooms, an industrial kitchen, and all other major appliances. The options were given in multiple choice format with an additional amenity in each option. The most popular choice (50% of respondents selected) was a dwelling with beds, a small living space, a bathroom, and a kitchenette. The next most popular choice, with 28.9% of respondents selecting it, was a dwelling with beds, a small living space, and a bathroom. The other four options which included one simpler arrangement and three more elaborate arrangements made up the remaining 21.1% of respondents. In regards to a question that asked about ideal dwelling size for two individuals, 50% of respondents selected 400-600 SF, 40.6% selected 600-1000 SF, and the remaining 9.6% chose options smaller and larger than the aforementioned. The following question asked individuals what general layout they envisioned for a cohousing community of single-unit dwellings and 50% of respondents thought they would prefer tightly clustered structures around a common house with group parking lots and walkways connecting dwellings. The other notable portion of respondents selected spread-out structures with driveways to each dwelling and a small parking lot at the common house. When asked about a location for a cohousing community, a significant majority selected a suburban setting while another notable chunk selected rural.

The questionnaire also included several questions about community features such as meals, group projects, mission driven communities, and financial structures. These results were meaningful for personal curiosity, but did not influence design. They can be found in Appendix B, 6-10.

Base File Setup in Civil 3D

The compilation of topographic, parcel, and roadway data led to the creation of the base file that would be used for future site design on the site. In addition to the downloadable GIS data, an existing on-site culvert was added to the base file for use as a future design point (as can be seen in the bottom left corner of Figure 2). Site topographic information is depicted by blue and green contour lines representing major and minor elevations respectively. The blue contours occur every 5 vertical feet. Surrounding parcels are depicted by thin white lines while the site boundary is shown as a thicker dashed line.

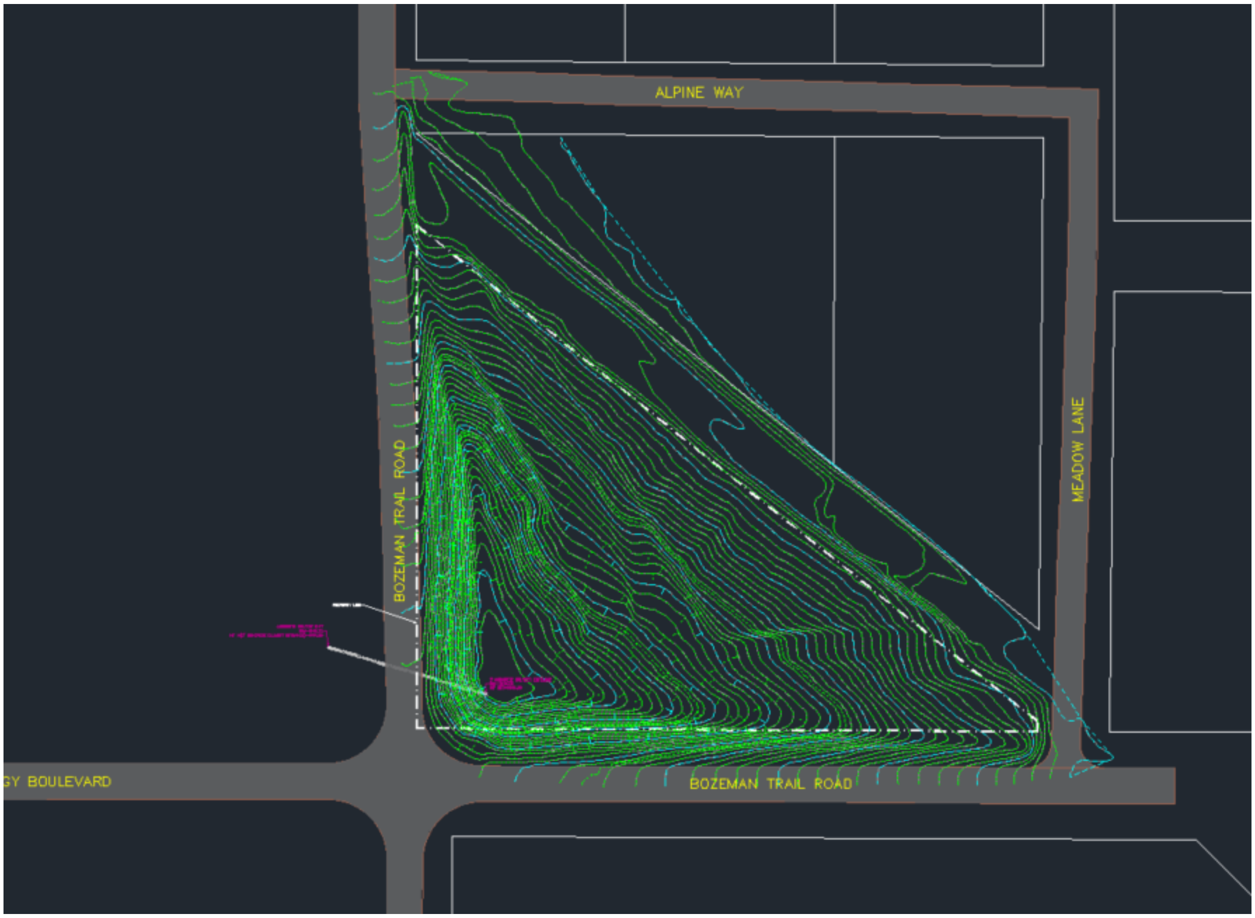

Figure 2: Base CAD file in Civil 3D with topographic surface, parcel boundaries, and roadways.

Legal Site Evaluation

Lot 3 is located in the R-1 zoning district of Bozeman which is defined as the low-density residential district [38]. Several of the legal constraints for development are related specifically to the zoning district the site is located in, while others are citywide.

For R-1 specific site ordinances, there are several components that pertain to the development of this project, all located in the Bozeman Zoning and Land Use document [33]. To begin, the site setback requirements are 25-feet for the front yard, since Bozeman Trail is an arterial road, and 20-feet for the backyard per 38.08.060. Drive aisles are permitted within the setback, but all parking spaces are prohibited in this area. The minimum dwelling density per net acre is 5 with a maximum lot coverage of 40%. For the project site, this would allow for 13 dwellings. Per section 38.540.020 which discusses parking lot design, the minimum stall sizes are 18-feet in length and 9-feet in width. The minimum drive-aisle width is 24 for a two-way aisle and 12-feet for a one-way aisle. In terms of number of spaces, for a community residential facility there must be 0.75 spaces per resident per section 38.540.050 [33]. There are several other parameters outlined for the R-1 district, such as roof slope, building height, and floor to area ratio, but these metrics do not influence site design much.

In regards to citywide ordinances, stormwater runoff estimation and driveway access were the two most significant factors to consider for site evaluation. Per table 38.400.090-1, full private accesses must be at least 660-feet away from intersections on arterial streets and 330-feet away on collector streets. For partial access (i.e., right turn only entrances and exits) these distances drop to 315-feet and 150-feet respectively [33]. These access constraints prohibit any driveway access from entering the site due to its size and relation to intersections. In light of these complications, the city would likely grant some sort of variance to allow for site access considering the restrictions create a hardship on the property owner. When contacted about this concern, a Bozeman Planner did not provide a new guideline for access (since this project is hypothetical in nature), but did confirm that a variance would be drafted in a real-life scenario.

For stormwater runoff estimation, the Bozeman Design Standards and Specification Policy document provides clear guidelines for how to undergo calculations [21]. To begin, it requires that the rational method is used where the runoff coefficient is multiplied by the average rainfall intensity and the site area. The runoff coefficients are provided in Table I-1 and rainfall intensities for Bozeman are provided in Figures I-1 and I-2. The document specifies that for residential calculations, a 10-year storm event should be used. In order to determine the rainfall intensity, the time of concentration needs to be calculated. A formula is provided that takes into account the average slope of the basin, the length of the basin and the rational method runoff coefficient. Once the time of concentration is known for the site, the peak runoff rate can be calculated. In regards to proposed development, the document specifies that BMPs must be implemented to infiltrate, evapotranspire or capture for reuse the first 0.5 inches of a 10-year 24-hour storm followed by 48 hours of no measurable precipitation. There are also several requirements outlined for the specifications of specific stormwater BMPs.

Physical Site Evaluation

The four main physical components of the site that were assessed were site soils, slopes, existing cover and features, and stormwater. The soil survey taken from the USDA soil map service showed just over 86% of the site hosting Anceney cobbly loam (155F), while the remainder of the site existed primarily of Blackmore silt loam (350C) (Figure 3). 155F is a relatively stable soil due to diversity in particle sizes and drains moderately well while 350C is a fertile soil, high in mineral content, and also drains well.

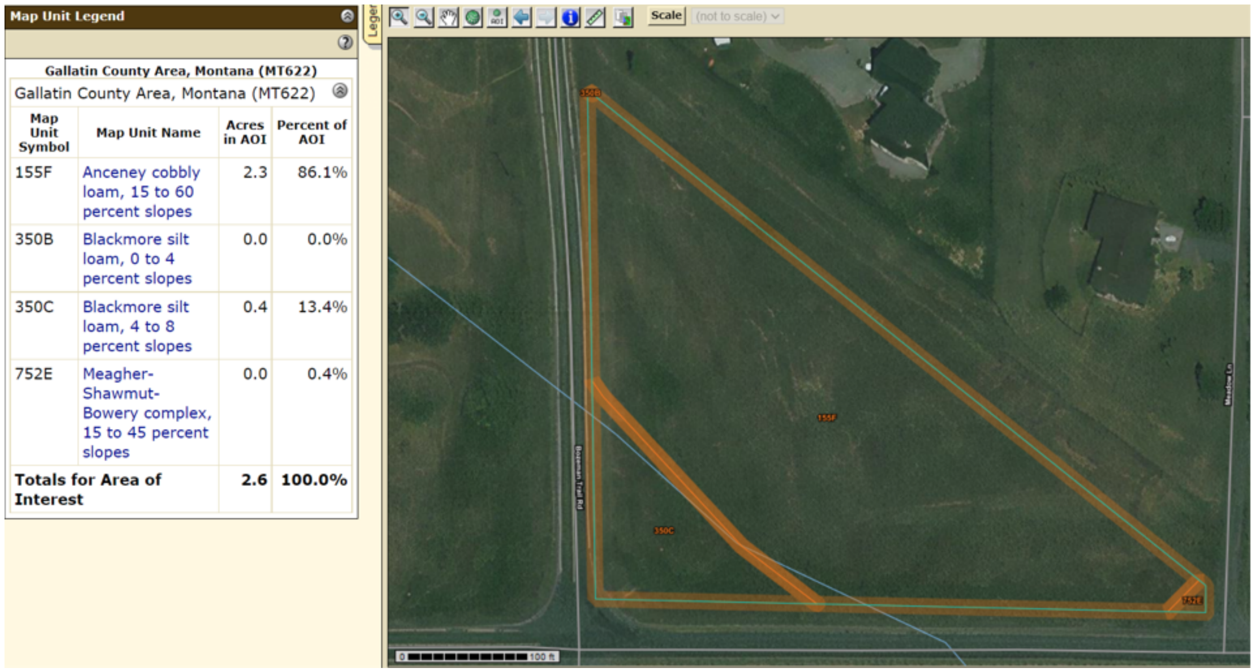

Figure 3: Soil types on site from USDA WebSoilSurvey.

As can be seen in Figure 2, the site contains mostly steep slopes, with an average site grade of 18.7%. The site contains its steepest slopes coming off of the north edge and east edge of Bozeman trail road where grades can be as much as 2:1. For the majority of the site, which slopes southwest from the right-of-way, the grades are less extreme, averaging 8-16%. The lowest elevation, located in the southwest corner of the site sits at 4944 feet, and the highest elevation, located in the southwest corner of the site sits at 4989 feet. The site is almost entirely covered in short prairie grass and contains no large rocks or vegetation. Located at the lowest point in the site, is the entrance to a 2-foot corrugated culvert pipe that crosses under Bozeman Trail Road and exits into a small wetland located to the west.

All stormwater that falls on the site drains to the culvert and is deposited in a wetland to the west. Based on tables included in the Bozeman Design Standards and Specifications Policy and known surface cover, the existing runoff coefficient for the entire site is 20 or 0.20. The time of concentration, which was found by measuring the furthest distance with the least slope from the culvert, is 16.76 minutes. With a storm duration of 16.76 minutes, the rainfall intensity on the 10-year storm IDF curve is 1.54 inches per hour. Given the rainfall intensity, site area, and runoff coefficient, the peak runoff rate for the site is 0.81 cfs (calculations can be found in Appendix C). This value designates the maximum rate of runoff allowed following development on the site which means stormwater management practices will need to be implemented to offset any additional runoff generated from construction.

Layout Concepts

Based on a combination of input from the Cohousing Survey and personal preference, it was decided that the development would be designed to accommodate 20 individuals consisting of two three-person families, five couples, and four solo individuals. This arrangement of community members would require eleven dwellings and it was decided that the dwellings would range in size from 200 - 500 square feet. Given this number of residents, fifteen parking spaces are required and firetruck accessibility is needed so that all dwellings could be reached with a hose if need-be (per sections 38.540.050 and 38.630.040 of the Bozeman Code of Ordinances). With these guidelines in place and the determined zoning parameters in mind, the following three layout concepts were developed.

The first design, pictured in Figure 4 includes a 15-space parking lot with two curb cuts into the minor-arterial portion of Bozeman trail road and a multi-purpose pedestrian way that is wide enough for vehicle access if necessary. All eleven dwellings surround a loop in this walkway with a green space in the middle and the common house to the northwest. The dwelling footprints in this design (as well as the other two) are placeholders for future development, but their sizes are roughly that which is anticipated. The two-way drive aisles leading into the parking lot were designed to improve vehicular circulation and the side of the site was selected due to the anticipated lower traffic volumes on the minor arterial street. All dwellings and parking spaces account for the setback requirements while some of the drive aisles exist within the setback limit. Given the orientation of the access point, the 25-foot front yard setback is on the west side of the site in this scenario. The common house was placed higher up on the site to provide a better view of the mountains to the south.

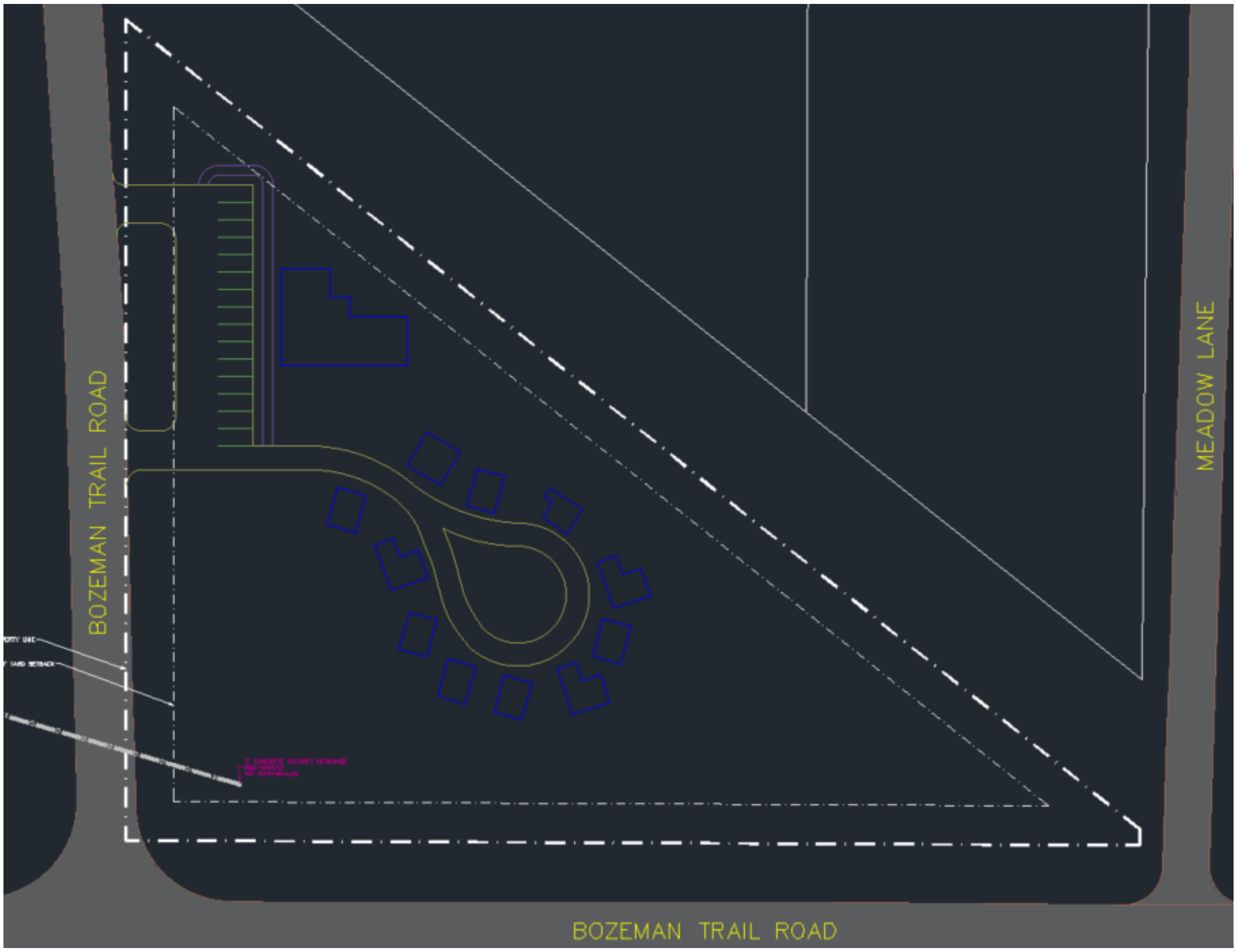

Figure 4: Layout Concept #1.

The second layout concept, portrayed in Figure 5, is somewhat of a mirror image of layout #1, except in this design, the two curb cuts are accessed from the principal arterial section of Bozeman Trail Road. This adjustment was intended to account for the lesser roadside slopes that exist on the southern side of the site compared to the western edge of the site. In addition to this change, the pedestrian way that provides access to the dwellings was lengthened roughly 40 feet to provide more spacing between the dwellings. In this alternative, the 25-foot front yard setback begins on the southern property boundary.

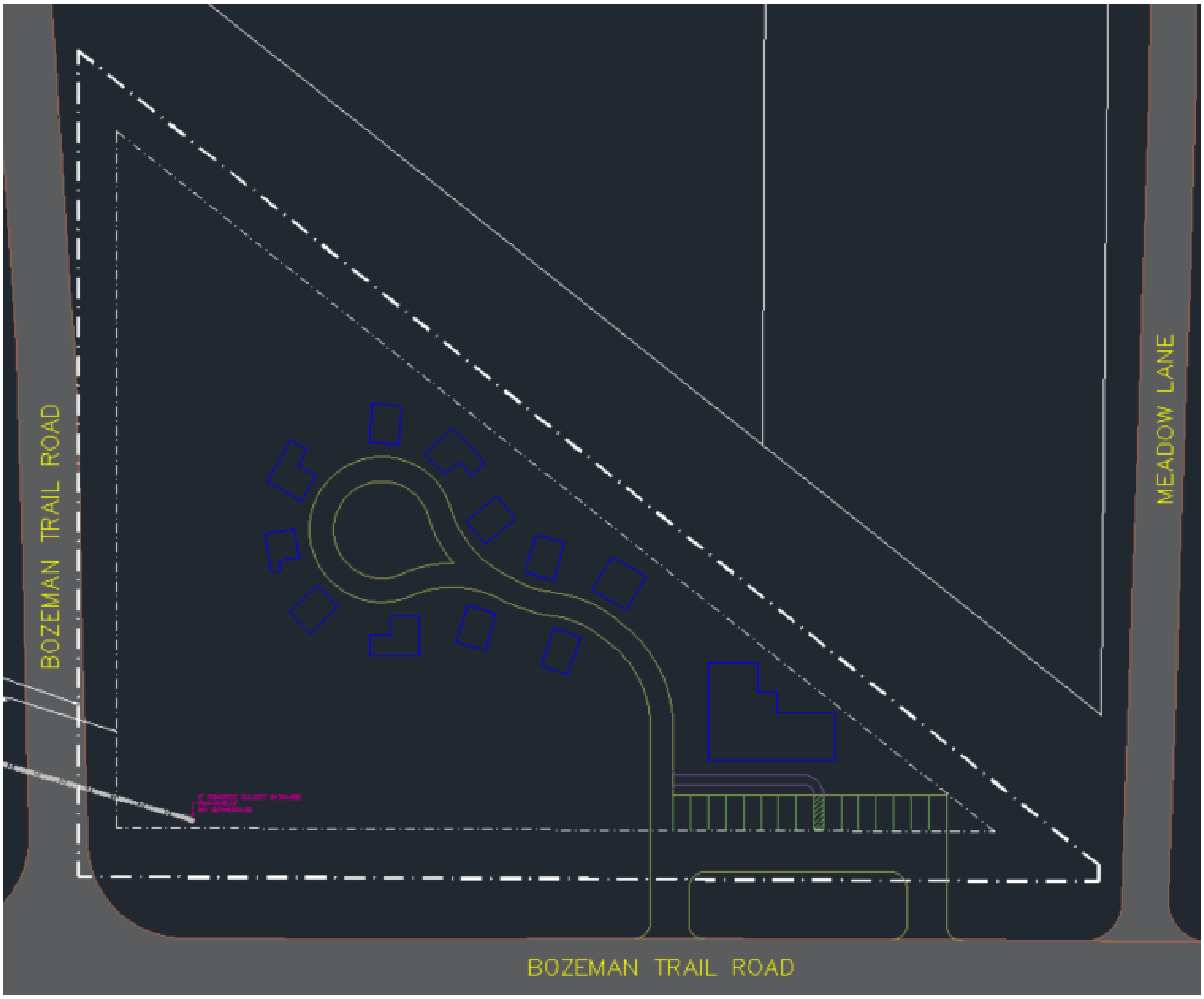

Figure 5: Layout Concept #2.

The third layout alternative, portrayed in Figure 6, differs more significantly from the other two as there is only one curb cut and the parking lot is set along the northern edge of the property instead of being adjacent to a roadway. The 12-foot-wide multi-purpose pedestrian way, shown in yellow, was shortened in this iteration to compensate for the longer drive aisle entrance to the parking lot, but two sections of 5-foot-wide pedestrian walkways (shown in purple) were added to provide adequate spacing for the dwellings. Given the lower placement of the common house on the site, this design anticipates a split-level structure where the main floor entrance exists on the parking lot side and a lower basement level entrance opens to a patio below. The same circular pedestrian way design was included in this iteration. Some considerations for the major changes in this alternative were gradeability and limiting curb cuts.

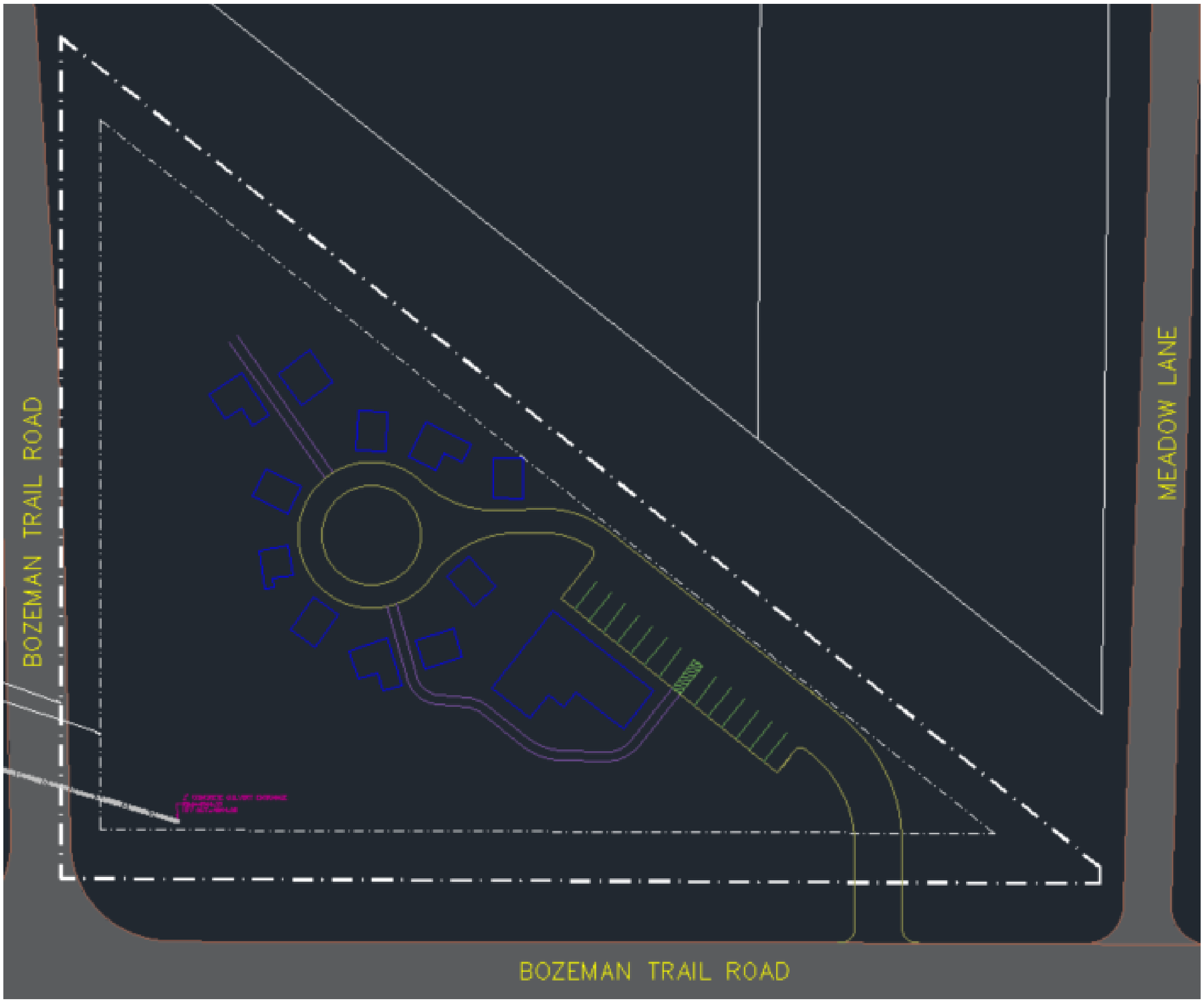

Figure 6: Layout Concept #3.

Selecting a Layout

When selecting the layout to move forward into the schematic stage of design, the following factors were assessed: gradeability, ease of drainage design, accessibility, limitation of curb cuts, dwelling spacing, internal circulation, and minimization of impervious surfaces. A grade of 1 through 5 was given to each layout alternative for each factor where a 5 was the highest score and 1 the lowest. Table 1 displays the results which elected Layout #3.

	Layout #1	Layout #2	Layout #3
Gradeability	1	2	3
Ease of Drainage Design	4	4	4
Accessibility	4	3	2
Limitation of Curb Cuts	2	2	5
Dwelling Spacing	2	4	3
Internal Circulation	4	4	5
Minimization of Impervious Surfaces	4	3	2
Total	**21**	**22**	**24**

Table 1: Layout alternative selection rankings by factor.

Designing a Wastewater Treatment System

To ensure all design influencing components were accounted for, each chapter of the Montana Standards for Subsurface Wastewater Treatment Systems was read through to pull important factors [24]. The first factors addressed were percolation and application rate. From the USDA Web Soil Survey, the portion of the lot where development will occur is primarily cobbly loam. From Table 2.1-1 in the standards document, soils of this nature have a percolation rate of 3-6 minutes per inch and an application rate of 0.8 gpd/ft^2.

Next, wastewater flow rates were assessed. From section 3.1.2, when the number of living units on a single absorption system is 10 or more, the design flow rate for each unit can be reduced to 100 gpd per person. Given this metric, the 20-person cohousing development will have a design flow rate of 2000 gpd. In regards to some system specific components, sections from chapter 4 outline that clean outs are required in the following scenarios: within 3 feet of a building, when pipe angles are greater than 45 degrees, and when pipe runs are greater than 150 feet.

In chapters 5 and 6, specifications for septic tanks and soil absorption systems were outlined. For septic tank sizing, section 5.1.6.2 specifies that total tank capacity must be 2.5 times the design flow when 10 or more living units are involved. This suggests a 5,000-gallon capacity given the 2,000 gpd design flow rate. Additionally, the base of septic tanks must not be more than 12-feet below grade and their heights must not exceed 78 inches. Lastly, for soil absorption systems, the total square footage of the system is equal to the design flow rate (2000 gpd) divided by the application rate (0.8 gpd/ft^2) per section 6.1.4.2 which comes out to 2,500 SF for the proposed development. However, per section 6.1.4.3, systems designed in soils with percolation rates between 3 and 50 mpi may be reduced by 50-percent, which yields a new area of 1,250 SF. Beyond just the total size, there are also several parameters regarding system dimensions. Section 6.1.3.2 specifies that gravity-fed absorption trenches must be 18-24 inches in width and section 6.1.3.6 notes that these trench runes must not exceed 100-feet in length. Per sections 6.1.3.3 and 6.1.3.5, these trenches must be separated by at least 5-feet and, at their base, be no more than 36-inches below grade and no less than 24-inches below grade. Their total height is 12-inches of vertical drain rock with a 4-inch perforated pipe inside. Piping from the dwellings to the septic tank, on the other hand, is done through a 4-inch ductile iron pipe. The entirety of wastewater system parameters is included in Table 2.

Metric	**Parameter**	**Value**
Percolation Rate	soil type: cobbly loam	3-6 min/inch
Application Rate	soil type: cobbly loam	0.8 gpd/ft^2
Design Flow Rate	100 gpd per person	2,000 gpd
Septic Tank Capacity	2.5 times design flow rate	5,000 gallons
Soil Absorption System Size	design flow rate divided by application rate (times 50% given percolation rate)	1,250 SF

Table 2: Wastewater system design points.

Given the requirements for the system, the specific design and location were developed as pictured in Figure 7. The choice to use two trench absorption systems and two septic tanks came from a limitation on space. Since absorption trenches need to be almost entirely level and can only exist between 2 and 3 feet below grade, the surface they reside under must also be very close to level. Thus, the area south of the common house and the area surrounded by the pedestrian walkway seemed to be logical locations.

The southernmost system consists of four 96-foot runs that are 24-inches in width and a connecting head-trench which connects the runs to the outlet pipe of the septic tank. The total area of this absorption system is 814 SF and accounts for effluent from 13 individuals. The northernmost system consists of two 27-foot runs, two 32-foot runs, two 34-foot runs and a head-trench that connects all six. All of these trenches are 24-inches wide and the total system area is 446 SF which is enough area to absorb effluent from 7 individuals. The combined area of the two systems is 1,260 SF which is more than the minimum requirement for this site and proposed occupancy (full calculations found in Appendix D).

In regards to the two septic tanks, the sizing and capacity was also calculated given the number of individuals it would serve. Since 5,000 gallons is required for 20 individuals, that means each individual needs 250 gallons for themselves. To support 7 individuals, a 1,750 gallon septic tank was required (roughly 234 cubic feet). Knowing that the septic tank could be no more than 78-inches in height, an 8x7.5x4-foot tank was designed with an internal capacity of 240 CF. Similarly, for the 13 individual system, a 3,250-gallon tank (434.5 SF) was required. This tank was designed at 11x10x4-feet which comes out to 440 CF (full calculations found in Appendix D). Two access ports are shown on the top of each tank as required by section 5.1.2.3 of the design standards.

Four-inch ductile iron pipes were drawn in Civil 3D to connect the dwellings to the septic tanks and eventually to the gravity-fed absorption systems. These pipes would later be given inverts following the grading design to ensure they existed with at least two feet of vertical cover and possessed slopes greater than 1%. Pipes were connected to one another strategically to minimize 45+% bends and intersections. Clean outs were included next to all dwellings and in the other required areas.

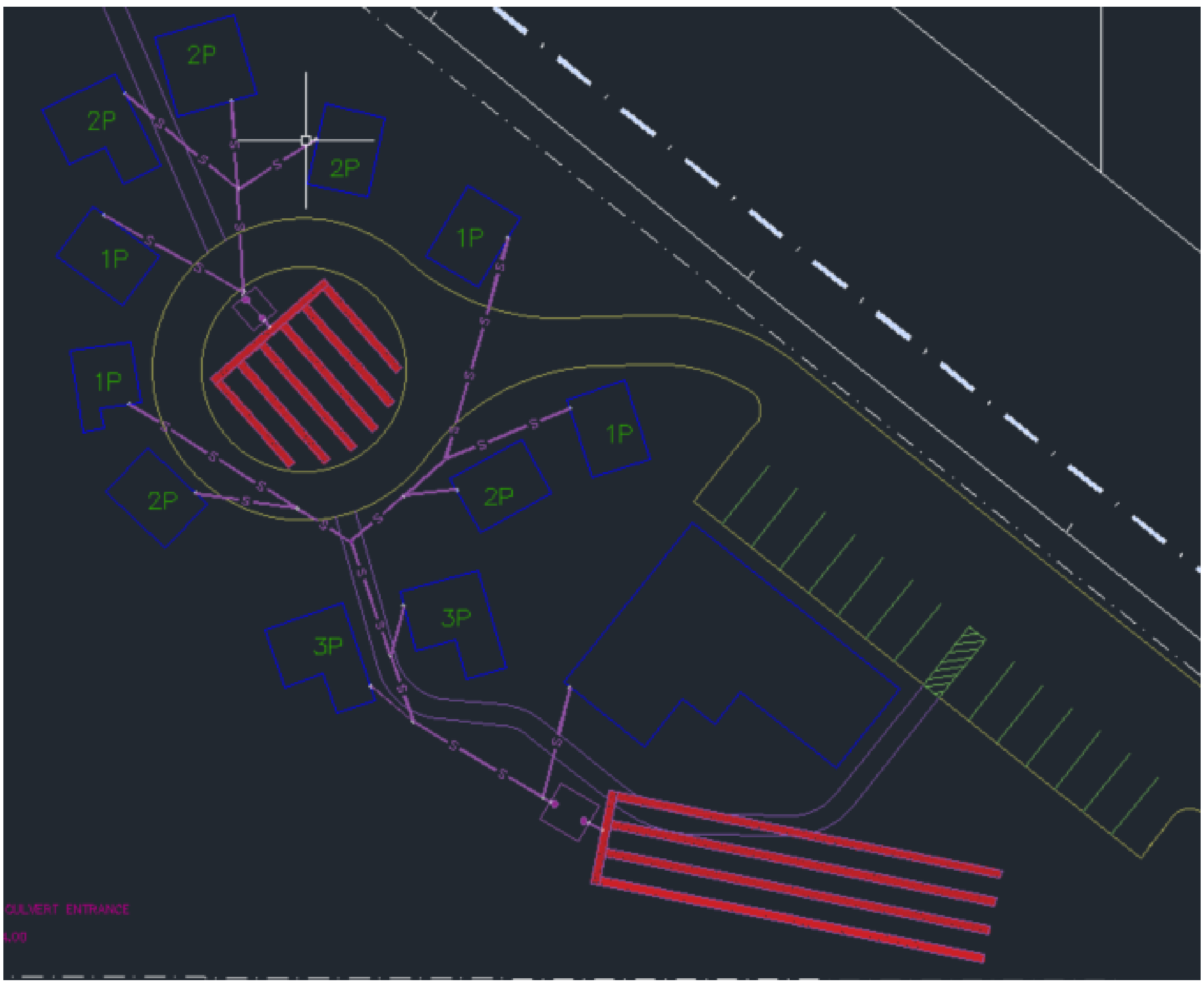

Figure 7: Wastewater system design.

Grading the Site

The site's grading plan, depicted in Figure 8, began with the design of a grass swale on the northern border of the property which pitches to the southeast and directs stormwater away from the parking lot and dwellings. The switchback contour lines create a natural channel for water to follow with the northern edge of the swale rising 4-8 feet above the bottom of the channel and the southern edge of the swale rising about 1.5 feet above the bottom of the channel. This swale directs water to a detention basin in the southeast corner of the site that is formed from the addition of the driveway. Since the driveway needed to come up to meet Bozeman Trail Road flush, it was a logical feature to add as it will assist with stormwater management. The driveway pitches down from the street at an average grade of 9% until it reaches the parking lot where it flattens out significantly. The parking lot is split down the middle to divert water away from the common house, where half of the lot pitches to the southwest and half of the lot pitches to the southeast.

Moving on to the area surrounding the common house, there are several key features to note. To the east of the common house, where the walkway leaves the parking lot, there is a steep grass slope with a stairway to accompany it. This hill declines 10 vertical feet and then levels out on the south side of the common house. The purpose of this design component was to bring the grade down to the basement level so that residents can walk out of the common house to the south on a different floor than they would enter from on the parking lot level. This change in elevation is accounted for on the west side of the house with a retaining wall (shown in light green). The area south of the common house is brought very close to level to accommodate for the leach field, the patio area next to the house, and to leave some room for recreation and potentially gardens. The two 3-person dwellings also reside on that lower level below the retaining wall to keep the family-units closer to the common house and to minimize the risk of children falling from the top of the wall.

In regards to the area where the rest of the dwellings reside, the pedestrian way leaving the parking lot slopes down to the common circle with a maximum grade 6.5%. Once the circle is reached the grade levels to about 3% to accommodate the second leach field and to make dwelling accessibility easier. This decline in slope was able to be included by continuing the retaining wall to the south of the dwellings. At its highest point the wall is 8-feet tall, rising from roughly 4963.5 to 4971.5 feet and at its lowest point (with the exception of the northernmost end which matches the grade) it is 3-feet tall, rising from 4969 to 4972 feet. The wall's low point occurs just to the west of the walkway and where the walkway intersects the retaining wall, there will be a small set of stairs. Immediately to the north of all retaining wall sections, the contours slope slightly away from the top of the wall to create a shallow swale for stormwater to run behind the dwellings until it reaches an eventual low point to the south of all of the 1 and 2-person dwellings.

As for the rest of the site to the west and south of the developed sections, the natural drainage pathways that existed in the initial condition were mostly conserved. Just as they had before, the two channels converge at the existing drainage culvert on the southwest corner of the property. The steepest slopes on the site are those to the south of the retaining wall and the lower leach field, as well as those pitching down the basin on the eastern side of the site. The maximum slope exists at roughly a 1:2 grade. Overall, the basic requirements for grading outlined in the methodology were met and the site surface was able to be manipulated to a degree where it would be buildable.

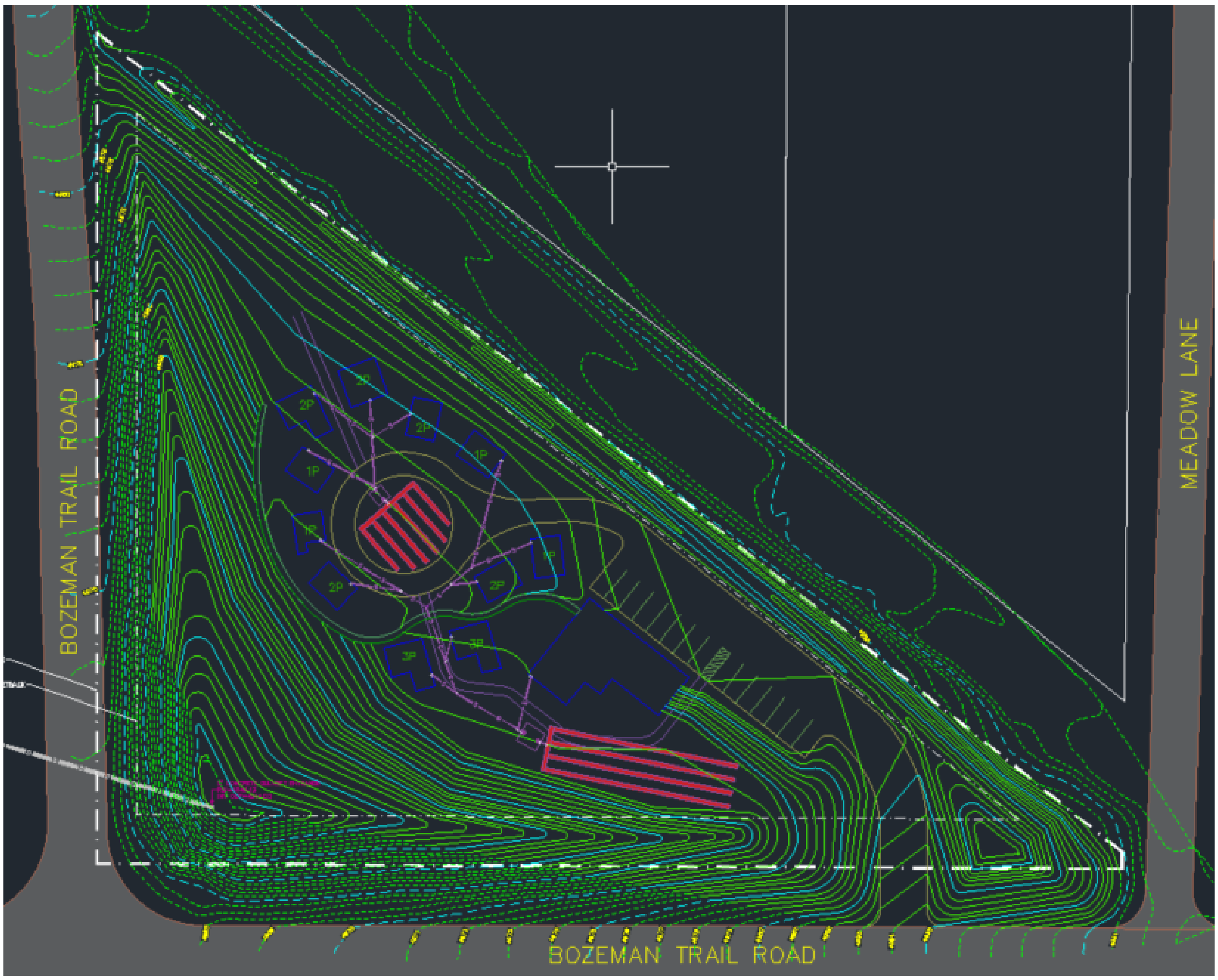

Figure 8: Proposed grading.

Selecting and Sizing Stormwater Best Management Practices

The first step taken in dealing with site stormwater was calculating the runoff volume difference between the existing and proposed conditions. From the *Physical Site Evaluation* section, the peak exiting runoff rate is 0.81 cfs with a time of concentration of 16.76 minutes. With a linear increase and decrease to and from the peak runoff rate, the total volume of runoff for this storm event is 814.5 CF (seen in Figure 9 as the blue function). This volume is calculated by geometrically finding the area under the function. To determine the new peak runoff rate, a new c-value for the site was determined. With the proposed impervious roof and pavement areas, (shown in Figure 10 with the blue hatch), the new site-weighted c-value is 0.293, a 46% increase from 0.2. When this value is inputted into the time-of-concentration formula, with the same distance and average slope, the proposed time-of-concentration is 15.04 minutes. Given the same storm intensity of 1.54 in/hr that was modeled for the existing conditions, the new peak flow rate is 1.17 cfs. The proposed un-intervened runoff rate over time is shown in Figure 9 as the red function and when the geometric integral of this function is calculated (via the Rational Method) the total volume generated is 1236.9 cf. The difference between the proposed and existing runoff volumes, 422.4 CF, is the amount of runoff that needs to be accounted for with stormwater BMPs (full calculations found in Appendix E).

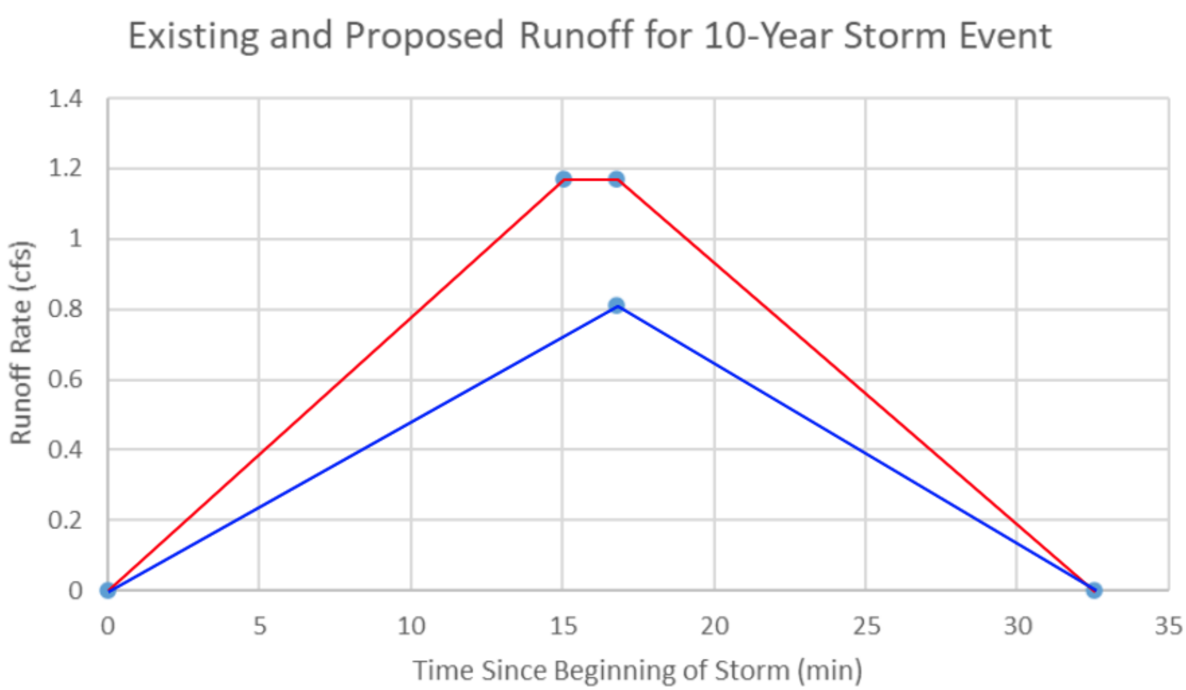

Figure 9: Existing and Proposed Runoff for a 10-Year Storm Event.

Next, a basic drainage layout was developed to allow for calculations on the site's most prominent stormwater conveyance features. As can be seen in Figure 10, a catch basin was placed in the southeast corner of the parking lot to direct a sizable portion of the parking-lot runoff to the detention basin at the southeast corner of the lot. This is made possible by the addition of a 6-inch concrete girder that runs along the south edge of the parking lot. (This feature also acts as a bumper for cars given the steep slope adjacent to the parking spaces). With the swale on the north border of the lot already draining to this basin, the total catchment area sits at 15,481 SF and is pictured in Figure 11 with the dashed-pink outline. The expectation is that this basin will detain all runoff from the 10-year storm event before reaching a level high enough that it begins to enter the area drain and travel under the driveway (pictured in Figure 11). The total volume conveyed by this BMP is 186.0 CF (calculations found in Appendix E).

The next catchment area, which encompasses nine dwellings and a sizable amount of pavement, occupies a total area of 27,004 SF. With a weighted c-value of 0.411, the total runoff volume generated during the 10-year storm event from this area is 394.6 CF. Given the approximate 81.1 CF of that total that comes from roof runoff, rain barrels were a logical feature to add to convey that portion of the runoff. These rain barrels offer far more than just stormwater conveyance too with the ability to be utilized for gardens, toilets, and showers. As for the rest of the runoff from this catchment area, two area drains were placed at low points just before the retaining wall with pipes that travel under the wall and out towards the southwest site low point.

The third and largest catchment area, occupies 70,855 SF of the site, has a weighted c-value of 0.227 and a total runoff volume of 571.8 CF for a 10-year storm event. Within this area, another 3150 SF of roof is included which allowed for the inclusion of more rain barrels which convey 89.5 CF of stormwater (full calculations found in Appendix E). The remainder of runoff from this area travels over mostly undeveloped surfaces and drains to the same southwest culvert it did prior to development.

With the inclusions of the rain barrels and the southeast detention basin, the total stormwater conveyed is 356.6 CF. This accounts for about 85% of the additional runoff generated by development. To address the remaining 15%, riprap slopes were included at the outfalls of the three area drains on the site and the two drainage channels on the south and west borders of the lot were planted to promote infiltration. While exact calculations for these BMPs were not determined, it is fair to say that between them all, they can convey the remaining 66 CF of stormwater.

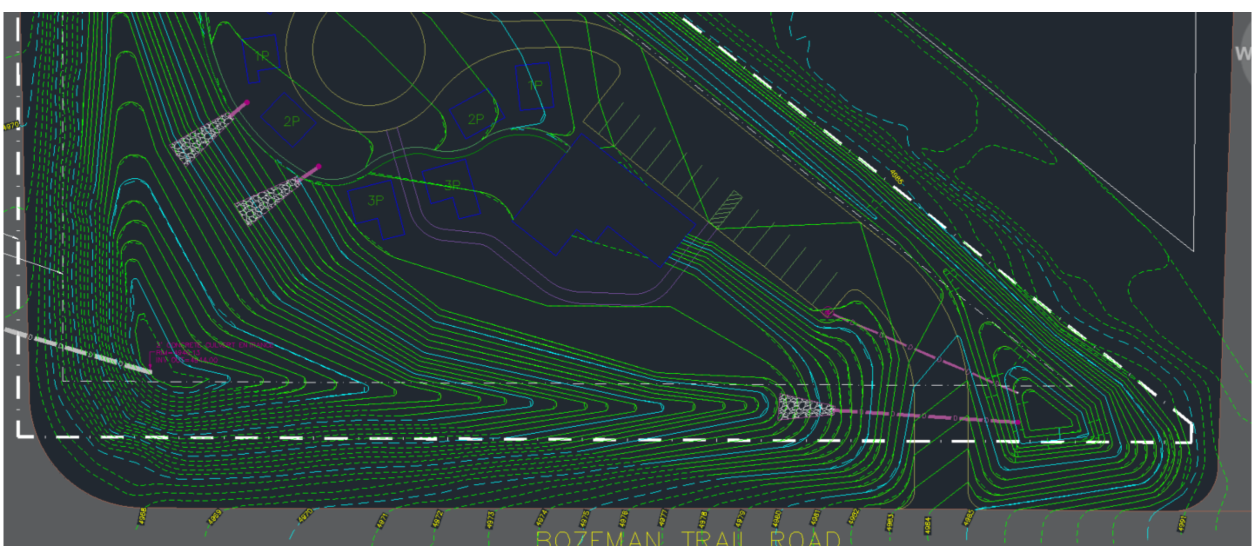

Figure 10: Stormwater BMPs.

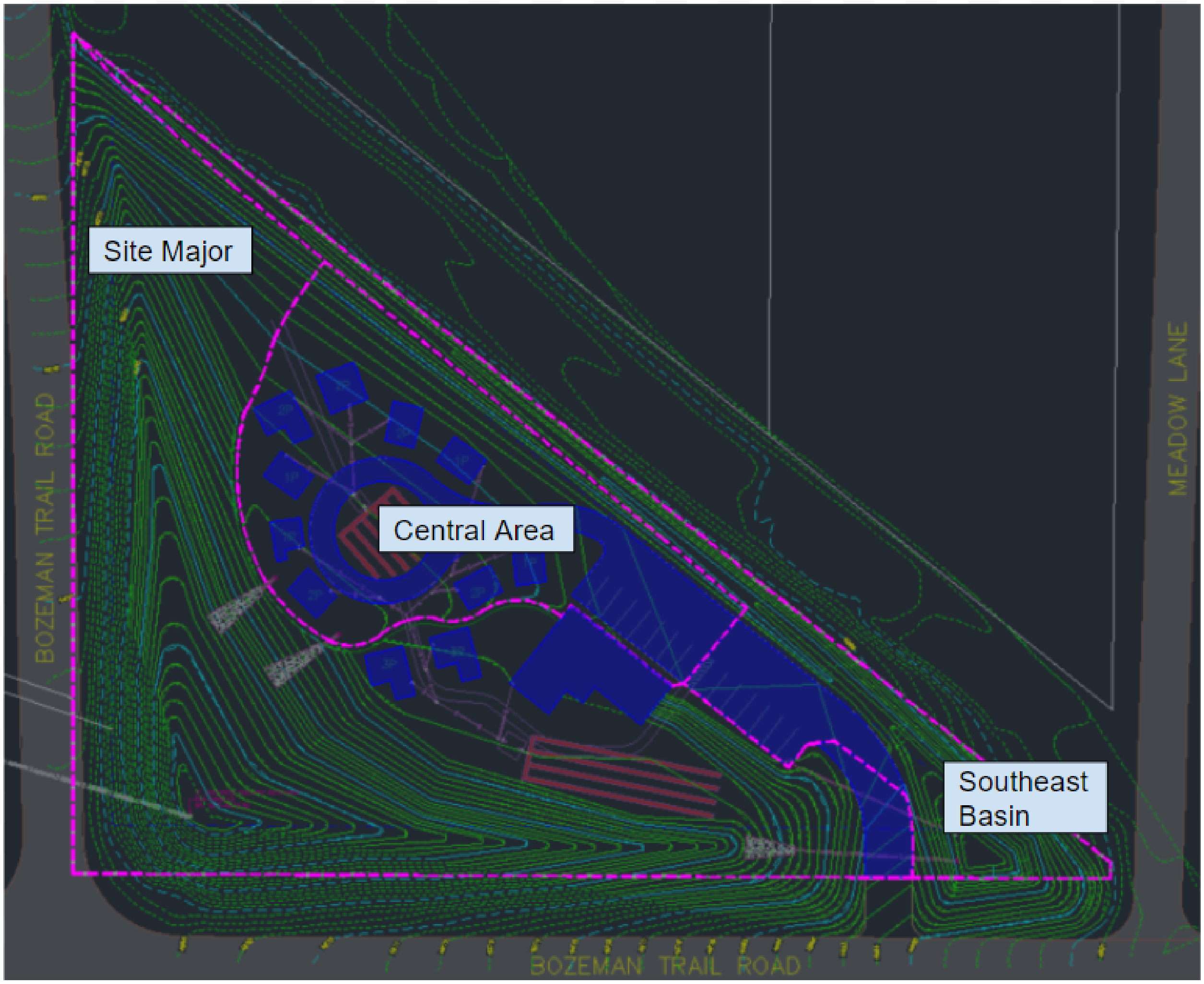

Figure 11: Site catchment areas.

Once stormwater BMPs were selected, more specific sizing could be done. The pipe connecting the catch basin in the parking lot to the detention basin sees a peak runoff rate of 0.10 cfs. At a 1.09% slope, a 6-inch HDPE pipe can convey 0.51 cfs [25], so this size was sufficient for the given storm event and for more extreme storms as well. The pipe connecting the detention basin area to the south drainage channel, similarly, sees a peak runoff rate of 0.19 cfs from the 10-year storm event. Consequently, a 6-inch HDPE pipe is also perfectly suitable to convey that rate of stormwater runoff. The remaining two pipes, exiting the two area drains adjacent to the retaining wall, see 0.31 cfs of runoff between the two of them. Seeing as 0.16 cfs is less than 0.51 cfs, 6-inch HDPE pipes are again sufficient. In regards to the rain barrels, a total volume of 170.6 CF, or 1276 gallons, needed to be stored. With a total site roof area of 6,000 SF, 0.21 gallons/SF is a proper metric for sizing rain barrels. For the 2,350 SF roof of the common house, a 500-gallon tank is necessary; while the 400 SF dwellings require 100 gallon tanks, and the remainder are covered with 80 gallon tanks (full calculations found in Appendix E).

Table 3 summarizes runoff rates and volumes for the three catchment areas, as well as for sub-catchment areas such as the catch-basin and roofs.

	Area (sf)	Weighted c-value	Runoff Rate for 10-Year Storm Event (cfs)	Runoff Volume for 10-Year Storm Event (cf)
Southeast Basin	**15,481**	**0.338**	**0.19**	**186.0**
Northern Swale	11,933	0.2	0.09	85.4
Parking Lot and Drive to Catch Basin	3,548	0.8	0.10	100.6
Central Area	**27,004**	**0.411**	**0.39**	**394.6**
Roofs to Rain Barrels	2,850	0.8	0.08	81.1
Pavement and Landscaped Surface to Area Drains	24,154	0.366	0.31	313.5
Site Major	**70,855**	**0.227**	**0.56**	**571.8**
Roofs to Rain Barrels	3,150	0.8	0.09	89.5
Other	67,705	0.212	0.47	482.3
Total	**113,340**	**0.293**	**1.17**	**1236.9**
Rain Barrels	-	-	-	170.6
Southeast Detention Basin	-	-	-	186.0
Total Conveyed	**-**	**-**	**-**	**356.6**
Existing -> Proposed Net	0	0.093	0.36	422.4

Table 3: Catchment Area Runoff and BMP Conveyance.

Selecting Well Location

As can be seen in Figure 12, the well (shown in orange) is located northwest of the northernmost dwellings on the site. This location is offset just over 50 feet from the sewer pipe exiting from the side of the 6-sided 2-person dwelling. Additionally, it is well over 100 feet from the north leach field and 55 feet from the nearest property line. The well is located on a grass surface with no nearby development to interfere with maintenance. In order to supply all twenty residents with 100 gallons of water per day, the well needs to pump about 1.4 gallons of water per minute, however the minimum flow rate required in residential communities is 5 gallons per minute and for a family of 4, a flow rate of 6 gallons per minute is recommended [26]. Considering rain barrels will supply a significant portion of water for showering and toilet flushing, but there are 20 residents drawing from the well, a flow rate of 15-20 gallons per minute would be optimal.

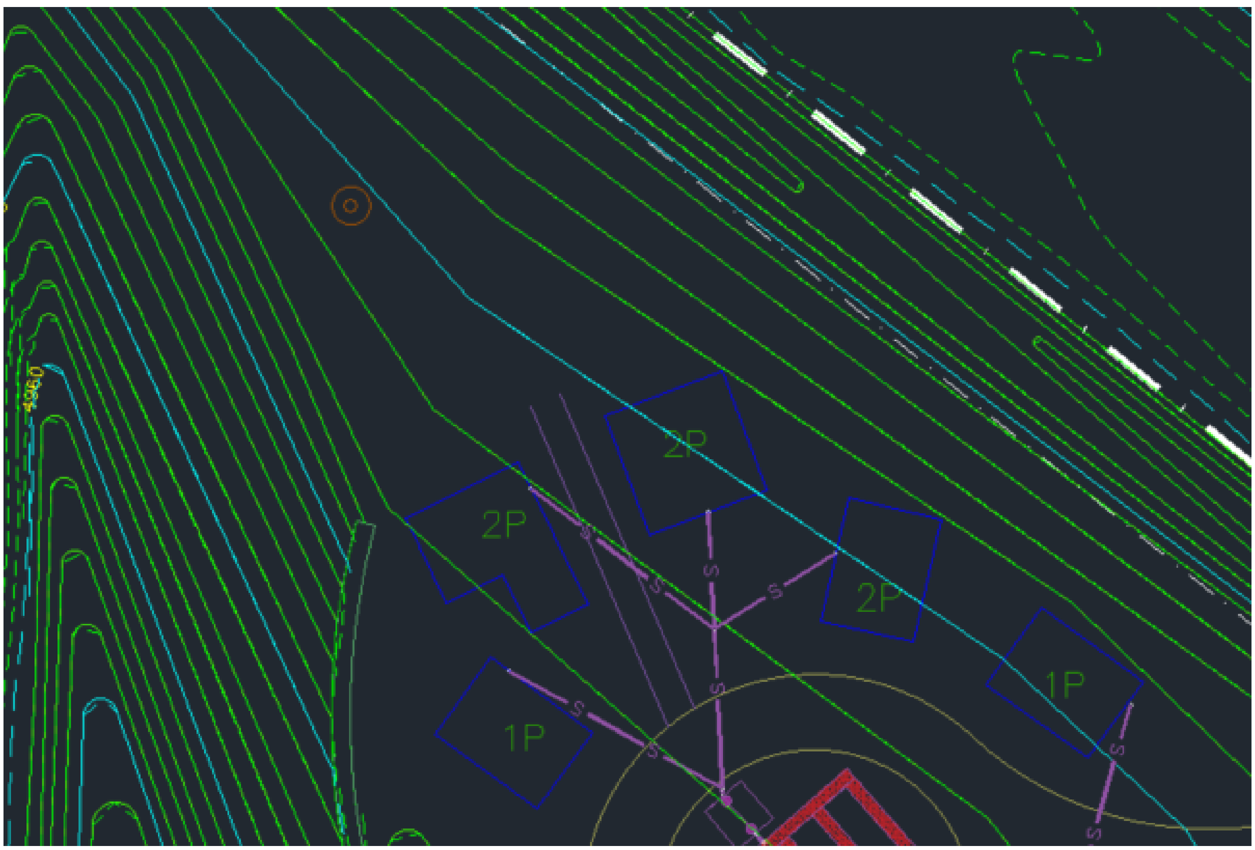

Figure 12: Well location.

Sizing Solar Electric System

After specifying the type and number of appliances per dwelling, the energy usage for each set of appliances were determined based on data from Silicon Valley Power [27]. Estimations on time-of-use for each appliance were based on the number of residents living in a dwelling and a reasonable guess of their daily routines. For instance, if a resident works from home two days a week for nine hours, their weekly desktop usage is 18 hours or roughly 3 hours per day. Similarly, if three residents share a toaster oven, it is fair to assume that on a daily basis, each might use it once for twenty minutes at a time, adding up to a total daily usage of one hour. For more significant electricity consuming appliances, such as lights and heaters, a more quantitative approach was followed.

Space heaters were deemed appropriate for all dwellings, and a 72,000 BTU heat pump covered the heating and hot water needs of the common house based on the square footage of the structures [39][28]. The space heaters all require 1.5 kWh/hour of electricity while the heat pump requires 37.5 kWh per square meter and 353 kWh/person/year for hot water [27][29]. As for lights, 75 lumens/SF were deemed necessary for bathrooms and kitchens, while 15 lumens/SF would cover bedrooms and other common spaces [30]. With this metric known, the number and type of lighting fixtures for each structure were determined and tabulated in tables 4-7. (It should be noted that while only one type of lightbulb was specified for each dwelling, in reality, many different sizes and types of lighting fixtures would be integrated into the design. Without developing interior layout plans of the dwellings, determining best light fixtures would be extremely difficult. Knowing the number of lumens and watts required for each dwelling is all that is necessary for sizing a solar system). Further assumptions and calculations for appliance sizing and usage can be found in Appendix F.

The daily energy usage for all appliances, as well as total daily usage per structure type can be found in Tables 4-7 below. Given that solar panels generate an average of 2 kWh of energy per day, the number of panels needed for each structure type were included in the tables as well [40].

Considering this system is designed to be grid-connected, it is reasonable to assume that during the summer (when heaters are not running) there will be an energy surplus, leading to the possibility of selling energy back to the grid. Montana runs an active net-metering program, which enables grid-connected systems to operate in the absence of batteries. All energy produced by the site's solar system that exceeds consumption, is bought back by the power supply company and a credit is given to the residents who own the system [41]. In an opposite respect, during the winter months when energy consumption is at its peak, the cohousing development will be able to pull energy from the public electric system. The system was designed to be net-zero on a yearly basis, but due to the vast swings in energy consumption, there will be periods where the system is both above and below this metric.

Appliance	Energy Usage per Unit	Quantity	Hours Used per Day	Daily Usage (kWh)
Space Heater	1.5 kWh per hour	1	11.5	17.25
LED Light (20W)	0.02 kWh per hour	4	8	0.64
Laptop	0.02 kWh per hour	1	2	0.04
Mini Fridge (25 CF)	250 kWh per year	1	24	0.68
Toaster Oven	0.75 kWh per hour	1	0.25	0.18
Coffee Maker	0.12 kWh per brew	1	One brew	0.12
Television (32" LED)	0.014 kWh per hour	1	1	0.014
Stereo+Speakers	0.1 kWh per hour	1	0.5	0.05
Total				**19.1**
Panels Required				**10**

Table 4: One-person dwelling daily energy consumption and solar panel count.

Appliance	Energy Usage per Unit	Quantity	Hours Used per Day	Daily Usage (kWh)
Space Heater	1.5 kWh per hour	1	11.5	17.25
LED Light (20W)	0.02 kWh per hour	5	8	0.8
Desktop Computer	0.06 kWh per hour	1	3	0.18
Monitor	0.04 kWh per hour	1	3	0.12
Laptop	0.02 kWh per hour	2	2	0.08
Mini Fridge (25 CF)	250 kWh per year	1	24	0.68
Toaster Oven	0.75 kWh per hour	1	0.75	0.54
Coffee Maker	0.12 kWh per brew	1	One brew	0.12
Television (40" LED)	0.02 kWh per hour	1	1	0.02
Stereo+Speakers	0.1 kWh per hour	1	0.5	0.05
Total				**20.1**
Panels Required				**11**

Table 5: Two-person dwelling daily energy consumption and solar panel count.

Appliance	Energy Usage per Unit	Quantity	Hours Used per Day	Daily Usage (kWh)
Space Heater	1.5 kWh per hour	1	11.5	17.25
LED Light (20W)	0.02 kWh per hour	5	8	0.8
Desktop Computer	0.06 kWh per hour	1	6	0.36
Monitor	0.04 kWh per hour	1	6	0.24
Laptop	0.02 kWh per hour	3	2	0.12
Mini Fridge (25 CF)	250 kWh per year	1	24	0.68
Toaster Oven	0.75 kWh per hour	1	1	0.72
Coffee Maker	0.12 kWh per brew	1	Two brews	0.24
Television (40” LED)	0.02 kWh per hour	1	2	0.04
Stereo+Speakers	0.1 kWh per hour	1	1	0.1
Total				**21.0**
Panels Required				**11**

Table 6: Three-person dwelling daily energy consumption and solar panel count.

Appliance	Energy Usage per Unit	Quantity	Hours Used per Day	Daily Usage (kWh)
72,000 BTU Geothermal Heat Pump	37.5 kWh per square meter per year	1	-	33.0
72,000 BTU Geothermal Hot Water Heater	353 kWh per person per year	1	-	19.3
LED Light (20W)	0.02 kWh per hour	67	8	10.7
Desktop Computer	0.06 kWh per hour	8	8	3.8
Monitor	0.04 kWh per hour	10	8	3.2
Laptop	0.02 kWh per hour	10	8	1.6
Oven	2.3 kWh per hour	2	1.5	6.9
Stove	1.5 kWh per hour	2	3	9.0
Dishwasher (industrial)	2.5 kWh per load	1	3 loads	7.5
Microwave	1.44 kWh per hour	2	0.77	2.2
Fridge (25 CF)	54 kWh per month	3	24	5.4
Freezer (20 CF)	90 kWH per month	2	24	6.0
Toaster Oven	0.75 kWh per hour	2	2	3.0
Coffee Maker	0.12 kWh per brew	2	Two brews	0.48
Washer	2.3 kWh per	1	Two loads	4.6

	load			
Dryer	2.5 kWh per load	1	Two loads	5.0
Television (65" LED)	0.025 kWh per hour	1	4	0.1
Stereo+Speakers	0.1 kWh per hour	3	2	0.6
Total				**122.4**
Panels Required				**62**

Table 7: Common House daily energy consumption and solar panel count.

Given the number of panels required for each structure, determining how many could be roof mounted was the next step. Since roof pitches and sizes are set to be determined during the modeling phase of the project, setting solar panel locations was done during this portion of the project as well.

Moving Civil 3D Surface into SketchUp

The imported and exploded surface in SketchUp can be seen in Figure 13. The areas absent of elevation values are locations where structures, walls, and walkways will eventually be added. The few other holes seen near the edges of the surface are areas absent of data from Civil 3D and will have to be manually filled-in as modeling progresses. The rough location of the driveway, parking lot, and Southeast basin can be seen in Figure 13.

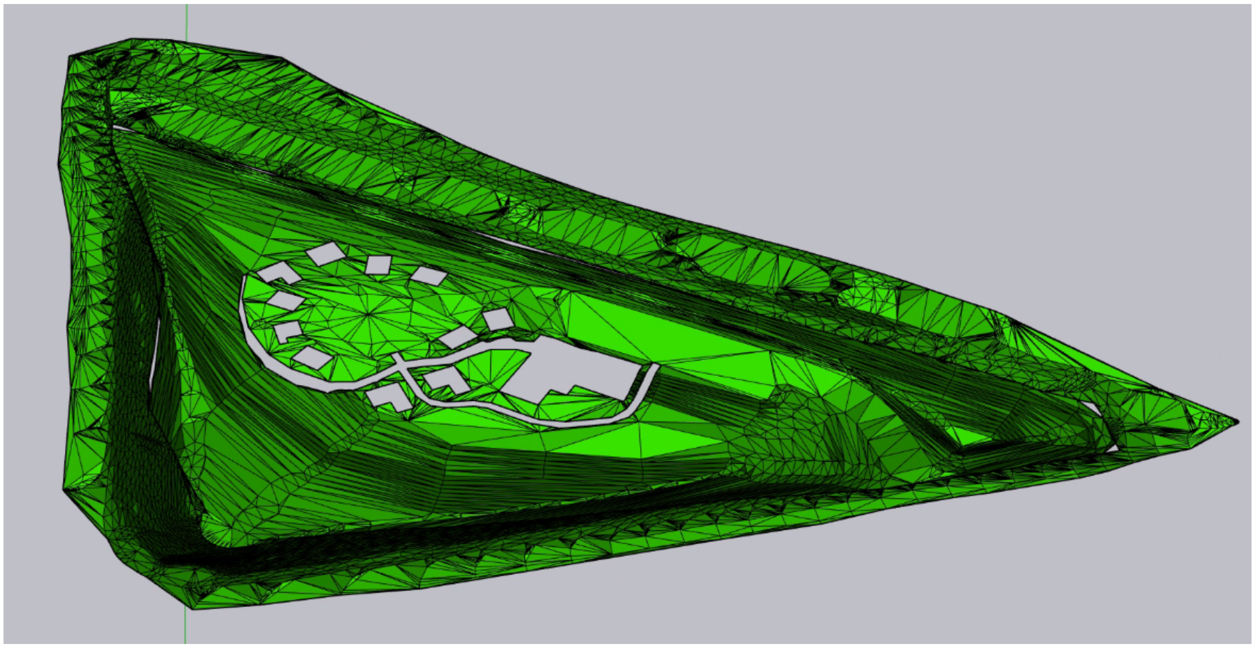

Figure 13: Civil 3D Surface moved into SketchUp.

Developing the Model in SketchUp

The final renders of the model are pictured in Figures 14 and 15. Within these captured SketchUp images, many notable site features can be observed, including extruded structures, plantings, walkways, gardens, solar arrays, cars, and pedestrians.

The eleven dwellings on the site are all between 14 and 16 feet in height with rooflines beginning at 11 feet regardless of the size. This design was selected to allow for standard 8-foot-tall first floor ceilings with a sloped-ceiling loft area above. The dwelling lofts provide the perfect space for a bed or two which would allow for a more spacious living area on the first floor. Roof pitches for all dwellings range between 6:12 and 9:12 which are all permissible in the R-1 zoning district per section 38.320.020D of Bozeman's zoning ordinances [33]. As for the common house, the 1,750 SF footprint was extruded 22 feet evenly and then given a maximum roof pitch of 6:12 to yield a total structure height of 27 feet from the lowest grade. This allows for two high-ceiling (10 foot) floors with an unfinished attic above. The main entrance for the common house is on the 2nd (main) level that meets the grade of the southern side of the parking lot. From this level, residents can walk out onto the large deck that overlooks the property and the mountains to the south. The first level of the common house is a walk-out basement that meets the grade of the pervious patio on the southern side of the house.

Given the available roof area and the average solar panel size of 40x65 inches, 140 total panels were able to be mounted on the roofs of the dwellings and common house [41]. With an anticipated 179 panels required to make the cohousing development a net-zero power consumer during the course of a full year, 39 more panels needed to be ground mounted. The naturally south facing slope of the site was a perfect place to mount an additional 40 panels which can be seen in Figure 14.

With all dwellings situated, other important site features could be added. Several large raised garden beds are included to the south of the common house to optimize time in sunlight and to increase accessibility. Other vertical gardens are located between dwellings that exist around the paved loop. Given the steep slopes on both sides of the driveway and on the south of the parking lot, a thick wooden guardrail was added to prevent any accidents, especially during the winter. In regards to site plantings, Blue Spruces, Juniper Bushes, and Feather Reed grasses were selected and placed generously around the site. All of these plants are native to Bozeman and complement the built environment nicely [34]. Although green grass is shown ubiquitously throughout the model, the intention is to leave existing prairie grass for the majority of the site and only plant Rye, Fescue, or Kentucky Blue Grass, in the areas immediately surrounding the dwellings and the common house. While not native, these three common lawn grasses take nicely to colder climates and are well equipped to withstand the changing seasons [42].

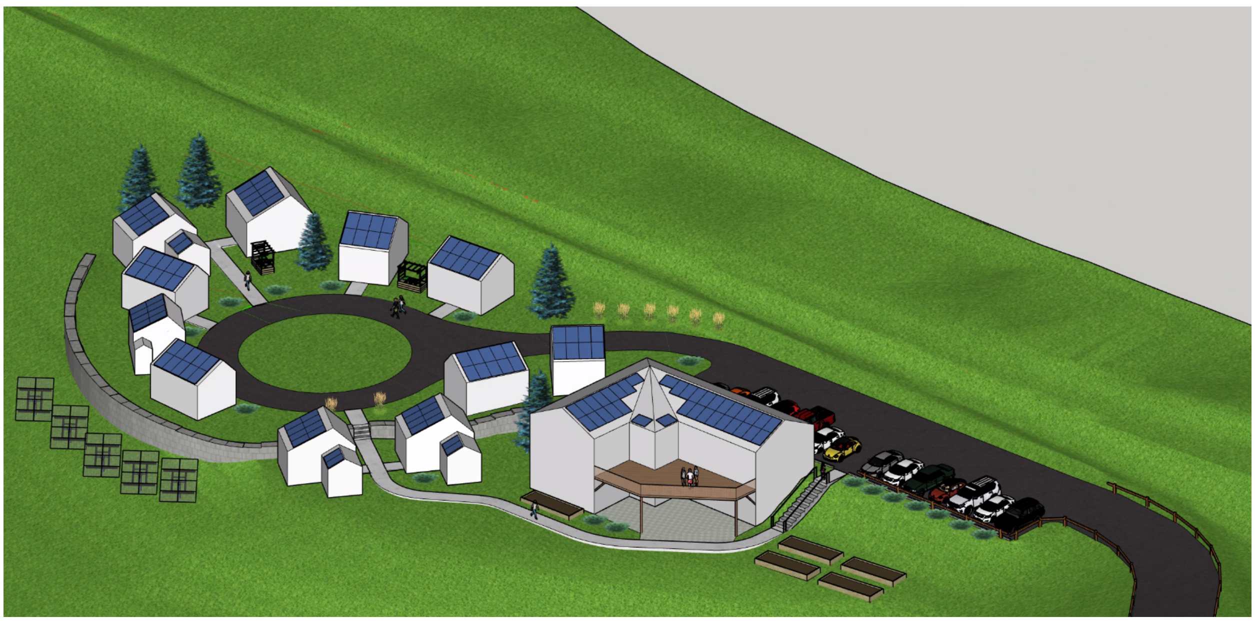

Figure 14: Completed model render #1.

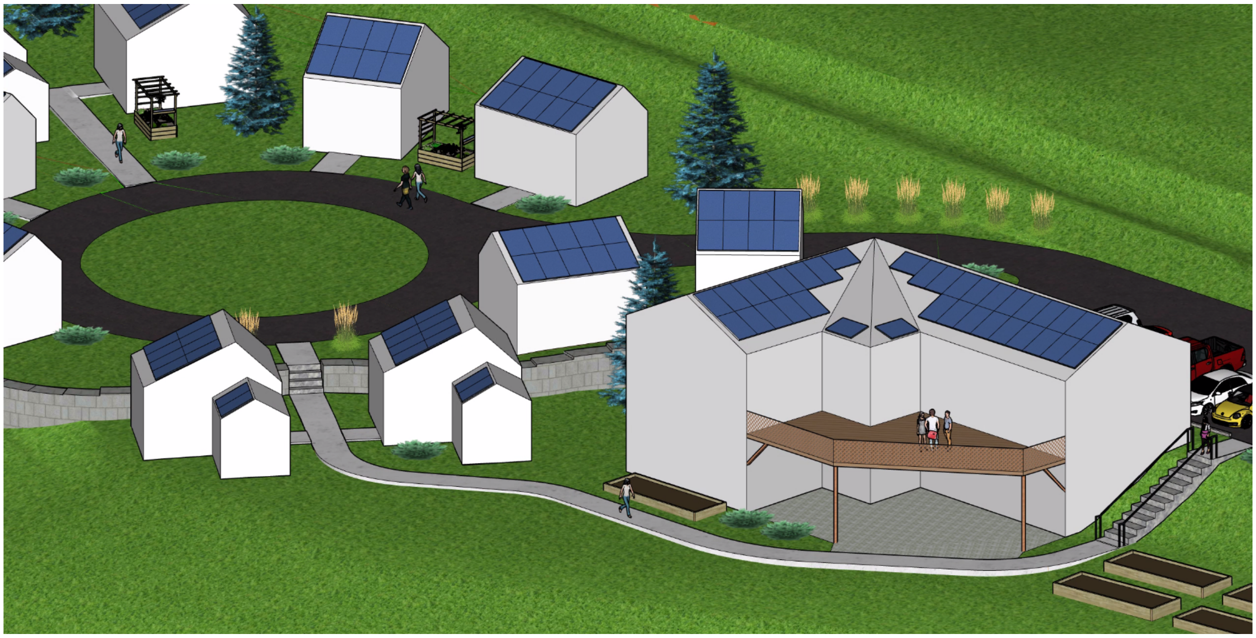

Figure 15: Completed model render #2.

Conducting Cut/Fill Analysis for the Proposed Surface

The results of the Cut/Fill analysis can be seen in Table 8.

	Cut	Fill	Net
Volume (CY)	3,167.26	11,331.11	**8,164.07**

Table 8: Cut/Fill analysis results.

It can be gathered from this analysis that an additional 8,164 cubic yards of fill will need to be transported to the site to complete the proposed development.

Cost Estimating the Project

The entire cost estimate for the project can be found in Table 9, with sources included as subscript next to the respective values. Assumptions for the estimate can be found in Appendix G.

Item	Material Cost per Unit ($)	Labor/Installation Cost per Unit ($)	Number of Units	Total ($)
Lot 3, Mountain Meadows Subdivision	305,540[37]	0	1	305,540
Dirt Fill	7/cubic yard[43]	20/cubic yard[43]	8,165	220,455
1-Person Tiny House	250/SF[44]		4x287.5	287,500
2-Person Tiny House	250/SF[44]		5x340	425,000
3-Person Tiny House	250/SF[44]		2x400	200,000
Common House	180/SF[45]		3500	630,000
Retaining Wall	20/SF[46]	15/SF[46]	1430	50,050
Solar Panels	4.37/watt[47]		45,000	196,650
Asphalt Drive/ Parking Lot/ Pedestrian Walk	7/SF[48]		11,655	81,585
3250 Gallon Septic Tank	3,500[49]	1,250[49]	1	3,500
1750 Gallon Septic Tank	2,250[49]	1,250[49]	1	2,250
Leach Fields	11/LF[50]		1260	13,860
Concrete Walk	3/SF[48]		1,190	3,570
Concrete Catch Basin	2,000[51]		1	2,000
6” HPDE Pipe	10.21/LF[52]	10/LF[52]	203	4,103
12” Area Drain	1,200[51]		2	2,400
Wood Guard Rail	330/16 LF[53]	10/LF[53]	302	9,290
Well	15,000[54]		1	15,000

RipRap with Fabric	45/SY[55]		25	1,125
Feather Reed Grass (6 ft)	80[56]		8	640
Blue Spruce (16 ft)	2,160[57]	150[57]	5	11,550
Juniper Bush	55[56]		20	1,100
Subtotal (structures)				1,542,500
Subtotal				2,467,118
Construction Management Fee	8%[58]		x2,467,118	197,369
Architecture Fee	10.46%[59]		x1,542,500	160,420
Total				**2,824,907**

Table 9: Cohousing development cost estimate.

Developing a Cost Structure for Residents

Table 10 displays the total cost and monthly cost per dwelling and per person. The mortgage rates are averages for Montana supplied by the US Bank and are all fixed [60]. It is quickly evident that the two and three-person dwellings are far more affordable than the one-person dwellings. Additionally, the 15-year mortgage plan yields a far lower total cost once the interest is added over time on top of the principle. Considering the average monthly rent in Bozeman is currently $1,400 for a one-bedroom, $1,900 for a two-bedroom, and $2,500 for a three bedroom, the cost benefits of cohousing are significant [61].

Mortgage Type	Dwelling Type	1-Person	2-Person	3-Person
15 Year (3.877%)	Total Price ($)	241,380	258,660	278,640
	Total Price per Person ($)	241,380	129,330	92,880
	Monthly Payment Per Dwelling ($)	1,341	1,437	1,548
	Monthly Payment per Person ($)	1,341	719	516
20 Year (4.602%)	Total Price ($)	280,080	300,240	323,040
	Total Price per Person ($)	280,080	150,120	107,680
	Monthly Payment Per Dwelling ($)	1,167	1,251	1,346
	Monthly Payment per Person ($)	1,167	626	449
30 Year (4.700)	Total Price ($)	341,280	365,760	393,840
	Total Price per Person ($)	341,280	182,880	131,280
	Monthly Payment Per Dwelling ($)	948	1,016	1,094
	Monthly Payment per Person ($)	948	508	365

Table 10: Cost structure for residents based on different mortgage schedules.

V. Conclusion

The completion of this project leaves the site plans at a schematic level, ready to be further developed into construction documents with accompanying architectural plans. A natural progression could be to outline more detailed structure footprints and then re-import the model into SketchUp, Revit, or an equivalent drafting software, to display fully developed structures on the proposed site plan. In regards to site work, full design of the water and electrical systems would need to be carried out to bring the project to a stage where it would be ready for preliminary construction document drafting. Were a full set of plans to be compiled with details and specifications, a far more accurate cost estimate could be conducted which would better inform monthly mortgage payments for the residents.

Even with its limitations, this MQP provided an invaluable learning experience, working with many constraints to perform engineering calculations and using them to inform site design. With the cost estimate conducted and mortgage schedules developed, funding the construction of the project seems very feasible for a group of twenty residents. Compared to home prices and monthly rent costs in the area, the proposed cohousing community would provide a far more affordable option to most residents and foster a healthy built environment for all those who called it home.

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Appendices

Appendix A - Project Proposal

Cohousing Development

Project Proposal

September 28, 2021

Belfast Cohousing and Ecovillage

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Advisor: Suzanne LePage

Design Statement

Site design is constrained by three main factors: the land, the law, and cost. This cohousing capstone design project will be no exception, and all three constraints will significantly influence the progression of design iterations.

During the stage of site selection, broad land constraints, like slope and forestation, will dictate which parcel of land is chosen for the proposed development. Additionally, the zoning districts in which the potential parcels reside will be referenced to determine if the allowable uses are somewhat in alignment with the envisioned cohousing community. Relative location of the property, acreage, and price will also all be considered in the selection of the parcel.

Once a parcel is selected, the three main constraints will be considered much more extensively as the project moves into the design phase. Real topographic data for the site will be pulled from an online data bank to begin the process of regrading and setting up a stormwater management system. NOAA rainfall data and U.S. Soil Survey information will also be referenced to assess site buildability and determine the optimal layout locations of drives, structures, and walkways. In addition to natural land constraints, relation to existing roadways and utilities will also be considered in an effort to maximize site efficiency and make use of established infrastructure.

In regards to legal constraints, zoning ordinances and allowable uses will be referenced in depth during the design stage to determine structure size, numbers, and location on the site. Local building codes will also place constraints on the development so those will be consulted before a final design alternative is selected. Since cohousing developments typically require variances to be constructed, allowable uses will not be followed entirely during design, but will be referenced throughout and used as guidelines.

In all stages of design, and following the design completion, cost will be considered for every major decision. While a complete cost estimate of the project will not be completed until the design is finished, rough estimates of alternative design features will be executed throughout to assess feasibility and keep the project budget on track. Ultimately, the entire project cost needs to be able to be covered through rent and mortgage payments from the future cohousing residents, so if the project seems to be veering away from a tentative target cost, the scope will be dialed back. Once a complete cost estimate is completed at the end of the project, various payment alternatives for future residents will be considered to determine optimal variations of full time residents and temporary lessees.

In addition to the three main constraints of site design, cohousing design involves a fourth which is the wants and needs of future residents. Since this project is conceptual in nature, there are no definitive future residents to consult. However, in place of this group, the CE 3070 class will provide input on their envisioned layout and community features, which will influence the design process throughout. Beyond just this class, friends and others interested in becoming residents of a cohousing community in the future will be referenced for additional opinions and guidance during the project.

Mission Statement:

The goal of this Major Qualifying Project (here on referred to as MQP) is to both physically and logistically design a cohousing development on an existing undeveloped parcel of land. The project will consist of four main components:

- a constraints analysis of the site (including physical and legal inhibitors of development),
- a two-dimensional site plan developed using Autodesk Civil 3D,
- a three-dimensional model of the structures on site developed using Autodesk Revit or SketchUp,
- a study of potential financing options for cohousing residents given a rough cost estimate of the sitework and structures.

The constraints put on the project will come from real topographic land data as well as zoning bylaws and other land-use regulations that pertain to the district the parcel of land exists in. During all stages of the project, existing cohousing and communal living developments (both in and outside of the United States) will be referenced for the purpose of idea generation and feasibility.

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Background

What is Cohousing

Cohousing, as defined by the Cohousing Association of America, is a type of intentional, collaborative housing in which residents actively participate in the design and operation of their neighborhood [1]. The concept took its beginnings in Denmark in the 1960s under the design leadership of architect Jan Gudmand Hoyer who established over forty cohousing developments during his career. Following Hoyer's first set of housing communities, two American architects, Kathryn McCamant and Charles Durrett, promoted the concept in the United States and today there are more than 160 cohousing developments in the country [2].

While the word "cohousing" may trigger thoughts of condominiums to some, and to others the visual of the ancient village commune, cohousing is actually an all encompassing term that describes the spectrum of communal living. Cohousing practices can be as simple as sharing lawn-care tools with neighbors or as involved as cooking group meals seven days a week and sharing all common spaces outside of the bedroom [2]. Although there are a plethora of reasons individuals might seek out cohousing as their lifestyle of choice, some of the most readily accepted benefits are affordability, decrease in physical and carbon footprint, and increase in sense of belonging.

Existing under the umbrella term "cohousing," are many different types of communities that live together such as multigenerational, senior, urban, and rural groups. Additionally, there are mission-oriented communities that are invested in a specific cause beyond their shared values and work as a team to carry out activities like environmental restoration, homesteading, and community service [3]. Regardless of the type, arrangement, and cause, the key shared attribute of cohousing is that it is intentional living where the residents of the community support one another and are actively involved in the progression and future of the development.

When establishing a new cohousing development there are many preliminary decisions that need to be addressed. While the physical layout of the site and living structures is important, this step is often prefaced by deciding on the financial and social structure of the community that will ultimately dictate how the houses are organized. Some communities, like the Belfast Cohousing & Ecovillage (BCE) in Downeast Maine, are developed by a private contractor and architect and then sold or leased to residents who earn membership status simply by living in the houses. This financial and mortgage arrangement follows essentially the same logic as a condominium complex where the shared spaces are built into the price of the home or the monthly rental fee. The community is further governed internally by a set of bylaws that are democratically decided upon by both permanent owners and temporary lessees [4]. Other cohousing developments are built and established by individuals who jointly share a mortgage and cover other expenses through arrangements outlined in community charters. Beyond these two main types, are hybrid communities that are built and established by members who live on the property, but are designed to accommodate a capacity larger than their initial membership size. The Maitreya Mountain Village (located in the mountains of Northern California) for instance, was started in 2008 by a couple as a single home for their family and over the years they added more and more houses with the established precedent that they could be purchased, leased, or rented for short periods of time. Since then they have taken in many full-time residents who share a community center and bath-house, but also many temporary guests who book nights or weeks on their property via AirBnB [5]. This organization structure allows for secure growth of the community and is a safer plan for individuals looking to establish their own cohousing development. Whether it be the first, second, or third option, deciding on the financial structure of the community is an integral early step in cohousing that will inevitably influence physical design.

Physical Site Constraints

Once an organizational and financial arrangement has been decided upon by either the developer or the group of future residents, the next major step is to select the parcel of land that the cohousing development is to be built on. Aviara Real Estate lists the three most significant factors to consider when buying land as location, natural hazards, and utility sources [6]. Location pertains to future land valuation and any other personal preferences of the potential residents, while natural hazards and utility sources pertain to site buildability.

Some of the most notable natural constraints to consider are soil composition, slope, obstructions (large rocks, trees etc…), wetlands, fire zones, and conservation land. Soil composition has a number of implications on the buildability of the site, but most significant is the cost of structure foundations and the longevity of the homes built on the land. Soil that is rich in clay and silt for instance absorbs water easily and can cause foundations to crack and heave as it expands [7]. Houses that are built on unstable soils of uniform particle size are also at risk, as faster erosion rates can quickly undermine a structure and render it unsafe [7]. In respect to sites with steep slopes, there are the obvious inhibiting factors such as the difficulty of building a level structure and driveways on the side of a hill, but there are also more subtle concerns such as increased stormwater runoff. Constructing a house, or houses, on a steep slope (usually defined as 20%+) is not only more difficult, but also more expensive as there is more excavation to be done and depending the location, blasting may be required [8]. Physical obstructions like large boulders bring about similar cost impacts as their removal or relocation is labor intensive and often mandates heavy machinery. In regards to wetlands and conservation land, there may be portions of the site that are simply unbuildable by law for both preservation and logistical reasons. Building a foundation in a swamp would cause great harm to the existing ecosystem and is undesirable to begin with because the foundation would be unstable and prone to flooding. While not currently regulated with land statutes like wetlands and conservation land, properties within frequent fire zones are problematic for apparent reasons and also bring about their own cost implications. While the price to build in these areas is likely not impacted by the fires, home insurance rates certainly are and any residents living in these zones can expect to pay premiums well beyond what it would cost to insure a home in a low-risk area [9].

In addition to natural factors, utility constraints also play a significant role in deciding on a parcel of land. Most notably, sewer, electric, and roadways are important utilities to consider, both for site selection and site design purposes. Although most sites have at least one edge of the property line adjacent to a roadway, connecting that roadway to the portion of the site that is buildable can become expensive if the distance is far and there are obstacles in the way. Other sites do not border an existing roadway altogether and require an easement on another piece of property to access the site at all. Such sites would incur significant costs to establish a drive all the way to the proposed structures and are less desirable for this reason. Another key utility component to consider is electricity. The three main options are to tie into the existing power grid and utilize the public supply from the given state, erect a wind or solar system on the site and still tie into the grid for supplementary support or sell back purposes, or erect an off-the-grid wind or solar system and bypass the need to tie into the public electric supply [10]. If an off-the-grid system is preferred then site location relative to existing power lines may not be an existing factor, however if individuals wish to still have access to the public electric grid then location becomes a very important consideration. Similarly to electric, site relation to an existing sewer main is significant in terms of cost and site design. Any new structures need to have a plan to properly dispose of sewage and if there is a nearby main, the structures can be connected to it via a pipe called a lateral [11]. The further the buildable portion of the site is from the sewer main, the higher the cost. In some situations, the sewer main is so far away that it makes more sense to construct a leach field on site where sewage will naturally dissipate into the soil via an underground trench system [11]. All of these utilities, in addition to others like gas, water, and internet are all important factors that influence the favorability of a parcel of land.

Legal Site Constraints

Zoning is a land-use management process that divides a municipality's land into districts with the broadest groups being residential, commercial, and industrial. Some typical regulations included in zoning ordinances include maximum dwelling densities, maximum structure heights, minimum dwelling setbacks, and signage restrictions [12]. While zoning ordinances are designed to assist a city or town in its path towards goals outlined in its master plan, they are not set in stone and can be amended through various processes or bypassed in special cases. Almost all zoning ordinances have systems in place where residents or businesses can apply for exceptions to the rules and these granted exceptions are known as variances [12].

Cohousing communities typically require variances or the creation of new zoning districts to come to fruition as they often come into conflict with density maximums and setback requirements. Additionally, common houses (a staple in most cohousing developments) are rarely included as an allowable use so new definitions need to be created for those as well [13].

Another potential avenue for cohousing creation is specifying the community as a subdivision. Subdivisions are parcels of land purchased by developers that are divided into smaller lots (typically neighborhoods) and sold off to residents either as land or properties with houses on them. In some instances, if there are more relaxed subdivision regulations, communities can share resources and possibly common spaces which condominium complexes frequently allow. However, in most cases, subdivision regulations are too stringent to allow for cohousing given rules about sidewalks, separate utility systems, and spaced housing which directly conflict with many of the benefits of communal living [13].

Overall, zoning does not tend to accommodate groups of unrelated individuals sharing spaces or living structures. Beyond just the number of "units" on a parcel being constrained, zoning regulations also cap the number of occupants residing in a unit that are unrelated or not sharing finances. Many zoning ordinances use language like "single-family" to describe the types of groups they allow to live in certain zoning districts which provides roadblocks to individuals seeking cohousing and other intentional living situations. While some communal living developments in the U.S. were able to be grandfathered in, most new intentional living communities need to work with their local zoning boards to reach a compromise on what is and is not permitted.

General Site Design

Site design describes the entire process of development on a piece of land, from selecting the parcel to stamping the final 100% Construction Documents. Larger projects typically involve landscape architects, civil engineers, and general contractors, while smaller ones have the possibility to be completed absent one or more of these entities. Regardless of the scale of the design, consistent coordination with the town or city where the site resides is necessary to ensure the project meets codes, zoning, and other legal regulations. Projects adapt along the way as new roadblocks make themselves apparent, which is why the process of designing and building is so extensive and thorough.

The first step in site design is a feasibility study. During these studies, future owners can determine—or work with others to determine—if their project vision is viable and roughly within the budget they are hoping to maintain. Civil engineers are often involved in this process as they can foresee significant cost items in the design that the owner may not have anticipated before. This is also the stage where the project team assesses the various types of permitting that will be required to develop and build on a piece of land [14].

Assuming that the project seems feasible, the team moves into the conceptual design stage, where a rough layout of the site plan is established. This step often entails potential structure outlines, parking and drive location, and general plans for larger utilities. With many other design factors ultimately coming into play, it is important to keep the conceptual design broad so that it can be adjusted slightly as the project moves forward. The main goal of this step is to allow the team to visualize what the site could look like upon completion. At the commencement of the conceptual design phase, plans are typically sent to the local governing body to identify and address any legal concerns before the design is progressed further [14].

Following conceptual design, is the schematic design stage. At this point the team has an idea of what they want the site to look like, and have to dive into site constraints to make adjustments and modifications. During the schematic design portion, natural constraints like subsurface conditions, wetlands, and large existing objects are considered for their impact to the conceptual design. Additionally, zoning and permitting are dove into more thoroughly to assess environmental impact and additional strain on existing infrastructure. Considerations like the change in pervious surfaces and stormwater runoff are inspected during this stage to ensure the new site is in compliance with local standards.

Once a more in-depth understanding of project challenges and solutions is established and a preliminary review and approval from the local governing body has occurred, the project moves into design development where grading, drainage, erosion and sediment control, demolition (which can include tree and rock removal), and utility design are progressed further to prepare for construction. Grading and drainage, specifically, go hand in hand because they both pertain to stormwater management and together keep surface flow rates to a reasonable degree. Erosion and sediment control keeps the site particulate runoff to a minimum while construction is underway (since stormwater systems may not fully be in place yet) and demolition occurs before structures and roadways are built. Design development is usually one of the longer stages of site design because plans are bounced back and forth between engineers and contractors. While designs might look good on paper, this is really the point where the people who will end up managing the construction, scrutinize the plans and determine buildability [14].

After design development concludes, the final stage of site design begins which is the construction document phase. At this point, only small tweaks are made to the overall design, and more efforts are focused on compiling details and specifications for all of the systems that were designed earlier. Pipe sizes, roadway materials, and electrical conduits are all outlined by engineers and once the construction documents are completed for bid, subcontractors will submit their materials to the engineers for review. Site design is ostensibly over at this stage and construction is all that is left to follow.

Site Design Software Applications

Understanding the stages of design is important to anyone looking to develop on a piece of land, but putting the concept into practice requires a bit more knowledge and the assistance of multiple software packages.

Before doing any design work at all, it is imperative to know what exists on a site in regards to elevations, natural features, and any land that is under environmental protection or within a buffer zone. Mapping a site can be done two different ways: through a formal site survey and via existing online GIS (geographic information system) data. The former is almost always completed for medium to large projects while the latter may be sufficient for smaller jobs and feasibility studies [15].

For most parcels of land in the United States, GIS data is available in online banks to be downloaded and used within ArcGIS, which is a mapping program frequently utilized by engineers. In addition to showing property lines, roadways, and town boundaries, ArcGIS allows users to bring in elevation and soil data, which can be grouped by slope and type respectively and then displayed in color-coordinated units. Beyond this, layers like wetlands and endangered species habitats can be pulled into a map to show areas of a site that may not be developable. Layers in ArcGIS can be expressed as points, lines, polygons, or surfaces depending on the data source that is being pulled from. Once all desired layers are pulled into an ArcGIS map for the parcel of interest, buffers can be added manually and watershed delineations can be conducted to develop a more complete picture of the existing site conditions [16].

Once a preliminary understanding of a site is gathered through ArcGIS, a more robust design application is required to begin drafting plans. Autodesk Civil 3D is by far the most utilized computer drafting program in the United States by site designers given the multitude of features it includes [17]. What differentiates Civil 3D from AutoCAD is its ability to map surfaces and structures in three dimensions which helps in determining buildability and in visualizing design more easily. In AutoCAD, a pipe is merely a polyline drawn on a flat surface, but in Civil 3D it is a tangible structure with inverts, a slope, and a diameter. One three-dimensional feature that is of particular interest when beginning a site design is the ability to pull in elevation points from an online data source (like GIS) and then tie the points together into a complex surface that emulates the parcel of interest. Through site design and grading, these points and elevations can be changed with the creation of new point elevations (called COGO points) or feature lines (think topographic maps). Following the establishment of a surface in Civil 3D, design work is often done from an aerial view of a two-dimensional site, although any points within the surface still have a real-world elevation and set of coordinates. Civil 3D is typically used for the majority of site design and takes a project all of the way to final construction documents.

Two other software applications that can be used throughout the site design process are Autodesk Revit and SketchUp. Compared to Civil 3D which is best tailored for horizontal design, Revit and SketchUp are primarily suited for vertical design and the modeling of structures that will populate a site. While SketchUp and Revit can theoretically be used for the same functions, the AEC (architecture, engineering and construction) industry tends to lean towards Revit for detailed architectural design and towards SketchUp for large-scale urban planning and preliminary conceptual designs [17]. Many users find SketchUp to be more intuitive and it is quicker to turn an idea into a model within the program, but in terms of drafting buildable structure plans that others will be able to follow, Revit is often the industry standard. Civil 3D has the ability to communicate with both SketchUp and Revit, but considering Revit and Civil 3D are both Autodesk applications, the link between the two is much more seamless. Fortunately for site designers looking to turn their site plans into conceptual models, SketchUp is now equipped to import a Civil 3D surface into a modeling space where building footprints can be turned into actual structures [17].

Cohousing Design

Compared to less intentional developments, cohousing design is a more involved process and often requires the inclusion of unique site features. The first main difference in the design process is in the planning of the community. While typical neighborhoods are often spearheaded by a developer driven design process, cohousing communities usually begin design through workshops with future residents and cohousing design professionals [18]. This process ensures that the design is representative of what the community wants and is inclusive for all of the residents. Rather than adjusting plans later when a new resident with special needs joins the community, the preparatory planning workshops help future residents foresee accommodations that might be needed and include them in the design from the beginning.

Beyond the process itself, there are a number of key design features that are indicative of cohousing communities and promote social interaction and ease of living. Three of the most significant components of design are the common house, pedestrian pathways and activity nodes, and shared outdoor spaces [18].

When determining the location of the common house, some factors to consider are accessibility from each dwelling, relation to the outdoor common area, and easy indoor and outdoor circulation. As is true with any public space, the main goal is to design an area that is not too tight that it is cramped and uninviting, but not too large that people are spread out and unable to interact comfortably. Many cohousing design teams will begin design with the placement of the common house and build out the dwellings and paths from there [18].

The pedestrian pathways portion of the design is the aspect that ties the entire community together. Where typical suburban neighborhoods have roadways, cohousing developments frequently have narrow walkways that go from dwelling to dwelling and from dwellings to the common house. The Cohousing Association of America recommends that these pathways be just around 4 feet if intended only for pedestrians and 10 feet wide if there is need for emergency vehicular access. Additionally, as they span the courtyard between the dwellings, this distance should be anywhere from 30 to 50 feet so that residents can communicate comfortably from porch to porch, while not feeling like their personal space is being impeded upon. When these pathways are combined with open front porches, they create a permeable membrane where people can circulate into conversations while on their way somewhere and easily exit because it is not a secluded space. Promoting interaction and connection are key in cohousing design and the organization of the site pathways plays a key role in this process.

The third main design feature of cohousing is the shared outdoor spaces. These spaces can take the form of a green open space, a patio, an outdoor dining or cooking area, and many other possibilities. Some important factors to consider when designing shared outdoor spaces are the climate, the needs/wants of the community, and the amount of area available. Large open spaces tend well to active communities where recreational games can be played, where smaller spaces tend to more stationary groups. If the community is looking to internally source some or all of their food, then the shared spaces may be devoted to farming and gardening. If the community is interested in sharing all meals and cooking together, then having an outdoor kitchen may make a lot of sense for that group. The paramount component of these design features is to assess how much space is available, learn what the group would like to see developed, and then work to coordinate the spaces within the given area.

On the whole, the mission of cohousing design is to create an intentional environment that lends itself to the people who are living in the development. The ever-ambiguous boundary between what is personal space, what is public space, and what is both will be sculpted by future residents during the design coordination and once the community is established. Integral to the entire process is ensuring that residents feel included and connected to both their cohousing community and to the larger community beyond [18]. An excellent cohousing design does not siphon off the group from other neighborhoods, but instead provides its own permeable membrane where members can stay or go as they please and feel comfortable doing both.

Methods

This cohousing design MQP will include the following progression of deliverables:

- Project Proposal (completion 9/27/21)
- Presentation and Workshop with CE 3070 Class (completion 10/8/21)
- Civil 3D Site Layout Alternatives (completion 11/26/21)
- Civil 3D Schematic Site Plan (completion 12/17/21)
- SketchUp Cohousing Model (completion 2/8/22)
- Cohousing Financial Model (completion 2/15/22)
- Project Report (completion 3/8/22)
- Final Project Presentation (completion 3/11/22)

Project Scheduling and Tracking

With many different components of the MQP occurring simultaneously, it will be essential to have a more detailed project progression timeline than just the deliverables themselves. Given the weekly MQP meetings already scheduled, a GANTT chart (Figure 1) was made with self-imposed progress check-points that need to be completed by each Tuesday meeting. While these deadlines are not definitive, the rough project outline will help ensure that I am continuously tracking to finish on time. Weekly meeting agendas will contain items completed in the previous week as well as items that are set to be completed in the following week. Items that require more time than is outlined in the GANTT chart will be made note of specifically so that future progress tracking can be adjusted.

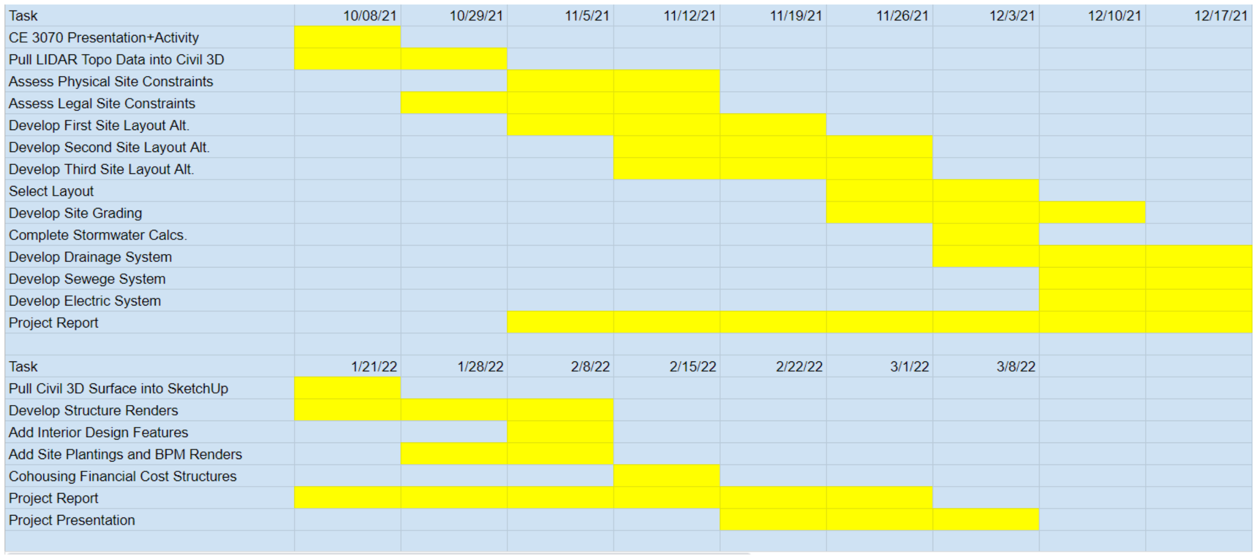

Figure 1: GANTT Chart Project Schedule

Site Selection

In order to develop a feasible site plan, a real parcel of land that is for sale will be selected and used for site design and modeling. This parcel of land will likely be somewhere between 3 and 20 acres in size and be located in Bozeman, Montana proper or in a surrounding community. Online real-estate search engines such as High West Realty, Zillow, and Bozeman Real Estate will be used for the preliminary land search and zoning and other site-specific considerations will help determine the final selections. Since most cohousing developments require zoning variances or the creation of a new zoning district entirely, it is unlikely that the existing zoning ordinances will allow for the concept site design that is being proposed. Given this expectation, parcels with zoning allowances that are reasonably accommodating (but not entirely) of cohousing will still be considered for final selection. Communication with various developers and realtors in the Bozeman area will assist with gaining access to subdivision covenants, bylaws, and any other building regulations.

Presentation and Workshop with CE 3070 Class

Once a parcel of land has been selected and the project proposal is completed, a presentation and workshop will be assembled and delivered to the CE 3070 class. This presentation will consist of a background on cohousing, a brief overview of site design and zoning ordinances, and a site-specific portion that goes over various possibilities for development on the parcel of land in Bozeman. The presentation will essentially be an overview of the research completed through the first 5-6 weeks of the term and help streamline the project moving forward.

Following the presentation, there will be a workshop discussion consisting of two main components. The first portion will be a class-wide discussion about the benefits and drawbacks of cohousing. This will be a time for people to express concerns or affirmations about the concept in general and will hopefully consist of dialogue about the social benefits and how it improves community. The second portion will be a more streamlined activity where groups will get a copy of the parcel of land in Bozeman and have the opportunity to lay out a vision for the site assuming there are no zoning regulations involved. The parcel outline will be accompanied by a survey of community design factors that each group can use to inform their concept design. The survey will include options for parameters such as number of residents and number of structures, as well as other questions about communal spaces and how they would separate public and private domains. After going over several of the designs and getting a consensus for commonalities in desired cohousing features, the designs and surveys will be collected to inform the later development of the MQP. At the end of the activity, there will be a period open for questions and comments on the project.

Existing Conditions Assessment and Civil 3D Base File

Before beginning any actual design work, the parcel of choice will be assessed to determine physical constraints. This process will begin by pulling soil data and slope data for the site from online GIS banks. If the site resides on/near a wetland or is fully/partially forested, then the data will be pulled into ArcGIS to determine wetland buffers and preferred building zones, but if not there will be no significant reason to use ArcGIS. The Montana State Library on the state website has full libraries of slope, forestry, and wetland GIS data and the USDA Web Soil Survey website has soil information for all registered land parcels in the United States. Once the buildable portion of the site has been determined, the process of setting up the CAD file will begin.

For this step, LIDAR topographic data will be pulled from the Montana State Library, as well as parcel boundaries that include the site of choice. This topographic data will then be downloaded as a shapefile of point data and imported into Civil 3D. Once in Civil 3D, the topographic data will be trimmed to the boundary of the site and then turned into a surface. At this point, all points within the site will have a real world coordinate, as well as a z-elevation. The geolocation feature in Civil 3D (which overlays aerial map imagery on the imported linework) will be used to identify any existing above-grade constraints like large rocks and trees. Next, basic building development rules from zoning, subdivision, and building bylaws will be referenced to add in some preliminary working lines into the CAD file. These lines will outline setbacks and any other major development boundaries that need to be followed. Once these are added to the drawing, the parcel is ready for some preliminary concept designs.

Site Concept Alternatives

The first stage of design work will involve some experimentation with various site layouts and structure footprints. Many of the first iterations will be done on paper to allow for faster design progression and ease of reworking to the more optimal layouts. This will be the time where community size and density are narrowed down to a more specific range that suits the site and cohousing vision. In place of typical cohousing design workshops, the preferences of students from the CE 3070 activity will be taken into consideration, as well those from friends who are interested in cohousing.

Once a select handful of designs are decided upon, the drafting will move to Civil 3D, where two-dimensional linework will outline drives, pedestrian ways, and building footprints. During this stage of design, building standards will be looked into more closely to ensure that the site features are in alignment with current policies. Drives, for instance, will need to be able to accommodate a fire truck entry and exit while walkways will need to maintain an accessible width. Careful attention to detail will be taken when drafting the site layout, as additional design elements like stormwater management, utilities, and grading will need to be built around it.

Schematic Design

Following the completion of a few site layout concepts, one will be selected to move to the schematic design stage. At this point, stormwater calculations will be done to determine the change in site permeability after the addition of proposed impervious surfaces. It is anticipated that all stormwater will be able to be treated on site with BMPs (best management practices) such as bioretention basins, rain gardens, and swales, but it may be necessary to pull municipal drainage system locations if there comes a need to tie into an existing catch basin or culvert. Once stormwater volume is calculated for various storm intensities, decisions on BMPs will be made to offset the increased runoff caused by the addition of walkways, roofs, and drives. Additionally, the existing site elevations will be assessed to determine where stormwater flows naturally over the property and where there are low points that may lead to ponding. Site cover, as well as soil type, will help inform the amount of runoff and assist in the design of drainage.

As stormwater BMPs are considered, grading will be developed to create new drainage paths and potentially new sub-basins on the site. Grading will optimally be designed to avoid large amounts of fill needing to be brought in to account for new raised areas. Ideally, soil will be cut from areas of the site with higher elevations and filled in areas with lower elevations to create a somewhat level space for the housing development. Civil 3D feature lines will be used to draw new contours for open spaces and COGO point spot grades will be used for corners of structures and any other significant elevation points. Likely, only a portion of the site will need to be regraded and the proposed surface will tie into the existing contours at its edges.

Another factor to consider when grading will be the addition of utilities. Depending on the size of the community, it may not be an option to tie into the existing sewer main (assuming there is one running along the adjacent roadway), so an on-site leach field may have to be designed. With the addition of this site feature, it will need to be ensured that all sewage pipes that connect the structures to the leach field are a sufficient amount below grade. Similarly, if electric ducts are to tie into the public grid, then grading will need to account for these cable runs. Even with solar solutions implemented on site, unless the goal is to be entirely off grid, it will still likely make sense to be able to pull electricity on lower light ways (think winter) and sell electricity back to the state on higher light days.

To conclude, the schematic design will involve the addition of stormwater management features, sewage systems, electricity solutions, and proposed site grading. Some of these additions may require the site layout to be revised slightly, but that is the point of undergoing design progression. Once the site plans are sufficiently settled, the project will be ready to move into the modeling phase.

SketchUp Model

The first step of turning the site layout design into a model will involve transitioning the proposed surface from Civil 3D into SketchUp. This process entails isolating the surface (typically in a new CAD file) and then triangulating it so that it can be imported. Once all of the connected triangle plains are in SketchUp, the surface will be smoothed with a brushing tool to emulate a more realistic landscape.

Next, the layout linework, including driveways, pedestrian ways, and building footprints will be overlaid on the surface so that structures can be built up in the correct location. The major portion of the modeling stage will involve designing concepts for the various structures on the site as the roadway and drives will not require too much additional work. Structures will not be developed to a standard that could be built from (i.e. including structural components such as wall studs), but will be sufficiently detailed so that viewers can look at renders and have a clear idea of what the interior and exterior would look like. The models of the common house and individual living quarters will include rudimentary interior design elements such as furniture pulled from online block banks, wall and ceiling paneling, and major furnishings like toilets and sinks.

The final portion of the site modeling phase will be the addition of landscaping and other exterior features. Site plantings, similarly to furniture, will be pulled from online block banks and positioned around the property to improve aesthetics. If the parcel already has existing forested areas or major vegetation, the model will detail those as well. All site elements will be designed to their actual size in SketchUp so there will be no need for a scale. While the model will not include the utility structures and pipes, major stormwater BPMs such as rain gardens, bioretention swales, and green roofs will be loosely rendered to help make the site more realistic. Although the surface will exist as a dimensionless set of planes, significant subgrade components such as continuous and spread footings will be included. The individual living quarters are not anticipated to have basements, but if the common house does, the model will detail it.

Cohousing Cost Structure

Following the completion of all design work, a cost structure for the entire project will be developed. The first component of the cost structure will be the total price of the project. The price of the land will be pulled from the real estate listing where it was selected and the site and structure costs will be estimated based on construction data from RSMeans. Many components of the site such as the driveways and walkways can be estimated using unit material costs and a square foot calculator, but special features such as septic systems and plantings will have to be added in separately. Cost estimates for site structures will begin with a base square footage estimate and then adjusted to account for special materials and green solutions such as solar arrays if they exist. If major excavation work is included in the design, cut and fill cost data will be pulled to account for it. Once all site and structure components have individual estimates, they will all be totalled together to determine a project subtotal. This subtotal will be multiplied by the going contractor fee in the area (typically around 10%) to develop a final total.

The next component of the cost structure will involve the creation of mock payment plans for cohousing residents. Given the design is tailored to a certain number of residents, the total project bill will be split amongst that number of people in several scenarios. One scenario may involve a smaller number of permanent residents paying down a mortgage on the development that is being subsidized by the rent paid by temporary lessees. Another scenario may involve a full capacity of permanent residents splitting a down payment for the project and sharing a mortgage as well. Given these two major possibilities for project payment, multiple iterations will be run to crunch numbers of different mortgage rates and loan durations. This final component of the project will help gauge feasibility and will hopefully demonstrate the affordability of minimalistic cohousing.

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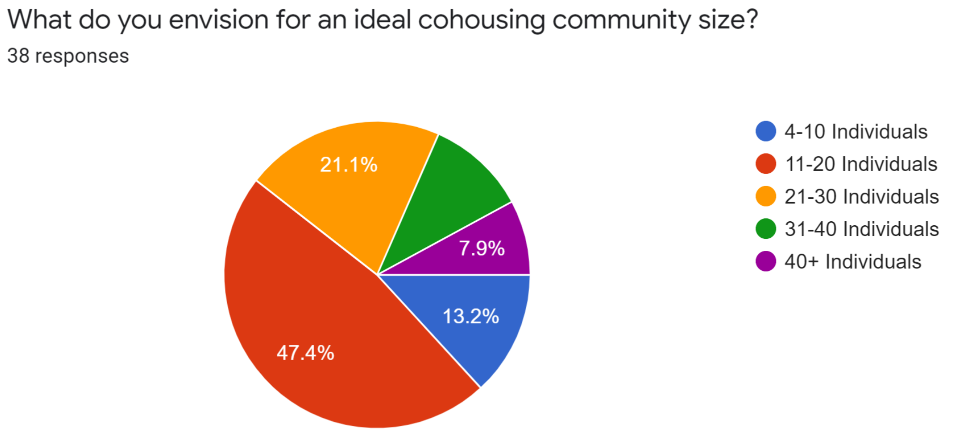
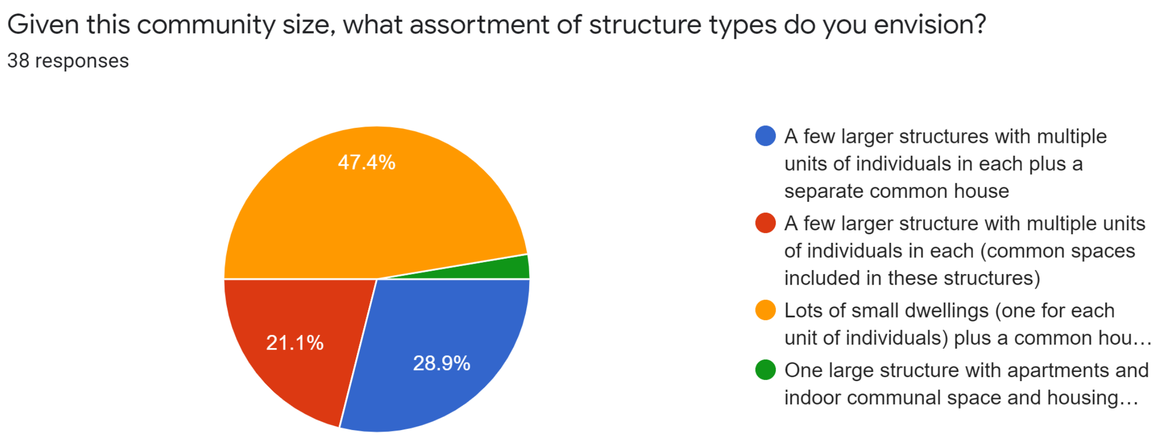
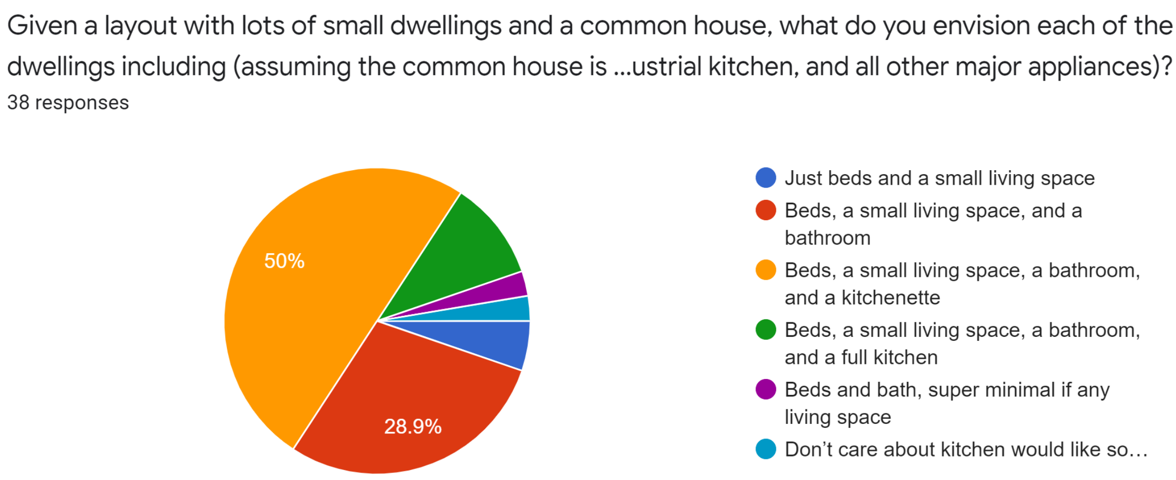
Appendix B - Cohousing Survey Results



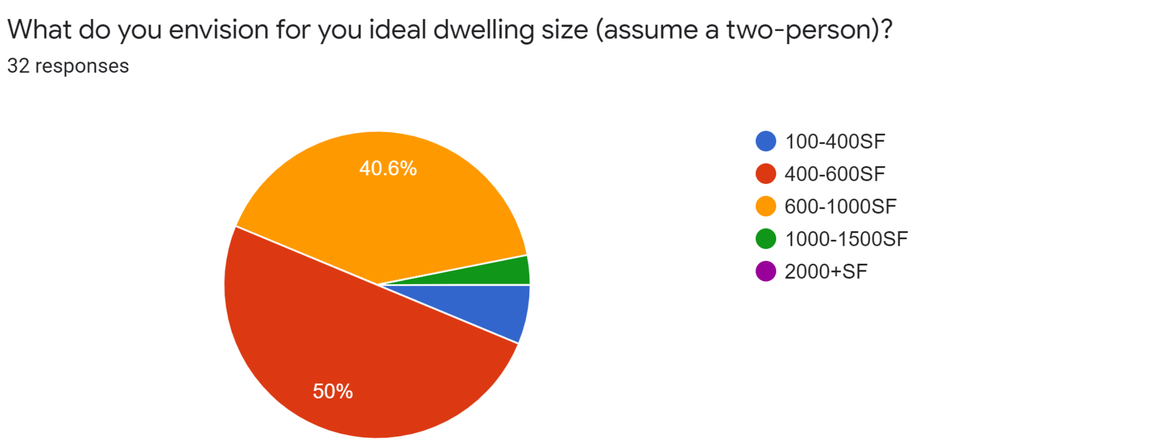
Appendix B-1: Ideal cohousing community size results.



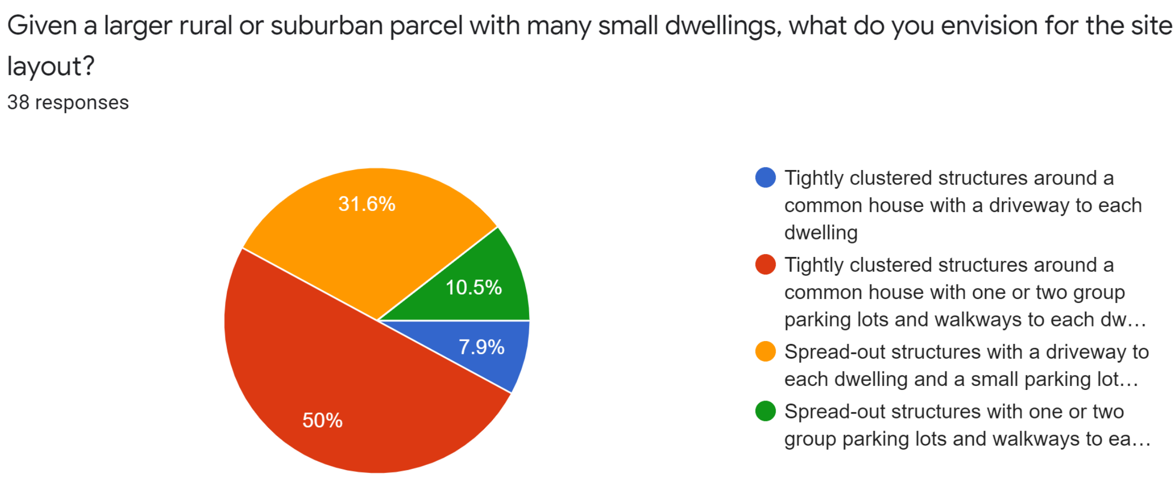
Appendix B-2: Cohousing structure preferences results.



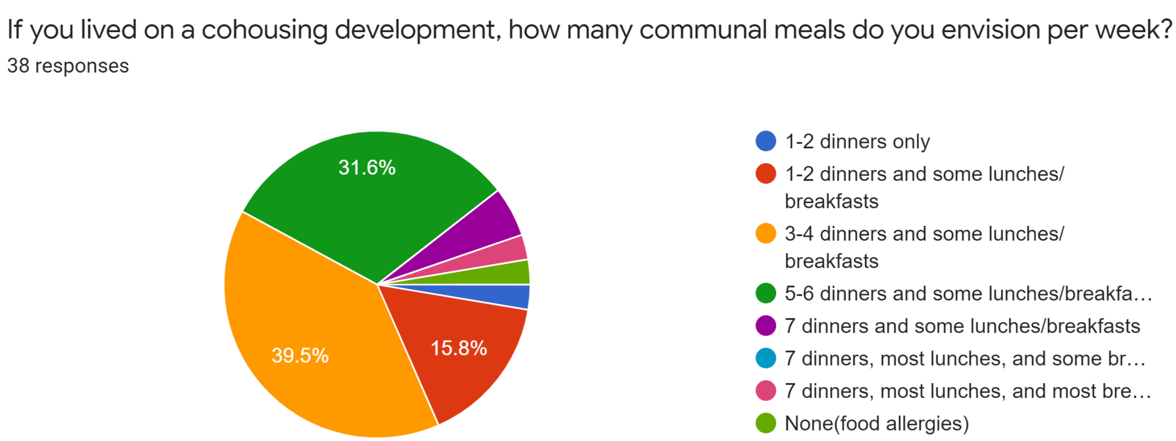
Appendix B-3: Dwelling preferences results.



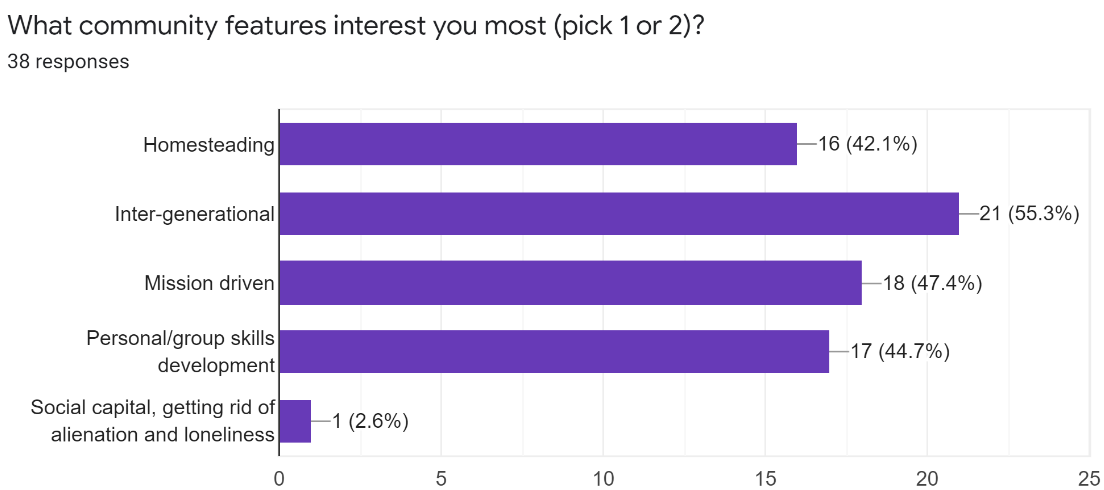
Appendix B-4: Dwelling size preference results.



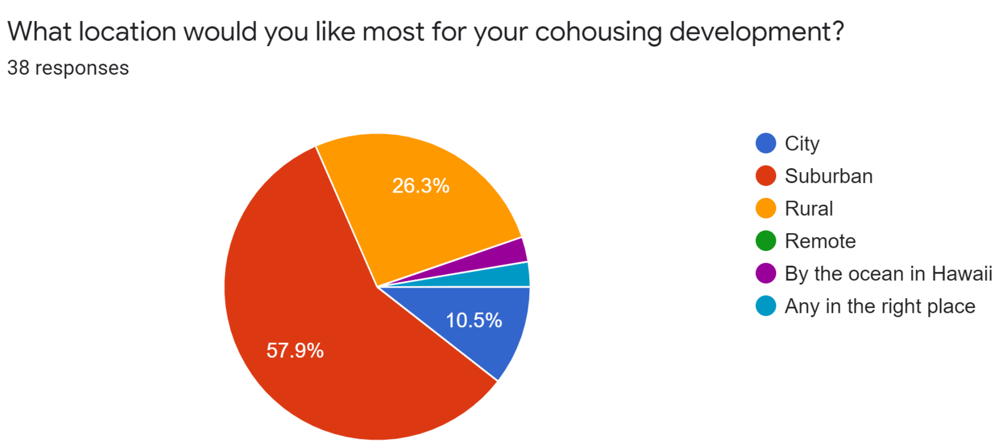
Appendix B-5: Site layout preference results.



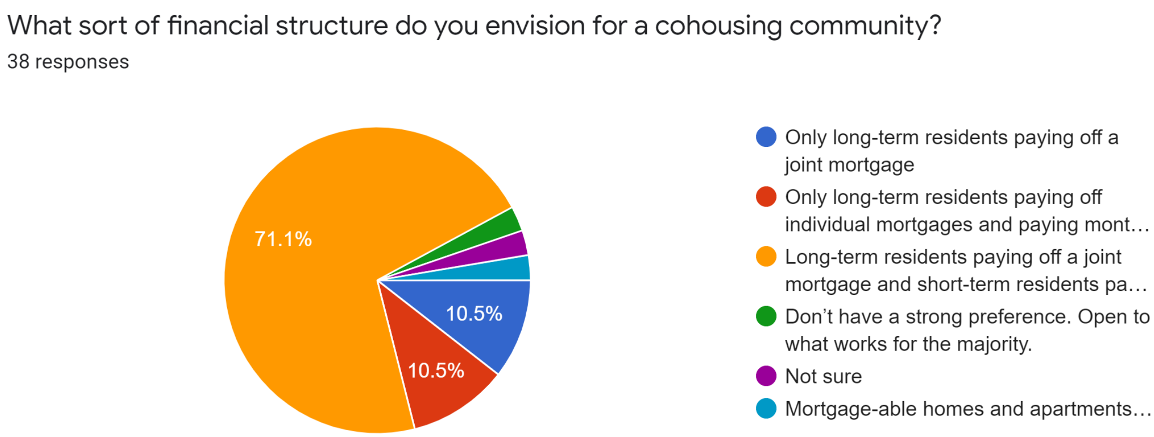
Appendix B-6: Group meal preference results.



Appendix B-7: Community features results.



Appendix B-8: Cohousing location preference results.



Appendix B-9: Cohousing financial structure preference results.

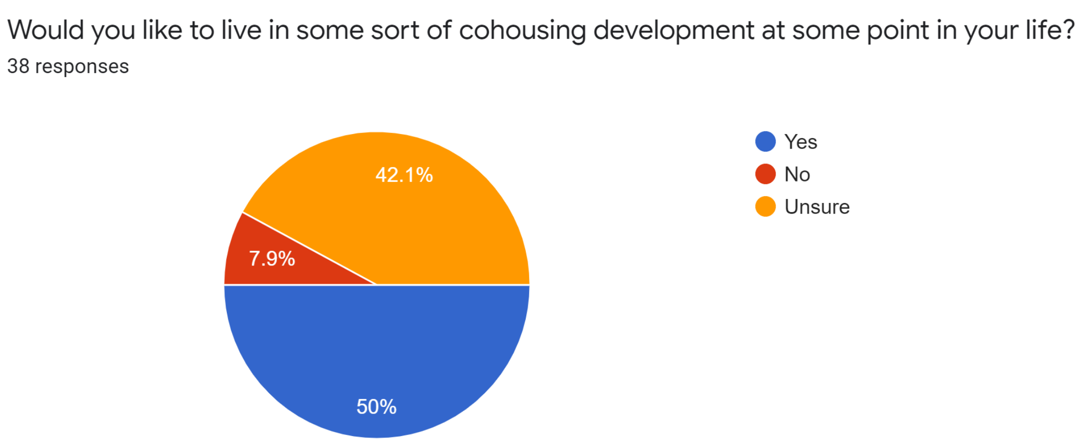


Figure B-10: Cohousing interest results.

Appendix C - Existing Stormwater Runoff Rate Calculations

To begin an area takeoff was conducted for the site in Civil 3D. As can be seen in Appendix C-1, where the green hatch represents pervious surfaces and the blue hatch represents impervious surfaces, virtually the entire site is pervious. Based on the runoff coefficients in the I-1 Table of the Design Standards and Specifications Policy, the weighted runoff coefficient was found to be 0.20. The following formula and calculation obtained that result:

$$[(A_I)(C_I)+(A_P)(C_P)]/A_T=C_W \qquad [(626SF)(0.8)+(112{,}714SF)(0.2)]/113{,}340SF=\mathbf{0.20}$$

Where A_I = impervious area, (C_I) = impervious runoff coefficient, A_P = pervious area, C_P = pervious runoff coefficient, A_T = total site area, and C_W = weighted runoff coefficient.

Next, the time of concentration was calculated. The distance used was that from the southeast corner of the site to the culvert in the southwest corner. The distance between these points was found to be 464 feet and the vertical rise over that distance was found to be 47 feet. This yields a slope of 10.13%. The following formulas and calculations were used to find the time of concentration:

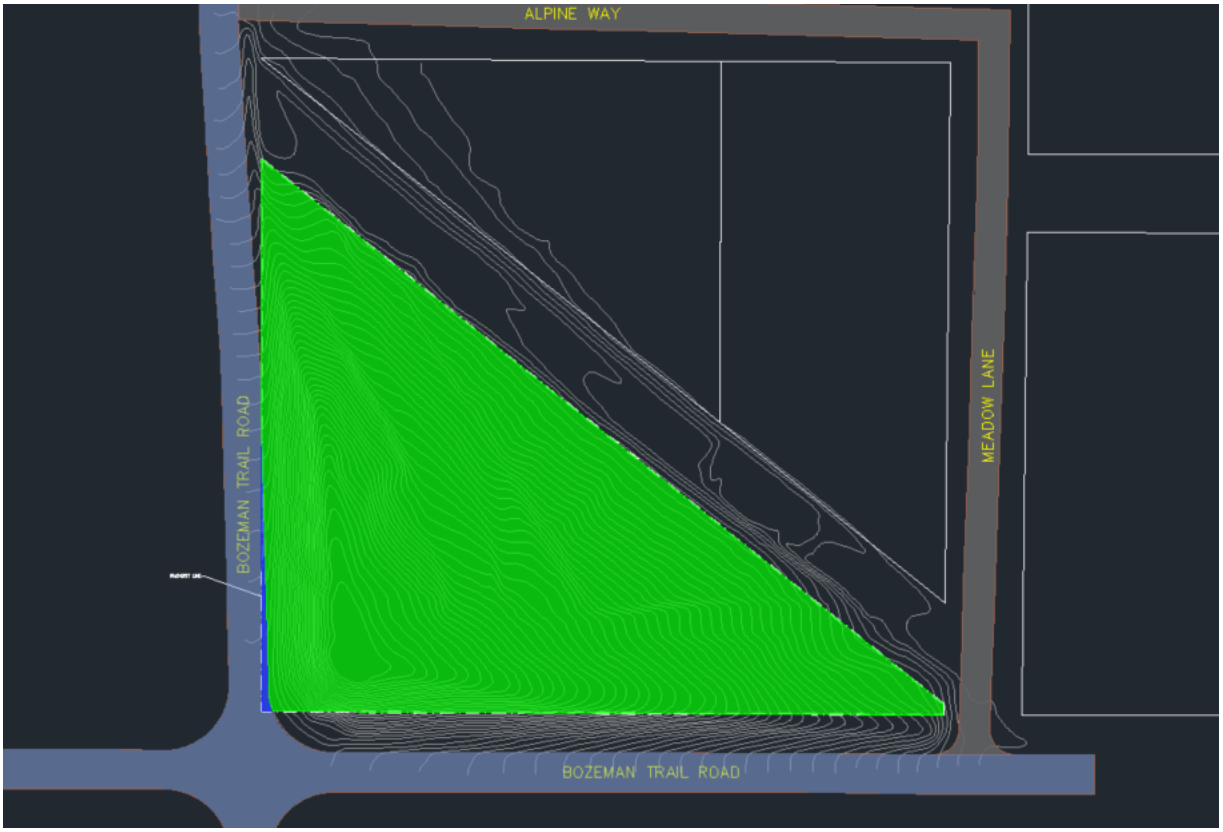
$$T_C=[1.87(1.1-CC_f)D^{1/2}]/S^{1/3} \qquad [1.87(1.1-(0.2)(1.0)464^{1/2}]/10.13^{1/3} = \mathbf{16.76\ min}$$

Where T_C = time of concentration, C = weighted runoff coefficient, C_f = frequency adjustment factor (which was deemed 1.0 from a table in the document), D = length of basin, and S = average slope of basin.

When this time of concentration was matched with a 10-year storm event (which was the prescribed storm event for residential areas in the Design Standards and Specifications Policy) on the Bozeman IDF curve, the rainfall intensity was found to be 1.54 inches per hour. Given the previously calculated values, the peak runoff rate was able to be determined using the following rational method formula:

$$Q=CiA \qquad (0.2)(1.54in/hr)(2.6acres) = \mathbf{0.81\ cfs}$$

Where Q = peak runoff rate, C = weighted runoff coefficient, i = rainfall intensity, and A = site area.



Appendix C-1: Stormwater area takeoff.

Appendix D - Wastewater System Sizing Calculations

The southern leach field was specified for 13 residents with a flow rate of 100 gpd/person. The application rate is 0.8 gpd/SF.

(13 people)(100 gpd/person)/(0.8 gpd/SF) = 1,624 SF

Given the high percolation rate (3-50 mpi), this system area can be divided in half.

1,624 SF/2 = **814 SF**

Trenches can be 24” (or 2’ in width)

The southern system was designed with 4 runs, each 96 feet in length.

(4 runs)(96 ft/run)(2 lateral ft/1 longitudinal ft) = 768 SF

All runs need to be separated by 5’ and connected by a header trench. Given this parameter, the header trench occupied the following area:
[(3 spaces)(5 longitudinal ft/space)+(4 runs)(2 longitudinal ft/run)](2 lateral ft/1 longitudinal ft) = 46 SF

The southern systems total are is:

768 SF+46 SF = **814 SF (100% of the required area)**

The northern leach field was specified for 7 residents with a flow rate of 100 gpd/person. The application rate is 0.8 gpd/SF.

(7 people)(100 gpd/person)/(0.8 gpd/SF) = 892 SF

Given the high percolation rate (3-50 mpi), this system area can be divided in half.

892 SF/2 = **446 SF**

Trenches can be 24” (or 2’ in width)

The northern system was designed with 6 runs, two 27-foot runs, two 32-foot runs, and two 34-foot runs.

[(2 runs)(27 ft/run+(2 runs)(32 ft/run)+(2 runs)(34 ft/run)](2 lateral ft/1 longitudinal ft) = 372 SF

All runs need to be separated by 5' and connected by a header trench. Given this parameter, the header trench occupied the following area:
[(5 spaces)(5 longitudinal ft/space)+(6 runs)(2 longitudinal ft/run)](2 lateral ft/1 longitudinal ft) = 74 SF

The southern systems total are is:

372 SF+74 SF = **446 SF (100% of the required area)**

Given this system needs to support 13 residents, the septic tank needs to be specified accordingly as well.

(5000 gallons/20 person) = 250 gallons/person

(250 gallons/person)(7 people) = 1,750 gallons

(1,750 gallons)(0.1337 gallons/CF) = **434.5 CF**

The tank can not be taller than 78" so is specified under 4' to add buffer.

Given a height of 4' and an intention to make the tank as close to a square as possible, the following dimensions were selected:

10ft * 11 ft * 4 ft = **440 CF (101.2% of the required volume)**

Appendix E - Proposed Stormwater Runoff Rate and Volume Calculations

A new area takeoff was done to determine the percentage of pervious and impervious surfaces. Given the new blue impervious surface covers outlined in Figure 11, the following weighted coefficient was calculated using the formula: $[(A_I)(C_I)+(A_P)(C_P)]/A_T=C_W$ and the c-values from the Bozeman Design Standards and Specifications for Stormwater Management.

[(95,695 SF)(0.8)+(11,655 SF)(0.2)+(11,655 SF)(0.8)]/113,340 SF = **0.293**

Where A_I = impervious area, (C_I) = impervious runoff coefficient, A_P = pervious area, C_P = pervious runoff coefficient, A_T = total site area, and C_W = weighted runoff coefficient.

The same calculations were then done to get weighted coefficients for the three major catchment areas for later use:

Southeast Basin				Central Area				Site Major		
Pervious	11933	0.2		Pervious	17491	0.2		Pervious	66261	0.2
Impervious	3548	0.8		Impervious	6663	0.8		Impervious	1444	0.8
Roof	0	0.8		Roof	2850	0.8		Roof	3150	0.8
Total Area	15481	0.338		Total Area	27004	0.411		Total Area	70855	0.227

With this new weighted c-value, the same storm event, and the same total area, a new peak runoff rate could be calculated using the rational method:

$Q=CiA$ (0.293)(1.54in/hr)(2.6 acres) = **1.17 cfs**

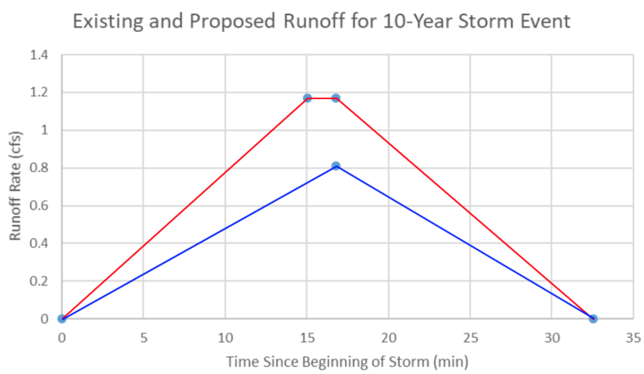
Where Q = peak runoff rate, C = weighted runoff coefficient, i = rainfall intensity, and A = site area.

Next, a new time of concentration was calculated using the new weighted c-value:

$T_C=[1.87(1.1-CC_f)D^{1/2}]/S^{1/3}$ $[1.87(1.1-(0.293)(1.0)464^{1/2}]/10.13^{1/3}$ = **15.04 min**

Where T_C = time of concentration, C = weighted runoff coefficient, C_f = frequency adjustment factor (which was deemed 1.0 from a table in the document), D = length of basin, and S = average slope of basin.

This allowed for the following graph to be created which shows the runoff rates at various time during the 10-year storm event for both proposed and existing conditions:



The total runoff volumes generated were determined via the rational method.

Existing: (33.52 min)(0.81cf/s)(60 sec/1 min)/2 = **814.5 CF**

Proposed: (31.8 min)(1.17cf/s)(60 sec/1 min)/2 + (1.72min)(1.17cf/s)(60 sec/1 min) = **1236.9 CF**
By subtracting the existing volume from the proposed volume, the net volume was found (i.e. the volume that needs to be conveyed by BMPs):

1236.9 CF - 814.5 CF = **422.4 CF**

Finally, stormwater BMP conveyance volumes were calculated, again using the rational method. The two major components were rain barrels and the southeast basin. For the rain barrels:

(6,000 SF of roof)(0.8)(1.54in/hr)(33.52 min)(60 sec/1 min)/(43,560 SF/acre)/2 = **170.6 CF**

For the southeast basin:

(15,481 SF)(0.338)(1.54in/hr)(33.52 min)(60 sec/1 min)(43,450 SF/acre)/2 = **186.0 CF**

Appendix F - Solar System: Assumptions, Calculations, and Sizing

The first major electrical appliances to size were heaters. For the dwellings, space heaters, with an hourly energy consumption of 1.5 kWh, were deemed appropriate. It was assumed that these heaters would be in use 24 hours a day from December-March, 18 hours a day in November, and 12 hours a day in October and April. Thus, their average daily usage is:

(4/12 months)(24 hours/day)+(2/12 months)(12 hours/day)+(1/12 months)(18 hours/day) = **11.5 hours/day**

and their average daily consumption is:

(11.5 hours/day)(1.5 kWh/hour) = **17.25 kWh/day**

For the common house, a much larger heating system was required. According to CNet, 3000-3500 SF houses require a 72,000 BTU heat pump, which can also serve as a hot water heater. Geothermal heat pumps, the selected heating method, put out 400% of the electrical energy they take in as heat energy. Accordingly, the heat needs of the house can be divided by four, when determining electrical energy consumption. Nordic Heating and Cooling suggests that the average Montana home needs 150 kWh of heat energy per square meter of the house per year. Thus, the average required daily heat energy for the common house is:

(3500 SF)(1 m^2/10.89 SF)(150 kWh)(1 year/365 days) = **132.1 kWh/day**

and the average daily electrical consumption from the heat pump is:

(132.1 kWh/day)/4 = **33.0 kWh/day**

Beyond just heat, the heat pump also needs to supply hot water to the residents of the cohousing development. Nordic Heating and Cooling states that the average hot water usage per person per year requires 1412.5 kWh of heat energy power per year. Given this metric, the required electrical consumption of the hot water heat pump on the cohousing development is:

(1412.5 kWh/year/person)(20 people)(1 year/365 days)/4 = **19.3 kWh.day**

The next significant electrical appliances to size and specify were the light fixtures. Quantity and type of light fixtures were determined based off of the required lumens/SF of the dwellings. According to Pooky, a lighting fixture company, bathrooms and kitchens require roughly 75 lumens/SF while bedrooms and other common spaces require 15 lumens/SF. Each dwelling has one 25 SF bathroom, which leaves the rest to common space or bedrooms.

One-person dwellings are, on average, 287.5 SF while two-person and three-person dwellings are 340 SF and 400 SF on average respectively. The common house has two 200 SF bathrooms, one 500 SF kitchen area, and the rest common space. Thus, the required lumens for each structure type are as follows:

Structure Type	Kitchen /Bathroom Area (SF)	Bedroom/ Commonspace Area (SF)	Lumens required for Kitchen /Bathroom Areas	Lumens required for Bedroom /Commonspace Areas	Total Lumens Required
1-Person Dwelling	25	263	1,875	3,938	5,813
2-Person Dwelling	25	315	1,875	4,725	6,600
3-Person Dwelling	25	385	1,875	5,775	7,650
Common House	900	2,600	67,500	39,000	106,500

Given a basic 20-Watt LED light bulb can supply 1,600 lumens, the number of lightbulbs per structure are as follows:

(106,500 lm)/(1,600 lm/bulb) = **67 bulbs for the common house**

(7,650 lm)/(1,600 lm/bulb) = **5 bulbs for the 3-bedroom dwellings**

(6,600 lm)/(1,600 lm/bulb) = **5 bulbs for the 2-bedroom dwellings**

(5,813 lm)/(1,600 lm/bulb) = **4 bulbs for the 1-bedroom dwellings**

As for usage, assuming a lights off period of 12 AM to 6 AM daily, the average number of dark waking hours per day during the year is 6 hours in Bozeman. With some buffer time added in, all lights were assumed to be on 8 hours each day.

Appendix G - Cost Estimate Assumptions

The following are all assumptions that influenced unit prices in the cost estimate:

- The common house was specified as premium grade and priced as furnished to account for the many appliances needed.
- The well connections and ductile iron sewer pipes were not priced separately and were instead included in the price-per-square-foot estimate for the dwellings and common house.
- The retaining wall height was deemed an average of 6 feet with granite blocks specified as the material and the higher end of the price spectrum selected given the 3-foot thickness of the wall.
- The solar panels were specified at 250 Watts each which equates to 2kWh per day if in sunlight for an average of 8 hours.
- The material selected for the driveway was blacktop asphalt and the lower end of the price range per square foot was selected given the large job.
- The material selected for the walkways was polished concrete with the average price-per-square-foot selected based on the medium size job.
- 3,000 and 2,000 gallon septic tanks were used for the cost estimate instead of the specified, 1,750 and 3,250 gallon.
- The mean of the price range was selected per linear foot of the leach field.
- The high end of the price range for well installations was selected given the number of residents it will be supplying water for.