Revitalization of the Riverlands: Trail Design in Sturbridge, MA

A Major Qualifying Project Report:

submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

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Abstract

The goal of this project was to design a trail connecting the Commercial Tourist District in Sturbridge, Massachusetts to the town's existing trails network. Through collaboration with the Trails Committee and data collection during site visits, the team developed a design using ArcMap and Civil3D that aligns with the Town's emphasis on sustainability and environmental impact. The project included considerations for delineations, materials, and steep slopes, as well as cost estimate calculations, stormwater analysis calculations, and stormwater management design.

Executive Summary

The Town of Sturbridge, Massachusetts is interested in expanding their network of recreational trails. The goal of this project was to design a trail system connecting the Sturbridge Commercial Tourist District to the existing local trails network in the Riverlands area to encourage residents and visitors to engage in outdoor recreation in Sturbridge, MA. This will promote tourism and a more active lifestyle among the community and visitors. The objectives to meet this goal were identified as:

1. Identify the problem and Town's vision
2. Evaluate existing conditions, design criteria, and constraints
3. Design multiple options
4. Finalize design and draft maintenance plan

To identify the problem and Town's vision, the team consulted with the Sturbridge Trails committee. The committee prioritized sustainability and environmental impact as the most important factors.

In order to evaluate the existing conditions, GIS files from the Town were combined with GPS data the team collected on site visits. This data was imported into ArcGIS and Civil 3D so the topography could be analyzed. The Town also provided *A Guide to the Trails and Open Spaces of Sturbridge* and *The Sturbridge Recreation Trails Master Plan.* These documents were used to compile the design criteria for the trails in Sturbridge.

The ArcGIS and Civil 3D files were then used to create four potential delineations. These four delineations (Figure 0.1) were evaluated based on environmental conditions, accessibility, and aesthetics. Delineation four was selected and adjusted based on Town feedback.

Figure 0.1: Delineation Options

Using the material design specifications and an estimated trail length, material quantities were calculated. The material quantities were multiplied by material prices in dollars obtained from local suppliers to calculate material costs. Labor and equipment costs were found using the 2009 edition of *RSMeans Heavy Construction Cost Data.* As RSMeans was broken down into specific tasks, a sequence of work was generated for each material option. Then, labor and equipment costs were calculated for each step and totaled. The labor and equipment costs were adjusted using a price index to better reflect today's prices, accounting for inflation.

The recommended material for the trail tread was the Aggregate: ½" stone compacted to 6" with a 2" surfacing of compacted stone dust. Overall, 57,024 ft^3 of ½" stone and 19,008 ft^3 of stone dust are required. Other costs include labor and construction costs. The total cost of construction for this project is roughly $93,800.

Steep slope solutions and stormwater management were also analyzed. It was determined that climbing turns were the best solution for when the slope exceeded an 8% grade, in order to maintain ADA guidelines and have minimal environmental impact. Using regional data, the volume of water that would flow towards the trail was calculated. Swales were designed for different sections of the trail to hold and redirect the water off the trail surface. The cross section for the areas with heavier stormwater flow is shown in Figure 0.2.

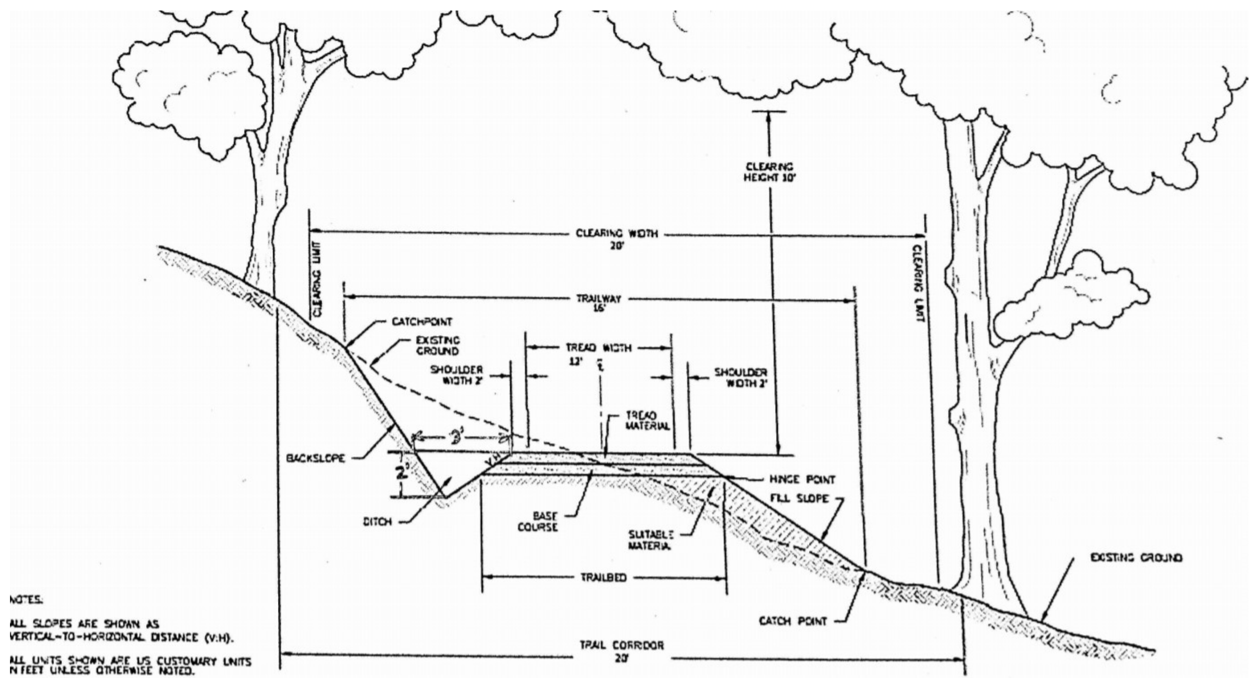

Figure 0.2: Trail Cross Section (Modified from US Department of Agriculture Forest Service)

A maintenance plan, inspection sheets, and technical memo were also developed to present as deliverables to the Town.

Capstone Design

This project resulted in the design of a trail, including the delineation, material cost estimate, trail cross sections, and stormwater management methods. This fulfills the ABET design capstone requirements. The project team followed certain design and method standards for trail design. The design considered the following aspects: environmental, sustainability, economic, constructability, ethical, health & safety, and social & political. Each of these areas were important considerations during the design phase.

Environmental

Protecting the environment in the surrounding area will affect the trail design. The final trail design included a stormwater management system to minimize erosion damage from runoff. Located near a river, flooding was also a design consideration. When considering a design, delineations with lower elevations would need to account for higher flow volumes. Different construction methods and materials were evaluated for their overall environmental impacts in order to minimize effects on the surrounding area.

Sustainability

A detailed maintenance plan was created to ensure the longevity of the trail. Material selection is important for how long the trail will last. It was important to perform a life-cycle cost analysis to show how maintenance costs compare to initial investments. Spending more money at the beginning may result in savings in the future. The trail was also designed to minimize erosion by accounting for trail grades and other factors such as water flow, which increases its long-term sustainability.

Economic

Economic constraints play a major role in all engineering design projects. Until a project is found to be economically feasible it will not move past the design phase. Fulfilling all design criteria is not useful if the project has too large of an overhead. On the other hand, ignoring design criteria for a low-cost project is of little use to the project owner. Performing a life-cycle cost estimate determined the best balance between cost and trail performance. The majority of expenses came from materials, equipment and labor, and maintenance.

Constructability

The project site is located in the woods, so construction methods needed to be considered based on existing access points and existing environmental conditions. To ensure the design could be easily constructed, materials and the required amount of grading were carefully considered.

Ethical

This project followed the American Society of Civil Engineers Code of Ethics. We aimed to provide the best final product for all the parties involved. This project upheld the First Canon of Engineers which states engineers shall "hold paramount the safety, health, and welfare to the public" (National Society of Professional Engineers, 2019).

Health & Safety

To ensure the health and safety of all users this project complied with the *Americans with Disabilities Act*. These regulations were followed closely since the trails are located in the woods and may pose greater danger to the users.

Social & Political

The final project aimed to satisfy the wants of the Sturbridge community. To accomplish this, inputs from various town representatives were used to determine design criteria. The trails were also designed to be accessible to a wide range of people and activities. Incorporating these social and political aspects aimed to improve the overall success of the project.

Professional Licensure Statement

The Professional Engineering license is intended to "protect the public by enforcing standards that restrict practice to qualified individuals who have met specific qualifications in education, work experience, and exams", according to the National Council of Engineers for Engineering and Surveying (NCEES). A license is a standard recognized by employers, clients, and governments as an assurance of skill, quality and dedication.

To ensure the safety and well-being of the public, an individual must do the following in order to become a licensed Professional Engineer (PE).

- Receive a four-year degree from an Accreditation Board for Engineering and Technology (ABET) accredited engineering program
- Pass the Fundamentals of Engineering (FE) exam to become an Engineer in Training (EIT)
- Complete four years of progressive engineering experience under the direction of a PE
- Pass the Principles and Practices of Engineering (PE) exam

Additionally, there may be more requirements based upon the State. After obtaining this license, a Professional Engineer can certify and sign off on engineering documents.

In order to implement this project, PE approval will be required to certify engineering documents, such as cross section designs, and to certify safety to the public.

Authorship

Section	Author	Editor
Introduction		
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Background		
Town History	Lindsey	Kyle
Town Vision for the Trails	Sarah	Kyle
Stakeholders	Sarah	Kyle
Trail Design	Kyle	Sarah
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Cost Estimate	Andy	Sarah
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Stormwater	Kyle	Sarah
Maintenance Plan	Andy	Kyle

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1. Introduction

Sturbridge, Massachusetts is a small town in Worcester County with a population under 10,000. The Town is approximately thirty-nine square miles, twenty percent of which is dedicated to open space. There are three main trail systems within this open space: The Grand Trunk Trail, Heins Farm Trails, and the Leadmine Mountain Trails. The Town of Sturbridge is looking to bolster their existing trail network to highlight this aspect of the community. (Sturbridge Trails Committee, 2017)

The goal of this project was to develop a trail design that will address both the Town of Sturbridge's overall vision for the trail system and provide an educational design experience. There is another MQP team that designed a pedestrian bridge to cross the Quinebaug River. The location of the bridge is incorporated into the design of the trail.

The Town of Sturbridge is interested in expanding their network of recreational trails located near the Commercial Tourist District, with the aim of supporting local business. The Town has a heavy dependence on tourists because its economic base is largely focused on leisure and hospitality sectors and retail trade. Sturbridge provides attractions with a sense of history, natural beauty, outdoor recreation, and a quaint town with a scenic drive. (Sturbridge Master Plan, 2010). Currently, the Town's open space trail systems are not entirely interconnected and do not encourage traffic exchange between the trails and the Commercial Tourist District. The Town of Sturbridge targets tourists who will return, extend their trip, and/or enjoy the outdoors. Connecting more hiking trails to the Commercial Tourist District are in line with the goals of the Sturbridge 2010 Master Plan.

2. Background

In order to appropriately develop a trail, it is important to understand the history of the land, economic factors, as well as trail and stormwater design practices. Analyzing these factors before design is crucial towards understanding the problem. This chapter describes the research done in order to prepare for this project.

2.1 Town History

Sturbridge is a quiet, peaceful town on the western edge of Central Massachusetts (Fig. 2.1). It spans from the Quinebaug river to the top of Leadmine mountains and is rich with natural lakes and acres of open space. Twenty percent of this small town's land is dedicated to open space due to the Community Preservation Act. (Sturbridge Trails Committee, 2017) This historic town contains multiple trails along old Native American paths, as well as the early transportation routes between Boston and New York. The Grand Trunk Trail (GTT) is built on the remnants of an abandoned railway that connected the communities of Brimfield, Sturbridge, and Southbridge. (Britannica, 2018)

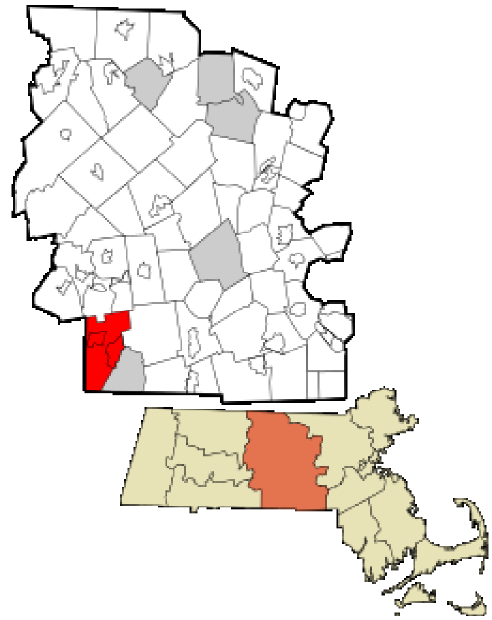


Figure 2.1: Location of Sturbridge in MA. "Sturbridge, Massachusetts."

The Grand Trunk Trail currently ends on the border of The Riverlands area (Fig. 2.2) of Sturbridge. Three parcels along Holland road — 51 Holland Road, 55 Holland Road and 52 Stallion Hill Road — make up The Riverlands. (Sturbridge Trails Committee, 2011) All of these parcels are owned by the Town of Sturbridge, but Opacum Land Trust Inc. oversees the 52 Stallion Hill Road and 51 Holland Road parcels. (Worcester District Registry of Deeds, Book 55837, Page 167) Opacum Land Trust, Inc. is a 13-town regional land conservation organization formed in 2000 to protect natural and cultural resources in South Central Massachusetts. Their aim for these parcels is to preserve wildlife habitat, water resources, passive recreation, and cultural features of the Riverlands. The land being protected can still be developed, but needs to be approved by Opacum. This creates opportunities for outdoor recreational activities such as hiking, horseback riding, kayaking, and fishing. Motorized wheelchairs are permitted where there are existing roads or hard surfaced trails.

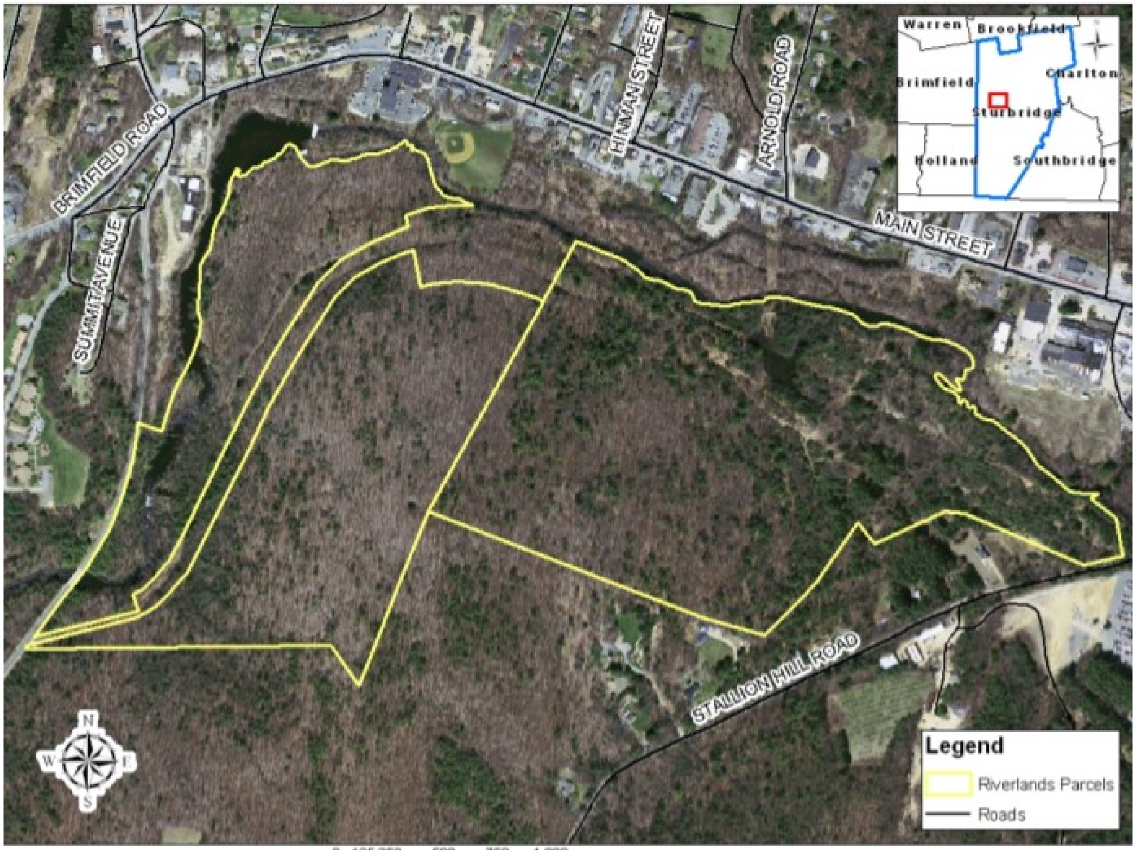


Figure 2.1: The Riverlands Area

Part of this site in the Northwestern corner was partially contaminated by a release of extractable hydrocarbon and hazardous materials from the past operation of textile mills. A company called Murifield Development was found responsible for this contamination. To protect and preserve this land, a grant of Conservation Restriction was awarded in 2007 for the Riverlands area. This is a way of helping landowners protect the conservation values of the property by defining allowed uses. Restrictions to the land use include constructing a permanent building, any mining or excavation, storing or dumping, cutting trees, activities detrimental to drainage, and use of any vehicles not being used for maintenance or safety.

Sturbridge pays tribute to the historic New England town feel with an attraction called "Old Sturbridge Village". It is one of the largest outdoor history museums in the region and recreates the life of early 1800s Massachusetts. This tourist attraction features costumed historians recreating everyday tasks like working on the farm, in trade shops, and life at home. This attraction also has souvenir shops, places to eat such as a tavern and a Village Scoop Shop. The addition of these Riverland trail systems will be located right across the street from Old Sturbridge Village on Stallion Hill Road, giving tourists and local residents access to a broader range of recreational activities. (Mission and Narrative, n.d.)

2.2 Town Vision for the Trails

The Town of Sturbridge formed the Sturbridge Trails Committee to organize the development and upkeep of its trails and recreational spaces. One of their goals is to connect all the Town's trail systems, one of them being the Grand Trunk Trail. (Figure 2.3) The Grand Trunk Trail has been developed from the Westville Reservoir to South Road. There is also a separate segment that connects to the Brimfield Reservoir dam; the central area near the Commercial Tourist District has not been completed. The focus of this project is the Grand Trunk Trail, as there are 2-3 miles that still need to be developed to connect existing segments of the trail.

The Sturbridge Trails Committee describes their vision in the *Recreation Trails Master Plan* as:

> "The Sturbridge Recreation Trails Master Plan seeks to highlight the community's small town character, vast open spaces, scenic character and abundant natural resources through the development of a diverse, interconnected system of recreation trails and signed touring routes. These facilities will provide improved access to the protected lands, the Quinebaug River, community gathering places, and cultural/historical sites. The trail system will bolster Sturbridge's brand as a conservation leader and the ample recreation opportunities will incentivize visitors to spend additional time in Town exploring our natural environment."

The Town is very environmentally minded and values making sustainable improvements to its open spaces. They believe trails and open spaces foster a sense of place and a healthy lifestyle. Some of the recreational activities the trails hope to support include walking, running, cycling, fishing, horse riding, and paddling. In addition to the trails being an attraction for the Town's residents, it should also be a tourist attraction. The *Recreation Trails Master Plan* emphasizes that the trail system should be closely connected to the Commercial Tourist District (a 1-mile strip along Route 20 containing Old Sturbridge Village and other amenities) to encourage tourists to remain engaged within Sturbridge for longer durations of time. This will bolster the local economy and promote outdoor recreation.

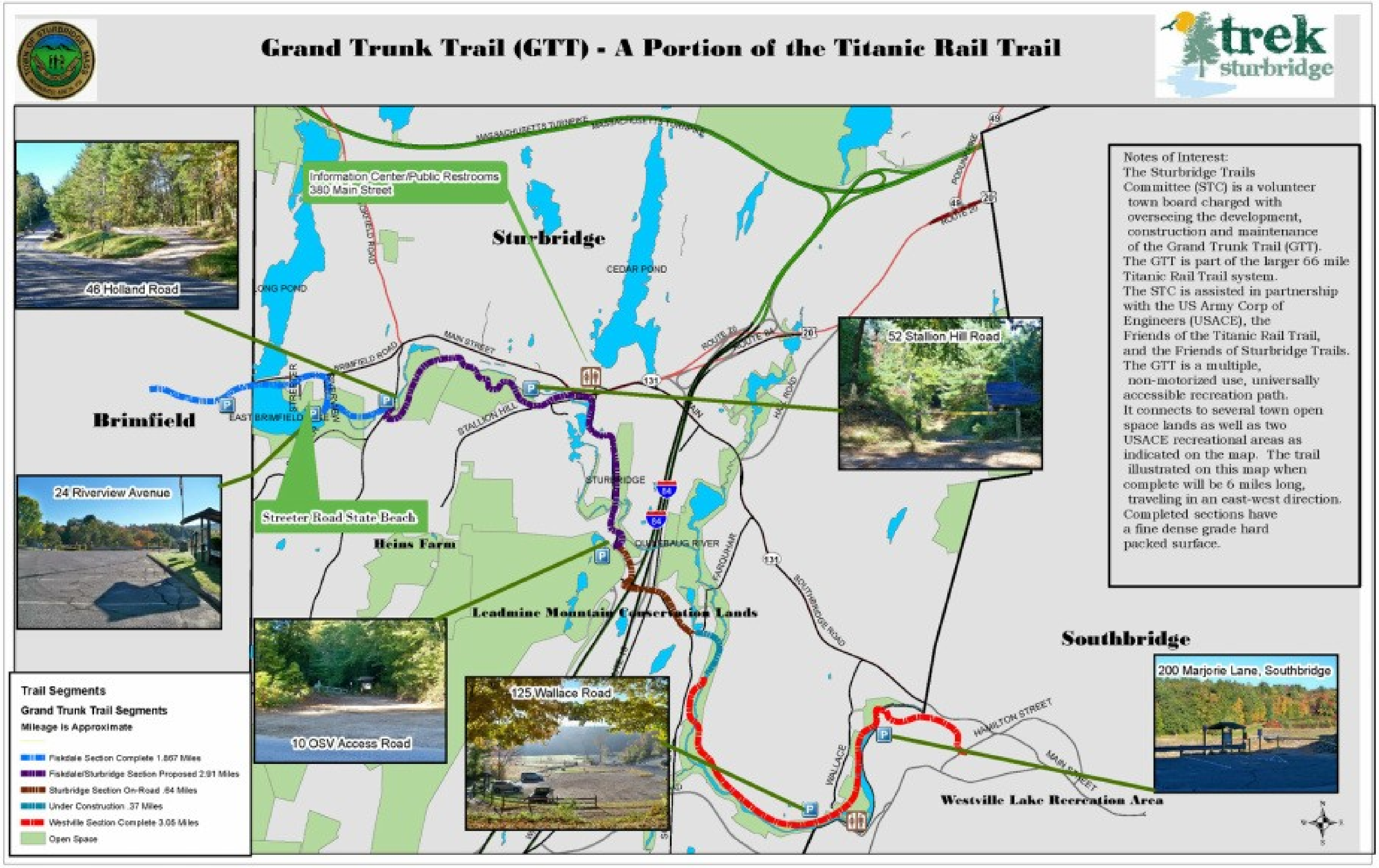


Figure 2.2: The full existing Grand Trunk Trail in Sturbridge, MA

2.3 Stakeholders

The Sturbridge Trails Committee is one of the main stakeholders in this project. It was established in 2009 and is made up of four members and four associate members[1]. The committee is responsible for trail planning, maintenance, and construction on public lands. Tom Chamberland, this MQP's Project sponsor, is an associate member of the Trails Committee.

Another stakeholder to consider is the Opacum Land Trust, which is a 13-town regional land conservation organization. It was founded in 2000 and aims to protect New England charm, encourage proactive environmental conservation as well as promote the creation of greenways and wildlife corridors. The parcels the project involves are part of the land trust's property. (Opacum Land Trust, 2019)

Some other stakeholders considered are the Army Corps of Engineers who have rights to flood the region when necessary, the volunteers who build and maintain the trails, as well as the tourists and Sturbridge residents who will be using the trails.

2.4 Trail Design

Designing an effective, sustainable trail is more than just simply clearing land between point A and point B. There are many different factors that must all be considered in order to create an effective design. It is important to take into account not only the location and difficulty of the trail, but also the intended users of the trail, the required maintenance and long-term sustainability of the design, as well as the tread surface and overall composition of the trail

Initially, it is important to consider the intended purpose of the trail. Who will be using the trail and what design criteria are important to them needs to be considered in the design. For example, if the trail is intended for use by the general public, the grade should be relatively low with a smooth surface, to make it accessible to as many different users as possible. In addition to a smooth surface and low grade, the trail should meet the ADA accessibility guidelines.

Finally, it is important that a maintenance plan is created and followed to ensure the longevity of the trail. This plan should include what factors may change on a relatively frequent basis, negatively affecting the trail's overall health. It should also address the recommended ways to fix these problems, such as removing piled sticks or gravel from the path.

[1] Conservation Agent, Town Planner, Town Administrator, Chair Community Preservation Committee and Economic Development/Tourism Coordinator.

2.5 Stormwater Best Management Practices

Ideally, trails should never be on flat ground. If the trail is on flat ground rather than a side slope, water can collect on the trail or run down and follow the trail, pulling sediment with it and causing severe erosion. This can also cause large depositions in other parts of the trail, greatly increasing the maintenance required. Any runoff should come down a slope onto the trail, run across it (or underneath it), and down another slope into a management area, river, or other location in order to not impact the trail itself. This means that the slope on either side of the trail should be steeper than the grade of the trail itself in order to limit runoff issues. It is necessary to follow along natural contours, using switchbacks and turns as needed to slowly change the elevation, rather than going straight down a steep slope. It is also important to ensure that any sediment that does get eroded from the trail does not deposit into natural water bodies, so silt fences can be installed to retain settlements if necessary.

Additionally, in places with high water flow, it can be beneficial to place a culvert or other water directing system under the trail in order to redirect water under or around the trail and prevent large amounts of water from impacting the sediment. The installation should not impact where runoff would naturally go before the trail was there to influence its path. Designing the trail with these factors in mind will not only increase the sustainability and lessen environmental impact, but will also decrease the amount of maintenance that will be needed in order to maintain the trail's condition. If the trails fell into disrepair it could impact the safety of users.

When selecting the appropriate method for stormwater management it is important to design for a specified year storm. In Sturbridge, the design storm is dependent on which management method is selected. For example, if the project requires culverts, they would need to be designed to manage the water volume of a 50-year storm. Projects that would require underground storm drains or catch basins should account for a 25-year storm. The maximum velocity water that can flow through a system is 10ft/sec. (Rules and regulations governing the subdivision of land Sturbridge, Massachusetts, 2002).

2.6 Cost Estimate

Total cost of construction is an important factor in trail design. Estimating the cost of the trail can be broken into two categories consisting of materials and labor/equipment costs.

Many materials were considered for the trail surfacing. Each material has its own characteristics that impact the overall trail quality. Materials were chosen based on the design specifications provided by the Town and an analysis of similar projects. Table 2.1 lists each of the materials considered (Rails-to-Trails Conservancy, 2020), and provides an assessment of four criteria: constructability; maintenance needs; accessibility; and environmental impact.

Table 2.1: Material Options				
Material	**Constructability**	**Maintenance**	**Accessibility**	**Environmental Impact**
Aggregate (½”)	Work can be done by volunteers. Would require plate compactor or roller for compaction and a skid steer or loader for moving material.	With minor upkeep this surfacing is expected to last 7-10 years.	Surfacing would comply with ADA standards.	Medium Level of Impact. Construction would require heavy machinery which produce carbon dioxide and noise pollution.
Asphalt	Necessary to provide multiple access points for a paving machine. This work would need to be done by the town highway division or outside contractor.	With minor upkeep this surfacing is expected to last 15 years.	Surfacing would comply with ADA standards.	Highest Level of Impact: Similar impacts to an aggregate surface but greater since more and larger machinery would be used. Finished surface also increases stormwater runoff.
Wood Chips	This work can be done by volunteers.	Material is biodegradable which will require complete resurfacing every two years.	Surfacing will not comply with ADA standards.	Lowest Level of Impact: Construction would have the smallest machinery but have more frequent work to upkeep the trail.

The construction of this trail will have its own design criteria; which will be presented through construction drawings and design specifications. This includes information on clearing limits, surfacing materials, construction methods and testing methods of the final product. Using this information, a list of materials with quantities can be calculated; this is also known as a material takeoff. Table 2.2 has the general design specification provided by the Town as well as other best practices (Sturbridge Trails Committee, 2017).

Table 2.2: Material Design Specifications	
Material	**Design Specifications**
Aggregate	½" stone will be compacted to 6" with a 2" surfacing of compacted stone dust
Asphalt	3" minimum thickness
Wood Chips	6" thickness
All Materials	12' wide trail

Labor costs were derived using *RSMeans Heavy Construction Cost Data.* This is an estimating tool commonly used in the construction field that tracks costs associated with construction projects such as crew make ups, labor efficiency, material costs and project overheads. The document contains a wide range of jobs and gives a suggested labor crew with equipment, expected workload for that crew, material costs, labor cost and equipment costs for different types of jobs. These prices are given in US dollars per unit of work. This tool can then be used to estimate the units of work and cost of a particular job.

3. Methodology

The goal of this project was to design a trail system connecting the Sturbridge Commercial Tourist District to the existing local trails network in the Riverlands area to encourage residents and visitors to engage in outdoor recreation in Sturbridge, MA. This will promote tourism and a more active lifestyle among the community and visitors. The objectives to meet this goal have been identified as:

1. Identify the problem and Town's vision
2. Evaluate existing conditions, design criteria and constraints
3. Design multiple options
4. Finalize design and draft maintenance plan

This chapter describes the approach to research and analysis methods for each objective. This is intended to show the steps that were taken to complete this project and the rationale behind them.

3.1 Objective 1: Identify the problem and Town's vision

The first step in project initiation was to communicate with stakeholders and develop goals and objectives that align with the intention of the Town of Sturbridge. The team met with Tom Chamberland and other members of the Sturbridge Trails Committee to gain an understanding of what the Town wanted. From those communications, a project proposal was developed (See Appendix A).

3.2 Objective 2: Evaluate existing conditions, design criteria and constraints

This objective provided the framework and general requirements for the design of the trail system. Through its completion, the requirements, limiting factors, and best practices for the design were identified.

3.2.1 Evaluate existing conditions of the site and surrounding areas

In order to identify restricting factors, the GIS data and town maps were compiled using MassGIS files and data provided by the Town. After organizing these maps in ArcMap, state contour data and wetlands data were added. Using ArcMap's import to CAD function, the file was converted to a drawing file. This data was not detailed enough to make and analyze a surface in AutoCAD Civil 3D, so data was collected manually as well. During the initial site visit a combination of a GPS, the Garmin eTrex 20x, and a phone app called Strava was used to collect elevation and coordinate data while walking through the site. Strava was used to follow the original abandoned and deteriorated trail. The Garmin device recorded elevation and coordinate data as the team progressed. See Appendix B for site visit reports.

The data from the Garmin was uploaded into Garmin's software, Basecamp. From there it was converted into a text file, edited in Excel, and then saved as a CSV file to include point ID's, Northings, Eastings and elevations. The CSV file was imported to Civil 3D. Using this data and field observations the team was able to identify areas that needed to be revisited with the Garmin. Using Basecamp, a new track was drawn and imported to the Garmin. More visits were made to the site, and the Garmin was used to follow tracks to gather more elevation data. The elevation data collected by the Garmin was imported to Civil 3D following the steps described above. In addition to elevation data, potential construction obstructions and areas of drainage concern were marked as waypoints with a corresponding description. All of the data collected was used to create a surface in Civil 3D.

3.2.2 Identify general best practices for trail design and design criteria

Design criteria outline the requirements for developing designs for a trail. The Town of Sturbridge's "A Guide to the Trails and Open Spaces of Sturbridge" (Trails Committee, 2017) was the primary source of information regarding trail design specifications, which include grade, trail width, clearance, and the cross section. An example of best practices was outlined in the Massachusetts Department of Conservation and Recreation's "Trails Guidelines and Best Practices Manual." (Mass DoC, 2014) The synthesis of these two documents provided the guidelines for the delineations and cross section designs.

3.3 Objective 3: Design multiple options and evaluate

This objective focused on the development of initial delineation options for the path and construction of the trails. These options were then evaluated and brought to stakeholders for review, and a design to move forward with was chosen.

3.3.1 Create options for delineation

Multiple delineations were created based on the surface in Civil 3D and the contour maps from the Town. Factors that limited alternate trail locations included existing grades, property boundaries, and environmental concerns. Once potential delineations were chosen, site visits verified that the options were practical.

3.3.2 Evaluate and score each option based on design criteria

Taking the design criteria and the Town's vision into consideration, a decision matrix was created for evaluating the delineation options. The matrix compared each delineation against six different considerations: aesthetics, accessibility, constructability, connectivity, sustainability, environmental impact. These categories were presented to the Trails Committee, and each member noted how important each category was. This was taken into consideration when rating each decision on a low-medium-high scale. Options for delineations, materials, and steep slope solutions were evaluated.

3.3.3 Design cross section for selected option

After collecting feedback from the stakeholders, cross sections were designed for the selected option. These drawings were modified from a PDF provided by Tom Chamberland and included the specifications for the trail such as grading, width, and outlines of potential construction items. This gives stakeholders a visual representation of the trail design before construction.

3.3.4 Cost Evaluation

Using the material design specifications and an estimated trail length, material quantities were calculated. The material quantities were multiplied by material prices in dollars obtained from local suppliers to calculate material costs. Labor and equipment costs were found using the 2009 edition of *RSMeans Heavy Construction Cost Data.* As RSMeans was broken down into specific tasks, a sequence of work was generated for each material option. Then, labor and equipment costs were calculated for each step and totaled. The labor and equipment costs were adjusted using a price index to better reflect today's prices, accounting for inflation. The materials costs used were current prices obtained from local suppliers. A final cost estimate was performed after the delineation was selected using the same methods.

3.4 Objective 4: Finalize design and draft maintenance plan

This objective focused on the finalization of the delineation, as well as the appropriate methods for stormwater management, and the creation of the maintenance plan. These were then merged to create a final deliverable for the Town and the Trails Committee.

3.4.1 Determine an appropriate method for stormwater management

After the delineation was chosen, it was necessary to analyze the stormwater flow in the area, specifically over the trail, to ensure that the trail will not be eroded away by storms. First, the map of the Riverlands area, including contours, was printed, and stormwater flow lines were drawn perpendicular to the contours to show the path of water flow. These paths were then used to divide the entire area into smaller catchment areas. The area of these sections upslope of the trails were then drawn and calculated in ArcMap. Using these areas, the Rational Method was then used to calculate the peak flow during a 24-hour, 25-year storm in each of the sections.

After peak flow was found, the areas that generated the most flow were identified. Then the time of concentration, using the greatest distance between a high point and the trail, was calculated using Manning's equation and the process outlined in the United States Department of Agriculture's Technical Report 55 (TR55). (United States Department of Agriculture, 1986). This concentration time was used to create a synthetic hydrograph, to show the change in flow over time. Calculating the area under this graph gave the total volume of stormwater generated in the area. This volume was then divided by the length of trail the sections lead to. Using the greatest value for all of the areas in need of drainage, an approximate cross section size for the drainage swale was determined. Using the same calculated values for the sections that need less drainage, another swale size was calculated to manage the smaller flows. These swales are intended simply to hold water and drain it to the wetlands and river, without it running across and potentially eroding the trail, as well as to keep the trail relatively dry.

Peak Flow: Rational Method

$Q_P = CiA$

Q_P = Peak Flow (cfs)
C = Runoff Coefficient
i = Rainfall Intensity (in/hr)
A = Area of Watershed (acres)

For Watershed Section 5

C taken from Mass DEP Hydrology handbook table of C values for rolling slope woodlands.

I value is equal to the 24 hour rainfall (5.3in) over the 24 hour period to give in/hr. (United States Department of Agriculture, 1986)

A is 8.414 acres for section 5.

$Q_P = 0.35 \times 0.221 \times 8.414 = 0.65$ ft^3/second

Concentration Time: Manning's equation

$T_{T1} = (0.007(nL)^{0.8}) / ((P_2)^{0.5}s^{0.4})$

(United States Department of Agriculture, 1986)

For Watershed Section 5: Length from high point to trail 1400'

T_{T1} = Travel time (1st 300 feet) (hr)
n = Manning's Roughness Coefficient
L = Flow Length (ft)
P_2 = 2 year, 24 hour Rainfall (in)
s = Slope of Grade Line

First 300'

Manning's coefficient taken from TR55 Table of Manning's Roughness Coefficients, for woods with light underbrush.

$T_{T1} = (0.007(0.4(300))^{0.8}) / ((3.0)^{0.5}(0.6)^{0.4} = 0.23$ hrs

Remaining Length

For Watershed Section 5: Remaining Length 1100’

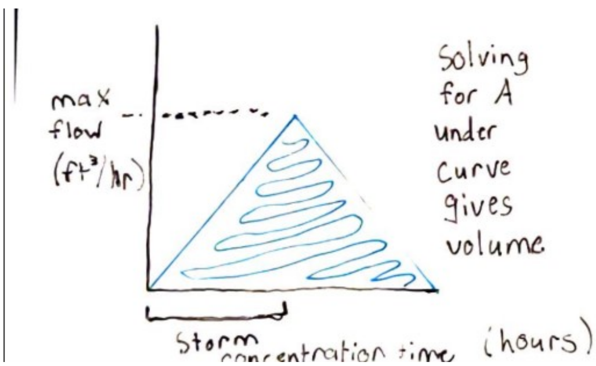
$T_{T2} = (L / 3600V)$

T_{T2} = Travel Time (After 300 feet) (hrs)
L = Length (ft)
V = Velocity (ft/s)

Velocity found using TR55 Graph of slope versus velocity on an unpaved surface. (United States Department of Agriculture, 1986)

$T_{T2} = (1100 / 3600(4.2)) = 0.07$ hours

Concentration time = Sum of travel times = 0.30 hours



Then, use synthetic hydrograph to get conservative estimate of total volume in the swale.

Area under curve = Volume

For Watershed Section 5

Volume = 0.65 ft^3/s x 3600s/hr x 0.30 hr = 702 ft^3

Max Volume divided by section length gives a cross sectional area for the swale.

For Section 5:

Trail section length of 297 feet.

702 / 297 = 2.36 ft^2

3.4.2 Draft maintenance plan

Developing a maintenance plan is important for the upkeep of a trail. The biggest factor in making this plan is the location of the trail, as different environments will have their own needs. A maintenance plan was drafted using the *North Country Trail Handbook* as a reference. This handbook outlines best practices for trail maintenance used for a trail system that runs from North Dakota to Vermont.

4. Results and Analysis

This chapter discusses the results of each objective from the methodology and the process of how they were evaluated.

4.1 Evaluate existing conditions, design criteria and constraints

4.1.1 Existing Conditions

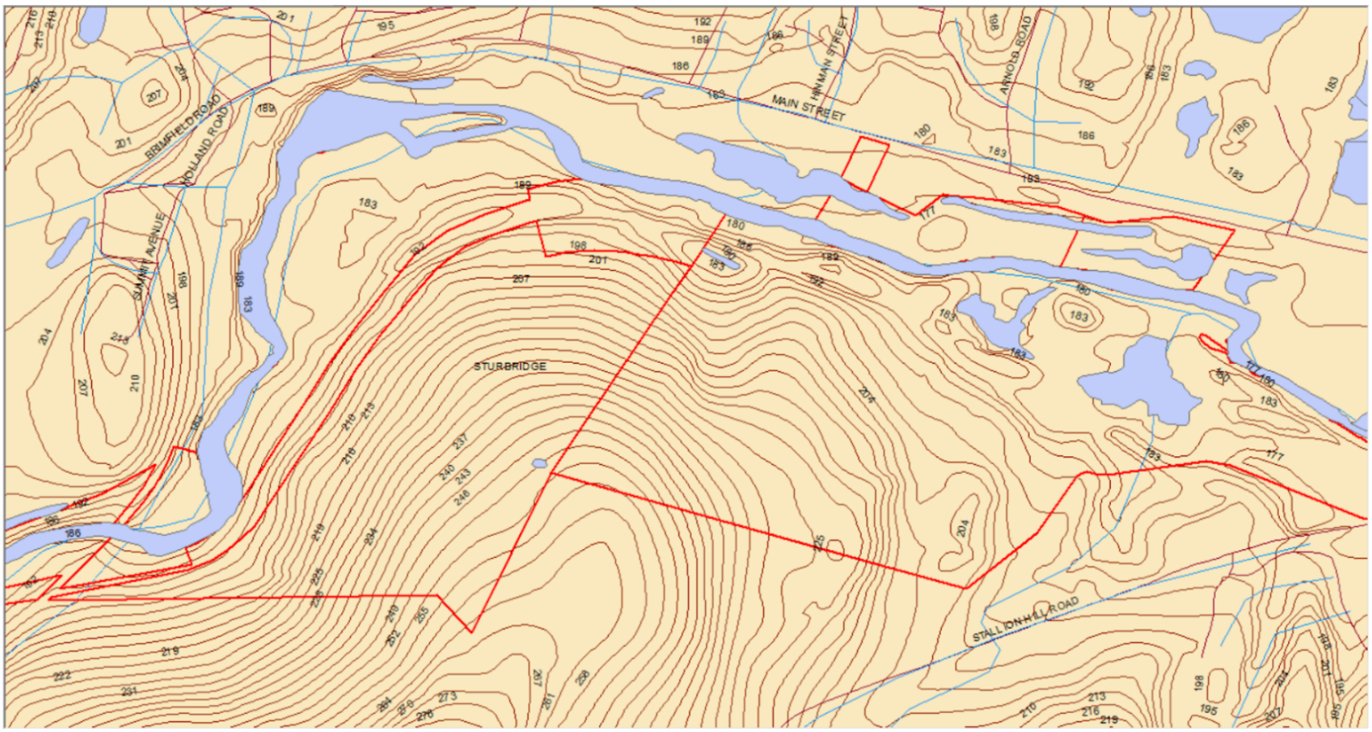


Figure 4.1: Topography of Site

Figure 4.1 shows the ArcGIS map that was generated using MassGIS files alongside data provided by the Town. The relevant parcels are outlined in red, the waterways and wetlands are shown, and the contours are labelled. The parcel and contour data was imported into Autodesk

Civil 3D and combined with site visit GPS data to create a Civil 3D surface, used for site analysis. This surface was used to design the delineations.

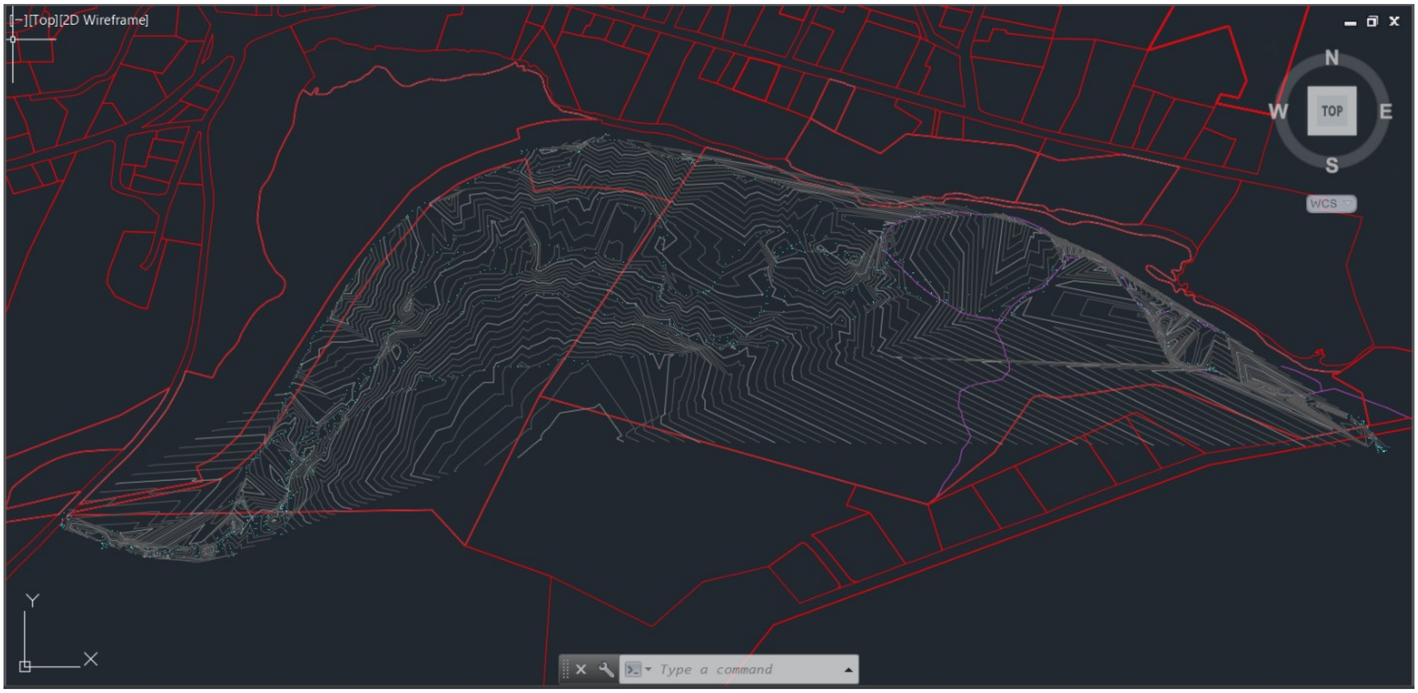


Figure 4.2: Civil 3D Surface

The Civil 3D file shows the parcels in red and the contours in grey. The purple line on the eastern side represents the location of the existing trail. The blue dots are the points that were gathered from the Garmin eTrex 20x GPS during various site visits.

4.1.2 Design Criteria

The design criteria for this project are consistent with specifications of the Grand Trunk Trail (GTT). The GTT is rated by the Trails Committee as “gentle,” which means it is an easier trail with delicate slopes that should allow for access to all. The Committee suggests the following recommendations:

- The tread should have an average slope of 5%.
- The maximum grade is rated at 8%. The areas that exceed the average slope should be less than 100 feet.
- The trail should be built on relatively mellow terrain, avoiding side slopes on very steep inclines on mountain sides.
- The trail should be 10-12 wide.
- The typical width of the corridor should be 16-20 feet.
- The clearing height must be at least 6 feet. (Sturbridge Trails Committee, 2011)

4.2 Preliminary Delineations

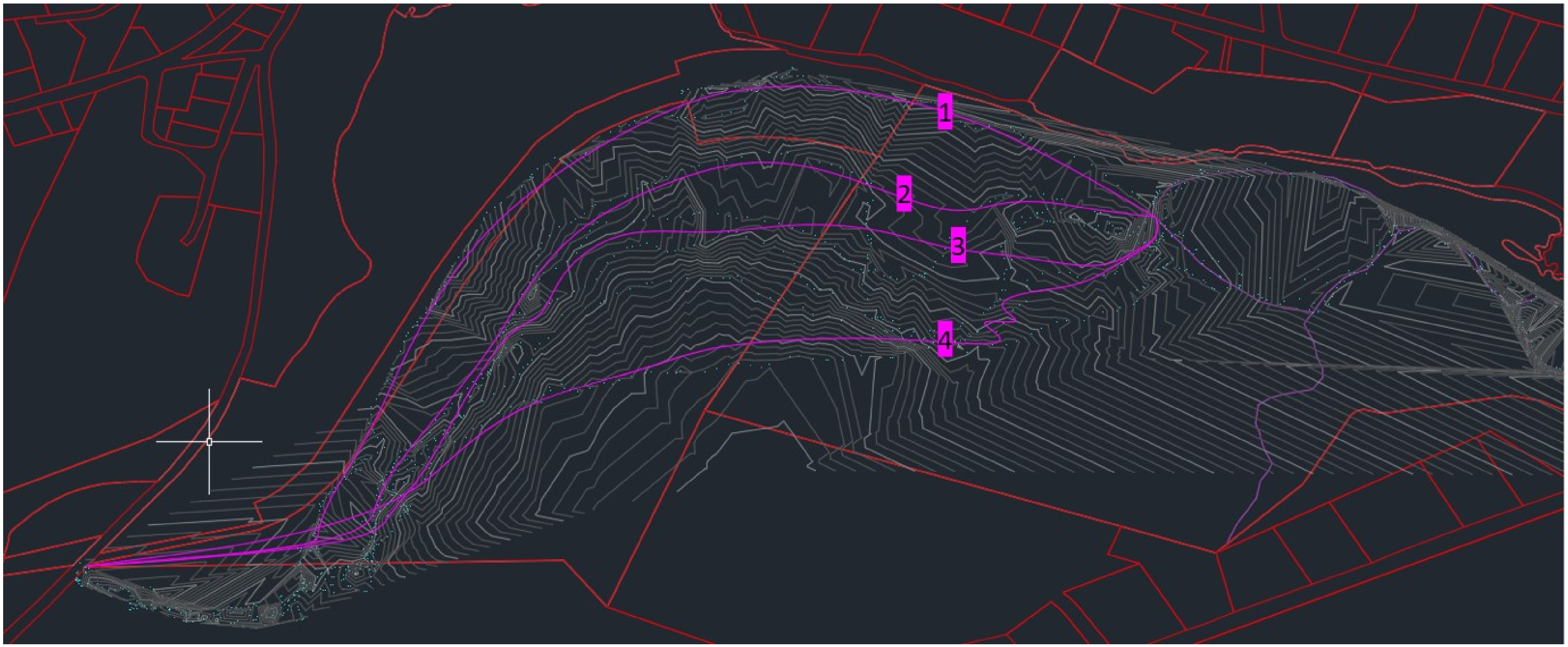


Figure 4.3: Delineation Options

Using the information from the created surface and observations during site visits, four delineations, shown in Figure 4.3, were drafted.

The first route

- Closely follows the original trail through the area, which is now deteriorated
- Is relatively flat along the full route
- Is close to wetland areas and has many potential issues with flooding
- Runs through a small gorge, with roughly fifteen-foot tall steep slopes on either side.

The second option

- Runs farther south, along the top of a ridge
- Appears as though part of this delineation was once used as a walking trail, and has since eroded away
- Is flat and easily accessible along the full route
- Has many issues with water flow and erosion

The third option

- Runs farther south than the second delineation
- Runs higher up on the slope of the area
- Lies at the bottom of a steep U-shaped slope area which appeared to experience a great deal of water flow

The fourth delineation

- Goes over the top of the U-shaped slope
- Maintains a safe distance from the steep area
- Includes path through slopes that are above limiting grade (8%)
- Avoids major issues with stormwater, since it is located near the top of the hill

The Trail Committee was presented with the four options on December 12, 2019 before a final decision was made. The Committee gave feedback on the importance of aesthetics, connectivity, constructability, cost, environmental impacts, and sustainability (Appendix H). They consistently rated environmental impacts and sustainability as the most important factors. Additionally, in discussion at the meeting, some members expressed an interest in being able to see the river from the trail, and how they wished for the hike to be a unique and interesting experience. Unfortunately, none of the viable delineations have a view of the river. However, the delineations are connected to the existing trail that has many locations with a good river view. Considering the importance of sustainability and minimizing environmental impact, it was decided that option four would be best, due to having the least interaction with stormwater and wetland areas; it also provides hikers with a pleasant aesthetic view of the forest.

4.3 Cost Estimate

A cost estimate for materials, labor and equipment was performed for the aggregate and asphalt surface options. This was not done for wood chips since the Town of Sturbridge would provide the materials and labor to construct this type of trail.

Preliminary calculations were done before selecting a final delineation. For these the trail length was assumed to be 1.8 miles (9,504ft) long, which is the length of the old Grand Trunk trail. This length was multiplied by the design specifications for material depths and trail width to find the total volume of material needed. Design specifications for each material can be found in the table below (Sturbridge Trails Committee, 2017).

Table 4.1: Material Design Specifications

Material	**Design Specifications**
Aggregate	½" stone will be compacted to 6" with a 2" surfacing of compacted stone dust
Asphalt	3" minimum thickness of asphalt with 6" ½" stone subbase
Wood Chips	6" thickness
All Materials	12' wide trail

The calculations used to find the material quantities can be found below:

Aggregate Surface

½" Stone: $9504' \times 0.5' \times 12' = 57{,}024 ft^3$

Stone Dust: $9504' \times 0.167' \times 12' = 19{,}008 ft^3$

Asphalt Surface

Hot-Mix Asphalt (HMA): $9504' \times 0.25' \times 12' = 28{,}512 ft^3$

½" Stone: $9504' \times 0.5' \times 12' = 57{,}024 ft^3$

Wood Chip Surface

Wood Chips: $9504' \times 0.5' \times 12' = 57{,}024 ft^3$

Each of the volumes was converted into tons using the material's unit weight. The tonnage of material was then multiplied by the suppliers' price per ton to determine a total material cost. The table below shows this information.

Table 4.2: Material Cost

Material	Volume (ft^3)	Unit Weight	Weight (tons)	Price per Ton	Total Cost
Aggregate	½" Stone: 57,024 Stone Dust: 19,008	½" Stone: 0.05244 tons per ft^3 Stone Dust: 0.045 tons per ft^3	½" Stone: 2,990 Stone Dust: 856	½" Stone: $11.40 Stone Dust: $6.70	$39,800
Asphalt	HMA: 28,512 ½" Stone: 57,024	HMA:0.0725 tons per ft^3 ½" Stone: 0.05244 tons per ft^3	HMA: 2,067 ½" Stone: 2,990	HMA: $67.00 ½" Stone: $11.40	$172,600
Wood Chips	57,204	N/A	N/A	Supplied by Town	N/A

Following the RSMeans Construction Sequence document's recommendations, aggregate surfacing was broken down into the following steps.

- Clear and grub vegetation
- Grade subgrade
- Haul materials to site
- Spread materials from the stockpile
- Compact materials

Asphalt surfacing was broken down into the following steps.

- Clear and grub vegetation
- Strip topsoil
- Grade subgrade for base course
- Haul materials to site
- Pave trail with 6” aggregate subgrade, 2” binder course and 1” top surface.

Tables 4.3 and 4.4 breakdown the costs for the labor and equipment associated with each material option. Calculations for this can be found in Appendix C.

Table 4.3: Aggregate Surface	
Clear and Grub Vegetation	$10,900
Grade Subgrade	$4,200
Haul Materials to Site	$18,000
Spread Materials from Stockpile	$6,800
Compact Surface	$900
Total Cost	**$40,800**

Table 4.4: Asphalt Surface	
Clear and Grub Vegetation	$11,000
Strip Topsoil	$5,000
Grade Subgrade for Base Course	$4,200
Haul Materials to Site	$26,000
Pave Surface	$49,100
Total Cost	**$95,300**

Price indexes provided by RSMeans were used to convert cost data from 2009 to the cost in 2020. The equation used and calculations for this can be found below.

$$Cost\ in\ 2020 = \frac{Cost\ in\ 2009}{\frac{Cost\ Index\ for\ 2009}{Cost\ Index\ for\ 2020}}$$

Aggregate Surface

$$Cost\ in\ 2020 = \frac{40{,}661.34}{\frac{180.10}{239.10}} = \$53{,}981.82$$

Asphalt Surface:

$$Cost\ in\ 2020 = \frac{95{,}117.16}{\frac{180.10}{239.10}}$$

Combining the labor and equipment costs with material costs gives the following overall totals. Total costs do not include any project overhead fees or any markup for unexpected costs or profitability. No cost was estimated for woodchips, as there was uncertainty whether the Town would purchase them or have an existing stockpile, and the cost of labor could be almost entirely negated by volunteers.

Table 4.5: Total Project Cost			
Material	**Material Cost**	**Labor and Equipment Cost**	**Total Cost**
Aggregate	$39,800	$54,000	$93,800
Asphalt	$172,600	$126,300	$298,900
Woodchips	Town DPW is responsible	—	—

The three material options were presented to the Trails Committee. This presentation included characteristics of each material and their associated costs. Following the same format as for the alternative delineations, the Committee gave feedback on the importance of aesthetics, connectivity, constructability, cost, environmental impacts, and sustainability. This feedback revealed that environmental impact, sustainability, and usability are of the most concern when selecting a material. It was determined that the aggregate surfacing would best meet these three categories.

4.4 Steep Slope Solutions

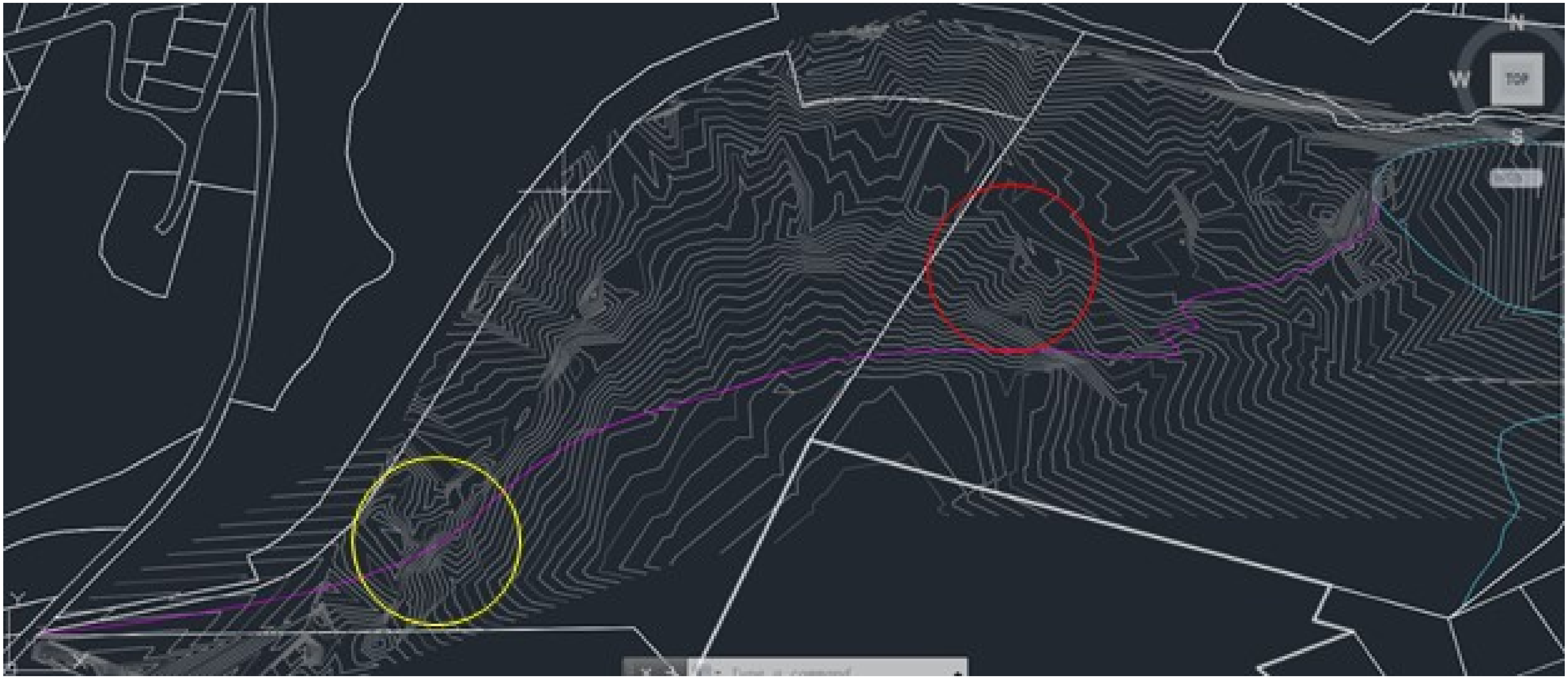


Figure 4 4: Original Delineation Highlighting Areas with Steep Slopes

There were two main areas of concern that needed steep slope solutions. The first area, represented by the yellow circle in Figure 4.4, was the entrance to the trail from Holland Road. The red circle represents steep slopes close to the trail. The areas identified exceed the ADA Accessibility standard of 8% slope, averaging about 13% slope where the delineation climbs, and therefore need to be designed around.

The first option is to implement multiple switchbacks in order to ensure the slope never exceeds the maximum 8% grade. Benefits of the switchback method include protection from excessive erosion. Retaining walls may need to be implemented to secure the structural integrity of the cut. Excavation and fill are required. Switchbacks are used when the slope exceeds 15 %. Switchbacks are most successful when there are fewer turns and longer straight paths (State of New Hampshire, 2017).

Climbing turns also reverse direction but maintain the existing grade throughout the turn. Generally, climbing turns are easier and less expensive to build than switchbacks. Construction is easier when the turn radius is relatively large (15 to 20 ft). Climbing turns require much less excavation and fill is not used. Climbing turns are typically constructed for slopes less than a 15% grade. (State of New Hampshire, 2017) This method would be ideal for solving the slope problem represented by the yellow circle in Figure 4.4.

Another option would be to design stairs made from rocks to aid in the steepness of the slope (Fig. 4.5). Installing stone slabs would help keep the natural beauty without it looking constructed. This would help the hiker ascend the slope with more ease; however, this option would not be ADA accessible (National Park Service, 2011). Re-grading the land is another possible solution for dealing with steep slopes. This option is very costly and will have major effects on the existing environment.

Figure 4.5: Stone Stairs. National Park Service, 2011

After presenting the options to the Town of Sturbridge, the importance of ADA Accessibility, sustainability, and environmental impact were identified. The stair option would compromise ADA accessibility, and therefore was no longer considered a potential solution. The most positive feedback supported installation of either switchbacks or climbing turns. Extending the trail is less expensive than the excavation and machinery required to re-grade the land. However, the Town wouldn't be opposed to re-grading the trail entrance at Holland Road if it is absolutely necessary.

4.5 Stormwater Analysis

Using regional rainfall data (Massachusetts Department of Environmental Protection) and the GIS data presented in Section 4.1.1 for the Riverlands, swales were designed for stormwater management. Contours and surface data were used to draw flow lines throughout the area to represent the paths the water takes. Figure 4.6 shows the flow lines, which were then used to divide the area into multiple catchment areas based upon where the water goes. Those smaller sections were then further divided based upon what section of trail the water would cross, giving eight sections, shown in Figure 4.7. Trail sections 1, 3, 5, and 7 were determined to be the best places to install larger volume drainage systems, so the water can be collected before crossing the trail, and directed downhill and discharged elsewhere.

Figure 4.6: Flow Lines

Section #	1	2	3	4	5	6	7	8
Section Area (ft^2)	229,870	355,610	477,635	765,600	366,500	437,930	662,805	872,865
Section Width (ft)	400	435	500	1,385	297	274	688	400

Figure 4.7: Trail Watershed Sections

Rainfall data for the region and calculating the areas of these sections in ArcMap allowed for the Rational Method to be used to calculate the peak flow of water each section experienced during a 24-hour, 25-year storm. Calculation of the concentration time for the area, creation of a synthetic hydrograph, and calculation of the area under the curve, gave the total volume experienced by each. The trail width of the sections requiring the larger drainage was then used to divide the volume, and the greatest value was chosen. Watershed section number five had the highest concentration time, and this time was used for calculations of all volumes. Sections 1, 3, 5, and 7 were determined to be the best sections for stormwater management, as drainage away from these parts would vastly decrease water on the other sections. All calculated values are shown in Figure 4.8.

	A	B	C	D	E	F	G
1	Section #	Area (ft^2)	Area(acres)	Trail Width (ft)	Qp (Peak Flow) (ft^3/s	Vmax(ft^3)	Area (ft^2)
2	1	229,870	5.28	400	0.41	440.51	1.10
3	2	355,610	8.16	435	0.63	681.46	1.57
4	3	477,635	10.96	500	0.85	915.30	1.83
5	4	765,600	17.58	1,385	1.36	1467.14	1.06
6	5	366,500	8.41	297	0.65	702.33	2.36
7	6	437,930	10.05	274	0.78	839.22	3.06
8	7	662,805	15.22	688	1.18	1270.15	1.85
9	8	872,865	20.04	400	1.55	1672.69	4.18
10							
11			43,560		Manning's Equation		
12			ft2/acre		Tt1 for first 300'		
13					0.23		
14					Tt2 for remaining 1,100'		
15					0.07		
16					Concentration Time (hr)		
17					0.30		

Figure 4.8: Stormwater Calculations

The largest required swale cross section is for section five, requiring 2.36 square feet. This can be obtained using an approximate swale size of two and a half feet wide and two feet deep, in a triangular shape. The sections of trail that were not selected to manage the greater volume of water would also still benefit from some level of stormwater management, so a smaller swale was selected, with dimensions of two feet wide and one foot deep.

5. Recommendations

This section highlights the recommended designs and solutions from each section in the report. The recommendations include a delineation, the materials, a construction cost estimate, steep slope and stormwater solutions, and a maintenance plan.

5.1 Delineation Selection

The recommended delineation is the fourth presented delineation option. This selection travels over the top of the large U-shaped gorge south of the existing trail and is located a safe distance from steep areas. This delineation includes slopes that are above a grade of 8% but does avoid issues with stormwater, since it is located near the top of the hill.

5.2 Material Selection

The recommended material for the trail tread was the Aggregate: ½” stone compacted to 6” with a 2” surfacing of compacted stone dust. The recommended cross section is shown in Figure 5.1. Overall, 57,024 ft^3 of ½” stone and 19,008 ft^3 of stone dust are required. The cost for this volume of material would be roughly $39,800. In order to implement the tread, the cost would be approximately $54,000 to cover the labor required for 1.2 miles of trail. This brings the total cost of construction for this project to roughly $93,800 (not including the costs to verify design with professional engineers, a professional survey, environmental analysis, or markup for contingencies). The fees included in this estimate cover the cost to clear and grub vegetation, grade subgrade, haul materials to site, spread materials from the stockpile, and compact materials.

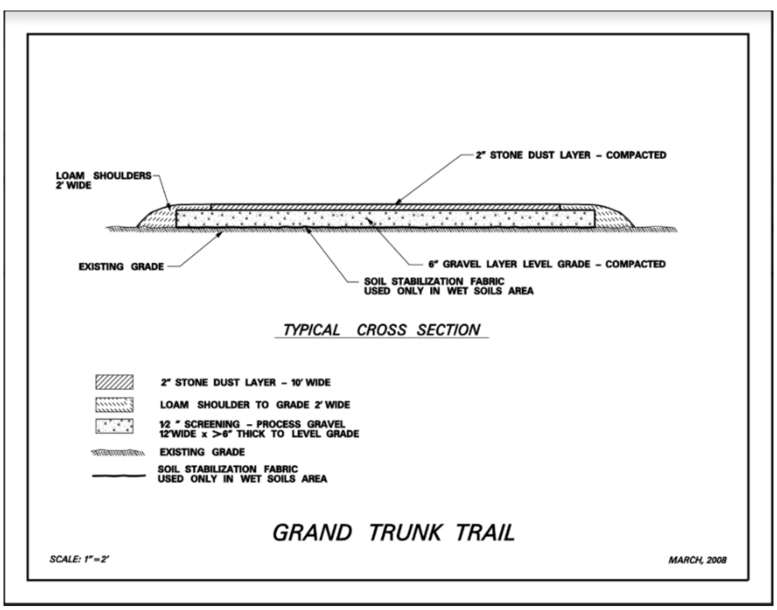


Figure 5.1: Trail Bed Material Cross Section (Modified from U.S. Department of Agriculture Forest Service)

5.3 Steep Slope Selection

Based on the existing slopes and the NH Trail Construction and Maintenance Manual, climbing turns were determined to be an effective way to solve slope issues. It is the least expensive ADA accessible option, and the slopes aren't steep enough to require switchbacks. The environmental impact of climbing turns is less than either re-grading or switchbacks due to less excavation of the land. There is ample room in the area to make climbing turns with large radii for ease of construction. Figure 5.2 displays the delineation after implementing the climbing turns. The original delineation was a length of roughly 0.8 miles, with 0.4 miles added by the climbing turns.

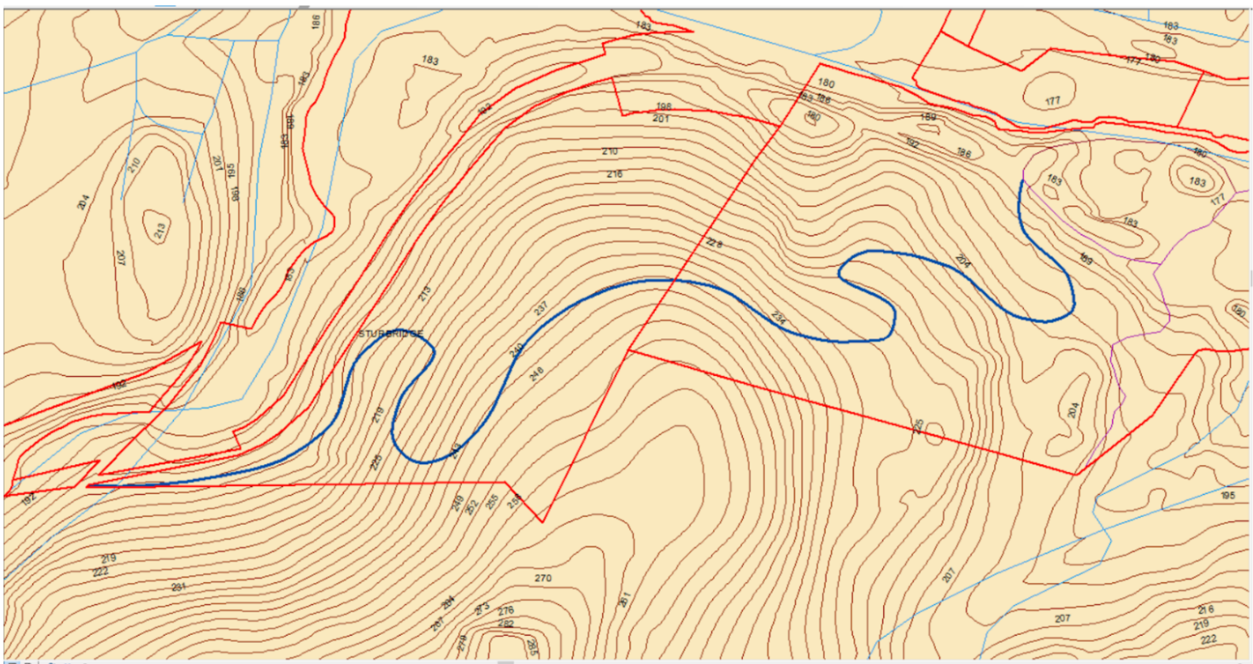


Figure 5.2: Delineation After Implementing Climbing Turns

5.4 Stormwater

Stormwater management is crucial to the long- term sustainability of the trail. It is important that flows across the trail are minimized to prevent erosion of the surface. This will result in fewer repairs and maintenance in the long run. Additionally, reduced puddling on the trail will ensure user comfort.

The recommended method of managing stormwater is through the use of drainage swales running parallel on the upslope side of the trail. As water flows down, it will collect in the swales, rather than run across the trail. The swales provide storage and redirection of stormwater to natural areas. There are eight different sections of trail identified, based on which watershed area leads to the trail. Four of these sections were identified to need larger- sized swales, while the other four need smaller-sized swales. The approximate sections are shown in Figure 5.3.

Plain blue lines show the sections requiring the smaller two-foot wide, one-foot deep swale. The highlighted green sections would experience a greater quantity of flow, and require the larger, three-foot-wide and two-foot-deep swale. The recommended cross sections are shown in Figures 5.4 and 5.5

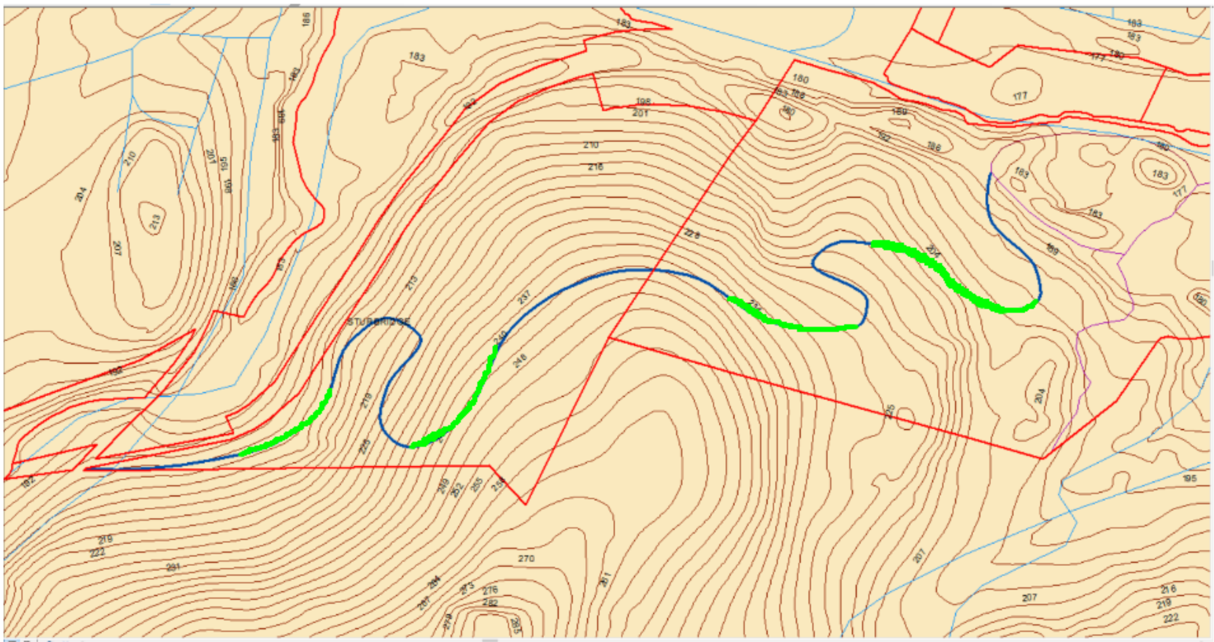


Figure 5.3: Swale Locations

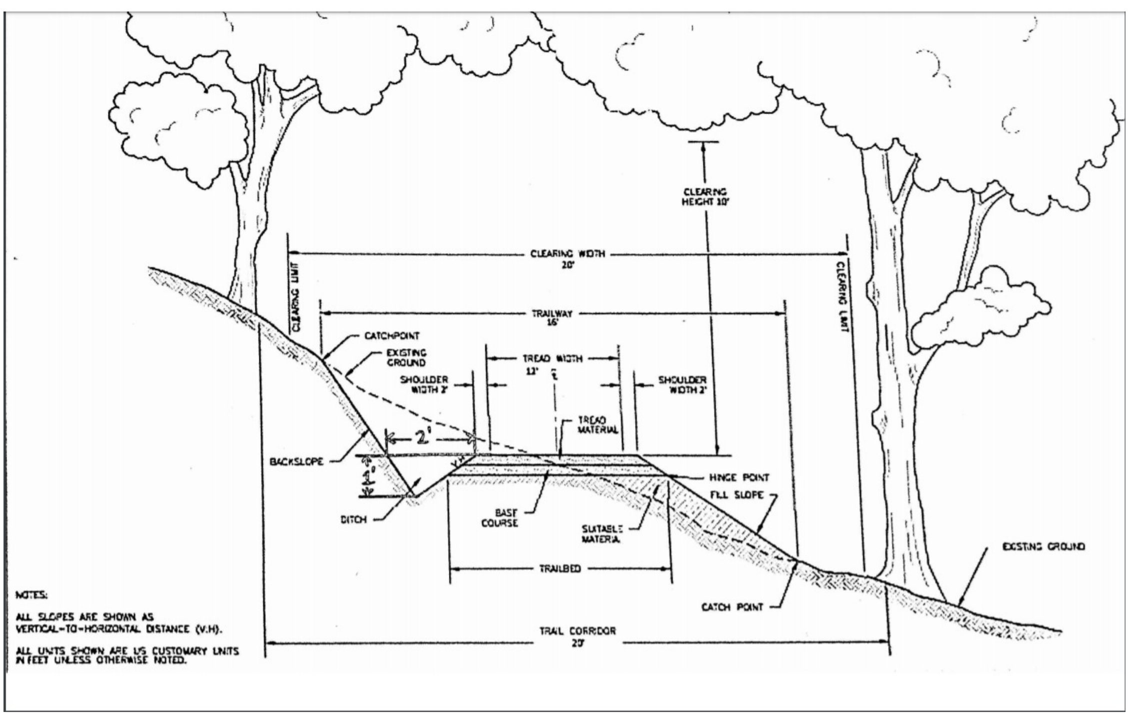


Figure 5.4: Typical Trail Cross Section (Modified from U.S. Department of Agriculture Forest Service)

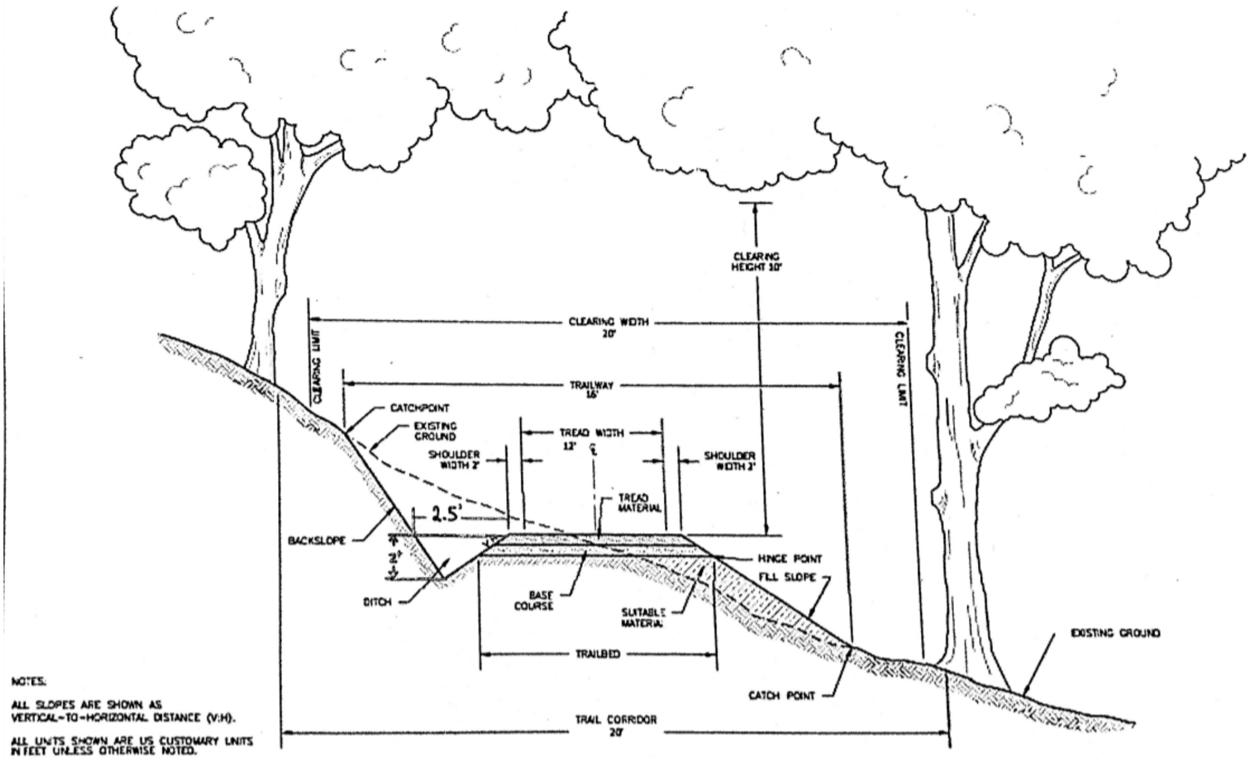


Figure 5.5: Heavy Stormwater Trail Cross Section (Modified from U.S. Department of Agriculture Forest Service)

5.5 Maintenance Plan

After construction, trail maintenance is essential for the sustainability of the trail. Performing regular trail inspections will identify maintenance concerns before they become more problematic. It is a best practice to have at least three of these inspections each year: the first being before Memorial Day, the next in the middle of the summer, and a final inspection during the fall before the winter season. Additional trail inspections should be performed after heavy storms that occur during the time that the trail is being used (North Country Trail Handbook, 2019).

Templates for each type of trail inspection can be found in Appendix E. The form should be filled out by someone familiar with the trail cross section, which can be printed on the back. Each form has a list of common concerns the trail may have for that time of the year. Inspections should not be limited to this list but instead used as a reference. When a problem is identified it should be recorded in the table with as many details as possible. It is best to record the location of the problem with a GPS. Severity of the problem should be ranked low, medium or high, using the best judgement of the inspector. The additional notes section in the table is used to better describe the individual problem, while the additional notes section at the bottom of the form is for general comments for the entire trail. Once the inspection sheet is complete it should be sent to the Sturbridge Trails Committee to review and keep on file.

It is also important to record any work done on the trail. A work tracking sheet can be found in Appendix F. This is to be filled out upon completion of the work by the person leading or supervising the job. Multiple rows should be used on the table if work was done at different locations or if different jobs were done at one location. Number of workers refers to the number of laborers working on one job and time spent working would be the time the crew worked. Total worker hours is equal to the number of workers times the time spent working. For example, if three laborers spent two hours resurfacing the trail, then the number of workers would be three, the time spent working would be two hours, and the total worker hours would be six hours.

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Appendices

Appendix A: Project Proposal

A Proposal for a Major Qualifying Project Report:
Submitted to Faculty of
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirements for the Degree of Bachelor of Science By

Sarah Butts
Lindsey Hamlett
Kyle Hanrahan
Andy Hubina

Date: October 7, 2019

Ethical

This project will follow the American Society of Civil Engineers Code of Ethics. It will provide the best final product for all the parties involved. This project will uphold the First Canon of Engineers which states engineers shall "hold paramount the safety, health, and welfare to the public" (National Society of Professional Engineers, 2019).

Health & Safety

To ensure the health and safety of all users this project will comply with the *American with Disabilities Act,* and *Massachusetts Building Code*. These regulations will be followed closely since the trails are located in the woods and may pose greater danger to the users. Stormwater management will comply with the *Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas.* This will maximize the efficiency of the design while protecting the environment.

Social & Political

The final project will aim to satisfy the wants of the Sturbridge community. To accomplish this, input from various town employees will be used to determine design criteria. The trails will also be designed to be accessible to a wide range of people. Incorporating these social and political aspects will improve the overall success of the project.

Table of Contents

1.0 Introduction

Sturbridge, Massachusetts is a small town in Worcester County with a population under 10,000. The Town is approximately thirty-nine square miles, twenty percent of which is dedicated to open space. There are three main trail systems within this open space; the Grand Trunk Trail, Heins Farm Trails, Leadmine Mountain Trails. The Town of Sturbridge is looking to bolster their existing trail network to highlight aspects of its community. (Sturbridge Trails Committee, 2017)

The Town of Sturbridge is interested in expanding their network of recreational trails located near the Commercial Tourist District, with the aim of supporting local business. Currently, all of the Town's open space trail systems are not entirely interconnected and do not encourage traffic exchange between the trails and an important source of income and cultural history in the Town, the Commercial Tourist District. Bringing these two areas together would increase tourism and promote a healthy lifestyle.

The goal of this project is to develop a trail design that will address both the Town of Sturbridge's overall vision for the trail system. There is another MQP team that will be designing a pedestrian bridge to cross the Quinebaug River. Its location will be incorporated into the design of the trail. This will be achieved through the completion of the objectives identified as; identify design criteria and constraints, design multiple options and evaluate, and finalize design and draft maintenance plan.

2.0 Background

The purpose of this section is to provide the reader with the necessary background information to understand the selected research methods. This section will discuss the following: the history of Sturbridge and the trails, the vision of the Town and Trails Committee, the stakeholders involved and general trail design best practices.

2.1 Town History

Sturbridge is a quiet, peaceful town on the western edge of Central Massachusetts. (Fig. 1) The town spans from the Quinebaug river to the top of Leadmine mountains and is rich with natural lakes and acres of open space. Twenty percent of this small town's land is dedicated to open space due to the Community Preservation Act. (Sturbridge Trails Committee, 2017) This historic town contains multiple trails along old Native American paths, as well as the early transportation routes between Boston and New York. The Grand Trunk trail is built on the remnants of an abandoned railway that connected the communities of Brimfield, Sturbridge, and Southbridge. (Britannica, 2018) The historical farming community of Sturbridge was one of the first places to start mining in New England. There is a spur trail named by the Nipmuc, "Tantiusques[1]," that passes through the Leadmine Wildlife Management Area and ends at Robert Crowd Site (Fig. 2). (Sturbridge Trails Committee, 2017) The Nipmuc originally mined graphite to

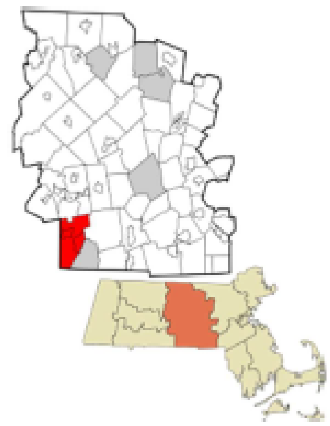

Figure 1: Location of Sturbridge in Massachusetts. (Wikipedia, 2018)

Figure 2: A trail map of the area where the mines started. This area is rich with minerals. (Maplets, n.d.)

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[1] A Nipmuc word meaning, "to a black deposit between two hills."

make ceremonial paints. In 1644, John Winthrop Jr. of the Massachusetts Bay Colony purchased the mine for lead and iron. This area is registered with the National Register of Historic Places because it was the center of one of New England's first mining operations. The significance of this title is that it is a part of a national program to support public and private efforts to identify, evaluate, and protect America's historic resources. Today, observers can still see evidence of the mines through mine cuts, ditches, and tailings pipes made by various mining operations (Fig. 3). (Sophia, 2018)

Figure 3: A photo of the remaining mining holes that can be found in the Tantiusques area. (Sophia, 2018)

Sturbridge pays tribute to the historic New England town feel with an attraction called "Old Sturbridge Village". It is the largest outdoor history museum in the Northeast and recreates the life of early 1800s Massachusetts. This tourist attraction features costumed historians recreating everyday tasks like working on the farm, in trade shops, and life at home. This attraction also has souvenir shops, places to eat such as a tavern and a Village Scoop Shop. (Old Sturbridge Village, 2019)

The Riverlands make up three combined parcels from Stallion Hill Road, to Holland Rd. The area was contaminated by a release of extractable hydrocarbon and hazardous materials from the past operation of textile mills. To protect and preserve this land, a grant of Conservation Restriction was awarded in 2007 for the Riverlands area. A conservation restriction is a way of helping landowners protect the conservation values of the property by defining allowed uses. Restrictions to the land use include constructing a permanent building; any mining or excavation, storing or dumping; cutting trees and other activities detrimental to drainage; and use of any vehicles not being used for maintenance or safety. Opacum Land Trust Inc. holds the conservation restriction for land located at 52 Stallion Hill Road, 51 Holland Road, totaling 140.57 acres. (Worcester District Registry of Deeds, Book 55837, Page 167) Their aim is to protect and preserve wildlife habitat, public access to Riverlands, water resources, passive recreation, and cultural features. This creates opportunities for outdoor recreational activities such as hiking, horseback riding, skiing, and fishing. Motorized wheelchairs are also permitted where there are existing roads or hard surfaced trails.

2.2 Town Vision for Trail Development

The Town of Sturbridge formed the Sturbridge Trails Committee to organize the development and upkeep of the trails and recreational spaces within the town. One of their goals is to connect all of the Town's trail systems, one of them being the Grand Trunk Trail (Fig 4). The Grand Trunk Trail has been developed from the Westville Reservoir to South Road. There is also a separate segment that connects to the Brimfield Reservoir dam; however, the central area near the Commercial Tourist District has not been completed. The focus of this project will be the Grand Trunk Trail, as there are 2-3 miles that still need to be developed to connect existing segments of the trail.

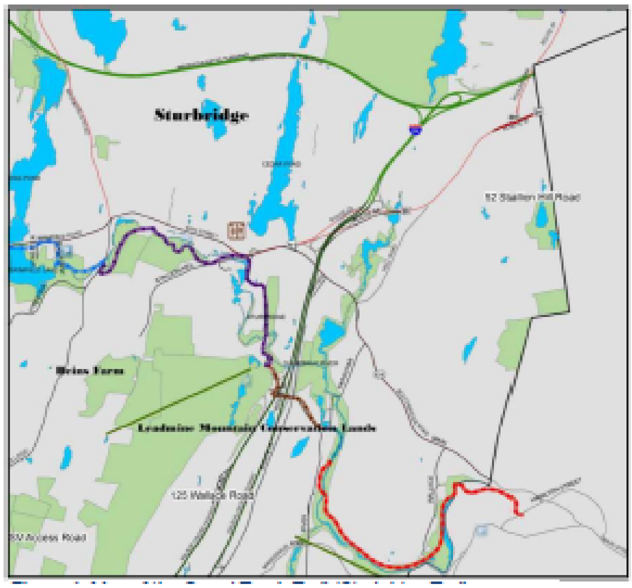

Figure 4: Map of the Grand Trunk Trail (Sturbridge Trails Committee)

The Sturbridge Trails Committee describes their vision in the Recreation Trails Master Plan as:

> "The Sturbridge Recreation Trails Master Plan seeks to highlight the community's small town character, vast open spaces, scenic character and abundant natural resources through the development of a diverse, interconnected system of recreation trails and signed touring routes. These facilities will provide improved access to the protected lands, the Quinebaug River, community gathering places, and cultural/historical rites. The trail system will bolster Sturbridge's brand as a conservation leader and the ample recreation opportunities will incentivize visitors to spend additional time in Town exploring our natural environment."

The town is very environmentally minded and values making sustainable improvements to its open spaces. They believe trails and open spaces foster a sense of place and encourage a healthy lifestyle. Some of the recreational activities supported by the trails include walking, running, cycling, fishing, horse riding, and paddling. In addition to being a draw for the Town's residents, the trails should also be a tourist attraction. The Recreation Trails Master Plan emphasizes that the trail system should be closely connected to the Commercial Tourist District to encourage tourists to remain engaged within the town for longer durations of time. This will bolster the local economy and promote outdoor recreation. (Kay-Linn Enterprises, 2012)

2.3 Stakeholders

The Trails Committee is one of the largest stakeholders in this project. It was established in 2009 and is made up of four members and four associate members. The committee is responsible for trail planning, maintenance, and construction on public lands. Tom Chamberland, this group's main contact, is an associate member of the Trails Committee[2].

Another stakeholder to consider is the Opacum Land Trust, which is a 13-town regional land conservation organization. It was founded in 2000 and aims to protect New England charm, encourages proactive environmental conservation as well as promotes the creation of greenways and wildlife corridors. This project involves land parcels that are under Opacum's oversight. (Opacum Land Trust, 2019)

Some other stakeholders to consider are the Army Corps of Engineers who have rights to flood the region when necessary, the volunteers who build and maintain the trails, as well as the tourists, and Sturbridge residents who will be using the trails.

2.4 Trail Design

Designing an effective, sustainable trail is more than just simply clearing land between point A and point B. There are many different factors in the design that must all be considered in order to create an effective design. It is important to take into account not only the location and difficulty of the trail, but also the intended users of the trail, the required maintenance and long-term sustainability of the design. The specific design parameters will include tread width,

[2] Other Town resources include the Conservation Agent, Town Planner, Town Administrator, Chair Community Preservation Committee and Economic Development/Tourism Coordinator.

surface, grade, turns, cross-slope, and clearing. The criteria to designing a sustainable trail must include physical, ecological, and economic sustainability. To maintain sustainability, the delineations must avoid sensitive ecological areas, develop in areas that have already been influenced by human activity, provide buffers around the trail, utilize natural filtration for stormwater management (vegetated swales and rain gardens), and limit tread erosion through design and construction. Sensitive ecological areas include wetlands, cultural and historic resources, steep slopes and endangered species. The Trail System must provide specific recreational experiences to users, connect to important destinations or population centers, and highlight the natural features surrounding the trail. (Department of Conservation and Recreation, 2012).

Firstly, it is important to consider the intended purpose of the trail. Who will be using the trail and what design criteria are important to them? For example, if the trail is intended for use by the general public, the grade should be relatively low with a smooth surface, to make it accessible to as many different users as possible. In addition to a smooth surface and low grade, the trail should account for accessibility of things like wheelchairs, if they would be used by the target audience. The design would then need to adjust the width to accommodate the needs of the intended user base.

Ideally, trails should never be completely flat. If the trail is on flat ground, rather than a side slope, water can collect on the trail or run down and follow the trail, pulling sediment with it. This could result in a large puddle or cause severe erosion. This can also cause large sediment depositions on other parts of the trail, greatly increasing the maintenance required. Any runoff should come down a slope onto the trail, run across it sideways, and down another slope into a management area, river, or other location not impacting the trail itself. The outslope of the trail should be sloped away from the hillside by 5%. Reversing the grade of the trail can help prevent water from collecting and running down the trail to reduce erosion. Most trails include grade trail reversals every 20-50 feet. It is important to follow near existing contours, using switchbacks if necessary to slowly lower the elevation, rather than going straight down a steep slope. It is also important to ensure that any sediment that does get eroded from the trail does not deposit into natural water bodies, so solutions such as vegetated filter strips or silt fences can be installed to prevent the sediments from being deposited into any nearby water bodies.

Additionally, in places with high water flow, it can be beneficial to place a culvert or other water directing system under the trail in order to redirect water under or around the trail and prevent large amounts of water from impacting the sediment. The installation should not impact where runoff water would naturally go, before the trail was there to influence its path. Designing the trail with these factors in mind will not only increase the sustainability and lessen environmental impact, but will also decrease the amount of maintenance that will be needed in order to maintain the trail's condition.

Finally, it is important that a maintenance plan is created and followed by the trail owner. This plan should include what factors may change on a relatively frequent basis, negatively affecting the trail's overall health. It should also address the recommended ways to fix these problems, such as removing piled sticks or gravel from the path.

3.0 Methodology

The purpose of this project is to expand the network of recreational trails in Sturbridge by connecting the Commercial Tourist District to the Grand Trunk Trail. This will promote tourism and a more active lifestyle among the community and visitors. The methodology will help to give a comprehensive understanding of both trail design best practices and design criteria.

The goal of this project is to design a trail system connecting the Sturbridge Commercial Tourist District to the existing local trails network in the Riverlands area to encourage residents and visitors to engage in outdoor recreation in Sturbridge, MA. The objectives to meet this goal have been identified as:

1. Identify design criteria and constraints
2. Design multiple options and evaluate
3. Finalize design and draft maintenance plan

This chapter will describe the approach to research and analysis methods for each objective. This is intended to show the steps that will be taken to complete this project and the rationale behind them.

3.1 Objective 1: Identify design criteria and constraints

This objective will provide the framework and general requirements for the design of the trail system. Through its completion, the requirements, limiting factors, and best practices for the design will be identified.

3.1.1 Identify the problem and goal

The first step in project initiation is to communicate with stakeholders, and develop goals and objectives that align with the intention of the Town of Sturbridge.

3.1.2 Evaluate existing conditions of the site and surrounding areas

In order to identify restricting factors, the GIS data and town maps will be compiled. Parcels of land on the property have certain protections and need to get approval before anything can be developed on the land. Using town documents and internet research, the team will make sure that all potential trail delineations will be on the town of Sturbridge's property. There are historic landmarks within the land such as Tantiusques that will affect initial delineations.

Topography, soil types and drainage patterns will be analyzed as part of the current site conditions. GIS data can be used to show the existing contours of the area including the slopes as well as data on types of soil present. This information can be used to estimate drainage patterns on the site. Site visits will provide any information that GIS is lacking.

Additionally research will be conducted on environmental concerns such as the contamination site, conservation restrictions, and existing obstructions, such as boulders and large trees.

3.1.3 Identify general best practices for trail design and design criteria

Content from manuals and other publications of trail design best practice will be integrated into the initial delineations. These examples will provide insight on strategies that have been proven to be effective. Combining these practices with the Town's specifications will generate the design criteria.

3.2 Objective 2: Design multiple options and evaluate

This objective will provide initial options for the path and construction of the trails. These options will then be evaluated and brought to stakeholders for review, and a design to move forward with will be chosen.

3.2.1 Create options for delineation

Multiple delineations will be created based off of information from GIS files, through sketches in ArcMap of paths that would satisfy initial design criteria. Factors that may limit trail location will include existing grades, property boundaries and any environmental concerns. Once potential delineations are chosen, a site visit will verify that the options are practical, as well as potentially provide greater insight and more options.

3.2.2 Evaluate and score each option based on design criteria

Using the chosen design criteria, a design matrix will be created for evaluating the delineation options. This will provide a numerical ranking system for how well each delineation meets the criteria. The top results from the design matrix will be considered for a final design. Multiple options will be presented to the stakeholders for review and feedback, and one option will be selected to move forward with.

3.2.3 Design cross section for selected option

After collecting feedback from the stakeholders, cross sections will be designed for the selected option. These drawings will be computer generated, and include the specifications for the trail such as grading, width, and outlines of potential construction items. This will give the stakeholders a visual representation of the trail design before construction.

3.3 Objective 3: Finalize design and draft maintenance plan

This objective will provide the town with a complete design package that includes a delineation, cross sections of the trail, methods of stormwater management, and a maintenance plan. This will allow the town to easily implement the design, as well as have the ability to maintain and preserve the trails.

3.3.1 Determine an appropriate method for stormwater management

In order to design a proper solution for any potential issues with stormwater, all sources of stormwater and runoff along the chosen trail delineation will be identified. A combination of on-site observation of potential at-risk areas and a water flow analysis based on the contours in the area will determine where runoff water starts and ends its course, as well as the volume of stormwater generated by various sized storms. The analysis will also include an impact assessment of how the implementation of the trail would interact with the current stormwater flow in the area. Best practices in stormwater management will guide the selection process for the most appropriate management strategy. The selected strategy will then need to be designed to fit the size of storm required by the zoning laws.

3.3.2 Adjust delineation and cross section if needed

Based on the stormwater analysis, it may be necessary or beneficial to adjust the trail delineation slightly. In the case that an adjustment in the path can solve a major stormwater issue, that will be considered. Another available solution would be constructing a stormwater management system, such as a culvert under the trail. This would result in a new cross section design for the area, including the culvert or other solution. Additionally, trail grade could be adjusted slightly to change the runoff water's behavior.

3.3.3 Finalize design and get town feedback

To finalize the design, every constraint will be reconsidered to ensure that the design satisfies the project's criteria. Afterwards the design will be presented to the Town and Trails Committee again to gather further feedback on the project as a whole, and receive recommendations for improvements. This presentation will include visuals of the design, including its path, cross section, storm water features, and any other features deemed necessary for the design.

3.3.4 Draft maintenance plan

After receiving and adjusting to town feedback, a maintenance plan will be created based upon the final design. This will involve any routine maintenance that may be necessary, such as clearing branches and removing debris. Also, it will include any maintenance that may be required after major storms, flooding, or other atypical events.

3.4 Project Schedule

Figure 5 indicates the intended project timeline. The timeline is divided into three terms, and approximately divided by the objectives stated in the methodology.

Figure 5: GANTT chart with schedule outline

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Appendix B: Site Visit Reports

MQP Site Visit: Sturbridge Trails

Site Visit Conducted By:	All group members (Lindsey, Andy, Kyle, Sarah, Prof. LePage, Prof. Albano)
Date:	9/5/19
Time in:	10:30am
Time Out:	12:20pm
Location:	301 Main Street, Sturbridge MA

Data Collected:

Reason for Visit:	Introduction to project and potential resources, an introductory tour of the site.
Questions Asked:	1. What is your goal/vision for this project? a. Why do you want to expand the trail? b. Who should we be coordinating with? c. What are your current/ideal consumers (Age, class, etc) d. Anything specific that you want the trail to connect- points of interest, other trails, etc e. History of the development of Sturbridge Trails 2. What are the demographics/zoning of the land surrounding the park? a. Are there any specific zoning rules we need to know about? 3. Are there any soil conditions we should consider? a. Is there any potential contamination in the area? b. Are there any protected species to be mindful of? 4. Do you have Cad/ GIS maps available? / original files of the maps on trails website
Questions Answered:	1. We received their planning documents explaining their goals a. To connect two sections of trails b. Mainly through Tom, will direct to any resources we might need c. Tourists and residents d. Yes, see 1a e. Answered in planning docs

	2. Commercial district, town conservation V zoning
	    a. none
	3. Yes, old mill with contamination, regular flooding, was a gravel mine
	    a. Yes, discharge from textile mill
	    b. A mussel in the river
	4. Yes, contact someone

Observations:	• We saw examples of how the current trails are designed to distribute water to prevent flooding. • We also saw where there has been drainage issues on the property.
Additional Notes:	Tom seems very knowledgeable in the area and will be a great resource to speak to in the future.

MQP Site Visit: Sturbridge Trails

Site Visit Conducted By:	Sarah Butts, Kyle Hanrahan, and Lindsey Hamlett
Date:	10/27/2019
Time in:	10:00 am
Time Out:	2:30 pm
Location:	52 Stallion Rd to Holland St

Data Collected:

Reason for Visit:	To collect data in the field and mark areas of concern on our GPS. Hiked from existing trail starting at Stallion Hill Rd to Holland road and back exploring different elevation alternatives.
Questions Asked:	1. Can we construct an 8 foot trail through this area? 2. Where on the trail will stormwater management create the most issues? 3. What are obstacles that can't be seen with GIS data? 4. How steep are the ridges?
Questions Answered:	1. The area closer to the river is very grown in and would require clearing trees to create this space. However higher up on the hill the trees are much more spaced out and could support the trail width with minimal environmental impact. 2. We were able to create tags using the GPS throughout the trail. We named each tag and took pictures of areas of concern. Most tags were in lower elevations closest to the river. 3. There is a large amount of dead trees in the woods area that would need to be cleared for design and aesthetic purposes. We also marked spots where large rocks could impact the direct delineation. 4. As we walked along the contours we were able to gather data on the elevation change. The ridges were steep but if you got to the top it was relatively flat.
Observations:	If we were to design on the higher elevations we may need to make cuts into the hill which will have environmental and stormwater

	impacts. Choosing the lower elevations would require tree clearing and more complex stormwater design. The higher elevations also had more aesthetically pleasing lighting and spacing. It was more enjoyable to walk through than the dark shaded lower side.
Additional Notes:	Many places in lower elevations were not solid and very mushy. It would be most beneficial to avoid these areas. We found signage for a petroleum pipe where we met with Holland Rd.

MQP Site Visit: Sturbridge Trails

Site Visit Conducted By:	Lindsey Hamlett
Date:	11/2/2019
Time in:	11:00
Time Out:	2:00
Location:	52 Stallion road to 55 Holland Rd

Data Collected:

Reason for Visit:	To hike our drafted delineations after our initial visit. Based off the data from the first visit the team developed another delineation to help us gather more data on the land.
Questions Asked:	a. What environmental constraints are present? b. Which of the two delineation elevations given would be best for trail placement?
Questions Answered:	a. The area of woods is full of dead trees that have fallen and make it difficult to navigate through the woods and staying on the exact delineation we have planned. The area covered on this visit also has parts with large boulders and parts with many small rocks. b. The higher elevations were easier to walk through and had a better view of the forest than the delineation at the lower elevation. The trees were more spaced out and less trees would need to be cut during construction to fit the size trail required.
Observations:	During the next visit we need to determine the importance of the rock wall and if there is a side that we need to stay on. Also if we need to cross it are the rocks secure to walk on? Is it safe or would we need to avoid crossing?
Additional Notes:	The data collected during this site visit will help to model the land as accurately as possible.

MQP Site Visit: Sturbridge Trails

Site Visit Conducted By:	Lindsey Hamlett and Andrew Hubina
Date:	11/09/19
Time in:	10:30 am
Time Out:	2:00 pm
Location:	52 Stallion road to 55 Holland Rd

Data Collected:

Reason for Visit:	To hike additional trail delineations. Both delineations will be used to gain more data points to important into Civil 3D to create a surface.
Questions Asked:	a. What environmental constraints are present? b. Which of our current dilenations are the most feasible moving forward?
Questions Answered:	a. There are multiple locations throughout the area with fallen trees and large boulders. Along the delineations there are small streams that carry stormwater runoff. Each of these concerns were marked in the GPS as waypoints. b. The higher elevations have remained as the better option for trail placement. These options have less stormwater concerns and will be easier for clearing.
Observations:	Throughout the open space there are areas with fallen trees, large boulders and small runoff streams. Each of these will need to be considered in our final design proposal.
Additional Notes:	Pictures were taken at each of the waypoints to better record the concerns.

Appendix C: Materials Calculations

Project

Sheet ___ of ___

Date

Subject Spread Fill from Stockpile Aggregate Prepared by

General Fill ~~Spr~~ Pg 229

Spread Fill, From Stock Pile with 2-1/2 C.Y. F.E. loader; 130 HP, 300' Haul

Crew 10-P: 1 Equip Oper, 0.5 Laborer, 1 Crawler Loader (3 C.Y.)

Daily Output: 600 L.C.Y per day

Labor Hours: 0.020 Hours per L.C.Y

2009 Bare Costs

Labor: $0.76 / L.C.Y

Equipment: $1.65 / L.C.Y

Total: $2.41 / L.C.Y

Project Has 76,032 L.C.Y of Material or 2,816 LCY

~~76,032 × 2.41 = $183,237.12 to move from stock pile to trai~~

Cost: 2,816 × 2.41 = $6,786.56 to move from stock pile to trail

Project

Sheet ___ of ___

Date

Subject: Hauling options for Aggregate

Prepared by

Hauling Pg 232

12 CY truck, Cycle 30 Miles, 35 MPH Avg, 15 minute wait/Ld/UnLD

Crew: B-34B: 1 Truck Driver, 1 Dump Truck (12 CY, 400 HP)

Daily Output: 84 L.C.Y. per day

Labor Hours: 0.095 Hours per LCY.

2009 Bare Costs

Labor: $3.04 / LCY

Equipment: $6.35 / LCY

Total: $9.39 / LCY

Project Has 76,032 L.C.F of Material or 2816 LCY

~~76,032 × 2.41 · 9.39 = $713,940.48 to haul material to site~~

Cost: 2,816 × 9.39 = $26,442.24 to haul materials to site

---

12 CY, Cycle 30 miles, 40 MPH, 15 min Wait/Ld/UNLD

Crew: B-34B 1 Truck Driver, 1 Dump Truck (12 CY, 400 HP)

Daily Out Put: 96 LCY/Day

Labor Hours: 0.083 Hours per LCY

2009 Bare Costs

Labor: $2.66 / LCY

Equipment: $5.55 / LCY

Total: $8.21 / LCY

Project has 76,032 LCF of Material or 2,816 LCY

~~76,032 × 8.21 = $624,222.72~~

Cost: 2,816 × 8.21 = $17,947.06 to haul materials to site

Project

Sheet ____ of ____

Date ____

Subject: Compaction for Aggregate

Prepared by ____

Compaction Pg ~~248~~ 247

~~Walk behind, vibrating plate 18" wide~~

Riding, vibrating roller, 6" Lifts, 2 passes

Crew B-10Y: 1 Equip Oper, 0.5 Laborer, 1 vibr. Roller, Towed, 5 tons

Daily output: 3000 ECY per Day

Labor Hours: 0.004 ~~E.C.Y.~~ Hours per E.C.Y.

2009 Bare Cost

- Labor: \$0.15 per ECY
- Equipment: \$0.16 per ECY
- Total: \$0.31 per ECY

This project has 76,032 ECF or 2,816 ECY

~~76,032 × 0.31 = \$ 23,569.92 for compaction~~

Cost: 2,816 × 0.31 = \$872.96 for compaction

Project

Date

Subject Stripping Topsoil Pavement

Prepared by

Topsoil Stripping And Stockpiling pg 211

Loam or Topsoil, remove and stockpile on site 6" Deep, 200' Haul

Crew B-10B: 1 Equip Operator, 0.5 Laborer, 1 Dozer 200 H.P.

Daily Output: 865 CY per Day

Labor Hours: 0.014 Hours per CY

2009 Bare Costs

Labor: $0.53 per CY

Equipment: $1.25 per CY

Total: $1.78 per CY

Project has 76,032 CF of Stripping or 2,816 CY

~~Cost: 76,032 × 1.78 = $135,336.96 for stripping topsoil~~

Cost: 2,816 × 1.78 = $5,012.48 for stripping top soil

Project

Date

Subject Hauling For Pavement

Prepared by

Hauling Pg 232

12 CY, Cycle 30 miles, 40 MPH, 15 Min Wait/LD/UNLD

Crew: B-34B

Daily Output: 96 LCY/Day

Labor Hours: 0.083 Hours/LCY

2009 Bare Costs

Labor: $2.66/LCY

Equipment: $5.55/LCY

Total: $8.21/LCY

Project Has 28,512 LCF of Asphalt or 1,056 LCY

Cost: 1,056 × 8.21 = $8,669.76 to haul Asphalt to site

Project Has 57,024 LCF of Stone Subbase or 2,112 LCY

Cost: 2,112 × 8.21 = $17,339.52 to haul gravel subbase to site

Total Cost: $8,669.76 + $17,339.52 = $26,009.28 to haul materials

Sheet ____ of ____

Project ____________________ Date ____________

Subject Subbase + Paving for Pavement   Prepared by ____________

Asphaltic Concrete Paving 6" Stone Base, 2" Binder Course, 1" Topping pg 277

Crew: B-25C 1 Labor Foreman, 3 Laborers, 2 Equip Operators, 1 Asphalt Paver, 1 Tandem Roller

Daily Output: 9,000 ft^2 per Day

Labor Hours: 0.005 hours per ft^2

2009 Bare Costs

Labor: ~~$0.01~~ $0.19 per ft^2

Equipment: $ 0.24 per ft^2

Total: $0.43 per ft^2

Project has 114,048 ft^2 of paving surface

Cost: 114,048 × 0.43 = $ 49,040.64 to pave trail

Sheet ____ of ____

Project ____ Date ____

Subject Clearing for Aggregate + Pavement Prepared by ____

Clear and Grub Site
Cut and Chip medium, trees up to 12" Diameter

Crew B-7: 1 Labor Foreman, 4 Laborers, ~~1 S.P. Crane (4x4, 5 ton)~~, 1 Equip Operator,
1 Brush Chipper (12", 130 H.P.), 1 Crawler Loader, 2 Chainsaws (Gas, 36" Long)

Daily Output: 0.70 Acres per Day

Labor Hours: 68.571 Hours per Acre

2009 Bare Costs
Labor: $2,300 per acre

Equipment: $ 1,850 per acre

Total: $ 4,150 per acre

This project has 114,048 ft² of clearing or 2.62 acres

Cost: 2.62 × 4,150 = $10,873 for clearing

Project

Sheet ______ of ______

Date ______

Subject: Subgrading for Aggregate and Pavement   Prepared by ______

Finish Grading

Grade subgrade for base course, roadways

Crews B-11L : 1 Equiptment Operator, ~~0.5 Laborer~~, 1 Laborer, 1 Grader 30,000 lbs

Daily Output: 3,500 SY per day

Labor Hours: 0.005 Hours per SY

2009 Bare Costs

Labor: $0.17 per SY

Equiptment: $ 0.16 per SY

Total: $0.33 per SY

This project has 114,048 ft^2 of surface or 12,672 SY

Cost: 12,672 × 0.33 = $ 4,181.76

Project

Subject Price Adjustment for Aggregate + Pavement Prepared by

Cost Adjustments

Aggregate 2009 Cost: $40,661.34

Cost Index for 2009 = 180.1
Cost Index for 2020 = 239.1

$\frac{180.1}{239.1}$ × Cost in 2020 = 40,661.34

Cost in 2020 = $53,981.82

Pavement Cost in 2009: $95,117.16

Cost Index for 2009 = 180.1
Cost Index for 2020 = 239.1

$\frac{180.1}{239.1}$ × Cost in 2020 = 95,117.16

Cost in 2020 = $126,277.14

Appendix D: Stormwater Calculations

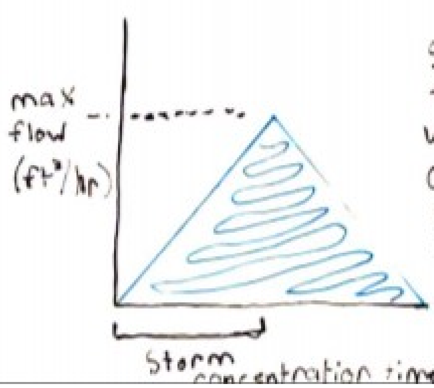
Storm water Calculations Using rational method

$Q_p = ciA$ — Q_p: peak flow (cfs); C = runoff coefficient = assumed (; I = rainfall intensity (in/hr); A: Area of contributing watershed (acres)

Section #

1. $Q_p = 0.35 \times \frac{5.3 in}{1 day} \times \frac{1 day}{24 hr} \times 229{,}870 ft^2 \times \frac{1 acre}{43{,}560 ft^2} = 0.41$
2. $Q_p = 0.35 \times \frac{5.3}{1} \times \frac{1}{24} \times 355{,}610 ft^2 \times 1/43{,}560 ft^2 = 0.63$
3. $Q_p = 0.35 \times \frac{5.3}{1} \times \frac{1}{24} \times 477{,}635 \times 1/43{,}560 = 0.85$
4. $Q_p = 0.35 \times \frac{5.3}{1} \times \frac{1}{24} \times 765{,}600 \times 1/43{,}560 = 1.36$
5. $Q_p = 0.35 \times \frac{5.3}{1} \times 1/24 \times 366{,}500 \times 1/43{,}560 = 0.65$
6. $Q_p = 0.35 \times \frac{5.3}{1} \times 1/24 \times 437{,}930 \times 1/43{,}560 = 0.78$
7. $Q_p = 0.35 \times \frac{5.3}{1} \times 1/24 \times 662{,}805 \times 1/43{,}560 = 1.18$
8. $Q_p = 0.35 \times \frac{5.3}{1} \times 1/24 \times 872{,}865 \times 1/43{,}560 = 1.55$

Then, create synthetic hydrograph



Solving for A under curve gives volume

$V_{max} = 0.65 \times 0.30 \times 3600$
$= 702 ft^3$

Manning's eq. Solving for conc. time

section 5

first 300' $T_{T_1} = \frac{.007((0.4)(300))^{0.8}}{(3.0)^{0.5}(0.6)^{0.4}} = 0.23$

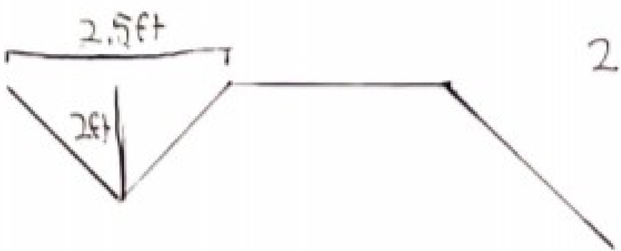
remaining 1100' $T_{T_2} = \frac{1100}{3600(4.2)} = 0.07$

Time of concentration = 0.30 hrs

Sizing Ditches: need larger ditch for sections 1, 3, 5, 7

Large size:

max volumes:	divided by	Section W	= cross section size (ft^2)
1. 440.51 ft^3		400 ft	= 1.10
3. 915.30 ft^3		500 ft	= 1.83
5. 702.33 ft^3		297 ft	= 2.36
7. 1,270.15 ft^3		688 ft	= 1.85



2.36 ft^2 necessary
2.5' wide
2ft deep

Appendix E: Inspection Sheets

The Sturbridge Trails Committee   treksturbridge@gmail.com

Spring Inspection Sheet

TO: Trail Inspector

Please submit completed form to The Sturbridge Trails Committee. Spring inspections should be completed and submitted before Memorial Day.

Name of Trail: ________________________   **Report Date:** ____________________

Name of Inspector: ____________________   **Phone Number:** __________________

Areas of Concern

- Fallen trees or limbs on trail.
- Overgrown vegetation inside clearing limits.
- All trail signage is in place and easy to read.
- Signs of water on trail or drainage concerns. If drainage ditches are overflowing, dig deeper as necessary.
- Make a list of larger jobs and the tools they will require.
- Schedule a plan to perform this work.
- Pick up all litter.

Location	Type of Problem	Severity (Low, Medium, High)	Additional Notes

Additional Notes:

____
____
____
____

Mid-Summer Inspection Sheet

TO: Trail Inspector

Please submit completed form to The Sturbridge Trails Committee. Spring inspections should be completed and submitted by the second Friday of July.

Name of Trail: ________________________ **Report Date:** ____________________

Name of Inspector: ____________________ **Phone Number:** __________________

Areas of Concern

- Remove all vegetation on trail way. This may need to be done more frequently depending on growth rate.
- Prune all brush and limbs growing into the clearing limits.
- All trail signage is in place and easy to read.
- Signs of water on trail or drainage concerns. If drainage ditches are overflowing, dig deeper as necessary.
- Updates on larger jobs identified previous inspection.
- Clean and maintain all drainage structures.
- Pick up all litter.

Location	Type of Problem	Severity (Low, Medium, High)	Additional Notes

Additional Notes:-

____
____
____
____

Fall Inspection Sheet

TO: Trail Inspector

Please submit completed form to The Sturbridge Trails Committee. Spring inspections should be completed and submitted by Halloween.

Name of Trail: ________________________ **Report Date:** ____________________

Name of Inspector: ____________________ **Phone Number:** __________________

Areas of Concern

- Ensure larger jobs will be complete before winter.
- Clear trail way of fallen trees, limbs and leaves.
- Overgrown vegetation inside clearing limits.
- All trail signage is in place and easy to read.
- Clean and maintain all drainage structures. If drainage ditches are overflowing, dig deeper as necessary.
- Pick up all litter.

Location	Type of Problem	Severity (Low, Medium, High)	Additional Notes

Additional Notes:-

____

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Post Storm Inspection Sheet

TO: Trail Inspector

Please submit completed form to The Sturbridge Trails Committee. Spring inspections should be completed and submitted 1 week after major storms when the trail is in use.

Name of Trail: ________________________ **Report Date:** ____________________

Name of Inspector: ____________________ **Phone Number:** __________________

Areas of Concern

- Trail surface is not damaged from rainfall.
- Signs of water on trail or drainage concerns. If drainage ditches are overflowing, dig deeper as necessary.
- Clear trail way of fallen trees or limbs.
- All trail signage is in place and easy to read.
- Pick up all litter.

Location	Type of Problem	Severity (Low, Medium, High)	Additional Notes

Additional Notes:-

____

____

____

____

Appendix F: Worker Hour Tracking Sheet

The Sturbridge Trails Committee   treksturbridge@gmail.com

Work Tracking Sheet

TO: Labor Supervisor

Please submit completed form to The Sturbridge Trails Committee in a timely manner. All work should be recorded as accurately as possible for future reference.

Name of Trail: ________________________   **Report Date:** ____________________

Name of Labor Supervisor: ____________________   **Phone Number:** __________________

Location of Work	Short Description of Work (include tools and equipment used)	Number of Workers	Time Spent Working	Total Worker Hours

*Total worker hours= Number of Workers x Time Spent Working

Additional Notes:
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____
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____
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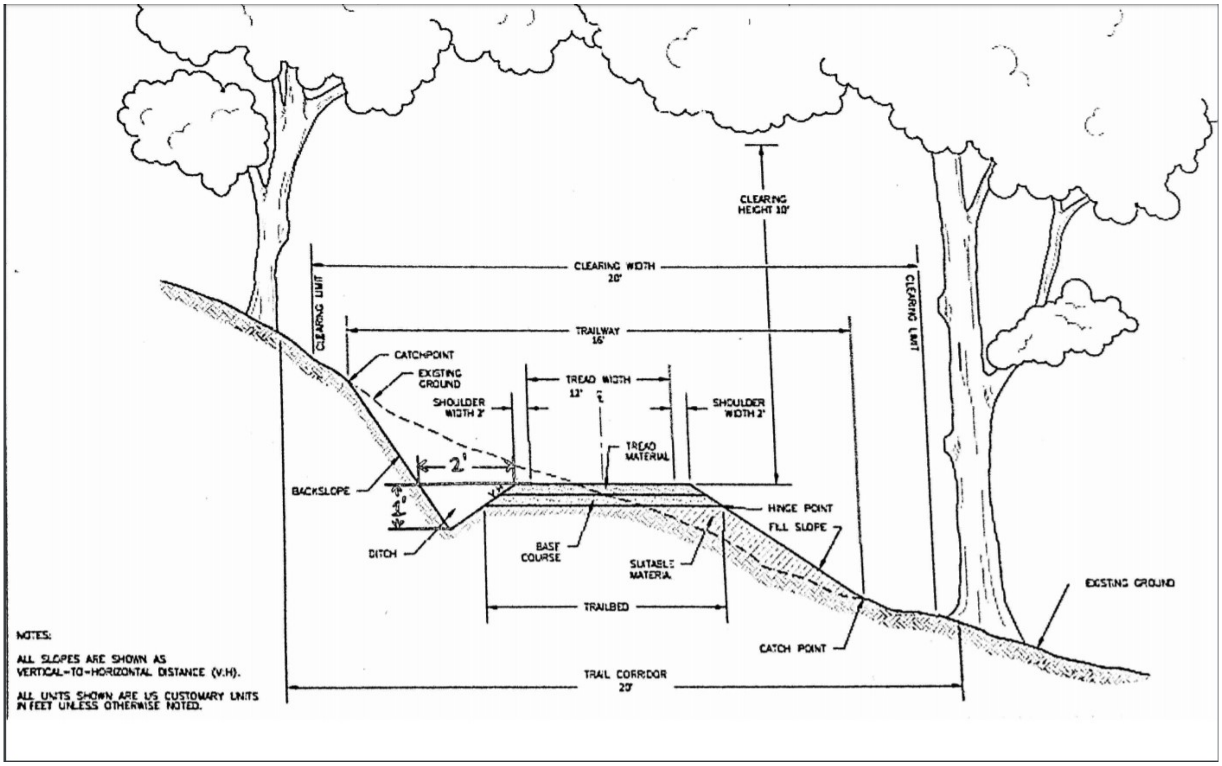
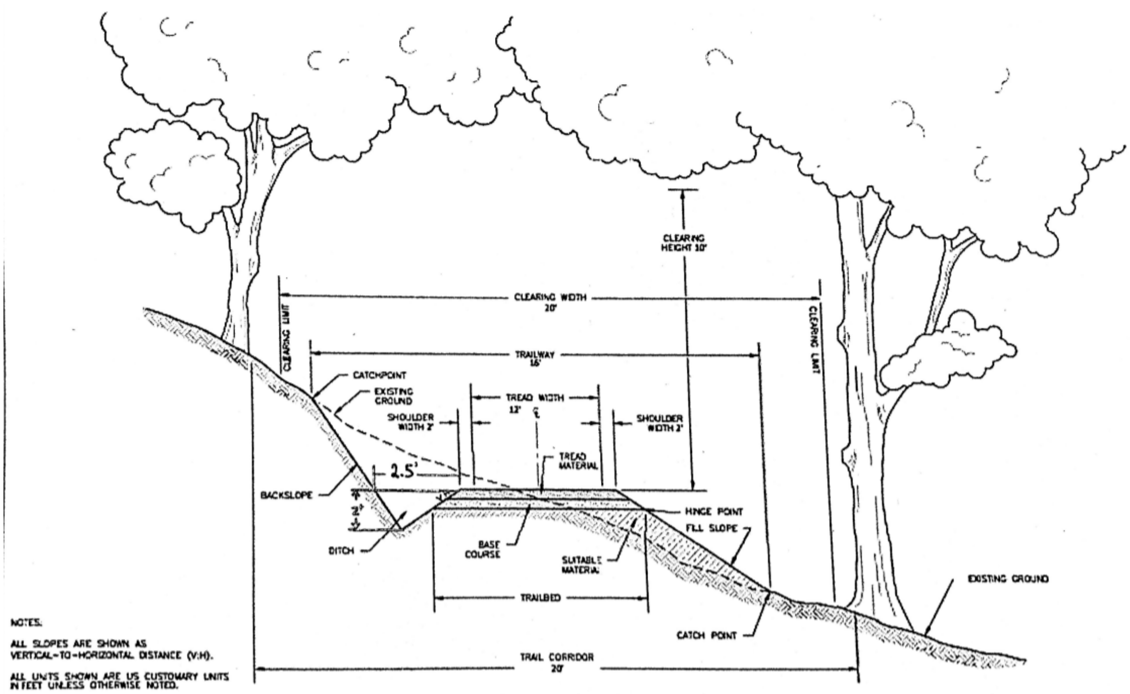
Appendix G: Cross Sections for Inspections





Appendix H: Town Feedback Data

Town Feedback - Delineations						
Aesthetics	Connectivity	Construction Requirements	Cost	Environmental Impact	Sustainability	Usability
4	4	2	1	5	5	3
4	5	3	3	5	4	5
4	5	4	4	5	4	4
5	5	2	1	1	5	3
5	5	3	3	5	4	4
5	4	4	4	5	5	5
2	1	5	5	4	4	5
5	3	4	5	5	3	5
5	5	3	5	5	5	5
4	4	3	3	5	5	4
5	5	4	4	4	5	5
2	4	4	4	3	4	3
4.17	**4.17**	**3.42**	**3.50**	**4.33**	**4.42**	**4.25**

Town Feedback - Materials						
Aesthetics	Connectivity	Construction Requirements	Cost	Environmental Impact	Sustainability	Usability
4	3	3	1	5	4	3
4	5	3	3	5	5	5
3	3	3	3	5	5	5
5	5	5	3	5	5	3
5	5	4	3	5	4	5
4	4	5	5	5	4	5
3	1	5	4	4	4	5
3	3	2	4	5	5	4
3	3	4	5	5	4	5
2	3	3	3	4	3	3
5	5	4	4	4	4	5
3	5	4	5	4	5	4
3.67	**3.75**	**3.75**	**3.58**	**4.67**	**4.33**	**4.33**

Town Feedback - Steep Slopes						
Aesthetics	Connectivity	Construction Requirements	Cost	Environmental Impact	Sustainability	Usability
4	4	2	1	5	4	5
4	5	3	3	5	3	5
5	5	3	3	5	5	5
5	5	5	3	5	5	3
4	5	4	3	5	4	4
4	4	5	5	5	5	5
1	1	5	3	4	5	5
5	4	4	5	5	5	5
4	4	3	5	4	5	5
3	4	3	4	4	4	3
4	5	4	4	4	5	5
3	4	5	5	3	4	4
3.83	**4.17**	**3.83**	**3.67**	**4.50**	**4.50**	**4.50**