Burncoat Ln Leicester, MA

Designing Paving Solutions for an Unpaved Private Road

By Clara Dublin and Shannon Logan

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Burncoat Ln Leicester, MA
Designing Paving Solutions for an Unpaved Private Road

A Major Qualifying Project Report

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By:

Clara Dublin

Shannon Logan

Report Submitted To:

Project Sponsor:

Mr. Kyle Bourque

Burncoat Ln Road Committee

Project Advisor:

Associate Professor Dr. Aaron Sakulich

Worcester Polytechnic Institute

Abstract

Burncoat Lane is a private, unpaved road demonstrating issues with drainage, freeze-thaw, and rutting. We identified solutions to address the current conditions and future maintenance of the road. We completed a road survey, explored private road regulations, and designed a decision matrix to compare possible solutions. We recommend fully paving the road as it has the longest lifespan, least required maintenance, and minimal environmental impact. We explored less expensive options, but they would require more upkeep from the road's residents.

Acknowledgments

The success of our project would not have been possible without the enthusiasm, dedication, and support of many groups of people. We have many people to thank for their help throughout this seven-month project.

First, we would like to thank our host, Mr. Bourque, and the Burncoat Lane Road Committee and residents. Mr. Bourque frequently made time in his schedule to meet with us to answer questions, supply his own experiences, and connect us with further areas to explore. We would also like to thank the residents of Burncoat Ln, who were extremely generous with their sharing of their street for our project. Many residents stopped us during our survey to ask about the project, about our thoughts and experiences, and about any help they could provide. The guidance and eager involvement by our host and our street made this project a success.

Second, we would like to thank the local contractors and realtors who worked with us throughout this project. A major component of our research was understanding the feasibility and economics behind our solutions, so the input we received from local professionals in these fields was invaluable. We appreciate their time, thoughtful feedback, and generosity.

Finally, we would like to thank our advisor, Professor Aaron Sakulich, for his support and unwavering dedication to this project's success. His contributions were vital to the development of our methods and the analysis of our results, helping us to create a strong and effective tool for future unpaved private road maintenance.

Authorship

The two students conducting this study worked closely together through all stages of the project, from initial methods to final report compilation. Work was shared evenly between both students, but specific leadership undertaken by each student is detailed below.

Clara Dublin was primarily responsible for conducting background research about unpaved roads and their health and environmental effects, investigating soil classification information, collecting research on gravel stabilization grids, and report drafting and editing.

Shannon Logan was primarily responsible for interacting with local contractors and realtors, compiling their feedback into cost and material feasibility analyses, researching commercially available equipment, and report drafting and editing.

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Executive Summary

According to the Federal Highway Administration, almost 35% of the roads in the United States are unpaved (Federal Highway Administration, n.d.). While these roads work well for some communities, others located in more extreme weather regions experience issues throughout the year arising from their unpaved roads, including negative environmental and health impacts. Runoff from unpaved roads can smother water habitats and accumulate in streambeds to make future flooding worse (Strayer, 2012). In dry seasons, airborne particles kicked up from vehicle traffic can cause many adverse health effects in those who inhale them (Khan and Strand, 2018). Finally, unpaved roads can have significant economic impacts on the vehicles driving on them, as the high demands for tires and other maintenance costs are paid for by the roads' users.

Burncoat Lane, located in Leicester, Massachusetts, is a private unpaved road that experiences many of the issues detailed above. New England weather causes enduring issues with drainage and freeze-thaw damage. The current solution is a biannual re-grading of the road surface with recycled asphalt millings provided by the Leicester Highway Department. This practice is supplemented with pothole filling with the excess millings as needed. All this work is done voluntarily by residents who own heavy equipment, but the maintenance is time and labor-intensive. The purpose of our project was to design a series of possible solutions to address the current conditions and future maintenance of Burncoat Ln and to then present our recommendations to the residents for their consideration.

Methods

To design these solutions, we formed three objectives: first, to complete a detailed survey of Burncoat Ln, second, to explore town regulations regarding private ways, and third, to suggest possible paving and drainage solutions for Burncoat Ln based on pros, cons, and cost.

To survey the road's geometry and current conditions, a steel tape was used by each member along opposite edges of the road to place flags at 75-foot increments. Then, the "Coordinates - GPS Formatter" app was used to record each flag's latitude, longitude, and elevation, and the steel tape was used to determine the road's width at that point. This procedure was followed for three trials. In addition to collecting these data, the total number of potholes was roughly tallied, with each pothole being classified as either "Minor" or "Major". The severity of

each pothole was evaluated using its depth, diameter, and an estimate of how vehicles would fare driving over it. The survey results allowed us to highlight areas of interest and use accurate values in the following analysis.

We also investigated the possible effects that town regulations regarding paving and private roads could have on solutions. To do this, state and town regulations regarding pavement materials and best practices relating to the upkeep of private roads were researched in the Town of Leicester website, the town clerk's page, and the transportation by-laws.

Finally, we combined all the previous data with thorough research on common paving and drainage solutions, which we accumulated from scholarly articles and by conducting interviews with pavement engineering professors, local paving contractors, and local realtors. Soil samples identified from Burncoat Ln in the USDA's National Cooperative Soil Survey were also used to identify the soil types present and to research their properties to specialize design. After compiling a list of possible solutions, quantitative parameters for each were defined. Those parameters were then compared to survey data and soil conditions to eliminate any that were not feasible. The remaining solutions were then placed in a weighted decision matrix aligning with the priorities of the Burncoat Ln Road Committee and assigned a series of scores. Two separate decision matrices were also created with alternative factor weights that reflected focuses on performance and environmental impact respectively. The total score for each solution was calculated by multiplying each criterion score with its corresponding weight, then finding the sum of those weighted scores.

Key Findings

Survey data were used to find the key geometric characteristics of the road. The length was found to be 0.68 miles, and it had large ranges in width, spanning from 11.6 feet to 53.4 feet, with an average width of 16.6 feet. This disparity makes reliable navigation difficult, to the point where two cars cannot pass each other in certain areas. The data were manipulated in three different ways to determine the average area of the road, yielding approximately 59,254 square feet. Additionally, the severity of the road's condition was also measured by its potholes. There were 508 potholes in total, with 361 deemed "Major", 191 deemed "Minor", and one deemed "Extreme".

We determined there were not many town regulations regarding how private roads must be maintained, aside from that they must be accessible to emergency vehicles. The town is not responsible for the maintenance of private roads, detailed in the *Town of Leicester General By-Laws.*

Based on the results from the previous objectives and extensive research into drainage and freeze-thaw, various suggestions were compiled to present to Burncoat Ln residents. Most of the road's soil has poor drainage with moderate to very high runoff, so we took this into consideration when curating our solutions. We narrowed our pool of options into four final recommendations compatible with Burncoat Ln's conditions, with each possessing different trade-offs in terms of cost, lifespan, ease of maintenance, etc. The four options are:

1. **Reshaping the road**

As the most cost-efficient option, either a rolling dip or grade break system would work best for Burncoat Ln's characteristics. The final decision between the two options would be up to residents based on trade-offs in the materials and equipment needed.

2. **Hiring a contractor to supply and compact their own millings**

Working with a contractor would allow greater customization of the aggregate mix, allowing for a higher ratio of "fines", which would increase the compatibility and, therefore, the lifespan of the road. According to one contractor, this would cost approximately $25,000 and last three to five years by itself or 15 to 20 with constant maintenance.

3. **Hiring a contractor to pave the road with asphalt**

While this was the most expensive option, the many advantages include its ease of maintenance, low recurring costs, and best benefits to current conditions. Further, paving eliminates dust concerns and minimizes environmental impacts from surface runoff. Finally, it can lower vehicle operating expenses, increase road safety, and benefit economic development of the area. This could cost $120,000, and last 20 years if it was a standalone project or 30 to 40 years if maintenance is kept up.

4. **Installing a gravel stabilization grid**

This grid reinforcement system filled by millings in the cell voids would act as reinforcement for the road base and allow for water to drain off the roadway. By creating a "slab effect" on the road, the stress from vehicle wheels would be spread over a much wider area, rather than loading going straight into the road at a point. This method would likely cost between $160,000 to $200,000.

When the four options and the control were scored and weighted with the host's priorities, hiring a contractor to pave the road scored the highest. The same options and ratings were input into two alternately weighted decision matrices, one prioritizing performance with no cost consideration, and one prioritizing minimal environmental impact. Paving scored the highest on these matrices as well.

Additional Findings

We also compiled some additional recommendations for the residents of Burncoat Ln to consider incorporating alongside a primary solution from the options detailed above.

Our first additional recommendation, utilizing a geotextile grid, could be used in conjunction with reshaping the road or having a contractor re-grade with their own millings. A geotextile grid is a woven or non-woven permeable geosynthetic that allows shear stresses to be carried within the reinforcement of the roadbed. This improves drainage and stabilization and greatly improves force distribution throughout the road. Due to their widespread availability, they are a cost-efficient optional addition.

Another option we explored was making Burncoat Ln a public street. We determined this is, likely, not viable due to the time and evidence required to make an argument for adoption. The evidence required includes proof that the general public has regularly used the private way for over 20 years and proof it was at one point a public way. Numerous historical records must be obtained in order for a case for adoption to be considered, and we encourage the residents of Burncoat Ln to investigate their eligibility if they choose to explore this option. If this proves unsuccessful, the Road Committee can also petition the town for certain maintenance services like snow clearing.

A final recommended preventative measure that could extend the road's lifespan is to consolidate service vehicle access to the entrance of Burncoat Ln from Rawson St. Constant access from heavy vehicles (mail and garbage trucks or commercial delivery vehicles) causes more stress on the road leading to continuous material displacement, observable in the road's 508 potholes. We recommend that those service deliveries and collections be moved closer to the entrance of the road on Rawson St, preventing heavy wheel loads from constantly stressing the road surface.

Alternative funding for the implementation of these solutions was also explored. The road is ineligible for most grants due to its status as a private way. We encourage Burncoat Ln residents to explore and research this option more thoroughly.

Recommendations & Conclusions

We recommend that Burncoat Ln be fully paved, as it would produce a drivable surface likely lasting 20 or more years. Further, if an additional topcoat was applied within the first few years of paving, it could add an additional 10 to 20 years of life. While it did receive the lowest score in the decision matrix for initial cost, the maintenance costs would be very low, as the paved road would only require minor pothole patching over the years. It also has the longest lifespan of any option explored and some of the best scores for environmental impacts and positive effects on drainage and freeze-thaw.

If the residents choose to pursue a different option, there are other less expensive solutions that do not offer the same remedies as paving but still have significant benefits. The most cost-effective option is to reshape and compact recycled millings with more specialized equipment. The next most expensive option, hiring a local contractor to supply and compact their own millings into a shape that aids drainage, would be a slight improvement in terms of quality than doing it independently, but the labor and material costs would be higher. An optional supplement to either of these two solutions is installing a geotextile grid before compacting. They are widely available and can lessen rutting, encourage drainage, and reduce the amount of millings needed overall. A third alternative solution is the installation of a gravel stabilization grid. This system's dispersal of road stresses and design to promote drainage make it an advantageous alternative to paving, but it has a high initial cost and can require semi-frequent maintenance and replacement. While we still recommend paving as the best long-term solution, we can also recommend these solutions depending on the priorities of the residents and their ability to invest in long-term benefits.

These recommendations could also be applied to other roads with similar circumstances. A general guide to improving unpaved roads does not apparently exist, so this research fills a knowledge gap that other residents of unpaved roads might find helpful. The solutions contained in this report can serve as a guide for future homeowners looking to improve their private roads, or even larger-scale companies and governments looking to understand their options regarding road paving.

1.0: Introduction .

In 2012, the Federal Highway Administration reported that 1,357,430 miles of road were unpaved in the United States, accounting for almost 35% of the country's roads (Federal Highway Administration, n.d.). While these roads work well for some communities, other communities located in more extreme weather regions experience a multitude of issues throughout the year arising from their unpaved roads. Common problems include lack of drainage in wet conditions, freeze-thaw damage in cold conditions, and resulting issues with accessibility and usage.

The issues caused by unpaved roads have impacts reaching past seasonal annoyance and mess. Extensive research shows that these roads can lead to a multitude of environmental, economic, and health repercussions. Erosion into adjoining waterways smothers stream habitats, changes streams' courses (posing threats to nearby plants, animals, and infrastructure), and accumulates within the waterbody to raise streambeds, making future flooding worse (Strayer, 2012). Traversing such roads has a significant economic impact on the vehicles traveling them, as high demands for tires and other increased maintenance costs are paid for by the roads' users. Further, because most unpaved roads are privately owned, any maintenance that the road requires must be funded entirely by the residents. Finally, airborne dust particles from unpaved roads have been linked to many adverse health effects, especially in the respiratory and cardiovascular systems, of the residents surrounding them (Khan and Strand, 2018). Effects on human health are especially prevalent in dry seasons and, paired with major drainage issues in the wet seasons, they demonstrate year-round concerns for the users of unpaved roads.

Burncoat Lane, located in Leicester, Massachusetts, is a private unpaved road that experiences many of the issues detailed above. New England weather creates issues with drainage and freeze-thaw damage, and residents are growing tired of enduring these complications. Due to its status as a private way, the Town of Leicester is not required to regularly service or maintain Burncoat Lane as it would with public roads. The Town of Leicester currently deposits asphalt millings on a biannual basis, but individuals on the road are responsible for spreading the millings across the road using their own equipment. Burncoat Lane has roughly 100 residents, many of whom use the road every day, so the street must be usable and reliable year-round.

The condition of the road is central to how the residents of Burncoat Lane experience everyday life, so the goal of this project is to improve the daily conditions. The purpose of our project is to design a series of possible solutions to address the current conditions and future maintenance of the road and to then present our compilation of recommendations to the residents for their consideration.

2.0: Background

In the following literature review, we first detail a brief history of unpaved roads in the United States and how their initial design no longer aligns with their modern demands. We then discuss those demands and the many shortcomings unpaved roads have in their effects on physical and environmental health. We also provide a summary of the issues facing Burncoat Ln and important considerations for the process of developing solutions for it.

2.1 Emergence of Unpaved Residential Roads in the United States

Due to settlers' desires to expand into Western territory after the United States' independence from Great Britain in 1783, the U.S. Congress passed the Land Ordinance of 1785. Under its place in the Articles of Confederation, the Ordinance outlined the process of surveying and land sale for all territory west of the Appalachian Mountains. In the history of urban planning, it is the origin of the methods used for creating townships, grid patterns, and the roads connecting them (United States Continental Congress, 1785). The Ordinance established the one-square-mile grid pattern on which most roads built after 1785 were designed and allowed for the creation of roughly 2.3 million miles of road throughout the United States (Miller et al., 1987).

Early settlements in the Western United States were built next to streams or other water bodies due to their many advantages. Streams provided an essential water source for drinking, washing, hydrating livestock, cultivating crops, and providing hydraulic power. Streams were also used as transportation corridors for moving goods between establishments (Gesford & Anderson, 2006). Eventually, roads were constructed alongside these waterways allowing for settlements to be connected by both land and water and opening up even further networking within territories (Miller et al., 1987). Streamside terrain proved to be ideal for the construction and traversing of these road networks. Generally, the land around waterways had relatively easy slopes for horses and wagons to travel on. Footpaths became roads, which eventually began to suffer from issues with erosion and sediment degradation which affected both the road itself and the stream it ran along (Miller et al., 1987).

With automobiles emerging into the United States consumer market in the early 20th century, rural roads began to shift toward gravel surfacing in the 1920s and 1930s (Miller et al., 1987). As early as 1928, there is scientific documentation of issues with unpaved roads. One, published in *The American Association for the Advancement of Science* and titled "'Washboard' or 'Corduroy' Effect Due to the Travel of Automobiles over Dirt and Graveled Roads", reports "corrugations" developing to "considerable size" after which maintenance becomes difficult. The report goes on to juxtapose the pros and cons of gravel grading versus dirt and to say that the only option to prevent roads being ruined by "pleasure cars" is to pave entirely with concrete (Treasher & Wilson, 1928).

2.2 Common Issues Resulting From Unpaved Roads

Since the beginning of rudimentary road paving in the early 20th century, research has followed its effects on human health, environmental well-being, and road upkeep. The Federal Highway Administration has multiple projects dedicated to road dust research, with funding supplied since 2019 to develop methods for estimating and assessing road dust effects (Federal Highway Administration, n.d.). In addition to this, many national, regional, and community-oriented publications have studies on dirt roads specific to their regions. Many cover topics like health, environment, and road resilience. In this section, these three issues arising from unpaved dirt roads are reviewed.

As car engines become cleaner and electric vehicles enter more garages in the United States, the Federal Highway Administration anticipates that road dust emissions will likely become a dominant factor in the air quality of surrounding communities (Federal Highway Administration, n.d.). Road dust is composed of solid particles that become airborne primarily from the friction from moving tires against unpaved roads. In the discussion of road dust effects, "fugitive" dust is often also included, which is dust not emitted from a definable source, such as open fields, storage piles, or, in this case, roadways, adding to airborne road dust in the atmosphere to form particulate matter (PM) (Khan & Strand, 2018). The study of these particles usually begins at PM_{10}, where the diameters of particles are 10 μm or smaller and can be easily inhaled or ingested. Further dangers of ingestion come from $PM_{2.5}$ particles, which are extremely fine, 2.5 μm or smaller in diameter, and very easy to inhale (Khan & Strand, 2018).

A literature review conducted in the Epidemiol Health Journal compiled information on adverse health effects and road dust from 46 studies across seven countries. It found the respiratory system was the most affected system in the human body, and some road dust particles were even identified in human body fluids. A study conducted in Connecticut and Massachusetts determined a significant positive association between the concentration of $PM_{2.5}$ particles in road dust and hospital admissions due to cardiovascular and respiratory complications (Khan & Strand, 2018). Aluminum, platinum, palladium, rhodium, chromium, barium, copper, zinc, arsenic, bohrium, vanadium, and polycyclic aromatic hydrocarbons (PAHs) were identified in multiple independent studies (Table 2.1).

Table 2.1: Health effects referenced in studies of road dust on human health and their frequency across 46 studies in the U.S. National Library of Medicine (Khan & Strand, 2018)

Organ System	**Disease**	**Frequency**
Respiratory	Chronic obstructive pulmonary disease	1
Respiratory	Asthma	6
Respiratory	Fungal infection	1
Respiratory	Deposition in the respiratory tract	4
Respiratory	Allergy	1
Respiratory	Carcinoma	5
Cardiovascular	Emergency cardiovascular disease issues	2
Cardiovascular	Increased mortality due to cardiovascular disease	3
Other	Low birth weight	1
Other	Non-specific carcinoma	7

Unpaved roads pose more dangerous health effects than this. While road dust concentrations, particularly of $PM_{2.5}$ particles, are much higher in late spring and summer than in winter, the early spring thaw, or mud season, can also create barriers to accessing health infrastructure. Deep rutting on road surfaces and continuous plastic deformations in a muddy road can make roads impassable for emergency vehicles (Henry et al., 2005).

While health impacts are important to consider, further impacts of unpaved roads can be seen in their effects on the environment. Freshwater ecologist Dr. David Strayer said that he often encounters a misconception that unpaved roads are "greener" than paved ones (Strayer, 2012).

Many assume that unpaved roads are more permeable than pavement options like asphalt or concrete and are, therefore, better for their surrounding environment. In reality, unpaved roads are often so compacted that very little water can drain through them. Because of this, unpaved dirt roads have just as poor of an ecological record as most paved roads (Strayer, 2012).

The main environmental issue of unpaved roads is their high subjectivity to erosion. In rain events, water passes over the road, carrying sediment with it into waterways. Loose sediment poses many adverse effects to water bodies, and unpaved roads are often identified as the worst hot spots for sediment generation (Strayer, 2012). Many unpaved roads have unstable surfaces and bases, which act like dams in rain events to concentrate water flows in such a way that it accelerates the erosion of roadways and adjacent soil. Chemical contaminants from the road– including oils, nutrients, and pesticides– bind to sediment and enter the waterways (Gesford & Anderson, 2006). This resulting runoff can smother stream habitats, reducing biodiversity and eliminating sensitive species. It can also cause streams to become unstable and change course, posing a threat to plants and animals that live in or along the stream (including humans and human infrastructure). Finally, sediment can accumulate within the waterbody and raise streambeds, making future flooding worse and creating a positive feedback loop of further road erosion (Strayer, 2012).

In the New England area, the main issue that unpaved roads face is drainage. Because roadways interfere with natural systems, they naturally collect water on their surfaces. In wet weather, this accumulation increases the draining water's volume and velocity, working in tandem with erosion to ruin road conditions (Gesford & Anderson, 2006). An unpaved road's subgrade largely determines how the road will fare in wet weather (see Figure 2.1). Most unpaved roads have a subgrade of soil which, when water-saturated, greatly reduces permeability and worsens conditions on the road's surface. Issues with drainage often go unaddressed and are instead temporarily solved by re-grading the surface. According to a collaborative study between the Pennsylvania Department of Transportation and Pennsylvania State University, "If there are drainage problems, [...] even the best maintenance is doomed unless drainage problems are taken care of first." (Gesford & Anderson, 2006).

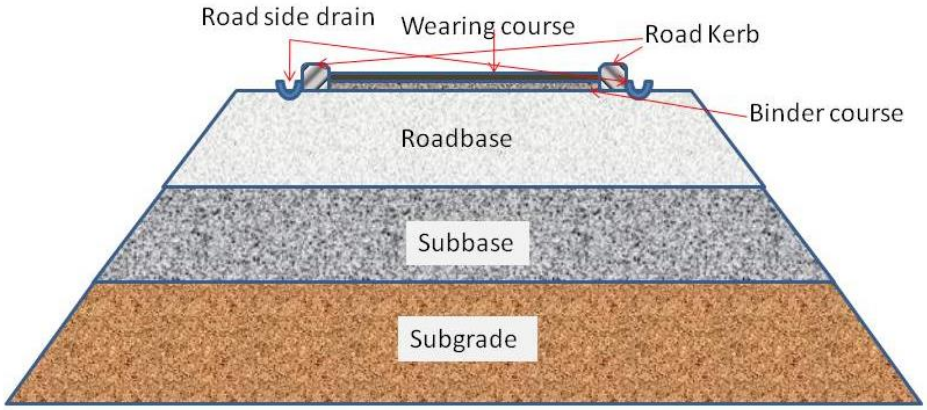

Figure 2.1: Cross-section of road design, defining subgrade

2.3 Specific Issues Facing Burncoat Lane

Burncoat Ln is almost entirely unpaved, causing a variety of concerns with its performance in different seasons of the year. In the wet season, the Burncoat Ln Road Committee reports that there are severe issues with drainage and puddling. In the cold season, there are further issues with the road surface freezing over. The current solution that the residents use is a biannual re-grading of the road surface with recycled asphalt grindings provided by the Leicester Highway Department. This practice is also coupled with pothole-filling as needed with the same millings. Residents who own their own heavy equipment volunteer to distribute the grindings. While ease of implementation and maintenance will be a significant factor in a solution, the limiting factor in any solution will be the budget.

The residents of Burncoat Ln are seeking a solution to assist in the drivability and maintenance upkeep of the road. In order for any suggestions to be given, there will be a set of factors that must be determined first. For any material or service being applied to the road, the square footage of the road must be known to determine the cost of the material. Materials like gravel or asphalt millings will be measured in cost per ton or cubic yard. The square footage and any obstacles in the way of the road can be determined by a land survey. A survey will provide the length, widths, and any irregularities in the road that would be important when resurfacing. Changes in elevation can be determined with a survey as well, which will help explore how nearby watersheds affect the area and where water naturally drains, as accommodating existing conditions is key to ensuring proper drainage (Walker, 2002).

3.0: Methods

The purpose of this project was to design a selection of paving solutions for Burncoat Ln in Leicester, MA. The private residential road has issues with drainage and freeze-thaw throughout the year, further exacerbated by deep potholes. These factors lead to sometimes-impassable road conditions year-round. To design these solutions, the following three objectives were formed, also seen in Figure 3.1:

1. Complete a detailed survey of Burncoat Ln
2. Explore town regulations regarding private ways
3. Suggest possible paving and drainage solutions for Burncoat Ln based on pros, cons, and cost

In this section, the specific methods used to meet each objective are outlined, along with the subsequent challenges and limitations.

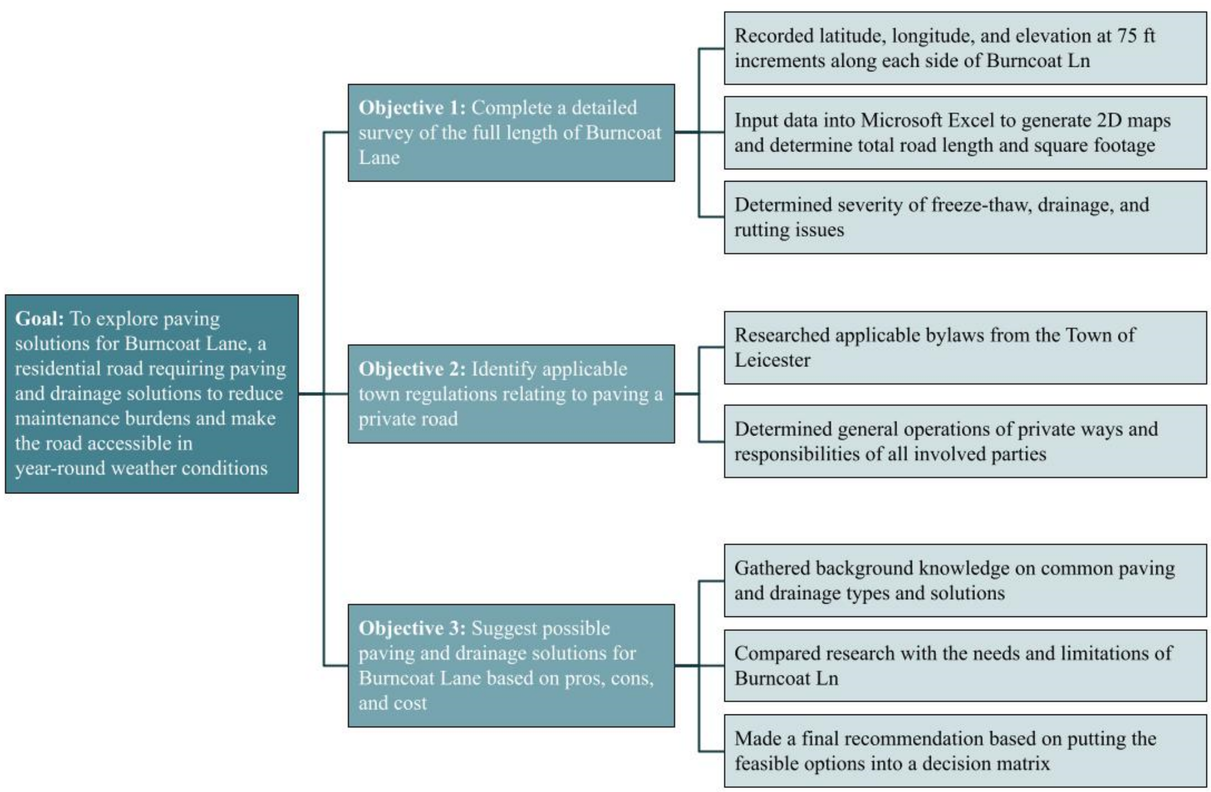

Figure 3.1: A roadmap of the methods utilized to complete this project, including goal, objective, and supplementary objective statements

3.2 Objective 1: Complete a detailed survey of Burncoat Ln

The first step in designing solutions to the road's problems was to understand the road's geometry and current conditions. To do this, a detailed survey of Burncoat Ln was carried out to be used in future analysis and in the neighborhood road committee's future considerations. The road survey was used to determine three main factors that would influence the analysis and recommendations: the length of the road, the square footage of the road, and the severity of the road's conditions, which had previously only been qualitatively described by residents.

A steel tape survey was chosen rather than a total station survey due to the length and curvature of the road, which would make repetitive total station movement and calibration impractical. Other surveying methods were also considered for this objective, and multiple accuracy tests were conducted to determine the best option. Google Maps and Arc Map were initially considered but were deemed unusable due to trees blocking the ariel views of Burncoat Ln. Instead, a field test comparison between a handheld Garmin GPS and a mobile device app was conducted to determine the precision of their coordinate readings in Institute Park. In this test, two flags were laid out one hundred feet apart and measured by a steel tape. Multiple trials of taking coordinate readings at each flag then calculating the distance between the two data points were carried out. The results of these accuracy tests, justifying the use of the final surveying method of a steel tape, are detailed in the results section.

In discussion with the project's host, it was decided that the key information to be obtained from the survey was the length of the road, any considerable obstacles in the road's path, and any significant changes in elevation that might lend themselves to specialized drainage considerations. These requirements were met with a simplified steel tape survey, which is why it was determined to be the most practical method.

When surveying the road, a steel tape was used by each member along opposite edges of the road, and marking flags were placed at 75-foot increments. This was based on the decision that the chosen increment length would provide enough detail in curvature and elevation to satisfy the needs of the survey. Then, the "Coordinates - GPS Formatter" app was used by each team member on their mobile phones to record each flag's latitude, longitude, and elevation, and the steel tape was used to determine the road's width at that point. Data points were recorded in each team member's respective field notebooks, then the procedure was repeated twice more for a total of three trials. In addition to collecting data at individual points, the total number of potholes was roughly tallied, with each pothole being marked as “Minor”, “Major”, or “Extreme”. The classification of each pothole was determined by evaluating its depth, diameter, and an estimate of how vehicles would fare driving over it. All the data collected from the survey allowed us to highlight areas of interest and use accurate numbers in following calculations.

The data from the three trials were averaged, then input into Microsoft Excel to produce a 2D map of Burncoat Ln by plotting longitude on the x-axis and latitude on the y-axis. A second map plotting the elevation of each point against the change in distance was planned, however, the accuracy of the survey methods did not allow for a conclusive final determination of elevation. Despite this, an average change in elevation was noted to consider in the designing of solutions.

The data points were also used to calculate the road’s length and its approximate square footage, both of which were necessary to conduct cost and feasibility analyses. First, the length of the road was determined by adding together the distances between each flag on each side of the road. This gave the total length of each side of the road in feet, so averaging the total length of each side gave an approximation of the road’s true length down its center. Second, the distance between points and the road width at each point were used to conduct three different square footage analyses. In the first method, the average road width was multiplied by the previously-determined road length in a simplified rectangular area calculation. In the second method, a derivation of the trapezoidal area formula was used that allowed the square footage between four points to be determined with the four side lengths (i.e. not knowing the height). This calculation was repeated down the points, then summed together for a final square footage of the entire road. One drawback of this formula was that it assumed that the trapezoid’s two bases (which were, in this case, the two road widths at neighboring points) were parallel, which they were not. Because of this limitation within the equation, the square footage value obtained from it was slightly smaller than the other two methods used. In the final method, a more modular approach to the first method was used, in which the area of a series of rectangles formed by neighboring points and their widths was calculated. The square footage of these rectangles were then summed together to give a final area for the road. See Table 3.1 for the equations used in the three area calculations.

Table 3.1: The three calculation methods used to determine square footage of Burncoat Ln

Method 1	$A = (avg\ road\ width)(road\ length)$
Method 2	$A = \sum \frac{(a+c)}{4(a-c)} \sqrt{(a+b-c+d)(a-b-c+d)(a+b-c-d)(-a+b+c+d)}$
Method 3	$A = \sum (distance\ between\ points\ on\ midline)(road\ width)$

These characteristics of Burncoat Ln informed the following decisions on the feasibility of paving and drainage solutions. Certain paving and drainage strategies are only compatible with certain road structures, so understanding the road's geometry allowed for the identification of compatible solutions, the process of which is detailed in Objective 3. Understanding the severity of the potholes was also crucial in the development of drainage solutions. A main concern brought up by the project host was that Burncoat Ln often collects large puddles in wet seasons. A component of the project focused on solving this issue. Finally, all the survey results were necessary to inform the cost estimates used in the analysis of solutions. As any solutions would be privately funded by the residents of Burncoat Ln, there was a priority on cost efficiency.

3.3 Objective 2: Explore town regulations regarding private ways

The possible effects that town regulations regarding paving and private roads could have on solutions were also investigated. To do this, state and town regulations regarding pavement materials and best practices relating to the upkeep of private roads were researched. This research was conducted by navigating the Town of Leicester website, the Town Clerk's page, and the subsequent by-laws. This could have also been done by going to the Leicester Town Hall, but it was decided that having an online version to refer to over the course of the project would be more practical.

3.4 Objective 3: Suggest solutions based on pros, cons, and cost

To compile a portfolio of solutions for the residents of Burncoat Ln, an understanding of common road systems' performance in different weather conditions, lifespans, and initial and recurring costs was required. All of these factors influenced the final set of recommendations, and each was compared against the committee's priority of cost efficiency.

The first step in collecting paving and drainage solutions was to gather background knowledge on common paving and drainage types. This was done through independent research of scholarly articles, reviewing local and state road regulations (see objective two), and conducting interviews with pavement engineering professors at Worcester Polytechnic Institute, local paving contractors, and local realtors. All interviews were conducted similarly, with one team member asking a prepared list of questions and the other taking notes from the conversation. For those who did not have availability for an interview, we asked the same questions as the other interviewees through email and logged the responses. Soil data from the National Cooperative Soil Survey (NCSS) conducted by the U.S. Department of Agriculture (USDA) were also used, accessed through the USDA's Web Soil Survey online database. Soil information was pulled from Burncoat Ln's position on the NCSS map to identify the present soil types and then used to research the properties of the soil to specialize design.

After compiling a comprehensive list of possible solutions, quantitative parameters for each possible solution were defined. Those parameters were then compared to survey data and soil conditions to eliminate any solutions that were not feasible. The remaining solutions were then placed in the weighted decision matrix shown in Figure 3.2 and assigned a series of scores.

The decision matrix's criteria were designed to compare important factors. The weights were determined in collaboration with the project host to ensure that all factors were correctly prioritized and were then placed on a one-to-ten scale, with one being not critical to consider and ten being the most critical to consider. For each solution, a one-to-ten scale was applied to each criterion's score, with one being completely unhelpful, five being moderately helpful, and ten being an excellent option. Two additional decision matrices were also created with alternative factor weights that reflected focuses on performance and environmental impact respectively. The total score for each solution was calculated by multiplying each criterion score with its corresponding weight, then finding the sum of those solution's weighted scores. The most points any solution could receive was 520, but no solution received perfect marks.

Criteria	Weight	Score				
		1: Control (Existing Conditions)	2: Reshape recycled millings with new equipment	3: Hire contractor to supply and compact finer millings	4: Hire Contractor to Pave Road	5: Install Gravel Stabilization Grid
Initial Cost	0					
Maintenance Cost	0					
Lifespan	0					
Ease of Maintenance	0					
Environmental Impacts	0					
Positive Effects on Drainage	0					
Positive Effects on Freeze-Thaw	0					
Total Score		0	0	0	0	0

Figure 3.2: Decision matrix used to assess solutions

Each of the criteria was designed to demonstrate important information used in the consideration of the final recommendations. Cost, both initial and recurring, was the most important consideration, followed by a solution's lifespan, ease of maintenance, environmental impacts, and desired outcomes with drainage and freeze-thaw. A balance of all these factors had to be achieved to successfully serve the needs of the community year-round.

The cost ranking of each solution was determined through talks with local contractors specializing in paving services. Following the determination of the road's length and area, we reached out to 22 contractors servicing Leicester, MA, and received responses from three. Of the companies that responded, interviews were conducted and non-binding cost estimates were received for various paving options. These cost estimates allowed the residents of Burncoat Ln to make a better-informed decision based on the road design solutions presented.

3.5 Limitations & Conclusions

While information was readily available to complete objective two, some limitations were encountered for objectives one and three. For objective one, a total station would have provided more accurate surveying data, but time restraints made it unfeasible. While the steel tape method was effective enough for the data we sought to collect, a total station could have opened more avenues for elevation analysis and map creation. Another limitation of our methods for objective one was our approach to tallying and classifying potholes. The difference between the "Major" and "Minor" classifications was an objective decision and, in some areas with high volume of rutting, accurate tallying was difficult. The main limitation encountered in the methods for objective three was the databases of public research we had access to pull preexisting unpaved road studies from. Some studies done on various solutions we explored were in foreign languages or not accessible with our WPI credentials.

4.0 Results & Analysis

In this section, we detail the key findings from our three objectives. Each objective's results allowed for holistic final recommendations explored at the end of this section. From objective one, we determined the key geometric properties of the road, including its length, change in widths, square footage, and estimated elevation change. Additionally, we tallied an estimated total of 508 potholes, classified as "Minor", "Major", and "Extreme" (see Figures 4.1 through 4.3 for an example of each pothole classification on Burncoat Ln) based on each rut's depth, width, and potential impact to vehicles driving over it.

Figures 4.1 – 4.3: Potholes on Burncoat Ln classified as "Minor", "Major", and "Extreme" (left to right respectively)

We used these details to interview local paving contractors, collect their recommendations, and compare those with the priorities and limitations of the road committee and with our own research. In the results for objective two, we detail the findings from our research into local regulations that would limit certain solutions. Finally, in the results for objective three, we lay out all the options we explored, how we determined certain options were or were not feasible, and the results from inputting the feasible solutions into the decision matrix. From the decision matrix, we determined that investing in a full paving of Burncoat Ln was the best option when factoring in costs, lifespan, ease of maintenance, and desired effects.

4.1 Objective 1: Complete a detailed survey of Burncoat Ln

Data from the accuracy test conducted in Institute Park (Worcester, MA) prior to the Burncoat Ln survey demonstrated that a mobile device app, "Coordinates - GPS Formatter", had the highest precision in its readings. The mobile device app had an average standard deviation of $1.53(10^{-5})$ meters for its coordinates and an average elevation standard deviation of $2.34(10^{-1})$

meters. Meanwhile, the handheld Garmin device had an average standard deviation of $1.78(10^{-4})$ meters for its coordinates, but an average elevation standard deviation of 2.57 meters. Because the mobile app was more precise in both coordinate and elevation readings and was easier to use in the field, we elected to use the app for the Burncoat Ln survey.

During the survey, we observed many notable road characteristics and conditions that factored into our solution design. First, there was a wide range of road widths throughout the road's total length of 0.68 miles. The road width ranged from its widest, 53.4 feet, at its connection to the main road, Rawson St, to its narrowest, 11.6 feet, approximately 0.5 miles down. These width disparities led to areas where two cars could not pass each other and made navigation by service trucks difficult (we observed Amazon Prime and USPS delivery trucks experience difficulty in driving over potholes and around other vehicles). The average road width was 16.6 feet and had an average total area of 59,254 square feet. The road had minor gradual slopes with no steep hills and an estimated change in elevation of around three feet. Figure 4.4 below shows the map generated from the survey of Burncoat Ln, created by plotting coordinates from 75-foot increments along both sides of the road.

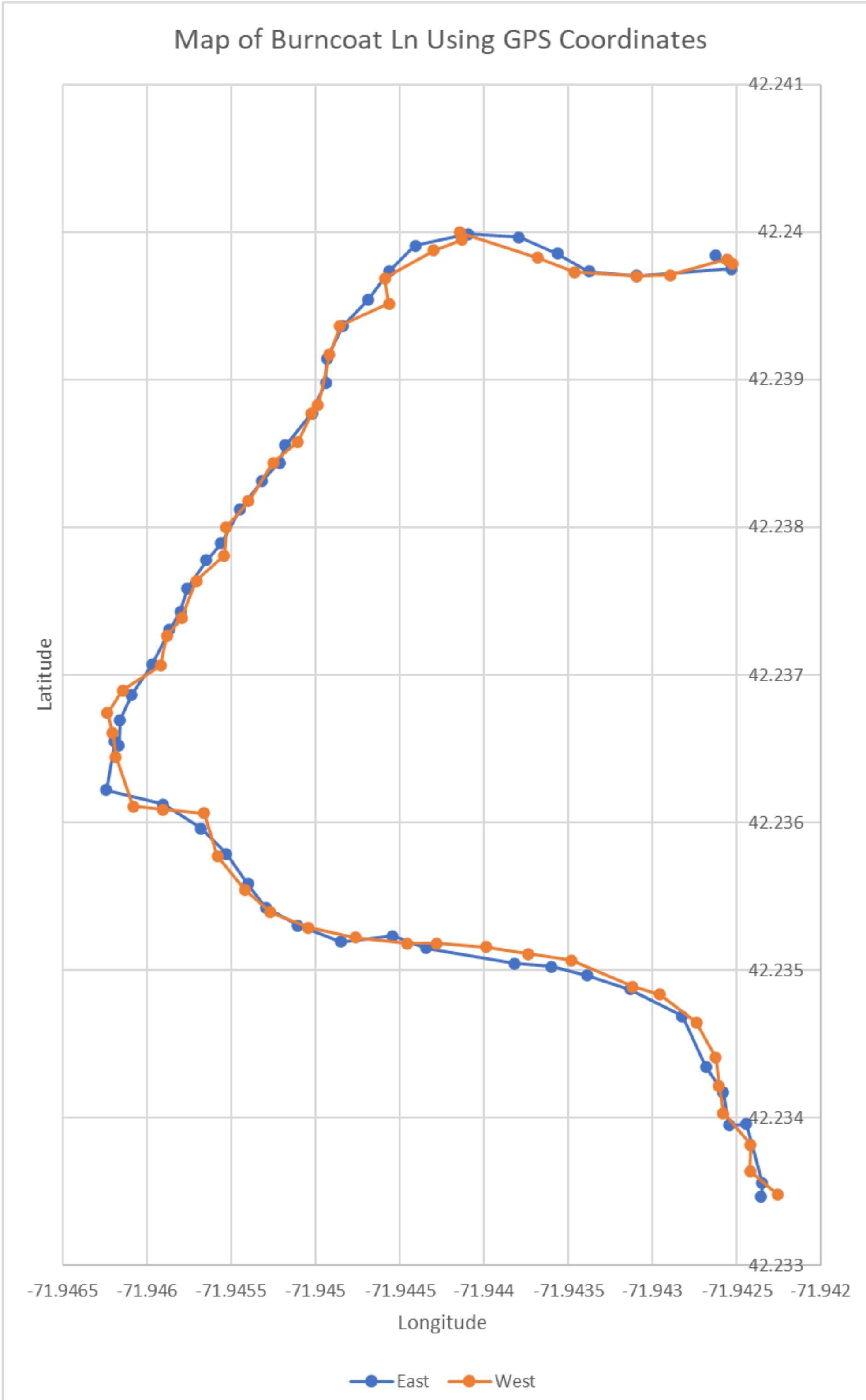

Figure 4.4: Map generated of Burncoat Ln with the blue and orange lines representing the Eastern and Western sides of the road respectively

From the three methods of square footage analyses, we determined the road's area to be between 58,242.81 and 59,761.88 square feet, with an average of 59,253.94 square feet. The deviation between the average and the extrema was 1,011.13 square feet, which is only an uncertainty of 1.71%. Because the square footage was only used to obtain cost estimates from contractors, this level of accuracy was adequate.

Additionally, we roughly tallied a total of 508 potholes, with 191 deemed "Minor", 361 deemed "Major", and one deemed "Extreme". Figures 4.5 through 4.8 below portray some of the potholes encountered in the survey. See Appendix A for additional road photos.

Figures 4.5 – 4.8: Pictures of road conditions at time of survey

4.2 Objective 2: Explore town regulations regarding private ways

We found that there were not many limitations regarding how private roads must be maintained in local and state legislation. Besides being accessible to emergency vehicles, decisions regarding the road surface and upkeep are left to the discretion of the residents. Private ways are not required to have storm drains, as such drains are typically controlled and paid for by the town and not used on private roads. The drawback of living on a private road like Burncoat Ln is that although the road is not required to follow many strict regulations, the cost of repairing and installing infrastructure falls to the residents themselves.

Chapter 23 of the Town of Leicester General By-Laws details the regulations for temporary repairs to private ways such as Burncoat Ln. The possible repairs done by the Town include "the removal of roadway surface and the regrading and installation of fill and roadway surface materials, including asphalt and concrete". On Burncoat Ln, the Highway Department deposits asphalt grindings at the request of members of Burncoat Ln's Road Committee. The grindings are then distributed throughout the street with an individual's personal equipment. When the residents of a private way can request larger repairs from the town, they must usually contact the Planning Board or Superintendent, who then go to the Select Board. Such repairs could include the transportation of heavy machinery to the road to compact the grindings, paving the road, or any process that would heavily require the Town's help. This complicated process is one reason why Burncoat Ln does not receive road care help from the town beyond the deposit of asphalt millings.

4.3 Objective 3: Suggest solutions based on pros, cons, and cost

The results from the first two objectives served the process of fulfilling objective three, where we compiled all the information assembled to make a final set of recommendations. In the designing of these solutions, we went through a process of eliminating options as they were determined infeasible.

To account for Burncoat Ln's specific conditions, we decided to explore the properties of the area's soil. Using the USDA's Web Soil Survey database, we determined that there were roughly six different soil types on Burncoat Ln: 71B, 73A, 305B, 307B, 307C, and 312B. Each soil type's locations throughout the road are shown in the following map, Figure 4.9.

Figure 4.9: Soil type map of Burncoat Ln from the USDA's Web Soil Survey database

The database specified the drainage and runoff classes, frequency of ponding and flooding, typical soil profiles, and typical water table depth of each soil type. Using the information generated for each of the soil types present of Burncoat Ln, we were able to generate Figures 4.10 and 4.11 and Table 4.1 which document areas by drainage and runoff classes.

Figure 4.10: Map of road soil's runoff classes

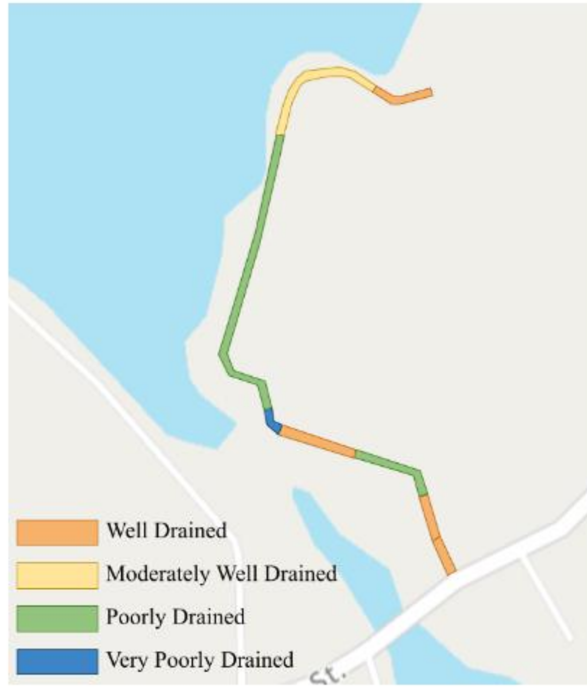

Figure 4.11: Map of road soil's drainage classes

Table 4.1: Definitions of runoff and drainage class rankings and criteria

Runoff Class*	Negligible	Very low rates of surface runoff during wet season
	Medium	Moderate rates of surface runoff during wet season
	Very High	High volume of surface runoff during wet season
Drainage Class**	Well Drained	Water is removed from the soil readily
	Moderately Well Drained	Water is removed from the soil somewhat slowly during some periods of the year
	Poorly Drained	Water is removed so slowly that the soil is wet at shallow depths periodically or remains wet for long periods
	Very Poorly Drained	Water is removed from the soil so slowly that free water remains at or very near the ground surface during much of the wet season

**Runoff Class Definition: The likelihood for surface runoff to occur during rainfall or snowmelt*
***Drainage Class Definition: The frequency and duration of wet periods under typical soil conditions*

In analyzing this information, we determined that Burncoat Ln had medium to very high runoff and ranged from well drained to poorly drained depending on the road's proximity to Burncoat Pond. We took these considerations into account in our research on possible solutions.

One potential solution, placing a crown on the road, was eliminated after further research clarified that crowns are most practical on larger double-lane roads, and crowned surfaces should be avoided on single-lane roads prone to rutting, which is the case for Burncoat Ln, due to the frequent required upkeep and the narrow width limiting two-way drainage (Bloser et al., 2012). Another reshaping option, installing an inslope that drains water to the inner curve of the road, was also deemed impractical because it is a more typical practice for a permanent paved road with a ditch line in place to direct runoff (Food and Agriculture Organization, 1998). The final option that was eliminated from consideration was the use of Perma-Zyme™ by Substrata. This soil stabilizer would be applied by a local contractor to the freshly-churned top six inches of the dirt roadway, where it bonds clay particles in the soil together to create a concrete-like surface with no environmental impact. This option was eliminated because it requires a clay content of at least 15% calculated by a mechanical sieve analysis, and based on the soil survey results, the top six inches of Burncoat Ln are too coarse to satisfy this requirement (Substrata, n.d.). Table 4.2 details all the solutions that were ever considered including those that were eliminated and those that moved on in consideration.

Table 4.2: All solutions presented for a final recommendation and whether they were considered in the final decision matrix

Considered?	**Solution**
Eliminated	Reshaping road with a crown or one-sided slope
	Use Perma-Zyme to stabilize road
Considered in Final Recommendation	Reshaping with recycled millings and new equipment
	Hiring a contractor to supply and compact finer millings
	Hiring a contractor to pave road with asphalt
	Installing a gravel stabilization grid

Reshaping the road with recycled millings and improved equipment

The most affordable solution that we explored was to reshape the existing road to encourage better drainage by using recycled millings and a new piece of equipment. Reshaping is a less technical but effective solution to drainage and can help direct water off the road. In our research on road reshaping, we compared five options: an inslope, a crown, an outslope, rolling dips (sometimes known as broad-based dips), and grade breaks (see Figure 4.12 through 4.14 for side profiles of all road shapes considered).

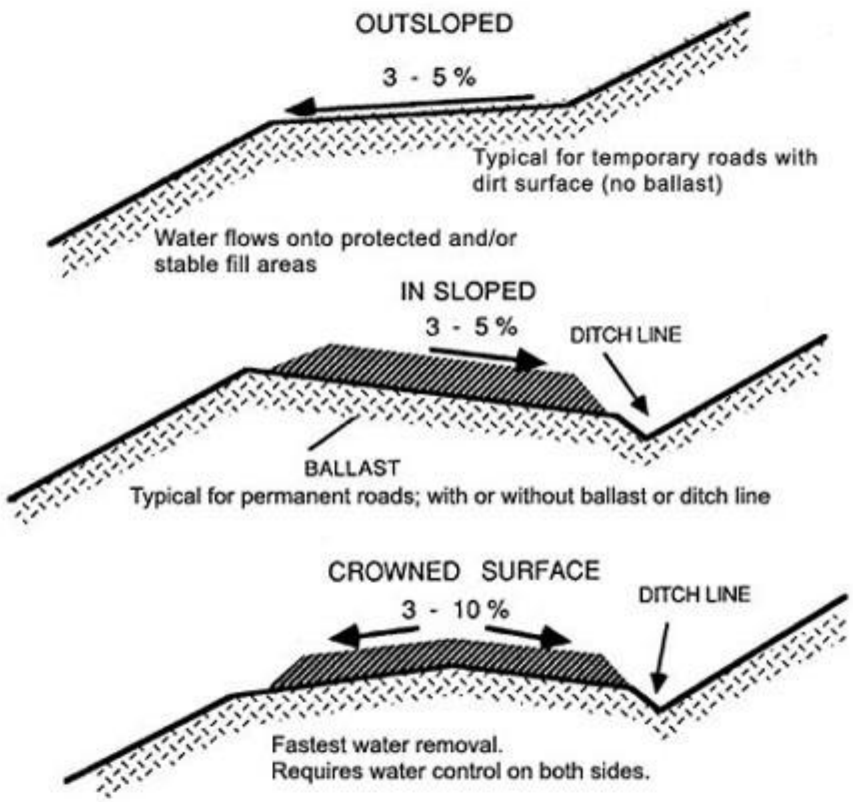

Figure 4.12: Side profiles of the three eliminated reshaping options explaining their construction and applications (Food and Agriculture Organization, 1998)

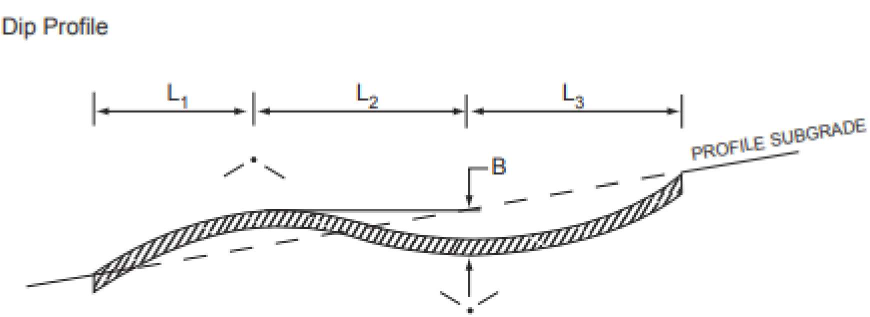

Figure 4.13: Side profile of a rolling dip construction (Bloser et al., 2012)

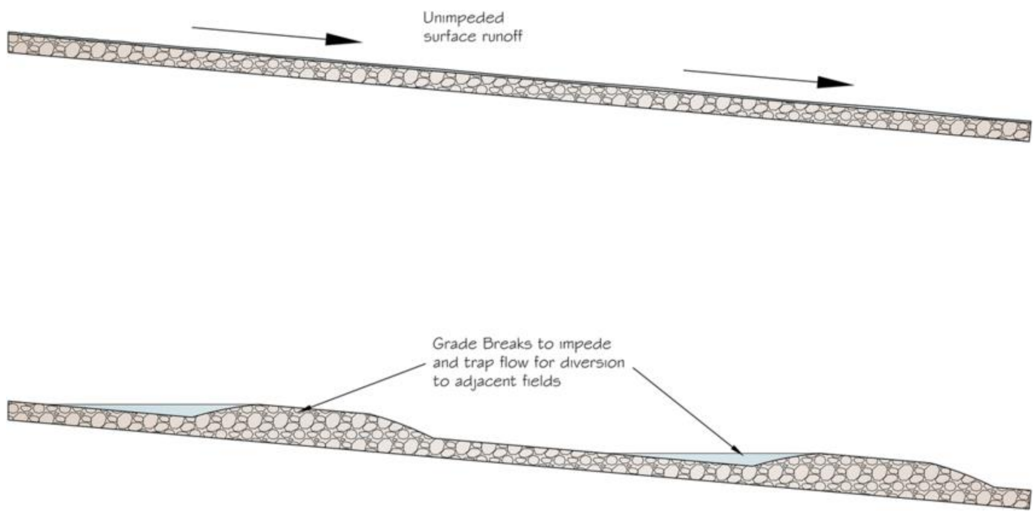

Figure 4.14: Side profile of a system of grade breaks (Fenton et al., 2021)

We first eliminated the inslope, as it would require an inside ditch and is commonly a good candidate for a sharply curved road, which Burncoat Ln is not. The next eliminated shape was a crown as, according to the USDA Center for Dirt and Gravel Road Studies, crowns are most effective on double-lane roads and unpaved roads should "avoid [the] crowned surface shape on single-lane roads prone to rutting" (Bloser et al., 2012). Based on our observations from our survey and resident testimonies, the road is regularly prone to rutting, so we removed a crown from our recommendation unless the road was to be paved or professionally compacted. The final shape we eliminated was the outslope. While this shape would be more effective than the crown and works well to direct water flow across dirt roads, we decided that it might complicate the logistics of fully paving the road in the future. If the road was outsloped at a 6% slope (an 8-inch difference for a road with an average width of 16 feet), paving with asphalt would require additional labor, material, and cost to even the roadway before construction (Bloser et al., 2012).

The final two promising candidates were the rolling dips and the grade breaks. Rolling dips are wide and shallow depressions across a road's width that channel water off the road (Walker, 2002). Fill material is placed just after the dip to create a raised bump that forces the water back down and off the road through the depression. The rolling dip has many benefits, such as replacing the need for culverts, reducing erosion, being inexpensive and easy to install, and needing little maintenance if placed and installed properly (Bloser et al., 2012). To install rolling dips, 20 to 40 tons of material is commonly needed, and the Center for Dirt and Gravel Road Studies recommends a three-to-four-inch stone to reinforce the bottom of the dip where the water will flow. The USDA also recommends using a bulldozer to shape the dips, a good grade operator to maintain the dips, and a vibratory roller or tamper to compact the bottom and top of the dips (Bloser et al., 2012). To construct effective dips, the depressions should be between three and six inches deep and angled at least 3% from the centerline of the road to encourage drainage (Bloser et al., 2012; Walker, 2002).

The second feasible reshaping option was a grade break, which is a system of raised rolls in the road grade designed to force water off the road's surface and into stabilized ditches or outlets (Bloser et al., 2012). Grade breaks are often an excellent option for unpaved roads in need of erosion control because they are reliable, inexpensive, easy to install and maintain, and continue to shed water even after the road surface shape is lost. They are best utilized on roads that are infrequently maintained with gentle-to-moderate slopes and low-speed travel. The Center for Dirt and Gravel Road Studies recommends 40 to 60 tons of material to create the breaks, which is roughly 20 tons more than a rolling dip. However, grade breaks require less equipment to install. Their construction is easiest with a bulldozer, but other earthmoving equipment (like excavators and graders) can also form the breaks effectively (Bloser et al., 2012).

Both a rolling dip and grade break system would benefit Burncoat Ln, so if road reshaping is chosen, the road committee should make a decision based on their preferred tradeoff between material and equipment. Many different equipment attachments could be used to shape the road in either of the ways above. Currently, residents of Burncoat Ln have a bucket attachment for a tractor that can be used to move millings around the street.

Once new millings are spread throughout the road, a compactor should be used to compact the surface of the road. This will help prevent rutting and lengthen the lifespan of the road system. A walk-behind vibratory plate compactor (Figure 4.15) would be the least expensive option, with rollers typically being more costly. A commercially available vibratory plate compactor ranges from $1,000 to $2,000; a walk-behind smooth drum roller (Figure 4.16) is typically around $15,000; and a small ride-on compactor is around $20,000 (Figure 4.17) (Patriot Tractor Equipment, n.d.). Any of the three would be beneficial to the road, as potholes are most commonly formed due to loose soil or gravel being compacted unevenly resulting in disproportionate losses of density (Rajib & El-Korchi, 2017). A ride-on compactor would be more expensive than any attachment for a ride-on tractor, but compacting the road with a residential and construction-grade vehicle could lead to significantly fewer potholes over time.

Figure 4.15 – 4.17: Commercially available road maintenance equipment (left to right: walk-behind vibratory plate compactor, walk-behind smooth drum roller, ride-on compactor)

Alternatively, a box blade attachment could be used on a personal tractor (Figure 4.18). The attachment's angled metal teeth, called scarifiers, rip up the existing road, loosening the layers of compacted gravel currently on the surface of the road. The roadway could then be compacted, leveled, and graded using the same attachment. Alternatives to a box blade could be a box scraper or scraper blade, which can be utilized for the same reasons except are not as proficient at moving large amounts of material (Figure 4.19). A box blade attachment typically costs between $1,500 to $2,000, and a scraper blade attachment between $1,000 to $1,500. A buyer's guide for the equipment discussed in this section is located in Appendix B. See Table 4.3 for our reasoning for the scores we assigned to this solution in the decision matrix.

 

Figures 4.18-4.19: Commercially available road maintenance tractor attachments (left to right: box blade attachment, scraper blade attachment)

Table 4.3: The reasoning supporting the scores assigned to reshaping the road with recycled millings and improved equipment

Criteria	Score (1-10)	Reasoning
Initial Cost	9	The recycled millings from the city are free, so the only cost is in the equipment chosen.
Maintenance Cost	8	The attachment would already be bought once maintenance is needed, so the only recurring cost would be repair if the equipment broke.
Lifespan	5	Road reshaping would have to be done likely every year to maintain its efficacy, especially if done without compaction.
Ease of Maintenance	7	The residents would be liable for maintenance, but the ease of reshaping and recompacting would depend on the equipment bought.
Environmental Impacts	7	While runoff would still persist to some extent, there would be less road treatment chemicals running into Burncoat Pond.
Positive Effects on Drainage	5	Because the roadway and subgrade would still be composed of the same materials that have been previously used, it would still be prone to the same issues, just reshaped to aid in drainage.
Positive Effects on Freeze-Thaw	5	

Hiring a contractor to supply and compact their own millings

Fine-tuning the size distribution of the road's millings can also be a cost-effective step toward better drainage and reinforcement. According to the Center for Dirt and Gravel Road Studies, a higher ratio of "fines", otherwise known as clay and silt particles, can provide a much more tightly packed road surface. This re-graded road surface allows for better drainage, but the mix designer must ensure that the ratio of fines is not too high, as this may create areas of slick mud and unbound aggregate (Walker, 2002). The surface of the road should be composed of angular crushed stone with sharp edges that compact into each other. This "puzzle" effect creates a solid top layer that simultaneously allows water to drain out. As a general rule, the crushed stone particles should be no larger than one inch in diameter (Walker, 2002). As a more reliable alternative to using donated millings from the town and spreading them using personal heavy machinery, a local contractor can be hired to supply and compact their own millings that can be more closely monitored to ensure they meet the above criteria.

In correspondence with local contractors about providing this service, Contractor A wrote,

> *"To truck in 800 ton of asphalt millings and send a grader, 10 ton roller, and a laborer for 2 days to spread 2" of millings over the entire rd reshape and regrade and compact entire rd you are looking at around $25,000. This would probably last 3-5 years with minimal maintenance and if maintained properly like taking care of small potholes and washout could last 15-20 years."*

See Table 4.4 for our reasoning for the scores we assigned to this solution in the decision matrix.

Table 4.4: The reasoning supporting the scores assigned to hiring a contractor to supply and compact their own millings

Criteria	Score (1-10)	Reasoning
Initial Cost	9	We determined that hiring a contractor to do this service was comparable to the residents doing it themselves with new equipment.
Maintenance Cost	8	Maintenance would be mostly pothole filling, which could be inexpensively hired out or done by the residents.
Lifespan	5	According to contractors, the lifespan would be roughly equivalent to if residents compacted their own millings.
Ease of Maintenance	7	Maintenance would mainly consist of minor pothole filling.
Environmental Impacts	7	Similar to compacting recycled millings, Burncoat Pond would still receive runoff from the road but less road treatment chemicals
Positive Effects on Drainage	5	Similar to compacting recycled millings, the road would still be prone to the same issues. However, the compaction and re-grading would provide a temporary barrier to this.
Positive Effects on Freeze-Thaw	5	

Hiring a contractor to pave the road with asphalt

While properly paving with asphalt was the most expensive option investigated, its investment has many advantages in its ease of maintenance, low recurring costs, and best benefits to drainage and freeze-thaw concerns. Further than this, paving eliminates dust control concerns and minimizes the environmental impacts of surface runoff. Finally, it can lower vehicle operating expenses, increase road safety, and benefit the economic development of the area (Local Road Research Board, 2004).

To pave Burncoat Ln, earthwork would first be conducted on the existing roadway to grade and slope the soil to encourage drainage. Next, a binder would be installed over the soil, composed of large aggregates mixed with oil to produce a durable layer that effectively "glues" the asphalt layer together. The asphalt is then heated and poured onto the surface where it is compacted with heavy machinery (Valle, 2021). Due to the materials, labor, and machinery required to properly pave a road, a local contractor must be brought in to conduct the work. As part of our research into this solution, we interviewed several local contractors that perform this service. Most contractors with whom we spoke suggested that the best option would be to pave the road with asphalt.

In correspondence with local contractors about providing this service, Contractor A wrote,

> *"The rd would be fine with one lift 2.5" of dense binder hma* [hot mix asphalt]. *In order to do the binder the existing rd would have to be reclaimed, re-graded and compacted. Reclaiming/Grading would be roughly $3.25* [per square yard] = *$22,750. Pave 2.5" dense binder would take roughly 1,000 ton @ $90-$95 ton would be about $95,000. Total price to reclaim, regrade compact, and pave a 2.5" binder course would be about 120k. They should get 20 yrs out of it depending what the subgrade looks like. If they were to do a top course over the binder within the first 4-5 years they could get 30-40 yrs out if the rd if the sub-base is decent."*

Contractor B gave a similar quote, and Contractor C provided only a quote of roughly $198,600 to re-claim, grade with a crown, compact in place, install a 2.5-inch binder compacted in place, then finish with a 1.5-inch state top compacted in place.

In order to understand the impact on the residents of paving the road, we also acquired real estate agents' opinions on how the state of a road could influence potential homebuyers. Three realtors from different firms were interviewed, and all agreed that there is not a specific amount or percentage that a home value is improved once the road is paved. However, all realtors agreed that unpaved roads typically have less interest in the first place. This, in turn, could lead to sellers listing their homes for a lower amount than what it could be worth. Buyers, wary of a road condition that would lead to extensive road maintenance and losses on investment, might not show interest in the property in the first place. Realtors also mentioned special concern for homes positioned near the end of the unpaved road. Homes at the end of a road have to depend on other residents to remove snow and keep up with maintenance to be able to leave the street, unlike a public paved road that is maintained by the town. This maintenance would be greatly reduced by paving the road, offering another benefit to paving Burncoat Ln with asphalt. See Table 4.5 for our reasoning for the scores we assigned to this solution in the decision matrix.

Table 4.5: The reasoning supporting the scores assigned to hiring a contractor to pave the road with asphalt

Criteria	Score (1-10)	Reasoning
Initial Cost	3	This option is the most cost-intensive, averaging around $150,000.
Maintenance Cost	8	After the initial installation cost, maintenance would be very minimal, meaning very low maintenance costs for at least 10 years.
Lifespan	10	Contractors estimate that an asphalt-paved road would last over 30 years, giving it the longest lifespan of these options.
Ease of Maintenance	9	After initial installation, maintenance would be very minimal for at least 10 years.
Environmental Impacts	9	Paving the road would eliminate dirt and gravel runoff from entering Burncoat Pond, minimizing fugitive dust and protecting the water ecosystems.
Positive Effects on Drainage	8	Paving and shaping an asphalt roadway will reduce puddling on the road and will lead to the best improvements to drainage and freeze-thaw conditions.
Positive Effects on Freeze-Thaw	8	

Installing a gravel stabilization grid

First developed by the U.S. Army Corps of Engineers for military use, variations of aggregate stabilization grids and geogrid mechanisms have been utilized and studied for unpaved roads as far back as World War II (Henry et al., 2005). Today, their main function is to act as reinforcement for the base of the road, while allowing water to permeate through the layer and drain off the roadway (Zhang and Hurta, 2008). Stabilization grids are often made in honeycomb or grid orientations, where aggregate from the base course is used as infill material in each cell. The geogrid allows wheel loads from vehicles to enter the "slab effect", where the stress from that load is spread out over a much wider area than it would be if it was loading straight into the road (Zhang and Hurta, 2008; Paradox Access Solutions, n.d.). The following Figures 4.20 and 4.21 produced by the company, ToughCell, demonstrate this effect.

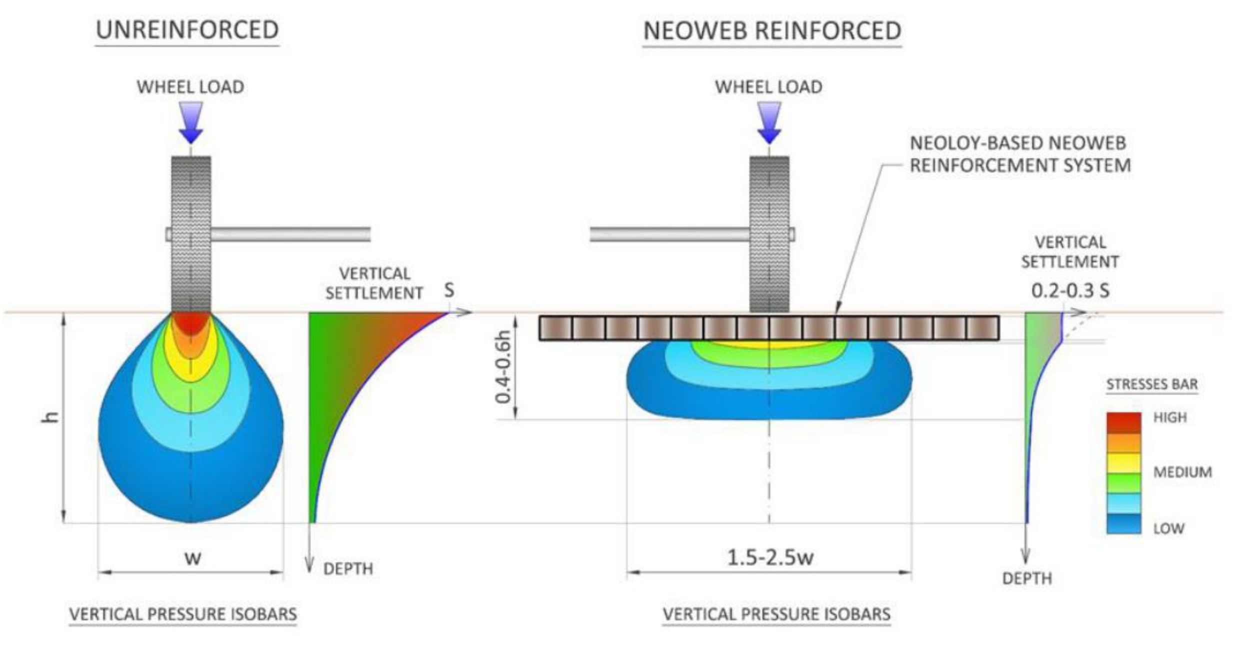

Figure 4.20: Demonstration of the “slab effect” under a gravel stabilization grid (Paradox Access Solutions, n.d.)

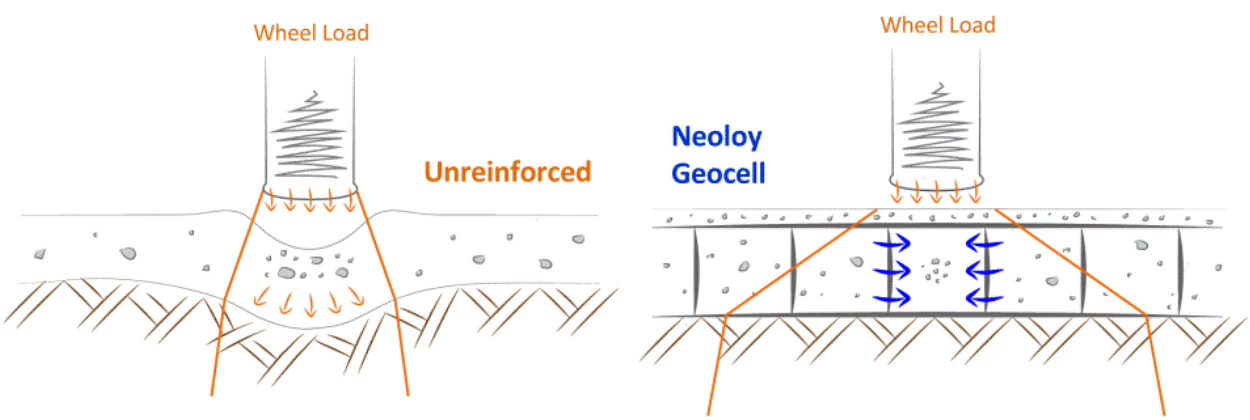

Figure 4.21: Demonstration of infill confinement under wheel loading (Paradox Access Solutions, n.d.)

The dispersal of road stresses and consolidation of material solve many issues associated with unpaved roads. Stabilization grids can reduce rutting, decrease the thickness of the material that would be required for an unreinforced roadway, and increase the road lifespan while minimizing the need to frequently re-grade (Góngora and Palmeira, 2012).

In communicating with U.S. distributors of gravel reinforcement systems, Supplier A wrote,

> *"Very rough budgetary prices for a single layer supply and installation of a typical 6" deep C or D grade* [product] *material ranges between $30 - $35 /* [Canadian dollars per square meter] *and prices will vary up or down depending on project scope, location, installation variables, etc."*

Scaling that estimated cost to the size of Burncoat Ln is the equivalent of between $164,000 and $192,000. A buyer's guide for gravel stabilization grids is located in Appendix B. See Table 4.6 for our reasoning for the scores we assigned to this solution in the decision matrix.

Table 4.6: The reasoning supporting the scores assigned to installing a gravel stabilization grid

Criteria	**Score** **(1-10)**	**Reasoning**
Initial Cost	4	This system would be very expensive if used for the entire length of Burncoat Ln, roughly equal with paving
Maintenance Cost	5	The system would have to be repaired and replaced every few years, accumulating higher maintenance costs. A contractor could be hired to maintain it, but this would raise maintenance costs.
Lifespan	5	The quality of the product will influence the lifespan of the system, but repetitive loading on it will require occasional milling replacement and system repair
Ease of Maintenance	6	The maintenance that would be required would be labor-intensive and precise. A contractor could be hired to maintain it.
Environmental Impacts	7	The grid would pose no threat to Burncoat Pond, but it still utilizes millings, which can still fly out and run off into the pond.
Positive Effects on Drainage	8	The system's ability to drain off moisture and disperse loading would greatly minimize potholing and rutting, aiding freeze-thaw prevention.
Positive Effects on Freeze-Thaw	8	

Analyzing solutions using the decision matrix

Each of the four options, reshaping the road with recycled millings and new equipment, hiring a contractor to supply and compact finer millings, hiring a contractor to pave the road with asphalt, and installing a gravel stabilization grid, were scored based on the research summarized above. The weighted scores were then compared against a control score of leaving the road with its existing conditions. Each factor was weighted according to the priorities of the Burncoat Ln Road Committee, which our host represented. On a multiplier scale of 1 through 10, he prioritized initial cost first at 10 and then maintenance cost as a secondary high priority at 9. He gave environmental impacts the next highest priority at 8, due to Burncoat Pond's status as a watershed district, where the pollutants of one water body would affect at least three others. Next, he gave lifespan and ease of maintenance a score of seven, positive effects on drainage a six, and positive effects on freeze-thaw a five. The results of each solution are shown in the following Table 4.7.

Table 4.7: Decision matrix with recommendation based on host's criteria weights

Criteria	Weight	Score				
		1: Control (Existing Conditions)	2: Reshape recycled millings with new equipment	3: Hire contractor to supply and compact finer millings	4: Hire Contractor to Pave Road	5: Install Gravel Stabilization Grid
Initial Cost	10	10	9	9	3	4
Maintenance Cost	9	9	10	8	8	5
Lifespan	7	1	5	5	10	5
Ease of Maintenance	7	3	4	7	9	6
Environmental Impacts	8	4	6	7	9	7
Positive Effects on Drainage	6	1	4	5	8	8
Positive Effects on Freeze-Thaw	5	1	4	5	8	8
Total Score		252	335	357	**395**	306

When the four options and the control were scored and weighted with the host's priorities, hiring a contractor to pave the road scored the highest. Hiring a contractor to supply and compact finer millings ranked second with 38 fewer points. While paving the road had the worst initial cost score, it excelled in the other six categories. The same options and ratings were input into two alternately weighted decision matrices, one prioritizing performance with no cost consideration and one prioritizing minimal environmental impact. Paving the road scored the highest on these matrices as well, as shown below in Tables 4.8 and 4.9.

Table 4.8: Decision matrix with recommendation based on optimized performance with no cost considerations

Criteria	Weight	Score				
		1: Control (Existing Conditions)	2: Reshape recycled millings with new equipment	3: Hire contractor to supply and compact finer millings	4: Hire Contractor to Pave Road	5: Install Gravel Stabilization Grid
Initial Cost	1	10	9	9	3	4
Maintenance Cost	1	9	10	8	8	5
Lifespan	10	1	5	5	10	5
Ease of Maintenance	8	3	4	7	9	6
Environmental Impacts	1	4	6	7	9	7
Positive Effects on Drainage	10	1	4	5	8	8
Positive Effects on Freeze-Thaw	10	1	4	5	8	8
Total Score		77	187	230	**352**	274

Table 4.9: Decision matrix with recommendation based on minimizing environmental impacts

Criteria	Weight	Score				
		1: Control (Existing Conditions)	2: Reshape recycled millings with new equipment	3: Hire contractor to supply and compact finer millings	4: Hire Contractor to Pave Road	5: Install Gravel Stabilization Grid
Initial Cost	1	10	9	9	3	4
Maintenance Cost	1	9	10	8	8	5
Lifespan	8	1	5	5	10	5
Ease of Maintenance	7	3	4	7	9	6
Environmental Impacts	10	4	6	7	9	7
Positive Effects on Drainage	10	1	4	5	8	8
Positive Effects on Freeze-Thaw	6	1	4	5	8	8
Total Score		104	211	256	**372**	289

By demonstrating that a fully paved road excelled regardless of criterion weight, we recommend investing in hiring a local contractor to properly pave Burncoat Ln with asphalt. This option provided the best long-term payoffs in terms of lifespan, ease of maintenance, and desired effects. The other solutions explored also address the issues facing the road, but have more shortcomings in their ease of maintenance, lifespan, or effectiveness in combating drainage and freeze-thaw.

4.4 Additional Findings

In this section, we expand on some additional recommendations we have for the residents of Burncoat Ln to consider incorporating alongside a main solution from the four options above.

Geotextile Grids

Geotextile grids could be used in addition to reshaping the road or having a contractor re-grade with their own millings. Unpaved roads generally have two layers: a subgrade (the existing soil on the site) and a base course (coarse aggregate laid on top). When these two layers mix, the bearing capacity of the aggregate is decreased and the road is weakened (Zhang and Hurta, 2008). A geotextile grid is a permeable geosynthetic made of textile materials, which allows for shear stress to be carried within the reinforcement and can reduce the amount of aggregate needed by up to a ⅓-inch reduction in thickness (Iowa DOT and Iowa Concrete Paving Association, n.d.). It can also help with drainage, as water can flow through the textile in a way that solid materials inhibit. Finally, it prevents the mixing between subgrade and gravel, which leads to less movement and less rutting (Góngora and Palmeira, 2012). These benefits can compound on top of each other, so it would be an advantageous option to consider. See Figure 4.22 for a profile of the fabric's placement in a road's structure.

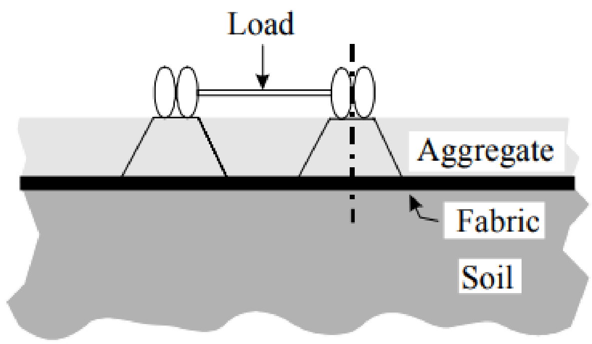

Figure 4.22: A profile of the geotextile fabric's placement in a road's structure

Geosynthetics come in both woven and nonwoven forms, with certain advantages and disadvantages to both. Woven geosynthetics are constructed from interlaced fibers, are less permeable than non-woven textiles, and have higher tensile strength and load capacity. On the other hand, non-woven geosynthetics are typically made from needle-punched rolls and are more permeable, allowing more water to drain through. Overall, woven textiles are ideal for stabilization and reinforcement applications, and non-woven textiles are ideal for drainage, separation, and filtration applications (Bearden and Labuz, 1998). The two types have the same typical cost for a roll at a home improvement store, roughly $0.10 per square foot (Lowes, Home Depot). We recommend either form of geotextile to the residents of Burncoat Ln, depending on availability and performance priorities.

Geosynthetics have been frequently studied in relation to gravel stabilization grids, as they have many of the same desired effects. The general consensus surrounding these comparisons is that the performance of a stabilization grid is superior, as it provides more confinement and maximizes force distribution (Zhang and Hurta, 2008). Because of this, we did not make the use of a geotextile a primary recommendation, but an additional finding to consider. If chosen to pursue, a buyer's guide for geotextiles is located in Appendix B.

Making Burncoat Ln a Public Way

In addition to exploring actions that the residents of Burncoat Ln can take to improve their road, we also looked into ways to have the work undertaken by the town by making the road a public way. We determined that this is likely not a viable option due to the resources and evidence required to make an argument for adoption, but we still chose to include the findings in the case that this avenue is pursued in the future.

According to the National Law Review, there are three means of creating a "public" way in Massachusetts. The first, by dedication, was discontinued in 1846 due to changes in road law. The second, by prescription, requires proof that the town's general public has regularly used the private way without interruption for over 20 years. The final option is to have a road named and accepted as public at the time of construction (Quick, 2019).

Proving that a private road was once public by prescription requires copious circumstantial evidence. In the 1995 case *Martin v. Building Inspector of Freetown*, the residents of a private road were able to establish grounds for public adoption by providing evidence that included government plans depicting the road from 1763, the testimony of an experienced local surveyor who also served as the director of the town's historical society, minutes from a 1764 town meeting which included action items for work on the road and a notation on the margin stating "voted", and an overlay of the 1979 U.S. Geological Survey Map over the 1763 plans and the town's assessors' maps that showed high congruence between the documents (Smithers, 2011).

As shown in this case, several types of evidence are required to establish that a private road was once a public way. Primarily, documentation must prove that the road was laid out by the town and accepted by a vote at a town meeting. If that documentation is ambiguous, then evidence of town-sponsored construction or repair can be added to solidify the case. In addition to compiling maps designating the road as public, surveying can also be used to show the exact location of the road which might offer insight into whether it was regularly used by the town's general public when it was built. Finally, evidence of attempts to discontinue the road could also prove whether the road was originally public or private in nature (Smithers, 2011). If the residents of Burncoat Ln do choose to investigate their eligibility for this process, we recommend that they compile a historic profile of their road. This can be done in partnership with Leicester assessors, historical societies, and library research.

Even if the residents of Burncoat Ln do not choose to pursue making their way public, there are still avenues to petition the town for certain maintenance services. According to the Massachusetts General Laws chapter 40 section 6C, "a city or town…may appropriate money for the removal of snow and ice from private ways". Expanded in section 6D, this service must be voted on at a town election to take effect with a majority affirming the decision. To bring this petition to a vote, a petition of 200 registered voters or of 20% of the total number of registered voters must be compiled (The 193rd General Court of the Commonwealth of Massachusetts, *Removal of Ice and Snow from Private Ways: Conditions*, n.d.; The 193rd General Court of the Commonwealth of Massachusetts, *Removal of Ice and Snow from Private Ways: Submission to Electorate: Ballot*, n.d.).

Consolidating Service Vehicle Access to Road Entrance

This is a small change that could be made to improve the condition and lifespan of the road. While surveying, we observed many large commercial vehicles, mail trucks, and garbage service trucks struggling to make their way down the road without hitting major potholes. Constant usage from these heavy vehicles cause more stress on the road and contribute to continual rutting, so one recommendation would be to move some of these services (garbage service, mail, or package delivery) towards the start of the road from Rawson St. This would prevent heavy wheel loads from being consistently applied to the road surface, which could help the road stay level for longer. See Figures 4.23 and 4.24 for examples of collective servicing that could be installed at the entrance to Burncoat Ln.

Figure 4.23-4.24: Collective trash and recycling bins and mailbox system to reduce repetitive heavy wheel loading from service and delivery trucks

Alternative Fundings and Grants

One of the main factors in weighing different options was cost. Residents of private roads have to pay for maintenance themselves, so we investigated any grants or programs that could be used to help pay for repairs. Most grants were ineligible either because the road is private, is not inside a flood zone, or is not in poor enough condition to warrant it. The road also does not have a Home Owners Association (HOA), which disqualifies it from other forms of long-term contracts with service providers. The residents of Burncoat Ln may wish to explore this option more thoroughly, as a full investigation into the grants was out of the scope of this project.

5.0: Recommendations & Conclusions

The goal of this project was to find the most cost-effective road design for Burncoat Ln in Leicester, MA. The design sought to address the current drainage and freeze-thaw issues on the road and combat rutting and potholing. Various road designs were assessed by the research team, and local contractors and realtors were interviewed to factor in industry-specific advice on feasibility, effectiveness, and lifespan. A series of decision matrices were designed by the team to quantify which option would be best for the road, with special focuses on cost, performance, and environmental impacts.

5.1 Recommendations

Based on the field data, research, and input from local professionals, we recommend that Burncoat Ln be fully paved. This would entail reclaiming the existing roadway, re-grading and compacting it, then paving a multi-inch binder on top. This process would produce a drivable surface likely lasting 20 or more years. Further, an additional topcoat applied within the first few years of paving could provide an additional 10 to 20 years of life. While paving did receive the lowest score in the decision matrix for initial cost, it highly excelled in all other categories, demonstrating the advantages of the investment. The maintenance costs would be very low, as the paved road would only require minor pothole patching over the years. It also has the longest lifespan of any option explored and some of the best scores for environmental impacts and positive effects on drainage and freeze-thaw. If Burncoat Ln was paved, less soil from the roadbed would mix with water and drain into the neighboring pond, minimizing threats of endangering and encroaching upon the natural habitats of wildlife.

A final benefit of paving that we explored was the potential increase in property value and interest by future home buyers. In talking with local realtors, we determined that a paved street in front of a property generally generates more interest than one on a dirt road. While there is not a tangible connection between paved roads and property values, multiple realtors reiterated that homes on unpaved roads typically gather less interest due to the uncertainty involved in maintenance and responsibility. Homes that are further down an unpaved road might struggle more with property interest because those residents must rely on other properties before them to maintain their section of the road. Paving is one solution to these reservations that homebuyers might have, which could increase interest and therefore the final offer amount that a property generates.

If the residents choose to pursue a different option, there are other less resource-intensive solutions that do not offer the same remedies as paving but can still have significant short-term benefits. The most cost-effective option is to reshape and compact recycled millings with more specialized equipment bought by the Burncoat Ln Road Committee. This would require semi-routine upkeep by the residents but would benefit drainage and freeze-thaw conditions. Furthermore, hiring a local contractor to supply and compact their own millings into a shape that aids drainage would be a slight improvement in terms of quality than doing it independently, but the labor and material costs would be higher. An optional supplement to either of these two solutions is installing a geotextile grid under the new millings before compacting. They are sold by the roll in many home improvement establishments and can aid in lessening rutting, encouraging drainage, and reducing the amount of millings needed overall. A third alternative solution that could benefit Burncoat Ln is the installation of a gravel stabilization grid, which is a grid- or honeycomb-shaped reinforcement that can be filled with millings in each cell. The stabilization grid helps to distribute car loads over a much wider area than if the car was driving on the direct surface, It also limits rutting, keeps millings in place, and allows surface water to drain through the infill layer to the subgrade. However, it can be expensive to install and maintain. While we still recommend paving as the best long-term solution to the issues facing Burncoat Ln, we can also recommend these solutions depending on the priorities of the residents.

Burncoat Ln's roadway is currently riddled with potholes of varying severity. A significant contributing factor to this could be the various delivery and service trucks that make routine stops along the road. Because residents use multiple services for mail delivery, trash and recycling pickup, and natural gas delivery, the frequency and volume of large trucks that produce greater stress on the road increase. One addition to any solution chosen could be to consolidate service providers and install drop-off bins and a central mailbox system near the entrance to the road off Rawson St. If service and delivery trucks did not have to travel so far down the road, then the need for maintenance would be reduced.

5.2 Concluding Statement and Greater Implications

When we spoke with residents that have lived on Burncoat Ln for decades, they said the state of the road has been in disrepair for as long as they have lived there. Implementation of any of the above options would improve their drivability and service requirements. If action is taken to repair the roadway, residents will be able to navigate the road more efficiently without excess potholing hurting machinery and blocking vehicle access. Although any of these designed solutions will have to be paid for by the residents of the road, the investment will result in a safer road that will last for long periods of time. With monetary assistance from each resident, a daily struggle could be fixed.

According to the FHA, almost 35% of the country's roads are unpaved (Federal Highway Administration, n.d.). These recommendations could also be applied to those roads with similar circumstances. In our research, we determined that a guide to improving unpaved roads did not already exist, so this research paper fills a knowledge gap that other residents of unpaved roads might find crucial. The solutions contained in this report can serve as a guide for future homeowners looking to improve their private roads, or even larger-scale companies and governments looking for innovative alternatives to road paving.

6.0: Capstone Design Statement

This Major Qualifying Project (MQP) involved the design of a portfolio of solutions for Burncoat Ln, a residential road in Leicester, MA requiring better road-care practices to reduce maintenance burdens and make the road accessible in year-round weather conditions. To achieve this, in-field surveying was conducted, with the results informing the recommendation of various solutions based on advantages and disadvantages in cost, lifespan, ease of maintenance, etc. Local and state-level regulations were also explored, to ensure that any solution utilized would be allowable under the requirements for private ways in Massachusetts. While constraints were encountered in the accuracy of surveying methods and limited facilities for soil and solution testing, they were addressed by using other means accessible to the team such as peer-reviewed literature and online government databases.

The completion of this design project relied on previous skill sets and course work completed at Worcester Polytechnic Institute. Classes such as Surveying (CE2020), Soil Mechanics (CE3041), Geology (GE2341), and the Analytical Mechanics series (CE2000-CE2002) were instrumental in providing a background in the understanding of earthwork, soil properties, and load application theory. Additional skill sets utilized for this project were the comprehension of lab processes and machinery (for example, soil sieving), proficiency in data-analysis tools like Microsoft Excel, and the understanding of the engineering design process, typically involving both analysis and synthesis. Analysis, the application of knowledge to predict the performance of the system, and synthesis, the creation of a new system based on the desired needs, were a revolving process throughout the project. This, coupled with the background provided from courses and project-based work allowed for the incorporation of engineering standards and the consideration of realistic constraints in this MQP.

Realistic constraints, including economic, environmental, social, political, ethical, health, manufacturability, and sustainability, were central to the design, analysis, and presentation of solutions throughout this project. Because any solution adopted by Burncoat Ln would be applied and funded by its residents, all the constraints detailed above were considered. They were mainly accounted for using the decision matrix which compared the five solutions to each other based on scores for initial and maintenance costs, environmental impacts, ease of maintenance, and more.

In conclusion, this project successfully fulfills the design requirement of the MQP process by delivering a portfolio of solutions for Burncoat Ln specially designed and analyzed for the road’s severity of issues, road composition, and underlying soil properties. The final deliverable includes five solutions with varying effectiveness in cost, lifespan, and ease of maintenance. Next, we detail the importance of licensure in the civil engineering profession and the process in which licensure is obtained.

7.0: Professional Licensure Statement

Licensure is a very important step in a young civil engineer's career. The National Council of Examiners for Engineering and Surveying holds both the Fundamentals of Engineering (FE) and Professional Engineer (PE) tests throughout the year. Once one becomes a Professional Engineer, they are allowed to sign off on final engineering plans and be held liable for details therein. This is useful for engineers looking to advance their career or open up their own practices.

The Civil Engineering FE exam is meant for college seniors or recent graduates and covers all areas of civil engineering including math, ethics, economics, statics, dynamics, materials, fluid mechanics, surveying, environmental, structural, geotechnical, transportation, and construction engineering disciplines. Once an engineer obtains their FE and a college degree in engineering, they become an Engineering In Training (EIT). Per Massachusetts requirements, after working for an acceptable and verifiable company under a Professional Engineer in the civil engineering field for four years, an EIT can register for and take the PE exam. One must graduate from an ABET-accredited college in order to take the PE Exam. Once an EIT passes the PE, they are allowed to stamp designs and engineering plans themselves.

After passing the PE exam, further licenses can be acquired (LEED, PLS, etc) but are not typically necessary to have a successful career. Some higher standards are required in certain states in terms of licensure, such as the Structural Engineering (SE) exam. Having an SE could be essential (depending on where you live) in order to be able to sign off on certain structural engineering plans or taller buildings. Certain states allow an engineer to practice structural engineering if they have been working for a certain number of years in the industry, and some states such as California and Washington also require Seismic Exams as well. This generally runs on a state by state basis, so it is important to check the requirements for what licensure is needed when moving to a new state.

Licensure is critical to ensuring practicing civil engineers are credible and can be trusted to safely design infrastructure. The FE and PE exams certify that engineers in each profession have the same detailed sets of knowledge needed to find solutions to problems and carry those tasks out in a safe manner. On an individual basis, licensure can ensure that engineers are confident in their own work because of their previous experience and knowledge shown by passing the FE or PE exam. These accreditations are important to the public because they can interact with their build environment while knowing that it all has been signed off by engineers who have proven their knowledge and can certify that all necessary safety conditions have been met.

8.0: References

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Appendix A: Photos of Burncoat Ln at Time of Survey











Appendix B: Buyers Guide for Commercially Available Products

Type	Item	Manufacturer	Carrier	Price	Link
Equipment & Attachments	Walk-Behind Vibratory Plate Compactor	WEN	Home Depot	$628	Link
		Tomahawk Power	Home Depot	$1,457	Link
	Walk-Behind Smooth Drum Roller	Multiquip-Mikasa	Patriot Equipment	$16,975	Link
		Bomag		Request Quote	Link
	Ride-On Compactor	CAT		Request Quote	Link
		CAT	United Rentals	$638 /day	Link
	Box Blade Attachment	Brinly-Hardy	Home Depot	$299	Link
		Handozer	Lowe's	$657	Link
	Scraper Blade Attachment	Agri-Fab	Lowe's	$400	Link
		CountyLine	Tractor Supply	$600	Link
Stabilization Grids & Geotextiles	Gravel Stabilization Grid	Cell-Tek	Landscape Discount	$73,164 (273 units)	Link
		Tough Cell	Paradox Access Solutions	$170,000 (for all material and installation)	Link
	Geotextile Fabric *(top: woven, bottom: nonwoven)*	Hanes Geo Components	Lowe's	$6,500 (10 units)	Link
		Hanes Geo Components	Lowe's	$15,492 (12 units)	Link

Appendix C: Contractor Communications

CONTRACTOR A:

Asphalt millings if placed and compacted correctly at the right time of year can last a long time if maintained. By maintained I am saying if a pothole or a small washout arises new millings gets placed and compacted. Lets assume the rd is 4,000' x16' = roughly 7,000sy. To truck in 800 ton of asphalt millings and send a grader, 10 ton roller, and a laborer for 2 days to spread 2" of millings over the entire rd reshape and regrade and compact entire rd you are looking at around $25,000. This would probably last 3-5 years with minimal maintenance and if maintained properly like taking care of small potholes and washout could last 15-20 years.

With paving you are correct. The rd would be fine with one lift 2.5" of dense binder hma. In order to do the binder the existing rd would have to be reclaimed, re-graded and compacted. Reclaiming/Grading would be roughly $3.25 sy = $22,750. Pave 2.5" dense binder would take roughly 1,000 ton @ $90-$95 ton would be about $95,000. Total price to reclaim, regrade compact, and pave a 2.5" binder course would be about 120k. They should get 20 yrs out of it depending what the subgrade looks like. If they were to do a top course over the binder within the first 4-5 years they could get 30-40 yrs out if the rd if the sub-base is decent.

Basically if they want to just bring in millings reshape the rd at an avg thickness 2" it will run about $4 sy.

If they want to reclaim the rd re-grade and compact, and place 2.5" binder it will cost about $17 sy.

Its all about the life they want to get, how much $ they want to spend, and how much they are willing to maintain it.

Thanks,

[name]

CONTRACTOR B:

As far as ride ability and roadway lifespan, I would highly recommend grading and leveling the existing roadway,compacting,installing a processed gravel layer,leveled and compacted to spec, then install 1 coat of Asphalt @ 3.5-4"inchs,compact to spec,let cure and fill edges with loam,dirt

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as far as lifespan and longevity, I would recommend Asphalt, if we went with a base coat @3" inchs it would be less costly and have about 30-40 year avg lifespan

The other option,would be to go with Asphalt millings,this has a similar rideability and with proper maintenance can last as long as 15-20 years and is far less costly than Asphalt

I can send a written quote with both options if you would like,I would just need the exact length of the road,I understand we are using 17'feet as a width,but I would like to have the length which I can get myself if you do not have it

And as far as a timeline,a great time to get this done would be mid April to mid may

CONTRACTOR C:

Contractor C

QUOTE

TO: SHANNON LOGAN-WPI
TN: 617 548-7406
EMAIL: smlogan@wpi.edu

INVOICE #020623

JOB	DATE	PAYMENT TERMS	DUE DATE
PROJECT: BURNCOAT LANE LEICESTER, MA	2/6/23	50% DEPOSIT	BALANCE UPON COMPLETION

	DESCRIPTION	UNIT PRICE	LINE TOTAL
•	APPROXIMATE AREA TO BE PAVED 61,866 SF		
•	OPTION 1:		
•	RECLAIM, GRADE WITH CROWN, COMPACT IN PLACE		$20,500.00
•			
•	OPTION 2:		
•	RECLAIM, GRADE WITH CROWN, COMPACT IN PLACE		
•	MILLINGS, GRADE, COMPACT IN PLACE		$75,300.00
•			
•	OPTION 3:		
•	RECLAIM, GRADE WITH CROWN, COMPACT IN PLACE		
•	INSTALL 2 ½" BINDER COMPACTED IN PLACE		
•	INSTALL 1 ½" STATE TOP COMPACTED IN PLACE		$198,600.00
		TOTAL	TBD

*NOTE: Not guaranteed for root crack, gas and/or soil stains, scuff marks, tire prints, washouts.
*NOTE: Prices are subject to change due to fluctuations in the cost of liquid asphalt. These fluctuations are beyond our control.
*NOTE: Deposit is requested at the time job is scheduled. Deposit is NOT cashed until the week of the scheduled job.

To accept this quotation sign here: ____________________

Return signed quote along with ½ down payment.