Planning a trail using landowner preferences: A multivariable least-cost path approach

by

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A REPORT

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Abstract

Recreational trails provide a valuable asset for communities, especially in rural areas. However, some adjacent landowners have serious concerns about the impact that a proposed trail and its users may have on their lives and property. While the least-cost path has been used to create recreational trails before, it has not been demonstrated in an area dominated by private property. This report seeks to create a tool that planners can use to create trails using a multivariate analysis. Landowner concerns and preferences for a trails route have been incorporated into a least-cost path model in addition to the preferences of trail users and taxpayers. The resulting paths provide a look at what a trail could look like, and how different variables alter its route and costs. Additionally, the feedback from the interviews with landowners will add to the existing literature of landowner attitudes about recreational trails.

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Introduction

Trails are becoming an important recreational feature of American cities. In this paper, the term “recreational trail” refers to a linear path used for recreational purposes such as walking, running, hiking, biking, or other non-motorized activities. The Recreational Trails Program includes other modes such as skating or skateboarding, equestrian activities, skiing, and some motorized vehicles such as motorbikes, ATVs, or snowmobiles (Recreational Trails Program, 2015). Trails have numerous benefits to communities and individuals. These include benefits to local economies (Beeton, 2010; Garrett-Peltier, 2011; Siderelis & Moore, 1995), individual health (Wang et al., 2005; West & Shores, 2011), and property values (Asabere & Huffman, 2009; Karadeniz, 2008; Lindsey et al., 2004; Nicholls & Crompton, 2005). Successful trail planning leverages these benefits to gain support from communities by including individuals owning land adjacent to the trail in planning discussions.

Trails are good for communities but building support for and planning the route of a trail can be difficult. Considering these benefits, trail planners and advocates must be aware of the factors that result in successful trails. Successful trail planning requires the support from nearby communities, and especially the support of adjacent landowners.

The purpose of this project is to identify and address the concerns expressed by adjacent landowners during recreational trail planning. This research will add to the existing literature on landowner concerns surrounding trails and provide a methodology for trail planners to identify and quantify the concerns of property owners. While 85% of trail projects do not spark any conflict between trail advocates and the public, some projects encounter verbal confrontations, legal battles, burned trestle bridges, and blocked trails (Doherty, 1998). Adjacent landowner support is key to the success and acceptance of a proposed trail project. Adjacent landowners are the only group who reap both the benefits and the costs of recreational trails (Turco et al., 1998).

While repurposed railroad corridors are most often used by trail planners, this project seeks to create a trail where no rail corridor exists. By talking with landowners, we can determine their preferences and concerns. Those factors can be incorporated into a least-cost path analysis to create trails based off the concerns of different stakeholder groups. The stakeholders examined in this report are trail users, taxpayers, and landowners. The questions that this project will seek to answer are “how can planners identify landowner preferences?” and “how can these preferences be incorporated into the least-cost path analysis?”

Background

Rural trail systems are often developed on abandoned and repurposed railroad rights-of-way. This was made possible through the National Trails System Act, which allows for trail creation through railbanking. Railbanking is an agreement between the railroad and a trail agency that allows for the recreational use of a railroad corridor while the railroad still maintains ownership in the case that the corridor might be used again (Conservancy, n.d.). Trails created using railbanking, and trails created through the purchase of a rail corridor are typically called "rail-trails". In 1986, rail-trail advocates formed the Rails-to-Trails Conservancy for the purpose of connecting communities with trails (Rails-to-Trails Conservancy, n.d.). Trails are sometimes also called "greenways" especially if they serve an ecological purpose, such as a wildlife habitat corridor.

While trails have many benefits, there are some valid concerns expressed by adjacent landowners. These concerns can include crime, litter, reduced privacy, trespassing, legal liability, and traffic congestion (Corning et al., 2012; Fish & Napier, 2001; Turco et al., 1998). Adjacent landowners bear both the benefits and costs of trails, due to their immediate proximity. Residents that live nearby (but not adjacent) receive most of the same benefits as adjacent landowners, but with fewer of the costs (Turco et al., 1998). Because of this cost-benefit relationship, adjacent residents and landowners play an important role in trail development and their concerns should be addressed.

The factors that influence trail planning and trail acceptance include community factors, adjacent landowner factors, and route factors. Trail planners should take all of these into consideration during the planning process, but ultimately adjacent landowners need to be in support of trail development. This group plays an important role in all three factors, and the trail project may ultimately fail if landowners are resistant.

Community Factors

The factors that influence support from the communities local to the trail are important to recognize and address during trail planning and management. A lack of community support for a proposed trail will slow the development process and may have an impact on trail development and usage. A survey of trail managers found that while 85% of trails met no opposition, trail development can face serious legal battles, verbal confrontations, and vandalism (Doherty, 1998). Therefore, it is important for planners to communicate the benefits of trails to the community, and to involve adjacent landowners in planning discussions.

Adjacent Landowner Factors

While landowners may seem hostile toward the idea of a trail near their property, many studies have shown that landowner support increases after the trail has opened (Corning et al., 2012; Feeney, 1997; Greer, 2001; Kaylen et al., 1993; Mazour, 1988; Turco et al., 1998). In a study of the Missouri River State Trail, Kaylen et al. (1993) found that concerns surrounding the trail were reduced after it opened.

Despite this trend, initial concerns will determine whether a trail will be built. Unsurprisingly, there are differences in initial and ongoing concerns between urban and rural property owners. Brooks (2005) found that rural property owners along 3 New York trails were less satisfied with the trails, despite rural trails having fewer problems. Greer (2001) also found "…a substantial and relatively stable level of opposition to trail development among rural property owners…" (pg. 53). Planning a trail to avoid rural areas is not always an option, because longer trails are more attractive for tourists (Taylor, 2015). Trails intended to attract tourists must run through rural areas.

It may be that rural landowners view their property as a means of support and are justifiably uneasy at the prospect of relinquishing future income. In a study of the perspectives of the balance between environmental and financial issues amongst rural Montana landowners Bastian et al. (2014) found that those coming from smaller towns were more likely to favor a balanced or financial perspective. Higher income residents were less likely to prioritize financial issues, and residents of counties with large coal mining industries were more likely to prioritize finances than environmental issues.

In a study in Ireland, Buckley et al. (2009) found that 51% of farmers surveyed would not agree to allowing recreational hikers access to their property. Of that group, 73% cited nuisance concerns as the reason ("despite the fact that the scenario proposed indemnification against insurance claims"), while 19% cited privacy and safety. Of the remaining farmers, 21% indicated that they would be willing to provide access free of charge, and 28% "indicated that financial compensation…would be required to ensure their participation (p. 1059). It should be noted that allowing hikers on one's land is different than allowing hikers on adjacent public property.

If landowner acceptance is indeed a function of use, then certain populations are more likely to support trails than others. If so, planners can strategically plan trail routes toward more supportive residents, reducing conflict during trail planning and development. To do so, planners must be aware of which groups are supportive of trails, and which are not.

The age of a resident is a factor that one would assume to negatively affect support. However, one study found the opposite. When surveying residents along the Kokosing Gap Trail, Fish & Napier (2001) found that older residents perceived more benefits than younger residents. These results have not been shown in other studies, so it can be assumed that the connection between age and support is dependent on the context of the study or other variables. The authors of the same study did notice a trend of negative support from farmers of cropland, but not farmers of pasture. Mazour (1988) drew a similar conclusion in a survey of landowners along Minnesota trails, but the author does not make a distinction between cropland and pasture.

Another characteristic of support is past experience with recreational trails. Past experience can include past use of a trail or living near a trail. Ivy (2001) surveyed landowners along greenway trails in Cary, North Carolina, and found that past experience as a trail user positively correlates with support for trails.

Route Factors

The route factors of a trail include route and trail material. These factors can have a huge impact on landowner acceptance and trail use. The route of a rail-trail is generally limited to the existing railroad right-of-way. However, in some cases, planners must make their own routing decisions. These decisions have been shown to affect landowner attitude and use. Mazour (1988) found that landowners whose property is divided by a trail have more negative attitudes towards trail development.

As was mentioned above, trail planners must address the concerns of adjacent landowners. The literature shows conflicting results concerning the closeness of property to trails and support. Brooks (2005) found that landowners owning property closer to trails reported more problems than those further away. An earlier study showed that residents living in homes closer to trails did not feel less safe than those living further away (Feeney, 1997). It can be assumed logically that at extremely short distances from residences, support for trails decreases.

The towns that trails run through may also impact trail success. Taylor (2015) found that trails with gateways towns can play an important role in use. Gateway towns act as a starting or stopping point for users. Trails that suddenly stop in the middle of nowhere can make recreational trips difficult for trail users. Taylor (2015) also found that attractions along the trail and in gateway towns can also increase trail use. These attractions could include wineries or events that influence a user's decision to use the trail.

Least-Cost Path

After accounting for all the factors concerning trail planning, it may be possible for planners to use a least-cost path approach to generate a trail. The least-cost path is a tool included in many types of geographic information systems (GIS) software. The tool uses a "frictional surface" to create a path between two points that encounters the least resistance (ESRI, n.d.). The frictional surface is a grid of cells, where the value of each cell represents the "cost" that a traveler would incur to cross that cell. This enables the use of multiple variables, as long as they are able to be quantified and weighted against each other. Figure 1 shows three diagrams that illustrate the least-cost path process. The first diagram represents the source raster, where the value of each cell represents the cost of traversing that location. The second diagram represents the cost raster, where the value of a given cell is the sum of cost between that cell and the source (along the cheapest path). The third diagram is the least cost path. To create this, the algorithm starts at the destination, and moves to the next adjacent cell of the least cost, until it reaches the destination.

Multi-variable least-cost path analyses are a common way of planning linear routes. Their use has been demonstrated for mining roads (Lechner et al., 2017), power lines (Bagli et al., 2011), and arctic all-weather roads (Atkinson et al., 2005). All of these studies include the weighting of their variables as a component of the methodology. Lechner et al. (2017) used social survey methods to identify their weighting scheme. Researchers created a questionnaire that asks respondents about the importance of different factors. Bagli et al. (2011) divided their variables into three criteria: human health, landscape, and nature. The weights for each variable (and criteria) were “assigned by the experts involved in the analysis through direct assessment” (p. 236). Table 1 shows the weights that Bagli et al. (2011) used for each criteria and sub-criteria.

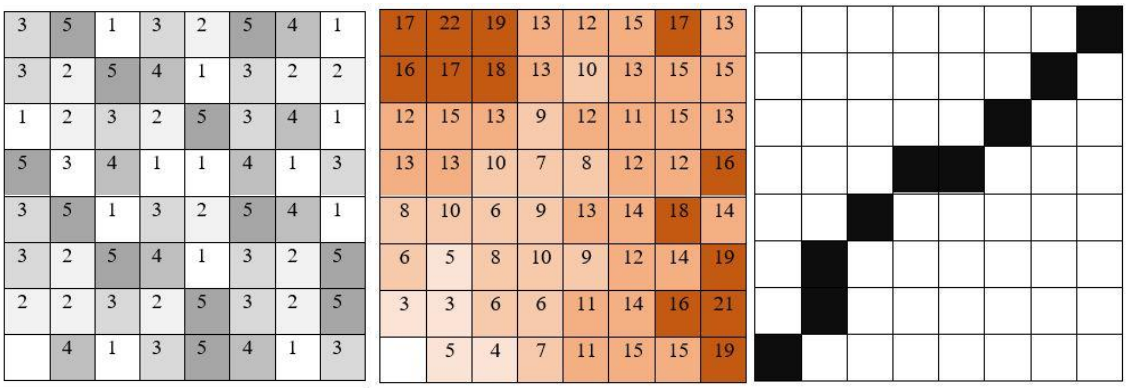

Figure 1: Three diagrams illustrating the least-cost path analysis. They are (left to right) source raster, cost raster, and the least-cost path.

Criteria	Weights	Sub-criteria	Weights for sub-criteria
Human Health	0.62	Density of building	0.30
		Distance from buildings	0.15
		Distance from sensitive buildings	0.15
		Average height of buildings	0.40
Landscape	0.19	Distance from cultural and recreational sites	0.10
		Visibility from cultural and recreational sites	0.50
		Visibility from residential buildings	0.40
Nature	0.19	Aspect	0.15
		Distance from infrastructure corridors	0.35
		Naturalness of the land cover	0.35
		Ridges	0.15

Table 1: The weights of criteria and sub-criteria used in Bagli et al. to create the frictional surface for their least-cost path analysis (2011, p. 236).

One application of least-cost path to footpaths is Rees (2004), who compared least-cost path trails to existing footpaths in the Welsh mountains. The results showed that the least-cost path trails are very similar to existing footpaths, indicating the accuracy of the tool. This study only used elevation and slope variables.

Snyder et al. (2008) used the tool to create an ATV trail through public land. The authors used variables such as slope and terrain to create the path but also buffers around streams and private property boundaries. Another interesting variable included user preference. The authors surveyed ATV enthusiasts to determine what environmental settings were most pleasing to ride in. Those settings were rated as less costly in the model, which made the path more likely to route through those settings.

Another project used a regression tree analysis to assign a cost to areas that are more vulnerable to degradation as the result of trail use (Tomczyk & Ewertowski, 2013). Variables used in this study include trail width, type of use, amount of use, surface geology, soil type, slope, aspect, profile curvature, planar curvature, elevation, landform, and type of plant community.

Monetary variables have also been incorporated into least-cost path models. Teng et al. (2011) created a model that made areas of high vegetation cover less costly. The authors assumed that trails in these areas would cost less to develop. This study was done in China, and the authors note that all urban land in China belongs to the state, increasing the ability of local or provincial governments to develop greenways and trails. In North America, private property ownership is the main constraint surround trail development.

Methodology

The first part of this project is a series of interviews with 8 landowners to determine and quantify their preferences. The second portion of the project is the development of a computer model in ArcMap 10.8 that creates the multivariate “frictional surface”. The output of this model is the surface that the least-cost path tool uses to create the route. The model incorporates the quantified interview results, and weighs each variable based on their importance.

Location and Data

Riley County was chosen because of the proposed route of the Quad-State Trail (Hugh, 2016), an ambitious multi-state effort to connect Nebraska, Iowa, Missouri, and Kansas with a series of recreational trails. Figure 2 shows the route of the proposed trail. Large portions of the project in Nebraska, Iowa, and Missouri have been completed, but there is a large gap between Marysville, Kansas, and Lawrence, Kansas that has not yet been started (Kansas Department of Transportation, 2019). This project aims to assess only a section of this gap, specifically the section through Riley County. This project will create paths between Manhattan and Randolph, Kansas.

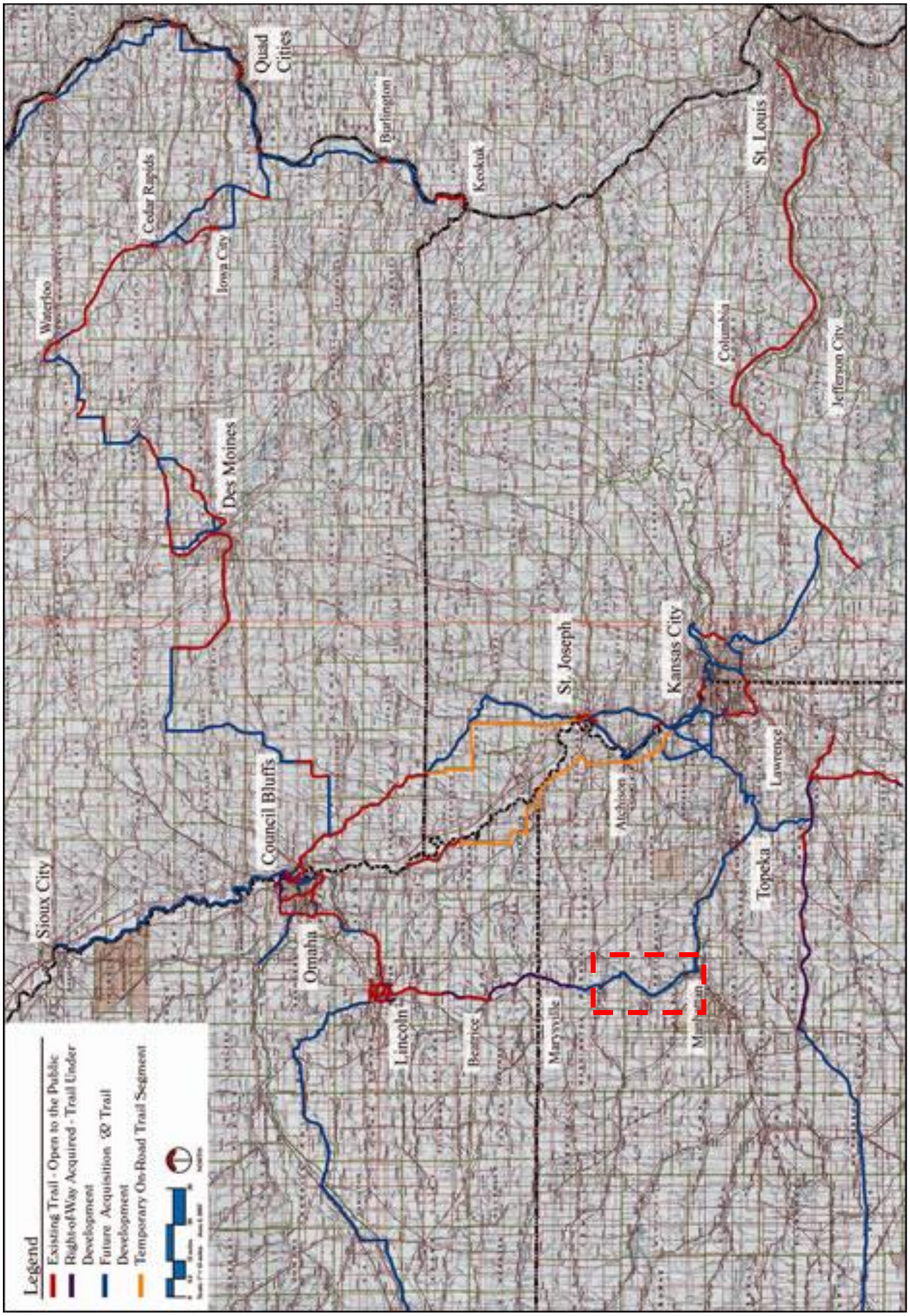

Figure 2: A map of the proposed quad-states trail project (*Quad-State Trail System Mapped--over 700 Miles of Trail Linking MO, KS, NE, IA*, n.d.). The red box shows the location of this study, relative to the whole system.

To create a more realistic path, the starting point was placed in Marlatt Park, and the ending point was placed in Fancy Creek State Park. To decrease the time the model takes to run, two large sections of Riley County were excluded. The area within these exclusions was deemed unimportant to the creation of the path because no realistic trail would route through these areas. The excluded areas are everywhere north of Fancy Creek and everywhere south of Marlatt Avenue and Fort Riley (Figure 3). The data for this project will come from several sources, which are listed in Table 2.

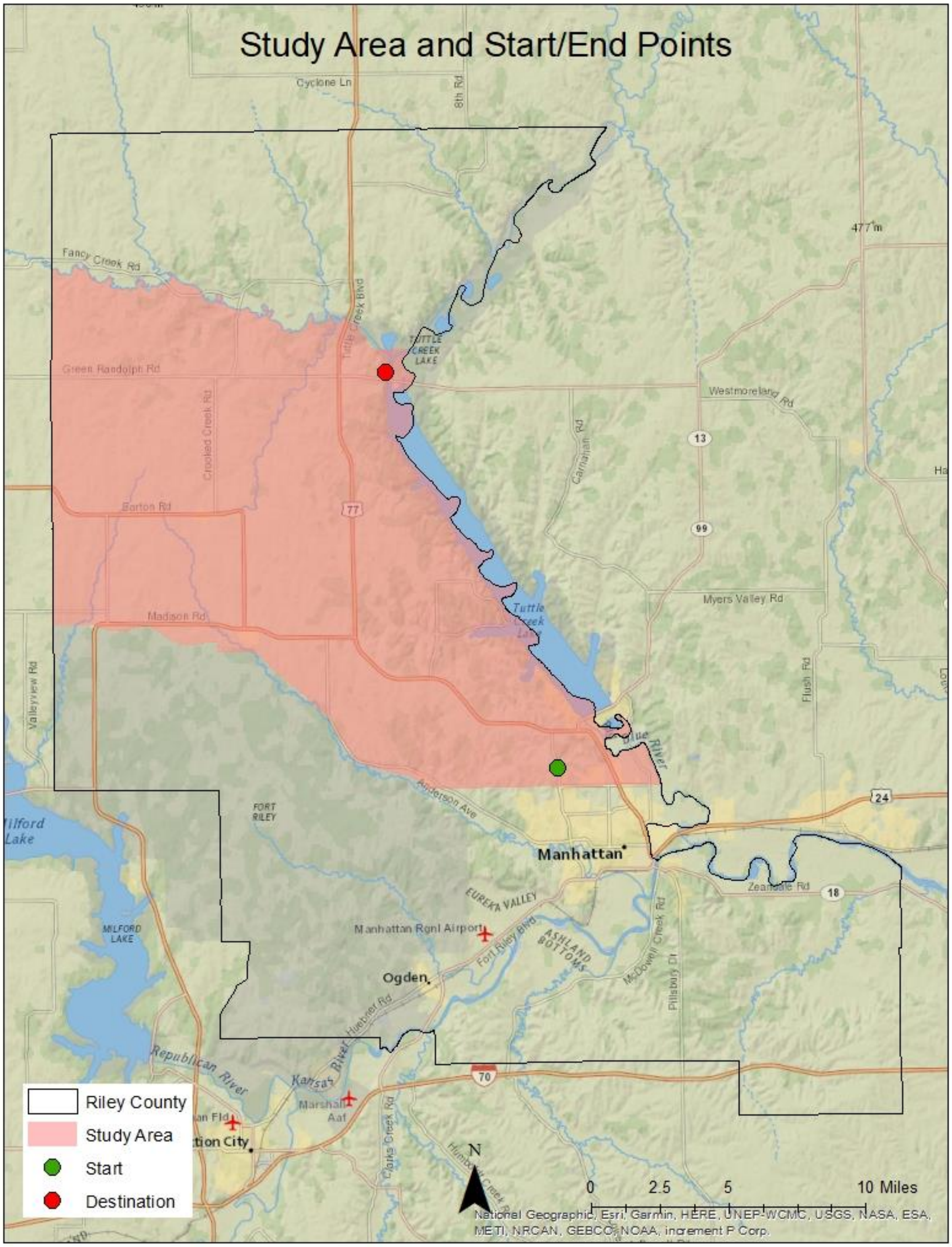

Figure 3: The areas of Riley County that were included in the study area.

Variable	Dataset	Source
Roads	TIGER/Line (2020)	U.S. Census Bureau
Property Value	Parcel Map (2020)	Riley County GIS, Property Assessor
Parcel Boundaries	Parcel Map (2020)	Riley County GIS, Property Assessor
Slope	National Elevation Dataset (2020)	Kansas Data Access and Support Center
Land Cover	National Land Cover Database (2016)	Multi-Resolution Land Characteristics Consortium
Streams and Lakes	National Hydrology Dataset (2020)	USGS
Building Footprints	Parcel Map (2020)	Riley County GIS

Table 2: Data and data sources.

Interviews

To get an in-depth understanding of the preferences of Riley County landowners, eight interviews were conducted. Five were conducted with ranchers or farmers, and three were conducted with rural residents (those who live outside of city limits but do not use their property as a source of income). Only landowners whose listed address was in or near the study area were considered. Parcels whose party name included the words “LLC”, “INC”, and “TRUST” were excluded to ensure that the name could be found in the phonebook. When the final list was completed, every 5^{th} name was cross-referenced with the phonebook to find their phone number and called to request their participation. Interviews lasted roughly 10 to 20 minutes, during which the researcher took written notes. The questions were open ended with the intention of starting a discussion about the concerns that a landowner might have, the impact that a recreational trail would have on an individual, and the impact a trail would have on their property. The interview protocol can be found in Appendix A -

Frictional Surface Model

The model is a combination of 14 variables using the raster calculator tool. Data in vector format is converted into rasters and reclassified so that the value of each cell reflects the cost of traversing that cell. Similarly, data that exists as a raster is reclassified. A raster is a method of storing and displaying geographic information as a continuous surface. The surface is represented by a grid of cells where each cell contains a value that represents a feature on the map. Different rasters can have different cell sizes depending on the data source. In this project, all rasters use 30 by 30-meter cells. This size was chosen because it is the size of the National Landcover Database raster. Where variables overlap, the raster calculator tool adds the layers together. The result is a frictional surface where the value of each cell is the total value of the included variables. Appendices F, G, H, I, J, K, and L show a conceptual diagram of the frictional surface model, with notes that provide background on its function.

Table 3 shows all the variables, and how they are reclassified. The least-cost path tool will avoid cells of higher cost and prefer areas of lower cost. Variables 4-16 are dummy variables, meaning that each cell is given 10 cost if the cell contains the variable, or 0 if it does not. This is so that the variables can be weighed against each other fairly. To get the property and the slope values into a range from zero to ten, the whole range was divided by one-tenth of the maximum value. This ensures that each cell has a proportional value.

While examining the histogram of the study area property values, it was determined that the cost of each cell was skewed heavily by a small number of very expensive parcels. Many of these parcels were within or near city boundaries and were not likely to interfere with the routing of the path. To improve the cost significance of relevant parcels, the outliers were eliminated by removing the 877 most expensive parcels (15% of the total parcels).

Number	Variable Name	Classification (True, False)
1	Slope	1-10, 0
2	Property Value ($/900m^2)	0-10, 0 (Excluding the highest 15%)
3	Building Buffers (Euclidian Distance)	5-10, 0
4	Grasslands	10, 0
5	Forests	10, 0

7	Stream Buffers (30 meters)	10, 0
8	Lake Buffer (100 meters)	10, 0
9	Parcel Boundary Buffers (15m)	0, 10
10	Road Buffer – County (70 ft)	10, 0
11	Road Buffer – “M” (70 ft)	10, 0
12	Road Buffer – State/Federal Highways (250 ft)	10, 0
13	Lakes	N/A, 0 (TRIM)
14	Building Footprints	N/A, 0 (TRIM)

Table 3: Variables and how they are reclassified.

To create a tiered building buffer the Euclidian distance tool was used to create a raster where every cell value is the distance between that point and the input data. In this case, the input data are building footprints. The Euclidian distance raster is then reclassified into different tiers based on the results of the interviews.

Land cover variables are derived from the National Landcover Database (NLCD). In the NLCD, different land covers are given a number. Land covers 41, 42, 43, and 52 all fit into the general category of “forests”. These values are selected using extract by attributes and reclassified. Likewise, land covers 71 and 81 are considered grasslands and are thus extracted and reclassified.

Road data is categorized into different road classifications. Road types “U” and “S” are state or federal highways, road type “C” are county roads, and road type “M” are everything else, except for driveways and access roads. The different road types are given a buffer value equal to half the approximate width of the right-of-way. The buffers are then converted to rasters and reclassified. Streams are converted and reclassified similarly. The buffer distance for streams is based on Snyder et al. (2008). The parcel map is converted from a polygon file to a polyline file. The lines are buffered at 15 meters (half the size of one cell) so that each parcel boundary buffer is exactly one cell wide. The lakes are given a 100-meter buffer and then converted to a raster and reclassified.

As the variables are combined, they are each given a weight that reflects how much impact they should have on the total cost of each cell. For example, if the slope is weighted as 0.20, that means that 20% of the final cost of each cell can be attributed to slope. Variables 17 and 18 are not combined in the frictional surface the same way that the others are. These are the "impenetrable" features that are trimmed out of the frictional surface, so the least-cost path analysis views these variables as the boundaries of the map. Figure 4 shows a simplified version of the frictional surface model.

In total, three different weighting schemes were created to fit the needs and preferences of three different stakeholder groups (Table 7). These stakeholders are landowners, trail users, and the taxpaying public. The weighting schemes and variable classifications are adjusted to reflect these preferences. Not every variable is included in every weighting scheme. Slope, property value, building buffers, water buffers, and the trim variables are all important for the success of any trail and are included in each least-cost path analysis. Other variables may be excluded from a weighting scheme if they are not pertinent to the stakeholder group.

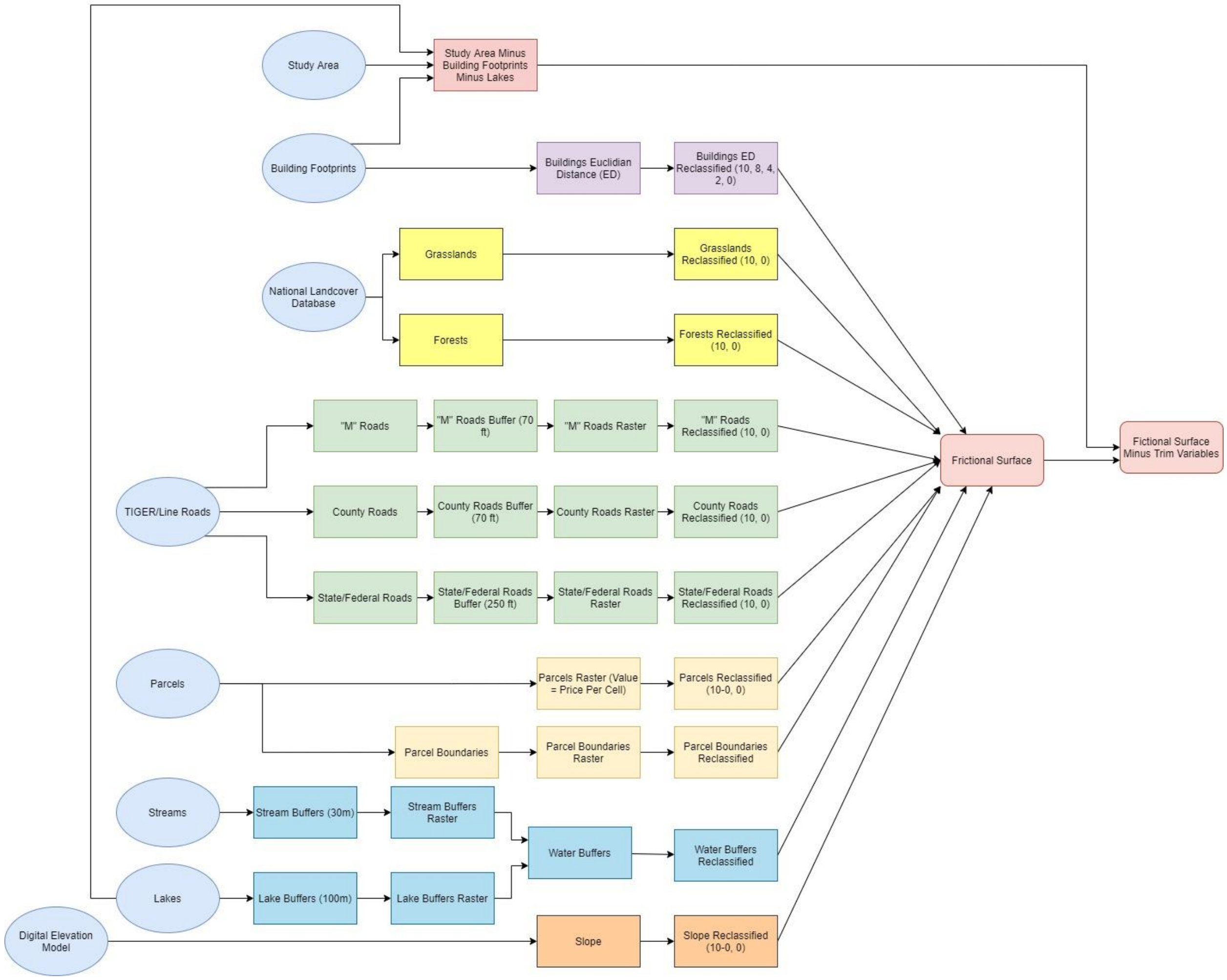

Figure 4: A simplified version of the frictional surface model that shows how the variables are reclassified and organized. An annotated version of the model is shown in Appendix F

Results

Interview Results

In total eight interviews were conducted. Of the total, five interviewees were farmers or ranchers, and three were residential landowners. Based on the feedback from the interviews, the two most important model variables for landowners are that the trail is not visible from their house and that the trail follows the property lines.

To address trail visibility, interviewees were asked at what distance would they prefer the trail remain from any building. Responses ranged from 300 feet to half a mile. Subjects were also asked if a trail routed through wooded areas would be preferable to a trail routed through grasslands. Six of the eight landowners interviewed stated that wooded areas were preferable to open areas. The remainder stated that they had no preference for this variable, or that they could not give an answer because of the characteristics of their property.

Ranchers are particularly concerned with the impact a trail would have on livestock and the operation of their farm. A trail bisecting a parcel would effectively cut their property in half, requiring additional gates and cattle guards. Additionally, ranchers were concerned with the impact that trail users would have on their livestock. One interviewee specifically noted that trail users might let their dog off the leash, and it would spook their cattle. Instead of bisecting private property, landowners stated that they would prefer if the trail followed existing fences.

Interviewee (#)	Class (A – Agricultural, R – Residential)	Buffer Size (Feet)	Forest/Grassland Preference	Land Use Preference (A – Agricultural, R – Residential)	Boundary Preference
1	A	1320	-	A	Yes
2	R	-	Forest	-	Yes
3	R	2640	Forest	-	Yes
4	R	<300	Forest	-	Yes
5	A	1320	-	R	Yes
6	A	2640	Forest	A	Yes
7	A	2640	Forest	A	Yes
8	A	300	Forest	R	Yes

Table 4: A summary of the interview results.

To address visibility concerns, interview responses have been combined to create a nested buffer effect around building footprints. Seven of the eight respondents gave a specific building buffer preference. Table 5 shows respondents' preferences. The responses shown in Table 5 are not mutually exclusive. For example, an interviewee who prefers a 1320-foot buffer around building footprints is counted twice. Once for 1320 feet, and once for 300 feet (because 1320 is greater than 300). Table 6 shows how the responses from the interviews were turned into a classification scheme. The notes that were taken during the interviews can be found in Appendix B -

Buffer Size	Responses
>300 feet	7
>1320 feet	5
>2640 feet	3
>5280 feet	0

Table 5: Building buffer preferences gathered from landowner interviews.

Buffer Size	Pre-weight Cost
<300 feet	10
300 - 1320 feet	8
1320 - 2640 feet	4
2640 - 5280 feet	2
>5280 feet	0

Table 6: The sizes of the tiered buffer system, and how they are classified.

Frictional Surface Weightings

Three weighting schemes were developed to reflect the preferences of three stakeholder groups: trail users, taxpayers, and landowners (the preferences of trail users and taxpayers were not collected in the interviews, but instead were assumed using the researcher's best judgment). Table 7 shows these weighting schemes.

<table>
<tr><td></td><td colspan="2">User Weighting</td><td colspan="2">Taxpayer Weighting</td><td colspan="2">Landowner Weighting</td></tr>
<tr><td>Variable</td><td>Classification (True, False)</td><td>Weight</td><td>Classification (True, False)</td><td>Weight</td><td>Classification (True, False)</td><td>Weight</td></tr>
<tr><td>Property Value</td><td>10-1, 0</td><td>5%</td><td>10-1, 0</td><td>25%</td><td>10-1, 0</td><td>10%</td></tr>
<tr><td>Slope</td><td>10-1, 0</td><td>30%</td><td>10-1, 0</td><td>25%</td><td>10-1, 0</td><td>10%</td></tr>
<tr><td>Building Buffers (300ft, 1320ft, 2640ft, 5280ft)</td><td>10, 8, 4, 2, 0</td><td>5%</td><td>10, 8, 4, 2, 0</td><td>5%</td><td>10, 8, 4, 2, 0</td><td>20%</td></tr>
<tr><td>Grasslands</td><td rowspan="2">0, 10</td><td rowspan="2">20%</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Forests</td><td>10, 0</td><td>10%</td><td>0, 10</td><td>10%</td></tr>
<tr><td>Water Buffers</td><td>10, 0</td><td>5%</td><td>10, 0</td><td>5%</td><td>10, 0</td><td>5%</td></tr>
</table>

Parcel Boundary Buffer	-	-	-	-	0, 10	25%
Road Buffer – County	10, 0	10%	0, 10	15%	0, 10	10%
Road Buffer – M	10, 0	10%				
Road Buffer – State/Federal Highways	10, 0	15%	10, 0	15%	10, 0	10%

Table 7: The variables, how they are classified, and how they are weighted to create the three frictional surfaces and paths.

The user weighting scheme is intended to create a path that is safe, scenic, and avoids difficult topography. Safety is addressed by increasing the weight of roadway buffers so that the path will avoid routes that cross or go alongside roads. Because state and federal highways typically have higher traffic volumes and higher speeds, those buffers are weighted higher than other road classes. To create a scenic path, grassland and forest land covers combined and weighted at 20 percent, but inversely classified. The classification is inverted so that additional cost is added to cells not containing grasslands and forests. This makes the least-cost path analysis prefer the selected variable (forests and grasslands). Finally, weight is given to the slope variable so that the path avoids steeper terrain that is difficult to traverse. The remaining weight is split evenly between the remaining variables.

The next weighting scheme is centered around the taxpaying public. The path is weighted in a way that will avoid high property costs, prefer local roads, and avoid land covers that would make trail construction difficult. County and “M” class road buffers are inversely classified so that the path will prefer these routes. Because of the bureaucratic struggles that come with altering a state or federal highway, the classification of these roadway buffers is not inversed, so that the path avoids this variable (state/federal highways). An additional cost is added to forested land covers because of the increased cost that clearing space for a trail would entail.

The final weighting scheme uses data collected from interviews with rural landowners to create a path based on their preferences. Because of the overwhelming preference for the trail to follow parcel boundaries, that variable is weighted the highest. Forests and grasslands are weighted at 10%, but forests are classified inversely. Property value and slope are both weighted at 10%, and the remaining four variables are all weighted at 5 percent. County and “M” roads are weighted inversely.

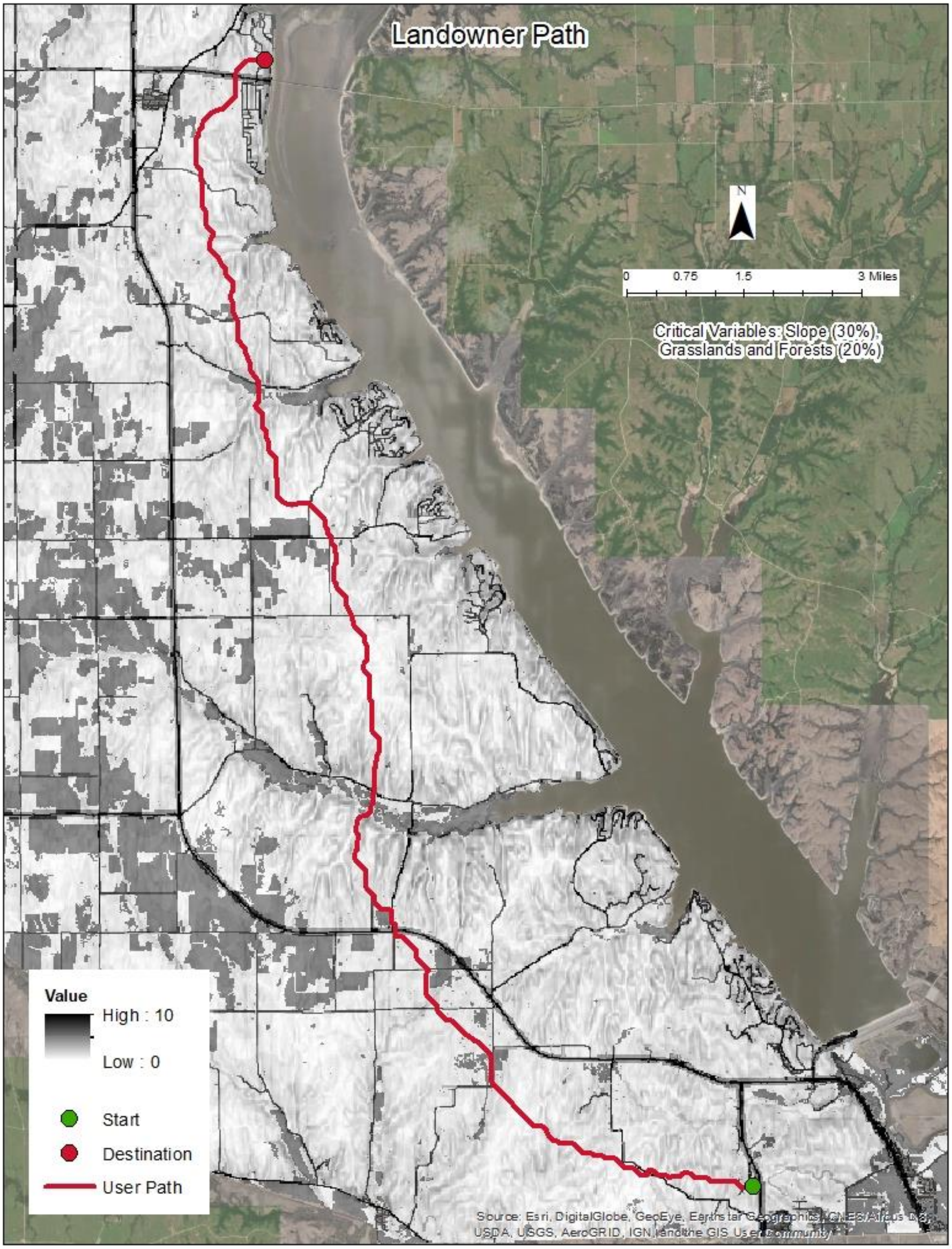

Figure 5: Trail User Model Run - Frictional surface and resulting path created from user variables and weights.

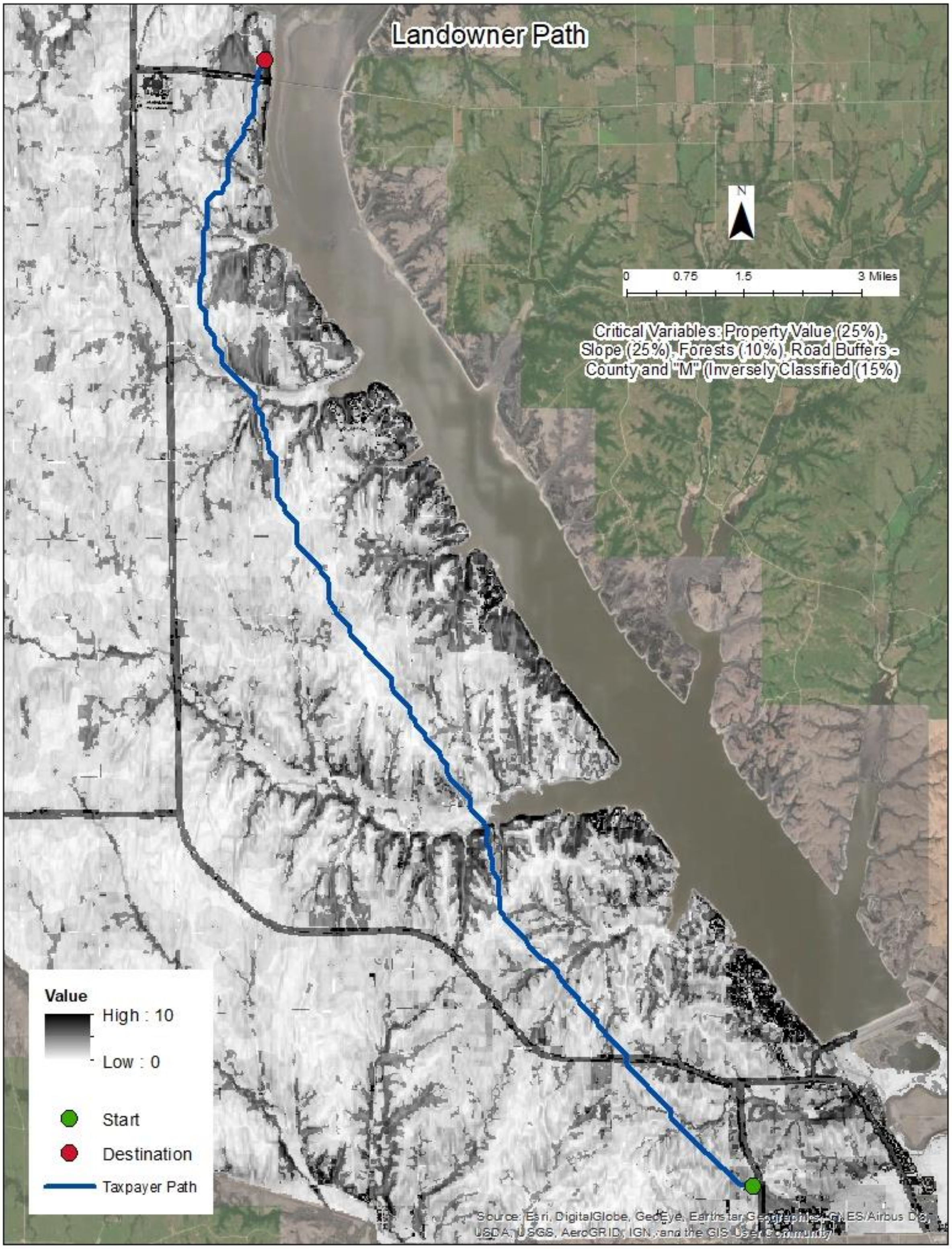

Figure 6: Taxpayer Model Run - Frictional surface and resulting path created using taxpayer variables and weights.

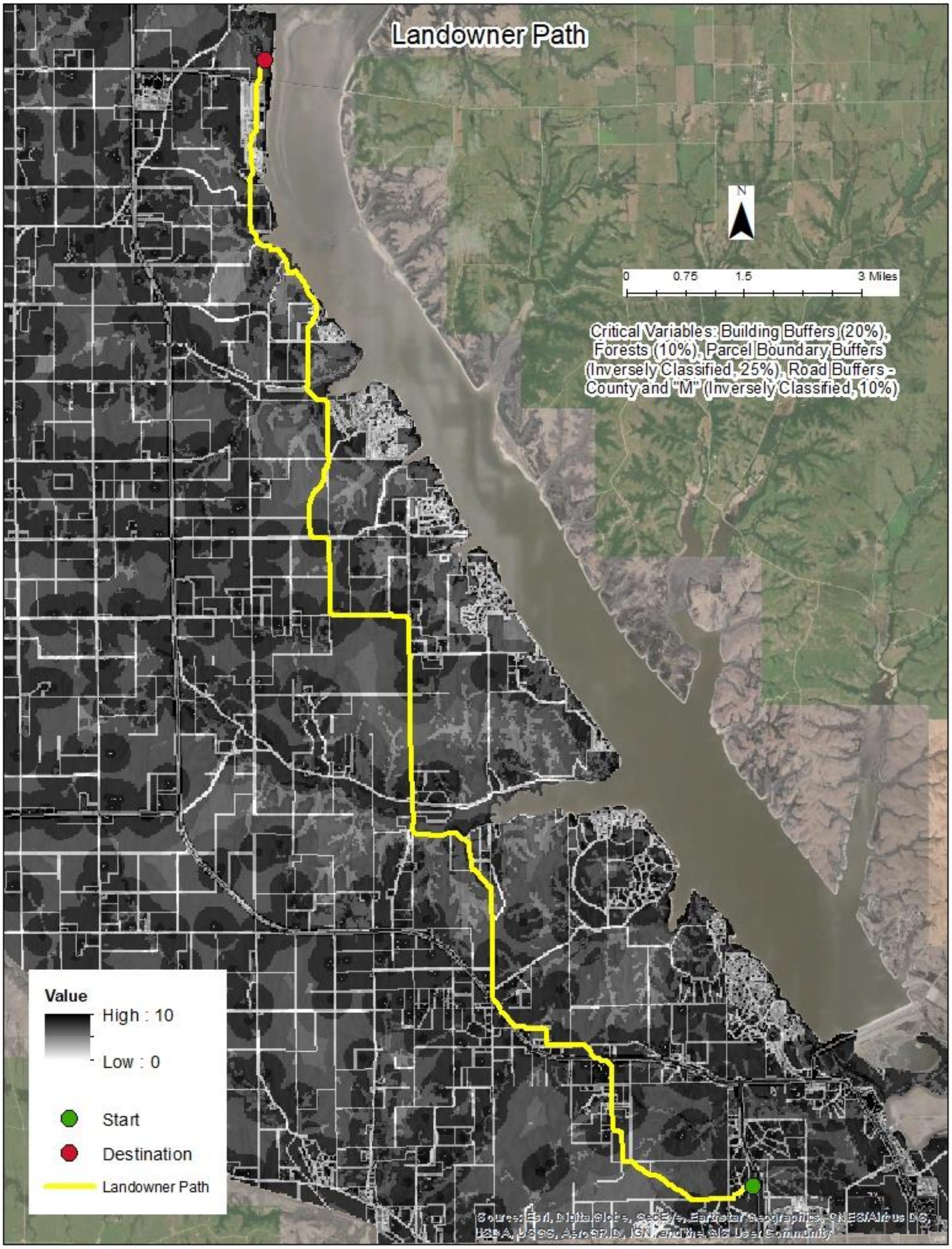

Figure 7: Landowner Model Run- Frictional surface and resulting path created using landowner variables and weights.

For a path to be successful, it must be evident that the path is avoiding (or preferring) important variables. In the case of the trail user path, those variables are slope, grasslands/forests, and roads. Figure 8 shows an enlarged section of the path near Mill Creek where the trail intentionally takes a longer route to avoid an area of steeper slopes. Figure 9 shows another section of the same trail. In this map, the trail is preferring forest/grassland areas over non-forest/grassland areas. Figure 10 shows how the trail avoids roads. Crossing roads between the start and end point is necessary, but the trail only does this when necessary and does so decisively.

The key criteria for a successful weighting scheme in the taxpayer trail are avoidance of high-cost property, avoidance of forested areas, and preference for existing county or "M" class roads. Figure 11 shows the taxpayer path avoiding a high-cost parcel. Figure 12 shows the taxpayer path cutting between two diagonally adjacent parcels that are high-cost. The path does not cross through either parcel for more than one cell. Figure 13 shows how the path chooses to follow a corridor near Baldwin Creek between two forested areas. In the case of road preference, Figure 14 shows how the trail follows local roads for a short distance.

The four important criteria to examine in the landowner path are a preference of forested areas, a preference for parcel boundaries, a preference for county and "M" class roads, and avoidance of building buffers. Figure 15 shows a section north of Baldwin Creek where the landowner path chooses to route through a forested area along Tuttle Creek Lake. Figure 16 shows the paths preference for parcel boundaries. Figure 17 shows another section where the trail follows existing roads for a considerable distance, even if the route it takes is longer. Figure 18 shows how the trail avoids building buffers. Because of the size of the largest two tiers of the building buffers (1 mile and ½ mile), there are many sections of the path where routing through a buffer cannot be avoided. However, there are few instances where the trail goes through the smallest (300 ft) buffer.

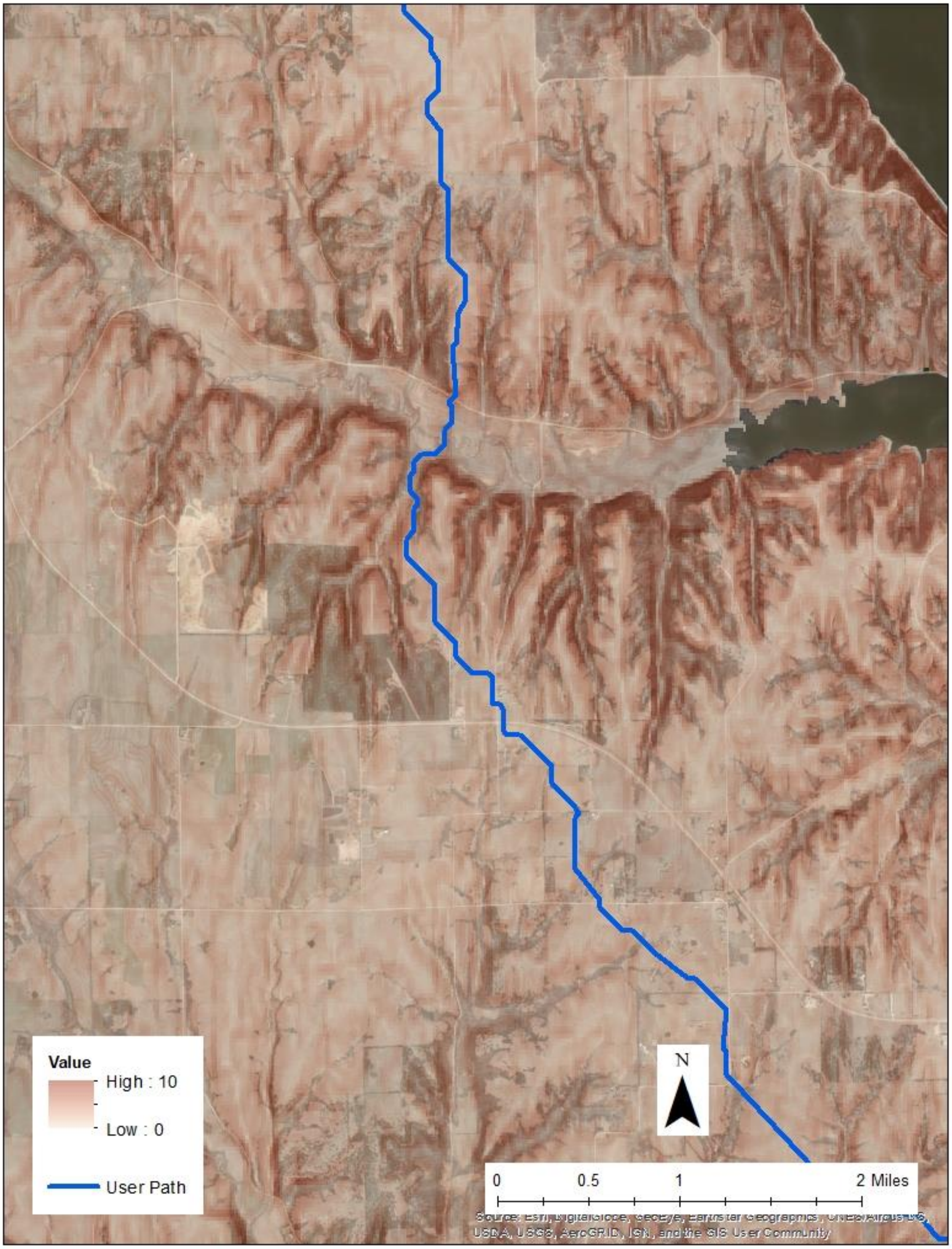

Figure 8: An enlarged section of the trail user path, showing how the path avoids areas of high slope (areas of darker color).

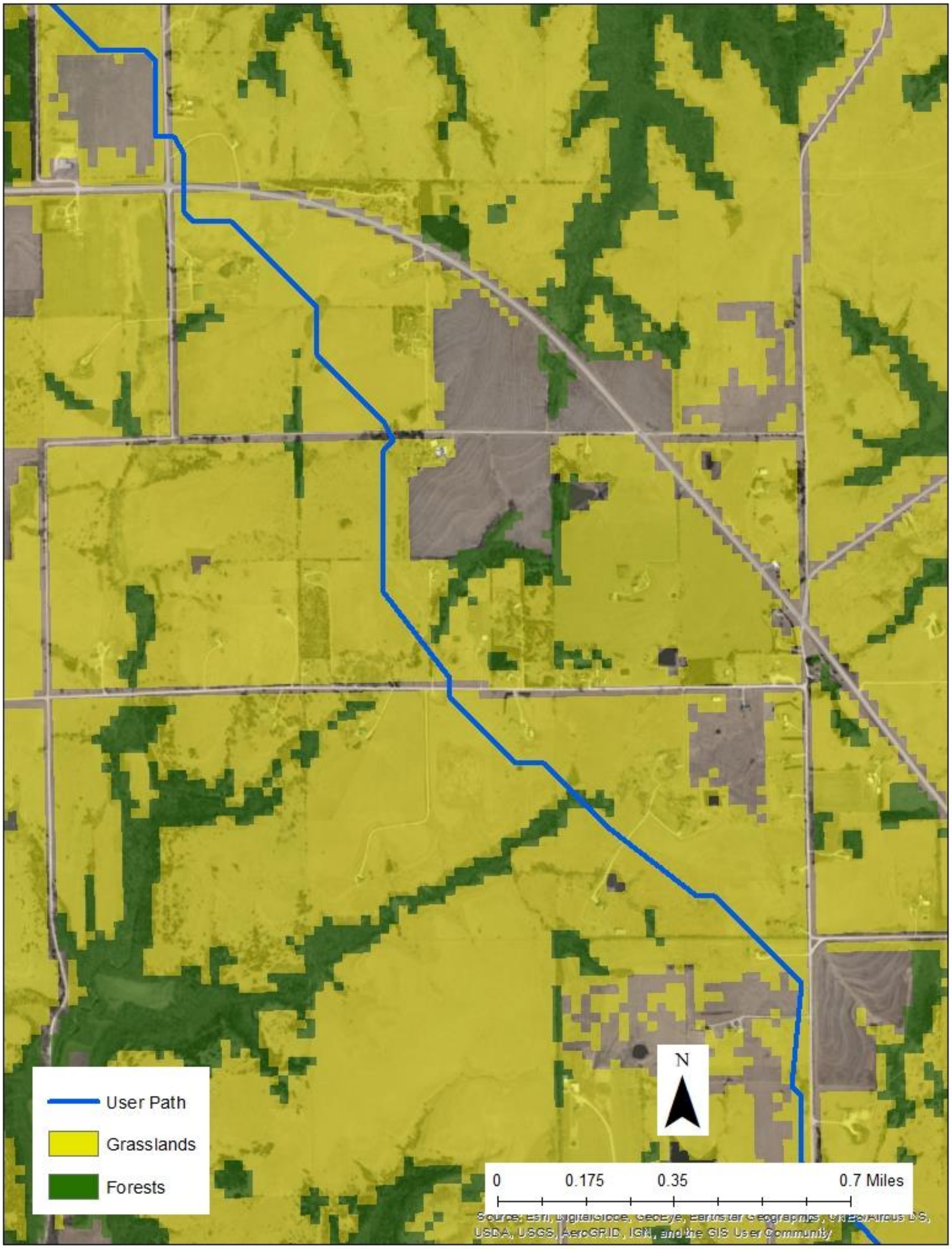

Figure 9: An enlarged section of the trail user path showing how the trail prefers forested and grassland areas.

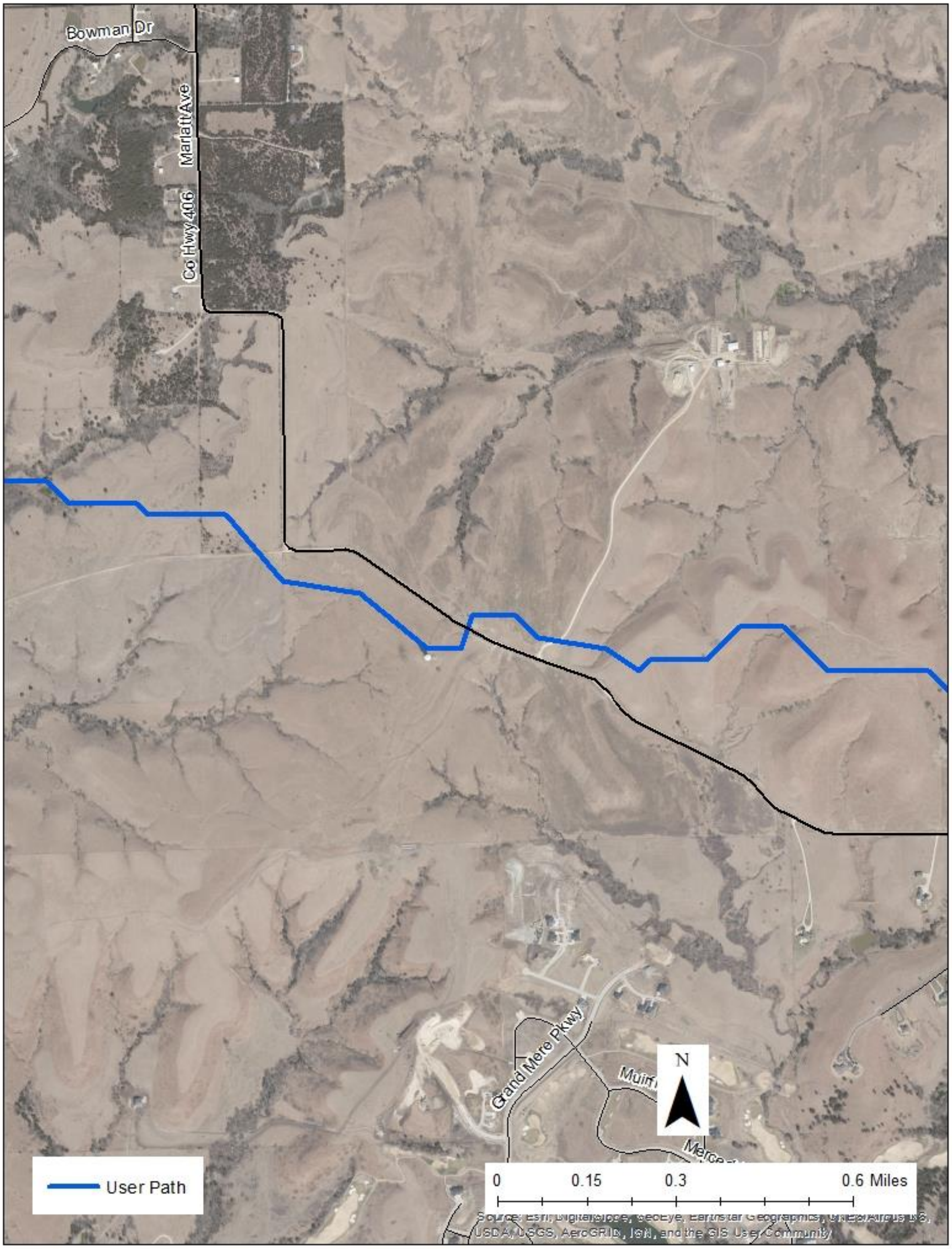

Figure 10: An enlarged section of the trail user path showing how the trail crosses roads when necessary, but does not follow them.

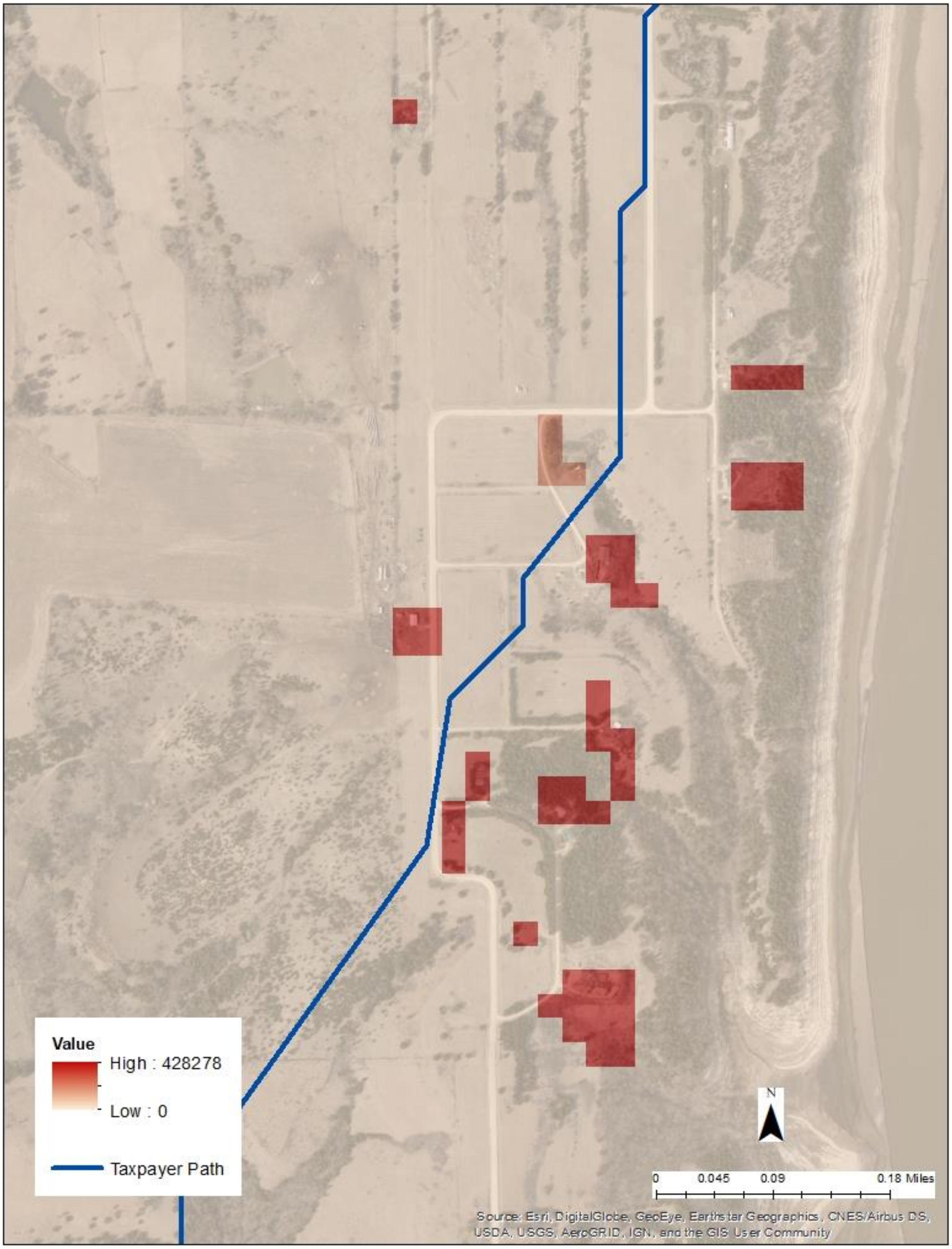

Figure 11: An enlarged section of the taxpayer path, showing how the path avoids high-cost properties represented here by dark red shading.

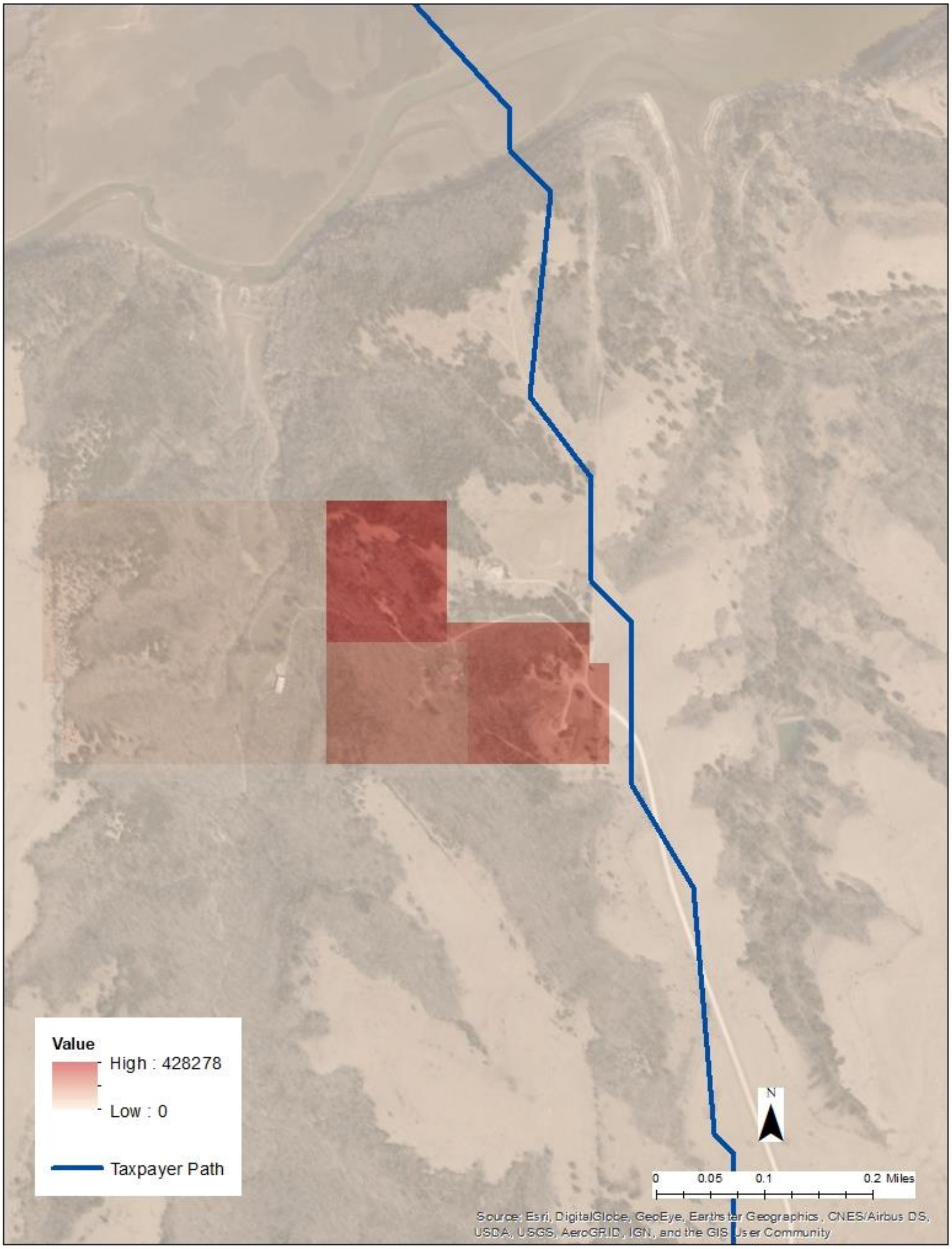

Figure 12: An enlarged section of the taxpayer path, showing how the path avoids high-cost properties represented here by dark red shading.

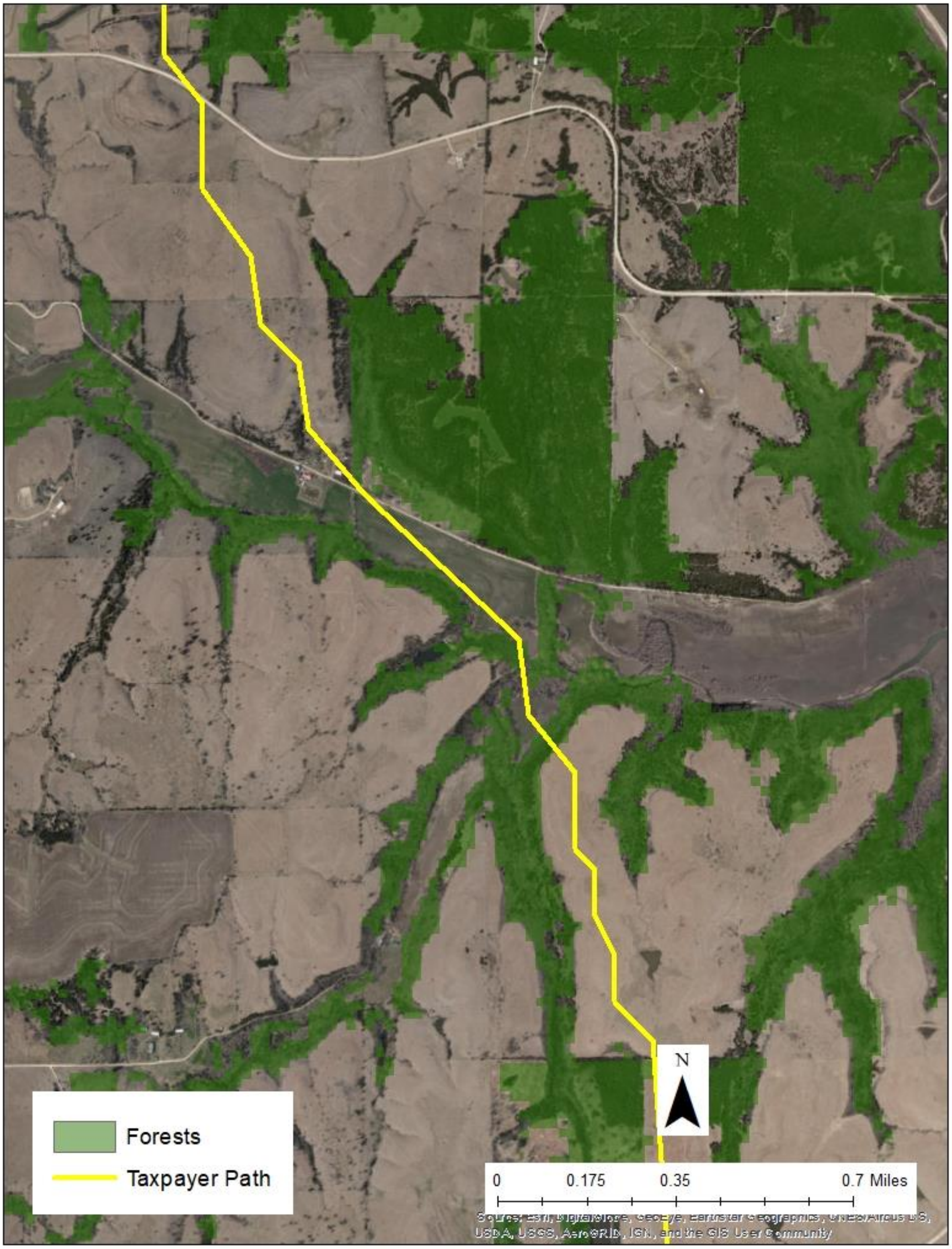

Figure 13: An enlarged section of the taxpayer path, showing how the path avoids forested areas.

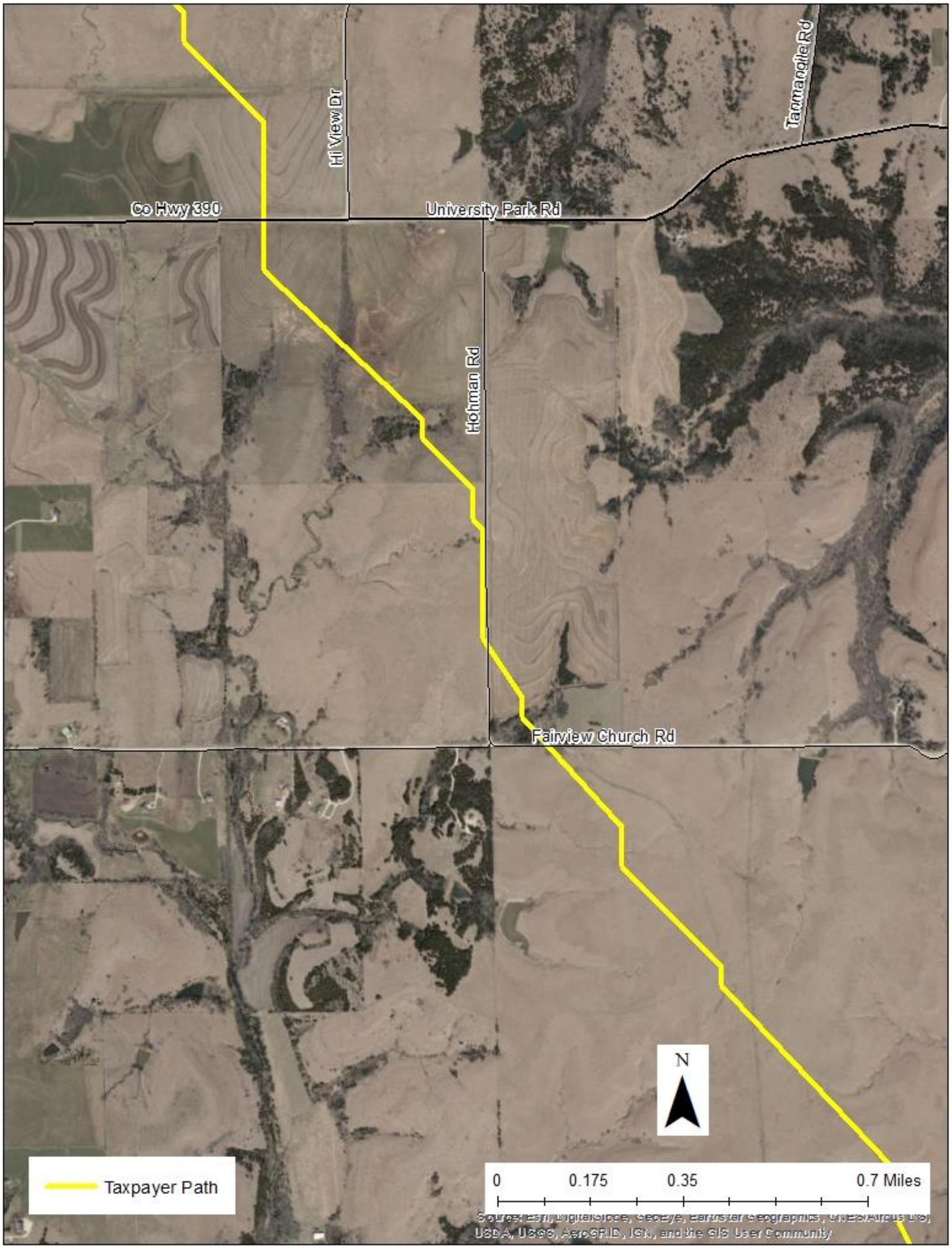

Figure 14: An enlarged section of the taxpayer path, showing how the path follows Hohman road briefly.

Figure 15: An enlarged section of the landowner path, showing how the path prefers forested areas.

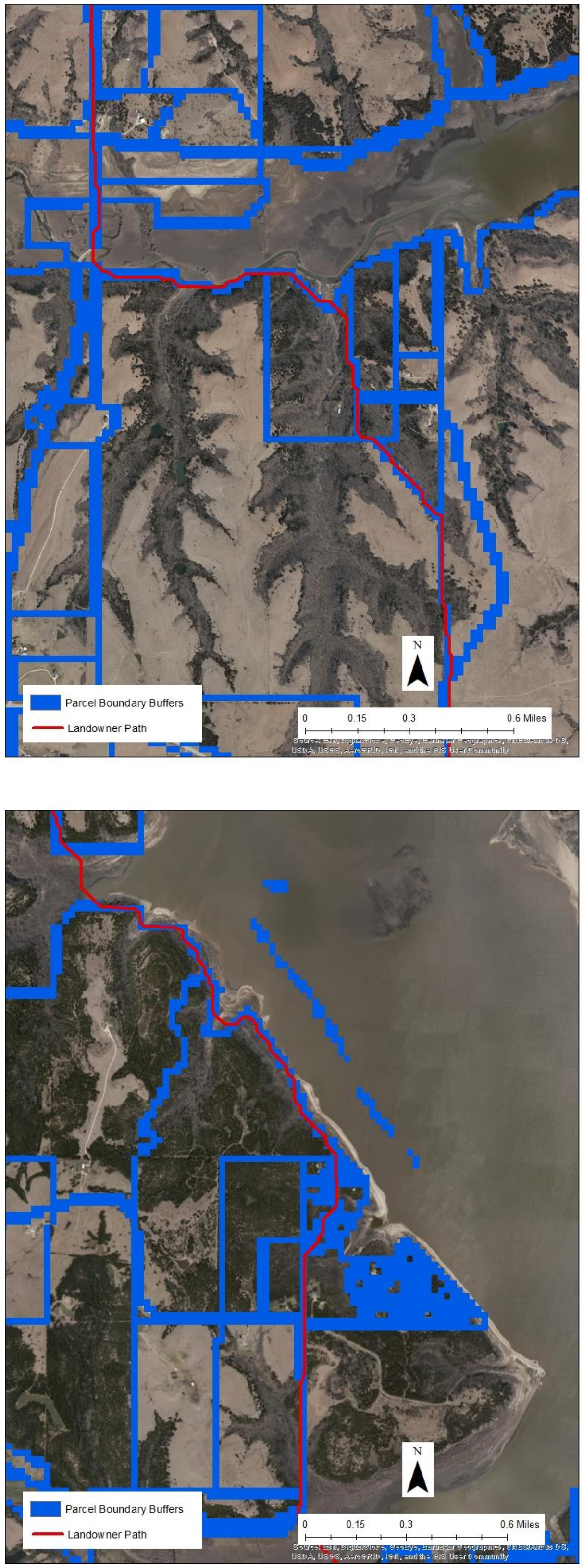

Figure 16: Two maps showing how the landowner trail follows parcel boundaries.

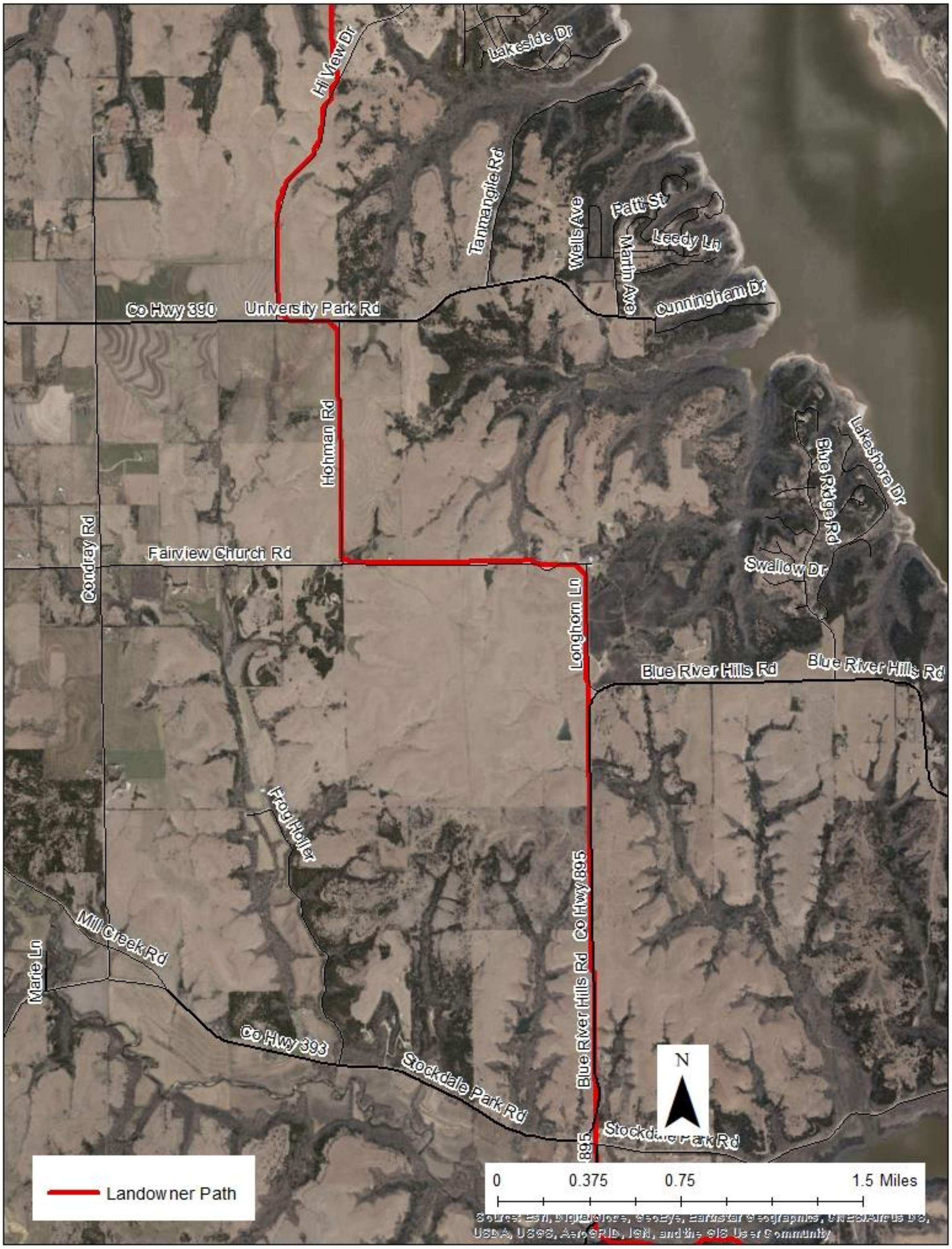

Figure 17: An enlarged section of the landowner path, showing how the path prefers county and "M" class roads.

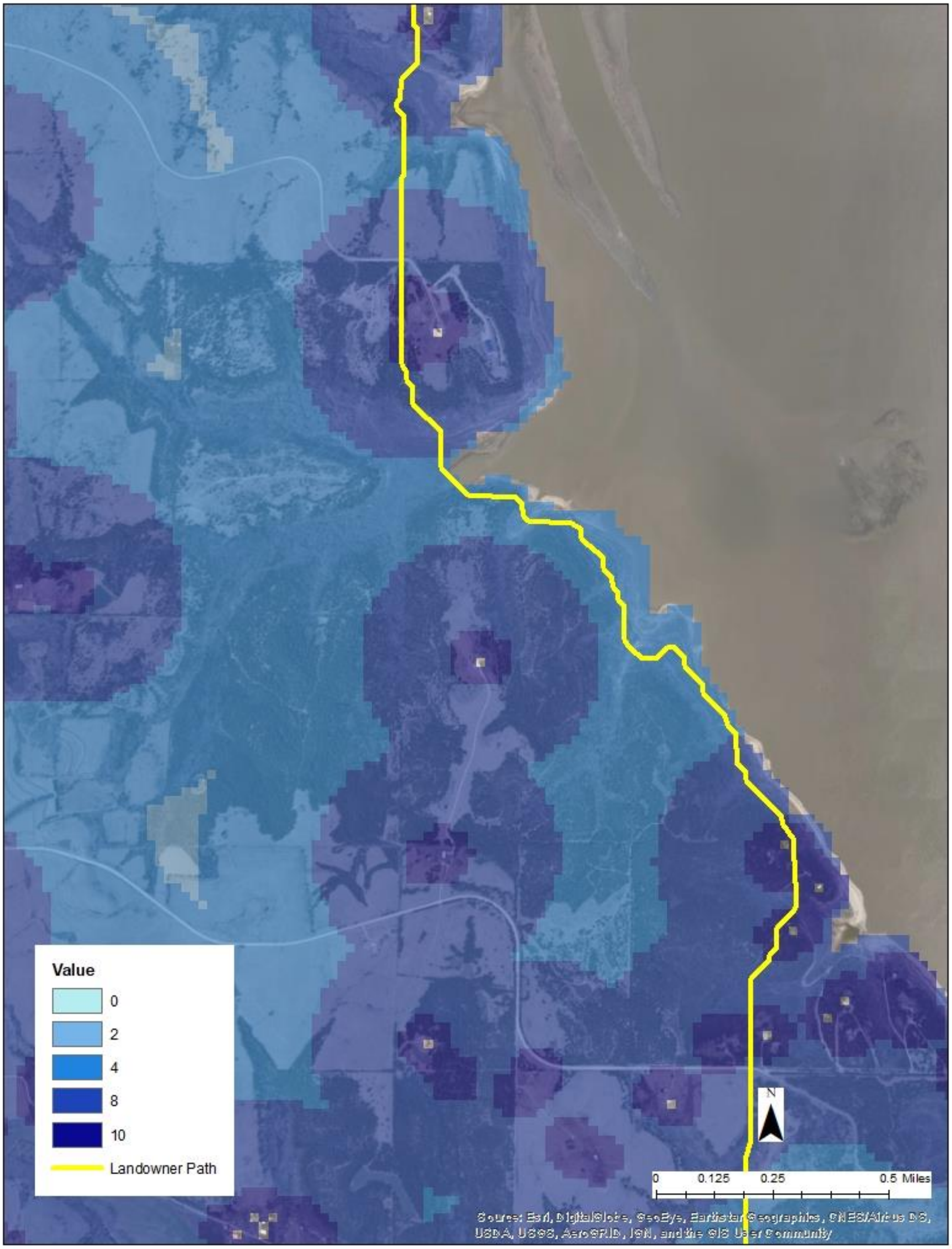

Figure 18: An enlarged section showing how the landowner path avoids building buffers.

Discussion

While all three of the paths created are of interest, it is important to compare and contrast their routes. Of particular importance are the locations where two or three of the paths follow the same or nearly the same route. These areas are ideal path locations for all three stakeholder groups. Figure 19 shows all three paths and their routes. All three paths choose to stay east of Highway 24 (green line), which rules out a large portion of the study area from consideration.

The three paths start their route in different ways. In Figure 20, we can see that the taxpayer path takes a very direct route towards the destination, while the landowner and user paths route west. The landowner path chooses to cross Highway 24 earlier than the user path, which continues west. Figure 21 shows how the user path crosses Highway 24 and how all three paths cross a draw where Mill Creek joins Tuttle Creek Lake. Areas like this are subject to semi-regular flooding, and only the landowner path crosses along an existing road. Figure 22 shows a portion of the study area further north. In this section, the landowner path follows the road for a considerable distance. This is an area of interest because of how close the paths come to each other. This figure also shows how all three paths cross another draw, where Baldwin Creek meets Tuttle Creek Lake. There is no road crossing at this location. Figure 23 shows the routes that each path takes to reach the destination point. The landowner path follows the forested shoreline and then joins the taxpayer path just south of the destination. The user path takes a longer route, before reaching the destination from the west.

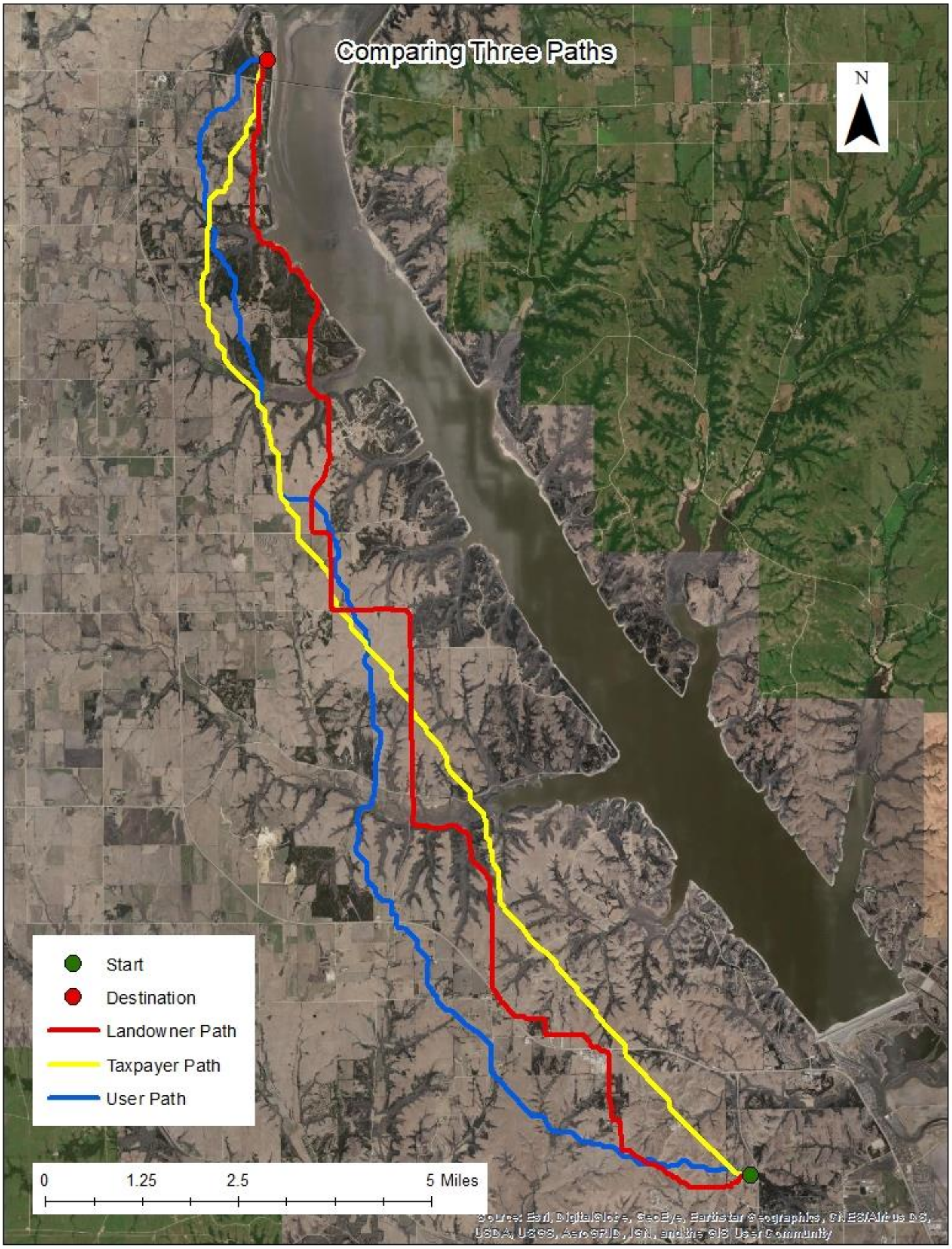

Figure 19: All three paths displayed at once.

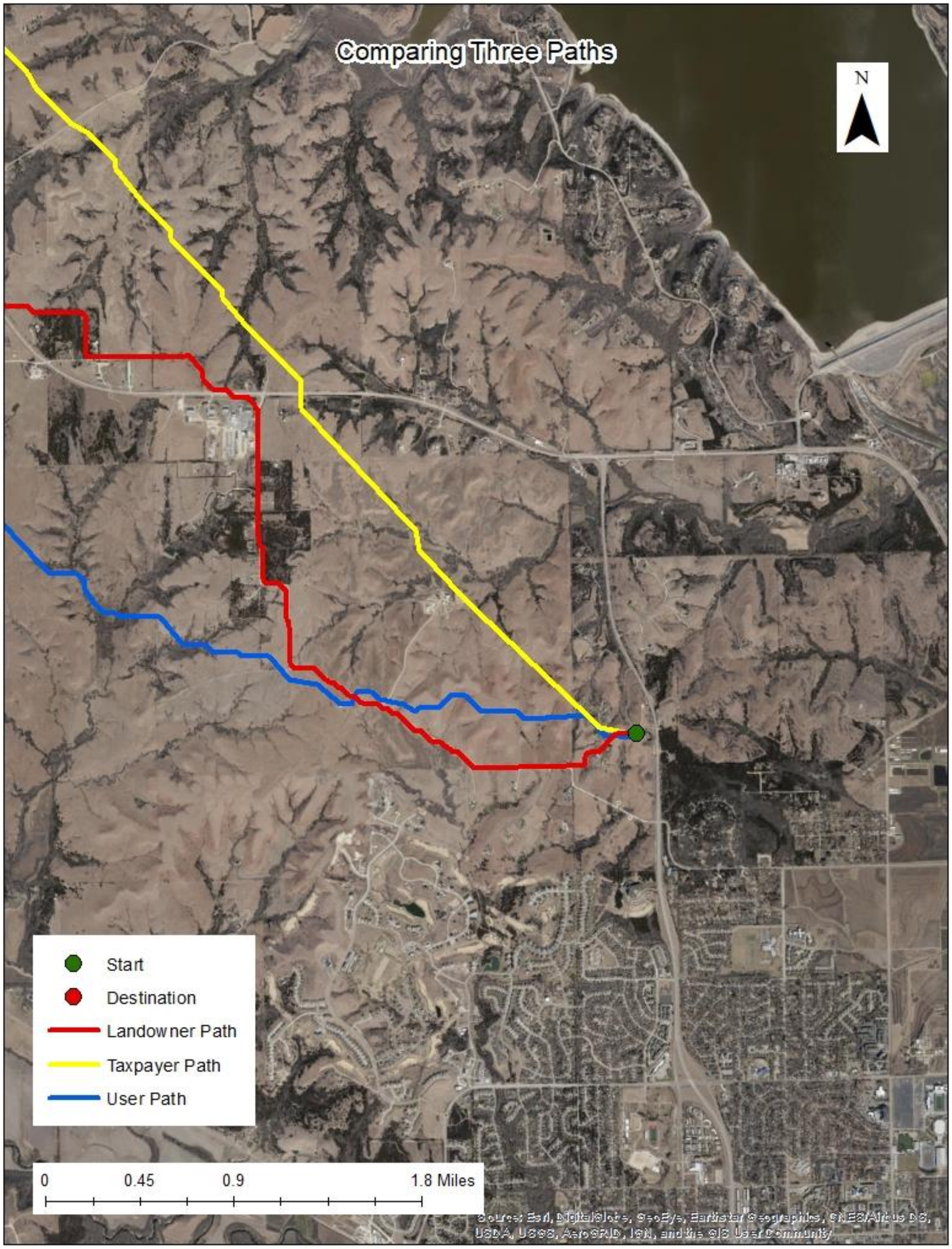

Figure 20: An enlarged section of all three paths near the starting point.

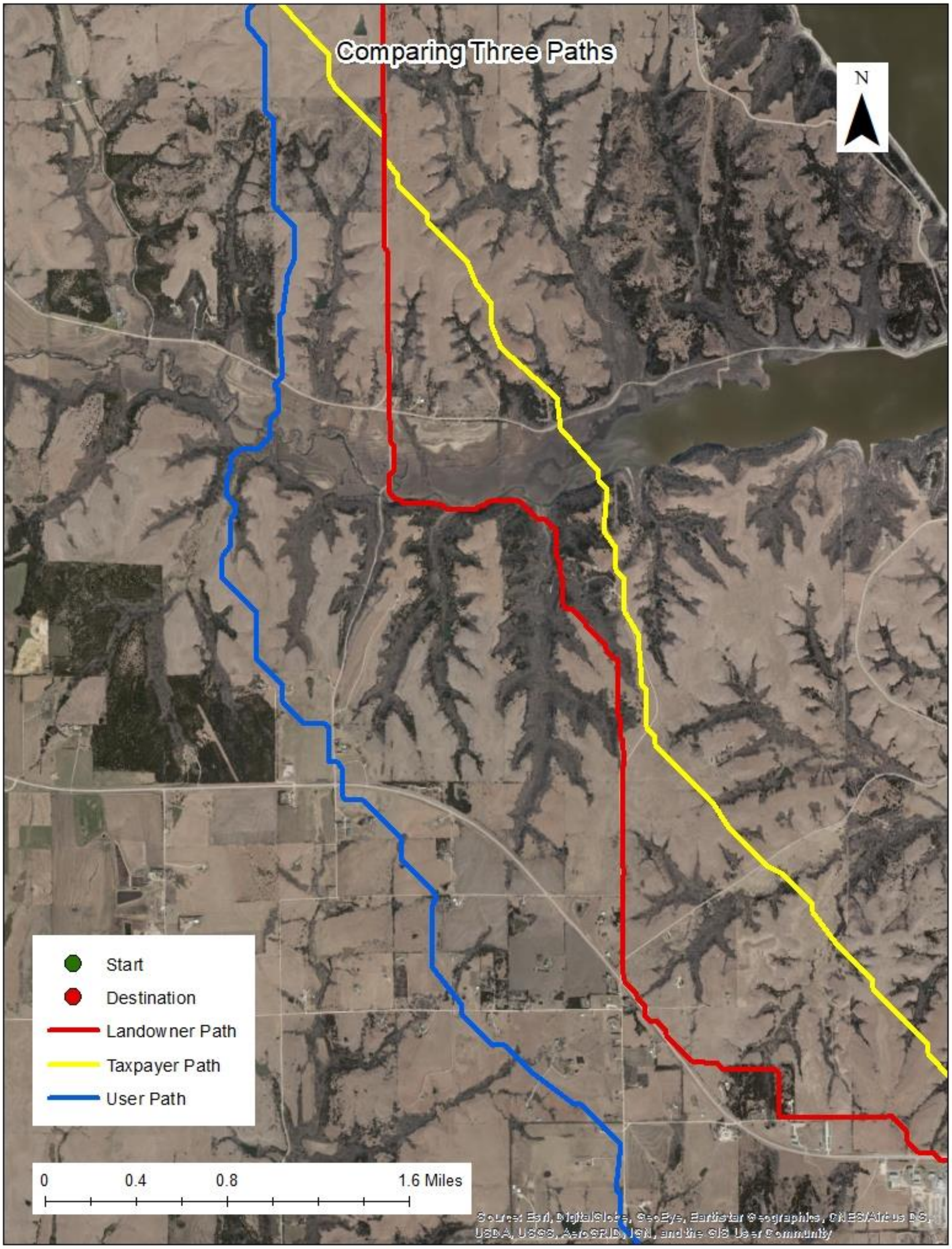

Figure 21: An enlarged section of all three paths near where Mill Creek joins Tuttle Creek Lake.

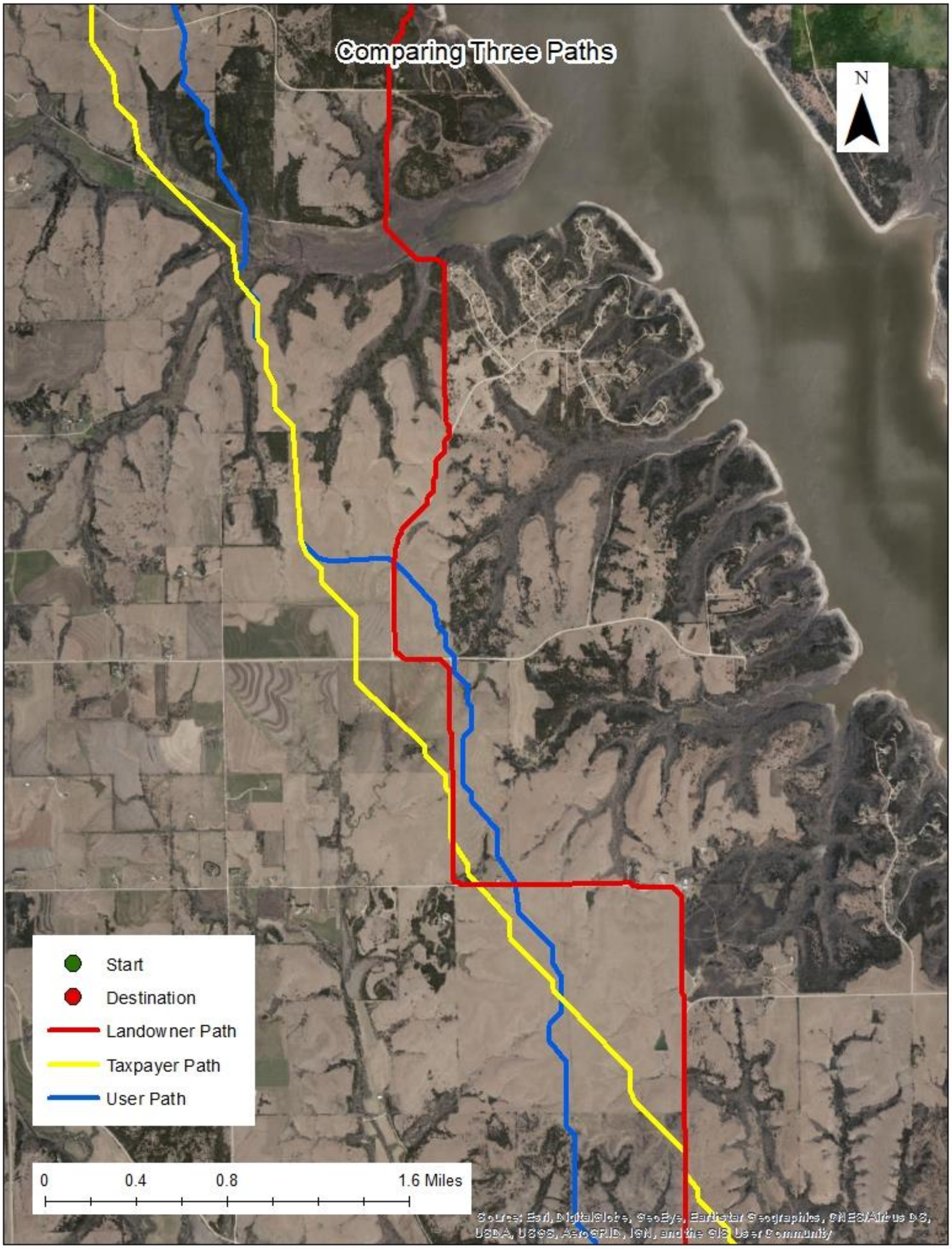

Figure 22: An enlarged section of all three paths showing how the paths traverse the landscape.

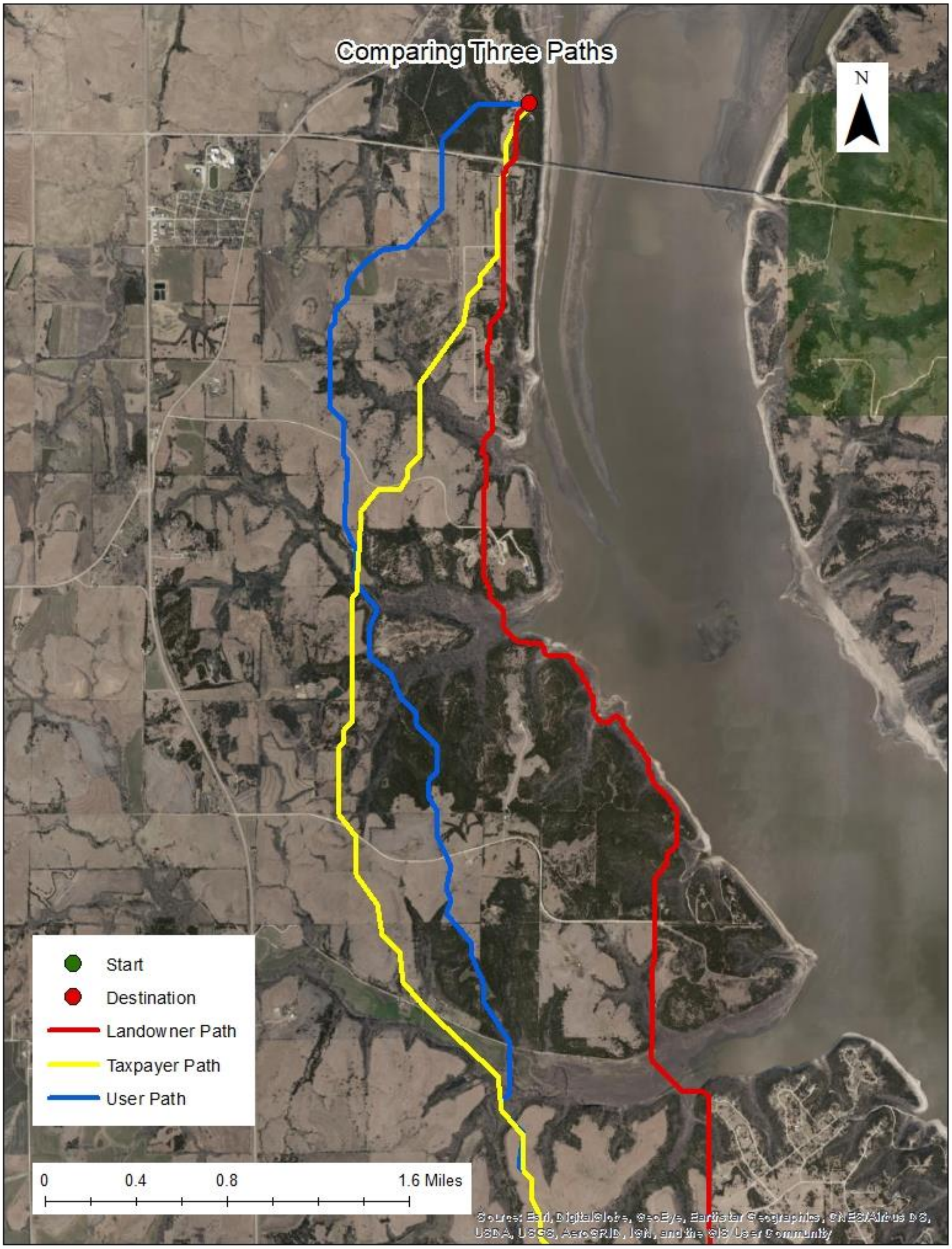

Figure 23: An enlarged map of all three paths showing how they reach the destination point.

The features of each path can be quantified based on their length, and the cost to acquire the property that they traverse. To find this, each cell that the path crosses is selected, and the price per cell (30m) is added together. Table 8 shows the length of each path, as well as the cost of the property. It should be noted that this calculation assumes that the trail's right-of-way is thirty meters wide and uses the assessed price of the property. Purchasing the necessary property would undoubtedly cost more.

Path	Length (ft)	Length (mi)	Cost to Acquire Property ($)	Cost ($) Per Mile
Taxpayer Path	92,989.09	17.61	$1,321,996	$75,071
User Path	105,904.59	20.06	$2,690,729	$134,134
Landowner Path	106,938.37	20.25	$2,217,634	$109,513

Table 8: Shows the length and cost to acquire the property that each path traverses, assuming the path is 30 meters wide.

The taxpayer path takes the most direct route between the two points and is the least expensive. The cheaper price is partially due to how short it is, but also because of the route it chooses. This is evident because of the smaller price per mile figure. The user path is the most expensive of the three, both in terms of total cost and price per mile. The landowner path is the longest, but not the most expensive. The reader should be aware that it would most likely cost much more than to acquire property for these paths than the figures listed in Table 8. This analysis is just being used to compare the results of the model.

While the right-of-way maybe thirty meters wide, only 10 feet of that width would be used as a trail (*Shared Use Path - Rural Design Guide*, n.d.). A similar calculation was done where the right-of-way width was reduced to 20 feet (10 feet for the trail, 5 feet on each side). The results of this calculation are shown in Table 9.

Path	Length (mi)	Cost to Acquire Property ($)	Cost ($) Per Mile
Taxpayer Path	17.61	$83,408	$4,736
User Path	20.06	$170,999	$8,524
Landowner Path	20.25	$122,564	$6,053

Table 9: Shows the length and cost to acquire property assuming that the path is 20 feet wide.

Another way to examine the differences between the three paths is to examine how long each path goes through forests, grasslands, and road buffers. To do this, the sections of each path that go through these features were identified and measured. Those numbers are then compared to the total length of each path to find the proportion of each path that goes through each feature. Table 10 shows these numbers and percentages. As you can see, the taxpayer path spends the shortest distance in forested areas. The taxpayer path and user path spend the majority of their length in grasslands, while the landowner path spends a majority of its length in road buffers. The road buffers may explain why the landowner path is the longest of the three, but not the most expensive (see Table 8).

Path	Forests (miles)	Portion of Total Length	Grasslands (miles)	Portion of Total Length	Road Buffers (miles)	Portion of Total Length
Taxpayer Path	0.9	5%	13.7	78%	1.5	8.5%
User Path	2.9	15%	16.7	83%	0.5	2.5%
Landowner Path	4.5	22%	6.1	30%	11.4	56.3%

Table 10: Shows how long each path travels through each feature (note: While grasslands and forests are mutually exclusive features, road buffers are not. Therefore, the percentages may not add up to 100%).

To better visualize the differences between the three maps, the standard deviation between the three frictional surfaces of each cell was calculated. Figure 24 shows the three trails and the standard deviation map. Red areas represent cells that vary the most (in cost) between the three frictional surfaces, and green cells vary less between the surfaces.

It is difficult to determine which variables stand out in this map, but all the roads have a lower standard deviation (Figure 25). This indicates that roads are weighted very consistently between the three surfaces. On the other hand, building buffers have the opposite effect. In Figure 26, we can see that cells within building buffers have a higher standard deviation. This indicates that building buffers contribute more to the differences between the surfaces.

Ultimately, these trails should not be considered as the perfect route for any of the three stakeholder groups. However, the trails could be used as a conversation starter when facilitating discussions with stakeholders.

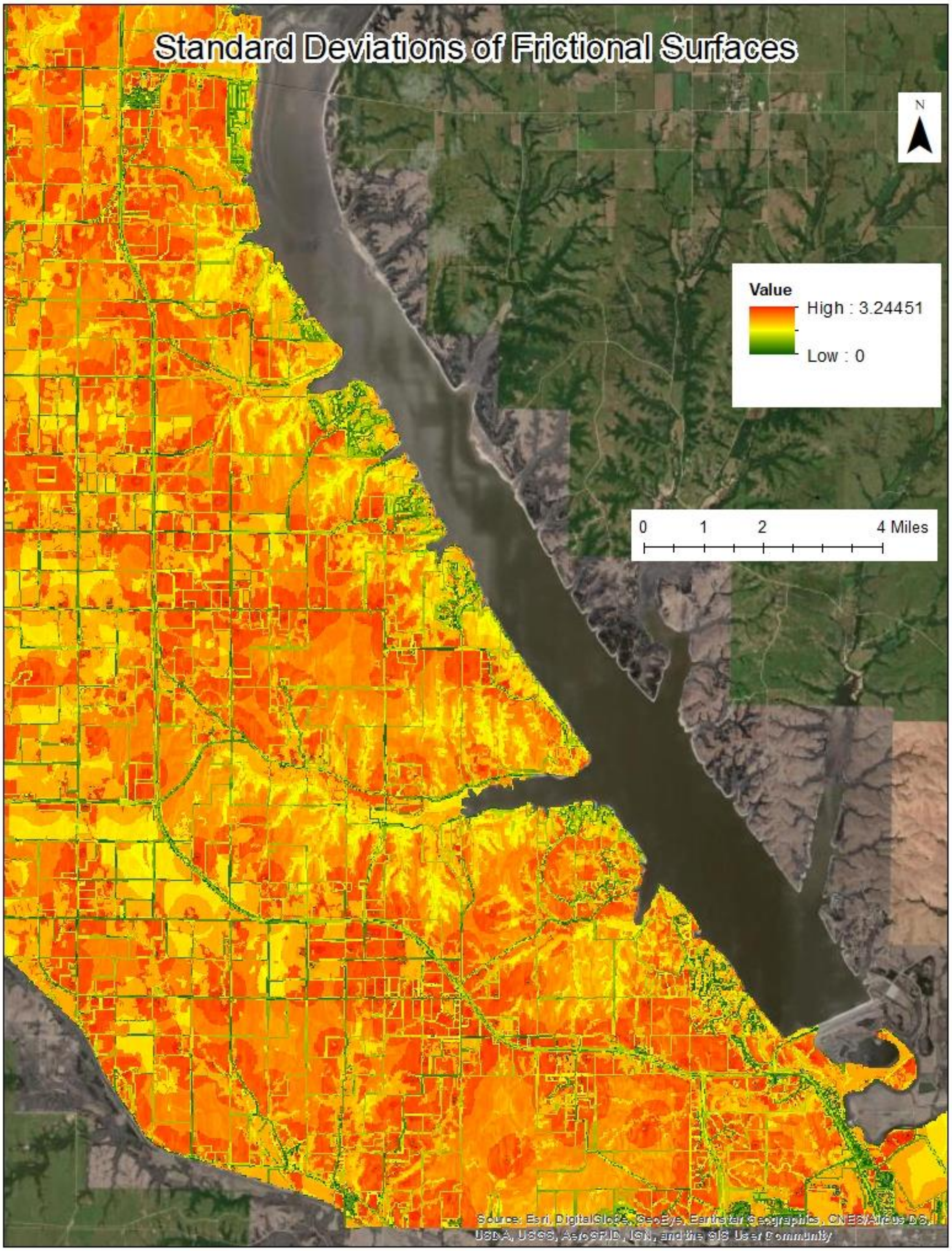

Figure 24: A map showing the standard deviation between the three frictional surfaces of each cell in the study area. Red areas show the most difference in cost between the three surfaces, and green areas show the least difference in cost.

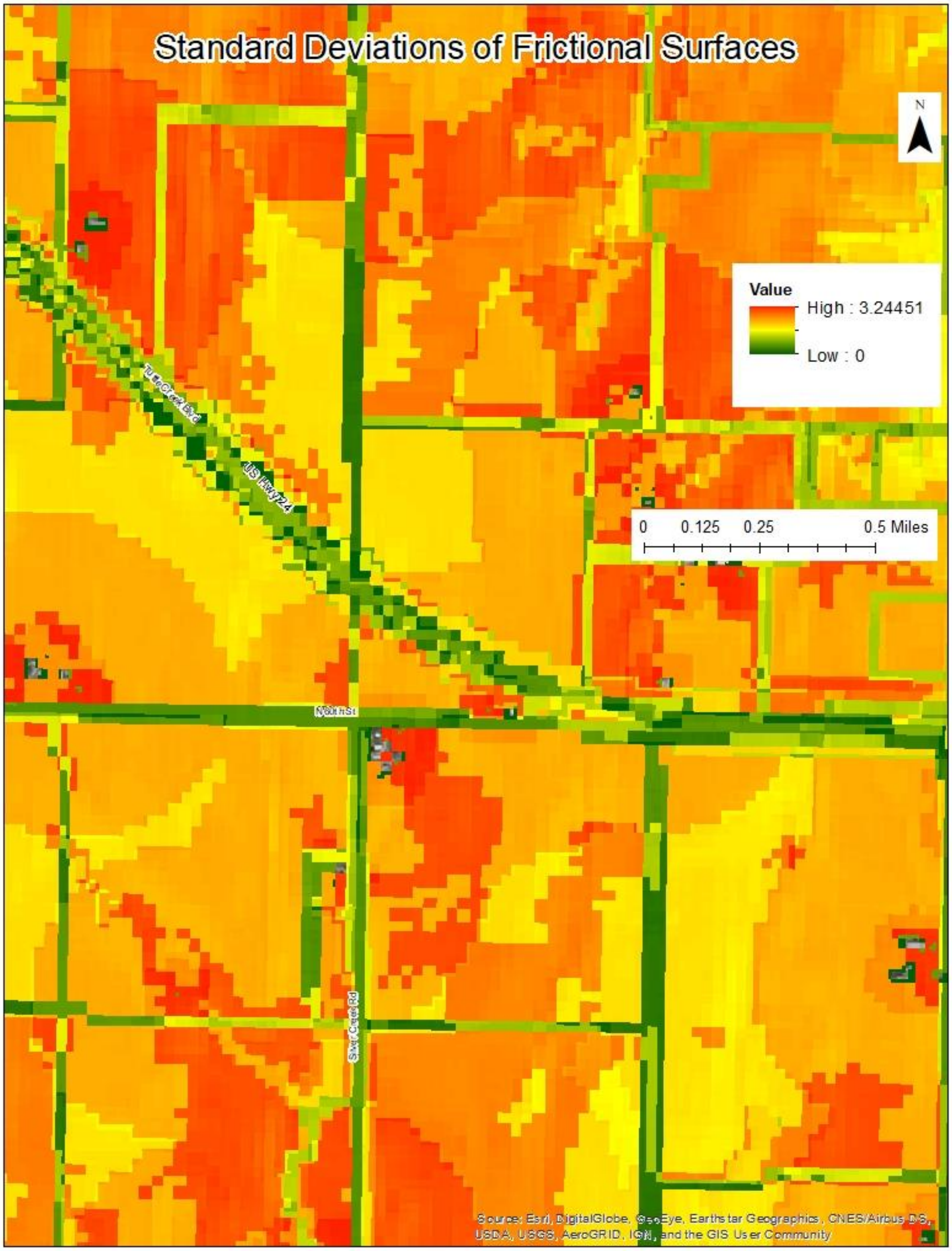

Figure 25: Shows how the standard deviation of cells along roads is lower, indicating less variation between the surfaces.

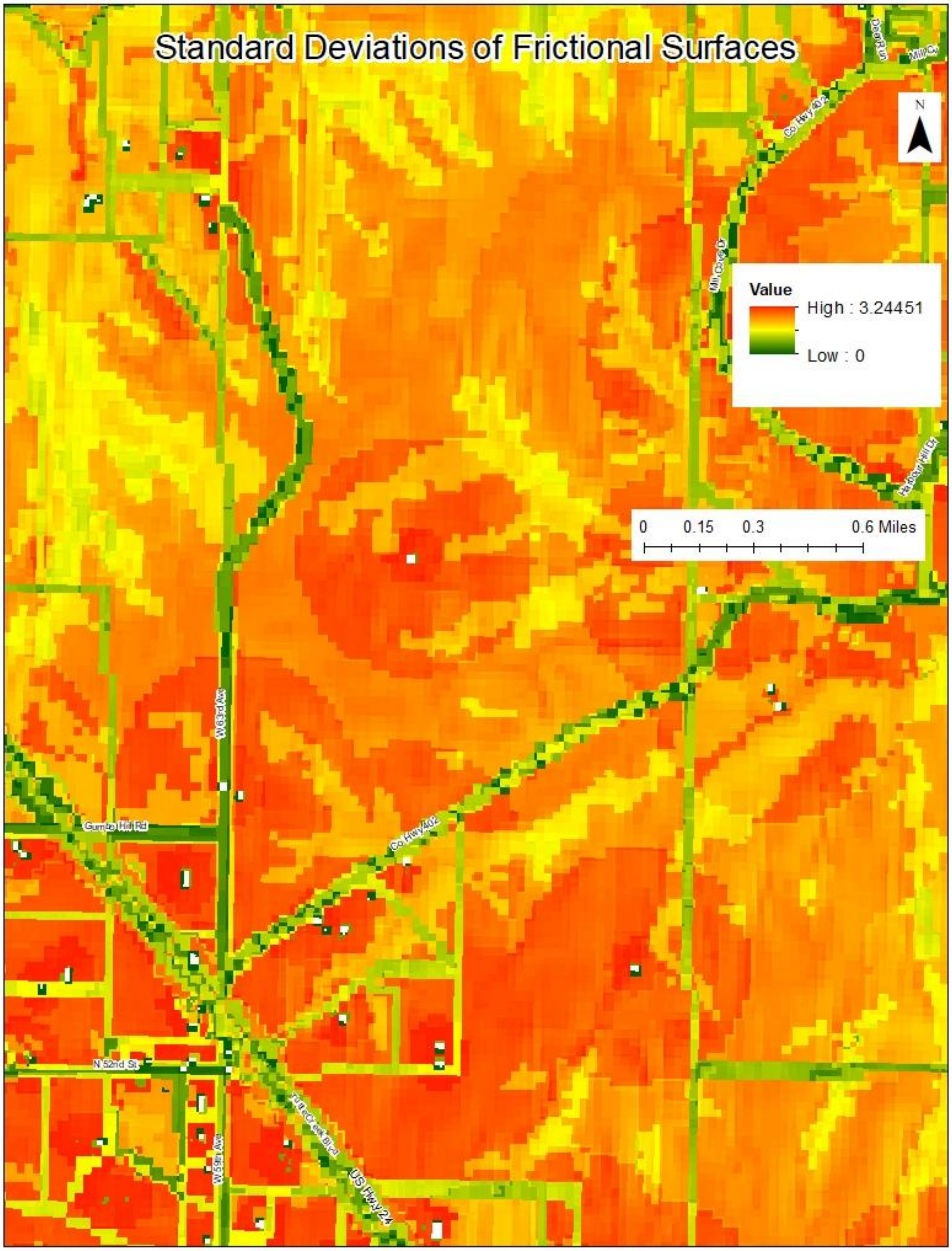

Figure 26: This map shows how building buffers have a higher standard deviation, which indicates that this feature contributes more to the variation between the three surfaces.

Conclusion

Recreational trails are an important community asset. They provide a unique leisure opportunity, as well as tourism for rural communities. Many regional trails are routed along repurposed railroad rights-of-way, which limits trail development between communities without a rail corridor. The goal of this project is to provide a method for trail planners to create trails without the use of a railroad corridor.

This project demonstrates how landowner preferences can be incorporated into the least-cost path. The method is just a framework for trail planning and more variables can be included. This tool could be used by planners to reduce the property acquisition costs or change the route of a trail to meet the preferences of stakeholders. Also, while this project was conducted at the county level, the same process could be done at larger or smaller scales. It could be used to plan a large regional trail or a trail through a single nature preserve.

The next step after this project would be to hold a meeting with stakeholders to discuss concerns and preferences. The goal of this meeting would be to create a weighting scheme that all stakeholders can agree with, as well as uncover variables not discovered in the interviews.

The least-cost path method for trail planning is not foolproof. Several variables influence the success of a trail project, many of which cannot be incorporated into a GIS model. The route does play an important role in the support of the trail from adjacent landowners. This does not discount the benefits of the least-cost path method in trail planning. It can help identify corridors where a trail could work. However, the process is not perfect. The least-cost path analysis should be used in tandem with traditional trail planning methods, not exclusively.

Future research could be done to more empirically identify and incorporate variables important to stakeholders. A quantification of trail construction costs per mile could help make the taxpayer path more accurate. Interviews with trail planners could also help identify variables for the taxpayer path to consider. A trail user path could also incorporate view preferences, similar to how Snyder et al. (2008) incorporated viewsheds into a trail for ATV riders. Viewsheds could also be used to identify areas visible from building footprints, to address landowner visibility concerns more accurately. A viewshed is all the area that can be seen from a given location. The researcher would need to create a raster that identifies every cell that can be seen (based on a digital elevation model) from within a building footprint. Alternatively, each cell could show the total number of buildings that are visible from that point.

Additionally, while streams and roads are incorporated in the model, they have not been incorporated in the most accurate way. Linear features like this create a barrier for pedestrians, and the paths may not cross streams and roads at the best location. Existing bridges and road crossing locations could be identified and set as start/destination points in the least-cost path model. The result would be a series of path segments starting or ending at crossing locations. The segments chained together would form a path. Different crossings would result in different paths, and those paths could be compared to ultimately determine the best crossing. Another method would be to add streams to the trim variables but give cost to the crossing locations. This would prevent the path from crossing a stream except at existing crossings. It would also give the algorithm more flexibility to choose different crossings. Both methods rely on existing crossings, but a stream without any existing crossings would have to be analyzed to determine the best location to cross.

The utility of this tool as it is used in this project does not extend far beyond the study area. Any future use of this tool should tailor the variables, classifications, and weights to that project. Also, the results of the interviews may not be applicable outside of this specific part of the county, as many of the preferences that interview subjects stated were based on the nature of the landscape. Rural landowners in heavily forested areas may have different preferences. The interview component of this project is a crucial step that should not be ignored. Interviews with landowners are the best way to connect a trail project with stakeholders to help them feel heard and meet their needs.

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Appendix A - Interview Protocol

RECRUITMENT PROCESS:

Participants will be determined using the publicly available parcel shapefile of Riley County, KS. I will select only the rural properties in the county. I will then order those properties by FID (feature ID)* from least to greatest and select every 10 parcels. Publicly owned parcels will not be selected. Selected parcels will be contacted by cross-referencing the owners name in the parcel map with a name in the phone book. I will then call landowners to confirm their participation.

Note: The FID score of a parcel has not relation to the nature of the parcel in question. It is just a unique identifier that the mapping program uses. I am using it as an arbitrary way to order the parcels.

INTERVIEW PROTOCOL:

CW: "Hello! My name is Caleb Whitehouse. I am a graduate student at Kansas State University studying regional and community planning. This interview is part of my master's report which is focused on recreational trail planning. The purpose of my research is to make a tool for planning the route of a recreational trail using publicly available information and computer mapping. I am conducting interviews with farmers, rancher, and residential landowners to determine the best place for a trail to cross private property.

You were chosen for this project because of your property's position along or near the proposed route of the Quad-States Trail, a project aiming to connect Nebraska, Iowa, Missouri, and Kansas with a ring of connected recreational trails. You should be aware that this trail is just a proposed project. There is very little chance that this trail will be built anytime soon. You should also know that your identity and the contents of this discussion will be confidential. The things we talk about today will have no impact on whether any future trail will be routed through your property.

I will be recording this conversation to evaluate later. Upon completion of this project, the recording will be deleted. You are free to stop this interview at any time, and I will not use any of your feedback. Are you ready to begin?"

I. "Do you see any risk to a trail? If so, what are they?"

   a. "Some people might say that litter or vandalism would become a problem."

b. “Some people might not want to be able to see the trail from their home.”

II. Trail impact on the owner:

“One of the goals of this discussion is to understand the impact a trail would have on the property owner. So how could a trail be routed through your property to minimize the impact on you?”

a. “Is there a minimum distance from your home (and/or outbuildings)?”

b. “Would you have a preferred route through your property?”

c. “Would you rather the trail go through woodland or grassland on your property?” Can you explain your answer?”

III. Trail impact on the property:

“I also want to know how the trail would impact your property. How could the trail be routed to minimize the impact on your property?”

a. “Is it more important that it stays away from agricultural land or residential land?”

b. “How would a trail impact the operation of your farm/ranch?”

c. “Some landowners would prefer if the trail didn’t cut their property in half. They would prefer a trail that ran along the property line.”

d. “Would you be willing to sell property to make this project possible, or would an easement be preferable?” *(An easement is a nonpossessory right to use and/or enter onto the real property of another without possessing it. It is best typified in the right of way which one landowner, A, may enjoy over the land of another, B)*

IV. “Is there any other feedback you can give me about your preferences for a trail?”

CONCLUSION AND DEBRIEFING STATEMENT:

CW: “Thank you so much for talking to me. The preferences you shared today will help me a lot. The name of my project is ‘Planning a Trail Using Landowner Preferences: A Multivariable

Least-Cost Path Approach'. If later you wish to withdraw you interview, you will have until [TBD] to tell me and I will do so. Do you have any questions about my project?"
CW: "Again, thank you for your time. If you want, I can write your name and email down and send you the paper when I finish."

Appendix B - Interview Notes

Interview 1: Rancher

- Risk: Damage to property, litter, privacy, unleashed dogs interfering with cattle
- Trail should follow fence lines.
- Prefers residential use over agricultural use
- Trail should follow existing easements
- Trail should use easements as opposed to property sale.
- ¼ mile buffer

Interview 2: Rural Resident

- Risk: "Bad people"
- Trail should prefer grasslands over forests.
- Trail should follow fence lines.

Interview 3: Rural Resident

- Risk: Maybe trespassing.
- ½ mile buffer
- Trail should prefer forests over grasslands
- Trail should follow fence lines.
- Trail should follow easements.

Interview 4: Rural Resident

- Risk: Using trail to case home.
- Trail should follow parcel boundaries
- Trail should be as far from the house as possible (100 yards minimum).
- Trail should not be visible from the house.
- Trail should prefer forests over grasslands.
- Trail should follow existing easements.

Interview 5: Rancher

- Risk: Vandalism
- ¼ mile buffer
- No grassland/forest preference
- Trail should stay away from agriculture use
- Trail should follow fence lines
- Trail should follow existing easements

Interview 6: Farmer/Rancher

- Risk: Trespassing, gate issues
- Trail should follow property boundaries
- Trail should prefer forested areas
- Trail should prefer agriculture use
- ½ mile buffer
- No easement preference
- Trail should provide access to public land that does not have road access to prevent trespassing.

Interview 7: Rancher

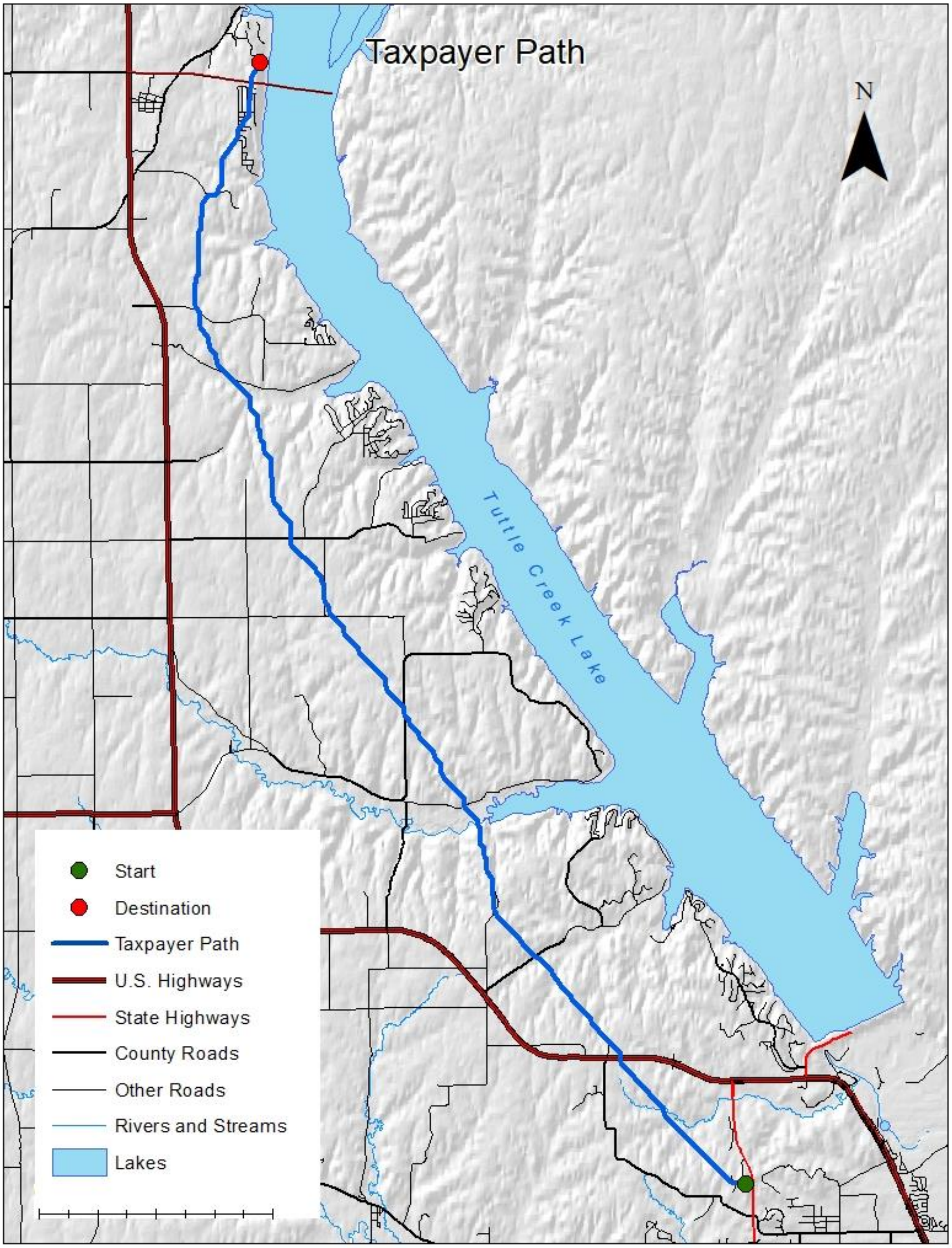
- Risk: Livestock, trespassing
- "We'd have to work together to minimize risk."
- Trail should follow property lines
- Trail should prefer forests over grasslands
- Trail should prefer agriculture use
- ½ mile buffer
- Trail should follow existing easements

Interview 8: Rancher

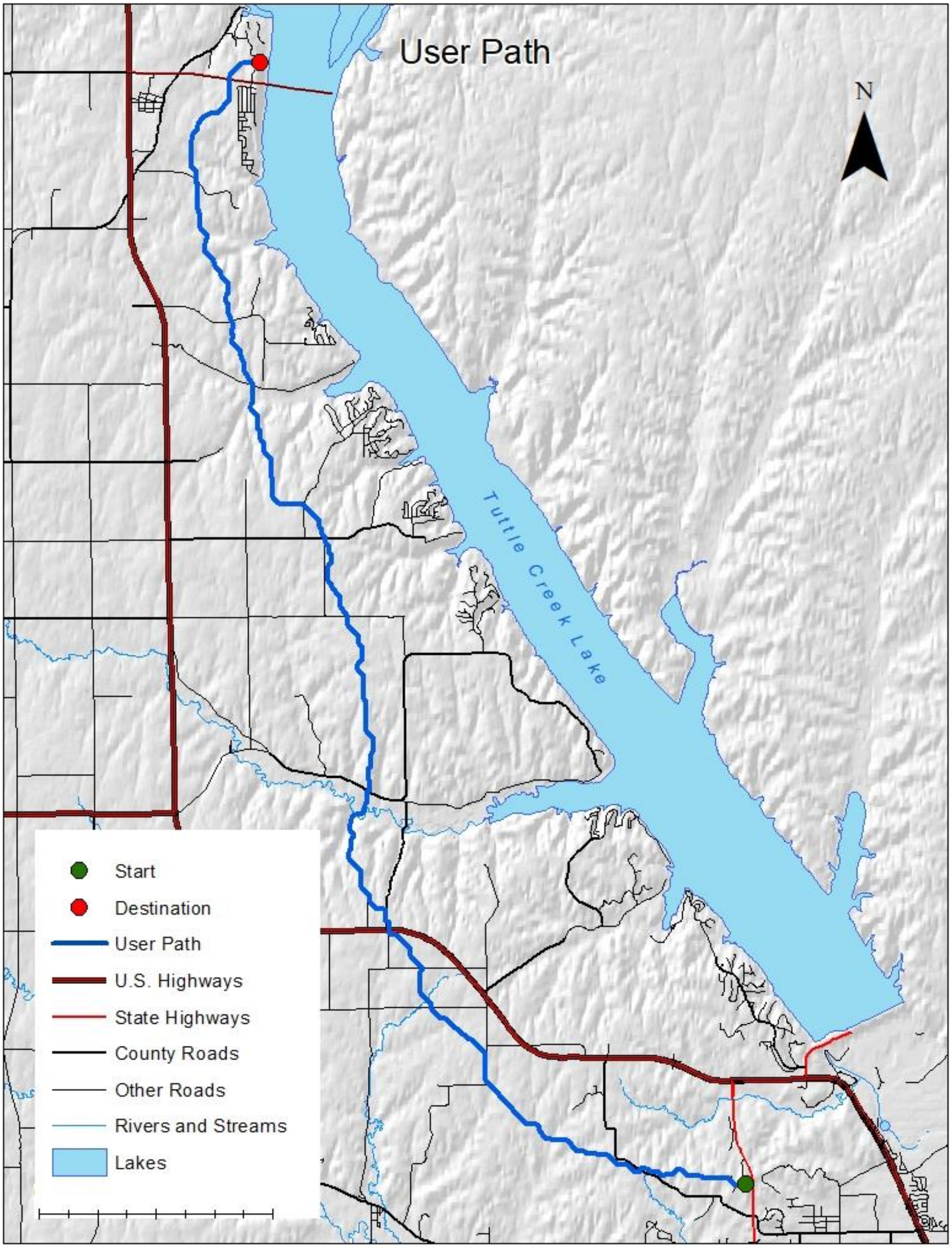
- Risk: Livestock
- Trail should follow property lines

- 300-foot buffer
- Trail should prefer forests over grasslands
- Trail should prefer residential use over agricultural use
- No easement preference

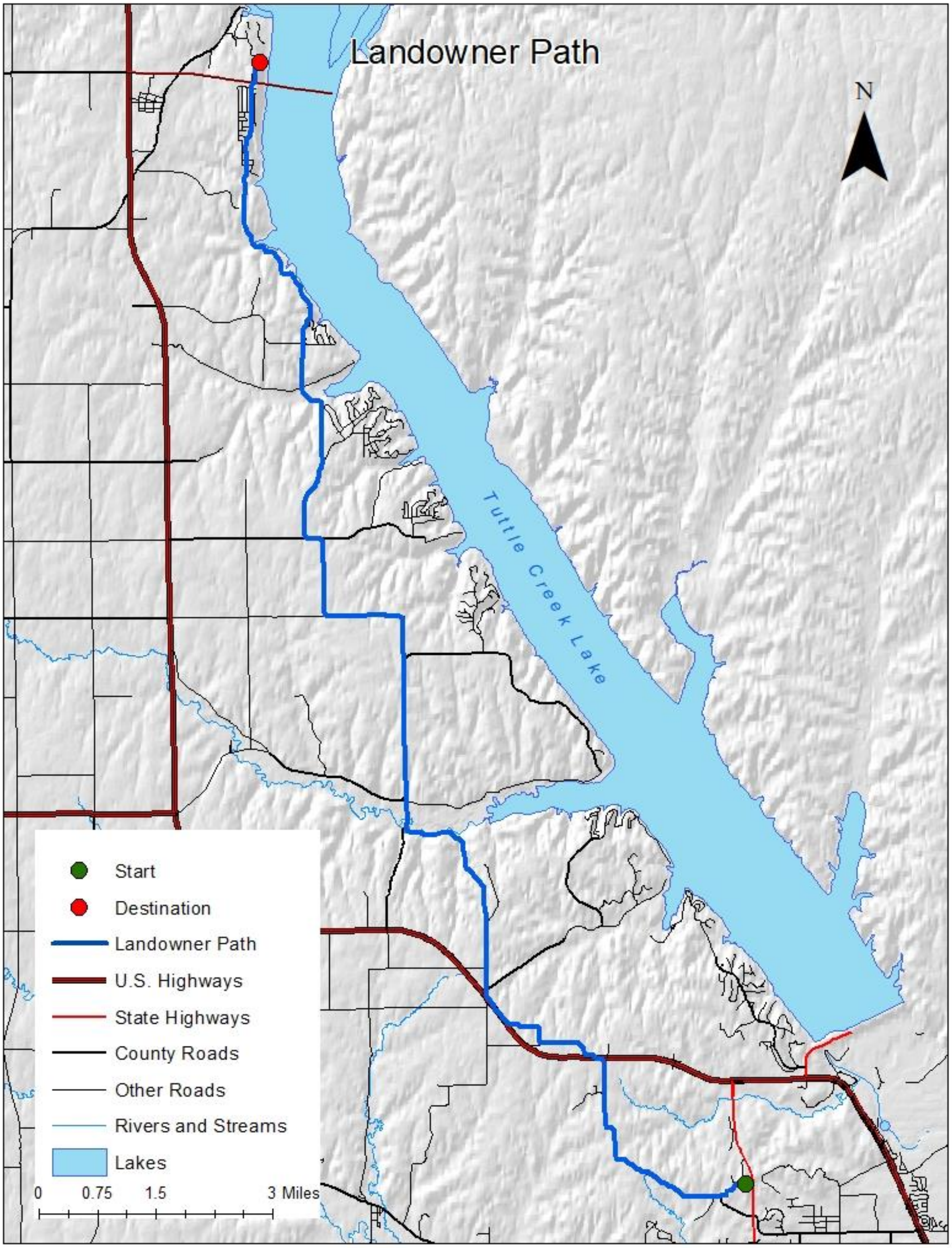
Appendix C - Full Page Trail Maps - Taxpayer



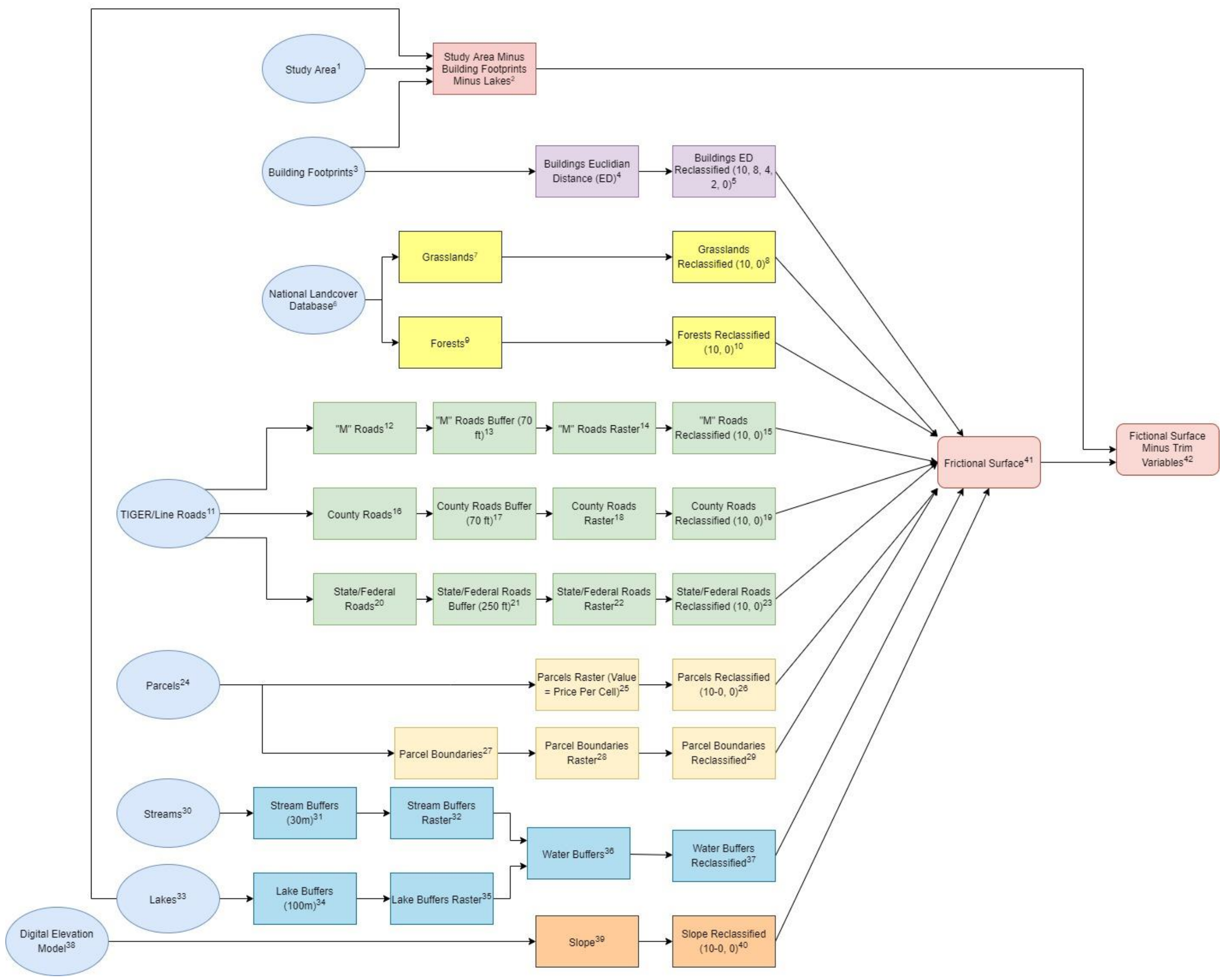
Appendix D - Full Page Trail Maps – Trail User



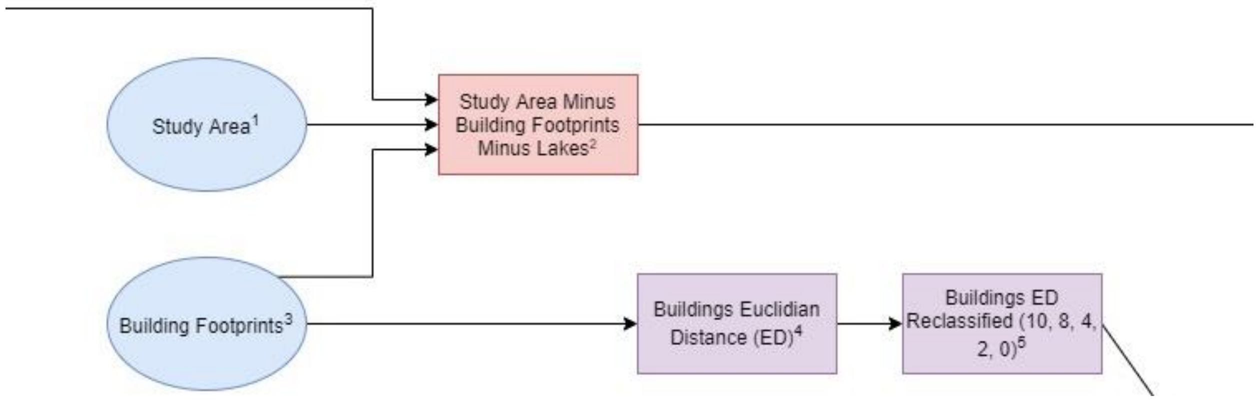
Appendix E - Full Page Trail Maps – Landowner



Appendix F - Frictional Surface Model Overview



Appendix G - Frictional Surface Model (Part 1)

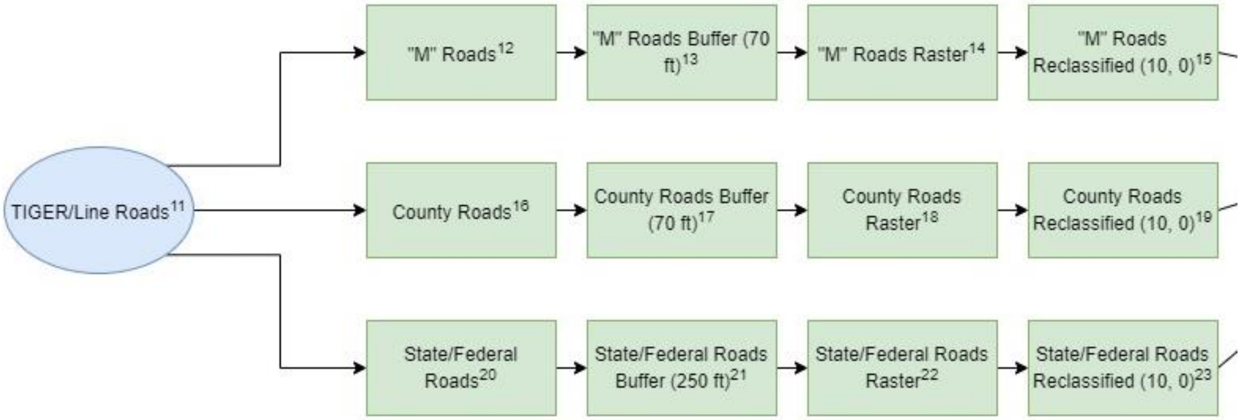


1. The study area is defined by the area in Riley County, Kansas north of Marlatt Avenue and Fort Riley, and South of Fancy Creek.
2. Using the erase tool, the model removes the building footprints and lakes from the study area.
3. The building footprints for all of Riley County.
4. The Euclidian distance tool creates a raster where each cells value is the distance between that cell and the input variable. In this case, the input variable is the building footprint layer.
5. Using the reclassify tool, the Euclidian distance raster is reclassified to create the tiered buffer system shown in Table 6.

Appendix H - Frictional Surface Model (Part 2)

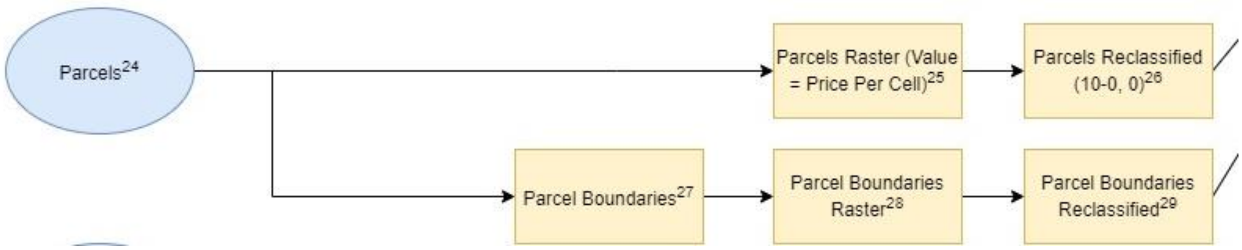
6. The National Landcover Database is a raster file that represents different landcover classifications categorically. For instance, cells with the value of 11 represent open water, and cells with the value of 31 represent barren land.
7. In this study, landcover classifications 71 and 81 are considered grasslands, so those values were isolated using the extract by attributes tool.
8. Using the reclassify tool, the landcover values are reclassified to 10, and all other cells to zero.
9. In this study, landcover classifications 41, 42, 43, and 52 are considered forests, so these values are isolated using the extract by attributes tool.
10. Using the reclassify tool, the landcover values are reclassified to 10, and all other cells to zero.

Appendix I - Frictional Surface Model (Part 3)



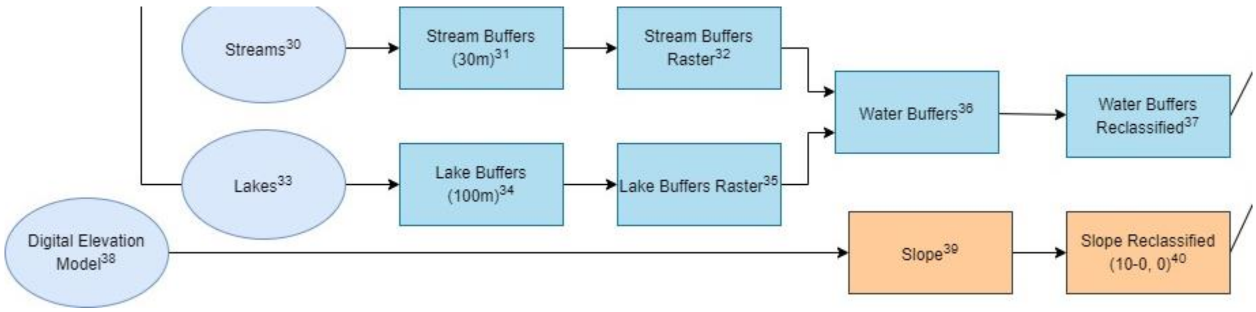
11. The TIGER/Line Roads file shows all the roads in Riley County. Road types are classified in the "RTTYP" field.
12. "M" roads are selected using the select tool and isolated. The "M" road category includes most roads.
13. The roads are given a 70-foot buffer, which is half the typical right-of-way-width for "M" roads in Riley County.
14. The buffered roads are converted into a raster.
15. The road buffer raster is reclassified so that cells within a road buffer have a value of 10, and cells not within a road buffer have a value of zero.
16. County roads are selected using the select tool and isolated.
17. The roads are given a 70-foot buffer, which is half the typical right-of-way-width for County roads in Riley County.
18. The buffered roads are converted into a raster.
19. The road buffer raster is reclassified so that cells within a road buffer have a value of 10, and cells not within a road buffer have a value of zero.
20. State/Federal Highways are selected using the select tool and isolated.
21. The roads are given a 250-foot buffer, which is half the typical right-of-way-width for County roads in Riley County.
22. The buffered roads are converted into a raster.
23. The road buffer raster is reclassified so that cells within a road buffer have a value of 10, and cells not within a road buffer have a value of zero.

Appendix J - Frictional Surface Model (Part 4)



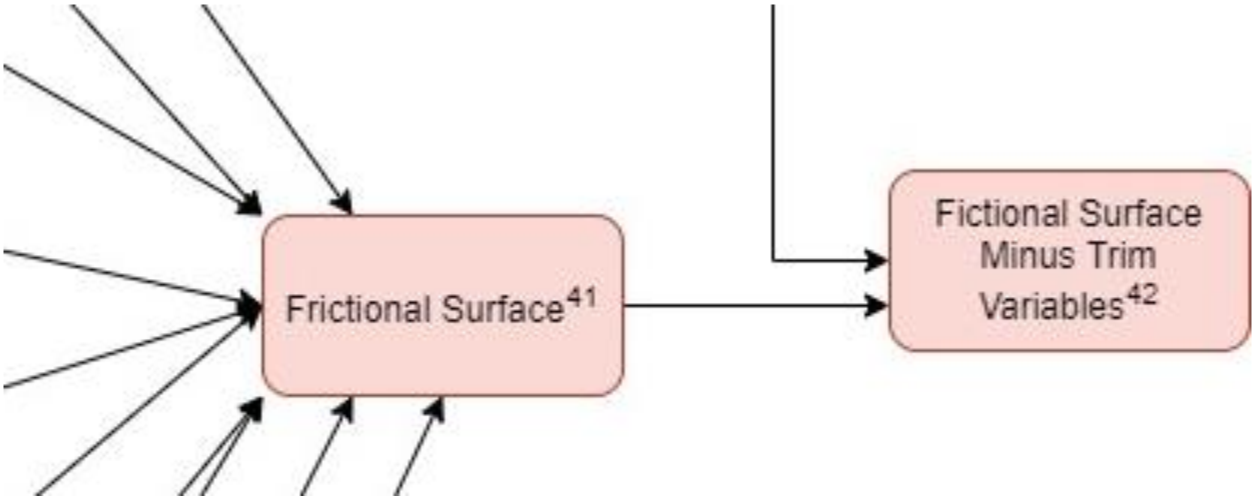
24. The parcel map is a polygon file that displays the shapes of all the parcels in the county, as well as property assessment data. A field that displays the price per 30x30 meter cell has been added.
25. The polygon layer is converted to a raster using the polygon to raster tool. The price per 30x30m cell field is set as the value field. The raster calculator tool also creates a plateau which sets the top 15% of property values to the same value.
26. The property values are reclassified using raster calculator by dividing the whole range of values by one-tenth of the maximum value.
27. The vertices of the parcel map are copied and pasted into a polyline shapefile to convert the polygon into a polyline file. This step is not done in model builder. The polylines are also given a 15-meter buffer, which is half the width of one cell.
28. The buffered parcel lines are converted into a raster.
29. The parcel boundary raster is reclassified so that all cells within a parcel boundary buffer are 0, and cells outside of a parcel boundary buffer are ten.

Appendix K - Frictional Surface (Part 5)



30. The streams layer is a polyline file of all the streams in the county.
31. The streams are given a 30-meter buffer.
32. The buffered streams layer is turned into a raster using polygon to raster.
33. The lakes layer is a polygon file of all standing water bodies in the county.
34. The lakes layer is given a 100-meter buffer.
35. The buffered lakes layer is turned into a raster using polygon to raster.
36. The stream buffer layer and the lake buffer layer are combined into one file using raster calculator.
37. The water buffer layer is reclassified using the reclassify tool so that cells within a water buffer have a value of 10, and cells not within a water buffer have a value of zero.
38. The digital elevation model is a raster where every cell is the elevation at that point.
39. The slope for every raster is calculated using the slope tool.
40. The slope layer is reclassified using raster calculator by dividing the whole range of values by one-tenth of the maximum value.

Appendix L - Frictional Surface Model (Part 6)



41. The variables are given a weight and combined in one raster calculator expression. The format of the expression is:

$$x = \text{Variable},\ w = \text{Weight},\ c = \text{Cost}$$

$$(x_1w_1) + (x_2w_2) + (x_3w_3) + (x_4w_4) = c$$

42. The trim variables (building footprints and lakes) are "cut" out of the final surface using extract by mask. The result makes cells within these variables "NoData" so that the least-cost path tool sees these cells as the boundary of the map.