Spring 2019

Greenway Trail Viewshed Characteristics: Planning Applications Using GIS and Remote Sensing

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GREENWAY TRAIL VIEWSHED CHARACTERISTICS: PLANNING APPLICATIONS USING GIS AND REMOTE SENSING

A Master's Thesis

Presented to

The Graduate College of

Missouri State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science, Geospatial Science

By

Aric Addison Beehler

May 2019

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Geography, Geology, and Planning

Missouri State University, May 2019

Master of Science

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ABSTRACT

This study applies theoretical findings relating greenway trail viewshed characteristics to a proposed greenway trail. Utilizing geographic information systems and remote sensing techniques, this study compares the viewshed characteristics of two proposed routes to connect an existent greenway trail system to Wilson's Creek National Battlefield in Greene County, MO. Light Detection and Ranging data is then used to map the viewshed of each route and calculate the openness and interconnectedness of each viewshed. High-resolution multispectral imagery is then used to calculate the Normalized Difference Vegetation Index measuring the "greenness" within each viewshed. Finally, parcel-level land use data is used to calculate the diversity of land use within each viewshed. The values from these measurements are then compared between the two routes to determine the potential for each in promoting increased trail use. The study sheds light on the uncertainties and limitations of applying these geospatial techniques to not-yet-existent trails, but the outcomes are promising. Even without further research, this study shows that objective viewshed criteria can be gathered to help inform greenway planning and development. This research aids planners by demonstrating methods for evaluating potential greenway trail construction sites remotely. This research also provides researchers with an applied case study adding to the existing body of literature.

KEYWORDS: greenway trails, linear parks, GIS, LiDAR, viewshed characteristics

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ACKNOWLEDGEMENTS

I would like to thank the many people who have helped me throughout my graduate studies and this thesis process. First, thank you to my advisor and thesis committee chair Dr. Judy Meyer for the unwavering support and guidance she has given me during my graduate studies and completion of this thesis. I would also like to thank Dr. Xin Miao and Dr. David R. Perkins IV for severing on my committee and providing crucial insight and advice.

I would also like to thank the rest of the department faculty that I have been privileged to work with during my graduate studies. A special thanks to Dr. Jun Luo and Dr. Xin Miao for their guidance during my time as a teaching assistant for their courses. I would also like to thank my undergraduate advisor Dr. F. Scott Worman for his encouragement and aid throughout my undergraduate and graduate education. Finally, I would to thank my wife Samantha for her patience, reassurance, and love while accompanying me on this journey.

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INTRODUCTION

In recent decades, greenway trails have become a topic of interest among planners and geographers. As cities grow, the amount of open space decreases and planners must search for new ways to provide residents with open, green spaces and access to them. Greenways can serve not only as linear parks but also as connectors between urban and rural greenspaces. Using greenway trails to connect parks and other greenspaces promotes sustainability by allowing for increased non-motorized transport to these greenspaces and other urban and rural areas.

As greenways became more popular over the turn of the century, researchers have identified greenway design characteristics that correlate positively with increased greenway use. Geographic Information Systems (GIS) have been particularly useful in identifying and measuring these characteristics. This study attempts to evaluate greenway design characteristics using GIS, remote sensing, and cartographic techniques to assess the potential of a proposed greenway trail. This study addresses options for connecting Wilson's Creek National Battlefield, outside of Republic, MO and Springfield, MO in Greene County, to existing trails in order to provide more options for non-motorized travel.

Greenway Trails and Sustainable Transportation

Greenway trails have become an increasingly pressing topic in urban, open space, park, and recreation planning. They provide a host of benefits and opportunities to communities, policymakers, and researchers. For communities, greenway trails can provide improved fitness and recreation possibilities, alternative transportation options, and enhanced quality of scenery. Greenway trails give policymakers the opportunity to provide these benefits by balancing diverse land uses in a single area. Researchers are presented with a means of studying outdoor recreation, sustainability, and transportation while helping to inform decisions made by planners and managers (Moore and Shafer 2001).

The popularity of greenway trails has grown as urban and regional planners have begun to identify and implement sustainable planning initiatives. Sustainable planning focuses on attempting to meet the needs of current and future populations, ensuring the health of the local, social, economic, and ecological systems, while also considering the effects of local actions on global systems (Berke and Conroy 2000). Although the sustainability of greenway trails is heavily context dependent, many significant benefits are possible if there is proper design and maintenance of the greenway trail systems (Lindsey 2003).

Among the many potential benefits related to creating a greener transportation infrastructure, connecting greenspace for non-motorized transportation stands out. Trail-based recreation is becoming increasingly popular. Although a quarter of all Americans between 1994 and 1995 participated in team-oriented sporting activities, two-thirds of Americans over the same period reported walking for recreation. In addition, one-third of Americans were found to have engaged in bicycling or running (Shafer et al. 2000). Hence, the types of recreation most closely associated with trail use is on the rise.

Bicycling has many advantages over motorized transportation. In large traffic-congested cities, researchers have shown bicycling to be the fastest and most environmentally friendly form of transportation for local commuting (Tranter 2012). Residents in smaller, less congested cities can also benefit from improvements in bicycle transportation infrastructure. Greenway trails have the potential to increase the amount of people who commute using bicycles, while insulating bicyclists from the inherent dangers of sharing the road with motorists.

Portland, OR, a city with a population of 582,000, has the highest bicycle commute share of any city in the United States at 6.3 percent. The city has a rich tradition of greenway trail development, and the last twenty years have seen an increase in funding directed at bicycle infrastructure. Portland also tracks alternative transportation use closely. It is no wonder that the city has served as a case study for one of the most thorough cost-benefit studies of bicycle infrastructure in the United States (Gotschi 2011).

Gotschi states, that the "benefits of cycling, such as the gain in physical activity and emission-free transportation, are generally understood, at least in broad qualitative terms, and undisputed" (Gotschi 2011, 49). Gotschi goes on to quantify this analysis by showing that by the year 2040 the city's investments in bicycling infrastructure would more than pay for themselves in fuel savings and would result in a health care savings of $388 to $594 million. The study also showed that the investments made in Portland would prevent the production of between 540 and 830 million metric tons of CO_2 production over the same time period (Gotschi 2011). As a reference, the entire United States emitted about 5311 million metric tons in 2016 (Environmental Protection Agency 2018).

As the study in Portland demonstrates, utilizing non-motorized transportation for recreation travel improves environmental sustainability through the reduction of CO_2 emissions. According to the Environmental Protection Agency (EPA), transportation emissions account for thirty-one percent of total carbon dioxide emissions in the United States (Environmental Protection Agency 2014). Furthermore, travel for recreational purposes accounts for 24 percent of passenger miles traveled in a 2009 according to a U.S. National Household Travel Survey (Chow et al. 2014). Hence, promoting and providing the opportunity for both commuter and recreational transportation options can help reduce a city's carbon footprint.

When greenways are utilized for transportation, there are also externalized benefits to public health. More than half of ground level ozone pollution comes from vehicle exhaust, and ground level ozone has been shown to cause asthma and trigger acute asthma attacks. This air pollution has a direct effect on health. Ground level ozone directly causes asthma and triggers acute asthma attacks. Asthma is the number one cause of visits to emergency rooms by children in the United States (Crompton 2012). Medical costs due to lack of activity and poor air quality can also be reduced by increased use of greenways for transportation. A greenway trail system benefit-cost analysis performed in Houston, TX, used a Trust for Public Lands review to estimate the total medical care savings from the expansion project and found it amounted to savings worth $13.9 million annually (Crompton 2012).

Promoting Trail Use

Typically, greenway trail developments involve many institutions and stakeholders. Sometimes, as in the Portland, OR case, the city invests planning staff time directly into projects. However, many greenway planners work for private, for-profit, and non-profit organizations. In some cases, as in Springfield, MO, city planners work directly through non-profits but also hire private consulting firms to perform analyses and produce reports. Hence, greenway trail planners are diverse, working at multiple scales and often with different, and sometimes competing, goals and visions.

It is useful to have objective criteria that all greenway trail planners can reference when analyzing potential developments. This is especially true when developing trails with the goal of increased transportation use. Many greenway studies have focused on selling greenway projects to policy makers and the public. This has resulted in a wealth of studies on greenway trails' effects on property values and other economic factors (Lindsey and Knapp 1999; Lindsey et al. 2004; Campbell and Monroe 2007; Crompton 2007; Ivy and Moore 2007; Eyler et al. 2008; Oh and Hammitt 2010; Crompton 2012; Payton and Ottensmann 2015). However, these studies have done little to evaluate user experience or describe how to promote increased greenway trail use.

Comparatively few studies have been conducted analyzing trail design features and their effects on use, but those that have done so have yielded interesting results. Measuring trail use and correlating use with design characteristics has resulted in identification of design features that correlate positively with increased trail use (Lindsey et al. 2008; Coutts 2009). This thesis suggests that planners should incorporate these design principles into new greenway trail developments, and over time, there will be data to evaluate their efficacy in practice.

The use of GIS and remote sensing techniques to measure design characteristics is particularly promising, because it provides objective data linked to trail attributes. Subjective arguments for and against greenway trail developments should play a role in the decision-making process, but having objective data to support options can only improve the planning process. Taking an objective approach can help planners evaluate sets of uniform criteria when planning a new trail development. Researchers have found four design factors that are positively associated with trail use. The four factors discussed here are viewshed openness, viewshed mystery, land use diversity within the trail viewshed, and the robustness of vegetation within the trail viewshed (Lindsey et al. 2008; Coutts 2009).

Viewsheds are an important concept in landscape design that refers to what landscape features can be seen from a particular viewing perspective (Lindsey et al. 2008). Viewshed openness is a measure of how much of particular viewshed is obstructed by topography of landscape features. Viewshed openness can be measured by calculating the percentage of a half mile buffer around a greenway trail that can be seen by a user traveling along it (Lindsey et. al. 2008). Although viewshed openness is positively associated with use, interconnectedness of viewsheds is negatively associated with use. Viewshed interconnectedness can be thought of as the amount of "mystery" the user experiences as opposed to open vistas. Users experience high amounts of mystery when they cannot see much of the trail in front of or behind them. Viewshed interconnectedness, referred to here as visual magnitude, can be measured by calculating how many times each cell in a viewshed raster can be seen from viewpoints along the trail (Lindsey et al. 2008).

The authors of these studies have acknowledged that more research in this area is needed. However, as Lindsey et al. (2008) points out, the ability to consistently measure these viewshed characteristics increases their reliability. In comparison, many studies evaluating economic factors such as the impact of greenway trails on property value have produced results that are contradictory and largely context dependent (Lindsey et al. 2004; Crompton 2012; Payton and Ottensmann 2015). Instead of focusing on factors that make greenway trails viable in specific areas, such as economically advantaged or disadvantaged neighborhoods, researchers should identify design guidelines that will promote greenway trail use in to inform future greenway trail development in any area.

Evaluating a Proposed Extension to Wilson's Creek Greenway

Although a handful of studies have been conducted on design factors' influence on greenway trail use, there is no evidence in the academic literature of an application of these guidelines to a proposed trail development. A study to evaluate a new trail development based on viewshed characteristics could add a new tool that helps planners define important factors to consider. This will also give planners more information to present to the public when collecting community input. This study evaluates of two proposed routes for a new greenway development linking the Wilson's Creek Greenway to Wilson's Creek National Battlefield outside of Springfield, MO.

Ozark Greenways is a Springfield, MO non-profit that develops greenway trails. The organization has planned to connect the existing Wilson's Creek Greenway which is already a part of the greater Ozark Greenway system to Wilson's Creek National Battlefield. Over the last several years, two potential routes have been proposed for the new greenway trail. This study seeks to determine which of these routes has the most potential to increase trail use in this area and create greater opportunities for increased non-motorized travel to the battlefield.

This study uses the methods established by Lindsey et al. (2008), Wilson et al. (2008), and Coutts (2009) to make this determination. Specifically, this study maps both proposed routes for the trail, measures their viewshed openness and interconnectedness, and calculates the land use diversity and robustness of vegetation within each viewshed. Other factors, such as total length and average slope of the trail will be also be considered. Although not empirically tied to increased trail use, trail length and slope are additional factors which will be included with this study as it will be presented to the Ozark Greenways to aid in their trail development decision.

LITERATURE REVIEW

The concept of urban greenways can be traced back to the mid-nineteenth century, yet there has been a proliferation of greenways only in the last half-century as people have become increasingly concerned about the environment (Little 1990). This increase may be explained by a number of factors including concern for the environment, providing open space in urban areas, and increasing biodiversity among others. During this same period, city planners have joined the movement by incorporating more green spaces into urban landscapes.

Definitions and History

Since the early 1990s, scholarly publications discussing greenways have increased. Much of the early literature focuses on greenway definitions. Some scholars categorize greenways based on form, while others define them by their functions. Once definitions for greenways began to solidify, scholars started shifting their focus to greenway trails' costs, benefits, and management (Moore and Shafer 2001).

Although trails are often established along greenway corridors, a trail may not be included in a greenway design depending on its purpose and intended use. So, beginning with the most general parameters, greenways are linear and often follow an existing landscape feature. The feature can be either natural, such as a river, stream, or ridgeline, or artificial such as a canal or scenic roadway (Moore and Shafer 2001).

Apart from their physical description, greenways are classified by their general use. Greenways are often corridors for non-motorized transportation for pedestrians or bicycles. Utilizing this transportation function, greenways connect other greenspaces such as parks and protected natural areas as well as cultural and historic sites. Further, greenways function as autonomous linear parks where greenspace is protected from development. However, landscape ecologists focus on greenways as connections between habitats for plants and animals. Because of the habitat conservation goal of these types of greenways, trails are excluded as they would attract human use and potential negative impacts on the habitat. These habitat conservation greenways are also designed without concern for following particular landscape features as greenways with trails do (Moore and Shafer 2001).

Greenways serve not only as autonomous linear parks but also as connectors between other green spaces. Although greenway projects have gained favor with planners, research on the subject has lagged. However, the last thirty years have seen an increasing number of publications on greenways, providing planners and geographers with much needed data on the subject.

Many scholars trace the origin of greenways to Frederick Law Olmsted's 1865 design for the University of California at Berkley (Little 1990). Olmsted put his greenway idea into practice by designing the Boston, MA park system, which included seven miles of connected parkways. Olmsted's sons carried on their father's greenway ideas by designing a greenway system in Portland, OR (Ergen 2013). A century and a half later, these projects have left their mark. Portland has the largest share of bicycle transportation use of any city in the United States (Gotschi 2011).

Other planners and landscape architects have followed in Olmsted's ground-breaking footsteps. During the Romantic Parks and City Beautiful movements of the late nineteenth and early twentieth centuries, planners included greenways in park and boulevard plans in major cities throughout the United States. Also known as part of the Eco-city movement, greenways became important components of city planning by the twenty-first century (Lindsey et al. 2008).

After the turn of the century, research shifted to understanding costs and benefits. Many of these studies focused on gathering evidence of economic benefits to help incentivize new greenway developments. Many of these studies were concerned with selling greenway trails to the public. Some used public surveys to determine people's willingness to fund greenway trail development (Lindsey and Knapp 1999). Others teased out distinctions in property owner's attitudes towards trails. Such studies concluded that property owners living directly adjacent to trails were less likely to approve of a trail then those nearby (Ivy and Moore 2007).

Several researchers have attempted to track property values around greenway trails. Most conclude that property values do increase around trails, but this is true primarily in wealthy neighborhoods. This is the case in Indianapolis, IN. Greg Lindsey et al. (2004) found that property values were higher around greenway trails in wealthier neighborhoods, but prices did not significantly increase or decrease around greenways in disadvantaged neighborhoods (Lindsey et al. 2004). This same pattern was shown in Charlotte, NC. There, properties around the Catawba Regional Trail were shown to be higher in wealthier neighborhoods but stagnant in lower-income neighborhoods adjacent to the trail (Campbell and Munroe 2007).

Greenway Trail Design

Throughout the 1990s and 2000s, several guides on greenway trail design were published. These guides focused on general practices and did not attempt to confirm efficacy by correlating them to use patterns (Lindsey et al. 2008). For instance, Little (1990) discusses conserving open space and greenness surrounding greenway trail corridors. Other authors emphasize the importance of trail slope, viewsheds, intersections, and amenities (Lindsey et al. 2008).

In their landmark book, Hellmund and Smith (2006) focus on combining social and ecological views of landscapes. The authors advise planners to "align the greenway so that users have views and experiences that give them a sense of the landscapes they are passing through" (Hellmund and Smith 2006, 212-213). The work also notes the importance of connectivity. The authors recommend connecting areas of diverse land use, which are often linked to socio-economic status, to increase access for the entire community (Hellmund and Smith 2006).

Lindsey et al. (2008) take note of these design characteristics and attempt to correlate them to trail use. The authors use five years of trail use data gathered from infrared trail counters on greenways in Indianapolis, IN. Then they apply ordinary least square regression modeling to determine the effects of independent variables for trail features on the dependent variable of trail use. The study uses temporal dummy variables for months of the year as well as weather and demographic variables derived from the author's 2006 study (Lindsey et al 2008).

The Lindsey et al. (2008) study results in the identification of five trail characteristics that are associated with increased trail use: openness of a trail viewshed, mystery or lack of viewshed connectedness, and greenness and land use diversity within the viewshed (Table 1). Coutts (2009) also correlates land use diversity with increased trail activity.

Instead of attempting to replicate Lindsey et al. (2008), this study capitalizes on a unique opportunity to apply their findings to plan a new greenway trail. Using the methods from Lindsey et al. 2008, this study measures openness of a trail viewshed, mystery or lack of viewshed connectedness, and greenness and land use diversity within the viewshed to evaluate two competing plans for a proposed greenway trail connecting Wilson's Creek Greenway to Wilson's Creek National Battlefield in Greene County, MO.

Table 1. The findings of the Lindsey et al. (2008) study comparing viewshed characteristics with trail use.

Trail characteristic	Hypothesized effect	Measured effect	Comments
Openness of trail viewshed	Positive	Positive	Trail use higher wherer views are more open
Mystery (Interconnectedness of trail viewshed)	Context dependent	Negative	Trail use higher where lower interconnectedness (i.e. visual magnitude) and more "mystery"
Trail Greenness relative to neighborhood greenness	Positive	Positive	Trail use higher where trail viewsheds are greener
Land use diversity within viewshed	Positive	Positive	Trail use higher where land uses in viewsheds are more diverse

STUDY AREA

This study is being conducted in southwest Greene County, MO, just outside of the city limits of Springfield, MO. Springfield, MO is in the southwestern part of the state. To gain an understanding of the population of Springfield, MO and its surrounding urban areas, we can reference The Springfield, MO Metropolitan Statistical Area (MSA) which includes Greene, Christian, Webster, Polk, and Dallas counties. The area has a population of over 456,000 (Springfield Regional Economic Partnership 2017). The City of Springfield is located within Greene County which covers 675 square miles and has a population of 288,690 (United States Census Bureau 2016).

The proposed trail is an extension of the Wilson's Creek Greenway. The Wilson's Creek Greenway is part of a 70-mile regional greenway trail system (Figure 1) developed by Ozark Greenways Inc. and maintained by the Springfield-Greene County Park Board (Ozark Greenways 2017). The new trail would connect the existing Wilson's Creek Greenway to Wilson's Creek National Battlefield, a cultural and historic site maintained by the United States National Park Service (National Park Service 2017).

Springfield-Greene County Park Board and Ozark Greenways Inc.

Springfield, MO voters approved a combined Springfield-Greene County Park Board in 1996. The Park Board and the City of Springfield adopted the Vision 20/20 Comprehensive Plan for Parks, Open Space, and Greenways in 1998. Since then the City of Springfield has incorporated the plan into their Field Guide 2030: A Strategic Path to Springfield's Future (City

Figure 1. Springfield Greenway Trails and Bike Route Network Map (Ozark Greenways Inc. 2017).

of Springfield, MO 2013). The updated plan outlines the Springfield-Greene County Park Board's commitment to greenways and park connectivity.

In Field Guide 2030, city planners discuss preserving open space by expanding parks and greenways. The document also details a plan to expand the greenway trail system to a minimum of 130 miles. The plan emphasizes connecting parks and subdivisions to the greenway trail system to allow for bicycle and pedestrian transportation. It also makes a commitment to land acquisition projects through Ozark Greenways as a land trust (City of Springfield, MO 2013). This legal agreement allows individuals or their estates to give parcels of land or grant easements to Ozark Greenways ensuring they will be protected and only used for greenways.

Ozark Greenways was formed in 1991 as a 501c3 non-profit group by private citizens. The group serves the greater Springfield area by preserving the natural landscape through a public-access greenway trail network. After construction of each new greenway project, the trail is incorporated into the Springfield-Greene County Park Board's park system. Ozark Greenways also works with other public partners, such as the City of Springfield and the regional metropolitan planning organization, Ozarks Transportation Organization (OTO), to plan and develop the regional greenway trail network. The organization is funded by private donations as well as government grants. Ozark Greenways' primary activities involve planning, fundraising, and trail easement acquisition (Ozark Greenways 2017).

Although Springfield's comprehensive plans have included an emphasis on greenway trail development, the city does not directly invest in these projects. The city does not track trail or bicycle transportation usage either. This makes it difficult to conduct studies analyzing the benefits and costs of the region's greenways or even track bicycle commute share. Unlike Portland, OR, Springfield has not seen significant public investment aimed at creating a pedestrian or bicycle friendly city. Many streets and roads lack sidewalks and the addition of on-street bike lanes has been piece-meal at best. Hence, garnering public support and financing of addition miles of greenway trails is a challenge.

Yet, if one takes a ride or a stroll on one of the area's greenway trails on a spring or fall day, these trails are often crowded with users. Even though the city government may lack the political will to fund these projects, the success of Ozark Greenways speaks to the popularity of the trails with residents. Fortunately, Springfield is home to several large corporations who contribute to local outdoor recreation and sustainability initiatives. Passionate members of the community also volunteer their time to help Ozark Greenways accomplish their mission.

Wilson's Creek National Battlefield

Wilson's Creek National Battlefield is a cultural and historic site in Greene County, MO. Wilson's Creek was the location of the first major Civil War battle fought west of the Mississippi River. The battle saw the death of the first Union general killed in action, Nathanial Lyon. The South won the battle on August 10, 1861. Wilson's Creek National Battlefield exists to commemorate and interpret the battle within the historical context (National Park Service 2017).

The battlefield is located southwest of the Springfield city limits between the towns of Battlefield, MO and Republic, MO. The battlefield contains a five-mile tour road which can be traveled by vehicle, bicycle, or on foot. The tour road takes visitors past historical interpretation sites and is a popular local place for walking and bike riding (Figure 2). There is also a seven-mile trail system available for horseback riding and hiking accessible from the tour road (National Park Service 2017).

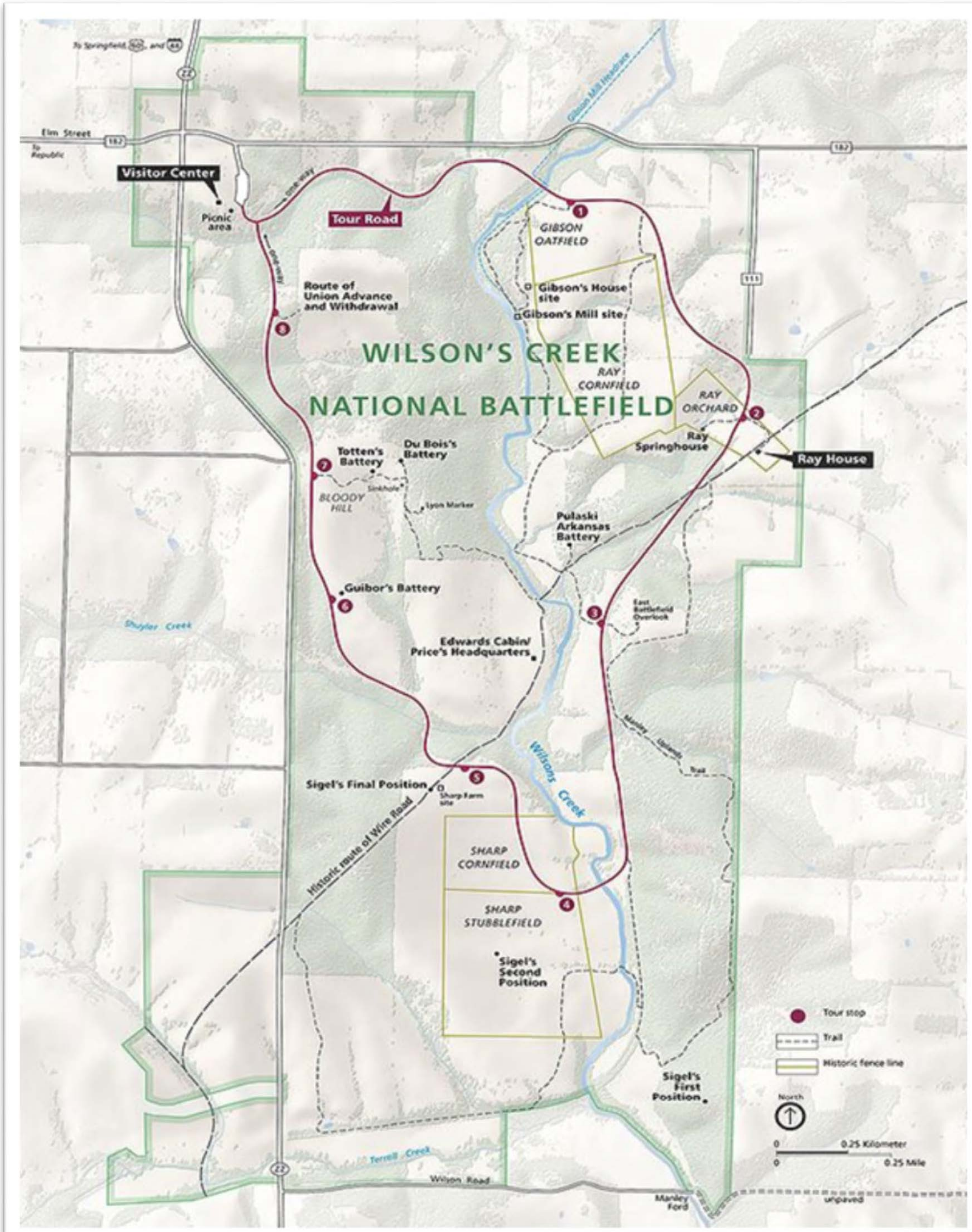

Figure 2. Wilson's Creek National Battlefield (National Park Service 2017)

The terrain within the historic site consists of open grassy fields and pockets of deciduous trees. The battlefield is bisected by Wilson's Creek, which flows north to south through site. The open vistas are one of the park's main attractions, and the interpretive signs along the loop road encourage park visitors to imagine the battle from these open-vista sites (Figure 3). Development around the battlefield is regulated to attempt to protect the historic scene and natural setting.

Protecting the natural open vistas of Wilson's Creek National Battlefield was the primary goal of a previous viewshed analysis of the site. A 1991 master's thesis by Janet Goucher used some of the first GIS software programs ever developed to evaluate the encroachment of urban development on the park (Goucher 1991). As the pristine and historically preserved state of the site are primary attractions for visitors, the increase in housing developments close to the battlefield over the past thirty years has made evaluating and protecting viewsheds all-the-more important.

According to Ozark Greenways, there have been plans to connect the battlefield to the greenway system for many years. This would allow bicyclists and pedestrians to travel to the battlefield by way of the Wilson's Creek Greenway. Incorporating the battlefield into the greenway system would promote the City of Springfield's and Ozark Greenways' goals of park and greenway connectivity for non-motorized transportation.

In addition, the proposed trail could serve a tourism development function by drawing on a large and increasing audience for both Civil War Battle history and bicycle touring at Wilson's Creek National Battlefield (National Park Service 2019). The terrain of Springfield's location on the Ozark Plateau means these bike routes are relatively level and suitable for family recreation as well as more serious bicycle enthusiasts (Figure 4).

Figure 3. Guibor's Battery re-creation at Wilson's Creek National Battlefield with inset of interpretive placard

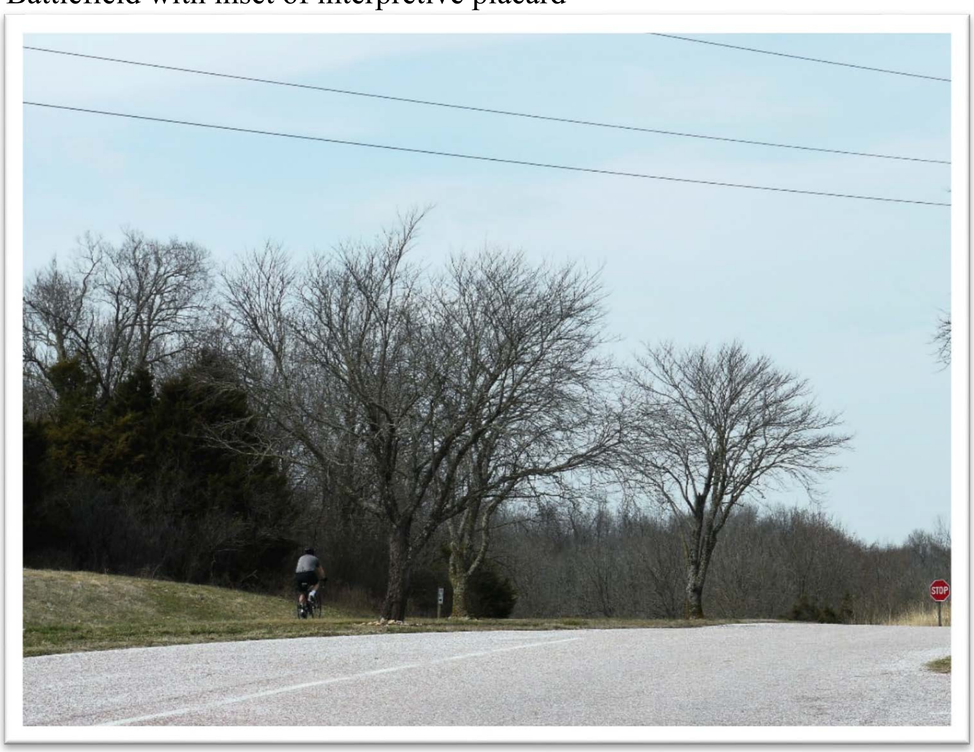

Figure 4. Bicyclist traveling along Wilson's Creek National Battlefield's Tour Road

METHODS

This study uses four geospatial analysis methods to determine the potential of the proposed greenway trails for increasing non-motorized transport to Wilson's Creek National Battlefield. Specifically, this study measures cumulative viewshed, greenness, land use diversity, and slope for each of the two proposed greenway trail additions. This research also evaluates other planning considerations that play a role in making financial decisions regarding the proposed trail. Total length of the trail will determine the cost of paving, and whether or not easements will need to be obtained or property purchased to build the trail on private property.

The study consists of three stages. First, the two competing trail segments are mapped using both quantitative and qualitative methods. Second, geospatial analysis is performed to measure the trail characteristics detailed in Lindsey et al. (2008). Third, the other planning considerations are identified and discussed.

Mapping the Proposed Trails

The first step is to map each trail segment. There are several different methods for planning the route of a recreation trail. Although the general path of each proposed trail has been provided by Ozark Greenways, there are still many specific decisions to make about its exact placement. This study uses a combination of Least Cost Path (LCP) analysis and expert knowledge of the area to determine the best path for each proposed route (Teng et. al. 2011).

The general path of the proposed routes has been determined by Ozark Greenways. Both proposed routes begin at the current endpoint of the Wilson's Creek Greenway, which ends where Wilson's Creek passes under West Republic Road (Figure 5). The first option for the

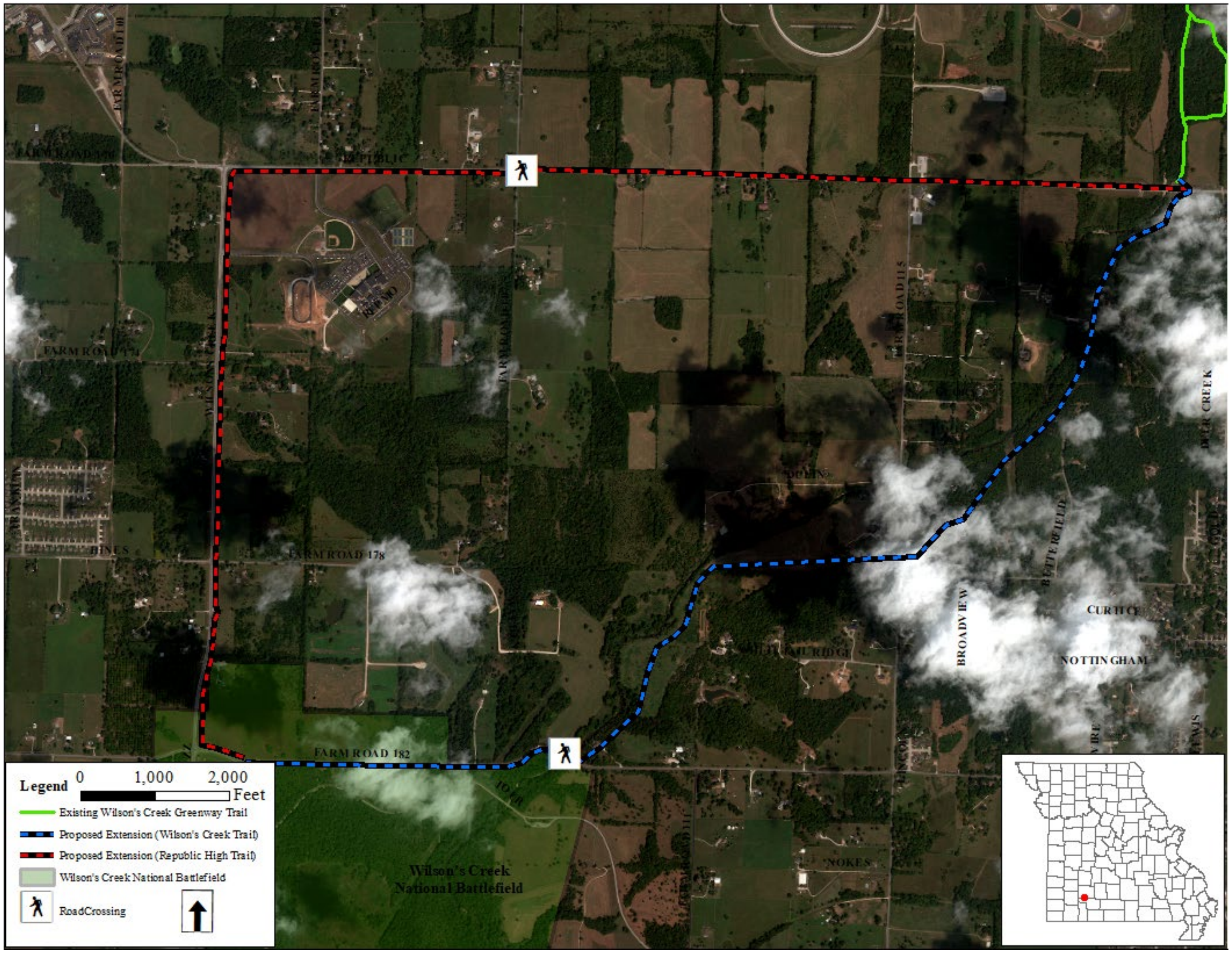

Figure 5. Proposed routes to connect Wilson’s Creek Greenway to Wilson’s Creek National Battlefield

proposed trail would follow Wilson's Creek until it intersects with West Farm Road 182. From there, it follows the road west to reach the entrance to Wilson's Creek National Battlefield.

The second option for the proposed trail would follow West Republic Road west until it reaches Republic High School. At this point, the trail passes behind the school and intersects with South State Highway ZZ before heading south to intersect with West Farm Road 182 and the entrance to the battlefield. Ozark Greenways has proposed converting Highway ZZ into "Wilson's Creek Boulevard," a scenic entry road lined with themed landscaping. The general path of both proposed routes is shown in Figure 5.

To determine the best path for each proposed route, an LCP analysis is performed between the end of the existing Wilson's Creek Greenway Trail and the entrance to Wilson's Creek National Battlefield. The LCP analysis has become an increasingly-popular GIS tool for planning trails and other linear paths and involves a combination of computer algorithms and expert knowledge to choose the ideal path based on user-defined criteria (Teng et. al. 2011).

The LCP analysis for this study is performed in ArcGIS for desktop v.10.4. It uses the distance traveled, slope of the terrain, and land use classifications as the criteria for the path. These two criteria are given weights based on their relative importance. Here, the slope of the terrain is weighted in favor of gentler slopes, because this makes the trail easier to construct and to travel. The land use variable is set to avoid residential land uses in favor or agricultural, tax-exempt, or commercial parcels, since it is more difficult to obtain easements from residential land owners.

The slope input for the program is a 0.5-meter resolution digital elevation model (DEM) raster file produced from Light Detection and Ranging (LiDAR) data. The DEM was created by isolating LiDAR points classified as "ground" in the LiDAR statistics. Then the ground classified points were used as the input for the LASD to raster tool in ArcMap. In this tool, the triangulation interpolation type was chosen with the linear interpretation method. This input is ideal for DEM production according to the software's tool help literature. In the input for the LASD to raster tool, the LiDAR points were sampled to 0.5 meters. This was done to match the resolution of the DEM to the resolution of the base imagery used.

The land use input for the program is a land use raster produced by converting a Greene County land use polygon feature class to a raster feature class. Once the output files for slope and land use are created, they are loaded into a weighted overlay in ArcMap. This weighted overlay along with a start and end point for the trail provide the input for the LCP analysis tools.

The LCP analysis results in a path that generally follows Wilson's Creek. The LCP-defined route is then modified manually to refine some less-ideal path choices. For example, in several areas, the algorithm chose to pass directly over one home, through several residences' front yards, and crossed Wilson's Creek twice. After adjusting the LCP route, what is left is a realistic path for the Wilson's Creek route for the proposed trail.

LCP analysis avoided the general path of the Republic Road to Highway ZZ trail segment due to the high number of residential parcels present, steeper slope of the terrain, and greater distance required to travel. Therefore, the Republic High Route required manual mapping and the consideration of additional factors. First, the path must stay within the right-of-way of both roads that run parallel with it. Second, to increase pedestrian safety, the path should avoid crossing roads whenever possible. Because it already relies on staying within right-of-way, this path is not limited by considerations of land use and requires little-to-no acquisition of private land.

As the measurement of the remotely sensed viewshed characteristics is the primary goal of this study, it should be noted that these tentative paths are produced mainly to serve as a basis for the rest of the study. If, for instance, the final chosen path was moved several feet or if a different point for a road crossing was chosen, it would likely have little effect on the other measures evaluated in this study.

LiDAR Viewshed Analysis

Viewsheds are an important component of landscape planning and design. Researchers have tried many different methods to evaluate or categorize the quality of viewsheds. These methods rely primarily on asking individuals to rate viewsheds based on opinion or predetermined criteria or values. With the recent advent and proliferation of high-powered computer processing and advanced geospatial software, more objective methods for viewshed analysis are available to researchers (Lindsey et al. 2008).

One particularly attractive method for digital viewshed analysis uses LiDAR data. LiDAR technology uses lasers, sensors, and GPS to remotely sense objects. Typically, LiDAR data is collected from aircraft which pass over an area bouncing pulses of a laser beam off the terrain below. Using the angle of the pulse, the time it takes to travel to its target and back, and the position of the sensor, a three-dimensional point cloud is created. This resultant point cloud gives a high-resolution sample of the terrain below. The LiDAR point cloud can then be used to create a digital surface model (DSM). A DSM gives a digital representation of above-ground features or of the ground itself if no features cover it (Lindsey et al. 2008).

The LiDAR data for this study was obtained from the Missouri Spatial Data Information Service (MSDIS). The data files were downloaded in the LAS file format and then imported into

ArcCatalog and combined into LAS datasets, or LASD. Statistics were then calculated and the datasets were constrained to a half mile buffer around each trail, and the proper local coordinate system was assigned to the dataset based on the metadata. Once the LASD for both study areas was created, several geoprocessing tools were used in ArcMap to delineate the viewshed for each proposed trail.

Point features or viewpoints were added at fifty-foot intervals along each trail. Then, the first return LiDAR points were isolated, because these are best at capturing above ground features. The LASD to Raster tool was used to convert the LiDAR data to a raster dataset. For the DSM creation binning interpolation with nearest neighbor cell assignment was used. According to the tool's help literature this interpolation method is best for creating DSMs considering both quality and processing time. The sampling distance was set to 0.5 meters to create a DSM that matched the resolution of the base imagery used. Finally, the DSM was input into the viewshed 2 tool for processing.

The viewshed 2 tool in ArcMap has a host of parameters. Choosing the "frequency" option causes the tool to create an output that serves as both a binary viewshed map and as a measure of visual magnitude. A binary viewshed displays whether each cell in the raster is visible or not from any of the viewpoints along the trail. Visual magnitude, a measure of viewshed connectedness, is derived from the frequency of observers who are able to see each pixel. For instance, if one pixel in the raster can be seen from six observer points along the trail, then that pixel is assigned the value of six. The only other parameter set in the viewshed 2 tool for this analysis is height of the observer, and is referred to as the "offset." This parameter was set to six feet to match the methods used in Lindsey et al. (2008).

Visual magnitude is only one of the two viewshed measures involved with this study. The other viewshed measurement used in Lindsey et al. (2008) is viewshed openness. Viewshed openness measures the total area visible within the viewshed and this measure is displayed as a percentage. For example, if the viewshed is 100 meters from the trail, and there are no terrain features blocking the view in a 100-meter circle around the trail point, the visual openness would be 100 percent (Wilson et al. 2008).

After the initial viewshed calculations were made, additional processing was needed to extract the desired statistics. The desired result of the visual magnitude measure is a mean visual magnitude for each viewshed (Lindsey et al. 2008). This was obtained by using the zonal statistics tool to output the visual magnitude readings from the half mile buffer around each trail as a table. As in Lindsey et al. (2008), the half mile buffer is used to constrain the data analysis area and allow for the viewshed openness calculation. The table is then converted to an Excel file. The Excel file contains the summary statistics for all of the visible pixels including the mean for the visual magnitude parameter.

The viewshed openness measure is also calculated from this same table output. The output statistic table gives a measurement of the visible area. Then the total area within the half mile buffer is obtained from the buffer's attribute table. To calculate the visual magnitude, the total visible area was divided by the total area within the half mile buffer (Lindsey et al. 2008). These steps were completed for both proposed routes of the trail addition.

Analyzing Greenness

The Normalized Difference Vegetation Index (NDVI) is a remotely-sensed measurement of vegetation characteristics. Using multispectral imagery, the NDVI can provide information on plant vigor, vegetative ground cover, and green biomass (Wilson et al. 2008). Specifically, the NDVI is the ratio of red to near-infrared (NIR) light reflectance from vegetation on the ground to an aerial sensor. The equation for calculating this index is NDVI = (NIR-RED) / (NIR+RED) (Pettorelli et al. 2005).

The NDVI calculation performed in this study uses multispectral imagery from the Worldview-2 satellite. The Digital Globe Foundation provided the imagery used here through a grant. The Worldview-2 captures images with multi-spectral bands, including the red band and two NIR bands, making the NDVI calculation possible. These multispectral bands are captured at a resolution of 1.85 meters which allows for the NDVI calculation to be made at a similarly high resolution to LiDAR derived viewshed raster. Worldview-2 panchromatic imagery was used at a resolution of 0.5 meters for the base imagery for all maps used in this study. Figure 6 shows the technical specifications for the Worldview-2 satellite, including a list of bands. The imagery used here is 26.3° off nadir with a max ground sampling distance of 0.57 meters.

The multi-spectral image processing used here was performed in ArcMap. First, the full multi-spectral image with all bands was loaded into ArcMap. Next, the NDVI function was performed through the image analysis window. Bands five and seven were used the red and infrared inputs. The output for the NDVI calculation was changed to “scientific.” This produces a range of values from one to negative one, where values less than zero denote the absence of vegetation (Pettorelli et al. 2005). This output was given for each cell in the half mile buffer.

This study is only interested in the NDVI within the viewshed, therefore further processing was still needed. The binary viewshed was overlaid on the NDVI map and another zonal statistics extraction was performed. This time, the binary viewshed was used as the zone

WorldView-2

Design and Specifications

Launch Information	Date: October 8, 2009 Launch Vehicle: Delta 7920 (9 strap-ons) Launch Site: Vandenberg Air Force Base, California
Orbit	Altitude: 770 km Type: Sun synchronous, 10:30 am descending node Period: 100 min.
Mission Life	10-12 years, including all consumables and degradables (e.g. propellant)
Spacecraft Size, Mass and Power	5.7 m (18.7 ft) tall x 2.5 m (8 ft) across 7.1 m (23 ft) across the deployed solar arrays 2615 kg (5765 lbs) 3.2 kW solar array, 100 Ahr battery
Sensor Bands	Panchromatic: 450 - 800 nm 8 Multispectral: Coastal: 400 - 450 nm Red: 630 -690 nm Blue: 450 - 510 nm Red Edge: 705 - 745 nm Green: 510 - 580 nm Near-IR1: 770 - 895 nm Yellow: 585 - 625 nm Near-IR2: 860 - 1040 nm
Sensor Resolution	Panchromatic: 0.46 m GSD at nadir, 0.52 m GSD at 20° off-nadir Multispectral: 1.85 m GSD at nadir, 2.07 m GSD at 20° off-nadir
Dynamic Range	11-bits per pixel
Swath Width	16.4 km at nadir
Attitude Determination and Control	3-axis stabilized Actuators: Control Moment Gyros (CMGs) Sensors: Star trackers, solid state IRU, GPS
Pointing Accuracy and Knowledge	Accuracy: <500 m at image start and stop Knowledge: Supports geolocation accuracy below
Retargeting Agility	Time to Slew 200 km: 10 sec
Onboard Storage	2199 Gb solid state with EDAC
Communications	Image and Ancillary Data: 800 Mbps X-band Housekeeping: 4, 16 or 32 kbps real-time, 524 kbps stored, X-band Command: 2 or 64 kbps S-band
Max Contiguous Area Collected in a Single Pass (30° off-nadir angle)	Mono: 138 x 112 km (8 strips) Stereo: 63 x 112 km (4 pairs)
Revisit Frequency (at 40°N Latitude)	1.1 days at 1 m GSD or less 3.7 days at 20° off-nadir or less (0.52 m GSD)
Geolocation Accuracy (CE90)	Demonstrated <3.5 m CE90 without ground control
Capacity	1 million km^2 per day

Figure 6. Worldview-2 Design and Specifications factsheet (Digital Globe 2012)

parameter. This produced a table showing only the NDVI for pixels that were also covered by the viewshed. From this, a mean calculation was performed on all the visible NDVI readings.

Land Use Diversity

To determine the diversity of land use in the viewshed this study uses parcel-level land use data provided by Greene County. The parcels were identified with 138 different land use codes and aggregated into five generalized codes: agricultural, industrial, commercial, residential, or tax exempt.

As in Lindsey et al. (2008), the values were used to calculate the Shannon Diversity Index (SHDI) for each trail viewshed. The SHDI is an index traditionally used to calculate the diversity of a species within a population. However, the index has many other applications including land use. The formula is $SHDI = \sum - (P_i * \ln P_i)$, where P_i is the proportion of the total observations of one land use class to the total observations of all land use classes. Higher output values from the SHDI correspond with greater diversity within the viewshed (Lindsey et al. 2008).

For an area analysis using SHDI, the total area of parcels is used as the total observations, because, if the number of parcels were used, the results will be skewed toward residential land uses where there are many small parcels. Hence, land such as agricultural fields that consist of larger parcels of land are under-represented in the calculation.

The calculation for SHDI was performed in Excel after extracting the necessary data from ArcMap. First, the parcels were classified by the five generalized land use codes. Then, the parcel data was extracted for the half mile buffer around each route. The zonal statistics tool was then used to extract the area covered by each land use class within the viewshed. This allowed for an output into Excel where the area in square feet was given for each land use classification so the calculation could performed.

Other Planning Considerations

The primary goal of this study is to measure the factors that have been correlated with increased trail use in other published studies. However, in partnership with Ozark Greenways, this study hopes to provide other measures to aid future trail planning decisions. The secondary factors that are evaluated in the project include determining average trail slope and the overall length of each trail. Some qualitative analysis was also explored, such as the value of having trails follow riparian corridors. The qualitative analyses are discussed further in the results and discussion sections.

The slope tool in ArcMap was used to determine the average slope of each trail. This uses the line data of each mapped route and overlays it on a slope raster derived from a digital elevation model (DEM) to determine the slope of the path. To do this, a DEM in each half mile buffer was created. The DEMs used in this study were produced using similar methods to the DSMs. Using LiDAR data, the last return LiDAR points were extracted. This can also be done by choosing the points classified as "ground" in the LiDAR data. The DEM raster was then used to create a slope raster with each cell assigned a slope value. The line feature and slope raster were then used as the inputs for a tool that calculated the slope of each trail. This results in the original line features' attribute tables being amended with the new slope information. The attribute table for each line file also contains the total length.

RESULTS

For each of remotely sensed measurements, results are produced for both proposed routes. In addition, each remotely sensed attribute is displayed cartographically for each route to help visualize and compare the two proposed routes based on the evaluated criteria. Each section of this chapter begins with a brief description of the results for each measure followed by cartographic representations of the data. Finally, a table with all results from both routes is displayed for comparison.

Final Route Results

Although the route following Wilson's Creek uses LCP analysis for the initial path, both final routes are mapped manually. To determine the path for each proposed route, several factors are considered. These factors include avoiding road and water crossings, avoiding residential property parcels, and routing paths through existing easements.

It should be noted that as development in the area continues after the publication of this research (2019), the chosen paths may no longer represent the best possible route for each trail. However, these paths should serve as a good starting point and are primarily used as a reference for the remote sensed measurements. The two routes are displayed using two maps for each route. All maps are at a 1:6000 scale to ensure feature detection at the displayed raster resolutions. Figures 7 and 8 shows the proposed Republic High Route and Figures 9 and 10 shows the Wilson's Creek Route.

Figure 7. The first segment of the Republic High Route.

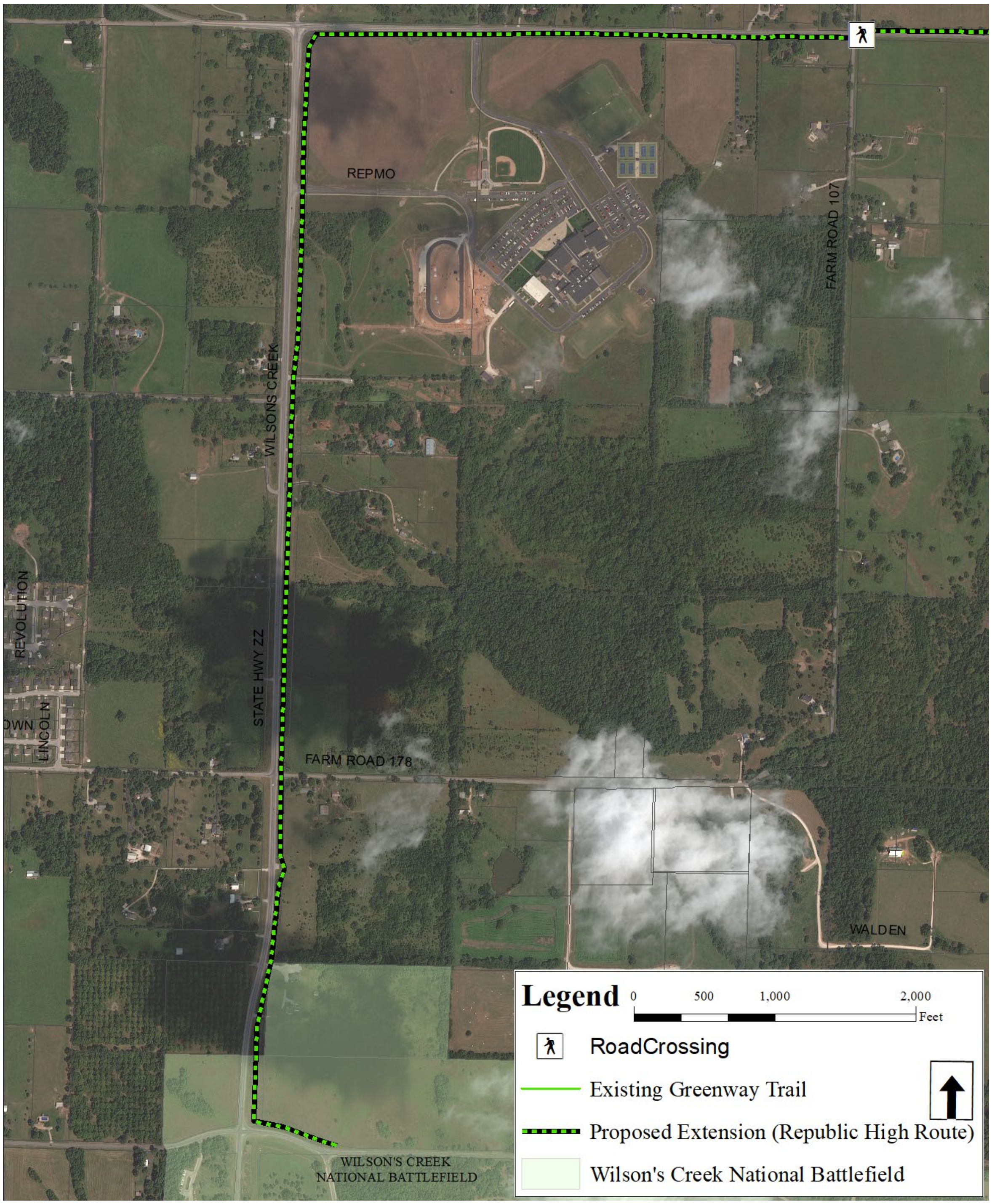

Figure 8. The second segment of the proposed Republic High Route

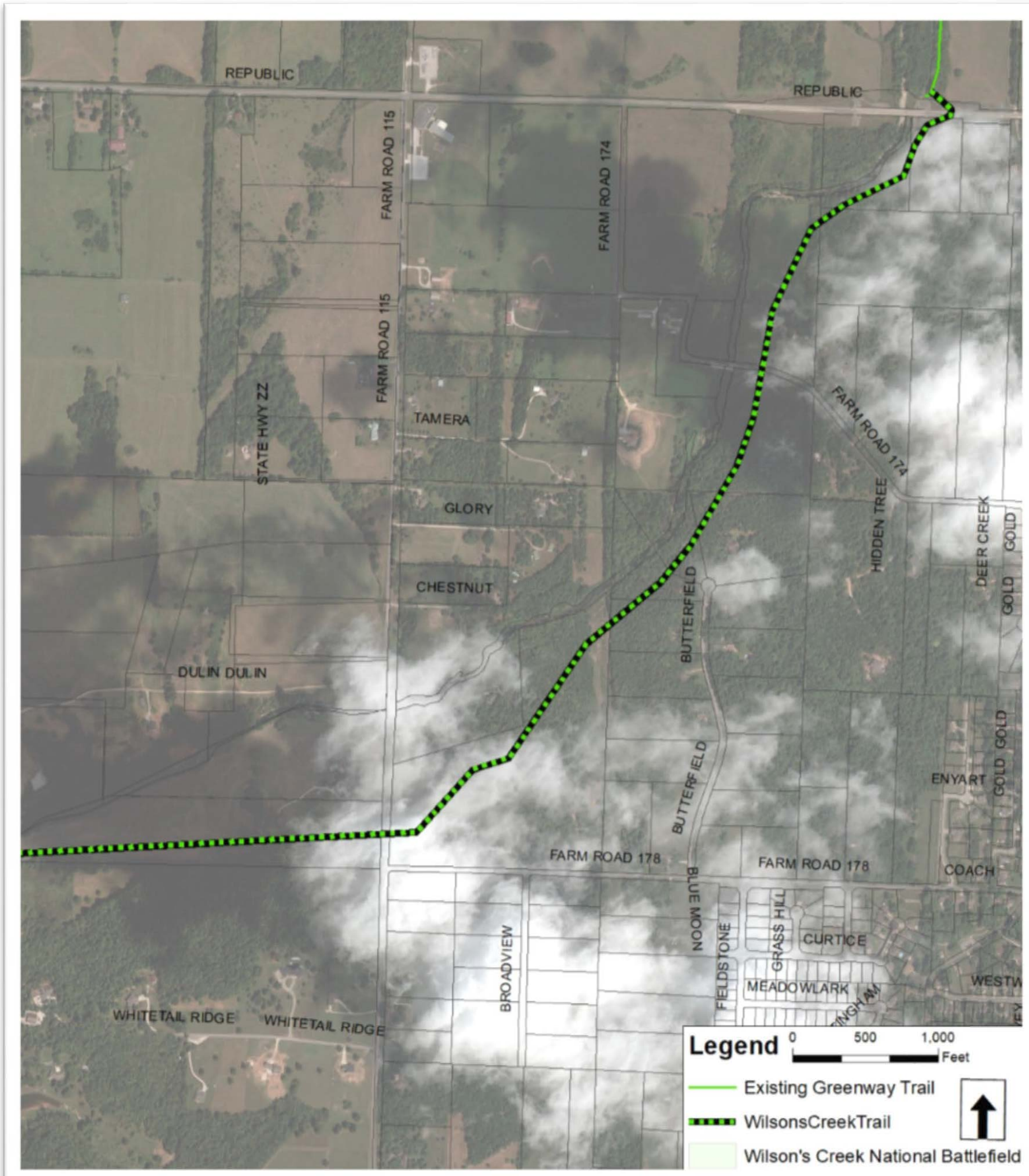

Figure 9. The first segment of the proposed Wilson's Creek Route.

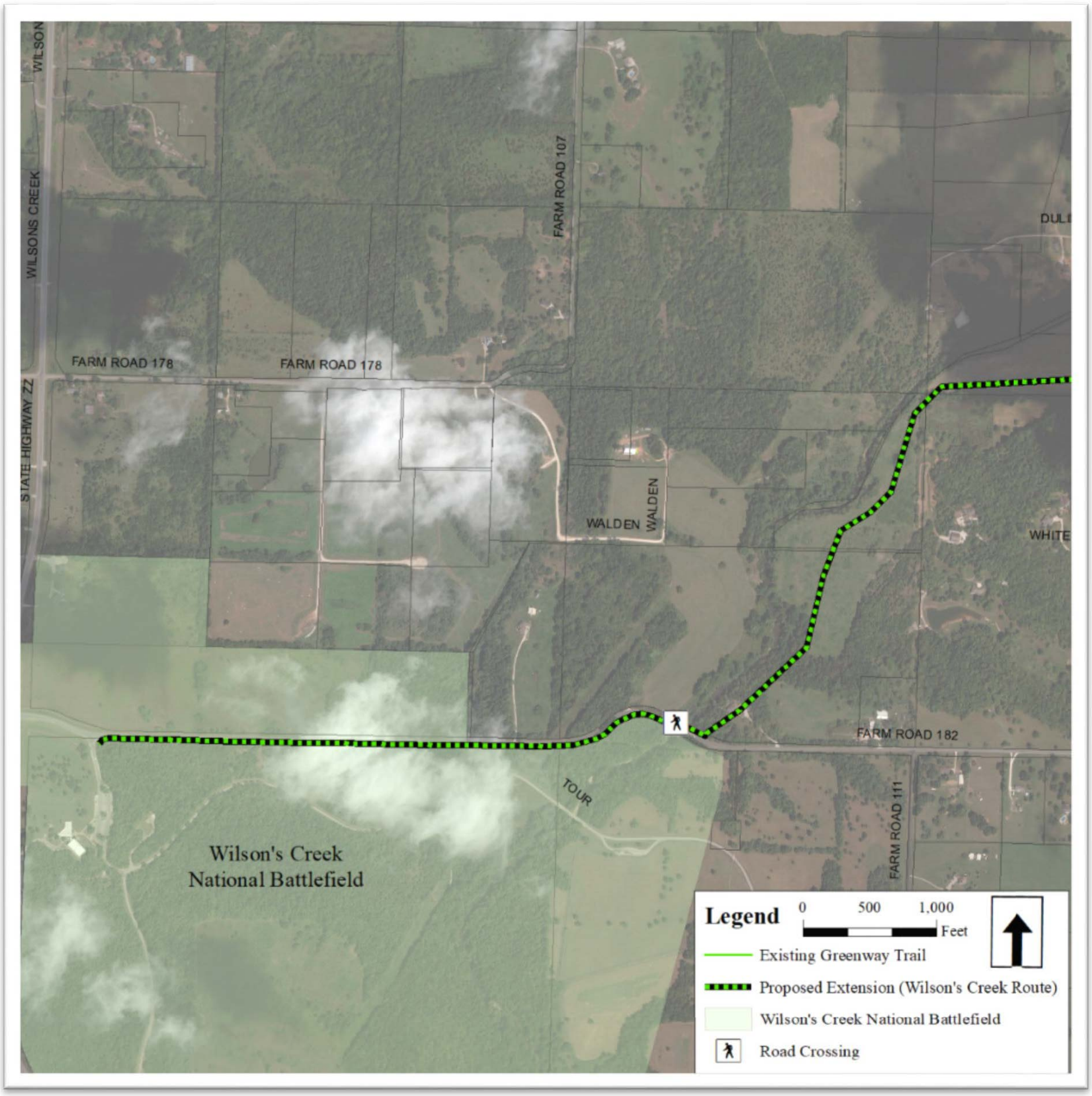

Figure 10. The second segment of the proposed Wilson's Creek Route

Viewshed Analysis

The following pages contain maps displaying the results of the LiDAR derived viewshed analysis. As with the trail route maps, these maps are at a scale of 1:6000. Figures 11 and 12 show the viewshed analysis for the Republic High Route and Figures 13 and 14 show the same analysis of the Wilson's Creek Route.

The maps clearly show that the visual magnitude parameter is higher in the Republic High Route (Figures 11 and 12). The mean visual magnitude for the Republic High Route is 6.88 with a median of 4, meaning the average cell in raster can be seen from 6.88 viewpoints along the trail. The viewshed openness for this route is 24.36 percent, meaning that of the total area within the half mile buffer, 35 percent is visible from at least one point along the trail.

Viewshed analysis of the Wilson's Creek Route returns slightly lower measures (Figures 13 and 14). The mean visual magnitude within the viewshed of the Wilson's Creek Route is 4.96, with a median of 3. The viewshed openness for this route is 17.71 percent.

Greenness Analysis

The results for the NDVI calculation within Republic High Route's viewshed are displayed in Figures 15 and 16, while Figures 17 and 18 show the calculation for the Wilson's Creek Route. The calculation resulted in a mean NDVI for the Republic High Route of 0.49 and a mean NDVI for the Wilson's Creek Route of 0.47.

Land Use Diversity Results

The land use diversity within each viewshed is displayed using one map and one table for each route. These maps are displayed at a smaller scale as they do not contain features at the higher spatial resolutions used in the previous maps. The result of the SHDI calculation for the

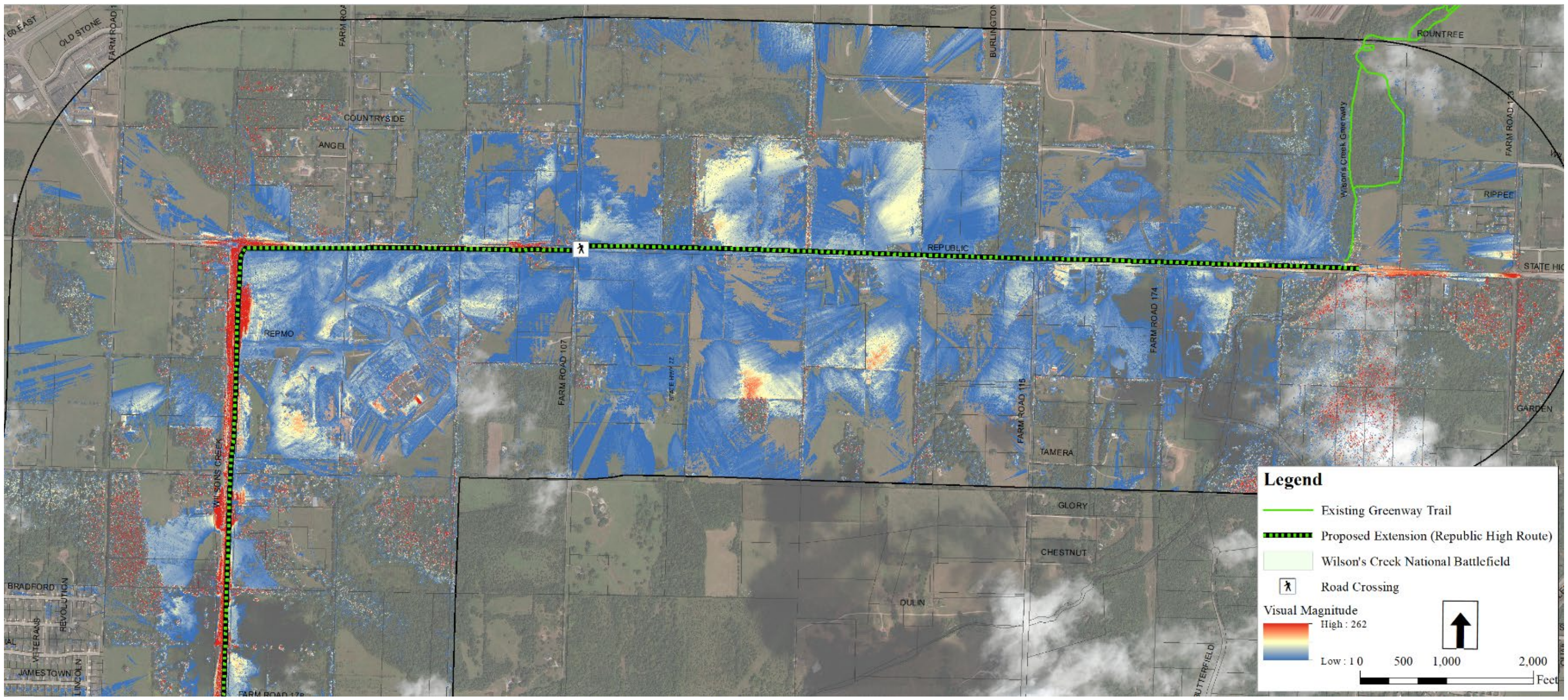

Figure 11. The results of the viewshed analysis on the first segment of the Republic High Route

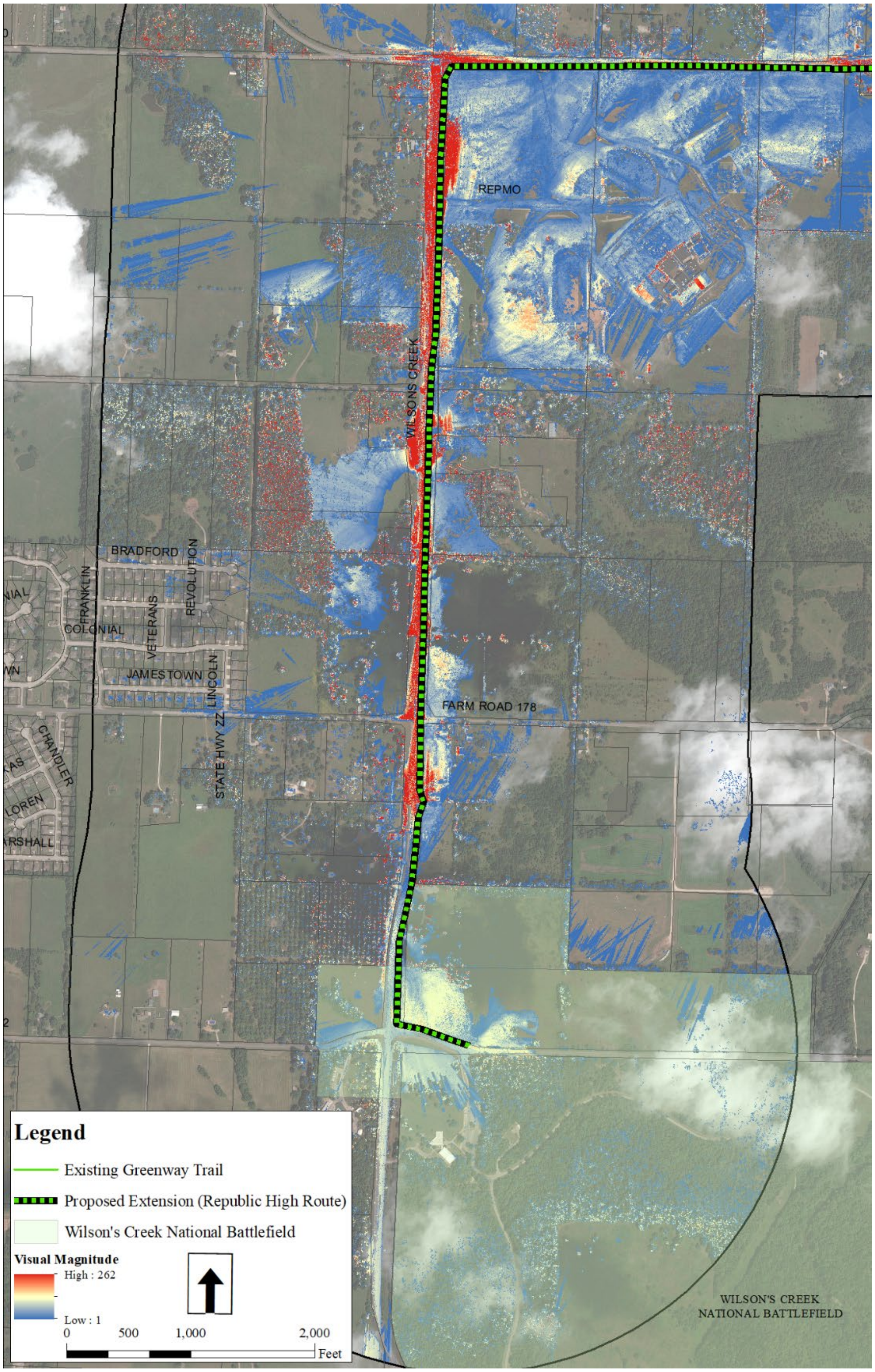

Figure 12. The results of the viewshed analysis on the second segment of the Republic High Route.

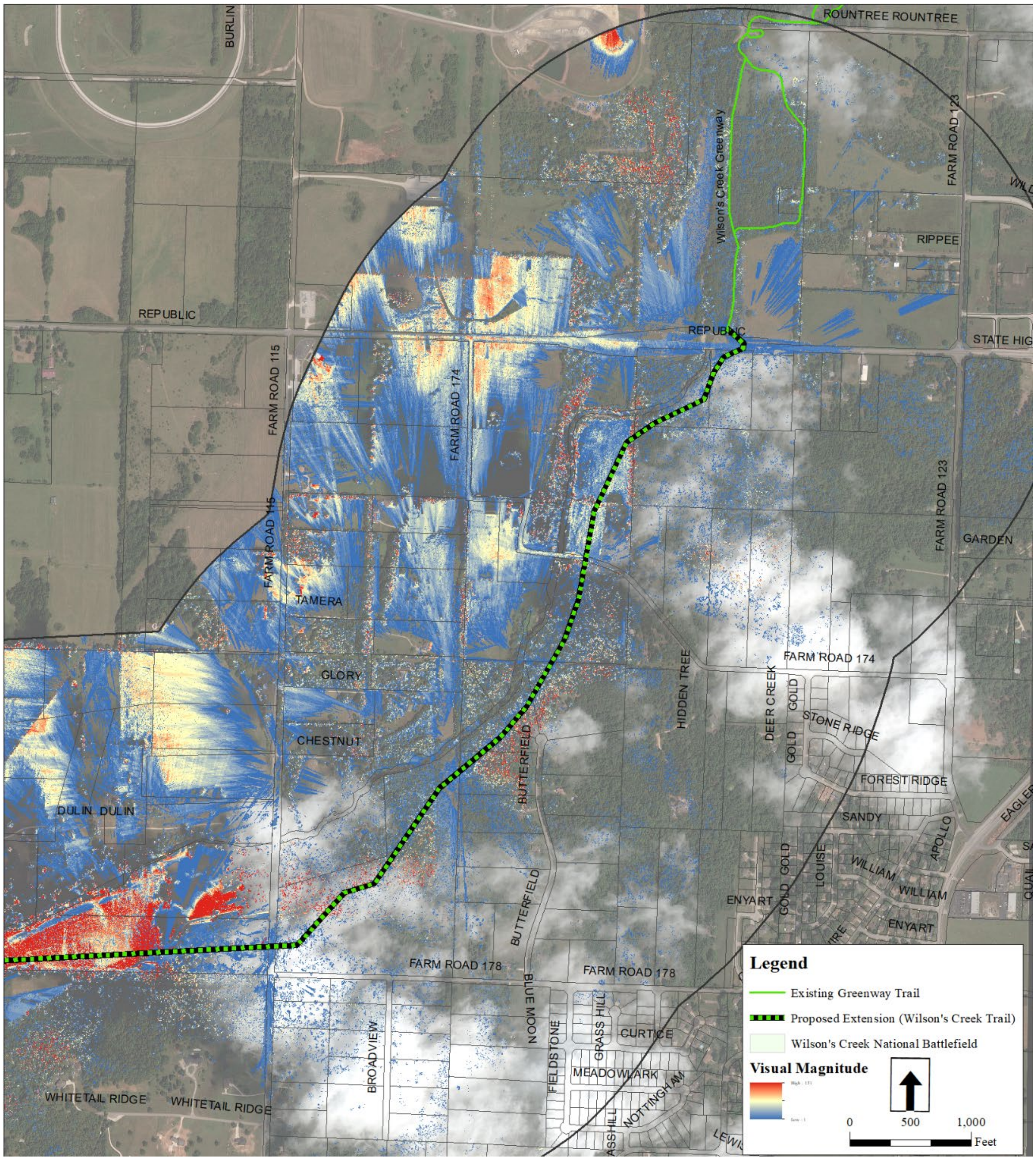

Figure 13. The results of the viewshed analysis on the first segment of the Wilson's Creek Route.

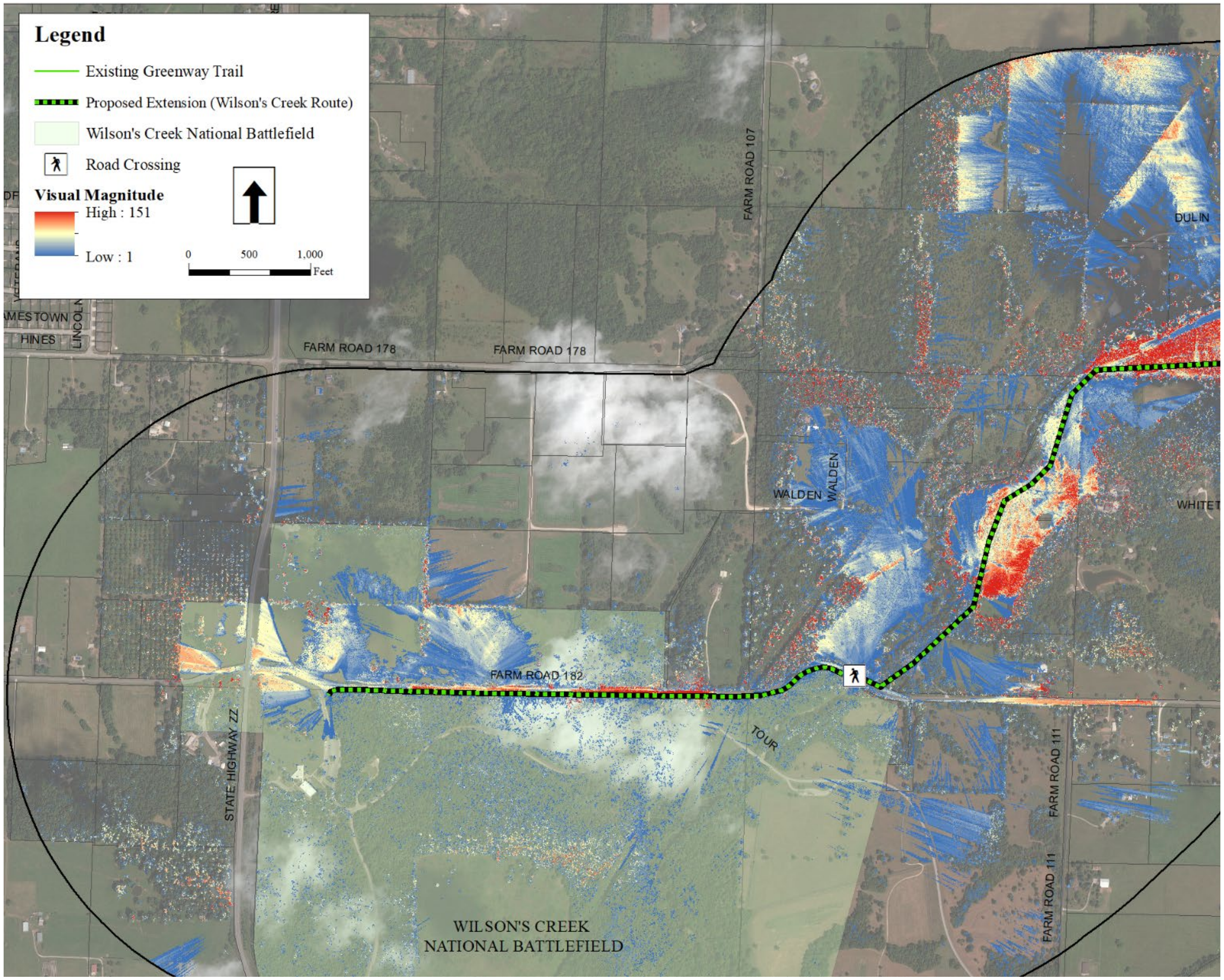

Figure 14. The results of the viewshed analysis on the second segment of the Wilson's Creek Route

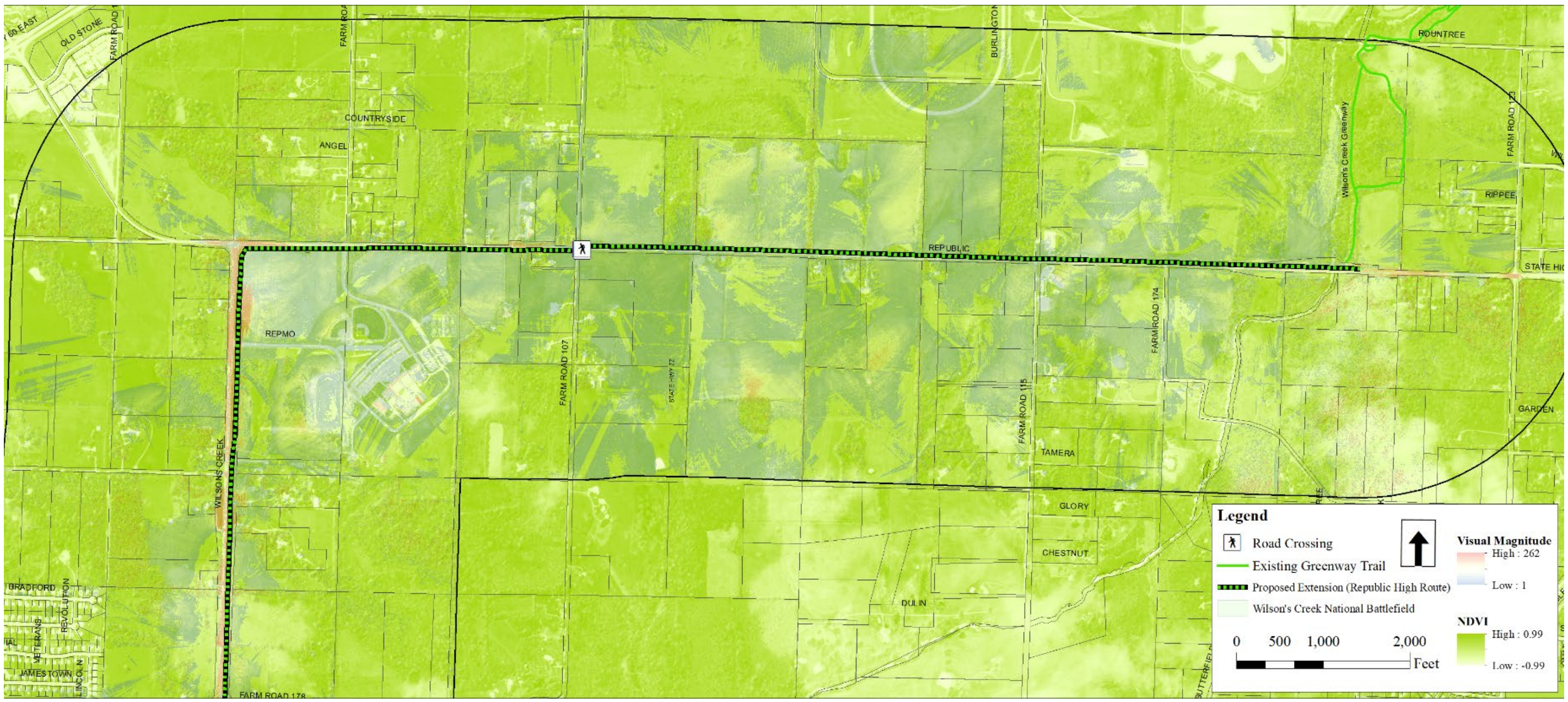

Figure 15. The visual magnitude analysis overlaid on the NDVI for the first segment of the Republic High Route

Figure 16. The visual magnitude analysis overlaid on the NDVI for the first segment of the Republic High Route

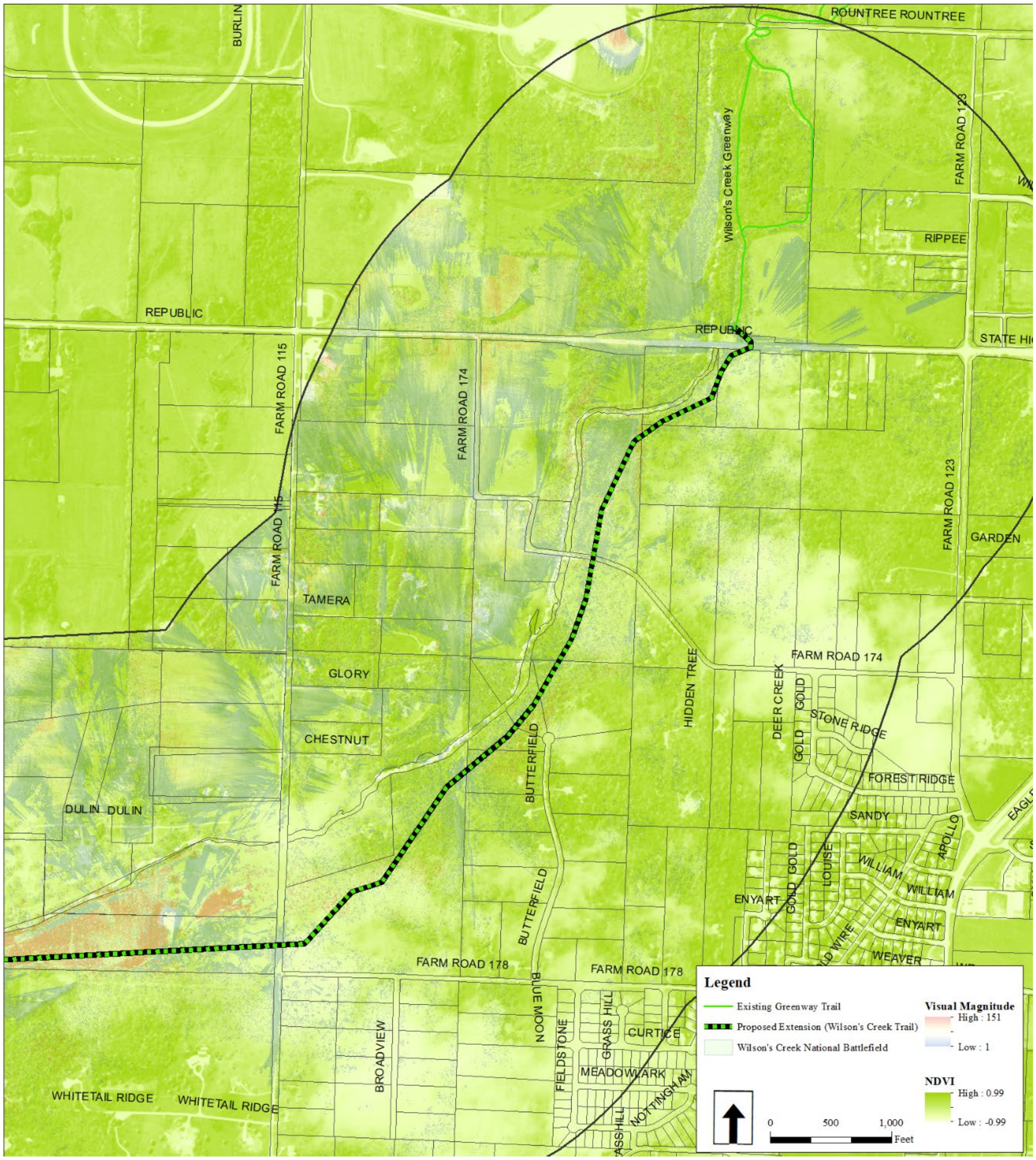

Figure 17. The visual magnitude analysis overlaid on the NDVI for the first segment of the Wilson's Creek Route

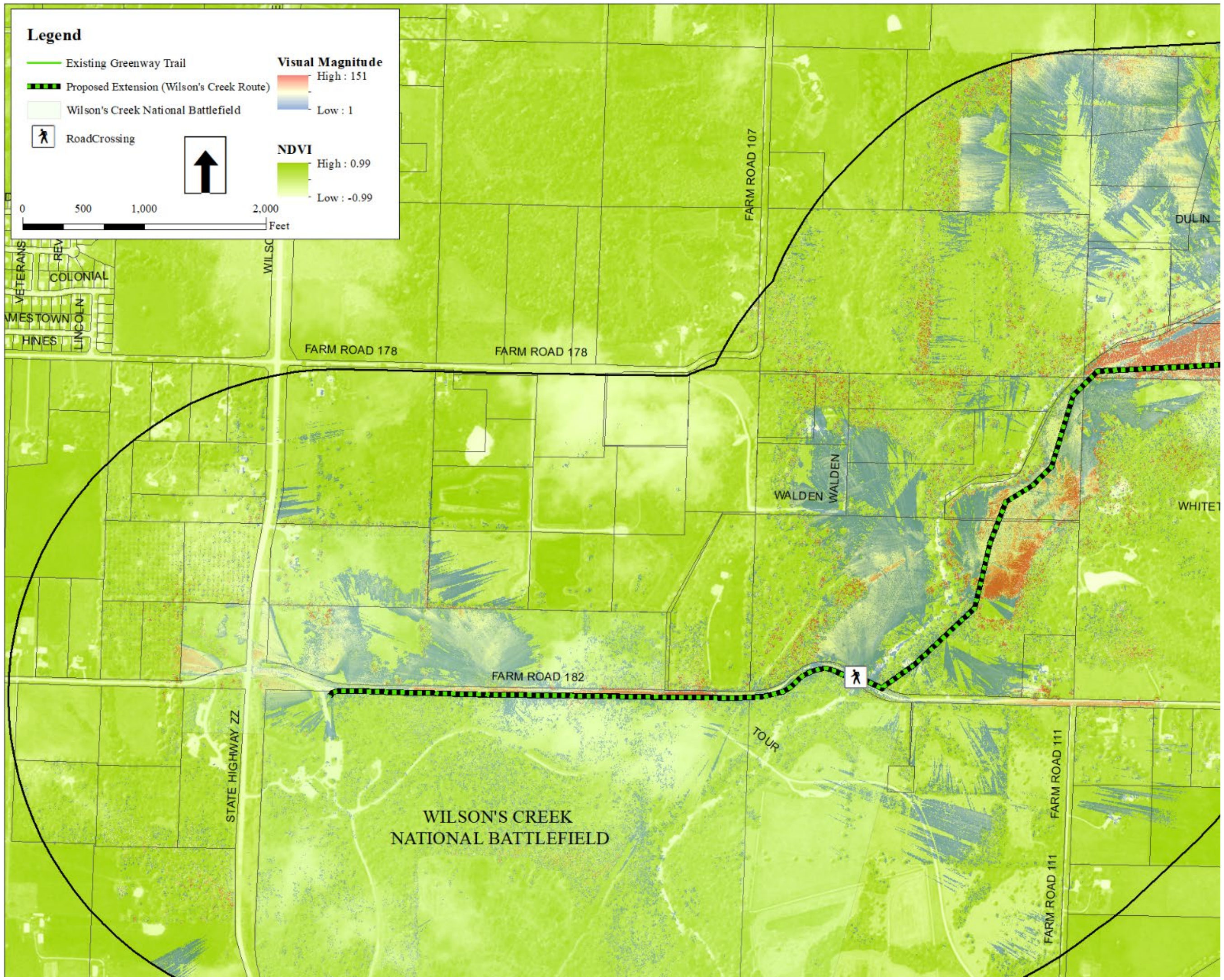

Figure 18. The visual magnitude analysis overlaid on the NDVI for the first segment of the Wilson's Creek Route

Republic High Route is 1.05 (Table 2) and 1.09 for the Wilson's Creek Route (Table 3). The maximum possible SHDI within these viewsheds is 1.61. The land use map is overlaid with the binary viewshed from the trail is shown in Figure 19 for the Republic High Route and Figure 20 for the Wilson's Creek Route.

Results

The final summarized results are displayed in Table 4. The results of the measure vary enough to provide some insight. Although the two routes are relatively close to each other, their viewsheds contain some unique terrain. This provides us some data to consider while determining the final route for the proposed trail. The results will be discussed in more detail in the following chapter.

Table 2. Republic High Route SHDI Calculation

Land use class	Area in square feet	P_i = sample/sum	$\ln(P_i)$	$P_i*\ln(P_i)$	SHDI = $\sum -(P_i * \ln P_i)$
Agricultural	10,791,324	0.433575521	-0.835689287	-0.362334418	
Industrial	12,206	0.000490415	-7.62025941	-0.003737086	
Commercial	807	0.000032424	-10.33661865	-0.000335152	
Residential	4,937,566	0.198382307	-1.617559267	-0.320895139	
Tax Exempt	9,147,242	0.367519334	-1.000979352	-0.367879265	
Total	24,889,145				1.05

Table 3. Wilson's Creek Route SHDI Calculation

Land use class	Area in square feet	P_i = sample/sum	$\ln(P_i)$	$P_i*\ln(P_i)$	SHDI = $\sum -(P_i * \ln P_i)$
Agricultural	481,624	0.382295884	-0.961560406	-0.367600585	
Industrial	170	0.00013494	-8.910680975	-0.001202407	
Commercial	39	0.000030957	-10.38291777	-0.000321422	
Residential	351,605	0.279091458	-1.276215746	-0.356180913	
Tax Exempt	426,382	0.338446762	-1.083388475	-0.366669321	
Total	1,259,820				1.09

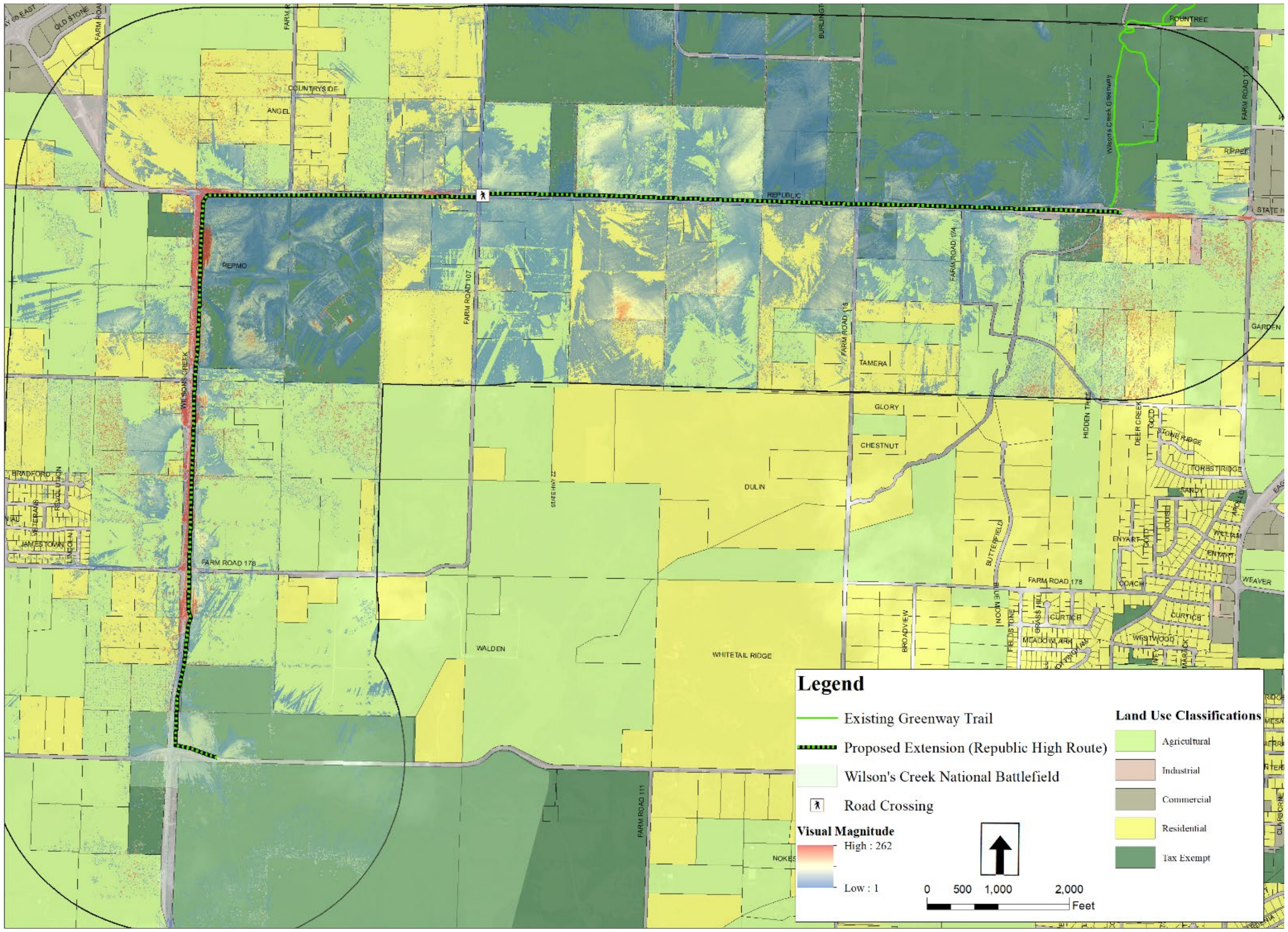

Figure 19. The visual magnitude analysis overlaid on land use classifications for the Republic High Route.

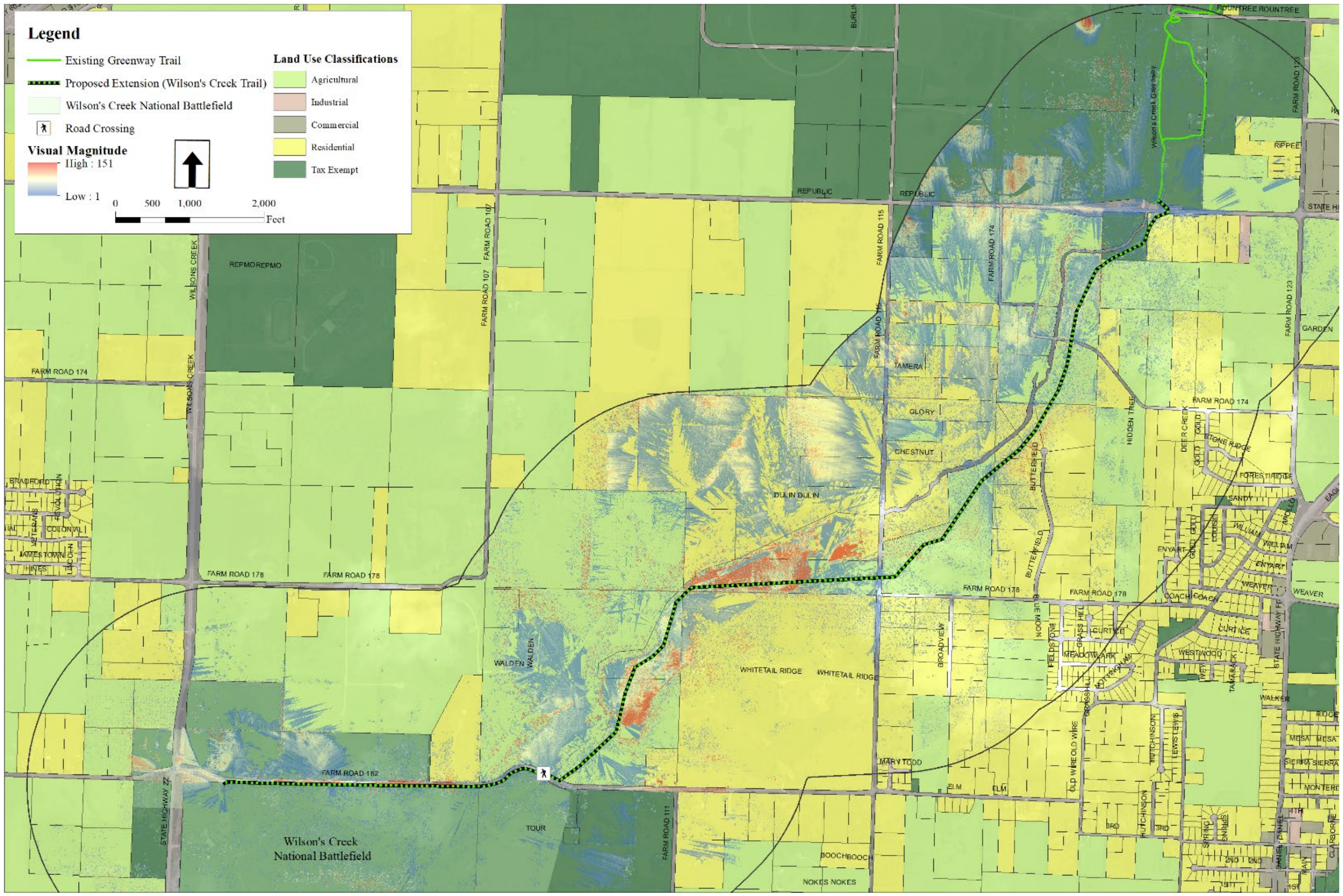

Figure 20. The visual magnitude analysis overlaid on parcel level land use classifications for the Wilson's Creek Route

Table 4. Results of the remotely sensed measurements along with average slope and total length of each propose route.

	Republic High Route	Wilson's Creek Route
Mean Visual Magnitude	6.88	4.96
Median Visual Magnitude	4	3
Viewshed Openness	24.36%	17.71%
Land Use Diversity (SHDI)	1.05	1.09
Mean NDVI	0.49	0.47
Average Slope	33.92°	45.18°
Total Length	21025 Ft	17371 Ft

DISCUSSION

The primary goal of this study is the comparison of two proposed routes based on the remotely sensed measures established in Lindsey et al. (2008). Beyond the analysis in Lindsey et al., several additional factors were evaluated to help contextualize route comparisons. These factors should be of interest to decision-makers involved in the planning process, such as Greene County, Ozark Greenways, and the OTO. This chapter compares the two proposed routes based on the remotely sensed measures. Then, several contextual and qualitative factors related to each route are discussed. After evaluating the results of this research, some of the limitations of the study and inherent uncertainties within the data are analyzed and discussed.

Evaluating the Remotely Sensed Measurements

The remotely sensed measurements for the two routes produced mixed results (Table 3). Starting with the viewshed measures, the Republic High Route returns higher measures for visual magnitude and viewshed openness. However, these two factors have been shown in other studies to have opposite effects on greenway trail use. Therefore, the Republic High Route scores higher for viewshed openness, which is associated with increased trail use. The Wilson's Creek Route's lower visual magnitude result corresponds with greater "mystery," which is also associated with increased trail use (Lindsey et al. 2008).

The differences in viewshed characteristics align with what one might expect. The Wilson's Creek Route is a traditional riparian corridor trail lined with trees and other vegetation. The Republic High Route is a road-side transportation corridor bordered primarily by fields with wide open vistas.

The results are also mixed for the land use diversity and greenness measures. The land use diversity, as measured by the SHDI within the viewshed, showed slightly higher land use diversity within the viewshed of the Wilson's Creek Route than the Republic High Route. The greenness surrounding each route as measured by the mean NDVI within each viewshed returned higher values for the Republic High Route. However, both routes returned quite similar results for both measures with a difference of only 0.04 for the SHDI output and 0.02 for the NDVI output.

Considering the higher amounts of vegetation, one might expect the Wilson's Creek Route to have a significantly higher NDVI measure. However, an analysis of the NDVI maps (Figures 15, 16, 17, and 18) shows that the grass in the open fields along the Republic High Route contributes significantly to the greenness score for the route. The NDVI readings are also affected by the cloud cover in the multispectral imagery.

Other Factors to Consider

There are many things to consider during the greenway trail planning process. This analysis will touch on several factors but is limited to those factors unique to the routes discussed here. The results for average slope and total length of each route produce mixed results (Table 3). The Republic High Route is less steep but has a greater total length than the Wilson's Creek Route. This results in the Republic High Route being easier to travel but longer. It should be noted that Lindsey et al. (2008) included average slope in their analysis and found the results varied too much from trail to trail to identify a relationship between trail use and slope.

In terms of the qualitative factors specific to each proposed route, the two illustrate different views regarding the basic design and function of greenway trails. The Republic High

Route exemplifies the route of a transportation corridor, functioning primarily as a means for non-motorized travel to Wilson's Creek National Battlefield. The Wilson's Creek Route exemplifies a scenic, linear greenspace, immersing the user in nature and a feeling of detachment from urban infrastructure.

These basic differences in the routes speak to some of the costs and benefits associated with greenway trails. The Republic High Route follows an existing transportation corridor and gives it several benefits. First, using existing easements associated with prior road construction reduces the time, effort, and financial burden of obtaining easements from land owners. Second, signage and wayfinding are easier, because the infrastructure is already in place.

Additionally, there is a proposal to change the name of the segment of Highway ZZ that leads to the park entrance into “Wilson's Creek Boulevard” (Figure 21). With the existing easements and available open space, this entrance boulevard makes this route a classic, multi-purpose linear park. As shown in Figure 21, the park entranceway could be lined with benches, lighting, and design elements consistent with Wilson's Creek National Battlefield. Thus, the Republic High Route creates an ideal gateway to the battlefield.

The Wilson's Creek Route also has advantages, especially due to its proximity to Wilson's Creek. Greenway trails built along riparian corridors typically help to protect their adjacent waterways by limiting development. Granting recreational or environmental easements along these corridors can create a buffer zone from other development (Hellmund and Smith 2006). This buffer zone provides several benefits for the waterway. Protecting vegetation along these corridors helps mitigate erosion and contamination associated with residential and other

Figure 21. Artist’s rendering of Wilson’s Creek Boulevard including themed amenities matching Wilson’s Creek National Battlefield’s historic aesthetic (Ozarks Transportation Organization 2018).

development. Non-permeable surfaces, such as streets, driveways, and parking lots close to the riparian zone increases runoff. Run-off increases erosion and the transportation of pollutants. Removal of vegetation in these areas also decreases filtration of these pollutants (Hellmund and Smith 2006). Hence, greenway trails protect permeable land surface and slow erosion and sedimentation and provide a host of positive ecological services.

Although many greenway trails are constructed with non-permeable surfaces, they are relatively low impact compared to major developments such as commercial or housing developments. However, any development and increased human presence leads to degradation of the natural environment. In a study by Lindsey (2003), the author showed that every ecosystem adjacent to a greenway trail in Indianapolis, IN showed greater degradation relative to comparative natural systems.

Limitations and Uncertainties

When using geospatial datasets, there are many limitations and uncertainties that must be recognized. Geospatial data products are costly and time-consuming to produce, and they are often difficult to obtain free of charge. The datasets and products that are cost-free are sometimes dated. Additionally, products from different suppliers may vary in quality.

The LiDAR data for this study was obtained from the Missouri Spatial Data Information Service (MSDIS). The metadata sheet provided by MSDIS provided important information regarding the source of the data. The metadata shows that The Sanborn Map Company performed the LiDAR data collection January 27-28, 2011. The Sanborn Map Company also processed the data. The mission and processing were funded by the United States Geological

Survey (USGS). This LiDAR data was produced for the USGS, and federal standards were followed when processing the data.

However, the specific techniques for processing the data are not included in the USGS metadata. As this data was processed primarily for the purpose of producing DEMs, some above ground features were removed during the process. It is unclear from referencing the metadata if the first return LiDAR points are affected by this removal or if removal is only applied to the DEM products.

If some of the first return LiDAR points are missing from the product used in this study, it could affect accuracy of the DSMs created for the viewshed analysis. However, a visual inspection of the first return LiDAR point cloud shows that many above ground features are present. It should also be noted that the vertical accuracy of the LiDAR data is 5.9 inches Root Mean Square Error (RMSE) for bare earth and 10.6 inches RMSE for vegetation.

The multispectral satellite imagery used to calculate the NDVI for this study was obtained from Digital Globe by way of an imagery grant provided by the Digital Globe Foundation. The imagery grant was crucial because the price would have made this study cost prohibitive. The high resolution provided by this satellite's sensor allowed making calculations at roughly the same spatial resolution as the LiDAR viewshed. The imagery was captured by the satellite on September 15, 2017.

Due to the strict requirements for the spatial resolution, study area, and reliance on a grant to secure the imagery, the image acquired is not ideal. The primary concern with the image is there are clouds present. When calculating NDVI from the image, the clouds return an extremely low NDVI measure. Therefore, where there are clouds present over the viewsheds, the NDVI reading will be inaccurate. Although the clouds are mostly evenly distributed between the two viewsheds, the Wilson's Creek Route appears to be slightly more affected by the cloud cover.

The land use data for this research was provided by Greene County, MO. The parcel data is from the year 2012, so these datasets were produced in different years with as much as six years between data sets. This temporal variance could affect the accuracy of this study. Despite these drawbacks, and although the NDVI data is significantly older than the other datasets, there has been little development in the study area over that time. This makes a drastic change in vegetation there unlikely over that time period, which provides some confidence in the validity of our data.

Besides the limitations and uncertainties in the data, some differences between this study and the Lindsey et al. (2008) should be noted. First, the variables analyzed in this study are not the only variables identified in Lindsey et al. (2008) to be associated with increased trail use. Lindsey et al. (2008) also found positive and negative associations with several other variables including railroad crossings, percent of path unpaved, trail intersections, and trail art density. The railroad crossings, percent path unpaved, and trail intersections were not included in this study, because the proposed routes do not contain any of these features or characteristics. The trail amenity density and trail art density variables were not addressed here because, as not-yet-existent trails, these variables are not present to measure. However, once the trail is constructed, the findings from Lindsey et al (2008) regarding these variables should be incorporated into the management of the trail.

Another major difference between this study and Lindsey et al. (2008) is the NDVI comparison. Lindsey et al. (2008) measured the difference between NDVI in the trail viewshed and compared it to the adjacent neighborhood that had access to the greenway trail. As neither route proposed here has an exclusive neighborhood access point, the NDVI within the trail viewsheds were compared against each other.

Finally, it is impossible to ensure that the methods of this study were conducted exactly as in Lindsey et al. (2008). GIS and remote sensing software and techniques vary and have evolved significantly over the last decade. Lindsey et al. (2008) provided few details on the data processing methods used in their study. Therefore, it is possible that there is some discrepancy between the methods used in Lindsey et al. (2008) and those used here.

Recent Planning Developments

In the time since this study began, a consulting firm has been tasked with evaluating future greenway trail development in the area. Alta Planning + Design consultants produced a report titled "Bicycle and Pedestrian Trail Investment Study" and delivered it to the OTO in October 2017 (Ozarks Transportation Organization 2017).

In this OTO document, there is a section titled "preferred alignments." The section identifies priority trail developments and preferred alignments for trails based on several criteria. Alta analyzed the extension to Wilson's Creek Greenway trail in this section. The consultants determined a route similar to the Republic High Route, as it is termed in this study, to be the best route for connecting the existing Wilson's Creek Greenway trail and Wilson's Creek National Battlefield (Ozarks Transportation Organization 2018).

Although the OTO document has established the Republic High Route as the desired alignment, no construction is planned at this time. As there are several organizations involved in the planning and construction of this trail, it is possible that changes to this plan could be made in the future.

Conclusions

This thesis provides geographers, planners, and researchers with a case study demonstrating how to apply design characteristics to a proposed greenway trail project. This applied study adds weight to the theoretical findings of previous studies. Planners and greenway promoters can use this information to conduct their own analyses and understand the uncertainties and limitations of such an analysis. It is hoped that doing so will drive greenway trail development practices in strategically-focused and empirical ways.

The remote sensing and GIS techniques used in this study have been utilized by government entities and industries for a long time to inform decision making. Yet, it is only within the last decade that researchers began applying them to greenway trail planning. More research is needed to further confirm the relationship between design characteristics and trail use. However, these tools are none-the-less powerful and practical, potentially saving greenway trail planners time and money by performing significant analysis remotely.

As with any community development project, citizens must be included in the planning process. This research does not detract from the importance of community outreach and hands-on approaches to planning. Instead, this research demonstrates the effectiveness of tools that help planners provide their communities with the most objective and thorough information. This allows citizens attending planning meetings to make decisions and provide feedback based on empirical and objective information.

Over the coming years, technology will play an increasingly important role in planning. As the movement toward smarter and more sustainable cities and communities progresses, planners should embrace technological advancements whenever possible. These technologies and techniques are already being used to evaluate and improve current systems. This thesis presents a model for applying them to future developments.

Researchers should continue to evaluate the underlying statistical models connecting these design characteristics to trail use, while also looking for ways to implement these findings in practical ways. This will lead to the development of best practices for these analyses. More bicycle traffic and trail use data is needed to push sustainable transportation and green design forward.

Although this thesis provides valuable insights and information to local planners, development in the Wilson's Creek National Battlefield area is ongoing. Hence, in the future, the chosen paths may no longer represent the best possible route for each trail. However, these paths should serve as a good starting point and are used primarily as a reference for the remote sensed measurements. Additionally, since the publication of the initial background research conducted for this study, some planning decisions for this project have been further evaluated.

The OTO's preferred alignments study determined that the best route for the trail would generally follow the path of the Republic High Route. However, the authors of the study, Alta Planning + Design, used a different set of criteria than the remotely sensed measurements evaluated in this study to determine the best route for the trail. For example, the document focuses on the generous right-of-way along both Republic Road and Highway ZZ. Furthermore, Alta points out that 46 percent of property fronting Highway ZZ is owned by either the National Park Service or the Republic school district (Ozarks Transportation Organization 2018). This should give even more options for trail construction along the corridor.

Finally, as mentioned in this study, the Ozark Greenway's idea of converting Highway ZZ into "Wilson's Creek Boulevard" is also discussed in the OTO document. This corridor conversion concept has several advantages. First, the plan for adding historically themed elements along the trail could also incorporate improved wayfinding or information kiosks (Ozarks Transportation Organization 2018). Second, connecting Wilson's Creek National Battlefield to Republic High School with a greenway trail would allow for walking field trips to the battlefield and other outdoor classroom experiences. Third, connecting the high school to the expanding greenway network in the area allows for non-motorized commuting options from adjacent neighborhoods to Republic High School. Connecting the greater greenway trail system to the City of Republic also works towards Ozark Greenway's goals of developing a truly regional trail system.

Although the remotely sensed measurements in this study were not drastically different for the two proposed routes, the Republic High Route did have a significantly higher result for viewshed openness. The Republic High Route also had significantly lower average slope than the Wilson's Creek Route. Hence, the only results from the remotely sensed measurements that showed significant difference between the two routes were in favor of the Republic High Route.

Provided with this knowledge, Ozark Greenways, OTO, and Greene County should have greater confidence that the Republic High Route is a good choice for locating a greenway trail as laid out in the preferred alignments document created by Alta. Although the analysis did not result in measurements that clearly differentiate the two routes, this study demonstrates that introducing additional evaluation criteria can help planners make the tough decisions required when planning a new greenway trail.

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