USING GEOSPATIAL TECHNOLOGIES

TO LOCATE TRAVEL NETWORKS:

A CASE STUDY IN FLAGSTAFF, ARIZONA

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ABSTRACT

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CORRYN LEE SMITH

Open space properties are important to communities since they provide passive recreation activities such as hiking, mountain biking, photography opportunities, and wildlife viewing. The City of Flagstaff's Observatory Mesa Natural Area is a designated open space property comprised of 2,251 acres. To develop comprehensive land management plans and projects for the Observatory Mesa Natural Area, a Global Positioning System (GPS) unit and geographic information system (GIS) technologies were used to collect ground data on the existing travel networks. During this ground data collection, many unauthorized, user-created trails were found within the property. Since roads and trails can be seen on high-resolution aerial imagery, an alternative geospatial technology, remote sensing, was used to see if travel networks could be determined without being in the field. To ensure credibility for these methods, the same procedures were performed on Lowell Observatory's Section 17 parcel, which neighbors the Observatory Mesa Natural Area. After performing a supervised classification with a maximum-likelihood classifier, the Observatory Mesa Natural Area was classified with a 72% accuracy and Lowell Observatory with a 92% accuracy. Nevertheless, many pixels were over-classified as a travel network due to the similarities of the ground vegetation. As a result, GPS and GIS are a better method of collecting data when compared to remote sensing. However, both methods can be used together to locate travel networks within open space properties.

Keywords: *Open Space, Travel Networks, GPS, GIS, Remote Sensing, Land Management*

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CHAPTER ONE

Introduction

Geospatial technologies are commonly used tools that allow users to collect, maintain, manipulate, and analyze various types of data in several disciplines such as planning, recreation, and land management. Geospatial technologies consist of four key subjects: geographic information systems (GIS), remote sensing, global position satellites (GPS), and information technology. These four factors are the backbone to the geospatial realm. Together, users can create maps, analyze images, and verify their results with accuracy assessments (American Association for the Advancement of Science, 2015).

For this thesis, geospatial technologies were used to examine the road and trail network within the City of Flagstaff's Observatory Mesa Natural Area (Sections 6, 8, 12, 18) and Lowell Observatory's property (Section 17). Planners and land managers can use geospatial technologies to locate the "where" in their data collection. For example, land managers could use geospatial technologies to locate where boundary encroachment occurs, create a vegetation database for the property, and propose restoration based on spatial data. Land managers can use remote sensing techniques to discover land cover change over time or use GIS tools to find land prone to floods or other natural disasters (Birch & Wachter, 2015). In return, the collected geospatial data can be analyzed and created into a comprehensive land management plan to protect the land, wildlife, and the public. According to PricewaterhouseCoopers, geospatial technologies are "an indispensable tool for visualize [ation]" (PricewaterhouseCoopers, 2014). Geospatial technologies give users the ability to create a meaningful map for themselves or for their audience. Maps can be a powerful tool to express a message in a meaningful way. Maps

can provide clarity, effective learning concepts, and enjoyment (Vitulli, Giles, & Shaw, 2014).
Therefore, maps could be an excellent tool to display data, problems, and solutions for land management.

The area of interest for this research is in Flagstaff, Arizona. Specially, the study areas include the entire Observatory Mesa Natural Area and Section 17 of Lowell Observatory (see Figure 1). Out of the few legally-designated open spaces areas in Flagstaff, Observatory Mesa Natural Area sparked an interest because of its size and recreational features. The Observatory Mesa Natural Area consists of 2,251 acres of city-owned parcels between Forest Service land and Lowell Observatory private property. The City of Flagstaff obtained Observatory Mesa Natural Area in December 2013 using funds from a 2004 voter approved bond and a grant from the Arizona State Parks. Since Observatory Mesa Natural Area is nearly 2,300 acres, the City of Flagstaff's Sustainability Section Open Space Program wanted information on the features that existed on the property before embarking on the management planning process. Likewise, the Open Space Program was interested in how many miles of trails and roads exist on the Observatory Mesa Natural Area. According to Flagstaff's Urban Trails System (FUTS), Observatory Mesa Natural Area has three official trails. Nevertheless, after examining the area on foot with a GPS unit, a plethora of unauthorized, user created trails and roads exist within Observatory Mesa Natural Area. Many of these unauthorized roads resemble old roadbeds that might have been used to navigate through the property before the City of Flagstaff bought the land. In addition, some of the trails have braids due to erosion and excessive use. The City of Flagstaff wanted a thorough inventory of all the roads and trails so they could create a management plan and trail system plan for the Observatory Mesa Natural Area (City of Flagstaff, 2016).

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Figure 1: Study sections include Observatory Mesa Natural Area and Lowell Observatory Section 17

1.1 Objectives

As stated in the Introduction, the City of Flagstaff wanted an inventory of various infrastructure features, such as travel networks, that are currently on Observatory Mesa Natural Area. Geospatial technologies, such as GIS and GPS, were used to collect data on Observatory Mesa Natural Area and to produce maps that can be used for future land management plans and projects. The first step of this data collection process took approximately 180 hours. During this data collection process, the idea of using remote sensing techniques to find travel networks from high-resolution imagery surfaced since the trails and roads are visible at one-meter resolution. Four band, one-meter resolution National Agriculture Imagery Program (NAIP) aerial imagery and remote sensing techniques will be used to detect travel networks within Observatory Mesa Natural Area. To see if these methods could be duplicated, the procedures will be reversed and repeated on Lowell Observatory's parcel, which neighbors the City of Flagstaff's property. The remote sensing process will be the first step on Lowell Observatory's parcel, followed by ground data collection. The collected travel networks from the ground data collection and remote sensing techniques will be compared to an authorized travel network map (shown in Figure 2). The overall research objective is to determine which geospatial technologies are most efficient to measure and monitor informal trail networks and how they can enhance land management planning efforts.

Figure 2: Authorized travel networks within study area. Source: Author

1.2 Research Questions

To answer this research objective, the following research questions are addressed in this

thesis:

1.) What geospatial technology method is the most time and cost efficient for

mapping locations of formal and informal travel networks for land

management plans (ground data collection with GPS and GIS or remote

sensing techniques)?

2.) How accurate are the results of the remote sensing techniques when compared

to ground data collection with GPS and GIS?

3.) Can the exact methods used for the Observatory Mesa Natural Area be

duplicated, but in reverse order, to determine travel networks within Lowell

Observatory's property?

4.) How can land managers, such as the City of Flagstaff and Lowell

Observatory, use these methods and results for their land management plans?

1.3 Hypotheses

The following hypotheses are tested within this thesis:

1.) Remote sensing will be a time and cost efficient method of extracting travel

networks when compared to ground data collection.

2.) The remote sensing results should yield at least 70% accuracy.

3.) Land managers should consider remote sensing techniques over ground data

collection especially with larger areas or when there are resource constraints.

1.4 Theoretical Framework

GPS, GIS, and remote sensing all have their advantages and disadvantages. With GIS and GPS, the user can survey the area of interest and collect the data that they observe. The user can use a GPS unit to obtain the specific location of the data that is being collected. In addition, GPS units can also hold additional information for the data at a specific location. GPS devices come in all shapes and sizes. Traditionally, GPS units are their own device, however, devices such as mobile phones and tablets can be used for GPS data collection. The most significant advantage of collecting ground data is the accuracy since the collector is recording data at specific location. However, errors can occur when users are in the field with a GPS unit. If the user is collecting data in a dense forest, the accuracy from the GPS unit could be affected since the radio signals from the satellites cannot penetrate thick vegetation (Letham, 1998 p.6). Likewise, overcast conditions can skew the signals as well. Collecting GPS data during Flagstaff's summer can be dangerous due to monsoon season. In other areas, intense heat, deep snow, and other implications can delay GPS data collection. Nevertheless, collecting GPS data provides the best accuracy since the user is in the field. However, the task can be time consuming, physically demanding, and unpredictable due to weather and/or technology.

Remote sensing requires the user to perform most of the analysis on a computer. Here, the user collects information from aerial and satellite images to find land cover classifications and spatial patterns. According to Congalton and Green (1999), remote sensing is "usually less expensive and faster than creating maps from information collected on the ground". If the user is familiar with its techniques, the user could obtain a remotely sensed image in a short amount of time. In addition, there are different types of imagery available for remote sensing analysis. Some of the free products that are available on USGS's Earth Explorer include Landsat, MODIS,

and NAIP (U.S. Geological Survey, 2016). These products are free to the public because they have either a high spatial resolution (such as 1-meter pixels) or a high spectral resolution (the number of bands in an image). Products that have both high spectral and spatial resolution are available, but need to be purchased. For this thesis, one-meter NAIP imagery will be used to find the travel networks on the Observatory Mesa. NAIP, the National Agriculture Imagery Program, is administered by USDA's Farm Service Agency (USDA, 2017). NAIP imagery is flown to obtain one-meter sized pixels. In addition, NAIP spectral resolution contains four bands: Blue (0.48 μm), Green (0.56 μm), Red (0.66 μm), and Near Infrared (0.83 μm). Although the high resolution can display details such as individual trees, shadows could be an issue when trying to categorize land cover classes. Since remote sensing cannot penetrate tree coverage, it may be difficult to find land cover classes in dense forest patches. Likewise, remote sensing software and extension licenses can be expensive and might not be available for students.

When examining the two geospatial methods, one can see the advantages and disadvantages each may have. Moreover, users can integrate both methods into their analysis to enhance their products. According to Campbell and Wynne (2011), both remote sensing and geographic information systems can be put together "into a common analytical framework" which can enrich the geospatial data. Topics such as urban infrastructure, emergency response, community planning, crime monitoring and analysis, real estate services, floodplain mapping, and precision farming are a few examples that use remote sensing and GIS enhance their final products.

The purpose of this thesis will examine both geospatial methods and discover any advantages and disadvantages the methods might have. Additionally, this thesis will review the results to determine what geospatial method is the most efficient for finding travel networks, the

accuracy of the remote sensing techniques, if the methods used for the Observatory Mesa Natural Area work for the Lowell Observatory property, and how land managers can use the findings for their own comprehensive land management planning efforts. Ultimately, using remote sensing, GIS, and GPS should provide an enhanced geospatial dataset of Observatory Mesa Natural Area and Lowell Observatory that could be used for future land management plans.

CHAPTER TWO

Literature Review

2.1 Open Space

According to the United States Environmental Protection Agency, locally established open space strategies "help communities protect their environment, improve quality of life, and preserve critical elements of the local heritage, culture, and economy" (USEPA, 2016). An open space is a piece of land that contains minimal infrastructure and will be protected from future development (USEPA, 2016). Throughout the literature, many sources claim that parks and open spaces are used interchangeably. However, the two terms could have different definitions. According to Healthy Active by Design (2017), parks can support active and passive recreation. Active recreation supports non-green spaces such as basketball and tennis courts, while passive recreations focus on green spaces such as lawns, trees, picnic areas, and walking trails. Open spaces are important to communities since they give individuals a place to exercise, relax, and enjoy the environment. Within this section, benefits of open spaces and various case studies will be examined to support the importance open spaces within the built environment.

Smart Growth America (2016) states that open spaces are used to protect environmental services such as drinking water sources, water and air quality protection, and critical wildlife habitat. They encourage municipalities to perform an inventory to see what natural land and open spaces they have so they can protect their most vulnerable areas. Water and air are important to the natural and built environment. If municipalities do not protect these resources, wildlife and human lives could be at risk. In conjunction with the Clean Water Act 1972 and Clean Air Act 1990, municipalities can improve the quality of the water and air by protecting current vegetation or by planting new vegetation. By adding and maintaining vegetation in places

of high and low density, one may see a positive impact on air quality, water quality, storm water management, and quality of life (USEPA, 2015). Additionally, trees and other vegetation can decrease greenhouse gas emissions because they can absorb carbon dioxide, sulfur dioxide, and carbon monoxide. According to Evans (2001), a healthy tree can hold around thirteen pounds of carbon each year, and an acre of trees can store approximately 2.6 tons of carbon dioxide. Trees and vegetation can also prevent soil erosion and filter storm water before it enters the aquifers and other ground water sources. Lastly, trees and other vegetation can improve quality of life since they can enhance aesthetics, provide wildlife habitat, and could reduce noise (EPA, 2015). Trees and vegetation can enrich a place, such as open space, by providing satisfying aromas, colorful atmospheres, and acting as a boundary to deliver "privacy, solitude, and security" (Evans, 2001). Overall, trees and vegetation provide open spaces an opportunity to improve water, air, and quality of life.

In addition, open space properties can provide valuable economic, health, and environmental benefits but many cities seem to lack in the open space areas (City Parks Alliance, 2016). Open spaces can provide economic benefits to the community since property values are greater for those properties neighboring an open space (City Parks Alliance, 2016). In addition to positive effects on nearby property values, open spaces may "provide fiscal benefits to municipal governments" (American Trails, 2010). American Trails (2010) states that many communities across the United States have elected to purchase parks and open space land instead of using the said land for residential development. The main reason behind this movement is that the existing community members could have a higher tax burden if new homes were built on the land. Lastly, residential development could result in noise, pollution, traffic congestion, and even "changes in the community character". On the other hand, parks and open spaces can

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provide the complete opposite effects such as outdoor white noise, opportunities for multi-modal transportation, and overall stable mental health (American Trails, 2010 and Healthy Spaces & Places, 2009).

One case study that examined urban growth, health, and open spaces occurred in Delaware County, Ohio. The study stated that Delaware County was growing, and because of this growth, many of the streams and rivers showed a rise in water levels because of the increase in impervious surfaces associated with development. In addition to the water levels, the air quality was poor since Delaware County experienced a lot of traffic congestion. The new development encouraged individuals to drive their car from point to point, which meant more people would be on the roads, and therefore, increased emissions. Since most people use their car for transportation, previous studies have found connections between land use patterns, modes of transportation, and obesity. In fact, Delaware County General Health District surveyed 1,067 adults and concluded that 39% were overweight and 18% were obese. Based on the poor water and air quality, traffic congestion, and unhealthy lifestyles, the study surveyed 65 adults from the initial survey and asked why they like living in Delaware County and what the biggest problems Delaware County currently faces are. The same study surveyed an additional 500 high school seniors and concluded that "preserving recreation and open space, preventing littering, improving environmental education, and addressing surface water quality" are top priorities for Delaware County (Roof & Sutherland, 2008). Delaware County developed a smart growth plan that focused on infill development, community renovation, and increase sustainable transportation options. These elements would help build the new greenway concept for the County. Overall, the new smart growth plan would have greenways that connect neighborhoods, parks, wildlife refuges, and protected lands. Public process involved the community in

identifying trails for the smart growth plan. The Preservation Parks of Delaware County

received a park levy for additional funding due to the results of this study. The additional

funding will give the Preservation Parks aid to build additional parks and trails throughout

Delaware County (Roof & Sutherland, 2008).

Like Delaware County, the Carolinas created a system of multiuse trails for people to

hike and/or bike on. The Carolina Thread Trail is designed to connect "greenways, parks,

natural preserves, historical sites, shopping centers, and tourist attractions" (Crouch, 2009). The

trail will deliver an area for the investigation of nature, history, and science while providing open

space in an area that is rapidly developing. In 2005, a local community foundation, the

Foundation for the Carolinas, contacted the regional leaders to determine specific elements that

can enhance their environment. After concluding that open space preservation was the most

needed element to better the neighborhood, the Foundation for the Carolinas gave $2 million to

two land preservations groups: the Catawba Lands Conservancy and the Trust for Public Land.

With further fundraising from both private and public entities, the project had enough funds to go

on with the project. The Thread Trail organizers went to fifteen counties and asked officials

what it would take for them to participate in the project. By doing so, the foundation assisted

each county to create their "own greenway master plan" (Crouch, 2009). Residents helped

inform the master plan process where they should put the trails and surfacing. Most counties

were willing to participate in the trail project. However, counties in the rural part of the

Carolinas were hesitate since they did not want people trespassing on private property. The rural

county residents stated that they did not want people walking up to livestock, and they were

afraid people would steal their farming equipment or produce. Overall, greenways attract

tourists, business, and home developers. In fact, houses that are along a greenway or near an

open space spend less time on the market when compared to those that are not along a trail system. The objective of the Carolina Thread Trail is to get people outside and enjoy the open space. Not only does the greenway improve air and water quality, they can boost the health of the community (Crouch, 2009).

With further investigation after reading Crouch's (2009) article, one can see that the Carolina's take pride in their Thread Trail system. The Carolina Thread Trail website is modern and up to date. Locals and tourists can use the website to see the different trail sections, a full overview map, upcoming events on the trails, and benefits that the trail system brings to the community. Individuals who may be unfamiliar with open space can view how trail systems provide health and environmental benefits and positive impacts on the economy. As stated on the Carolina Thread Trail website, having designated open space encourages individuals to go outside and interact with nature and each other. As the community uses the open space, the individuals can receive a multitude of physical and psychological health benefits. The website states that open spaces can relieve stress and anxiety and be used as therapy for those with Attention Deficit Disorder. Furthermore, the Thread Trail is an opportunity to help bring communities together, improve the social health of the communities, promote regional thinking, and reconnect children with nature. The Carolina Thread Trail is an excellent example of how open space including greenways, can enrich the economy, environment, and health of the communities (Carolina Thread Trail, 2016).

Besides greenways and trails, open space also includes parks and open areas that encourage people to be physically active by walking, cycling, jogging, skating, or skiing. One study by Takemi et al. (2015) looks at how open spaces and recreational walking are related. For this study, Takemi et al. (2015) surveyed park-goers to determine if they can walk to a public

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open space from their house or work. Surprisingly, 63% said that they do not walk to the open space. In addition, the survey asked how many public open spaces are within 1.6 kilometers from their residence. They were also asked what features they like to see at the open spaces. The survey found the average participant had approximately four open space areas within the 1.6-kilometer buffer. Likewise, the most common element that people look for in an open space is the ability to have their dog off leash. Participates said that they are most likely to use a public open space for recreational walking if they could have their dog off leash. They are also interested in having some infrastructure, such as public restrooms, cafes, and other dog-related facilities such as water fountains, waste bags, and disposal stations. In the discussion section of the study, Takemi et al. (2015) revealed that the study area in Australia is a very dog friendly community. In fact, 40% of the community owns at least one dog. Therefore, public open spaces that are dog friendly are more likely to be used than those that are not. In conclusion, they found that constructing one high-quality open space area would be more effective for recreational walking than having open spaces of lower quality (Takemi et al., 2015).

As one can see through the literature by Takemi et al. (2015), Crouch (2009), and Roof and Sutherland (2008), that promoting recreation is a common theme in open spaces. In the United States, one out of three adults are obese, and 85% of adults use a car to get their work (CDC, 2015; Chase, 2010). Adding trail systems, parks, and greenways to American cities is an important step to encourage individuals to be healthy. Though one may think parks and open spaces are more prevalent in suburban neighborhoods, open spaces exist in the large American cities such as Chicago, St. Louis, Memphis, and Atlanta. In Knack's article *Parks in Tough Times* (2009), Knack explains how cities with tight budgets can still obtain the open spaces that they want for their community. One way to keep costs down is with "low-maintenance

landscaping" (Knack, 2009). With this technique, the city allows vegetation to grow and achieve its natural state. By keeping the vegetation natural, the city can spend less money on maintenance such as mowing. Additionally, planting natural vegetation that is suitable for the terrain and climate of the city can also reduce water bills for the city. Knack also explains that open spaces should "acknowledge demographic shifts" (Knack, 2009). When one imagines parks, they might immediately think of playgrounds and children. However, parks and open spaces should cater to all demographics. Instead of spending money on playground equipment, open spaces focus on the natural environment to provide activities such as wildlife viewing, photography, walking, and mountain biking. Open spaces can be utilized by adults too. In addition, parks can provide a space for community dance lessons or arts and crafts sessions. In Knack's article (2009), she talks about Peter Harnik, one of the cofounders of the Rails to Trails Conservancy. Harnik stated that "many cities have wonderful traditional parks that are underused. Adding activities could be a way to revive them" (Knack, 2009).

Shelby Farms Park Conservancy, a dedicated open space in Memphis, Tennessee, contains 4,500 acres of green space and almost seven miles of urban trails. Shelby Farms Park Conservancy is an excellent open space of those who live in Memphis and want to get away from the city. Shelby Farms has been constructing their new Heart of the Park Enhancement that will add restroom facilities, a new visitor's center, an event and café center, and a restored wetland. Visitors can keep up to date with the construction on the Shelby Farms Park's website. Shelby Farms engages the public by displaying a full calendar of upcoming events on their website. These events include walking club events, a dog festival, BMX meet up, mobile farmers market, and stroller walking events. Per the Office of Sustainability for the Memphis and Shelby County Government, the necessity of green space is important to their community

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since it enhances the economy, environment, and overall health (Shelby Farms Park, 2016). Adams, Executive Director of the Office of Sustainability, stated that people who have access to parks will likely exercise more. Additionally, connecting with the natural world through open spaces improves psychological health. Lastly, neighborhoods that are adjacent to open spaces have shown a decrease in crime (Adams, 2014).

2.1.1 Flagstaff, Arizona

Flagstaff, Arizona, a smaller city when compared to Memphis, takes pride in its outdoor recreation opportunities. The City of Flagstaff Parks and Recreation department currently manage eighteen neighborhood parks, three community parks, and three regional parks. As defined by Healthy Active by Design (2017), parks can support passive and active recreation activities such as ramadas, skate tracks, and racquetball courts. However, open spaces support only passive recreation and promote using the already existing land for activities and entertainment. The City of Flagstaff's Open Space Program has been receiving more attention after two open space properties were bought in 2012. The City of Flagstaff purchased Picture Canyon Natural and Cultural Preserve and Observatory Mesa Natural Area with funds from a voter approved open space bond in 2004 and a Growing Smarter Grant from the Arizona State Parks. Picture Canyon Natural and Cultural Preserve's 477.8 acres of land was purchased for $4.778 million. The City of Flagstaff is promoting Picture Canyon as a resource for the community to learn more about the geology, archaeology, and ecology while partaking in outdoor recreation. Picture Canyon Natural and Cultural Preserve contains two trails and a section of the Arizona Trail. The community can experience the natural environment while also discovering historical petroglyphs.

In addition to Picture Canyon Natural and Cultural Preserve, the City of Flagstaff also used the bond and 2013 Growing Smarter grant money to acquire Observatory Mesa Natural Area, a 2,251-acre section of land that is home to wildlife and natural vegetation. Observatory Mesa has three official trails. However, the City of Flagstaff plan to develop a comprehensive trail system plan and potentially install additional infrastructure such as a restroom facility, benches, a parking lot off Forest Service Road 515, and picnic tables.

When referring to the literature on open spaces, one could see the benefits that the Observatory Mesa Natural Area may bring to the City of Flagstaff. Open spaces are not only bringing value to the surrounding properties, but it also provides a natural outlet for members of the community. The Observatory Mesa Natural Area is a designated open space property and will remain protected no matter how much development occurs in the City of Flagstaff.

2.2 Travel Networks

For this thesis, a travel network is defined as a system of trails, roads, and primitive roads, which states that a travel network is designed for both motorized and nonmotorized use (United States Bureau of Land Management, 2006, p.28). According to the United States Forest Service, a trail "is a narrow highway over which a pack animal can travel with safety during the usual period when the need for a highway exists" (United States Forest Service, 1915, p. 8). Likewise, the National Park Service defines a trail as a "linear corridor, on land or water, with protected status and public access for recreation or transportation" and "can be used to preserve open space" (National Park Service, 1990, p.2). Besides trails, roads and primitive roads are also defined in a travel network. A majority of the Forest Service roads were built over fifty years ago for the purpose of harvesting timber and removing logs (USDA Forest Service, 2002). Today, less than twenty percent of the forest roads are fully maintained, and projections state that

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the entire Forest Service road network will be in "overall poor condition by 2020" (USDA Forest Service, 2002). The overall difference between a road and a primitive road is the type of vehicle that can drive on that road. Primitive roads tend to be high-clearance and 4x4 routes (United States Bureau of Land Management, 2006, p. 9). Though Forest Service roads might not be maintained, it is possible that they could become primitive roads due to frequent use and erosion. Nevertheless, Forest Service roads may be used as corridors by joggers, mountain bikers, and horseback riders, especially if the roads connect near a designed trail system. Therefore, trails and dirt roads are forms of travel networks that will be observed in this thesis.

Trails serve as a form of transportation whether they are in an urban environment or in the wilderness. Trails in open space areas can act as a corridor between places of interest and connect individuals to additional travel networks. Since open spaces rely on the natural environment, trails and dirt roads provide appropriate passageways for individuals to jog, hike, or mountain bike on. Nevertheless, it is important for land managers to have an established trail system to protect sensitive wildlife and vegetation as well as the users (California State Parks, 2009).

User created trails, whether for mountain biking or hiking, can disturb the vegetation, soils, and animal habitat (California State Parks, 2009). According to JI Safety Health & Environment (JISHE, 2017), there are seven reasons why social trails can be problematic for landowners and managers. 1) It may be illegal to alter or construct on land that are owned by others without proper consent. 2) Social trails could have a negative effect on the property. Social trails might alter the land drainage patterns or cause damage to vegetation. 3) Social trails could damage habitats and disturb wildlife. 4) Social trails could damage cultural or archaeology sites. 5) Creation of social trails can disrupt land management techniques. 6) Social trails could

be hazardous to other patrons. 7) Individuals who create and use social trails could face physical risks.

In addition, Flink, Olka, & Searns (2001) emphasize that users can damage travel networks and the surrounding environment if the trail does not suit their wants or needs. Since mountain bikers yearn for steep grades, it is possible that they could damage the trail's natural surface for a thrilling ride. However, damaging the trail can cause erosion, which could lead to additional user created trails if the targeted corridor is too eroded (Flink, Olka, & Searns, 2001).

Nevertheless, organizations such as the International Mountain Bicycling Association (IMBA) and American Hiking Society (AHS) encourage trail users to have proper etiquette when utilizing travel networks. For example, the IMBA (2017) has six main rules of the trail for mountain bikers to take notice of. The first rule is to "Ride Open Trails." This rule tells the mountain bikers to respect all trail and roads. Mountain bikers should not trespass on private land, do not ride on paths that are closed, and always ask a land manager if clarification is needed. Likewise, the second rule is to "Leave No Trace." This rule explains that mountain bikers should be aware of the sensitivity of the environment that they may be in. This rule educates mountain bikers that muddy trails and roads can widen the trail and to not cut switchbacks. The IMBA stresses that users should "[stay] on existing trails and not [create] new ones". Moreover, the AHS has a hiking etiquette fact sheet for hikers. Most of the rules are for safety. However, the American Hiking Society also states the possibility of trail widening. Like the International Mountain Bicycling Association, the American Hiking Society tells hikers to walk through wet areas instead of going around puddles. By walking around puddles, the road or trail could widen. The American Hiking Society states that widening existing dirt paths is terrible of trail sustainability. Lastly, they emphasize that hikers should "help preserve the trail

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by staying on the trail" (AHS, 2013). Though users might be tempted to create a new trail, it is important for them to stay on designated travel networks for the sake of the sensitive environment and for their safety.

Whether a planner is creating a new comprehensive plan or a City Council member is interested in multi-modal funding, the initial step for any travel network management plan is to take an inventory of existing roads and trails (Flink, Olka, & Searns, 2001). According to Proudman and Rajala, trail assessments are power tools that can be used for planning trail maintenance and budgets, prioritizing projects, and act as a general guide for land managers (Proudman & Rajala, 1981, p.223). The inventory process should identify the condition of the travel networks, and if motorized vehicles are allowed. In addition, the inventory process should also take note of any unauthorized social trails that appear on the property (JI Safety Health & Environment, no date). Lastly, the inventory should also record the road or trail's usage type. Pedestrians paths tend to be six to eight feet wide, while mountain bikers favor narrow, single-track trails that might consist of "sharper grades and soft surfaces" (Flink, Olka, & Searns, 2001). Nevertheless, failure to assess travel networks can "result in more problems, expense, and ultimate frustration than any other aspect of trail work" (Birkby, 1996, p. 104). By creating a complete inventory, land managers can properly plan projects depending on the outcomes of the assessment.

After a thorough inventory, land managers can consider what actions need to be done, especially for unauthorized trails. According to the Forestry Commission England, land managers have four choices when it comes to handling social trails (Forestry Commission England, 2015). The first action land managers can take is to "adopt and inspect" the social trails (Forestry Commission England, 2015). If the social trail seems safe and receives many users,

land managers can adopt the trail and add it to their travel network map. Like established trails

and roads, any adopted path should be properly inspected to make sure it is safe for mountain

bikers and pedestrians. Secondly, the Forestry Commission England suggests that land mangers

could choose to "intervene and make safe (then tolerate and monitor to adopt) (Forestry

Commission England, 2015). This option would be suitable if the desired social trail wants to

continue to be used, but needs some assistance to ensure safety for the users. Third, land

managers can tolerate and monitor the social trail. Here, the social trail will stay as it is, and

users understand the risks they might encounter wither their own actions. Last, land managers

can resort to closing and removing the social trail (Forestry Commission England, 2015). This

option would be best if the unauthorized trail seems to dangerous and has negative effects on its

surrounding environment. Overall, unauthorized travel networks should be acknowledge after an

inventory, and land managers should decide if they want to adopt the social trails and roads,

perform trail maintenance to ensure safety, or close the trail all together.

2.3 Geographic Information Systems

Geographic Information Systems (GIS) consist of data and software that allows users to

collect, store, retrieve, transform, and display spatial data (Burrough, 1986, p.6). A GIS provides

the infrastructure for organizing and gathering spatial data, gives access to tools for analysis, and

provides features to create meaningful maps with the analyzed data (Wade & Sommer, 2006

p.90). Though the main objective of a GIS is to manage and analyze spatial data, it also aids as

an important decision maker for planners, engineers, and land managers (Lang, 1998, p.1). With

a GIS, users can find patterns and other relationships that were missed in earlier analysis.

Users can create their own spatial data using a GPS unit or by assigning points, lines, or

polygons a geographic location within a GIS (Wade & Sommer, 2006, p.196). In addition, users

can find spatial data on the internet for any specific project. A GIS allows the user to stack different layers on top of each other for an exhaustive analysis (Lang, 1998, p.4). By using different spatial layers, users can see problems and create solutions based on the shared geography (Lang, 1998, p.4). For example, farmers can use GIS to see what areas are suitable for crops based on water locations, soil type, and elevation. If the user has access to a GIS and the necessary spatial data, any project is possible.

Currently, there are several GIS software available, including QGIS, GRASS, MapWindow, and OpenMap are free to download and are open source (Kerski & Clark, 2012, p.241). This means that anyone who has a desire to use GIS can download a free program to use. However, other GIS software such as ESRI ArcGIS, Erdas ER Mapper, and MapInfo Pro require the user to purchase a license to use the software (Kerski & Clark, 2012, p.241). In addition, free and accessible spatial data layers can be downloaded from various data portals and clearinghouses. Kerski and Clark (2012) suggest exploring data portals such as the USGS National Map or the USDA Geospatial Data Gateway. If an individual is looking for smaller scale data, many states, counties, and city governments have raster and vector data available for the public (Kerski & Clark, 2012, p.180). Therefore, it is easy for users to access a GIS and publically available data for analysis and map creation without having to spend money (Balram & Dragicevic, 2006, p.110).

As the age of technology advances, software that was once only made for computers are now available for mobile devices. Mobile applications that support a GIS can record and display data in real-time (Balram & Dragicevic, 2006, p.325). Mobile applications such as MapIt, WolfGIS, and Maps 3D are free and can be downloaded on most smartphone devices (Hyeong, 2013). These mobile applications use Wi-Fi or cellular phone signals to connect to the server

and database (Balram & Dragicevic, 2006, p. 325). Like GIS software, some mobile

applications require a paid license in order to use. Collector for ArcGIS is a mobile application

that syncs to a paid ArcGIS account. The Collector app allows users to record and update data

while in the field or on the ArcGIS Online website. The Collector app can be used for any type

of data collection such as recording trees on a university campus, bicycle racks throughout a city,

or community artwork.

The ESRI Collector mobile application gives users access to collect field data without

owning a GPS unit. Likewise, the Collector app operates as a GIS since users can instantly

manipulate, edit, and store the data. Ian Lindsay of Purdue University gave a presentation of

how the Collector app was used in collecting archaeological data in Armenia (Lindsay, 2014).

First, Lindsay explained how a tablet and the Collector app can cost less than $1,000 while a

Trimble GPS device and other software such as ArcPad can cost more than $5,000. Within the

tablet-based mobile GIS methods, Lindsay had access to a built-in GPS with five meters

accuracy, a compass, network connection, and access to GIS apps such as Google Earth and

Collector for ArcGIS. Lindsay emphasizes that mobile GIS collection should be efficient,

collaborative, and affordable while in the field. While in Armenia, Lindsay states that aerial

imagery on the tablet allowed the users to perform a "virtual survey" to see what potential sites

they want to record and ground verify (Lindsay, 2014). Likewise, the Collector app can collect

data in an online or offline mode, which is important for areas where mobile network connection

might be scarce. Since the user can see their collected data on the table in real-time, the user can

quickly avoid redundancy and errors by fixing the data in the field. Lindsay mentioned that the

Collector app is compatible for Androids and iOS devices, which means that anyone with a

smartphone should be able to download the application on their device. Lastly, Lindsay

concluded that the Collector app is an affordable alternative for organizations and institutes with tight budgets. If they have access to a tablet or mobile device and an ESRI license, the Collector app is an efficient and affordable option for recording data (Lindsay, 2014).

As observed in the literature, Geographic Information Systems can be used to manage, edit, and store various types of data. Nevertheless, GIS is not only for computers, but can now be found in mobile applications for tablets and smartphone devices. Biologists, students, land managers, and recreationists can use GIS for data collection, analysis, and visualization. With the modern advance of technology, free, open source software is available for anyone who has a desire to use GIS. Likewise, many mobile applications are free on the smartphones and tablet devices and can be an affordable option when compared to a survey-grade GPS unit. In conclusion, geographic information systems serve as a digital toolbox that enhances projects due to its abilities to perform spatial analysis techniques, and therefore, becomes "one of the most powerful tools in planning and decision making" (Juppenlatz & Tian, 1996, p. 3).

2.4 Remote Sensing

Remote sensing is a geospatial technology that acquires information about areas or objects from analysis for data obtained by a device that is not does not interact with the areas or objects (Lillesand & Kiefer, 1999, p.1). The most commonly used device for remote sensing are satellites or aircrafts (Juppenlatz & Tian, 1996, p.12). Remote sensing satellites come in various spatial, spectral, and temporal resolution. Spatial resolution indicates the scale of the pixels within the imagery. For example, NAIP aerial imagery has a spatial resolution of one-meter. Therefore, one pixel in a NAIP image equals a one-meter-by-one-meter area on the ground. (Franklin, 2001, p.98). Landsat satellites have a spatial resolution of thirty meters, which states that one pixel equals thirty meters on the Earth's surface (Campbell & Wynne, 2011, p.173).

Spectral resolution indicates the "number and dimension of specific wavelength intervals in the electromagnetic spectrum to which a sensor is sensitive to" (Franklin, 2001, p.98). Landsat 8, for example, has a high spectral resolution since it has eleven bands, while INKONOS satellite has four bands (Campbell & Wynne, 2011, p.189). Lastly, temporal resolution refers to how frequent the satellite records data over the same location in its orbit (Franklin, 2001, p.99). MODIS satellite provides coverage every two days, while Landsat takes sixteen days to complete its world-wide coverage (Campbell & Wynne, 2011, p.624). Nevertheless, it is difficult to find a free imagery from a satellite that has a high spatial, spectral, and temporal resolution. Commercial satellites such as GeoEye-I, QuickBird, and WorldView-2 contain the desired spatial, spectral, and temporal resolution. However, users must pay to receive the imagery (Campbell & Wynne, 2011, p.189).

Remote sensing satellites tend to be favored for their high spectral resolution and frequent temporal resolution. With a high spectral resolution, users can observe the different band wavelengths using remote sensing software to find phenomena that the naked eye cannot see (Juppenlatz & Tian, 1996, p.12). For example, Landsat 4 and 5 each have seven bands that can be used for different remote sensing analysis. While the naked can see blue, green, and red, the thematic mapper sensor on Landsat 4 and 5 also have a near infrared, near-middle infrared, thermal infrared, and middle infrared bands (Juppenlatz & Tian, 1996, p.15). The near-infrared band can detect strong vegetation reflectance while near-middle infrared band can detect the reflectance of most rock surfaces (Juppenlatz & Tian, 1996, p.15). While these satellites give users the ability to perform various analysis with the high spectral resolution, this course spatial resolution cannot determine fine details on the earth. Landsat and MODIS satellites may have a course spatial resolution, but they have made it possible to look at environmental patterns on a

global scale (Campbell & Wynne, 2011, p. 614). Nevertheless, smaller study areas, such as Observatory Mesa Natural Area, will benefit from the amount of details that are visible in high spatial resolution imagery.

The National Agricultural Imagery Program (NAIP) gathers aerial imagery by flying aircrafts to record imagery at one-meter spatial resolution (Kerski & Clark, 2012, p.112). Because of the high spatial resolution, users can see details in the imagery. However, NAIP only has four bands: blue, green, red, and near infrared. As for temporal resolution, NAIP obtains imagery during agricultural growing seasons in the United States, which indicates that vegetation will be "leaf-on" (Campbell & Wynne, 2011, p.93). There is no exact time frame displayed on the USDA's website of how often NAIP imagery is collected. However, the USDA has an interactive map of the continental United States displaying the imagery collection coverage history for each state (United States Department of Agriculture, 2015). NAIP imagery can be purchased directly from the USDA or can be downloaded for free on websites such as the Texas Natural Resources Information System (TNRIS), the Virginia Information Technologies Agency (VITA), or USGS EarthExplorer (Kerski & Clark, 2012, p.113). Though NAIP aerial imagery is free to the public and contains high spatial resolution, restrictions regarding the lack of spectral resolution may occur during certain remote sensing techniques.

To find a suitable method for this thesis, several textbooks and journal articles were examined to see what has been done in the past. In the article "Urban Road Extraction from High-Resolution Optical Satellite Images" by Long and Zhao (2005), the authors used segmentation to determine roads in an urban setting. When using high-resolution imagery, there is a higher chance of having "noise" in your image—such noises include shadows, trees paralleling roadways, and even vehicles. In their study, Long and Zhao (2005) used a cleaning

and strengthening algorithm (MMCSA) to remove any geometric noise that was in their image. Next, they used the mean shift procedure to filter and segment the image. Once they had their segmented image, Long and Zhao (2005), used a convex hull algorithm to detect edges of the roads—this process eliminated the buildings and false roads that were located in the blocks. Though this article was in depth with the different algorithms that were used, the segmentation technique will be attempted on Observatory Mesa Natural Area.

In another article, Singh and Garg (2014) also state that high spatial resolution imagery can pick up details, like shadows, that might interfere with image classification. Singh and Garg (2014) use a fuzzy clustering algorithm to group the pixels into different classes, except for the roads. Fuzzy clustering is best used for mixed pixels (mixels) classification. When performing the segmentation, Signh and Garg (2014) explain how roads could be classified in multiple segments or misclassified because of shadows and features surrounding the road edges. To make the roads more fluid, the authors merged the roads. To merge, one must look at the distance from the different road segments as well as "the angle of orientation between the two adjacent fragments of road area" (Signh & Garg, 2014). When running remote sensing techniques on Observatory Mesa Natural Area, it is possible that shadows could interfere with the classification due to the high spatial resolution. Nevertheless, techniques used by Signh and Garg will be considered when running the image classification.

Since this project will be focused on the ENVI remote sensing software, Neubert and Herold (2008) explored the segmentation quality with ENVI software and BerkleyImgseg 0.54 software. In their article, the Feature Extraction Module 4.4, an extension in the ENVI software, was used to segment aerial imagery. Neubert and Herold (2008) stated that ability to see the process in real time was a huge advantage for the extension. Nevertheless, the results ended up

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being over segmented. Since there are license limitations at Northern Arizona University, the Feature Extraction Module might not be available to use in this study.

In Cleve et al (2008), object based classification was compared to an unsupervised classification on high spatial resolution imagery. The imagery that was used only consist of blue, green, and red bands. However, it had a spatial resolution of 15 cm. The objective of their study was to use both techniques to find built areas, surface vegetation, trees, and shadows. For the unsupervised classification, ISODATA in the Erdas Imagine 8.7 software was used to group clusters of pixels by a minimum spectral distance. With an unsupervised classification, the user tells the software how many classes they are looking for with a desired threshold. This process is not fully automated since the user needs to define and accept the classes that were created. Once an unsupervised classification is done, the same image is imported in the eCognition software for an object based classification. Within this classification, nearest neighbor and user-defined fuzzy classification was used to define the segmentation. After the two process were complete, Cleve et al (2008) discovered that the object based classification showed a higher accuracy when compared to the unsupervised classification. Though object based classification is the ideal method for this thesis, the object based classification license is not available for this project. Therefore, a thorough supervised classification will be used to extract trees, ground vegetation, and travel networks.

According to Campbell and Wynne (2011) supervised classification is the "process of using samples of known identity to classify pixels of unknown identity" (Campbell & Wynne, 2011, p. 349). To perform a supervised classification, the user defines pixels based on their land cover classification. Next, the remote sensing software takes in the information that is given to determine what other pixels fall within the defined land cover class. As a user selects supervised

classification as their remote sensing method, the user can tell the software what classifier to use, such as minimum-distance-to-means, parallelepiped, or maximum likelihood (Lillesand & Kiefer, 1999, p.538).

The minimum-distance-to-means classifier takes the mean value of each spectral band in the image. Next, an unknown pixel is classified based on the distance "between the value of the unknown pixel and each of the category means" (Lillesand & Kiefer, 1999, p.539). However, minimum-distance-to-means has a difficult time classifying land cover classes that are too similar, such as sand and urban (Lillesand & Kiefer, 1999, p.539). Therefore, this classifier will not be used for detecting travel networks on Observatory Mesa Natural Area and Lowell Observatory due to the similarities of travel networks and ground vegetation.

The parallelepiped classifier takes the range of the highest and lowest digital number value in each band and "appears as a rectangular area in a two-channel scatter diagram" (Lillesand & Kiefer, 1999, p.539). An unknown pixel is classified accordingly to the range. Though the parallelepiped classifier is very fast and efficient, it has difficulties determining where certain pixels might be classified as if they are too similar to other land cover classes. For example, if an unknown pixel falls in an overlap of two different ranges, it will be classified as "not sure" (Lillesand & Kiefer, 1999, p.539). For this thesis, the parallelepiped classifier will be used to see what the outcome may be. However, it might be difficult of the classifier to determine differences in ground vegetation and travel networks.

Lastly, Gaussian maximum likelihood classifier is another common classifier used in supervised classification. Unlike minimum-to-distance-means and parallelepiped, the maximum likelihood classifier looks at "variation that may be present within spectral categories" (Campbell & Wynne, 2011, p.359). This classifier relies on the training data to determine the estimated

means and variances of the different land cover classes, which are then used to determine the probabilities (Campbell & Wynne, 2011, p.360). The maximum likelihood classifier determines the class type of the pixels by their mean, average, and variability of brightness. Nevertheless, the maximum likelihood classification method used a large number of computations to classify each pixel (Lillesand & Kiefer, 1999, p.543). Therefore, this method might be slower to run. However, this method will be the prime choice for classifying trees, ground vegetation, and travel networks within Observatory Mesa Natural Area and Lowell Observatory.

2.5 Geospatial Technologies for Open Spaces and Travel Networks

As observed from the literature, geospatial technologies can enhance data collection and analysis for various types of industries such as land managers for open space properties. Land managers can benefit from geospatial technologies, especially if they want to perform an inventory of their property. By using a GPS unit, collected data will have coordinates attached for various types of spatial analysis and observations. Once data has been collected, land managers can use a GIS to store, manage, analyze, edit, and produce maps of the spatial data (Burrough, 1986, p.6). Nevertheless, land managers can also use remote sensing techniques, such as a supervised classification with a maximum-likelihood classifier, to identify certain data such as roads and trails without physically being in the field (Franklin, 2001, p.205). With remote sensing, land managers can use imagery and various band-wavelengths to find vegetation, barren earth, and water (Campbell & Wynne, 2011, p. 337). Moreover, land managers could use GIS, GPS, and remote sensing to find information about their property such as tree coverage, water tanks, and travel networks. When using these technologies, land managers can determine if they need to perform tree-thinning, close certain areas for restoration, or adopt unauthorized trails as a part of an official trail system (Forestry Commission England,

2015). Since the data collection on open space properties can be endless, this thesis will focus

on travel networks since the roads and trails within the study areas are commonly used by

community members. Methodology consisting of the three types of geospatial technologies will

be performed to see what method is the most efficient for land managers to use to find travel

networks within public open space properties.

CHAPTER THREE

Methods

Since this study is broken into two study areas (Observatory Mesa Natural Area and Lowell Observatory), the methods section will have two parts, one for each study area. Within both study areas, there are three components in which the methods were executed: (1) ground data collection, (2) remote sensing techniques, and (3) accuracy assessment. The ground data collection will review the study area, the techniques and devices used to collect data, and the means of storing the collected data. The remote sensing technique section will discuss the software and methods of how the tasks were carried out. For the remote sensing techniques, the three land cover classifications are trees, ground vegetation, and travel networks (Figures 3 &4). Lastly, the accuracy assessment will explain how the remote sensing techniques were assessed for accuracy. For this study, ground data collection, remote sensing techniques, and an accuracy assessment is the method order for the Observatory Mesa Natural Area. For Lowell Observatory, the first method will be the remote sensing process followed by the accuracy assessment and ground data collection.

Figure 3: Field example of ground vegetation. Source: Author

*Figure 4: **Left:** Tree land cover classification   **Right:** Travel network land cover classification*
Source: Author

3.1 Observatory Mesa

3.1.1 Study Area

The Observatory Mesa Natural Area was bought by the City of Flagstaff in December

2013. Before taking over ownership, the parcels that make up Observatory Mesa Natural Area

(Sections 12, 6, 8, & 18) were designated State Trust Land parcels owned by Arizona State Land

Department. Currently, the Arizona State Land Department oversees approximately 9.2 million

acres of State Trust land. The Federal Enabling Act granted the State Trust lands to the State of

Arizona when Arizona was declared the 48th state in 1912. As stated on the Arizona State Land

Department's website, "these lands are held in trust and managed for the sole purpose of

generating revenues for the 13 State Trust land beneficiaries, the largest of which is Arizona's K-12 education" (Arizona State Land Department).

The City of Flagstaff purchased the 2,251 acres of Observatory Mesa Natural Area from the Arizona State Land Department with the assistance of a 2004 voter-approved Open Space bond and a 2013 Growing Smarter grant from Arizona State Parks (City of Flagstaff, 2016). When the City of Flagstaff purchased the land, Observatory Mesa Natural Area was legally-designated as public open space. As open space, Observatory Mesa Natural Area is primarily used for passive outdoor recreation such as mountain biking, jogging, hiking, and horse-back riding. In addition, the Observatory Mesa Natural Area hosts a section of the Flagstaff Loop Trail and one Flagstaff Urban Trail Systems (FUTS) trail—Tunnel Springs Trail.

The typical tourist might not explore the Observatory Mesa Natural Area during their stay. However, many locals take advantage of the trails and roads that exist on the Observatory Mesa Natural Area. Currently, there are six ways to access Observatory Mesa Natural Area (see Figure 5).

1. Thorpe Park Bark Park via Mars Hill FUTS Trail

2. Forest Service Road 515 East Gate off N Westridge Road

3. Tunnel Springs FUTS Trail by Railroad Springs Neighborhood

4. A1 Mountain Road/Forest Service Road 515 West

5. Intersection of Forest Service Road 506, 9113C, and 515A

6. Flagstaff Loop Trail heading South/Counterclockwise

Figure 5: Observatory Mesa Natural Area trailheads. Source: Author
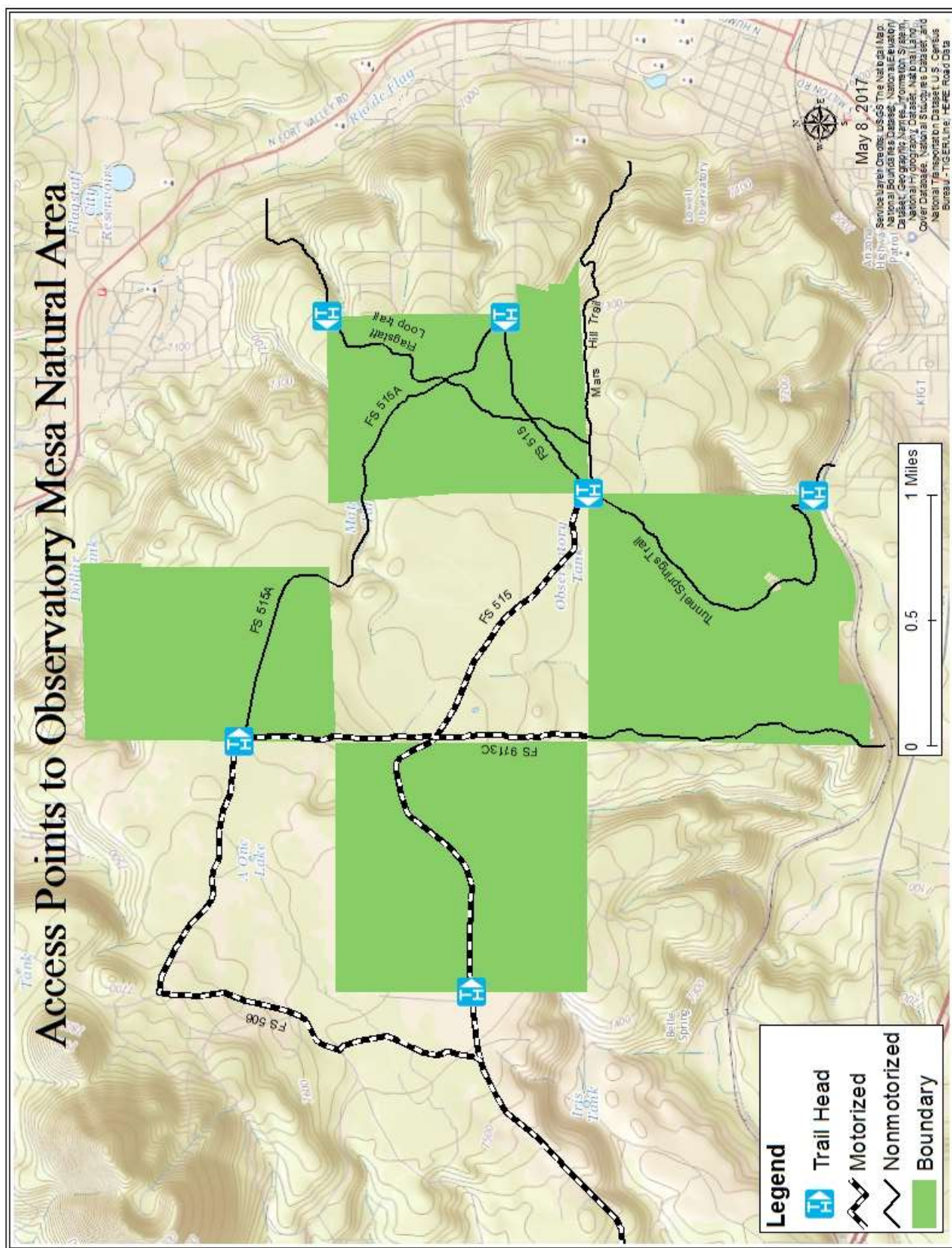
In addition to outdoor recreation, the Observatory Mesa Natural Area may be used for hunting, geocaching/letterboxing, photography opportunities, and wildlife viewing. To keep the area as natural as possible and to meet the requirements of the Growing Smarter grant, motorized vehicles are only allowed on authorized Forest Service roads. The Observatory Mesa has kiosks with maps and information at all major entrances onto the City of Flagstaff's property.

The interest in the Observatory Mesa Natural Area for this thesis occurred during an internship as an Open Space Aide for the City of Flagstaff's Sustainability Section. The City of Flagstaff wanted a complete inventory of the features that exist on the property and their conditions before developing any type of land management plans. While collecting ground data during the internship, the number of unauthorized roads and trails on the property accounted for most of the features that were being collected. These social travel networks tell the City of Flagstaff where users go while exploring Observatory Mesa Natural Area. Since the social trails were recorded, the City of Flagstaff can either adopt the trails or close them for restoration. Likewise, the City of Flagstaff can update trail maps for users, add appropriate signage and kiosks on the property, and even add benches for individuals to rest while on Observatory Mesa Natural Area. By knowing where individuals like to go on Observatory Mesa Natural Area, the City of Flagstaff can create appropriate land management plans to ensure protection for the environment, wildlife, and community users.

3.1.2 Ground Data Collection

The ground data collection phase took place during the Open Space Aide internship with the City of Flagstaff's Sustainability Section. Ground data collection began on June 15th, 2016 and lasted until August 11th, 2016. The overall objective for the collection process was to create an inventory of all of the attributes and features that exist on the four sections of Observatory

Mesa Natural Area. The complete inventory would act as the foundation for the City of Flagstaff's land management plan for Observatory Mesa Natural Area

For the ground data collection process, conversations with the City of Flagstaff's GIS team were held to make sure the collection process would be smooth and efficient. Instead of using a high-grade GPS like a Trimble unit, the GIS team suggested using a tablet or mobile device to use ESRI's Collector mobile application. The GIS team recommended this method since the Collector mobile application automatically sends the collected data onto ArcGIS Online. When using a Trimble unit, the user must download and post-process all the collected data onto a computer. By using the ESRI Collector app, the data downloading and post-processing steps were eliminated. Since the collected data were also being sent to the City of Flagstaff' ArcGIS Online account, the data was safe from accidental deletion. Therefore, the ESRI Collector app was a safe and time efficient method for collecting the data on Observatory Mesa Natural Area.

The City of Flagstaff GIS team created the geodatabases and feature classes for the data collection on Observatory Mesa Natural Area. There were two main feature classes: lines and points. See Figures 6 & 7 for the fields and their associated attributes.

- Feature
  - Road
  - Trail
  - Fence
- Type
  - Established/Legal (Road or Trail)
  - Social/Illegal (Road or Trail)
  - Wooden (Fence)
  - Barbed Wire (Fence)
- Condition
  - Good
  - Highly Degraded
  - Needs Replacement
- Width
  - Single Track (Road or Trail)
  - Double Track (Road or Trail)
- Comments
  - Notes for the feature being collected
- Name (Road or Trail) if applicable

Figure 6: Line features and their attributes

- Feature
  - Cattleguard
  - Gate
  - Other
  - Point of Interest
  - Sign
  - Transient Encampment
  - Trash Pile
  - Water Tank
- Description
  - Notes about the item being collected

Figure 7: Point features and their attributes

The chosen device for data collection was an iPad generation 2. This device was already owned by the City of Flagstaff's Sustainability Section. To ensure proper and frequent data uploads to the ArcGIS Online Cloud, a Verizon Wireless hotspot unit was provided by the Sustainability Section. The iPad2 connected to the Verizon Wireless hotspot unit via Bluetooth.

In addition, this also provided internet and email access while on the Observatory Mesa Natural Area.

When the ground data collection process began, the iPad2 with the Verizon Wireless hotspot unit was averaging around 150-meter accuracy. Though accuracy did not need to be sub-meter for this project, a poor accuracy of 150 meters was not efficient. The GIS team investigated and concluded that a Garmin GLO GPS enhancer could be the solution for this problem. The Garmin GLO GPS enhancer can connect to any tablet or mobile device via Bluetooth. The device gathers the positions from both GPS and GLONASS satellite constellations, which could end up being up to twenty-four satellites. Per Garmin, the GLO device "updates its position information at ten times per second", which means that the GLO device is updating its position ten times more than the average GPS receivers that are found in most mobile devices (Garmin). Unfortunately, the City of Flagstaff did not have any Garmin GLOs in their inventory, so three devices were purchased for future data collection projects.

While the Garmin GLOs were being shipped for the data collection process, a personal Samsung Galaxy S5 was used for a few days until the Garmin GLO arrived. One advantage of the ESRI Collector mobile application is that if the user has an ArcGIS Online account, they can use the Collector app on any supported device. While there are several ESRI Collector web applications that the public can participate in, the data collection for Observatory Mesa Natural Area was restricted to only users who were within the City of Flagstaff's Organization. While the personal Samsung Galaxy S5 on a Verizon Wireless network produced accuracy between three to ten meters, mobile data usage could be a concern. The owner of any personal device should be aware of the data usage and battery drainage while running the mobile app.

Once all the devices were ready, the data collection process was manageable and user-friendly. Having never used ESRI Collector before, the mobile application was simple and easy to follow. When the user opens their Collector app on a tablet or mobile device, the user has the option to select what project they would like to collect data for. After selecting the appropriate project, the Collector app retrieves the project's data onto the screen. When the Collector app knows the user's location, a blue dot appears on the map where that user is currently located. Within the mobile app, one can also see the accuracy of their GPS. For this project, the connected Garmin GLO kept a constant accuracy of five meters. Once an acceptable GPS accuracy is achieved, field data collection may begin.

While the ESRI Collector application supplies users with a handful of basemaps, the GIS Team added their own high-resolution aerial imagery from the City of Flagstaff as a basemap for this project. In addition, they added a slightly transparent boundary polygon of Observatory Mesa Natural Area. The high-resolution aerial imagery and boundary polygon were useful when collecting the field data. Also, all the collected data appears on the screen, which is useful when collecting large land areas such as Observatory Mesa Natural Area. When a feature was ready to be collected, one would touch the "add" button to begin the collection process. The various types of drop-down menus appeared on the screen to correctly attribute the feature. The drop-down fields reflected the geodatabase and feature classes that were originally created by the GIS Team. During this data collection phase, all fields were filled out to the best of their ability. The geodatabase created by the GIS team allowed for attachments which meant users may attach a photo of the collected object. The geo-tagged photos can be useful for the City of Flagstaff since they can view the photos and have an idea what the object looks like and where it is located on the property.

Since the Observatory Mesa Natural Area is divided up in four sections, this made the sequence of data collection easy to keep track of. The western most section, Section 8, was the first area to be collected. First, Forest Service Road 515 was walked and observed to see what other roads and trails intersect the main arterial. During this process, all trails and roads that crossed Forest Service Road 515 were marked on the GPS as well as signs, water tanks, and points of interest. Braids that exist on the roads and trails were also collected and noted as a "braid" in the comments section. Once Forest Service Road 515 was collected, the fence line boundaries were next. When collecting the fences, downed and damaged fence locations were also recorded on the map as "other". When contemplating what area to collect next, the high-resolution imagery provided by the City of Flagstaff was a significant tool for visualizing where possible trails and roads might exist. It was during this method that remote sensing techniques might be able to detect the travel networks on the Observatory Mesa Natural Area. In addition to the high-resolution imagery, a proposed Observatory Mesa Acquisition Area map (Appendix B) was provided by the City of Flagstaff. The map displayed all the known trails and Forest Service Roads on the property. The Observatory Mesa Acquisition Area map was also ground truthed to verify that all the declared travel networks were on the property.

Besides the high-resolution imagery provided by the City of Flagstaff and the Observatory Mesa Acquisition Area Map, Strava Heat Map was used to also see where social trails may occur. Strava Heat Map is a mobile application where bikers and joggers can GPS their routes. The user's route is uploaded to the Strava Heat Map and displays where other athletes train. Strava compiles all of the routes and create a heat map to display routes that are frequently used. To understand where social trails were located, a screen capture of the Strava Heat Map website zoomed into the area of interest was georeferenced in ArcMap Desktop. Once

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the Strava Heat Map aligned with the study area, one can see the many paths that community

members take while on Observatory Mesa Natural Area (see Figure 8). Figure 8 displays the

most frequently used trails in a thick, bright blue line, while other recorded routes appear as thin
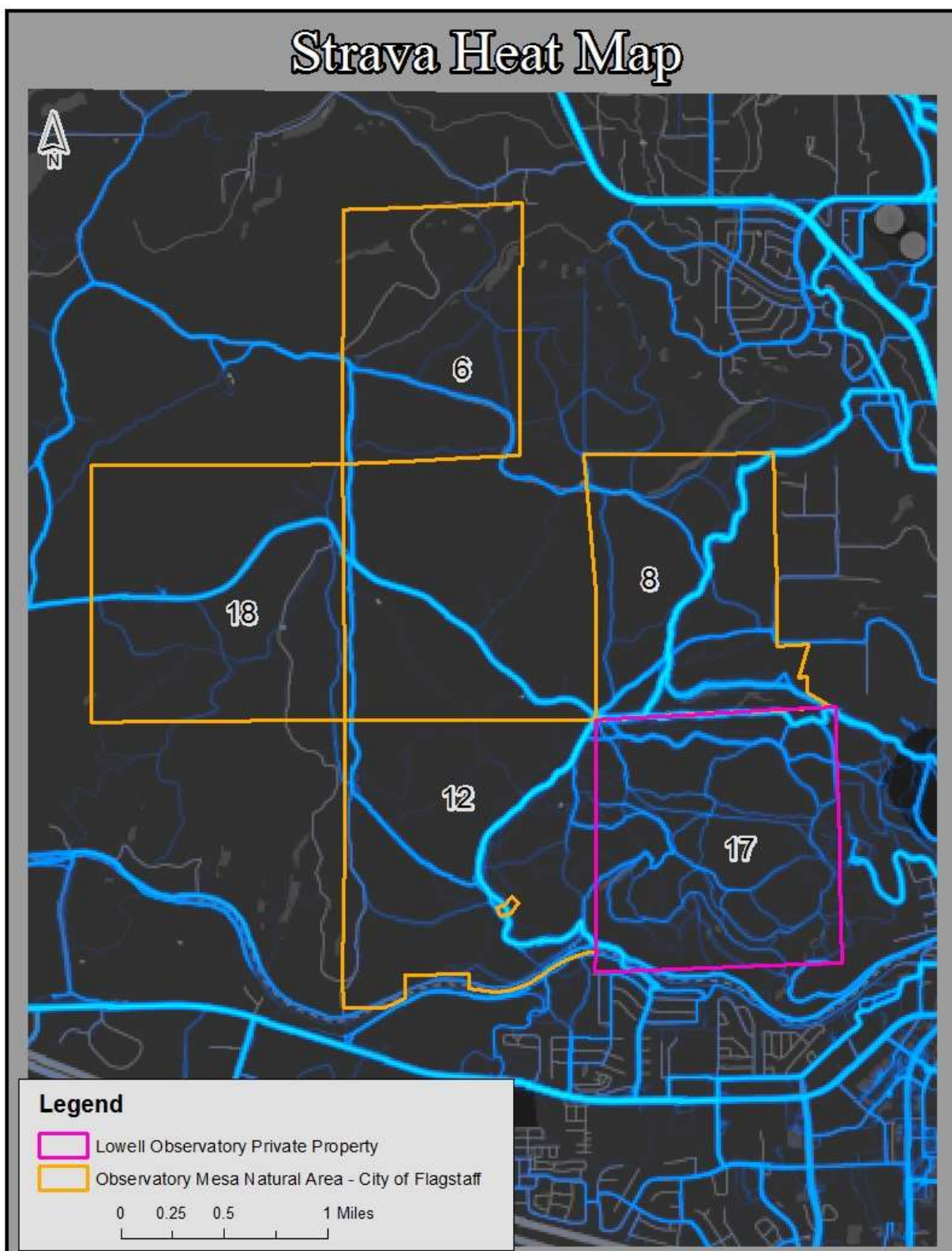
blue lines (Strava, 2017).

Figure 8: Strava heat map image georeferenced to the study area. Source: Strava, 2017.

After completing Section 8, Section 18 was the next be recorded. The same methods occurred: walk the main artery (Tunnel Springs Trail) to locate possible trail crossings, walk the boundary of the property for gates and additional trails leading from surrounding properties, and then fill in the gaps by walking the social trails and roads, collecting signs, water tanks, and other points of interest. Once again, the high-resolution imagery and the Acquisition Area Map were used to verify any missing data. After finishing Section 18, the same methods were repeated for Sections 6 and 12.

The overall ground data collection of Sections 6, 8, 12, and 18 took eleven weeks at fifteen hours a week. According to the Fitbit device that was worn, approximately 150 miles were walked during the data collection process. Because summers in Flagstaff are monsoon season, weather did play a role in postponing some data collection. For safety reasons, any time dark clouds appeared over on the Observatory Mesa Natural Area, data collection was put to a halt until the weather cleared up. In conclusion, the ground data collection for the Observatory Mesa Natural Area took two and a half months to collect and should be up-to-date unless new social trails have been created since then.

3.1.3 Remote Sensing Techniques

When referring to the literature, object-based image analysis would have been ideal for extracting the roads and trails on the Observatory Mesa Natural Area. With object-based image analysis, the program detects similar pixels and creates meaningful objects. This method is useful for extracting linear features such as roads and trails. Nevertheless, ENVI's object-based license was not available for this project. However, alternative remote sensing techniques such as segmentation and supervised classification were used to find the roads and trails located on the Observatory Mesa Natural Area.

Since the study area consists of almost 2,300 acres, high spatial resolution imagery was necessary to view the travel networks on the property. First, WorldView-3 satellite imagery was considered due to its high spatial resolution (sub-meter) and high spectral resolution (over 20 bands); however, this imagery is difficult to come by (Digital Globe, 2013). With help from colleagues at the US Geological Survey, WorldView-3 imagery for the Observatory Mesa Natural Area was available, but could not be used due to the intense shadows of the ponderosa pine trees on the property (see Figure 9).

Figure 9: Example of WorldView-3 Imagery on a Trail within Observatory Mesa Natural Area
Source: Digital Globe, 2016.

Therefore, National Agriculture Imagery Program (NAIP) was considered since the imagery has a high spatial resolution of one meter. Although high spectral resolution like WorldView-3 would have been ideal for the remote sensing analysis, NAIP imagery had the minimum four bands that were needed for this project: Blue, Green, Red, and Near Infrared. In

addition, NAIP imagery is free to download on USGS's EarthExplorer website (U.S. Geological Survey, 2016).

3.1.3.1 Pre-Processing

While investigating the available imagery on the USGS EarthExplorer website, two NAIP tiles, "M_3511151_NW_12_1_20150617_20150826" and "M_3511151_NE_12_1_20150617_20150826", were downloaded for this thesis. Since NAIP imagery is collected by aerial photography, it is not coming from a satellite. Therefore, the selected NAIP imagery does not need to be radiometric calibrated or atmospherically corrected (USDA, 2015). The first method of pre-processing the data is to mosaic the two tiles together to create one image.

First, the two NAIP tiles were mosaicked in ENVI Classic 5.3. However, the final mosaicked product had a coordinate system of "Arbitrary." Although the classification would have been fine with an arbitrary coordinate system, the Observatory Mesa Boundary shapefile could not subset the mosaicked image. Therefore, ENVI Standard 5.3's Seamless Mosaic tool was used to stitch the two tiles together. This method gave the final mosaicked image the correct coordinate system of WGS 1984 Web Mercator Auxiliary Sphere. Once the coordinate system was correct, the Subset Data from Region of Interest (ROIs) tool was used to clip out the Observatory Mesa Natural Area with the boundary shapefile.

Once the imagery was mosaicked, individual pixels were examined with ENVI's Z Profile (Spectrum) Tool. This tool displays each pixel's spectral profile to see the reflection value of the pixel along the different wavelengths. Nevertheless, the wavelengths were not displaying on the spectral profile graph. A quick and simple fix to this problem resulted in

editing the metadata for the image and defining the wavelengths for each band (see Table 1).

After the metadata was edited, each pixel's spectral profile was displaying correctly. At this

stage, the imagery is ready for classification.

Table 1: Band wavelengths for NAIP Imagery (University of Calgary Department of Geography, 2010).

Band	Spectral Resolution (nanometers)
Blue	485
Green	560
Red	660
Near-infrared	830

3.1.3.2 Image Classification

Since object-based image analysis was not available for this project, the segmentation

tool was the first image classification tool to be used to find the travel networks on the

Observatory Mesa Natural Area. Before the segmentation tool could be used, the image had to

be classified in some way for the tool to run. Instead of collecting pixel samples to run a

classification, the band math function in ENVI was used to calculate the Normalized Difference

Vegetation Index (NDVI) on the area. The following equation was used:

$$NDVI = \left(\frac{\text{NIR}-\text{RED}}{\text{NIR}+\text{RED}}\right) \qquad \textbf{or} \qquad NDVI = \left(\frac{Band\ 4 - Band\ 3}{Band\ 4 + Band3}\right)$$

Although NDVI is mostly used to find vegetation, a low NDVI value could identify bare

earth features. In an article by Arulbalaji and Gurugnanam (2014), NDVI could be used to

identify different land cover types such as barren rock, shrubs or grasslands, and dense

vegetation. Arulbalaji and Gurugnanam (2014) used different NDVI values to classify six

different land cover classes. For their barren area and rock surface class, NDVI values between -0.35 to 0.078 were used. Once the NDVI band of the Observatory Mesa Natural Area was created with the band math function, the Cursor Location/Value tool was used to display the NDVI values for the selected pixels that composed either a trail or road. Unlike Arulbalaji and Gurugnanam (2014), the Observatory Mesa's barren rock/travel networks had NDVI values of 0.075 to 0.16. This threshold was used in the segmentation image tool as well as the default population as 100. The output segmented image looked decent for Sections 8, 18, and 12. However, the northern most part, Section 6, did not display any travel networks with the segmentation tool. The NDVI thresholds and population values were changed several times for the segmentation. Nevertheless, the segmentation tool was still not extracting the travel networks on Section 6.

Since the segmentation tool was not outputting the expected results, a maximum likelihood supervised classification was used to find the travel networks on the Observatory Mesa Natural Area. First, three region of interests (ROIs) were created with training pixels for the supervised classification: tree, ground vegetation, and travel networks. When exploring the spectral profiles of the different classes, one could see that the profile for the travel network and ground vegetation were slightly different (see Figure 10). In a true color composition, the ground vegetation appears bright white while most of the trails and roads are a light or dark brown. Since this imagery was collected in June 2015, it is possible that the travel networks could be muddy and appear darker than the ground vegetation if a recent summer storm occurred. Pixels were selected by hand and classified with their corresponding land cover class. Once the three ROIs were defined with pixels, the maximum likelihood supervised classification tool at 95% was operated on the imagery.
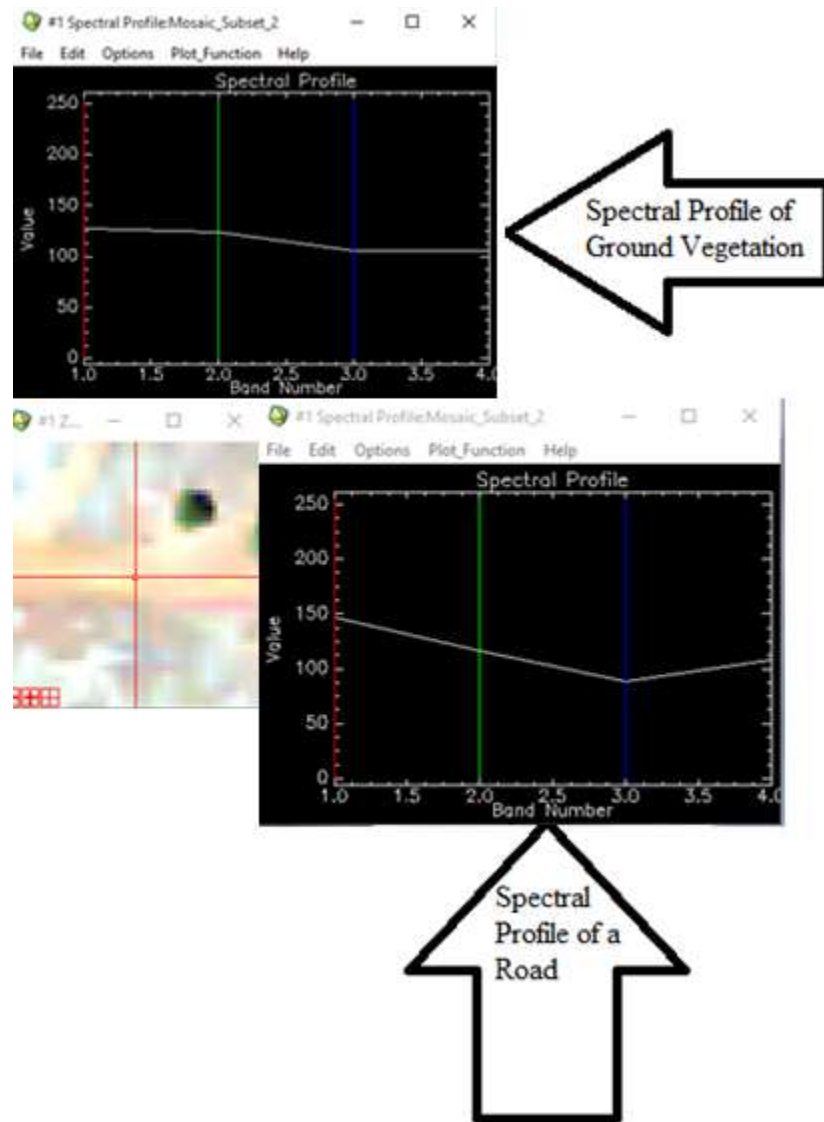
49

Figure 10: Spectral profiles of ground vegetation and a road

The output of the maximum likelihood supervised classification displayed a majority of the roads and trails on the property. Nevertheless, an unsupervised classification and parallelepiped supervised classification were used to see what kind of outputs these methods would produce. The unsupervised classification using K-means at three classes gave an unsatisfactory result. This method was quickly discarded since it did not have the desired

results. Next, the parallelepiped supervised classification using the same ROI as the maximum likelihood was performed. The classification turned out better than the unsupervised classification, but not a great as the maximum likelihood. The parallelepiped method classified more unclassified pixels when compared to the maximum likelihood classification. After experimenting with the different classification methods, the maximum likelihood classification displayed the best desired results for this project.

3.1.4 Accuracy Assessment

Furthermore, the results from the supervised classification do not mean anything until an accuracy assessment takes place. The accuracy assessment lets the users and producers know how accurate the classification may be. To conduct an accuracy assessment, random points need to be generated for the final classified image.

While in the ENVI software, random points can be generated for each land use class. The Generate Random Sample Using Ground Truth ROIs tool created 300 random points to use for the accuracy assessment. Equalized Random was selected, so each class would have 100 points for the assessment. During this process, unclassified pixels were excluded. Once the 300 points were generated, it was difficult to navigate to the different random points in the ENVI software. Since each point needed to be recorded for the accuracy assessment, the 300 points were exported out in their respective land-use class (tree, ground vegetation, and travel network) as shapefiles and imported into ArcMap Desktop 10.4. By using ArcMap, the assessor can easily navigate the three hundred points using the attribute table. An Excel spreadsheet was created listing the three hundred points with their appropriate land-use class as classified in ENVI. A third column was created to record the true land cover class as determined using the travel network shapefile derived from the GPS data and the NAIP imagery. Once all 300 points were

classified, an error matrix was performed to determine the user's, producer's, and overall accuracy of the supervised classification on the Observatory Mesa Natural Area.

3.2 Lowell Observatory

3.2.1 Study Area

To verify the methods used for Observatory Mesa Natural Area, neighboring Section 17, will be used to determine if the methodology could be repeated. Lowell Observatory's Section 17 was selected for several reasons. First, it is neighboring Observatory Mesa Natural Area. Though not officially declared open space property, this section of land consists of 640 acres and is used for passive recreation by joggers, hikers, and mountain bikers. The Mars Hill FUTS trail goes through the northern part of the property, where it then connects to Tunnel Springs Trail and Forest Service Road 515. Secondly, the data for this property is accessible since it is neighboring Observatory Mesa Natural Area. The same NAIP imagery tiles will be used for the remote sensing techniques. As for acquiring ground data, Section 17 is easy to access by parking at Lowell Observatory and taking one of the many trails on the property. Lastly, permission to walk on the property to gather ground data was an easy process. Ms. Anne LaBruzzo, Deputy Director for Administration at Lowell Observatory, stated that there are no permits needed to travel on the grounds. While an alternative section of land could work to verify the methodology, Lowell Observatory Section 17 was the best option due to its location, frequent use, and easy permissions.

Nevertheless, it should be noted that Lowell Observatory Section 17 does not home the actual observatory. According to the Coconino County Parcel Viewer, Lowell Observatory owns three parcels (Coconino County, 2017). Parcel number 100-140-01A consist of 62.96 acres. This parcel neighbors Thorpe Park and contains a majority of W Mars Hill Road (see Figure 11).

Parcel 100-120-01B contains the actual observatory and holds a parking lot of visitors who want to explore Section 17 trails (see Figure 12). Lastly, parcel 111-030-01A is Section 17 which is adjacent to Observatory Mesa Natural Area Sections 18 and 8. For this thesis, only Section 17 owned by Lowell Observatory will be examined.
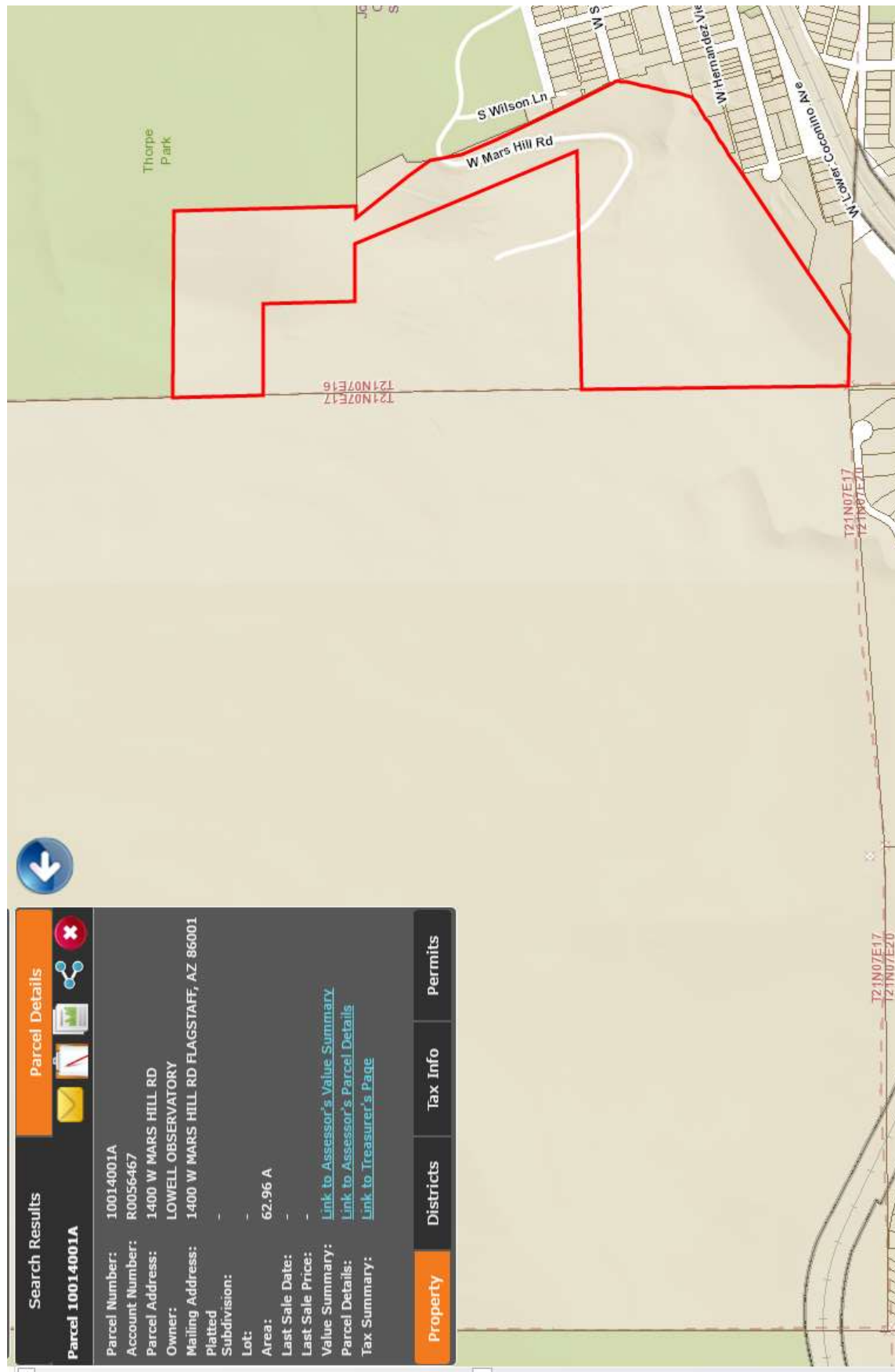
Figure 11: Lowell Observatory Parcel 100-140-01A. Source: Coconino County Parcel Viewer (2017).
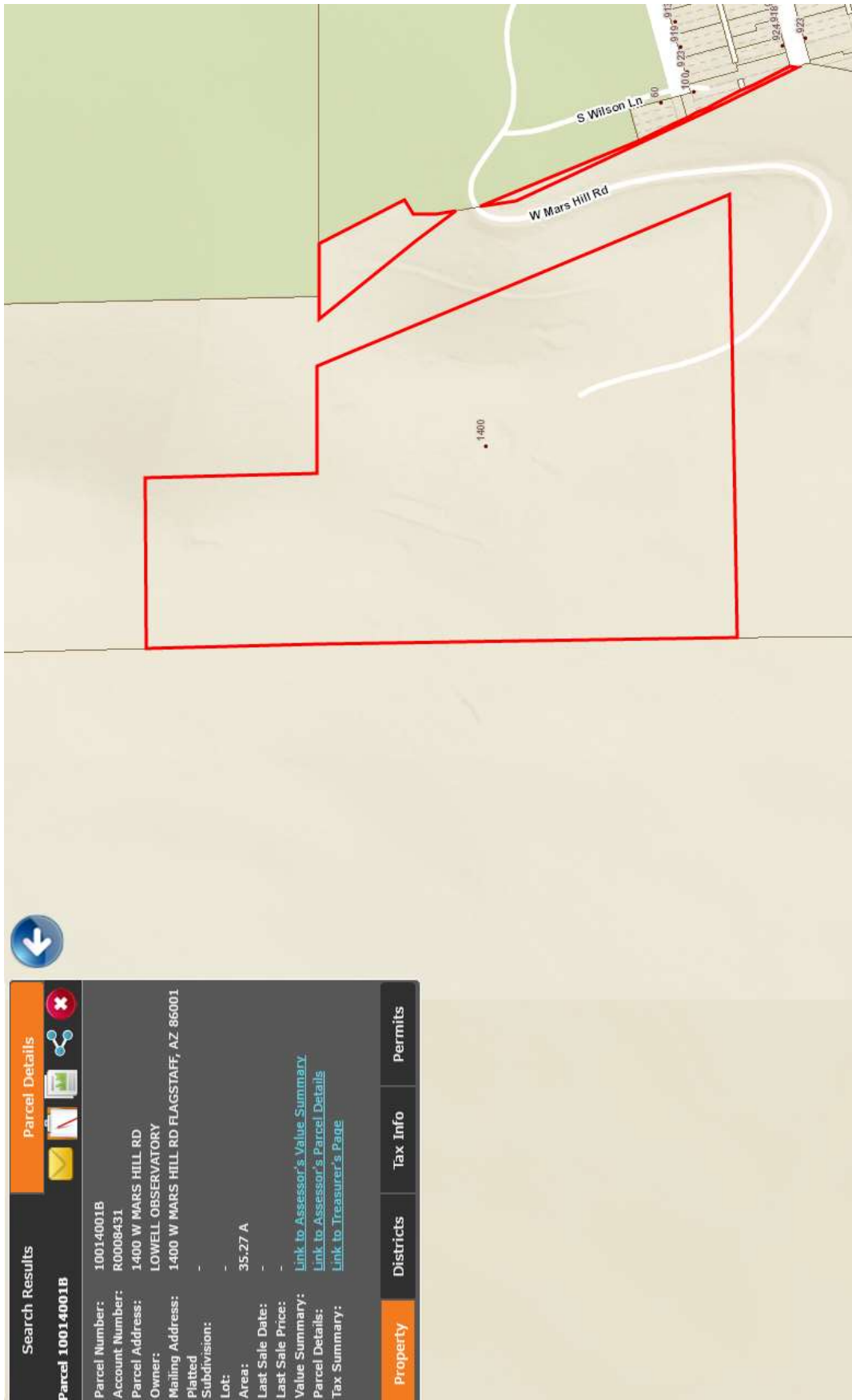
Figure 12: Lowell Observatory Parcel 100-140-01B. Source: Coconino County Parcel Viewer (2017).

3.2.2 Remote Sensing Techniques

Since the Lowell Observatory property is adjacent to the Observatory Mesa Natural Area, the same mosaicked NAIP imagery was used to perform the remote sensing techniques. As learned from the methods used for the Observatory Mesa Natural Area, a supervised classification using maximum likelihood at 95% was used for Section 17 as well. Once again, three ROIs were created—travel networks, trees, and ground vegetation. Once the training pixels for each ROI was defined from the NAIP imagery, the supervised classification with maximum likelihood classifier was executed.

Once the supervised classification was performed on Lowell Observatory, the finished product was observed to see if the two known travel networks were present in the classification: Forest Service Road 515E and Mars Hill FUTS Trail. When looking at the classification, the Mars Hill FUTS Trail did not get classified. Therefore, the three ROIs were adjusted so that more pure pixels of each of the three classes were recorded. Once more, the supervised classification with maximum likelihood at 95% was performed on Section 17. This time, Mars Hill Trail is more visible than the first classification. Figure 13 displays the first and second classification with the true color imagery—here, one can observe that Mars Hill Trail is not visible from the first classification. Nevertheless, an accuracy assessment will need to be done to ensure accuracy on the remote sensing product.
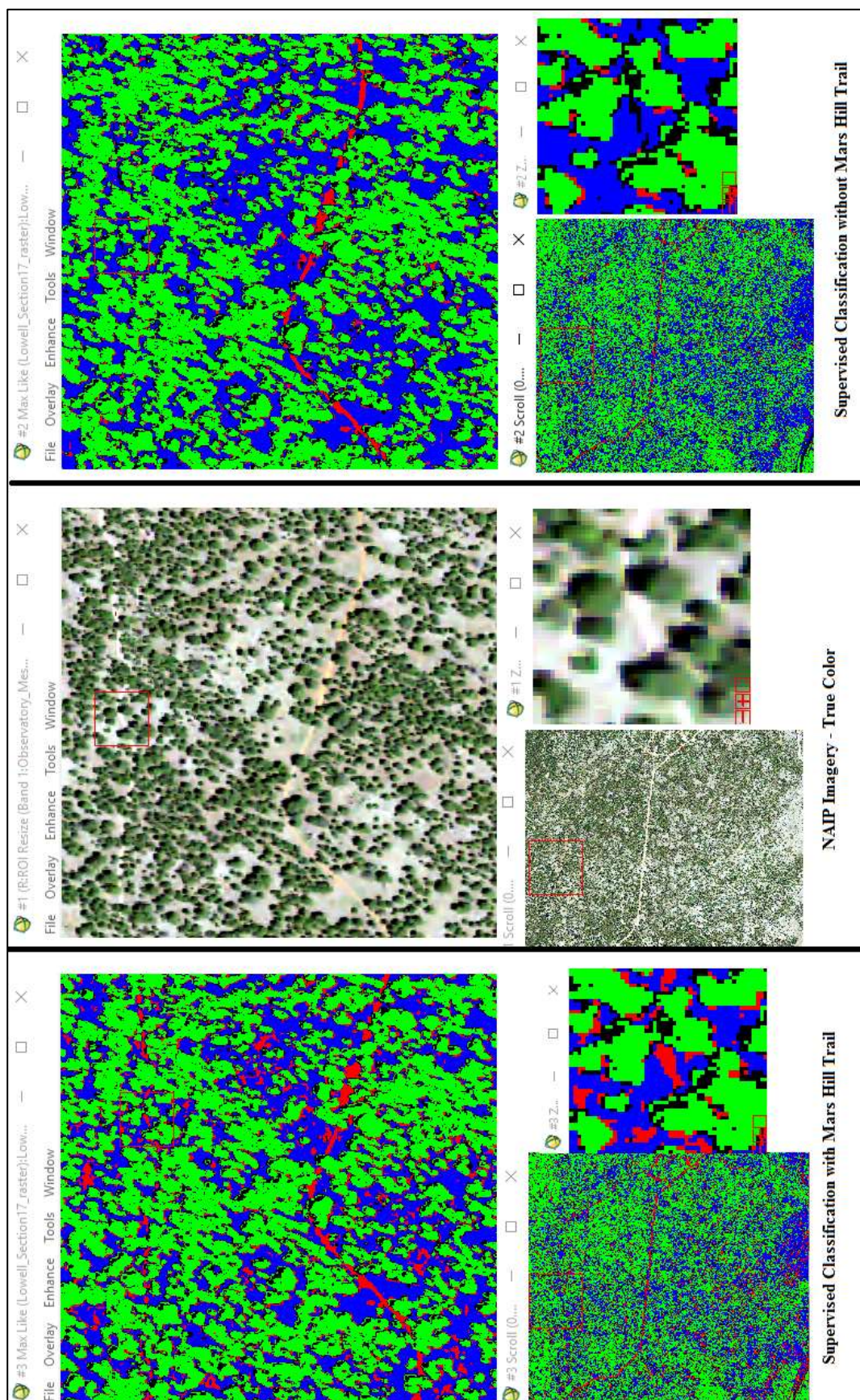
Figure 13: Mars Hill Trail on Section 17. Source: Author

3.2.3 Accuracy Assessment and Ground Data Collection

Like the Observatory Mesa Natural Area methods, ENVI's Generate Random Samples using Ground Truth ROIs was used to create random points for the accuracy assessment. This time, twenty-five random points for each of the three classes were generated using the equal random option. The random generated points were exported out a shapefile, so all seventy-five points could be seen on the map. When examining the random distribution, one could observe that many of the random generated points were being clustered together (see Figure 14). Random clustered points would not work for the accuracy assessment. Nevertheless, ArcMap Desktop's Create Random Points tool was used to generate random points. With Create Random Points, the Lowell Observatory Property shapefile was the constraining feature class, and all other tool options were left at their default value. Once the tool was executed, the new set of generated random points were not as clustered like the points that were created in ENVI. However, this tool did not classify what each point was being classified as. Therefore, an Excel spreadsheet was created to list all seventy-five points and their land cover class from the supervised classification.

Figure 14: Random points clustered on Lowell Observatory. Source: Author

Once the accuracy assessment was set-up, the seventy-five random points were uploaded
to a Garmin eTrex 20x GPS unit with the DNRGPS software. The DNRGPS software can take a
shapefile and upload it to a GPS unit by converting the shapefile to a GPX. Likewise, data can
be downloaded from the GPS into a shapefile using this software (Minnesota Department of
Natural Resources, 2011). The seventy-five points were verified on the Garmin eTrex 20x unit
and on ArcMap Desktop (see Figure 15). Once the data were uploaded to the GPS device, the
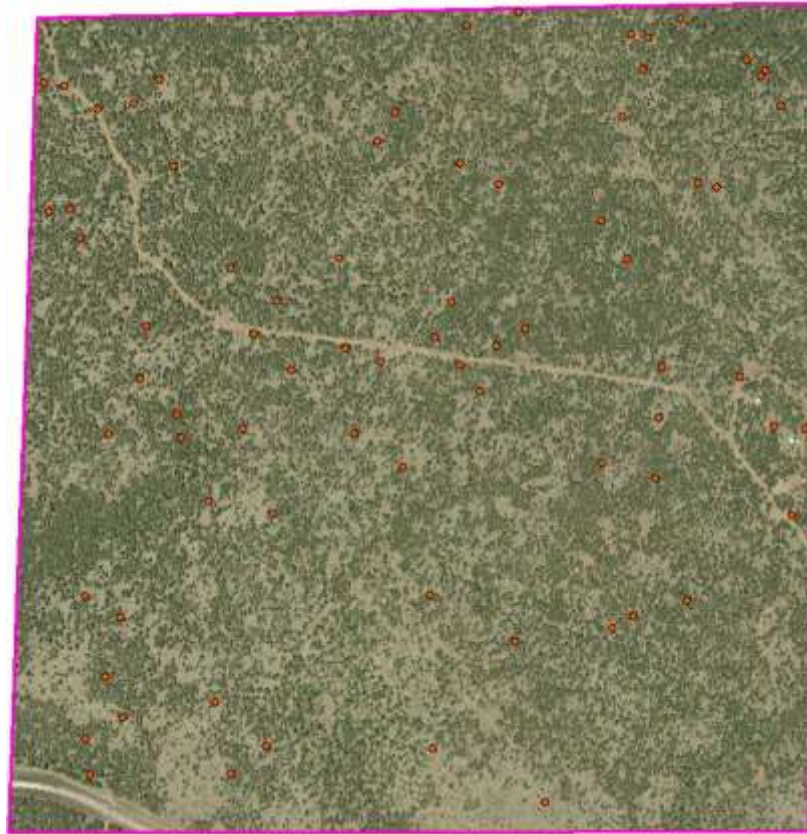in-field accuracy assessment was ready to begin.

Figure 15: Distribution on Random Points on Lowell Observatory. Source: Author

Ground data collection on Lowell Observatory took place between March 3rd, 2017 and March 10th, 2017. The ground data collection was delayed a few times because of snow and rain. The original accuracy assessment goal was to go to all seventy-five points to ground truth the supervised classification. However, the methodology was changed to only collect the roads and trails with the Garmin eTrex20 GPS unit. The seventy-five points will still be assessed for accuracy on the computer to save time. An abundance of roads and trails exist on Lowell Observatory Section 17. Therefore, the ground data collection process recorded all the trails and roads within the study of interest.

Once the data from Lowell Observatory was collected, the seventy-five points were assessed for accuracy using the same methods that were used on Observatory Mesa Natural

Area. However, the amount of travel networks points that were assessed were very few.

Therefore, an additional accuracy assessment of only the travel networks was needed to

determine how accurate the remote sensing techniques detected the trails. Since the roads and

trails were collected with a GPS, the accuracy assessment will rely on the ground truth data for

accuracy.

To only look at the travel networks from the supervised classification, a definition query

within ArcMap was used to only display pixels that were classified as a travel network. Once the

classified travel network pixels were displayed, the Create Random Points tool was used to

populate random points in pixels with the travel network classification. However, the tool

created points for every classified travel network pixel (see Figure 17). Assessing every pixel

would be too time consuming for this thesis, so a python script was used to select a subset of the

randomly created points.

Figure 16: Create Random Points within the classified travel network pixels.
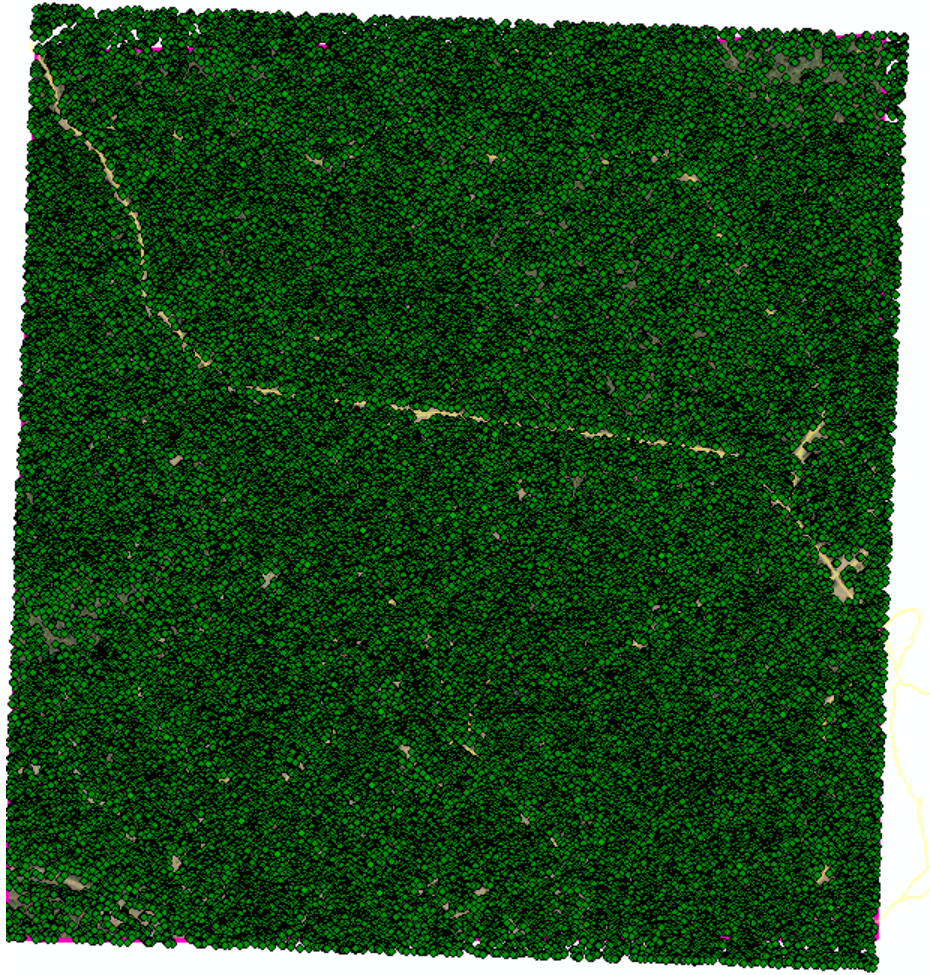
Figure 17: Random Points from Travel Networks on Lowell

GIS Stack Exchange, a question and answer website for cartographers, geographers, and GIS professionals, was consulted to determine the best solution to randomly select points within a shapefile in ArcMap. Within one community forum on GIS Stack Exchange, Brundage (2015) suggests the Python programming script in Figure 18. The python console within ArcMap ran the script with the count of sixty points. The script selected the random sixty points, which were then exported out as their own shapefile for accessibility and future analysis (see Figure 19).

```
def SelectRandomByCount (layer, count):
    import random
    layerCount = int (arcpy.GetCount_management (layer).getOutput (0))
    if layerCount < count:
        print "input count is greater than layer count"
        return

    oids = [oid for oid, in arcpy.da.SearchCursor (layer, "OID@")]
    oidFldName = arcpy.Describe (layer).OIDFieldName
    delimOidFld = arcpy.AddFieldDelimiters (layer, oidFldName)
    randOids = random.sample (oids, count)
    oidsStr = ", ".join (map (str, randOids))
    sql = "{0} IN ({1})".format (delimOidFld, oidsStr)
    arcpy.SelectLayerByAttribute_management (layer, "", sql)
```

Figure 18: Python Script to select Random from Random points. Source: Brundage (2015).
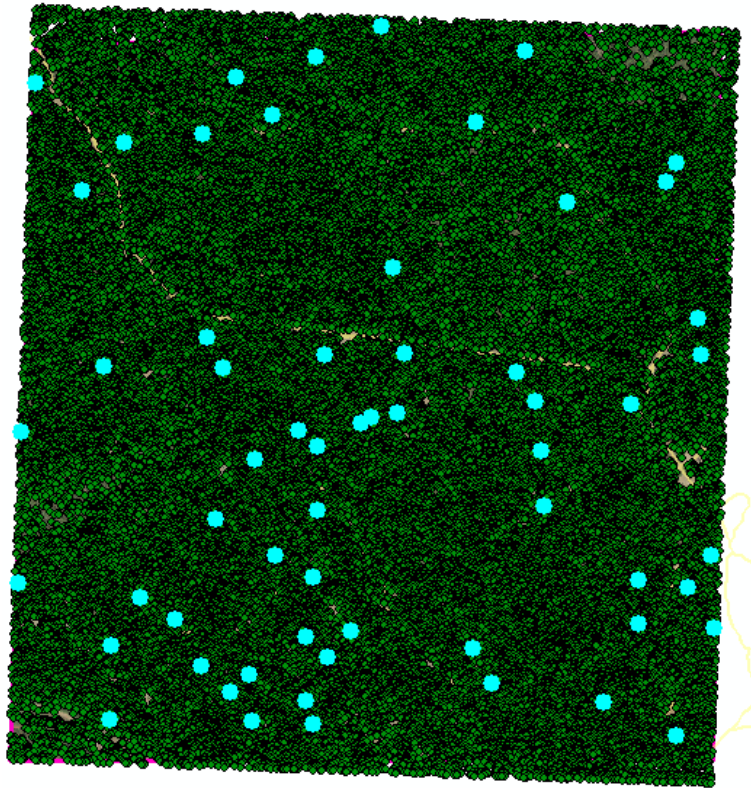
Figure 19: Random Points Selected from random travel network points

The random sixty points were placed in an Excel Spreadsheet with their land cover class as travel network. All sixty points were examined against the NAIP imagery and the travel network shapefile that was collected with a GPS. Once all sixty points were assessed, an error matrix was created to determine the accuracy of the travel networks. However, only three out of the sixty points were located on a ground verified travel network (see Figure 20). The method was attempted again with 120 randomly generated points (see Figure 21). After going through each point, the accuracy for the travel networked remained the same.
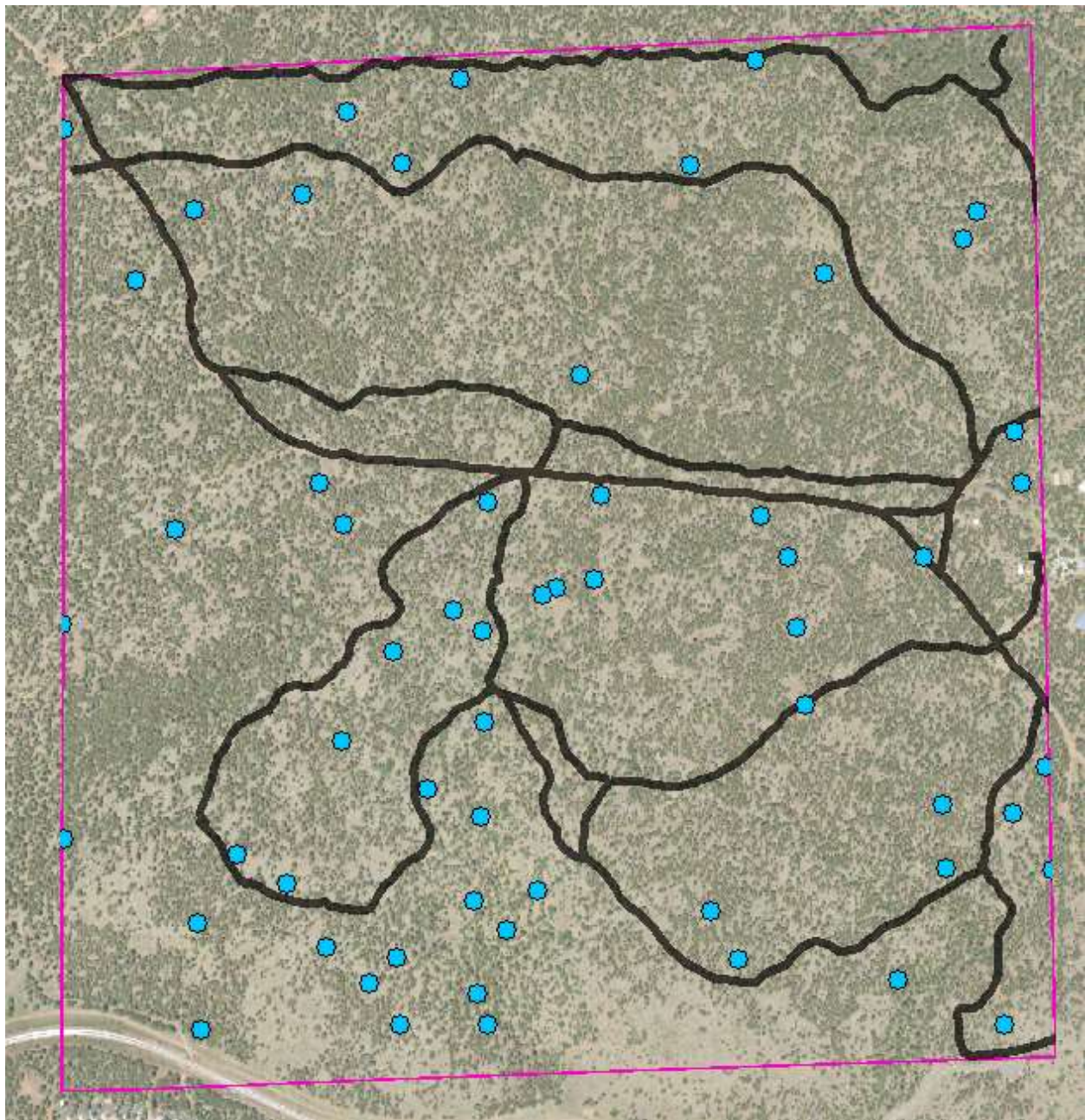
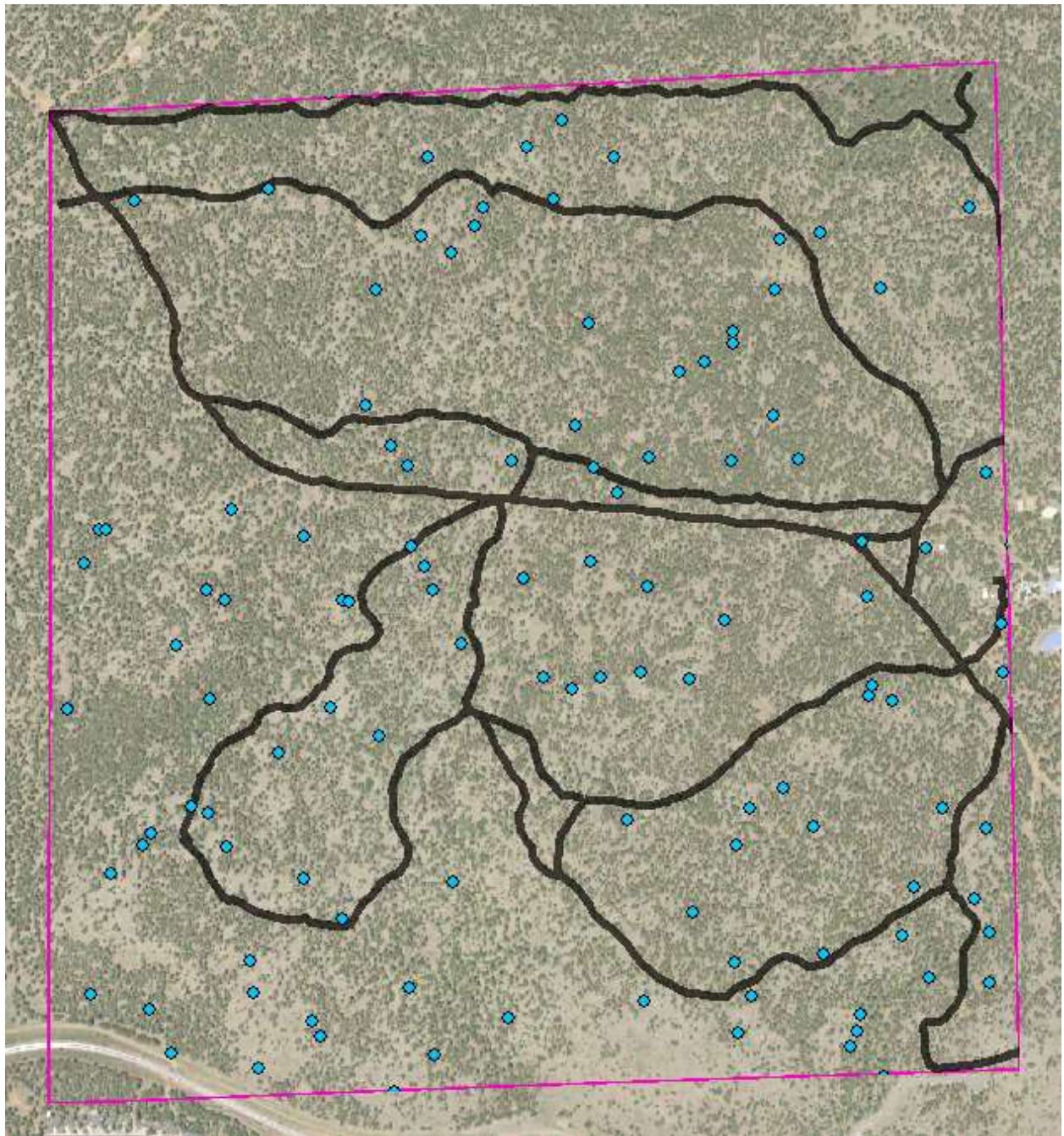*Figure 20: Sixty randomly generated travel network points on Lowell Observatory*

Figure 21: 120 randomly generated travel network points on Lowell Observatory

CHAPTER FOUR
Results

4.1 Observatory Mesa Natural Area

4.1.1 Ground Data Collection Results

Map compositions were created in ArcMap Desktop 10.4 with the GPS data that was collected with the ESRI Collector App. Within ArcGIS Online, the layer containing the data was downloaded to a personal computer and viewed in ArcMap Desktop. Overview maps of the entire Observatory Mesa Natural Area were produced as well as individual maps for each section. Each of the four sections have an overview map of the entire GPS collected data, an authorized/unauthorized trail map, an authorized/unauthorized road map, and a road conditions map (except Section 12).

4.1.1.1 Observatory Mesa Natural Area Overview Results

Figure 22 displays the entire ground data collection for Observatory Mesa Natural Area. This map compositions shows all of the roads, trails, fence lines, cattle guards, gates, areas of significant erosion, signs, transient encampments, trash piles, and water tanks that were identified within Observatory Mesa Natural Area. The significance of this figure displays where the City of Flagstaff might need trash clean up events, extra patrol for illegal camping, and where travel networks might need to be closed due to severe erosion.
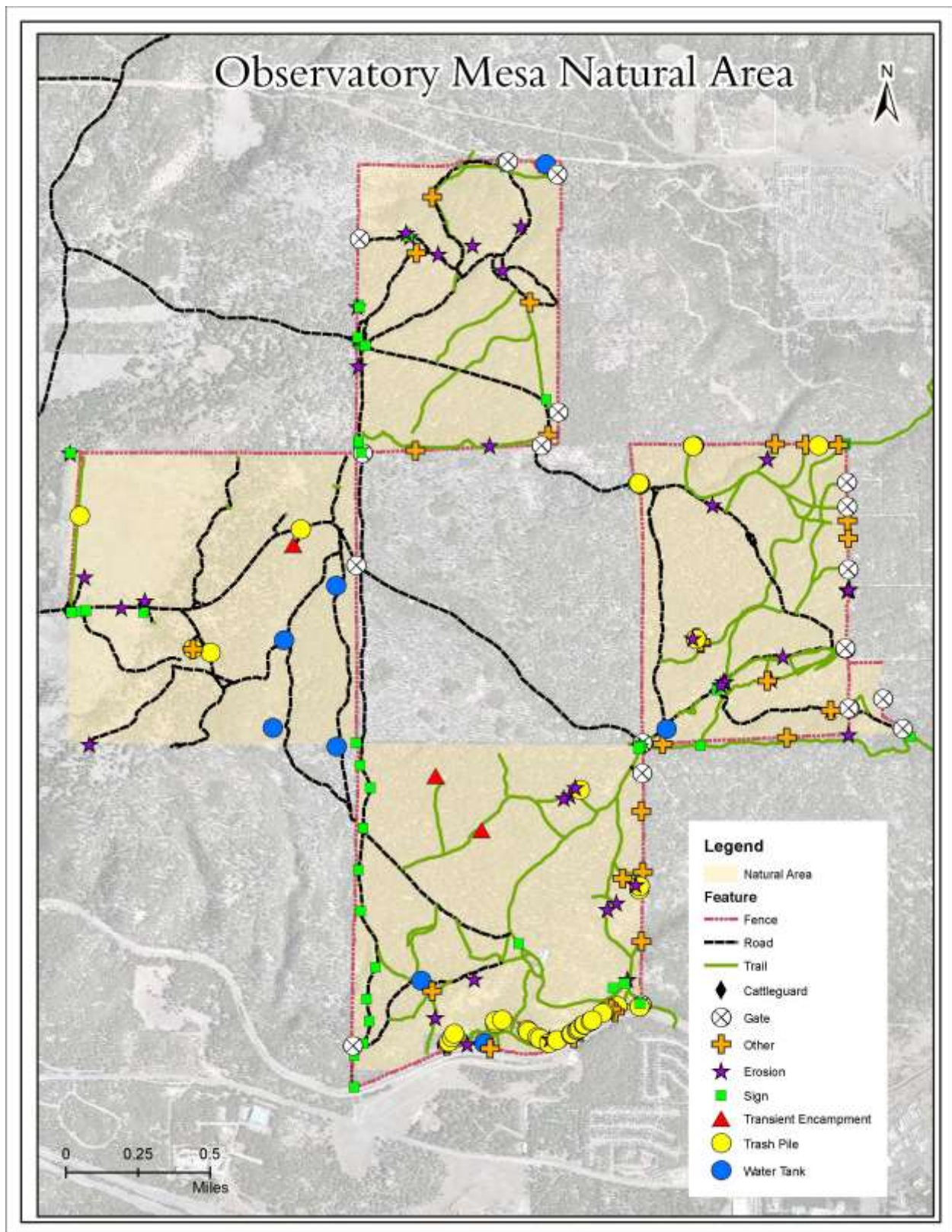
Figure 22: Overview Map of Observatory Mesa Natural Area with all GPS data. Source: Author

Figure 23 displays the same fences, trails, and roads as Figure 20, only the point data has been removed from the map composition. With the point data removed, one can notice the trails and roads that may be hidden from Figure 22.

Figure 24 shows the trails that were collected on Observatory Mesa Natural Area and if they are an authorized or unauthorized trail. As stated in the literature review, a trail is a corridor that was not designed for motorized used. Notice the number of unauthorized trails when compared to the official trails within Observatory Mesa Natural Area.

Like the previous figure, Figure 25 is displaying the same trails on Observatory Mesa Natural Area. However, Figure 25 is also showing the conditions of each trail segment. Notice that most trails are in good condition. Nevertheless, there are a handful of trails that are highly degraded. If these trails were to be adopted into the City of Flagstaff's trail system, the City of Flagstaff might want to keep a note that certain sections have erosion and could benefit from trail restoration or reconstruction.

Figure 26 shows the roads that were collected on Observatory Mesa Natural Area and if they are an authorized or unauthorized. As stated in the literature review, a road may be used by motorized vehicles. However, some of the Forest Service roads are no longer accessible by motorized vehicles. The public may only have motorized access on the Forest Service roads listed on the Coconino National Forest Travel Map (Coconino National Forest, 2017).

Like Figure 25, Figure 27 displays the road conditions for all the collected roads on Observatory Mesa Natural Area. The City of Flagstaff may use this map to know what road segments are heavily eroded and may need restoration or reconstruction.
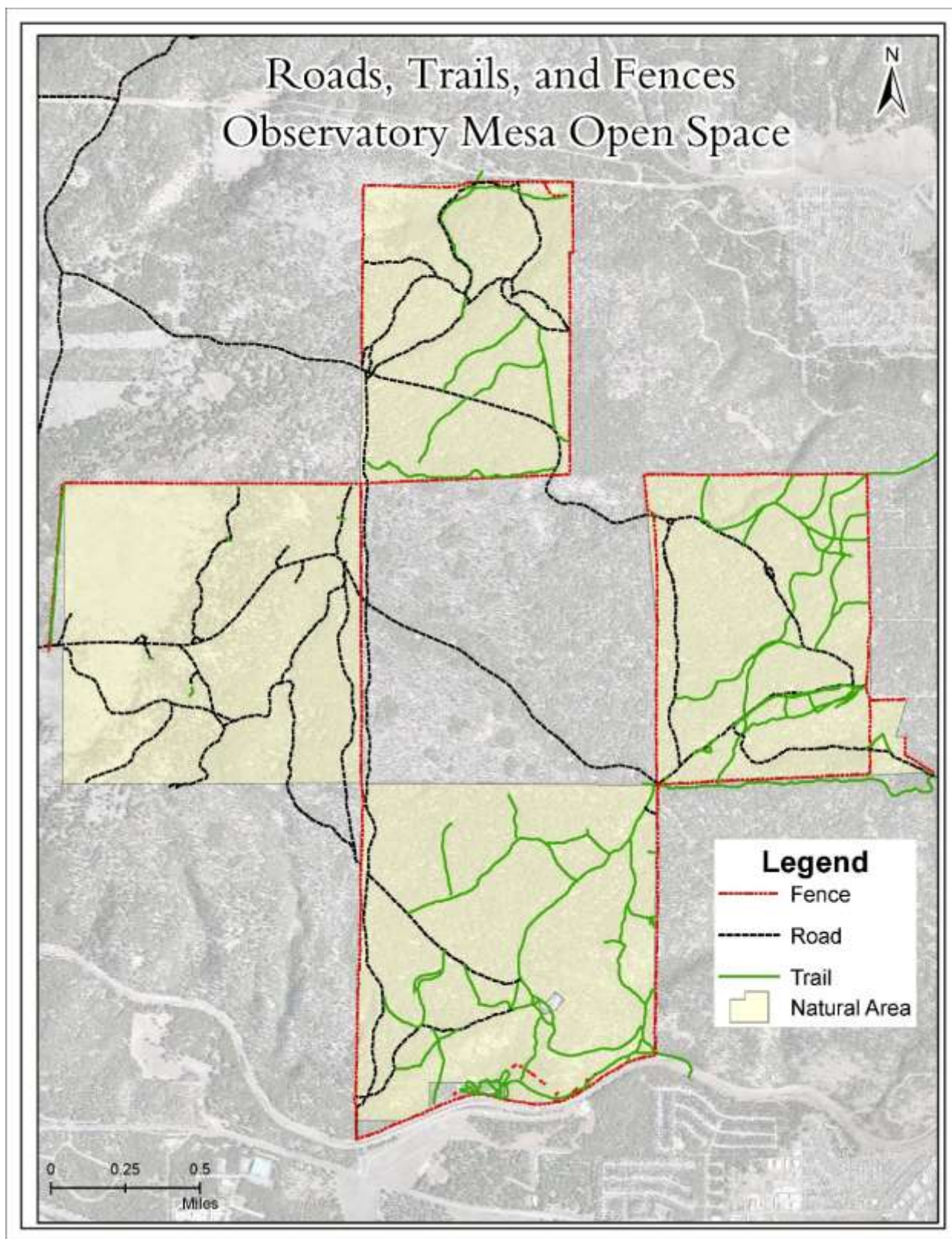
Figure 23: Line features collected on Observatory Mesa Natural Area. Source: Author

Figure 24: Overview Map of Trails on Observatory Mesa Natural Area. Source: Author

Figure 25: Overview map of trail conditions on Observatory Mesa Natural Area. Source: Author

Figure 26: Overview map of roads on Observatory Mesa Natural Area. Source: Author

Figure 27: Overview map of road conditions on Observatory Mesa Natural Area. Source: Author

4.1.1.2 Section 6 (Observatory Mesa Natural Area) Results

Section 6, the northernmost section on Observatory Mesa Natural Area, might not receive a lot of use as evidence by the lack of trash piles, transient encampments and erosion along the trail networks. Figure 28 displays a zoomed-in version of Section 6 and all its collected data. Since there are no official trails on Section 6, Figure 29 shows all the unauthorized trails that were found during the ground data collection phase. Likewise, Figure 30 displays all the roads in Section 6. In Figure 30, one may notice that only one road out of the entire road system is not an authorized road. Lastly, Figure 31 tells the City of Flagstaff that only one road segment in the entire section is highly degraded.

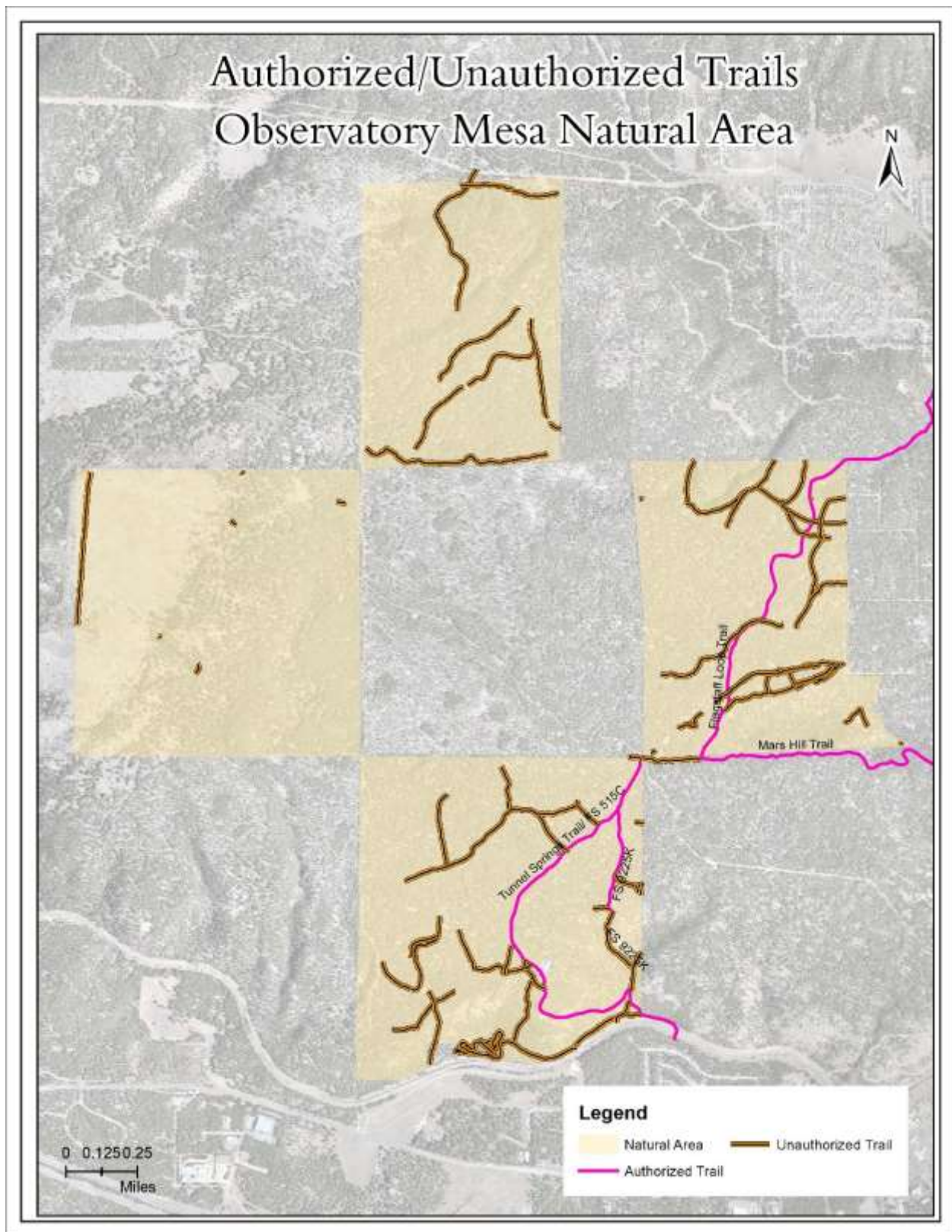*Figure 28: Overview map of Section 6 on Observatory Mesa Natural Area. Source: Author*

Figure 29: Section 6 trails on Observatory Mesa Natural Area. Source: Author

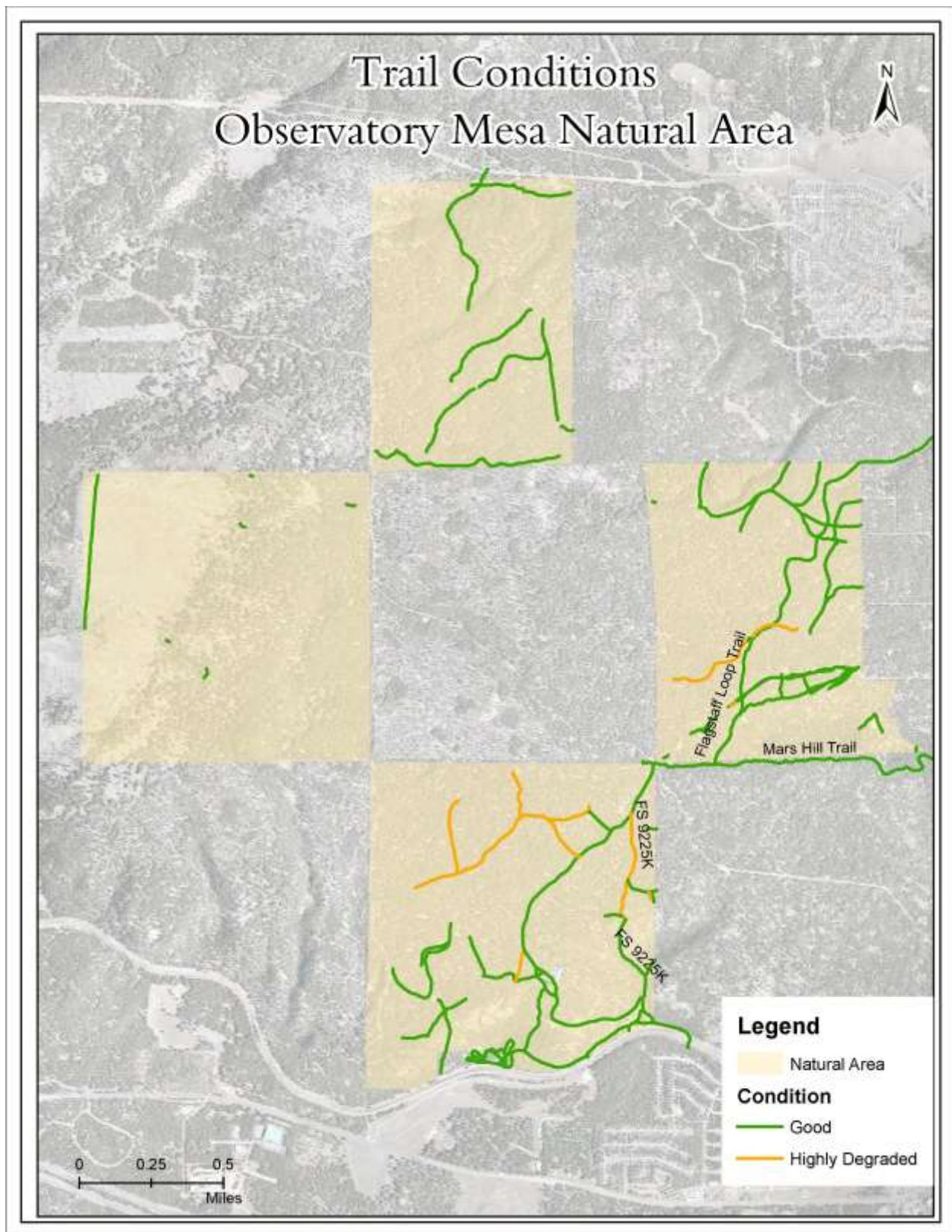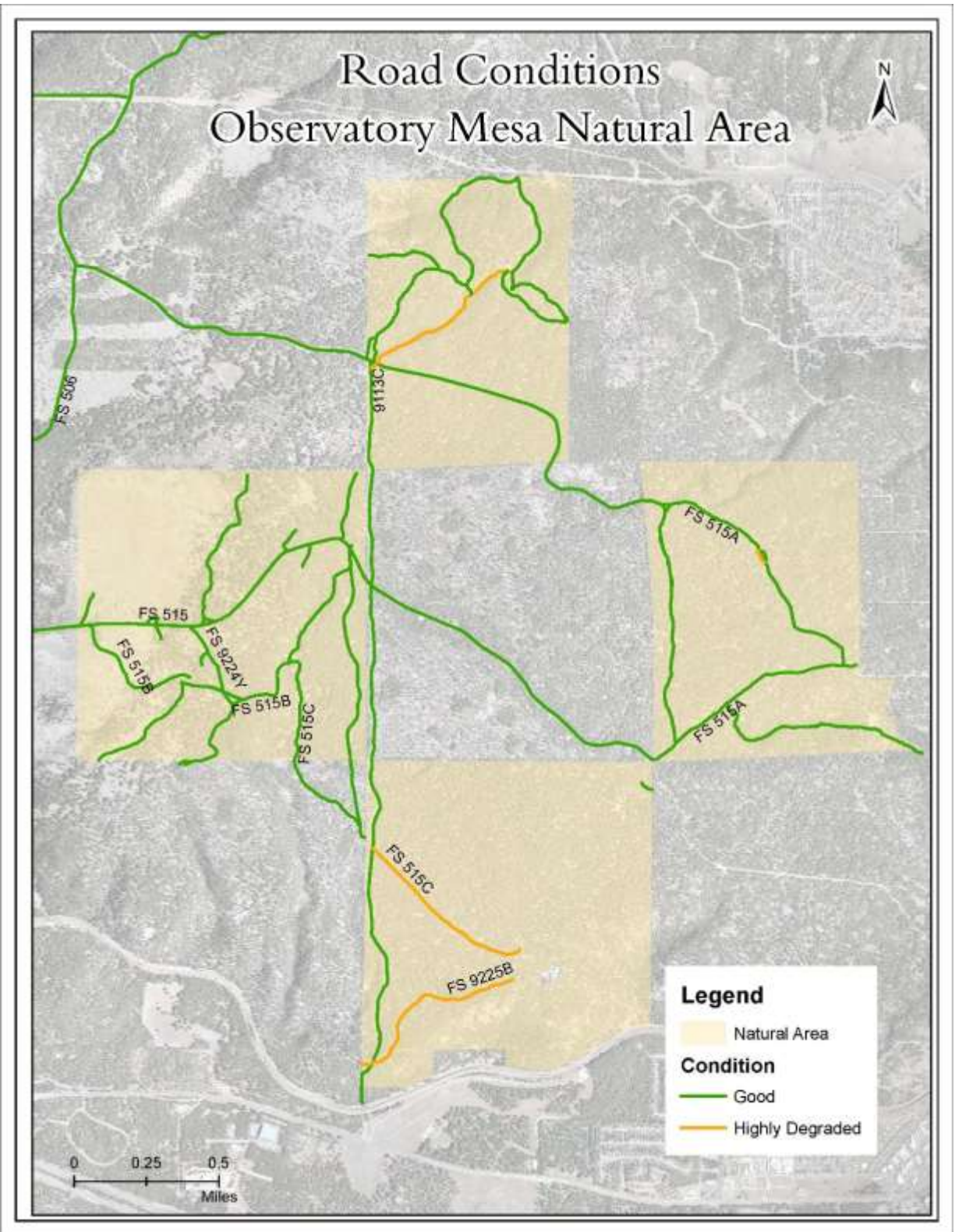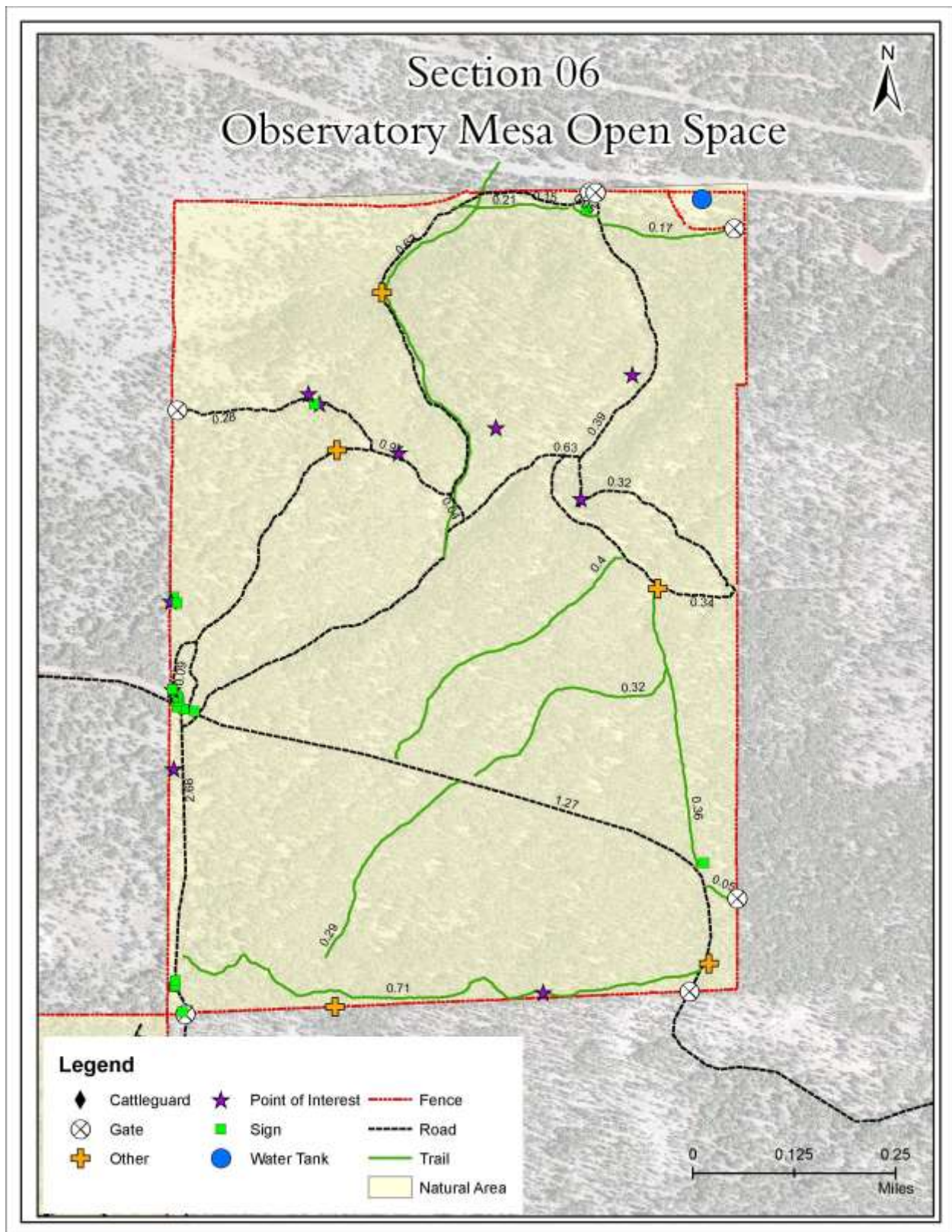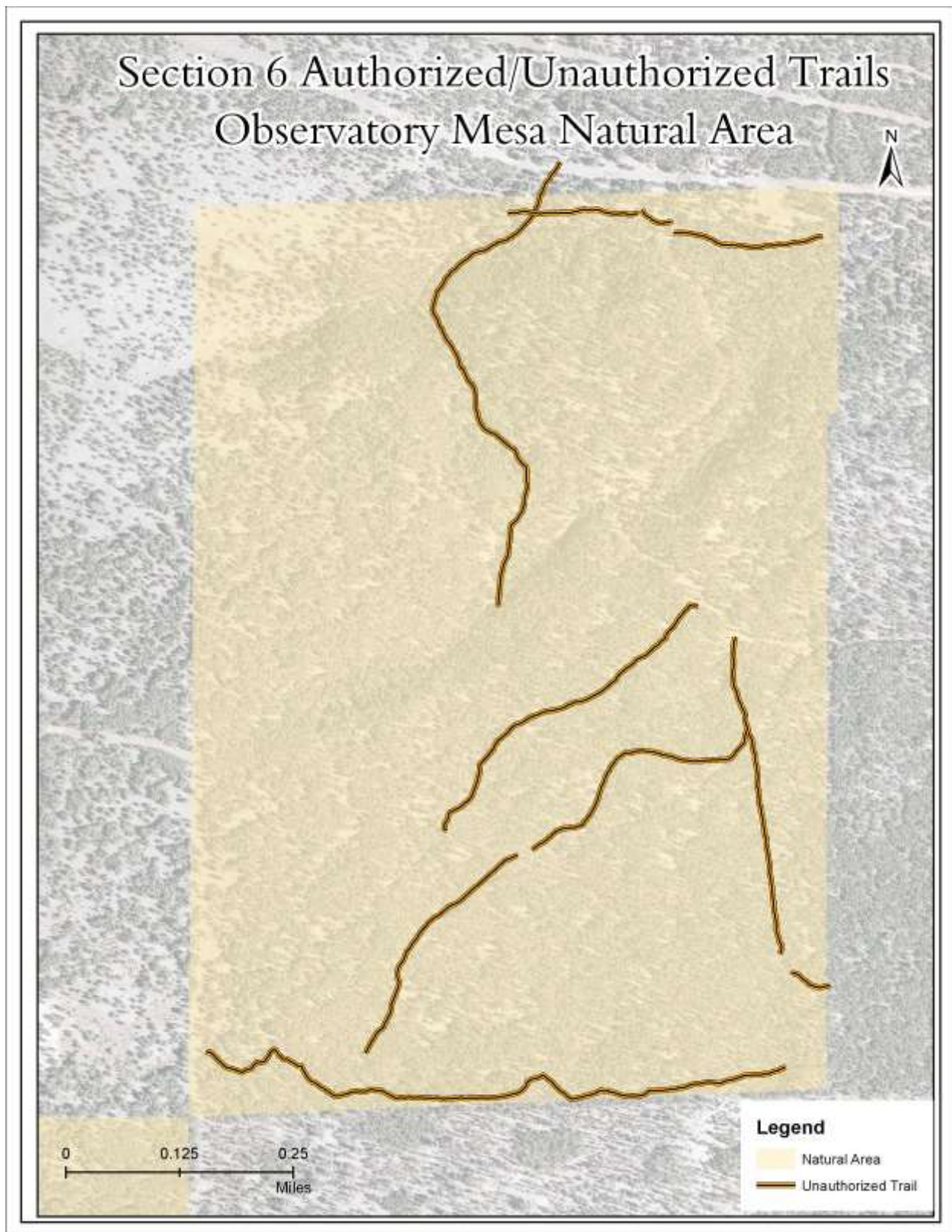*Figure 30: Section 6 roads Observatory Mesa Natural Area. Source: Author*

Figure 31: Section 6 road conditions on Observatory Mesa Natural Area. Source: Author

4.1.1.3 Section 8 (Observatory Mesa Natural Area) Results

Section 8, the easternmost section on Observatory Mesa Natural Area, might receive the most public use due to its proximity to Mars Hill Trail and the abundance of unauthorized trails on the property. Figure 32 displays all the collected data from the ground data collection phase. One can immediately notice the multiple trail segments that appear on this map composition. Figure 33 gives the user a closer look of all the trails that were collected on Section 8. The only authorized trail that runs through this section is a segment of the Flagstaff Loop Trail. When examining Figure 33, one may see that several unauthorized trails cross the official Flagstaff Loop Trail. The City of Flagstaff could use this information to place appropriate signage, or adopt the social trails and create an updated map for users. Next, Figure 34 shows the authorized and unauthorized roads in Section 8. Though Section 8 contains many unauthorized trails, it only has one unauthorized road. Lastly, Figure 35 shows that all the major roads are in good condition. One may see that there is one braid that is highly degraded due to erosion.

Figure 32: Overview map of Section 8 on Observatory Mesa Natural Area. Source: Author

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Figure 33: Section 8 trails on Observatory Mesa Natural Area. Source: Author
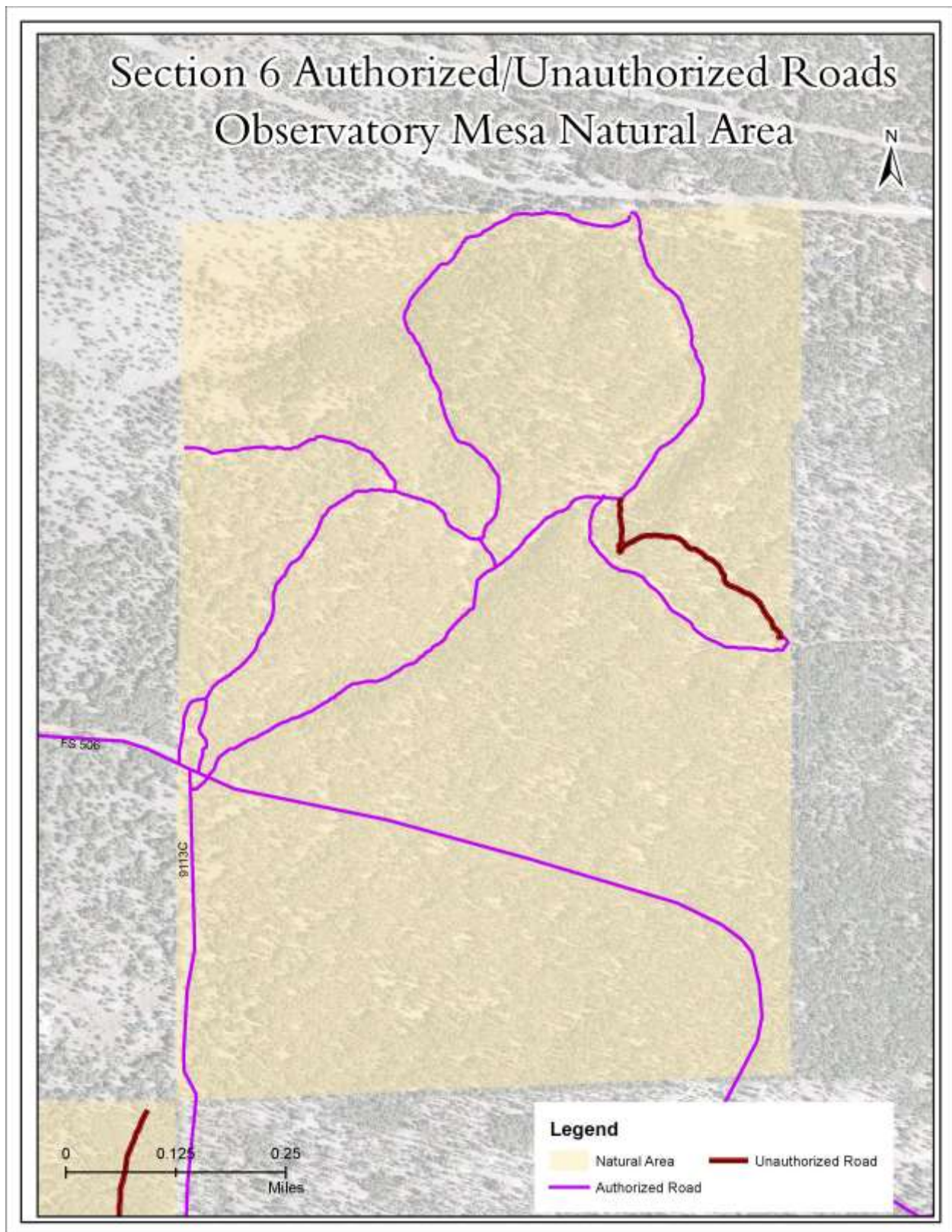
Figure 34: Section 8 roads on Observatory Mesa Natural Area. Source: Author
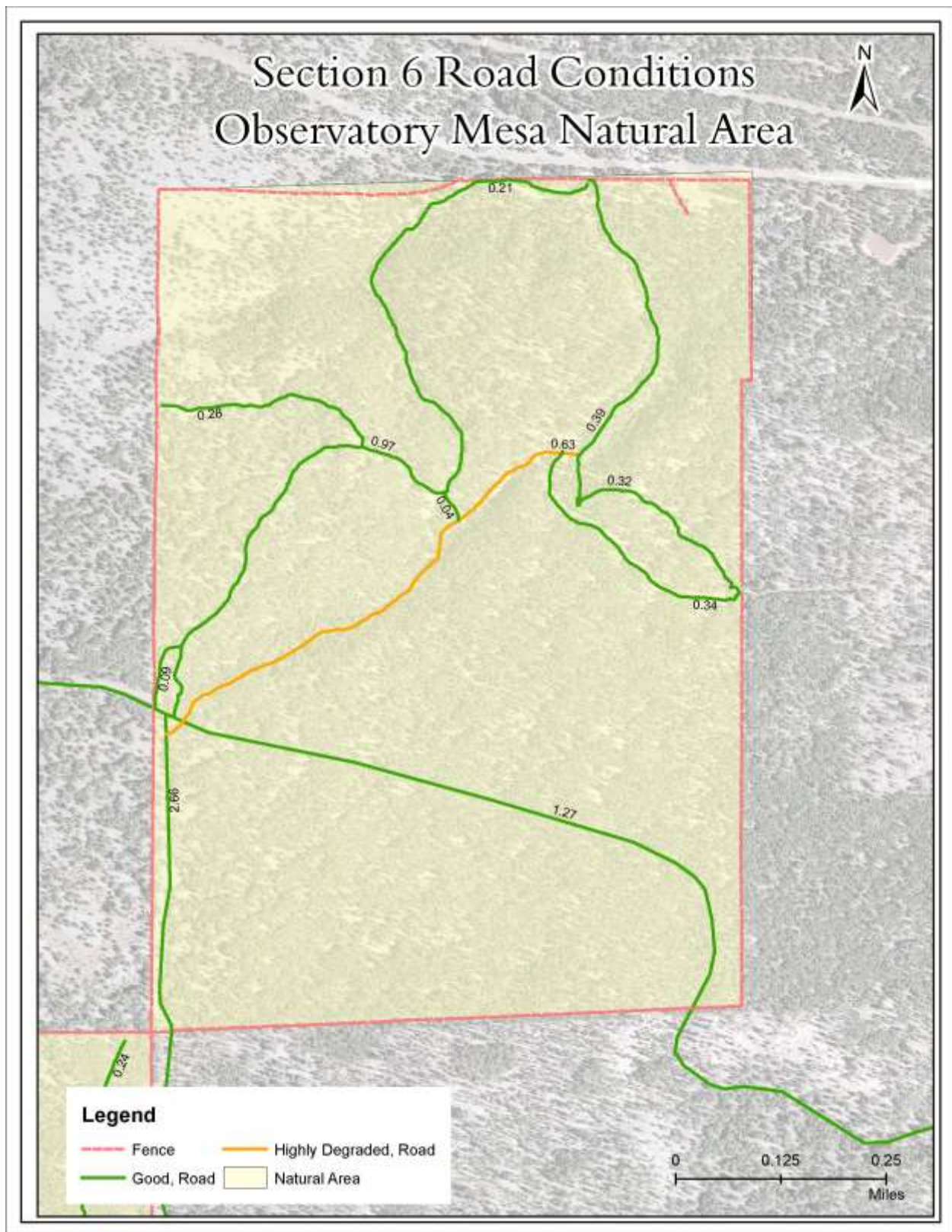
Figure 35: Section 8 road conditions on Observatory Mesa Natural Area. Source: Author

4.1.1.4 Section 12 (Observatory Mesa Natural Area) Results

Section 12, the westernmost section on Observatory Mesa Natural Area, can be viewed

on Figure 34. As shown in Figure 36, Section 12 contains several water tanks, signs, and points

of interest. Since Section 12 does not have any authorized trails, Figure 37 displays where

unauthorized trails exist within this section. Since Section 12 contains many roads, Figure 38

shows all the unauthorized and authorized roads. During summer 2016, the Flagstaff Fire

Department was thinning trees in Section 12 as part of the Flagstaff Watershed Protection

Project. During this project, it is possible that unauthorized roads may appear due to the

thinning. Likewise, a few small sections of unauthorized roads occur off the main arterial, Forest

Service Road 515. It is possible that these unauthorized road sections were once short corridors

for camping spots when the property was State Trust Land. Since camping is prohibited on City

of Flagstaff property, these small sections of old roads have no purpose anymore. The City of

Flagstaff could use these small sections to place picnic tables or restroom facilities.
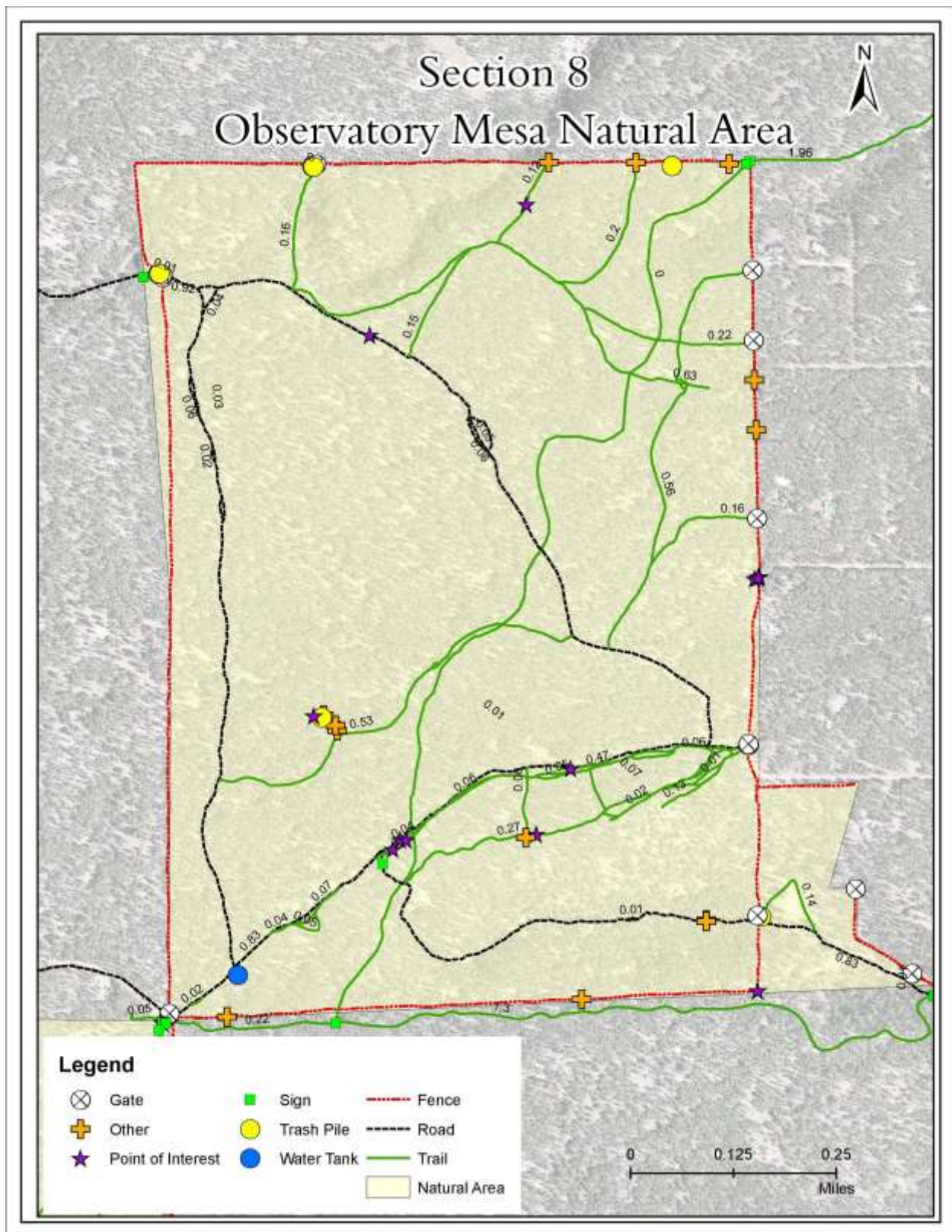
Figure 36: Overview map of Section 12 on Observatory Mesa Natural Area. Source: Author
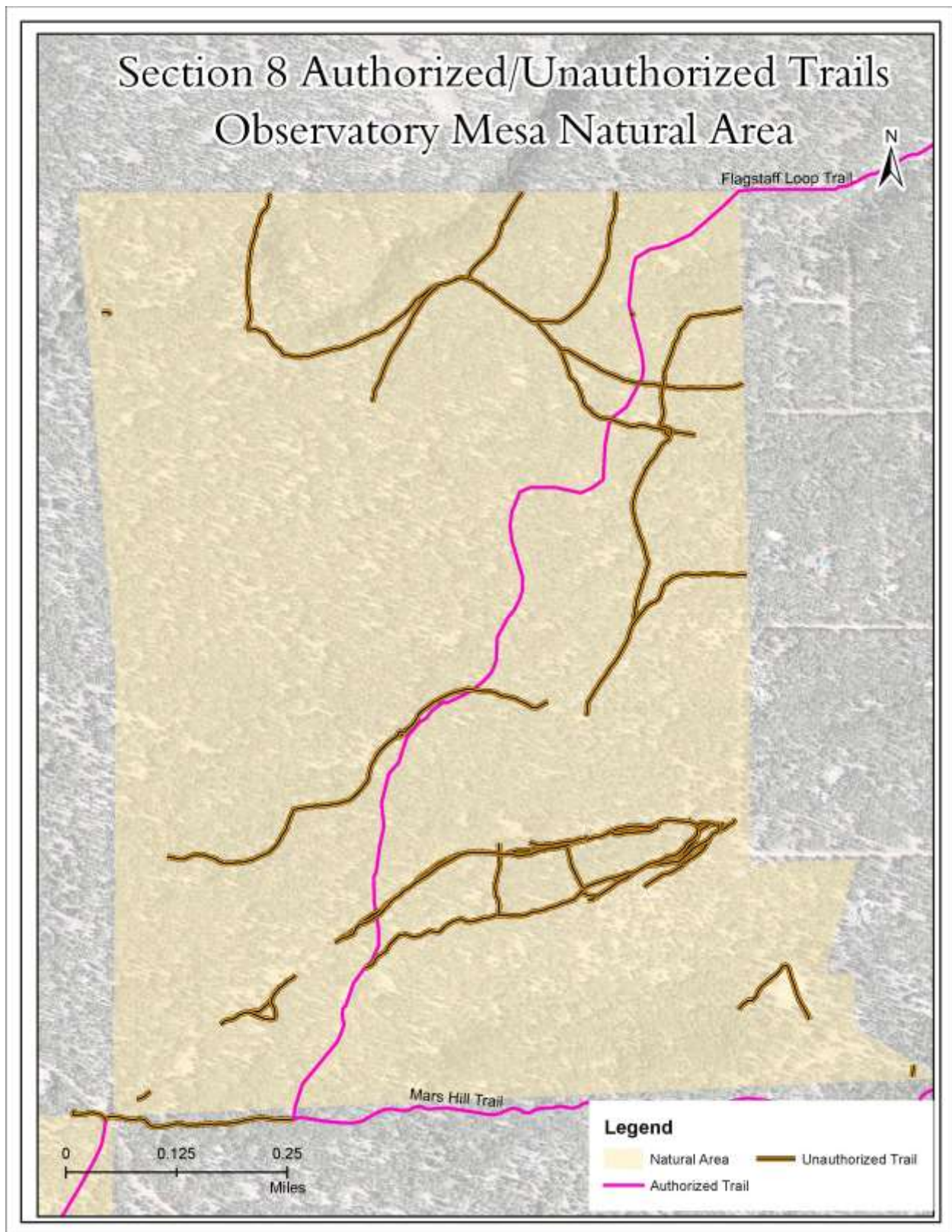
Figure 37: Section 12 trails on Observatory Mesa Natural Area. Source: Author

Figure 38: Section 12 roads on Observatory Mesa Natural Area. Source: Author

4.1.1.5 Section 18 (Observatory Mesa Natural Area) Results

Section 18, the southernmost section on Observatory Mesa Natural Area, contains several trash piles and points of interest as shown in Figure 39. Figure 39 shows the City of Flagstaff where certain areas need to be cleaned and patrolled for transients. Since the trails cannot be seen in Figure 39, Figure 40 displays all the trails that exist on Section 18. Section 18 only has one authorized trail – Tunnel Springs Trail. Like Section 12, Section 18 has had a significant amount of tree thinning for the Flagstaff Watershed Protection Project. Because of this project, several unauthorized roads have been created and the existing roads have been highly degraded (shown in Figure 42). According to the ground data collection, no unauthorized roads exist in Section 18 (shown in Figure 41).
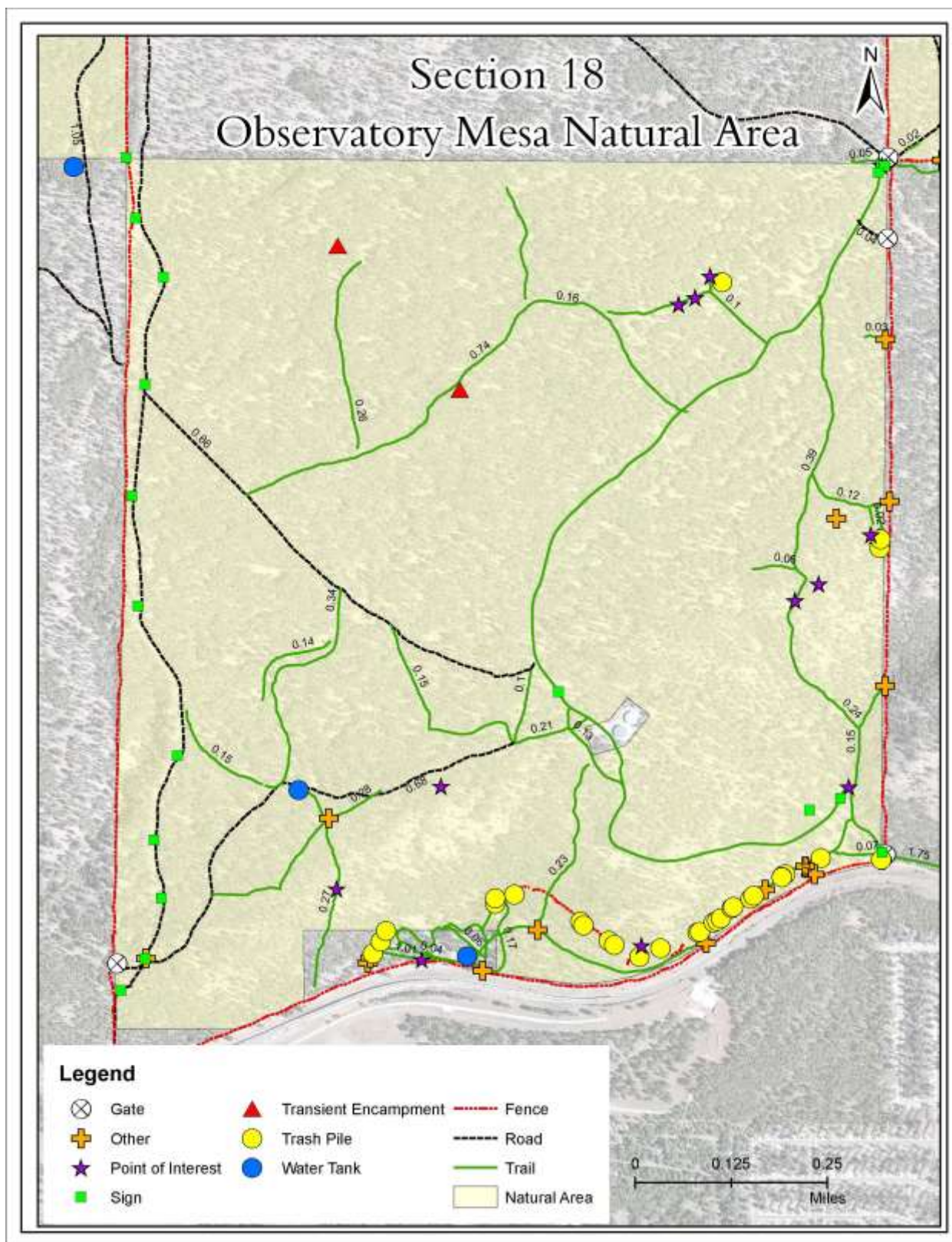
Figure 39: Overview map of Section 18 on Observatory Mesa Natural Area. Source: Author

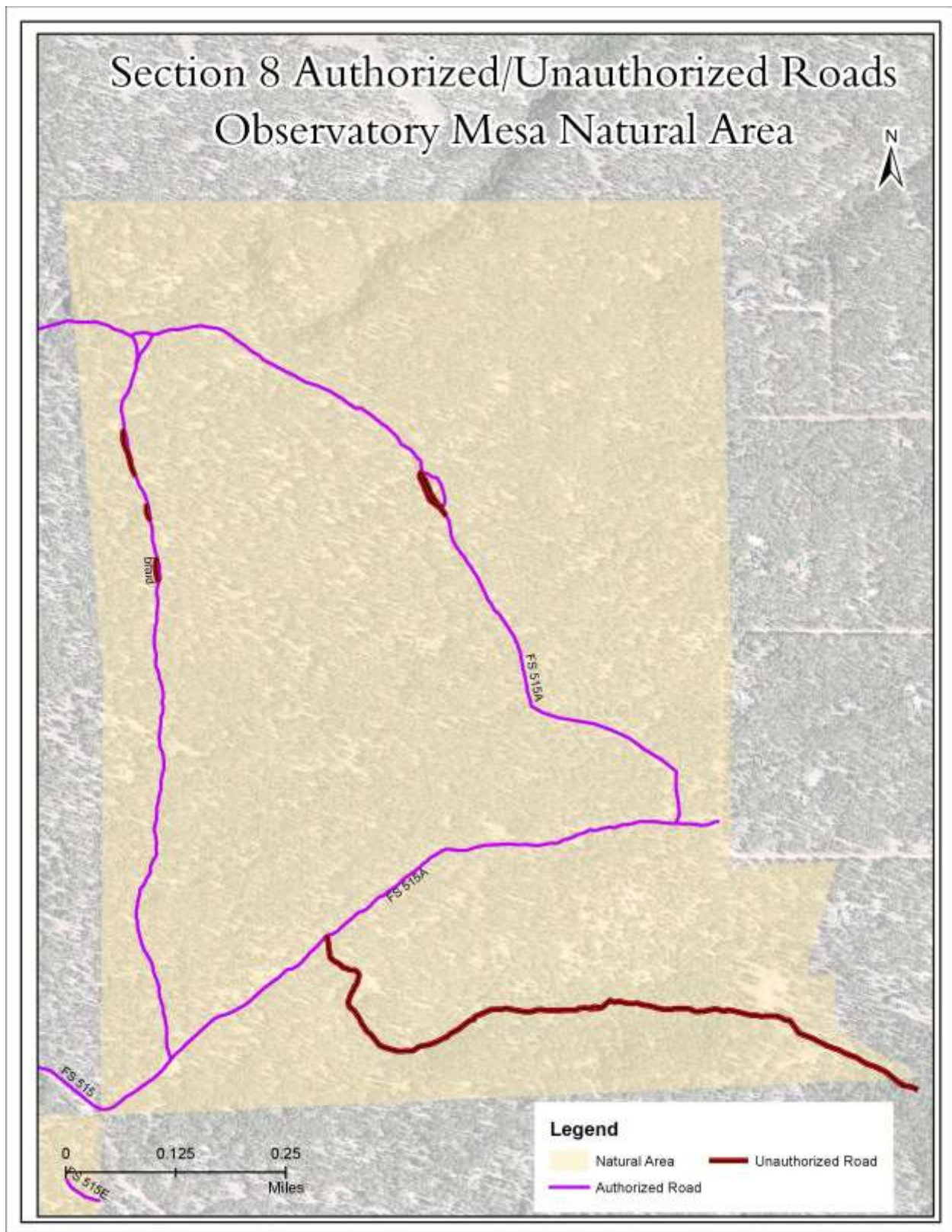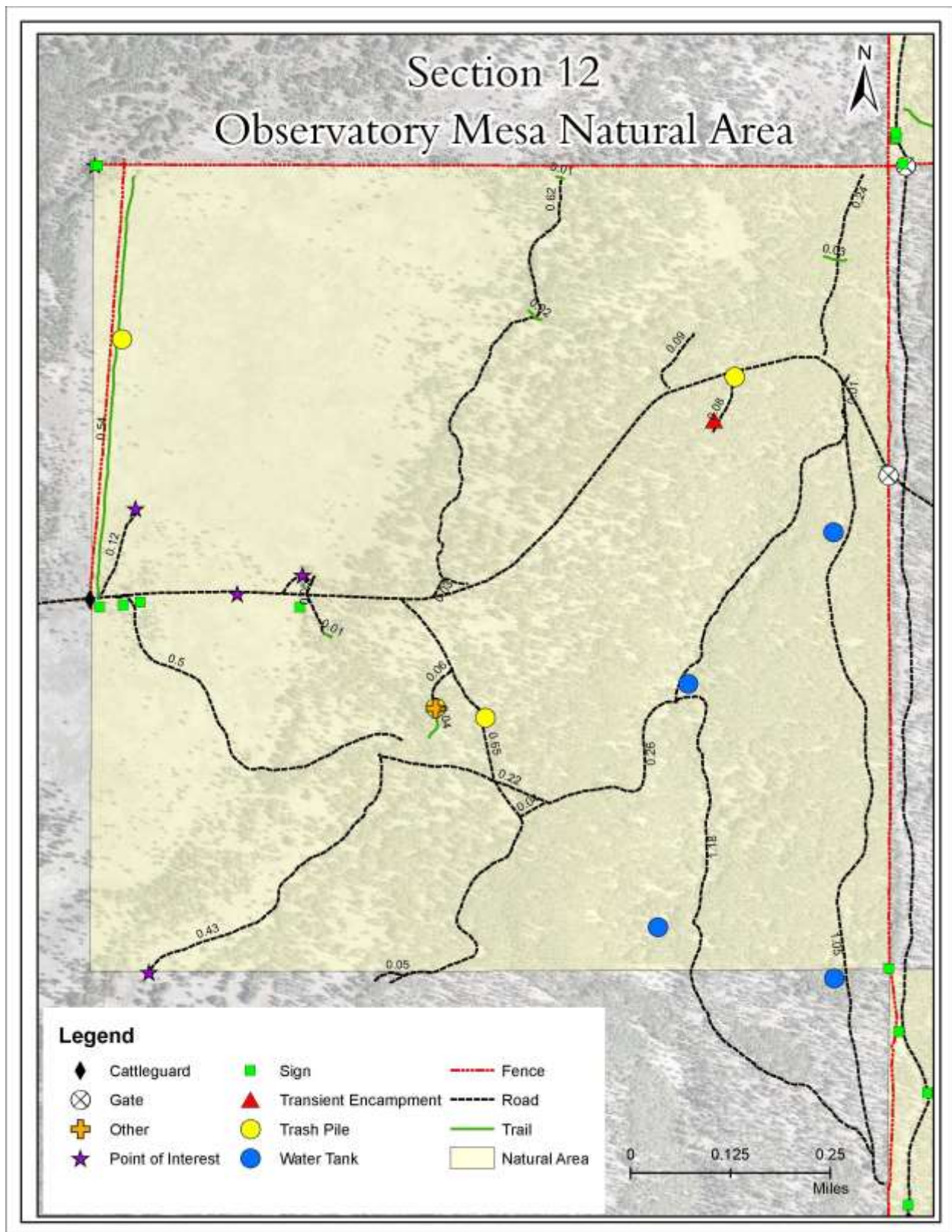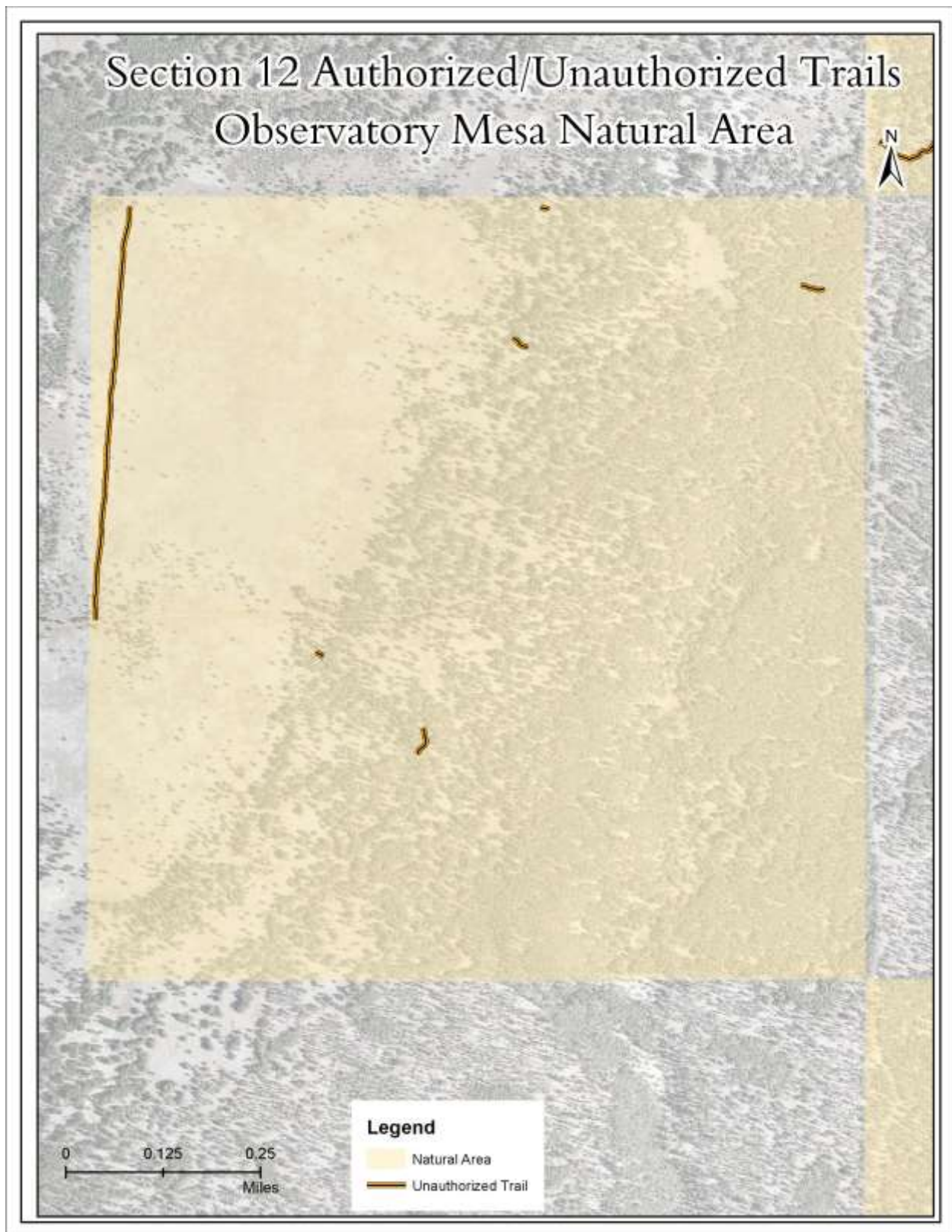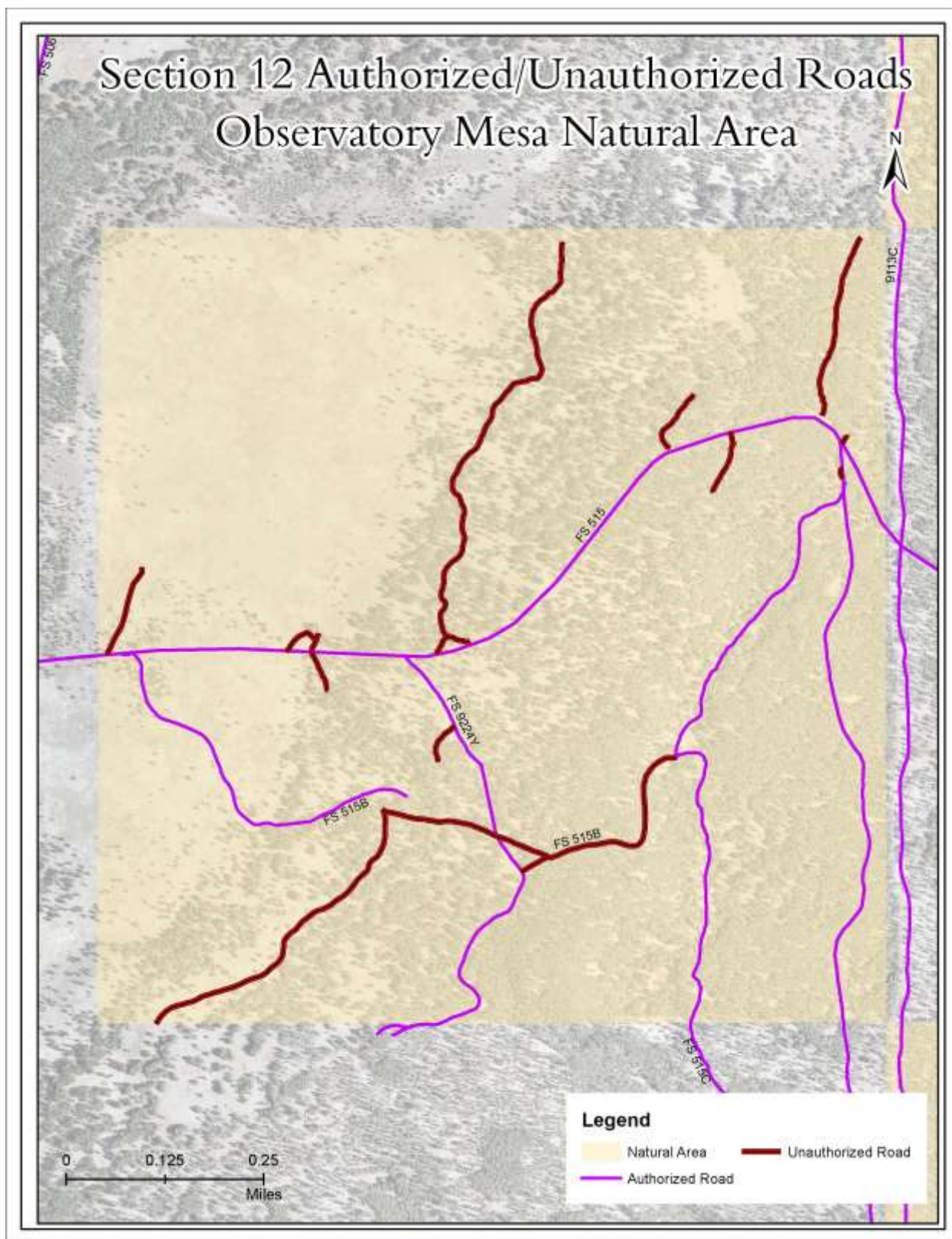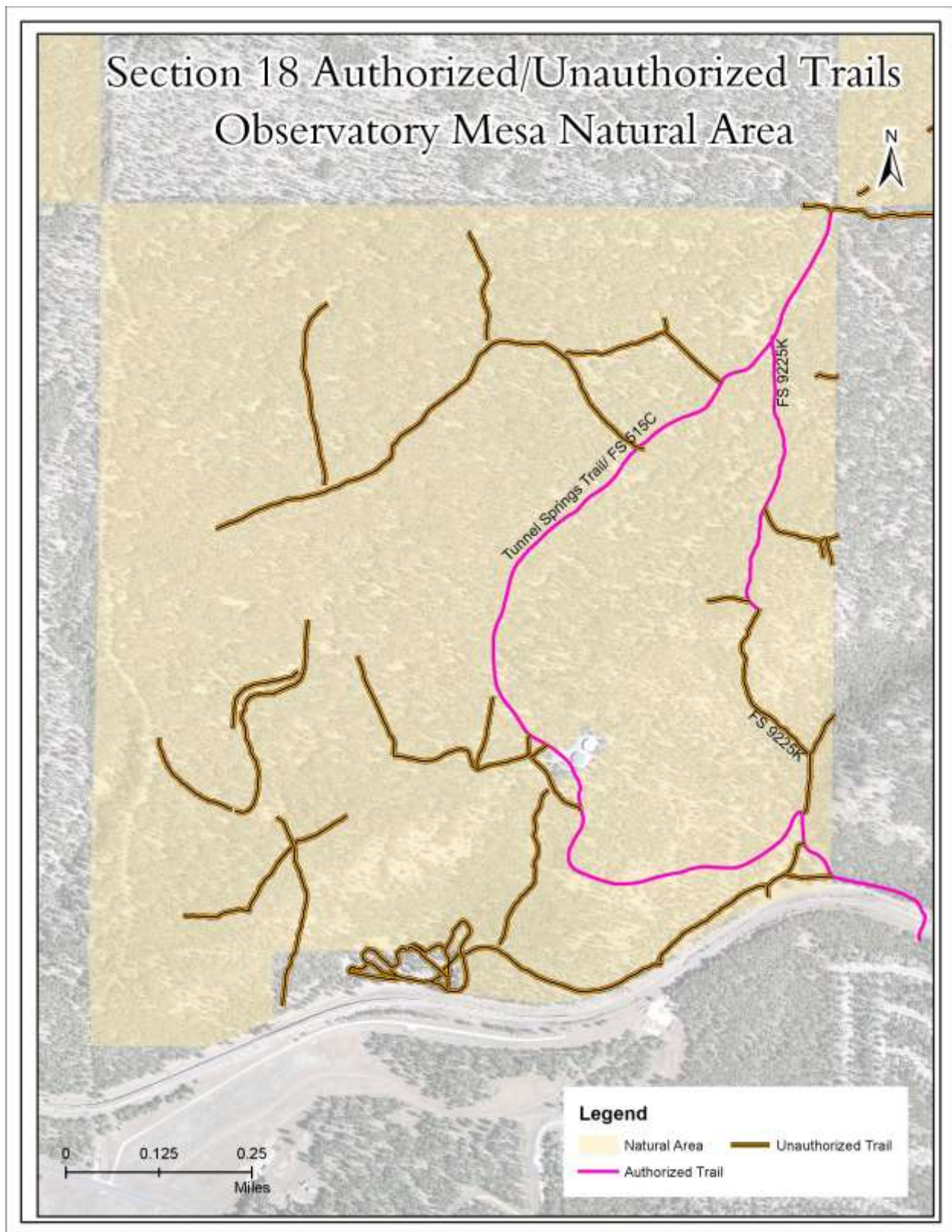*Figure 40: Section 18 trails on Observatory Mesa Natural Area. Source: Author*
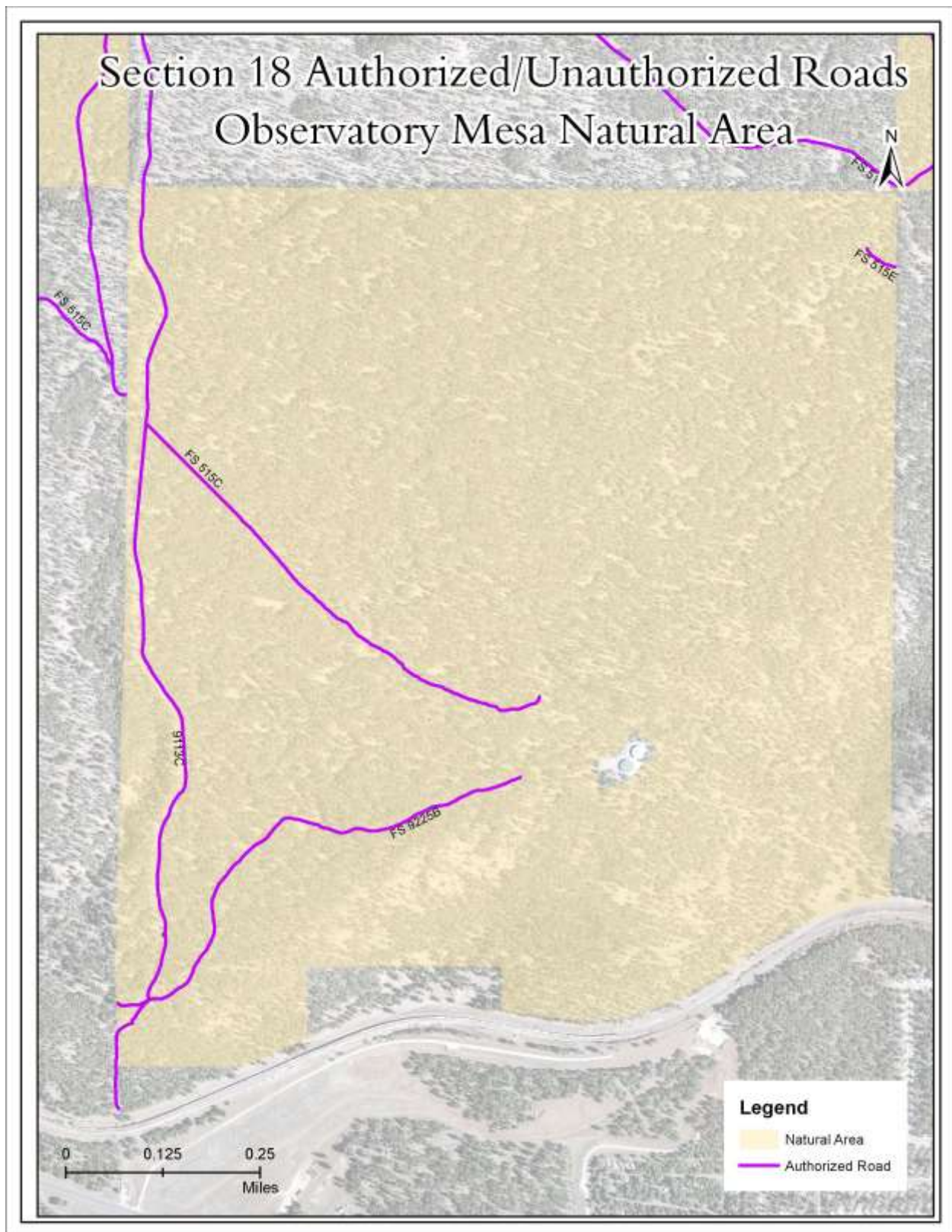
Figure 41: Section 18 roads on Observatory Mesa Natural Area. Source: Author
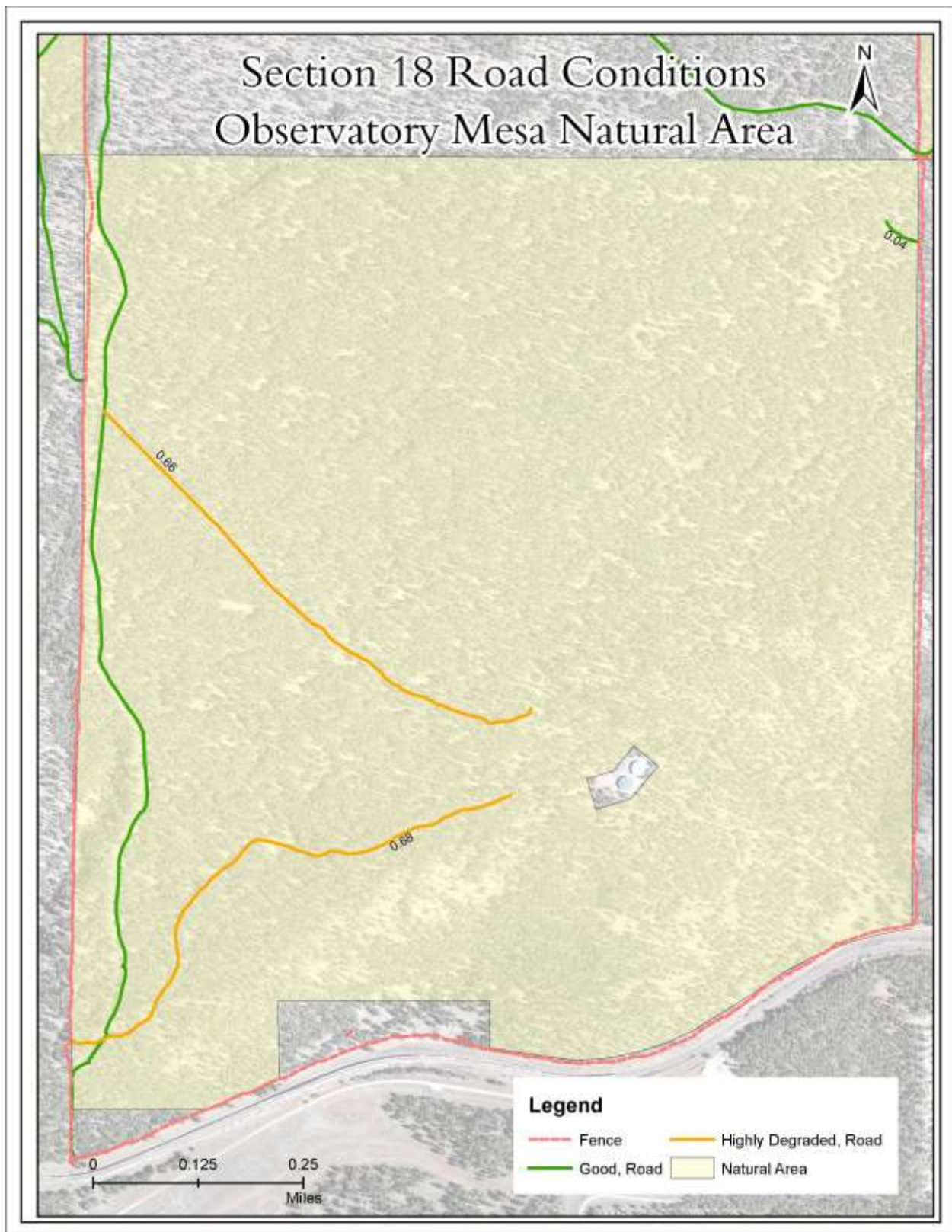
Figure 42: Section 18 road conditions on Observatory Mesa Natural Area. Source: Author

4.1.2 Remote Sensing Results

Within this section, all the results for the various remote sensing classification techniques are displayed. Since the producer and users need to know how the accuracy of the remote sensing results, this section also has the accuracy assessment error matrix and land cover area percentage tables. This section concludes with a discussion for the results for this part of the thesis.

4.1.2.1 Classification

As stated in Chapter Three, several different classification tools were used in the ENVI software. The segmentation tool was the first classification technique to display the travel networks. NDVI values of 0.075 to 0.16 were used in the segmentation tool to extract the corridors. As one can see in Figure 43, several linear features appear where a road or trail exists. However, Section 6 is missing nearly all its roads and trails. In addition, several ground vegetation pixels were picked up in the segmentation—therefore, many dots appear around the roads and trails.

Figure 43: Segmentation tool output

Once the segmentation tool was ruled out, an unsupervised classification was performed

to see if the computer could find three land cover classes in the NAIP imagery. Figure 44

displays the result of the unsupervised classification with three land cover classes.

Unfortunately, this output does not display any linear features nor does it properly show three

different land cover classes.
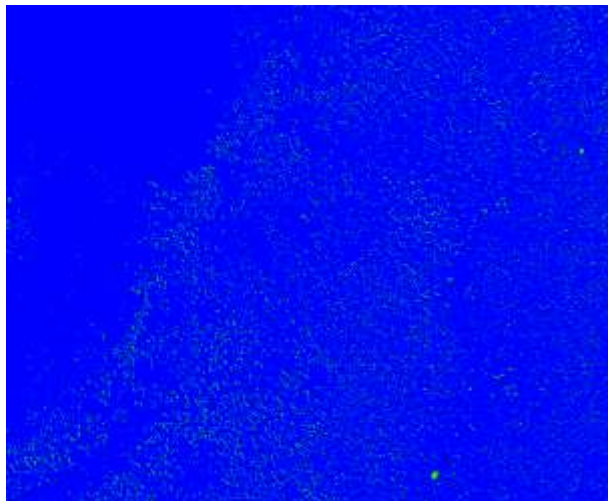
Figure 44: Unsupervised classification with three classes

After reading the literature, a parallelepiped classifier was performed since it is very fast to run. As shown in Figure 45, the parallelepiped classifier could detect Forest Service Road 515 within Section 12. However, there are several black, unclassified pixels within Figure 45. Though this method was the best so far, the maximum-likelihood classifier will be used to see if the unclassified pixels can be classified.
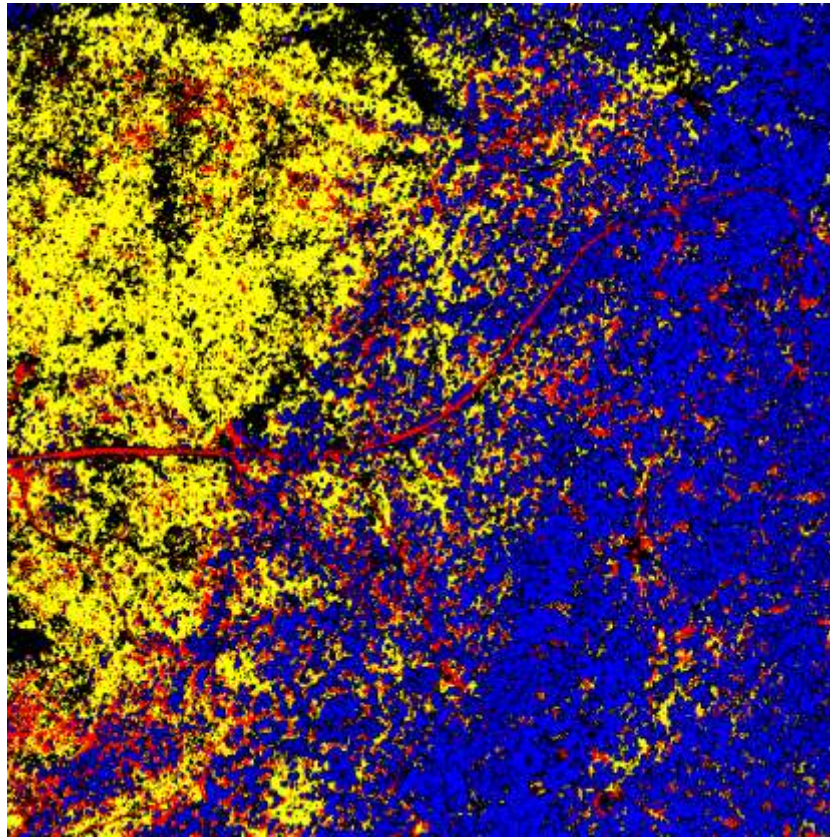
Figure 45: Parallelepiped classification

The maximum-likelihood classifier displayed the best results when compared to the segmentation tool, parallelepiped classifier, and the unsupervised classification. Figure 46 displays the final image classification for the entire Observatory Mesa Natural Area.

Figure 46: Supervised classification of Observatory Mesa Natural Area. Source: Author

Figure 47 shows the maximum-likelihood supervised classification output for Section 6. One can see that the Forest Service Roads appear within the classification. However, the southernmost road, Forest Service Road 515A is very faint and might be covered by trees.

Figure 48 shows the maximum-likelihood supervised classification for Section 8. One can see the main corridor, Forest Service Road 515, very well. One might faintly see the other roads that connect to Forest Service Road 515 to the north. However, it is rather difficult to find the unauthorized road that meets Forest Service Road 515 to the south.

Figure 49 displays the results of the maximum-likelihood classifier for Section 12 on Observatory Mesa Natural Area. Like Figure 48, one can easily find Forest Service Road 515 through the middle of the property. Likewise, other roads such as 9013L, 9224Y, and some of 515C and 515D appear in the classification. The large open area that appears in the northwest section of the property is also properly classified as ground vegetation. There are a few areas where pixels are classified as a travel network. However, one may see that these pixels do not fit within a linear feature.

Figure 50 shows the maximum-likelihood classifier for Section 18 on Observatory Mesa Natural Area. One can find the Forest Service Road 9113C that runs north to south on the west side of the parcel. Unfortunately, Tunnel Springs Trail is very hard to see within this classification as well as Forest Service roads 515C and 9225B. Since the NAIP imagery is from 2015, it is possible that it might not include the recent tree thinning for the Flagstaff Watershed Protection Project.
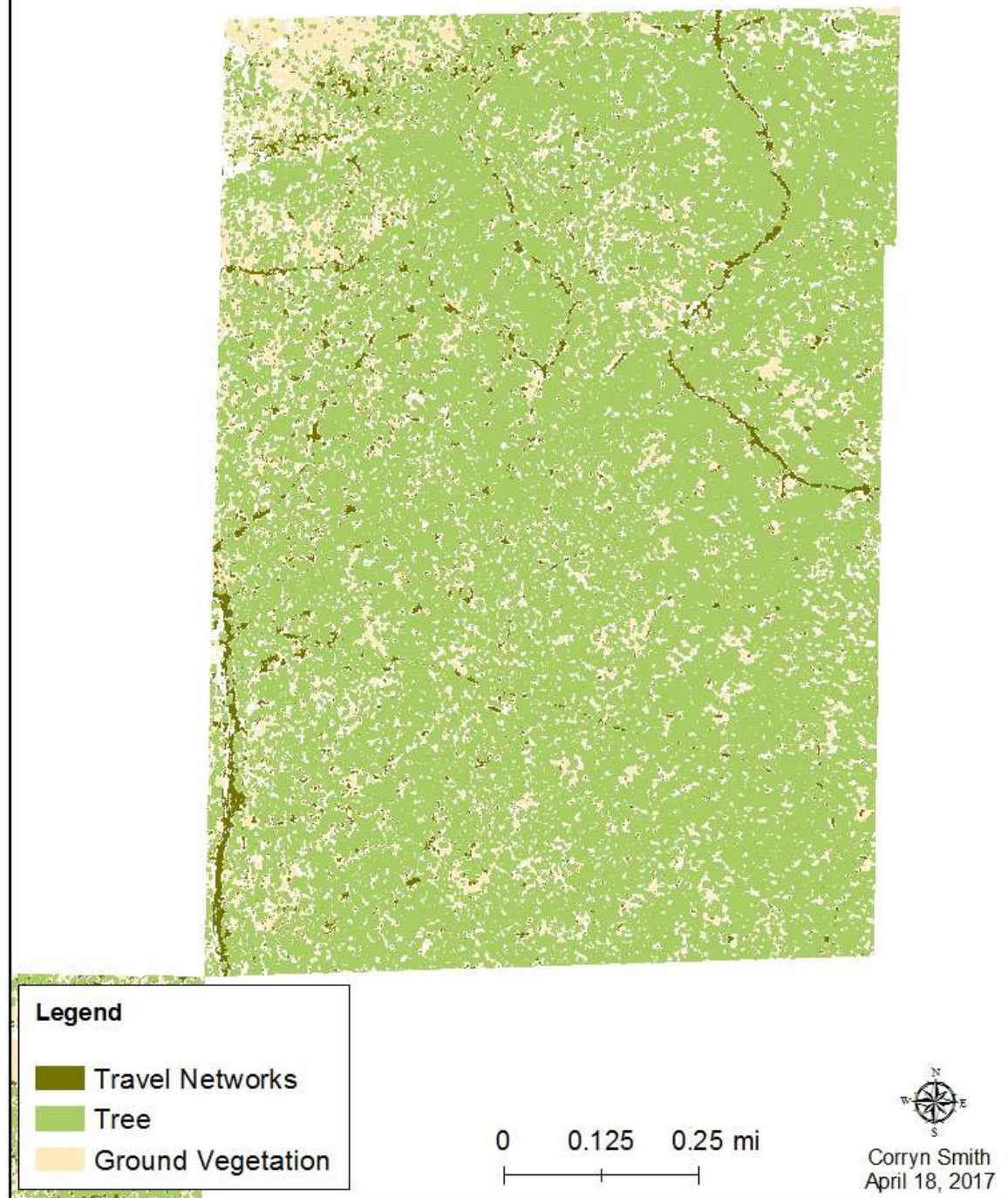
Figure 47: Supervised classification of Section 6. Source: Author
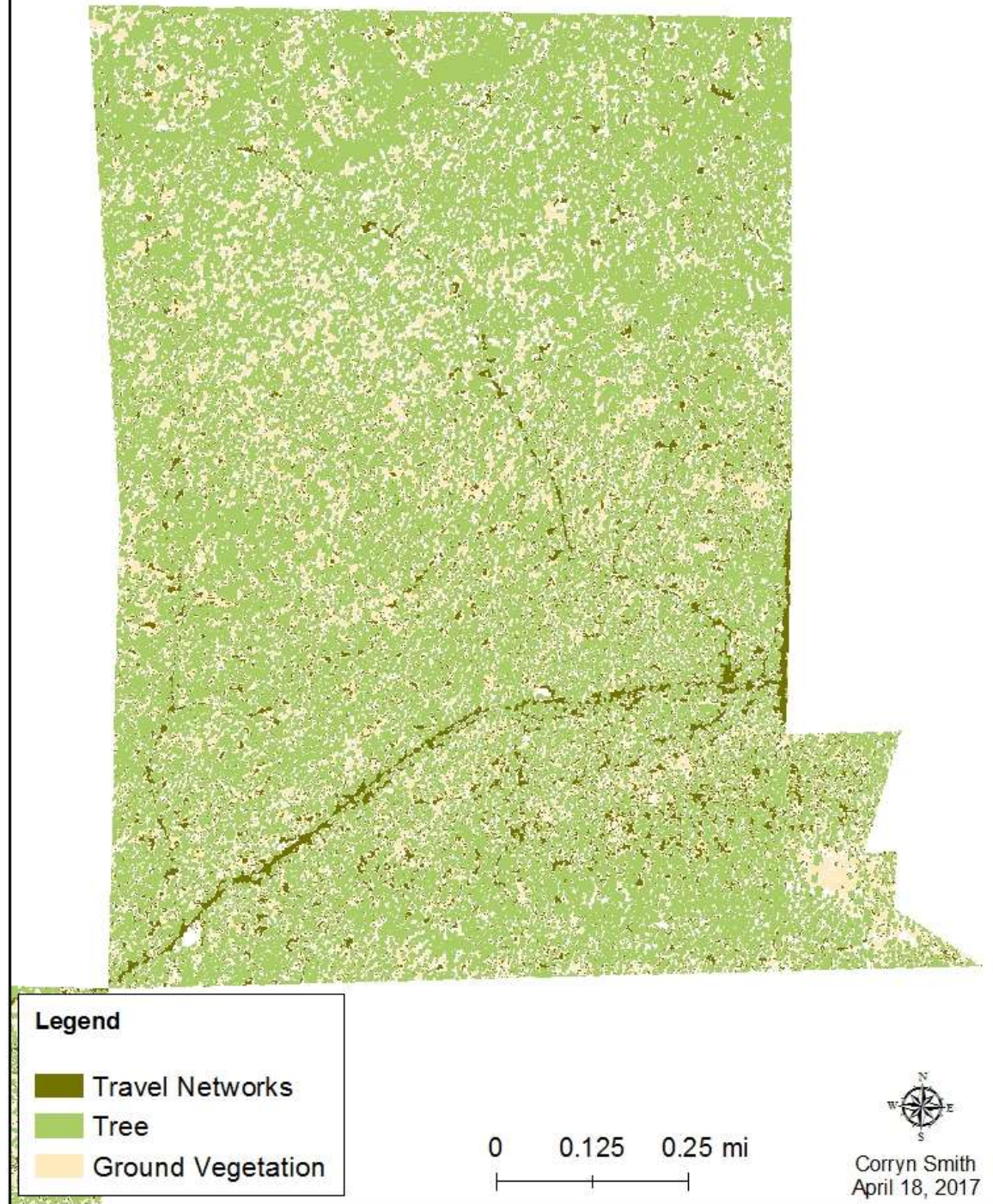
Figure 48: Supervised classification of Section 8. Source: Author
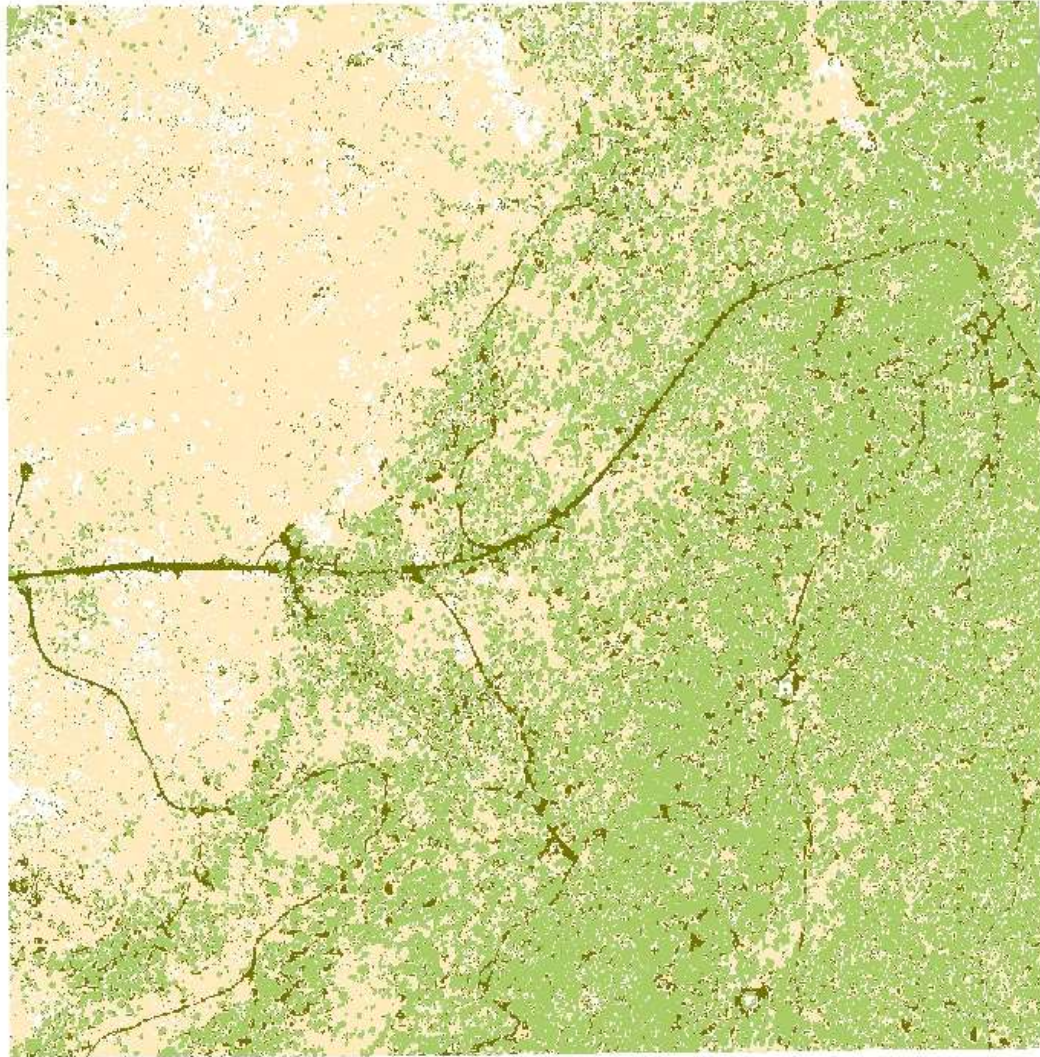
Figure 49: Supervised classification of Section 12. Source: Author
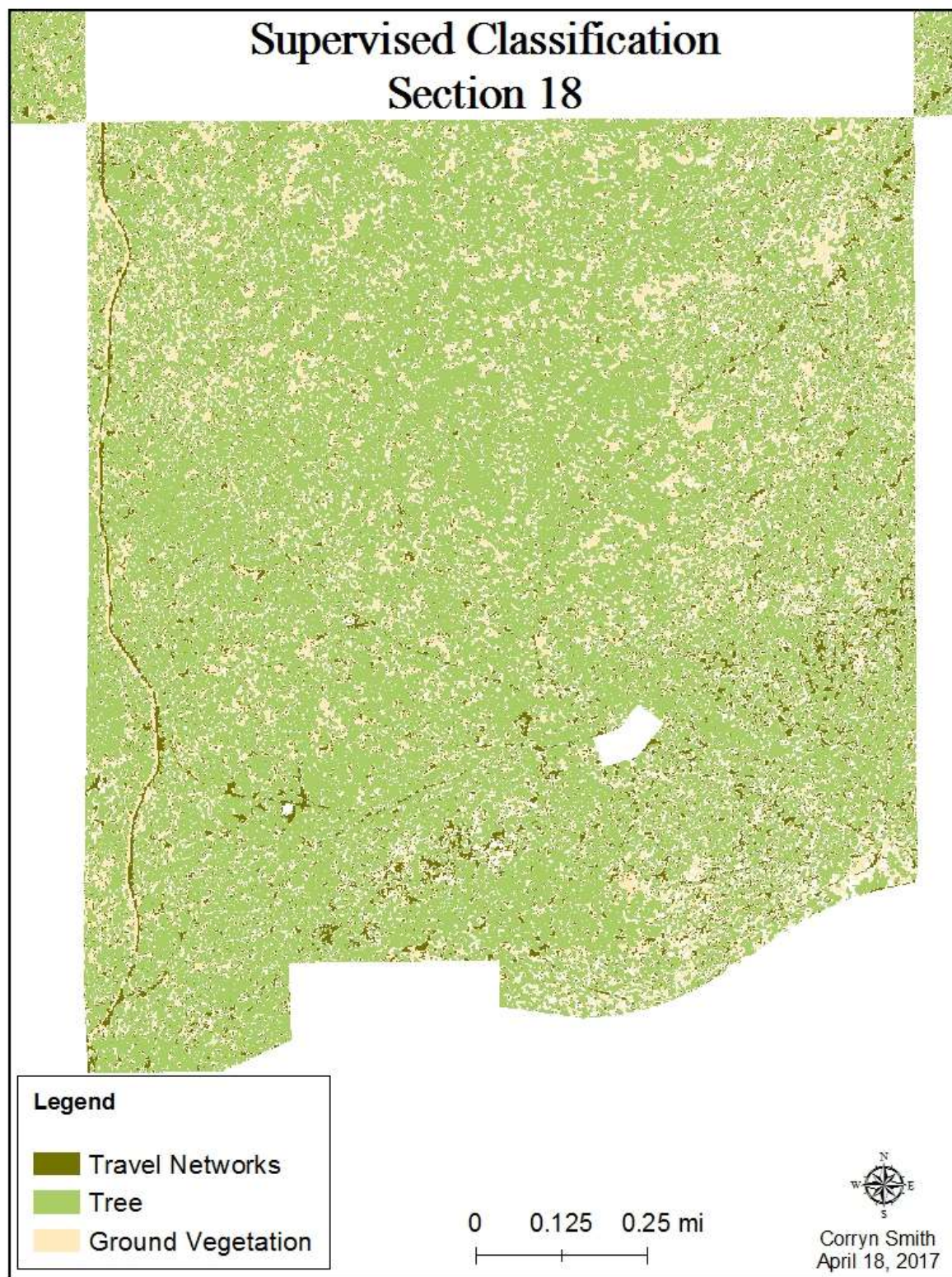
Figure 50: Supervised classification of Section 18. Source: Author

Once the supervised classification is complete, users can run statistics within ENVI's software to find out the percent coverage for each land cover class. As shown in Table 2, unclassified pixels, or pixels that could not be grouped in one of the three classes as defined in the training data, take up over two-thirds of the property. After looking at the results, ENVI accounted for Forest Service Section 7, the parcel in the middle of Observatory Mesa Natural Area, as all unclassified since the imagery was excluded during the remote sensing process. Nevertheless, one can see that trees make up much of the land cover within Observatory Mesa Natural Area.

Table 2: Land Cover Coverage derived from Supervised Classification Maximum Likelihood for Observatory Mesa Natural Area

Land Cover Class	Percent Coverage
Unclassified	68.32%
Travel Networks	2.15%
Tree/Forest	22.90%
Ground Vegetation	6.63%

4.1.2.2 Accuracy Assessment

For the accuracy assessment, 300 random points were produced by ENVI. The points were then exported out as shapefiles, so the accuracy assessment could be performed in ArcMap. Figure 51 shows the distribution of random points. Yellow represents ground vegetation pixels, red represents travel network pixels, and blue represents tree pixels.
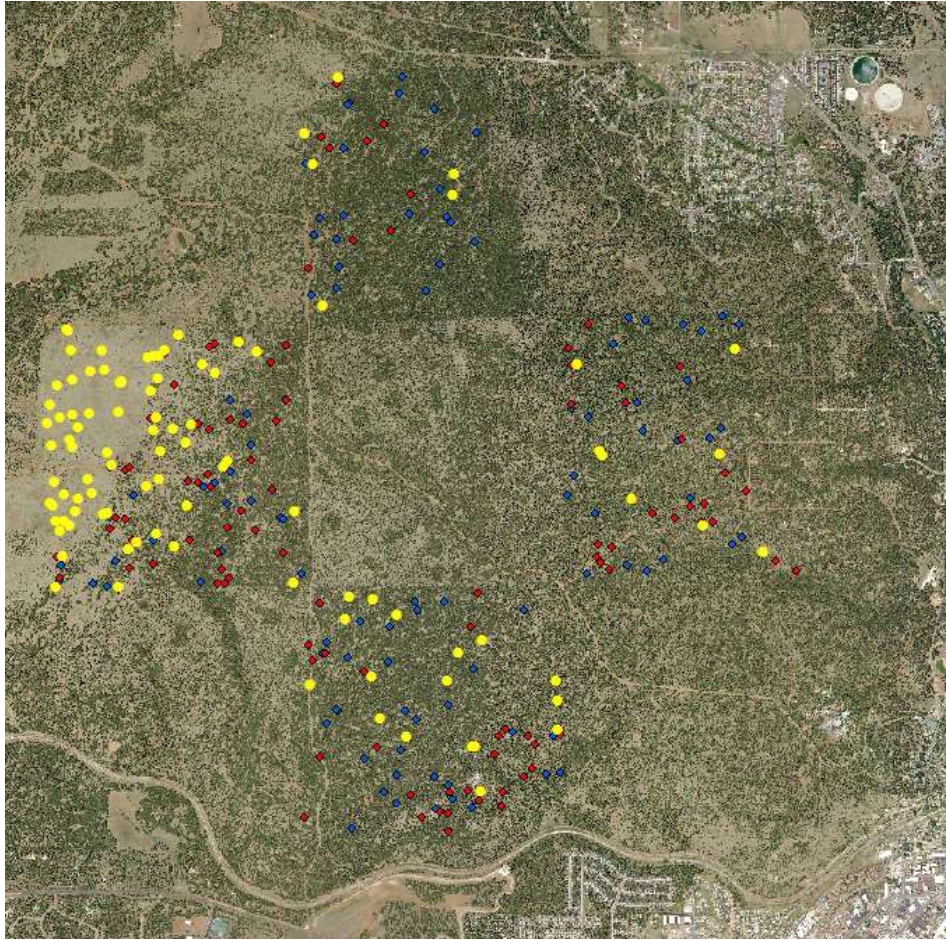
Figure 51: Random points for accuracy assessment on Observatory Mesa Natural Area. Source: Author

According to Congalton and Green (1999), accuracy assessments are best expressed in an error matrix. The error matrix compares the reference data, or ground collected data, to the classified data, or data derived from remote sensing techniques. The column land cover classification represents the reference data and the rows represent the classified data. The overall accuracy is the sum of the correctly classified pixels divided by the total number of pixels. Table 3 shows that 219 out of 300 pixels were correctly classified in the maximum-likelihood classifier. Therefore, the remote sensing technique has an overall accuracy of 73%.

Table 3: Error Matrix for Observatory Mesa Natural Area

Land Cover Class	Ground Vegetation	Trees	Travel Networks	Total Row
Ground Vegetation	**97**	0	3	100
Trees	3	**96**	1	100
Travel Network	73	1	**26**	100
Total Column	173	97	30	219

Overall Accuracy = 73%

Producer's and user's accuracy are another technique to find the accuracies for individual land cover classes instead of just the overall accuracy (Congalton & Green, 1999). The producer's accuracy describes how accurate the classification correctly classified pixels during the remote sensing process. For producer's accuracy, one takes the number of correct sample units and divides by the total number of sample units as indicated by the reference data (total column). For example, ground vegetation had 97 correctly classified pixels and 173 total pixels were classified as ground vegetation. Therefore, ground vegetation had a 56% producer's accuracy.

User's accuracy determines the accuracy of what appears on the ground. For this equation, one takes the total number of classified pixels and divided by the total number of pixels that are classified as that class (total row). For ground vegetation, 97 pixels were correctly classified and 100 total pixels were classified as ground vegetation. Therefore, user's accuracy for ground vegetation is 97% accurate. When looking at ground vegetation, the producer can claim that 56% of the time an area that was ground vegetation will appear as ground vegetation on map, and a user of the final map will find 97% of the time the map says an area is ground vegetation will be ground vegetation in the field. Table 4 displays the producer's accuracy and user's accuracy for all three land cover classifications.

Table 4: Accuracies for each land cover class for Observatory Mesa Natural Area

Land Cover Class	Producer's Accuracy	User's Accuracy
Ground Vegetation	56%	97%
Trees	99%	96%
Travel Networks	86%	26%

4.1.2.3 Remote Sensing Results Discussion

The accuracy assessment results were higher than expected. Nevertheless, the user's accuracy for the travel networks were very poor at 26%. When looking at the maximum likelihood supervised classification results, one can see that the algorithm over-classified the travel networks. When going forth with this project idea, the lack of literature and methods of extracting travel networks made it evident that there was a chance of this procedure not working at all. According to Shahi et al (2015), "road extraction is challenging" when it comes to remote sensing applications. Extracting travel networks with satellite and aerial imagery may be difficult due to spatial and spectral resolution. Likewise, travel networks may be hidden in shadows or can be difficult to see in thick vegetation. Nevertheless, roads and trails are important features when it comes to land management planning, and such features should be kept up to date (Rajeswari et al., 2011).

Moreover, the final maximum likelihood classification highlights most Forest Service Roads that are located on the Observatory Mesa as well as Flagstaff FUTS trails. Though using remote sensing techniques was a little challenging, the overall accuracy of the project ended up being 73%. For a land manager, the high accuracy of trees and ground vegetation are significant. However, the low travel network accuracy of 26% may not be helpful. In this situation, it is possible for a land manager to pay extra money and spend more time surveying and collecting ground data with a GPS than using imagery to locate travel networks.

4.2 Lowell Observatory

4.2.1 Remote Sensing Result

In this section, the supervised classification map composition of Lowell Observatory

Section 17 is displayed with the same three land cover classifications: tree, ground vegetation,

and travel networks. Along with the map composition, the accuracy assessment matrix and

tables are shown in Chapter 4 Section 2.1.1. Lastly, this section has a more in-depth results

discussion section due to the overclassified pixels.

4.2.1.1 Supervised Classification

Since the maximum-likelihood classifier displayed the best classification results on

Observatory Mesa Natural Area, the same classifier was used for Lowell Observatory. When

looking at Figure 52, one can see the main road that runs through the center of the parcel. Other

sections of roads and trails are visible on the map. However, Mars Hill Trail is still very faint

and is hard to see in the classification. In addition, there is an abundance of overclassified travel

network pixels in the lower left corner above the railroad track.

Figure 52: Supervised classification Lowell Observatory Section 17. Source: Author

ENVI's statistics were ran on the Lowell Observatory classification output to determine the land cover class percent coverage for the parcel. As one can see in Table 5, trees cover almost half of the parcel, and ground vegetation cover a little over a quarter.

Table 5: Land Cover Coverage on Lowell Observatory Section 17

Land Cover Class	Percent Coverage
Unclassified	13%
Travel Networks	10%
Tree/Forest	49%
Ground Vegetation	28%

4.2.1.2 Accuracy Assessment

Figure 53 shows the 75 random points within Lowell Observatory for the accuracy assessment. One may see that only a few points out are located on a travel network. Because the distribution of random points is not equalized, the accuracy for travel networks will not a correctly represented.
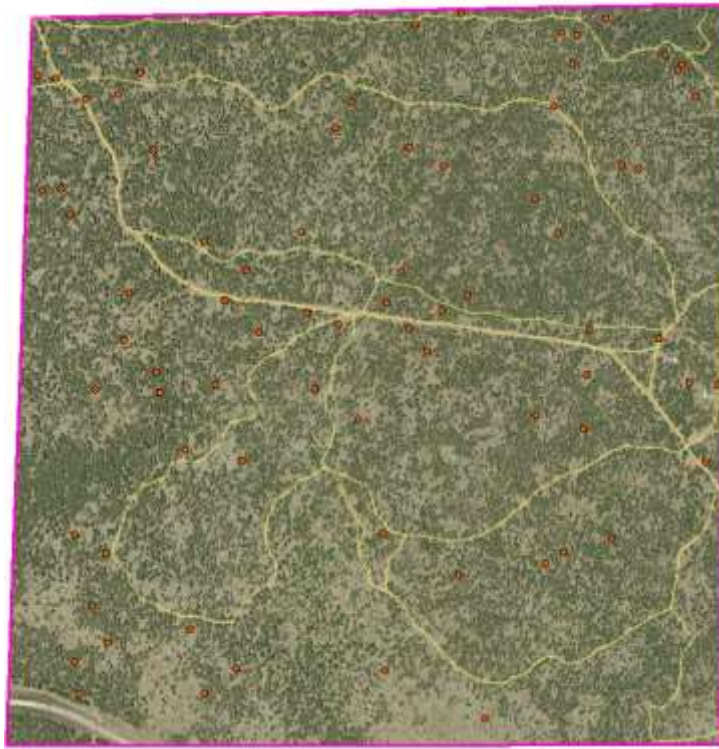
Figure 53: 75 Accuracy assessment points compared to GPS collected travel networks on Lowell Observatory. Source: Author

The 75 points were assessed for accuracy even though the travel network points were very few. Using the same techniques as Observatory Mesa Natural Area, Table 6 displays the Error Matrix for the initial 75 points. In addition, Table 7 displays the producer's and user's accuracy for the three land cover classifications.

Table 6: Error Matrix for Lowell Observatory Section 17

Land Cover Classification	Tree	Ground Vegetation	Travel Networks	Total Row
Tree	**49**	2	0	51
Ground Vegetation	1	**19**	3	23
Travel Networks	0	0	**1**	1
Total Column	50	21	4	75

Overall Accuracy 92%

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Table 7: Accuracies for each land cover class for Lowell Observatory Section 17

Land Cover Classification	Producer's Accuracy	User's Accuracy
Tree	98%	96%
Ground Vegetation	90%	83%
Travel Networks	25%	100%

As mention in the methods, an accuracy assessment on only the travel network land cover classification was performed to see what the true accuracy may be for that land cover class. In Table 8, the count of random points were all pixels that were classified as a travel network from the remote sensing classification. The travel network accuracy displays the percentage of pixels that are a travel network on the ground. Notice that with a sixty-point increase, the accuracy is almost the same.

Table 8: Lowell Observatory Travel Network Accuracy

Count of Random Points	Travel Network Accuracy
60	5%
120	6%

4.2.1.3 Remote Sensing Results Discussion

As stated in the methods section for Lowell Observatory (Chapter 3 Section 3.2.2), Mars Hill Trail (part of FUTS) was not properly classified from the first round of supervised classification. Therefore, nineteen additional training samples were selected to enhance the maximum likelihood supervised classification. With these additional nineteen samples, Mars Hill Trail finally appeared in segments. However, when the additional nineteen samples were selected, it also increased the amount of travel network classified pixels throughout Lowell Observatory. In this case, the maximum likelihood classifier over-classified the amount of travel network pixels within Lowell Observatory. While in the field, one may notice the color

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similarities of the travel networks and ground vegetation. Due to the nearby pine trees, both

travel networks and ground vegetation may be covered with brown pine needles. When both

land cover classes are covered in the same material, it is easy for both to be identified as the

same land cover class when running remote sensing methods.

When examining the classification output, one can see "salt and pepper" noise – a

speckled appearance of "misclassified isolated pixels" (ESRI, 2016). To remove salt and pepper

noise, one can use tools within the Generalization toolset in ArcMap Desktop. Under this

toolset, the Majority Filter tool was used to remove any isolated pixels from the supervised

classification. Afterwards, the result from the Majority Filter tool was ran through the Boundary

Clean tool to smooth out edges and to lump pixels together. The output of the Boundary Clean

tool gave the travel networks a smoother look within the classification and re-classified small salt

and pepper noise (see Figure 54). Nevertheless, the Majority Filter and Boundary Clean tools

did not erase all the over-classified travel network pixels (see Figure 55).
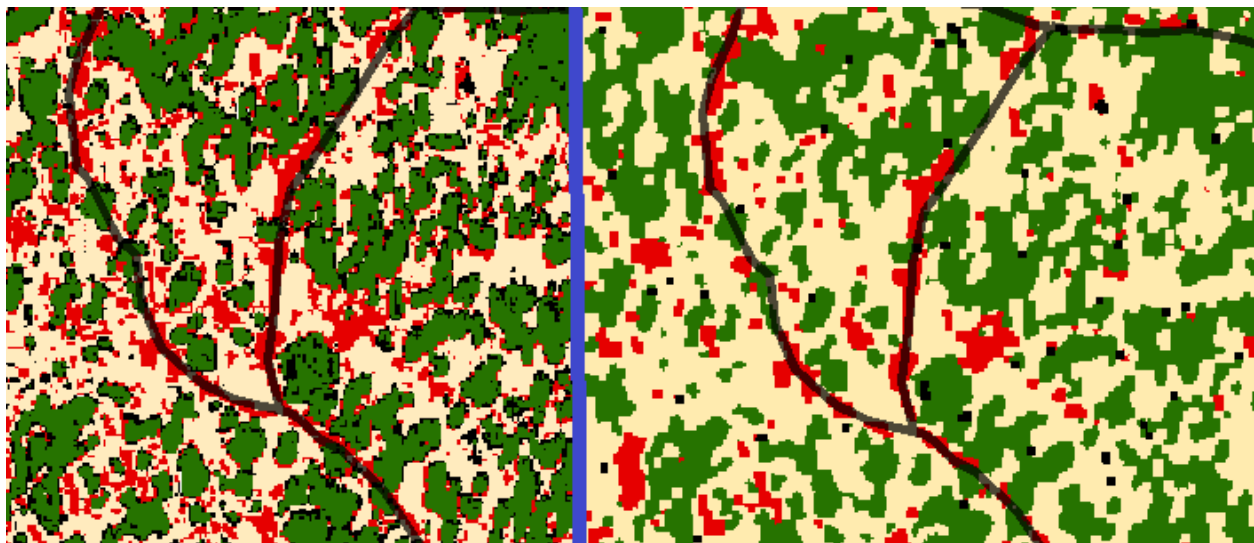
*Figure 54: **Left:** Before Post-Processing **Right:** After Post-Processing. Source: Author*
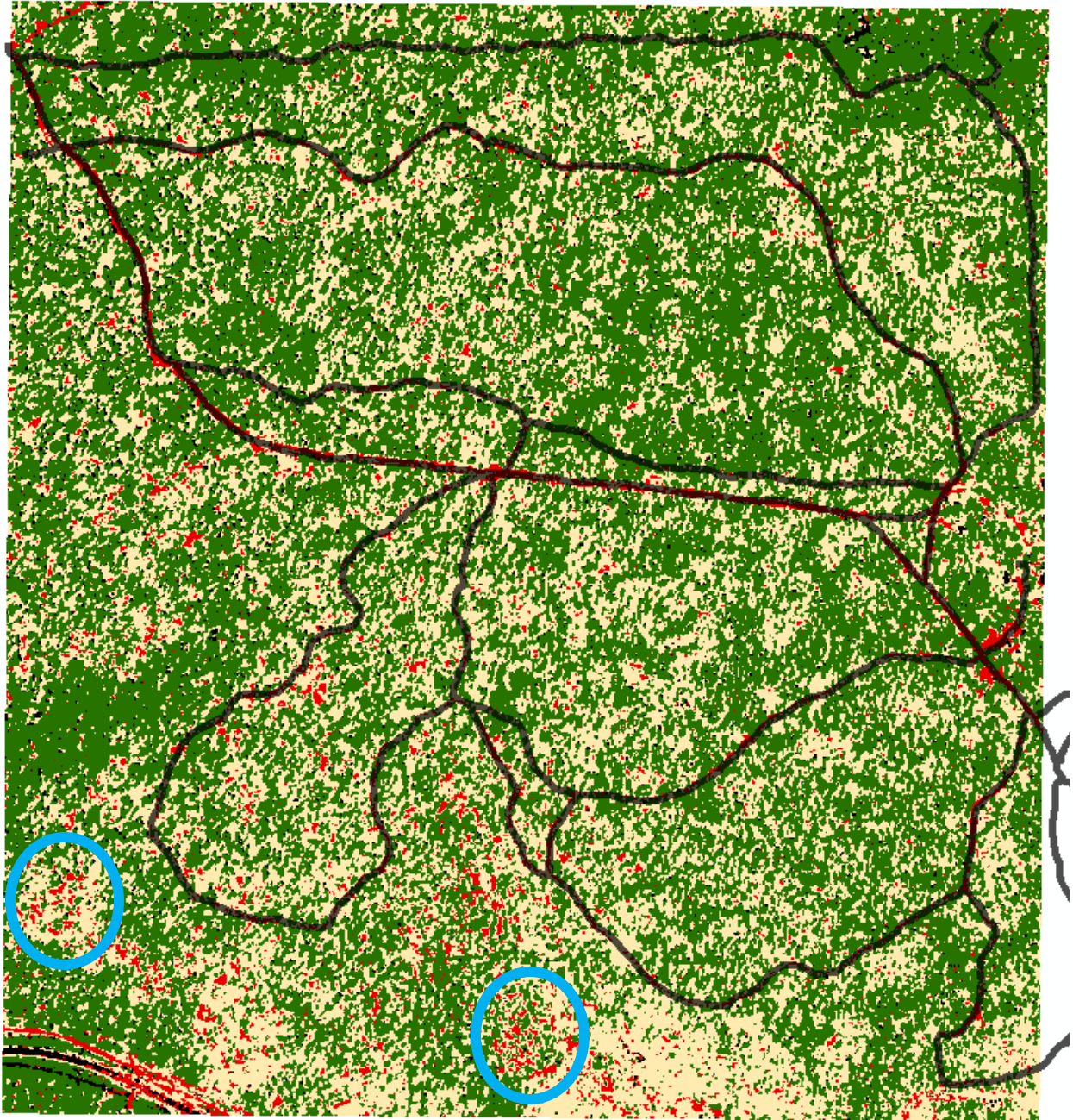
Figure 55: Over-classified travel network pixels circled in blue after post-processing. Source: Author

Since there were several pixels over-classified as a travel network, this skewed the

accuracy assessment. Since the accuracy for the travel networks were not properly

acknowledged in the first assessment, an additional assessment took place on only pixels

classified as a travel network. Sixty random points classified as a travel network were assessed.

These sixty points declared the accuracy of the travel networks were 5%. The sample of random

points were doubled to 120. Once again, the accuracy for the travel networks were 6%. Since

there were many over-classified pixels, this made the accuracy very poor for the travel networks.

When examining the supervised classification, one can identify areas that represent trails (see

Figure 56) while other areas appear as misclassified information (see Figure 57).
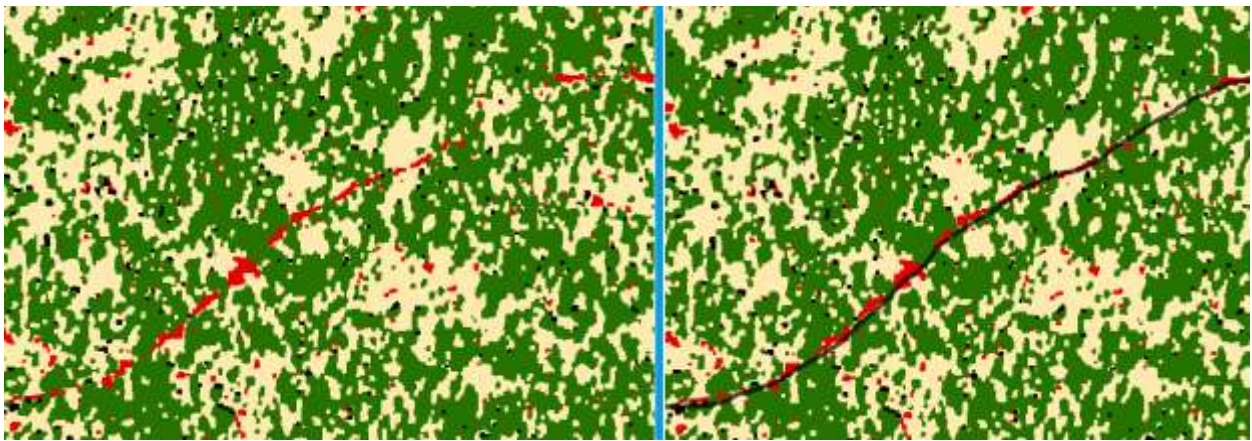
*Figure 56: **Left:** Classified Travel Network **Right:** Classified Travel Network with GPS Travel Network. Source: Author*
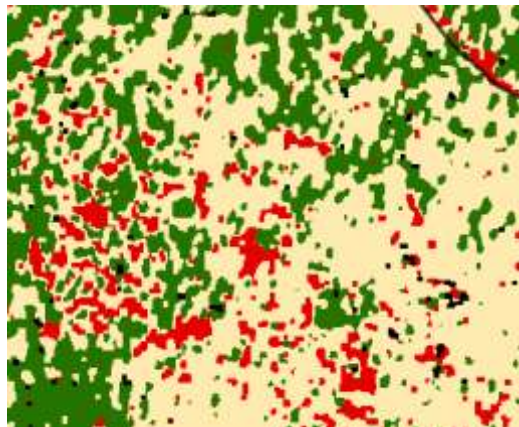
Figure 57: Overclassified travel network pixels. Source: Author

4.2.2 Lowell Observatory Ground Data Collection Results

Roads and trails were collected with a Garmin eTrex 20x unit. The data was uploaded onto ArcMap Desktop and then displayed on a map. Figure 58 shows the routes that were collected for this thesis. According to the Proposed Observatory Mesa Acquisition Area map (Appendix B), only Forest Service Road 515E and Mars Hill Trail appear on Lowell Observatory. Figure 59 displays Forest Service Road 515E and Mars Hill Trail in a different color. One can notice that there is an entire travel network system south of FS 515E. Since the Section 17 boundary was not on the GPS unit, a few trails were collected outside of the study section. As one can see, there are several roads and trails that exist on Lowell Observatory Section 17.
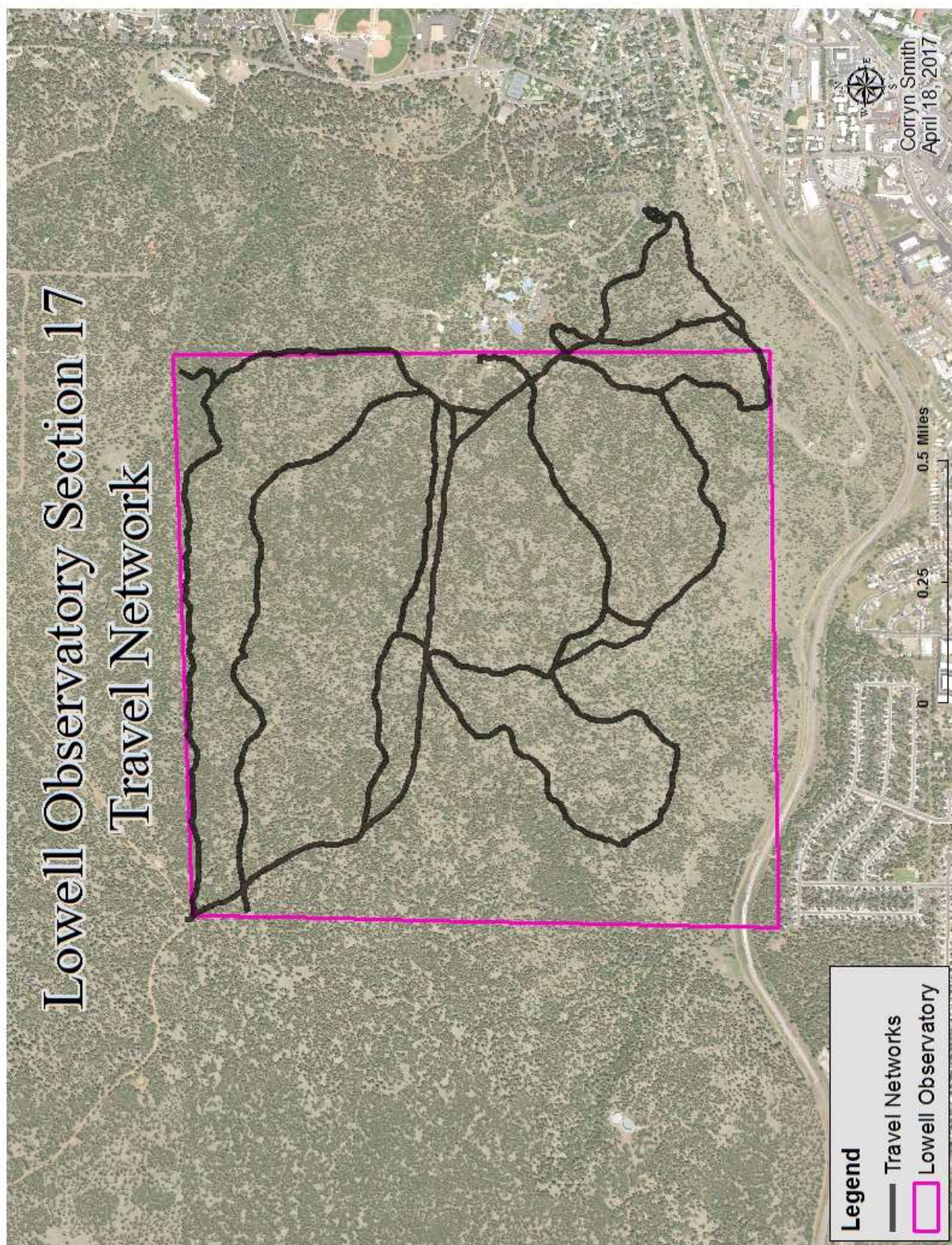
Figure 58: Map of travel networks located on Lowell Observatory. Source: Author
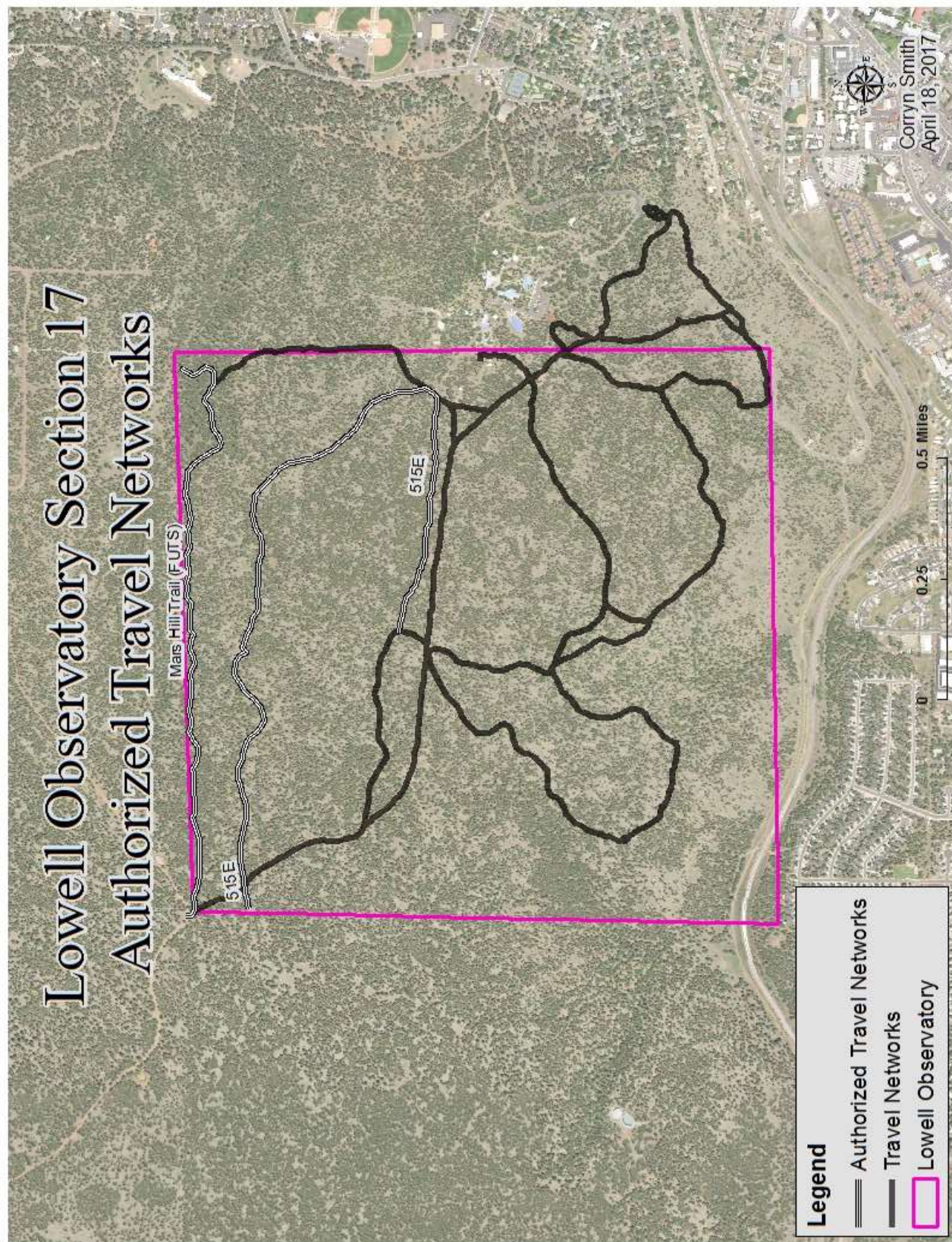
Figure 59: Map of authorized roads on Lowell Observatory. Source: Author

CHAPTER FIVE
Conclusions

5.1 Summary

      The overall research objective of this thesis was to determine which geospatial

technology are the most efficient to monitor and measure travel networks and how they can

enhance land management planning efforts. The initial geospatial technology method used GPS

to collect ground data and a GIS for data analysis. The second method used four band, one-

meter resolution NAIP aerial imagery to detect travel networks using remote sensing techniques.

Both methods were fully completed on Observatory Mesa Natural Area, and then they were

again attempted on neighboring parcel Lowell Observatory Section 17. To fully answer the

research objective, four research questions were addressed in Chapter One:

    1.) What geospatial technology method is the most time and cost efficient for

        mapping locations of formal and informal travel networks for land

        management plans (ground data collection with GPS and GIS or remote

        sensing techniques)?

    2.) How accurate are the results of the remote sensing techniques when compared

        to ground data collection with GPS and GIS?

    3.) Can the exact methods used for the Observatory Mesa Natural Area be

        duplicated, but in reverse order, to determine travel networks within Lowell

        Observatory's property?

    4.) How can land managers, such as the City of Flagstaff and Lowell

        Observatory, use these methods and results for their land management plans?

After examining the results of this thesis, both geospatial methods have their pros and cons. Regarding research question #1, ground data collection with the GPS and GIS for Observatory Mesa Natural Area took approximately 180 hours. In addition, the City of Flagstaff had to allocate costs for the Verizon Wireless mobile data hotspot, the one-time fee for the Garmin GLO, and the license for ESRI ArcGIS Online account. However, all the roads and trails were surveyed and thoroughly collected. For the ground data collection on Lowell Observatory Section 17, a Garmin eTrex 20x unit was borrowed from Northern Arizona University's Geography, Planning & Recreation Department. This unit retails on Garmin's website for $200. In addition, a license for ArcMap Desktop was needed to create random points and to upload the line features to create map compositions. However, a free, open source software such as QGIS could have been used in the event an ArcMap Desktop license was not available. Both methods of collecting ground data are relatively inexpensive when compared to ground data that needs to be collected with sub-meter accuracy. Nevertheless, the GPS and GIS method took time and physical stamina to collect the necessary data. For land managers who might be tight on time and funds, ground data collection might not be the best option for them.

When examining the remote sensing techniques to address research question #1, the four band, one-meter NAIP imagery was free to download. USGS's Earth Explorer website has a wide collection of various types of imagery that is free to download and use. However, the remote sensing software, ENVI, requires a license to use. In addition, the ENVI license that was used for this thesis did not include other packages such as Feature Extraction, which would have been ideal for extracting linear features (Neubert & Herold, 2008). Nevertheless, selecting training pixels for the three land cover classes and running the supervised classification took only a few hours for both study areas. As stated by Congalton and Green (1999), remote sensing is

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"usually less expensive and faster than creating maps from information collected on the ground". The remote sensing techniques were faster and imagery can be free, but land managers might have to purchase a software to run the classifications. Though remote sensing might be the most cost and time efficient, land managers might not want to solely rely on this method due to the poor accuracies that could exist in the outcome which relates to research question #2. If land managers have access to a free or cheap remote sensing software license, running a supervised classification in just a few hours could give the land managers an idea of travel networks that could exist on their property.

Research question #2 asks how accurate the remote sensing techniques are when compared to the ground data collection with GPS and GIS. Though remote sensing can quickly classify the areas of interest, it is important to know how accurate the results are. According to Congalton and Green (1999), if remotely sensed data will be used for any kind of decision making process, then it is important to know the quality of data. If a land manager decides to use this method and the results are not ideal, then remote sensing might not be the best method of that area. For this study, the overall accuracy for the remotely sensed data were 73% accurate on Observatory Mesa Natural Area and 92% accurate on Lowell Observatory. These data sets were derived from the maximum-likelihood classifier. However, these remote sensing techniques might not be the best method for extracting travel networks on heavily wooded open space properties. The maximum-likelihood classifier could identify roads and trails that were not significantly covered by trees and were not covered in pine needles. Since the travel networks and ground vegetation had similar spectral characteristics, some pixels were over-classified as travel networks. Because of this over-classification, the travel networks land cover class had poor accuracy on both Observatory Mesa Natural Area and Lowell Observatory. When

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comparing the remotely sensed data to the GPS collected data, the GPS data is the most accurate since it was collected from firsthand experience in the field.

The third research question investigates that the same methods used for Observatory Mesa Natural Area would also work for Lowell Observatory Section 17. Since these study areas border each other, the same land cover classes were used for the remote sensing techniques. Lowell Observatory only used the maximum-likelihood classifier since that method worked the best for Observatory Mesa Natural Area. Since the training pixels were adjusted to extract the Mars Hill Trail, many pixels were overclassified as a travel network when they were ground vegetation in the field. While Lowell Observatory had a higher overall accuracy when compared to Observatory Mesa Natural Area, the producer's and user's accuracy for the travel networks were significantly different. For Observatory Mesa Natural Area, the travel networks had a producer's accuracy of 86% and a user's accuracy of 26% while Lowell Observatory had a producer's accuracy of 25% and a user's accuracy of 100%. Since Lowell Observatory had a low representation of travel network points for the accuracy assessment, an additional assessment was performed. The final assessment concluded that only 5% of the travel network points were correctly classified as a travel network on Lowell Observatory. Since many pixels were overclassified as a travel network, this substantially lowered the accuracy of the travel networks on Lowell Observatory. In addition, some of the trails were hard to detect on Lowell Observatory due to the intense tree coverage on the property. Since Lowell Observatory is private property, the Flagstaff Watershed Protection Project is not thinning trees on Section 17. However, the Flagstaff Watershed Protection Project has been thinning trees on all four sections of Observatory Mesa Natural Area. As mentioned in Shai et al. (2015), trails and roads might be hidden under shadows or thick vegetation, which happened to be the case for both Lowell

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Observatory and Observatory Mesa Natural Area. When examining the map compositions of the

supervised classifications, one may see that a travel network is disconnected from a section of

tree pixels or unclassified pixels. In addition, pine needles were another element that covered the

travel networks. While surveying Lowell Observatory, parts of the ground vegetation were also

covered in pine needles. Therefore, pine needles might be another factor why some travel

networks were classified as ground vegetation and vice versa.

Research question #4 asks how land managers, such as City of Flagstaff and Lowell

Observatory, can use the methods and results for land management planning efforts. Land

managers can observe how the ESRI Collector mobile application was used to collect ground

data without buying an additional GPS unit. Using devices that are already owned can save an

organization money when it comes to a GPS device. Though a license for ArcGIS Online is

required to use the Collector App, most government agencies use ESRI for their GIS

departments. In addition, land managers can use remote sensing techniques as a visual aid to

determine where travel networks might exist on their property. If an agency is interested in only

using remote sensing to collect data, they might want to invest some funds to purchase high

spectral resolution imagery such as WorldView-3. By using high spectral resolution imagery,

users can create band indices with shortwave infrared bands to pull out bare earth travel

networks (Shahi et al., 2015). In addition, alternative remote sensing techniques could be used

for further investigation. An object based image analysis software extension could allow the

user to find linear features such as roads and trails (Cleve et al., 2008). As for the results, the

City of Flagstaff and Lowell Observatory can use the travel network map compositions to

determine if they want to adopt the segments into their trails system, or close areas off to the

public for restoration or reconstruction. Though remote sensing can be cheaper and faster, it is possible that it might not yield the accuracy needed for decision making.

Referring back to Chapter One, three hypotheses were tested within this thesis:

1.) Remote sensing will be a time and cost efficient method of extracting travel networks when compared to ground data collection.

2.) The remote sensing results should yield at least 70% accuracy.

3.) Land managers should consider remote sensing techniques over ground data collection especially with larger areas or when there are resource constraints.

Hypothesis #1 states that remote sensing techniques would be the preferred method since it can be time and cost efficient for land managers. According to Campbell (1983), data can be cheap or free, methods can operate at a fast pace, and accuracies can be very good and can be ground verified. When observing the remote sensing methods for this project, the acquired NAIP aerial imagery was free to download. In addition, finding the right remote sensing technique did not take as much time as the ground data collection process. After trial and error, the supervised classification with a maximum likelihood was the fastest and most accurate technique out of all of the methods that were attempted. However, the remote sensing software, ENVI, was available at no additional cost since a software license was provided by Northern Arizona University. Therefore, remote sensing was a time and cost efficient method for finding travel networks when compared to ground data collection.

Since Congalton and Green (1999) state that the accuracy of remotely sensed data is very important, hypothesis #2 states that remote sensing results should have at least a 70% accuracy. Observatory Mesa Natural Area has an overall accuracy of 73% while Lowell Observatory

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Section 17 has an overall accuracy of 92%. When looking at the random points, the travel networks were not properly represented for Lowell Observatory. In addition, some land cover classifications have a higher producer's accuracy and a lower user's accuracy or vice versa. Hypothesis #2 did not state if the producer's, user's, and overall accuracy had to be at least 70%. If the hypothesis is only looking at overall accuracy, then the hypothesis is true. However, if the hypothesis is also including producer's and user's accuracy, then the hypothesis tested false.

Hypothesis #3 predicts that remote sensing techniques would be the preferred method over ground data collection. Though this thesis suggests that remote sensing can be cheaper and faster, it might not yield the desired results. The remote sensing methods extracted a majority of the roads that were in the two study areas, however, some trails could not be detected due to thick vegetation. Using only remote sensing techniques to extract travel networks could give land managers an idea of the networks that appear on the land, but the results might not be accurate enough for land management planning. Overall, remote sensing can be a supplemental aid for locating travel networks, but might not be the preferred method if the accuracy is low.

Recalling the overall objective, this thesis determined which geospatial technology was best to locate travel networks within public and semi-public lands. Though the hypotheses suggest remote sensing techniques would be the best method, GPS and GIS have the best overall accuracy which is important for decision making and land management plans. Though remote sensing is cheaper and faster, the travel networks did not provide a high enough accuracy to solely depend on the remotely sensed data (Congalton & Green, 1999, p.2). Factors such as dense tree coverage, shadows, over-classified pixels, and the constraint of only have four-band imagery, remote sensing could not compete for the accuracy that ground collected data holds.

Though ground collection with a GPS could be skewed by dense vegetation and cloud coverage, the collected data will only be a few meters off (Letham, 1998 p.6).

In addition, this thesis displays how both geospatial technologies can be used together to examine open space properties for travel networks. Campbell and Wynne (2011) state that GIS and remote sensing can be combined "into a common analytical framework" which enhances the geospatial data. While GIS is a powerful tool for decision making, remote sensing can be just as powerful since certain techniques can find features that the human eye physically cannot see (Juppenlatz & Tian, 1996, p. 3, & Campbell & Wynne, 2011, p. 337). By performing the remote sensing techniques first on Lowell Observatory, one could see the main travel networks that appear on the section without being in the field (Franklin, 2001, p.205). Since the current travel networks were unknown on Lowell Observatory, the remote sensing results provided an idea of where to walk to collect the travel networks with a GPS. In this example, land managers could run remote sensing techniques, such as a supervised classification, to quickly see the travel networks on the land. By doing the remote sensing method first, land managers can gauge how many miles of travel networks that would need to be surveyed for an inventory collection. Likewise, land managers can use this information to ensure that there are enough funds to pay someone to collect the ground data. While this thesis explains that remote sensing techniques for extracting travel networks may not have the appropriate accuracy to stand alone, both geospatial methods can be used to find travel networks within public and semi-public lands. By performing remote sensing methods first, land managers can see what exists on the land and determine what they need to do before collecting the ground data.

5.2 Predictions

Using the knowledge gained from this thesis, land managers can efficiently acquire ground data such as travel networks for land management plans. Though remote sensing techniques might not yield the desired results, land managers can collect ground data by using a mobile device such as an iPad2. Though a license is required, land managers can set up a geodatabase for the ESRI collector mobile app to gather data in the field. Along with this method, the data can be stored directly to ArcGIS Online if the device is connected to mobile data or wireless connection. In addition, users can edit the data while in the field by using the touch screen.

By collecting data such as travel networks, land managers can visualize where community members are going on the property. Social trails can be harmful to the natural wildlife, environment, and users. After collecting the social trails, land managers can decide if they want to adopt the trails into their trail system or close the area off for restoration. Since the travel networks were collected for Observatory Mesa Natural Area and Lowell Observatory, both parties can analyze the data and decide what actions need to be taken.

Since both study areas are very popular for passive recreation, the community would benefit from maps of the roads and trails. The City of Flagstaff and Lowell Observatory can use the travel network data to determine where to place map kiosks, trail markers, and benches on the properties. Lastly, using crowdsource GPS mobile applications, such as Strava Heat Maps, can display real-time trips made by users. For Observatory Mesa Natural Area, using Strava Heat Maps would be beneficial to find where new unauthorized roads or trails since the property consists of nearly 2,300 acres. Likewise, Strava Heat Maps display which travel networks are

used the most. By knowing what road or trail is popular, land managers could note that a certain section might be more prone to erosion or litter.

5.3 Additional Research

Land managers for open space properties can use geospatial technologies for many projects regarding travel networks. Land managers can use digital elevation models (DEM) to discover the elevation profiles of the various trails on the property. DEMs can be downloaded from USGS's National Map viewer and opened in a GIS. In addition, land managers could use DEMs to run tools such as cost distance and path distance to find what areas might be suitable for a new trail based on elevation. Likewise, other GIS geoprocessing features, such as surface analysis tools, could help determine where to put resting benches or trail markers with slope and contours. Additionally, land managers can create heat maps with other data like trash piles or transient encampments to determine what areas are prone to trash and might need to be patrolled more often. By creating an inventory of the existing travel networks, land managers can examine their property and determine the necessary steps to ensure safety for the wildlife, environment, and community users.
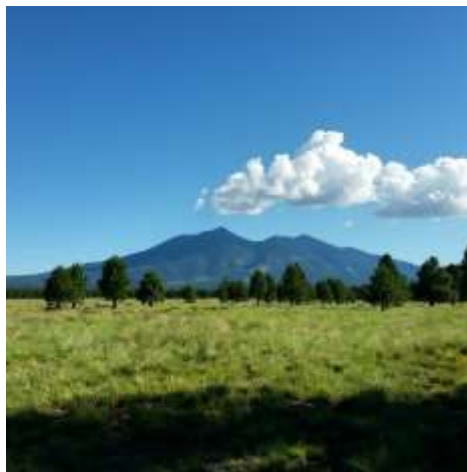
Figure 60: View of San Francisco Peaks on Observatory Mesa Natural Area. Source: Author

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APPENDIX A

CITY OF FLAGSTAFF PERMIT FORMS

City of Flagstaff

Open Space Program Research Permit Application

Date of Application:

Location:

X ☐ Observatory Mesa Natural Area ☐ Picture Canyon Natural and Cultural Preserve

Permit Type:

X ☐ New Research Permit ☐ Renewal of Research Permit

Corryn Smith	7705309688	cs2748@nau.edu
Applicant:	*Phone:*	*Email:*
Northern Arizona University/ Alan Lew		*Alan.lew@nau.edu*
Organization:	*Phone:*	*Email:*
SBS West (Bldg 70) Northern Arizona University, McConnell Drive, Flagstaff, AZ		
Address:		

*If this is a student research project, the contact information for the advisor must be provided.

Brief Description of Research (please include a project title, objectives, and description):

Using GeoSpatial Technologies to Locate Travel Networks on the City of Flagstaff's Observatory Mesa

For this Thesis project, geospatial technologies such as GIS, GPS, and remote sensing will be used to find roads and trails on the Observatory Mesa. First, the travel networks will be collected with a GPS and then stored within a GIS. Next, remote sensing methods will be used to see if travel networks can be discovered using aerial imagery. This thesis will discover how different geospatial technologies can be used for managing open space land.

Topic: Check any keywords that apply to your research:

☐ Archaeology   ☐ Habitat Restoration
☐ Botany/Plant Ecology ☐ Hydrology
☐ Conservation Biology X ☐ Land Management
☐ Environmental Education ☐ Soil Science
☐ Forestry   ☐ Wildlife Biology
☐ Geology   ☐ X Other: Geospatial Technologies

The Applicant shall indemnify, defend and hold harmless the City, its council, boards and commissions, officers, and employees from all losses, claims, suits, payments and judgments, demands, expenses, attorneys' fees or actions of any kind resulting from personal injury to any person, including employees,

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subcontractors or agents of the Applicant or damages to any property arising or alleged to have arisen out of actions stemming from this Research Permit, except any such injury or damages arising out of the sole negligence of the City, its officers, agents or employees. This indemnification provision shall survive conclusion of this Research Permit. **I have read and understand all of the attached policies and will abide by all policies, rules, regulations, and conditions of use as written. I understand that the Research Permit is not transferrable to any other individual or group.**

_____   December 5, 2016
Applicant's Signature   **Date**

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Open Space Program Research Permit Information

The City of Flagstaff (City) encourages the use of Observatory Mesa Natural Area and Picture Canyon Natural and Cultural Preserve as research laboratories as contemplated by A.R.S. §§ 1551 *et seq.* The City has initiated a requirement for users of these protected open space properties to apply for and receive an Open Space Program Research Permit:

1. This Application has no fees and will be accepted at any time. Allow up to 30 days for review.

2. Submit to the Open Space Program at NaturalAreas@flagstaffaz.gov.

3. Permits expire on December 31 of each year, but are renewable by filing a yearly progress report with the City on or before November 30 that describes the progress of the research, goals for the remainder of the research, and anticipated remaining duration.

Application Requirements for Conducting Research within Open Space Properties:

A. **Proposed Location of Site:** Include a map of the location(s) for the research project. If you are uncertain of the location, what type and size of sites are required for the research project?

B. **Duration of Study:** When is the anticipated start and end date of the research project? How frequently will the site be visited?

C. **Funding Information:** Identify the source of funding for the project. If grant funded, the name of the funding program, granting agency, grant amount, and a project narrative from the grant application.

D. **Research Methods:** Describe the research methodology and all equipment that will be used, including any potentially destructive sampling or invasive activities such as soil disturbance, chemical application, specimen collection, loud equipment, etc.

E. **Restoration or Mitigation Plan:** Describe plan for restoring or mitigating any potential impacts to the site as part of the research project, including removal of research equipment within one month of completing the research project.

F. **Collections:** Detail any expected research collections, including the number of samples, the amount contained in each sample, and the disposition of the samples.

G. **Permits and Approvals:** Provide proof of necessary federal, state and institutional permits (i.e., state permits for collecting any state or federally listed plants, or permits from the Arizona State Museum for any research project requiring ground disturbance within established cultural sites).

AGREEMENT

As of the date identified on this Application, the City and the Applicant agree that the City will authorize the Applicant to conduct research on the Open Space Properties identified in this Application in exchange for providing copies of any data collected as part of the research project, as well as any reports and/or publications created as a result of the research project.

The Applicant agrees to inform researchers, students, or any other individuals involved in the research project of this obligation to provide the City copies of any data collected, as well as any reports and/or publications created as a result of the research project.

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Proposed Location of Site: The entire 2,251 acres of Observatory Mesa Natural Area
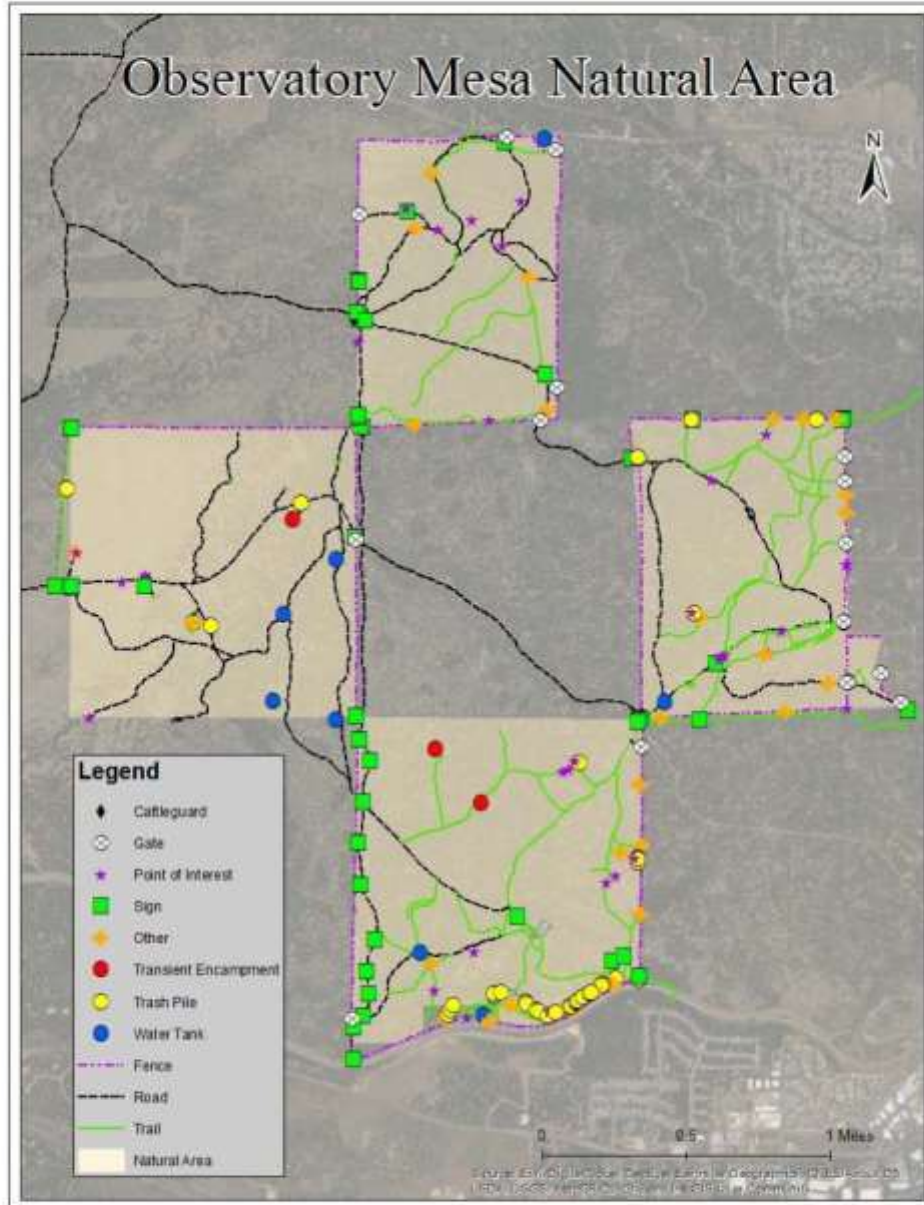
B. **Duration of Study:** The anticipated start date is June 2016 until May 2017. The site will be visited only a few times to verify the aerial imagery to the classified data.

C. **Funding Information:** This project does not need any funding.

D. **Research Methods:** The initial data collected used an ipad 2 with a Garmin Glo (GPS enhancer) to collect various features such as roads, trail, trash piles, and points of interest. The remaining part of this project is to survey the area using satellite and aerial imagery.

E. **Restoration or Mitigation Plan:** The overarching goal of this project is to find travel networks on the Observatory Mesa. All data collection will keep to the already established roads and trails in the area. There will no potential impacts regarding field equipment for this project.

F. **Collections:** There will be no placement of materials for this project. Collection of data for this project is used with a GPS or aerial/satellite imagery.

G. **Permits and Approvals:** N/A

City of Flagstaff

City of Flagstaff Open Space Program
211 W. Aspen Avenue
Flagstaff, AZ 86001

February 8, 2016

Dear Ms. Smith,

Thank you for submitting a Research Permit Application to investigate how accurate it is to use geospatial technologies to locate travel networks on Observatory Mesa Natural Area.

The Open Space Program recognizes that you completed most of your field data collection while serving as the Open Space Aide during the summer of 2016, but you are approved to visit Observatory Mesa Natural Area to verify the aerial imagery and collect additional data.

Given the management policies of Observatory Mesa Natural Area, please note that you are required to access your research sites using Forest Service roads that are designated as "open for public use" under the most recent Travel Management Rule decision. You can download the most recent Motor Vehicle Use Map at:
http://www.fs.usda.gov/detail/coconino/landmanagement/projects/?cid=stelprdb5356224.

The Open Space Program Research Policy requires that research permits expire on December 31st of each year. Your permit is valid through December 31st, 2017, or until the project is completed. At that time, you will need to submit a progress report to either renew or closeout your permit.

Additionally, please note that by submitting your permit, you have agreed to hold the City harmless from all losses, claims, suits, payments and judgments, demands, expenses, attorneys' fees or actions of any kind resulting from personal injury to any person, except any injury or damages arising out of the sole negligence of the City, its officers, agents or employees.

Lastly, in exchange for hosting your research project on a City open space property, you are required to provide copies of any data collected as part of your research project, as well as any reports and/or publications that result from this research to the Open Space Program as a condition of your permit.

If you have questions or would like further discussion regarding your project or the Open Space Program's research requirements, please do not hesitate to contact me directly at BEmery@flagstaffaz.gov or (928) 213-2154.

Sincerely,

Elizabeth "Betsy" Emery
Open Space Specialist
City of Flagstaff Open Space Program

APPENDIX B

CITY OF FLAGSTAFF

PROPOSED OBSERVATORY MESA

ACQUISTION AREA

Proposed Observatory Mesa Acquisition Area

Map Explanation
- Flagstaff City Boundary
- Areas of Interest
- Forest Service Roads
- FUTS Trails