

DUDE, WHERE'S MY INTERNET: AN EXAMINATION OF BROADBAND
INTERNET ACCESS, INFRASTRUCTURE, AND POTENTIAL FOR EXPANSION
IN MISSOURI

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by
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have examined the THESIS entitled
DUDE, WHERE'S MY INTERNET: AN EXAMINATION OF BROADBAND
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Presented by Nathan John Easley

A candidate for the degree of

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ABSTRACT

Broadband Internet is increasingly becoming a necessity in today's society. Providers of these services are expanding access to the high-speed Internet as well as its speed and capacity. With the recent release of the National Broadband Map and the National Telecommunications and Information Agency (NTIA) supported broadband research projects, more is becoming known about *where* and to *what extent* these providers are offering their services. As such, more is known about how areas of the United States (U.S.) vary in their level of access to these services. Within the state of Missouri, Governor Jay Nixon has set a goal of making broadband available to over 95% of residents. Of particular interest are those areas that are not effectively provided access to broadband. Areas without access also likely vary in the amount of effort or investment necessary to make access available. That is, the closer an unserved community is to existing infrastructure and service, the lower the cost to connect them to the existing broadband network. Broadband providers do not typically release their service areas, or footprints, to the public in any detail, making it difficult to assess which areas receive service and which do not. Moreover, assessing proximity of unserved areas to the middle mile, the infrastructure linking each Internet provider to the backbone, is even more

difficult due to lack of publicly available information about this infrastructure.

Additionally, in the cases where the location of middle mile infrastructure has been documented, it is often recorded at a coarse spatial resolution making it difficult to evaluate the precise location of this infrastructure.

To address these issues, this thesis examines methodologies for evaluating access to broadband service and inferring the location of supporting infrastructure. To do this, a range of different representations of the geographic extent to which broadband providers provide access are evaluated. Next, a methodology is proposed for using what is known about the geographies of provider service areas--and the spatial relationship among each other--to infer where middle mile infrastructure might likely be located within a region of interest. Given that middle mile infrastructure is likely located along utility rights of way, the inferred locations of middle mile can then compared relative to the geographic location of features known to be rights of way, including those supporting public utilities, such as roads, utilities, and pipelines, to further refine the approximation of middle mile. The developed analysis framework is then used to assess access to broadband in the state of Missouri and to evaluate the potential effort required to extend service to areas without access. First, the level of access is measured by combining all broadband provider footprints to evaluate where access does and does not exist. Next, the location of middle mile is inferred through transformation of provider service areas to into their medial axis. Using those results, the locations of the modeled middle mile is compared to the location of a recently built middle mile extension in south-central Missouri to evaluate the model's performance and to provide better understand which right of way features most closely correspond with the actual middle-mile. Finally, locations for potential middle

mile expansion into unserved areas are identified using a combination of the distance of an unserved area from current service, presence of population, and connection to areas with access through right of way infrastructure. The results indicate that the governor's goal of 95% access to Missouri residents has been met. Additionally, while there are areas within the state that do not have access to Broadband, only a few of them have the population demand present to entice Internet service providers to expand their infrastructure into the areas.

CHAPTER 1. INTRODUCTION

1.1 Introduction

The growth of Broadband Internet has been similar to the expansion of electricity in the 20th century in its expansion from urban to rural areas. Internet access has transformed over the past two decades from dial up narrowband on an as-needed basis through phone lines to always-on broadband with increased speed and capacity. These increased speeds open up new opportunities to increase productivity and economic output. Expansion of broadband service leads to new employment opportunities, the lowering of unemployment, decreased locational disadvantages, and the potential to add over \$8 billion to the GDP of the US (Holt and Jamison 2009). These advances in speed make new technology and possibilities available to those with high-speed Internet including streaming video, cloud computing, and telemedicine (FCC 2012a).

The need for robust and wide-ranging broadband Internet reaches all the way to government agencies lending their financial and regulatory support. Additionally, the concerns about the gap in service between urban and rural areas continue to grow. This digital divide in broadband access between the haves and have-nots threatens to leave entire groups behind and prevent them from taking advantage of the economic, educational, and productivity advantages broadband access can provide to subscribers. Groups of individuals in exurbs and rural areas without service continue to ask for access to this high-speed Internet. Providers are struggling to add service to these high-demand areas while enhancing capacity in current, and more profitable, service areas.

As Internet service has grown from a luxury to a part of everyday life for many American households and businesses, service providers are faced with many challenges. Challenges include how to provide access to those who want service but are in remote areas, how to balance the demand to increase speeds for current subscribers with the financial cost of those undertakings, how to protect infrastructure so outages are at a minimum, and how to ensure that all groups receive service at the highest quality and speed. With the penetration of broadband into almost all aspects of everyday life, having reliable service is key to economic growth in a variety of sectors of the economy such as large business, small business, government, education, healthcare, and agriculture (Gillett, Lehr, and Osorio 2004).

1.2 Network Access and Vulnerability

As broadband takes on greater importance in business operations, the need for reliable service becomes more important. One of the advantages of broadband is the increase in productivity and opportunity that results from the increase in speed. This advantage comes with potential downsides. Increasingly, more and more businesses and activities are tied to Internet access. According to a recent Business Roundtable (2007) article, disruptions in broadband service can result in dips in productivity and economic losses of over one million dollars per day for a single large company. In order to prevent future outages of service, providers must be vigilant in expanding the robustness and redundancy of their broadband infrastructure to ensure protection of portions of their network vulnerable to a variety of threats.

According to Morales (2011), Broadband Internet is the great infrastructure challenge for the United States in the 21st century. Provider networks can cover hundreds of square miles, making monitoring each foot of fiber and copper a costly undertaking. Additionally, the process of connecting a single residence to the Internet requires a variety of infrastructure pieces working in unison to carry data across multiple miles. Complicating the situation is the fact that often each piece of infrastructure is owned by or leased from a different company, separate from the Internet service provider ("ISP") paid to provide Internet access (Iannone 2012).

This challenge of balancing protection and fortification of existing broadband infrastructure and expanding service to provide access to unserved populations to reduce their vulnerability is a daunting prospect for broadband providers. As individuals and communities push for expansion of broadband access, the need arises to identify areas with broadband access and those without access. While individual providers know which areas they serve, they are reluctant to share this data. Moreover, government agencies tasked with collecting and publicizing broadband service areas throughout the United States have not agreed on a common standard for measuring access, let alone a definition of what data transmission speed constitutes high-speed Internet. For example, the Federal Communications Commission (FCC) utilizes ZIP Codes and Census tracts as areal units of analysis for measuring broadband access while the National Telecommunications and Information Agency (NTIA) utilizes Census blocks (Grubestic 2012a; NTIA 2012). Both representations of service areas are known to introduce a level of error in service areas, making it difficult to confidently assess the level of broadband access (Grubestic and Matisziw 2006; Grubestic 2008; 2012a).

1.3 Broadband Adoption and the Middle Mile

In order to study broadband providers' infrastructure, the location of system components and the way in which they are connected needs to be known. Three major segments make up the sequence of getting a residence or business connected to the internet: first-mile, middle-mile, and the last-mile. The core network, or backbone, is infrastructure interconnected around the country and the world with major access and exchange points spread throughout the network. Access and exchange points are locations along the backbone network where Internet service providers can connect their subscribers to the Internet. This connection constitutes the first-mile. The next step to connect the Internet to a residence is the middle-mile. The middle-mile is a connection of the access and exchange points of a provider to a series of local provider exchange points or central offices, located throughout the provider service area. Middle-mile holds significant importance as it provides a key link between the provider's exchange and access points on the backbone and the fiber/copper that constitutes the last-mile. The last-mile is a series of connections spread out from local exchange points and central offices to reach individual residences or businesses within a provider's service area (Iannone 2012). Figure 1 shows an example of the backbone to last-mile connection sequence.

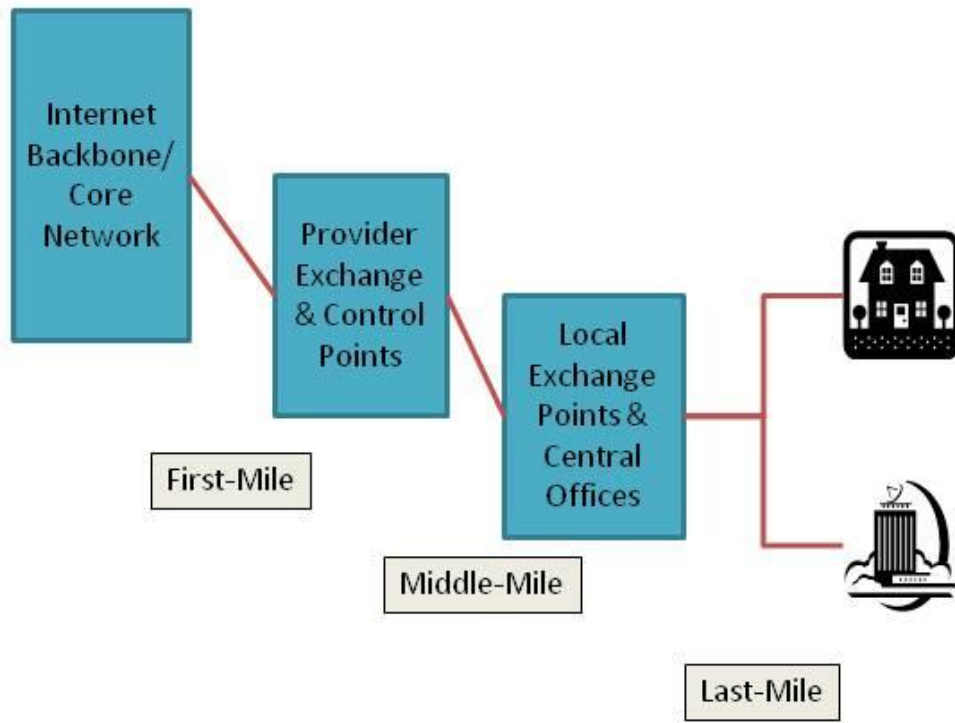


Figure 1. Example of Backbone to Last-Mile connection sequence.

As mentioned in Section 1.2, many providers do not release information on the extent of their service areas or report it at a coarse level of resolution to maintain a competitive advantage. Middle-mile providers take a similar approach with little publicly released information about where middle-mile is located. However, the presence of broadband providers could serve as a guide for inferring the location of middle-mile. In order for a broadband provider to serve an area, middle-mile must connect that provider to the backbone. Therefore, a reasonable assumption can be made that middle-mile is likely proximate to areas known to have broadband service. Additionally, the more companies that provide broadband access in an area, the higher the probability of middle-mile being present within that area. Conversely, a much lower probability of middle-mile being present exists in areas not currently served by a broadband provider.

Although not advertised, middle-mile infrastructure has to be constructed in order to bring broadband access to an area. Most middle-mile is buried along existing right of way corridors, such as those associated with roads, electrical corridors, railroads, and pipelines (Prasad and Chakravarti 1996). Locating middle-mile in these areas is advantageous for two reasons, first that it means lower cost in acquiring rights to use the land and secondly there is a higher certainty that the existing right of way entity will allow the middle-mile provider to build on their land (Cooper 2000). Thus, while the actual location of middle-mile may not be known, spatial indicators on the likelihood or suitability of a location for supporting middle-mile infrastructure, such as proximity to rights of way and areas currently served by providers, do exist. However, little research has been done to use these spatial indicators to infer the location of middle-mile infrastructure.

To address the issues mentioned in this Chapter, this thesis first reviews the pertinent aspects of broadband adoption, access, and locational inference. In Chapter 3, a framework for evaluating access to broadband is detailed, along with a methodology for inferring location of middle-mile service corridors. Chapter 4 introduces an application of these methods to assess access to broadband and identify potential areas for expansion of access within portions of the state of Missouri. A medial axis transformation of provider service areas is then applied to infer the location of middle-mile infrastructure in Missouri. Next, Chapter 5 details the extent to which broadband access varies within the state, the level of correspondence between the location of inferred middle-mile, known middle-mile, and known rights of way, as well an assessment of which unserved areas have the greatest locational potential for receiving broadband access in the future. Finally, conclusions and future research directions are outlined in Chapter 6.

CHAPTER 2. LITERATURE REVIEW

2.1 Network Analysis and Access

Networks are part of everyday life in the provision of services such as transportation, utilities, or telecommunications. Features in a network can be represented as nodes and arcs, where the nodes represent components of a system and where the arcs represent a direct linkage between pairs of nodes. The characteristics of networks can be measured in a variety of ways. Networks can be planar, where a node exists anywhere two arcs intersect, or non-planar, with arcs crossing without a node being present (Taaffe and Gauthier 1973). With respect to the flow of goods or services along a network, the arcs can be directed, where they only flow in one direction, or undirected, with flow moving through an arc in either direction (Church and Murray 2009). Topology, or the interconnectedness of arcs and nodes in a network, is important to examining their characteristics. Many different measures exist to characterize the properties of networks. For instance, simple global measures for approximating connectivity include the alpha index and gamma index. Additional measures are also commonly used to better analyze the local characteristics of network components, such as the degree of node, number of paths between nodes, the shortest path between two nodes, as well as many others (Taaffe and Gauthier 1973; Matisziw and Murray 2009a). As networked systems continue to play a larger role in our daily lives, the development of new analysis techniques to model the impact of outages, expansions, or new connections grows as well. Given that social cohesion and economic development can be negatively impacted by lack of service or disruption to a system, additional study is

necessary to understand how to avert outages to telecommunications networks (Taylor 2012).

Lack of access to networked services can also be thought of as a form of vulnerability. Vulnerability within a network can be evaluated in a variety of ways (Grubestic and Murray 2006). While no standard definition for network vulnerability exists, most studies on the subject refer to examination of exposure and probability of the structure of the network (Jenelius, Petersen, and Mattsson 2006). When studying telecommunications networks, the potential impact of component losses are the most important aspect to investigate and study. A typical investigation might focus on identifying the components, that if removed or disabled, would reduce network performance the most, whether it be the largest population losing access, the greatest increase in travel time, or another measure of network performance (Murray 2011).

The spatial configuration of networks can influence the vulnerability of populations to potential threats. For instance, in order to promote efficient operation, many telecommunications networks are arranged in a hub and spoke configuration with a central, critical node connected to all the other periphery nodes by a single arc in order to efficiently provide connectivity (Kim and O'Kelly 2009). The hub and spoke configuration of broadband backbone creates critical nodes at the juncture of multiple arcs. Disabling or removing these hub nodes could result in significant loss of network capability (Grubestic and Murray 2006). Moreover, these sparser network topologies can also degrade their robustness to damaging events (Matisziw, Grubestic, and Guo 2012).

With respect to access, vulnerability can also be measured as the number of providers that can serve a particular area (Higgs 2004). Higher vulnerability in this

sense could be associated with areas having a smaller number of options for broadband service. Similarly, areas with more providers could be viewed as less vulnerable given they might have lower cost of accessing a service and redundancy in infrastructure and service. Having multiple providers in a given area provides the opportunity to change providers as needed to take advantage of higher speeds or more appealing options.

Vulnerability can also be viewed from the opportunity cost of not having access to broadband. As mentioned in Sections 1.1 and 1.2, the economic and social advantages of having access to broadband are wide ranging. Having poor or no access to broadband can be defined as vulnerability; given that individuals cannot take advantage of opportunities unique to high-speed Internet access. Additionally, individuals with narrowband, or low speed Internet access, could also be viewed as more vulnerable since they are also unable to take advantage of the features broadband Internet provides such as video conferencing.

2.2 Spatial Representation of Broadband

Tracking the location and development of broadband networks is challenging for those outside the telecommunication industry, due to a lack of access to information and data. The Federal Communications Commission (FCC) requires providers to submit Form 477, disclosing service footprints and the speed of the network (Grubestic 2008). Data reported on this form has little detail, does not cover prices charged or the size of the broadband provider, and is reported at the ZIP code level - and more recently the Census tract level – reducing the meaningfulness of any spatial analyses that could be used to evaluate access to broadband networks. Any company providing mobile,

wireless, or wired broadband to any end user within the U.S. is required to file Form 477 twice a year on March 1 and September 1. Providers who file the form are responsible for reporting all 2010 Census tracts where they provide any broadband service (FCC).

Recently, the National Telecommunication and Information Agency (NTIA) released the National Broadband Map (Grubestic 2008; NTIA 2012). This broadband map is an improvement over Form 477 as reporting of service areas is completed at the smaller Census block level. However, a level of error still exists. If any provider has any service area in a given Census block, the entire block is considered served in the state submission and subsequently on the National Broadband Map (Grubestic 2012a, 2012b). Further confusing the situation is the provision in the project methodology that any Census block greater than two square miles be broken up by road segments. This leads to some providers appearing to cover a much greater area in the submission to NITA, and subsequent publication on the National Broadband Map.

As shown in Table 1, the National Broadband Map differs from Form 477 in the methodology of collection of spatial data. While Form 477 allows providers to send their service areas directly to the reporting agency, the National Broadband Map has additional layers of collection and analysis. Requests are sent to all broadband providers to submit some representation of the geographic extent of its service to researchers in each state working on the NTIA funded State Broadband Initiative (SBI). The NTIA requires that data for the map be submitted as all Census blocks within each state with broadband providers servicing residences and businesses inside each block. The format in which companies actually submit their areas of service is highly varied. Data submission formats range from common Geographic Information System (GIS) geographically

referenced service areas, to engineering drawings, to hand-drawn maps of service areas, requiring each state's researchers convert the data into a geographically referenced polygon (or polygons) using a GIS to meet the NTIA standard. Next, the service area polygons for each provider now represented at the Census block level, are aggregated to identify which blocks have service. Once all providers have been aggregated at the block level, the Census blocks are run through the NTIA provided quality assurance, data checking program. Once the Census block data is successfully verified, it is submitted to the NTIA for publication on the National Broadband Map. The data on the National Broadband Map website is displayed differently from data submitted by each state. The two options for determining where access exists are to search by address or navigate through a map of the U.S. to a given area as shown in Figures 2-4. Neither method explicitly visualized access to broadband service at the Census block level.

There are, however, still spatial limitations present as data provided by the telecommunications sector tends to have imperfections (Grubestic 2010, 2008; Grubestic 2012a; Grubestic and Murray 2005). The researchers in each state working on the State Broadband Initiative (SBI) for the National Broadband Map send requests to the broadband providers to report their service areas. These requests, meanproviders can simply choose to not participate in the project and not submit their service areas. Furthermore, providers who do participate in the project can report their service area as the area where they currently provide broadband speed service along with any additional area they could theoretically provide service to in the next ten days. This provision introduces the possibility for error in the service areas these providers submit. Additionally, some providers yet to be identified as broadband providers and might not

receive a request to submit their service area for inclusion in the map (Grubestic 2012a). Furthermore, some providers submit their service areas already overlaid onto Census blocks, further compounding error. In addition to aggregating the data into larger spatial units of analysis, the possibility exists for errors in accuracy in the collection and reporting of service area footprints by providers. A preferable methodology for reporting broadband service both regionally and nationally would be to utilize the actual provider service areas collected in the NTIA study, avoiding aggregation, an approach detailed later in Chapter 3.

Service Area Source Data	Collection Agency	Method of Collection	Areal Unit of Analysis
Old Form 477 (pre-2010)	FCC	Broadband Providers required to submit their areas of service directly to FCC	ZIP Codes
New Form 477 (2010-present)	FCC	Broadband Providers required to submit their areas of service directly to FCC	Census Tracts
National Broadband Map	NTIA	Spatial data for each provider collected on state level by researchers as part of the NTIA study. The NTIA collects and publicizes data on national level.	Census blocks. Any block larger than 2 square miles is broken up by road segments.

Table 1. Form 477 vs. the National Broadband Map Methodology.

700 broadway, columbia, mo

FIND

Search Results: Broadband Providers for this Area

Below is the list of broadband providers operating in all or part of the census block for the address above. If you entered a zip code or city name, the list below only displays the broadband providers offering service in the Census Block that is in the center of that zip code or city. See About and the FAQ to learn more about the data gathering process.

Help improve this data by confirming the availability and speed information. This dataset is updated approximately every six months and your input is important to us. Click **Expand All** to see details about each provider and to give us feedback.

Show All • Show Wired • Show Wireless

Expand All

Advertised Speeds Above 3 Mbps

Data as of: 06/30/12

Mediacom Communications Corp.	50 - 100 Mbps	»
CenturyLink, Inc.	10 - 25 Mbps	»
RadioWire.net	10 - 25 Mbps	»
AT&T Inc.	3 - 6 Mbps	

Advertised Speeds Above 768 Kbps and Below 3 Mbps

Data as of: 06/30/12

T-Mobile	1.5 - 3 Mbps	
Verizon Communications Inc.	768 Kbps - 1.5 Mbps	
Sprint Nextel Corporation	768 Kbps - 1.5 Mbps	
Telephone and Data Systems, Inc.	768 Kbps - 1.5 Mbps	

Most Common Speed: 10 Mbps

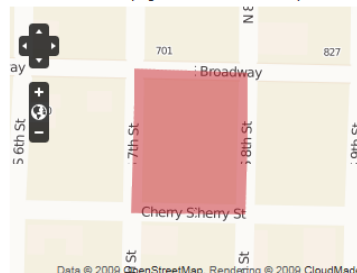
Data Source • Download • API Call

Broadband services delivered via satellite are available to U.S. customers throughout all 50 States. Please click here for more information on individual Satellite Broadband service providers

Is your broadband provider listed? If not, please enter the provider below

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Tweet

Like 0

Map »

Map my community

Rank »

Rank my community

Summarize »

View statistics about my community

Provider »

View statistics about providers

Broadband Classroom »

Learn more about broadband

Endpage »

Figure 2. Example Search Results Based on Address from BroadbandMap.gov (NTIA 2013b)

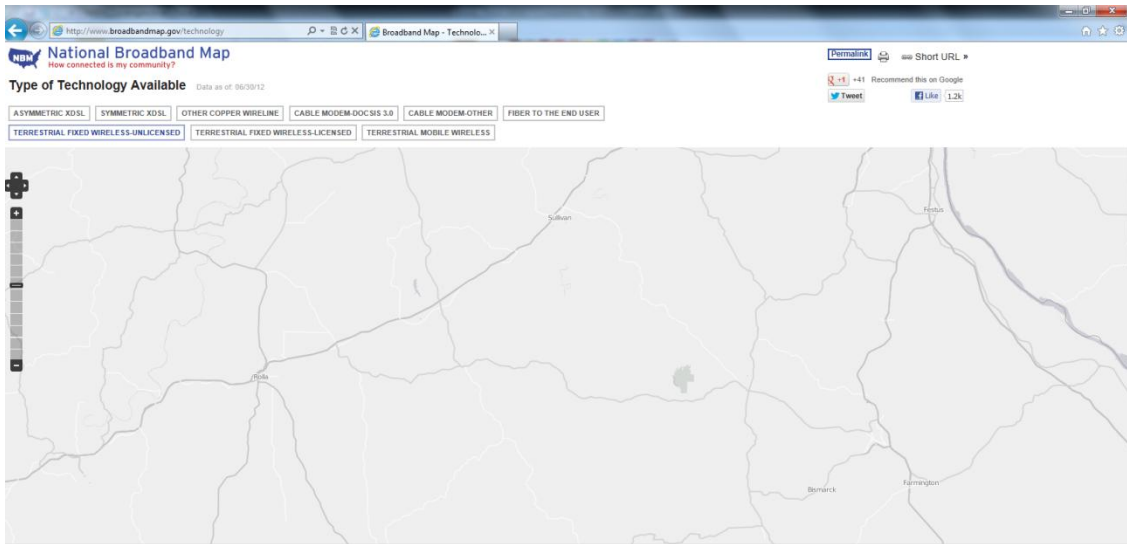


Figure 3. Example Explore Maps Result (No Access) on BroadbandMap.gov (NTIA 2013b)

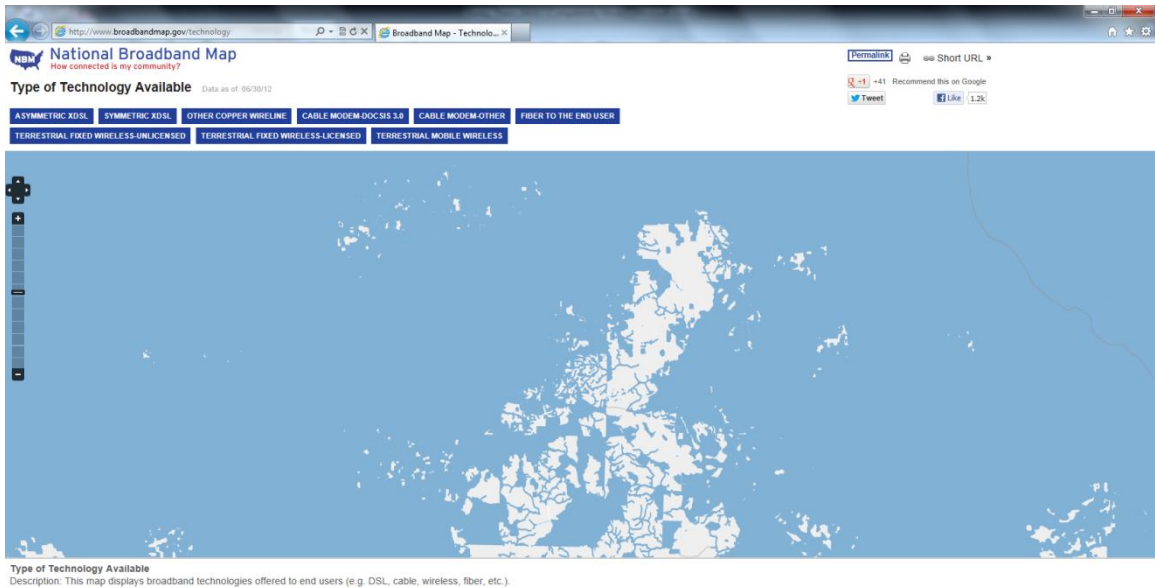


Figure 4. Example Explore Maps Result (with Access) on BroadbandMap.gov (NTIA 2013b)

2.3 Broadband Adoption and Access

The evolution of the Internet and methods for assessing access has changed over the past two decades. In the mid to late 1990s, narrowband, dial up Internet was the fastest and most widely available method for accessing the Internet. During the 2000s, broadband (with a larger capacity for data and increased speeds) became commercially and residentially available. The Federal Communications Commission (FCC) and the National Telecommunications and Information Agency (NTIA) lead the federal government's effort for growth and regulation of broadband throughout the United States. The passing of the Broadband Data Improvement Act in 2008 and the American Recovery and Reinvestment Act in 2009 began an ambitious effort on the part of the NTIA, the FCC, the 50 states, and other territories to improve the quality and expand the reach of broadband (FCC 2010; Grubestic 2012b). Included within these efforts is the State Broadband Initiative, or SBI, as mentioned in Section 2.2. The SBI focuses on improving broadband efforts on the local level to promote economic growth and to map broadband providers, service areas, and speeds throughout each state twice a year. Within Missouri, collection and analysis of this data is the form of service footprints, or service areas, for each individual provider. Completion of this thesis coincided with work on the Missouri SBI. Access to broadband provider footprints afforded the opportunity to develop a statewide network of broadband service for further analysis.

The adoption of broadband has not been uniformly distributed over the U.S. A higher percentage of individuals living in urban areas are likely to have broadband as compared to rural areas. This urban versus rural digital divide is more than an issue of access. Urban areas tend to have more providers, which increases competition and

lowers prices. These lower prices lead to more consumers willing to subscribe to broadband (Grubestic and Murray 2002, 2004; Savage and Waldman 2005). Conversely, rural areas tend to have lower demand for broadband, less providers, less competition, and higher prices. The combination of these factors promotes growth of broadband in urban areas and discourages it in rural areas, leading to fears of rural and certain downtrodden urban areas being left behind in the digital age (Grubestic 2006; Grubestic and Murray 2004).

The size of a provider is known to be a determinant of whether service will be provided in a given area; the largest independent local exchange carriers ("ILEC"), such as Verizon, tend to congregate in urban areas, while the smaller ILEC's tend to provide service in rural areas (Wood 2008). Additionally, the type of material utilized to deploy and carry data from the backbone to last mile can impact the distance from which broadband can be deployed from a central office or local exchange. In the 1990's and earlier, copper wire encompassed the majority of the infrastructure carrying telecommunications signals to home and businesses. In the last twenty years, fiber optic material has gained popularity for use in broadband and other telecommunications infrastructure. Fiber optics provides multiple advantages over copper wire, including being less likely to deteriorate and the ability to carry data at a higher quality, speed, and quantity than copper. Areas with only copper wire infrastructure are limited in their data capacity and the number of users who can access the Internet in that given area (Iannone 2012).

Regulation by the Federal Government and its agencies standardizes commercial and residential broadband. The NTIA classifies broadband as any Internet connection

with at least 768 kilobits per second (kbps) download speed and 200 kbps upload speed. Instead of being accessed by dialing into a phone line, broadband Internet can be accessed through a variety of mediums including cable, digital subscriber lines (DSL), optical fiber, mobile, wireless, and satellite (FCC 2010, 2012a). Consumers view these different modes of broadband Internet as interchangeable with the exception of mobile, wireless, and satellite broadband. Future trends in broadband could see individuals choose to only have mobile and no other type of broadband access (Cardona et al. 2009).

Recent initiatives and policies have promoted to the growth of broadband, especially in rural and urban areas previously without service. The FCC and the NTIA recently created initiatives including the creation of the Connect America fund for expansion of rural broadband, the release of the National Broadband Plan, awards of over \$7.2 billion for improving broadband infrastructure nationwide, and the State Broadband Initiative for mapping broadband service areas and promoting growth in the local level (FCC 2011a, 2012b).

The National Broadband Plan identifies middle-mile infrastructure as an area for investment and growth. It advocates for the expansion of middle-mile to rural electric co-ops and community anchor institutions, such as schools and government buildings. Furthermore, middle-mile tends to be the most costly portion of Internet service cost, leading the FCC to advocate for regulation of middle-mile resale costs (FCC 2010). Local governments also play a role in promoting the growth of broadband Internet as they serve up to four roles: consumers attracting demand, rule makers passing legislation, financier providing subsidies, and infrastructure developers providing service through municipal utilities (Gillett, Lehr, and Osorio 2004). A variety of local government

initiatives led to improvements in broadband access in rural areas; however, they still lag behind urban areas (Economic Research Service 2009).

Access and accessibility are key measures for understanding how locations vary with respect to their ability to utilize a system. While the terms are often used interchangeably, they are completely different. Access refers to the opportunity to enter a network and take advantage of goods and services it provides. Accessibility is the ability to move throughout a network once access has occurred (Matisziw and Grubestic 2010).

Access to broadband at a particular location can be assumed to exist if individuals at that location can subscribe to a broadband service (Higgs 2004). This approach to measuring access is the most commonly utilized approach to evaluate access to broadband networks. This measure of access is binary in nature; either a location falls within a provider's service area and has access to the network or the location is outside the current service areas and does not have access.

Another key measure of access to broadband is a location's proximity to service (Grubestic and Murray 2002). More recently called relative location, this form of access is measured based on the proximity of any given location to broadband infrastructure and other key components for service (Higgs 2004). Areas closer to key portions of the broadband infrastructure, such as a point of presence or exchange stations, have a higher probability of having access to broadband than areas located further away from this infrastructure. Conversely, the further a location is from these types of infrastructure, the lower the probability they have access to broadband.

Beyond the proximity to broadband service, another measure of access is the density of providers in a given area. Instead of focusing on the distance from critical

infrastructure in a given area, this concept of access focuses on the number of providers serving an area. Commonly utilized in healthcare related studies on access, this method is called the container approach to access (Higgs 2004). The basic premise of the approach is that having multiple broadband providers in an area provides a higher level of access than having a single provider or none at all in the same area. For instance, having multiple options for subscribing to broadband service along with the option to change to another provider if one was to discontinue their service could be beneficial for customers. Additionally, having multiple providers in a given area should theoretically spur competition for customers and result in lower prices. One unique, but critical, factor determining whether broadband access is present is population. For providers to make a profit, they need customers. The static and costly nature of broadband infrastructure ensures that no provider would simply choose to stop providing broadband service in a given area once they have built or acquired the ability to provide service. Therefore, broadband providers place their infrastructure and provide service in areas with population and customers present.

A variety of other factors contributes to whether access to broadband is present in any given area. These include: the condition of critical infrastructure, resources available for expansion of infrastructure and service, and the regulatory environment present (Wood 2008). A final consideration in regards to access is whether an individual decides to take advantage of available broadband services. Broadband is not a necessity in everyone's daily life like food or water, so even if access is available, they must make the decision to take advantage of broadband service. Whether or not the individual elects to take adopt broadband, the opportunity is present to gain access to the network.

2.4 Reasoning about the Location of Network Infrastructure

The need to expand the reach of and increase the robustness of broadband networks often requires additional fiber optic/copper infrastructure to be installed in the field. This need for expansion is one of the keys to the continued growth of broadband and spurring an increased level of competition among providers in rural areas (Kandutsch 2013; Cooper 2000). Despite the importance and advantages of high-speed Internet access, finding land to host this critical infrastructure and connect to the larger network is a challenge as the “not-in-my-backyard” mentality often arises.

Existing right of way access provides a solution to expanding and reinforcing middle-mile and other broadband infrastructure. Right of way for this infrastructure often corresponds to a wide variety of other types of large-scale infrastructure including terrestrial (state and federal highways, local roads, and railroads), areal (utility poles), and subterranean (pipelines, sewers, and subways) (Cooper 2000; Prasad and Chakravarti 1996). Among these options, electric utilities are the most prevalent type of infrastructure utilized to expand broadband. A mixture of utilities, roads, and railways are second and highways alone are third (Prasad and Chakravarti 1996). These types of infrastructure typically already exist in the environment with easement or space to co-locate more infrastructures. This suitable land leads an Internet provider looking to secure right of way rights for their new fiber or copper a few options. They can purchase the right to place their infrastructure on the land, lease the right to build, or exchange equity in their company for the right to build infrastructure on the right of way as a group of pipeline companies did for a nationwide broadband startup company (Gosmano 2000; Prasad and Chakravarti 1996). Some right of way has historically or continues to be

more challenging for providers to work with. Before 1988, the Federal Highway Administration did not allow any utility, including telecommunications providers, to utilize the right of way on Interstate highways for their infrastructure given safety considerations (US Department of Transportation 2012). Additionally, railroads have increasingly raised the costs for utility to companies to lease the right of way along their tracks or expand their infrastructure along the right of way (Tanner 2000; Schmick 2006).

Challenges to securing right of way rights in order to expand broadband infrastructure still exist. The Telecommunications Act of 1996 advanced telecommunications through a variety of regulatory and de-regulatory measures. It also removed barriers of entry for companies wishing to provide Internet access and break up the monopolistic nature of telecommunications (FCC 1996). Also contained within the act are provisions addressing access to and the maximum rate charged for a telecommunications company to place their infrastructure (including middle-mile) onto utility poles (Kandutsch 2013). Differing interpretations of this portion of the act exist, often stalling of deployment of broadband infrastructure on existing utilities. A 2011 FCC Order on pole attachments overhauled the process for approving and deploying broadband infrastructure on utility poles, however, legal battles continue as Internet service providers attempt to accelerate the process of securing right of way to expand their middle-mile and other infrastructure (FCC 2011b; Kandutsch 2013).

The constraints in placement of middle-mile infrastructure coincident to rights of way can be useful in the process of determining the location of middle-mile infrastructure. With respect to areas already served by providers, it could be assumed that portions of their service areas located more centrally would have a higher probability

of being proximate to middle-mile infrastructure. One way to identify the locations most central to a polygon is to examine its medial axis or skeleton. A polygon's medial axis is the set of points within a polygon equidistant from their two nearest points on the object's boundary. The medial axis is utilized across a variety of disciplines, from the development of sensor networks, to determining the optimal location for facilities (Bruck, Gao, and Jiang 2006; Matisziw and Murray 2009b). Applications of medial axes in spatial and geographic contexts include the transformation of polygons to single lines or points, determining boundaries between landforms, and the development of river networks are recent practical applications of medial axes (Christensen 1998, McAllister and Snoeyink 2000; O'Kelly 2012). Thus, given the characteristics of the medial axis, it might provide a good representation of where provider activity intersects with middle-mile. However, there is not much literature with a focus on inferring spatial relationships using a medial axis.

Next, Chapter 3 provides a methodology for comparing different representations of access to broadband. Additionally, a methodology for using the service areas of terrestrial broadband providers to infer the location of supporting infrastructure is detailed.

CHAPTER 3. METHODOLOGY

Despite explosive growth over the past two decades and the movement towards becoming a necessity for everyday life, not much research has been conducted on actual Broadband providers' service areas. Research exists on the spatial aspects of broadband networks, but few of these studies have access to complete broadband provider service areas in a region since they are not publically distributed by the providers, the NTIA, or the FCC. Further, there is little data publically available on the location of the infrastructure supporting broadband service. This thesis seeks to address this research gap and to draw upon a unique set of broadband data to better understand how well previous assessments of access to broadband have represented the situation in Missouri. Focus for this thesis centers around two different processes. The first is to evaluate access to broadband with respect to actual provider volunteered service areas, comparing and contrasting with traditional aggregate measures such as those mentioned in Section 2.2. The second step is to develop a methodology for using provider service footprints to infer the location of middle-mile infrastructure, connecting terrestrial broadband providers. Given this approach, the inferred infrastructure locations can be compared to existing right of way corridors throughout a region to evaluate the most accurate predictor. These existing right of way corridors can be combined with measurement of broadband access from the first portion of the thesis to evaluate the location of missing or new infrastructure.

3.1 Measuring Access to Broadband

As mentioned in Chapter 2, two primary approaches are currently employed to evaluate access to commercial broadband service within the U.S. Utilizing a variety of rules and processing techniques, the FCC's Form 477 and the NTIA's National Broadband Map both attempt to describe levels of broadband access. Unfortunately, both methods introduce error and uncertainty due to the way they associate provider service areas with the areal units used to represent areas with a demand for broadband (i.e. ZIP Codes, Census tracts, etc.) and the resulting post-processing of provider information that occurs.

This thesis attempts to build upon this framework for evaluating and measuring access to broadband as shown in Figure 5. Each individual provider service area is presented as one or more polygons. Using a GIS, all service area polygons are combined together into a single layer and any overlapping service area boundaries are dissolved to produce a generic representation of service access to mask the service extent of individual providers. Once this is completed, a spatial query can be performed to identify where broadband service does and does not exist throughout a study area. Next, the geometrically overlaid broadband service area results can be overlaid onto areal units from Form 477 and the National Broadband Map in a GIS to evaluate where access is and is not present based on each type of areal unit. Figure 6 illustrates an example of this entire process. Given that raw provider service areas are used, areal unit analysis can be compared with a representation of services that is not constrained by areal unit delineation, but rather the geometry of the volunteered service areas themselves. Calculation of what percentage of the study area does and does not have access can be

computed for each of the four methods. Finally, evaluation in the amount of difference in access between the different methods can be analyzed.

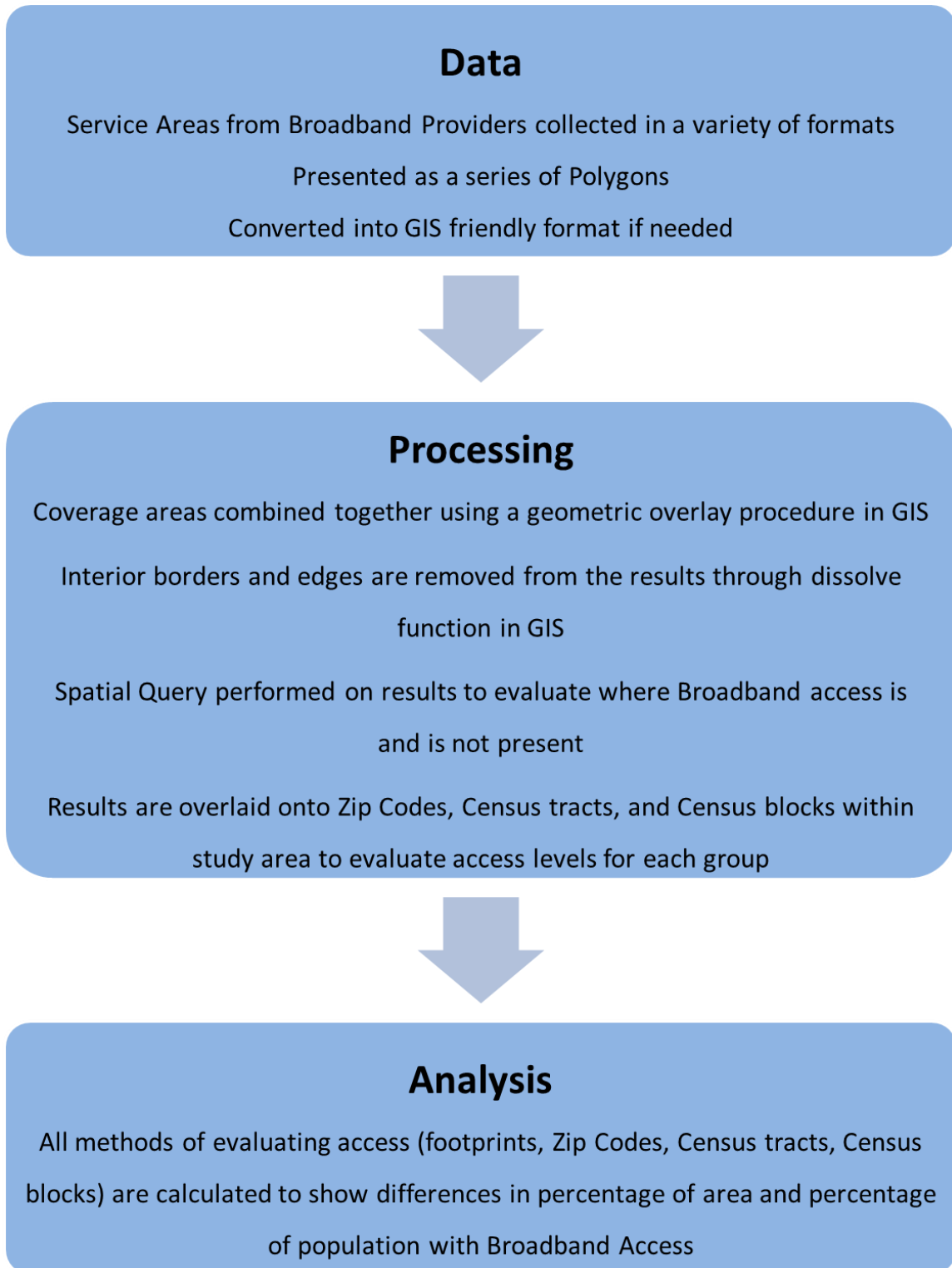


Figure 5. Methodology for Evaluating Access to Broadband.

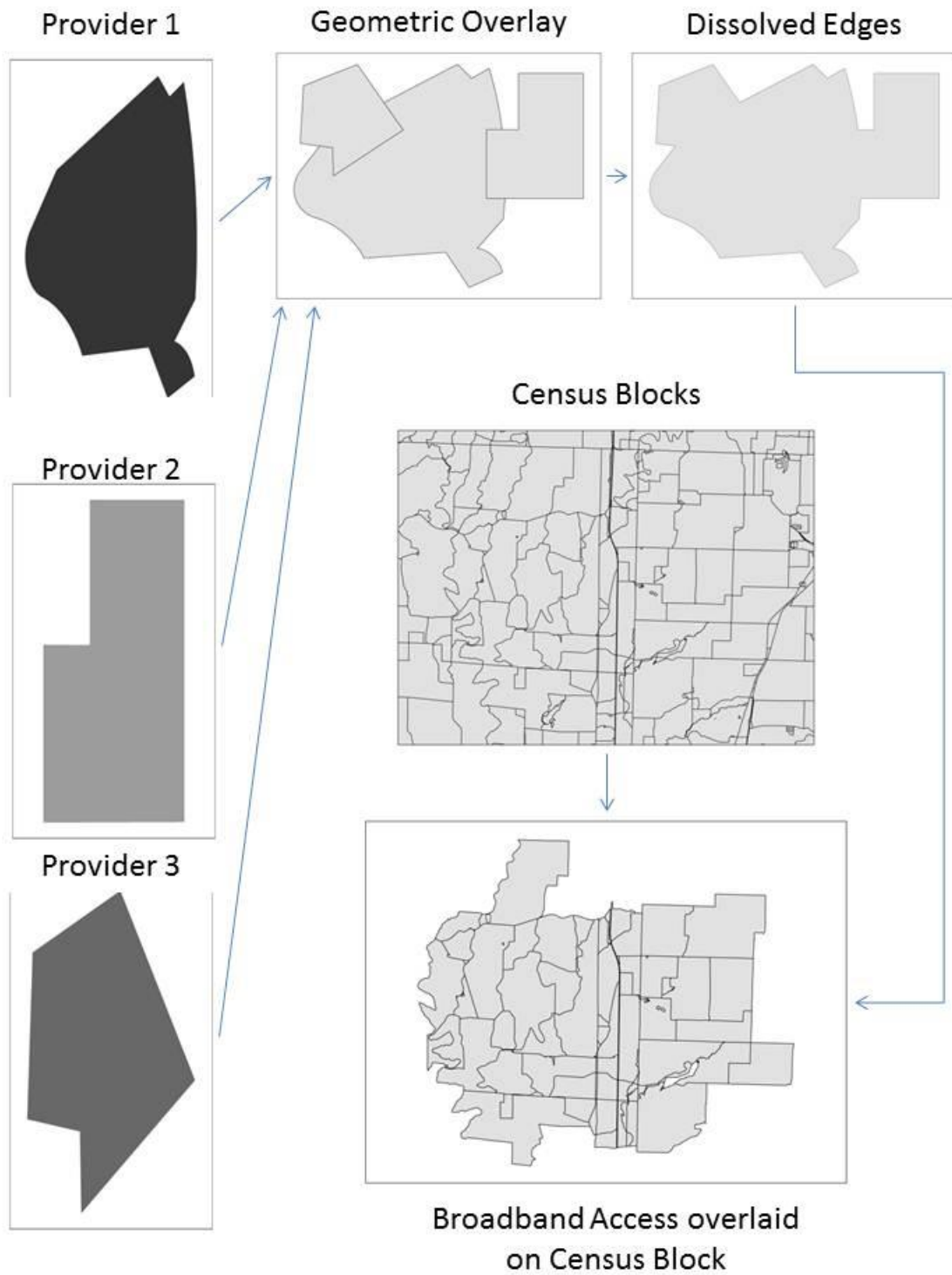


Figure 6. Example of Processing steps for associating access with Census blocks.

3.2 Inference of Missing and Future Access Corridors

This portion of the thesis attempts to develop a methodology for identifying potential middle-mile locations, inferring the location of broadband service that is currently unreported, and evaluating areas currently without access with the highest probability of service expansion in the future. The proposed methodology involves further analysis of provider service areas as shown in Figure 7.

The geographical areas served by each terrestrial provider are typically reported in the form of polygons. The first step in the process is to transform each service area polygon into a medial axis. These medial axes can then serve as a spatial proxy for the likely middle-mile locations associated with each provider. While a variety of methods can be used for this transformation, commercial GIS software typically provides the tools to accomplish this task through the combination of geometrical routines built into the software. In particular, the medial axis for a polygon can be approximated using a GIS by:

- a) Transforming the boundary of the polygon to a polyline feature
- b) Representing the line features as a dense set of points at a set interval
- c) Creating Triangulated Irregular Networks (TINs) from the points
- d) Creating central interior points within each TIN
- e) Removing those TIN triangles whose interior point falls outside the boundary of the original polygon
- f) Creating Minimum Enclosed Circles from each TIN within the original polygon boundary

- g) Computing the 1-Center from each Minimum Enclosing Circle
- h) Calculating the Distance to nearest boundary point found in Step B to represent the width of the polygon at that location
- i) Creating Medial Axis Lines by connecting 1 Center locations

Following this procedure for all provider service areas, the medial axes of each polygon can be approximated. The steps for the transformation are illustrated in Figures 8-15.

Once the medial axes for each provider are created, they can be compared with the location of known middle-mile infrastructure to evaluate the extent to which they correspond. Should portions of the medial axes should align in path, shape, and direction with this known middle-mile, more certainty could be placed on the method. Next, other known right of way corridors, including federal and state highways, local roads, railroads, utility corridors, and gas pipelines can be compared to the known and inferred middle-mile locations at various intervals of distance. Given that middle-mile infrastructure is known to follow these rights-of-way, correspondence with these facilities can be used to further constrain and adjust the inferred middle-mile locations. A geometric intersection between each unique right of way category and the inferred/actual medial axes can be applied to help assess where the highest percentage of overlap occurs and determine which type of right of way infrastructure most closely aligns with the middle-mile.

Using known middle-mile in the area, inference of missing providers can be evaluated as well. To accomplish this, locations of known middle-mile within a study area could be geometrically intersected with areas without broadband access, such as those identified in Section 3.1, using a GIS. Locations in the intersection would then represent areas where broadband infrastructure is present, in the form of known middle-

mile, but where no provider reported service in that area. Areas identified as having no broadband provider, but with known middle-mile present are more likely to have missing or unreported broadband providers in the area. The identified areas could be further verified by comparing them with ground truth observations of access. If none of the points fall in identified areas, then this further reinforces the lack of a provider in the area. If any point falls inside an identified area, that would suggest there are providers in the area that may not be participating in the project. This evaluation of all the areas without access provides a more narrow area for further investigation of missing or unreported providers.

Once a connection and link is established with the best right of way predictor, whether it be a road, pipeline, or utility, that chosen right of way infrastructure can be used to begin to infer which areas have the greatest potential to have access and infrastructure expanded to them in the future. A GIS can be used to perform a spatial query of the geometrically overlaid provider service areas from Section 3.1 and the boundaries of all cities in the study area. The result of this query will be areas where population, or demand, is present but where there is no current broadband access. The identified areas can be verified through comparison with ground truth observations of access. If none of the points are located inside the identified areas, it will reinforce the lack of a provider and access in those areas. If a point does fall within one of the identified areas, it would suggest the presence of broadband access in the area. Next, those populated areas without access are compared and ranked based on three criteria: proximity to areas with current access, proximity to known and inferred middle-mile, and their proximity to right of way infrastructure. Euclidean, or straight-line, distance is

utilized for measurement of proximity. These three criteria are measured and evaluated to determine which areas have the highest and lowest probability of expansion of broadband service and infrastructure in the future. Combining these results with the results of access from Section 3.1, the two sets of results give insight into the current state of broadband within a given area of study and the potential for access expansion in the future.

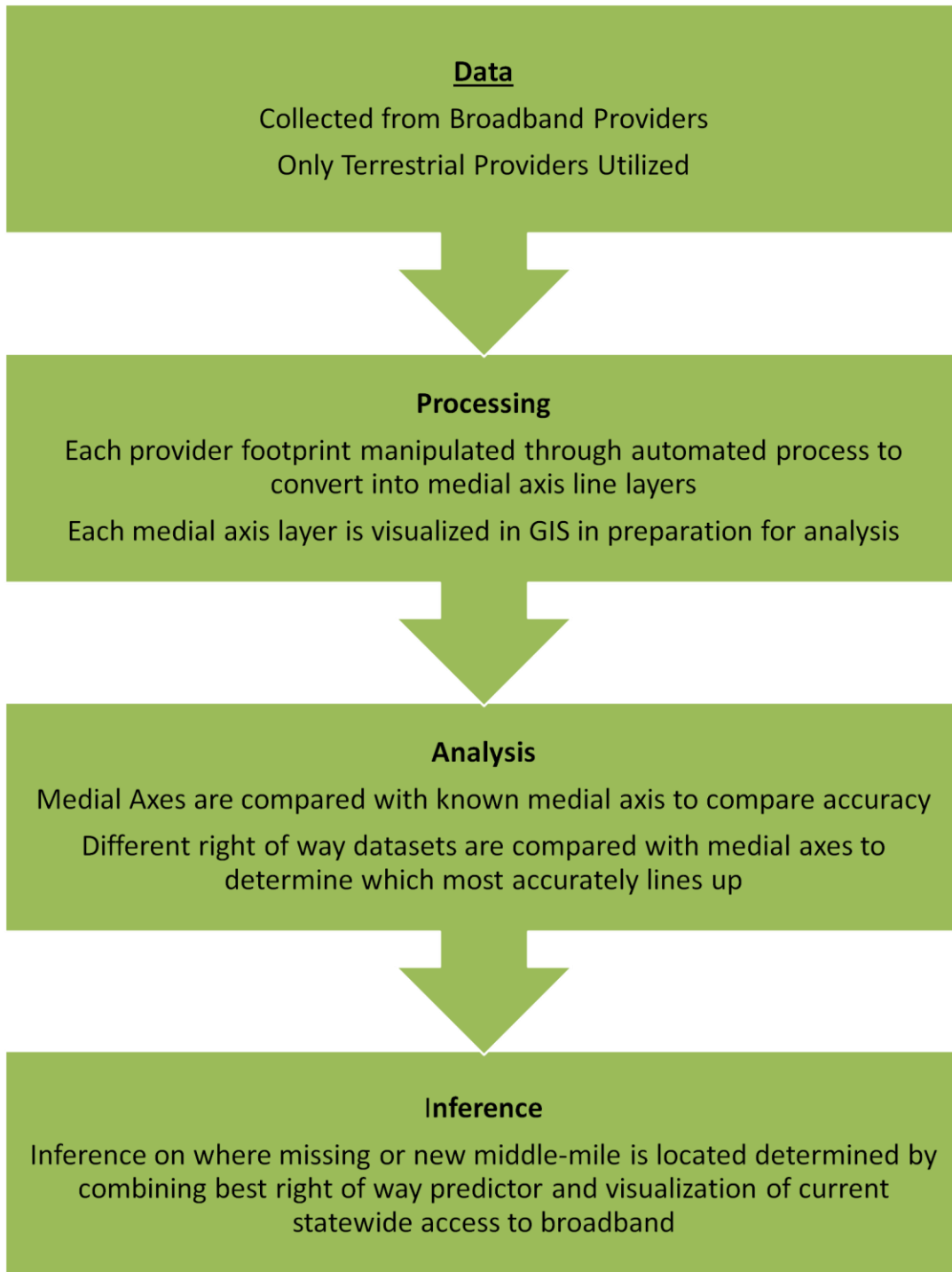


Figure 7. Methodology for Inferring Location of Middle-Mile.

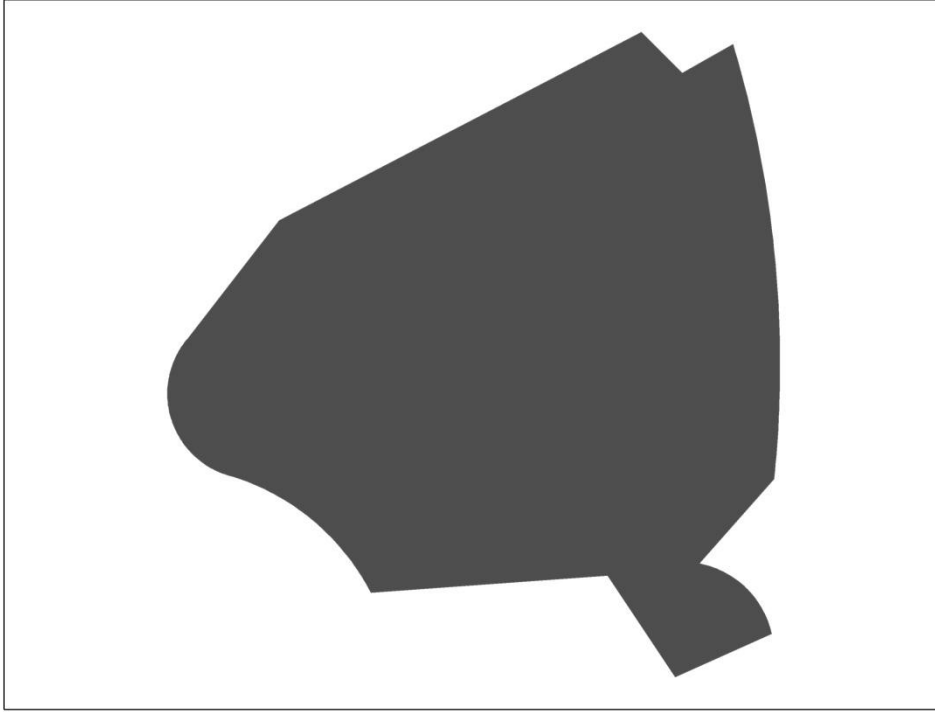


Figure 8. Example Service Footprint Reported by a Broadband Provider.

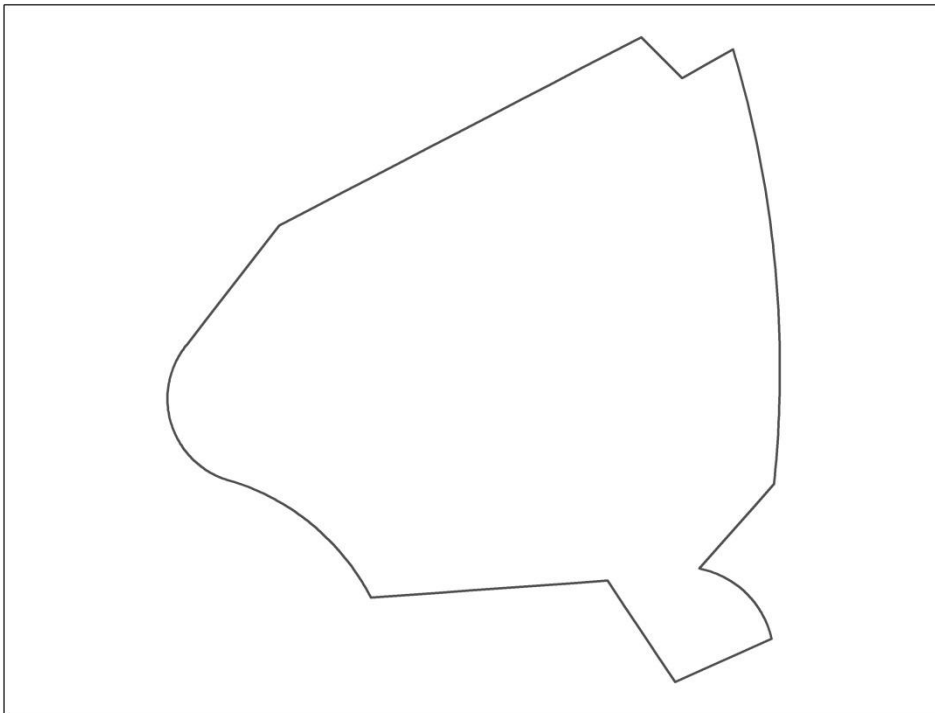


Figure 9. Polygon Transformed into Line Segments.

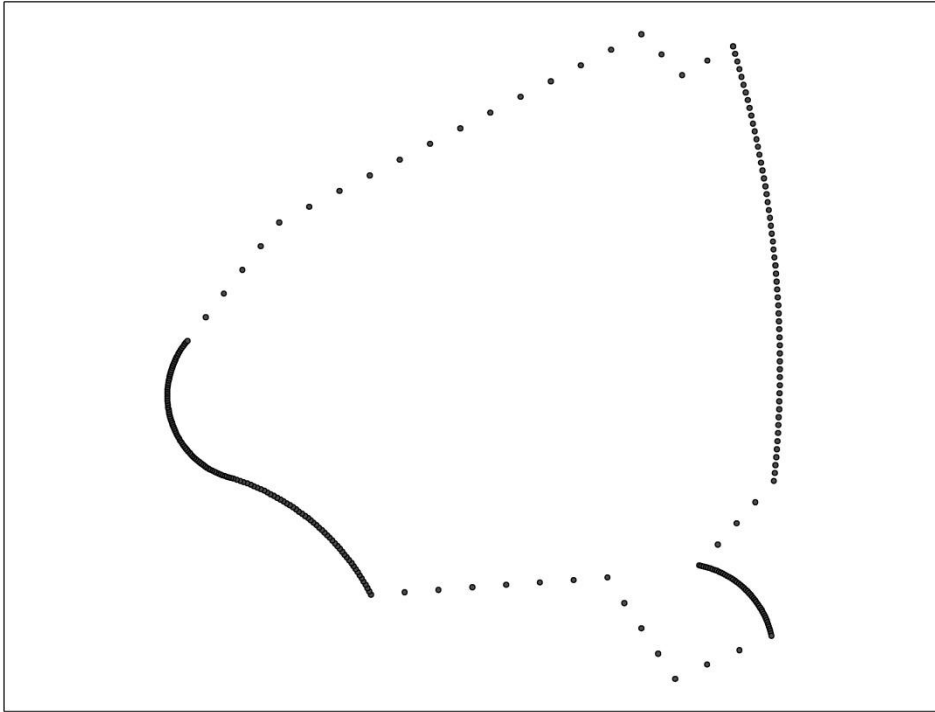


Figure 10. Line Segment Transformed to Points.

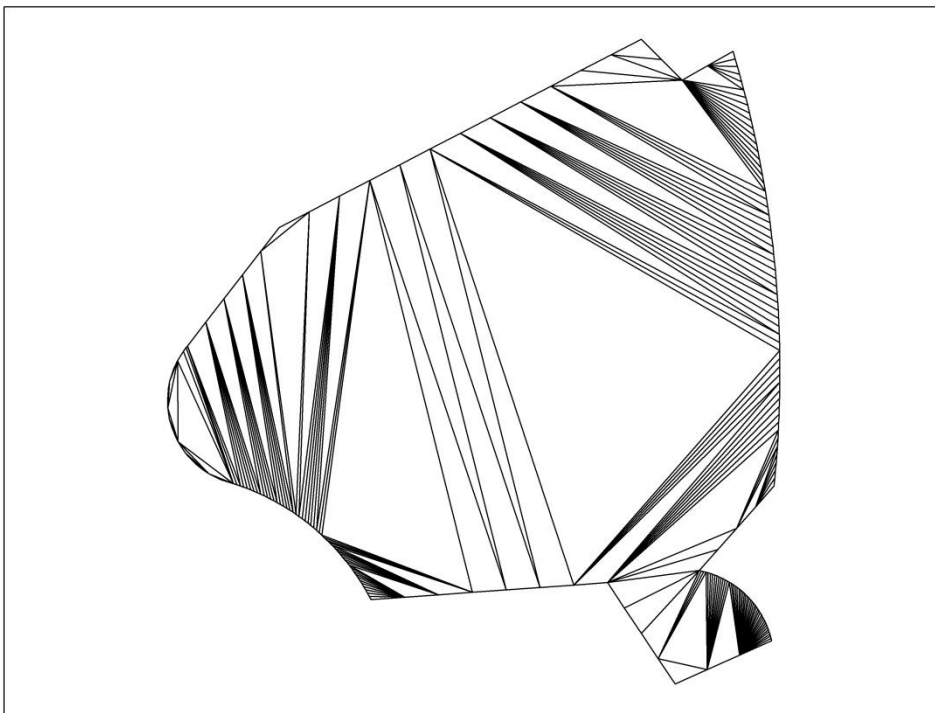


Figure 11. Creation of Triangulated Irregular Network.

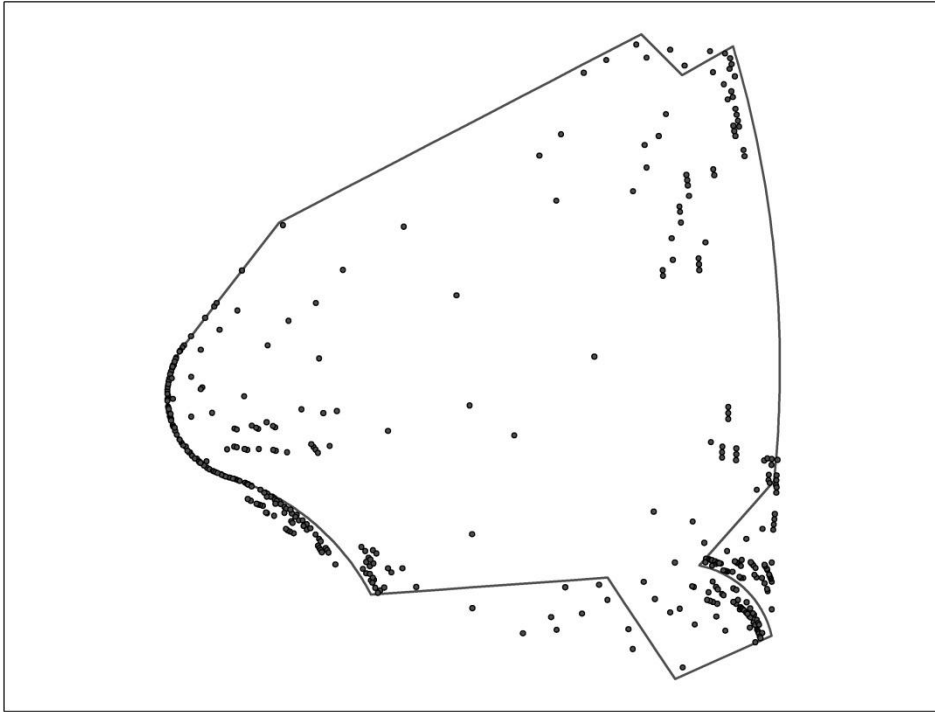


Figure 12. Interior Points of TIN Triangles.

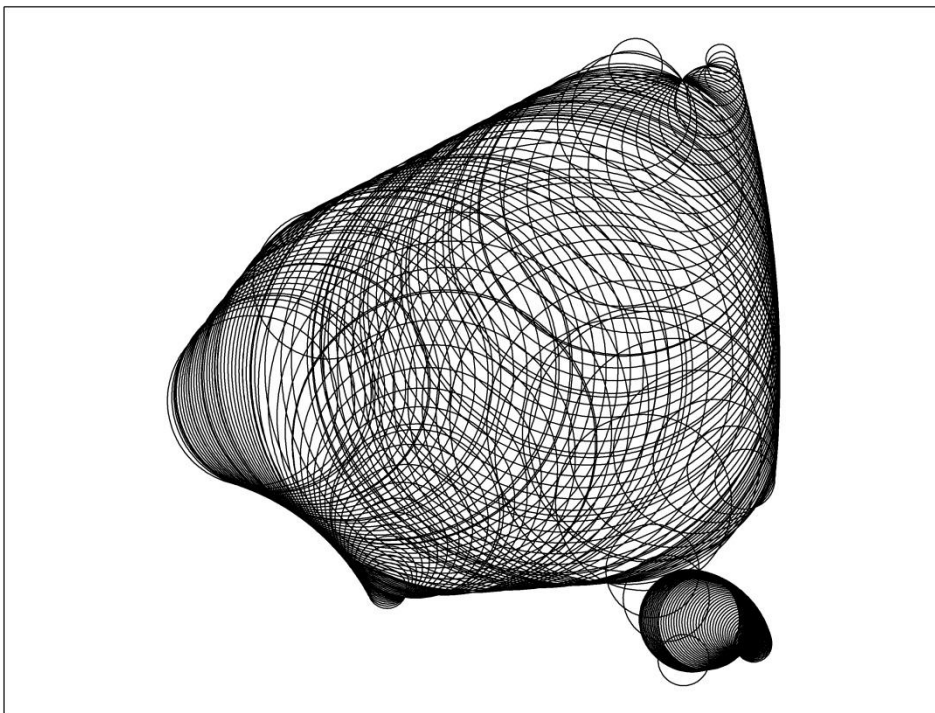


Figure 13. Minimum Enclosing Circle for TIN Triangles.

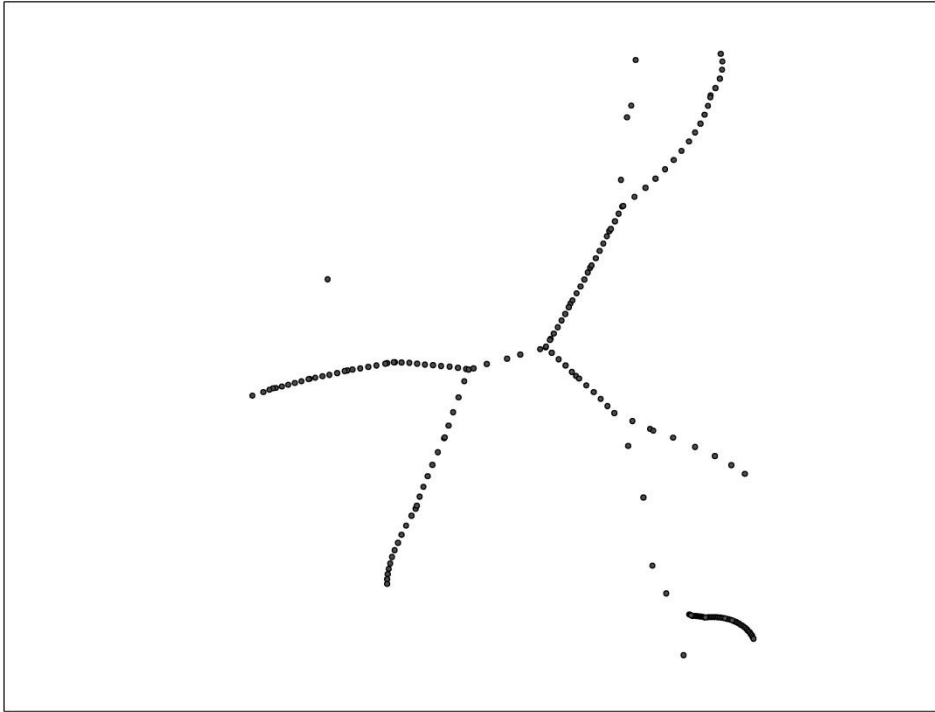


Figure 14. Center Points of Minimum Enclosing Circles.

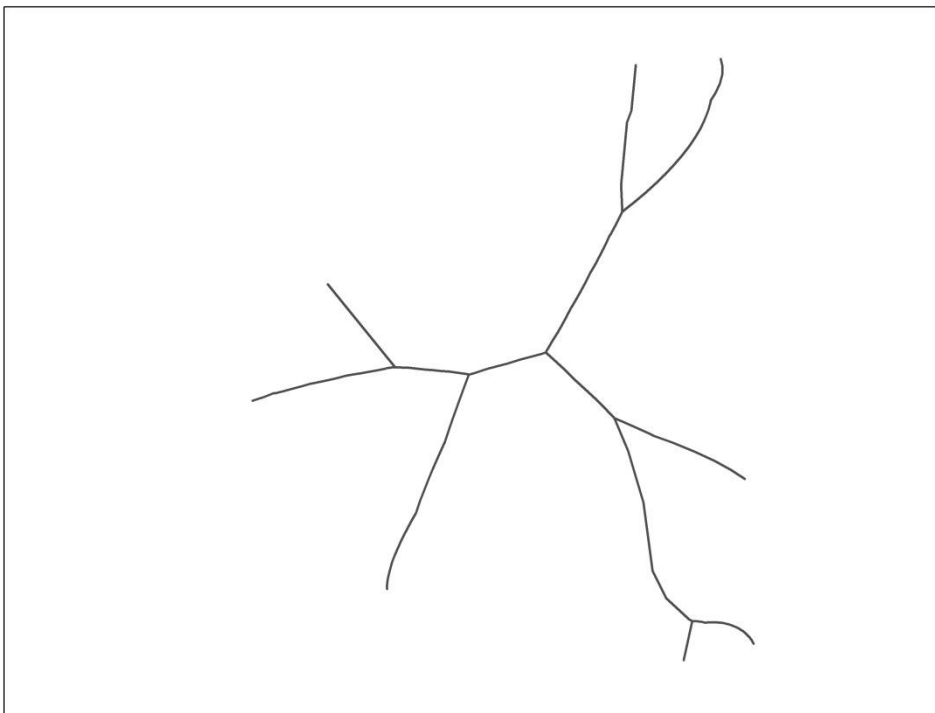


Figure 15. Example Medial Axis.

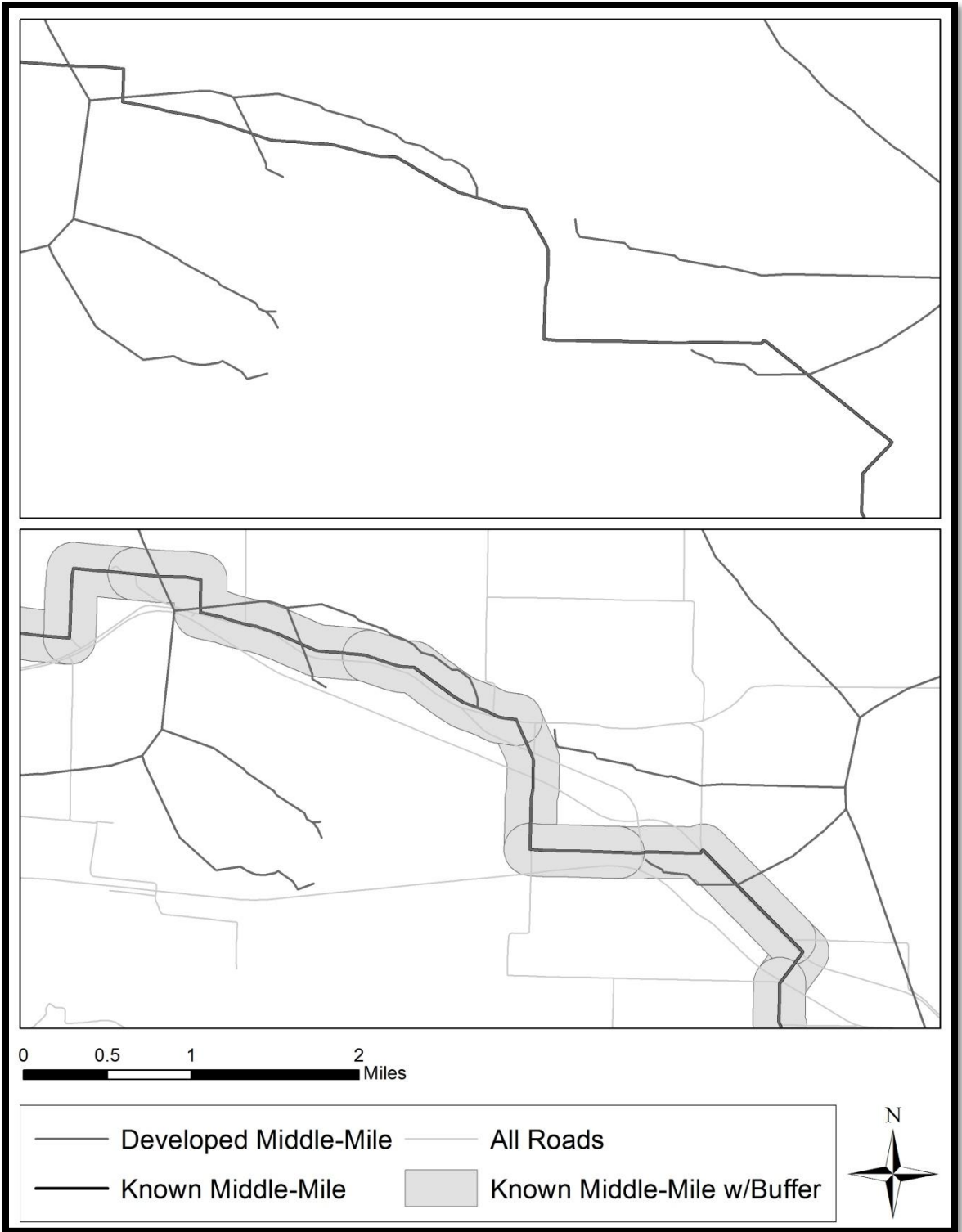


Figure 16. Example of Known and Inferred Middle-Mile Intersection with Roads.

CHAPTER 4. DATA AND APPLICATION

4.1 Study Area

The methodology outlined in Chapter 3 is now applied to assess access to commercial broadband services in Missouri. Missouri is located in the Central United States, bordered by Iowa to the North, Illinois, Kentucky, and Tennessee to the East, Arkansas to the South, and Nebraska, Kansas, and Oklahoma to the West. The state contains 69,683 square miles, making it the 21st largest state. As of the 2010 Census, the population was 5,988,927, making it the 18th most populated state. The state has two large metropolitan areas with population greater than one million, St. Louis and Kansas City. Conversely, there are large portions of the state with little or no population. A 2010 Community Population Survey by the NTIA found only 64.3% of residents surveyed had access to broadband. This ranked Missouri 38th out of the 50 states in percentage of households with Broadband access (NTIA 2010).

Access to broadband is first evaluated for the entire state as shown in Figure 17. As mentioned previously, ZIP Codes, Census tracts, and Census blocks are all common subdivisions of a state used for evaluating access. In Missouri, there are 1,094 ZIP Codes, 1,023 Census tracts, and 3,258 Census blocks (US Census 2010). The provider submitted service areas indicate that some have access while others do not as shown in Figure 16. Most of the state is provided access to Broadband with the exception for a few regions in North-central, South-central, and South-east Missouri. A few other smaller areas with no access exist in North-east and South-west Missouri. Areas in close proximity to Interstate and U.S. Highways almost completely have access available. The

larger metropolitan areas in the state including St. Louis, Kansas City, and Springfield have provider service areas covering all of their city limits.

While access is evaluated statewide, the study of middle-mile and inference of unreported and expanded infrastructure focuses on a 31 county area in South-central Missouri shown in Figure 18. The counties inside this region include Benton, Camden, Christian, Cole, Cooper, Crawford, Dallas, Douglas, Franklin, Gasconade, Greene, Hickory, Howell, Laclede, Maries, Miller, Moniteau, Morgan, Oregon, Osage, Ozark, Pettis, Phelps, Polk, Pulaski, Shannon, Stone, Taney, Texas, Webster, and Wright. This region of the state includes a mixture of urban and rural development and existing middle-mile, the location of which is known. As shown in Figure 16, the provider submitted service areas indicate that this geographic region of the state contains multiple areas with no access to broadband. Also shown in Figure 17 are some portions of recently constructed middle-mile, funded through the American Recovery and Reinvestment Act.

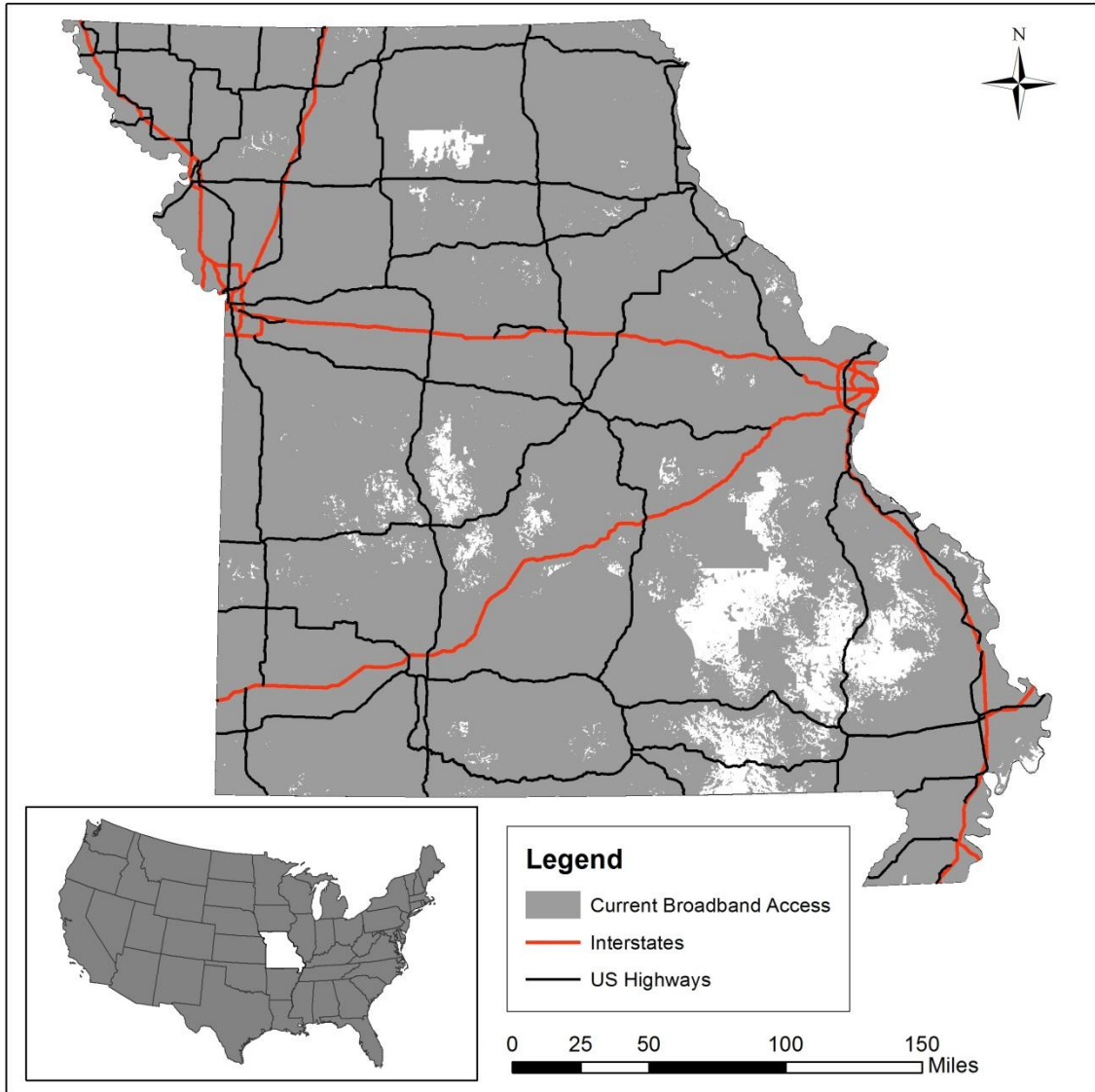


Figure 17. Broadband Access in Missouri – provider volunteered service areas - Date.

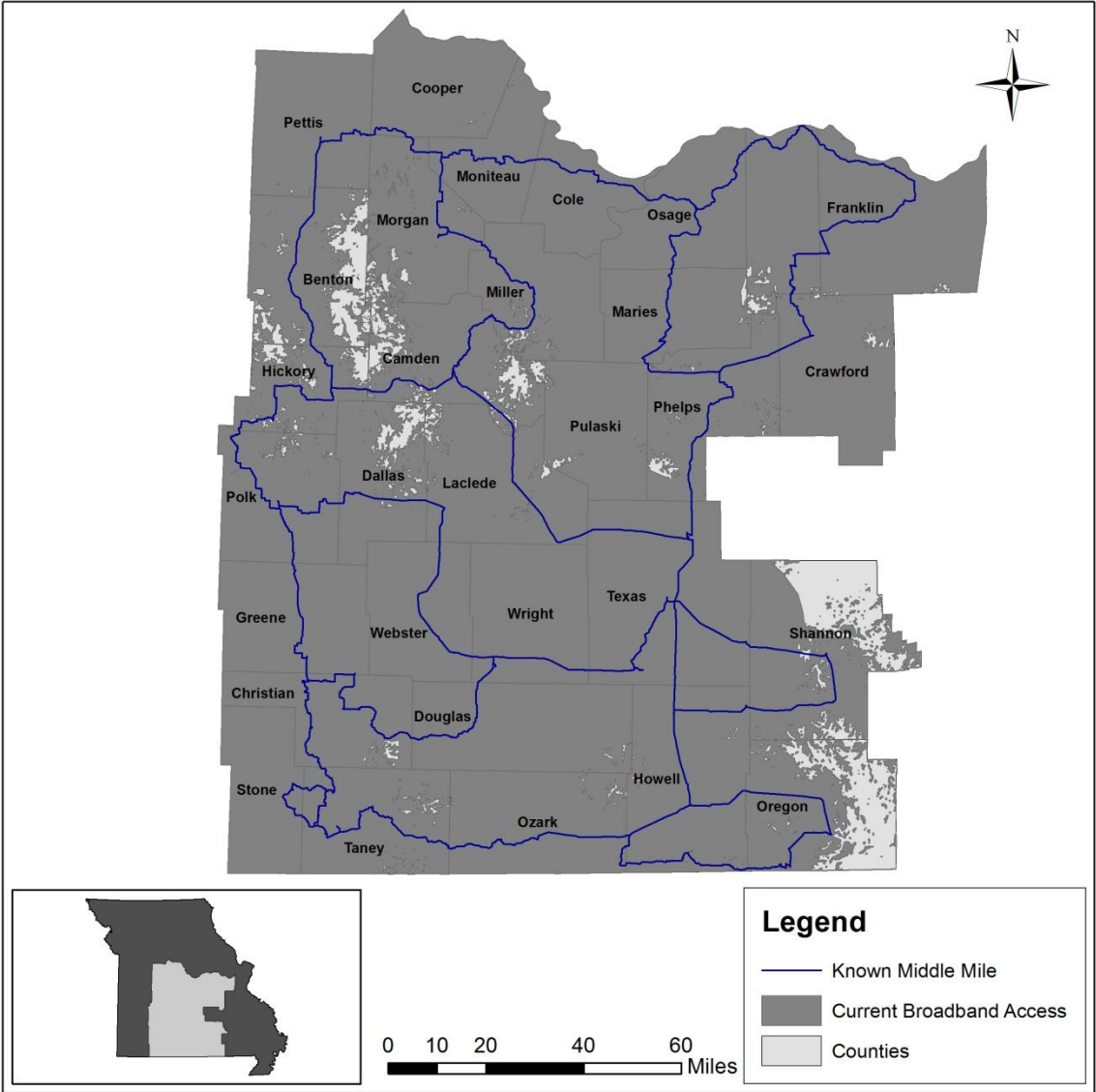


Figure 18. Study Area for Middle-Mile Inference and Future Expansion.

4.2 Data

Multiple data sources are utilized in this thesis. The primary source is a collection of broadband provider footprints for the state of Missouri. While typically not released publicly by providers, this provider data is collected by GeoDecisions, a geospatial and information technology subsidiary of Gannett Fleming, as part of the State Broadband Initiative (SBI) for Missouri. All parties working on the project signed a Non-Disclosure Agreement (Appendix A) before gaining access to the data. Every six months, GeoDecisions puts out a "call for providers" to all known broadband providers with service in Missouri. This call goes to companies that have previously submitted their footprints along with other companies identified as broadband providers through the FCC Form 477 database, data mining, word of mouth, and other outreach efforts (GeoDecisions 2013).

Provider volunteered service areas are submitted in a variety of formats to GeoDecisions. These formats include GIS-ready geodatabases and shapefiles, AutoCad digital drawings, other drafting and engineering software files, photographs of service areas, and hand drawn maps of the service areas. While individuals involved with the project strive for accurate data, the NTIA guidelines for the SBI introduce the possibility for uncertainty and ambiguity. Providers not only report their current service areas as having access, but also any area they could theoretically provide service to in the next ten business days in order to maintain some degree of data privacy (Grubestic 2012b; NTIA 2012). Once a broadband provider company submits their service areas to GeoDecisions, the data is converted into a shapefile (ESRI's format for storing georeferenced vector features), then each is imported into a geodatabase if it is not already in this format.

Addition and editing of attributes required by the NTIA, including technology of transmission, or type of Broadband, and maximum and minimum speed is attributed to each provider area. Ultimately, all provider geodatabases are combined into a comprehensive geodatabase model (Appendix B). Next, Census blocks geometrically intersecting provider service area polygons for both terrestrial and wireless technology are then considered to have access. The resulting data layers contain provider service at the Census block level for both terrestrial and wireless technology.

The NTIA requires the completed data submission for each state by April 1 and October 1. Two to three weeks before the deadline, GeoDecisions delivers the geodatabase to the mapping team at the Geographic Resources Center at the University of Missouri. Wireless providers are removed from the Census blocks and returned to their original polygon, or polygons, spatial format. Community Anchor Institutions, such as government buildings, emergency services, and schools are added in the form of points. All data is imported to a single geodatabase with multiple datasets and run through the NTIA quality assurance/quality control program to ensure all necessary attribute and spatial data is present and no topological errors exist. Once the data passes this error-check program, it is uploaded to a NTIA ftp site so it can be added to the National Broadband Map (GeoDecisions 2013).

For this project, the service areas submitted by providers and transformed to shapefiles by GeoDecisions are used for analysis. Each shapefile contains polygon features represent those areas of the state served by a provider. In order to protect the confidentiality of the provider data, in this study, each provider footprint was scrubbed of any unique identifying information. Completion of this step involved assigning a number

to each provider and utilizing that number for differentiation between providers.

Additionally, clearing of the attribute table of each provider of any unique, identifying information ensured no connection of any footprint to any provider.

October 2011 provider service area data, from Submission 4 to the NTIA, for the state of Missouri are further analyzed in this thesis. The data represented 106 provider footprints from 94 unique broadband providers; as polygon features in a shapefile format. The provider's reported service areas range from 0.0066 to 10,173 square miles. Only providers considered to offer broadband service are included in this study; that is, those with service that meets or exceeds the NTIA 768/200kbps speed threshold (Grubestic 2012b). This threshold varies from the FCC definition of broadband. However, since the SBI submits their data to the NTIA, utilization of their speed threshold took precedent.

The project collected data from a variety of types of broadband providers, including terrestrial, wireless, satellite, and mobile, however, only providers claiming terrestrial service are retained for subsequent analysis. Of the 94 providers in Submission 4, 68 of them claimed the ability to provide terrestrial broadband service. Terrestrial service includes Symmetric xDSL, Asymmetric xDSL, Cable, and Fiber. Satellite, wireless, and mobile broadband are excluded due to the different configuration of these types of networks. Mobile, wireless, and satellite networks send their signals over the air, providing service to an area with only one physical connection to the network at a tower or other control point. Terrestrial networks require each user to have a physical connection to the network in order to receive service. Spatial representation and development of terrestrial networks would be more accurate because of the need for all network infrastructures to be connected in order to be a part of the network of any given

provider. Currently, it is thought that these 94 providers represent approximately 80% of the broadband providers in the state (GeoDecisions 2013).

Another data source is the location of a recently built middle-mile. The American Recovery and Reinvestment Act (ARRA) provided the funding for the nationwide broadband project. One portion of the funds sponsored the mapping initiative in each state, district, and territory. Another portion of the allocation fulfilled the goal of expanding of broadband infrastructure. Individual companies bid for funds on a variety of projects to expand new or reinforce existing middle-mile. In Missouri, three different companies received funding to build new infrastructure: BlueBird Media in the Northern half of the state, Show-Me Technologies in the Southern half, and University Corporation for Advanced Internet Development as part of the nationwide expansion of Internet2 (NTIA 2013a). Show-Me Technologies shared their complete build of new middle-mile infrastructure with the mapping team as part of their agreement in receiving ARRA funds. This data, provided in ESRI's shapefile format, included the location of all the newly built middle-mile in the 31 county region in South-central Missouri mentioned in Section 3.1 and shown in Figure 18. This known middle-mile data provides a basis for comparison with middle-mile that will be inferred.

Another data set employed for the study included road locations. A year 2011 road layer for the state of Missouri documenting the location of Interstate, federal and state highways, along with county and other local roads created by the Missouri Department of Transportation (MODOT) is used to approximate the location of telecommunication rights of way. Providers' broadband infrastructure typically runs along previously established right of way to minimize the cost and time to negotiate

rights to lay their infrastructure over large areas of land. Once the medial axis for each provider has been rendered to approximate the location of middle-mile infrastructure, the inferred middle-mile can then be compared with previously established rights of way, such as roads, railroads, pipelines, and electrical transmission line corridors. Performing this comparison allows for a more precise and accurate middle-mile network as well as the ability to identify the best right of way predictor for use in analysis. Along with roads, the location of other features commonly corresponding with rights of way such as gas pipelines and electric corridors were acquired for the study site. Collection of this data came from two paper maps compiled by the Missouri Public Service Commission. The electrical transmission line map was produced in 1985 and the gas pipeline map was last revised and published in May 1995. Each map was first georeferenced, followed by the digitization of pipeline and electric corridors from each map. Similar to the roads layer mentioned previously, both pipelines and electric corridors serve as viable right of way for broadband infrastructure. Comparing pipeline and electric corridors to the inferred and known middle-mile results allows for a check of the accuracy of the outputs along with a known right of way predictor for use in analysis.

An additional set of data utilized for the study is US Census block and tract level demographic data from the 2010 Census. The tracts and blocks, along with ZIP Codes, are utilized as the areal units of analysis of access to broadband throughout the state. All three units include a variety of demographic and socioeconomic data including total population and area. Additionally, the block is the smallest unit of spatial representation the Census utilizes. Need for this data is due to the need to study access and future access within the developed broadband network. Analysis of access requires population

data at the block level in order to infer missing and potential expansion of access. Missouri's geography includes large plots of national forests and military land owned by the federal government. Expanding access to these areas is likely less of a priority than in other populated areas, and the block data will help to isolate blocks with no population or that fall within federal owned land. Once these blocks are identified, they can be eliminated from being evaluated when completing the inference of future middle-mile and broadband service areas portion of the thesis.

One set of data utilized was speed test data from the MoBroadbandNow.com website (Missouri 2013). This data is an excel worksheet composed of the location of each resident of the state who took an Ookla broadband speedtest on mobroadbandnow. This data is a record of broadband users who navigated to the website, clicked on the speedtest icon and allowed Ookla to record their geographic location (in the form of Latitude and Longitude), IP address, broadband provider, download speed, and upload speed. The results were displayed to the user and also logged into a database managed by GeoDecisions. The excel worksheet contained latitude and longitude data, meaning it could be shown as point features using a GIS, representing the location of each speed test user. Provider service areas used in the thesis were current as of October 2011.

Therefore only the speed test results from April 2011 to October 2011 were used. During this timeframe, 5,354 speed tests were conducted, yielding 5,354 points for comparison.

The final two data sets utilized for this thesis were city boundary and railroad locations, both available from the Missouri Spatial Data Information Service (MSDIS) in January 2013. The railroad data provided another type of right of way for comparison with the known and inferred middle-mile. The city boundary data is used for the second

portion of the thesis to infer the location for expansion of middle-mile and provider networks.

4.3 Analysis of Access and Inference of Middle-Mile

ArcGIS 10, a commercial GIS, in conjunction with the Python programming language are used to implement the processes and methods discussed in this thesis. The medial axis routine, as initially coded in Python by Dr. Matisziw, was adapted to transform provider polygons into medial axes. All computations and analysis were executed on an Intel Pentium 4, 3 GHZ processor with 8 MB RAM running a 64-bit version of Windows 7.

Access is evaluated through comparison of different representations of space, such as those used by the FCC and the NTIA for reporting broadband service. Current service areas are also evaluated through a geometric overlay of all provider footprints. Specifically the polygons from the 68 provider shapefiles were merged in ArcGIS and overlapping areas were dissolved into a single polygon to simplify the representation of service access. The output of this process was a single polygon layer representing all area of the state that one or more provider claimed the ability to serve as shown in Figure 18. Once the single polygon service area for the state is created, it can be geometrically overlaid onto ZIP Codes, Census tracts, and Census blocks to evaluate the areas within the state of Missouri with and without access. Results are calculated to compare the total square mileage of the state with the square mileage of each areal unit with access. Additionally, the total population of the state is also compared with the total population

for each areal unit that has access. Results are presented in both total square miles and population along with percentage of square mileage and population with access.

Inference of unreported and potential expansion of middle-mile required the 68 terrestrial provider service areas from Section 3.1 along with potential right of way corridors for the study area. Each terrestrial provider footprint was processed using the medial axis routine from Section 3.2. The resulting medial axes, represented inferred middle-mile. They were then combined with known middle-mile from ShowMe Technologies into a single polyline service area using the 'merge' function in ArcGIS. Next, each right of way asset type was clipped so that only the assets in the study area are retained. A geometric intersection function was executed. The intersections evaluated the number of right of way assets within 100, 500, and 2,000-feet of the known and inferred middle-mile to evaluate the level of overlap between the assets. Due to the questions about the accuracy of the data along with the varying widths of the different right of way types, a decision was made to evaluate all right of way within these three values. This ensured right of way and middle-mile that reasonably align are considered to be intersected and included in the results. Results were calculated to evaluate length of middle-mile and right of way intersection along with the percentage of middle-mile intersecting with each right of way type. The right of way with the highest percentage of intersection is used for inference of potential new middle-mile since it is most closely aligned right of way.

Inference of unreported or missing providers/middle-mile was next to be evaluated. A geometric intersection was executed between ShowMe known middle-mile in the study area and the areas that were determined to not have access from earlier in

Chapter 4. The results of this intersection are areas where Broadband infrastructure is present, but no Broadband provider reports serving the area.

In order to infer the location where broadband and middle-mile infrastructure would most logically be expanded, additional analysis is necessary. The two best indicators of broadband service are proximity to providers and population as mentioned in Section 2.3. Taking that into consideration, identifying areas where population (demand) is present, but no broadband access is available would meet these criteria. In order to find these areas, a geometric intersection was performed between areas without access from Section 3.1 and the areas within city boundaries of all cities and villages in the study area. The areas selected therefore are those having population, but without access to broadband. Next, these areas are ranked with respect to potential for Broadband service and access expansion. Three measures are used to develop these rankings. The first is the Euclidean distance, or proximity, of each potential expansion area to the nearest area with access. The second is the proximity of each potential expansion area to known and inferred middle-mile from Section 3.2. The final measure is the distance of each potential expansion area to the nearest most closely aligned right of way identified previously. The proximity to middle-mile and right of way are used to ensure the potential service expansion areas can be connected to existing service areas. The greater the distance between a potential expansion area and middle-mile and right of way, the lower the probability of broadband being expanded into that area.

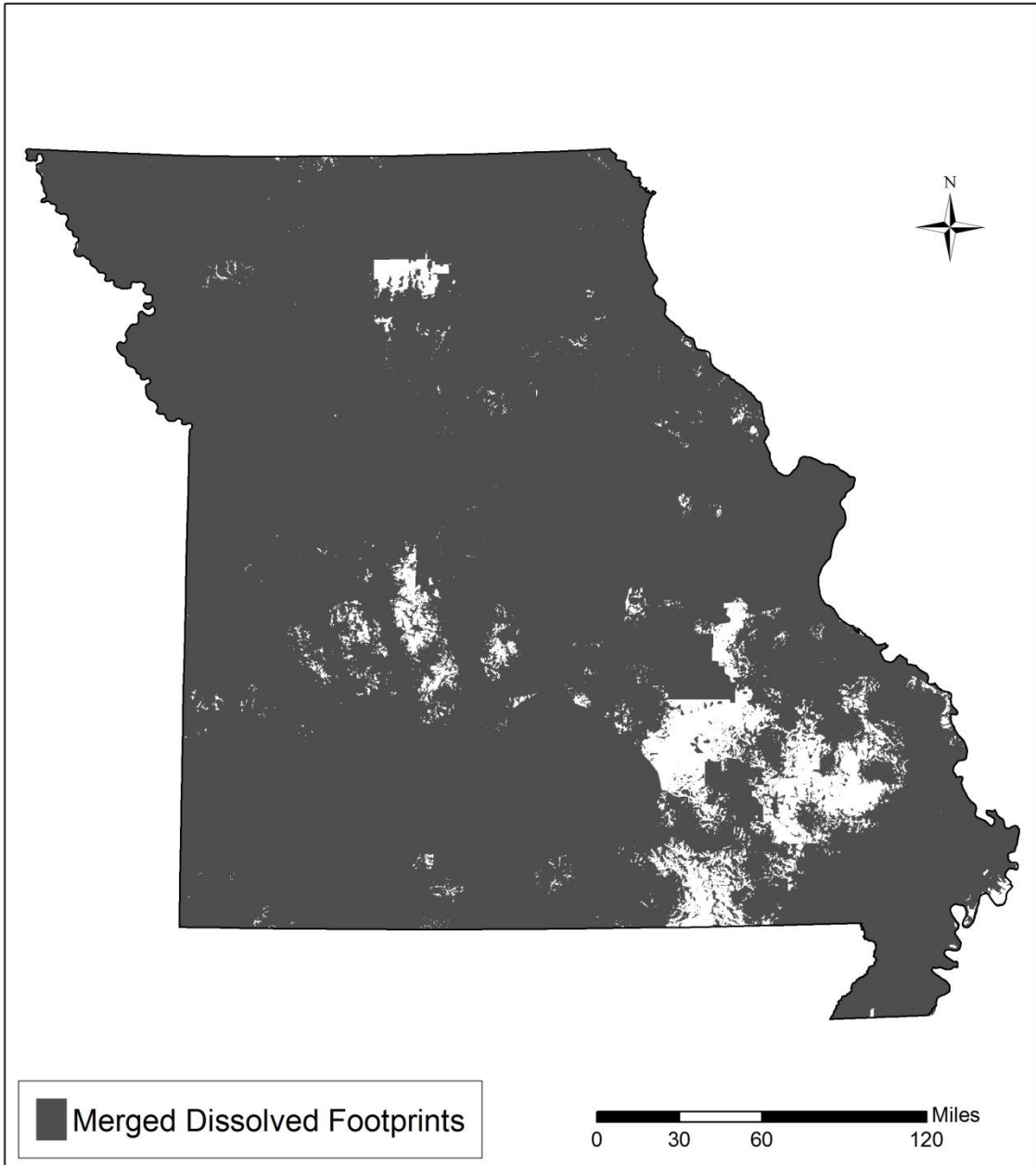


Figure 19. Access to terrestrial broadband in Missouri – Provider volunteered service areas.

CHAPTER 5. RESULTS AND DISCUSSION

5.1 Broadband Access

The results of the geometric overlay of the provider volunteered service areas with various areal units of analysis (blocks, tracts, ZIP Codes, and no areal unit of analysis) exhibits differences in the amount of area and population with access to broadband. Table 2 shows the number of areal units with access to broadband along with the percentage of each unit with access. The results in Table 3 depict the total area of each areal unit with broadband access in addition to the percentage of each areal unit. Table 4 presents similar results for each areal unit, but focus on the total population with access along with the percentage of population with access. Figures 20-29 show levels of access based on the four different methods for evaluating access reviewed in Section 3.1..

The results for the old Form 477, the ZIP Code, indicates that 100% of the ZIP Codes within Missouri have at least one broadband provider claiming service to that area based on all three method of access measured: total units, area covered, and population. Results for the new Form 477, the Census tract representation, are similar with 100% of tracts having access to broadband based on the four different methods of evaluating access.

When evaluating access using the NTIA method and areal unit of analysis for the National Broadband Map, the Census block, there was not complete service based on any of the three measures. 3,077 of the 3,258, or 94.44%, of Census blocks were found to have access. 98.61% of the total area within Missouri had access based on Census blocks, while 99.88% of the population in the state had access.

The final method, use of the single polygon, "merged" provider footprints, could only be calculated based on area with and without access. This was due to the lack of geometric overlay onto an areal unit describing population. The results for this method showed 93.84% of the state had access to broadband, which was the lowest area with access of the four methods used in the study.

The results of the portion of the thesis pertaining to access to broadband support the findings of prior research in that representation of broadband access is very much influenced by the areal unit of analysis employed. Although Grubestic (2010, 2012b) mention the challenges in acquiring publicly released data from the FCC Form 477 and the NTIA National Broadband Map in a useful format for analysis, this study had access to the majority of provider submitted footprints in the Missouri. The results of combining then overlaying these service areas onto ZIP Codes and Census tracts showed that 100% of the area and population within Missouri had access to broadband. The footprints each provider submitted are clearly contrary to this, as there are portions of Southern Missouri without access to broadband.

Results of the overlay of the single polygon, "merged" provider data onto Census blocks aligned more closely the provider submitted data. These results indicate an absence of broadband for some areas and population in Missouri. This difference in area and population coverage from the Form 477 reporting methods is likely due to the smaller size of Census blocks. While there are 1,023 Census tracts in the state, there are 3,258 Census blocks including multiple Census blocks inside each tract. Therefore, while large portions of a tract might not have access, the entire unit is reported to have access. However, for Census blocks, access is reported differently. Instead of showing

all the blocks in an area the size of a tract as having access, only the blocks with broadband service present inside would be considered to have access. This discrepancy stems from the Modified Areal Unit Problem (MUAP), where the differing sizes/shapes of areal units can result in service, access, or another measure being represented differently (Church and Murray 2009).

A trend that developed from analysis of service areas at the block level is that a larger percentage of population was identified as having access than the percentage of area with access. Census blocks are designed to be small; however, within rural areas they can become as large as a county. With this in mind, many of the blocks without access have low or no population, meaning they are larger than blocks in higher populated areas. As mentioned in Chapter 2, broadband providers have incentive to place their infrastructure and provide services in areas where customers will subscribe and pay for those services. Therefore, the large size and low number of potential subscribers makes these blocks less likely to have broadband access provided to them now or in the future. Additionally, the higher level of access measurement based on population versus area covered supports the hypothesis that providers will be found in populated areas in higher density. A larger customer base can also result in more competition and an increase in the level of service. This can further widen the digital divide and leave rural residents further behind in broadband adoption.

Similarly, when the merged provider service areas were not overlaid onto any unit of measurement, the amount of area covered was smaller than for ZIP Codes, tracts, and blocks. While this "merged" representation of service areas is the most accurate measure of access in the Missouri, limitations still exist with respect to the utility of the data.

First, the data is not released to the public in an easy to use format as it was for these. Providers' service areas are proprietary and it is necessary to keep them guarded to maintain a competitive advantage. Even though great care was taken to ensure all unique identifying metadata and other attributes were removed from the data, it is doubtful all providers in the state would be willing to release their service areas to researchers in the future. This makes replication of this method less likely to occur once the SBI ends in 2014. Second, the use of Census data for calculation of population is a result of blocks and tracts being the only units released with accurate and uniform population data available. While the method of not overlaying the single polygon, "merged" service areas provides the most accurate measure of areas with access, little additional analysis can be performed. No calculation of percentage of population with access was possible, let alone the ability to perform analysis that is more detailed based on age, ethnicity, education level, or other categories of data the Census collects and publishes.

A variety of geographic and demographic factors could contribute to the lack of access within certain areas of Missouri. Shannon County was identified as a county with large areas without access to broadband. Shannon is the second largest county in the state based on area, but only has a population just above 8,000. This large area, small population combination leads to a low population density. Areas with low population density could have a greater challenge gaining access to broadband due to the low economic return in the form of customers relative to a higher amount of infrastructure investment necessary to provide access to residents in the county. Additionally, Shannon County has a large amount of National Park Service land. These lands typically have few if any residents, meaning there is little reason for broadband providers to extend their

infrastructure and service into these areas.

Geographic factors could contribute to the lack of access within Camden County. Camden County contains Lake of the Ozarks, a large dam created reservoir, containing inlets and coves throughout. The lake covers the county from East to West, providing a challenge for connecting both sides of the lake to broadband infrastructure and access. Additionally, much of the land along the lake is privately owned with only private road access. This leads to additional challenges in providing broadband access to the "fingers" of land along the lake and limits where infrastructure can be placed in order to connect residences. Furthermore, a portion of the population in the county is seasonal, leading to part time residents only requiring broadband service during portions of the year.

Service Area Source Data	Areal Unit of Analysis	Total Units in Missouri	Units with Access	% of Units with Access
Form 477 (pre-2010)	ZIP Codes	1,094	1,094	100
Form 477 (post-2010)	Census Tracts	1,023	1,023	100
National Broadband Map	Census Blocks	3,258	3,077	94.44
Provider Footprints	None	N/A	N/A	N/A

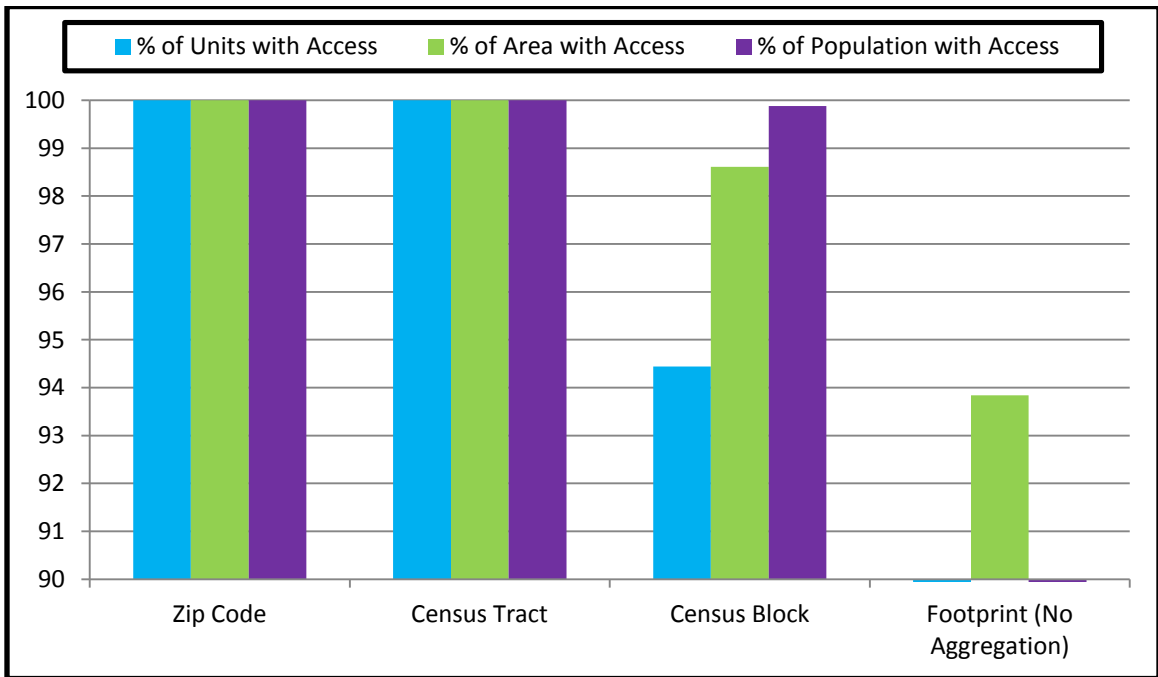
Table 2. Broadband Access: Number of Areal Units with Access.

Service Area Source Data	Areal Unit of Analysis	Area with Access in Missouri (sq mi)	Area without Access in Missouri (sq mi)	% of Missouri with Access
Form 477 (pre 2010)	ZIP Codes	69,683	0	100
Form 477 (post 2010)	Census Tracts	69,683	0	100
National Broadband Map	Census Blocks	68,715	968	98.61
Provider Footprints	None	65,388	4,295	93.84

Table 3. Broadband Access: Area Served.

Service Area Source Data	Areal Unit of Analysis	Population with Access in Missouri	Population without Access in Missouri	% of Population in Missouri with Access
Form 477 (pre 2010)	ZIP Codes	5,988,927	0	100
Form 477 (post 2010)	Census Tracts	5,988,927	0	100
National Broadband Map	Census Blocks	5,982,029	6,898	99.88
Provider Footprints	None	N/A	N/A	N/A

Table 4. Broadband Access: Population Served.



Graph 1. Comparison of Methods for Measuring Broadband Access.

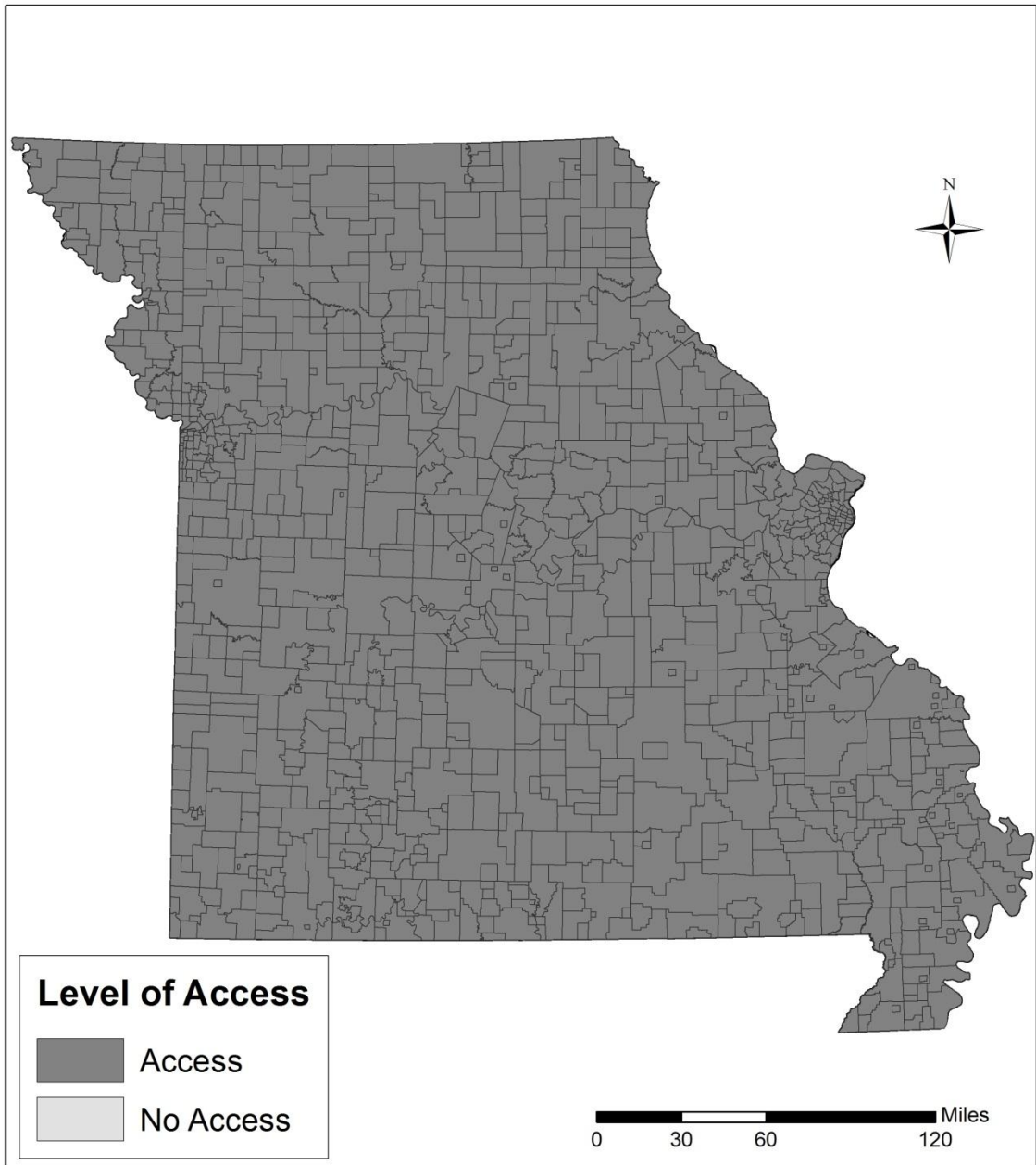


Figure 20. Broadband Access at ZIP Code Level (Old Form 477).

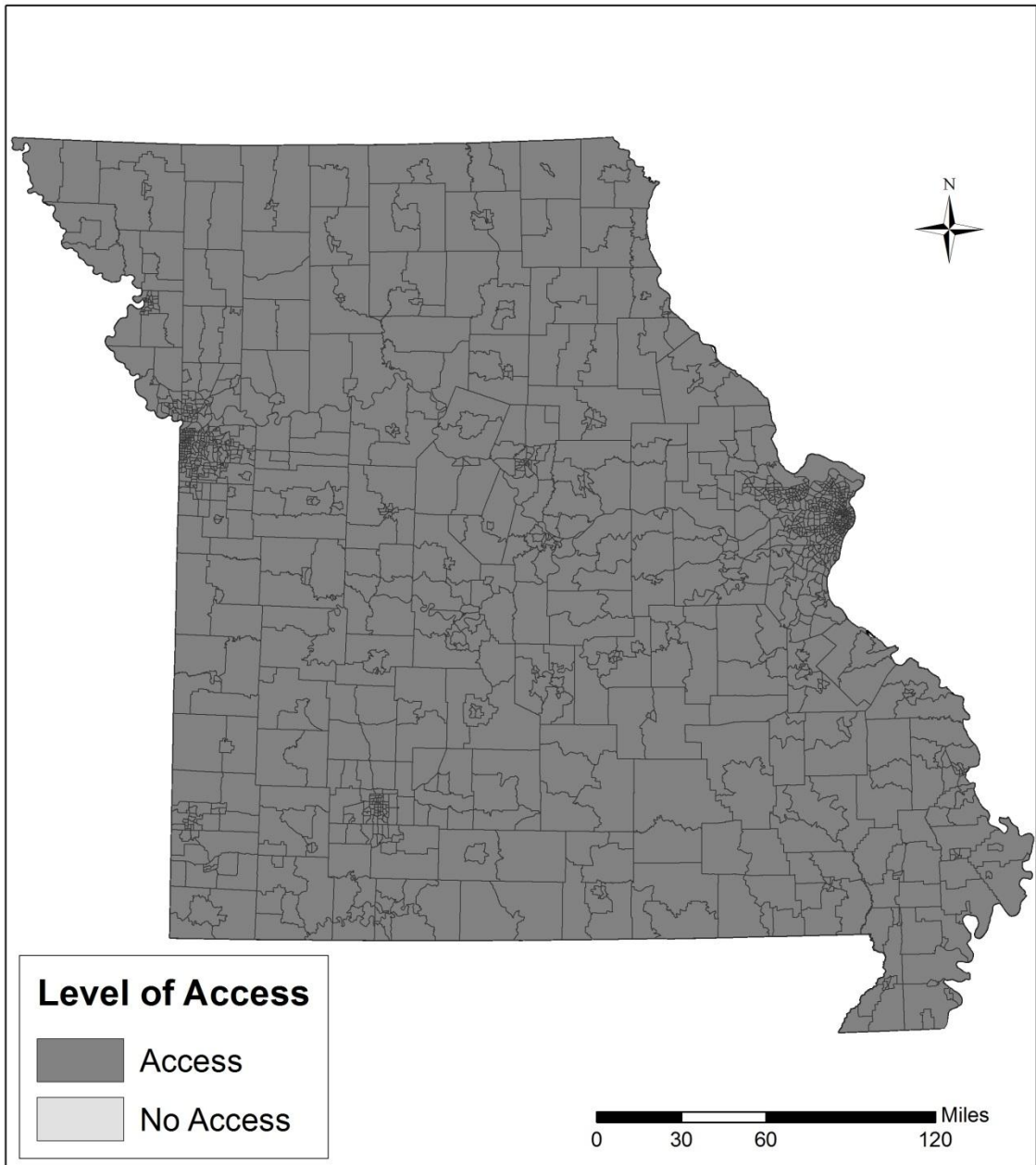


Figure 21. Broadband Access at Census Tract Level (New Form 477).

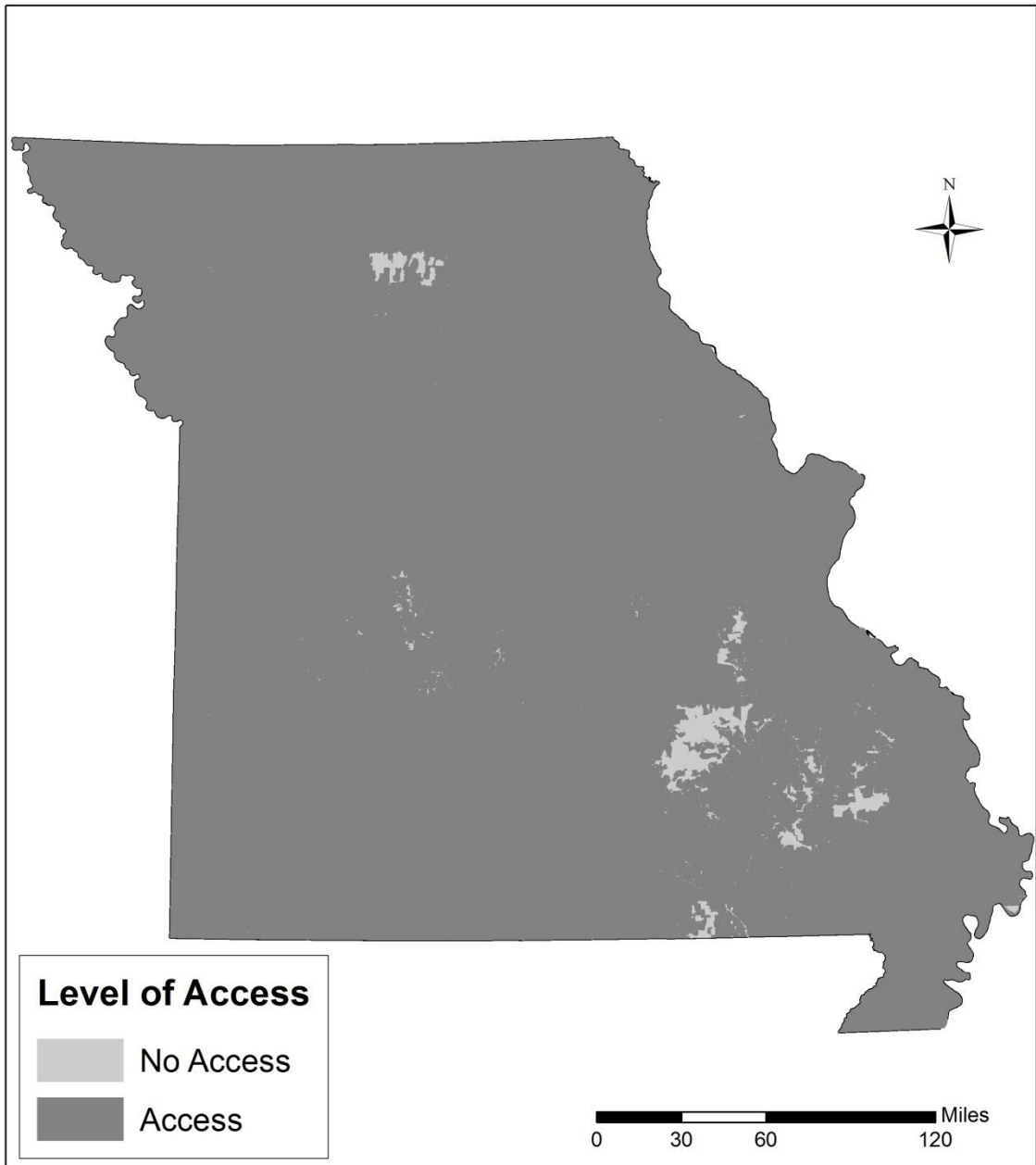


Figure 22. Broadband Access at Census Block Level (approximation of National Broadband Map).

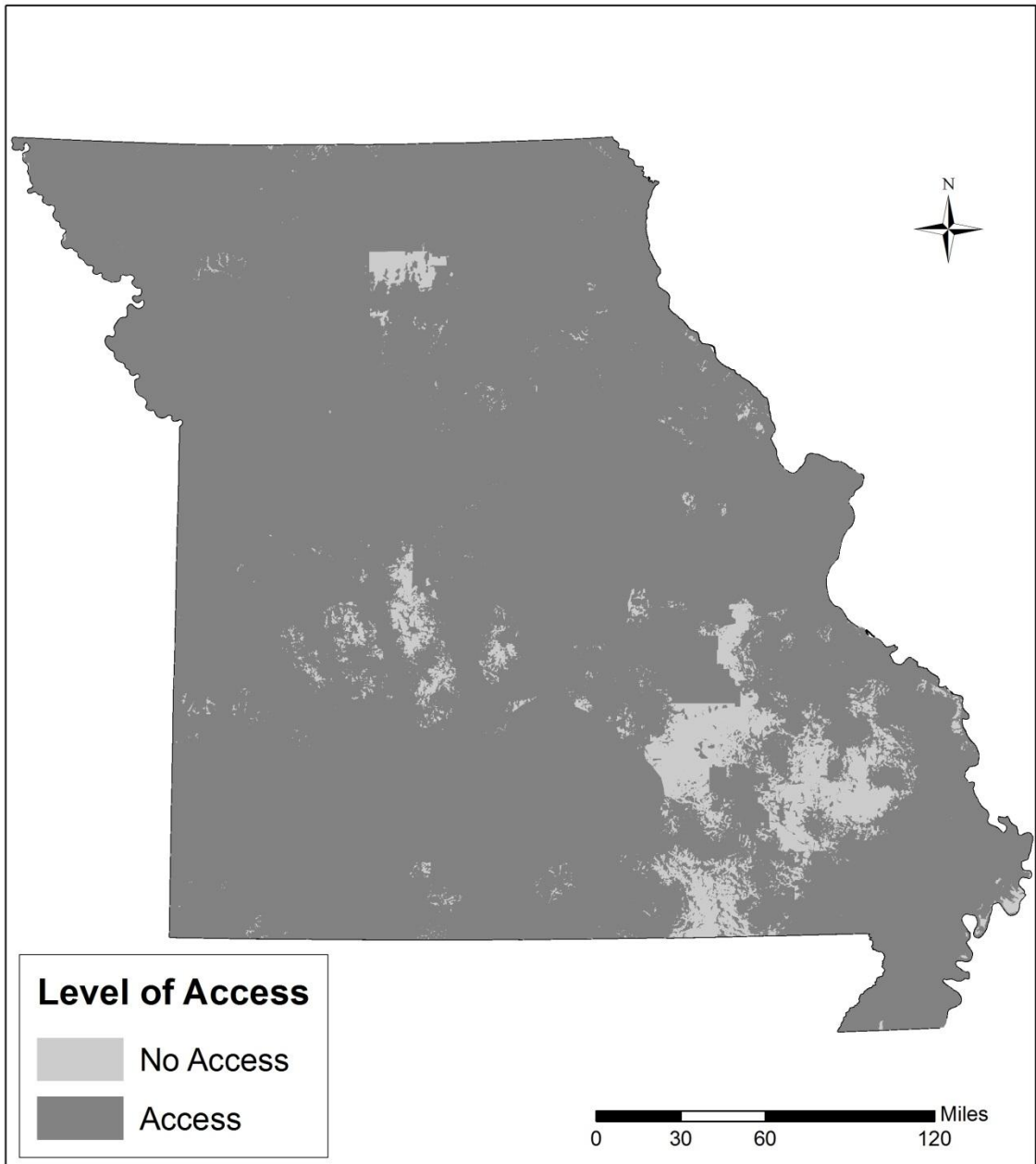


Figure 23. Broadband Access at Provider Footprint Level.

5.2 Inference of Missing and Future Access Areas

As mentioned in Chapter 3, the process for inferring the location of unknown and future middle-mile and broadband access began with the need to identify which right of way features most closely aligned with the known middle-mile. The results of comparing the level of intersection within 100, 500, and 2,000-feet of possible right of way features with known middle-mile are listed in Tables 5, 6, and 7. At 100 feet, roads most closely lined up with 96.70% of the known middle-mile. At 500 feet, roads again were the most closely aligned, with 98.49% of known middle-mile in the study area lining up with roads. At 2,000 feet, the results were similar with 99.78% of known middle-mile spatially proximate to roads. The next type of right of way exhibiting a high spatial correspondence with middle-mile was electrical transmission lines. At 100 feet, 45.87% of known middle-mile is proximate to electrical lines. At 500 and 2000 feet, 47.22% and 62.63% of electrical transmission lines spatially correspond with known middle-mile respectively.

Assessing the amount of both known and inferred middle-mile falling within 500 feet of right of way features, roads showed a similar higher percentage of correspondence with middle-mile than the other types of right of way. The results for all four right of way types are shown in Table 8. Based on the high percentage of known and inferred middle-mile intersecting with roads, they were chosen as the right of way type for use in inference of future middle-mile and provider access areas. Due to the hierarchy of roads within a given state, the decision was made to not use all the roads in the study area for measuring proximity to right of way. Instead, roads were divided by type into six categories to evaluate which type most closely corresponded with the location of middle-

mile. These categories included: Interstates, U.S. Highways, State Highways, County Routes, County Roads, and City Streets. Roads in each category were geometrically intersected within 500 feet with the known and inferred middle-mile in the study area. The results are listed below in Table 9. With 45.22%, County Roads had the highest percentage of middle-mile intersecting it and was utilized as the right of way for measuring proximity. Interstate highways had the lowest intersection percentage at 2.09%. One explanation for this low percentage of intersection is that before 1988 no utility, including telecommunications, could be laid within the right of way of any Interstate Highway as mentioned in Section 2.4.

Before attempting to infer the location of future service and infrastructure expansion areas, an attempt was made to search for unreported Broadband infrastructure and providers. The ShowMe middle-mile in the study area was geometrically intersected with the areas evaluated to not have access in Section 5.1. twenty-three unserved areas were found to be in intersection with the known middle-mile. These areas were spread across Hickory, Camden, Dallas, Howell, Oregon, Shannon, and Phelps counties. Each of the 23 locations were compared with the Ookla broadband speed test dataset locations to evaluate if there were any ground truth observations of access recorded at those sites. None of the 23 locations with known middle-mile/no provider had speed test locations associated with them. The location of these areas is shown in Figures 26-28. The size of these areas of potentially unreported provider service ranged from 0.0007 to 4.387 square miles, with 19 of them measuring less than one square mile – the largest of which were located in Hickory, Camden, and Shannon counties.

A variety of reasons could explain the presence of these areas proximate to broadband infrastructure being associated with no provider service. First, there could be middle-mile running through the identified areas, but no interconnection points in those areas where providers could "connect" to the network. Cost, lack of demand, or no provider willing to provide service in the area could be the causes of this lack of interconnect points. Another possibility is that there are broadband providers in these areas but they chose to not participate in the SBI and submit their service areas. Additionally, a provider could provide service in the areas, but have not yet been identified and targeted by the Missouri SBI. Finally, the possibility exists that some of these areas do have current broadband service, but the footprints of their service areas submitted to the SBI were not accurate.

As the SBI moves forward, these areas should be explored for providers, as there is infrastructure proximate, but no Broadband provider. As mentioned in Chapter 4, GeoDecisions and the University of Missouri SBI team attempt to verify the coverage areas of new and expanded providers after each submission. An addition to this field verification process could include visits to these identified areas to discuss with residents and businesses to attempt in an effort to identify missing or unreported broadband providers.

The process to infer the location of potential area of broadband service expansion started with the single polygon, "merged" service areas representation discussed in Chapter 3.1. It provided the location of where broadband access was and was not present in the study area. A geometric intersection of city boundaries (which represent populated places for this Thesis) with this "merged" service area identified nine unique locations

fitting the initial criteria of having population and demand, but not access present. Of these nine locations, one was located on a river, making it unlikely access would need to be expanded there. Each of the eight remaining locations was compared with the Ookla broadband speed test dataset locations to evaluate if there were any overlapping locations. None of the eight locations with population demand but no current access had speed test locations within them. The distance of each potential expansion area to the nearest county road, the right of way type identified to most likely intersect with middle-mile, ranged from 0 to 3,721 feet. Proximity to the nearest known or inferred middle-mile ranged from 164 to 14,191 feet. Once the three measures were computed for each of the eight areas, they were ranked from most likely to least likely to have access and infrastructure expanded to them. The results of these three metrics for each potential expansion area are listed in Table 10. The location of each potential expansion area is shown in Figures 29-36.

The portion of the thesis focusing on utilization of medial axis routine to predict the location of middle-mile and evaluate the right of way type most utilized for broadband infrastructure produced results that corresponded at a high percentage to known middle-mile and right of way within the study area. The routine successfully produced medial axes mimicking middle-mile infrastructure that intersected with known middle-mile from ShowMe technologies. The level of intersection with the different right of way infrastructures in the study area was over 96% for roads within 100-feet of the known middle-mile and over 98% within 500 feet of the known middle-mile, validating the medial axis routine. As mentioned previously, the reasoning for use of the additional distance within a certain number of feet from the known middle-mile was the

possibility of having incomplete or inaccurate datasets. All of the right of way data was collected from publicly available services meaning there could a variety of factors impacting the accuracy of the data. For this study, the gas pipeline and electrical corridors utilized were only the largest major assets in the area, which would explain why those two categories had a much lower correspondence with middle-mile location.

Additionally, intersecting the middle-mile results with the different right of way methods identified roads being the most accurate indicator of middle-mile with electrical corridors being the second most accurate. This did not match the order mentioned in the literature as electrical corridors and poles were mentioned as the most common right of way type for expansion of broadband infrastructure with roads second. The results still presented electrical corridors and roads as the top two types of infrastructure for use in broadband infrastructure. One of the possible reasons for the switch in level of correspondences the possibility of an incomplete electrical dataset. Above ground electrical poles connecting houses and neighborhoods to substations were mentioned as part of the electrical infrastructure most commonly utilized for broadband infrastructure, but were not included in the data used for this thesis.

Another trend that was identified from the inference of missing and future middle-mile was the differences in the number of areas and the size of each group. Areas identified as locations where broadband providers were possibly missing were more numerous (23 missing areas to 9 areas of expansion) and covered a larger square mileage of the study area than the areas inferred for future expansion of access and infrastructure. Keeping this in mind, the potential exists that the amount of broadband access in Missouri is actually higher than the coverage information the providers submitted

suggests. Additionally, there might not be as great an area within the state containing population and demanding broadband service and access. Both these statements suggest that there might be a larger population with access to broadband service than has been previously thought.

The results of attempting to infer areas the greatest locational potential for receiving future broadband service and infrastructure expansion identified eight areas of mostly insignificant size. With the exception of the area in Brumley, many of the areas were small. While all the areas were located inside of city limits, these results suggest there are not many places in the study area where a demand exists for broadband access that is not being filled (or could be within ten days) by at least one provider. One reason for the limited number of areas in need could stem from the methodology utilized. The literature suggested that broadband infrastructure and service was most likely to be located in areas with population, hence the utilization of city limits in combination with areas without access to evaluate where future expansion is most likely to take place.

Right of Way Type	Length of Known Middle-Mile (feet)	% of Middle-Mile
Roads	6,871,551.86	96.70%
Railroads	1,551,431.18	21.83%
Gas Pipelines	823,373.84	11.59%
Electrical Corridors	3,259,304.22	45.87%

Table 5. Known Middle-Mile Locations within 100 ft of different types of rights of way.

Right of Way Type	Length of Known Middle-Mile (feet)	% of Middle-Mile
Roads	6,998,646.57	98.49%
Railroads	1,573,930.98	22.15%
Gas Pipelines	861,765.23	12.13%
Electrical Corridors	3,355,253.41	47.22%

Table 6. Known Middle-Mile Locations within 500 ft of different types of rights of way.

Right of Way Type	Length of Known Middle-Mile (feet)	% of Middle-Mile
Roads	7,090,798.32	99.78%
Railroads	1,885,526.03	26.53%
Gas Pipelines	1,106,042.81	15.56%
Electrical Corridors	4,450,839.00	62.63%

Table 7. Known Middle-Mile Locations within 2000 ft of different types of rights of way.

	% of Middle-Mile at 500 feet	% when adding Roads	% when adding Electrical Corridors	% when adding Railroads	% adding Gas Pipelines	Total % of Middle-Mile
Roads	65.22%		2.33%	0.08%	0.35%	67.98%
Electrical Corridors	13.17%	54.38%		0.08%	0.35%	67.98%
Railroads	6.62%	58.69%	2.32%		0.35%	67.98%
Gas Pipelines	3.13%	62.47%	2.29%	0.08%		67.98%

Table 8. Percent of Middle-Mile associated with different Right of Way Types.

Road Type	Length of Middle-Mile (feet)	% of Middle-Mile
Interstates	1,955,186.69	2.09%
US Highways	7,087,069.46	7.57%
Missouri Highways	11,352,172.96	12.13%
County Routes	15,967,500.21	17.06%
County Roads	42,338,726.13	45.23%
City Streets	15,230,358.70	16.27%

Table 9. Road Type Intersection Percentage with all Middle-Mile with 500 ft buffer.

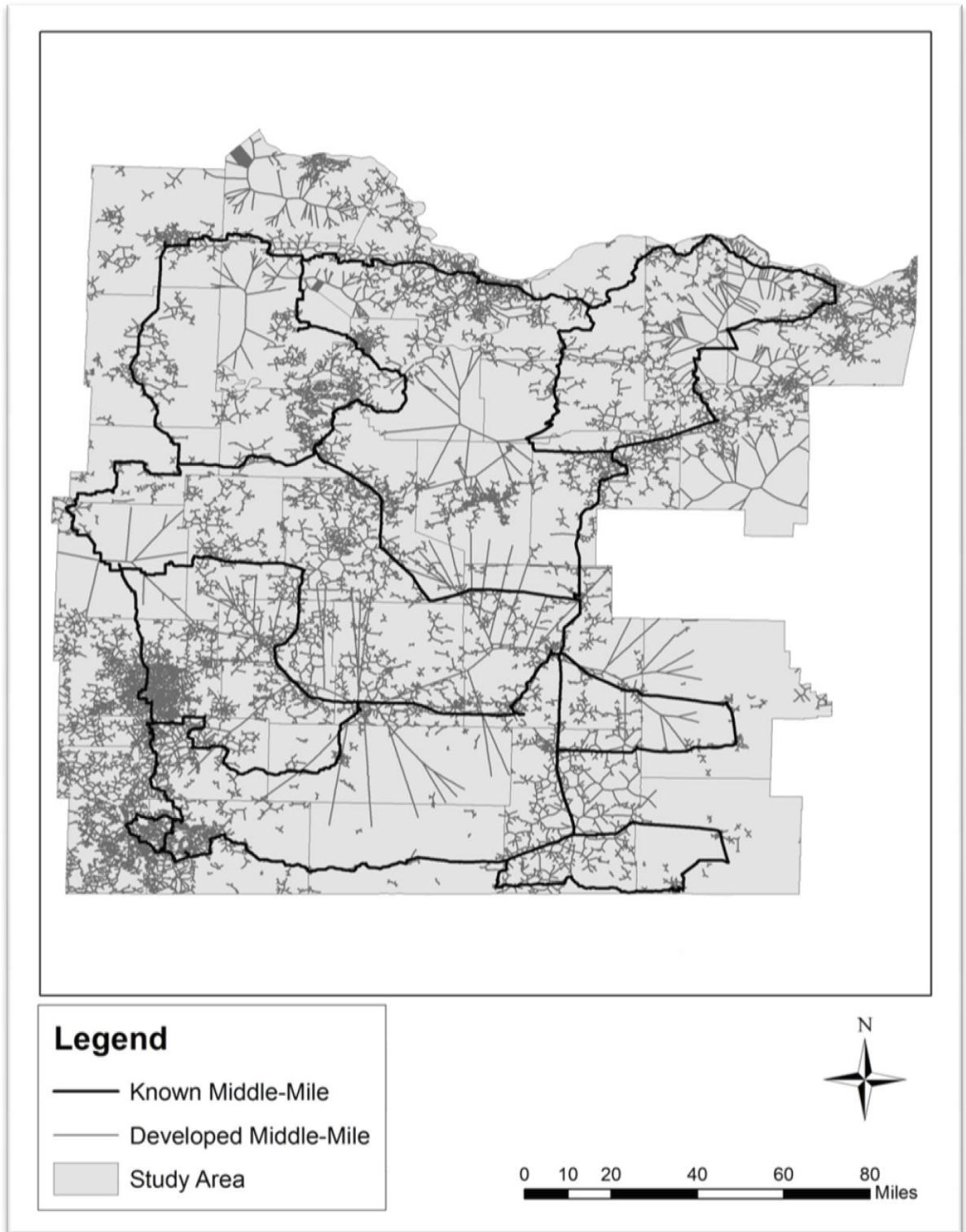


Figure 24. Comparison of Known Middle-Mile with Inferred Middle-Mile.

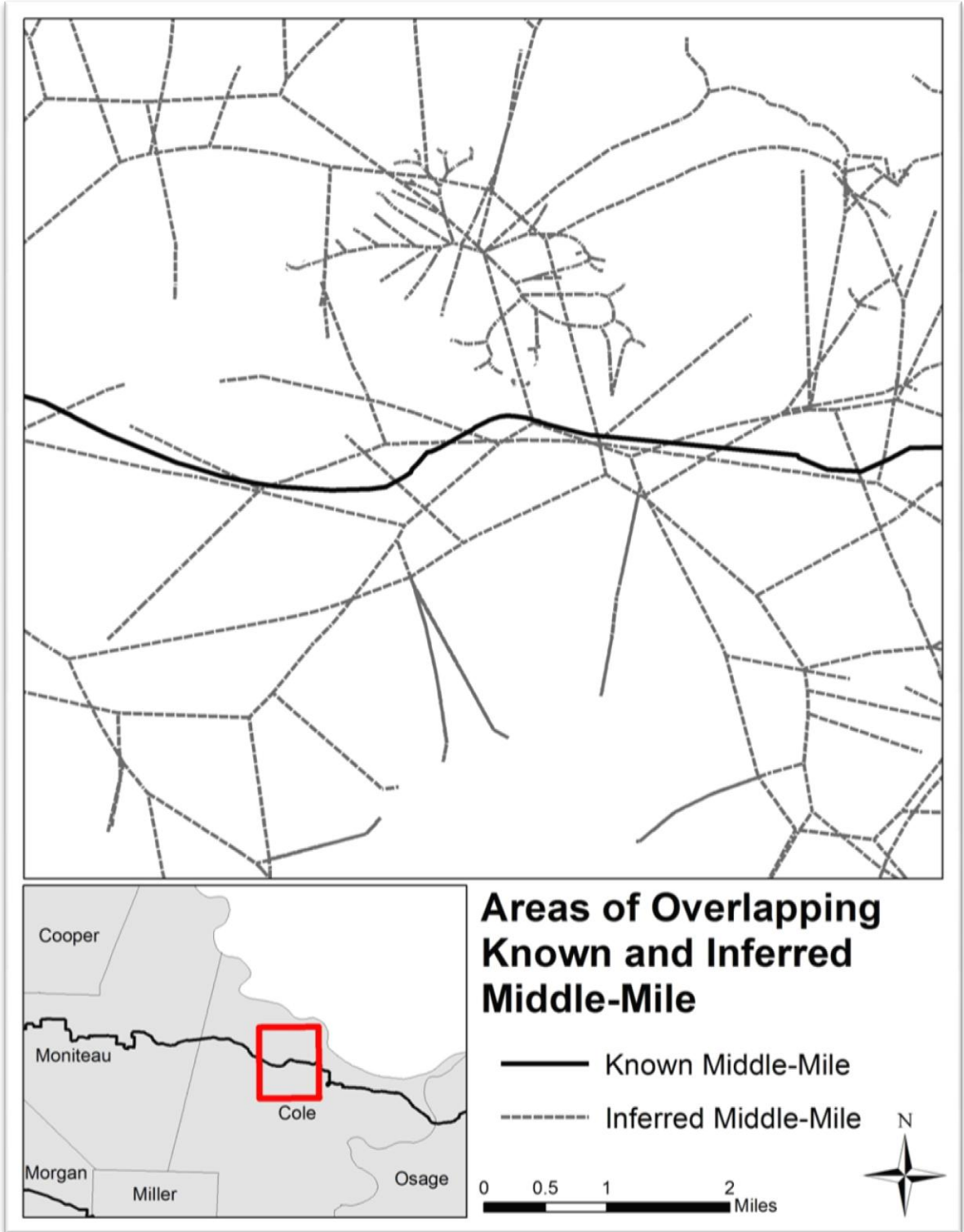


Figure 25. Area in Cole County with closely aligned Known and Inferred Middle-Mile.

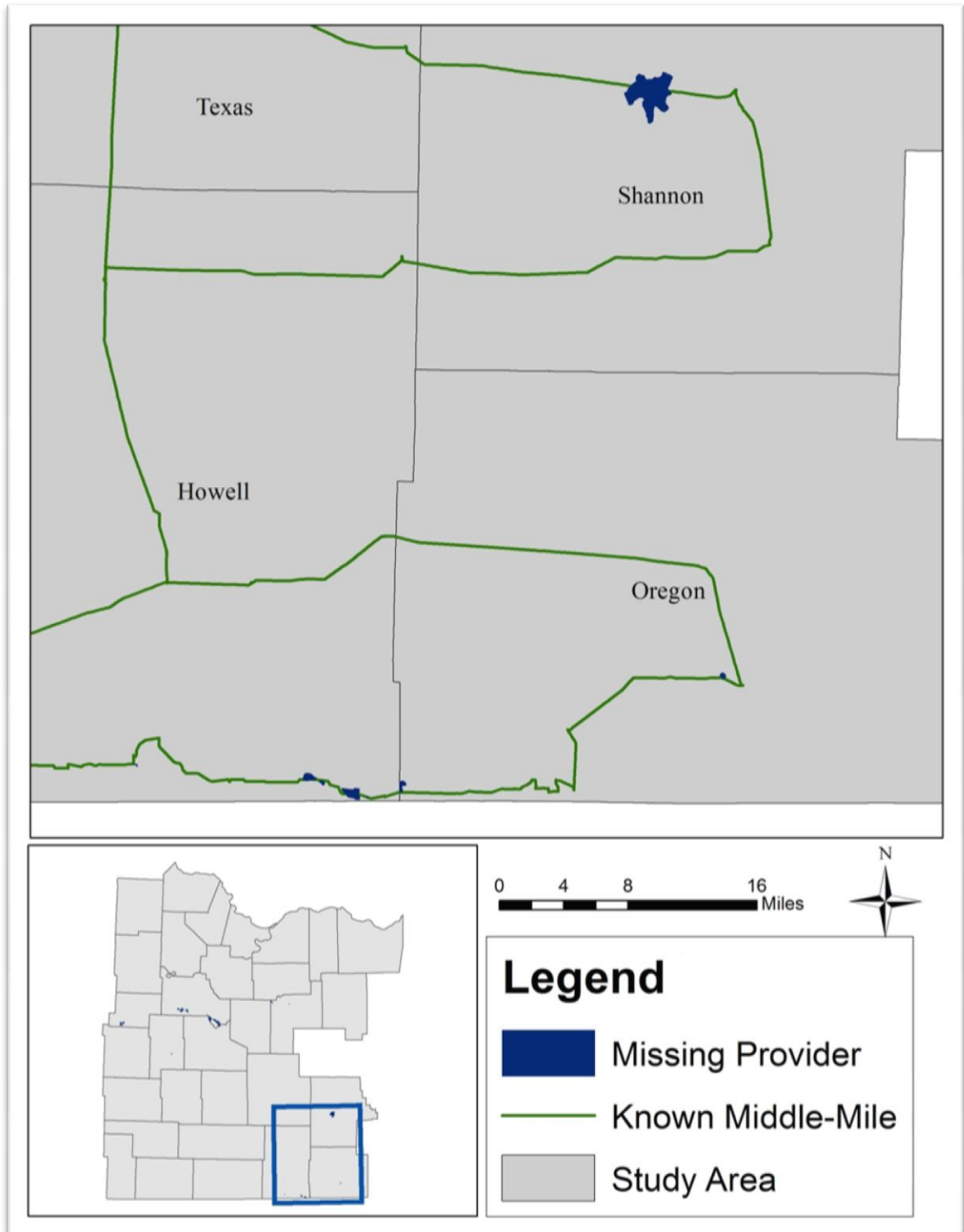


Figure 26. Potential Missing Middle-Mile/Providers in Howell, Shannon, and Oregon Counties.

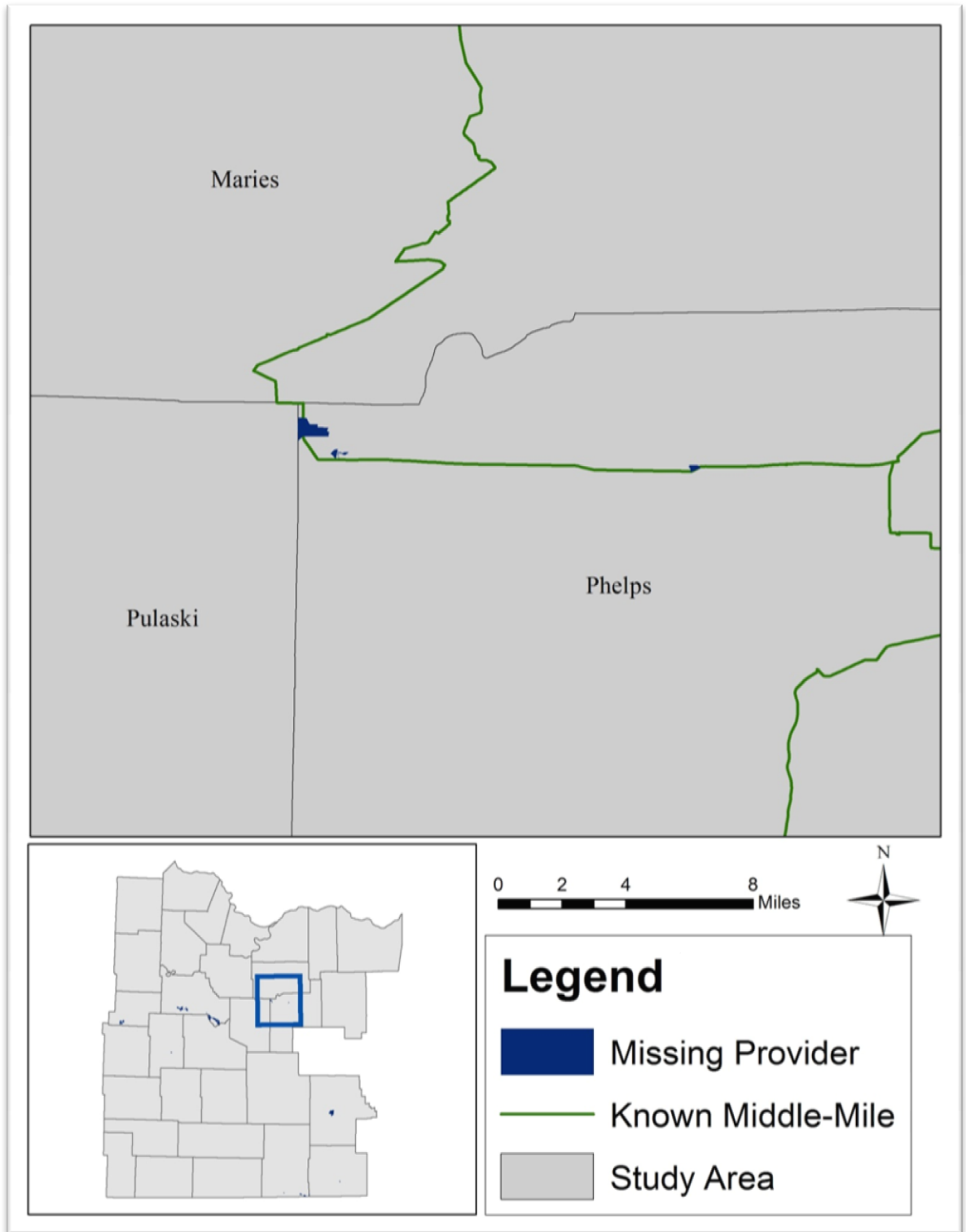


Figure 27. Potential Missing Middle-Mile/Providers in Phelps County.

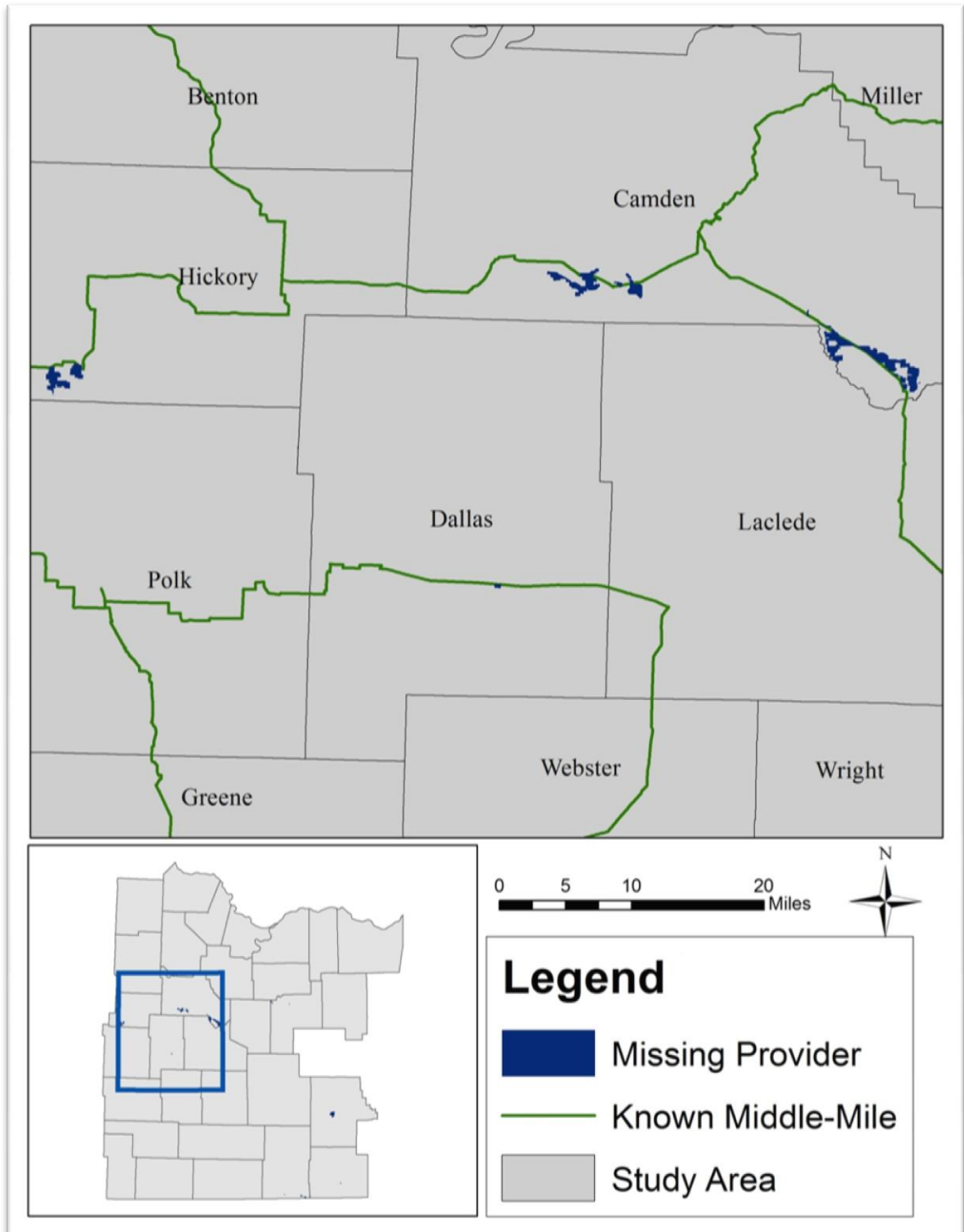


Figure 28. Potential Missing Middle-Mile/Providers in Hickory, Camden, and Dallas Counties.

Rank	Place	Distance to Current Access (feet)	Distance to Middle-Mile (feet)	Distance to County Roads (feet)	Area of Region (square miles)
1	Climax Springs 3	0	164	0	0.0019
2	Hermitage	0	376	32	0.0002
2	Climax Springs 2	0	1,288	0	0.0093
4	Climax Springs 1	0	1,046	520	0.0019
5	Evergreen 1	0	1,356	3,721	0.0569
6	Evergreen 2	0	3,069	2,374	0.0569
7	Brumley	0	7,566	0	0.4169
8	Ft. Leonard Wood	0	14,191	2,781	0.0859

Table 10. Ranked List of Potential Areas for Expansion of Access.

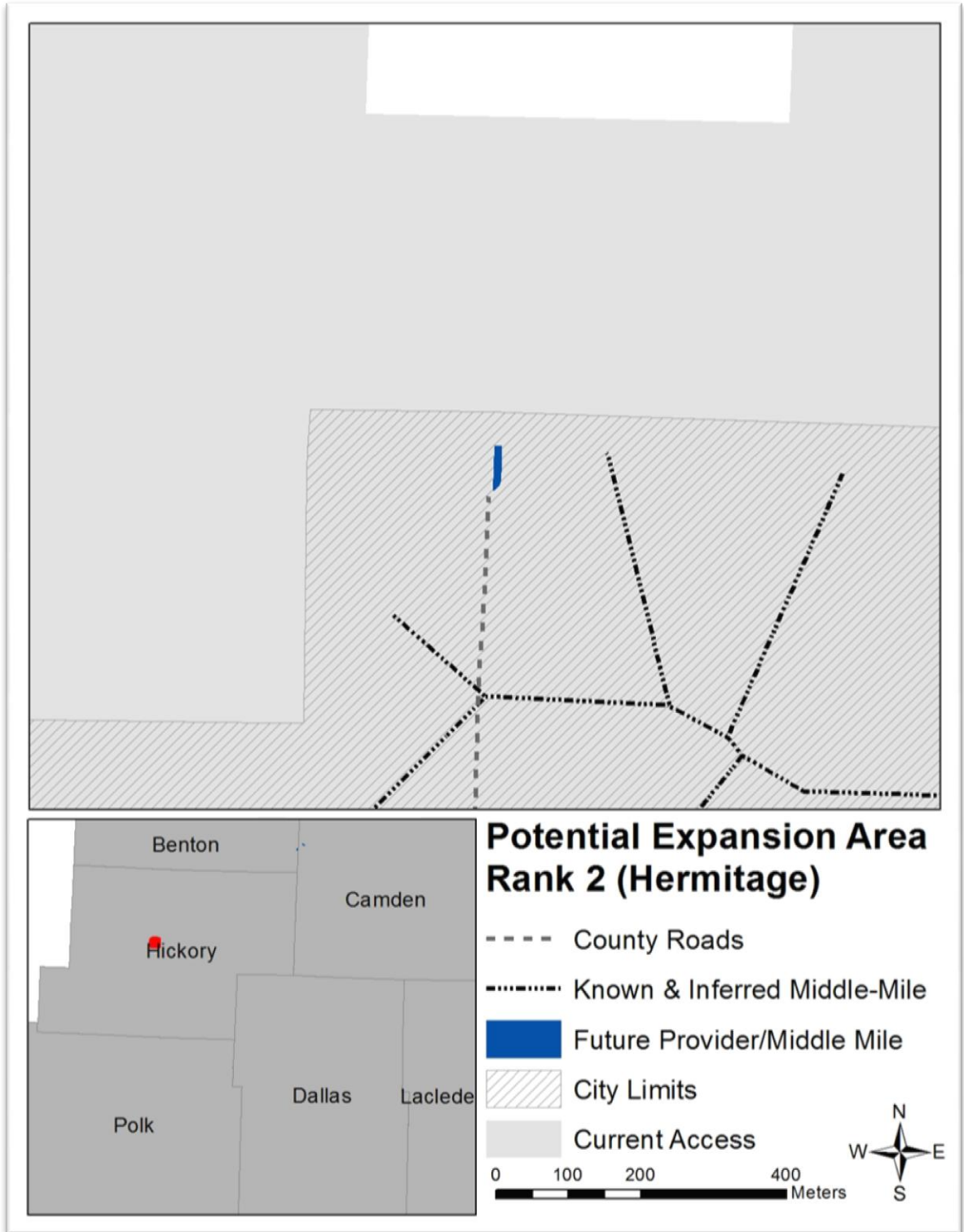


Figure 30. Potential Expansion Area with Rank 2 (Hermitage).

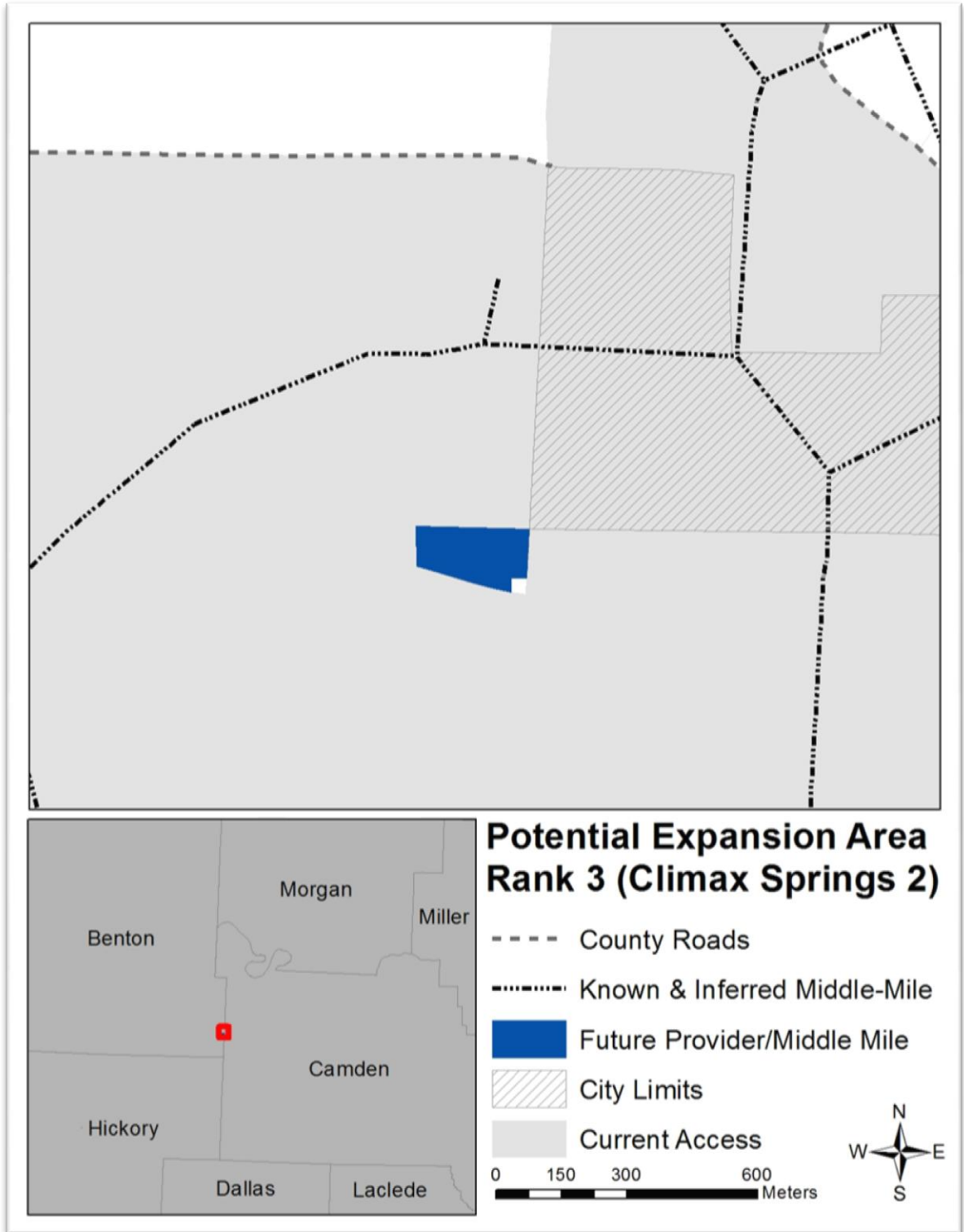


Figure 31. Potential Expansion Area with Rank 3 (Climax Springs 2).

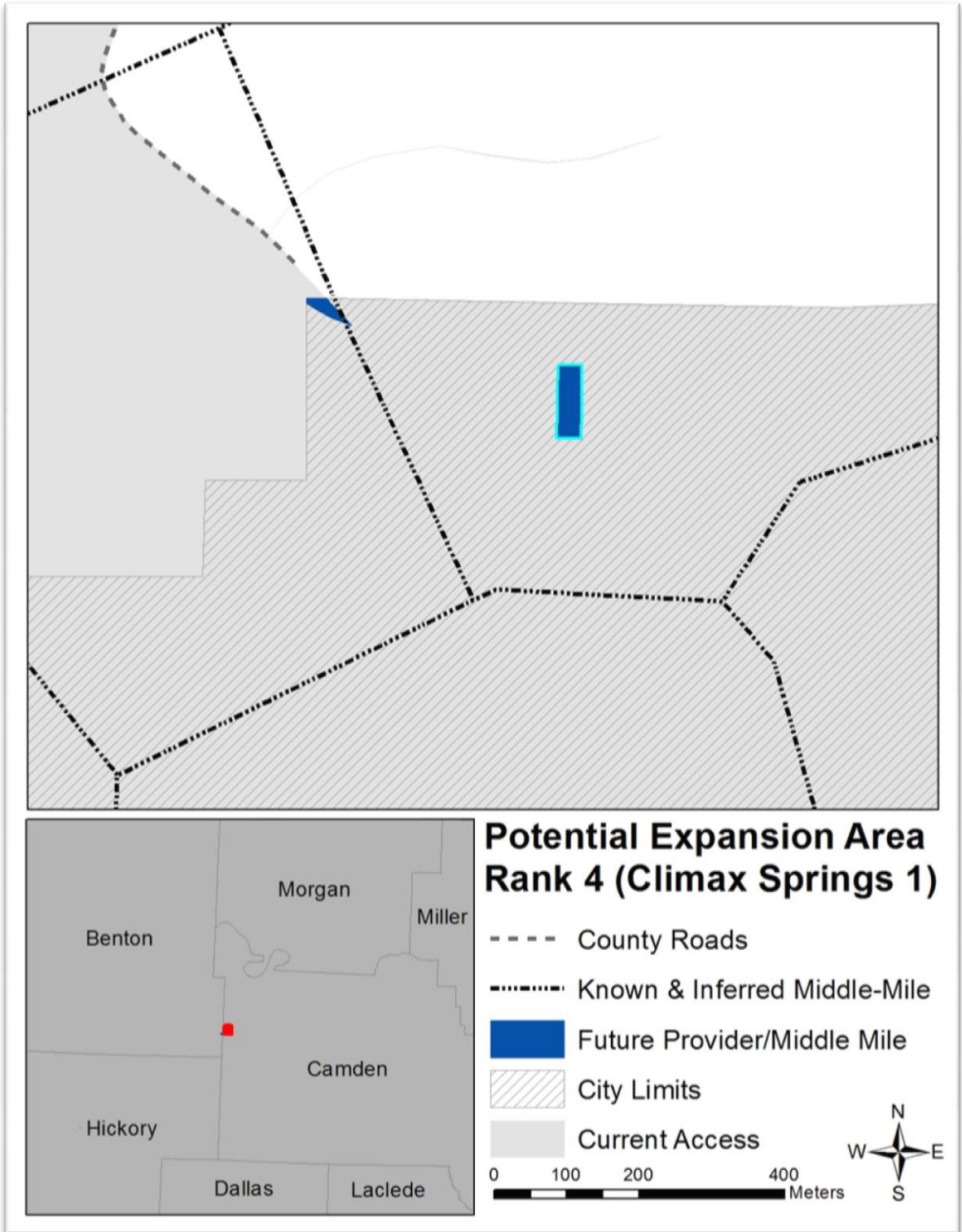


Figure 32. Potential Expansion Area with Rank 4 (Climax Springs 1).

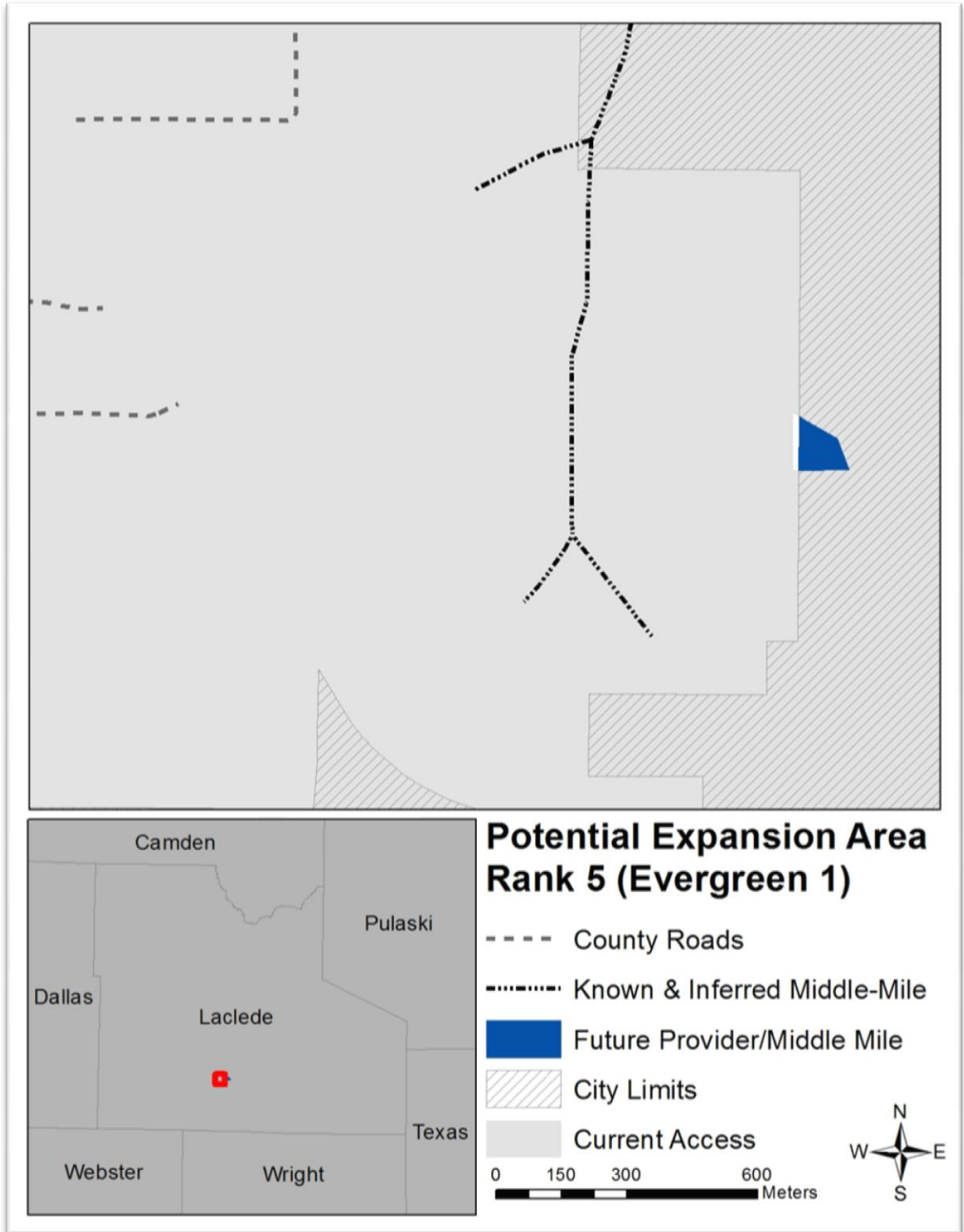


Figure 33. Potential Expansion Area with Rank 5 (Evergreen 1).

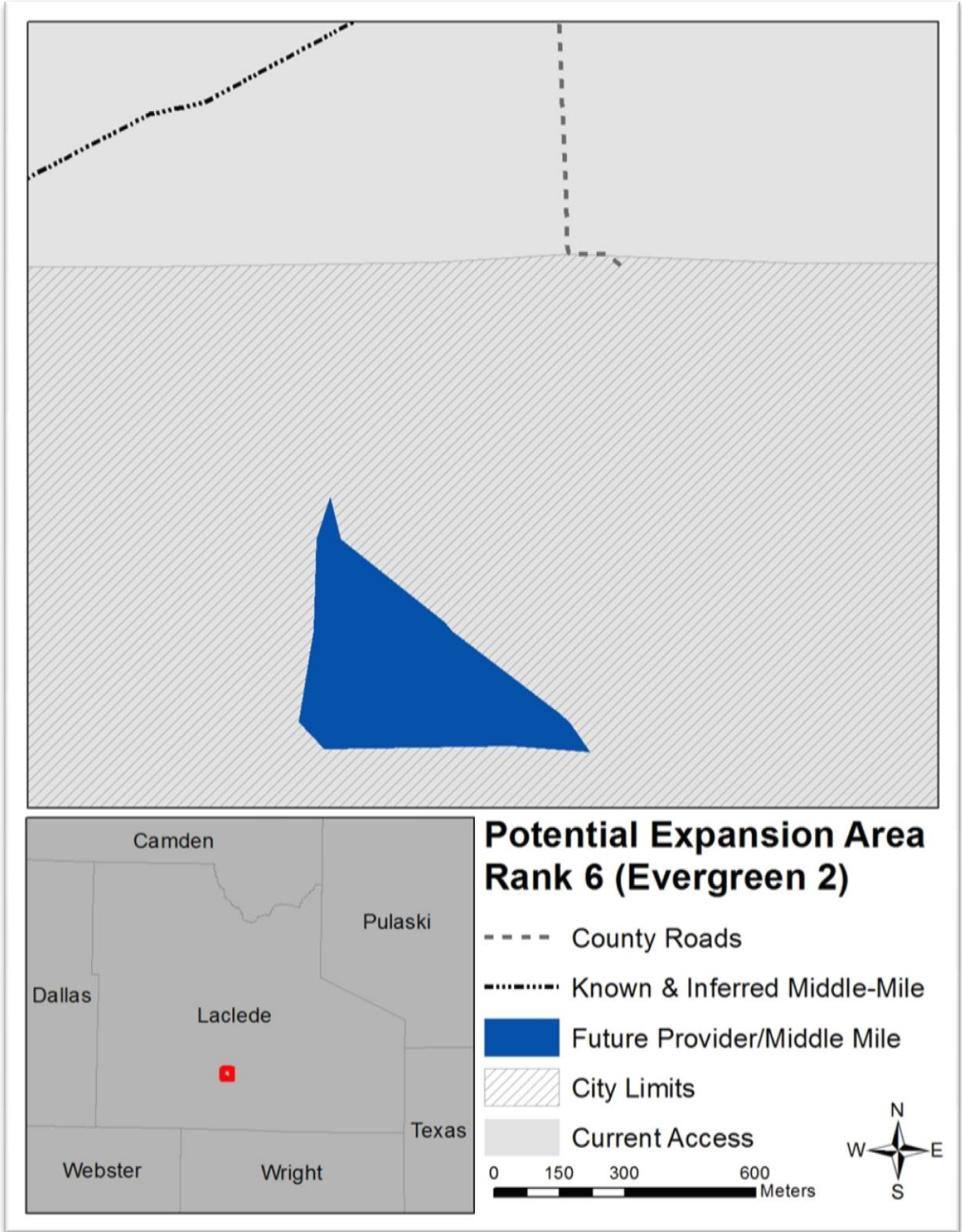


Figure 34. Potential Expansion Area with Rank 6 (Evergreen 2).

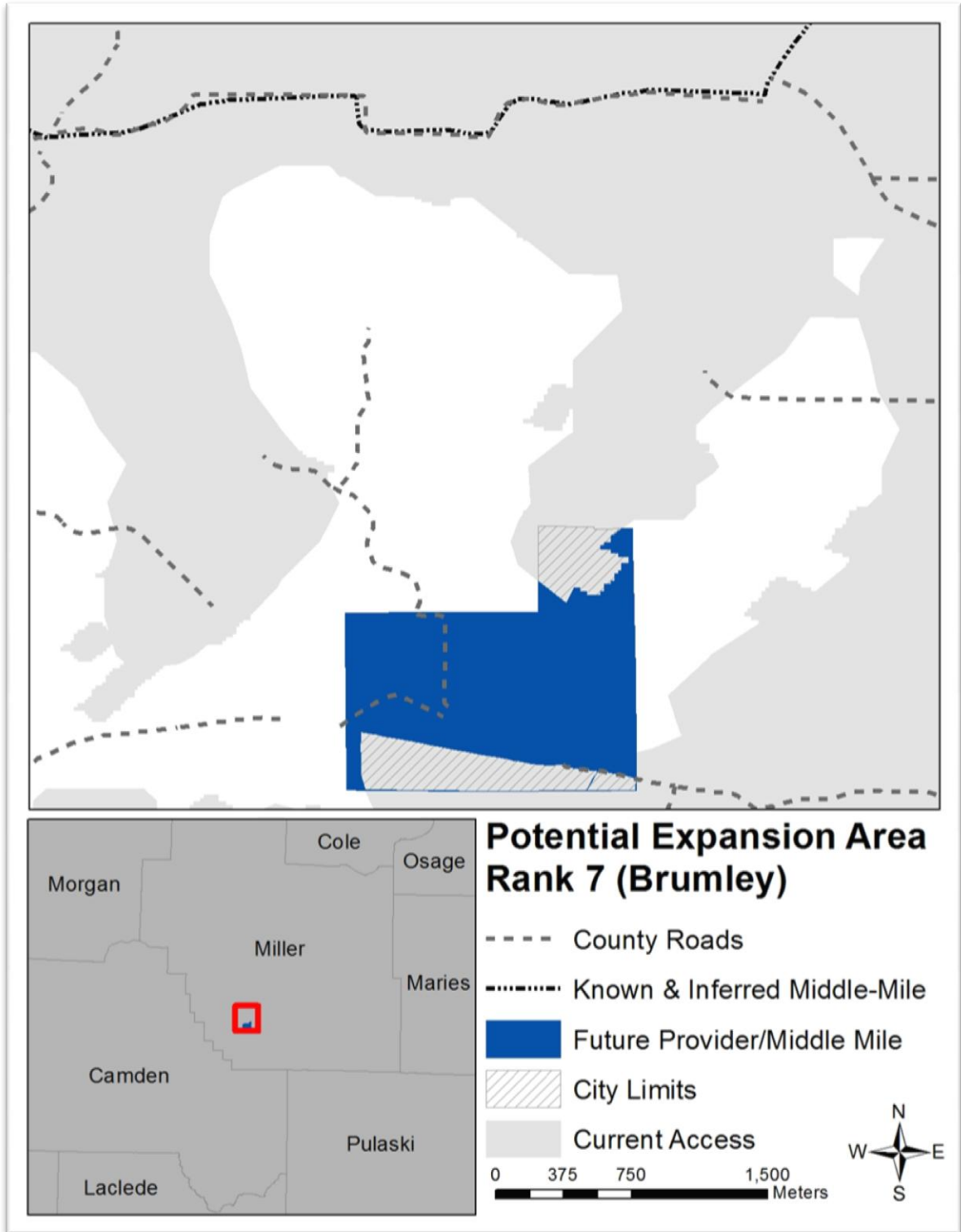


Figure 35. Potential Expansion Area with Rank 7 (Brumley).

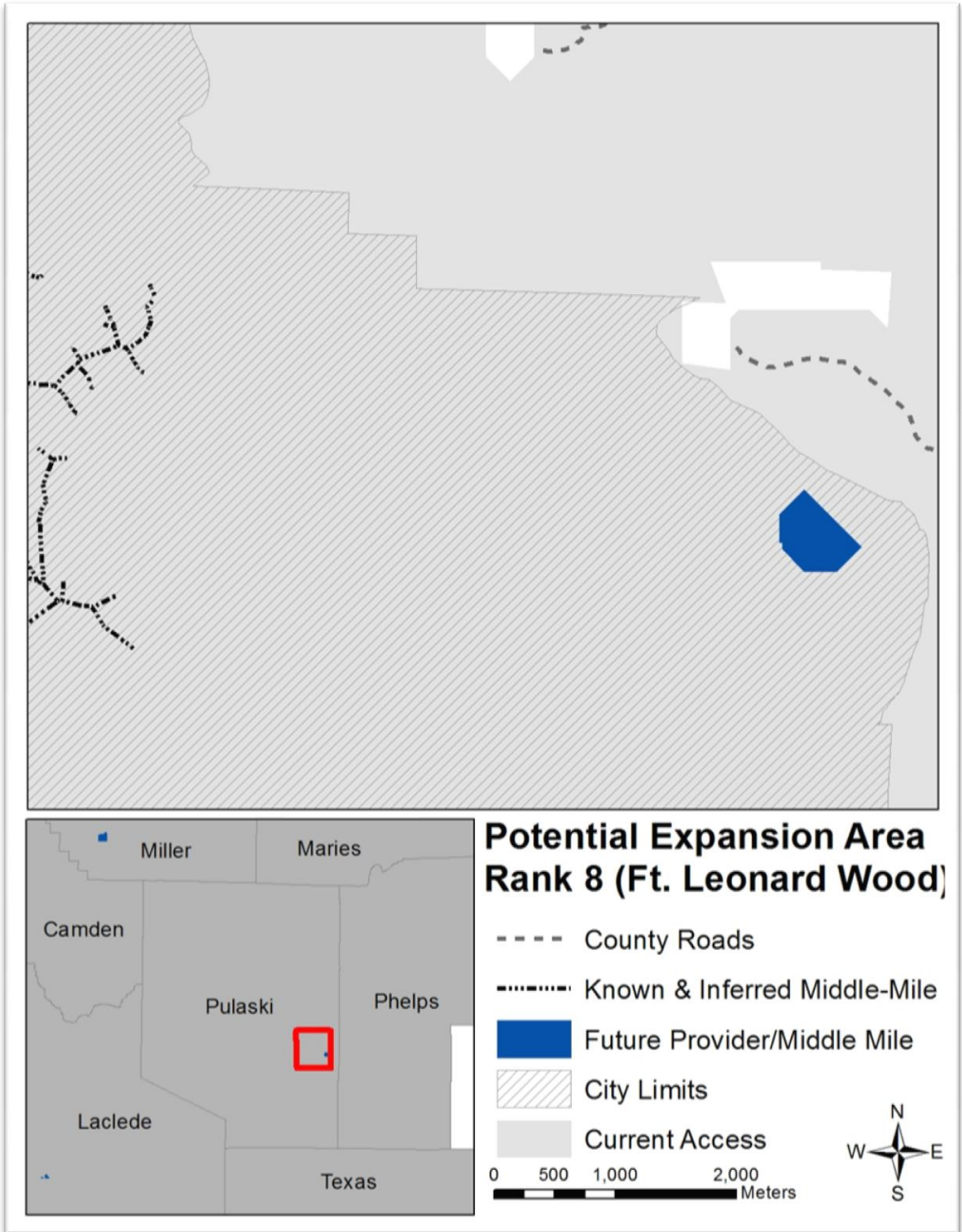


Figure 36. Potential Expansion Area with Rank 8 (Ft. Leonard Wood).

5.3 Research Limitations

The opportunity to utilize broadband provider supplied service data is a unique opportunity given the proprietary nature of the information. Analyzing this detailed data was imperative in order to better assess the quality of the FCC and the NTIA current representation of access. There are, however, limitations as to the utility of this data in accurately document access to broadband. Broadband infrastructure can cover hundreds of square miles for a large provider. With so many miles of fiber and cable being installed over decades, the possibility for uncertainty and ambiguity as to the exact location of the infrastructure can exist. Providers might think they reported accurate data, but errors in surveying and recording the location of this infrastructure could reduce the level of accuracy. Even when providers submit their most accurate service area footprints for the SBI, there is also always the potential for error (accidental and/or intentional) in reporting. Prior to delivering the data to the mapping team at the University of Missouri, multiple individuals manipulated and edited the data at the providers and GeoDecisions offices. Thus, the potential for incorrect digitization of service area or other misrepresentations of service could occur, each of which in turn could have biased the subsequent analysis.

Another potential source of uncertainty when using this broadband data is the potential for missing providers (Grubestic 2012b). As local governments and municipal utilities continue to fill in the gaps of broadband service, the number of companies providing broadband Internet access grows. Although the SBI is in the fourth year and seventh collection cycle, there is still the potential that some provider service areas were unreported or overlooked and therefore not considered in this analysis. Other providers

have given promises of submitting their service areas for inclusion in the initiative, but either fail to follow through on those promises or do not deliver them in time to be included in the submission to the NTIA. These providers could be located in the areas identified as having known middle-mile infrastructure present but no broadband provider present.

An additional limitation of the data stems from a policy the NTIA added when launching the State Broadband Initiative. When providers prepare service footprints for submission to the SBI in their state, the NTIA allowed uncertainty in their service areas. More specifically, they considered any area that a provider could theoretically add service to in 10 business days as served (Grubestic 2012b; NTIA 2012). The motivation for this provision is unknown. One possibility is the build-out buffer is an effort to ease providers' concerns about releasing their service area footprints to non-employees. One would hope providers were honest in their submissions and reported their current service areas. Whatever the reason, this provision adds another element of uncertainty to the preciseness and accuracy of provider service areas and can impact the results and analysis of the data. Examples of provider footprints submitted to GeoDecisions are shown in Figure 37. While one footprint would appear to be accurate based on the lack of a discernible shape, the other appears as though a circle was drawn and two slices were removed. Additionally, some broadband providers' pre aggregate their service areas onto Census Blocks. While this might seem like providers are attempting to make the collection and processing portion of GeoDecisions' job easier, these service areas do not represent the most accurate portrayal of where access is and is not present.

Dark or unlit fiber throughout the state provides another limitation to the results. Dark fiber is middle-mile fiber that has already been laid in the ground and is ready for use, but is not currently utilized. There are a variety of reasons for this fiber not being used. Whatever the reason, this unlit fiber presents an opportunity to expand and reinforce middle-mile infrastructure and broadband access. Within Missouri, the Missouri Department of Transportation is reported to have miles of dark fiber along the Interstates that is not being utilized (Hanson 2005). The exact location of this dark fiber is unknown, but it could serve to better augment research such as undertaken in this thesis in the future should such information become available.

A final limitation that could have impacted the data and results of the thesis is the impact of boundaries on the developed medial axis and subsequent inference of future expansion areas. All data submitted to the SBI by providers was edited to include only the service areas within the state of Missouri. For providers with service near the boundary for the state, the possibility exists that their service areas may overlap into bordering states. This, the output of the medial axis routine, could have been skewed to end at the state boundary instead of continuing through the actual service area into a bordering state.

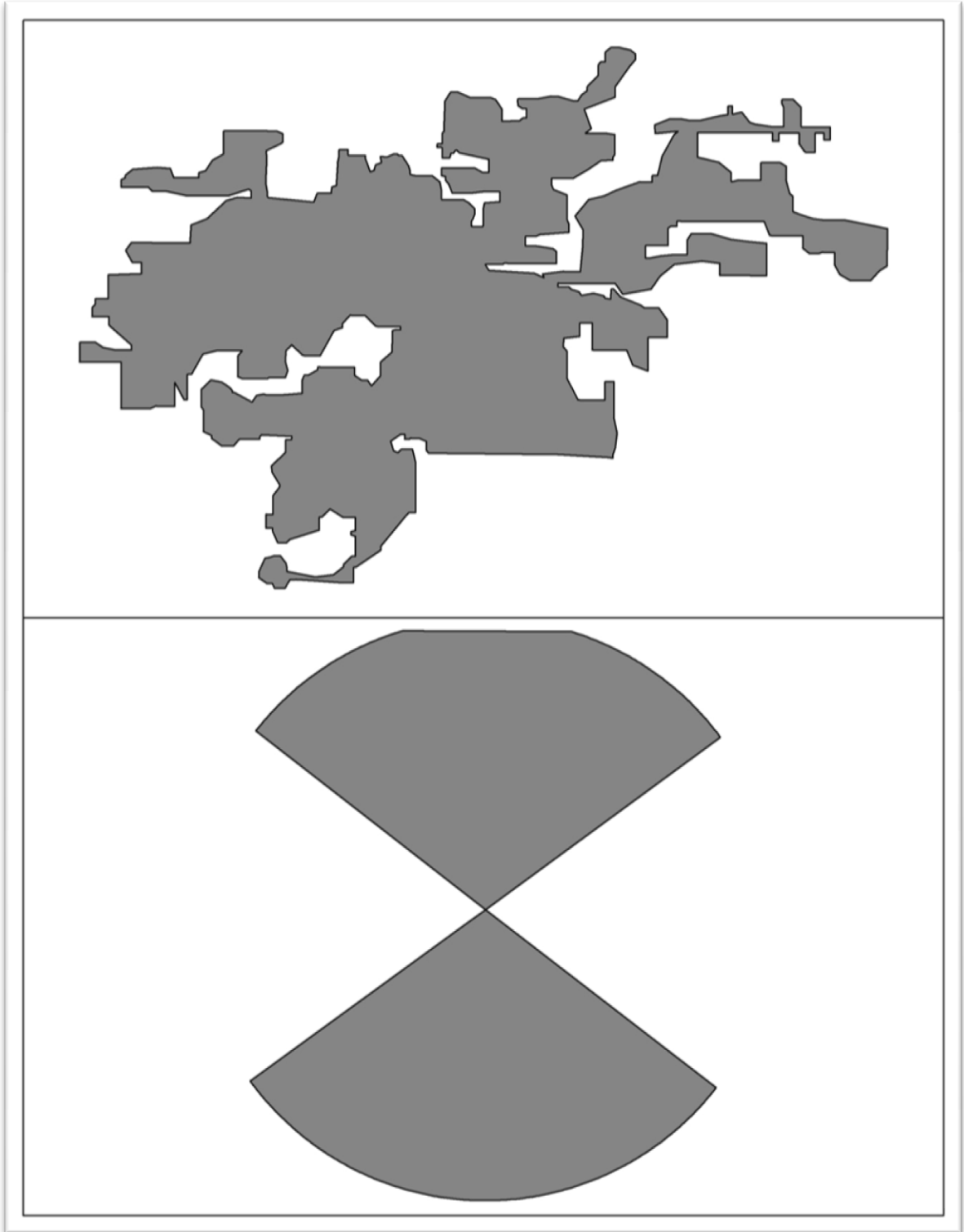


Figure 37. Example of Two Provider Submitted Service Areas.

CHAPTER 6. CONCLUSIONS

6.1 Conclusions

This thesis focused on two main objectives. The first was to evaluate and compare the current level of broadband access within the state of Missouri relative to four different areal representations of demand for service. The second was to assess the middle-mile infrastructure for South-central Missouri in an attempt to identify the location of unreported broadband provider along with the location future broadband service and infrastructure. Both of these objectives were successfully completed and presented in this thesis.

The study of current broadband access in the Missouri and the different service areas source data types for representing access levels result in very different representations of access given the areal unit of analysis. The FCC Form 477 methods of rendering access (ZIP Codes and more recently Census tracts) indicate that 100% of the state has access to broadband. However, the likelihood of this being accurate is low, given that there are areas within the state where that access is not present (Missouri 2013). The NTIA National Broadband Map method utilizing Census blocks helps corroborate this given it indicates that 100% of the state does not have access, rather only 99% of the population and 98% of the area. These results are most likely more realistic and closer to the actual access levels in the state. Evaluation of the provider footprints alone suggests that only around 93% of the state has access. While using provider service areas is likely the most accurate depiction of access, limited analysis can be performed beyond calculation of service area without somehow associating them with

areal units of analysis, such as Census blocks. In order to develop a more accurate method for determining broadband access in Missouri and other states, the FCC and the NTIA could consider combining their resources for reporting related to broadband access.

The use of a medial axis routine to infer the location of broadband infrastructure provided an opportunity to apply a previously utilized method in a new way. Combining this inferred middle-mile with known middle-mile in the area provided an opportunity to analyze the existing right of way in South-central Missouri and evaluate the right of way types with the highest correspondence with both known and inferred middle-mile. These results provide an opportunity to infer the location of broadband infrastructure which is not readily available to most researchers. Additionally, this portion of the thesis can be replicated in other areas of Missouri and the US to study differences in middle-mile, access, and attempt to infer areas where access is most likely to be expanded in the future.

The portion of this thesis that identified locations in which broadband providers and service could exist but may not be reported identified 23 unique locations. These locations were proximate to middle-mile supporting a known provider located near them, but were found to be unserved. The presence of middle-mile suggests that there is potential broadband access available for the area. Reasons for no provider reporting these areas as part of their service footprint could include: a provider not participating in the SBI; a provider, or providers, with service in the area have not been identified to request their footprints for the project; or a low level of accuracy, or some sort of error being present, in footprints leading to areas being evaluated as having no access.

The research which infers and evaluates areas in South-central Missouri that are most likely to have expansion of broadband infrastructure and service identified nine areas which may warrant further analysis. Of the nine areas identified, only eight of them were viable locations where residences or businesses could be present. The eight viable areas for future service were first identified based on two criteria: the areas had to be located in locations found to not have current access, but likely do have population present. The eight areas identified were ranked based on three criteria. These criteria were distance from current access, distance from known or inferred middle-mile, and distance from the nearest county road. Combining the three measures provided a quantitative method for ranking the areas with the highest locational potential for having service and infrastructure introduced.

Additionally, this study served as a snapshot of the state of broadband as of October 2011 when the provider service data was received. Revisiting this study in the future would certainly help understand how representation of access to broadband has changed over time. Comparing the changes in access and provider location over multiple submission periods would allow for further study and analysis of broadband within the state.

The goal of the Governor Nixon of Missouri was to make Broadband available to at least 95% of residents of the state by the end of 2014 (Missouri 2013). The articulation of this goal was rather vague, as there was no mention of how this 95% goal would be measured. If the reported population of an area was used to measure the percentage of Missouri with Broadband access, then the Governor's goal has likely been met. However, if the percentage of area with access is the measurement, then the goal has

likely not been met. Either way, the high percentage of residents with access combined with the small number and size of areas where demand is present but access is not available, suggests this goal has likely been met. Many of the residents without broadband access are located in pockets of rural designated land within Missouri.

This research and results could be used to address a wide range of policy issues and to better inform decision-making efforts. The continued growth and importance of broadband means more policy makers are invested in the growth and further development of broadband for their constituents and oversight areas. The nineteen Regional Planning Commissions throughout Missouri are interested in broadband availability and adoption in their regions due to the economic and educational impacts. Being able to determine with some level of accuracy where there is and is not access in their region assists them with targeting and recruiting broadband companies to provide service in those areas along with enhancing their understanding of which populations do and do not have access to service. Additionally, the Public Service Commission, the Department of Economic Development, and other government agencies would benefit from understanding where broadband access is currently available and what percentage of residents of the state are able to take advantage of high speed internet. This can help shape their policies related to broadband and give them an understanding of what areas in the state are being left behind with respect to access.

Beyond Missouri, this thesis and research is useful to any other state and territory that is participating in the SBI with the NTIA. With the NTIA providing a uniform set of guidelines for collection and submission of provider service area data, any other state or researcher with access to provider data in their region could replicate the methodology

from this thesis. With collection occurring at equal intervals in each participating state, comparison of access levels between each measure of access could be compared at both the state and national level. Additionally, the medial axis routine could be applied within each participating state that is able to evaluate their level of access.

6.2 Future Directions

In the future, a variety of changes or revisions to the study of broadband access are possible. As mentioned previously, updating the provider data to the most recent submission to the SBI would change the access and inference results in some way. This study focused on the state of Missouri due to availability of data from that area. Future study could be replicated and centered on any other area, as long as data was available. Furthermore, getting more complete right of way data with a higher level of accuracy could result in different locations being identified for future expansion of broadband service and infrastructure.

One change to the methodology might be to enhance the representation of the medial axes of the provider service areas. For instance, one could use a lower number of points to represent the boundary of the service areas. The boundary of service areas was densified to ensure that representative points were no further than 500 meters from one another in this study, however, increasing or decreasing the value would change the resulting pattern of the medial axis for each provider. Another change could be to streamline the medial axes by removing the branches of the axes and only using the main branch of the axes for analysis. This change in medial axis could in turn change the right of way method evaluated to be the best indicator and predictor of middle-mile

infrastructure. A final change could be to modify the methodology for inferring future middle-mile and provider service areas. This study used proximity and population as indicators, but future study could use density of providers or other access methods to evaluate where broadband access might expand in the future.

APPENDIX A

NONDISCLOSURE AGREEMENT

THIS NONDISCLOSURE AGREEMENT ("Agreement"), dated and effective as of _____, 2010, is made by and among the Parties to this Agreement, which are _____ including its affiliates (collectively referred to hereinafter as "the Company"), and the State of Missouri, Office of Administration ("OA"), The Curators of the University of Missouri on behalf of the University of Missouri - Columbia ("MU"), GeoDecisions, a Division of Gannett Fleming, Inc. ("GeoDecisions"), and CBG Communications, Inc. ("CBG") (collectively referred to hereinafter as "the State Parties," except where otherwise indicated.)

WHEREAS:

- I. The National Telecommunications and Information Administration (NTIA) has made available a grant program to fund broadband mapping known as the State Broadband Data and Development (SBDD) grant program, which is governed by the Notice of Funds Availability (NOFA) first published in volume 74, number 129, at page 32545 of the Federal Register and subsequently clarified in volume 74, number 154, at page 40569 of the Federal Register, both of which are incorporated fully herein; and
- II. Both OA and MU have partnered with the mapping entities, GeoDecisions and CBG, to implement the SBDD grant program; and
- III. The Company possesses confidential and proprietary information necessary to such implementation and acknowledges that it desires to share certain of that information with the State Parties and with the NTIA; and
- IV. When the Company shares that information with the State Parties, the confidential and limited use conditions of this Agreement shall apply; and
- V. Missouri law allows governmental entities to close records that: 1) relate to scientific and technological innovations in which the owner has a proprietary interest pursuant to §610.021(15); and 2) fall within the definition of "trade secret" pursuant to the Uniform Trade Secrets Act, §417.450, RSMo.; and 3) have been submitted to an institution of higher education in connection with a proposal to license intellectual property or perform sponsored research and which contains sales projections or other business plan information the disclosure of which may endanger the competitiveness of a business, §610.021(22); and

NOW THEREFORE, the Parties agree as follows:

TERMS:

- a) "Confidential Information" shall be defined in identical terms to the SBDD NOFA and any subsequent SBDD NOFA Clarification(s).
- b) All Confidential Information received by the State Parties from the Company may be used as follows:
 - i) The State Parties may use the Company's information to derive maps, interactive websites and tabular data representations of the Company's broadband coverage area, network information, coverage attributes, and such other uses as may be required to implement the SBDD, referred to as the State Parties' Work Product; and
 - ii) The State Parties may, at a given location, estimate broadband coverage and identify broadband providers within the associated census block or estimated area, including Company, if applicable; and
 - iii) That State Parties may provide the NTIA with any such State Works as may be reasonably required by the terms and conditions as outlined in any applicable NOFA. The Company acknowledges that such provision may likely result in the disclosure of Confidential Information to governmental authorities and that, once such disclosures are made by the State Parties as required by a Project, the State Parties

are fully released from any liability for the actions of the third party governmental authority regarding the disclosure, sharing or use of such Confidential Information; and,

- iv) The State Parties may use the Confidential Information in any other way to the extent such use is consistent with this Agreement and the SBDD program, that does not result in disclosing it, and
- v) The Company waives any claims of ownership to the State Parties' Work Products.
- c) Per the terms of this Agreement, the State Parties will protect Confidential Information provided to it from any use, distribution or disclosure pursuant to §610.021 (14), (15) and (22) and §417.450, RSMo, except as permitted herein.
- d) Confidential Information provided to Recipient in written or other tangible or electronic form shall be marked by Company with a confidential and proprietary notice prior to receipt by the State Parties.
- e) Parties acknowledge that any discrepancy between the SBDD NOFA and the terms provided for herein shall be resolved in favor of the SBDD NOFA. Nothing contained herein shall be construed to limit the State Parties' reporting and data sharing obligations under the SBDD NOFA, including sharing of Company's Confidential Information with NTIA pursuant to the terms of the SBDD NOFA and Clarification.
- f) The State Parties may provide Confidential Information only to those employees, consultants, independent contractors and agents who:
 - i) Have a substantive need to know such Confidential Information in connection with the State Parties' Work Product;
 - ii) Have been advised of the confidential and proprietary nature of such Confidential Information; and
 - iii) Have agreed in writing prior to disclosure to protect from unauthorized disclosure all confidential and proprietary information to which they have access in the course of their participation in the creation of the State Parties' Work Product in accordance with all the terms of this Agreement.
- g) Confidential Information does not include information the State Parties lawfully obtain from any source other than Company, provided that such source lawfully disclosed such information.
- h) If the State Parties are required to provide Confidential Information to any court, government agency or third party pursuant to written court order, subpoena, Missouri Sunshine Law request, or other process of law, they must provide the Company with prompt written notice of such requirement or request and cooperate with the Company to protect against or limit the scope of the disclosure.
 - i) All Confidential Information remains at all times the Company's property. Any State Party Recipient may make tangible or electronic copies and notes of Confidential Information only as necessary for use as authorized herein. All such copies or notes must be marked with the same confidential and proprietary notice as appears on the original. All such copies will be destroyed when the State Parties' Work Product is fully completed and finally approved, and all originals shall be either destroyed or returned to the Company, at the Company's option.
 - j) The State Parties may publicly identify the Company as a contributing broadband service provider, provided no information covered by this Agreement is revealed. No license for use, beyond that provided for herein, under any trademark, patent, copyright, trade secret or other intellectual property right is either granted or implied by disclosure of Confidential Information to the State Parties.
- k) If and to the extent any provision of this Agreement is held invalid or unenforceable, all other provisions of this Agreement shall remain in full force and effect to the fullest extent permitted by law.

- l) This Agreement is binding upon and inures to the benefit of the Parties and their heirs, executors, legal and personal representatives, successors and assigns, as the case may be.
- m) This Agreement is the entire agreement between the Parties hereunder and may not be modified or amended except by a written instrument signed by all Parties. Each Party has read this Agreement, understands it and agrees to be bound by its terms and conditions. There are no understandings or representations with respect to the subject matter hereof, express or implied, that are not stated herein. This Agreement may be executed in counterparts, and signatures exchanged by facsimile or other electronic means are effective for all purposes hereunder to the same extent as original signatures.
- n) This Agreement shall be governed, construed, and enforced in accordance with the laws of the State of Missouri, without regard to its principles of conflict of law.

IN WITNESS WHEREOF, the Parties have read and agreed to this Nondisclosure Agreement as evidenced by the signatures of the Parties' authorized representatives below:

Company:

By: _____
(Authorized Signature)

Name: _____

Title: _____

GeoDecisions, a Division of Gannett Fleming, Inc.:

By: _____
(Authorized Signature)

Name: _____

Title: _____

**State of Missouri, Office of Administration,
Information Technology and Services Division:**

By: _____
(Authorized Signature)

Name: _____

Title: _____

The Curators of the University of Missouri:

By: _____
(Authorized Signature)

Name: _____

Title: _____

CBG Communications, Inc.:

By: _____
(Authorized Signature)

Name: _____

Title: _____

APPENDIX B

SBDD Data Transfer Model June 2011

The image displays a series of screenshots from a software application, likely a data transfer model. The screenshots are organized into several columns and rows, showing different views and data tables. The tables contain columns for 'ID', 'Name', 'Description', and 'Status'. Some tables have red headers. The screenshots are arranged in a grid-like fashion, showing different views of the same data or related configuration options.

Key elements visible in the screenshots include:

- Navigation menus and toolbars at the top of the windows.
- Tables with columns for 'ID', 'Name', 'Description', and 'Status'.
- Red headers in some tables, possibly indicating a specific data category or status.
- Configuration options and checkboxes in some windows.
- Search and filter fields in some views.

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