MEASURING TRANSPORTATION ACCESSIBILITY FOR MPOS AND FOR THE STATE OF ND

Prepared for:

North Dakota Department of Transportation (NDDOT), and The ND MPOs – Bismarck – Mandan, Grand Forks East Grand Forks and FM MetroCOG

Prepared by:

Advance Traffic Analysis Center (ATAC)

Upper Great Plains Transportation Institute (UGPTI)

North Dakota State University (NDSU)

Fargo, ND

August, 2020

TABLE OF CONTENTS

TABLE OF CONTENTS 2
LIST OF FIGURES 4
LIST OF APPENDIX TABLES 6
LIST OF APPENDIX FIGURES 7
Executive Summary 8
1. Introduction 9
2. Measures of Accessibility: 10
3. Sugar access methodology 12
3.1. Accessibility Metrics Calculation in Sugar Access 12
3.1.1. Travel Time Accessibility Metric 12
3.1.2. Destination Summation Accessibility Metric 13
3.1.3. Access Score Accessibility Metric 13
4. data requirements to measure accessibility 14
4.1. Data Collection for Accessibility Measures in ND 15
4.1.1. Data for ND State Wide Level 16
4.1.2. Data for MPOs Level 16
5. RESULTS OF ACCESSIBILITY MEASURES – STATE WIDE 17
6. results of accessibility measures - mpos 25
6.1. Fargo - Moorhead MPO 25
6.1.1. Auto Access to Jobs, Medical Services, and Grocery Stores 25
6.1.2. Public Transit Access to Jobs, Medical Services, and Grocery Stores 32
6.1.3. Walk Access to Jobs, Medical Services, and Grocery Stores 39
6.2. Grand Forks – East Grand Forks MPO 46
6.2.1. Auto Access to Jobs, Medical Services, and Grocery Stores 46
6.2.2. Public Transit Access to Jobs, Medical Services, and Grocery Stores 53
6.2.3. Walk Access to Jobs, Medical Services, and Grocery Stores 60
6.3. Bismarck – Mandan MPO 67
6.3.1. Auto Access to Jobs, Medical Services, and Grocery Stores 67
6.3.2. Walk Access to Jobs, Medical Services, and Grocery Stores 74
7. CONCLUSIONS AND FUTURE IMPROVEMENTS 81
References 83
APPENDIX A. SUGAR ACCESS SOCIOECONOMIC DATA ATTRIBUTES 85

APPENDIX B. SUGAR ACCESS POINT OF INTEREST DATA ATTRIBUTES 87
APPENDIX C. SUGAR ACCESS ROADWAY NETWORK ATTRIBUTES 91
APPENDIX D. SUGAR ACCESS PUBLIC TRANSIT NETWORK ATTRIBUTES 95
APPENDIX E. ND ROADWAY NETWORK, ZONAL, AND POI DATA 98
APPENDIX F. MPOS ROADWAY NETWROK, PUBLIC TRANSIT NETWORK, ZONAL, AND POI DATA 100

LIST OF FIGURES

Figure Page

Figure 5.1. Auto Access to Jobs within 15 Minutes Travel Time in North Dakota 18
Figure 5.2. Auto Access to Jobs within 30 Minutes Travel Time in North Dakota 19
Figure 5.3. Auto Access to Medical Services Within 15 Minutes Travel Time in North Dakota 21
Figure 5.4. Auto Access to Medical Services Within 30 Minutes Travel Time in North Dakota 22
Figure 5.5. Auto Access to Grocery Stores Within 30 Minutes Travel Time in North Dakota 23
Figure 5.7. Auto Access to Grocery Stores Within 15 Minutes Travel Time in North Dakota 24
Figure 6.1. Auto Access to Jobs within 15 Minutes in F-M 26
Figure 6.2. Auto Access to Jobs within 30 Minutes in F-M 27
Figure 6.3. Auto Access to Medical Services within 15 Minutes in F-M 28
Figure 6.4. Auto Access to Medical Services within 30 Minutes in F-M 29
Figure 6.5. Auto Access to Grocery Stores within 15 Minutes in F-M 30
Figure 6.6. Auto Access to Grocery Stores within 30 Minutes in F-M 31
Figure 6.7. Public Transit Access to Jobs within 30 Minutes in F-M 33
Figure 6.8. Public Transit Access to Jobs within 60 Minutes in F-M 34
Figure 6.9. Public Transit Access to Medical Services within 30 Minutes in F-M 35
Figure 6.10. Public Transit Access to Medical Services within 60 Minutes in F-M 36
Figure 6.11. Public Transit Access to Grocery Stores within 30 Minutes in F-M 37
Figure 6.12. Public Transit Access to Grocery Stores within 60 Minutes in F-M 38
Figure 6.13. Walk Access to Jobs within 15 Minutes in F-M 40
Figure 6.14. Walk Access to Jobs within 30 Minutes in F-M 41
Figure 6.15. Walk Access to Medical Services within 15 Minutes in F-M 42
Figure 6.16. Walk Access to Medical Services within 30 Minutes in F-M 43
Figure 6.17. Walk Access to Grocery Stores within 15 Minutes in F-M 44
Figure 6.18. Walk Access to Grocery Stores within 30 Minutes in F-M 45
Figure 6.19. Auto Access to Jobs within 15 Minutes in GF-EGF 47
Figure 6.20. Auto Access to Jobs within 30 Minutes in GF-EGF 48
Figure 6.21. Auto Access to Medical Services within 15 Minutes in GF-EGF 49
Figure 6.22. Auto Access to Medical Services within 30 Minutes in GF-EGF 50
Figure 6.23. Auto Access to Grocery Stores within 15 Minutes in GF-EGF 51
Figure 6.24. Auto Access to Grocery Stores within 30 Minutes in GF-EGF 52
Figure 6.25. Transit Access to Jobs within 30 Minutes in GF-EGF 54
Figure 6.26. Transit Access to Jobs within 60 Minutes in GF-EGF 55
Figure 6.27. Transit Access to Medical Services within 30 Minutes in GF-EGF 56
Figure 6.28. Transit Access to Medical Services within 60 Minutes in GF-EGF 57
Figure 6.29. Transit Access to Grocery Stores within 30 Minutes in GF-EGF 58
Figure 6.30. Transit Access to Grocery Stores within 60 Minutes in GF-EGF 59
Figure 6.31. Walk Access to Jobs within 15 Minutes in GF-EGF 61
Figure 6.32. Walk Access to Jobs within 30 Minutes in GF-EGF 62
Figure 6.33. Walk Access to Medical Services within 15 Minutes in GF-EGF 63
Figure 6.34. Walk Access to Medical Services within 30 Minutes in GF-EGF 64

Figure 6.35. Walk Access to Grocery Stores within 15 Minutes in GF-EGF 65
Figure 6.36. Walk Access to Grocery Stores within 30 Minutes in GF-EGF 66
Figure 6.37. Auto Access to Jobs within 15 Minutes in B-M 68
Figure 6.38. Auto Access to Jobs within 30 Minutes in B-M 69
Figure 6.39. Auto Access to Medical Services within 15 Minutes in B-M 70
Figure 6.40. Auto Access to Medical Services within 30 Minutes in B-M 71
Figure 6.41. Auto Access to Grocery Stores within 15 Minutes in B-M 72
Figure 6.42. Auto Access to Grocery Stores within 30 Minutes in B-M 73
Figure 6.43. Walk Access to Jobs within 15 Minutes in B-M 75
Figure 6.44. Walk Access to Jobs within 30 Minutes in B-M 76
Figure 6.45. Walk Access to Medical Services within 15 Minutes in B-M 77
Figure 6.46. Walk Access to Medical Services within 30 Minutes in B-M 78
Figure 6.47. Walk Access to Grocery Stores within 15 Minutes in B-M 79
Figure 6.48. Walk Access to Grocery Stores within 30 Minutes in B-M 80

LIST OF APPENDIX TABLES

Table Page

A.1. Sugar Access Socioeconomic Data Attributes 85
B.1. Sugar Access POI Attributes 87
B.2. Sugar Access HERE and CITILABS POI Classification Codes and Description 89
C.1. Sugar Access Roadway Network Link Attributes 91
C.2. Sugar Access Roadway Node Attributes 94
D.1. Sugar Access Public Transit Network Line Attributes 95
D.2. Sugar Access Public Transit Network Link Attributes 96
D.3. Sugar Access Public Transit Network Node Attributes 97

LIST OF APPENDIX FIGURES

Figure Page

E.1. North Dakota Zones and Point of Interest Data 98
E.2. North Dakota Roadway Network 99
F.1. F-M POI Data 100
F.2. F-M Roadway Network Data 101
F.3. F-M Public Transit Network 102
F.4. GF-EGF POI Data 103
F.5. GF-EGF Roadway Network 104
F.6. GF-EGF Public Transit Network 105
F.7. B-M POI Data 106
F.8. B-M Roadway Network 107

EXECUTIVE SUMMARY

This project covers the development of Accessibility measures for the State of North Dakota at the county level and for the three North Dakota MPOs. It explains the procedures, constraints and considerations for the use of the model as an evaluation tool to measure the effectiveness off the transportation system to meet the needs of residents.

Transportation accessibility is an important component of the transportation planning process. Accessibilities can determine what mode of transportation we need to have a livable society. It measures the ability for people to reach various activities. Within North Dakota, the transportation plans typically include a section about accessibility. However, these have not been explicitly measured. This report details the development of a model to effectively measure transportation accessibility for North Dakota and for the MPOs. For North Dakota, census tracts are used to measure accessibilities whereas the transportation analysis zones for each MPO are used for the MPO geographies. Accessibilities are measured for different modes – auto, transit – (fixed route transit), walk/bike for different activities. These activities include jobs, medical services and grocery stores. As we move forward, it will be important to measure access to other types of activities that the NDDOT and the MPOs deem important.

A literature review was conducted regarding accessibility measurements and applications. The details of the networks, sociodemographic data and measurements are documented in this report. Accessibility measures were developed using Sugar Access. The package was selected since all the planning models within the MPOs are developed using CUBE. Additionally, the package provides an excellent method and tool to measure, score and understand accessibilities to employment opportunities, public services, errands and other types of services from a multimodal perspective.

The output shows that overall, the state performs very well when we take auto access into account. Walk and transit access measurements perform at lower levels when compared to auto access as expected. For the MPO and cities, all citizens within all the MPOs and the major cities could have good auto access to jobs within 15 minutes. Within 30 minutes, all the cities also have excellent access to jobs.

As we move forward in evaluating accessibilities to services within North Dakota, it will be important to incorporate explicit accessibility measures when developing and scoring different projects. Additionally, the NDDOT and the MPOs should provide additional guidance as to what their threshold measures for accessibility are for different types of activities. For example, we use a 15 minute measurement as the minimum accessibility measurement for auto. It is plausible that an MPO or the NDDOT will want to use lower or higher threshold based on the vision for that MPO.

1. INTRODUCTION

Accessibility in transportation is defined as "a measure of the ease of an individual to pursue an activity of a desired type, at a desired location, by a desired mode, and at a desired time" (Bhat et al. 2000). Accessibility metrics estimated for a region help guide land use and transportation planning, siting decisions, equity analysis, logistical operations, and other policy making decisions (McCahill, 2018). Accessibility allows the capability of capturing the complex associations between transportation systems, and land use and also offers social perspective on planning in transportation (Hansen, 1959) (Banister, 2008). Accessibility is regarded as one of the most inclusive measures to evaluate the performance of transportation systems and land use in a region (Boisjoly & El-Geneidy, 2017) that go beyond mobility measures. In essence accessibility measures capture in a very broad sense all measures of land use and transportation. Travel demand is derived demand and people travel to meet other needs. Accessibility measurements capture the ability of people living within a particular geography to be able to reach those activities.

Accessibility is largely dependent upon the land use component i.e. the spatial distribution of destinations, and people's ability to move from one location to another i.e. the transport component (Geurs & Wee, 2004). Litman (2019) outlined six key factors that can affect accessibility and they are: 1) mobility, 2) proximity, 3) transportation system connectivity, 4) affordability, 5) convenience, and 6) social acceptability. Mobility refers to ease of physical movement by providing quality of travel modes/options to people. Proximity is defined as distances between locations/destinations, and is primarily based on land use factors, such as development mix and density. Transportation system connectivity potentially include sidewalk density, public transit and road networks, and quality of connections between different modes, such as bike and transit station, and connections of transit to airports. Affordability basically refers to monetary out of pocket cost incurred to traveler. Convenience is defined as ease of getting travel information, and carrying luggage etc. Social acceptability is related to people's ability to use certain transportation mode that sometime depends upon their social status (Litman, 2019).

The scientist's argued that mobility metrics should not be used as principal measures for overall transportation system performance, while they can be useful in assessment of individual transportation facilities (e.g., roadway links and intersections) (Banister, 2008) (Norquist, 2011). From one of the perspectives of transportation system: vehicular traffic is considered as a subset

of mobility, and mobility as a subset of accessibility. Accessibility provides the broadest context in transportation planning because reaching desired destination is the ultimate goal of most travelers. Accessibility based transportation planning offers broader range of possible solutions to transportation problems (Litman, 2019). Transportation policy goals can be advanced by including modal accessibility scores e.g. by improving the walking accessibility to some specific non-employment destinations (grocery stores, hospitals etc.) can result in higher property values and lower vehicle miles traveled (VMT) (Sundquist, McCahill, & Dredske, 2017).

This study evaluates the accessibility for North Dakota state and three Metropolitan Planning Organizations (MPOs) using "Sugar Access" accessibility measurement tool. A review of the various transportation plans for each MPO and for the NDDOT shows that there is mention of accessibility, however, the plans do not explicitly measure accessibilities. This project effectively measures accessibility for different modes for the MPOs and the counties in North Dakota. The three MPOs considered in the study are Bismarck-Mandan (B-M), Grand Forks-East Grand Forks (GF-EGF) and Fargo-Moorhead (F-M). The accessibility analysis is conducted separately for walk, transit and auto modes of transportation and for different types of destinations i.e., work, hospitals, and grocery stores etc. The study results will provide useful inputs and policy recommendations for future transportation planning projects and decisions in North Dakota.

2. MEASURES OF ACCESSIBILITY:

There are three types of commonly used accessibility measuring techniques in the literature and they are: 1) cumulative opportunities, 2) gravity measure, and 3) utility measure. Cumulative opportunities accessibility measure takes into account distance and purpose of a trip and is the simplest of the three accessibility measures. In cumulative opportunities measure, a travel time or distance threshold is defined first and then the total number of potential activities that can be reached within that threshold travel time or distance is the accessibility for that spatial location. The generalized formulation to measure cumulative opportunity accessibility measure is following:

$$A_d = \sum_d O_d \quad (1)$$

Where "d" is the threshold travel time or distance, O_d is an activity/opportunity that can be accessed within threshold "d".

The gravity based accessibility measure is based on the assumption that with increasing distance or travel time, the spatial interaction or accessibility between origins and destinations decays. Unlike cumulative opportunities measure, that uses a discrete distance or travel time measure, gravity has the advantage of using continuous measure in the form of "distance decay function" that is used to discount accessibility with increasing travel time or distance from the given location. The general form of gravity based accessibility measure is given below:

$$A_i = \sum_j \frac{O_j}{t_{ij}^{\alpha}} \quad (2)$$

Where A_i is the accessibility measure for location "i", t_{ij} represents travel time or distance between location i and j, O_j is the opportunity at location "j", α is the distance decay parameter. A higher α value represents a faster decay in the attraction to desired destination or quicker reduction in accessibility.

The utility measure for accessibility is based on the perceived utility of individual for different travel options. Weibull (1980) describes that utility based accessibility measure does not reduce with the addition of choices, and also does not decrease if the average of any one utility choice increases (Weibull, 1980). The general form of utility based accessibility measure is following:

$$A_m = E[Max_{i \in C} U_{im}] = \ln \sum_{i \in C} \exp(V_{im}) \quad (3)$$

Where A_m is the accessibility for individual "m" and is defined as the expected value (E) of the maximum of available utilities in overall spatial destination "i" within the choice set "C".

Even though, gravity-based measure provides better reflection of people's travel behavior but is difficult to communicate and interpret (Geurs & Wee, 2004). Cumulative-opportunity based measure on the other hand is more easy to create and interpret and also its results are found highly correlated with gravity-based measure (El-Geneidy & Levinson, 2006). In the next section we will discuss about "Sugar Access" accessibility measurement tool and the methodology it employs to measure accessibility.

3. SUGAR ACCESS METHODOLOGY

Sugar Access is an ArcGIS extension tool for transportation planners developed by CITILABS. CITILABS is a firm that provides software, professional services, and data analysis in order to help model and predict the movement of goods and people. Sugar Access allows transportation planners and engineers to model accessibility to different types of location e.g., employment, grocery stores, restaurants, and medical services etc., using driving, biking, transit, and walking modes. The software tool can be set up to evaluate accessibility using any one the transportation modes mentioned or using multiple modes at the same time. The tool uses transportation network data (roadway and transit), zonal census data, points of interest (POI) data (origins and destinations), roadway travel times, and transit information to evaluate accessibility. Sugar Access also allows to conduct scenario analysis in order to examine the impacts of proposed transportation improvements and land use changes on accessibility level in communities. For example, the transportation agency could include a future transit line in the already existing transit network to compare the present versus future accessibility levels. Finally, the software tool uses default decay curves separately for each transportation mode and can be adjusted according to local environments or populations. These decay curves are taken from observed travel behavior and represent user's willingness to use each transportation mode based on travel time or distance.

3.1. Accessibility Metrics Calculation in Sugar Access

Accessibility can be calculated and measured in different ways, simple accessibility metrics account for analyzing the travel times from given origins to specific type of destinations while other metrics can evaluate access to multiple types of destinations at the same time. Transportation accessibility has both temporal and modal aspects that need to be considered. Sugar Access implements accessibility metrics that can examine accessibility to different types of destinations at different times of a day, and for different transportation modes. The three types of accessibility analysis methods used within Sugar Access are described in the following subsections.

3.1.1. Travel Time Accessibility Metric

The travel time accessibility metric evaluates the minimum travel time to a POI or particular type of destination. Therefore, the accessibility metrics are calculated for every zone in the study area. In most of the cases, there may be multiple POIs that are being examined at the

same time, such as hospitals throughout a city. In such cases, the analysis will be to validate the minimum travel time to reach a hospital for the entire population. The travel time accessibility metric in the mathematical form is defined as:

$$TTA_{ik} = \min(t_{ij}) \ for \ S_{jk} > 0 \quad (4)$$

Where TTA_{ik} is travel time accessibility for zone i to destination k, S_{jk} represents sum of destination (POIs) k within zone j, and t_{ij} represents travel time between zone i and j.

3.1.2. Destination Summation Accessibility Metric

The destination summation accessibility metric examines the cumulative access to a particular destination type. For every zone in the study area, it will determine the POIs or number of destinations that are accessible within certain travel time threshold. For example, for measuring employment accessibility, the analysis will validate the number of jobs that are accessible within the specified travel time threshold. The travel time decay function is also applied in destination summation accessibility metric estimation. This function allows for each destination to be weighted differently based on user's willingness to travel. A gravity based function is implemented such that it reflects the relative value of destinations to user based on their nearness to the origin. The equation to define destination summation accessibility metric is given as:

$$DS_{ik} = \sum_j S_{jk} \, g(t_{ij}) \, h(t_{ij}) \quad (5)$$

Where,

$$g(t_{ij}) = \begin{Bmatrix} 1 \ if \ t_{ij} \leq T \\ 0 \ if \ t_{ij} > T \end{Bmatrix} \quad (6)$$

DS_{ik} represents destination summation accessibility to destination k for zone i, T is the travel time threshold, and $h(t_{ij})$ is the travel time decay function.

3.1.3. Access Score Accessibility Metric

The access score accessibility metric also examines the cumulative access to different types of destinations in one metric and implicitly implements travel time decay function. This method sets a target number of POIs for each category. The "target" defines the number of desired POIs for an origin to be considered sufficiently accessible to that specific destination type. The

accessibility metric then assigns a score out of 100 to be awarded for the category if the target is met. This method also employs weight factors for individual POI to customize an access score in order to represent different trip types. The equation to define access score accessibility metric is outlined below:

$$AS_{ik} = \min(\sum_j (S_{jk}\ g(t_{ij})), M_k) \quad (7)$$

$$AS_i = \min(\sum_k \frac{AS_{ik}}{M_k}\ W_k, 100) \quad (8)$$

Where, AS_i is access score accessibility for zone i, k represents destination type indicator, S_{jk} represents sum of destinations (POIs) within zone j for destination (POI) type k, $g(t_{ij})$ is travel time decay function, M_k is points of interest target for destination (POI) type k, and W_k represents points of interest weight factor for destination (POI) type k.

4. DATA REQUIREMENTS TO MEASURE ACCESSIBILITY

There are four main types of data that are being used in Sugar Access to measure accessibility metrics. These data types include: 1) socioeconomic data, 2) POIs, 3) roadway network data, and 4) public transit network data. Sugar Access uses available government socioeconomic or census data to improve accessibility analysis. Jobs and population data is gathered from 2015 LODES (LEHD (Longitudinal Employer-Household Dynamics) Origin-Destination Employer Statistics), 2010 census, and 2016 American Community Survey (ACS) databases, respectively. The socioeconomic data attributes along with brief description used in Sugar Access are given in Appendix A. For Sugar Access "HERE" provides POI information for different regions and cities. This information includes local destinations such as parks, hospitals, restaurants, and schools etc., all geocoded for respective city. This POI information can be utilized when examining accessibility to additional destinations that are not summarized in census polygons data. HERE also provides specific codes for each POI type that helps to query out the specific type of destination that anyone want to include in their analysis.

CITILABS has defined its own classification scheme for POI data instead of simply using HERE facility types classification. There are two main advantages of using its own classification: 1) it allows the accumulation of facility type codes into types of destination that are more related to accessibility analysis and 2) it allows the addition of this classification scheme for future

accessibility analyses including types of destinations that are currently not considered within the HERE classification scheme. The complete POI data attributes for accessibility analysis in Sugar Access are shown in Appendix B. The next important data type used for accessibility analysis is roadway network data. In order to conduct a comprehensive multi-modal accessibility analysis, a complete and accurate roadway network data must be used. HERE provides roadway network data for Sugar Access and are available for purchase from CITILABS in CUBE GDB or NET+SHP formats. The roadway network attributes according to Sugar Access format are shown in Appendix C.

In order to explore the role of public transit in providing accessibility to different types of destinations, a detailed public transit network data is needed. A public transit network can keep important information such as run times and headways in addition to the physical network attributes. General Transit Feed Specification (GTFS) files are used to generate public transit network data for Sugar Access accessibility analysis. GTFS feed is comprised of a series of text files which include information about public transit stops, trips, routes, and other transit schedule data. The locations of public transit stops are connected to the underlying roadway network in order to allow for a comprehensive multi-modal accessibility analysis. The public transit network used in Sugar Access has three basic type of attributes: 1) line attributes, 2) link attributes, and 3) node attributes. The transit line attributes represent a complete transit route shape file. The transit link attributes represent segments of a complete route in between every two nodes (nodes can be stop location or not). The nodes are the point shape file that represent either stop point if it is a stop location for a particular route or just a node on transit network. The public transit network attributes along with brief description used by Sugar Access are given in Appendix D.

4.1. Data Collection for Accessibility Measures in ND

This study did not use the data package available with Sugar Access. The data used for accessibility analysis in this study was obtained from different sources for ND state and MPOs level accessibility analysis. The raw data was then converted into Sugar Access data format in order to run the accessibility models for the state and MPOs. The main data types included for accessibility analysis are socioeconomic data, POIs data, roadway network data, and public transit network data. The next sub-sections will describe the spatial granularity of these data types at statewide and MPO levels.

4.1.1. Data for ND State Wide Level

The socioeconomic data for ND state was obtained from US Census Bureau. The data was obtained at census tracts level. There are total 205 census tracts in North Dakota state. The jobs, population and other socioeconomic data obtained from Census Bureau in raw form was then converted into Sugar Access data format (see Appendix A). The main socioeconomic data types obtained were jobs, age, employment by age, household size, household owner by age, jobs by income, race, and total population. The detailed and complete roadway network data for ND state was obtained from NDDOT. The roadway network included all the local roads, collectors, and major arterials or state highways. The attributes for roadway network were also set according to Sugar Access attributes format (see Appendix C). The POI data for ND state was also obtained from NDDOT. The POI data at state level was also coded and categorized based on classification scheme defined by CITILABS for Sugar Access accessibility analysis (see Appendix B). The statewide roadway network, socioeconomic zones, and POI data for ND state in the graphical form are shown in Appendix E.

4.1.2. Data for MPOs Level

The sizes of the zones used for MPOs accessibility analysis were same as used for respective MPO travel demand model development. The number of zones used in F-M, GF-EGF, and B-M for accessibility analysis are 722, 550, and 406, respectively. Part of the socioeconomic data (mainly jobs) for the three MPOs was obtained from MPO zonal data used for respective MPO travel demand models development. Some of the data attributes were not included in the travel demand models zonal data and were obtained from US Census Bureau. Some of these attributes for example include employment by age, household owner by age, and different race categories etc. The Census Bureau provide data at county level. So, the ratios were estimated for each socioeconomic category in the respective county. These estimated ratios were then multiplied with total jobs or total population available in the travel demand model zonal data in order to obtain data for desired attributes. Finally, the socioeconomic data for all three MPOs was set according to Sugar Access data format (see Appendix A).

The next data type is POI data for MPOs. The POI data for MPOs was obtained from the same source as for the state i.e., NDDOT. The POI data for MPOs was extracted for the respective MPO study area from the state POI data. The roadway network data used for MPOs accessibility

analysis was obtained from same roadway network data used to develop MPOs travel demand models. The attributes of the roadway network data for each MPO were adjusted according to Sugar Access format (see Appendix C).

F-M and GF-EGF MPOs have public transit networks operated in their areas. The detailed public transit networks were developed for these two MPOs using online available GTFS data. The GTFS are the series of text files available online for each public transit network in the US. Some of the important and necessary information these text files contain are public transit routes, stops (geographic location), stop times (difference between arrival and departure time), trips, and time headway between trips (frequency of service). The detailed and accurate public transit networks for F-M and GF-EGF were developed using Sugar Network Editor by incorporating GTFS information. The public transit network attributes for both MPOs were set according to Sugar Access format (see Appendix D). The roadway network, public transit network, socioeconomic, and POI data for MPOs in the graphical form are shown in Appendix F.

5. RESULTS OF ACCESSIBILITY MEASURES – STATE WIDE

The accessibility models were run at state wide level for people's ability to access jobs, grocery stores, and medical services by using auto mode. The travel time thresholds used for accessibility analysis were 15-minute and 30-minute. As mentioned in previous section, census tracts in the state were used as zones for accessibility evaluation. Figure 5.1 and Figure 5.2 represent auto access to jobs within 15-minute and 30-minute travel time thresholds, respectively in North Dakota. Total number of jobs estimated in North Dakota were 400454. The accessibility results indicate that within 15-minute travel time threshold, most of the North Dakota census tracts have zero access to jobs. For both travel time thresholds, census tracts within urban counties (Cass, Burleigh, and Grand Forks) have high access to jobs. Census tracts in Ward county also have high access to jobs within 30-minute travel time threshold. Overall, the accessibility results revealed that North Dakota state have low access to jobs except urban counties in 15-minute and 30-minute

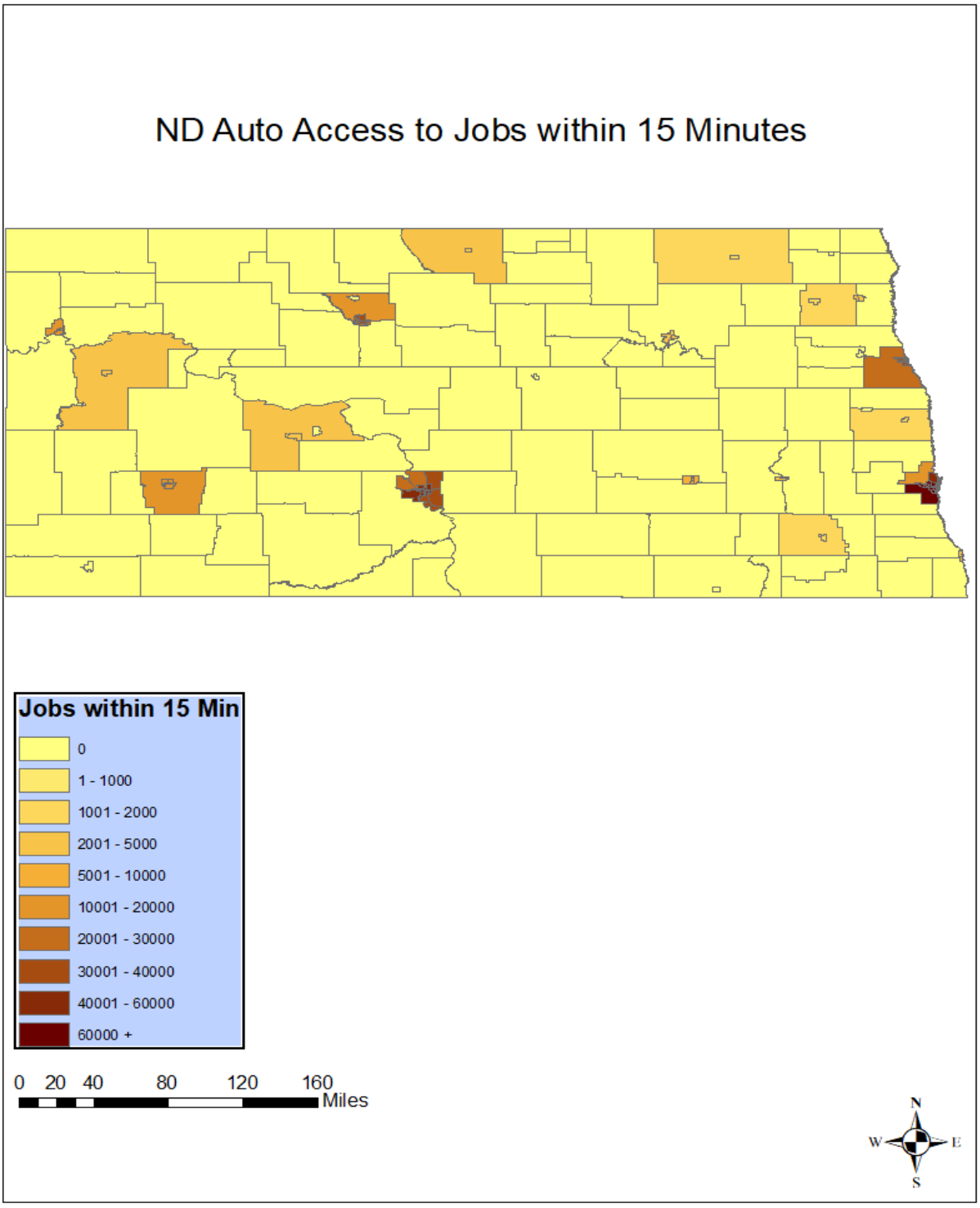

Figure 5.1. Auto Access to Jobs within 15 Minutes Travel Time in North Dakota

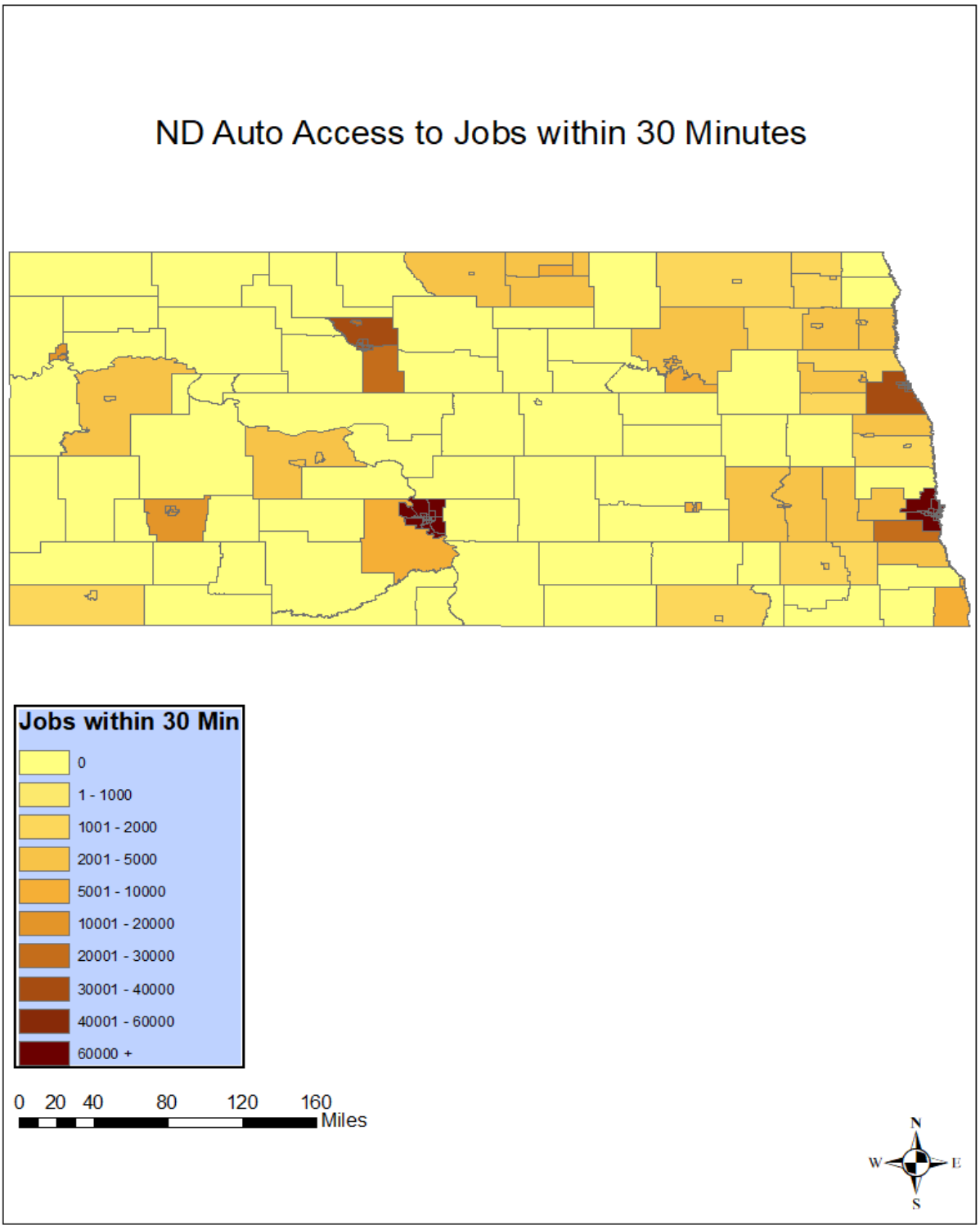

Figure 5.2. Auto Access to Jobs within 30 Minutes Travel Time in North Dakota

travel time thresholds. Figure 5.3 shows the auto access to medical services in North Dakota state within 15-minute travel time threshold. Total number of medical services used for accessibility analysis in North Dakota state were 7606. The results indicate that within 15-minute travel time threshold, the census tracts in urban counties (Cass, Burleigh, and Grand Forks) have high access to medical services. Most of the counties in North Dakota have very low access to medical services within 15-minute travel time threshold using automobile. Figure 5.4 shows the access to medical services within 30-minute travel time threshold using automobile in North Dakota. The accessibility results indicate that census tracts in Ward county also have high access to medical services along with census tracts in other three urban counties within 30-minute travel time threshold. Overall, most of the counties have low access to medical services within 30-minute travel time threshold using automobile.

Figure 5.5 and Figure 5.6 represent the auto access to grocery stores within 15-minute and 30-minute travel time thresholds, respectively in North Dakota state. The total number of grocery stores used for accessibility analysis in North Dakota state were 227. Within 15-minute travel time threshold, census tracts in only Cass county have high access to grocery stores, while census tracts in Grand Forks, Burleigh, and Stark counties have medium access to grocery stores using automobile. Most of the counties have very low access to grocery stores within 15-minute travel time threshold using automobile in North Dakota state. Within 30-minute auto travel time threshold, the accessibility results revealed that census tracts in Cass, Burleigh, Grand Forks, and Ward counties have high access to grocery stores. Again, overall the accessibility to grocery stores within 30-minute auto travel time threshold is low for most of the counties.

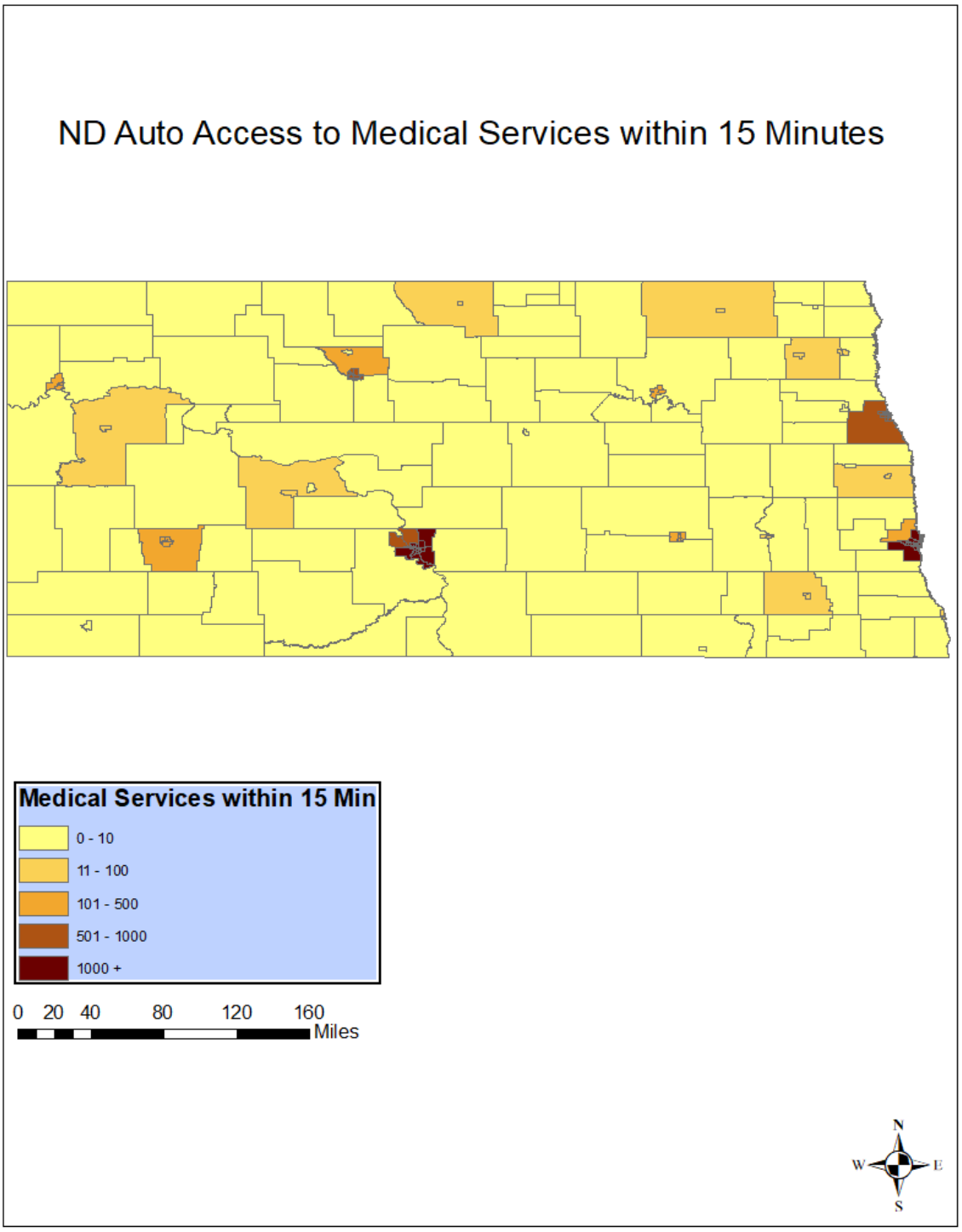

Figure 5.3. Auto Access to Medical Services Within 15 Minutes Travel Time in North Dakota

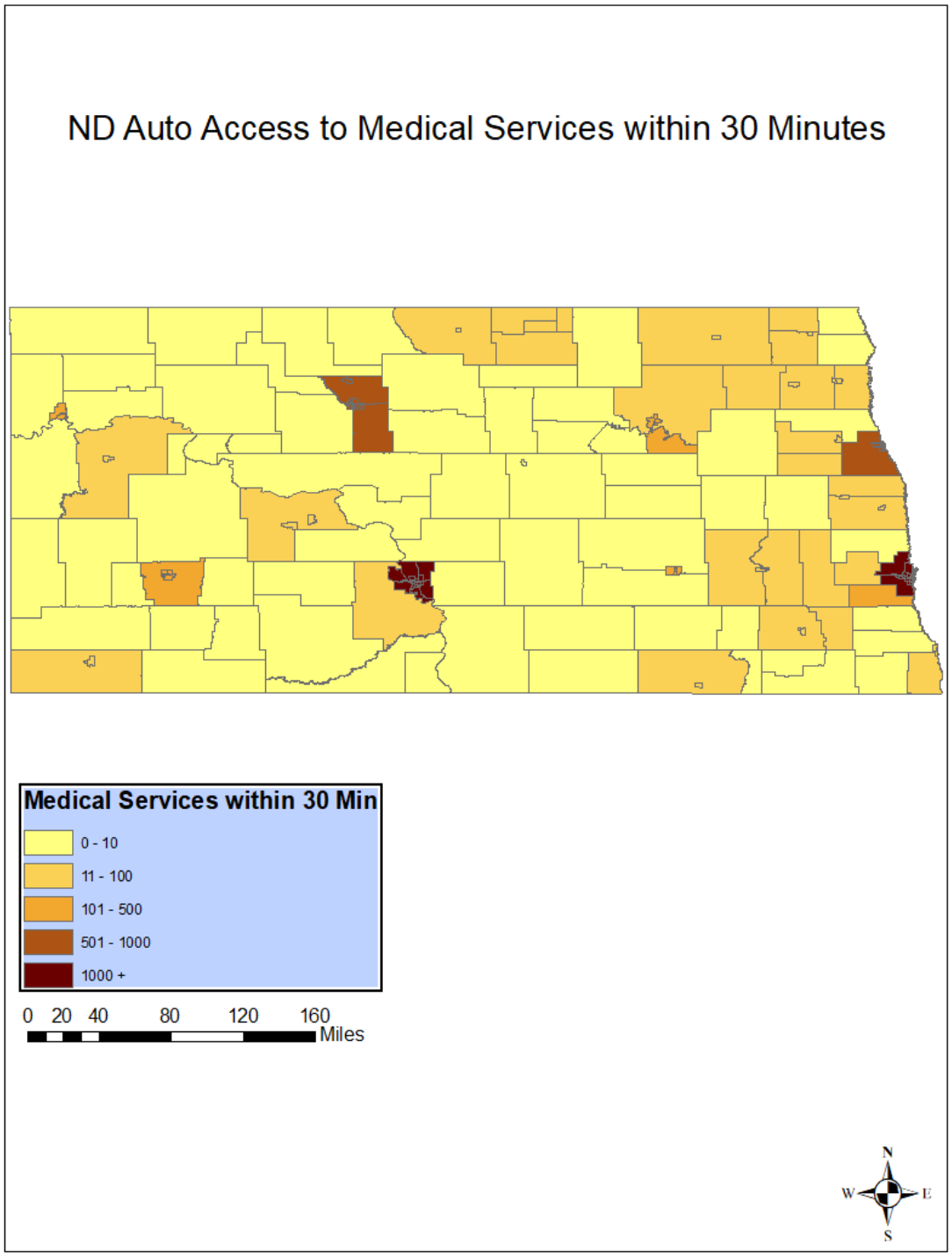

Figure 5.4. Auto Access to Medical Services Within 30 Minutes Travel Time in North Dakota

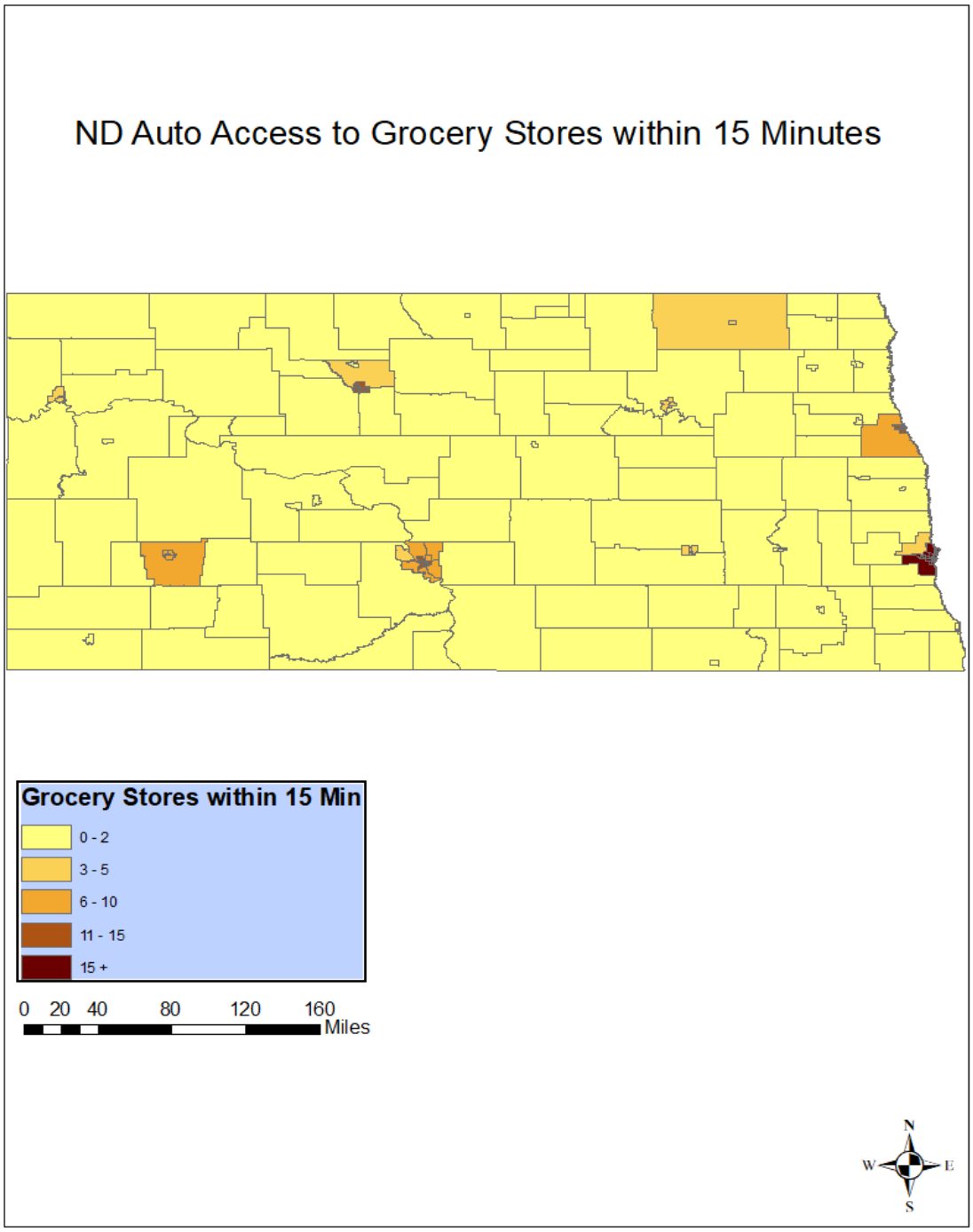

Figure 5.5. Auto Access to Grocery Stores Within 30 Minutes Travel Time in North Dakota

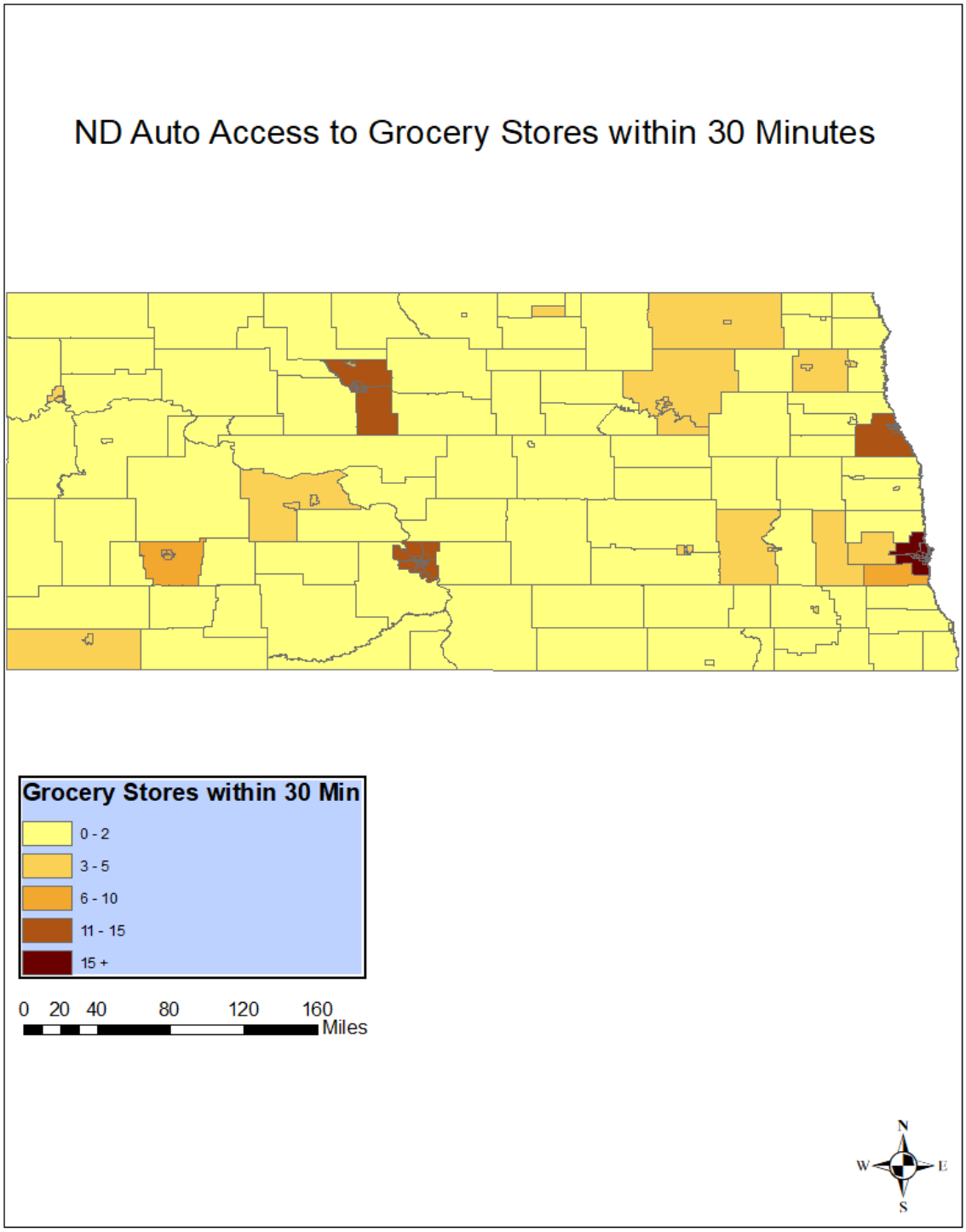

Figure 5.6. Auto Access to Grocery Stores Within 15 Minutes Travel Time in North Dakota

6. RESULTS OF ACCESSIBILITY MEASURES - MPOS

The accessibility models were run separately for F-M, GF-EGF, and B-M MPOs. The destination types considered for accessibility analysis were same as for state wide i.e., jobs, grocery stores, and medical services. For F-M and GF-EGF MPOs, the accessibility models were run by considering auto, walk, and public transit modes. As public transit service is not available in B-M MPO, only auto and walk modes were considered for accessibility assessment. The next sub-sections will describe the accessibility results for the three MPOs.

6.1. Fargo - Moorhead MPO

In this section, the accessibility results for F-M MPO are presented. The next sub-sections will describe the people's ability to access jobs, medical services, and grocery stores using auto, public transit, and walk mode, respectively in the F-M area.

6.1.1. Auto Access to Jobs, Medical Services, and Grocery Stores

Figure 6.1 and Figure 6.2 shows the people's ability to access jobs within 15-minute and 30 minute travel time, respectively using auto mode in F-M MPO area. Total number of estimated jobs in F-M were 127305. Within 15-minute travel time threshold, the accessibility to jobs is low in suburbs or outskirts of the metropolitan area. The accessibility results for 30-minute travel time threshold indicate that auto access to jobs is high in F-M MPO area. Overall, the results revealed that auto access to jobs in F-M is better. Figure 6.3 and Figure 6.4 shows the auto access to medical services within 15-minute and 30-minute travel time, respectively in the F-M area. Total number of medical services used for accessibility evaluation F-M metropolitan area were 2174. Within 15-minute travel time threshold, the accessibility results indicate that access to medical services in the outskirts of the metropolitan area is low. The accessibility to medical services within 30-minute auto travel time threshold is high in the F-M. Figure 6.5 and Figure 6.6 shows the auto access to grocery stores in F-M area within 15-minute and 30-minute travel time, respectively. Total number of grocery stores estimated in the F-M area were 36. The auto access to grocery stores was again low in the suburbs or outskirts of the metropolitan area within 15-minute travel time threshold. The accessibility in F-M was high within 30-minute travel time threshold. Overall, the accessibility results in this section indicate that accessibility to all three amenities (jobs, medical services, and grocery stores) is high in F-M area using auto mode.

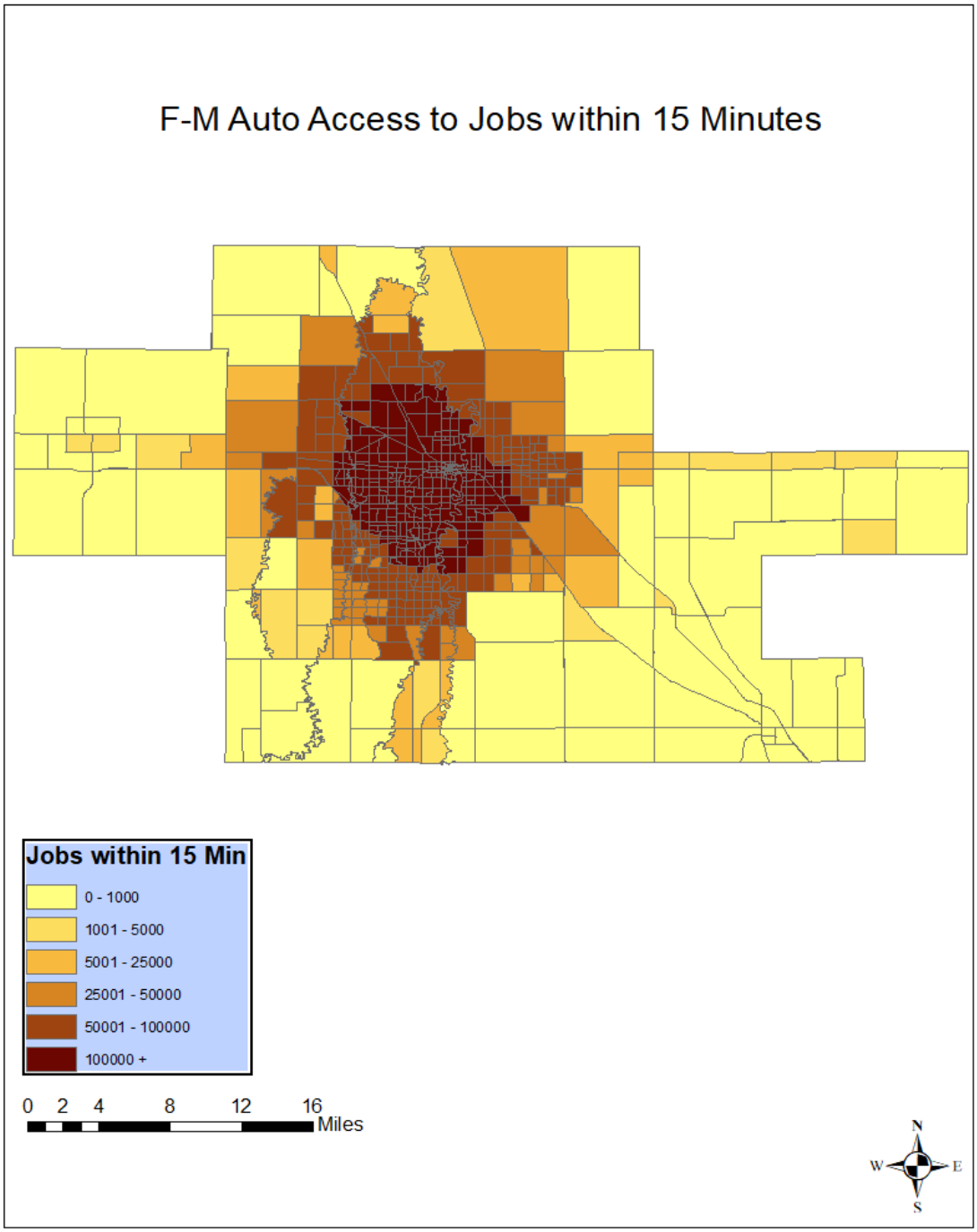

Figure 6.1. Auto Access to Jobs within 15 Minutes in F-M

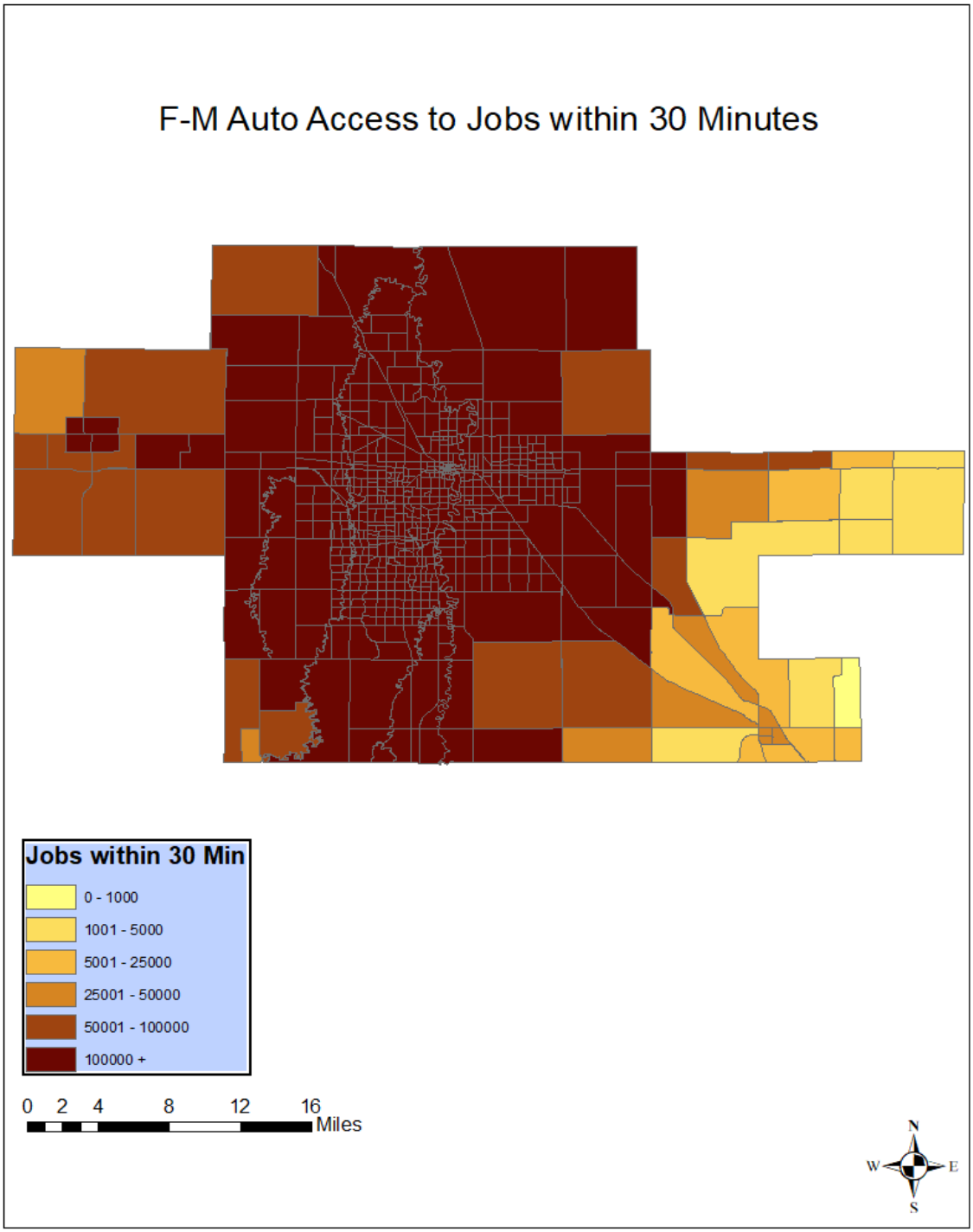

Figure 6.2. Auto Access to Jobs within 30 Minutes in F-M

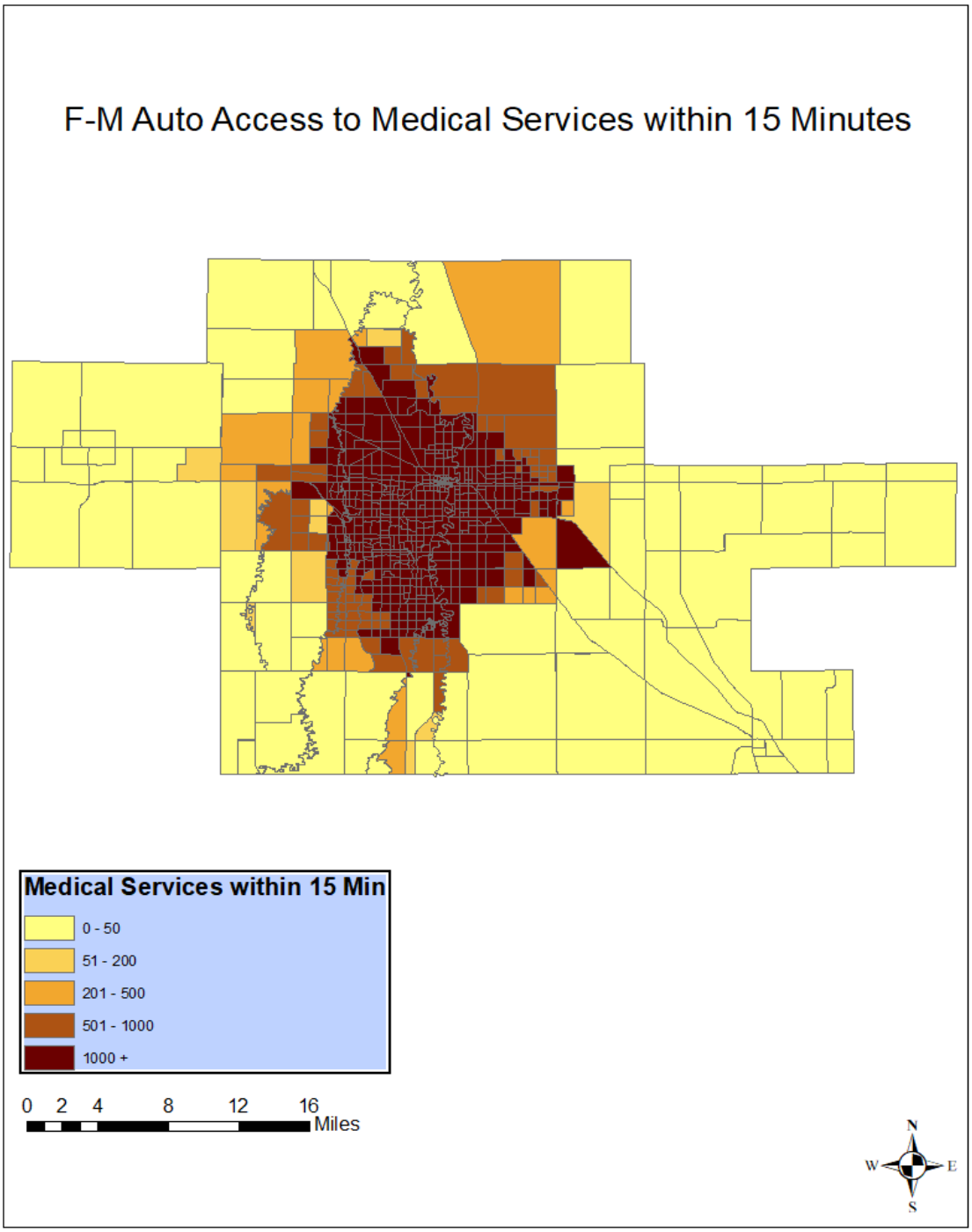

Figure 6.3. Auto Access to Medical Services within 15 Minutes in F-M

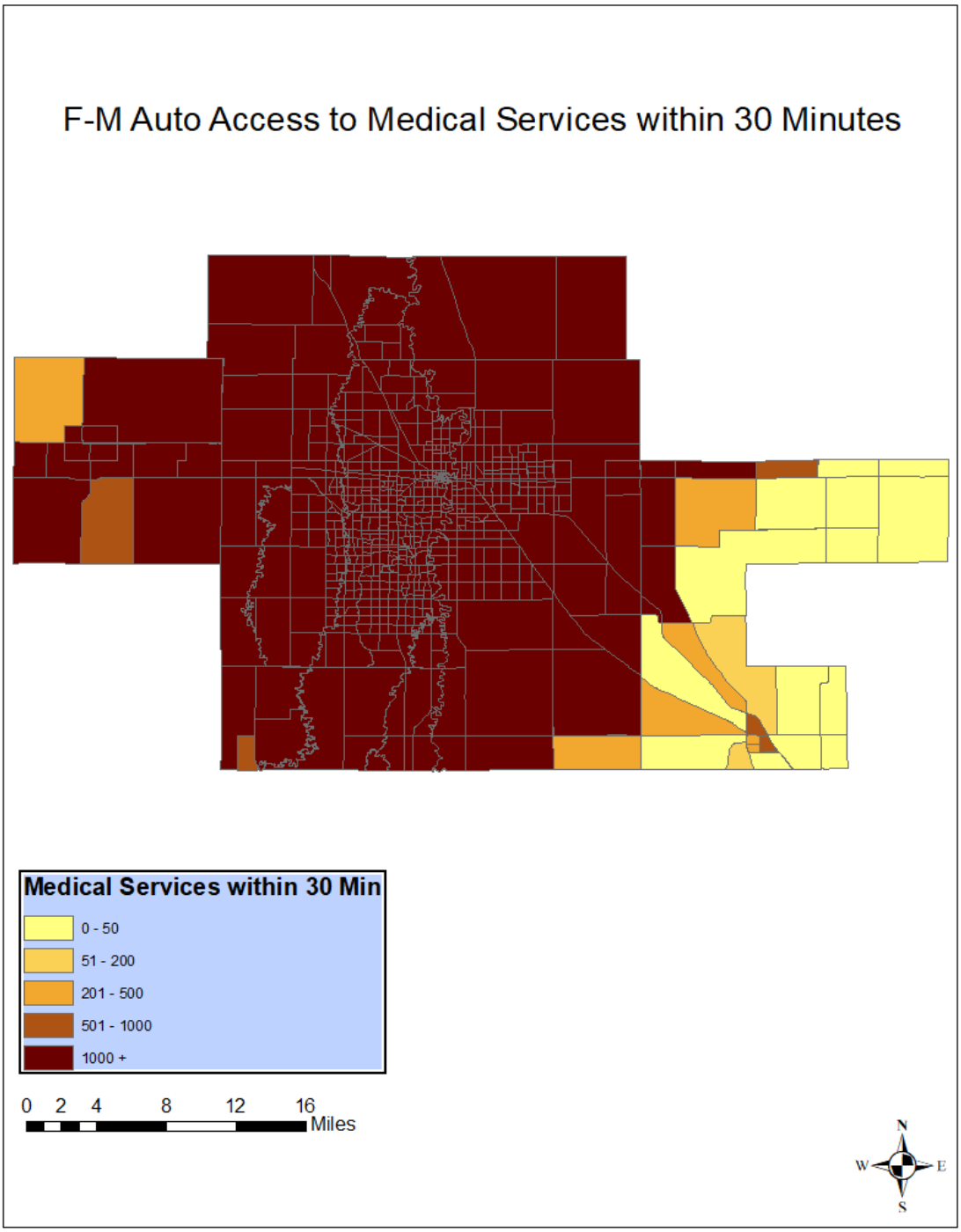

Figure 6.4. Auto Access to Medical Services within 30 Minutes in F-M

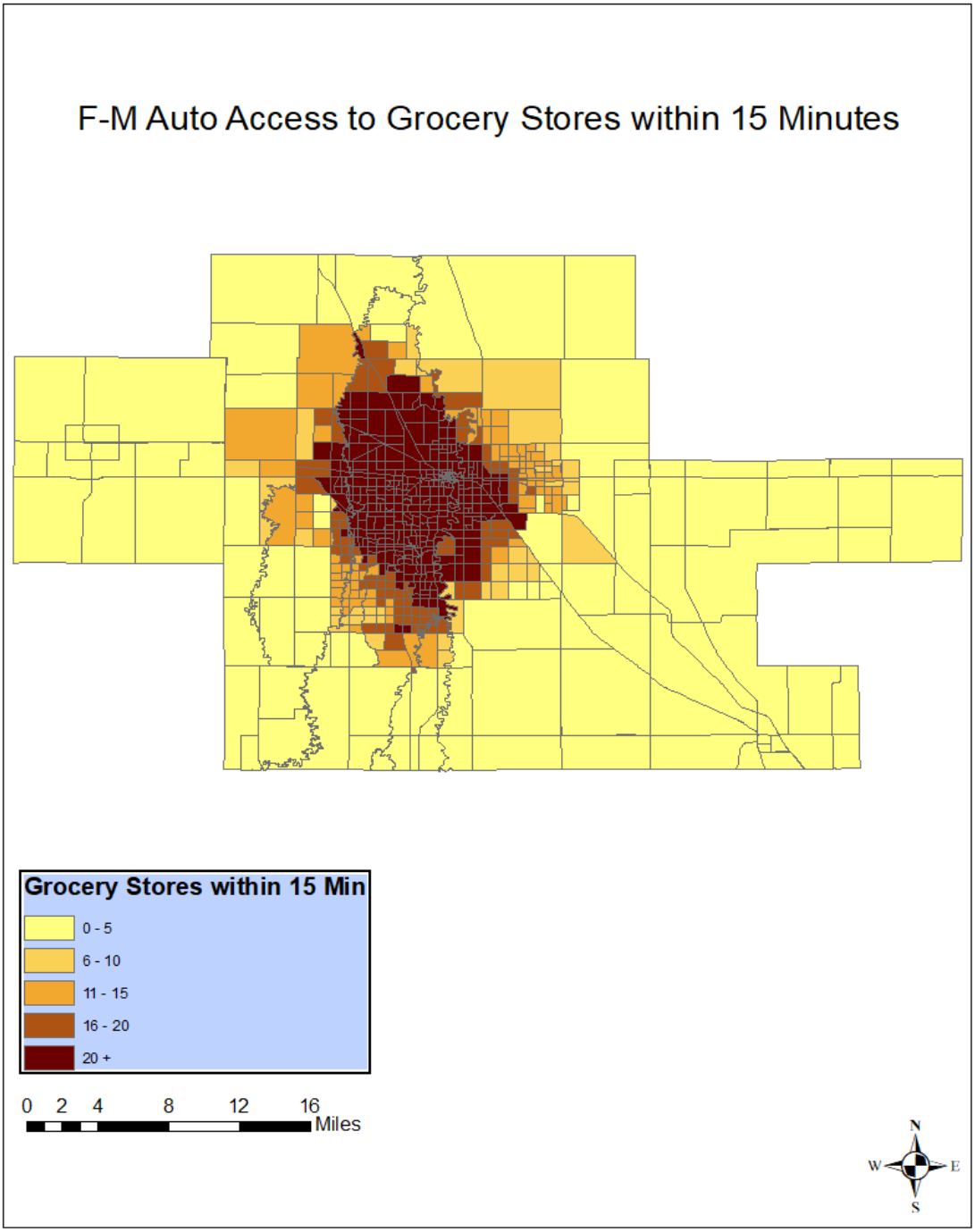

Figure 6.5. Auto Access to Grocery Stores within 15 Minutes in F-M

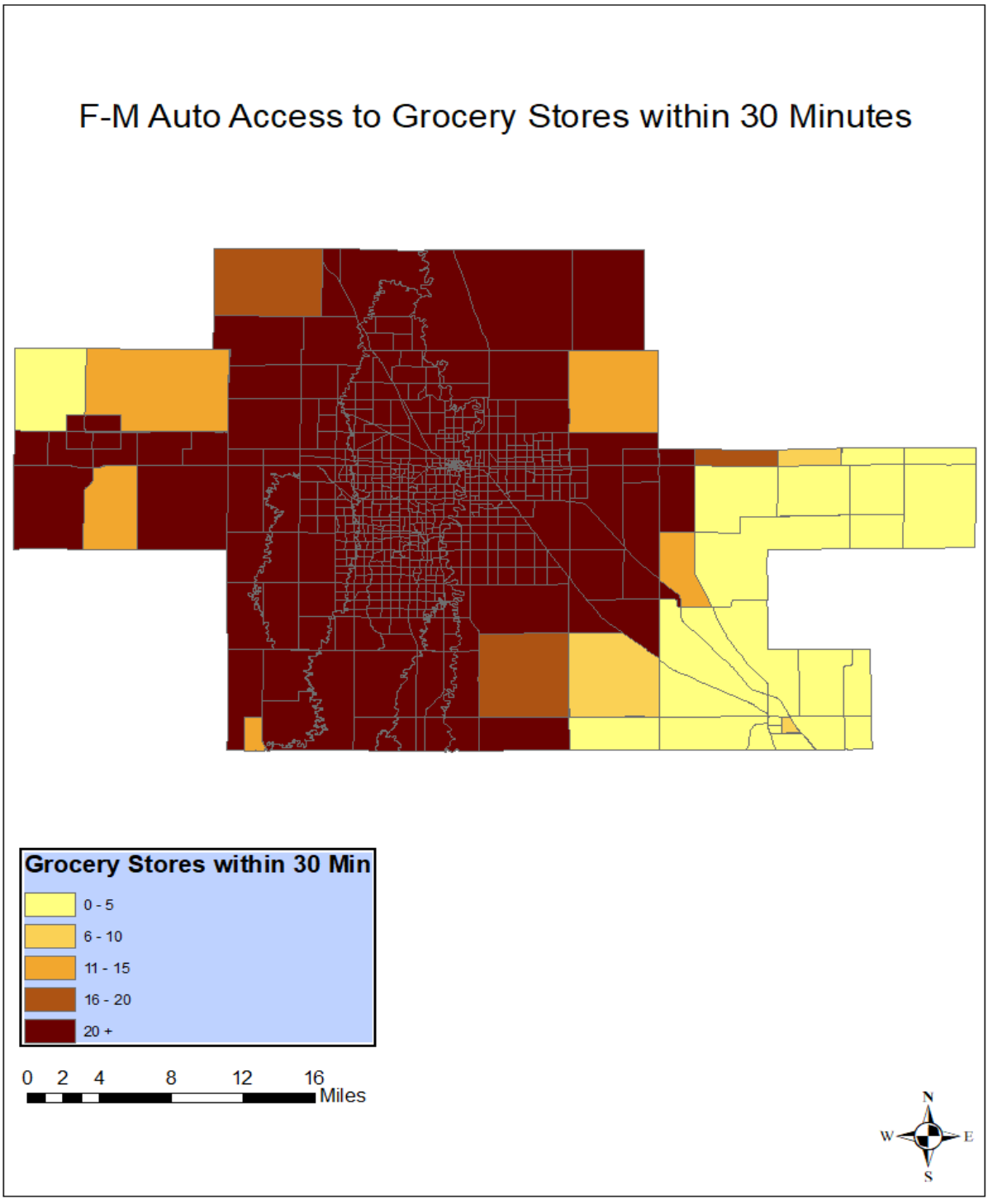

Figure 6.6. Auto Access to Grocery Stores within 30 Minutes in F-M

6.1.2. Public Transit Access to Jobs, Medical Services, and Grocery Stores

Figure 6.7 and Figure 6.8 shows the public transit access to jobs within 30-minute and 60-minute travel time thresholds, respectively. The accessibility results indicate that people's ability to access jobs is low in most parts of the F-M area within 30-minute travel time threshold using public transit. The accessibility results within 60-minute transit travel time revealed that access to jobs is high in the main urban areas while low in the suburbs of the F-M MPO area. Figure 6.9 and Figure 6.10 represent the public transit access to medical services within 30-minute and 60-minute travel time thresholds, respectively in the F-M area. The accessibility results indicate that within 30-minute travel time threshold, the people's ability to access medical services is low in most parts of the F-M area. Within 60-minute transit travel time, the accessibility to medical services was high in the main urban areas while low in the suburbs of the metropolitan area.

Figure 6.11 shows the public transit access to grocery stores within 30-minute travel time threshold in the F-M metropolitan area. The accessibility results indicate that people's ability to access grocery stores within 30-minute transit travel time is very low in most parts of the metropolitan area. Figure 6.12 shows the public transit access to grocery stores within 60-minute travel time threshold. The results revealed that people's ability to access grocery stores within 60-minute transit travel time is high in the main urban area while low in other parts of the F-M area. Overall, the results indicate that people's ability to access amenities (jobs, medical services, and grocery stores) using public transit is low except in the main urban area of F-M.

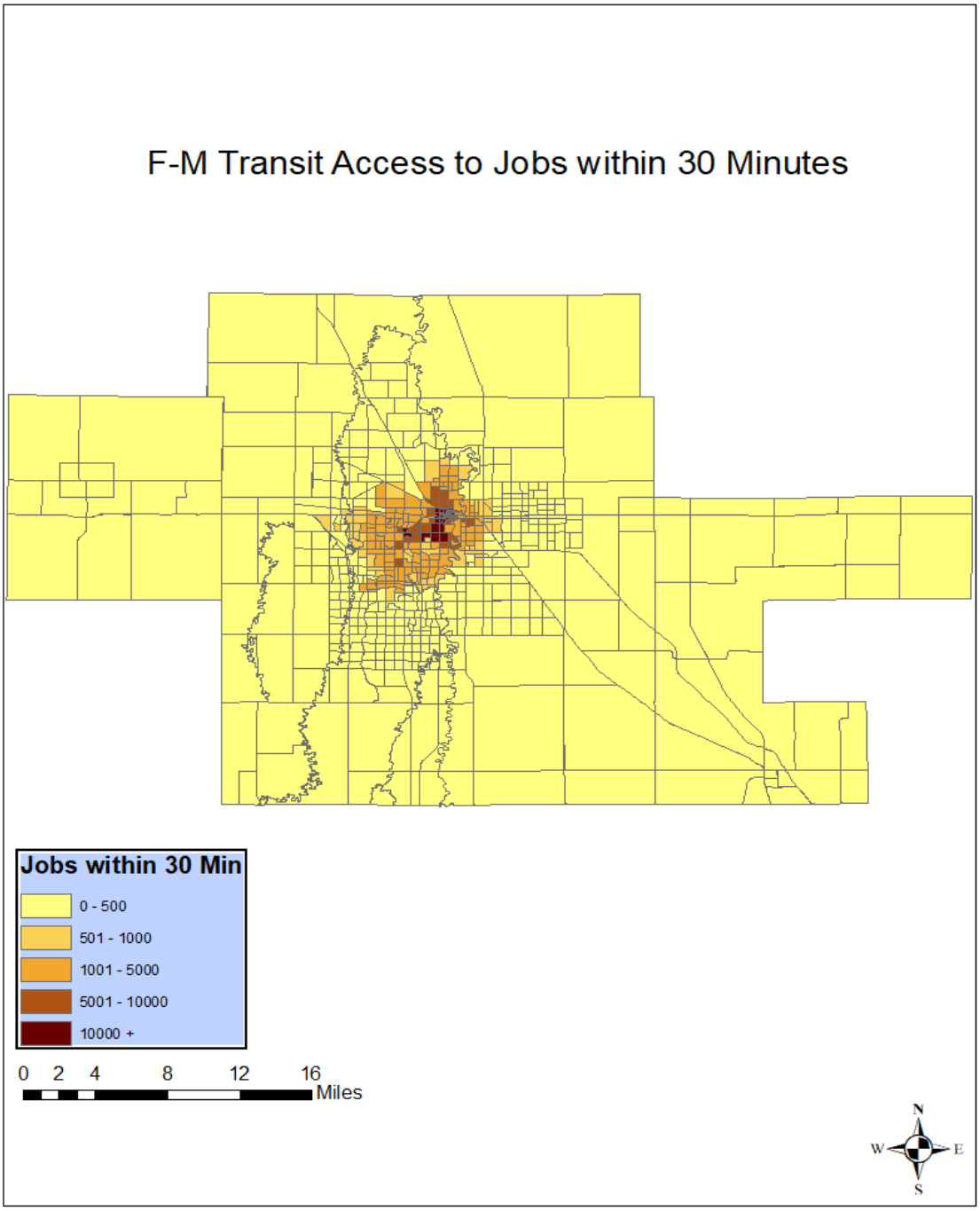

Figure 6.7. Public Transit Access to Jobs within 30 Minutes in F-M

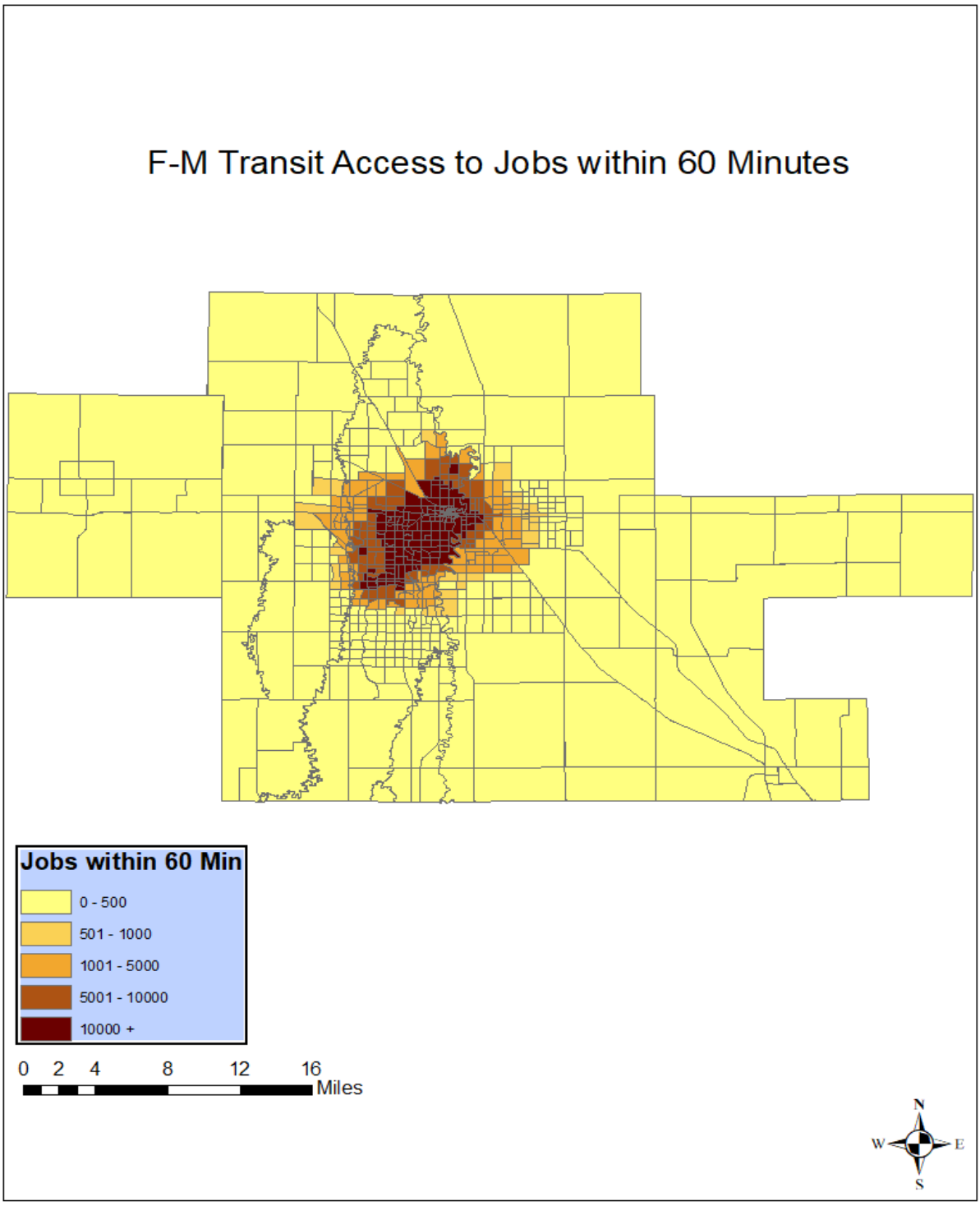

Figure 6.8. Public Transit Access to Jobs within 60 Minutes in F-M

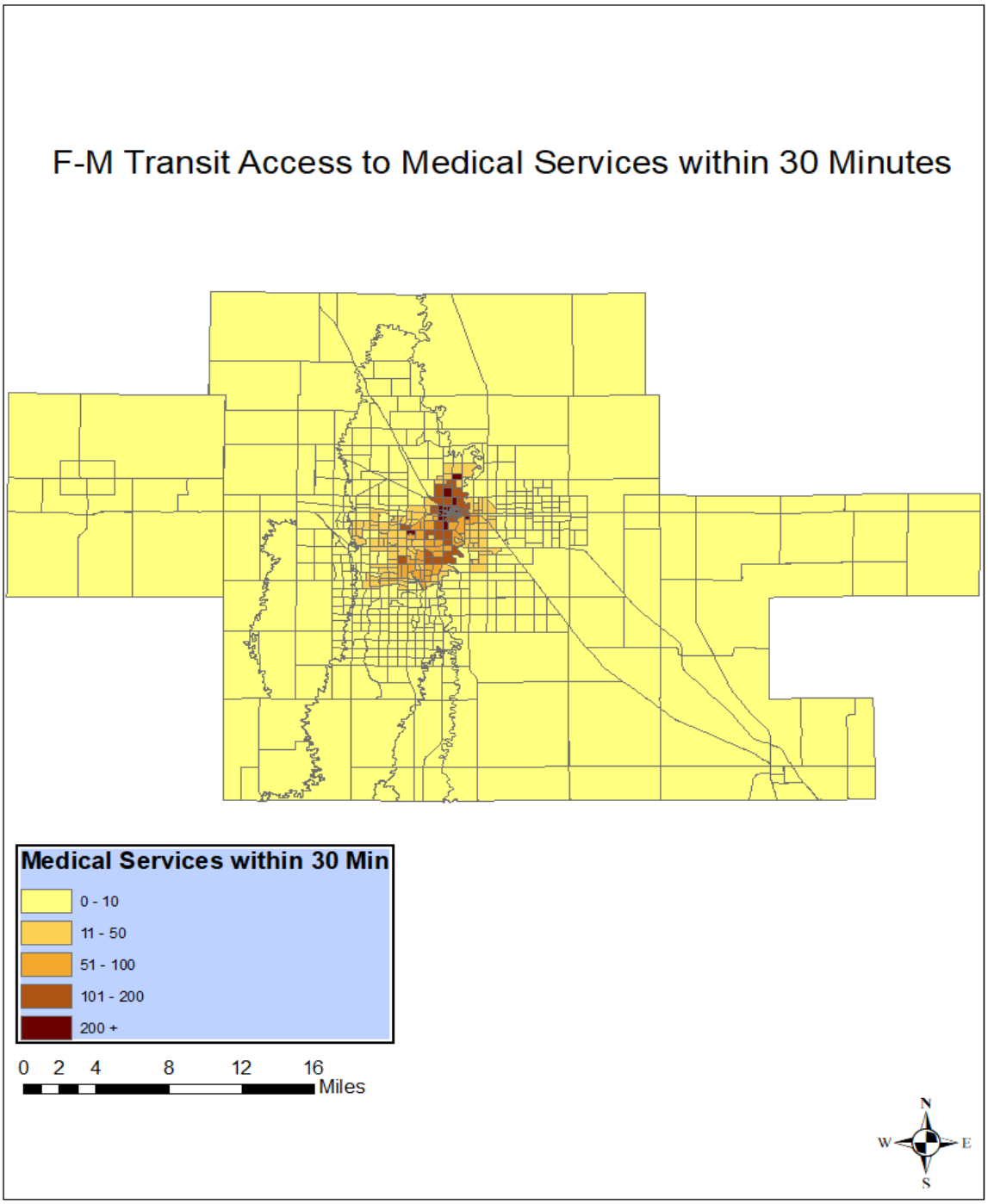

Figure 6.9. Public Transit Access to Medical Services within 30 Minutes in F-M

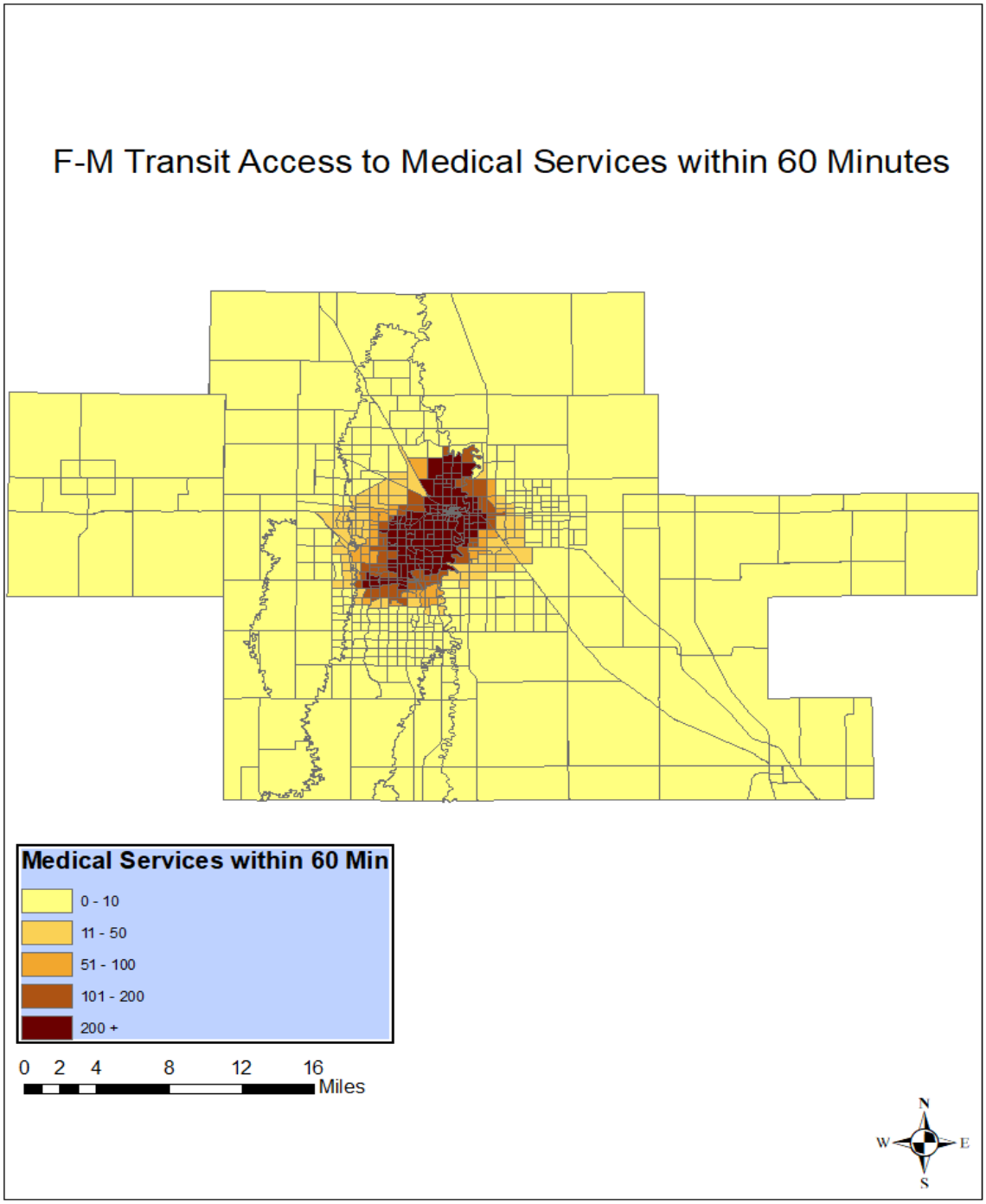

Figure 6.10. Public Transit Access to Medical Services within 60 Minutes in F-M

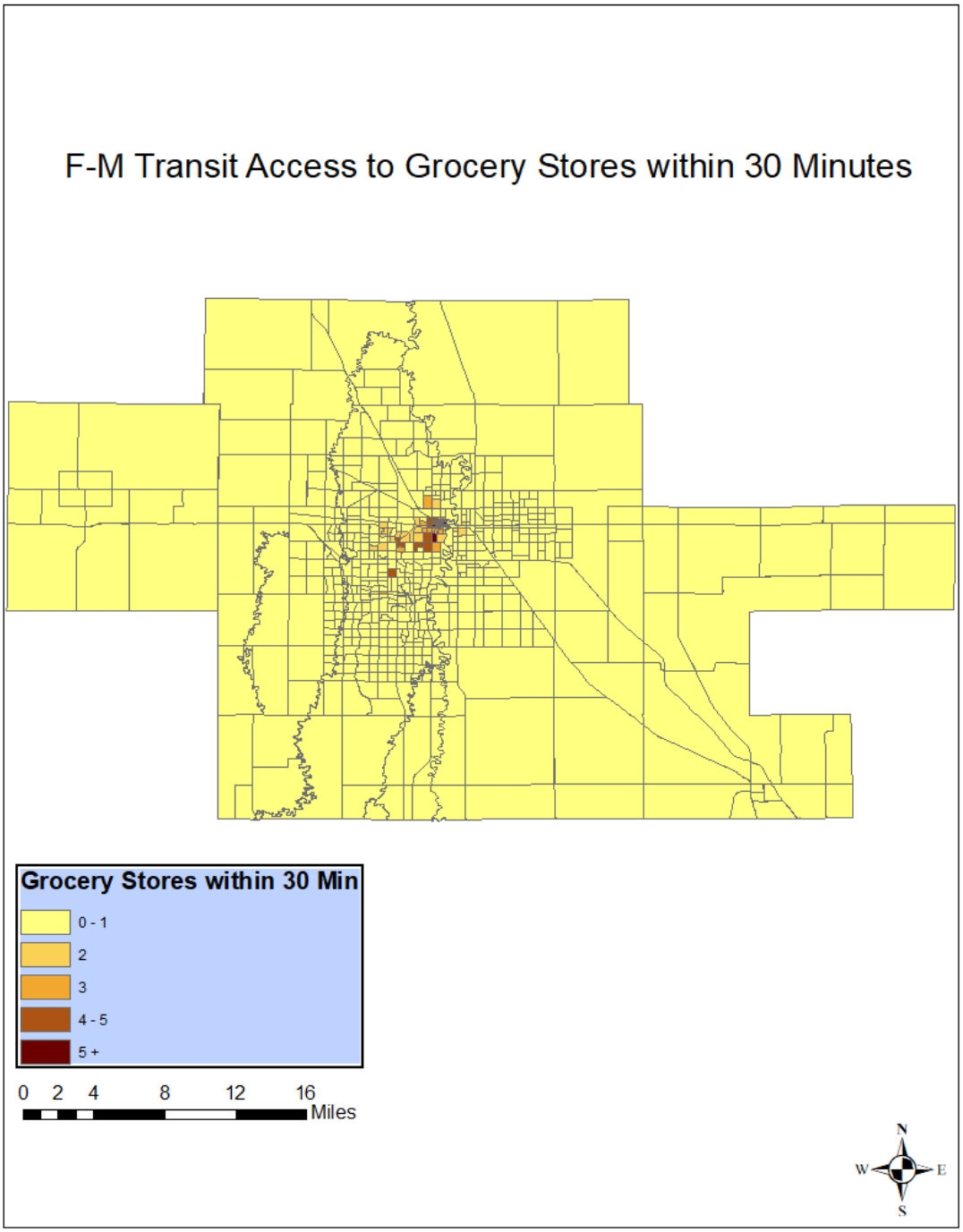

Figure 6.11. Public Transit Access to Grocery Stores within 30 Minutes in F-M

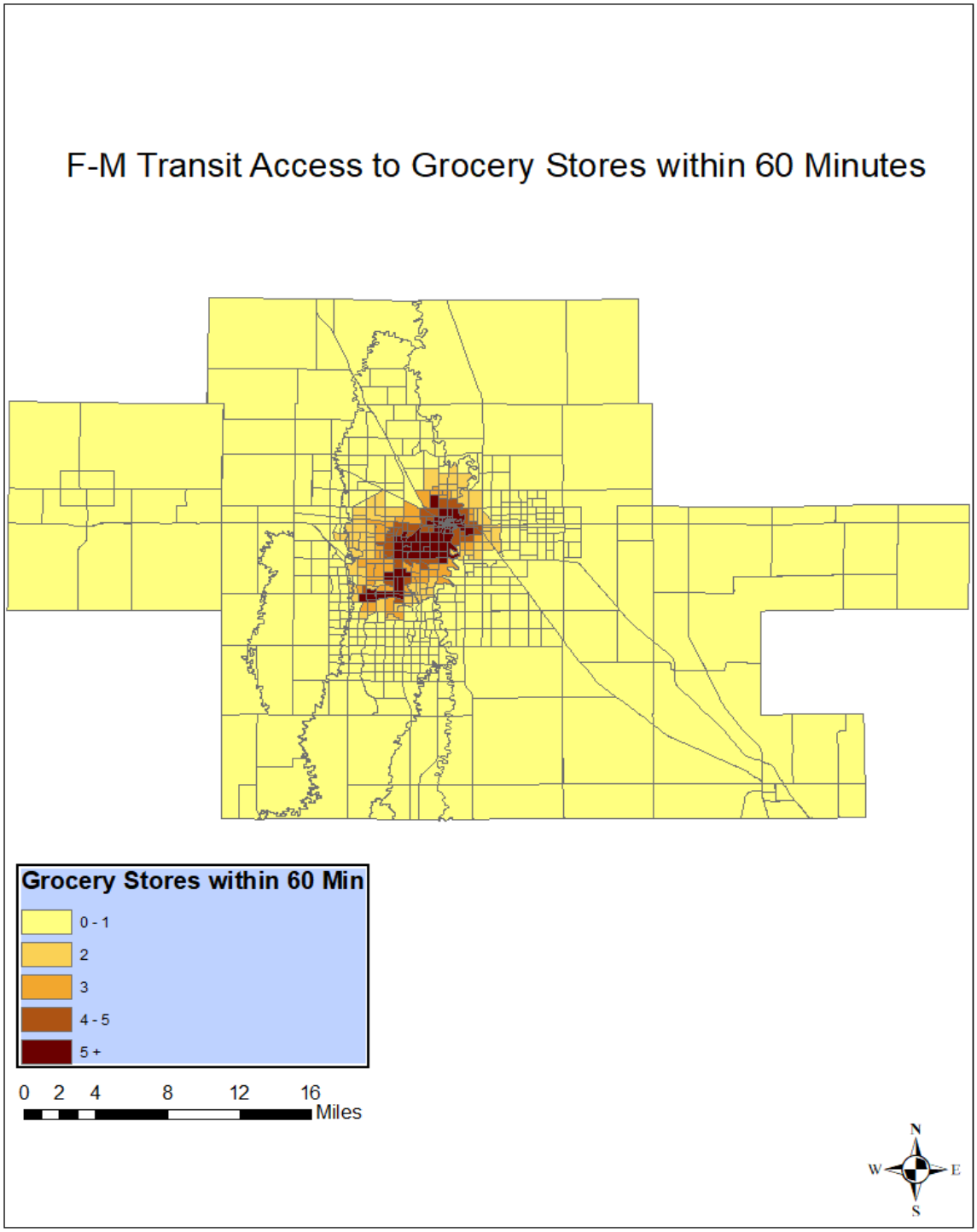

Figure 6.12. Public Transit Access to Grocery Stores within 60 Minutes in F-M

6.1.3. Walk Access to Jobs, Medical Services, and Grocery Stores

This section includes the accessibility results in terms of walk access to jobs, medical services, and grocery stores in the F-M MPO area. Figure 6.13 and Figure 6.14 represent the walk access to jobs within 15-minute and 30-minute travel time thresholds, respectively. The results indicate that within 15-minute walk travel time threshold, the people's ability to access jobs is low in most parts of the metropolitan area. Within 30-minute walk travel time, the access to jobs is high in the main urban area while low in suburbs of the F-M.

Figure 6.15 shows the walk access to medical services within 15-minute travel time threshold. The results indicate that walk access to medical services within 15-minute is very low in most parts of the F-M metropolitan area. Figure 6.16 represents the walk access to medical services within 30-minute travel time threshold. The results revealed that within 30-minute walk travel time, people's ability to access medical services is low in most parts of the F-M area with the exception of main urban area. Figure 6.17 and Figure 6.18 shows the walk access to grocery stores within 15-minute and 30-minute travel time thresholds, respectively in the F-M. The accessibility results revealed that people's ability to access grocery stores using walk mode is very low in most parts of the metropolitan area. Overall, the accessibility in terms of walk access to amenities (jobs, medical services, and grocery stores) in the F-M area is low.

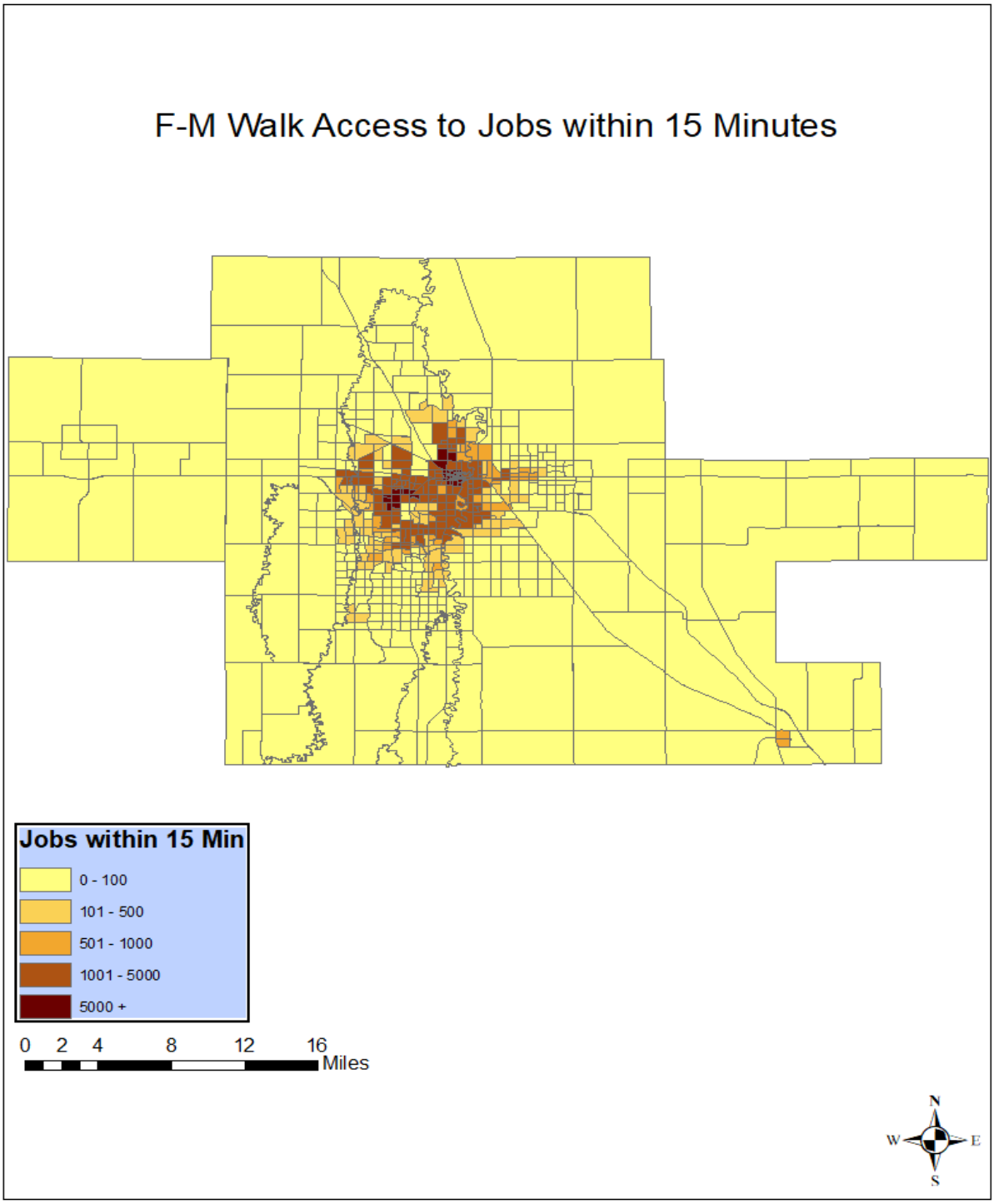

Figure 6.13. Walk Access to Jobs within 15 Minutes in F-M

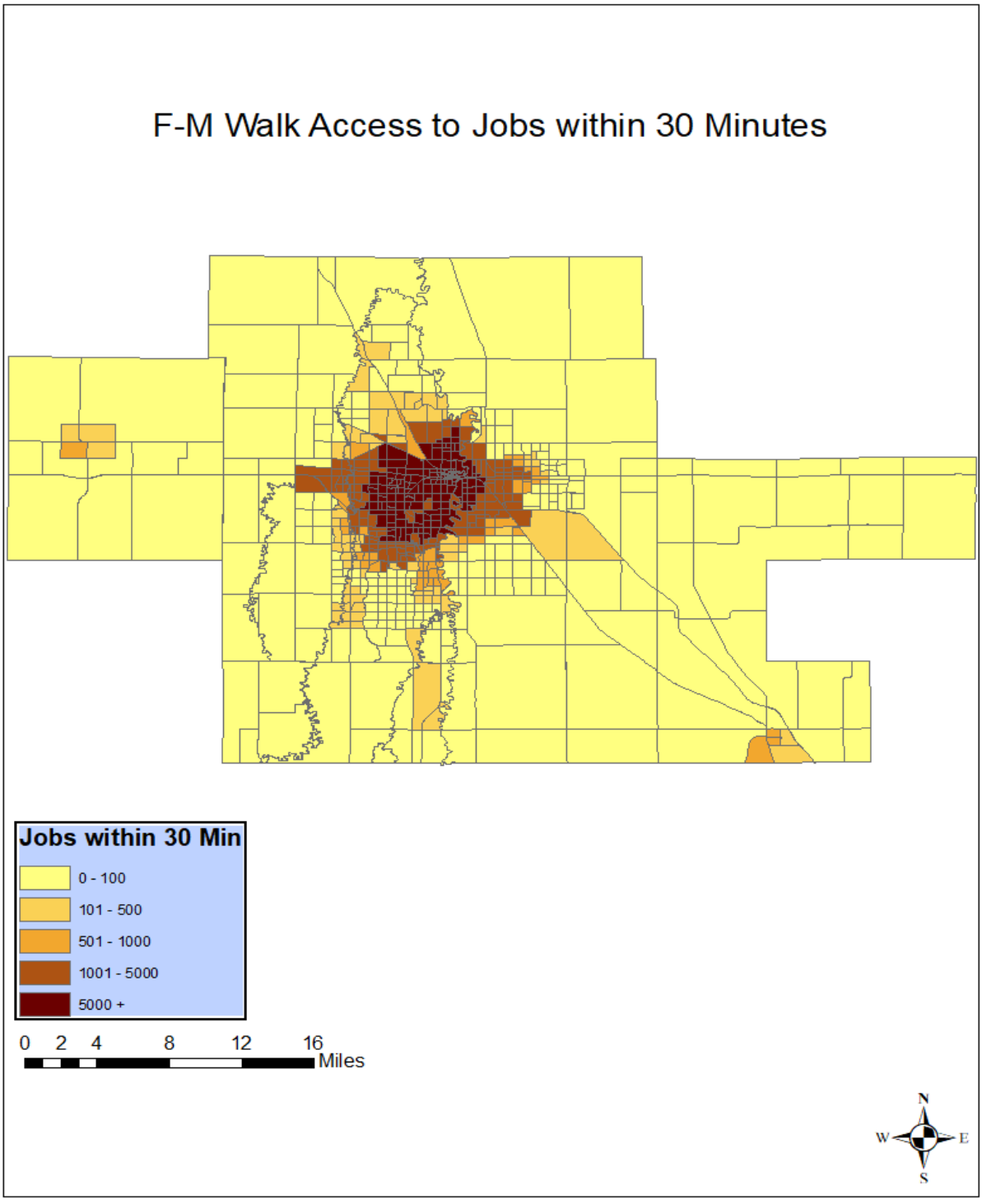

Figure 6.14. Walk Access to Jobs within 30 Minutes in F-M

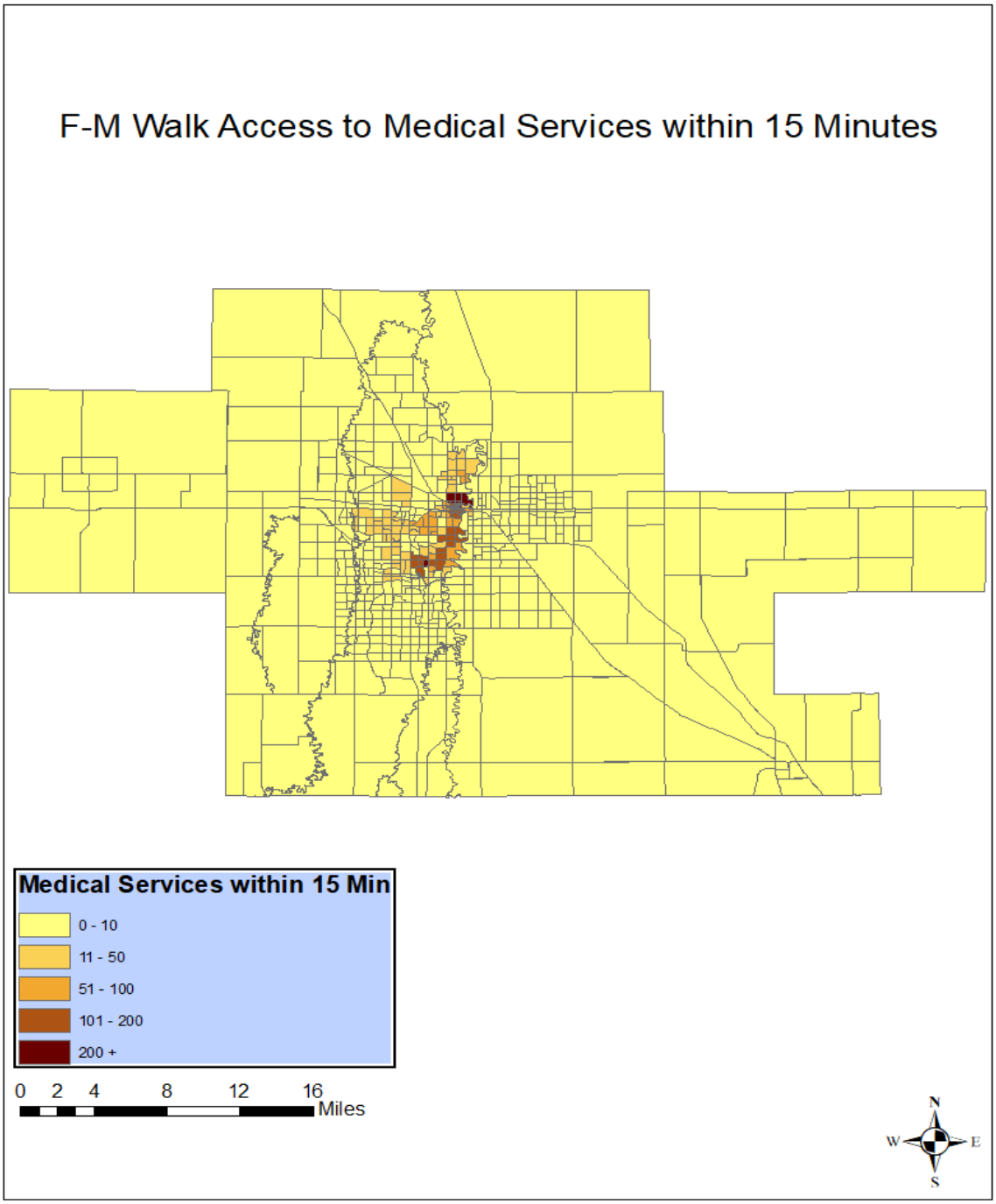

Figure 6.15. Walk Access to Medical Services within 15 Minutes in F-M

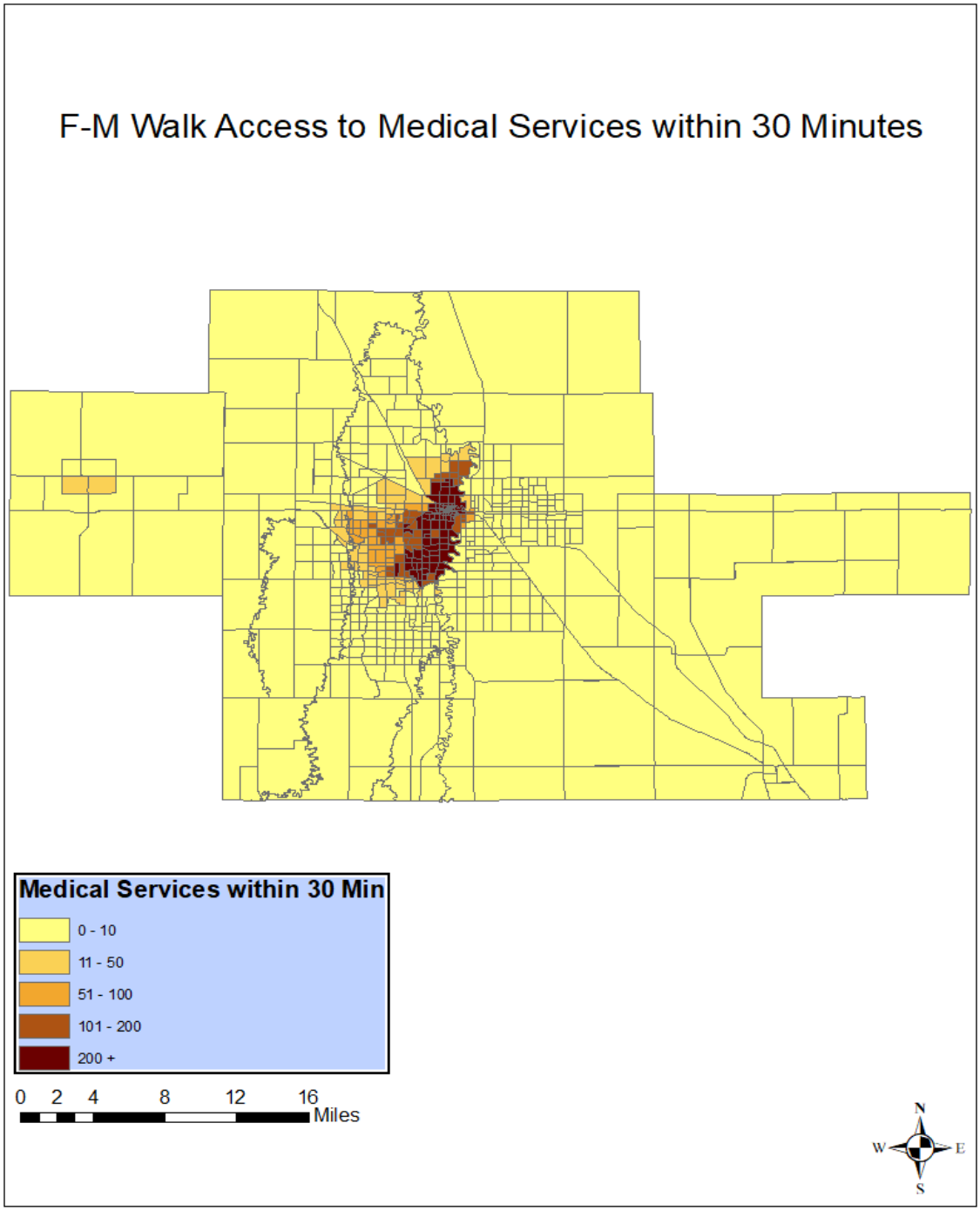

Figure 6.16. Walk Access to Medical Services within 30 Minutes in F-M

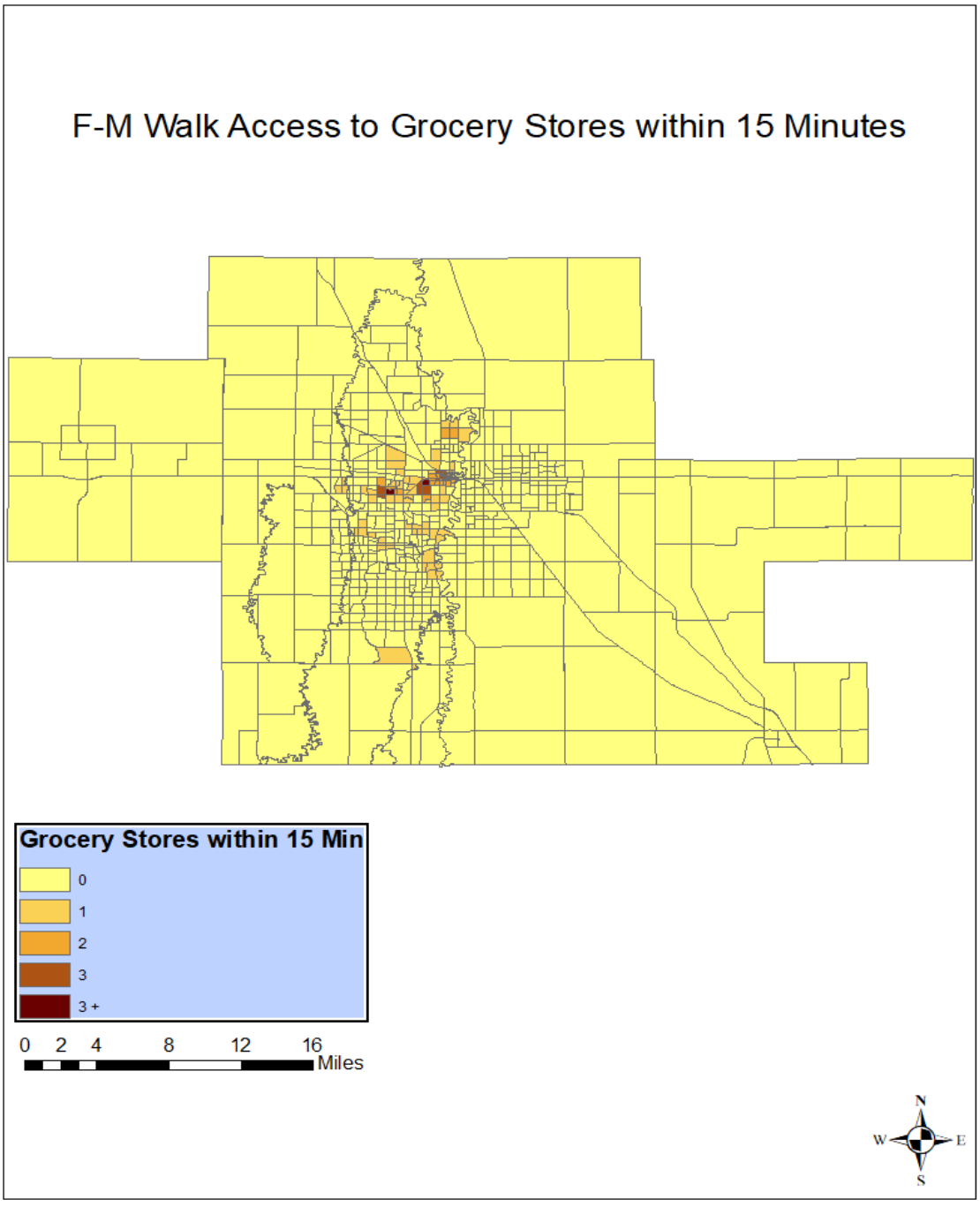

Figure 6.17. Walk Access to Grocery Stores within 15 Minutes in F-M

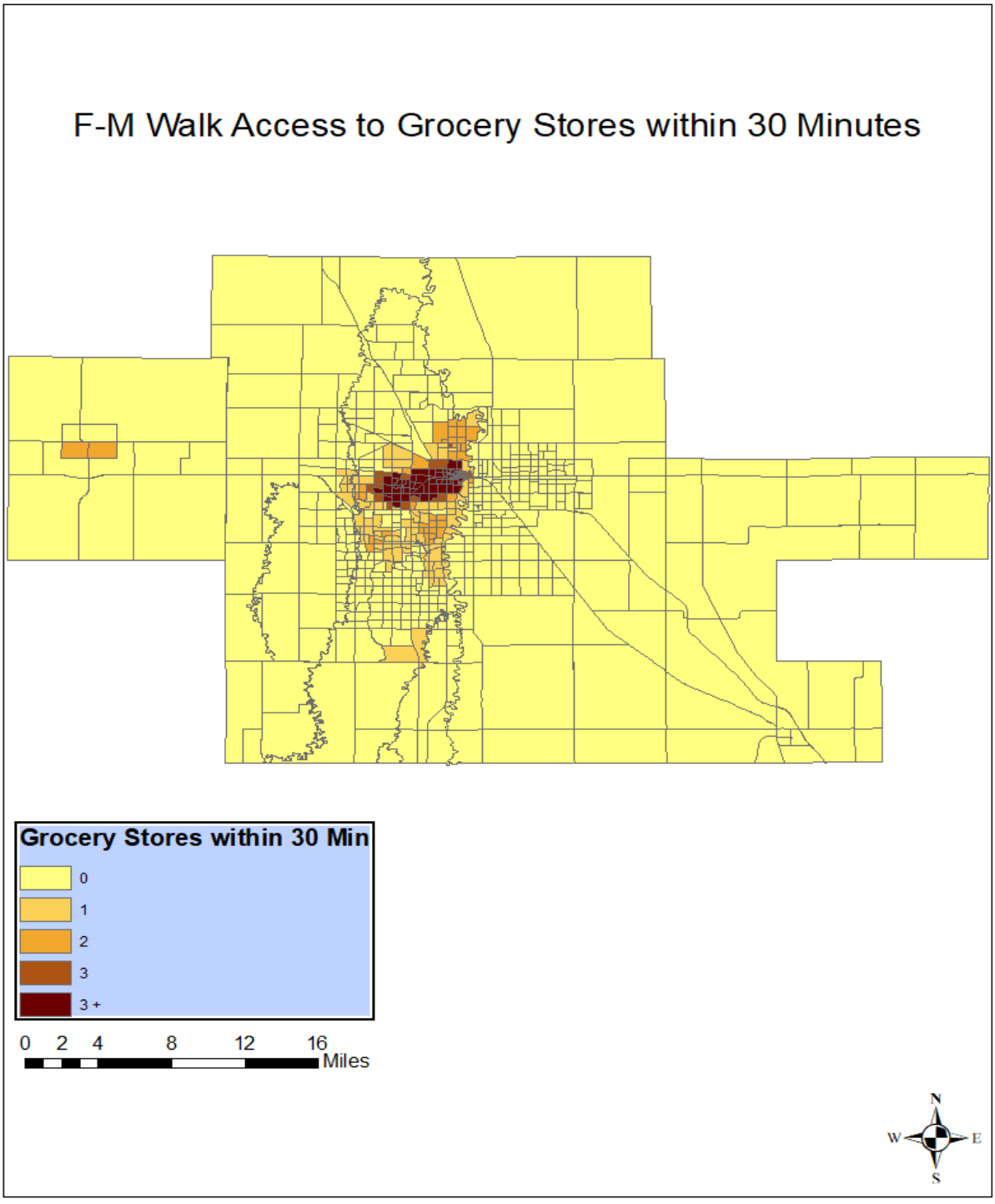

Figure 6.18. Walk Access to Grocery Stores within 30 Minutes in F-M

6.2. Grand Forks – East Grand Forks MPO

This section includes the accessibility results for GF-EGF MPO. The next sub-sections will present the people's ability to access jobs, medical services, and grocery stores by using auto, public transit, and walk modes, respectively in the GF-EGF MPO area.

6.2.1. Auto Access to Jobs, Medical Services, and Grocery Stores

Figure 6.19 and Figure 6.20 shows the auto access to jobs within 15-minute and 30-minute travel time thresholds, respectively in the GF-EGF area. Total number of jobs estimated in the GF-EGF metropolitan area were 41487. The accessibility results revealed that people's ability to access jobs in GF-EGF metropolitan area is very high by using auto mode. Figure 6.21 and Figure 6.22 represents the auto access to medical services within 15-minute and 30-minute travel time thresholds, respectively in the GF-EGF. Total number of medical services used for accessibility evaluation in the GF-EGF MPO area were 948. The accessibility results indicate that access to medical services using auto mode is very high in the GF-EGF metropolitan area.

Figure 6.23 and Figure 6.24 shows the auto access to grocery stores within 15-minute and 30-minute travel time thresholds, respectively in the GF-EGF MPO area. Total number of grocery stores used in the accessibility evaluation for GF-EGF MPO area were 13. Similar to the jobs and medical services accessibility, the access to grocery stores is also very high in the GF-EGF metropolitan area using auto mode. These results make sense as GF-EGF MPO area is small with lower population and that may be the reason for people's high accessibility to locations using their own vehicle.

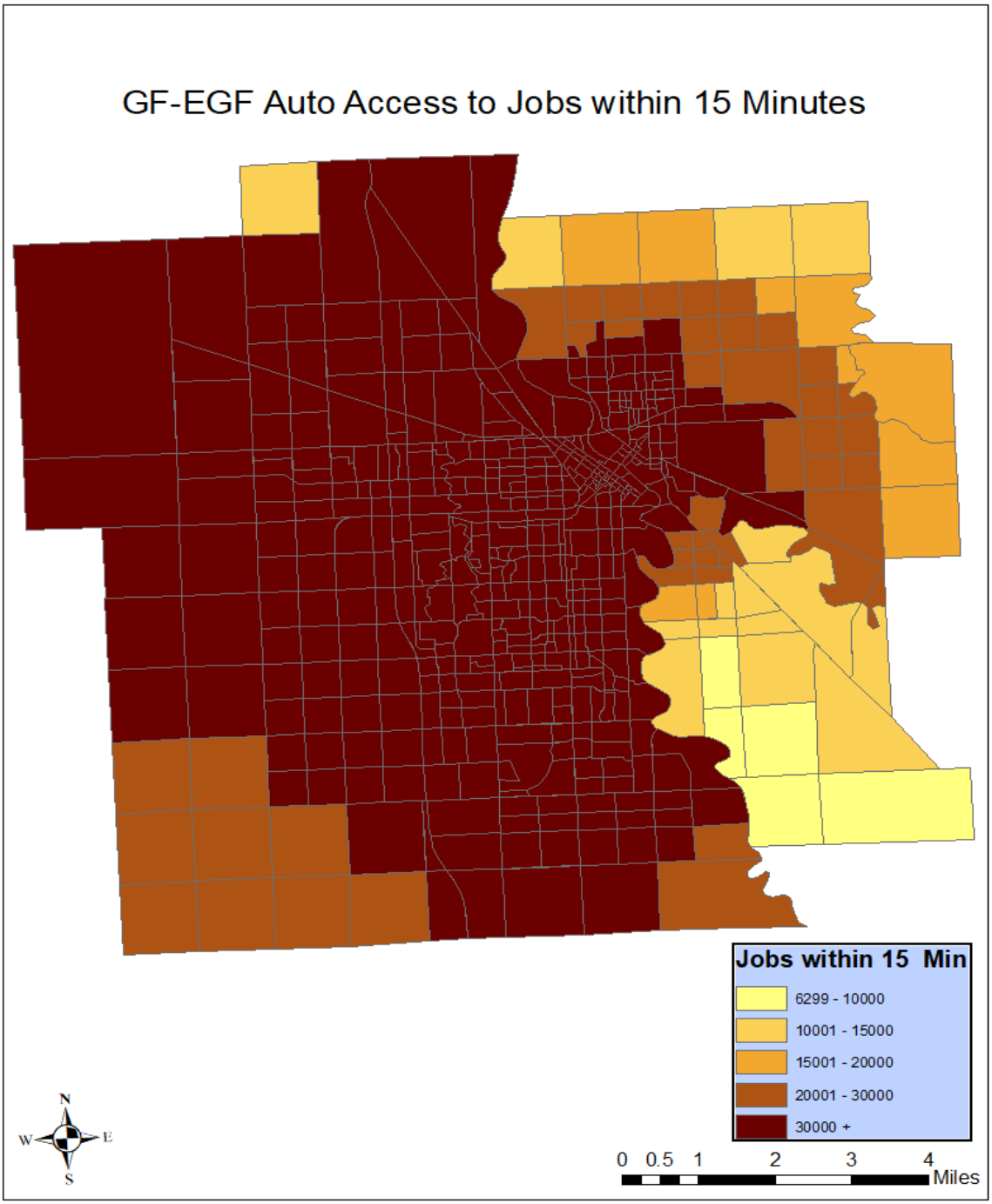

Figure 6.19. Auto Access to Jobs within 15 Minutes in GF-EGF

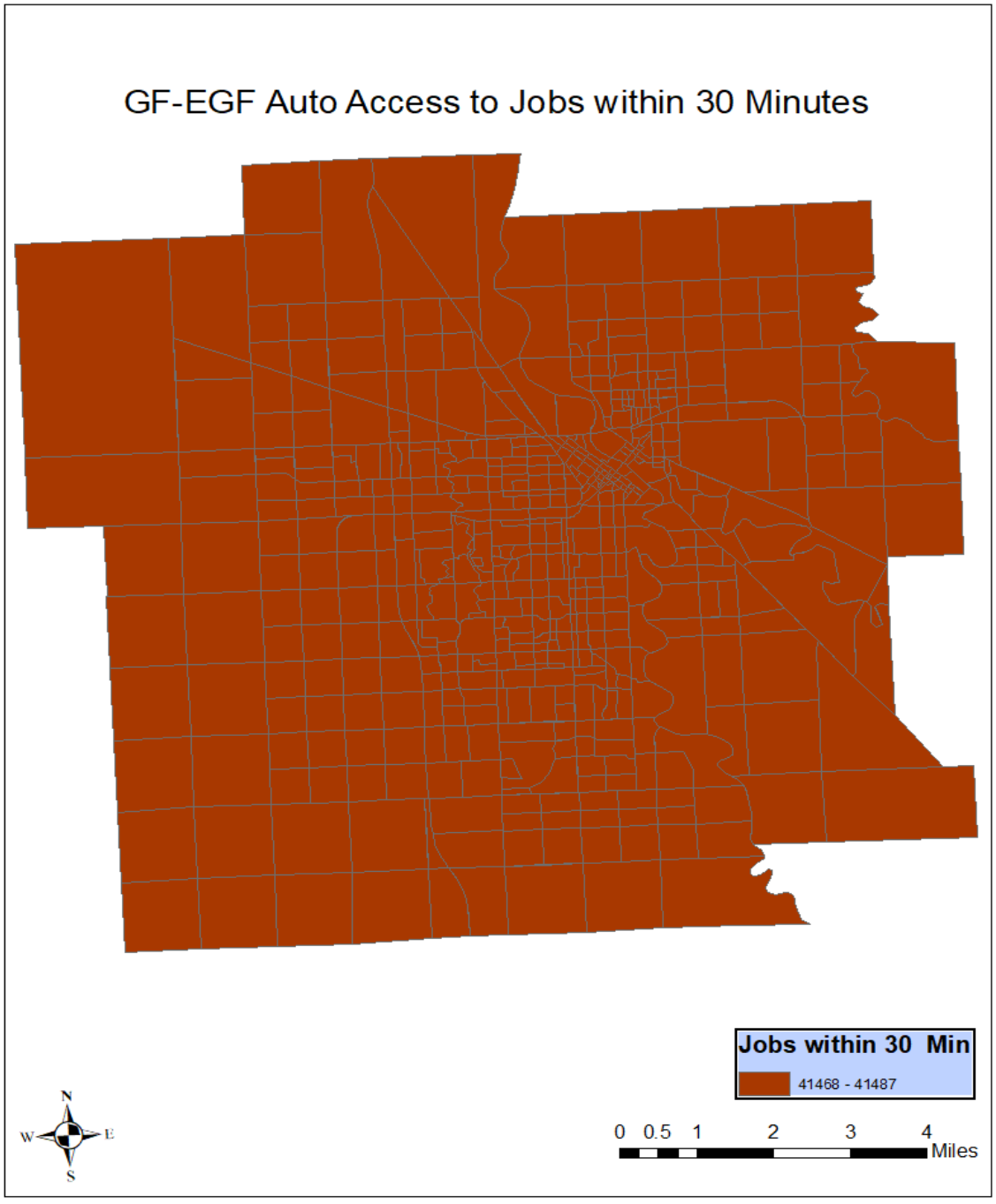

Figure 6.20. Auto Access to Jobs within 30 Minutes in GF-EGF

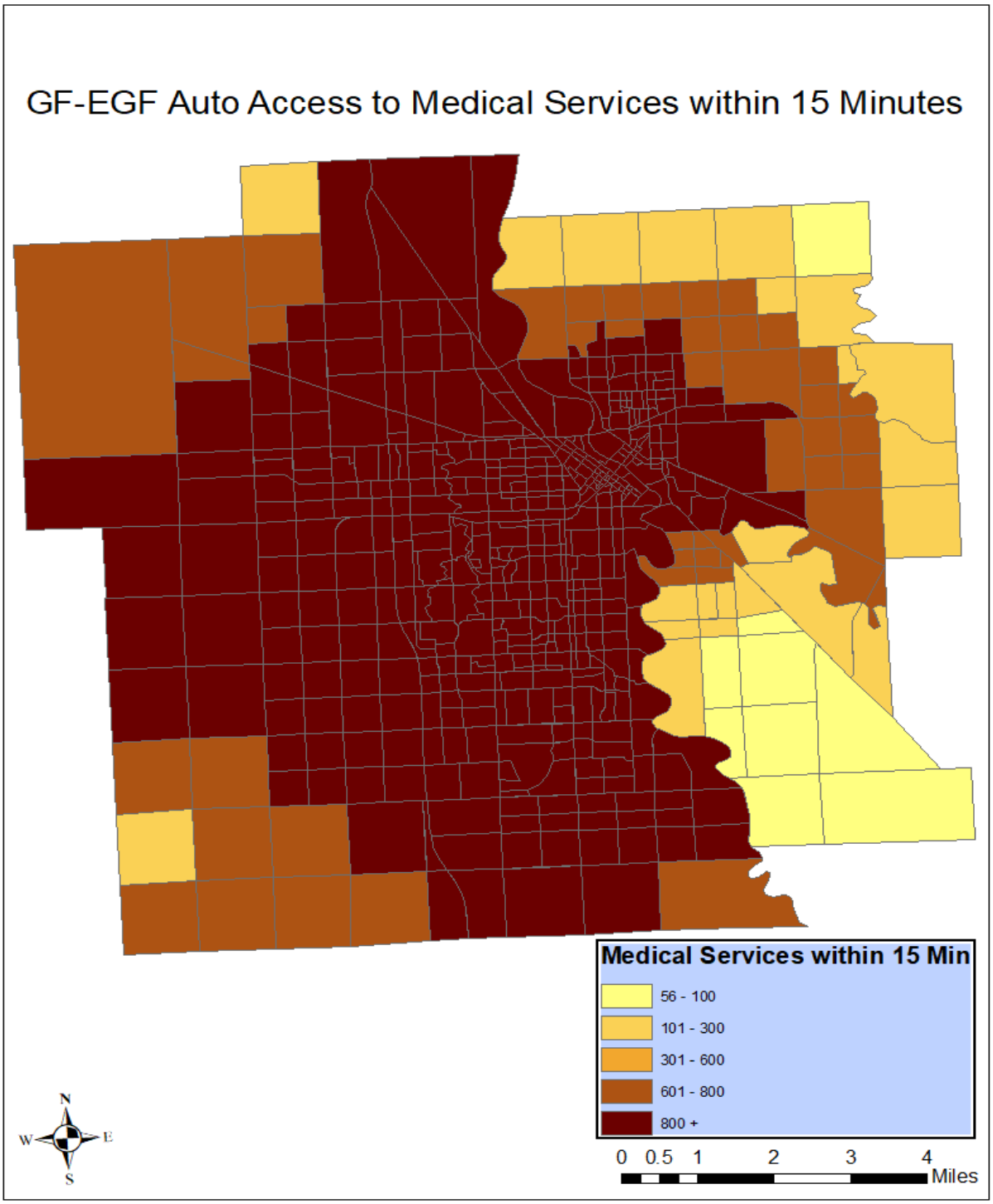

Figure 6.21. Auto Access to Medical Services within 15 Minutes in GF-EGF

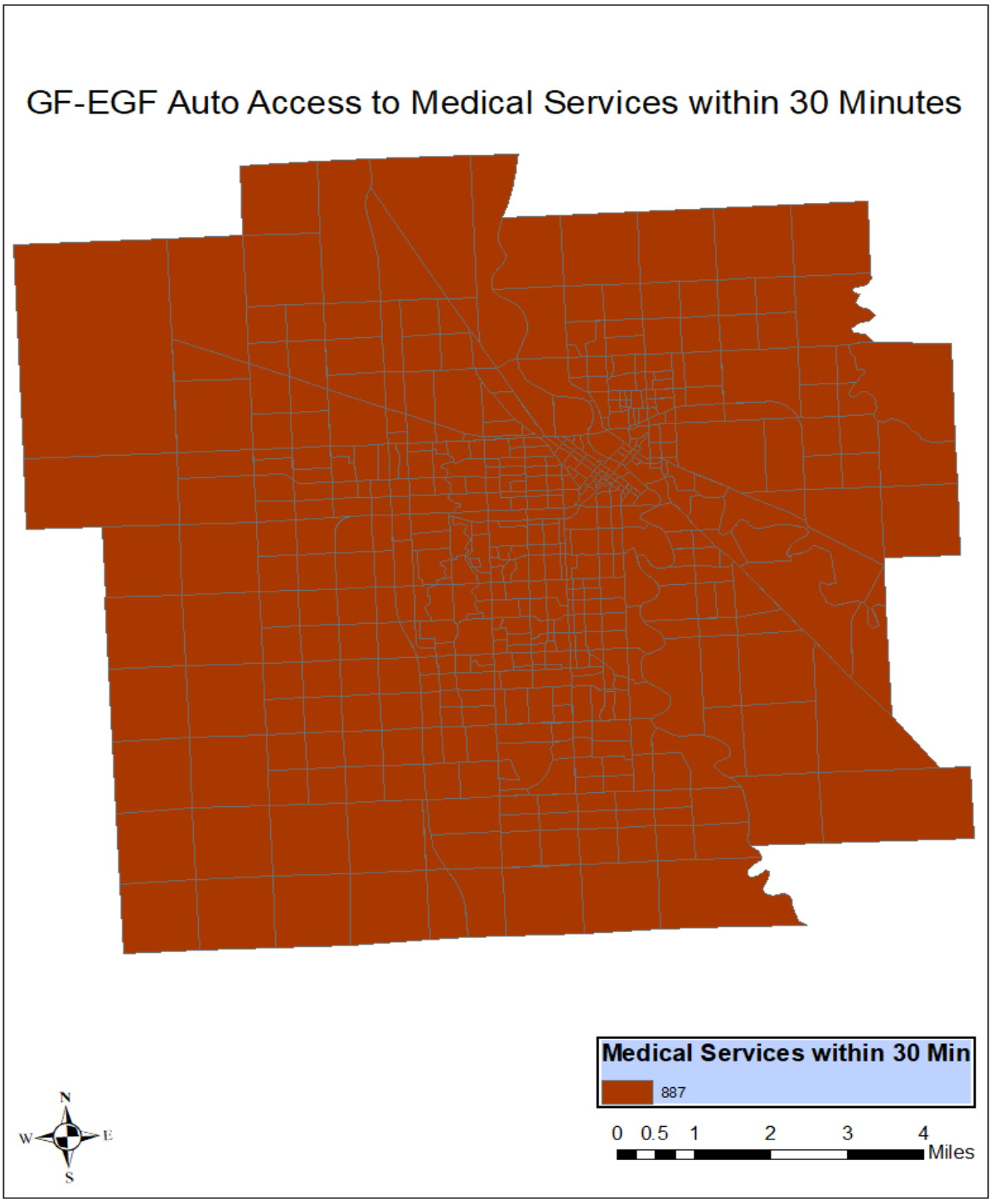

Figure 6.22. Auto Access to Medical Services within 30 Minutes in GF-EGF

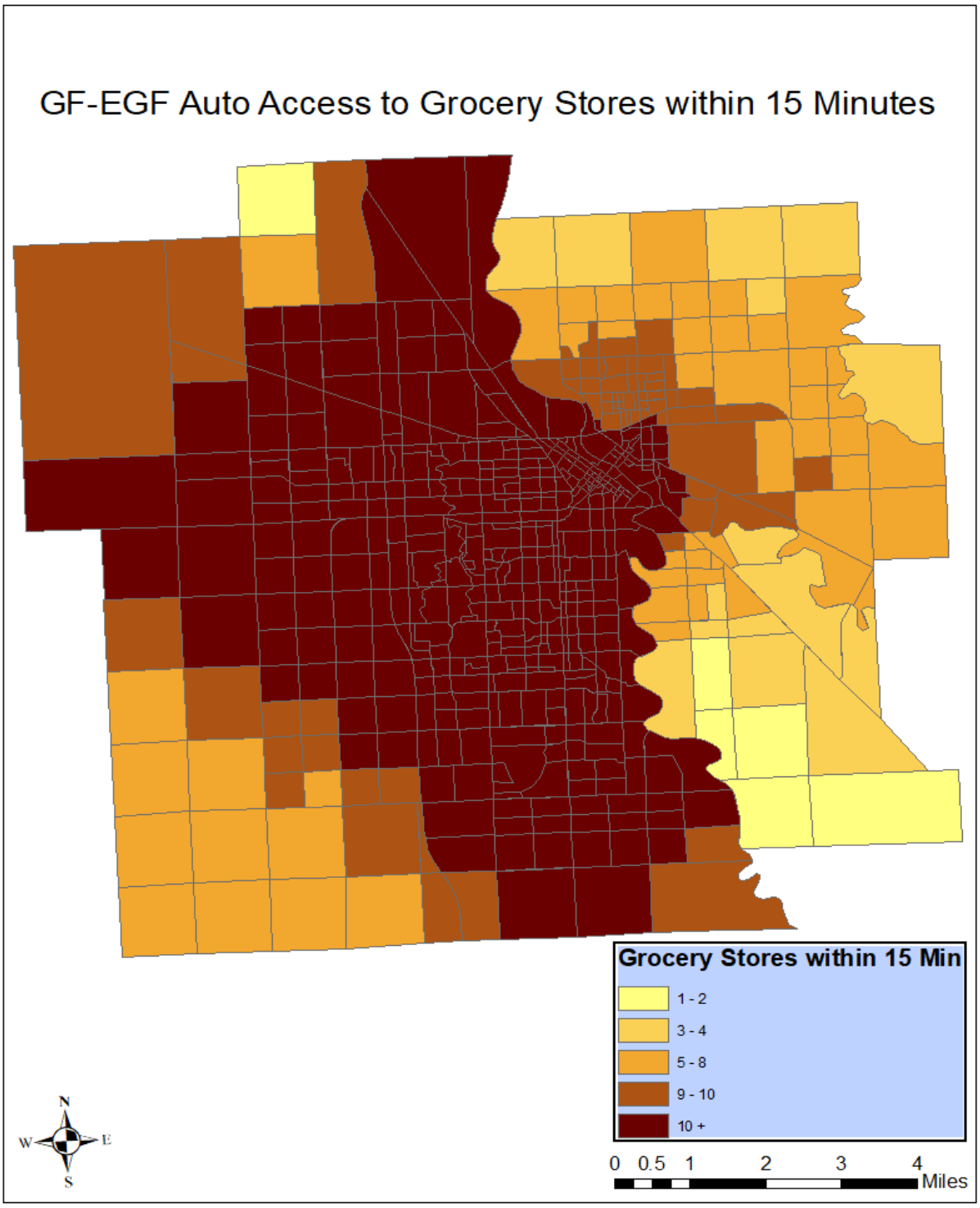

Figure 6.23. Auto Access to Grocery Stores within 15 Minutes in GF-EGF

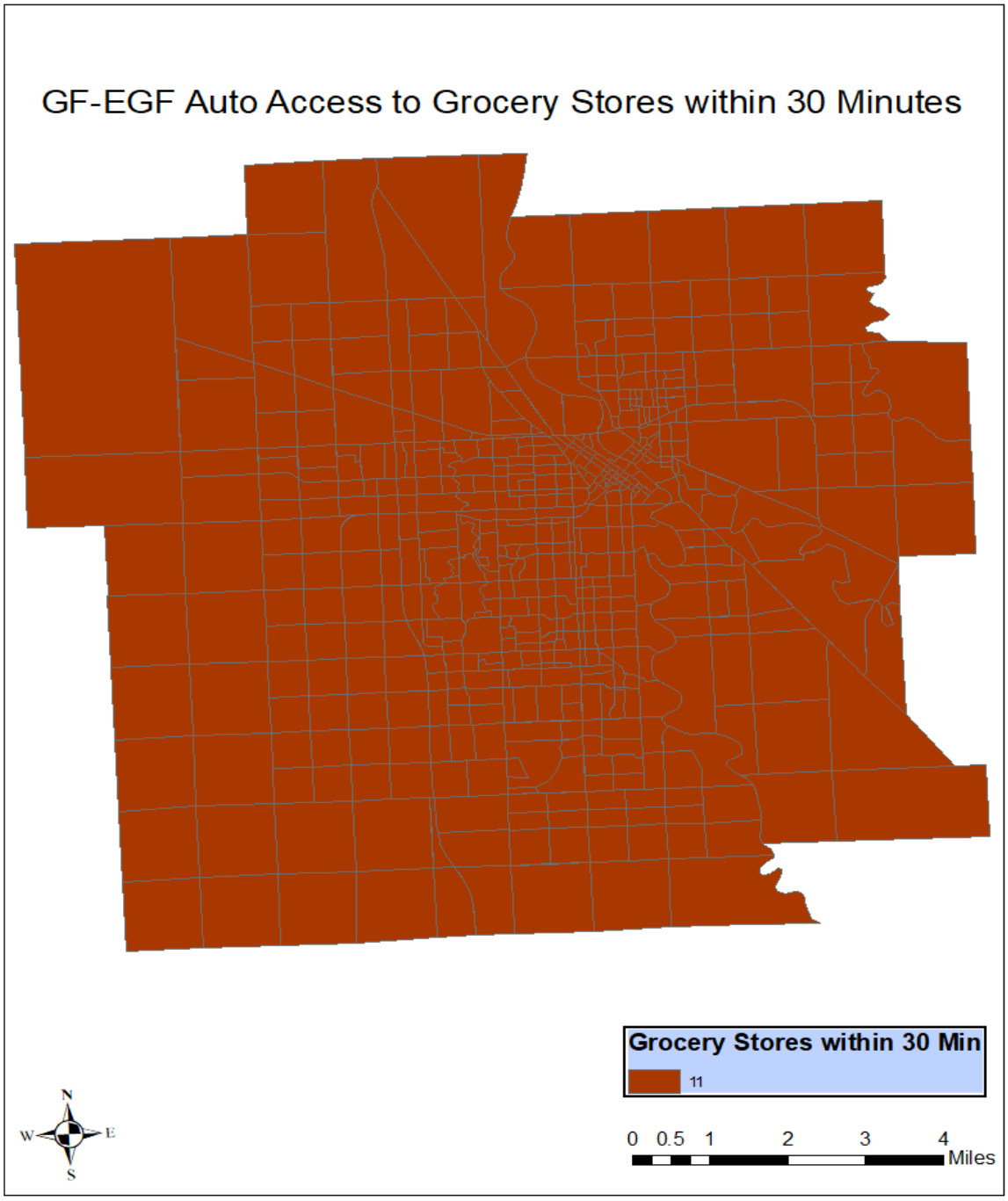

Figure 6.24. Auto Access to Grocery Stores within 30 Minutes in GF-EGF

6.2.2. Public Transit Access to Jobs, Medical Services, and Grocery Stores

This section includes the accessibility results in terms of public transit access to jobs, medical services, and grocery stores in the GF-EGF metropolitan area. Figure 6.25 shows the public transit access to jobs within 30-minute travel time in the GF-EGF area. The results indicate that access to jobs within 30-minute transit travel time is medium to high in the main urban area while low in the suburbs of the GF-EGF. Figure 6.26 shows the accessibility to jobs using public transit within 60-minute travel time threshold in the GF-EGF metropolitan area. The results revealed that public transit access to jobs within 60-minute travel time is high in the main urban area while medium in the suburbs of the GF-EGF area.

Figure 6.27 and Figure 6.28 shows the public transit access to medical services within 30-minute and 60-minute travel time thresholds, respectively in the GF-EGF MPO. The accessibility results indicate that public transit access to medical services is high in the main urban areas while low in the suburbs of the GF-EGF MPO area. Figure 6.29 represents the public transit access to grocery stores within 30-minute travel time in the GF-EGF. The results revealed that people's ability to access grocery stores within 30-minute transit travel time is medium to high in the main urban areas while low in the suburbs of the GF-EGF MPO area. Figure 6.30 shows the public transit access to grocery stores within 60-minute travel time in the GF-EGF. The results revealed that accessibility to grocery stores within 60-minute transit travel time is high in the main urban area while low to medium in the outskirts of the GF-EGF MPO area. Overall, the public transit access to amenities (jobs, medical services, and grocery stores) is good in GF-EGF MPO area.

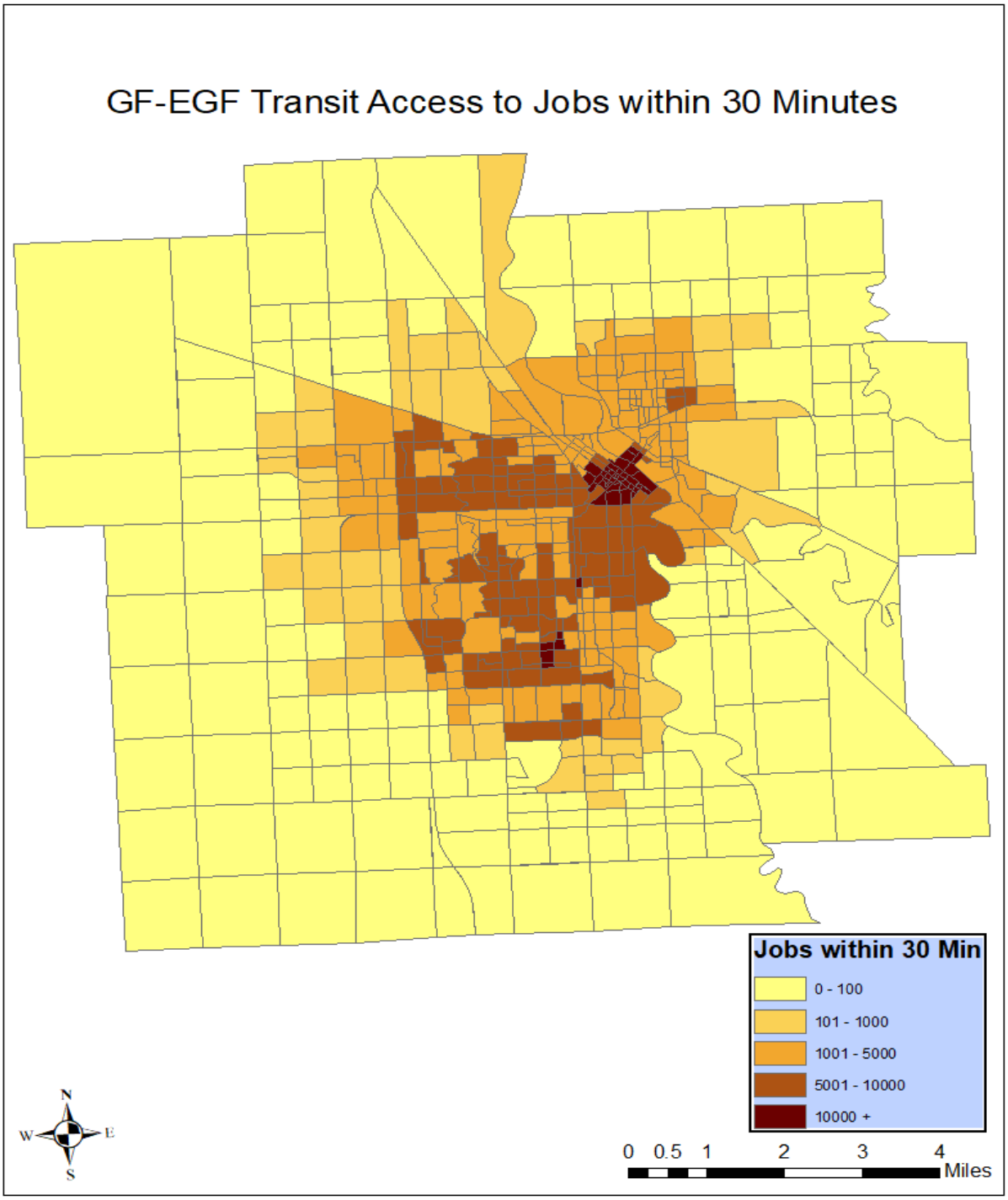

Figure 6.25. Transit Access to Jobs within 30 Minutes in GF-EGF

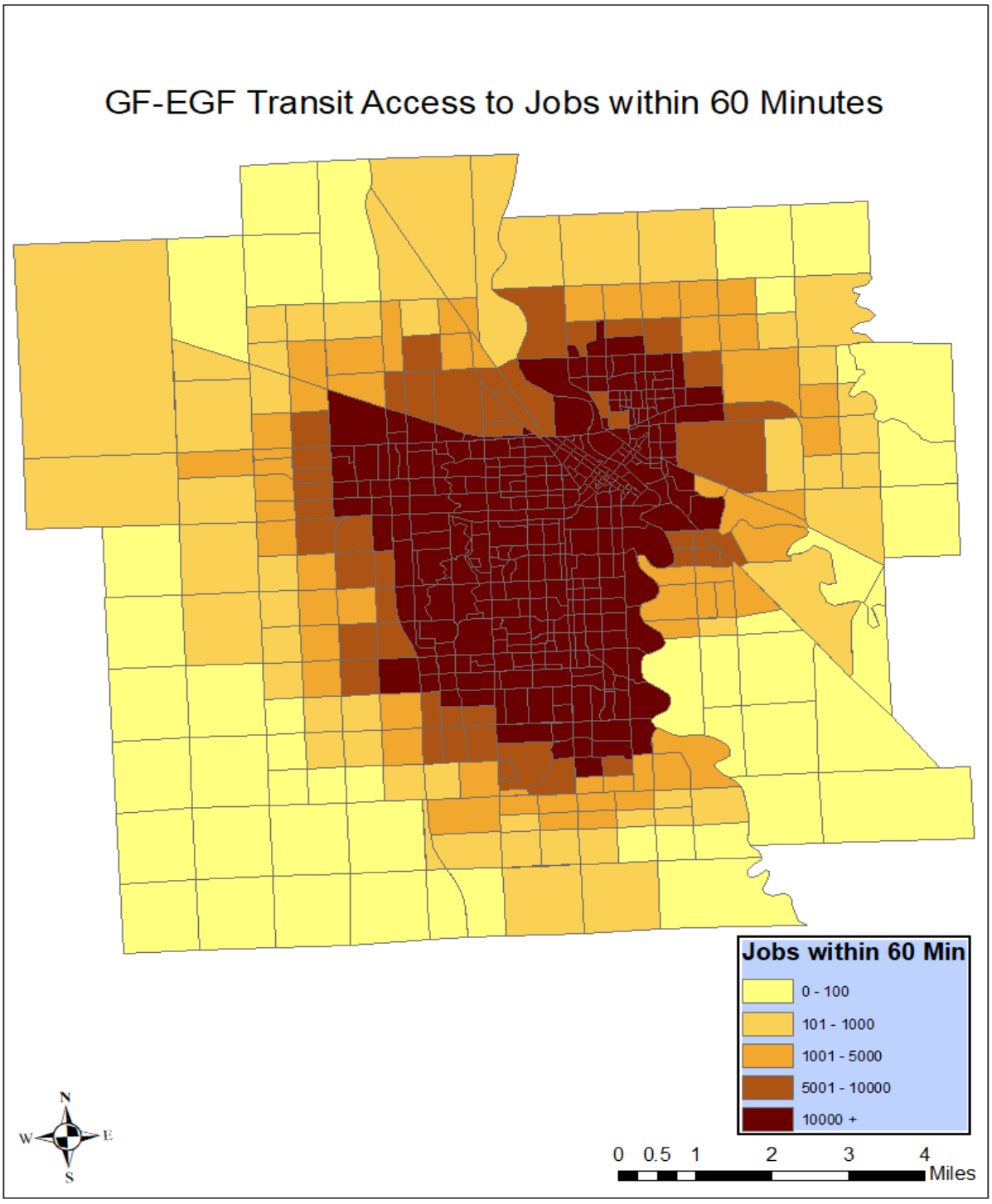

Figure 6.26. Transit Access to Jobs within 60 Minutes in GF-EGF

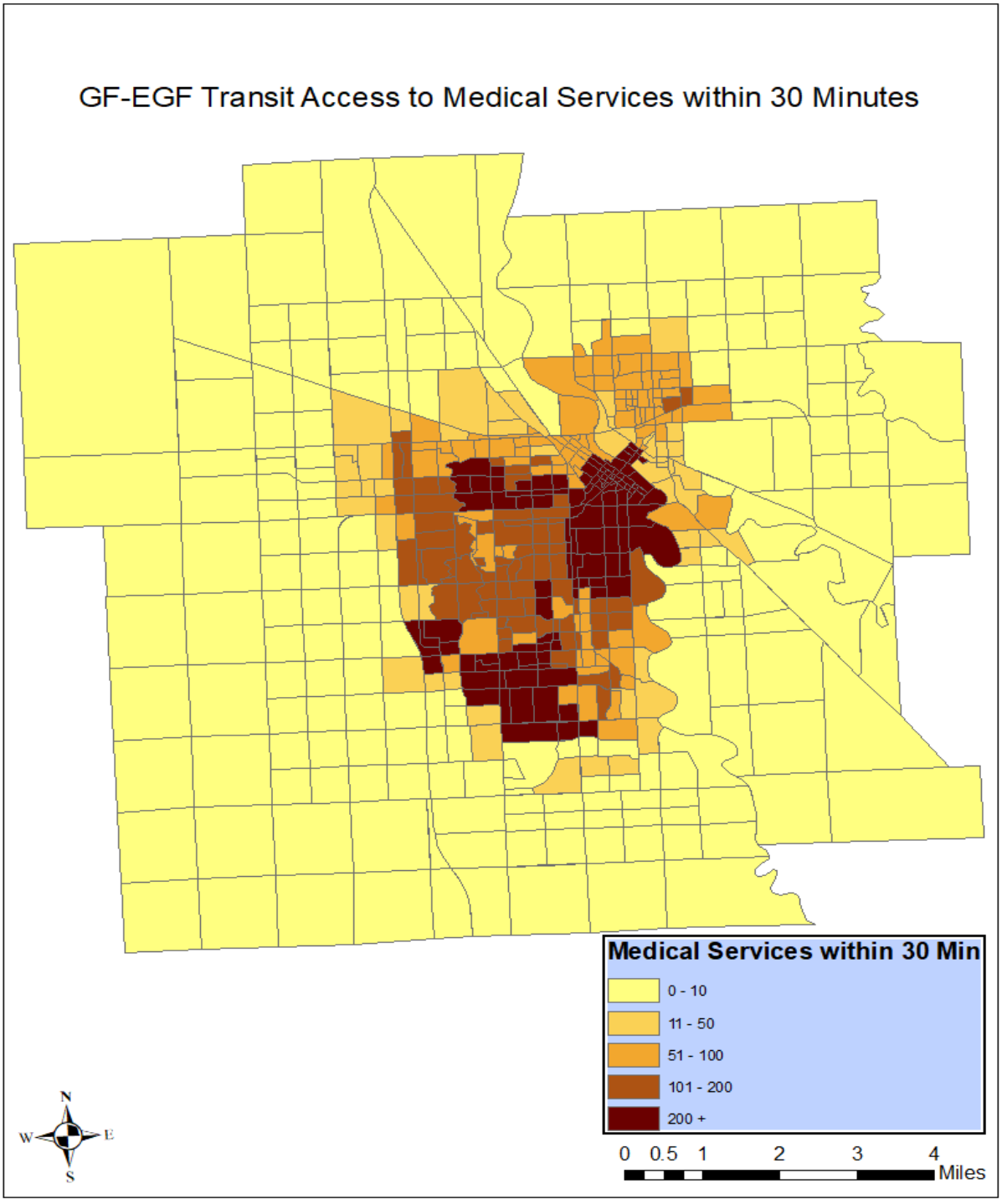

Figure 6.27. Transit Access to Medical Services within 30 Minutes in GF-EGF

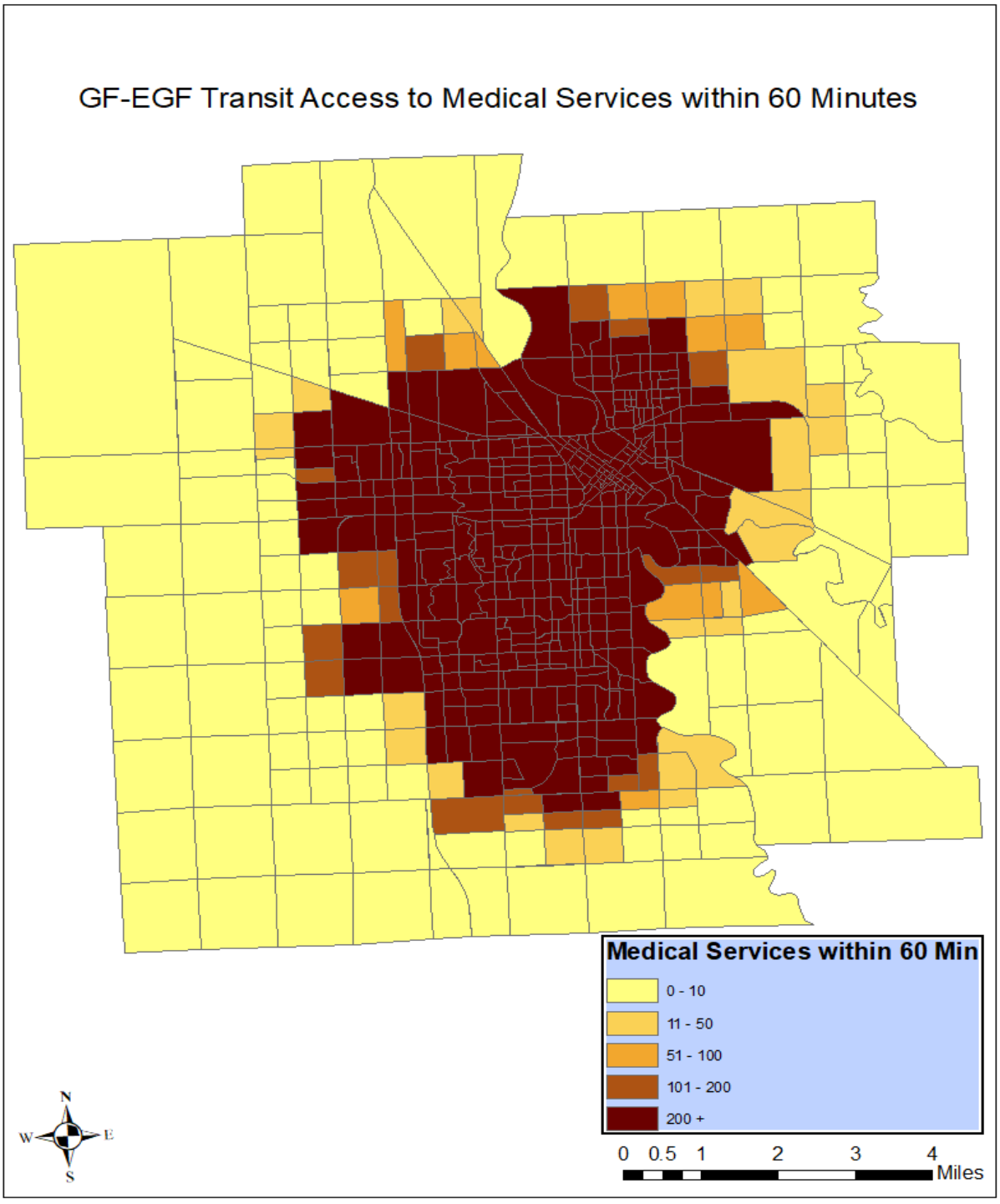

Figure 6.28. Transit Access to Medical Services within 60 Minutes in GF-EGF

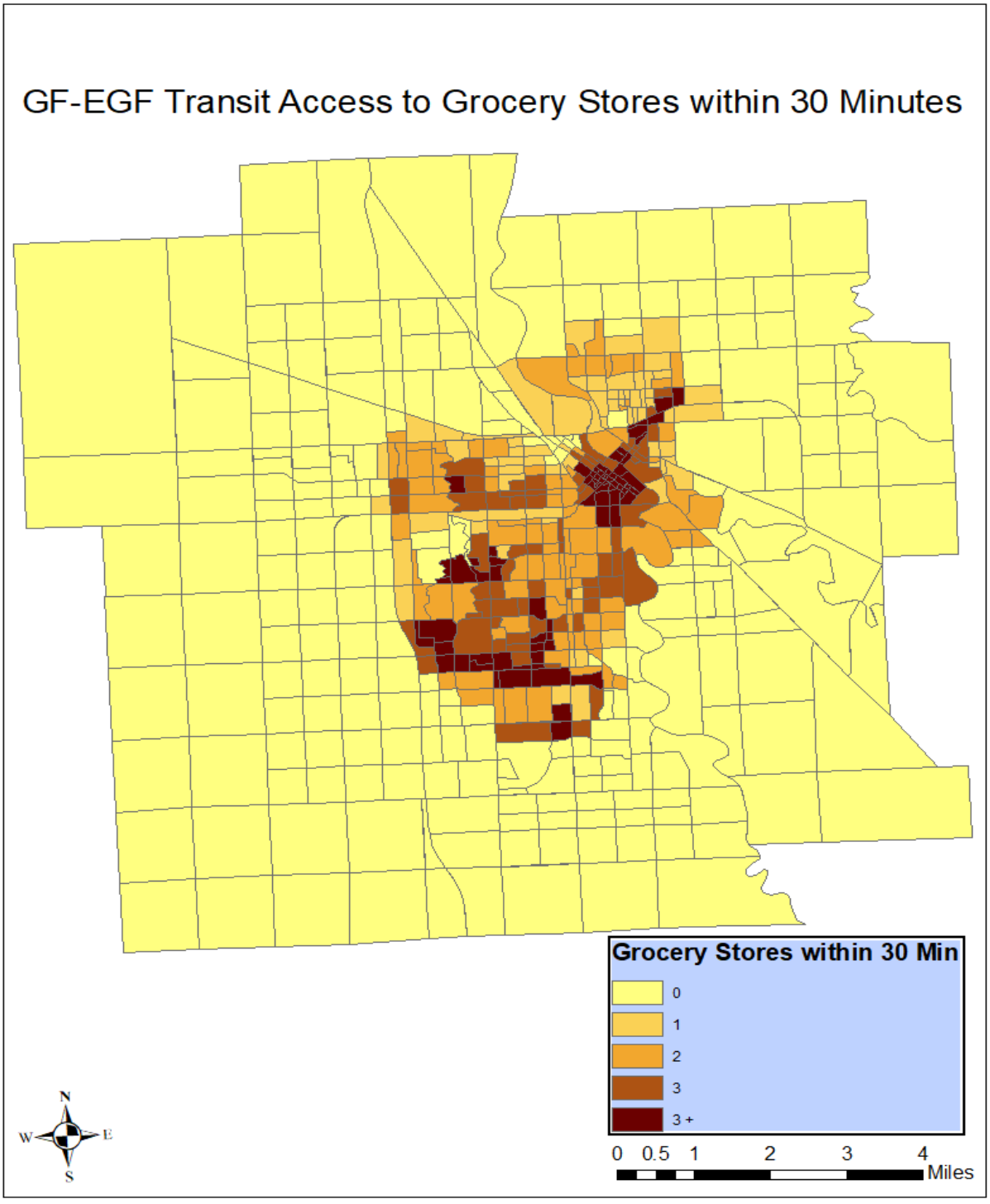

Figure 6.29. Transit Access to Grocery Stores within 30 Minutes in GF-EGF

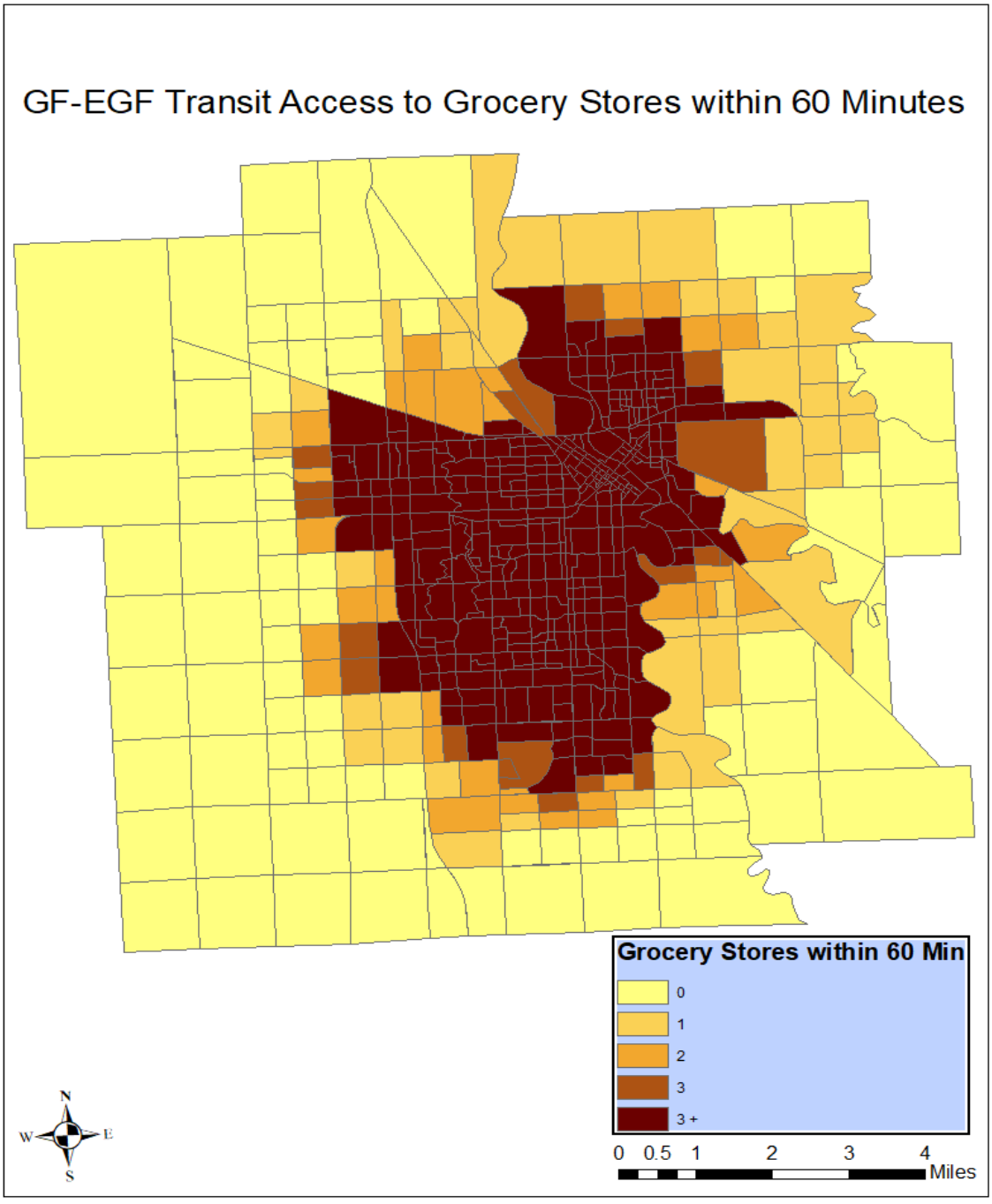

Figure 6.30. Transit Access to Grocery Stores within 60 Minutes in GF-EGF

6.2.3. Walk Access to Jobs, Medical Services, and Grocery Stores

This section includes the accessibility results in terms of walk access to jobs, medical services, and grocery stores in the GF-EGF MPO area. Figure 6.31 shows the walk access to jobs within 15-minute travel time in the GF-EGF MPO area. The results revealed that walk access to jobs within 15-minute travel time is medium to high in the main urban areas while low in the outskirts of the GF-EGF MPO area. Figure 6.32 represents the access to jobs within 30-minute travel time using walk mode in the GF-EGF. The results indicate that people's ability to access jobs within 30-minute walk travel time is high in the main urban areas while low to medium in the suburbs of the GF-EGF MPO area.

Figure 6.33 and Figure 6.34 shows the walk access to medical services within 15-minute and 30-minute travel time thresholds, respectively in the GF-EGF MPO area. Within 15-minute walk travel time threshold, the results indicate that accessibility to medical services is low in most parts of the MPO area. The accessibility results for 30-minute walk travel time revealed that people's ability to access medical services is medium to high in the main urban areas while low in the suburbs of the GF-EGF MPO area. Figure 6.35 shows the access to grocery stores within 15-minute travel time using walk mode in the GF-EGF. The results indicate that accessibility to grocery stores is very low in most parts of the GF-EGF MPO area. Figure 6.36 represents the walk access to grocery stores within 30-minute travel time in the GF-EGF. The results revealed that people's ability to access grocery stores within 30-minute walk travel time is medium to high in the main urban area while low in the suburbs of the GF-EGF MPO area. Overall, the accessibility results revealed that walk access to amenities (jobs, medical services, and grocery stores) is low in the GF-EGF MPO area.

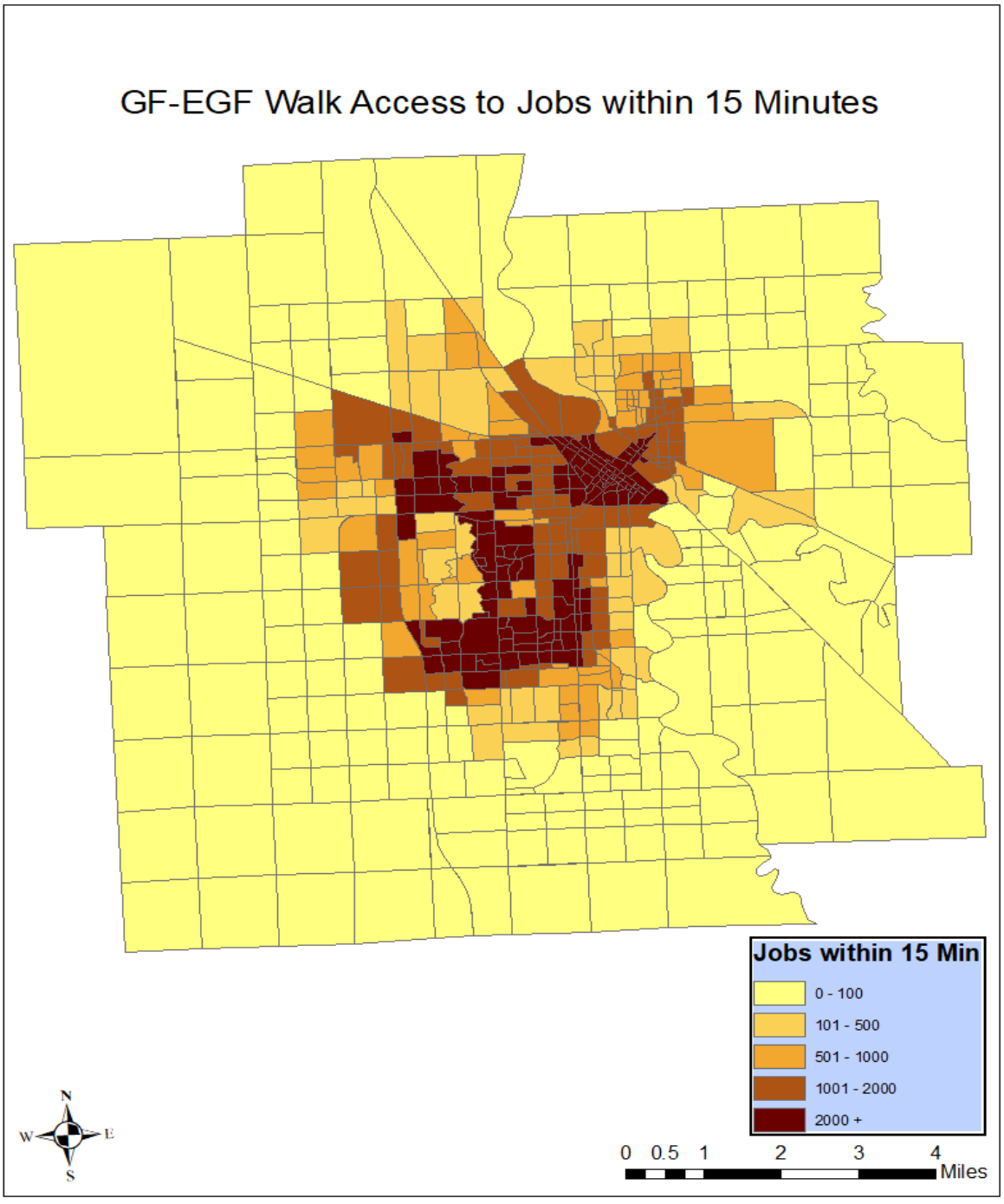

Figure 6.31. Walk Access to Jobs within 15 Minutes in GF-EGF

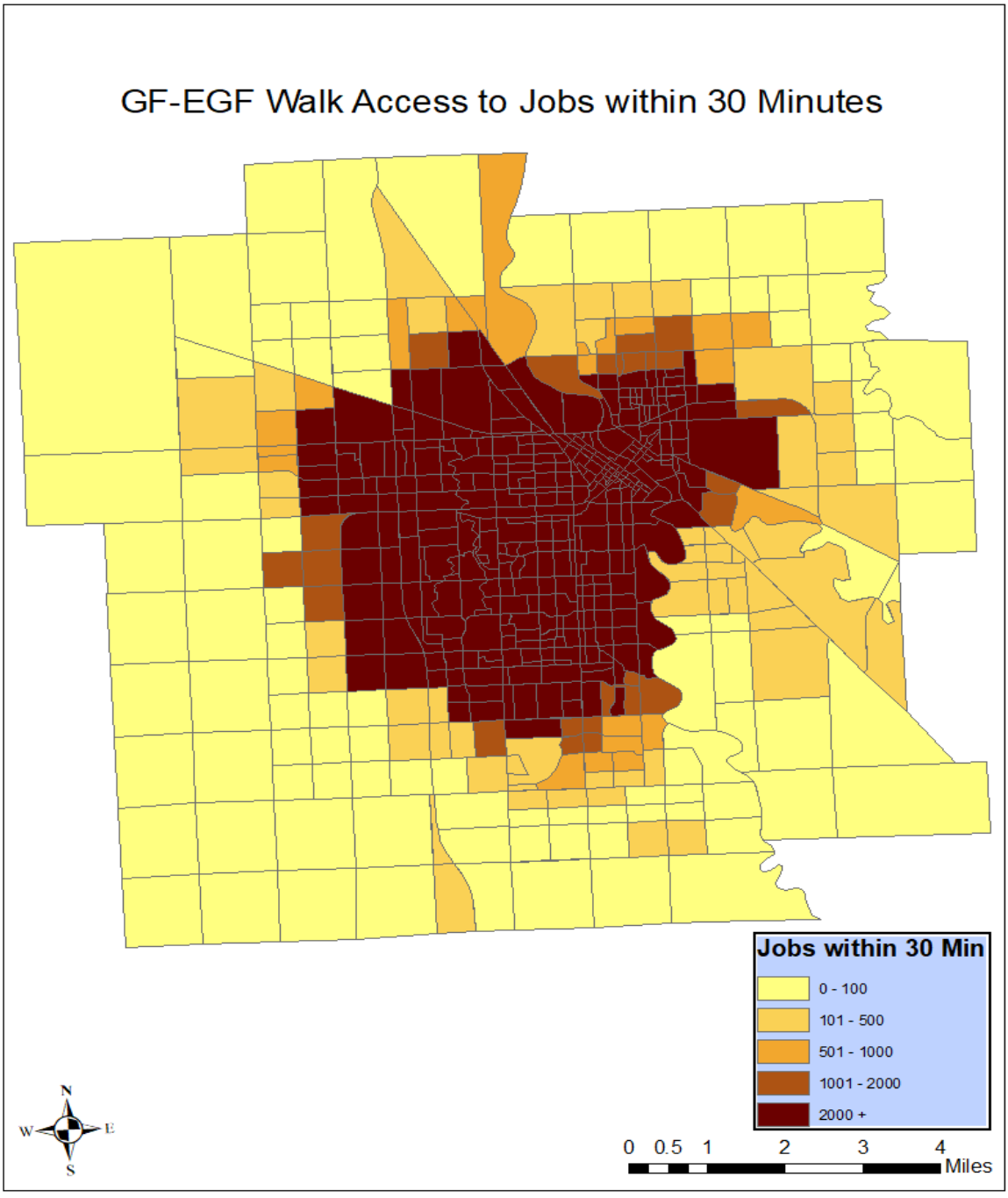

Figure 6.32. Walk Access to Jobs within 30 Minutes in GF-EGF

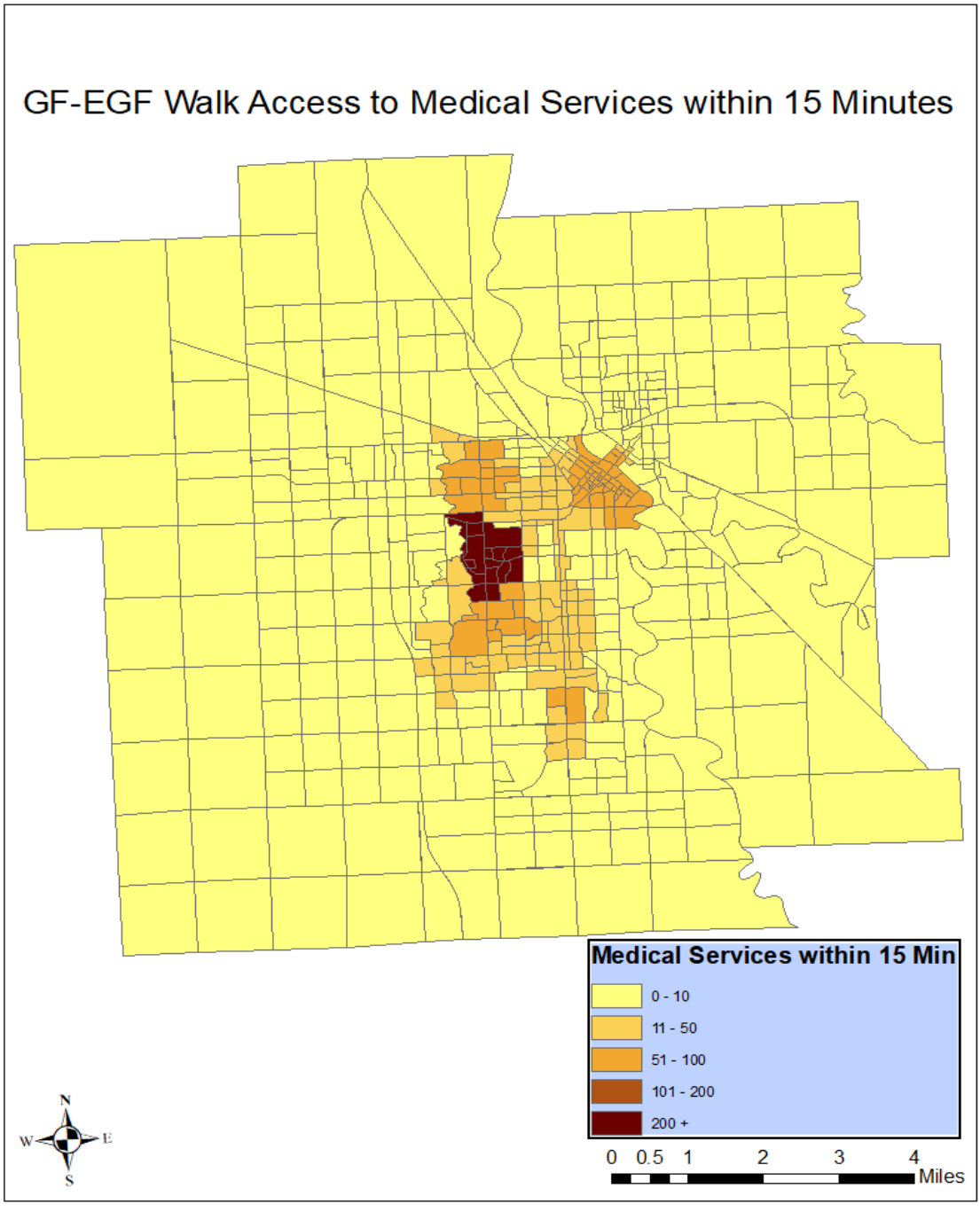

Figure 6.33. Walk Access to Medical Services within 15 Minutes in GF-EGF

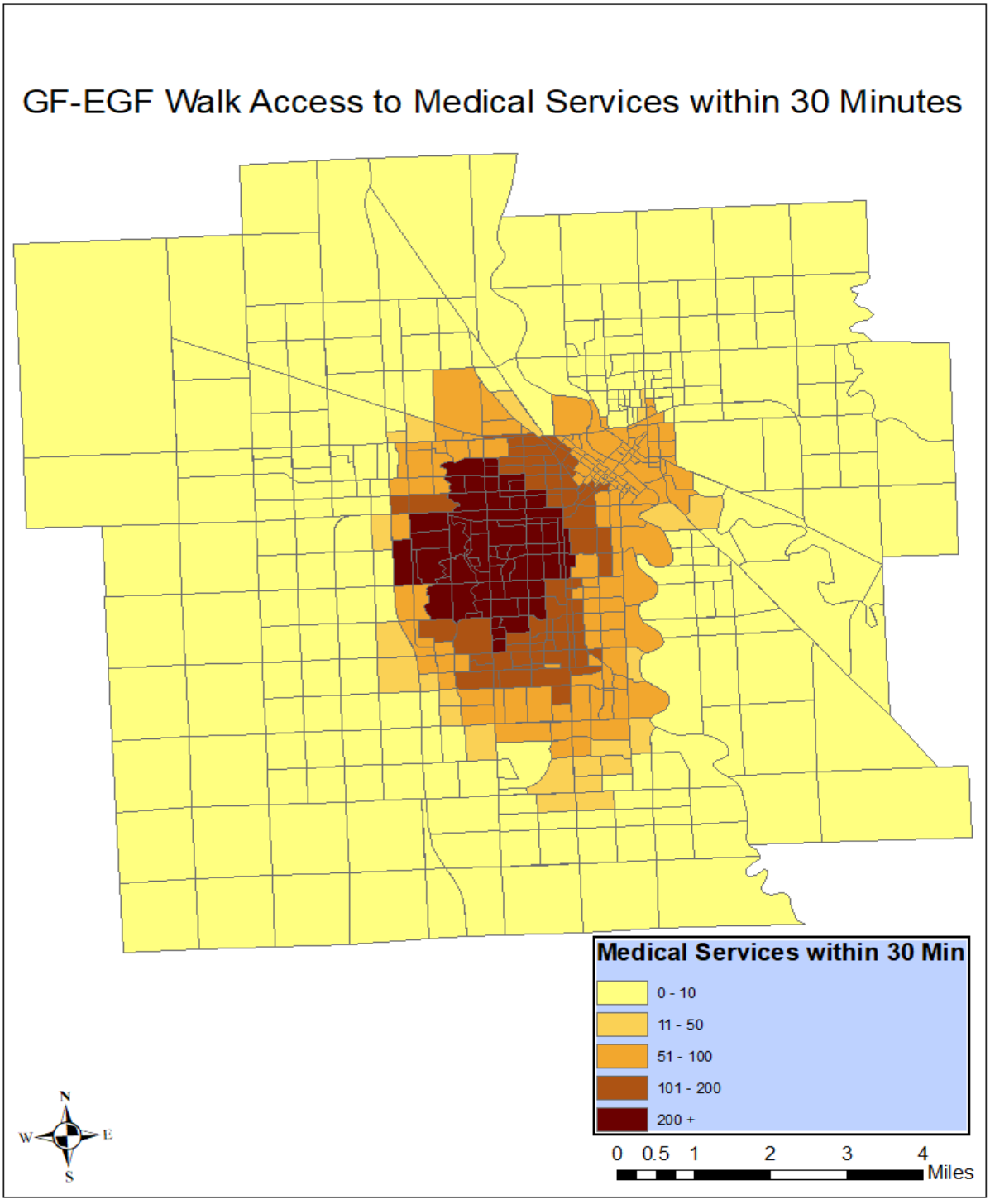

Figure 6.34. Walk Access to Medical Services within 30 Minutes in GF-EGF

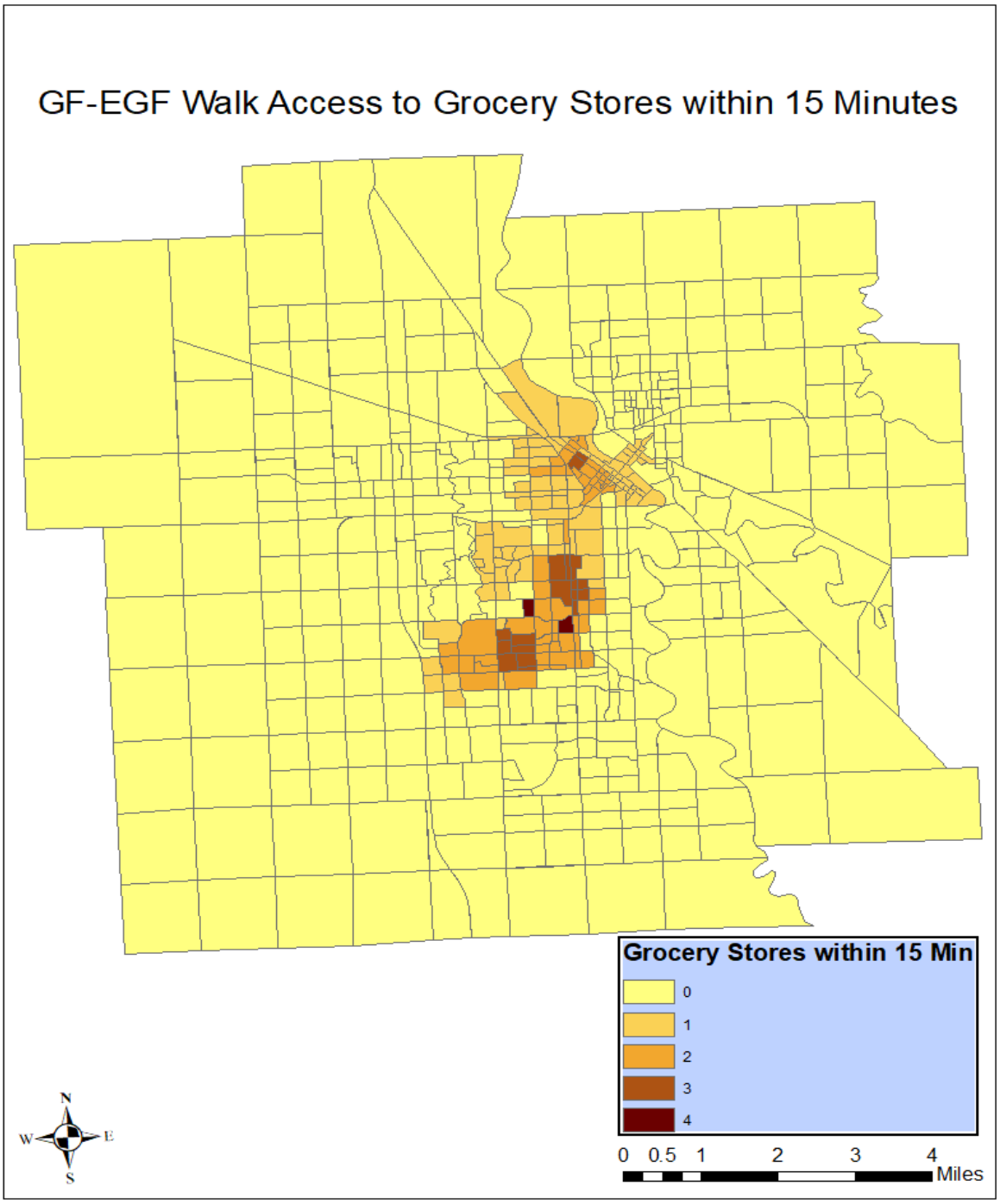

Figure 6.35. Walk Access to Grocery Stores within 15 Minutes in GF-EGF

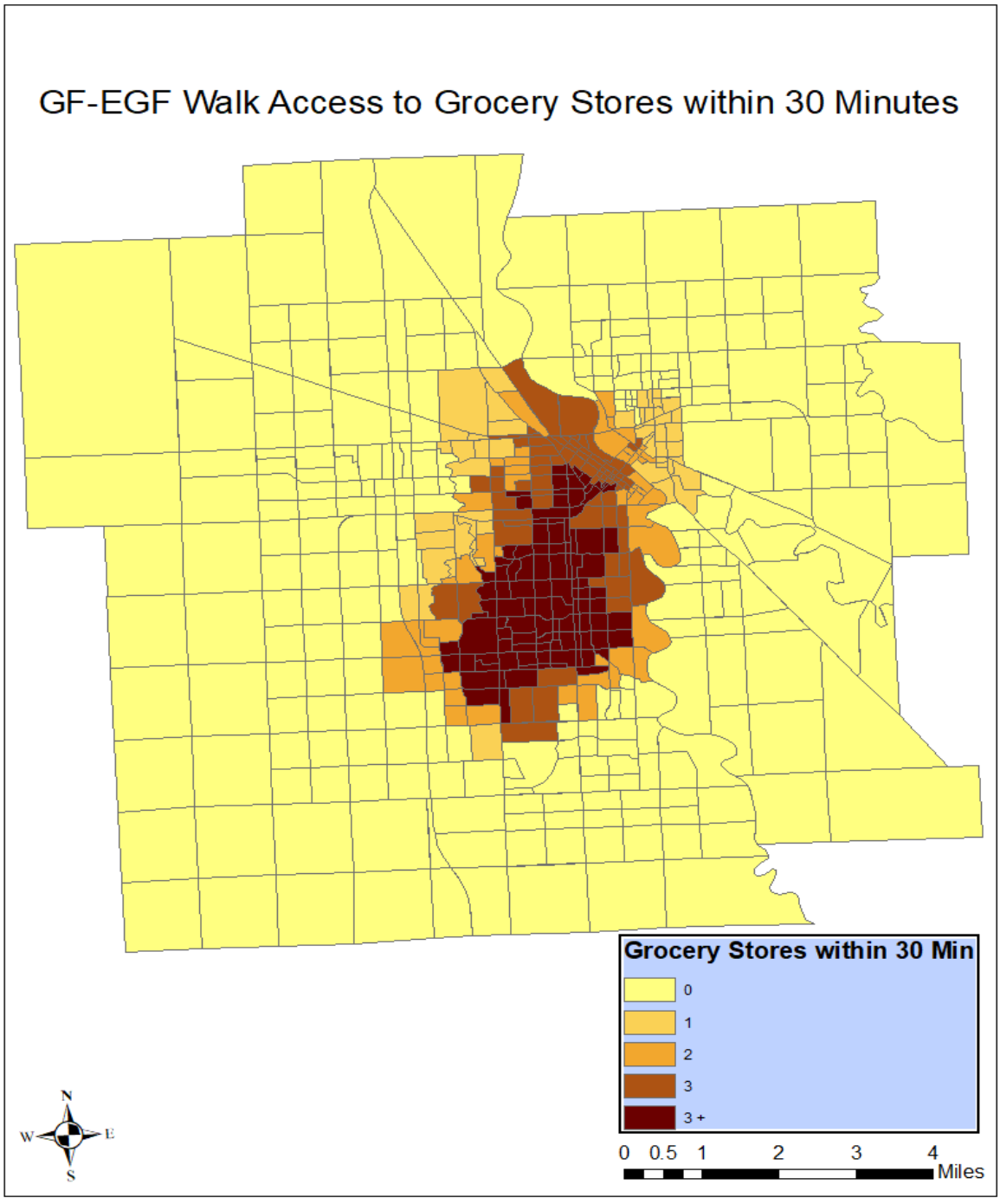

Figure 6.36. Walk Access to Grocery Stores within 30 Minutes in GF-EGF

6.3. Bismarck – Mandan MPO

This section includes the accessibility results for B-M MPO. The next sub-sections will present the people's ability to access jobs, medical services, and grocery stores by using auto and walk modes, respectively in the B-M MPO area.

6.3.1. Auto Access to Jobs, Medical Services, and Grocery Stores

This section comprises the accessibility results in terms of auto access to jobs, medical services, and grocery stores in the B-M. Figure 6.37 and Figure 6.38 shows the auto access to jobs within 15-minute and 30-minute travel time thresholds, respectively in the B-M MPO area. Total number of jobs estimated in the B-M MPO area were 71811. Within 15-minute auto travel time, the access to jobs is high in main urban area while medium access in the outskirts of the B-M MPO area. The access to jobs is high in almost all of the B-M MPO area within 30-minute auto travel time.

Figure 6.39 and Figure 6.40 represent the access to medical services within 15-minute and 30-minute travel time thresholds, respectively in the B-M MPO area using auto mode. The accumulative number of medical services used for accessibility evaluation in the B-M MPO area were 1610. Within 15-minute auto travel time, the accessibility to medical services was high in the main urban areas while low to medium in the suburbs of the B-M MPO area. The accessibility results for 30-minute auto travel time indicate that people's ability to access medical services is high in almost all of the B-M MPO area. Figure 6.41 represents the auto access to grocery stores within 15-minute travel time in the B-M. Total number of grocery stores used for accessibility analysis were 13 in the B-M. The results indicate that accessibility to grocery stores within 15-minute auto travel time is medium to high in the main urban area while low in the suburbs of the B-M MPO area. Figure 6.42 shows the auto access to grocery stores within 30-minute travel time threshold in the B-M. The results revealed that auto access to jobs within 30-minute travel time is high in almost all of the B-M MPO area. Overall, the accessibility results revealed that auto access to amenities (jobs, medical services, and grocery stores) is medium to high in the B-M MPO area.

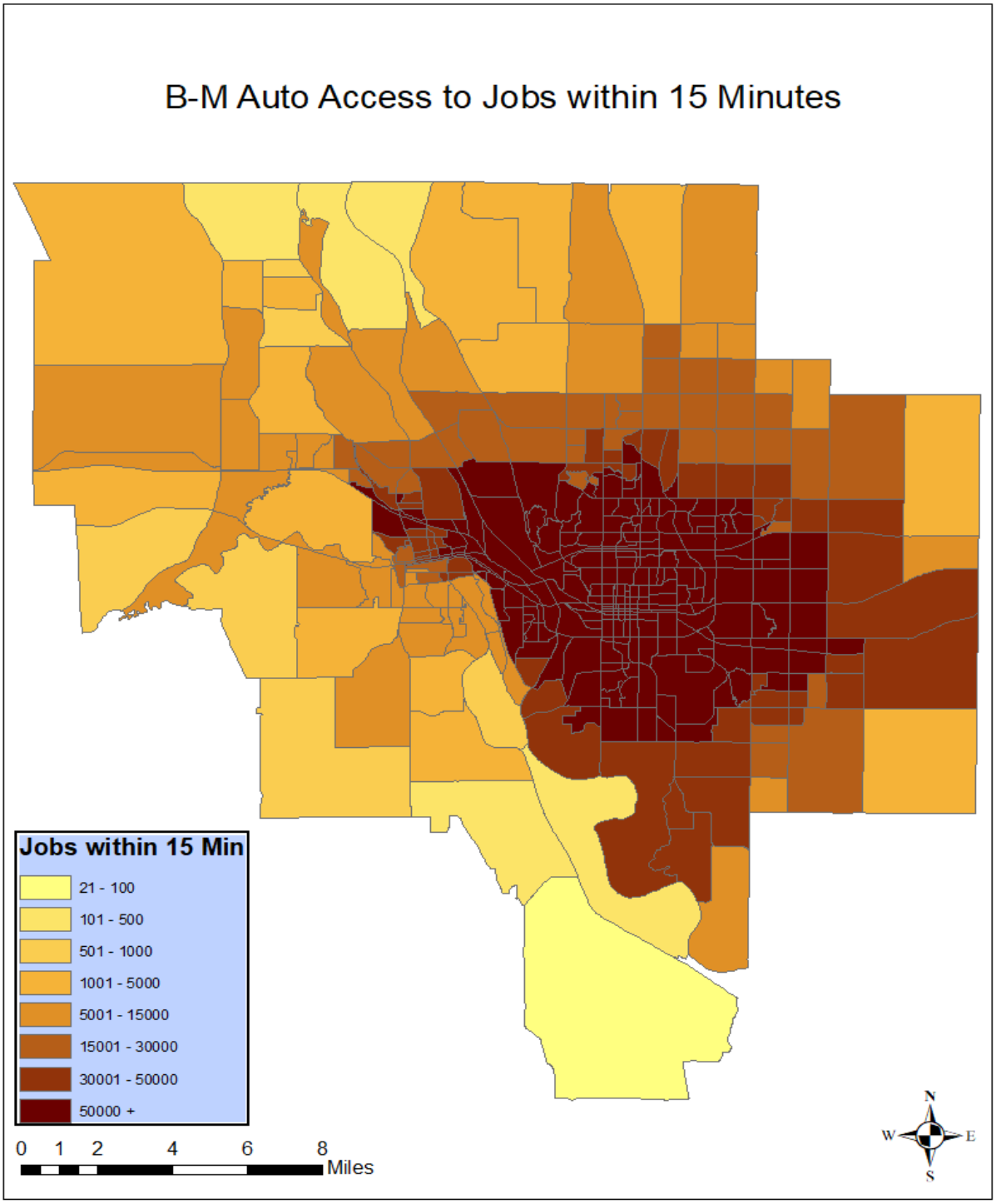

Figure 6.37. Auto Access to Jobs within 15 Minutes in B-M

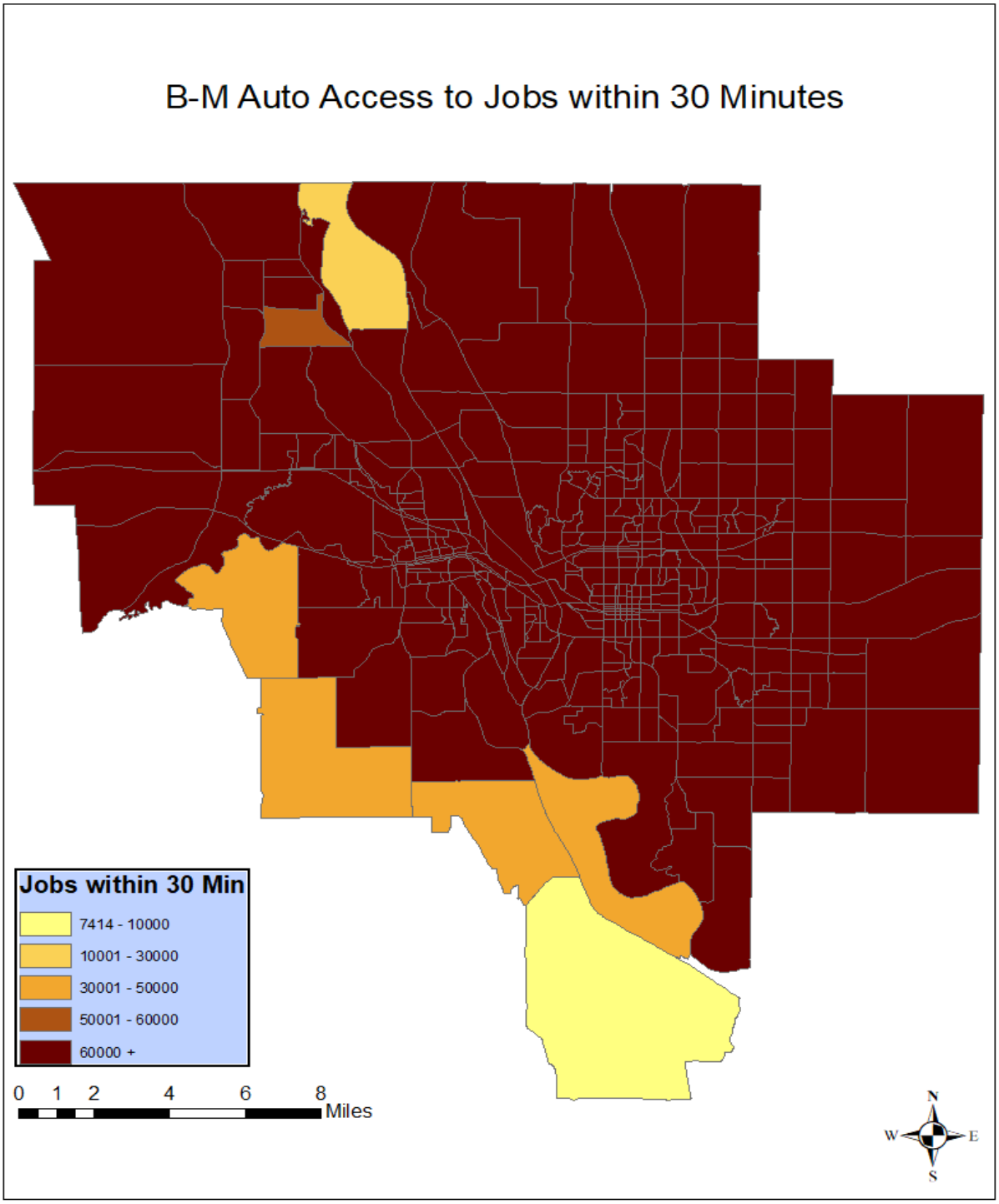

Figure 6.38. Auto Access to Jobs within 30 Minutes in B-M

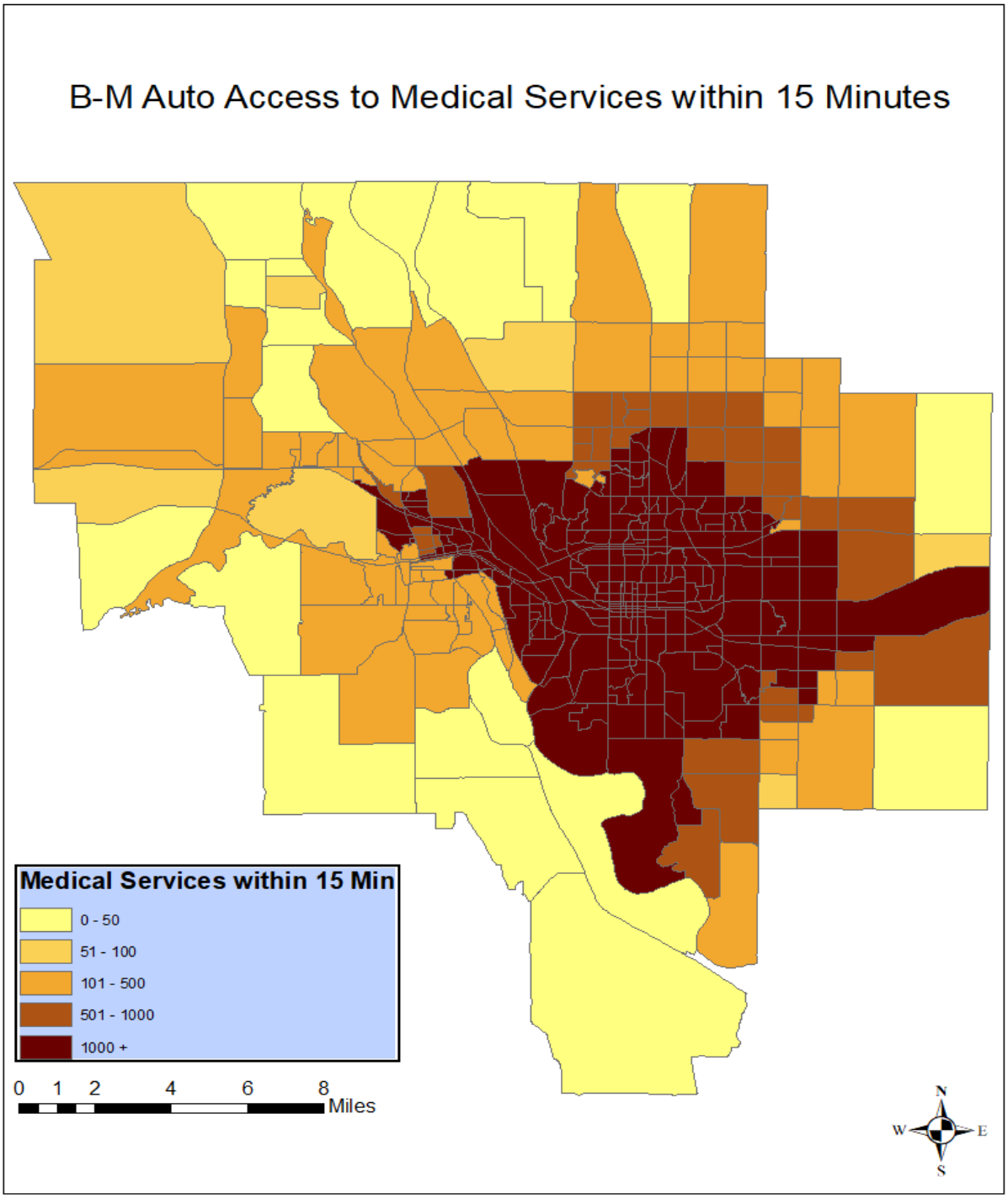

Figure 6.39. Auto Access to Medical Services within 15 Minutes in B-M

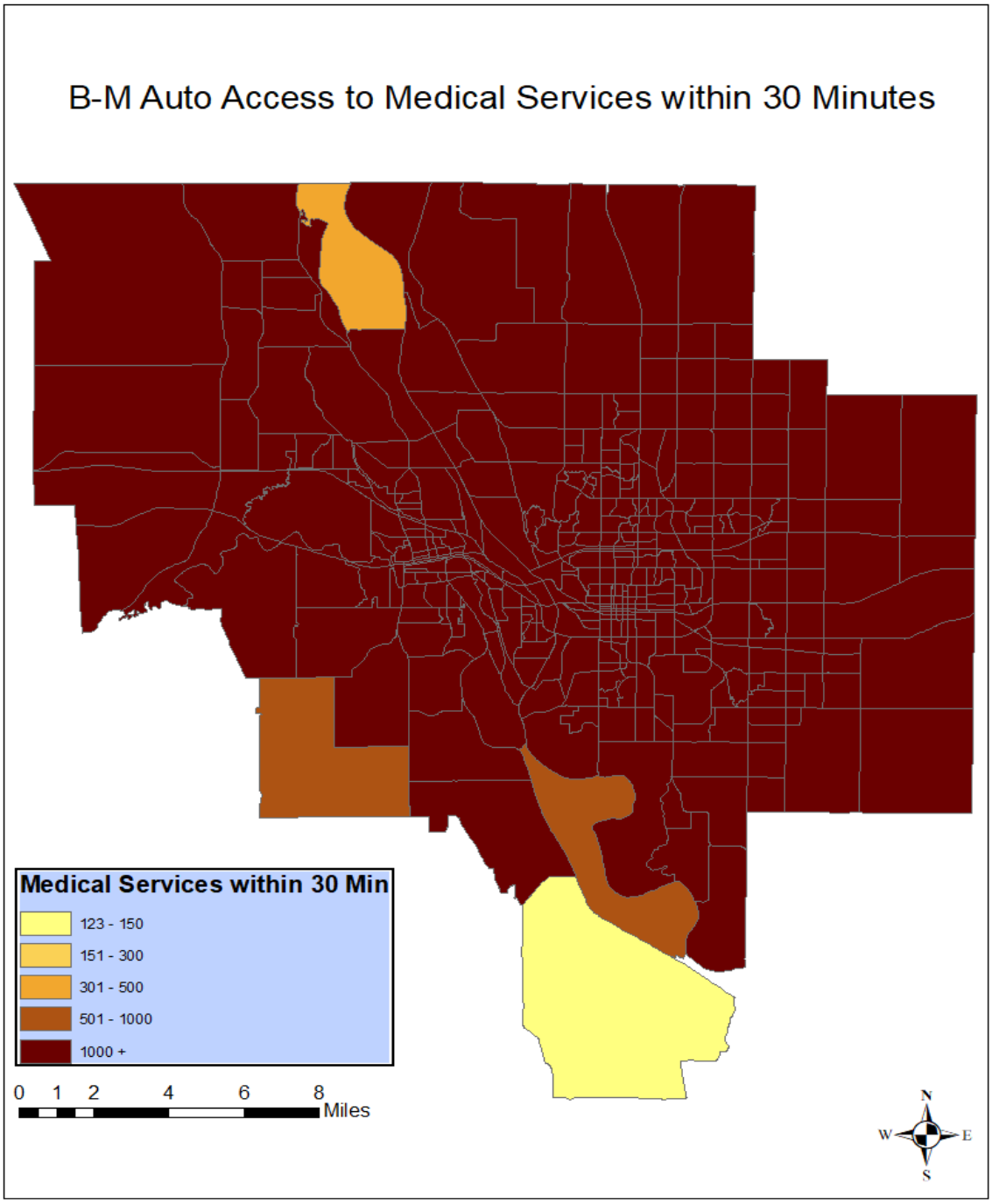

Figure 6.40. Auto Access to Medical Services within 30 Minutes in B-M

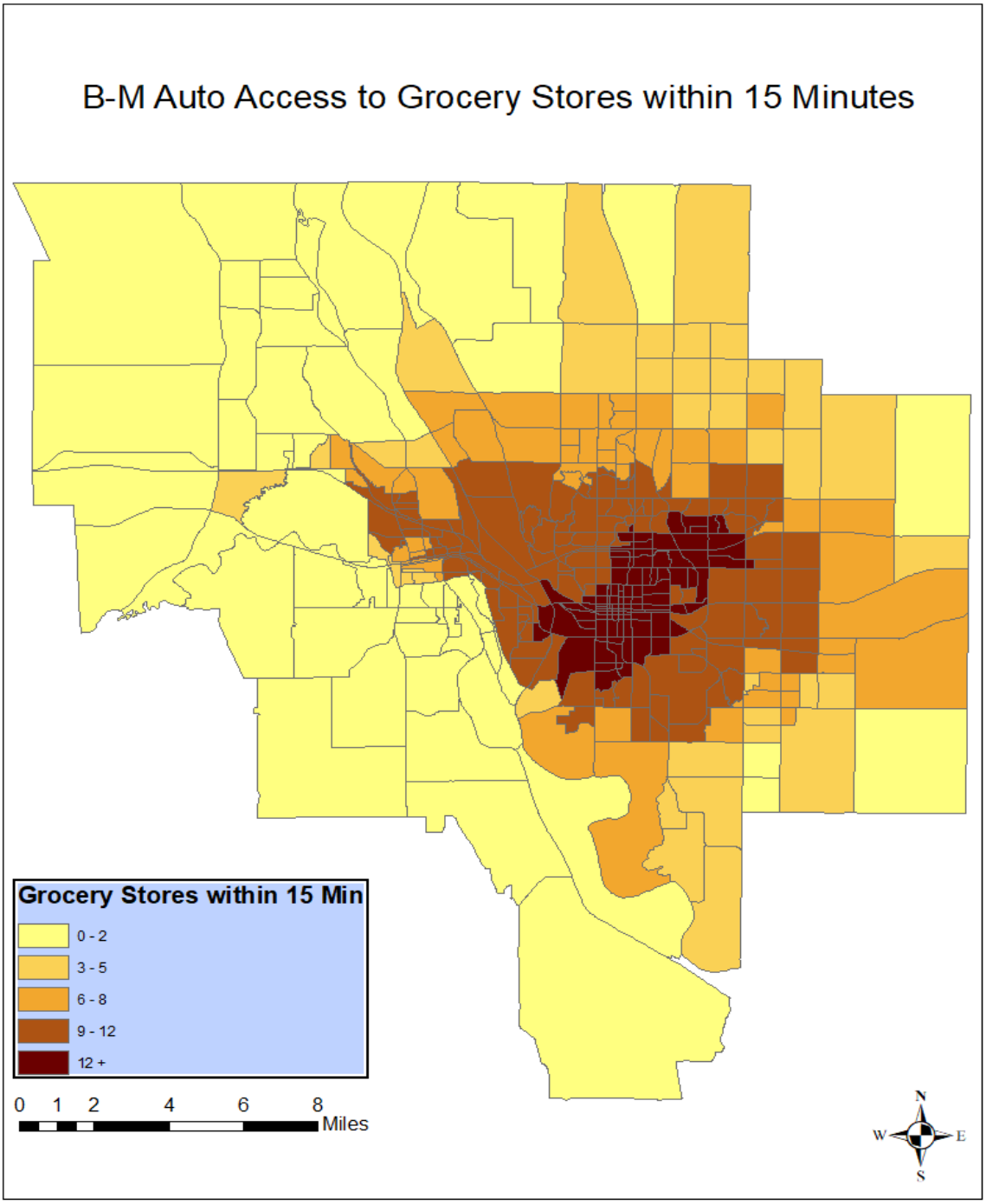

Figure 6.41. Auto Access to Grocery Stores within 15 Minutes in B-M

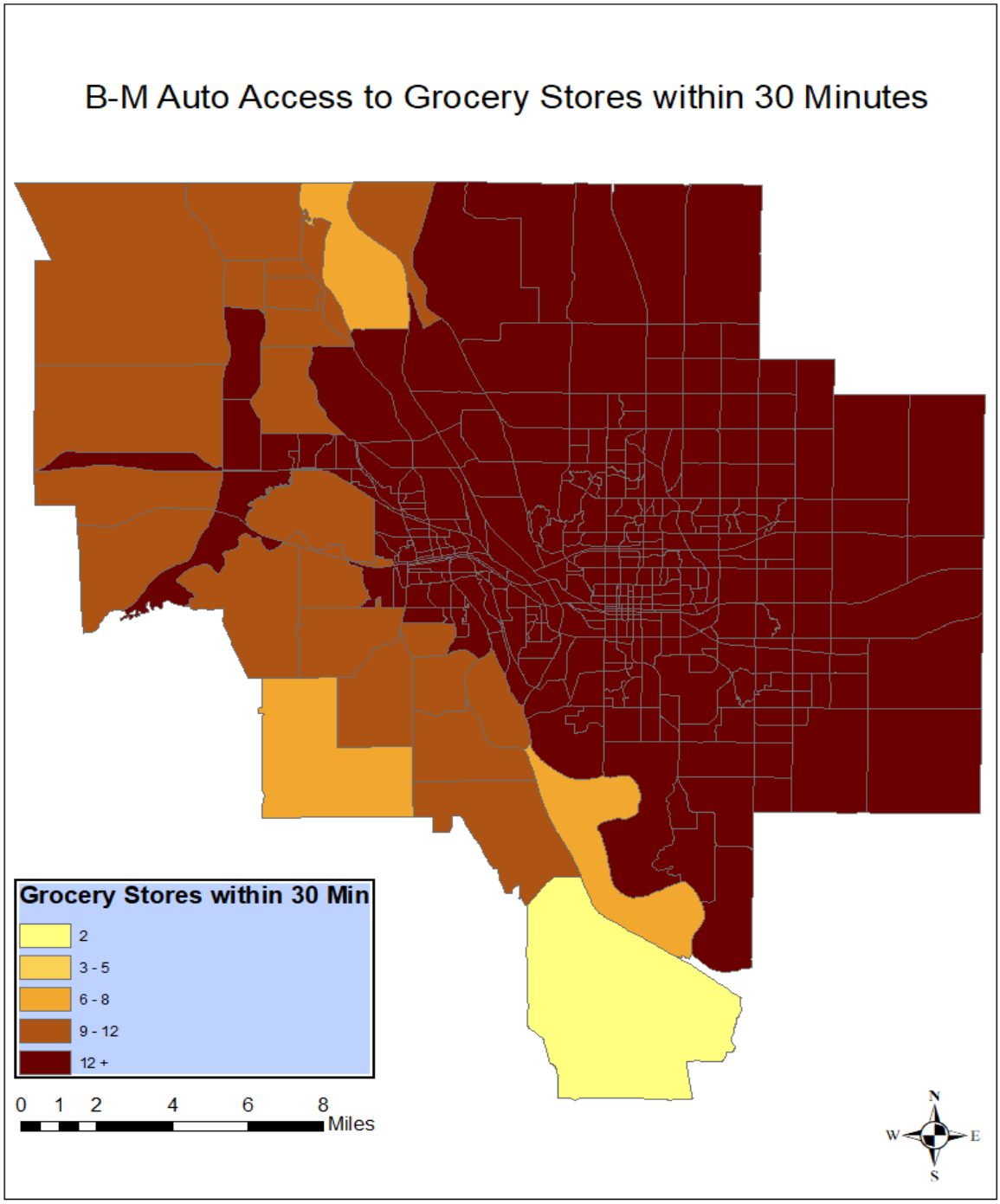

Figure 6.42. Auto Access to Grocery Stores within 30 Minutes in B-M

6.3.2. Walk Access to Jobs, Medical Services, and Grocery Stores

This section includes the accessibility results in terms of walk access to jobs, medical services, and grocery stores in the B-M MPO area. Figure 6.43 and Figure 6.44 represents the walk access to jobs within 15-minute and 30-minute travel time thresholds, respectively in the B-M MPO area. The results indicate that walk access to jobs is medium to high in the main urban area while very low in the suburbs of the B-M MPO area. Figure 6.45 and Figure 6.46 shows the walk access to medical services within 15-minute and 30-minute travel time thresholds, respectively in the B-M. Within 15-minute travel time threshold, the walk access to medical services is low in almost all of the B-M MPO area. The people's ability to access medical services is medium in main urban area while low in the suburbs of the B-M MPO area within 30-minute walk travel time.

Figure 6.47 shows the walk access to grocery stores within 15-minute travel time threshold in the B-M MPO area. The results indicate that people's ability to access grocery stores is very low in almost all the B-M MPO area within 15-minute walk travel time. Figure 6.48 represents the access to grocery stores within 30-minute travel time threshold in the B-M MPO area using walk mode. The accessibility results revealed that people's ability to access grocery stores within 30-minute walk travel time is medium in main urban area while very low in the suburbs of the B-M MPO area. Overall, the accessibility results in this section revealed that walk access to amenities (jobs, medical services, and grocery stores) is low in the B-M MPO area.

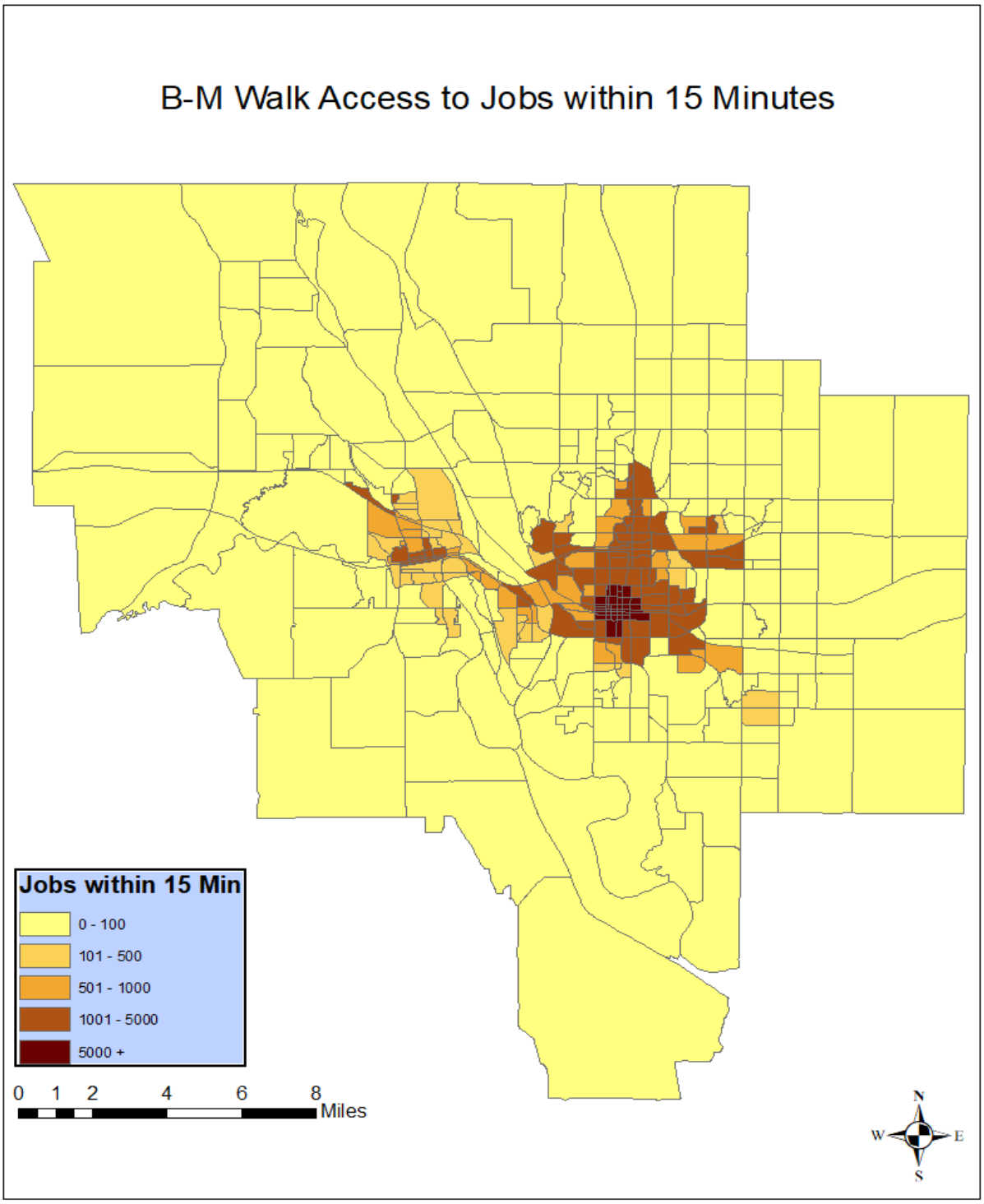

Figure 6.43. Walk Access to Jobs within 15 Minutes in B-M

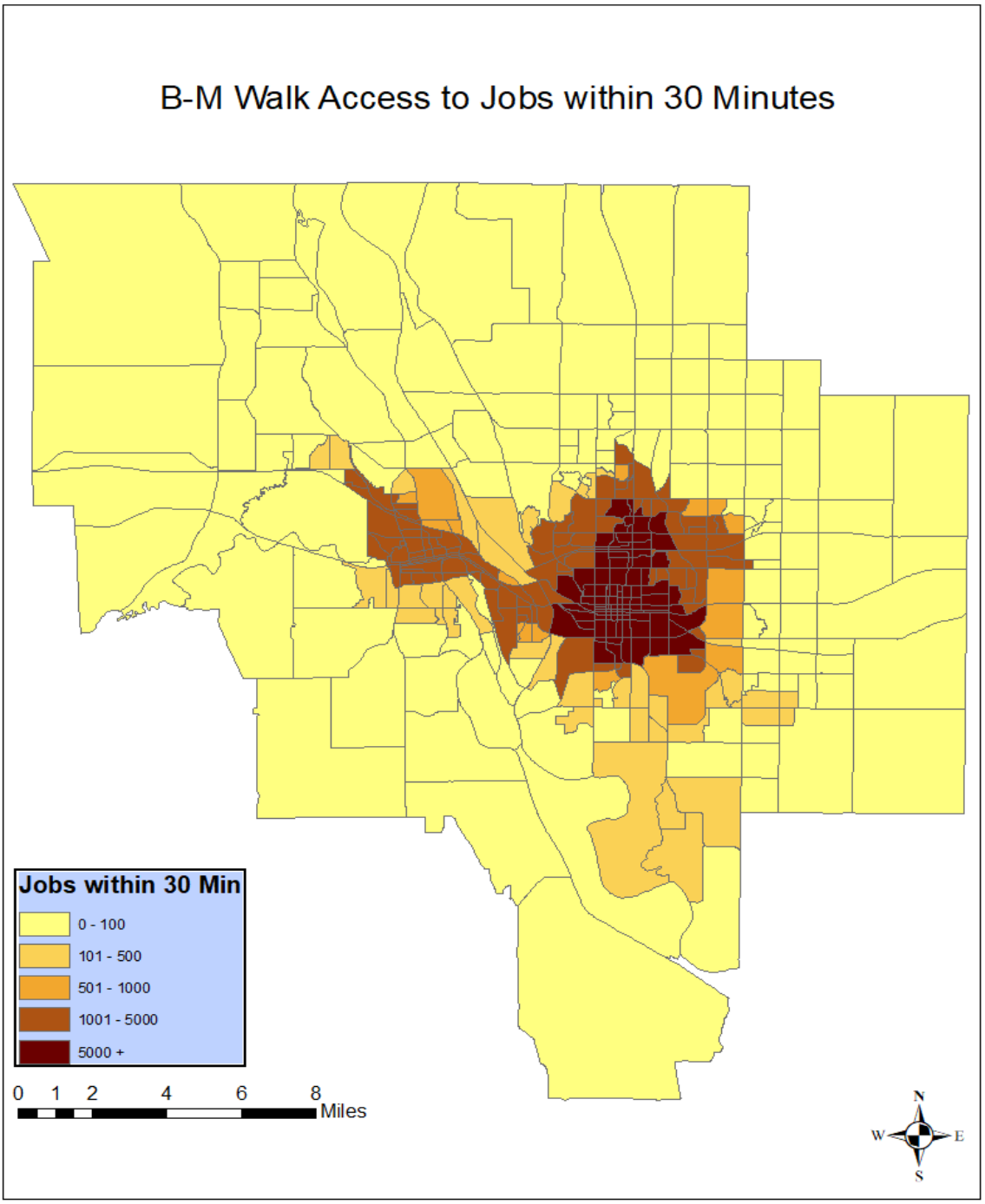

Figure 6.44. Walk Access to Jobs within 30 Minutes in B-M

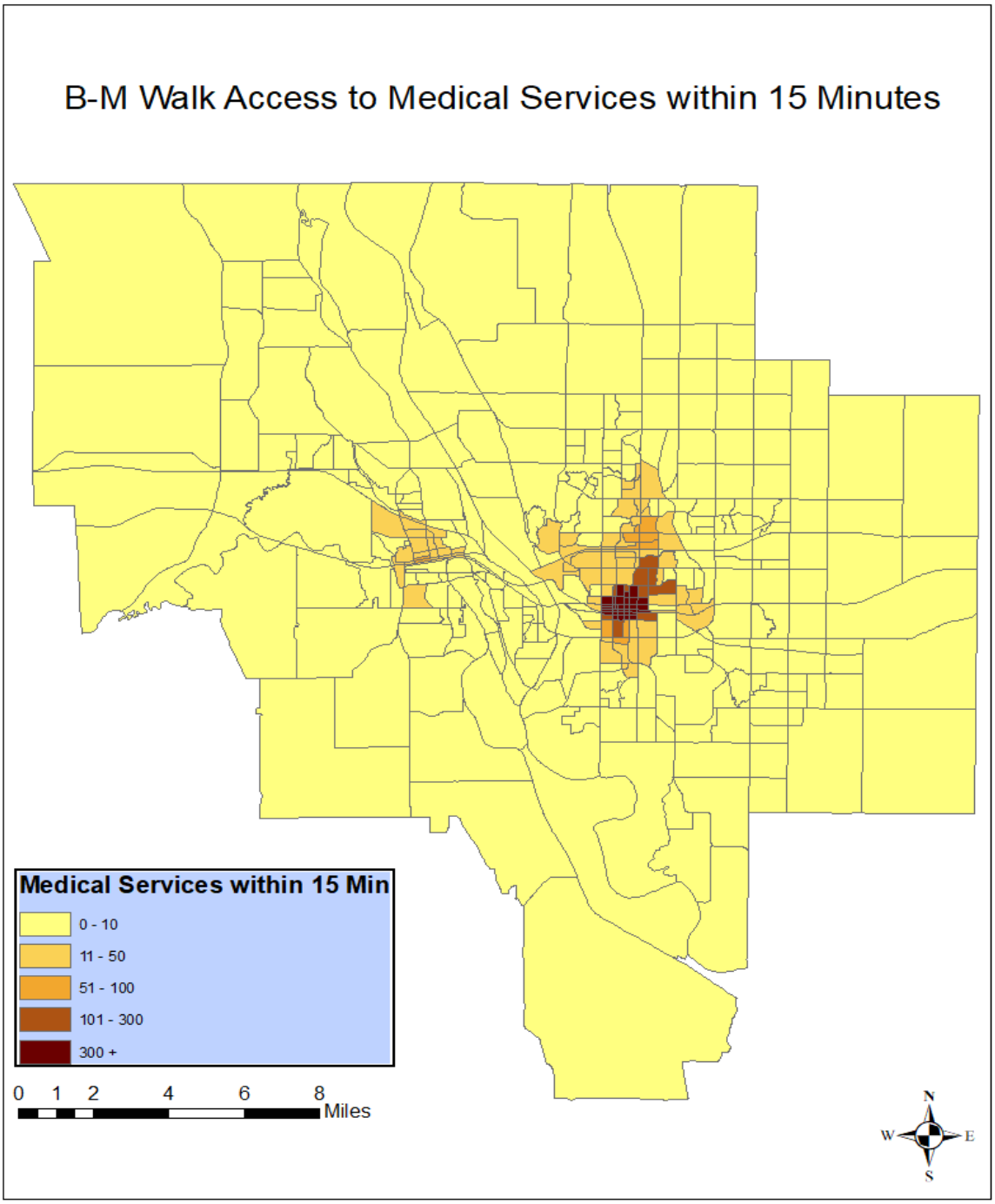

Figure 6.45. Walk Access to Medical Services within 15 Minutes in B-M

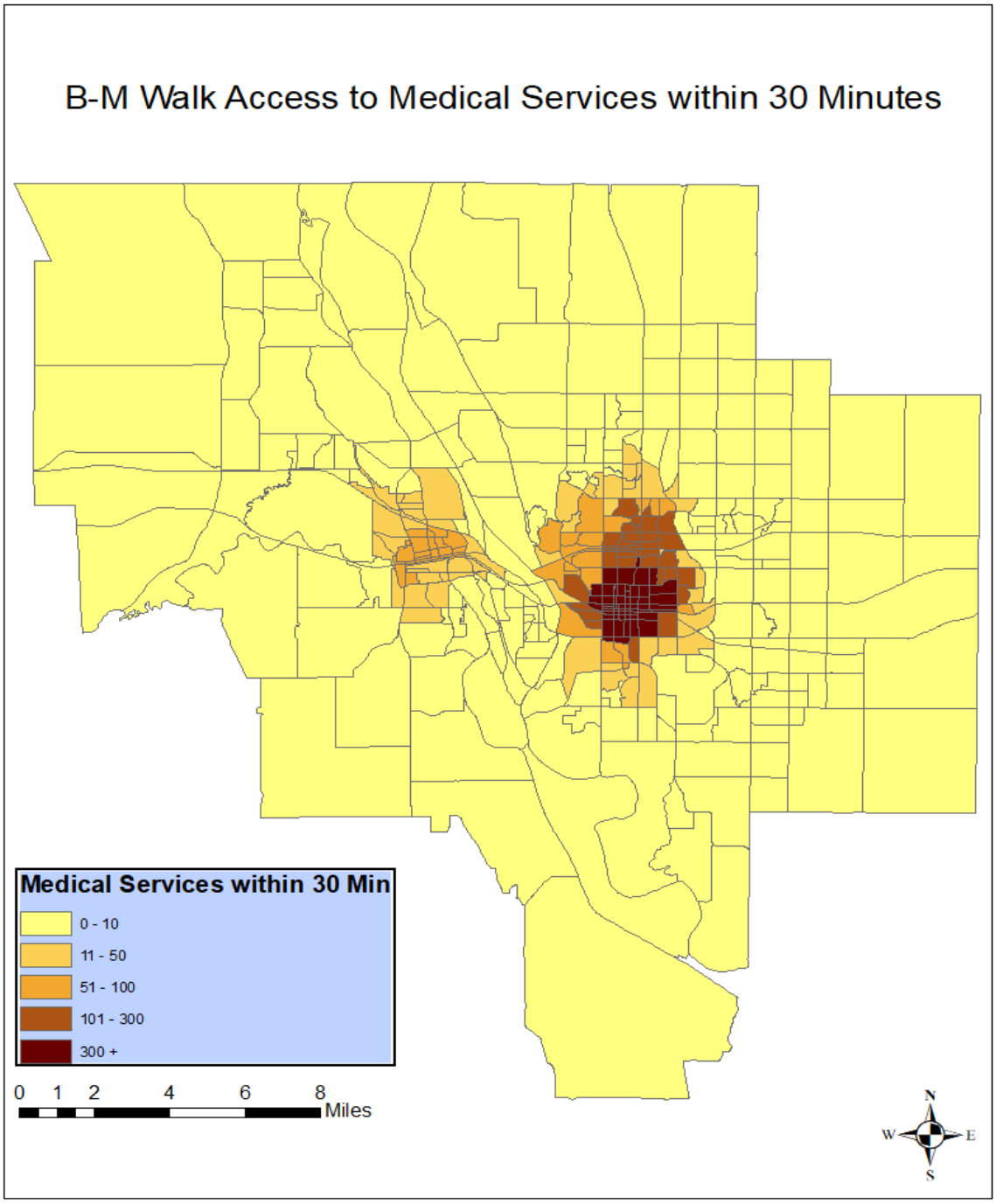

Figure 6.46. Walk Access to Medical Services within 30 Minutes in B-M

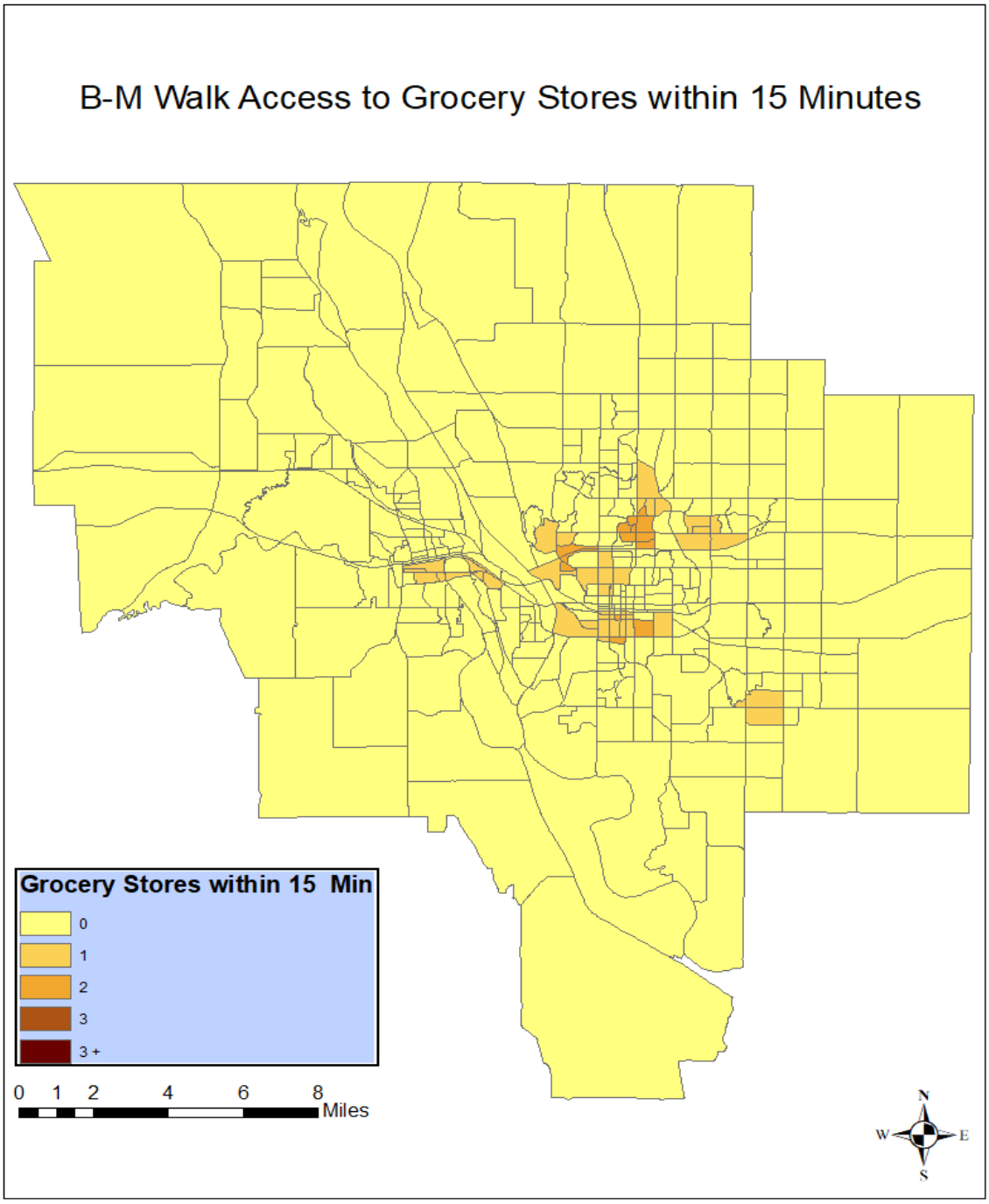

Figure 6.47. Walk Access to Grocery Stores within 15 Minutes in B-M

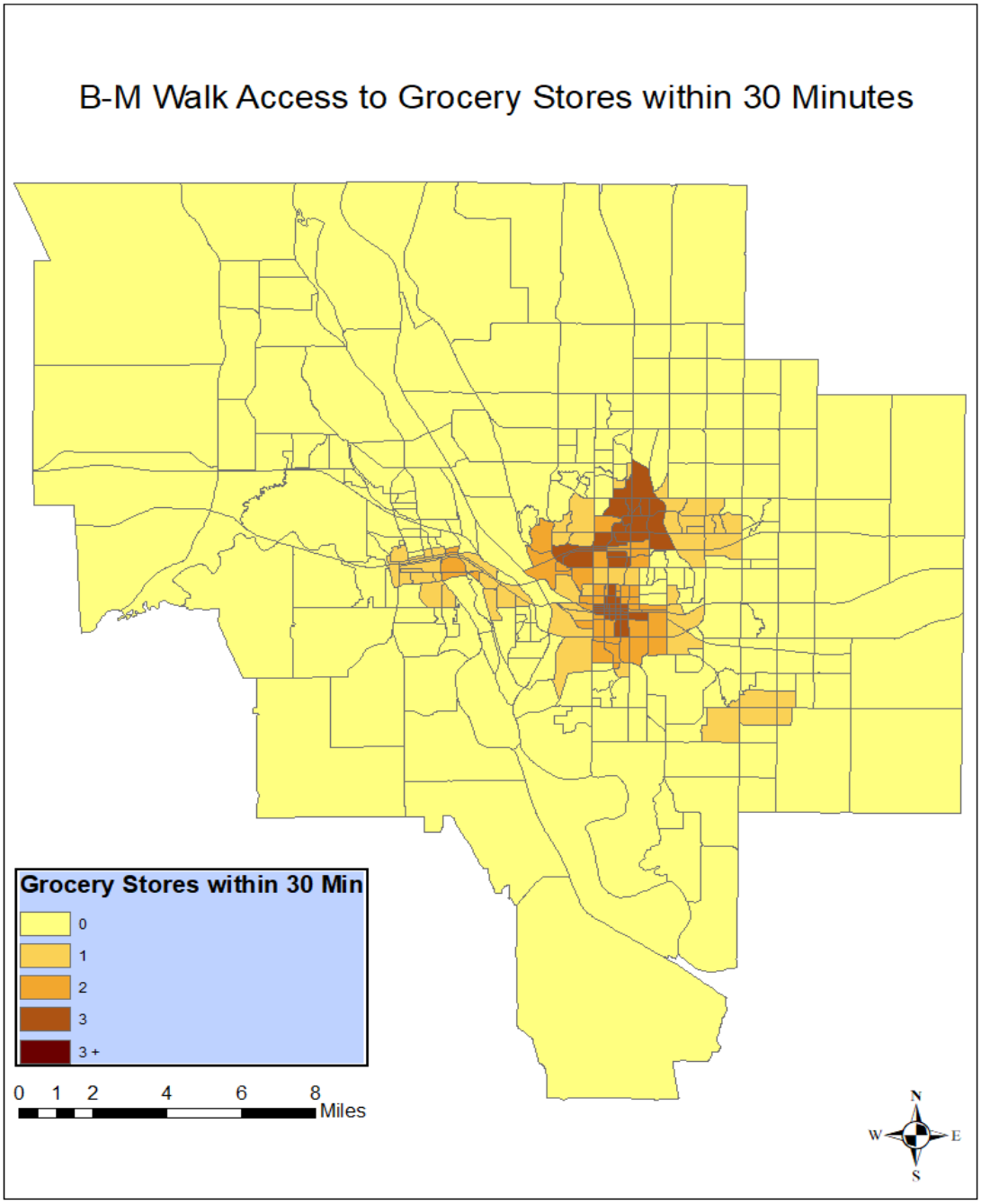

Figure 6.48. Walk Access to Grocery Stores within 30 Minutes in B-M

7. CONCLUSIONS AND FUTURE IMPROVEMENTS

In this study, the accessibility models were develop at state wide level and for three MPOs (FM Metro COG, Grand Forks – East Grand Forks, and Bismarck Manda) in order to assess people's ability to access jobs, medical services, and grocery stores. The accessibility analysis at state wide level was performed by considering auto mode. The auto travel time thresholds for which the accessibility analysis was performed were 15-minute and 30-minute. The accessibility results at state wide level revealed that auto access to jobs and medical services is high in the urban counties census tracts which include Cass, Burleigh, Grand Forks, and Ward within both 15-minute and 30-minute travel time thresholds. The auto access to these amenities is low in other counties census tracts within both travel time thresholds. The lower accessibilities are in part related to geographies that are used for the rest of the state and for future studies; these will have to be adjusted so that all the major towns are included. In terms of auto access to grocery stores, it is concluded that census tracts in only Cass county have high access to grocery stores, while census tracts in Burleigh, Grand Forks, and Stark counties have medium access within 15-minute travel time threshold. The auto access to grocery stores was high for census tracts in Cass, Grand Forks, Burleigh, and Ward counties in 30-minute travel time threshold. Most of the census tracts in the remaining counties have very low access to grocery stores.

For F-M MPO, the accessibility analysis was performed by considering auto, public transit, and walk modes. The travel time thresholds considered for auto and walk modes were 15-minute and 30-minute, while for public transit the thresholds were 30-minute and 60-minute. The accessibility results in terms of auto access to jobs, medical services, and grocery stores revealed that people's ability to access these three amenities is medium to high in the Metro COG MPO area. In terms of public transit mode, it is concluded that people's ability to access these amenities is high in the main urban area while low in the suburbs of the Metro COG MPO area. It is concluded that accessibility to jobs, medical services, and grocery stores was low using walk mode in the F-M MPO area.

The next MPO for which the accessibility analysis was performed is GF-EGF. For this MPO, there were also three modes considered for accessibility evaluation i.e., auto, public transit, and walk. The accessibility results revealed that auto access to amenities (jobs, medical services, and grocery stores) was high in almost all of the MPO area. These results are intuitive because

GF-EGF MPO is a small area with less population, so people can easily access different locations using their own vehicle. In terms of public transit access to these amenities, it is concluded that accessibility is medium to high in the GF-EGF MPO area. In terms of walk mode, the accessibility results revealed that access to amenities is low in the GF-EGF MPO area.

The accessibility analysis was also performed for B-M MPO by considering auto and walk mode. In terms of auto access to amenities (jobs, medical services, and grocery stores), it is concluded that B-M MPO area have medium to high access. In terms of walk mode, it is concluded that access to amenities is low in the B-M MPO area.

Although, this study evaluates accessibility to important amenities at state wide level and for three MPOs, there is still improvement that needs to be considered in the future studies. The future study can include intercity paratransit service for state wide level accessibility analysis. Also in the MPOs, the future study should consider including on-demand response transit in the public transit accessibility analysis. For example, the Metro COG MPO recently introduced on-demand response transit for North Dakota State University (NDSU) students from 07:00 pm to 11:00 pm on weekdays during a regular semester. Accessibility is also considered an important equity evaluation tool as it includes both people and location of different destination types. The future studies should also consider evaluating social equity analysis in terms of ability to access important destinations by people belonging to different social classes. This study did not consider bike access to amenities. Future studies can include bike access to different type of destinations. This can be a sub-area analysis by considering specific parts of the city such as downtown, university area, or access to parks and grocery stores. The study can be conducted by using bike share data and also by conducting survey to include people who have their own bikes. Another possible improvement can be by developing local distance decay functions for different modes of travel by conducting survey. The respondents can be asked about their willing to pay for different modes of travel under different circumstances. Future studies should also include scenario analysis for different future improvement projects. This can include for example, examining the change in accessibility by adding a new transit route in a specific area. In this study, the accessibility was evaluated for all jobs combined. Future studies can also evaluate access to different types of jobs, (e.g., low income, medium income, high income, industry jobs, and educational jobs etc.,) individually.

REFERENCES

Banister, D. (2008). The sustainable mobility paradigm. *Transport Policy*, 73-80. Retrieved from https://doi.org/10.1016/j.tranpol.2007.10.005

Bhat, C., Handy, S., Kockelman, K., Mahmassani, H., Chen, Q., & Weston, L. (2000). *Development of an Urban Accessibility Index: Literature Review.* The University of Texas at Austin, Texas Department of Transportation.

Boisjoly, G., & El-Geneidy, A. M. (2017). How to get there? A critical assessment of accessibility objectives and indicators in metropolitan transportation plans. *Transport Policy, 55*, 38-50. Retrieved from http://dx.doi.org/10.1016/j.tranpol.2016.12.011

El-Geneidy, A. M., & Levinson, D. M. (2006). *Access to Destinations: Development of Accessibility Measures.* University of Minnesota, St-Paul, Minnesota.

Geurs, K. T., & Wee, B. v. (2004). Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography, 12*(2), 127-140.

Geurs, K. T., Krizek, K. J., & Reggiani, A. (2012). Accessibility analysis and transport planning: an introduction. In K. T. Geurs, K. J. Krizek, & A. Reggiani, *Accessibility Analysis and Transport Planning: Challenges for Europe and North America* (pp. 1-12). Edward Elgar Publishing Limited, Northampton.

Hansen, W. G. (1959). How Accessibility Shapes Land Use. *Journal of the American Institute of Planners*.

Manaugh, K., Badami, M. G., & El-Geneidy, A. M. (2015). Integrating social equity into urban transportation planning: A critical evaluation of equity objectives and measures in transportation plans in North America. *Transport Policy, 37*, 167-176.

McCahill, C. (2018). Non-work accessibility and related outcomes. *Research in Transportation Business & Management*. doi:https://doi.org/10.1016/j.rtbm.2018.07.002

Norquist, J. (2011). *The Case for Congestion.* CityLab. Retrieved from https://www.citylab.com/transportation/2011/12/case-congestion/717/

Sundquist, E., McCahill, C., & Dredske, L. (2017). *Accessibility in practice: A guide for transportation and land use decision making.* University of Wisconsin-Madison. State Smart Transportation Initiative.

APPENDIX A. SUGAR ACCESS SOCIOECONOMIC DATA ATTRIBUTES

Table A.1. Sugar Access Socioeconomic Data Attributes

FIELD	DEFINITION	DESCRIPTION
bgid	Block Group ID	FIPS Census Block-Group ID Code
statefp10	State ID	FIPS Census State ID Code
countyfp10	County ID	FIPS Census County ID Code
tractce10	Census Tract ID	Census Tract ID Code
blockce	Census Block ID	Census Block ID Code
blockid10	Census Block Whole ID	Unique Census Block ID Code
households	Number of Households	Number of households in Census Block
hhr##_##	Age of Household Owner	Number of heads of household from age ## to age ##
hh##	Household Population	Number of households with ## population
population	Total Population	Total population
white	White Population	Total White Population
black	Black Population	Total Black Population
amer_ind	American Indian Population	Total American Indian Population
asian	Asian Population	Total Asian Population
pac_isl	Pacific Islander Population	Total Pacific Islander Population
other	Other Population	Total population of other races
tworace	Two or more race population	Total population of two or more race
hispanic	Hispanic/Latino Population	Total population of Hispanic/Latino race
his_nonwhi	Non-White Hispanic/Latino Population	Total population of Non-White Hispanic/Latino race
veterans	Veteran Population	Total population of Veterans
disabled	Disabled Population (18 years and over)	Total population of disabled with age 18 or more
novehicle	No Vehicle Population	Total population without vehicle ownership
poverty	Population below poverty level	Total population with income below poverty level
lim_eng	Limited English Speaking Households	Total households with limited English speaking status
a#_to_#	Age of Population	Population of Census Block from age ## to age ##
schoolkids	School Aged Kids	Number of kids between age 5 to 17
seniors	Senior Aged People	Number of people with age 65 and above
jobs	Number of Jobs	Total number of jobs
emp_to29	Workers Under Age 29	Number of jobs for workers age 29 or younger
emp_30_54	Workers Between Age 30 to 54	Number of jobs for workers between age 30 to 54

emp_over55	Workers Over Age 55	Number of jobs for workers age 55 or over
lowincjobs	Low Income Jobs	Number of jobs with earnings $1250/month or less
medincjobs	Medium Income Jobs	Number of jobs with earnings between $1251/month to $3333/month
higincjobs	High Income Jobs	Number of jobs with earnings $3333/month or more
agri_fish	Agricultural Jobs	Number of jobs in NAICS sector 11 (Agriculture, Forestry, Fishing and Hunting)
mining	Mining Jobs	Number of jobs in NAICS sector 21 (Mining, Quarrying, and Oil and Gas Extraction)
utility	Utility Jobs	Number of jobs in NAICS sector 22 (Utilities)
construct	Construction Jobs	Number of jobs in NAICS sector 23 (Construction)
manufactur	Manufacturing Jobs	Number of jobs in NAICS sector 31 to 33 (Manufacturing)
wholesale	Wholesale Trade Jobs	Number of jobs in NAICS sector 42 (Wholesale Trade)
retail	Retail Trade Jobs	Number of jobs in NAICS sector 44-45 (Retail Trade)
transport	Transportation Jobs	Number of jobs in NAICS sector 48-49 (Transportation and Warehousing)
informatio	Information Jobs	Number of jobs in NAICS sector 51 (Information)
fina_insu	Finance/Insurance Jobs	Number of jobs in NAICS sector 52 (Finance and Insurance)
reestate	Real Estate Jobs	Number of jobs in NAICS sector 53 (Real Estate Rental and Leasing)
prof_serv	Professional Services Jobs	Number of jobs in NAICS sector 54 (Professional, Scientific, and Technical Services)
mgmt	Management Jobs	Number of jobs in NAICS sector 55 (Management of Companies and Enterprises)
admi_wast	Administrative Jobs	Number of jobs in NAICS sector 56 (Administrative and Support and Waste Management and Remediation Services
education	Education Jobs	Number of jobs in NAICS sector 61 (Educational Services)
		Number of jobs in NAICS sector 62

health	Healthcare Jobs	(Health Care and Social Assistance)
arts_rec	Arts, Entertainment Jobs	Number of jobs in NAICS sector 71 (Arts, Entertainment, and Recreation)
accomod	Hospitality Jobs	Number of jobs in NAICS sector 72 (Accommodation and Food Services)
othr_serv	Other Services Jobs	Number of jobs in NAICS sector 81 (Other Services)
public	Public Administration Jobs	Number of jobs in NAICS sector 92 (Public Administration)

APPENDIX B. SUGAR ACCESS POINT OF INTEREST DATA ATTRIBUTES

Table B.1. Sugar Access POI Attributes

Field	Definition	Description
OBJECTID	ID number	ID number for each link from the original shapefile.
LINK_ID	Road Link ID	Here inherited road link ID
POI_ID	POI ID	Here inherited unique POI ID
SEQ_NO	POI Sequence Number	Sequence of POI if more than one POIs at same address
FAC_TYPE	Facility Type	POI facility type code, summarized in Here_Categ field
POI_NAME	POI Name	Name of POI
POI_LANGCD	POI Name Language	Language in which POI address record is kept
POI_NMTYPE	Not a Sugar Access Attribute	
POI_ST_NUM	POI Street Address	Street address of POI
ST_NUM_FUL	Not a Sugar Access Attribute	
ST_NFUL_LC	Not a Sugar Access Attribute	
ST_NAME	Street Name	Name of street which POI is located
ST_LANGCD	Street Name Language	Language in which street name is kept
POI_ST_SD	POI Street Side	Side of street which POI is located
ACC_TYPE	Not a Sugar Access Attribute	
PH_NUMBER	Phone Number	Telephone number for POI
CHAIN_ID	POI Chain ID	Unique ID of chain store if POI is a chain
NAT_IMPORT	Not a Sugar Access Attribute	
PRIVATE	Private Facility	Indicates whether POI is a private facility
IN_VICIN	Not a Sugar Access Attribute	
NUM_PARENT	Not a Sugar Access Attribute	
NUM_CHILD	Not a Sugar Access Attribute	
PERCFRREF	Not a Sugar Access Attribute	
VANCITY_ID	Not a Sugar Access Attribute	
ACT_ADDR	Acting Address	Acting full address for POI
ACT_LANGCD	Acting Address Language	Language in which POI acting address record is kept
ACT_ST_NAM	Acting Street Name	Acting address street name for POI
ACT_ST_NUM	Acting Street Number	Acting address street number for POI
ACT_ADMIN	Acting City	Acting address city for POI
ACT_POSTAL	Acting Postal Code	Acting address postal code for POI
OPEN_24	Open 24 Hour Indicator	Indicates if a petrol/gasoline station is open 24 hours a day
DIESEL	Diesel Fuel Indicator	Indicates if a Petrol/Gasoline station supports the sale of diesel fuel
BLD_TYPE	Building Type	Type of building if religious

		affiliation
ENTR_TYPE	Not a Sugar Access Attribute	
FOOD_TYPE	Cuisine Type	The identification of cuisine served in a restaurant
ALT_FOOD	Alternate Cuisine Type	The identification of a second or alternate cuisine in a restaurant
REG_FOOD	Regional Cuisine	The identification of regional sub-cuisine types
RESTR_TYPE	Restaurant Type	Describes the type of facility for a restaurant POI
REST_TYPE	Rest Area Type	Type of services available at a rest area
POINTCLASS	Citilabs POI Code	Citilab's categorized POI code to represent each Citilab's POI category
HERE_FACIL	Here Facility Code	Inherited here facility code unique to each Here POI category
CATEGORIES	Citilabs POI Category	Citilab's POI category
HERE_CATEG	Here POI Category	Here's POI category

Table B.2. Sugar Access HERE and CITILABS POI Classification Codes and Description

POINTCLASS	HERE_FACIL	CATEGORIES	HERE_CATEG
100	5400	Grocery Store	Grocery Store
110	9565	Pharmacy	Pharmacy

120	9535	Convenience Store	Convenience Store
130	9545	Department Store	Department Store
140	9537	Clothing Store	Clothing Store
141	9568	Sporting Goods Store	Sporting Goods Store
150	9986	Home Improvement Store	Home Improvement & Hardware Store
151	9560	Home Specialty Store	Home Specialty Store
160	9988	Office Supply & Services Store	Office Supply & Services Store
170	9995	Bookstore	Bookstore
180	6512	Shopping Complex/Specialty Store	Shopping
180	9567	Shopping Complex/Specialty Store	Specialty Store
181	9987	Consumer Electronic Store	Consumer Electronic Store
190	9530	Post Office	Post Office
200	5800	Restaurants	Restaurants
200	9996	Restaurants	Coffee Shop
210	9532	Bars/Nightlife	Bar or Pub
210	2084	Bars/Nightlife	Winery
210	5813	Bars/Nightlife	Nightlife
310	8200	Higher Education	Higher Education
300	8211	School	School
320	8231	Library	Library
400	3578	Financial Institutions	ATM
400	6000	Financial Institutions	Bank
410	5000	Business Facility	Business Facility
420	5511	Auto Dealership	Auto Dealership
420	5512	Auto Dealership	Auto Dealership - Used
420	5571	Auto Dealership	Motorcycle Dealership
421	7510	Car Rental	Car Rental
430	5540	Gas Station	Petrol/Gasoline Station
440	7538	Auto Service & Maintenance	Auto Service & Maintenance
450	7011	Hotel	Hotel
500	7929	Performing Arts	Performing Arts
510	7832	Cinema	Cinema
600	8060	Healthcare	Hospital
600	9583	Healthcare	Medical Service
610	9121	Government Services	City Hall
610	9211	Government Services	Court House
610	9221	Government Services	Police Station
710	7992	Outdoor Sports Facilities	Golf Course
711	7998	Indoor Sports Facilities	Ice Skating Rink

711	7997	Indoor Sports Facilities	Sports Centre
710	7012	Outdoor Sports Facilities	Ski Resort
710	7014	Outdoor Sports Facilities	Ski Lift
720	7947	Outdoor Recreation Areas	Park/Recreation Area
720	9517	Outdoor Recreation Areas	Campground
700	5999	Tourist Attractions	Historical Monument
700	7999	Tourist Attractions	Tourist Attractions
700	8410	Tourist Attractions	Museum
700	9718	Tourist Attractions	Animal Park
701	7389	Tourist Information	Tourist Information
702	7994	Community Center	Community Center
705	9522	Highway Infrastructure	Truck Stop Plaza
705	9710	Highway Infrastructure	Weigh Station
705	7897	Highway Infrastructure	Rest Area
730	7996	Amusement Park	Amusement Park
740	7985	Casino	Casino
750	7940	Arenas/Convention Centers	Sports Complex
750	7990	Arenas/Convention Centers	Convention/Exhibition Centre
760	4580	Other Recreational Activities	Public Sport Airport
760	4493	Other Recreational Activities	Marina
770	4013	Transportation Hubs	Train Station
770	4100	Transportation Hubs	Commuter Rail Station
770	4170	Transportation Hubs	Bus Station
770	4482	Transportation Hubs	Ferry Terminal
775	9050	Bike Infrastructure	Bicycle Sharing Location
775	9051	Bike Infrastructure	Bicycle Parking
780	7520	Parking Structure	Parking Lot
780	7521	Parking Structure	Parking Garage
780	7522	Parking Structure	Park and Ride Lot
800	0	Citilabs Reserved Codes	
900	0	User Reserved Codes	

APPENDIX C. SUGAR ACCESS ROADWAY NETWORK ATTRIBUTES

Table C.1. Sugar Access Roadway Network Link Attributes

Field	Definition	Description
OBJECTID	ID number	ID number for each link from the original shapefile.
A	A Node	Node that signifies the beginning of the link
B	B Node	Node that signifies the end of the link
SHAPE_Length	Length	Length of link as defined in geo layer
LINK_ID	ID of Link	Unique identifier for the link specific to Here Network. A specific link ID is required under this attribute name, regardless of network type.
A_ID	Here A Node	A Node ID specific to Here Network. Informational only, not used in accessibility analysis.
B_ID	Here B Node	B Node ID specific to Here Network. Informational only, not used in accessibility analysis.
SPDFLAG	Speed data identifier	Created attribute based on the presence of Here traffic data. Informational only, not used in accessibility analysis.
SPD_LIMIT	Speed Limit	Here Posted Speed Limit.
LANES	Lanes per direction	Computed based on Here Lane attributes.
ST_NAME	Street Name	Name of street. Informational only, not used in accessibility analysis.
FEAT_ID	Feature ID	Unique identifier for the feature.
FUNC_CLASS	Functional Class	Functional Class defines a hierarchical network used to determine a logical and efficient route for a traveler. Highways are defined as a '1', and does not allow direct connections from zones. Whereas local non-arterial streets and trails are defined as a '5'. The analysis does not delineate between other values.
DIVIDER	Divider	This attribute identifies the presence of a physical traffic blocking divider. Informational only, not used in accessibility analysis.
DIR_TRAVEL	Link Direction	Here attribute describing direction of travel (F, T, B) from, towards or both relative to the A & B node

AR_AUTO	Access Automobiles	Identifies if automobiles are allowed on a link.
AR_BUS	Access Buses	Identifies if buses are allowed on a link.
AR_PEDEST	Access Pedestrians	Identifies if pedestrians are allowed on a link.
AR_TRAFF	Access Through Traffic	Identifies if through traffic is allowed on a link. This attribute determines whether automobiles can connect to and use the link during accessibility analysis.
PAVED	Paved Road	Describes roads that are made of materials which create a solid surface. Informational only, not used in accessibility analysis.
PRIVATE	Private Road	Identifies roads not maintained by an organization responsible for maintenance of public roads. Private roads are not made to be through routes within Sugar.
RAMP	Ramp	Ramps are connectors that provide access between roads that do not cross at grade. Ramps are not connected to through Centroid Connectors.
TOLLWAY	Tollway	This attribute identifies a link for which a fee must be paid to use the road. Informational only, not used in accessibility analysis.
POIACCESS	Points of Interest Access Road	POI Access Roads connect Points of Interest (POIs) to the road network. These roads provide the only means of entrance or exit from a POI to a public road.
CONTRACC	Controlled Access	Controlled Access identifies roads with limited entrances and exits that allow uninterrupted high speed traffic flow. Controlled access roads are not connected to through Centroid Connectors.
PUB_ACCESS	Public Access	The Public Access attribute indicates whether or not the Link allows public access. Informational only, not used in accessibility analysis.
DISTANCE	Distance	The length of the link in miles.
TMC	Traffic Monitor Code	Here link ID code. Informational only, not used in accessibility analysis.
BIKE	Bike Allowance Attribute	Binary, takes on own value. Determines whether bike can

		be used on link.
BIKE_FACIL	Bike Facility Type	Acceptable values: 0,1,2 corresponding to No facility, bike lane, protected bike lane (default value 0)
AM_SPD	AM Link Speed	Average hourly link speed (7-9 am)
MD_SPD	Midday Link Speed	Average hourly link speed (11-1 pm)
PM_SPD	PM Link Speed	Average hourly link speed (4-6 pm)
OP_SPD	Off Peak Link Speed	Average hourly link speed (12-2 am)

Table C.2. Sugar Access Roadway Node Attributes

Field	Definition	Description
OBJECTID	ID number	ID number for each node from the original shapefile.
N	Node Number	Assigned Node ID in roadway network. Automatically created with node creation.

STOP_ID	Transit Stop ID	Designates this node as a transit node from original transit network. This field is automatically updated in accessibility analysis from transit network. No Updating necessary.
STOP_NAME	Transit Stop Name	Name of transit stop associated with this node from original transit network. Informational only, not used in accessibility analysis.
STOP_LAT	Transit Stop Latitude	Latitude of transit stop associated with this node from original transit network.
STOP_LON	Transit Stop Longitude	Longitude of transit stop associated with this node from original transit network
NID	Here Node ID	Original Here node ID. Informational only, not used in accessibility analysis
LINK_CNT	Link Count	Here Native attribute, signifies how many different streets are attached to this node. Informational only, not used in accessibility analysis
WALK	Walk Allowance	Binary, takes on AR_PEDEST link attribute value. This attribute will Automatically be updated on the backend when the accessibility analysis is ran.
BIKE	Bike Allowance	Binary, takes on BIKE link attribute value. This attribute will Automatically be updated on the backend when the accessibility analysis is ran.
BUS	Bus Allowance	Binary, takes on AR_Bus link attribute value. This attribute will automatically be updated on the backend when the accessibility analysis is ran.

APPENDIX D. SUGAR ACCESS PUBLIC TRANSIT NETWORK ATTRIBUTES

Table D.1. Sugar Access Public Transit Network Line Attributes

Field	**Definition**	**Description**
OBJECTID	ID number	ID number for each link from the original shapefile.

NAME	Name of Line	Unique string identifier for a transit line.
LONGNAME	Second Name	Second unique string identifier for a transit line.
MODE	Transit Mode	Integer indicating mode of transit line. Valid values range from 1-999. Does not affect accessibility analysis.
OPERATOR	Operator of Line	*Optional.* Integer indicating operator of the transit line. Valid values range from 1 to 999.
ONEWAY	One Way Indicator	*Optional.* Flag indicating whether line is one way. T – Coded line is a one-way line. F – Coded line is a two-way line. The reverse direction is treated as a separate line for processing.
CIRCULAR	Circular Indicator	*Optional.* Flag indicating whether a line is circular or linear. T - Program makes all nodes into stop nodes. F – Program uses node designation.
HEADWAY_1	AM Peak Headway	AM peak headway specified from GTFS file, averaged between 7-10 AM.
HEADWAY_2	PM Peak Headway	PM peak headway specified from GTFS file, averaged between 4-8 PM.
HEADWAY_3	Midday Headway	Midday headway specified from GTFS file, averaged between 10 AM-4 PM.
HEADWAY_4	Evening Headway	Off peak headway specified from GTFS file, averaged between 8 PM-1 AM.
HEADWAY_5	Daily Average Headway	Daily headway specified from GTFS file, average across entire day.
XYSPEED	Line Speed	*Optional.* Speed on qualified links in this transit line. Valid values range from 1 to 300. Defaulted to 20 for Sugar Access.

Table D.2. Sugar Access Public Transit Network Link Attributes

Field	**Definition**	**Description**
OBJECTID	ID number	ID number for each node from the original shapefile.
A	A Node	Start node of transit link, references same node number as roadway network.
B	B Node	End node of transit link, references same node number as roadway

		network.
LINEID	Associated Line	Link's associated transit line.
SEQNO	Sequence Number	Sequence of link in transit line relative to the links in the line.

Table D.3. Sugar Access Public Transit Network Node Attributes

Field	**Definition**	**Description**
OBJECTID	ID number	ID number for each node from the original shapefile.
LINEID	Associated Line	Node's associated transit line.
SEQNO	Sequence Number	Sequence of node in transit line relative to the nodes in the line.
STOPNODE	Stop Indicator	Indicator for whether node is a stop or not. Check box to allow access to the transit line. Not checking the box will indicate that transit line does not stop at this node.
NODES	Node Number	Transit node number, references the same node number as the roadway network.
RT	Run Time	*Optional.* Intermediate run time from the line's first node to the most recently coded node. Valid values are numbers greater than or equal to 1.

APPENDIX E. ND ROADWAY NETWORK, ZONAL, AND POI DATA

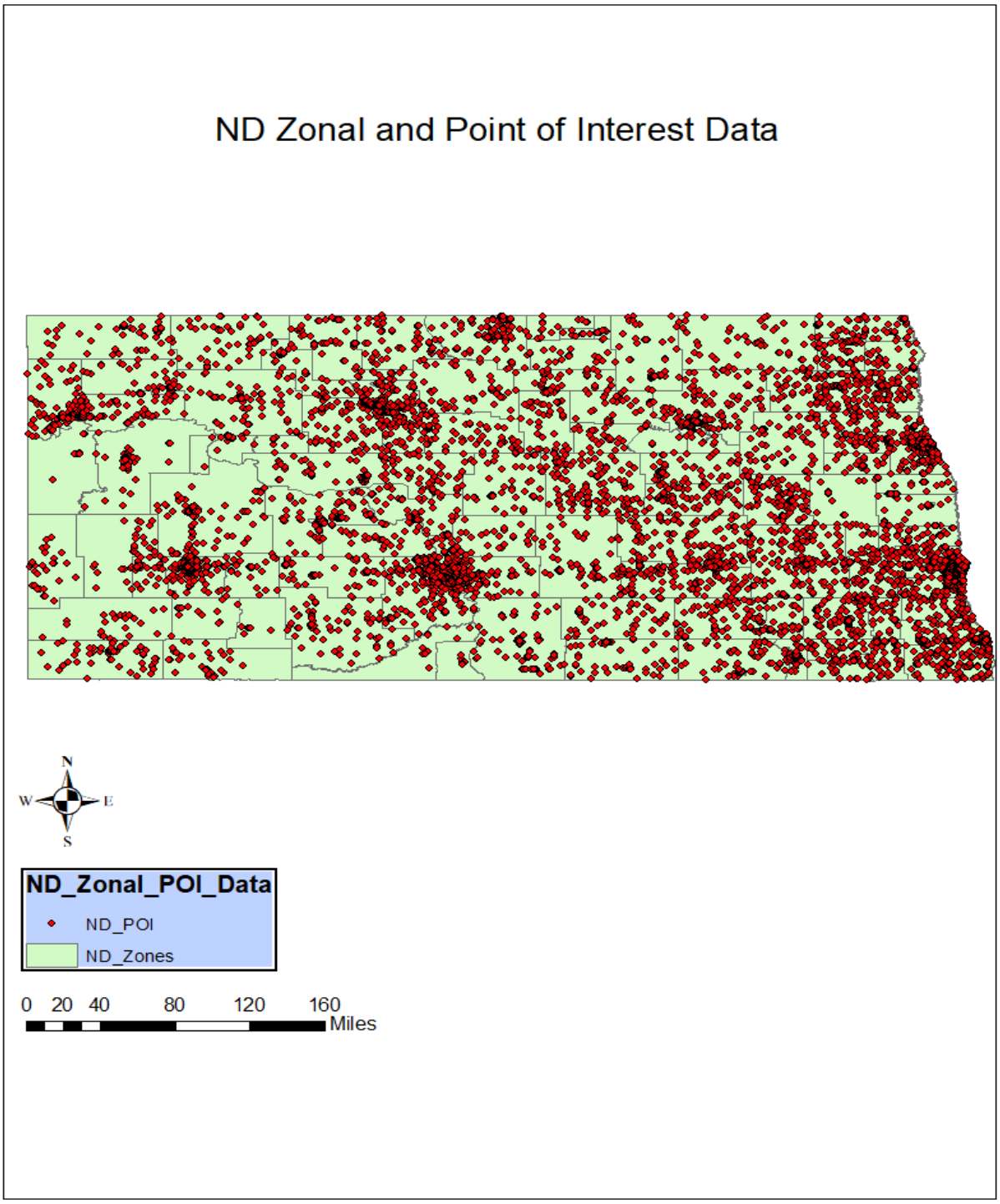

Figure E.1. North Dakota Zones and Point of Interest Data

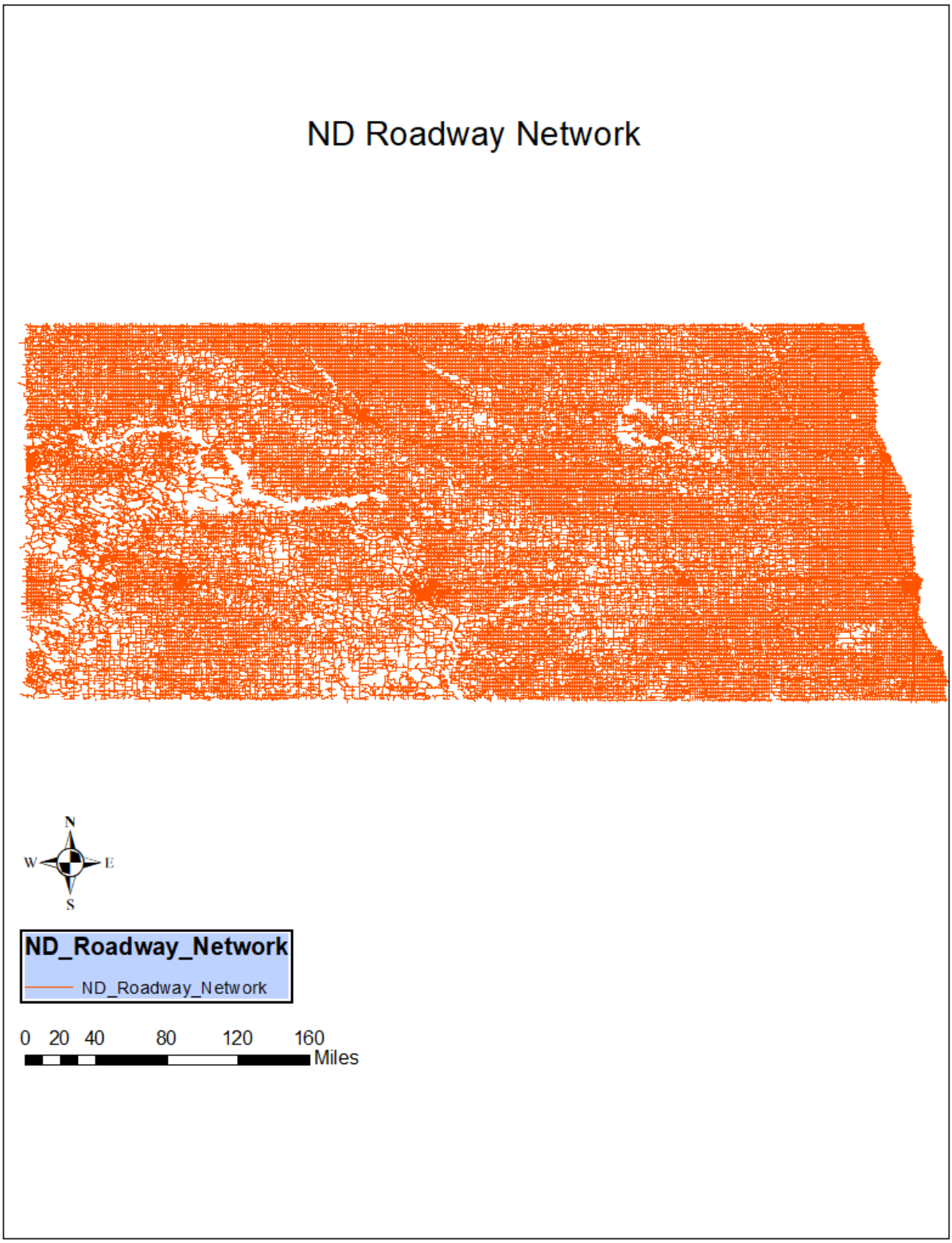

Figure E.2. North Dakota Roadway Network

APPENDIX F. MPOS ROADWAY NETWROK, PUBLIC TRANSIT NETWORK, ZONAL, AND POI DATA

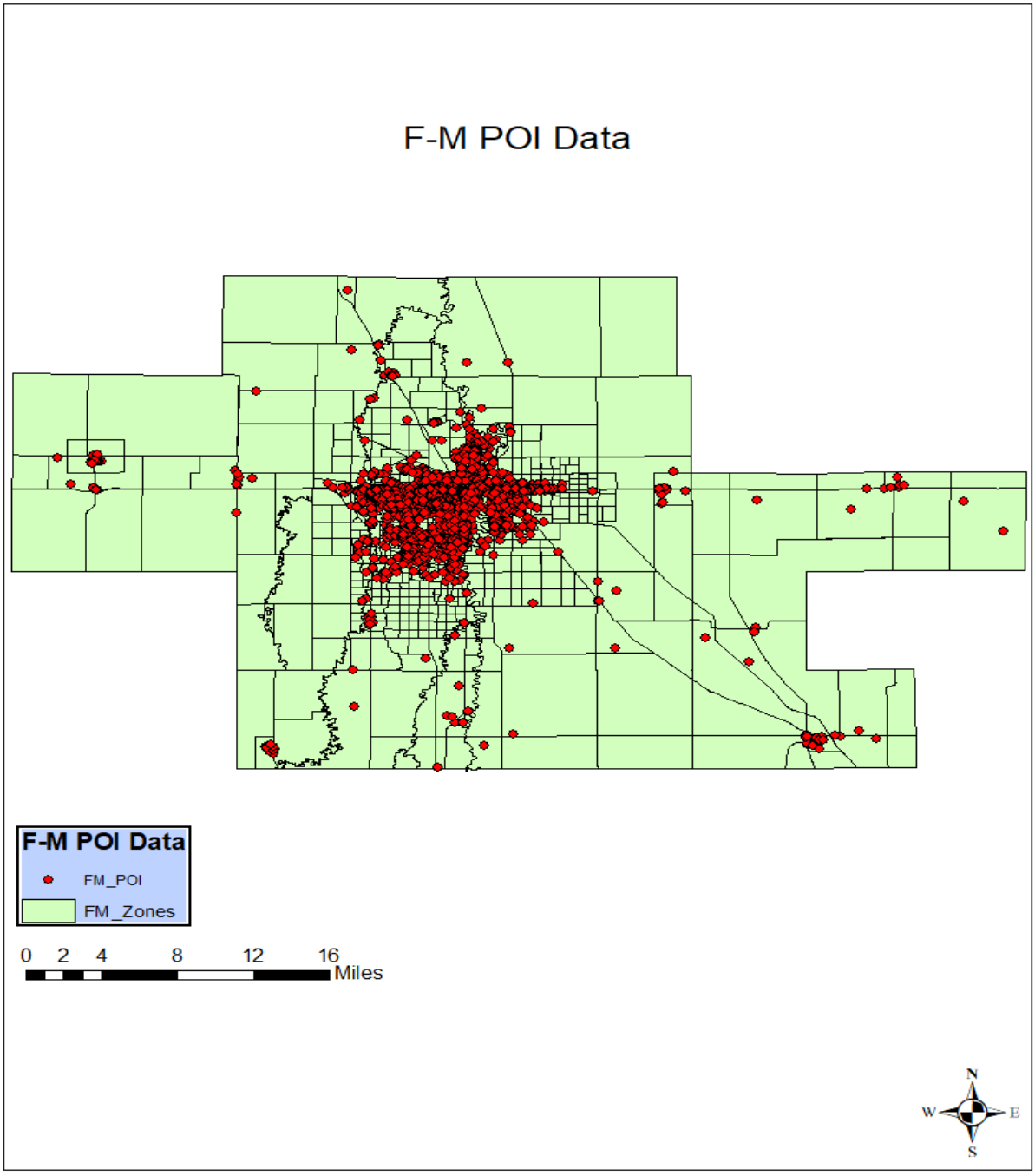

Figure F.1. F-M POI Data

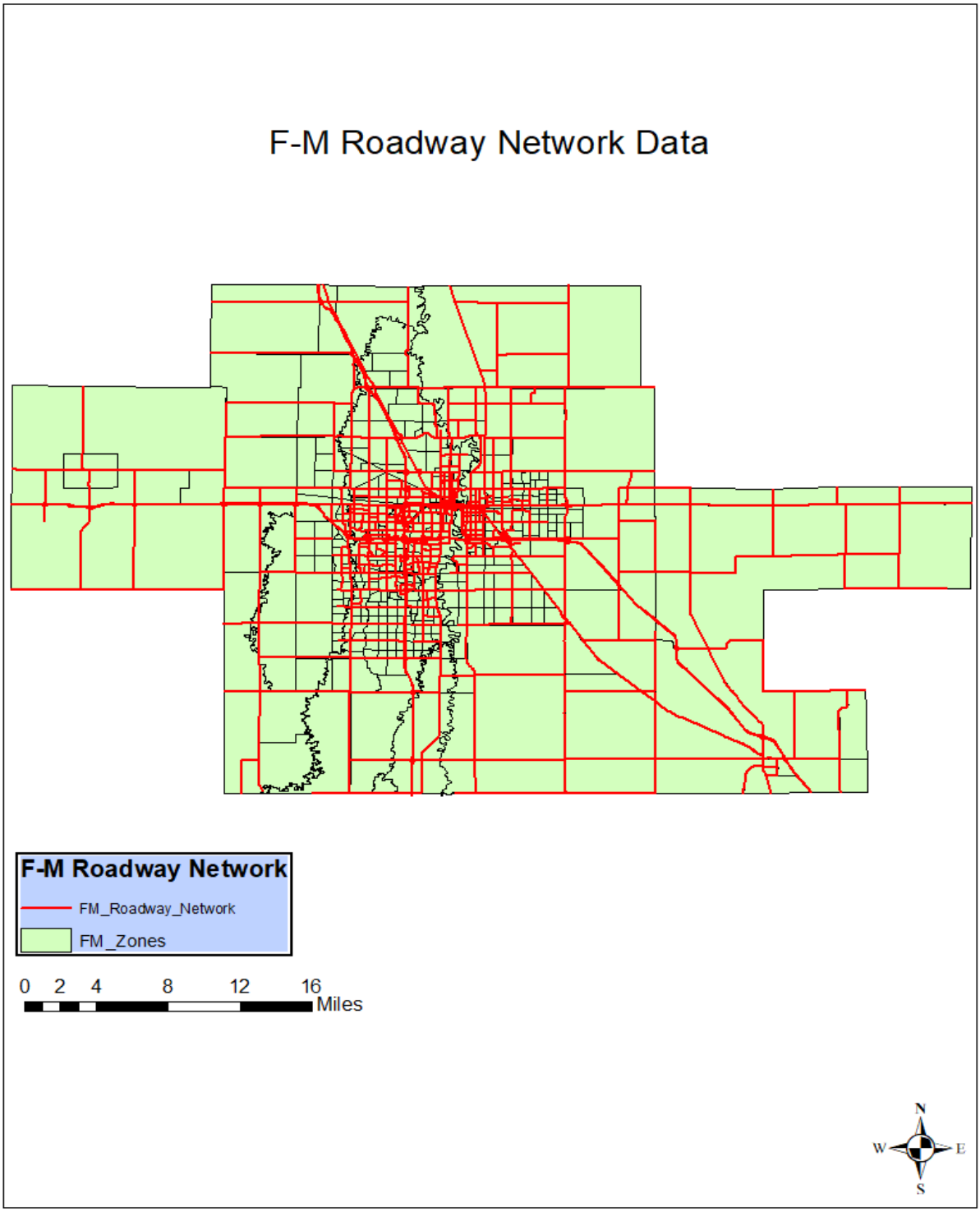

Figure F.2. F-M Roadway Network Data

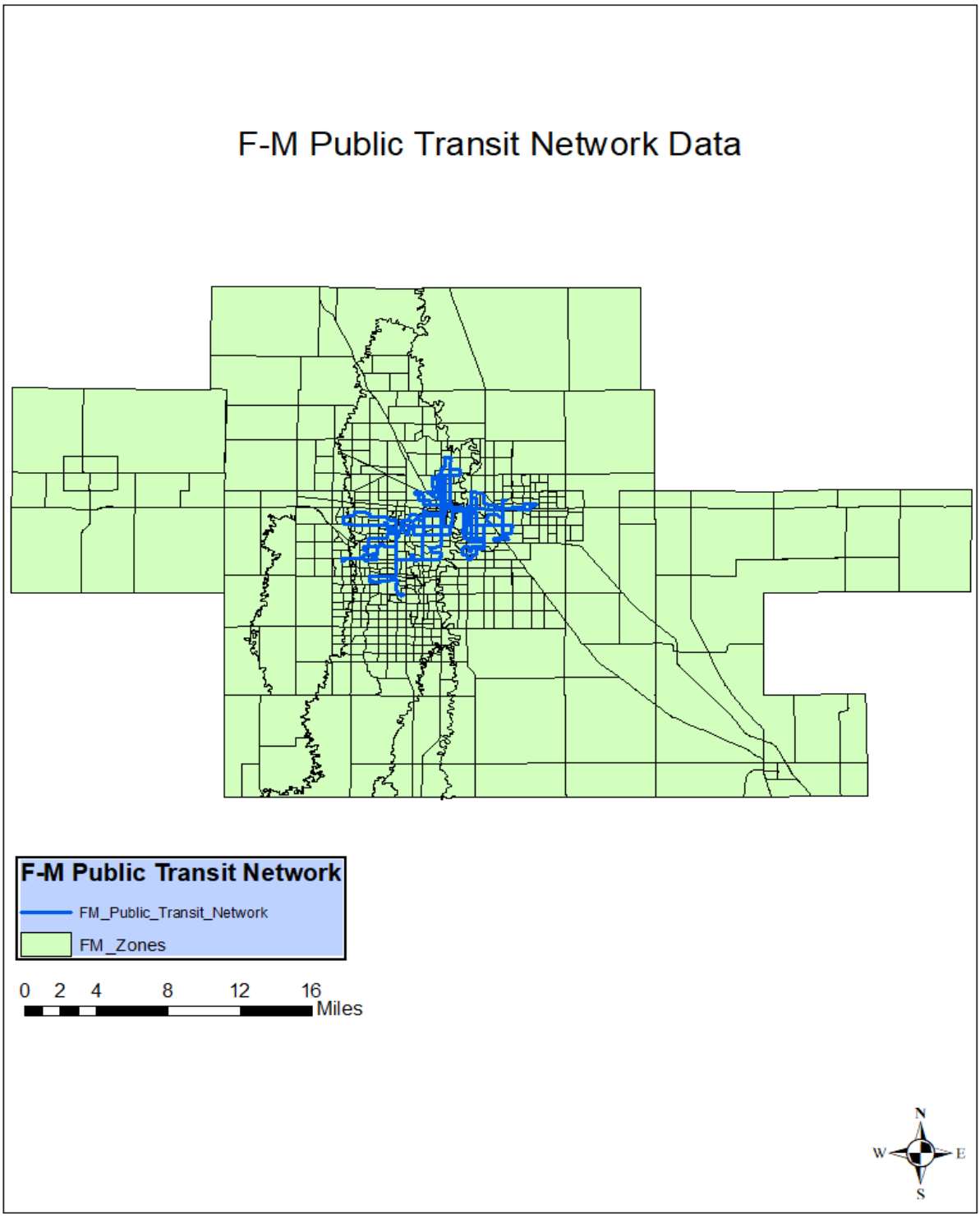

Figure F.3. F-M Public Transit Network

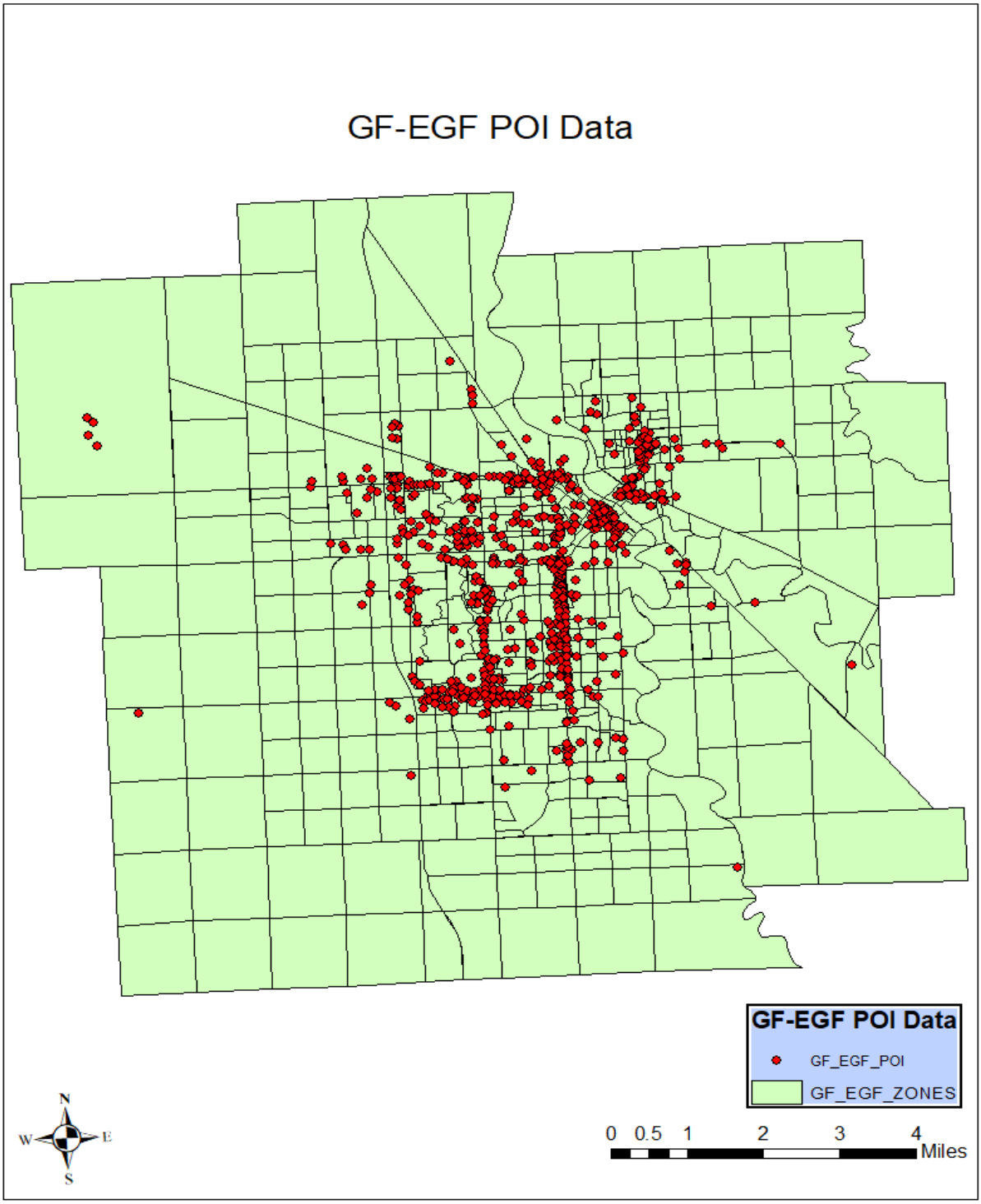

Figure F.4. GF-EGF POI Data

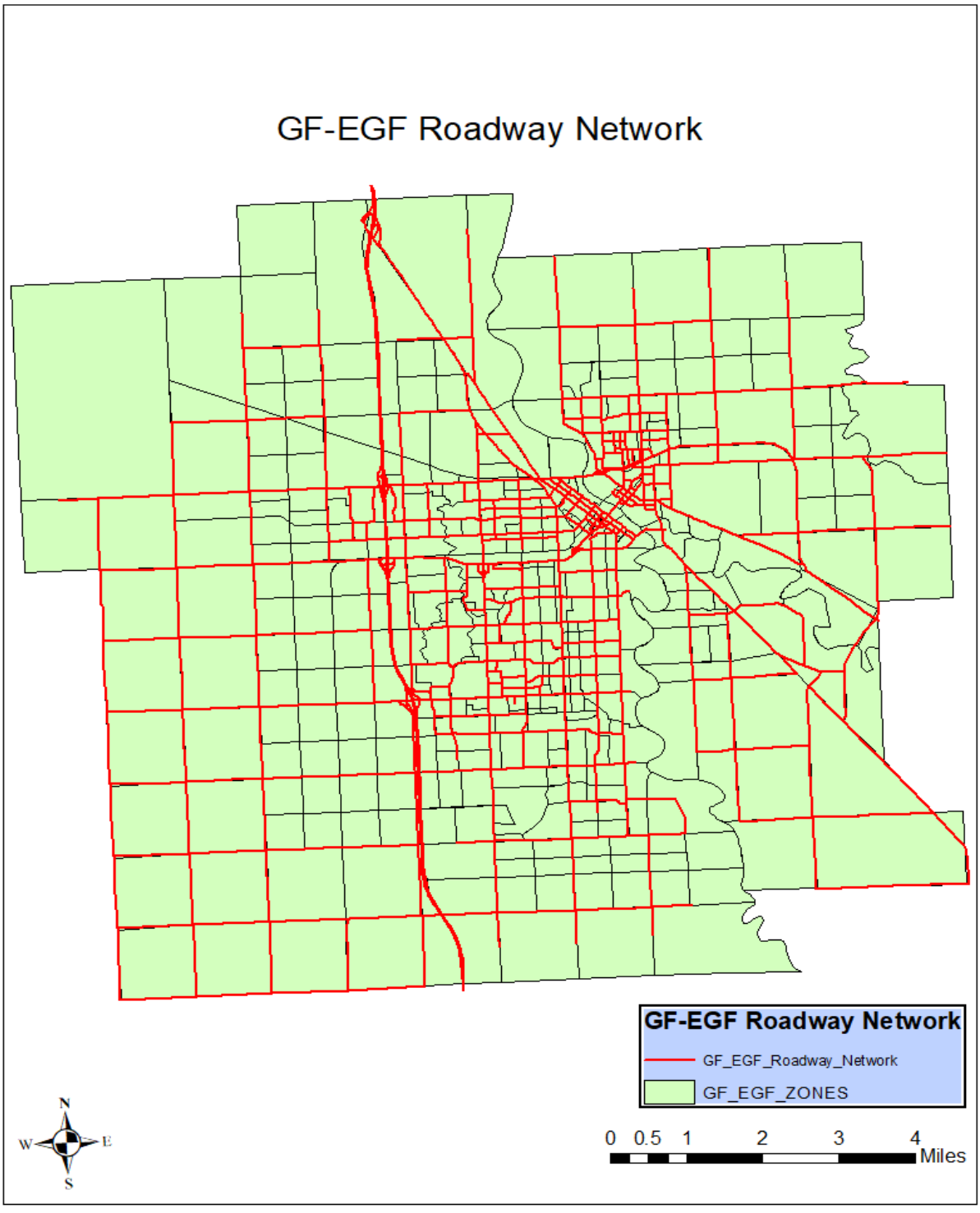

Figure F.5. GF-EGF Roadway Network

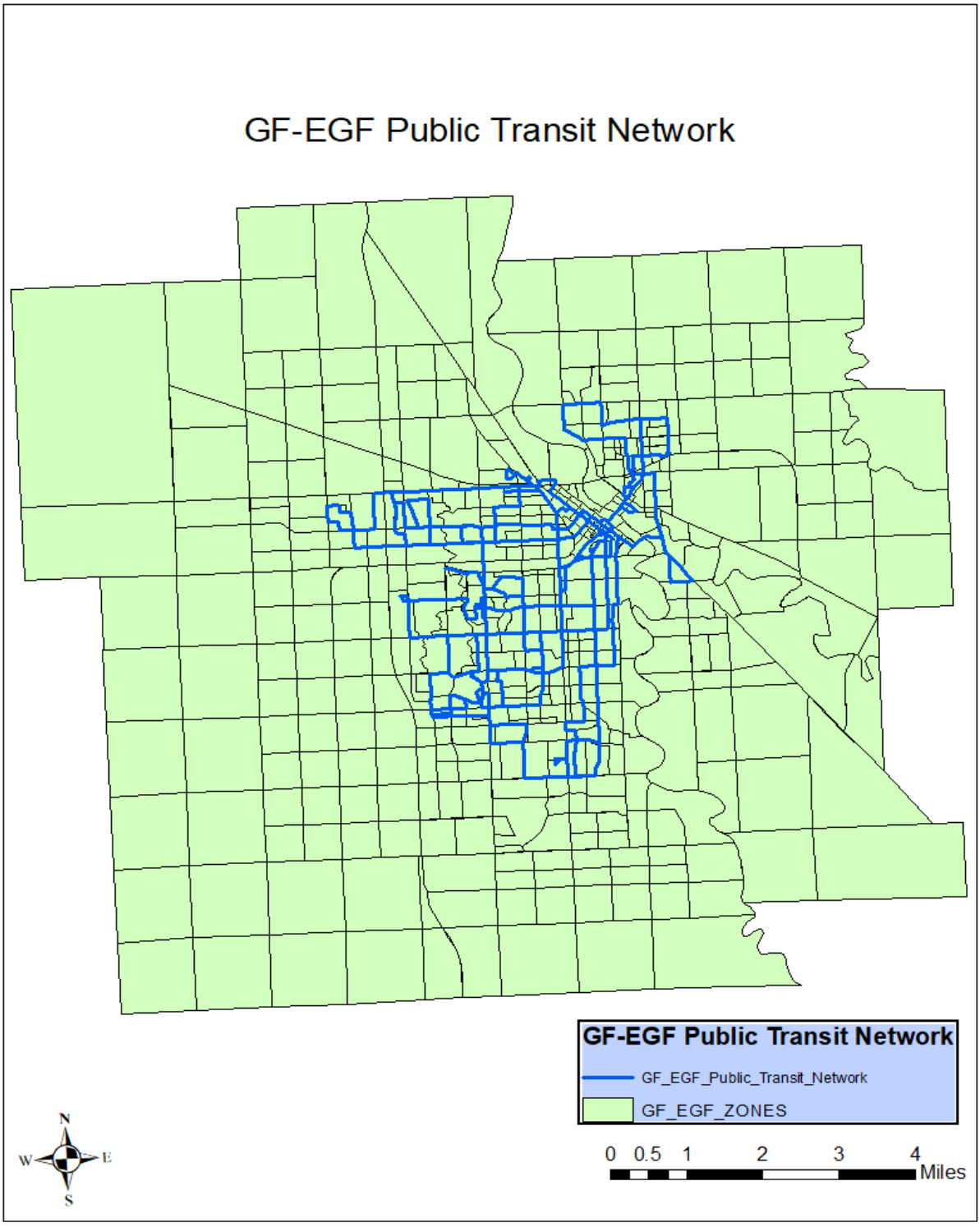

Figure F.6. GF-EGF Public Transit Network

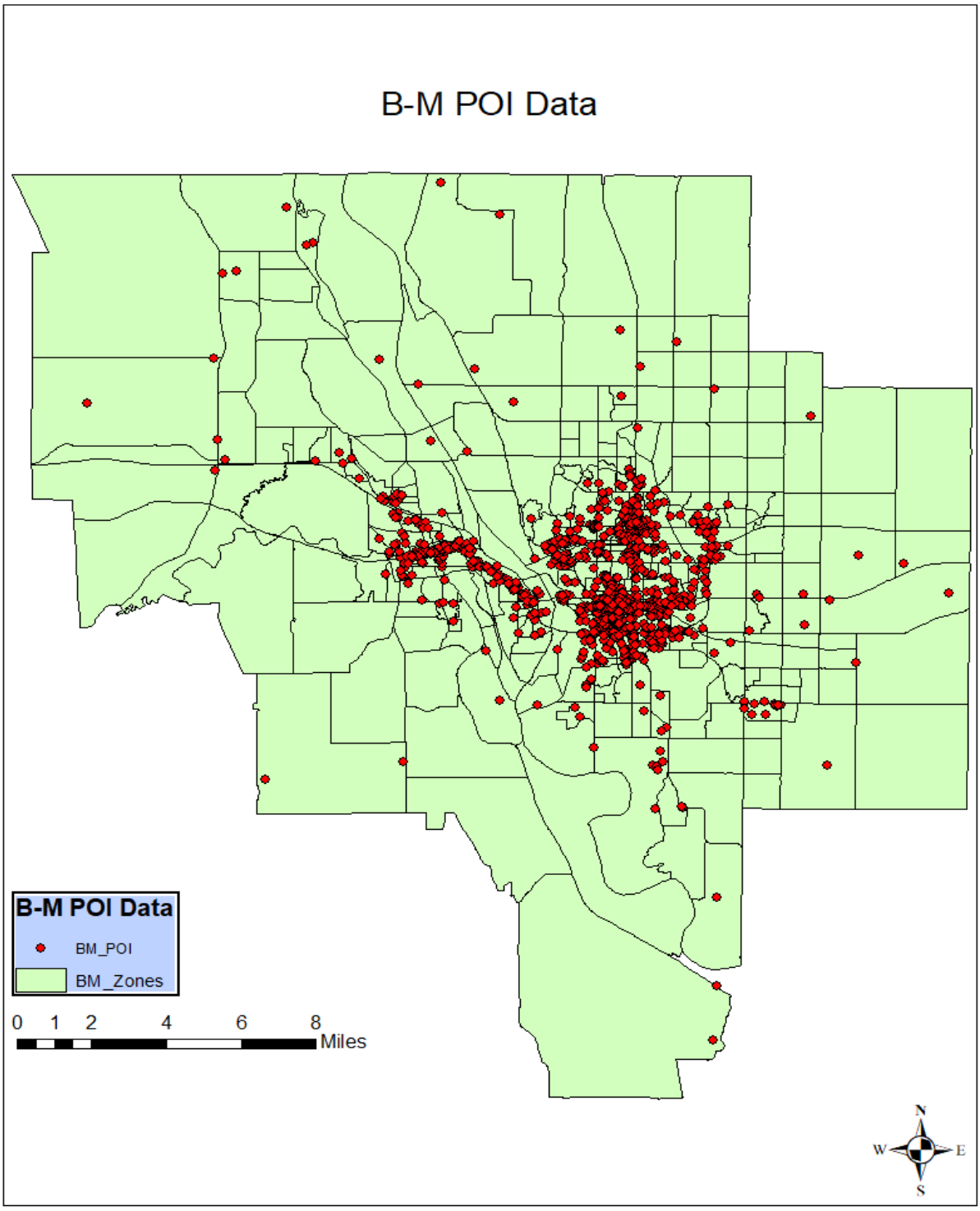

Figure F.7. B-M POI Data

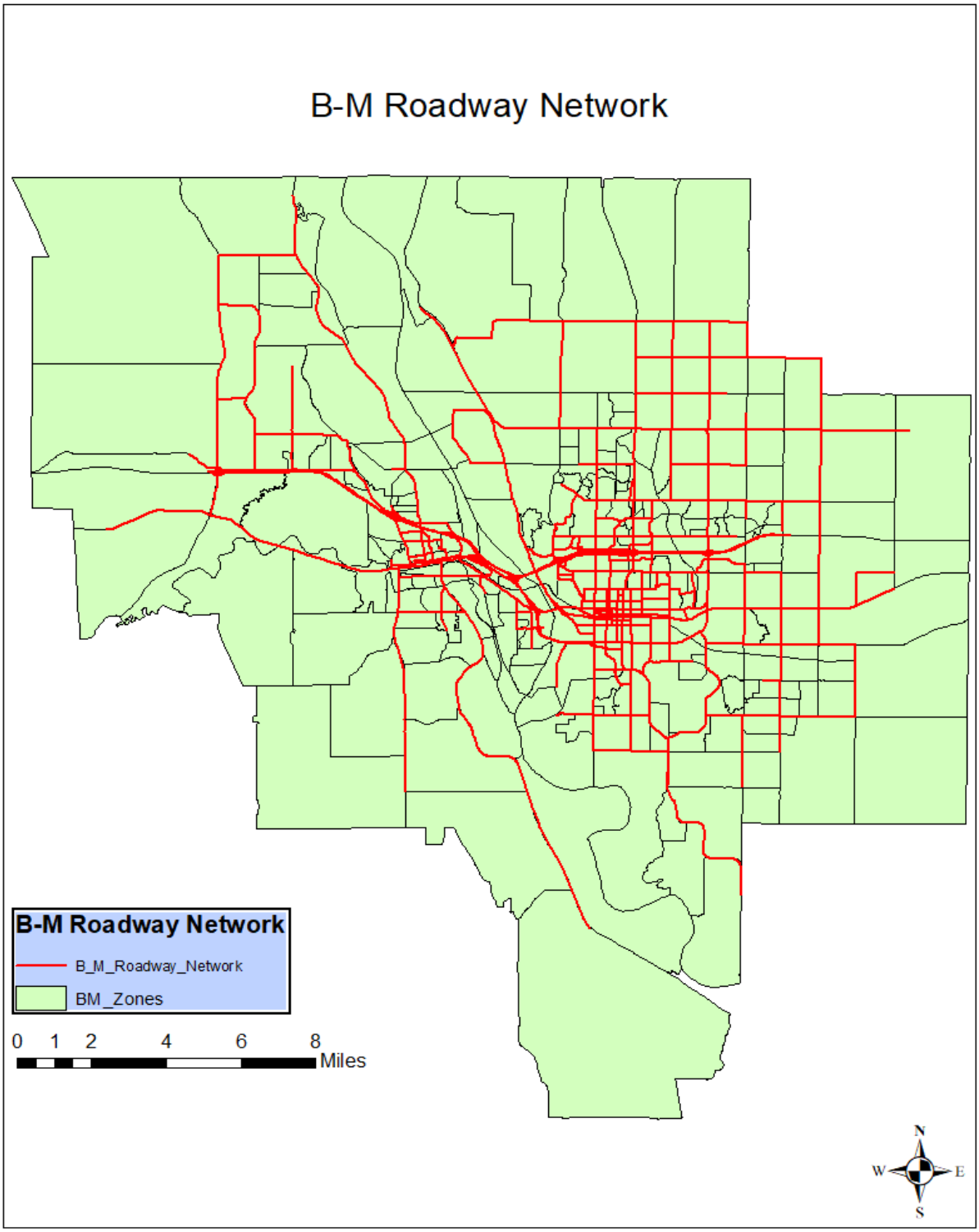

Figure F.8. B-M Roadway Network