Service Area Analysis for Fire Stations in Evanston, Illinois

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Abstract

This project demonstrates how a service area analysis is performed in ArcGIS for fire station service areas, and then applies the technique to Evanston, Illinois. It discusses the importance of response time and addresses other factors that are relevant to a service area analysis, including population density and staffing.

Introduction

Service area analysis can be used to calculate travel times along a network from one or more service locations. A common application of such an analysis is to calculate response times for fire trucks and other emergency vehicles in a community (Mitchell, 1999).

This type of analysis is also called "Travel Time Modeling" (ESRI, 2007) since the goal is to predict *response times* for each area—that is, how much time it would take a fire truck or other emergency vehicle to reach an incident a given distance from the fire station.

Project Description

Statement of the Problem

Fire and other emergency response times are important because a fire can reach its most dangerous stage (called "flashover") in about 8 to 10 minutes (Hensler, 2008); any delay in reaching a fire site increases the risk of loss of life and/or property.

The National Fire Protection Association (NFPA) has established standard response times for fire fighters. Generally speaking, the NFPA recommends that the first fire engine reach a fire within 6 minutes (Dedman, 2005; ESRI, 2007; Hensler, 2008). This time includes dispatch time (1 minute), turnout time (1 minute), and travel time (4 minutes). It's important to note that the response time calculated by ArcGIS typically refers only to the travel time portion of the calculation.

While response time is an important part of conducting a service analysis, a community must address several questions when deciding how to deploy its fire services:

- What types of services are delivered by the fire department?
- What is a reasonable travel time for the community?
- What is the size of the area being served and the type and amount of resources available?

- What level of risk is the community willing to accept?

  (ESRI, 2007)

Purpose of the Project

This project seeks to answer three questions (which determine the project's structure):

1. How does one use ArcGIS to perform a service analysis? In this section I demonstrate how to use ArcGIS to perform a service analysis (based on the hypothetical scenario of a single fire station in Evanston, Illinois).

2. Do Evanston's current fire station service areas meet response time standards established by the NFPA? In this section I apply ArcGIS service analysis techniques to the actual five fire stations in Evanston, Illinois.

3. What factors other than response time might influence how we think about Evanston's service areas? In this section I examine other factors related to fire station service areas:
    - Response and response density
    - Area of the service areas
    - Population density of the service areas
    - Staffing and equipment allocation to each service area

Here is some basic information about Evanston, Illinois:

- General Information
    - Population: 74,239 (2000 Census)
    - Area: 7.8 sq. miles
    - Miles of Streets: 147
    - Miles of Alleys: 76
- Fire Protection
    - Number of Firefighters: 107
    - Number of Stations: 5
    - Responses in 2006: 8,099 (3,364 Fire + 4,735 EMS)

Methodology for Parts 1 and 2

Parts 1 and 2 follow the same methodology so I've grouped them together for this discussion. I'll discuss Part 3's methodology later.

The procedures used for Parts 1 and 2 are as follows:

1. Obtain and modify the necessary data
    a. Obtain TIGER/Line shapefiles for Illinois, Cook County, and county subdivisions
        i. Select Evanston area in ArcMap
        ii. Remove non-road "edges" (railroads, "El" tracks, rivers, shorelines, etc.) [see below for more information]
        iii. Prepare a cost field for travel time based on speed limits of each road segment [see below for details]
    b. Create point shapefile for Evanston fire station locations
2. Prepare the network files in ArcCatalog
    a. Create a Personal Geodatabase
    b. Create Feature Dataset
    c. Import street data from TIGER/Line shapefile
    d. Import fire station(s)
    e. Create the Network Dataset
3. Create the service area map in ArcMap
    a. Import the Network Dataset and related files
    b. Start Network Analyst extension
    c. Create a new Service Area
    d. Load Locations (the fire stations)
    e. Enter desired default breaks for travel time ("response time") in the Layer Properties dialog
        - I chose breaks of 1, 2, 4, 6 and 8 minutes for Part 1
        - I chose breaks of 1, 2 and 4 minutes for Part 2
    f. Adjust polygon properties (overlapping, etc.) in the Layer Properties dialog
    g. Solve the Network

A couple of these steps are worth discussing in more detail.

Data preparation

It's important to remove all non-road edges (railroads, "El" tracks, rivers, shorelines, etc.). If these edges are not removed, the resulting service area will be very inaccurate as shown in Figure 1.

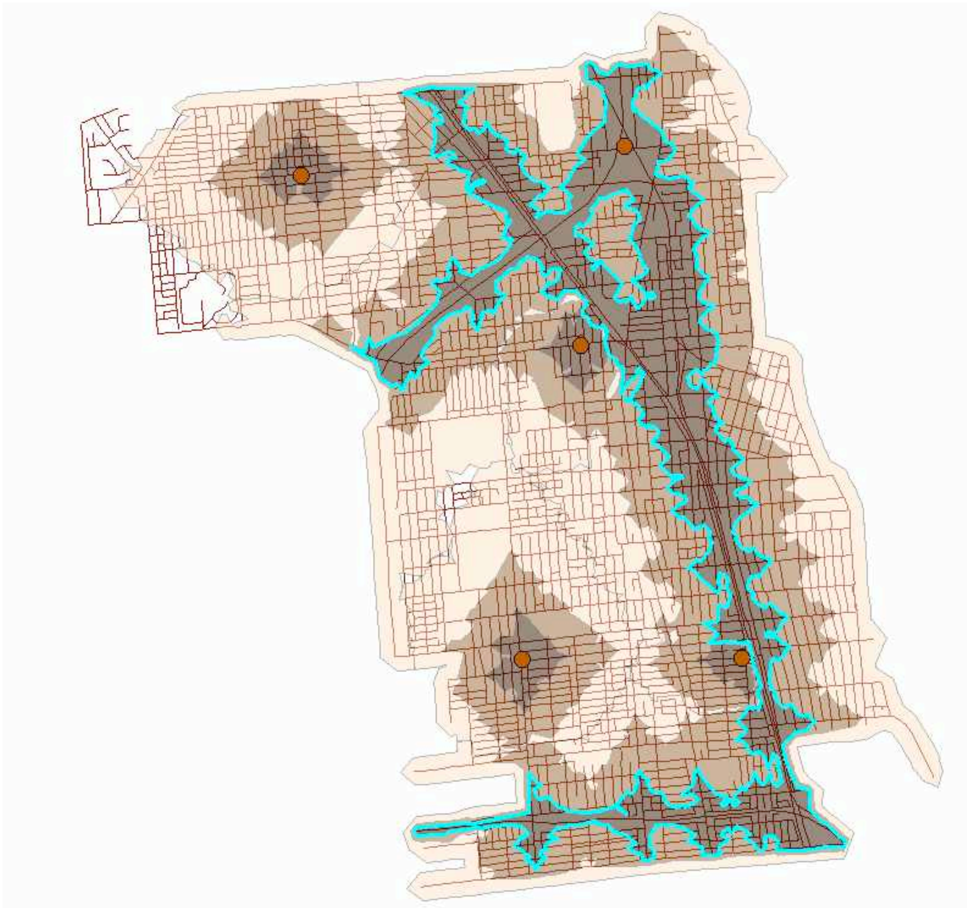

Figure 1. Map highlighting the unusually elongated (and inaccurate) service area of a fire station. The error is due to the accidental inclusion of railroad edges in the shapefile.

Travel Time as Cost

A service area analysis can be performed using only the length of a road segments as the basis for an emergency route's "cost" or "impedance": the longer the route, the higher the cost (i.e., higher response time). To achieve more precision in this cost calculation, other variables can be used, including speed limits, turns, traffic signals and one-way streets (Mitchell, 1999).

For this project I used travel time. To determine travel time, I have to know the speed limits for all the roads in my network. The roads shape file included a length field, but not a speed limit field. I had to create "speed limit" field and enter speed limits into the attribute table for each of my roads:

- Alleys: 15 mph
- Residential streets: 25 mph
- Main roads (Sheridan, Ridge, Asbury, Dodge): 30 mph

I obtained these figures through personal knowledge of Evanston.

Then I created a cost field called "travel time," and calculated the values using the formula

$$\text{Travel Time} = \text{length} \;/\; (\text{speed limit} * 5280 \;/\; 60)$$

The resulting attribute table is shown in Figure 2.

Attributes of evanston_edges_export

FULLNAME	length (feet)	speed limit (mph	travel time (min)	S
Alley	110	15	0.083	32
Wesley Ave	108	25	0.049	32
Greenleaf St	309	25	0.141	32
Alley	435	15	0.33	32
Alley	140	15	0.106	32
Emerson St	204	25	0.093	32
Alley	206	15	0.156	32
Alley	209	15	0.158	32
Church St	450	25	0.205	32
Church St	205	25	0.093	32
Davis St	198	25	0.09	32

Figure 2. Attribute table for Evanston streets/edges shapefile, with added fields "length," "speed limit" and "travel time."

ArcGIS automatically recognizes travel time (in minutes) as a “cost” field when creating the Network (see Figure 3).

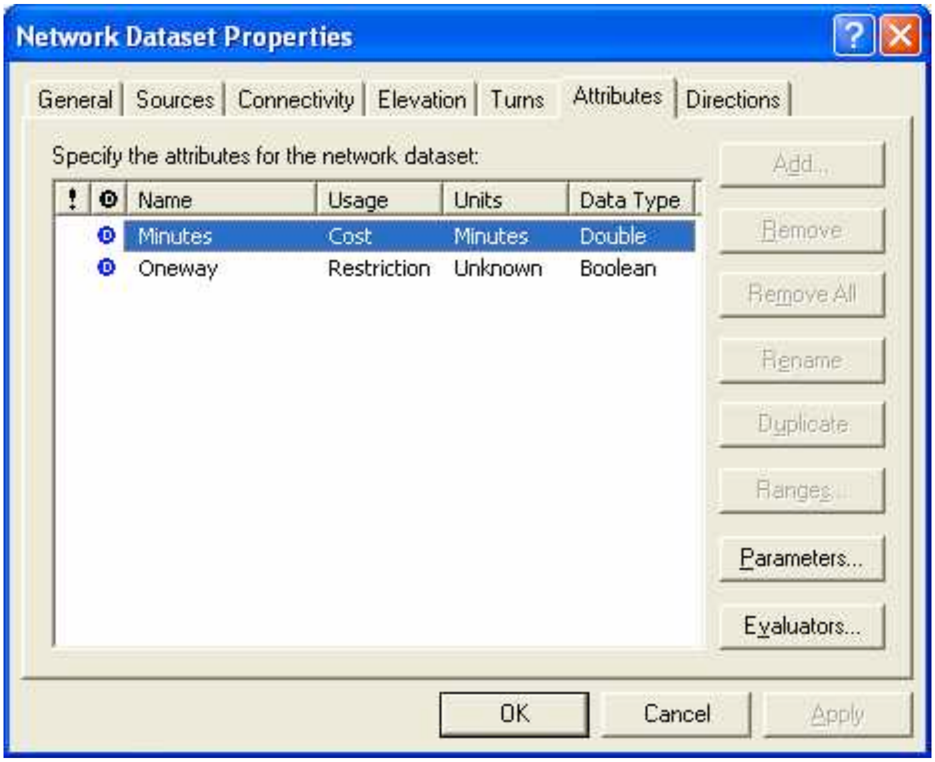

Figure 3. Network Dataset Properties dialog showing the field used to calculate the “cost” of traveling along the network.

Results for Part 1 and 2

The results for Parts 1 and 2 are shown as maps (see Figures 4 and 5).

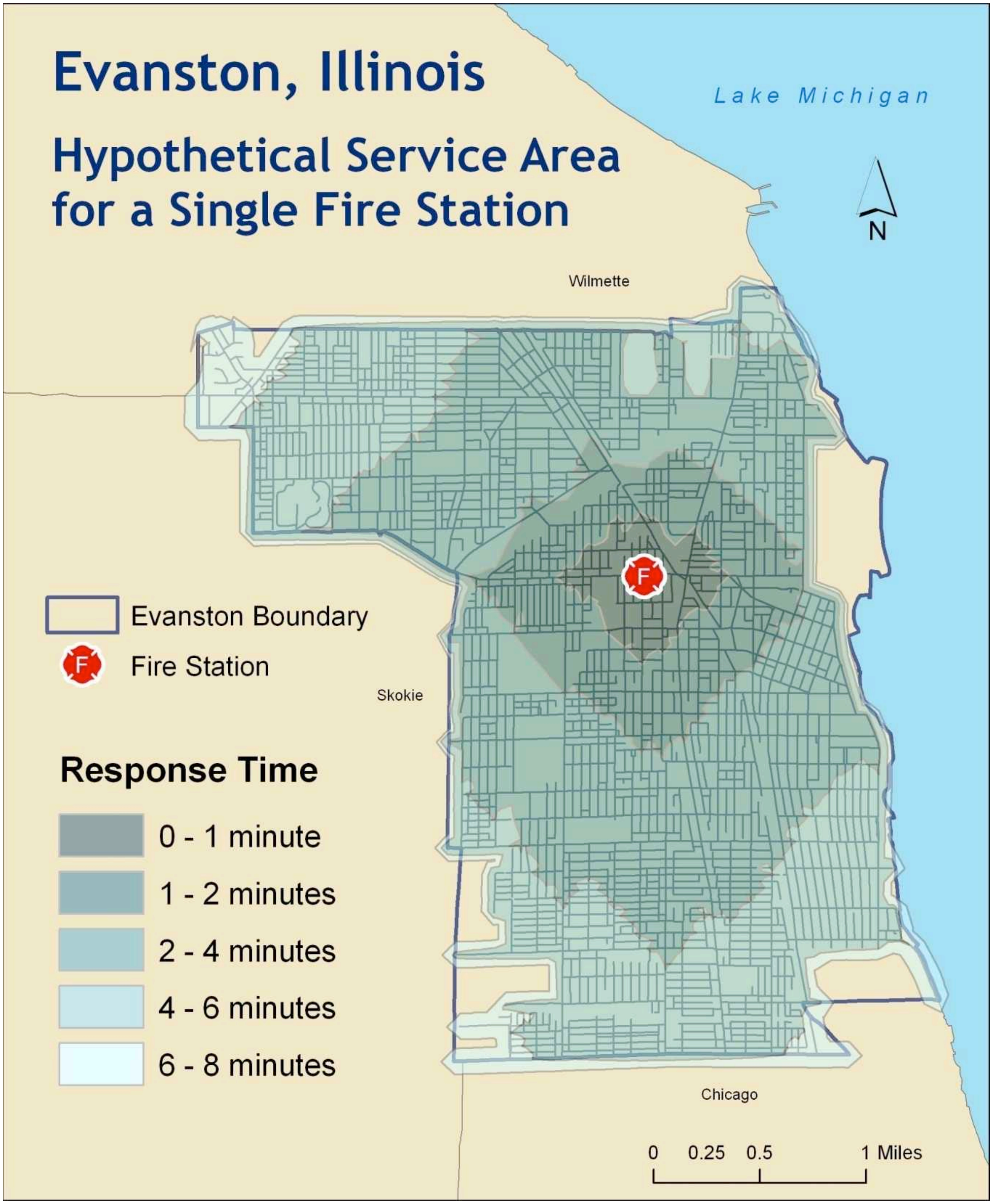

Figure 4. Map for Part 1: "Hypothetical Service Area for a Single Fire Station."

The map for Part 1 (Figure 4) demonstrates that a single fire station would not be sufficient to service the entire city of Evanston because two area rings have response times that exceed the recommended response (travel) time of 4 minutes.

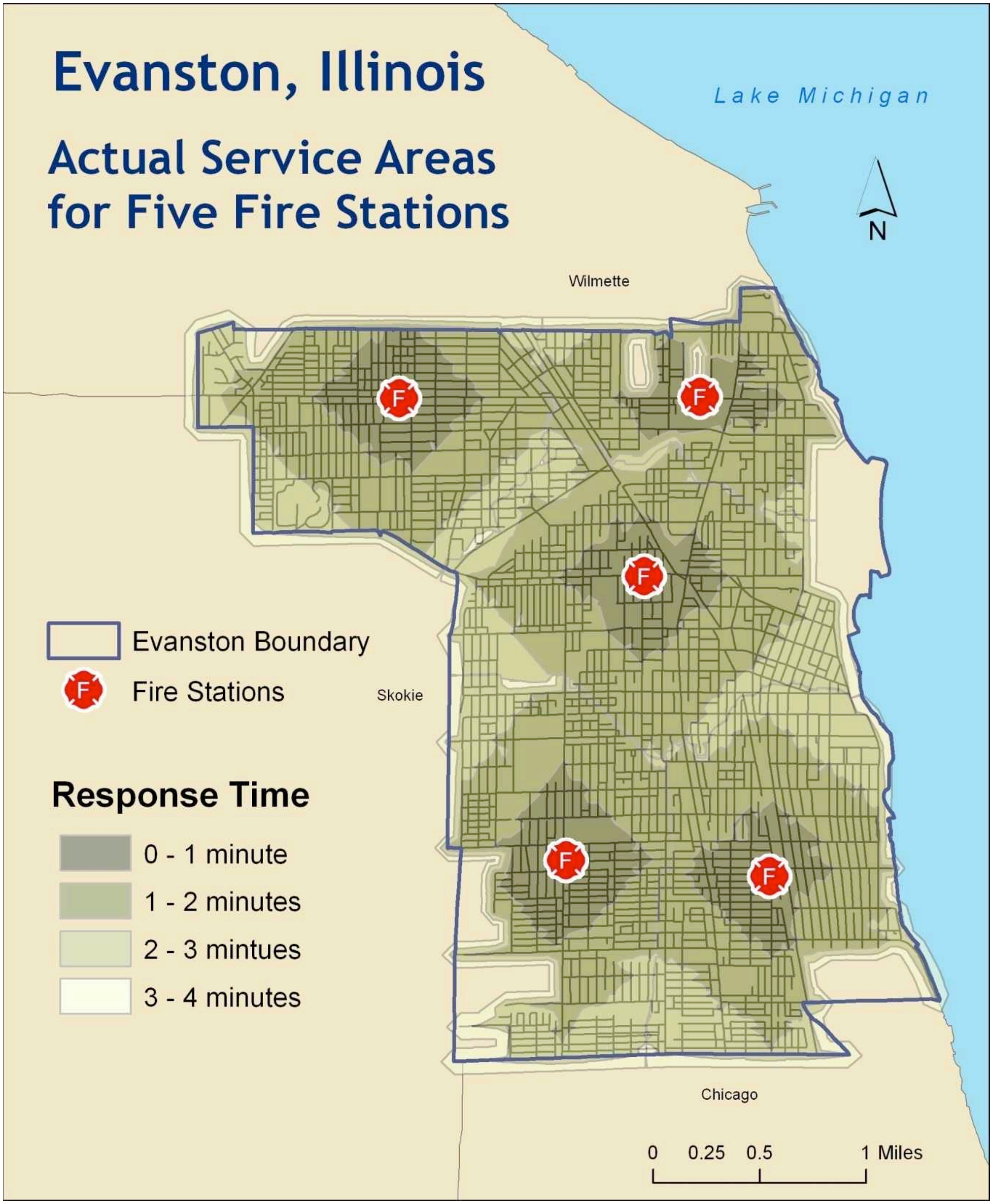

Figure 5. Map for Part 2: "Actual Service Areas for Five Fire Stations."

The map for Part 2 (Figure 5) predicts that all of Evanston's fire station service areas should satisfy the recommended response (travel) time of 4 minutes. In fact, Evanston's actual average response time supports this prediction: the city's actual average response time is 3 minutes, 45 seconds (City of Evanston, 2010).

Methodology and Results for Part 3

In Part 3 of my project I address other factors such as area, population and staffing. The methodology involves using census data and ArcGIS's selection and editing tools to create several maps:

- **Map A**: Typical Monthly Response Density by Census Tract
- **Map B**: Population Density by Census Tract
- **Map C**: Fire Station Service Areas—Area Comparison (Adjusted to include Associated Census Blocks)
- **Map D**: Fire Station Service Areas—Population Density Comparison (Based on Associated Census Blocks)
- **Map E**: Station Staffing/Equipment Levels Compared to Population Density (Adjusted to Include Census Blocks)

I'll discuss the methodology of each map next.

Map A: Typical Monthly Response Density by Census Tract

Map A addresses the question: "Which parts of the city generate the most emergency calls and fire station responses?"

Here's the methodology for map A:

1. Obtain tract census data for Cook County
2. Obtain response data for Evanston Fire Department [see below for more information]
3. Select data for Evanston area
4. Create new fields for response numbers and response density
5. Create map based on existing area field

The City of Evanston does not provide response data for "service area," but it does provide monthly data for census tracts (see Figure 6).

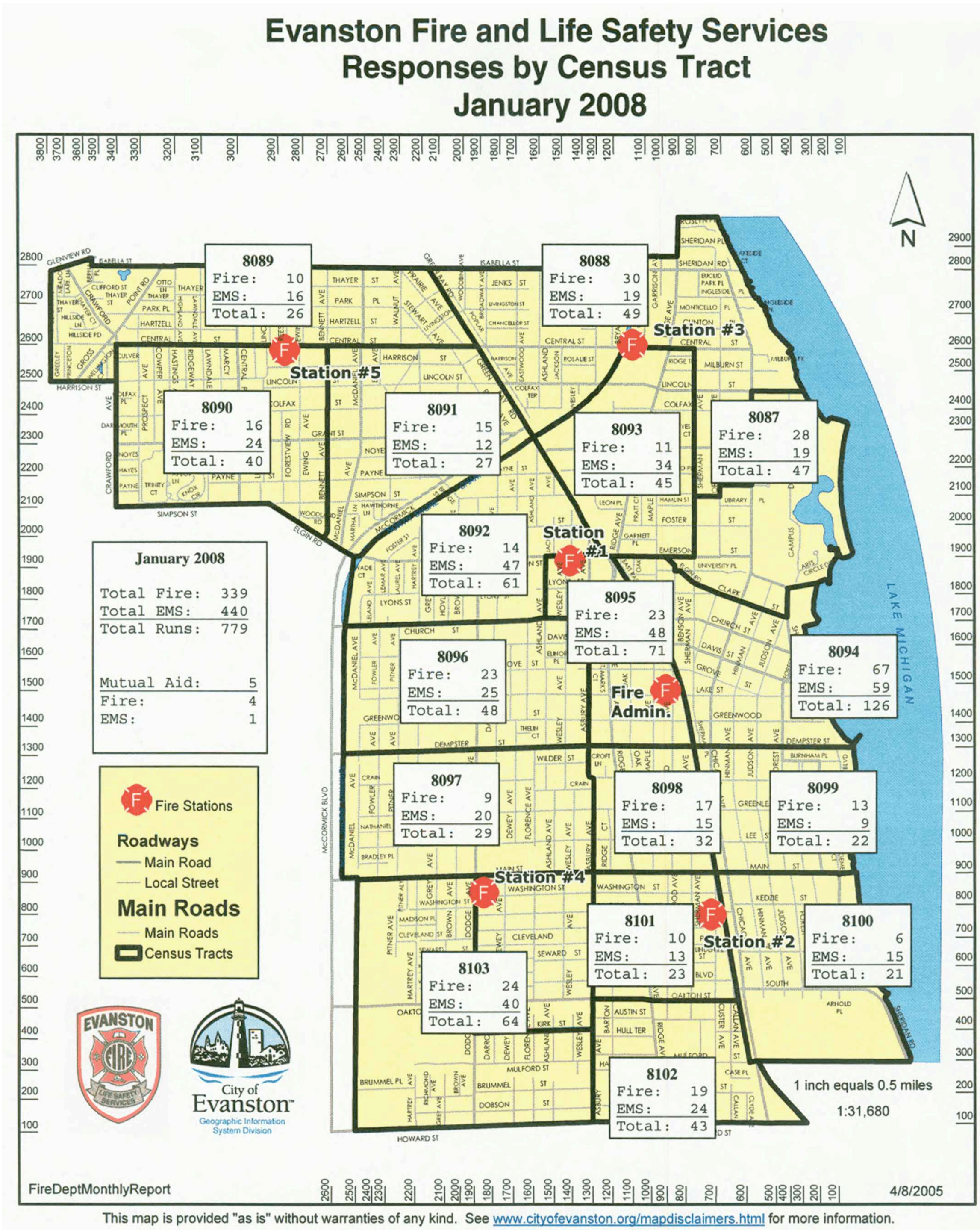

Figure 6. City of Evanston map, “Evanston Fire and Life Safety Services, Responses by Census Tract, January 2008” (City of Evanston, 2010).

It’s hard to tell from this map whether some tracts receive proportionally more calls than others, or whether responses are related to population. I created a new map based on this data to show response density (see Figure 7).

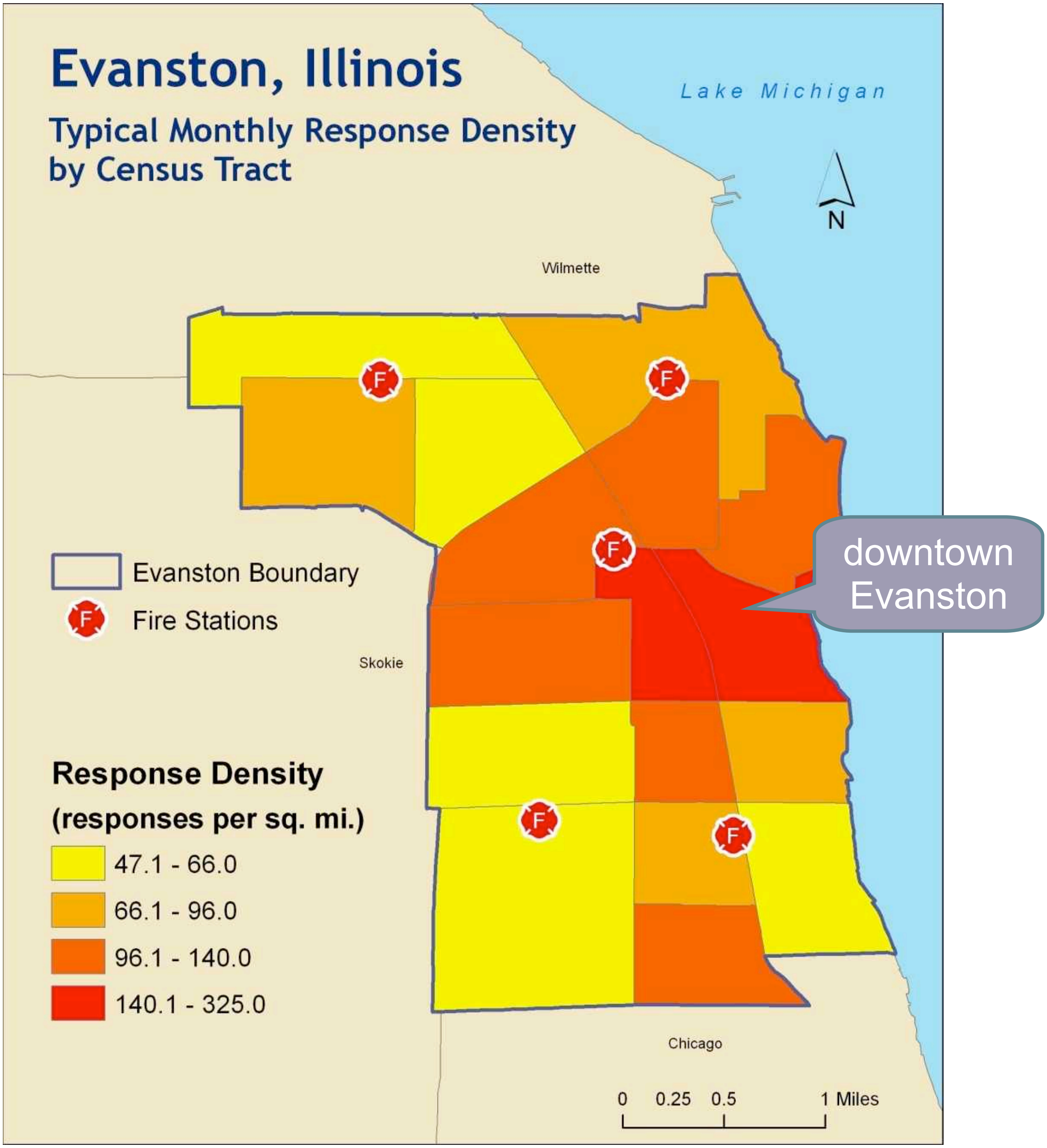

Figure 7. Map A: “Typical Monthly Response Density by Census Tract.”

Map A (Figure 7) shows that the downtown area is the source of the highest number of emergency calls per square mile. The density varies significantly from tract to tract. Could this data be related to population? To find out, I created a population density map (discussed next).

Map B: Population Density by Census Tract

Map B addresses the question, "Which parts of the city are the most densely populated?"

The methodology for Map B:

1. Obtain tract census data for Cook County
2. Select data for Evanston area
3. Create map based on newly-created population density field

The results are shown in Figure 8.

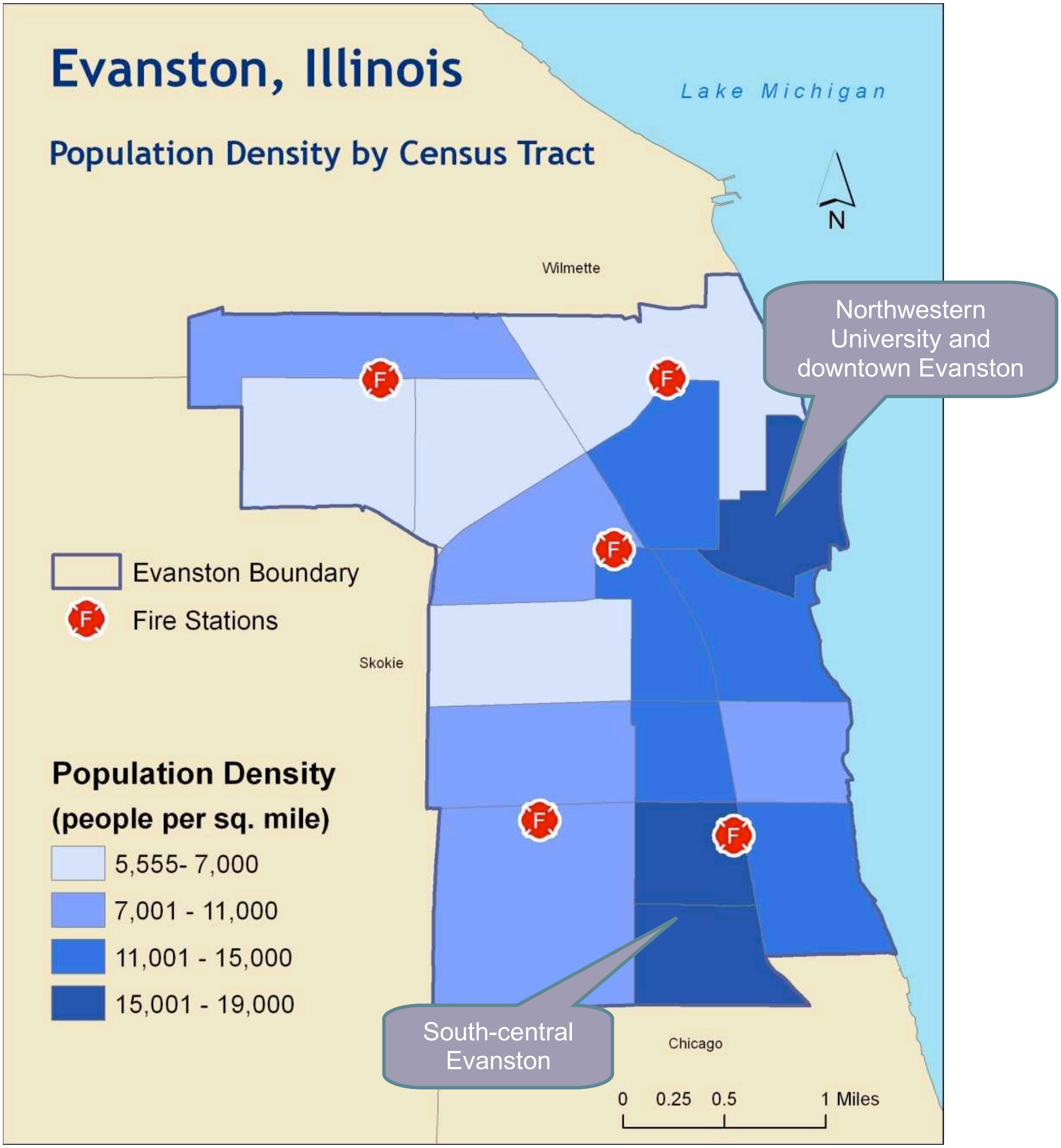

Figure 8. Map B: "Population Density by Census Tract."

The population density map (see Figure 8) shows the highest population density in the downtown area and the Northwestern University campus, as well as two tracts in south central Evanston.

Comparing maps A and B side by side (Figure 9) we see that tracts with high response density generally correspond to the more densely populated tracts, but the correlation isn't perfect.

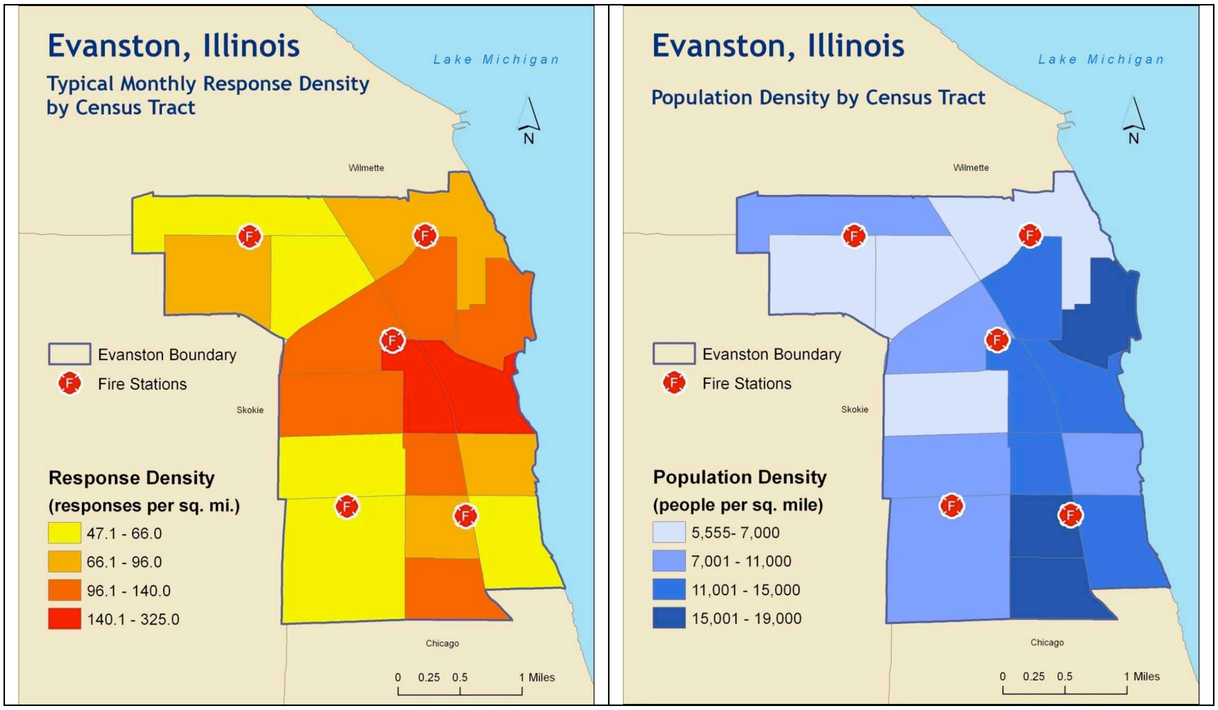

Figure 9. Comparison of Maps A and B.

Maps C, D, and E

So how do I compare this tract information with my service areas? I don't have more detailed spatial data for responses, so I decide to continue my analysis using population data at the block level. I decide to create new polygons based on the total extent of the service areas and the census blocks with which they are associated.

The methodology for maps C, D, and E:

1. Obtain block census data for Cook County
2. Select data for Evanston area
3. Create new shape files for the total extent of each service area (i.e., all the rings for the area)
4. Match each service area to its associated census blocks
    - "Select by Location" all blocks whose centroid falls within a given service area, and export selection data to create five new shape files.
    - This step has the affect of slightly changing both the area and topology of each service area [see below]
5. Use the "Append" tool to combine the new shape files into a single shape file for mapping purposes

6. Obtain staffing and equipment data for each fire station (for Map E)
7. Create map based on the appropriate field(s)

Because the original network dataset didn't include roads in some areas such as Northwestern University and large parks, I have to adjust the size of the service areas to include all the census blocks. The Northwestern University area straddles two service areas, so I allocate the blocks roughly evenly, effectively extending the existing boundary eastward between the two areas (see Figure 10).

Performing this step ensures that I don't overlook the student populations living on campus.

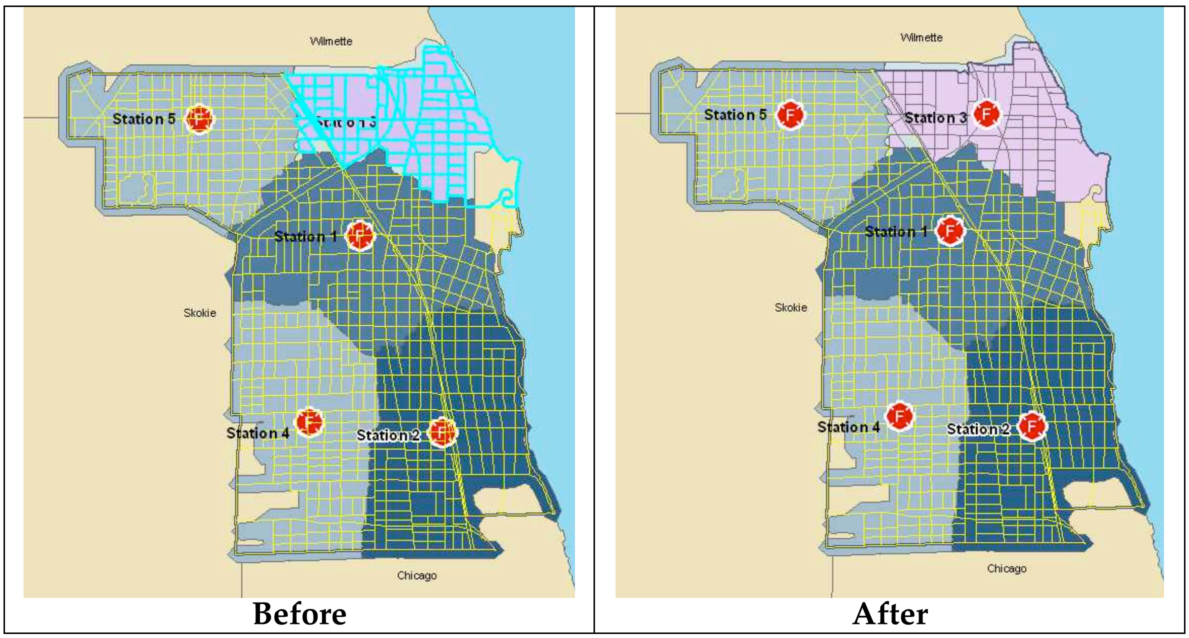

Figure 10. Original service area map with census blocks overlaid, demonstrating that the original service areas did not include all census blocks in the City of Evanston. This example shows how the service area for Station 3 was manually extended to include a census block representing the northern portion of the Northwestern University campus. A similar procedure was used for Station 1 (for the southern portion of campus).

The final maps utilizing census block data (Maps C, D, and E) are presented below.

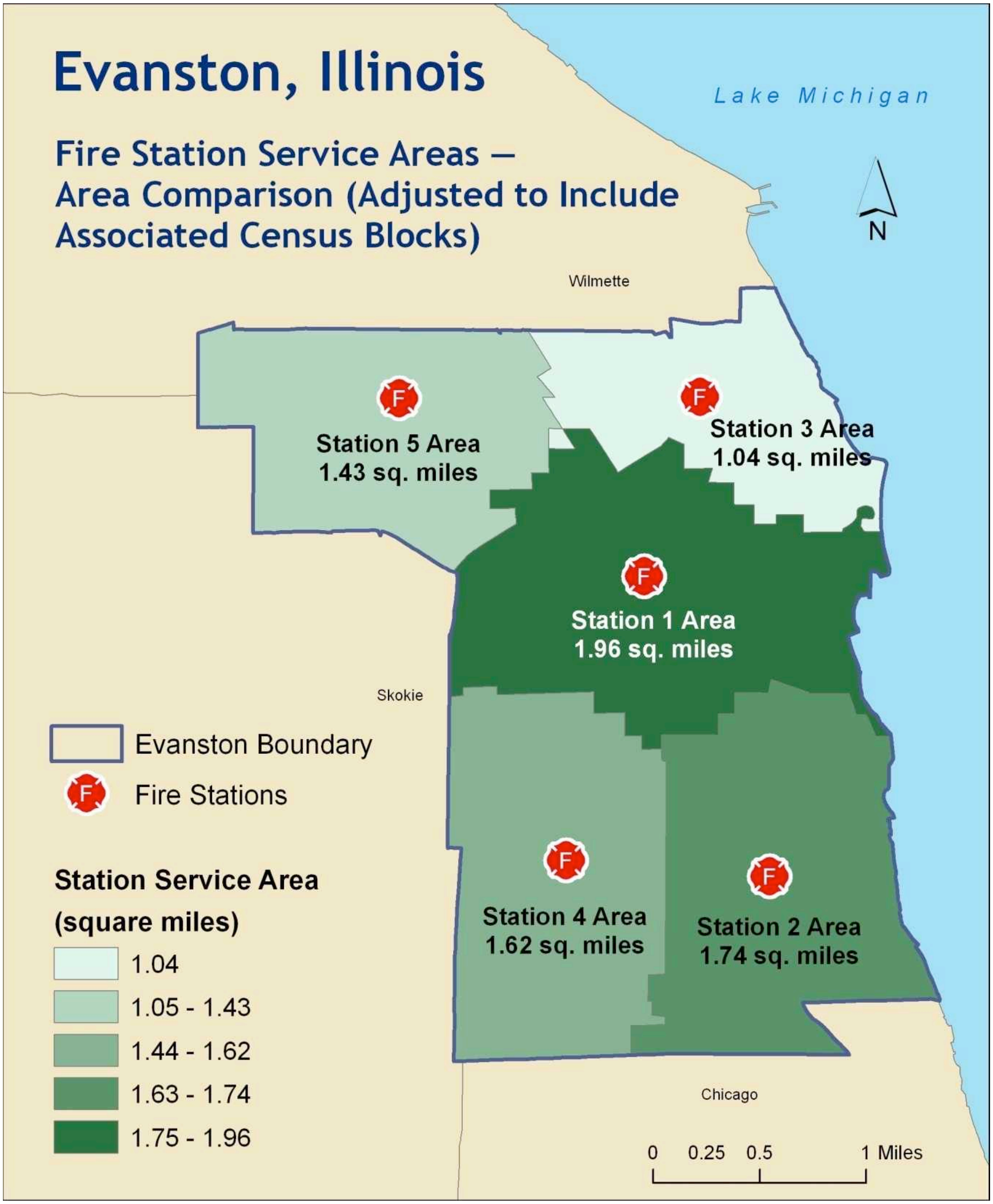

Figure 11. Map C: "Fire Station Service Areas—Area Comparison."

The area comparison in Map C (Figure 11) shows that Station 1, in central Evanston, has the largest service area at 1.96 square miles. Station 3 in the northeast corner has the smallest.

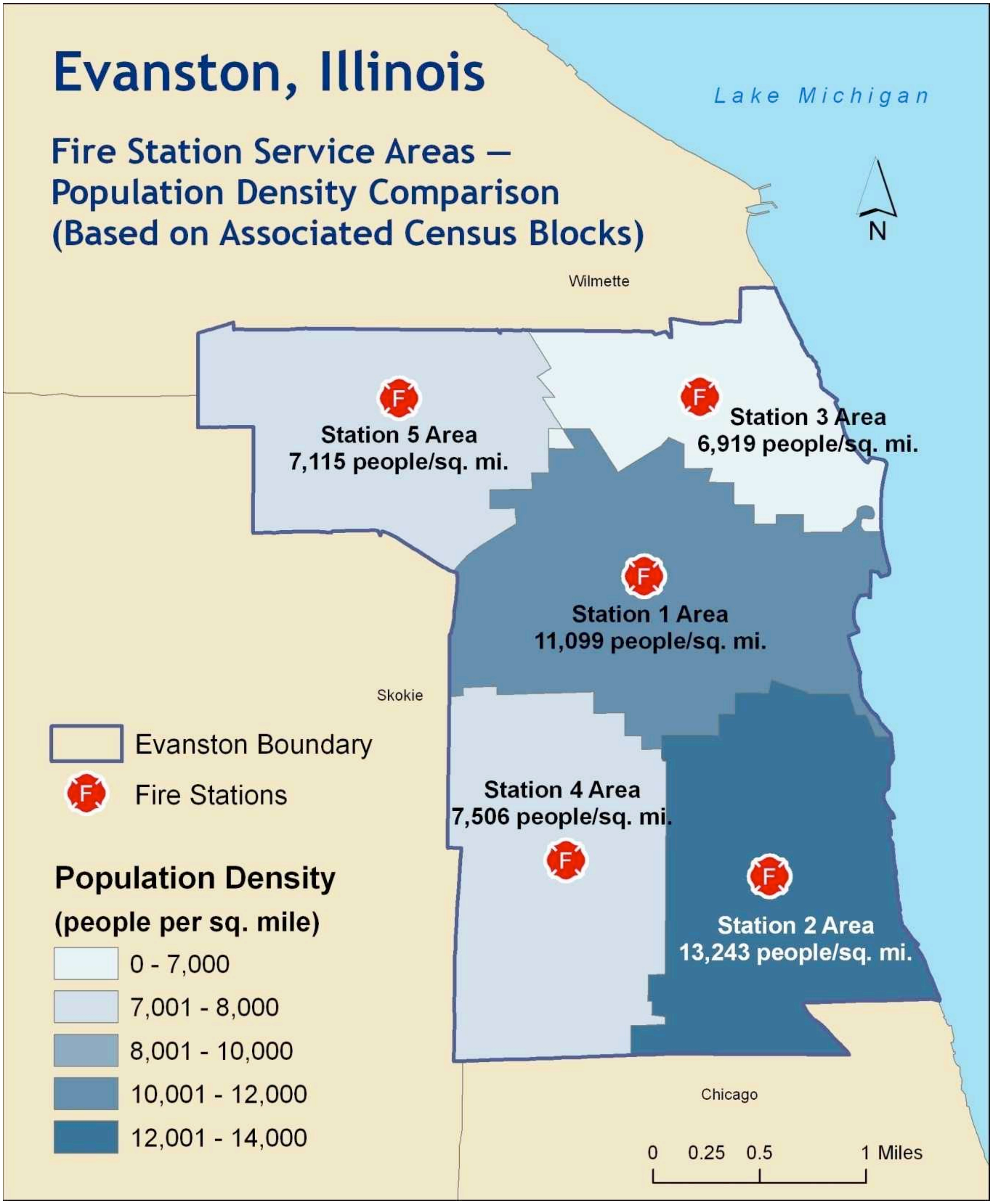

Figure 12. Map D: "Fire Station Service Areas—Population Density Comparison."

Map D (Figure 12) shows that the Station 2 area has the highest population density, with 13,243 people per square mile. The Station 3 area has the lowest density. So how is this information useful? That question is addressed by map E.

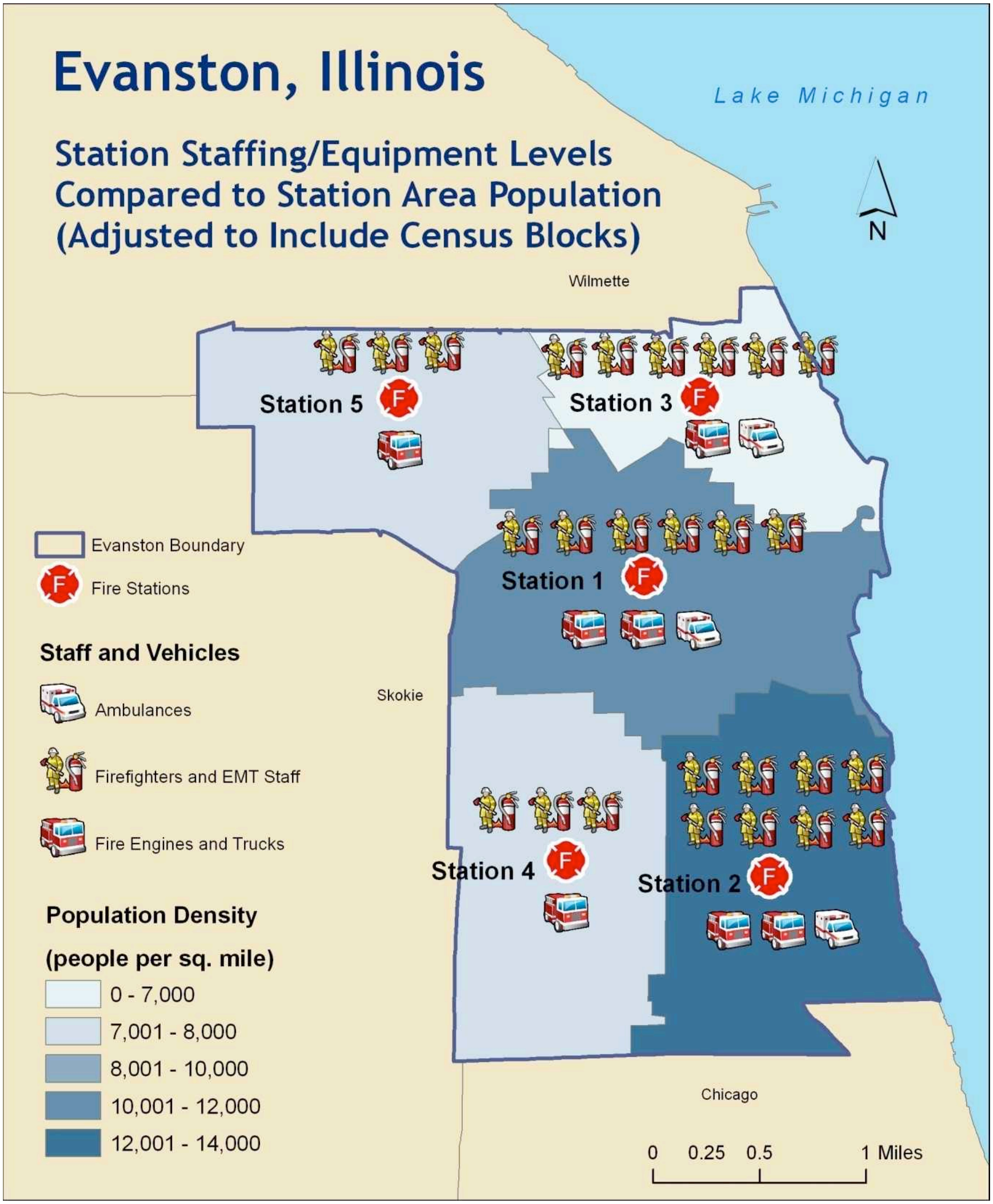

Figure 13. Map E: "Station Staffing/Equipment Levels Compared to Population Density."

Map E (Figure 13) compares staff and vehicle levels for each fire station service area with that area's population density. The most densely populated service areas (Stations 1 and 2) have the highest level of staff and vehicles with six and eight staff respectively, and three vehicles each. This correlation suggests that population information might have been used to aid decisions such as staffing levels or equipment purchases. Interestingly, the northeast service area (Station 3), which has the lowest population density, also has six staff; one might infer that Evanston's staffing decisions were not based solely on population density. What other factors might be involved?

Although the response density map (Map A) and the staffing and population map (Map E) don't portray precisely the same population areas, a comparison is useful (see Figure 14).

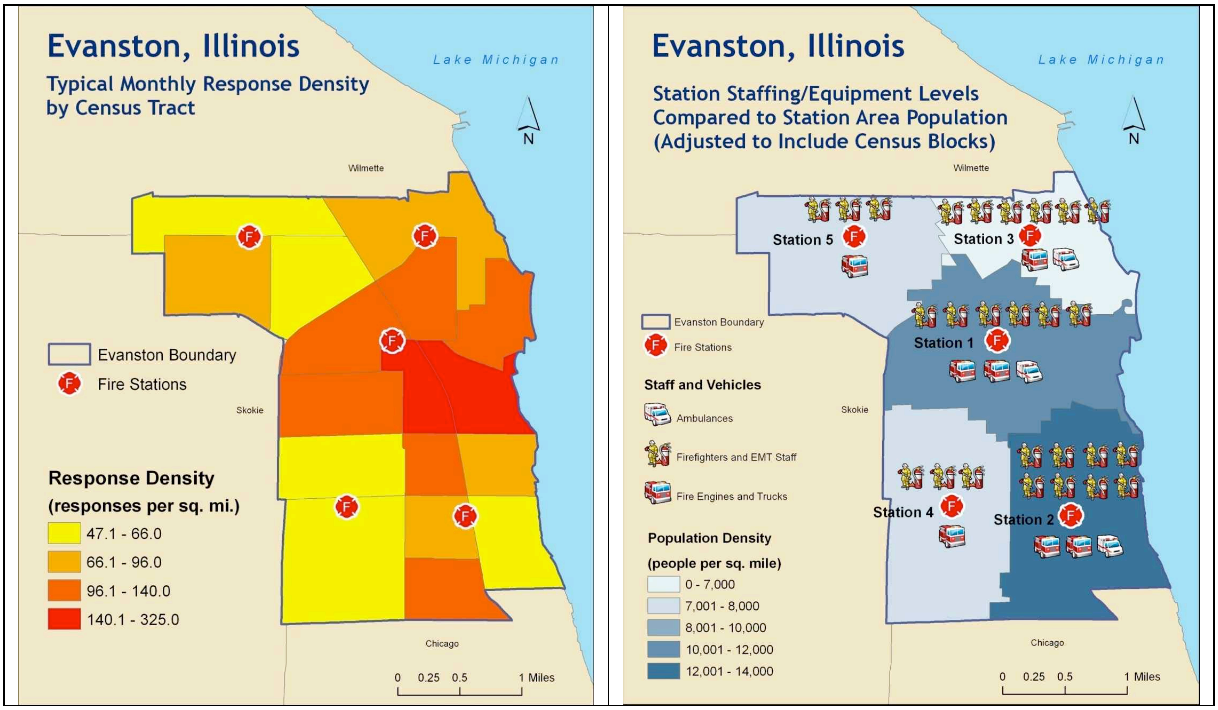

Figure 14. Comparison of Maps A and E.

The areas in the northwest (Station 5) and southwest (Station 4) correlate very well, as both have low response density *and* low population density. The response and population densities of the central area (Station 1) also correlate well, with medium scores in both measures.

I observed earlier that the northeast area has the lowest population density. If one were to make staffing decisions based on population density alone, Station 3 in the northeast corner appears to be overstaffed. But the response density in that area is moderate to high, so one might infer that Evanston's staffing decisions for that region took into account response density and were not based solely on population density. The proximity of the Northwestern University campus and the fact that Station 3 area borders another city (Wilmette) might also have been factors in deciding how to staff the station.

Discussion

In addition to demonstrating the application of service area analysis, this project raises at least two important topics: data accuracy, the implications of response time data for local governments, and the influence of other factors.

Data accuracy

When analyzing a service area, it's important not only to have the appropriate edges but also accurate census data. I had been concerned that the Northwestern University student population (which includes over 8,000 undergraduates) might have been under-represented in my data, either through an error in my methodology or poor student participation in the census. But according to Park (2010), the university student population had 98% participation in the 2000 census, largely because the university gathered student census data as part of its registration process. The same article stated the university discontinued this practice before the 2010 school year (Park, 2010), so it's worth noting that any maps based on 2010 census data might be less representative.

Implications of response time data for local governments

The project raises several implications for local governments dealing with service areas. For example, increases in response time could be used to justify increases in staff or equipment, while decreases in response time might be used to justify staff cuts or even the elimination of a station. And if staff were cut, the trade off would be longer response times, so any staff reductions likely would be controversial for the community.

Influence of other factors

Any decision regarding the management of service areas is no doubt influenced by a complex array of factors, with no single factor dictating how a service area should be staffed or equipped. Further research would be necessary to understand these factors. For example, perhaps an area bordering another community shares its services with the neighboring community. This could justify a relatively higher level of staffing at certain border areas. A large student population might also play a role in such staffing decisions.

Conclusion

Service area analysis is an extremely valuable tool for calculating ideal response times and station locations. Actual response times should be logged and monitored over time to see if they vary from the ideal response times in the original plan. At the government level, decisions about staffing and equipping fire stations can be based on response time data, but other factors should be considered, including population distribution, accuracy of census data (e.g., transient student populations), community needs, or the services areas of neighboring communities.

Sources

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