Emergency Preparedness and Planning Using GIS: A Case Study Application for Strategies and Challenges

Stephen J. Misterek
Department of Resource Analysis, Saint Mary's University of Minnesota, Minneapolis, MN 55404

Keywords: Public Safety, Emergency Preparedness, Emergency Planning, Emergency Response, CRI, Geographic Information Science, Anthrax

Abstract

Government agencies have been tasked to prepare for a wide range of events when it comes to emergency preparation, planning, and response. Disaster planning, at its core, tends to deal with preparing a response to critical and complicated events with unknown situational variables, and unpredictable temporal and spatial constraints. A situation itself can come in the form of natural or manmade disasters that are intended and targeted events or accidental occurrences. Geographic Information Systems (GIS) can be an important tool for the purposes of mitigating damages incurred during disaster events by providing tools and data to be used in a response planning. But how can GIS be used to plan for the complexities and unknowns of a given situation? As GIS becomes ubiquitous in planning and managing events and responses to situations, how can GIS be implemented in a way that leverages the technology to its fullest potential. The intent of this study is to explore opportunities and challenges that are presented at local governmental levels for preparing a plan to deal with responses to an event using GIS as a tool for planning situational response mechanisms.

Introduction

It seems clear that pre-planning activities would play a critical role in the effective deployment of crucial resources used to deal with the circumstances of any disaster situation. The root of the problem for outlining a response plan to an event is knowing (or not knowing) what you will be responding to. All disaster events are considered important due to the potential impacts on humans and/or the environment. Disaster planning, therefore, is an attempt to identify who and what would be harmed in a given situation and how resources might be applied to mitigate the harm presented (Ingelsby, 2002).

The first challenge is identifying the characteristics of the inhabitants and environment of a particular area. The variables involved in defining the physical area and socio-economic tendencies of inhabitants are relatively static and stable. Because these variables can be predetermined, this should be the most unproblematic part of preparation.

The second challenge is discovering characteristics that define the particular disaster event(s) that requires a response. This challenge is one that cannot be isolated as easily. New information will be presented as time proceeds from the time the event occurs and, ideally, that information would be accounted for in the response

Misterek, Stephen J. 2008. Emergency Preparedness and Planning Using GIS: A Case Study Application for Strategies and Challenges. Papers in Resource Analysis. 11 pp. Volume 11. Saint Mary's University of Minnesota University Central Services Press. Winona, MN. Retrieved (date) http://www.gis.smumn.edu

plan. All characteristics cannot be predicted, but many variables can be identified prior to an event and prepared for.

The third and most difficult challenge to be accounted for in an event response situation is the unpredictable variables that will only become apparent during the event itself. Difficult decisions must be made to determine how unforeseen variables will best be handled, or if limited resources should be applied to their identification in a pre-event planning module. In many cases the answer might be no.

In considering the range of events that may be presented, pre-planning is a tremendous time and resource intensive task (Radke et al., 2002). The questions remain: What event is being prepared for? Where might the event take place? What variables can be isolated and planned for and how do they change from one emergency to the next? In light of these questions, how is the response likely be carried out? GIS is just one tool in the equation to maximize the effectiveness of a response effort, so how can it best be utilized in the plan before and during the event?

Disaster events might range from “natural” disasters such as hurricanes, tornadoes, floods, geologic events, or structural failure to “man-made” disasters such as bio-terrorism, chemical terrorism, radioactive events, hazardous material release and many others.

This paper presents a case study example to explore the complexity of producing response plan information for an emergency event. The case study explores variables and strategies used to prepare a response plan for a bioterrorism event for an unnamed metropolitan area. The study focuses specifically on the introduction of airborne anthrax to a metropolitan statistical area (MSA). While this is only one potential example of how GIS can be utilized in plan preparation for emergency response, it does serve to highlight the complexity involved and requires identification of key criteria for using spatial analysis to plan elements of the response plan. It should be noted that there are other bioterrorism possibilities (botulism, hemorrhagic fever viruses, plague, radiation, smallpox, and tularemia to name a few) (Hughes and Gerberding, 2002) that could threaten the safety of a population. Given this, a reasonable assessment is necessary to understand if the criteria from this analysis could be reused to plan for other similar types of events.

Background

On October 1^{st,} 2008, The Department of Homeland Security Health and Human Services (HHS) announced they would be able to declare emergencies and enter into the phase of response to a potential outdoor anthrax attack (Anonymous, 2008). Furthermore, this announcement stated that work has been done to authorize the assistance of the U.S. Postal Service (USPS) to assist in disaster mitigation activities if HHS declared an anthrax attack, a potentially important option for successful disaster response. This announcement highlights work completed to identify one potential response to this sort of bioterrorist attack. There are known infrastructure capabilities and constraints that begin to define any emergency response plan, and this example serves as a useful case study to better illustrate how GIS might be used to better refine response plans.

In the case of an anthrax attack, local governments would need to dispense prophylactic antibiotic medication within 48 hours to a potentially large number of people (Anonymous, 2007b). The Cities Readiness Initiative (CRI) is a federally funded program which aims to provide a national approach for preparedness, response, and recovery methods in the event of a large scale public health emergency (Sapp, n.d.). This program identifies key methods of delivery for prophylactic medication, the potential sources of those medicines, and defines policy guidelines and the authority for implementation efforts. The response plans themselves need to be defined, and medical countermeasure distribution capabilities and methods must be executed at local level(s) of government. CRI funding was distributed to local government entities located in designated Metropolitan Statistical Areas (MSA). This approach allows for response solutions to be better tailored to each designated locale based on area characteristics.

This leaves some key questions. What are the local area characteristics that need to be considered for proper and effective prophylactic dissemination to the public? Are these characteristics defined by geographical or demographic qualities, or both? Which of these characteristics can be handled in a pre-plan methodology and is there adequate data resources to define them? What are those data sources? Finally, how can each of these defined characteristics, and their representative data sources, be used for fair and useful analysis, driving strategies to increase plan effectiveness?

There are five (5) primary methods for the dissemination of oral prophylaxis (Anonymous, 2007a):

1. Classical Points of Dispensing (or PODs) for medicines or vaccines. This is the primary method local governments currently use. Using this method, the federal government delivers prophylactic antibiotic medical kits to local authorities who then redeliver those medical kits to the local population from predetermined facilities. This mechanism has been used by many communities over time, albeit not on the scope or at the tempo that a major bioterrorism event would require.

2. Direct residential Delivery of Antibiotics by Postal Carriers. With this approach, postal workers deliver medicine directly to residences. Discussions are ongoing with the U.S. Postal Service to explore the advantages and limitations of this approach.

3. Pre-Deployed Emergency Community Pharmaceutical Caches. Locally stored pharmaceutical supplies are pre-cached and are prepositioned at selected locations like hospitals, schools or government centers.

4. Pre-Event Dispensing to First Responders. Provisions of prophylactic antibiotics positioned for dissemination to trained first responders to provide effective and targeted antibiotic delivery during emergency events.

5. Pre-Event Placement of Pharmaceuticals in individual households. In emergency situations families could have in-home medical kits for use as directed by the government.

These methods may be classified as “Push” and “Pull” methods of distribution. In the “Push” method category, efforts are made to actively deliver the essential medicines to the public. In the "Pull" methodology, the public is asked to come to specified distribution sites. Planning activities need to be carried out with each of these methods in mind to make sure that the most effective combination of resources and tactics are deployed. There are demonstrated advantages and deficiencies with each of these methods and the best response would likely utilize some combination of the five (Inglesby, 2002).

For the purposes of this study, the focus is on how GIS might be used in designing a "Push" response via a USPS mail carrier (#2 above). This method would inevitably have a limited number of medical kits to deliver (MacDonald, 2005), which defines the need to identify how to most effectively deliver the available supply. This need requires identification of the geographic area most at risk and the location of populations best served by the USPS "Push" method. Isolating either, or both, of these factors would bolster effective mitigation efforts (Wein, 2008). The primary question that needs to be answered is who and where are those individuals?

Methods

Data Acquisition

The first step in the process includes gathering demographic and vector data for conversion to raster datasets. Determination criteria for data selected was based on availability and demographic factors that were described in interviews with government officials specializing in public safety and emergency preparedness.

Since the project objective was based on identifying populations that would most readily be helped by postal delivery of prophylactic antibiotics, the selected demographic characteristics include: Median Household Income (IHMED), Number of Individuals Age 65+ Below Poverty Level, Number of Families Below Poverty Level (POVFAMS), and Households With Children Ages 6 or Less (LFKID_6).

Data was downloaded and collected from MetroGIS using the MetroGIS DataFinder. Census Tracts and Zipcode information were downloaded in Shapefile format and tabular data was derived in .dbf format.

Software and Data Manipulation

Queries were performed on all data to parse out the values for the identified MSA (Figure 1). The shapefile for

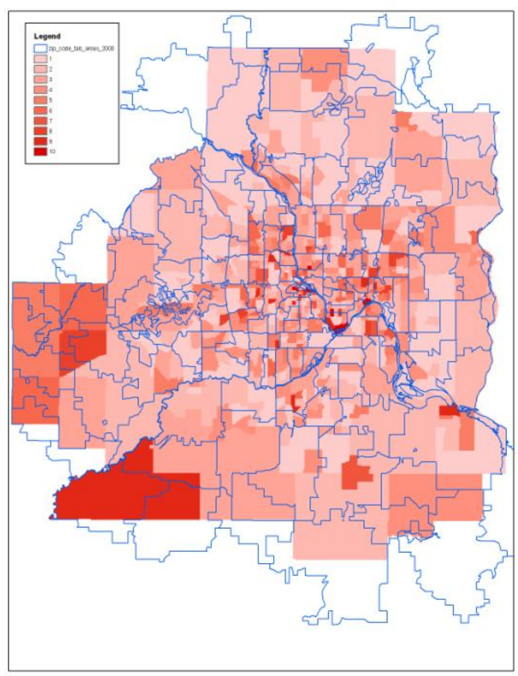

Figure 1. Example of a vector dataset for MSA Census Tracts representing Number of Individuals Age 65+ and Below Poverty Level. Darker red colors indicate a higher rate of occurrence for that Census Tract.

census tracts was combined with each of the tabular sets of census data using the join function. Each join was used to create a vector dataset. Software used for this project includes ESRI's ArcGIS 9.2 and the Spatial Analyst extension.

Calculating Raster Values

Each of the four vector datasets was classified into 10 classes using Jenks Natural Breaks. Each vector dataset was converted to a raster dataset using Spatial Analyst. Raster data sets were created using an output cell size of 200 meters.

Each raster dataset was then reclassified, again using Spatial Analyst, and again using Jenks Natural Breaks for classification into 10 class ranges (Figure 2). Reclassification was used to

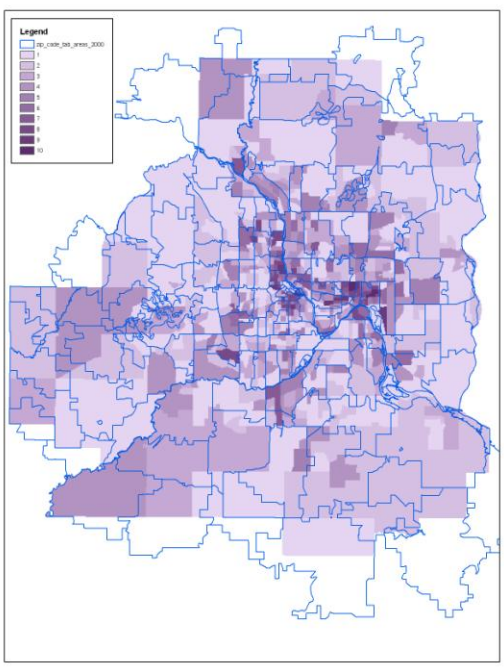

Figure 2. Example of reclassified raster data for MSA Census Tracts Number of Families Below Poverty Level. Darker purple colors indicate a higher rate of occurrence for that Census Tract.

assign a value to each class with a range from 1 to 10, with 10 representing the highest vulnerability levels based on rate of occurrence and 1 being the lowest, respectively.

Each of the four classes was weighted by importance as determined by how each category affects the ability of postal delivery to be effective. Using the Raster Calculator in Spatial Analyst, weights were applied to each grid.

Assumptions were used in determining the weight criteria. Because this case study was derived without official government leadership, weights were assigned as an example of how this technique might be applied. Each category was chosen as an example of issues that represent assumed vulnerability via unofficial discussions with emergency planning professionals.

Calculating Weight

Using the Raster Calculator, values were derived and combined from the reclassified grids. To better determine the cumulative suitability of census tracts for targeted mail delivery of prophylactic antibiotic regimens, each grid was summed together.

Grids were combined and quantified to represent a cumulative calculation for each census tract area (Figure 3). The expression used in this calculation consisted of the following Map Algebra statement:

*([reclass of household median income] * 0.35) + ([reclass poverty and age 65+] * 0.25) + ([reclass families under poverty] * 0.2) + ([reclass children age <6] * 0.2)*

Spatial Join and Combined Weight

To create the final outputs and recommendations for this study, the resulting weighted and classified value information for each census tract

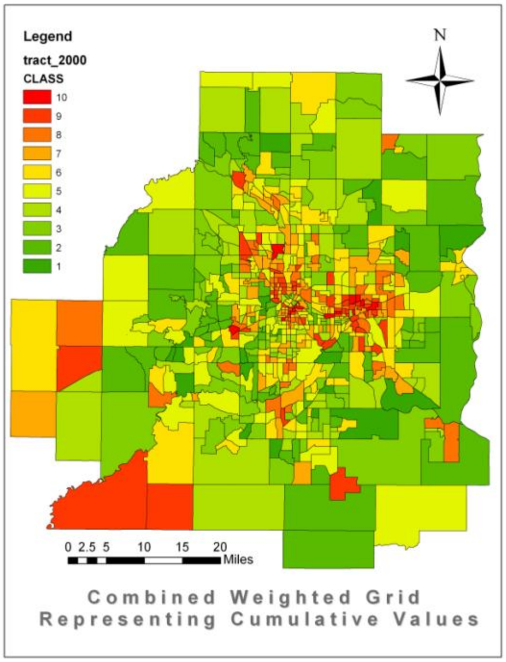

Figure 3. Output for Cumulated Weighted and Reclassified Raster Data. Red colors represent highest vulnerability and green the lowest.

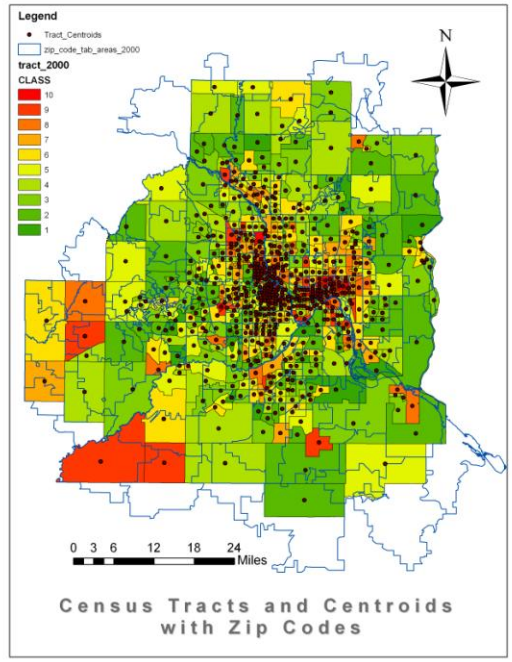

Figure 4. Point Feature Class created from Census Tract Polygons and Zip Code areas.

polygon needed to be incorporated into zip codes for recommended use in postal carrier assignments. A spatial join was performed to integrate the weighted calculation values of each census tract to its associated zip code polygon.

Because zip code and census tract boundaries do not match, the first step was to convert the tract polygons to a point feature class (Figure 4). The resulting point feature was used in a spatial join with a zip code polygon feature. This allows the zip code polygons to inherit the weighted calculated values derived for each census tract.

The results of this spatial join produced two new fields. The first data field is the SUM calculation of the weighted value from each census tract polygon whose centroid falls within each respective zip code area. The second field contains the AVERAGE value for all tract values with the same spatial coincident of having its centroid fall within a zip code area.

The results derived from each of the two calculations provide different resulting spatial patterns. The map in Figure 5 shows the geographic results for the combined SUM totals of all weighted and classified values that fell within each zip code area. The spatial pattern seems to show a greater densification of high values toward the center of the study area. The SUM values inherited by the zip code polygons tend to show a spiking pattern in the data. This is likely because, as point (centroid) density increases toward the center of the study area, there is a higher likelihood of those polygons inheriting the SUM values of more centroid points than along the periphery where those points are less dense.

The spatial pattern resulting from a display of the same data, but using the AVERAGE calculation, indicates a less

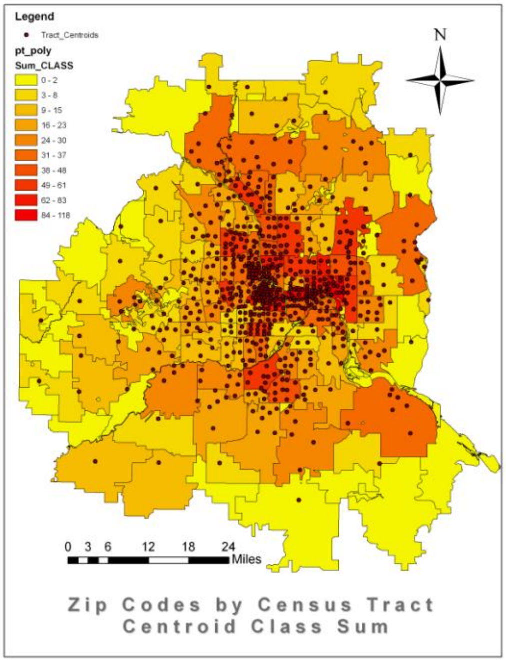

Figure 5. Class values for Zip Code Areas using the SUM calculation. Darker red colors indicate a higher value for that zip code where yellow indicate a lesser value.

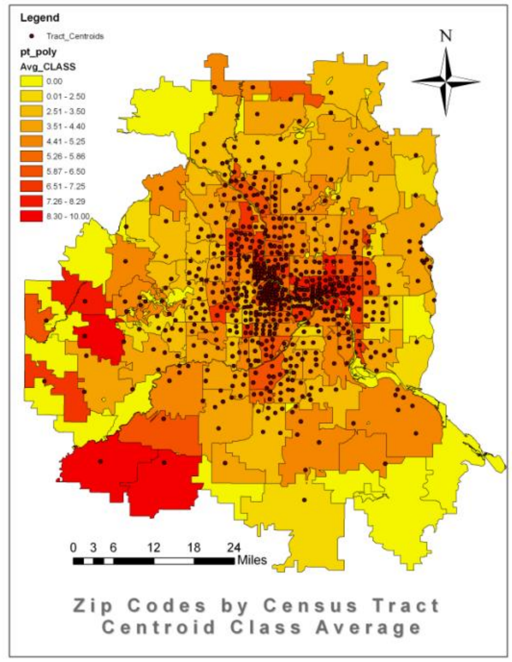

Figure 6. Values for Zip Code Areas using the *AVERAGE* calculation. Darker red colors indicate a higher value for that zip code where yellow indicate a lesser value.

dense conglomeration of high values toward the middle of the study area (Figure 6). Using the AVERAGE calculation, you tend to get a smoothing effect on the data. This is because, by taking the average value of the tracts whose centroids are coincident with a zip code area, you can eliminate the difference caused by one zip code area having a higher concentration of centroids within its boundary. The resulting display is affected by the census tracts becoming less dense as one moves from the center toward the periphery of the study area as represented by the dispersion of points displayed on the study areas.

Results/Discussion

The final results culminate in Figures 5 and 6, but decisions still need to be made by emergency planning professionals.

While the AVERAGE calculation (Figure 6) seems to be better aligned (the areas on the periphery of the census tract map in Figure 4 maintain coincident high value areas on the zip code map in Figure 6) to the values represented in the actual census tracts prior to the spatial join with zip code areas, the SUM calculation (Figure 5) seems to account for total population density in zip code areas, and this may be valuable information. Either result may be acceptable to emergency response planners. Choosing an analysis process that is derived from a SUM result or an AVERAGE result will need to be a decision that government leaders must determine.

It could be viewed that the SUM calculation is the more useful of the two results. It is possible to argue that it better shows the areas that, if served by the postal delivery method, would best meet the overall goals of timely, orderly, and effective dissemination of prophylactic medicine regimens by serving the most populated areas of an MSA. The SUM calculation results better display areas where population density actually exists. It seems reasonable to conclude that this would be a critical factor that would dramatically influence the effectiveness of any distribution effort utilizing mail carriers. It might be posited that delivery to a high density area would allow for the most medical kits to be delivered in the shortest amount of time to the highest amount of people. This would result in a more dramatic decrease of people reporting to PODS. The fact that population density appears coincident with the high value areas of chosen demographic criterion further supports the argument for its potential effectiveness.

Additionally, it seems reasonable that any response plan might begin under the assumption that an intentional aerosolized event would be intended to inflict maximum damage, so highly populated areas might be more at risk.

There is no correct answer at the end of this study. This is an important point. The intent of this case was to introduce some of the ways that GIS might be used to help consider an emergency response plan. The true driver for the effectiveness of any GIS analysis is the thinking, criteria determination, and analysis preparation that can be determined in advance of an emergency situation. The goal of this study is not to singularly determine criteria, but rather to show how appropriate criteria might be utilized.

While the criterion chosen was not the focus of this study, it does merit discussion. Much conversation took place as to how and why each weight was chosen and to which categories they were applied. It was recognized that some of the categories chosen did have some repetitious qualities as all were from data concerned with poverty.

Justification for the categories chosen is two-fold. The first justification is data availability. The second justification is based on vulnerable populations. Because this case study was designed primarily as an example of how available data might be used, the categories chosen were derived from discussions and interviews with professionals in the emergency preparedness field. Other variables considered for this case were populations that speak a primary language other than English, population density, and locations relevant to the point of incident or the origination point of an event.

The primary goals of USPS delivery of prophylactic antibiotics are to improve, organize, and track targeted delivery of antibiotics. This addresses several issues that would need to be solved in an emergency aerosolized anthrax event (Ingelsby, 2002). The issues faced are timely and orderly dissemination of medical kits, security provisions for Points of Distribution Sites (PODS), tracked delivery of a limited resource, communication to the public and effectiveness of dissemination.

The USPS service method helps to meet these goals by getting prophylactic medical kits distributed in a timely, orderly, and tracked first push to the public identified as priority, whatever the justification for that may be. The results suggest:

1) “Push” medical regimens to the population most at risk of infection

2) Reduce traffic at PODS
3) Reduce traffic at emergency rooms and hospitals
4) Distribute information and a medical regimen to residents that are most unable to effectively travel to those PODS

The methodology proposed here helps to solve three of the four goals stated. The first stated goal (to push medical regimens to the population most at risk of infection) would generally require further information that would be unavailable until after the occurrence of a biological event (Wein, 2008). Situational aspects of any biological event would require further investigation by authorities, during mitigation efforts, to discover and measure patterns as they emerge. Information would need to be gathered, verified, and applied in addition to this case methodology as vital information about the nature of the situation is revealed and confirmed. Information on the event(s) origination point or likely dispersion patterns of the airborne substance would be useful information for further analysis.

Ultimately, the calculations in this case determined areas more suitable for the USPS “Push” delivery method by employing user-selected criteria. These areas are easily identified using the zonal statistics tool in Spatial Analyst. To increase the effectiveness of a response, responders can view where attention and resources could be applied to offer more effective mitigation practices and have that information available to decision makers before those decisions need to be made. GIS can be used to create a more useful emergency preparedness plan.

Further Opportunities

Many preparations can be made well in advance of an emergency. In the case presented here, criteria were identified for weighting census tract areas based on socioeconomic characteristics. A weakness in this study was that many location characteristics for an actual event are not accounted for. In the case study of anthrax release in Sverdlovsk, a town in the former Soviet Union, spatial patterns did develop based on the point of anthrax release, prevailing winds, and subject exposures based on relative proximity to the release (Meselson, 1994). After the release occurred infectious areas were predictable in that infected people were most prevalent in the downwind area of the release.

There are several ways that this type of information might surface in a developing emergency situation and depending on the geographic characteristics of the location; the response technique may have different requirements. If the event location can be identified, then reasonable assumptions could be made to further isolate areas that would have a higher level of exposure potential. In those cases, mitigation plans could be further suited to that particular area and initial response resources could be deployed in a phased manner to increase the efficiency and effectiveness of limited resources. The use of a simple buffer mechanism (Figure 7) could be employed to localize an immediate response area in a more phased approach to directed prophylaxis delivery. The employment of this mechanism would be based on a defined point of incident. Another example of how a responding agency might choose to handle a location-based selection would be in response to a situation like those

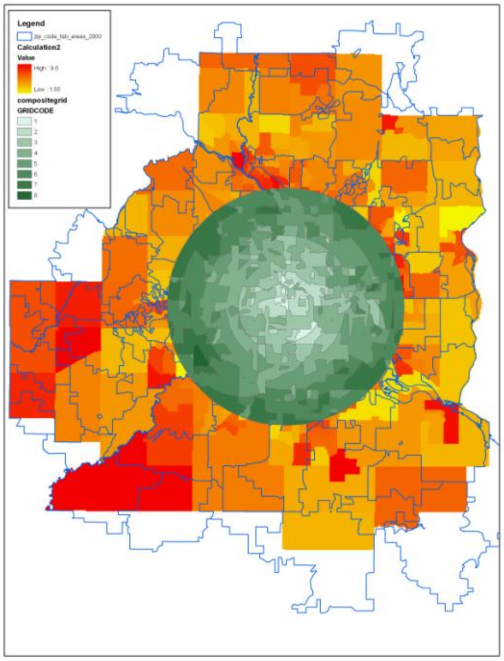

Figure 7. Example of potential weighted buffer zone created from point of incident. The red-orange color scheme represents weighted and classified census tracts while the blue-green buffer represents additional weights based on proximity to an anthrax release.

described in Sverdlovsk and Northeast (Meselson, 1994; Inglesby, 2002) and might choose to take into account the effects of environmental factors such as wind in how response resources should be applied to an area (Figure 8). This information might be derived from plume modeling software such as ALOHA, or even from a more crude estimation based on conditional information collected in the field.

Conclusion

In conclusion, this case studied variables that may be considered to provide useful spatial analysis for emergency planners. While many components were identified prior to an emergency event, planning and program design was necessary to create a repeatable process framework to be applied across event mechanisms.

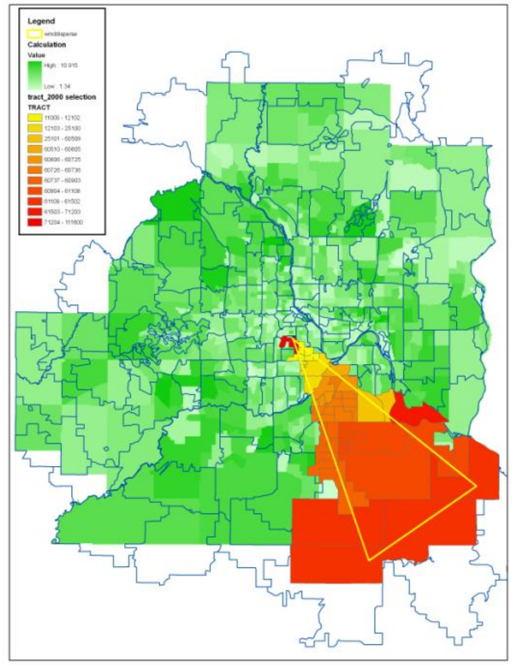

Figure 8. Example of possible weighted spatial component created from point of incident and estimated wind dispersion.

While much more work would need to be completed in this case study to isolate the actual variables and criteria for consideration, it serves as a good example of considerations and lays a foundation for spatial analysis that may be carried out in the planning and implementation phases of an emergency situation.

By defining criteria and a methodology prior to an emergency event, this case study provided an example of a sample framework for profiling where resources can best be used to provide USPS "Push" resources in the event of an anthrax event.

Acknowledgements

I would like to thank Laura Eiklenberg for her expertise, insight and assistance on this project. I would particularly like to thank John Ebert of the Resource Analysis staff at Saint Mary's University of Minnesota for his guidance and

exceptional support throughout this process.

References

Anonymous. 2007a. CDC Coordinating Office for Terrorism Preparedness and Emergency Response (COTPER). Retrieved August 2008 from http://www.bt.cdc.gov /agent/anthrax/prep/pdf/medkit-evaluation-summary-2007.pdf.

Anonymous. 2007b. Mass Dispensing and the Cities Readiness Initiative. *Yale Center for Public Health Preparedness. Vol. 2 Issue 10.* http://publichealth.yale.edu/ycphp/newsletters/2007newsletters/CRI.pdf.

Anonymous. 2008. U.S. Department of Health and Human Services. Press Release 10/01/2008. Retrieved September, 2008 from http://www.hhs.gov/news/press/ 2008pres/10/20081001a.html.

Hughes, J. and Gerberding, J. 2002. Anthrax Bioterrorism: Lessons Learned and Future Directions. *CDC Emerging Infectious Diseases. Oct. 2002. Vol. 8 No. 10.* http://www.cdc.gov/ncidod/EID/vol8no10/02-0466.htm.

Inglesby, T. V. 2002. Anthrax: A Possible Case History. *CDC Emerging Infectious Diseases. July 2002. Vol. 5 No. 4*.

MacDonald, E. 2005. Spore Wars. 6/6/05. Retrieved October, 2008 from http://www.forbes.com/forbes/2005 /0606/162.html.

Meselson, M. 1994. The Sverdlovsk Anthrax Outbreak of 1979. *Science vol. 226*. p 1202.

Radke, J., Cova, T., Sheridan, M., Troy, A., Mu, L., and Johnson, R. 2002. Challenges for GIS in Emergency Preparedness and Response. ESRI White Paper. Retrieved September 2008 from http://www.esri.com/library /whitepapers/pdfs/challenges.pdf.

Sapp, T. n.d. Cities Readiness Initiative. Retrieved September 2008. http://bioterrorism.dhmh.state.md.us/docs_and_pdfs/CRI_presentation.ppt.

Wein, L. M. 2008. Neither Snow, Nor Rain, Nor Anthrax. The New York Times, October 13, 2008. Retrieved September 2008 from http://info.med.yale.edu /eph/ycphp/ newsletters/2007newsletters/CRI.pdf.