Setting Sacramento Ablaze: Spatial network-based assessment of wildfire vulnerability in Sacramento County, California

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Introduction

Wildfires are one of the most frequent natural disasters in California, causing devastating and widespread damage to the environment, economy, and society. In the past two decades, changes in climate and land utilization due to human activities have not only lengthened the wildfire season, but also significantly increased the severity and amount of land burned by wildfires (Nauman, 2020). The California Department of Forestry and Fire Rescue (CALFIRE) provides GIS data for wildfire response and management in the state, including emergency evacuation and planning. We feel, however, that there are gaps in the data provided by CALFIRE, particularly in assessing vulnerable populations.

We present in this paper a methodology for the evaluation of populations vulnerable to wildfires in Sacramento County, CA, at the block group level. First, we identify the populations not serviced by existing wildfire evacuation shelters by running a service area network analysis. Next, we determine the impact of utilizing new facilities to meet the demand of the unserviced populations followed by delineation of populations in need of new facilities. Additionally, we identify the most socially at-risk populations using Social Vulnerability estimates from the CDC and those areas at most risk from Wildfires using the Fire Severity Index. This will determine the need for further utilizing more public schools and libraries to suggest facilities that could be converted to fire evacuation centers based on to accommodate underserved, socially vulnerable populations in Sacramento County.

Vulnerability Analysis

Input Data Layers

- Sacramento County Boundary
- Sacramento Census Block Boundaries
- CDC Social Vulnerability Index (SVI)
- CALFIRE Fire Threat

To determine the performance of wildfire emergency shelters, our group conducted a suitability analysis to identify priority areas of Sacramento County. Our criteria for selecting a new emergency shelter locations is as follows. Priority should be given to areas of the county with:

1. a high fire hazard threat,
2. socially vulnerable communities,
3. and high population count.

We utilized three publicly-available datasets to represent these criteria in our analysis. Fire hazard threat data was downloaded from the California Department of Forestry and Fire Protection (CALFIRE). Fire hazard severity zones are ranked on a scale from -2 to 3, where areas with a ranking of -2 are the least at risk and areas with a ranking of 3 are the most at risk. To assess social vulnerability, we downloaded the 2018 Social Vulnerability Index (SVI) created by the Center for Disease Control. This layer aggregates social vulnerability factors, such as socioeconomic status (e.g. income, employment status), household composition (e.g. age, disability status), minority and language sta-

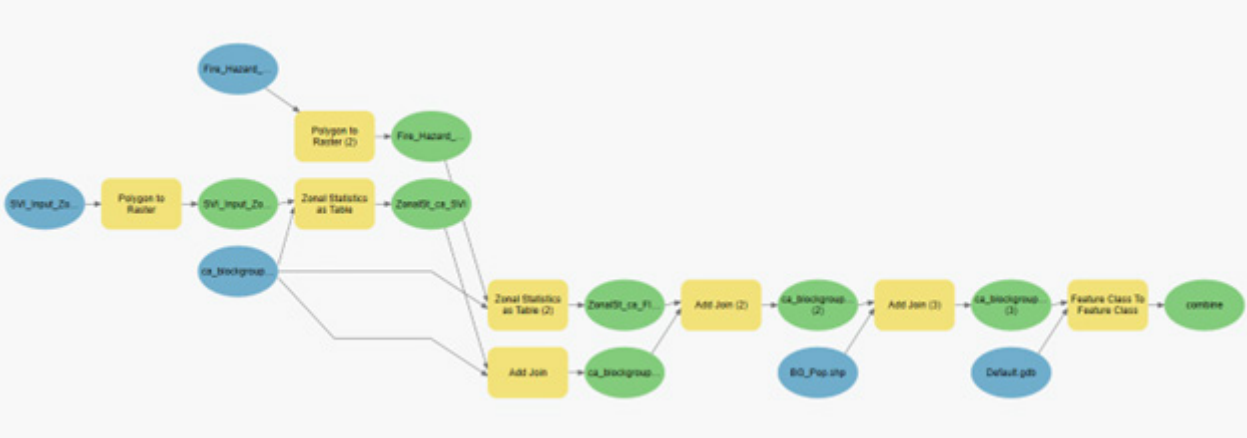

Figure 1: Disaggregating social vulnerability, fire threat severity, and population data to the census block group level.

tus, housing type (e.g. multi-unit structure), and transportation ability. Population data were downloaded from 2020 Census population estimates.

Our suitability analysis was conducted at the Census Block Group level. To prepare our data layers for the analysis, we projected each using the projected coordinate system NAD 1983 UTM Zone 10 N. Once all the layers were in the same projection, we clipped the Census Block Group, SVI, and fire hazard zone layers to the Sacramento County boundary.

We decided to use model builder to automate the analysis workflow. The first part of the process was dedicated to disaggregating SVI and fire hazard severity zone data to the block level. We started by converting the SVI and fire hazard severity zone shapefiles to raster layers using the Polygon to Raster tool. Both raster layers had a 10 meter cell size. Then we used the Zonal Statistics as Table tool to find the mean social vulnerability and median fire hazard severity level for each census block group. The output tables, along with block group population data, were then joined to the Census Block Group shapefile using each blocks unique ID (figure 1).

Rating Schedule				
SVI	**Fire Hazard Severity (Code)**	**Population**	**Rating**	**Risk-Level**
0.001300 - 0.257900	-2	0 - 1,076	1	Lowest
0.257901 - 0.493000	-1	1,076.1 - 1,693	2	Low
0.493001 - 0.745400	0-1	1,693.1 - 2,442	3	Medium
0.745401 - 0.998600	2-3	2,442.1 - 4,834	4	High

Figure 2: The rating schedule for our three variables. A rating of 1 represents the lowest severity, and a rating of 4 represents maximum severity.

The next step in our suitability analysis model was to create a rating schedule for our three variables (figure 2). We binned each variable (using natural breaks) into four classes and assigned each a rating between 1 and 4, 1 being the lowest risk and 4 being the maximum.

Rating our variables required the reclassification of variables in our model builder using some short Python 3 code (figure 3).

Once all variables had been reclassified, we combined our layers using the ordinal combination method. We concatenated our variables to better understand what each block group was at the highest risk of. Then, to identify our priority areas, we calculated the sum of the ratings for each of the three layers. Block groups with the largest sums (> 9) were identified as the most at risk.

```
def Reclass(SVI):
    if (SVI >= 0 and SVI<= 0.2579):
        return 1
    elif (SVI >= 0.257901 and SVI<= 0.493000):
        return 2
    elif (SVI >= 0.493001 and SVI<= 0.745400):
        return 3
    elif (SVI >= 0.745401 and SVI<= 0.998600):
        return 4
```

Figure 4. An example of some of the short Python 3 code we used to reclassify the SVI variable.

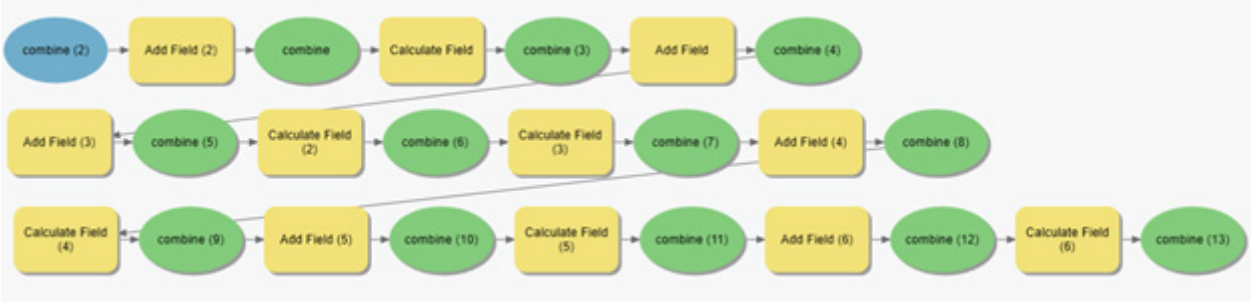

Figure 3: To rate each variable we had to create a new field and reclassify the old values using short Python 3 code.

Network Development & Analysis

Input Data Layers

- Sacramento Roads Network
- Sacramento County Parcel Data
- Sacramento Public Schools
- Sacramento Public Libraries

There are several steps associated with Network Development & Analysis. The first segment of the workflow is concerned with building a network out of the existing Sacramento County Roads Geodatabase to perform location reallocation of parcel demand points to National Emergency Shelter Facilities managed by CALFIRE. The Network Dataset was built out of the Sacramento County Road Network with the following parameters:

1. Time Cost - Time in Minutes determined by dividing the distance cost by the speed limit(mph) apportioned to each segregated street ID.
2. Distance Cost - Length of the Network Element in Miles.
3. Drive Mode - The default drive mode of Automobile is selected as it is assumed that Households will drive to the Evacuation Facilities.
4. Restrictions

   One Way - Based on the Nomenclatures, "TF" and "FT" , Movement along and to and fro the network is restricted.

   Private - Private roads are prohibited from network access.
5. Hierarchy - Based on the available Road Class Data, a hierarchy of Streets is created for use in Turn Category and Network Priority. The Road Classes are demarcated in figure 5.

Parcel Point Creation

A Point Parcel Count of 45,466 is generated from the Sacramento County Parcel with the points placed inside at the centroid of each parcel. This is advantageous as opposed to using block group centroids as the latter does not indicate the clear route network and distribution of population within the block group. Additionally, many parcels may be closer to evacuation facilities in the adjacent block groups. One major drawback is that the points are not indicative of the total population contained within them and therefore are not highly accurate but this is a data limitation because it is impossible to get population demarcated parcel data. Currently Parcel Data for Analysis has been demarcated on its residential land use. Future studies should further delineate using time of day, parcel type to focus on commercial parcels as well and reassess location allocation.

Four Types of Analysis were undertaken to ascertain the strength of Sacramento County's Evacuation Preparations. The main concern with these analyses was to understand two main aspects: **Accessibility** and **Capacity**.

Accessibility

The Service Areas of 5 & 10 Minutes were determined and the coverage of Residential Parcel Points was noted. By Visual Assay, It was found that most residential parcels were covered by the service areas of the evacuation facilities excepting several fringe parcels. A few isolated areas were not covered by the drive times, and

Class Name	Hierarchy
H (Highway)	1
R (Highway Ramp)	1
A (Arterial)	2
C	3
LOCAL	3

Figure 3: To rate each variable we had to create a new field and reclassify the old values using short Python 3 code.

a particularly large portion with higher severity was noted on the eastern fringe. By using an existing school in that area as a new evacuation facility, the uncovered parcel points were now within a 5 minute drive time of the new facility.

Figure 4. An unserviced area of residential parcels with no exisitng public faciltiies nearby

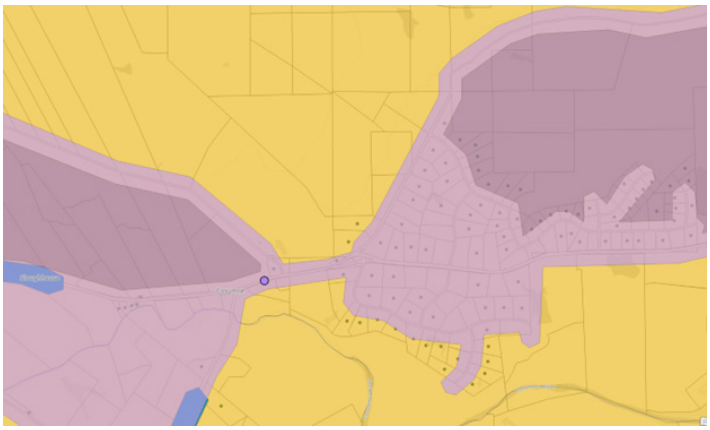

Figure 5. An unserviced area of residential parcels with an existing nearby public facility. Converting this facility to an emergency shelter services all the parcels in a 5 minute drive time

Capacity

The Capacity of all the Evacuation Facilities were added to consider the total capacity of the county for evacuation. Simultaneously all the parcel points were added to get the total population under threat. It was found that the average capacity of a facility is 515 Persons. The total capacity requirement was found to be nearly four times the current capacity with a total requirement of 452,456 Persons. This may be an unachievable count as it will require the creation of 600 new facilities with a capacity of 515 each. Given that there are around 150 school buildings that are currently available, the additional need should be addressed with careful policy planning.

Assessment of Vulnerable Block Groups

Using the Vulnerability Index, several Block Groups were found to be highly vulnerable at values of 9 & one block group at a value of 10. The Weighted Mean Center for these Block Groups were determined and a service area allocation for a 5 Minute Drive Time for each block group was created. Facilities and their capacities within this service area polygon were noted and found to be inadequate at a ratio of 1:4 with a deficit of 60000 capacity.

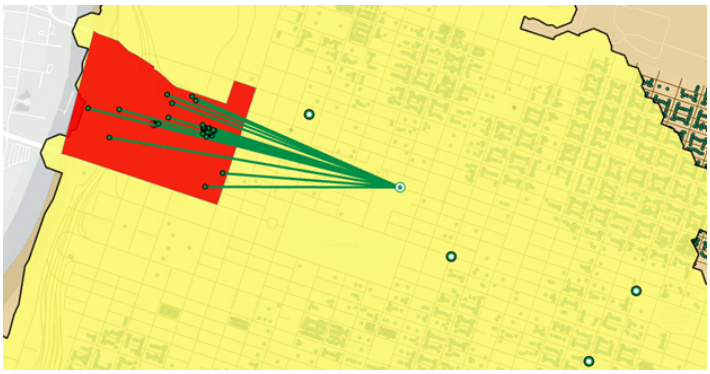

Figure 8. Location allocation example for a highly vulnerable Census block group in our study area.

Methodology for Location Allocation & Future Recommendations

Post determination of capacity deficit, the allocation of different facilities need to be derived. For instance, in the Block Group above, the nearest existing facility has sufficient capacity for the entire block group but this is not true for all vulnerable block groups. Similar analysis needs to be undertaken for all county block groups to determine the location and capacity allocation of new facilities.

- The location allocation will need to be undertaken in addition to existing facilities to ensure that new facilities are added to the existing evacuation network.
- Vulnerable Block Groups should be given high priority in evacuation as inequity factors might also result in low vehicle ownership.
- Additionally, this location allocation can also be used to plan the capacity of required facilities thereby providing all the necessary information for cal fire to plan its future evacuation model.

- Post this, local level route maps need to be created to help civilians understand the routes to be taken to reach their point of nearest evacuation within the required drive times.
- Service areas analysis needs to be undertaken periodically to understand the impact of population growth, road network changes, traffic congestion on accessibility and capacity.
- A GIS based Evacuation Web Map can be created to assist county fire department to better service vulnerable populations.

Limitations

There were several limitations with regard to the network development that have been highlighted above and the network can be better developed with the following data - Time of Day Use, Commercial and Residential People and Employment Count, Height Restrictions for Various Road Classes, and Traffic and Congestion Data for this Model to be truly reflective of drive times. We foresee that drive times and accessible facilities will reduce dramatically if the congestion data is input. Therefore the network model needs further information.

A major limitation of this exercise was the residential parcel point count which amounts to ~456,000. Given that there are 284 Existing Calfire National Evacuation Facilities, high computing power is required to be able to undertake the location allocation adequately which would have been the most suitable model to determine the real capacity and accessibility of evacuation facilities. In lieu of this, service areas and other methodologies were undertaken and we recommend that location allocation be performed in addition to these metrics.

It is also to be noted that the exact spatial population distribution cannot be derived as it requires high precision residential data that is not available. The distribution of residential parcel points provides the advantage of better modeling accessibility but comes at the cost of actual population numbers. Therefore, the analysis above is a conservative estimate at ~456,000 Residents (One Resident per Residential Parcel Point) and is not indicative of actual capacity needs which is much higher for the county at 1.5 Million Residents and a major factor to be considered in future analyses.

Discussion

The main results show that **capacity is the major concern with Sacramento County's Evacuation Plan** while accessibility is well covered with only one major parcel cluster unserviced and very few service area gaps that can be covered by creating smaller area evacuation facilities. Four Major Takeaways are derived from this study:-

Vulnerability: Different Block Groups have different vulnerability as per the derived scale and are not geographically adjacent, distributed randomly across the county. There are several block groups that are highly vulnerable with a scale value of 9 & 10. This is a combination of Wildfire Threat, Population and the Social Vulnerability Index.

Accessibility: A Visual Assay of Countywide Service Area Polygons shows Parcel clusters that are not serviced with 10 Minute Drive Times. There is one particular vulnerable area with a dense parcel cluster not within a 5 or 10 min drivetime to an emergency shelter. If we add one facility in the specified location which is an existing school, those parcels will be serviced. Additionally, parcels at urban fringes in small numbers not within drive times can be serviced by creating small capacity evacuation facilities in the areas.

Capacity: A comparative analysis of accessibility and capacity shows that only around 30% of the population is serviced in terms of capacity. Additionally new facilities need to be created to increase occupancy coverage. In Vulnerable Block Groups, Facilities within 5 Min Drive Times only cover 25% of Block Group Population. Therefore Priority needs to be given for these geographical entities. With an average occupancy of 515 Persons as per the current conditions, we would need at least 600 more shelters to reach 100% coverage

Highly Vulnerable Block Groups are not serviced adequately by necessary capacity although all the mean population weighted centers of these block groups are accessible by facilities within a 5 minute drive time but very few evacuation facilities fall within these areas. **Interventions must include increasing the number of evacuation facilities and increasing the capacity of existing facilities.**

Location Allocation: Planning of Capacity extent of individual existing facilities must be undertaken by doing location allocation analysis facility by facility to determine parcel point demand gaps. The servicing of these demand gaps must be further analyzed by the determination of new facilities with maximum capacitated coverage as per the network problem type.

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Appendix

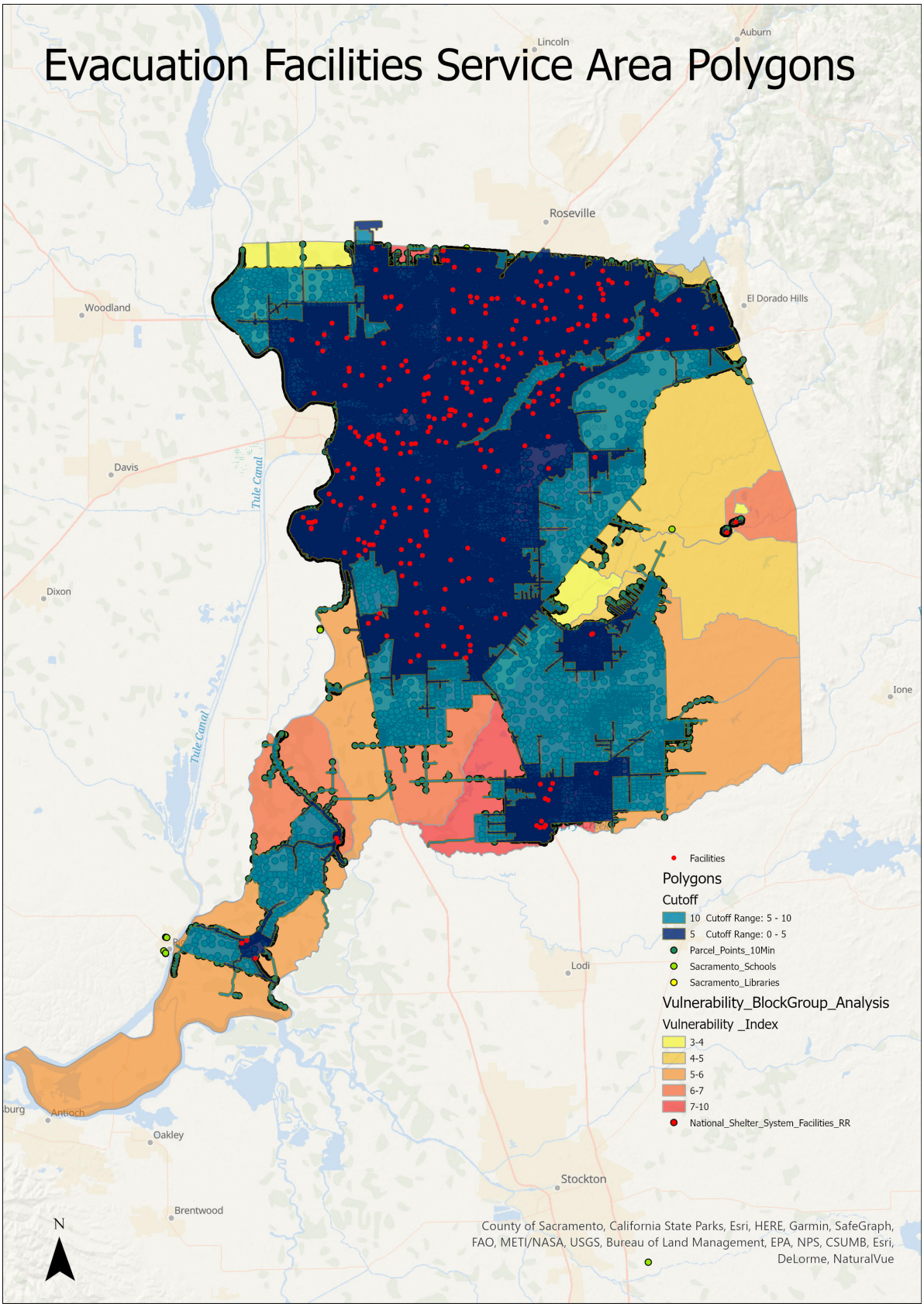

Figure A1. Output of 5 and 10 mile service areas for existing emergency shelter facilities.

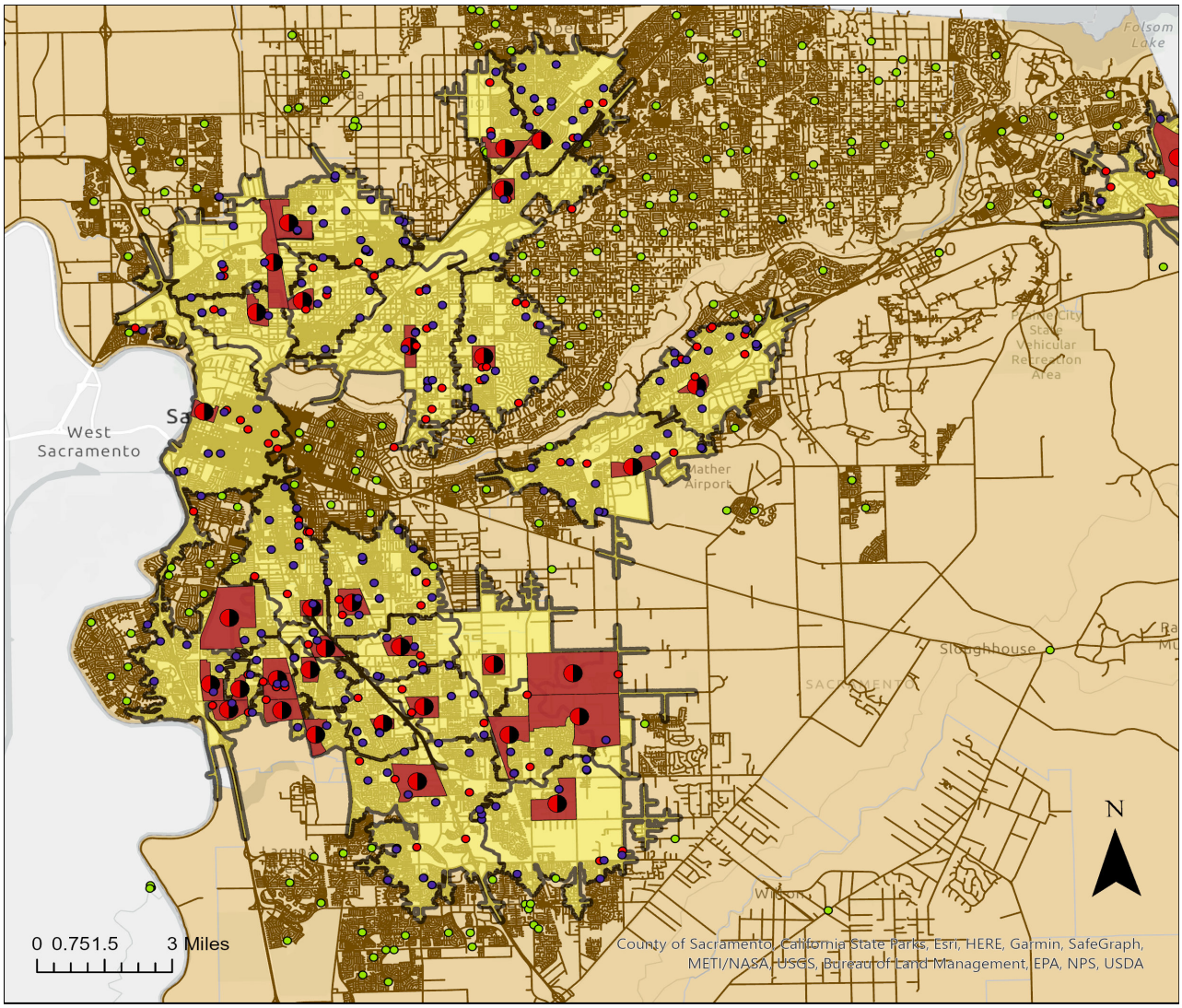

Figure A2. 5 minute drive time service area polygons for most vulnerbale block groups.