A DSS for Improving CAP's Efficiency in Flood Hazard Mitigation Assistance

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ABSTRACT

Natural hazards, particularly flood hazards, are increasingly becoming a significant threat to civil infrastructure and overall public safety nationwide. Underserved communities may not have the necessary local support and or manpower to conduct necessary preparedness work on their own. Disaster management organizations aiming to increase their impact and assistance to such communities can use informatics and geospatial data analysis to gain actionable information, understanding, and better decision-making from the vast amounts of raw data available. This paper outlines a proposed Decision Support System for the Civil Air Patrol (a non-profit civilian volunteer auxiliary to the US Air Force who provides disaster assistance) which uses data processing and analytics to identify communities most at risk for flood hazards based on the Federal Emergency Management Agency's National Risk Index. This information is synthesized with organizational data to provide a prioritized ranking of where the organization can have the most impact for community flood hazard mitigation based on the location and status of its own assets. The workflow's code functioned and produced results. However, further development and validation of the system is necessary in order to ensure computational efficiency, user-friendliness, as well as validity of results.

INTRODUCTION

Natural hazards, particularly flood hazards, are increasingly becoming a significant threat to civil infrastructure and overall public safety nationwide. The Civil Air Patrol (CAP), a non-profit organization that contributes volunteer manpower in the Disaster Management field, has historically been primarily involved in the post-disaster Response and Recovery phases of Disaster Management. CAP has been integrating GIS and geospatial analysis into its operational and business functions to work more seamlessly with disaster management agencies. CAP's Geospatial Program aims to lead a shift in the organization to increase its contributions in the Prevention, Mitigation, and Preparation phases of Disaster Management. One way CAP can contribute to building community preparedness and resilience in the pre-disaster phases, specifically for flood hazards, is by aiding communities with updates to FEMA Flood Maps. FEMA flood maps provide the basis for the FEMA National Flood Insurance Program's Flood Insurance Rate Maps (FIRM). Updates to these maps are a collaborative effort between local communities and FEMA. FEMA works with communities via its local leaders to collect data, conduct hydrological analysis, and gain public and expert input before combining inputs into a computer model which creates the flood maps. CAP's Geospatial Program can lead CAP in aiding communities in this effort by developing a spatially enabled decision support system (DSS) which identifies underserved communities in need of assistance to update their FEMA Flood Maps and further assess the organization's local capability to provide potential assistance. This paper describes a DSS designed to identify where CAP's volunteer manpower and equipment to can be of most impact in flood hazard prevention, mitigation, and preparation by prioritizing its efforts in developing relationships with communities who need it the most and assist in the timely, economical, high-resolution collection of spatial data to aid in this process.

Flood Hazards

Floods can occur anywhere and have different effects on communities depending on the intensity and extent of a disaster event, the community's vulnerability to being socially affected by the disaster, as well as the community's resilience in responding and recovering from the disaster (Federal Emergency Management Agency, 2020). The risk for flooding can be caused by heavy rains, poor drainage, and even construction projects and areas (Federal Emergency Management Agency, 2020). Flooding is defined as water overflow on land and can range from a few inches to multiple feet (Federal Emergency Management Agency, 2020). Floods are the most commonly occurring natural disaster and the leading cause of natural disaster fatalities across the world (Federal Emergency Management Agency, 2020).

RiskMAP

The Federal Emergency Management Agency's (FEMA) RiskMAP (Risk Mapping, Assessment and Planning) program is an iterative program which collects, analyzes, and maintains hydrological and engineering data to assess flood risk across the nation. RiskMAP data serves as the foundation for other regulatory and non-regulatory FEMA products and services dealing with flood hazards such as the National Flood Hazard Layer (NFHL) and the National Flood Insurance Program's (NFIP) Flood Insurance Rate Maps (FIRM). Updates to these maps throughout a RiskMAP project are a collaborative effort between local communities and FEMA. FEMA works with communities via its local leaders to collect data, conduct hydrological analysis, and gain public and expert input before combining inputs into computer models which create the flood maps.

Civil Air Patrol Geospatial Program

The Civil Air Patrol (CAP) is the civilian volunteer auxiliary to the US Air Force. CAP "carries out emergency service missions […] in the air and on the ground […] to search for and find the lost, provide [aid] in times of disaster and work to keep the homeland safe (Civil Air Patrol, 2023). Its [~60K volunteer] members selflessly devote their time, energy, and expertise toward the well-being of their communities" (Civil Air Patrol, 2023). CAP and its thousands of ambitious volunteers are an invaluable resource to local, state, and federal emergency management and other government agencies at little to no cost to the local government and subsequently the taxpayer.

CAP's Geospatial Program was established in 2018 with a goal of equipping CAP with the power of location intelligence and improved data driven decision making in general across both internal and external operational and business functions (Civil Air Patrol, 2023). The CAP Geospatial Team aims to lead as innovators within the organization. Overall, CAP has historically been mostly involved in the Response and Recovery phases of Disaster Management. The CAP Geospatial Team is currently working to lead a shift in the organization with the integration of GIS and spatial data analysis to increase its contributions in the Prevention, Mitigation, and Preparation phases of Disaster Management.

Objective

From the early works in natural hazards research, Kaplan and Garrick (1981) "… emphasize that the purpose of risk analysis and risk quantification is always to provide input to an underlying decision problem which involves not just risks but also other forms of costs and benefits." There is no shortage of disaster management work to be done, whether in the pre or post disaster phases. The question is then, as a support organization, where should CAP work to prioritize its efforts in the pre-disaster phases to maximize positive impact on communities and the public's safety from flood hazards?

One way CAP can contribute to building community preparedness and resilience in the pre-disaster phases, specifically in flood hazards, is by aiding communities with updates to FEMA flood maps during the RiskMAP project process. CAP's Geospatial Program can lead CAP in assessing where its assets can most impactfully aid communities in this effort by developing a spatially enabled decision support system (DSS) which identifies underserved communities most in need of assistance to update Flood Maps in their area and further assesses the organization's local capability to provide support to these communities.

The objective of this paper is to identify where CAP should prioritize its efforts to maximize positive impact on communities and the public's safety from flood hazards by developing and implementing a data driven decision support system for the improvement of community disaster preparedness and the continual work of natural hazard risk reduction.

METHODOLOGY

The decision support system's methodology and analysis framework are visualized in Figure 1. The overarching process involves a combination and relative ranking of communities represented by county geographies with NRI flood risk, RiskMAP study activity, and CAP volunteer availability as inputs.

Source Data

CAPWATCH

Proprietary data from CAP's CAPWATCH database is used to model the organization's support posture. The database consists of multiple related tables delivered as text files in a comma separated format. The data must first be converted from text files to comma separated value (csv) files to be able to conduct necessary joins between different tables in which the required data lies.

The combined information from the CAPWATCH database tables is sourced to help answer the question… *Where is CAP capable of providing disaster assistance volunteers?*

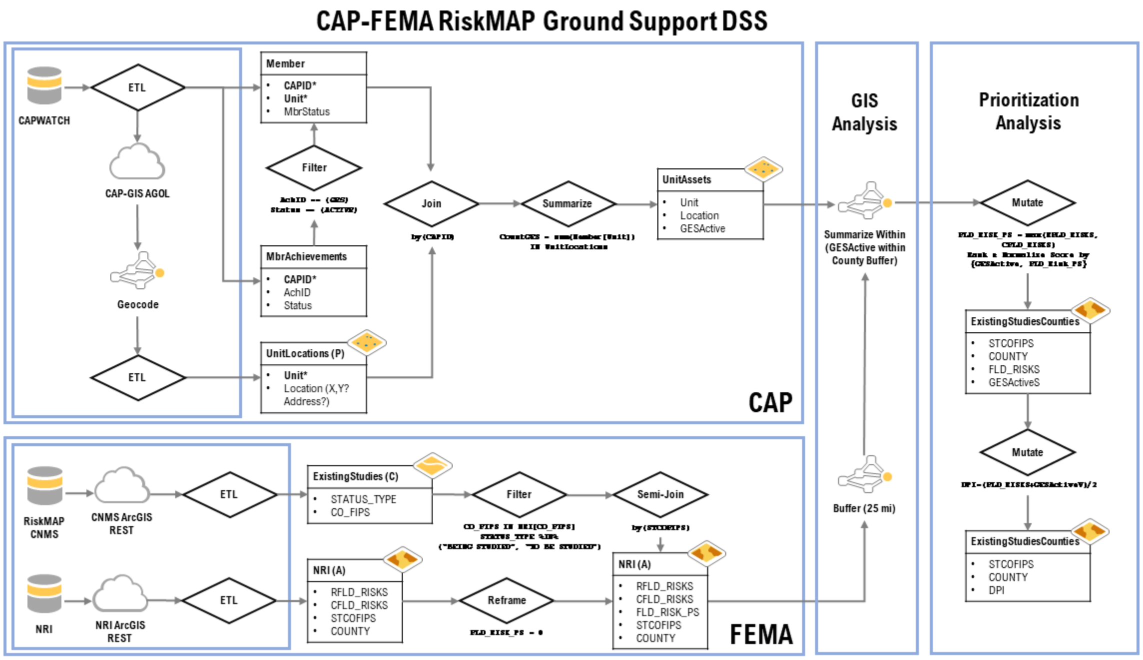

Figure 1: CAP-FEMA RiskMAP Ground Support DSS

RiskMAP (Risk Mapping, Assessment, and Planning) Coordinated Needs Management Strategy (CNMS)

The Coordinated Needs Management Strategy (CNMS) database is a part of FEMA's Risk Mapping, Assessment, and Planning (RiskMAP) program where hydrological units are prioritized and managed within the RiskMAP process. CNMS identifies and tracks the life cycle and mapping needs of flood hazard studies (Federal Emergency Management Agency, 2020). The CNMS provides a geospatial database of riverine studies, coastal studies, unvalidated stream reaches, and mapping request information to provide data on what areas are being studied for physical and hydrological flooding risk (Federal Emergency Management Agency, 2020).

The RiskMAP program allows for each flood risk project to be tailored to the needs and capabilities of the affected community (Federal Emergency Management Agency, 2020). Information from the CNMS database is sourced to help answer the question… *What areas are being studied for physical, hydrological flooding risk?*

National Risk Index (NRI)

A community's overall risk to flood hazards is sourced from FEMA's National Risk Index (NRI) for county level. The recently developed NRI dataset (2016-2020) is built upon a comprehensive understanding of past and current research in the field of natural hazards. It accounts for multiple relevant consequence enhancing and reduction risk components for natural hazards within the US. The inputs are processed to create a relative risk index which can be applied to various standard geographic enumeration scales, including census tracts, counties, and states (FEMA, 2021).

To achieve this overall index score, the NRI combines University of South Carolina's Hazards and Vulnerability Research Institute (HVRI) Baseline Resilience Indicators for Communities (HVRI BRIC) index, an updated version of the Social Vulnerability Index (SoVI®) (University of South Carolina, 2013), along with an Expected Annual Loss calculation for 18 different natural hazards. The NRI's methodology can be manually calculated and modeled based on publicly available source data. Information from the NRI database is sourced to help answer the question… *Which communities are most at risk to the Socio-economic effects of Flooding?*

Data Extract, Transform, Load Processing

CAPWATCH

Tables extracted include the membership table (*Member*) which contains relevant high level administrative data for each CAP member including their ID number [*CAPID*], unit number [*Unit*], and their membership status [*MbrStatus*]. The [*MbrStatus*] attribute is used to filter out only members that are active, and the [*CAPID*] and [*Unit*] attributes are used later to conduct joins with other tables.

The [*MbrAchievements*] table is extracted with the CAP ID [*CAPID*], achievement ID [*AchID*], and achievement status [*Status*] attributes. [*AchID*] and [*Status*] attributes are used to filter out records such that only active General Emergency Services (GES) qualifications are selected. These records are joined with the active membership data via [*CAPID*] to further filter down to only active members with active GES qualification.

Finally, the unit information, including geospatial data is extracted from the existing geocoded *Unit Locations – Primary View* hosted feature layer within CAP's ArcGIS Online environment. This geospatial web service consists of data extracted from CAPWATCH's (*Organization*) and (*OrgAddress*) tables which is processed from its tabular format into a geospatial data format. The data is geocoded from either existing *x*,*y* Latitude and Longitude coordinates or interpolated from street address.

Member counts are summarized for each unit using the [*Unit*] attribute to relate the (*Member*) and (*Unit*) tables. This summary results in an additional count attribute of active and GES qualified members for each unit [*GESActive*].

Table 1: UnitAssets table with summarized active GES count

```
> head(UnitAssets[,c(2:5,13:14,17)], 5)
   Charter__ Region Wing Unit Latitude Longitude GESActive
1 PCR-AK-000    PCR   AK    0  61.2404 -149.8012      3007
2 PCR-AK-001    PCR   AK    1  61.2404 -149.8012      1740
3 PCR-AK-009    PCR   AK    9  64.8339 -147.7165       345
4 PCR-AK-011    PCR   AK   11  60.5644 -151.2019       252
5 PCR-AK-015    PCR   AK   15  61.2173 -149.8448       526
```

RiskMAP Coordinated Needs Management Strategy

Extracted CNMS data consists of a selection of records (reaches and coastline segments) in which an active or pending study is currently recorded:

```
# Filter Active and Pending studies...
CNMSActive = filter(CNMS[c('STATUS_TYPE', 'CO_FIPS')],
                    STATUS_TYPE %in% c('BEING STUDIED', 'TO BE STUDIED'))
```

Figure 2: Code snippet of CNMS table filtering

The selected records are additionally extracted with the [*CO_FIPS*] attribute. This attribute is equivalent to the [*STCOFIPS*] attribute within the NRI dataset; a unique ID number including state Federal Information Processing Standard (FIPS) ID (first two digits) combined with county FIPS ID within the state. This attribute is extracted and renamed to match the NRI's [*STCOFIPS*] in order to conduct joins in the next steps with NRI Counties. This attribute can additionally be used to filter out counties for a specific state or states in further steps for Wing (state level) or Regional prioritization analysis. The example in this paper is filtered to only counties within Virginia ([*STCOFIPS*] beginning with 51…).

Table 2: Filtered CNMS table

```
    STATUS_TYPE STCOFIPS
1 BEING STUDIED    51071
2 TO BE STUDIED    51005
3 TO BE STUDIED    51005
4 TO BE STUDIED    51017
5 TO BE STUDIED    51017
```

National Risk Index

The NRI provides hundreds of attribute columns for each table record (geographic enumeration unit). Separate database tables are available for enumeration units at different geographic scales (census, county, state). For this analysis, county tables were used as the geographic unit. Both the Riverine Flooding [*RFLD_SCORES*] and Coastal Flooding [*CFLD_SCORES*] risk score indices are extracted from the NRI's extensive database which covers data for each of the 18 different hazard risk scores assessed in the NRI process. Additionally, the county's FIPS ID [*STCOFIPS*] is extracted to join with other tables in later processing and analysis.

The NRI table is reframed with an additional blank integer column, [*FLD_RISK_PS*], in which the highest flood risk score between riverine and coastal flooding is selected and copied as the "Prevailing Risk Score".

The first join is a semi-join between the NRI and Active CNMS tables. This semi-join simultaneously conducts a filter on the NRI table resulting in a filtered NRI table which contains records only for counties with active or pending associated RiskMAP studies. Figures 3 and 4 visualize the NRI risk scores for Riverine and Coastal flooding. For all plotted map figures, counties are grayed out based on the joined CNMS data within which no active or pending RiskMAP studies are present and are not included in the total count of counties being analyzed.

Geospatial Prioritization Analysis

Once the bulk of extract, transform, and load processing has been completed on the source data, geospatial prioritization analysis can begin. Geospatial functions are used from the "sf" library loaded in the initiation of the DSS code and must be installed as a dependency prior to being able to run.

Composite Flood Risk Index

To start, more tabular analysis is continued to determine an overall composite flood risk index based on the prevailing flood risk index from previous steps (riverine or coastal). An overall composite flood risk index for each county is computed based on ranking the prevailing flood risk against all counties with active or pending RiskMAP studies then dividing the county's rank by the total number of counties with active or pending RiskMAP studies. Overall composite flood risk index is visualized in Figure 5.

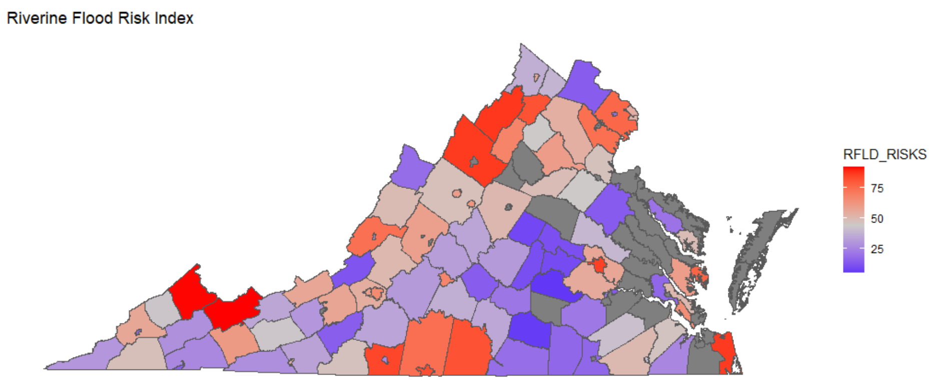

Figure 3: NRI Riverine Flood Risk Index Score

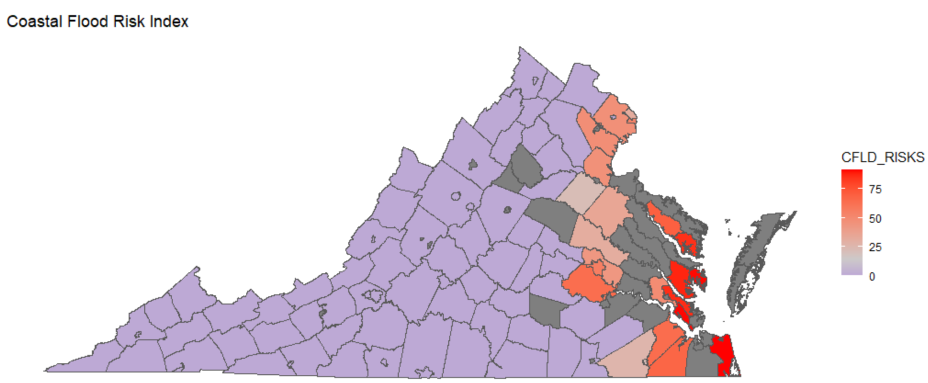

Figure 4: NRI Coastal Flood Risk Index Score

Availability Index

To obtain the organization's response posture represented by active GES qualified member counts within proximity of each county, active GES member counts from the (*UnitAssets*) table are joined with a point file (shapefile) of unit locations to be used in geospatial analysis. First, a 25-mile buffer is computed for each county geometry. Next, the count of available active GES qualified members for each county [*GESActive*] is counted by summing the [*GESActive*] counts for each unit intersecting or within the county's 25 mi buffer. The total available active GES count values by county along with unit locations by active GES count for Virginia counties are visualized in Figure 7. Counties with no units within their 25-mile buffer (zero available active GES members) assigned a zero.

After the previous step, which constitutes the geospatial analysis, further tabular analysis is conducted to obtain the normalized availability index – the organization's input variable to the final decision prioritization index. The normalized GES availability score [*GESActiveS*] for each county is computed by ranking the counties [*GESActiveV*] by available GES count [*GESActive*] then dividing by the number of counties with active or pending RiskMAP studies. Tied counties are given the same availability rank and score based on the average of the untied ranks occupied. Counties with zero active GES members available based on intersecting units are given a zero value for [*GESActive*] and are still computed a rank and score. The availability index for Virginia counties is visualized in Figure 8.

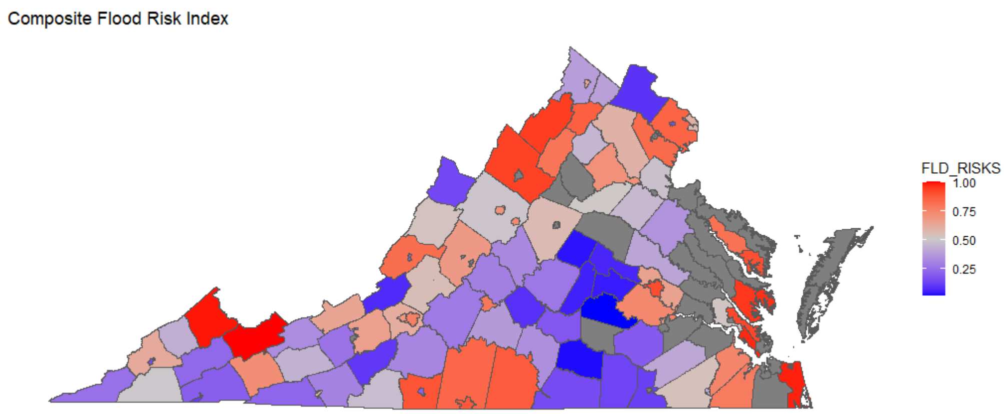

Figure 5: Composite Flood Risk Index

```
# join unit asset information to unit point locations
UnitsPt = UnitsPt %>% mutate(GESActive = UnitAssets$GESActive)

# set 25 mi buffer distance in meters
distance = 40234

# Create a 25 mi buffer around each county
buffer = st_buffer(CountiesA, dist = distance)

# Intersect unit point locations with county buffers
intersected_points = st_intersection(buffer, UnitsPt)
intersected_points = intersected_points[!grepl('001$',
                                       intersected_points$Charter__),]

# Summarize active GES members from intersecting units for each county
summary_table = st_drop_geometry(intersected_points) %>%
  group_by(STCOFIPS) %>%
  summarise(GESActive = sum(GESActive)) %>%
  select(STCOFIPS, GESActive)

# Join summary table to counties; Keep only STCOFIPS & GESActive
CountiesA = left_join(CountiesA, summary_table, by = "STCOFIPS")
CountiesA = CountiesA[c('STCOFIPS', 'GESActive')]
```

Figure 6: Code snippet of sf geospatial analysis in R

Decision Prioritization Index

Finally, the final Decision Prioritization Index [*DPI*] is computed based on the composite flood risk index [*FLD_RISKS*] and availability index [*GESActiveS*] inputs. The synthesis of the input variables into the DPI for each county is a function of the sum of index scores {[*FLD_RISKS*], [*GESActiveS*]} for the county divided by the total number of index scores (two). The DPI for Virginia counties is visualized in Figure 9.

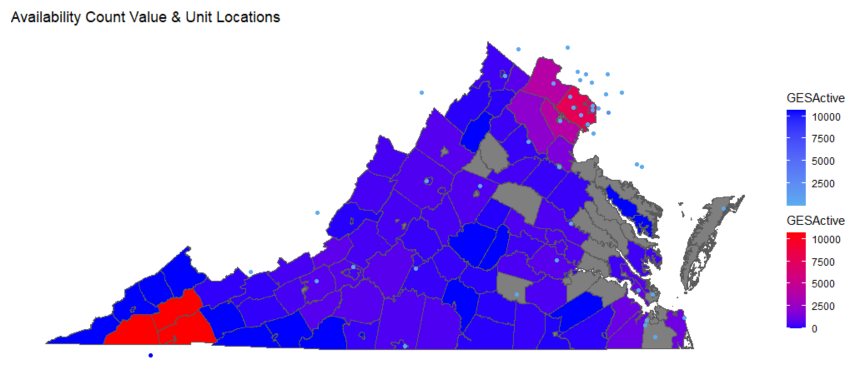

Figure 7: Active GES Availability Counts & Unit Locations

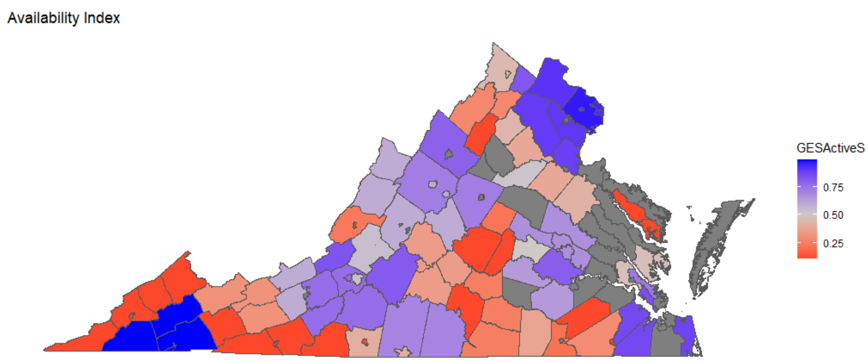

Figure 8: Active GES Availability Index

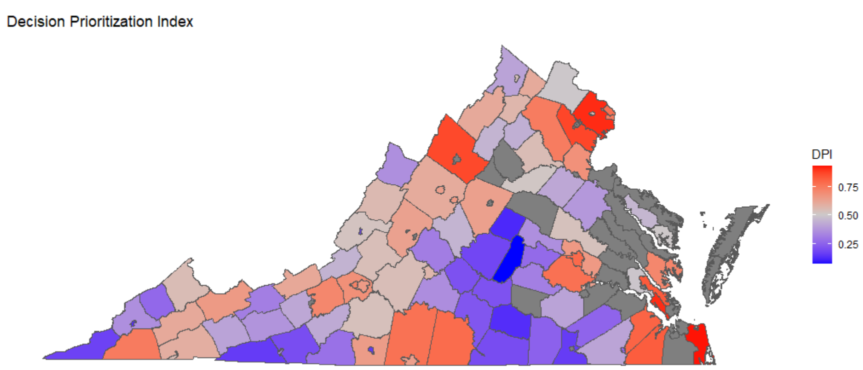

Figure 9: Decision Prioritization Index

RESULTS

For Virginia counties, the DSS analysis code produced results indicating that the top five counties with a combined high flood risk along with a high availability of active GES qualified CAP members include: 1) Virginia Beach, 2) Fairfax, 3) Newport News, 4) Prince William, and 5) Rockingham. Relevant DPI input values and final DPI scores are summarized for the top five counties in Table 3 and visualized in Figure 10.

Table 3: Summarized data for top 5 Prioritization Counties

	STCOFIPS	COUNTY	GESActive	GESActiveS	FLD_RISKS	DPI
1	51810	Virginia Beach	1203	0.87	0.98	0.925
2	51059	Fairfax	7769	0.96	0.85	0.905
3	51700	Newport News	993	0.84	0.97	0.905
4	51153	Prince William	3953	0.90	0.83	0.865
5	51165	Rockingham	695	0.79	0.93	0.860

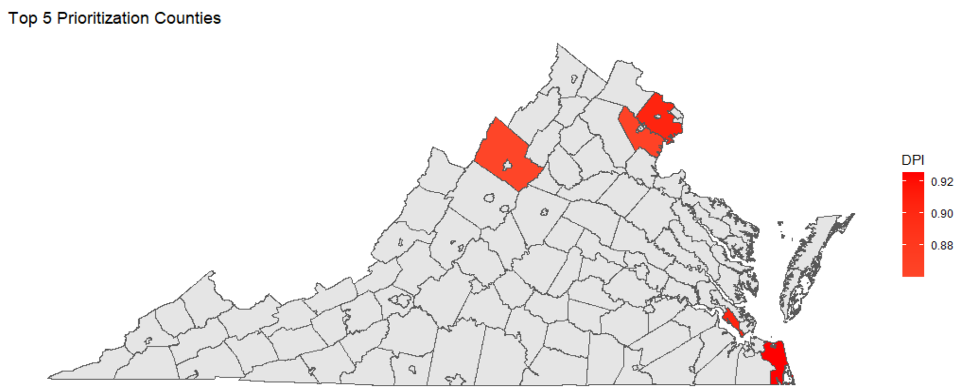

Figure 10: Top 5 Prioritization Counties

DISCUSSION

The DSS workflow's code was carefully assessed and validated for functionality. However, further validation of the computational methodology to arrive at the final Decision Prioritization Index is necessary to ensure valid analysis and results. It should be noted that further investigation of CAPWATCH source data should be conducted to ensure validity of aggregated counts. During analysis, one unit was attributed to having approximately 10,000 active GES qualified volunteers. This is highly unlikely. It is unclear whether this was a headquarters unit which counted all of its subordinate units, but even this is unlikely. Further investigation is necessary prior to implementation.

Other considerations should be to compute active GES member availability solely by individual member location instead of aggregating counts by unit location, and enumerate active and pending studies by centerline milage and adding to the DPI. Additionally, the same workflow can be applied to other assets (aircraft, vehicles, communications equipment, etc.) for other use cases.

The DSS's code should be revised to streamline computational efficiency throughout the system's workflow. Once the DSS's framework is fully developed and validated, further development can be carried out to design and implement a dynamic, user-friendly graphic user interface and dashboard for key decision makers to utilize in this strategic decision process.

CONCLUSION

Flood hazards are becoming an increasing threat to the civil infrastructure. GIS is designed to integrate with other data analysis and business solutions to enhance strategic and operational decision-making processes. The use of GIS and geospatial data analysis in organizational informatics can help in identifying where CAP should prioritize its efforts to maximize positive impact on communities and the public's safety from flood hazards. By developing and implementing a data driven DSS for the improvement of community disaster preparedness and the continual work of natural hazard risk reduction, CAP can expand its Emergency Services mission further into the Prevention, Mitigation, and Preparation phases of Disaster Management.

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