GIS Analysis of Helicopter Rescue in San Bernardino County, California

by

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Dedication

To my parents, Wayne and Natalie Fisher; my wife, Brianna Crawley; and my children, Roscoe, Avelina, and Merielle.

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List of Abbreviations

DEM	Digital Elevation Model
GIS	Geographic information science
GPS	Global Positioning System
HLZ	Helicopter Landing Zone
MAUP	Modifiable Areal Unit Problem
NVG	Night Vision Goggles
SAR	Search and Rescue
SBSD	San Bernardino County Sheriff's Department
SSI	Spatial Sciences Institute
TAZ	Traffic Analysis Zone
USC	University of Southern California
USCG	United States Coast Guard

Abstract

People become lost and injured in remote areas on a daily basis. Search and rescue personnel, including members of the military, law enforcement agencies, fire departments, emergency medical services, and volunteer teams stand by for the opportunity to rescue someone. This requires the development of teamwork and skills and the acquisition and maintenance of equipment. Rapid and accurate analysis of geographic information plays a critical role in ensuring resources are used as safely and effectively as possible in search and rescue operations.

Historical search and rescue records contain a wealth of information that can guide training, drive recruitment of new members, and define the necessary capabilities of equipment and personnel. Although they may not have been collected with the intent of providing data for spatial analysis, the geographic information contained in rescue documentation can provide information as to the trends in where rescues are occurring, which can help anticipate future incidents and improve readiness.

This thesis is a retrospective application of geographic information science to the records of the San Bernardino County sheriff's air rescue program. The hoist rescues performed since the program's inception in 1993 were georeferenced, digitized, and used as the basis for a geodatabase. The spatial pattern of air rescues in the county was analyzed to identify the areas of greatest rescue activity and seasonal trends in locations and elevations. This information will help leaders on the team guide training and preparation and help define the necessary capabilities of rescue helicopters for work in the county. In addition, by showing trends in rescue activity in certain areas and times of the year, recommendations are made for preventative measures to keep hikers and climbers safe. The analysis methods here can be applied to similar projects throughout the United States and beyond.

Chapter 1 Introduction

The San Bernardino County sheriff's air rescue program provides helicopter search and rescue and medical transport services throughout the county. Search and rescue is an inherently geospatial activity, as location and terrain dictate every aspect of training for, planning, managing, and executing missions. Rotary-wing search and rescue is particularly demanding for the helicopter and aircrew and depends strongly on teamwork, elevation, and weather conditions. This project will use geographic information science (GIS) to analyze the activities and enhance the capabilities of the sheriff's air rescue program by creating a database of rescues and analyzing trends in the data.

1.1. The San Bernardino County Sheriff's Air Rescue Program

The county of San Bernardino, California, with an area of over 20,000 square miles, is the largest county in the continental United States. It is approximately the size of the state of West Virginia. The San Bernardino Mountains cut across the southwestern part of the county, and the Mojave Desert occupies the area north and east of the mountains. A section of Joshua Tree National Park is in the eastern part of the county. Approximately eighty percent of the population lives south of the mountains in the Ontario-San Bernardino-Riverside metropolitan area (San Bernardino County 2015). Figure 1 shows the state of California, San Bernardino County, and the locations of the sheriff's aviation helicopters and trauma centers with helipads.

The terrain in the county is extremely varied. The San Bernardino Mountains include several peaks above 10,000 feet, with the tallest, San Gorgonio Mountain, at 11,503 feet. The mountains receive abundant snow in the winter, while it may be hot and dry in the Mojave Desert at the same time.

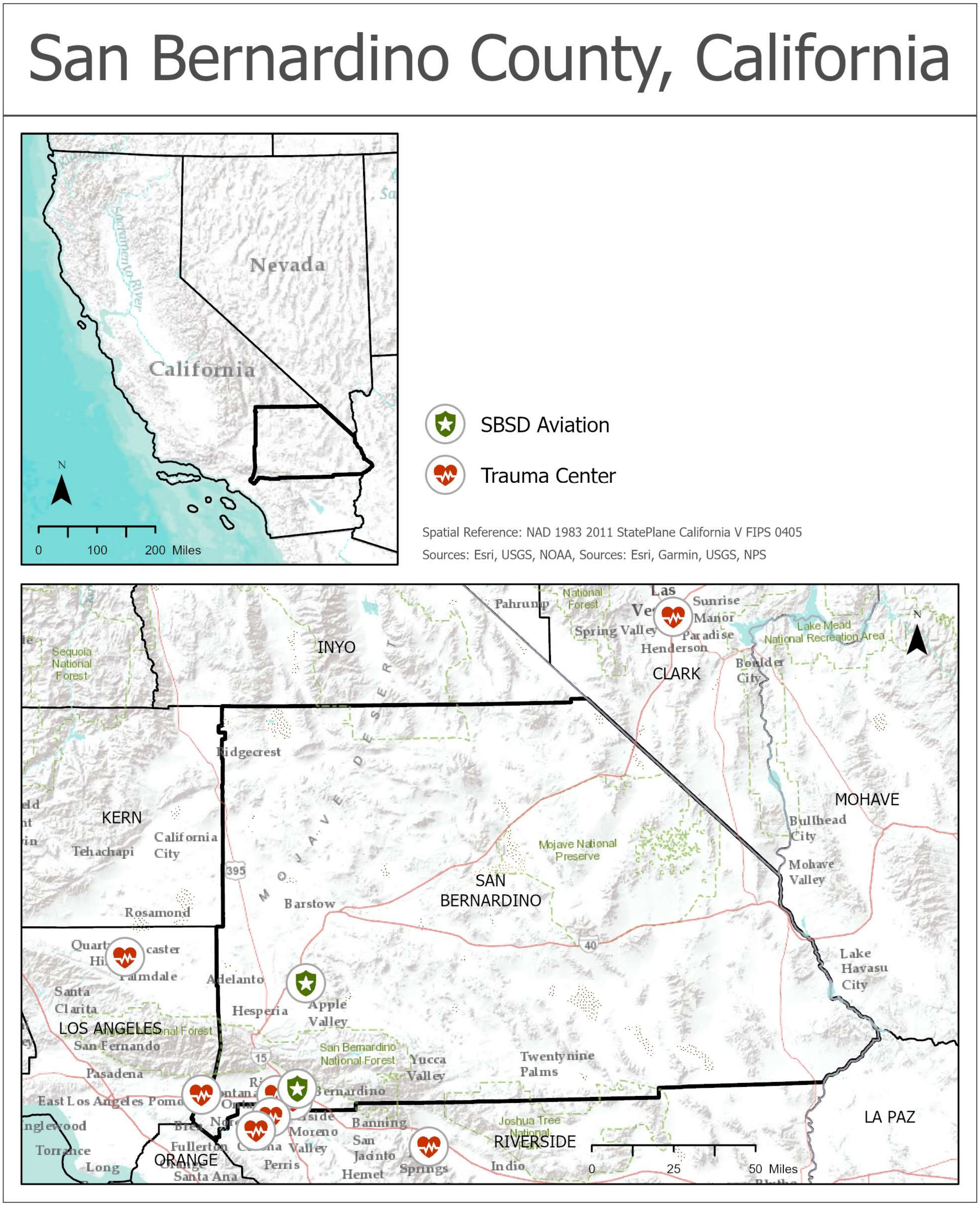


Figure 1 San Bernardino County, sheriff’s aviation, and trauma centers

Every year, hundreds of people become lost or injured in remote areas of San Bernardino County. There are many highly trafficked hiking and climbing areas in the mountains, with trailheads easily accessible from all of southern California. The desert areas north of the mountains have hiking trails and many areas for riding dirt bikes and other off-road vehicles. Section 26614 of the California Government Code states that "[t]he board of supervisors of a county may authorize the sheriff to search for and rescue persons who are lost or are in danger of their lives within or in the immediate vicinity of the county." (California Legislative Information 2020) Section 12.0511 of the San Bernardino County Code of Ordinances makes this authorization and states that "the Sheriff shall have the authority to search for and rescue persons who are lost or are in danger of their lives within or in the immediate vicinity of the County." (San Bernardino County, CA Code of Ordinances 2019) In accordance with these statutes, the sheriff's department coordinates volunteer search and rescue teams that respond with trained personnel to find, rescue, treat, and evacuate lost and injured people in remote areas (San Bernardino County Sheriff's SAR 2020).

The sheriff's department also maintains a rescue helicopter, which provides 24/7 search and rescue and medical transport services throughout the county. The sheriff's air rescue team is made up of physicians, physician assistants, nurses, paramedics, and technical rescue experts who volunteer their time on the rescue helicopter (San Bernardino County Sheriff's Department 2020). The volunteer team provides medics on Friday, Saturday, and Sunday, while San Bernardino County Fire paramedics staff the rescue helicopter Monday through Thursday. Full-time sheriff's deputies in the aviation unit are also trained as rescuers and perform rescues after hours. The rescue helicopters have medical equipment comparable to an ambulance, although, depending on their qualifications, some air medics have a greater scope of practice than a paramedic on an ambulance or fire engine. The vast size, long distances, and rugged terrain of the county mean that rescuers using helicopters can often find, access, treat, and transport patients more quickly than ground resources.

1.2. Helicopter Hoist Rescue

The safest way to get a person into or out of a helicopter is for it to land. The sheriff's department uses two procedures to insert or extract people if it is unable to land. If the helicopter can hover within a few feet of the ground, rescuers can do a hover step, in which they enter or exit by climbing the skids. If trees or terrain prevent a hover step, a hoist is necessary. A hoist involves lowering the rescuer and equipment to the ground using a winch with a steel cable while the helicopter hovers. The rescuer packages the victim in a harness or litter, then the victim and rescuer are raised back into the helicopter. This type of rescue is demanding for the helicopter and aircrew. The ability to perform a hoist rescue depends on a combination of the power and weight of the helicopter; the amount of fuel, personnel, and equipment on board; the skill and teamwork of the pilot, crew chief, and medic; and the elevation, temperature, and wind.

When performing a hoist rescue, the sheriff's department helicopters usually fly with one pilot, one crew chief, and one or two air medics. The crew chief has the greatest responsibility during a hoist operation. While the helicopter is flying to the target area, the crew chief ensures the cabin is ready and reviews emergency procedures with the pilot. When the helicopter is near the target area, the crew chief opens the door and stands on the skid. At this point, the pilot cannot see the ground below the helicopter, so the crew chief guides the pilot into position using the intercom. When the helicopter is hovering in the right place, the crew chief ensures the hook is connected properly and operates the hoist to lower the rescuer and any necessary equipment to the ground. When the rescuers have packaged the victim, the crew chief raises the victim and rescuers back into the helicopter. The team almost always has one person at a time on the hoist, so multiple evolutions are necessary to recover more than one person.

1.3. Sheriff's Aviation Aircraft and Equipment

The San Bernardino County sheriff's aviation unit has a fleet of helicopters and airplanes. Its main facility is at the San Bernardino International Airport, with one patrol helicopter on duty at the Apple Valley Airport.

1.3.1 Patrol Helicopters

The sheriff's patrol helicopters are Eurocopter AS350 B3 "AStar" or Airbus H125 models. They are almost identical but have different names because Eurocopter became Airbus Helicopters in 2014 (Faury 2014). They are single-engine, three-blade light utility helicopters with 848 horsepower and 3433 lb. empty weight (Airbus 2020). They have a cargo hook that can carry a bucket for fire-fighting operations. They can also be equipped with an external hoist for rescues. The hoist is a Goodrich 44301-10-5 Rescue Hoist with 170 feet of 3/16 inch steel cable and a maximum rated load of 500 lbs (Goodrich Hoist and Winch 2020). The small size of the cabin usually prevents victims from being brought inside while the helicopter is in flight, so they are kept outside on the hook until it can land, at which time they are brought inside or transferred to a ground ambulance. The call sign for the patrol helicopters is 40 King followed by the last digit of the tail number. Figure 2 shows 40 King 3 during a hoist operation with the crew chief standing on the skid.

1.3.2 Medium Helicopters

The sheriff's department has three Huey-type helicopters that are mostly used for rescue. They can also be equipped with buckets or tanks for firefighting. Air Rescue 306 is a Super

Figure 2 40 King 3 conducting a hoist.

Huey, which means that it has an upgraded engine, transmission, drive shaft, and tail rotor compared to a regular Huey. It has one engine, approximately 1800 horsepower, and 5721 lb. empty weight. Air Rescue 307 is a Bell 212, which is the civilian version of the military Huey. It has two engines, approximately the same horsepower as 306, and 6710 lb. empty weight. Air Rescue 308 is a regular Huey, with one engine, 1300 horsepower, and 5338 lb. empty weight. The medium helicopters can be equipped with a Lucas Aerospace rescue hoist, which has been known as the Goodrich 43205 since the Goodrich Corporation acquired the successor of Lucas Aerospace in 2002 (Goodrich Hoist and Winch 2020). It has 250 feet of 3/16 inch steel cable and a maximum rated load of 600 lbs (Goodrich Hoist and Winch 2020). Figure 3 shows Air Rescue 306 conducting a hoist with a Stokes litter. The medium helicopters are large enough to bring a victim inside while in flight, where they can be treated by a medic while flying to the hospital.

For both the patrol and medium helicopters, the hoist creates an off-center load on the helicopter, which the pilot must counter to maintain a stable hover. In most cases, the ability of the pilot to correct for the changing center of gravity limits the amount of weight that can be lifted before the rated capacity of the hoist is reached.

Figure 3 Air Rescue 306 conducting a hoist with a Stokes litter.

1.3.3 Rescue Devices

For hoist rescues of ambulatory patients, the air medics use the Hotseat, which is a nylon harness manufactured by CMC. It is put on like a jacket and has rings that connect to the hoist hook (CMC 2020).

If a victim is in such a precarious position that the rescuer is not able to disconnect from the hoist hook, the air medics use the Lifesaver Victim Harness, which is made by CMC (CMC 2020). The victim harness is a belt with leg loops, which the rescuer puts on the victim, and the rescuer and victim are raised up to the helicopter together.

The air medics have two devices for non-ambulatory patients. On the medium helicopters, they use a Stokes litter, which is made from titanium or steel rails and wire mesh

(CMC 2020). It is designed to protect the patient but not catch the rotor wash underneath the helicopter, which can cause it to spin. The patient is usually packaged on a rigid backboard, which fits into the Stokes litter. The Stokes litter has a steel cable "spider strap" system, which connects to its rails and has a ring for the hoist hook.

The patrol helicopters do not have enough room inside for a rigid Stokes litter. For non-ambulatory patients, they use the Bauman Air Bag, which is a soft nylon litter. The patient is packaged on a rigid backboard, then placed into the bag and secured with straps. The Bauman Air Bag has nylon straps that connect to a ring for the hoist hook.

1.4. Dispatch Protocols and Decision Making

The rescue helicopter is usually dispatched for rescues by the San Bernardino County Consolidated Fire Agencies (CONFIRE) dispatch center, which dispatches fire and emergency medical services and coordinates mutual aid requests throughout the county (San Bernardino County Fire 2020). The dispatchers can dispatch the rescue helicopter if they receive a call in which the reporting party describes a victim in a place that will be difficult or impossible for ground resources to access. The dispatchers can instruct callers in remote areas with GPS-enabled phones to access their location information and read their coordinates, which they can include with the dispatch information.

The rescue helicopter is also often requested by ground units who are unable to reach a victim or make contact and face a protracted extraction to the road due to steep terrain, water, or other hazards. On mountain roads, which are often narrow and windy with steep drop offs and no guard rails, cars that go off the road may not be far from it, but the terrain may be so steep and unstable they are difficult to access and require a hoist rescue. Even in populated areas, there can be situations where victims are inaccessible, such as when people become stranded in flood control channels.

Ground units can request the helicopter if their driving time to the hospital is longer than the victim's condition will allow. The rescue helicopter responds to motor vehicle collisions with severe injuries in remote parts of the county because its transport time to the hospital can be much faster than that of a ground ambulance. In these cases, the helicopter is usually able to land on the road near the site of the incident and a hoist rescue is not necessary.

Decisions taking into account expense, training of personnel, maintenance requirements, and weight have to be made and continually revised about the equipment the helicopter carries and the readiness posture of the team. The records of rescues the sheriff's department has performed can give a basis to these decisions and also guide efforts to prevent injuries from happening. This project will focus on the spatial and temporal patterns of hoist rescues of hikers and climbers. Hoist rescues also often involve operators of on- and off-road vehicles, but because they travel faster and cover longer distances, they tend to occur in extremely remote areas and have a very diffuse spatial distribution. The hoist rescues of hikers and climbers occur in more concentrated areas, which will be more amenable to preventative measures.

1.5. Helicopter Capabilities and Density Altitude

To conduct a hoist rescue, a helicopter must maintain a stable hover and take on an external load. This is a demanding task, because hovering requires more power than landing or forward flight. The helicopter's ability to hover depends on a number of factors, the most important of which are its total weight, the power of its engine, and the ability of its tail rotor to counter the torque of the main rotor blades.

A helicopter requires more power to hover at high altitudes because there is less air pressure for the rotor blades to push against and generate lift. High temperatures and humidity are unfavorable because they have the effect of lowering the air pressure. Altitude and temperature can be combined in a formula to approximate the density altitude, which is the altitude the helicopter "feels" it is flying (AOPA 2020):

$$A_d = A_p + [120 \times (T - T_{ISA})], \tag{1}$$

Where A_d is the density altitude in feet, A_p is the uncorrected altitude, T is the outside air temperature in degrees Celcius, and $T_{ISA} = 15 - \left(\frac{2 \times A_p}{1000}\right)$, the standard temperature at the uncorrected altitude.

Using the formula, the density altitude at 6,000 ft. and 90^0 F (32^0 C) is approximately 9,500 ft. Figure 4 is a chart that allows the user to calculate density altitude based on pressure altitude and temperature (Schappert 2020).

Air Rescue 308 is a Huey and is the least capable helicopter in the sheriff's department's fleet. It was recently equipped with a hoist and has been used to perform several hoist rescues. It is the assessment of the pilots in the aviation unit that Air Rescue 308 can perform hoist rescues at elevations up to 6000 ft. Above this elevation the helicopter is not able to reliably perform hoists.

Mt. San Antonio and San Gorgonio Mountain, two of the most popular mountains for hiking in San Bernardino County, have elevations of 10,069 and 11,503 ft., respectively. They see heavy traffic and rescue activity year round. Big Bear Lake, which is surrounded by mountains with ski areas, hiking trails, and rock climbing locations, has an elevation of 6,750 ft. With so many possibly hazardous outdoor activities occurring above 6,000 ft., it is reasonable to expect there will be a significant need for hoist rescues at and above that elevation.

The database of rescues the aviation unit has performed will allow the spatial distribution of rescues above and below 6000 ft. to be visualized and demonstrate the importance of a helicopter to be capable of hoist rescues above this level. These results will help the leadership of the aviation unit to determine the role of Air Rescue 308 as a rescue ship and the necessary capabilities of a new rescue helicopter, if it is to be replaced.

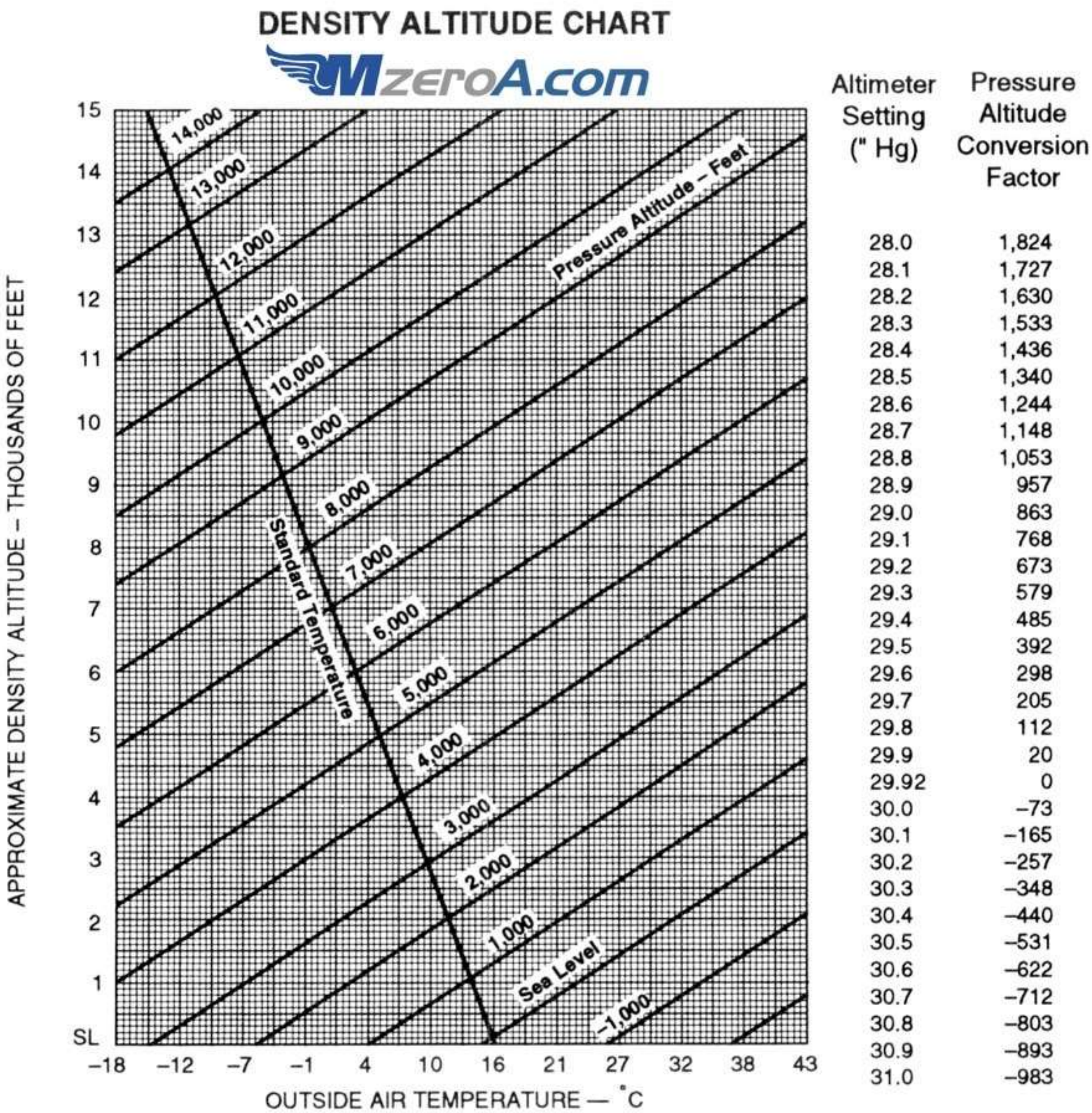


Figure 4 Density Altitude Chart

1.6. GIS Analysis of Rescue Records

The San Bernardino sheriff's rescue helicopter program has performed hundreds of hoist rescues since it developed the capability in 1993. The records of these rescues were only recently tabulated and digitized, and have not been georeferenced, mapped, or analyzed in any way. The rescue records contain a wealth of information that can be used to preserve the legacy of the people involved in the rescues; express the accomplishments of the program to the leadership of the county, the sheriff's department, and the public; understand the utilization of equipment; guide training; and identify hazardous areas that may be candidates for preventative measures.

GIS provides the tools to organize, store, visualize, and learn from geographic information. This project applies GIS these rescue records and demonstrates a few types of analysis that can be performed on them. The next chapter discusses articles on georeferencing locations from historical text descriptions, spatial analysis of search and rescue records, and statistical spatial calculations on incident data. Chapter 3 describes the format of the rescue records, the georeferencing process, and the details of the calculations performed. Chapter 4 presents the results of the analysis, with maps and tables showing the locations of rescues and trends in number and location over the months of the year and the years the program has been active. Finally, chapter 5 concludes with additional ways GIS can be applied to the rescue helicopter program and a framework for improving data collection to facilitate future studies.

Chapter 2 Related Work

GIS is a framework for collecting, managing, analyzing, and visualizing information associated with locations (Esri 2020). It provides the tools to analyze and learn from the spatial patterns of interesting phenomena. The articles discussed in this chapter develop techniques and apply them to topics similar to those of this project.

Section 2.1 describes publications that discuss georeferencing historical records so they can be analyzed using GIS, and section 2.2 describes statistical spatial analysis of incident data. Section 2.3 describes GIS analyses of search and rescue incidents to predict future demand for services, guide training and allocate resources.

2.1. Georeferencing Described Locations in Historical Records

The primary challenge in the development of the hoist rescue database was that the majority of the records contain a description of the location of the rescue, while only a few have geographic coordinates. To populate the database and perform analysis, the described locations had to be georeferenced, or assigned digital representations. Wieczorek et al. (2004) addressed a similar problem with the millions of geological, biological, and cultural specimens in the collections of natural history museums. Global Positioning Systems (GPS) enable modern expeditions to record coordinates when collecting specimens, but there is also a large catalog of legacy specimens whose locations were recorded with descriptive text (Wieczorek, Guo, and Hijmans 2004). To make the records describing the collection of these specimens available for spatial analysis, the locations, which are described following conventions that differ between disciplines and institutions, have inconsistent accuracy, no standard format, and usually no metadata describing how they were determined, must be georeferenced.

Wieczorek et al. describe four methods to interpret described locations and assign a digital representation to them. The first is the point method, in which each location is given a single point. This method ignores the fact that locality descriptions usually refer to areas, and the resulting points do not reflect the specificity with which they were recorded, which limits their usefulness for spatial analysis. The second is the shape method, in which the locations are represented by polygons or buffered points or polylines. This method gives the best representation of the location, but involves a complicated process to individually generate each vector object and requires access to GIS software, expertise in using it, and more storage space than a single pair of coordinates.

The third method is the bounding-box method, in which each location is described by two coordinate pairs that form the corners of a rectangle. This method is simpler and requires less storage space than the shape method, but results in a less specific representation of the location. The fourth method, and the focus of the paper, is the point-radius method, in which each location is represented by a coordinate pair and a distance that reflects the extent of its area and its uncertainty, taking into account contributions from the locality description, map scale, datum, and the precision and accuracy of the source material. The resulting representations are consistent, reproducible, and provide a measure of their uncertainty, which allows them to be used for spatial analysis.

In a later article, Doherty and Wieczorek et al. applied the shape and point-radius methods to locations described in records of search and rescue incidents in Yosemite National Park (Doherty, Liu, Doke, Guo, and Wieczorek 2011). They georeferenced six incidents using both methods and found the shape method reduced the uncertainty area up to 99.2% compared to the point-radius method, but that the time required to process an incident increased from five to

15 minutes for the point-radius method to 15 to 90 minutes for the shape method. The location with the greatest percentage difference between the point-radius and shape method areas was described as being "on the Four-Mile trail approximately 1.5 miles up from the Four-Mile Trailhead." The shape method allowed the location to be represented as a buffered line, while the circle created by the point-radius method had to have a much larger area to be sure to include the described location.

Although the authors found that the shape method resulted in more precise representations of described locations than the point-radius method, the time it took to georeference the records made the shape method impractical for use on a large dataset. For the analysis part of their study, they examined 1,356 search and rescue incidents that occurred in Yosemite National Park between 2005 and 2010 and found that 1,271, or 93%, of them could be georeferenced using the point-radius method with a mean uncertainty radius of 560 $^+/_-$ 51 m and uncertainty area of 3.60 $^+/_-$ 0.840 km^2. The 95th percentile of the uncertainty radii was 2,026 m, so a 2 km grid was defined over the study area. The size of the grid was chosen based on the uncertainty of the location data, so that although the authors did not know exactly where the rescues occurred, they could be certain they were assigned to the correct grid cell. The incidents were aggregated over the grid and Moran's I and Getis-Ord G_i* calculations were carried out. The Moran's I calculation indicated the distribution of rescues exhibited statistically significant clustering.

The Getis-Ord G_i^* analysis found statistically significant hot spots, mostly around the hiking trails in the Yosemite Valley, but the uncertainty of the georeferenced locations limited their analysis to a very large grid. A grid square with 2 km is too large an area for the result to be useful in learning much about rescue incidents involving hikers or climbers. To conduct a higher resolution analysis that would give results closer to the scale of a hiking trail and differentiate between smaller features, the uncertainty of the underlying locations would have to be greatly reduced. Partly based on the results of this study, the Parks Service started to use GPS units to record coordinates during search and rescue operations and include them with the documentation in a new records management system.

2.2. Statistical Spatial Analysis of Incident Data

In order to perform statistical spatial calculations on incident data, the study area must be partitioned into zones, and statistics must be calculated based on the incidents occurring in each zone. The zones provide the foundation for statistical calculations, which can determine if a spatial pattern exhibits statistically significant clustering or is the result of a random process. The amount of memory and computer time required to perform calculations increase with the number of zones. For phenomena with a high degree of spatial heterogeneity, a partitioning scheme with identical zones, such as a regular grid, may be undesirable because there may be a small number of cells with significant values separated by large numbers of cells with insignificant values. To avoid wasting memory and computer time on areas that will not contribute to the results, researchers partition their study areas into zones based on their data and study areas. The details of the partitioning scheme must be carefully considered, because the results of the statistical calculations depend on the relationships between the zones. This phenomenon is known as the modifiable areal unit problem (MAUP) (Openshaw 1983). The references in this section perform statistical calculations on incident data. Although they do not address wilderness search and rescue incidents, the techniques can be applied to any point pattern.

A journal article by Xu et al. considers the effects of different aggregation schemes on the analysis of traffic collisions, a phenomenon with extreme spatial heterogeneity (Xu, Huang, Donga, and Abdel-Aty 2014). To assess the crash risk of roads, regional safety modelers correlate the number of crashes with environmental factors such as the amount of traffic, density of intersections, speed limit, and land use, as well as demographic factors such as population density, median household income, and employment status. To perform a sensitivity analysis on the aggregation scheme, the authors start with small base units and explore how the results of statistical calculations change when they are combined into larger regions

The authors used 738 traffic analysis zones (TAZ) in Hillsborough County, Florida as their base units. TAZs are used in transportation planning and are not specifically made for traffic crash analysis. They partitioned the TAZs based on the homogeneity of their risk factors according to 14 different schemes that had between 50 and 700 resulting zones. They found that the spatial autocorrelation of the number of crashes calculated by the Moran's *I* statistic decreased with the number of zones, possibly because areas with similar crash risk were aggregated together. The authors explored how the sensitivity of the variables in their model changed with aggregation and found that aggregations with smaller units had more significant variables. The correlation of median household income and population density with crashes were consistent over variations in aggregation. Overall, the authors found their results were consistent with the original TAZs and they could avoid the MAUP with aggregations that had approximately 350 zones, about half the original number.

In a similar study, Nelson and Brewer compare the spatial autocorrelation of median income for the state of Pennsylvania and cancer diagnosis rates for the state of New York across census block, census tract, and county levels of aggregation (Nelson and Brewer 2015). To understand the stability of the values across the different scales, they calculated the deviations of the median incomes and cancer diagnosis rates for the counties from the census tracts and the counties and census tracts from the census blocks within them. They found that the spatial clustering of cancer diagnosis rates was less significant than that of median income, but they had similar trends across scales. They found the smaller geographical units had greater variability and that the relationships between census blocks and tracts were more similar than between census blocks and counties.

They conclude that there is not one level of aggregation that is correct in every case, but the appropriate level of aggregation depends on the stability of the phenomenon being studied across different scales, and that exploring the effects of aggregation can increase the understanding of phenomena by showing the scale of their operations and interactions.

A journal article by Kalinic and Krisp compares kernel density and Getis-Ord G_i^* calculations on crime incidents in San Francisco (Kalinic and Krisp 2018). They obtained crime data from the San Francisco Open Data Portal that included the date of the crime incident, the category of the crime, the police district in which it occurred, and the latitude and longitude coordinates of the location. They performed kernel density calculations with several search radii. Larger search radii produced a smoother density surface, while smaller search radii preserved more spatial detail. By changing the search radius, they were able to manipulate the size of the high crime clusters that emerged from the resulting density surface.

While the kernel density is essentially a visualization of the data, a Getis-Ord G_i^* calculation can increase the understanding of an observed pattern by indicating whether it exhibits statistically significant clustering or can be explained by a random distribution. To perform a Getis-Ord G_i^* calculation on their crime incident data, the authors generated a hexagonal grid that covered the areas of the city of San Francisco where crimes had been reported. The grid covered most of the city, but there were no cells in places where no crimes had been reported, such as on freeways and lakes and in parts of parks. They aggregated the crime data over the grid by calculating the number of crimes reported with coordinates within each cell. For a grid cell with a large number of crimes to be part of a statistically significant cluster, it must be surrounded by cells with similar statistics. The results showed two clusters of grid cells with high crime statistics and less than 1% probability of being due to a random distribution. These hot spots corresponded to areas of high kernel density, but the authors noted that not all the areas of high kernel density were statistically significant clusters, and had a higher probability of being due to a random distribution.

For their Getis-Ord G_i^* calculation, the authors used the default parameters of their GIS software. They did not report the size of their grid or the weighting parameters for the neighborhood used in the calculation. While they explored the effects of changing the parameters of their kernel density calculation, they did not discuss their Getis-Ord G_i^* calculation parameters, which can also affect the results. In their conclusion, the authors suggest that kernel density and hot spot calculations should be used in conjunction because they can provide different insights into a spatial distribution.

2.3. Spatial Analysis of Search and Rescue Incidents

Analysis of search and rescue incidents can yield insights into the behavior of lost people, identify hazardous areas where people become injured and confusing sections of trails where people lose their way, and can help anticipate where incidents will occur at different times of the year. The references in this section use GIS to analyze the georeferenced operations of rescue services.

Continuing the work that was described in section 2.1, Doherty et al. analyzed Yosemite National Park search and rescue records to understand the applicability of mobility models to the behavior of lost people (Doherty, Guo, Doke, and Ferguson 2014). They considered 213 Parks Service searches that occurred between 2000 and 2010 for missing people who were involved in ground-based activities, were last seen in Yosemite National Park, and were found in the park or within walking distance of it. The places the subjects were last seen and the places they were found were georeferenced using the point-radius method and used to compare the predictions of lost person mobility models. A mobility model is an algorithm that attempts to predict the behavior of a lost person based on their demographic information and the terrain (Koester 2008). Developing an accurate lost person mobility model is a worthwhile endeavor because search teams have limited resources, so accurately predicting the most likely route and speed of the missing person can greatly reduce the area to be searched.

Another application for legacy search and rescue records is to use them to predict where and when incidents will occur in the future. Doherty et al. used Yosemite National Park search and rescue records as input for a presence and background learning algorithm, which correlates the presence of search and rescue incidents with background environmental variables, such as the elevation, land cover, slope, and distance from trails, roads, streams, and lakes (Doherty, Guo, Li, and Doke 2014). They georeferenced 2,081 records of search and rescue incidents that occurred between 2001 and 2010 using the point-radius method, with 95% of the uncertainty radii falling between 269 and 866 m. The learning algorithm used the points as input, and the authors state the precision is within acceptable limits based on other published studies.

The authors trained the learning algorithm with the full set of 2,081 records from 2001 to 2010 and calculated a suitability probability, which classified 22.9% of the area of Yosemite National Park as “suitable habitat” for search and rescue incidents. They compared the locations of 186 search and rescue incidents from 2011 that were not part of the training set, and found that 91% occurred in areas classified as "likely."

To see how the spatial distribution of search and rescue incidents changed throughout the year, the authors separated the rescue records by month and created 12 training sets for the learning algorithm. The area of the park classified as "likely" varied from 5% in April to 27% in August. 72% of the search and rescue incidents occurred between May and August, and the spatial distribution of rescues varied for each month. The learning algorithm classified the locations of only 64% and 75% of the incidents in January and February as "likely," but the result was over 90% for incidents in April, May, June, August, September, November, and December.

This analysis can help park managers decide where to focus their efforts to prevent injuries at different times of year and to allocate search and rescue resources in areas where incidents are likely to occur.

By correlating an incident with background environmental features, the presence and background algorithm attempts to learn more spatial information from it than its location. The presence of an incident at one location will increase the suitability of other locations with similar environmental characteristics. The authors report the sensitivity of their analysis, which is reflected by the number of incidents whose locations they classify as "likely." They do not report any measure of its specificity, which would be reflected by the area classified as likely in which no incidents occurred.

In addition, and more importantly, the learning algorithm does not consider human traffic, which is the most important factor leading to search and rescue incidents. The authors had access to monthly numbers of visitors entering the park, but no finer-grained statistics for traffic at individual features or on individual trails. Yosemite is a vast park, with many remote areas that require considerable effort to access, and the visitation of different areas varies greatly. A comparison of the sensitivity of the suitability probabilities calculated by the learning algorithm and the sensitivity of the suitability probabilities calculated with only the locations of incidents would provide a measure of how well the environmental variables considered in the paper represent the combination of environmental hazard and human traffic that leads to search and rescue incidents.

The United States Coast Guard (USCG) District 14, based in Honolulu, Hawaii, is responsible for a search and rescue region of more than 12 million square miles of the Pacific Ocean from near the Philippines to about halfway between Hawaii and the west coast of the continental United States. A spatiotemporal analysis of historic search and rescue incidents may help the Coast Guard determine where to position rescue assets at different times of the year. An article by Hornberger et al. presents a framework for comparing aggregation methods for this dataset (Hornberger, Cox, and Hill 2019).

The authors compare quadrat methods, in which square grids are laid over the entire study area, with zonal distribution models, which can have zones of different areas depending on factors such as the distance from land or historical trends in distress calls. They use a training dataset of 2629 search and rescue missions that occurred from 2011-2015 and compare the predictions of their model to a test dataset of 1080 incidents that occurred from 2016-2017.

The authors generated six quadrat grids, five with uniform cells named grids *A* through *E*, and one named grid *F* in which the cells containing Guam and the Hawaiian islands, where the greatest number of incidents occur, were further divided into 1^0 squares. The quadrat grids had between one and 212 zones. They also generated two zonal distributions based on *k*-means clustering algorithms, one based on the number of resources assigned to historical rescues and one based on the ranges of Coast Guard rescue assets, such as ships, helicopters, and airplanes.

The authors measured the accuracy of the aggregation methods by calculating distance- and volume-based errors. The distance-based aggregation error is the sum of the differences between where incidents were modeled as occurring and where they actually occurred, and the weighted version is weighted by the number of assets deployed to each incident. The authors found that the distance-based aggregation error decreased with increasing number of zones for the quadrat methods, and that the *k*-means clustering methods had smaller errors than the quadrat grids with similar number of zones.

The volume-based aggregation error is the difference between the monthly demand predicted by a deterministic model based on the training set of incidents and the actual demand calculated from the test set. The authors found the volume error increased with the number of zones for the quadrat grids and that the *k*-means clustering grid had a greater volume error than the quadrat grids with similar numbers of zones, perhaps because the greater number of zones gave the algorithm more opportunities to over- or under-predict the actual demand.

The references in this chapter that explored the MAUP all used the aggregation with the smallest zones, either census blocks, TAZs, or the incident points themselves, as the "gold standard" against which they compared other aggregation methods. They examined ways in which larger and fewer zones could be used while preserving the results of statistical calculations or minimizing the error introduced by changing the representation of locations. If the memory and computer time required for the finer aggregation are reasonable, however, there is no reason to compromise the accuracy of the results by using a more coarse aggregation.

Chapter 3 Methodology

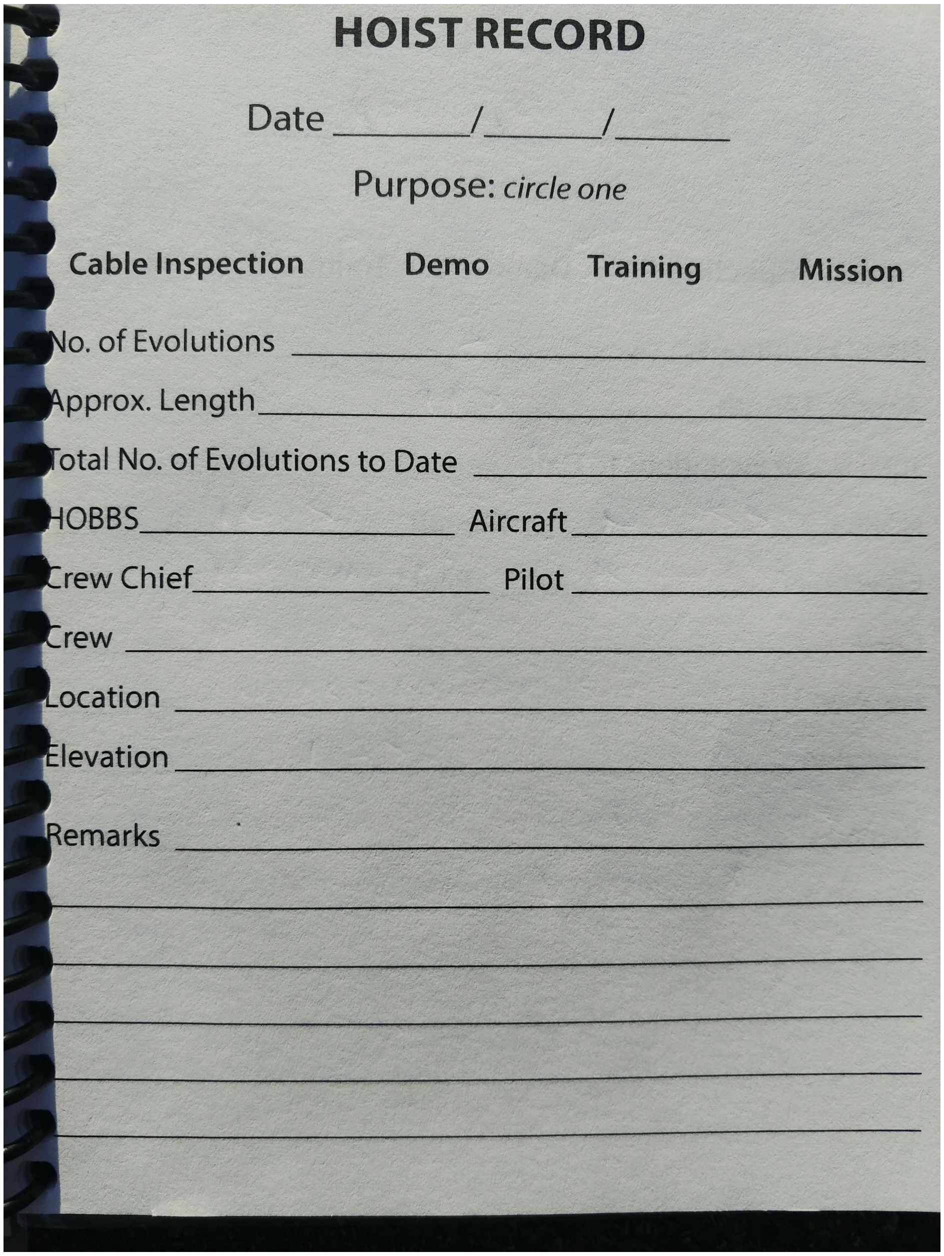
This chapter reviews the methodology for the project. Section 3.1 discusses the construction of the rescue geodatabase, section 3.2 discusses the aggregation of the rescue statistics over a grid and the statistical calculations carried out using it, and section 3.3 discusses the kernel density calculations carried out to visualize the distribution of rescues.

3.1. Rescue Geodatabase

The goal of the database was to support the analysis of the hoist rescue records to find spatial and seasonal patterns to, in turn, improve readiness and recommend preventative measures. The attributes of the rescue records necessary for this analysis were the date, number of victims rescued, location, and elevation. The accuracy and precision of the locations associated with the rescue records is of utmost importance to support spatial analysis. Making use of the other attributes recorded in the rescue documentation, such as the aircraft, personnel, and rescue devices used, is beyond the scope of this project.

3.1.1. Sheriff's Aviation Documentation

The dataset that inspired this project is the sheriff's aviation hoist log books. Each hoist, which is a piece of equipment that can be transferred between helicopters, has a paper log book, in which an entry is recorded every time it is used. The books are used to track issues and damage and schedule maintenance tasks such as inspecting and replacing cables. The most recent log books record the date; the purpose of the hoist; the number and running total of evolutions; the length of cable used; the aircraft and the number of hours on it; the personnel; the location and elevation; and a narrative. Figure 5 shows a blank page of a hoist log book.


HOIST RECORD

Date ______/______/______

Purpose: *circle one*

Cable Inspection **Demo** **Training** **Mission**

No. of Evolutions ______

Approx. Length ______

Total No. of Evolutions to Date ______

HOBBS ______ Aircraft ______

Crew Chief ______ Pilot ______

Crew ______

Location ______

Elevation ______

Remarks ______

Figure 5 A page of a hoist log book.

Recently, members of the air rescue team obtained access to the archive of hoist logs, which consisted of 33 books. They transcribed the mission hoists into an Excel spreadsheet, which became the basis for this project. The spreadsheet has the attributes listed above and some others that were found in the narrative sections. The additional attributes in the Excel spreadsheet include whether the hoist occurred during the day or night, the outside air temperature, the number of victims and dogs rescued, the rescue devices used, whether the rescue was a pickoff, whether the rescue was assisted by a ground team, whether hover steps were performed, whether a static discharge cable was used, and whether the hoist was an insertion of the sheriff's dive team. The records in the log books are of varying completeness, with some providing information on every attribute listed above, while others only have a date and list of personnel. There are 921 records in the spreadsheet. Figure 6 shows the format of the Excel spreadsheet.

Hoist Number	Date	Aircraft	D/N	Location	Elev	Pilot	Crew Chief	Rider 1	Rider 2	OAT	Hoist Length	Rescue Device	Pick Off	Evolu-tions	Vic's	Dogs	Helitack Assist	Hover Steps	Static Discharge Cable	Dive Team
1	3/17/2011	306	D	Cucamonga Canyon	2800	Jim Landry	Mike Ells	Stacy Price	Randy Gerwig		125	Stokes Basket		6	1					
1	4/17/2011	306	D	Deep Creek	3000	Al Daniel	Steve Miller	Bernie Horak	Dave Carney		125	Stokes Basket		9	1					
1	5/1/2011	306	D	Cucamonga Canyon		Al Daniel	Carlos Quezada	Wayne Hess			125	Stokes Basket		4	1					
1	5/21/2011	306	D	Angelus Oaks	6500	Al Daniel	Wayne Hess	Greg Daye			125			2	0					

Figure 6 Format of the Excel hoist rescue spreadsheet.

The fields of the spreadsheet that pertain to this project are **Date**, **Location**, **Elev**, and **Vic's**. The **Date** field records the date of the rescue in MM/DD/YYYY format, which is recognized by the Excel and ArcGIS Pro programs, so the records can be sorted and selected by date. The first rescue was recorded on December 1, 1993 and the most recent rescue included in this project was recorded on September 5, 2020. The **Vic's** field records the number of victims rescued. Seven hundred sixty-nine records have one victim. The greatest number of victims recorded for a rescue is eight.

The **Elev** field records the elevation of the rescue in feet. The lowest elevation recorded is 500 ft. and the highest is 10,700 ft. The precision of the elevation data is not immediately apparent, as there are no written guidelines in the aviation unit as to the proper source of elevation data or how it should be recorded. One likely source of elevation data for recent hoists is Google Earth, as the program is currently installed on the computers at the aviation unit and it is standard procedure to check the elevation at the coordinates when they are supplied with the

dispatch information. The aviation unit was performing hoist rescues before Google Earth was available, however, so it cannot be assumed to be the source for all elevation data.
Another likely source of elevation data is the pilot, as it is an important factor in their consideration of the capability of the helicopter to perform the hoist, so they are very aware of their altitude and how much power the helicopter requires to achieve a stable hover and complete the rescue.

The level of rounding of the elevation is at the discretion of the crew member completing the hoist record, usually the crew chief. Of the 921 rescue records, 80 have no elevation recorded, three have elevations recorded to the ones place, 11 have elevations recorded to the tens place, 543 have elevations recorded to the hundreds place, 280 have elevations recorded to the thousands place, and four report elevations of “10,000 ft.” Because the majority of the elevations are reported to the hundreds place, an error of $^{+}/_{-}$ 100 ft. was assumed as the precision of the elevation data.

The **Location** field of the spreadsheet contains a text description of where the rescue occurred. None of the hoist records include coordinates. Like the elevation, the location description is recorded at the discretion of the crew member completing the hoist record. There are no set standards in the sheriff’s aviation unit as to the nomenclature or extent of the described locations. The descriptions of the locations depend on the training lineage of the crew member, the colloquial location names they prefer, and the level of precision with which they choose to describe where the rescue took place. Thirty-nine rescues have no location recorded, and several are described with very general locations. For example, “Joshua Tree National Park,” “Riverside County,” and “San Gorgonio Wilderness” are the recorded locations for rescues in the spreadsheet. Locations such as these are too general and imprecise to support the spatial analysis of this project, so records had to be discarded from the database if information to improve the precision of their locations could not be found.

In addition to the hoist log books, an additional form of documentation called an "Unusual Occurrence Report," commonly referred to as a "blue card," is recorded for some rescues. The purpose of the blue cards is to account for aircraft and personnel time when they are spent on missions outside the usual scope of the aviation unit. If the victim of the rescue is not a San Bernardino County resident, section 26614.5 of the California Government Code states "[t]he county or city and county of residence of a person searched for or rescued by the sheriff under the authority of Section 26614 shall pay to the county or city and county conducting such search or rescue…all of the reasonable expenses…of such search or rescue." (California Legislative Information 2020) In this case, the blue card records the aircraft and personnel hours for the purpose of billing the victim's county of residence for the rescue. The format of the blue card has changed several times throughout the study time period, with the most recent version recording the date, GPS coordinates, personnel, aircraft, victim information, and a narrative describing the incident. Figure 7 shows the most recent blue card format.

An archive of 520 blue cards was obtained from sheriff's aviation. Many of the blue cards describe activities other than hoists, such as hover steps, rescues in which the helicopter was able to land, inter-facility transports, and time spent assisting searches. Some of the blue cards that document hoist rescues, however, contain GPS coordinates or descriptions of the rescue in the narrative section that improve the precision of the location in the record.

The sheriff's aviation documentation described in this section are a maintenance record and an accounting form. They contain geographic information, but were not collected with the intent of making maps or being the basis for spatial analysis. Although the records were recorded in a somewhat haphazard fashion and without geographic best practices in mind, the subsequent sections demonstrate how different attributes and data sources can be combined to produce spatial information of sufficient precision to support analysis that can identify spatial and temporal trends, improve preparation, and direct preventative measures.

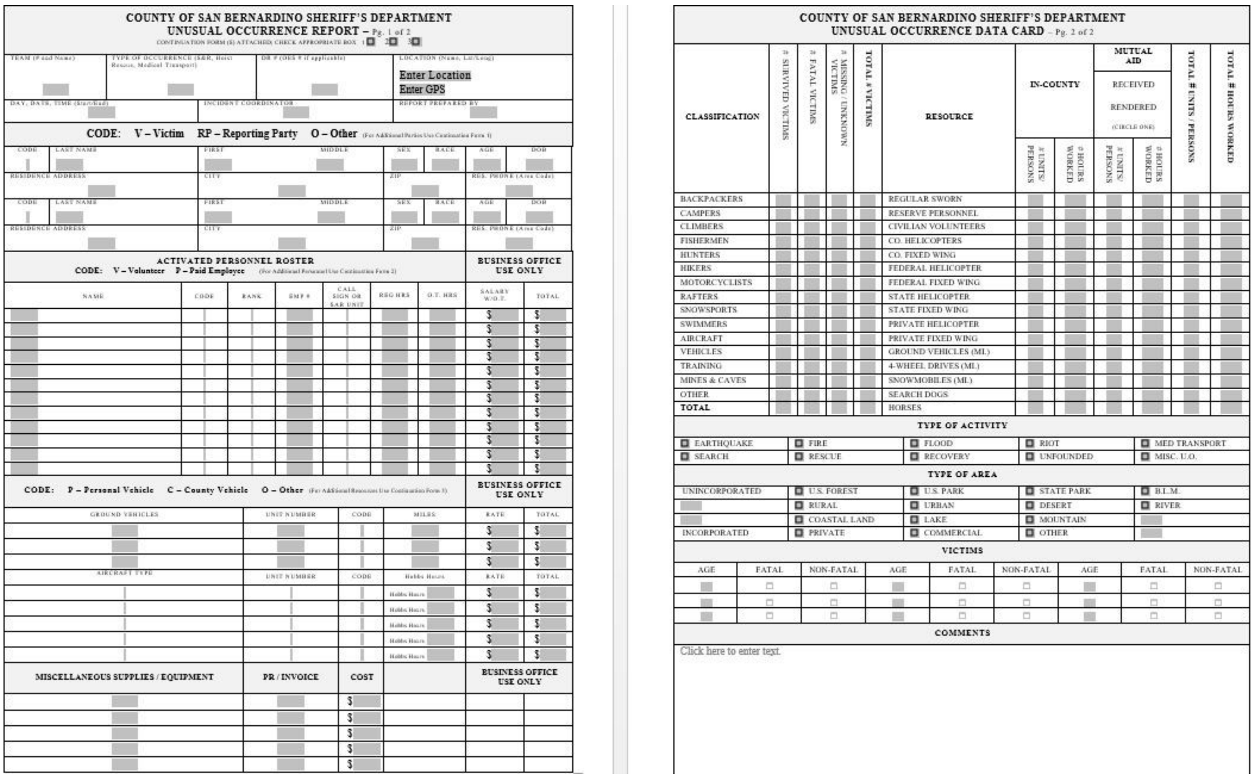


Figure 7 Most recent Blue Card format.

3.1.2. Database Construction

The first step in constructing the rescue database was to georeference the locations described in the hoist records. To create the most precise representation of the described locations, the shape method was used, in which a polygon represents the location of each rescue, as described in section 2.1. Two hundred eighty-seven unique location descriptions were identified from the 921 rescue records. Topographic maps were downloaded from the USGS National Map Viewer (USGS 2020) and printed. Experienced members of the aviation unit assisted in finding the described locations on the topographic maps. One member, in particular, has been a volunteer crew chief and air medic since the inception of the program and has participated in hundreds of rescues. Prior to joining the air rescue team, he was a member of a San Bernardino sheriff's ground search and rescue team and a patrolman with the forest service. He was very familiar with the locations described in the hoist records and spent hours identifying them on the topo maps. The locations were confirmed with internet searches, with many trip reports and blog posts providing clues as to the vernacular place names used by different groups. For example, the dirt bike community refers to a section of Forest Service Trail 1W17 as the "Malcolm Smith Trail," while the topographic maps label it the "Redonda Ridge Trail." All three names appear in the hoist rescue records but could be consolidated to one feature after confirming they referred to the same feature.

Once they had been identified on the paper topo maps and confirmed with internet searches, the list of unique locations was imported into ArcGIS Pro and used to create a feature class. A polygon was created for each location, with the goal of creating the smallest polygon that covered everywhere a crewmember recording a rescue in a log book would associate with its name. Some degree of subjectivity was involved in creating the polygons. The boundaries for canyons were defined by following the ridge lines on either side. The boundaries for linear features such as trails, roads, and creeks were defined by creating a 50 m buffer on each side for their entire lengths. The boundary lines for peaks were drawn by identifying the saddle points that separated them from their neighboring peaks and roughly following contour lines to connect them.

After polygons were created for the unique locations, the rescue spreadsheet was joined to the locations feature class with a one-to-many join, resulting in a new rescue feature class where each rescue record had a polygon geometry corresponding to its described location. Thirty-nine rescues had no location recorded and were discarded.

The next step was to parse the blue cards for those describing hoist rescues and examine them for useful information. Thirty-four blue cards were found to correspond to hoist rescues and have information not recorded in the log book. Nine blue cards reported latitude/longitude coordinates, four in degrees minutes seconds format, one in decimal minutes, and four in decimal degrees. Since WGS84 is the default datum for Google Earth, Google Maps, and iPhone and Android GPS systems, it was assumed to be the datum of the blue card coordinates. The coordinates were plotted and found to be consistent with the blue card narratives and locations and elevations contained in the hoist records, so the polygons for those rescues were changed to small circles enclosing the coordinate points. Three blue cards included elevations that were not reported in the hoist records, so they were filled in. The 25 blue cards that did not have coordinates had descriptions in their narrative sections that allowed the rescue locations to be determined more precisely.

For example, the narrative section of one blue card contained the text, “dispatched to Cucamonga Canyon for person that had fallen off cliff laying on edge of water.” The hoist record spreadsheet listed a rescue occurring on that date at 3000 ft. in Cucamonga Canyon. The combination of the location description, the elevation, and the narrative stating the victim was next to the water allowed the polygon for the rescue to be modified to a very small area. Figure 8 shows the process of georeferencing this rescue with Cucamonga Canyon in blue, the area between 2900 and 3100 ft. in the canyon in red, and the part of the red area near the creek in the bottom of the canyon in yellow.

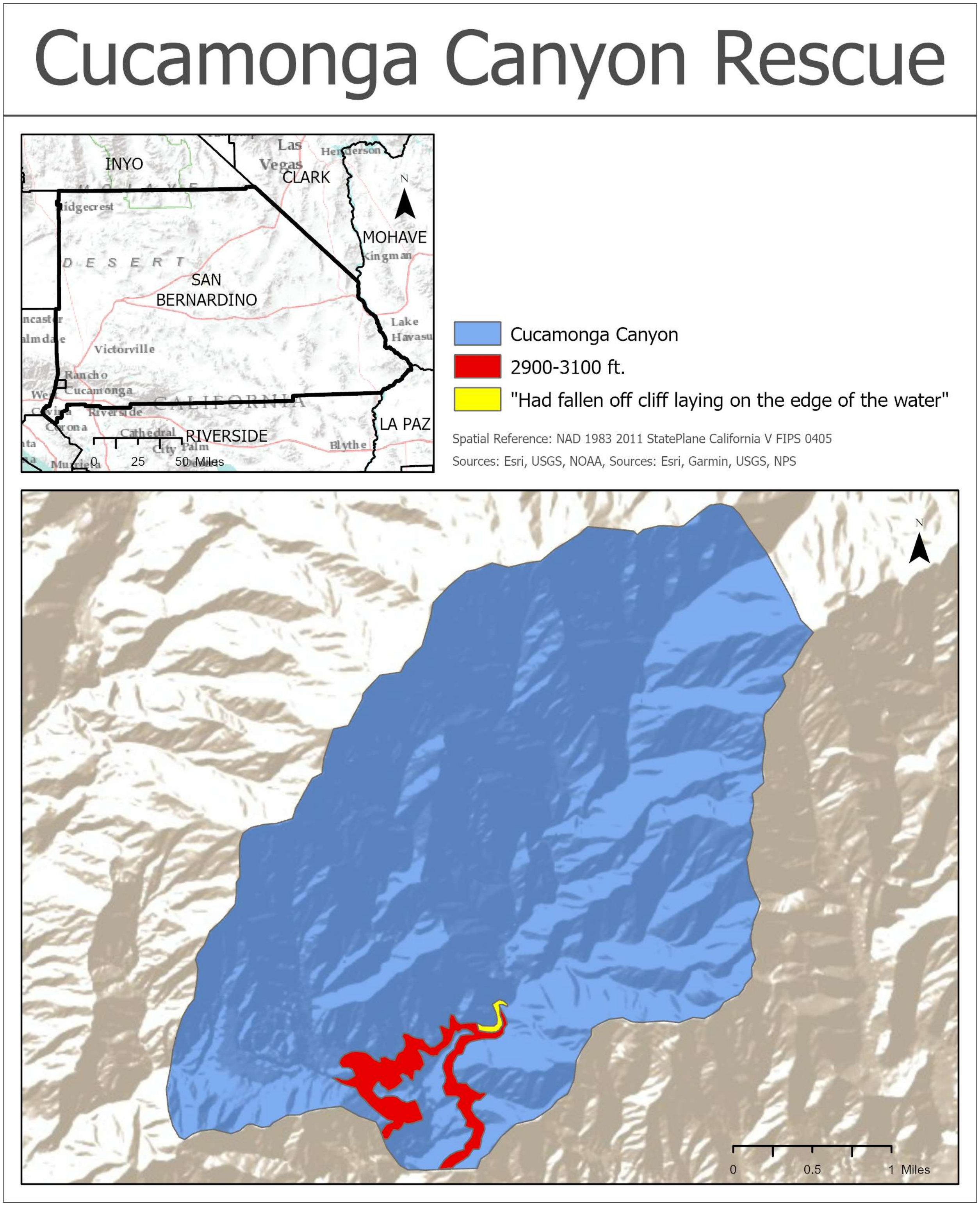


Figure 8 Georeferencing process for a rescue in Cucamonga Canyon.

Another blue card narrative contained the text, “Victims located by 40K5 two peaks east of Cucamonga Peak at the 8500' level.” The hoist record for that date indicated a rescue on the Cucamonga Peak Trail. It was a simple matter to follow the trail, which was on the topographic map, east from Cucamonga Peak to the second peak and find the closest intersection of the trail with the 8500 ft. contour line.

When the rescue locations had been modified to include all of the blue card information, the next step was to modify them using the elevation field of the hoist records. The intersection of the described location and reported elevation was found for each record. Many of the described locations were linear features such as hiking trails, creeks, ridges, or sections of road that start at a low elevation and climb continuously to a peak or junction. In these cases, the described location intersects the reported elevation at one point and the location polygon can be modified. The uncertainty in the elevation data was assumed to be +/-100 ft., and an approximately 50 m buffer was drawn around the linear objects, which resulted in very precise location polygons for the rescue records.

After the information in the hoist records and blue cards had been included in the database, sheriff’s aviation personnel who were listed as participating in rescues with documentation that was incomplete or had imprecise location descriptions were consulted to see if they could provide additional information as to where the rescues took place.

One retired pilot, in particular, had extensive personal records that made it possible to complete several hoist rescue records with missing information. He used Google Earth to point out the locations of rescues whose described locations were not precise or had not been found with web searches and consultations with other team members.

During the process of individually examining the rescue records, those with location descriptions that were too vague to be definitively determined after the blue cards, elevation information, and sheriff's aviation personnel were considered were discarded. For example, three rescue records had "29 Palms USMC Base," listed as their location, 14 had "Joshua Tree National Park," and 10 had "San Gorgonio Wilderness." During this step, 139 records were eliminated, leaving 743 rescue records in the database. The records that remain in the database are an incomplete representation of the operations of the aviation unit, and high density clusters may be missing from the analysis, but without more precise location information, there is no way to include them. If geographic coordinates are collected for future rescues, the georeferencing process can be eliminated, the precision of the locations will be improved, and all records will be included.

At this point, the 95th percentile of the areas of the polygons representing the locations of the rescues was approximately 48,000 square meters, which corresponds to a square with 220 m sides or a circle with a radius of 124 m. The process of creating the polygons for the rescue records was not entirely objective. Some interpretation was involved in determining the extent of the described locations and the meaning of the blue card narratives. The combination of the described locations, elevations, blue card information, and consultation with sheriff's aviation personnel, however, allowed the locations of 743, or 81%, of the 921 rescue records to be precisely determined.

3.1.3. Selecting Hiking and Climbing Records

The intent of this project is to focus on rescues of hikers and climbers. To eliminate rescues involving cars, off road vehicles, and people in populated areas, such as flood control channels, a TIGER/Line shapefile of roads in San Bernardino County was downloaded from the

U.S. Census Bureau's Web Interface (US Census Bureau 2019). Features classified as primary, secondary, local, and private roads; 4wd trails; ramps, service drives, and parking lots; and stairways and alleys were selected and used to create a new feature class of roads. Features classified as walkways, pedestrian trails, bike paths, and bridle paths were excluded. Some hiking trails that were incorrectly classified as roads were deleted from the feature class. Rescues located within 50 m of features in the roads feature class were selected and eliminated. In addition, rescues whose locations were identified by road mile markers, which are almost always cars over the side, were eliminated. Eighty records were eliminated from the database in this step, leaving 663.

The rescue database, with location polygons providing a representation of where the rescues happened, is the foundation for the analysis phase of the project. Understanding the process of determining the locations of the rescues will inform the decisions made about what types of analysis can be carried out to get the greatest benefit from this information.

3.2. Spatial Analysis of Rescues

This section describes the spatial analysis of the rescue records. Section 3.2.1 discusses the aggregation of the rescue statistics over a hexagonal grid and visualization and analysis of rescues by elevation. Section 3.2.2 presents the Moran's *I* calculation to determine the spatial autocorrelation of the rescues, and Section 3.2.3 discusses the hot spot calculations, which use the Getis-Ord G_i^* statistic to identify significant clusters of values. Section 3.2.4 concludes with the subsequent temporal hot spot calculations and the statistics gathered on the areas of highest concentration of rescues.

3.2.1. Hexagonal Grid and Visualization of Rescues by Elevation

To provide a framework for the visualization and analysis of the rescue data, a hexagonal grid with cells of 50,000 m^2 area was generated over the area in San Bernardino, Los Angeles, and Riverside counties bounded by the northernmost, southernmost, easternmost, and westernmost rescues in the geodatabase. The cells have sides approximately 140 m long. The cell size was chosen to be slightly larger than the 95th percentile area of the rescue location polygons, so the rescues can be aggregated into the appropriate cells while preserving as much spatial detail as possible. The area of the grid cells is larger than the uncertainty in the location of 95% of the rescues, it is the finest possible grid that can be supported by the precision of the data. Initially, 1,215,869 cells formed the grid.

In order to support accurate spatial statistical calculations, the extent of the grid must reflect the areas where hoist rescues of hikers and climbers can happen. The purpose of the calculations is to analyze the distribution of where rescues did happen within the area where they can happen. As was discussed in section 3.1.3, rescues occurring in populated areas and near roads were not considered. To remove these areas from the grid, cells within 50 m of the roads feature class used to select and eliminate rescues were deleted.

Another area where hoist rescues cannot happen is where it is flat enough for a helicopter to land. To identify and remove areas of flat terrain from the grid, a 1/3 arc-second digital elevation model (DEM) was downloaded from the USGS National Map (USGS 2020). This DEM has a resolution of approximately 10 m. A slope was calculated from the DEM and areas with slope less than six degrees were eliminated from the grid. There are many factors that influence a helicopter's ability to land, such as the wind, elevation, visibility, and ground cover. The sheriff's department helicopters should consistently be able to land in areas with slope of less than six degrees. In addition to flat areas, this step eliminated bodies of water from the grid, which are also areas where hoist rescues cannot happen.

After these steps, 357,805 grid cells remained. These cells cover the parts of the study area more than 50 m from roads and with slope 6 degrees or greater. The extent of the grid is shown in blue in figure 9.

The grid had the smallest cell size that could be supported by the precision of the locations of the rescues, with homogeneous cells throughout its extent. The grid is the closest possible representation of the pattern of the rescue locations and preserved as much spatial detail as possible. The memory and computer time required for the spatial statistical calculations were reasonable, so there was no need to use a coarser grid, which would increase the error in the representation of the rescue locations and possibly change the results, as discussed in chapter 2.

The rescues were aggregated over the final grid by joining the rescues to the cells within which the centroid of their polygons were located. The total number of victims for the rescues joined to each cell was calculated. The greatest number of victims for one cell was 54. Three hundred cells had one or more victims, and the rest had zero. Figure 9 shows the hexagonal grid and the rescue location polygons in six areas of high concentration of rescues that are investigated in detail in the upcoming chapters. The rescue location polygons are gold and become darker when they overlap.

As requested by the leadership of the aviation division, the rescues above and below 6,000 ft. were visualized so their numbers and locations could be compared. To accomplish this visualization, the grid was symbolized with circles proportional to the number of victims for the rescues in each cell, with different colors for rescues above and below 6,000 ft.

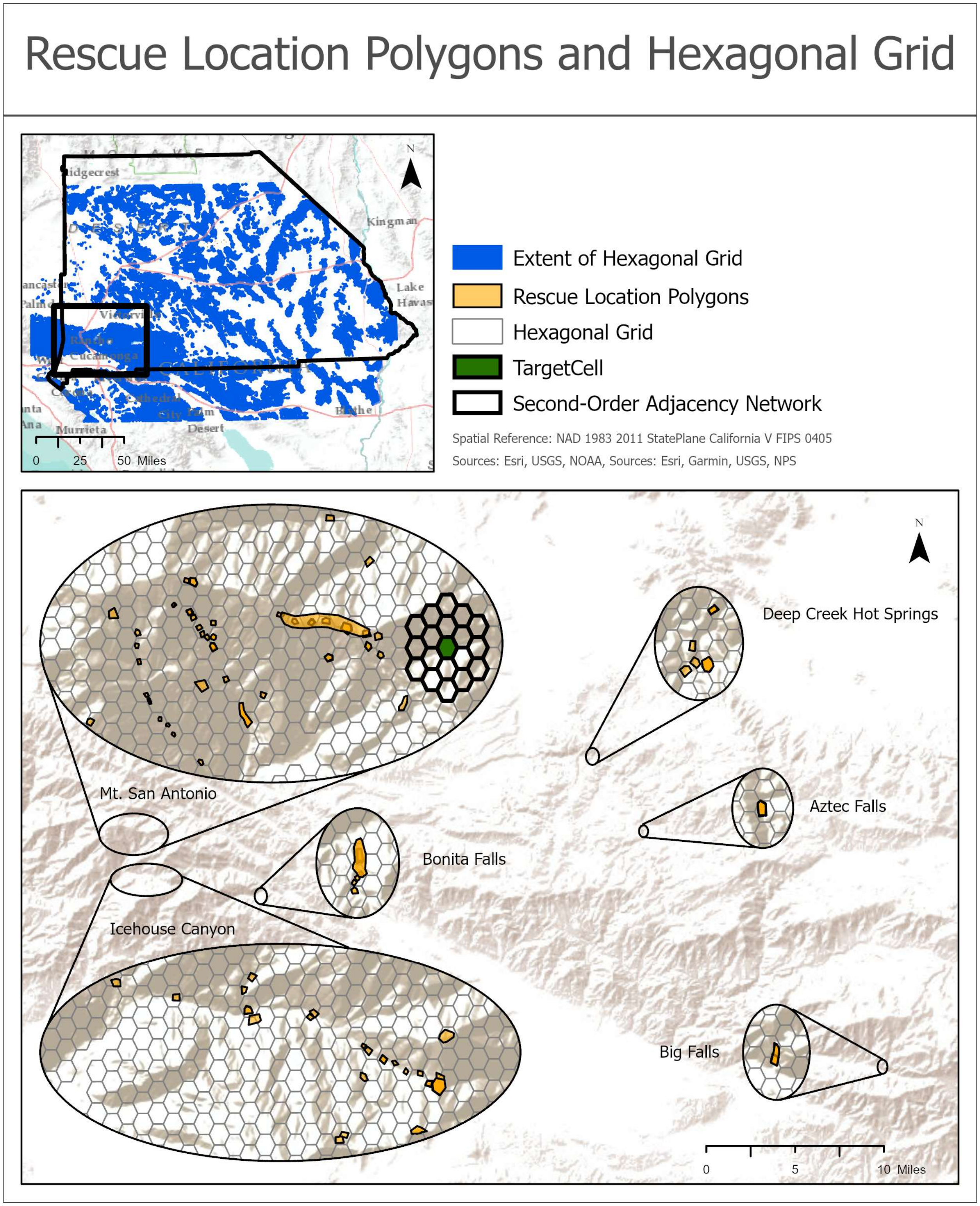


Figure 9 Rescue location polygons and hexagonal grid.

To demonstrate the trends in elevation of rescues, charts were generated for the numbers of rescues above and below 6,000 ft. for the years since the inception of the program, the months of the year, and the different types of helicopters.

3.2.2. Moran's I Calculation

The global Moran's *I* statistic measures whether a spatial distribution is clustered, random, or dispersed. It is defined by the following formula:

$$I = \frac{n}{W} \frac{\sum_{i,j} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_i (x_i - \bar{x})^2}, \tag{2}$$

where n is the number of features, x_i is the value of variable x for the feature i, w_{ij} is the statistical weight between features i and j, W is the sum of all the w_{ij}, and $\bar{x}$ is the mean value of the variable x (Anselin 1995).

The Z_I score for the statistic is calculated by the formula

$$Z_I = \frac{I - E(I)}{\sqrt{V(I)}}, \tag{3}$$

where

$$E(I) = \frac{-1}{(n-1)} \tag{4}$$

and

$$V(I) = E(I^2) - E(I)^2. \tag{5}$$

The global Moran's *I* formula calculates the cross product between the deviation of the value of a point from the mean and the deviations of the values of the points near it. The values that are calculated and summed are determined by the matrix of statistical weights. For example, if the user wants features within a distance *d* of each other to be considered equally in the

Moran's I calculation, the w_{ij} will be one if points i and j are within d of each other and zero otherwise.

If a point with a value higher than the mean has neighbors whose values are also higher than the mean, their cross products will be positive. Similarly, if a point with a value lower than the mean has neighbors with values lower than the mean, their cross products will also be positive. If a point with a value higher than the mean has neighbors whose values are lower than the mean, their cross products will be negative. The cross products of a point with neighbors whose values are both higher and lower than the mean will cancel each other out and not contribute to the overall sum. As a result, a positive value of the I statistic indicates that points with similar values are clustered together, a value near zero indicates the values are randomly distributed, and a negative value indicates the values are dispersed, meaning that points tend to be surrounded by points with dissimilar values.

To determine the statistical significance of the I statistic, the distribution is compared to the null hypothesis, which is that the distribution is the result of a random process with no pattern or correlation. For a set of n features, there are $n!$ possible permutations of the values of the features. The expected value and variance of the I statistic for these permutations are calculated and compared with the I statistic of the actual distribution. The z_I score is the number of standard deviations the I statistic of the distribution is from the expected value. The p-value indicates the probability that the distribution is random. A low p-value means that there is a low probability the distribution is random and the null hypothesis can be rejected.

To characterize the degree to which the distribution of rescues is clustered, random, or disperse, a Moran's I calculation was carried out using the hexagonal grid described in section 3.2.1. The calculation used a second-order adjacency network with a fixed distance band, so for a target cell, its first and second nearest neighbor cells were given a statistical weight of one and all other cells were given a weight of zero. Figure 9 shows the second-order adjacency network for a target cell near Mt. San Antonio. The network size was chosen to be of the approximate scale of the canyons and other features in the study area, so that the rescues described as happening in one location could become a cluster, but rescues in neighboring locations would not contribute. As can be seen in Figure 9, the areas of Mt. San Antonio and Icehouse Canyon are greater than one network, while the areas of the other locations are smaller.

3.2.3. Getis-Ord G_i^* Calculation

The Getis-Ord G_i^* statistic identifies statistically significant hot and cold spots by calculating the degree of clustering around every feature (Getis and Ord 1992). While the Moran's *I* statistic is a global statistic, which returns one set of results for the entire pattern, the Getis-Ord G_i^* statistic is calculated for each feature individually. The resulting pattern shows where statistically significant clusters of high values, or hot spots, and low values, or cold spots, are located.

The Getis-Ord G_i^* statistic is calculated by the following formula:

$$G_i^* = \frac{\sum_j w_{ij}x_j - \bar{x}\sum_j w_{ij}}{S\sqrt{\frac{\left[n\sum_j w_{ij}^2 - \left(\sum_j w_{ij}\right)^2\right]}{n-1}}}, \tag{6}$$

where n is the number of features, x_i is the value of variable x for the feature i, w_{ij} is the statistical weight between features i and j, and $\bar{x}$ is the mean value of the variable x, and

$$S = \sqrt{\frac{\sum_j x_j^2}{n} - \bar{x}^2}. \tag{7}$$

The G_i^* statistic is a *z*-score. Essentially, it indicates how many standard deviations the proportion of the total value of the variable x that is found near feature i is from the expected value.

To identify statistically significant hot spots, a Getis-Ord G_i^* calculation was carried out using the hexagonal grid. As with the Moran's *I* calculation, a second-order adjacency network was used with a fixed distance band. The locations with the highest G_i^* values were identified for further study.

3.2.4. Temporal Density and Hot Spot Calculations

The areas with the six highest G_i^* values from the hot spot calculation were identified to analyze for seasonal trends. The rescues in the database were separated by months, and a hot spot calculation with the same parameters described in the previous section was carried out for each month. Statistics were gathered for the rescues occurring in the top six areas for each month to accompany the hot spot results. The resulting seasonal trends can help anticipate operations and guide preventative efforts to the areas and times where the greatest number of rescues occur.

3.3. Kernel Density

A kernel density calculation places a circular kernel function on each point in a distribution. The kernel function has a smoothly curved surface, has its maximum value at its origin, and goes to zero at a defined search radius. If a weighting attribute is specified, the area under the function centered on a point is equal to the attribute value for that point. If no attribute is specified, the area under the function is equal to one. The kernel function implemented in

ArcGIS Pro is a quartic function (Silverman 1986). Figure 10 shows a one-dimensional quartic kernel function with a search radius of one and an area of one (Amberg 2021). The value of the density at a point *(x,y)* is the sum of the values of the kernel functions centered on points within the search radius:

$$D(x,y) = \frac{1}{r^2}\sum_i \left\{\frac{3}{\pi} x_i \left[1 - \left(\frac{r_i}{r}\right)^2\right]^2\right\}, \text{ for } r_i < r, \tag{8}$$

Where D is the kernel density, $i = 1, \ldots, n$ are the input points, r is the search radius, x_i is the value of the attribute *x* of point i, and r_i is the distance between *(x,y)* and point i.

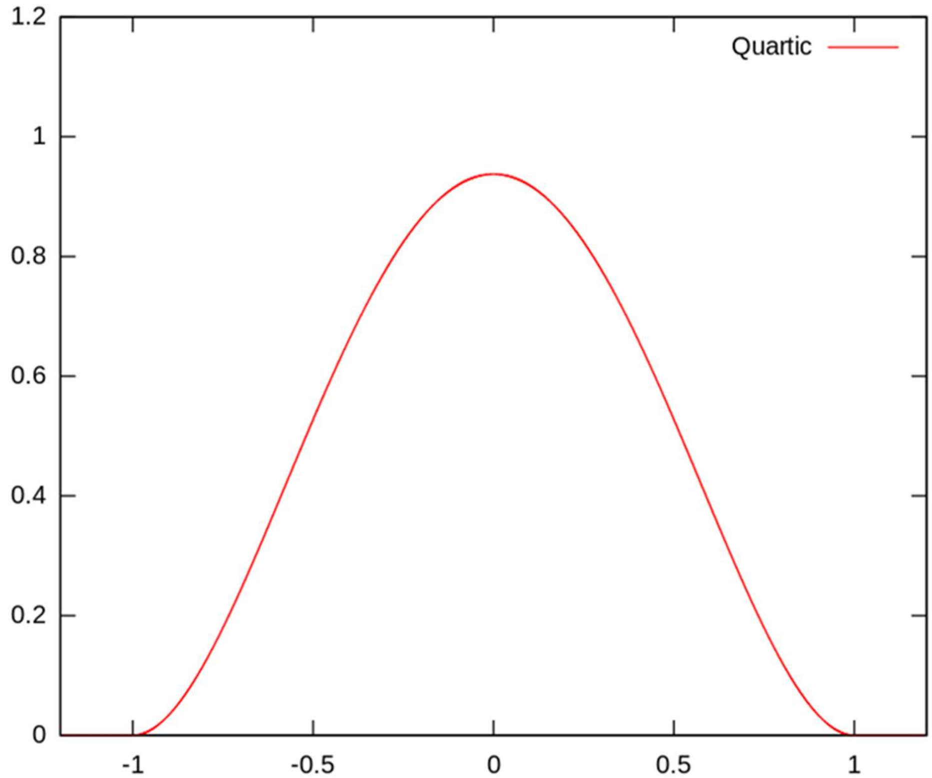


Figure 10 quartic kernel function

To represent the density, a raster, or grid, is defined over the study area. The value for each raster cell is calculated by evaluating the density at the center of the cell. Kernel densities are used to create a generalized view of a set of point data. Larger values of the search radius spread each point out over a greater area and give a smoother density surface, while smaller values retain more detail. A smaller raster cell size will give a finer-grained view of the density surface at the expense of using more computing time and storage space.

For this project, kernel densities were calculated in conjunction with the hot spot calculations to provide two different perspectives on the distribution of rescues. A point was placed at the centroid of the location polygon for each rescue record. Using these points, a kernel density was calculated with a search radius of 2200 m and the number of victims as the specified attribute. The density was represented with a square grid with 500 m sides. The search radius was chosen to create a density general enough to allow rescues near each other to combine while preserving the spatial pattern. The precision of the location information is more than sufficient to support these parameters. The resulting raster shows a density detailed enough to identify areas of high concentration of rescues and contrast the density with the results of the hot spot calculation.

To accompany the temporal hot spot calculations, kernel density calculations were also carried out for each month using the same parameters as for the overall dataset.

Chapter 4 Results

This chapter describes the results of analysis of the rescue geodatabase. Section 4.1 discusses the trends in the elevations of the hoist rescues in the database. Section 4.2 presents the results of the hot spot and kernel density calculations, and section 4.3 presents the results of the subsequent temporal calculations carried out on the areas with the highest G_i^* scores.

4.1. Trends in the Elevation of Hoist Rescues

Figure 11 shows the hoist rescues in the database, aggregated over a hexagonal grid and symbolized with circles proportional to the total number of victims in each cell as described in section 3.2.1. The vast majority of hoist rescues occur in the mountains in the southwest part of the county. Rescues below 6,000 ft. are blue and rescues above 6,000 ft. are orange. The main areas where rescues above 6,000 ft. have occurred are near Mt. San Antonio, San Gorgonio Mountain, and Big Bear, with a few near Mt. San Jacinto in Riverside County and one on Clark Mountain near the Nevada border. The hoist rescues below 6,000 ft. are concentrated in the lower areas of the mountains. Lytle Creek and Deep Creek are two areas that account for many of the lower elevation rescues. Figure 12 shows a series of charts with statistics for rescues above and below 6,000 ft. In every chart, rescues below 6,000 ft. are blue and rescues above 6,000 ft. are orange.

The top left chart in Figure 12 shows the numbers of rescues above and below 6,000 ft. for each year from 1994 to 2019. From 1994 to 2008 the aviation unit performed ten to fifteen hoist rescues below 6,000 ft. and five to ten hoist rescues above 6,000 ft. per year. In 2008 the aviation unit began to revise its hoist rescue procedures and pursue them more aggressively, which led to an increase in the number of hoist rescues below 6,000 ft. from nine in 2008 to 37 in

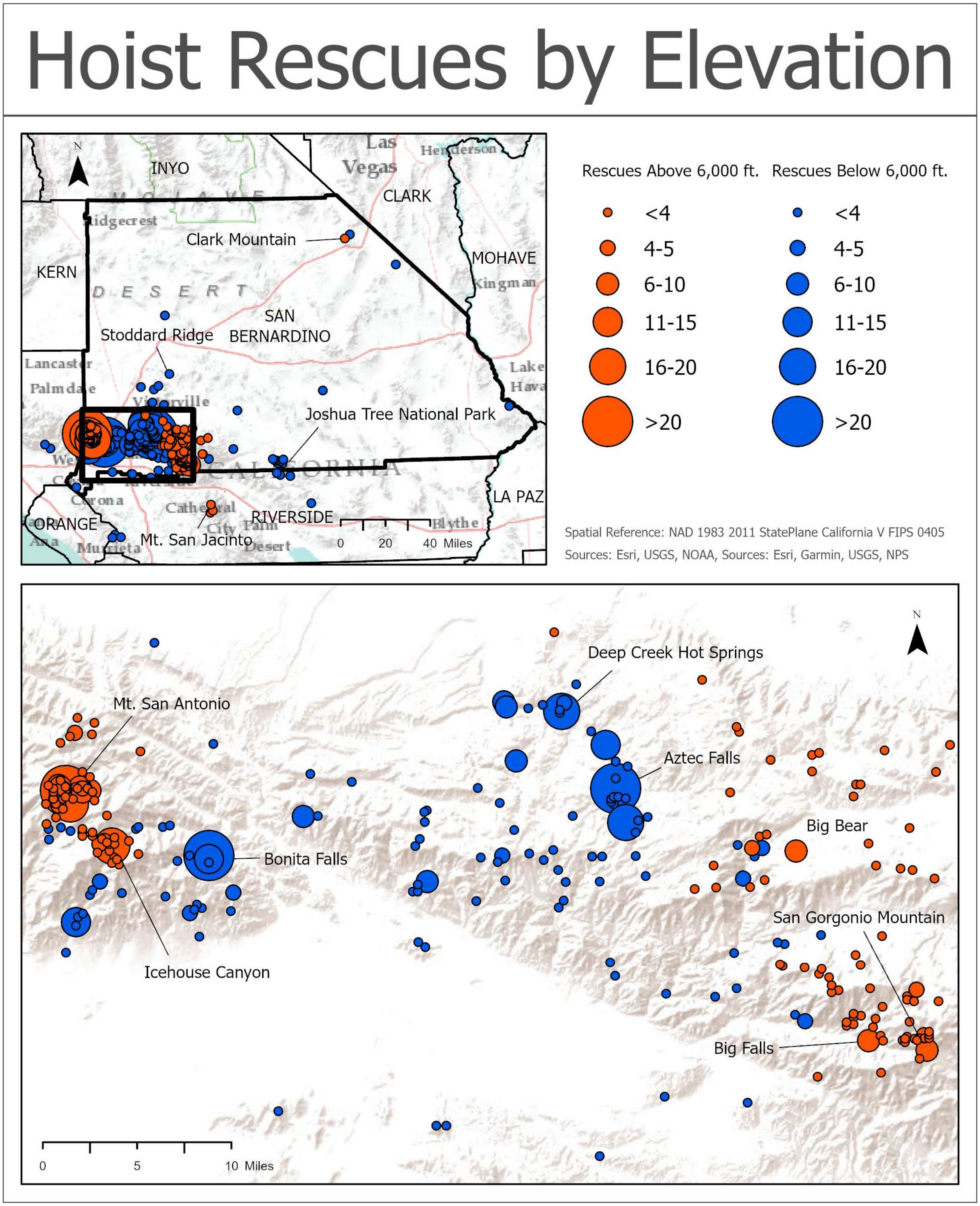


Figure 11 Hoist Rescues above and below 6,000 ft.

2012. From 2010 to 2019 the aviation unit performed between 26 and 46 hoist rescues below 6,000 ft. per year. After an approximately five-year lag, the number of rescues above 6,000 ft. also increased, from seven in 2010 to 44 in 2017. From 2015 to 2019 the aviation unit performed between 34 and 44 hoist rescues above 6,000 ft. per year.

The bottom left chart of Figure 12 shows the numbers of hoist rescues by month. July has the greatest number of hoist rescues below 6,000 ft., with the numbers generally increasing during the spring, at their highest levels in the summer, decreasing in the fall, and at their lowest levels in the winter. The hoist rescues above 6,000 ft. follow a similar trend, except that January has the fourth highest monthly total. The highest monthly totals are in June, July, and August, when the higher temperatures will have the greatest effect on the density altitude as described in Section 1.5.

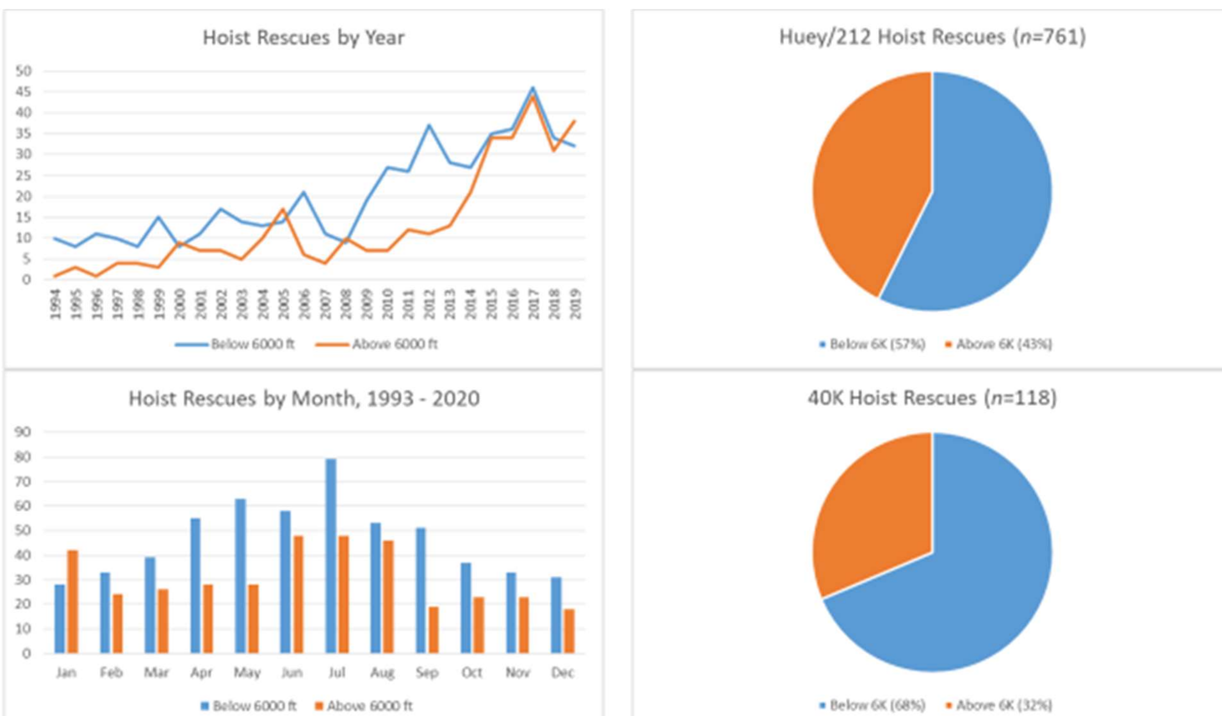


Figure 12 Statistics of rescues above and below 6,000 ft.

The charts on the right side of Figure 12 show the proportion of rescues performed by the medium helicopters and patrol helicopters. The medium helicopters have performed 761 hoist rescues, with 43% of them above 6,000 ft. The patrol helicopters have performed 118 hoist rescues, with 32% of them over 6,000 ft.

The results of this section clearly demonstrate a significant and sustained need for hoist rescues above 6,000 ft., with the greatest demand during the hottest part of the year. A rescue helicopter that can only perform hoist rescues below 6,000 ft. will be limited in its ability to provide this service in the county.

4.2. Statistical and Kernel Density Calculations

To determine the spatial autocorrelation of the distribution of rescues, the rescues were aggregated over a hexagonal grid with 50,000 m^2 cells as described in section 3.2.1. A global Moran's *I* calculation was carried out using a second-order adjacency network and a fixed distance band. The resulting z_I was 45.0 and the *p*-value was 0.00, meaning the calculated *I* statistic was 45 standard deviations from the expected value for a random distribution, which indicates statistically significant spatial autocorrelation.

To identify statistically significant rescue hot spots, a Getis-Ord G_i^* calculation was carried out using the same hexagonal grid, second-order adjacency network, and fixed distance band. The results are shown in the bottom inset of figure 13. Cells with G_i^* scores greater than 10 are shown in red, with the color becoming darker with greater G_i^* score. Because their G_i^* scores are so high, the *p*-value for all of these cells is 0.00. The hexagons shown are larger than those of the grid because the actual grid cells are too small to be seen at the scale of the inset map.

As described in section 3.2.2, a point was placed at the centroid of the location polygon of each of the 663 rescue records in the geodatabase. A kernel density was generated with the number of victims as the weighting attribute, a 2200 m search radius, and a 500 m cell size. Because the number of victims was used as the weighting attribute, a rescue in which two victims were rescued contributes twice as much to the density as a rescue with one victim.

After it was calculated, the density raster was symbolized with a color gradient, with low densities being transparent, then becoming blue, red, and yellow with increasing density. The units of the kernel density are victims rescued over the study time period per square meter. This is not a meaningful objective quantity, but the kernel density provides a qualitative indication of areas with a high concentration of rescues. The kernel density is shown in the top inset of Figure 13. The six areas with the highest G_i^* scores are labeled in both insets. The next few paragraphs introduce these areas from west to east:

Mt. San Antonio, also known as Mt. Baldy, is a very popular mountain for hiking, climbing, and skiing. The highest G_i^* score on Mt. Baldy is 67.7. It is a very prominent peak, with summit elevation 10,069 ft. It is visible from a large portion of southern California and is usually covered with snow during the winter. The closest ski area to Los Angeles is located on the east side of the mountain, and a large bowl on the south face is used for backcountry skiing. The Sierra Club maintains a ski hut in the bowl at an elevation of 8,300 ft. A section of trail called the Devil's Backbone traverses a ridge between approximately 8,600 and 9,200 ft. with steep drop-offs on both sides that connects the ski area to the summit. The steep and icy terrain in these areas during the winter results in falls that can end in serious injuries and fatalities. During the summer, hikers often lose the trail during their descent from the summit, go down the wrong canyon, and find themselves unable to continue when it gets dark. The combination of an attractive and highly visible mountain, hazardous terrain, and easy access to a large population

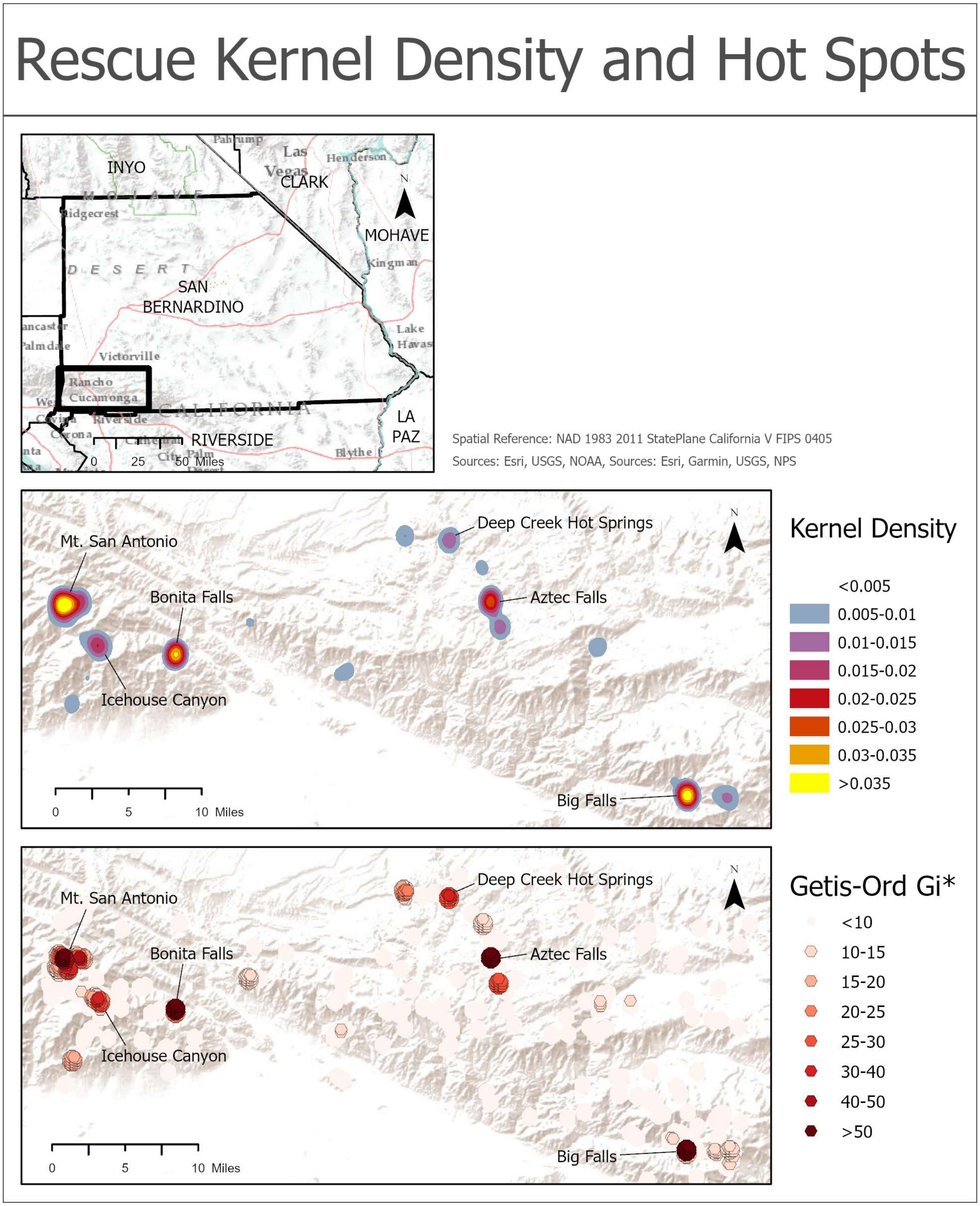


Figure 13 Rescue kernel density and G_i^* scores.

results in many search and rescue operations throughout the year, some of which become hoist rescues.

Icehouse Canyon is located along the road that leads to the Mt. Baldy trailheads and ski area. It branches off San Antonio Canyon at approximately 5,000 ft. elevation and climbs to a ridge, intersecting it at Icehouse Saddle at approximately 7,600 ft. The ridge connects to the ski area and the summit of Mt. San Antonio. There are several north-facing side canyons that are popular for ice climbing in the winter. The highest G_i^* score in Icehouse Canyon is 35.1.

Bonita Falls is a series of waterfalls located on the south fork of Lytle Creek. The lowest waterfall drops approximately 160 ft. to the bottom of Bonita Canyon, which is at 3,100 ft. elevation and is accessible by a $^3/_4$ mile hike from the road. There are several cascades higher in the canyon, with a total height of almost 500 ft. Bonita Falls is heavily impacted by human activity, with abundant graffiti and trash during the summer, when there is the most traffic. It is possible to climb past the lowest waterfall to see the other waterfalls in higher parts of the canyon, which are up to approximately 3,600 ft. elevation, but the trails are extremely steep and narrow. Hikers often fall and get injured or become stuck when they are unable to continue climbing up or climb back down. The highest G_i^* score at Bonita Falls is 79.8.

The Deep Creek Hot Springs are geothermal hot springs located along Deep Creek. Several pools have been constructed in which the temperature is controlled by mixing the hot spring and creek waters. The shortest hike is from the north, with a 1.8 mile trail that descends almost 1000 ft. from a ranch outside of Hesperia to the hot springs at 3600 ft. The trail is steep, sandy, and strenuous, with no shade in the summer. The Pacific Crest Trail also passes by the hot springs. The hot springs are clothing optional, and there are several cliffs that people jump off into the creek. The combination of natural beauty, party atmosphere, alcohol and drug use, and hazardous terrain make this a frequent location for hoist rescues. The highest G_i^* score at Deep Creek is 31.2.

Aztec Falls is a popular swimming hole along Deep Creek near the town of Lake Arrowhead at approximately 4,500 ft. elevation. There are a number of cliffs that people jump off into the water, which can lead to injuries. It is accessible by a ½ mile hike along the Pacific Crest Trail from a parking area. On May 22, 2020, the Forest Service closed Aztec Falls due to human impact, including illegal campfires, graffiti, trash, and gridlock in the parking area and surrounding Forest Service roads that has prevented ambulances from responding to calls (USFS 2020). Between the closure date and September 2020, two hoist rescues were recorded at Aztec Falls, compared to four in 2019, four in 2018, twelve in 2017, and six in 2016. The highest G_i^* score at Aztec Falls is 63.8.

Big Falls is the tallest permanent waterfall in southern California. It is located on the edge of the San Gorgonio Wilderness near the town of Forest Falls. The lowest waterfall has a drop of approximately 200 ft. The observation area for the waterfall is at approximately 6,000 ft. and is reached by a ½ mile hike from a parking lot. Like Bonita Falls, it is possible to climb past the first waterfall to the higher waterfalls in the canyon, which go up to approximately 6,400 ft. The trail is narrow, steep, loose, and makes several stream crossings. Due to the number of rescues in the upper part of the canyon, the Forest Service closed Big Falls beyond the observation area in July 2019 (Gundran 2019). The closure was renewed in May 2020 until May 2021 (USFS 2020). Since the closure, there have been three hoist rescues in 2019 and three in 2020, compared with ten in 2018, none in 2017, and eight in 2016. Big Falls has the highest G_i^* score in the study area at 97.1.

The six locations identified in this section make up a tiny fraction of the area of the county, but account for 365 of the 937, or 39%, of the victims rescued via hoist during the study time period, according to the database. By focusing on these six areas, the team can train and prepare for more than a third of its rescues. These areas may also provide opportunities to mitigate hazards to prevent injuries. In the next section, hot spots, densities, and statistics for the hoist rescues in these six areas are presented for each month to identify seasonal trends.

4.3. Monthly Hot Spots and Kernel Densities of Rescue Incidents

The database records were separated by month and hot spot and kernel density calculations were carried out on a study area containing the top six locations. The hot spot calculations used the same grid, second-order adjacency network, and fixed distance band as the calculations on the overall data set. The kernel densities used a search radius of 2200 m and a cell size of 500 m, the same parameters as the analysis of the whole dataset. The symbology of the hot spots and densities were adjusted from the previous section because the G_i^* scores and densities were different after being separated into months, and are the same for all twelve months. The grid cells were once again symbolized with hexagons larger than the actual grid cells so they would be visible in the inset maps. A chart with the number of victims rescued in the top six locations was generated for each month and included with the figures. Locations with more than five rescues for the month were labeled on the hot spot and density maps.

Figure 15 shows the hot spots and kernel densities for March, April, and May, which are relatively slow months for hoist rescues. The kernel densities are in the left insets and the hot spots are on the right. In March, the greatest number of rescues were on Mt. San Antonio and

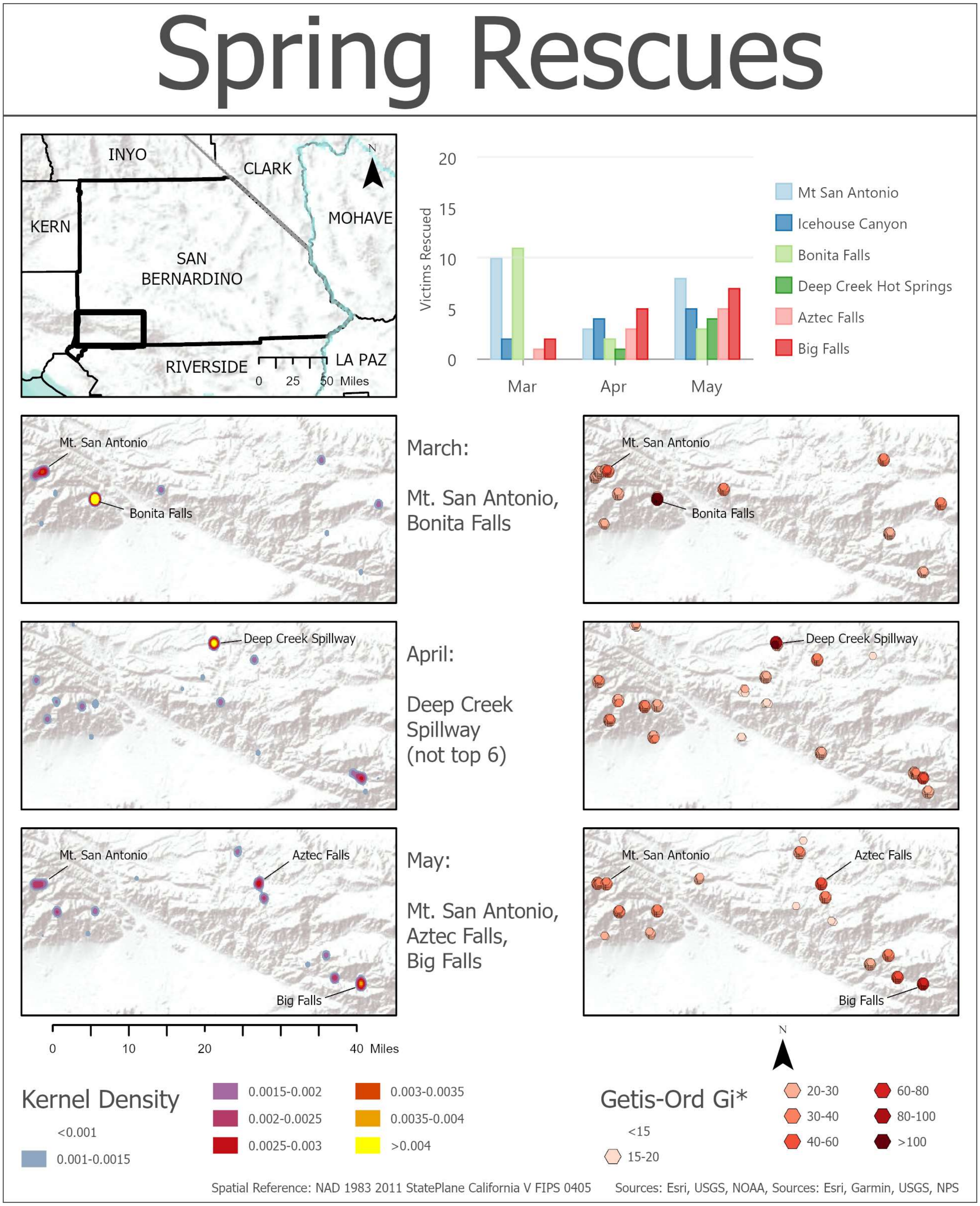


Figure 14 Kernel densities and hot spots for March, April, and May.

Bonita Falls. The G_i^* score on Mt. San Antonio is 52.6 and the G_i^* score for Bonita falls is 122. The high number of rescues at Bonita Falls is somewhat unexpected because, as a waterfall and swimming destination, it should see its highest traffic and number of rescues in the summer. The high number of rescues in March can be traced to an incident on March 20, 2016, when five victims were rescued, and another on March 20, 2019, when three victims were rescued. These two incidents account for eight of the eleven rescues at Bonita Falls in March.

In April, the highest G_i^* score is at the Deep Creek spillway, which is not one of the top six locations identified by the overall hot spot calculation. The G_i^* at the Deep Creek spillway is 105. Four hoist rescues have been recorded at that location in April, with five victims being rescued on April 16, 2020. The other three rescues had one victim each.

In May, the greatest number of rescues were on Mt. San Antonio and at Aztec Falls and Big Falls. The G_i^* score at Big Falls is 73.1, the G_i^* score at Aztec Falls is 58.9, and the G_i^* score on Mt. San Antonio is 31.4. Because it encompasses a larger area than the neighborhood considered in the calculation, the G_i^* score on Mt. San Antonio is lower than that of Aztec Falls and Big Falls, although eight rescues were performed there in May, while Aztec Falls had five and Big Falls had seven.

Figure 15 shows the hot spots and kernel densities for June, July, and August, the busiest months for hoist rescues. Forty-eight percent of the rescues in the top six areas occurred in these months. In June the greatest number of rescues were at Mt. San Antonio, Aztec Falls, and Big Falls. The G_i^* score for Big Falls is 92.1, the G_i^* score for Aztec Falls is 88.6, and the G_i^* score for Mt. San Antonio is 39.2.

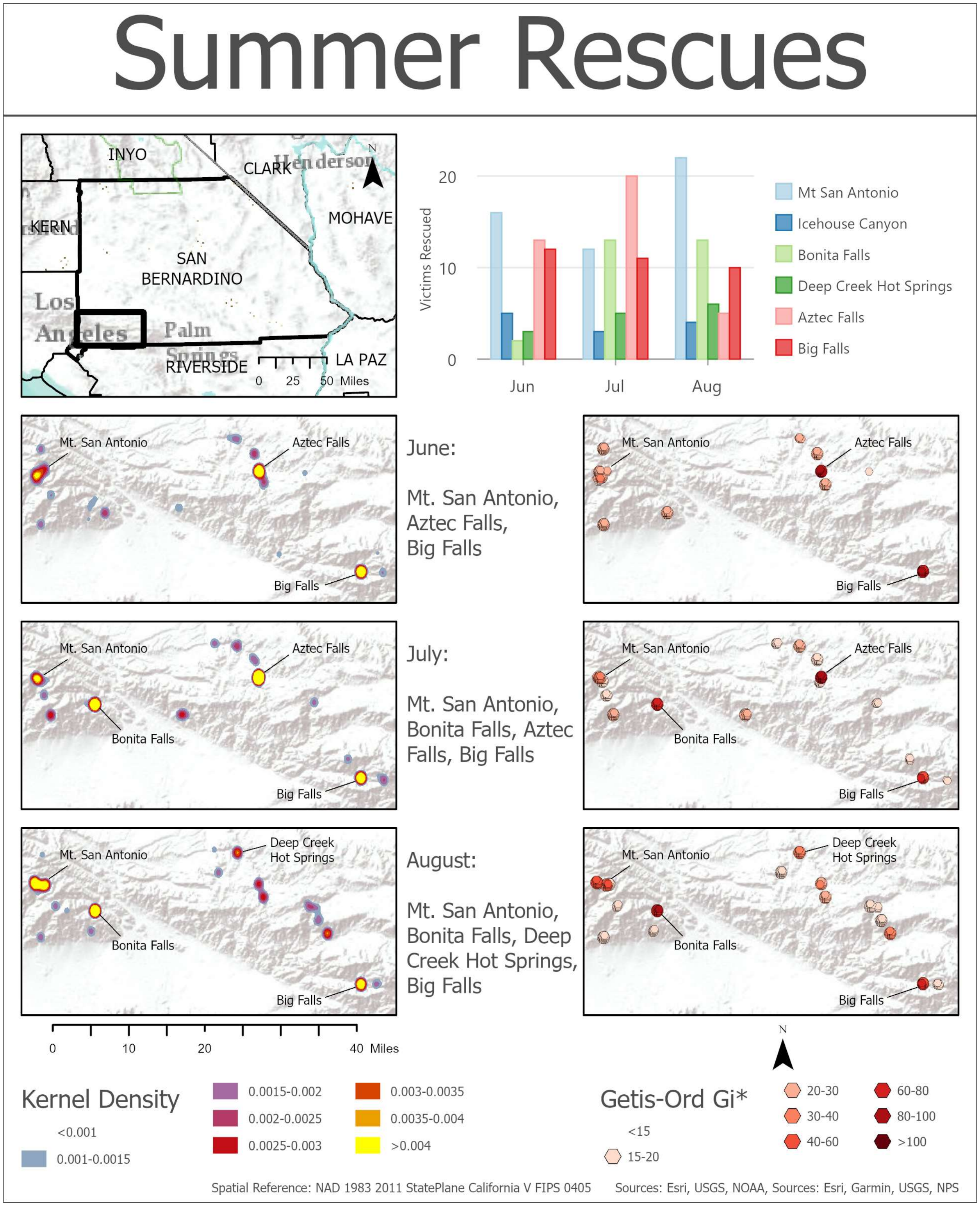


Figure 15 Kernel densities and hot spots for June, July, and August.

Once again, Mt. San Antonio had more rescues (16) than Aztec Falls (13) and Big Falls (12), but a lower G_i^* score.

In July the greatest number of rescues were on Mt. San Antonio and at Bonita Falls, Aztec Falls, and Big Falls. The G_i^* score for Aztec Falls is 99.1, the G_i^* score for Bonita Falls is 76.5, and the G_i^* score for Big Falls is 64.8. The G_i^* score for Mt. San Antonio is 30.3, although 12 rescues were recorded there, in comparison to 11 at Big Falls.

In August the highest number of rescues were on Mt. San Antonio and at Bonita Falls, Deep Creek Hot Springs, and Big Falls. The G_i^* score for Bonita Falls is 83.5 and the G_i^* score for Big Falls is 69.6. The the G_i^* score for Mt. San Antonio is 59.7, and the G_i^* score for Deep Creek Hot Springs is 36.8. Mt. San Antonio had the greatest number of rescues in August with 22, but its G_i^* score is lower than that of Bonita Falls and Big Falls.

Figure 16 shows the hot spots and kernel densities for September, October, and November. There were fewer hoist rescues during these months than the summer. In September the highest G_i^* scores are in the Devore foothills, which is not one of the top six locations, and Big Falls. The G_i^* score for Big Falls for September is 84.8 and the G_i^* score for the Devore foothills is 83.2. The high number of rescues in the Devore foothills in September can be traced to a rescue on September 30, 2010, when eight victims were rescued.

A high kernel density can be seen in October in Siberia Creek, which is not one of the top six locations. The high number of hoist rescues in October in the Siberia Creek area can be traced to a rescue of three victims on October 12, 1998 and rescues of three and two victims on

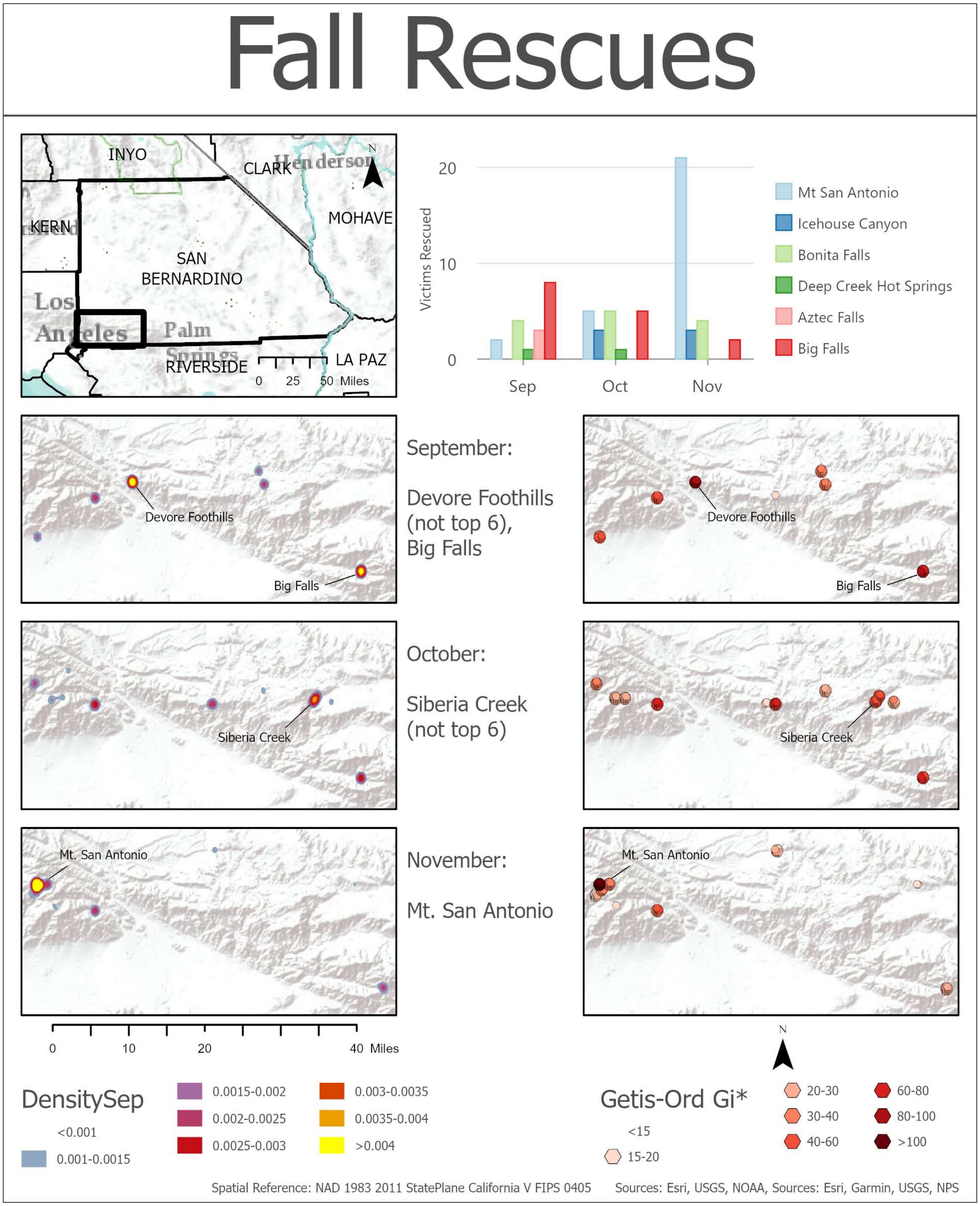


Figure 16 Kernel densities and hot spots for September, October, and November.

October 16 and 17, 2014. The G_i^* score for Siberia Creek for October is 57.3. Big Falls and Bonita Falls both have G_i^* scores of 66.8, although they had only five rescues each in October.

In November the greatest number of rescues was on Mt. San Antonio. Twenty-one rescues were recorded, which is its second highest monthly total after August. This number can be traced to rescues of four victims on November 27, 2005 from Devil's Backbone, four on November 27, 2010 from the Sierra Hut, and six on November 17, 2014 from the Sierra Hut. The G_i^* score for Mt. San Antonio in November is 105.

Figure 17 shows the hot spots and kernel densities for December, January, and February. December is a slow month for hoist rescues. The greatest number of rescues were on Mt. San Antonio and in Icehouse Canyon. Mt. San Antonio had eight rescues and Icehouse Canyon had 6, but they have the same G_i^* score of 70.6.

January has the third highest number of hoist rescues for a month on Mt. San Antonio with 20. The G_i^* score for Mt. San Antonio is 145. Three rescues recorded in January on Mt. San Antonio had two victims and the rest had one, so the number was not inflated by rescues with multiple victims and reflects a large number of separate incidents. The large number of rescues in January on Mt. San Antonio is probably the reason that January has the fourth highest number of rescues above 6,000 ft., as seen in Figure 10.

The greatest number of rescues in February were on Mt. San Antonio, with eight, and in Icehouse Canyon, with 14. The G_i^* score for Mt. San Antonio is 63, and the G_i^* score for Icehouse Canyon is 104. The number in Icehouse Canyon can be traced to two rescues on February 6, 2006 with four and five victims.

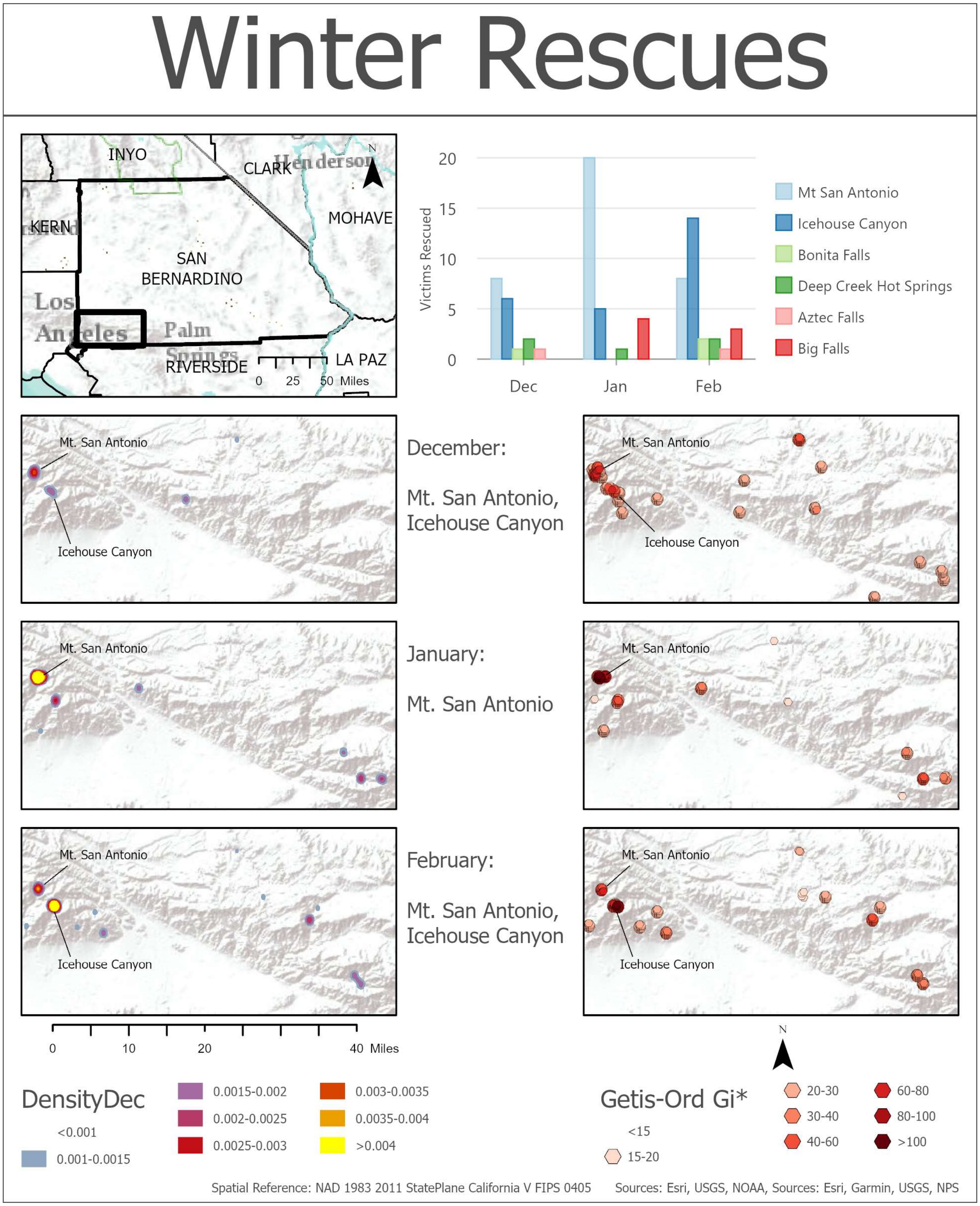


Figure 17 Kernel densities and hot spots for December, January, and February.

The monthly hot spot and density calculations, along with the charts of rescue statistics, provide a record of the hoist rescue activity at the top six locations throughout the year. The side-by-side comparison of the hot spot and density calculations with the rescue statistics shows the importance of comparing locations with similar sizes in a hot spot calculation. Because they cover more area than the second-order adjacency network used for the calculation, rescues recorded as happening in the areas designated as Mt. San Antonio or Icehouse Canyon may not contribute to the G_i^* score for the same target grid cell. As a result, the G_i^* scores for Mt. San Antonio and Icehouse Canyon are lower than the other areas for the same number of rescues. The size of the cluster could not be increased, however, because a larger cluster would allow neighboring canyons to contribute to each other and produce imprecise results. Subdividing Mt. San Antonio and Icehouse Canyon into smaller locations the size of a second-order adjacency network would give the named locations consistent size, which would give the hot spot calculations a consistent basis and make the G_i^* scores more comparable with each other. Smaller locations, however, would not be consistent with the usage of the names of these areas within the hiking community or sheriff's aviation.

As demonstrated in this section, the hoist rescue database allows the incidents behind unexpected monthly hoist rescue statistics to be investigated. In many cases, a high density in an area can be traced to a small number of incidents in which multiple victims were rescued.

Chapter 5 Conclusion

The main conclusion that can be drawn from this project is that the aviation unit's records, although their original purpose was equipment maintenance and accounting, contain valuable geographic information about its operations. The combination of hoist log books, blue cards, and personal records of unit members allowed the locations of rescues to be determined precisely enough to analyze trends in the elevation of hoist rescues and identify the areas of highest concentration of rescues and seasonal trends in those areas. The process of georeferencing and digitizing the records was labor intensive, but the results can contribute to discussions about the history, current status, and future of the hoist rescue program in the sheriff's department. Section 5.1 discusses the trends in the elevations and locations of hoist rescues. Section 5.2 discusses potential applications and analysis possibilities for the database, and section 5.3 discusses other ways in which GIS can be applied to the operations of the aviation unit. Finally, section 5.4 discusses the potential for search and rescue agencies to use GIS to learn from their historical records and improve their operations.

5.1. Trends in Hoist Rescues

Mt. San Antonio, Icehouse Canyon, Bonita Falls, Deep Creek Hot Springs, Aztec Falls, and Big Falls share characteristics that result in frequent hoist rescues. They are exciting locations that attract large numbers of people, they have hazardous terrain that can result in injuries, they pose challenges for ground teams to move injured victims, and there are few flat, clear areas large enough to land a helicopter close to where injuries occur. The identification of these locations and the seasonal trends in rescue activity will probably not come as a surprise to experienced members of the aviation unit. The results will, however, provide objective evidence for the anecdotal knowledge of unit members and a basis for discussions with people interested in but unfamiliar with the team's operations, such as the leadership of the sheriff's department, officials in the San Bernardino County government, and new members of the team. The personnel in the aviation unit is constantly changing due to retirements, promotions, and changes in assignment. A record of hoist records can make it easy to bring new members up to speed with this aspect of the unit's activities and understand how the equipment is used. The elevation trends in figure 9, for example, can be used to build a case for the necessary capabilities of a new rescue helicopter for work in the county.

The seasonal trends in hoist rescues generally show that Mt. San Antonio experiences a high number of rescues in the summer and winter, Icehouse Canyon is busy in the late winter, and the three waterfalls see their greatest activity in the summer. The results also show, however, that hoist rescues can occur in these areas at unexpected times. In addition, the top six areas account for almost 40% of rescues, so the remaining 60% of rescues occur in other parts of the county and surrounding areas. The analysis of the rescue records can help anticipate rescue activity and focus readiness and prevention efforts in certain areas, but the aviation unit must maintain the ability to respond to a rescue anywhere in the county at any time.

The results of this project can be used to direct efforts to prevent injuries in the areas where the most hoist rescues happen. The ground search and rescue team whose area includes Mt. San Antonio, Icehouse Canyon, and Bonita Falls, for example, could use this information to anticipate rescues or plan patrols on Mt. San Antonio in January and Icehouse Canyon in February. The team could also plan patrols on Mt. San Antonio and Bonita Falls in the summer.

The Forest Service has closed Aztec Falls and the area above the first waterfall at Big Falls to visitors. Based on the seasonal trends in hoist rescues in those locations before the closures, it can be recommended that the Forest Service should focus its efforts in maintaining barriers and signs and patrolling the trailheads to keep people out of the closed areas in June, July, and August.

5.2. Hoist Rescue Database Analysis Possibilities

There are many possibilities for analysis using the hoist rescue database beyond what was carried out in this project, and possibilities to improve the documentation so that in the future, no records have to be discarded, there is no uncertainty as to the locations of rescues, and more pertinent information is available for analysis. Sections 5.2.1 and 5.2.2 describe additional applications of the current database and section 5.2.3 describes ways to augment the rescue documentation to collect more useful information.

5.2.1. Rescue Database Analysis Possibilities

The hot spot and kernel density calculations described in Chapters 3 and 4 used the number of victims as the weighting attribute. In several of the monthly calculations, a high G_i^* score and density could be traced to a small number of incidents in which multiple victims were rescued. These results reflect the number of people that were rescued, but if the leadership of the unit preferred to use the number of incidents as a measure of rescue activity, it would be a simple task to recalculate the hot spots and kernel densities with the number of incidents and no weighting attribute.

The rescue database records the aircraft that was used in each hoist rescue. This attribute was used to compare the elevations of rescues performed by the patrol and medium helicopters, as shown in figure 10, but was not used in the hot spot or kernel density calculations. Air Rescue 306 and 307 have approximately the same power, but 307 weighs almost 1000 lbs. more than 306. The documentation for this attribute is not perfect, as 235, or 31%, of the 761 hoist rescues performed by the medium helicopters do not specify the aircraft. However, it may be interesting to compare the elevations of the rescues performed by 306 and 307 to see if the additional weight has made a difference in the rescues the helicopters have performed. Air Rescue 308 has only performed nine hoist rescues since it was equipped with a hoist, but as it continues to be used as a hoist ship, the locations, elevations, and temperatures of its rescues can be used to refine the assessment of its capabilities.

Another attribute of the rescue database that was found in the narrative section of some hoist records and blue cards is whether the rescue was assisted by a helitac-trained ground team. In these rescues, the aircrew relied on personnel from a fire or police department, the California Highway Patrol, or a volunteer search and rescue team to perform an aspect of the hoist rescue, usually packaging the victim in a rescue device and connecting the hoist hook. The locations where these rescues have taken place and agencies involved in assisting the rescues can help the aviation unit determine where and with whom to conduct joint trainings. Training with other agencies allows their personnel to become familiar with the rescue procedures, hand and arm signals, equipment, and radio frequencies used by the aviation unit, and will improve the coordination and safety of the rescues they perform together.

The aviation unit has used night vision goggles (NVGs) for years for patrol purposes, and has recently begun performing hoist rescues at night with them. Establishing and maintaining the capability of pilots and crew chiefs to perform hoist rescues with NVGs requires a significant amount of training. Tracking and analyzing the trends in night rescues can help demonstrate the need for this capability and justify the investment of time and money to maintain it.

5.2.2. Application Dashboard

Another possibility for the rescue database would be to create an application dashboard to make the information available for analysis via the internet. A web GIS could generate maps and figures based on the results of searches by date, location, elevation, person, or any other attribute of the database. The dashboard would be useful for the leadership of the aviation unit, who could use it to generate maps and charts similar to the ones in Figures 11 and 12 for use in their planning and discussions with sheriff's department and San Bernardino County officials. The dashboard would also be an excellent way to inform the public about the rescues the aviation unit performs and allow users to generate maps based on their own interests. The application dashboard would also be a good way to drive recruitment and appeal for donations.

Current and former aviation unit members would probably enjoy using the application dashboard to generate maps and statistics of the rescues they participated in and compare them to others. Although it would not analyze or apply directly to rescue operations, the ability to see maps and charts documenting their rescues would be a morale boost. The most important component of the aviation unit is the people, and the members of the air rescue team are volunteers. The application dashboard would be a way to recognize their contributions and honor their legacy by making the most of the information gathered about their rescues.

5.2.3. Information Gathering

The process of georeferencing the hoist rescues and the analysis that was carried out using the database can help determine what information should be collected about future rescue operations and how the documentation forms and processes should be changed. Recording GPS coordinates for each rescue would eliminate the georeferencing process and the need to discard records when their locations cannot be precisely determined from text descriptions. Obtaining GPS coordinates would be a trivial matter for the patrol helicopters, because they have an integrated navigation system and a large map display in their dashboards. The medium helicopters do not have integrated navigation systems, and the pilot and crew chief may be too busy to record a location using a handheld GPS device during a hoist rescue, when they have other procedures to follow. If they were collected, though, GPS coordinates would precisely determine the location and elevation of each rescue, which would improve the hot spot and density calculations of sections 4.2 and 4.3 and allow other types of analysis to be carried out.

Recording GPS coordinates would eliminate the uncertainty in the locations of the hoist rescues and allow them to be recorded as points rather than as polygons. To conduct spatial autocorrelation and hot spot calculations, however, the rescues would still have to be aggregated over a grid. In this thesis project, the size of the grid cells was dictated by the area of the rescue location polygons, and was chosen to reflect the uncertainty of the rescue locations while preserving as much spatial detail as possible. If the rescue locations were recorded as exact points, grid cells of any size could be used. It would be interesting to explore the MAUP by comparing the memory, computer time, and results of statistical calculations for different aggregation schemes in a fashion similar to the references in sections 2.2 and 2.3.

Another useful piece of information that is currently not regularly being collected is the outside air temperature. As was discussed in section 1.5, the temperature has a large effect on how helicopters function. The outside air temperature, along with the elevation, would allow the density altitude to be calculated for each rescue, which would help build understanding of the capabilities of the helicopters and inform pilots and crew chiefs when a rescue is approaching their limits and measures to reduce weight should be taken.

The database developed in this project records only the rescues the aviation unit has successfully handled, and thus reflects a "survivor bias." To understand the limits of the helicopters, it would be useful to have records of rescues they were unable to perform with an explanation of whether the rescue was prevented by visibility, elevation, weather conditions, or other factors. The dispatch system may be a source for information about instances when the helicopter was requested but was unable to complete the rescue. Analyzing how many rescues the aviation unit was unable to complete and the reasons they were unable to complete them could define its limiting factors and build a case for how many more rescues would likely be performed with more capable helicopters or different training requirements for crew members.

To streamline the process of collecting data about future hoist missions, a database could be established using a program such as Microsoft Access (Microsoft 2020) with an interface for users to create and add records. If updating this database became a standard procedure for documenting rescues, the records could be used to generate blue cards and eliminate the need for the hoist log books. The geographic coordinates and other attributes of the records could be exported to the web GIS discussed in section 5.2.2 to keep it up to date.

5.3. Other Applications of GIS for Air Rescue

There are many other ways in which GIS can be used to enhance the operations of the aviation unit beyond recording and analyzing hoist rescues. One mission the rescue helicopters are regularly tasked with is transporting ground search and rescue team members to areas they have been assigned to search. Inserting teams by helicopter increases the amount of time they have to search their assigned areas and reduces their exposure to hazardous terrain.

The sheriff's Incident Management Team (IMT) is a volunteer team that runs the command post during large scale search operations (Nicolet 2011). The members use GIS to record victim information, such as their planned route and place last seen; assign search areas based on the probable behavior of the victim; and document areas searched and clues found. The use of GIS in search and rescue has been an active area of research in recent years (Pfau 2018). Tools developed to predict the behavior of lost hikers have been used in USC master's thesis projects that analyzed the records of search operations in Oregon (Johnson 2106) and identified places where people lost their way in Yosemite National Park (Danser 2018). The IMT's records of recent large scale searches could be used to identify areas that have been assigned to search teams in more than one operation. Hikers go missing several times a year on Mt. San Antonio, for example, and there are probably areas that have been searched as part of more than one operation. The records could be used to find the search areas that would benefit the most from having teams inserted by helicopter because they are difficult to access from trailheads.

Within these search areas, GIS could be used to identify large, clear, flat areas as candidate helicopter landing zones (HLZs). A recent USC master's thesis developed a method to use GIS to identify candidate HLZs that volunteer teams could survey in person for use in disaster relief operations (Darby 2017). A one-meter digital elevation model (DEM) is available for most of the San Bernardino Mountains from the USGS National Map website (USGS 2020), and could be used to calculate slope. Land cover data is available from the National Land Cover Database (MRLC 2020), electrical transmission line data is available from the California Energy Commission (California Energy Commission 2020), and electrical distribution line data is available from Southern California Edison (SCE 2020). With these inputs, it would be possible to perform a site suitability analysis and identify candidate landing sites that would be useful for search operations.

The candidate sites would have to be surveyed in person to confirm their suitability, then a list with the names, coordinates, elevations, and descriptions of the sites could be compiled. The list would be shared with the IMT and aviation unit and would allow the IMT to plan the insertion of search teams by helicopter.

The sites would not be maintained, and using them would be at the discretion of the pilot, but the list of sites would be an important resource for the IMT in planning search operations.

5.4. GIS Analysis of Rescue Operations

Historical search and rescue records represent an opportunity for agencies to learn from the operations they have carried out. Retrospective studies of these records can identify trends in where and when missions happen and help teams determine the best ways to prepare for and handle them. Even if the records do not include coordinates or were not collected with the intent of supporting geographic analysis, it is possible, by combining different sources of information, to georeference the locations of incidents with enough precision to identify spatial and temporal patterns.

Search and rescue operations often happen at inconvenient times and in uncomfortable and dangerous conditions. Many of the people who carry them out are volunteers. A very good way to honor their efforts is to learn as much as possible from these operations to anticipate future incidents, guide prevention efforts, and improve their teams' training and readiness.

The precision of the information recorded in search and rescue documentation limits the analysis that it can support. Improving the data collection process, for example by including geographic coordinates and automatically updating a database, can ensure that the greatest possible benefit is realized from operations in the future, so that search and rescue incidents can be prevented, and teams can be as prepared as possible to handle them when they do occur.

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