A Methodology for Modeling Evacuation in New Orleans

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Introduction

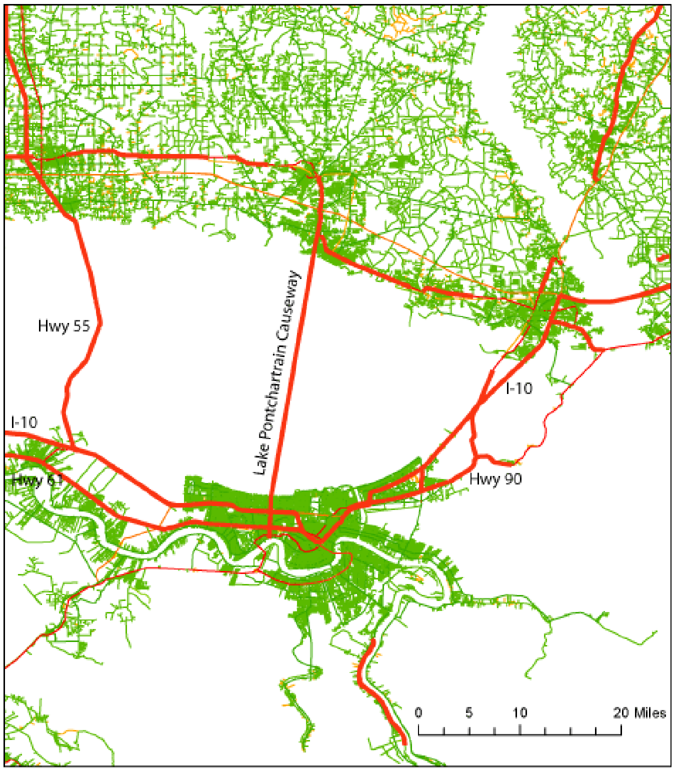
New Orleans is a large metropolitan area that is regularly affected by large weather events from tropical storms to hurricanes. In the fall of 2005, Hurricane Katrina hit the city with enough force to break levees and flood the majority of the populated areas. This was not the first time the city was flooded due to a storm, but it was the first time that the rest of the nation was allowed to watch such a monumental domestic disaster on national television. The plight of the residents who remained in the city became evident as the storm passed and the extent of damage became known. The slow response by all levels of government has raised questions about environmental justice and emergency management and preparedness. Thousands of residents, most of whom did not have access to a personal vehicle or were housed in institutions such as hospitals or prisons, suffered in squalid conditions waiting for relief, while many others died in what were considered evacuation shelters. It became clear that the emergency management and execution of evacuation orders was insufficient to address such a large disaster.

This paper presents a methodology for creating an evacuation model for New Orleans. This model focuses on considering car-less households and individuals who are incapable of driving themselves to safety. This model is based on many assumptions, the largest of which is that it uses pre-Katrina population data. It is unlikely that New Orleans' demographics will reflect pre-Katrina conditions any time in the near future. Thus, this paper focuses on the methodology of the modeling rather than the results.

I. Basic Evacuation Model

The first evacuation analysis that was conducted was to model a private vehicle-based evacuation. To do this, many assumptions were made. First, it was assumed that all households would have access to a vehicle. Next, it was assumed that due to the unique geography of New Orleans, the key bottlenecks during evacuation would be the five highways that lead out of the city. Two routes, I-10 Westbound and Highway 61 (Airline Highway) leave New Orleans westbound. Two other routes, I-10 Eastbound and Highway 90, exit to the east. Finally, the Causeway crosses Lake Pontchartrain to the north. This assumption simplifies the modeling of the network into a problem that can be solved visually. Traffic moving within the city would be constrained only by the ability of the bottlenecks

Figure 1: Map of Bottleneck Routes



This assumption of routes matches with the recently published evacuation plan for New Orleans. During an evacuation, I-10 operates as a contraflow freeway in both directions. This means that the two inbound lanes handle traffic in the reverse direction, increasing the total outbound capacity. The other three routes operate as bi-directional highways.

Capacities of these five evacuation routes were estimated using typical maximum flow rates. Flow rates for freeways under contraflow operations were taken from a study on contraflow operations by Wolshon. Table 1 shows the capacities estimated for the five evacuation routes. Next, population was allocated to the routes based on their capacity. With this assumption, all routes would be used to maximum capacity, and the queues at each bottleneck would last the same amount of time. From this, a total number of vehicles per route could be calculated, based on an average occupancy level of 2 persons per vehicle. Finally, using the initial assumed capacities, the duration of the queue at each bottleneck was determined.

Table 1: Population Allocation by Evacuation Route and Queue Duration

Route	Facility Type	Capacity (vehicles per hour)	Percent of Total	Population Allocated	Total Vehicles	Queue Duration (hours)
I-10 Eastbound (contraflow)	4 lane, limited-access	5000	30.1	125,000	62,500	12.5
I-10 Westbound (contraflow)	4 lane, limited-access	5000	30.1	125,000	62,500	12.5
Lake Pontchartrain Causeway	4 lane, arterial	3400	20.5	85,000	42,500	12.5
Highway 90	2 lane, arterial	1600	9.6	40,000	20,000	12.5
Highway 61 (Airline Highway)	2 lane, arterial	1600	9.6	40,000	20,000	12.5

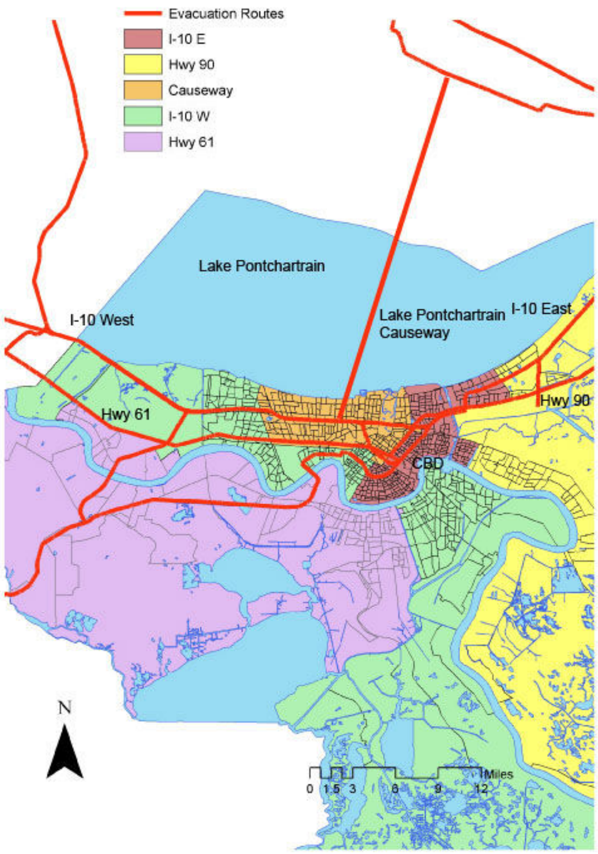
These numbers are highly influenced by the many assumptions, but could easily be changed if more refined data about the road capacities, vehicle occupancies or population were obtained.

Using the allocated populations, evacuation zones were created for the five-parish region around New Orleans. These zones were sized and located to match with the estimated capacities of the adjacent evacuation routes, and to minimize distance and confusion for evacuees. While it would have been possible to optimize the boundaries of these zones, highly irregular boundaries would pose a problem in quickly informing the public how to recognize which evacuation zone they reside in. If emergency workers and residents can't decipher the evacuation zones, they will not be effective. Thus, the zones were created using clearly defined and easily understood boundaries such as canals, major roads, and Parish lines, while at the same time attempting to allocate the population to conform to the capacities of the evacuation routes. The final zones are shown in Figure 1 and summarized in Table 2. They roughly match the ideal allocated population, while maintaining reasonably uncomplicated boundaries.

Table 2: Evacuation Zone Boundaries and Allocated Population Counts

Route	Boundaries	Capacity (vehicles per hour)	Population Allocated	Total Vehicles	Queue Duration (hours)
I-10 Eastbound (contraflow)	Orleans Parish, Lower 9th Ward East New Orleans, west of Read Blvd Orleans Parish, Between London Canal and Industrial Canal Orleans Parish, southeast of Broad Ave Orleans Parish, east of Broadway	5000	105,954	52,977	10.6
I-10 Westbound (contraflow)	West Bank of Plaqmines Parish West Bank of Jefferson Parish, east of Peters Street West Bank of Orleans Parish East Bank of St Charles Parish, north of Hwy 61 East Bank of Jefferson Parish, west of David Dr & Power Blvd & south of Hwy 61 Orleans Parish south of Airline Hwy & west of Broadway St	5000	125,816	62,908	12.6
Lake Pontchartrain Causeway	Jefferson & Orleans Parish, north of Airline Highway & west of London Canal	3400	89,175	44,587	13.1
Highway 90	East Bank of Plaqmines Parish St Bernard Parish East New Orelans, east of Read Blvd	1600	41,948	20,974	13.1
Highway 61 (Airline Highway)	West Bank of St Charles Parish East Bank of St Charles Parish, south of Hwy 61 West Bank of Jefferson Parish, west of Peters Street	1600	51,830	25,915	16.2

Figure 2: Map of Evacuation Zones



II. Revised Model: Taking into Account Demographic and Geographic Constraints

The revised model attempts to answer three questions:

1. Who are the evacuees and where are they coming from?
2. How are they getting out? And,
3. Where are they going?

Overall Calculation Assumptions

The next step in the modeling process was to investigate the priority population, determine the appropriate mode and route of evacuation and then locate a safe destination. Each section will detail the many assumptions and data sources that went into constructing this model.

A. Where are the Evacuees coming from?

Assumptions

This model assumes that the priority evacuation collection points should be within the city in close proximity to populations with the greatest need. Need was determined both geographically as well as demographically. Obviously low-lying areas or those that have historically flooded are high priority evacuation sites. Furthermore, populations without access to a private vehicle (car-less households) as well as populations living in large institutions such as hospitals and prisons are to be the primary evacuees for the first stage of the mass transit/public evacuation. This is because they are the most vulnerable and require specialize personnel such as doctors and prison guards to escort them in transit. At the same time, they are incapable of evacuating themselves. The institutionalized population was largely left behind during the recent Katrina disaster while those with private vehicles were able to escape disaster.

The 'Who Model'

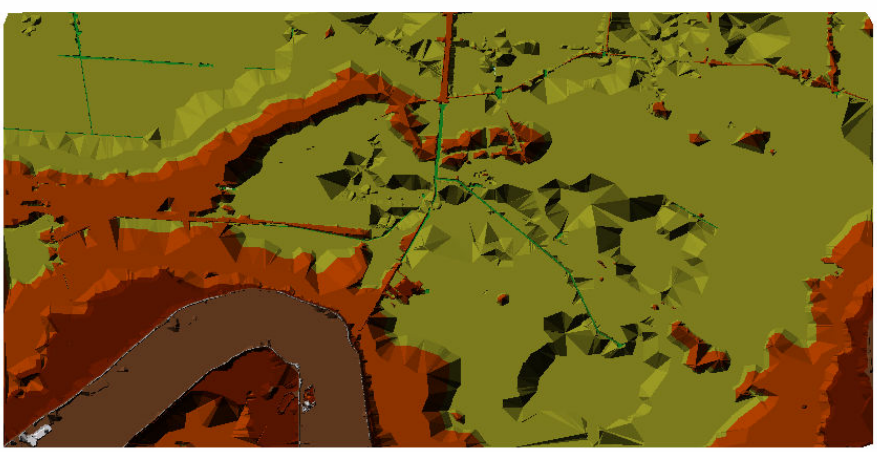
The evacuation was prioritized or 'staged' to ensure that those who are in the greatest danger or with the largest mobility constraints can get out of New Orleans first.

Creating Elevation and Historic Flood Constraints

Elevation is an important factor when considering flood-potential, so an elevation TIN from existing contour data was created using 3D analyst. TINs for both 2-foot and 5-foot contour data were generated.

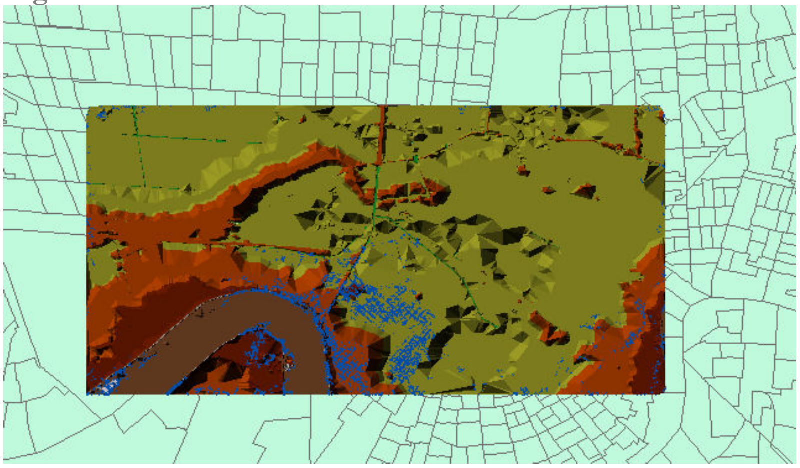
2-foot contour data was more fine-grained but also very slow to work with.

Figure 3: 2-Foot TIN of New Orleans



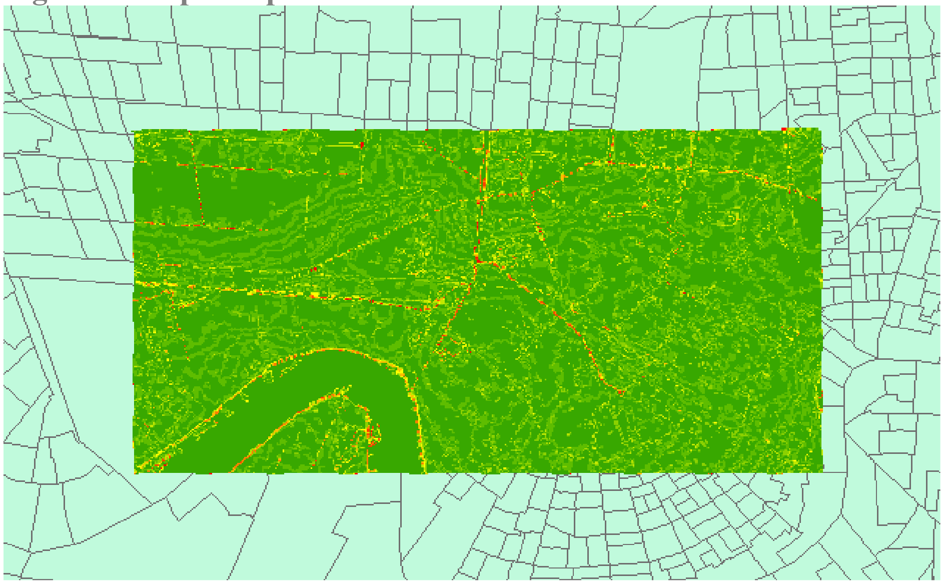
5-foot contour data produced a less accurate TIN but it was much faster/easier to work with.

Figure 4: 5-Foot TIN of New Orleans



To ensure that the staging sites are not located in areas that are at the bottom of slopes where water could pool a slope map for the same area was created. As can be seen from the map below, New Orleans, like most of Louisiana, is relatively flat and slope poses no threat.

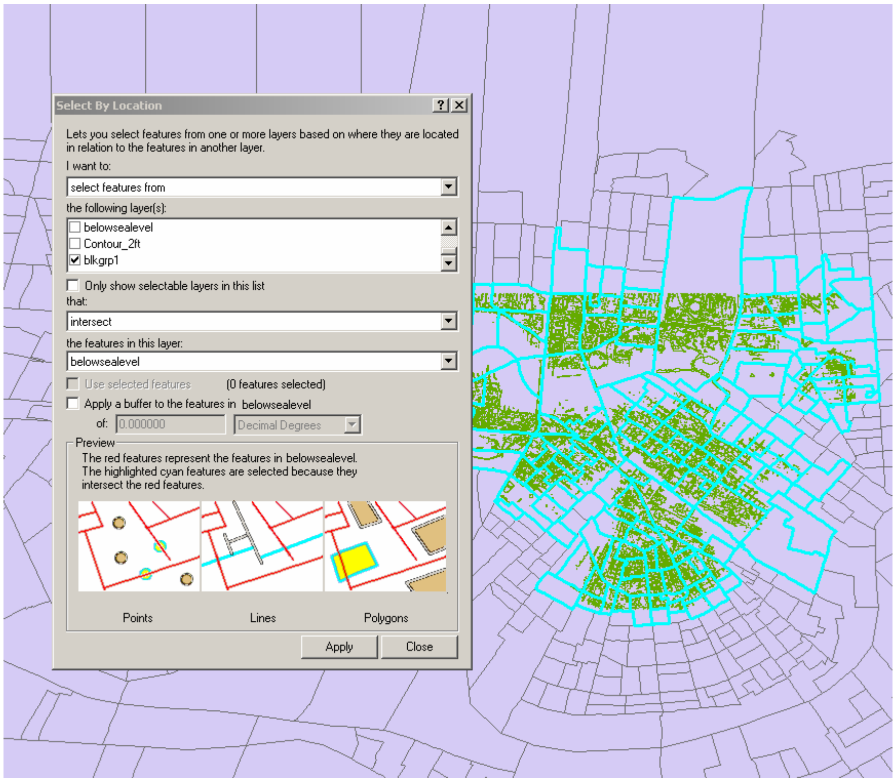
Figure 5: Slope Map of New Orleans



Determining 'Risky Sites' (locations below sea-level)

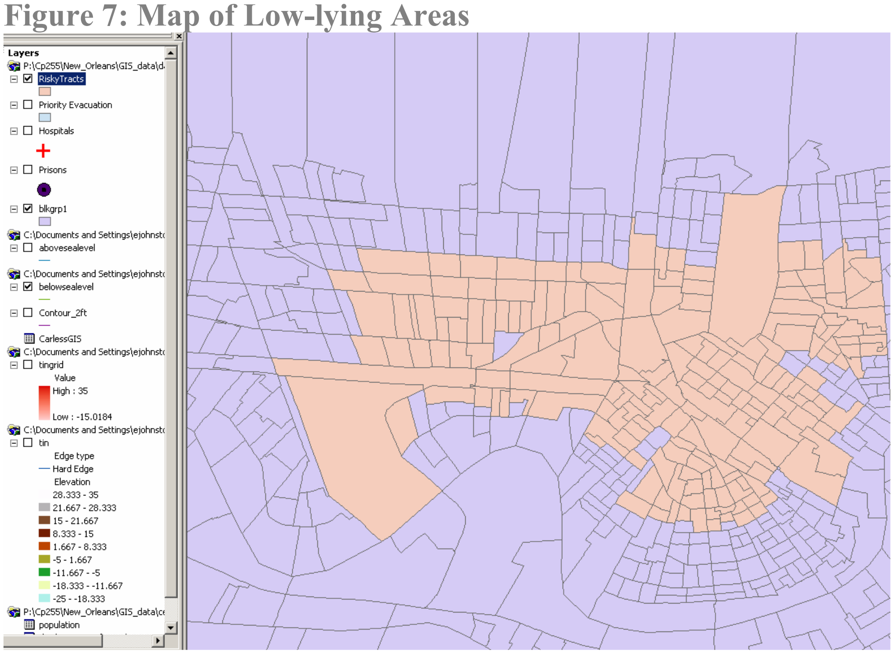
Using the TIN and the attribute file for the contour data, a selection by attribute of contour lines that are below sea level was performed.

Figure 6: Map of Low-lying Area Selection Process



This created a layer of sites deemed 'Risky Blocks' that are below sea level.

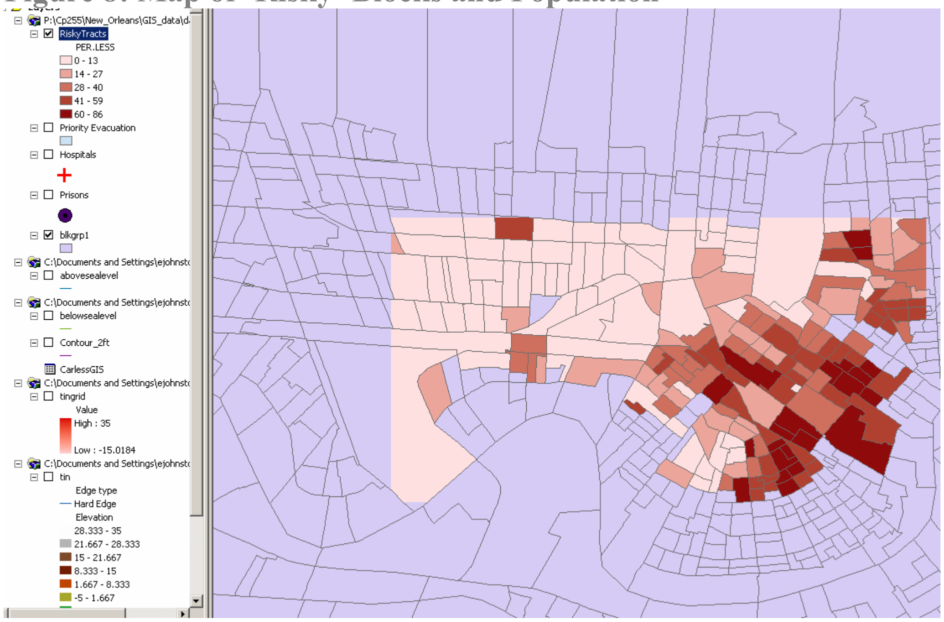
Figure 7: Map of Low-lying Areas



Adding Demographic Risk

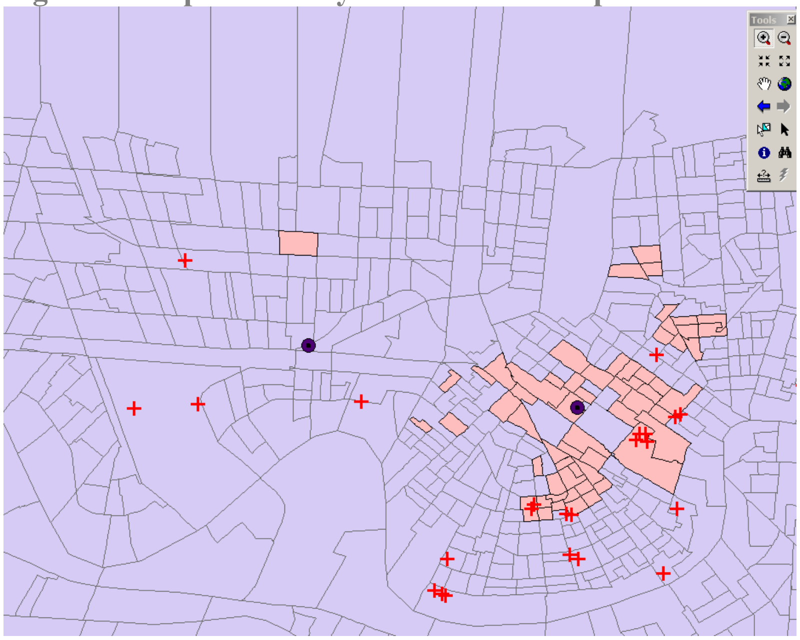
Low elevation alone does not indicate a population that needs assistance, so demographic ‘risk’ data (car ownership rate) was also incorporated into the model. The map below shows the percent of car-less households by block group – with the darker reds indicating low-ownership, i.e. the greatest need.

Figure 8: Map of ‘Risky’ Blocks and Population



From this map, a layer of block groups with 40% or higher car-less households was created. Using the “Intersect” function under “Selection by Location”, this information was added to the ‘Risky Blocks’ shapefile to create the map below which shows only block groups that are below sea level AND have low car-ownership rates. This map also shows the institutions that were designated as needing assistance to create a total picture of ‘Needy Locations’

Figure 9: Map of Priority Elevation and Population Evacuation Locations



Using Historic Data

Because the contour data available was geographically limited, the analysis was completed again using historic flood data from Katrina. This map is similar to the last in that it also determines areas that are at high risk and therefore in great demand for priority evacuation.

Using the select by location, intersect function (see below) a layer of 'Flood Prone' block groups was created.

Figure 10: Map of Historic Flood Selection Process

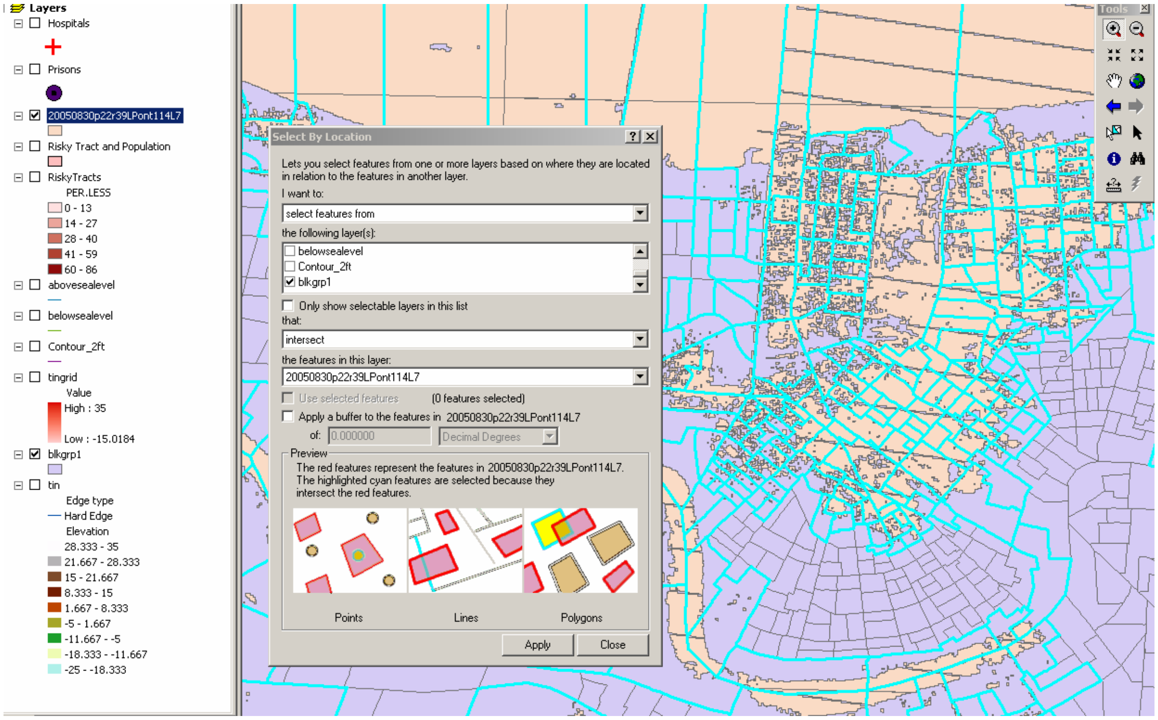
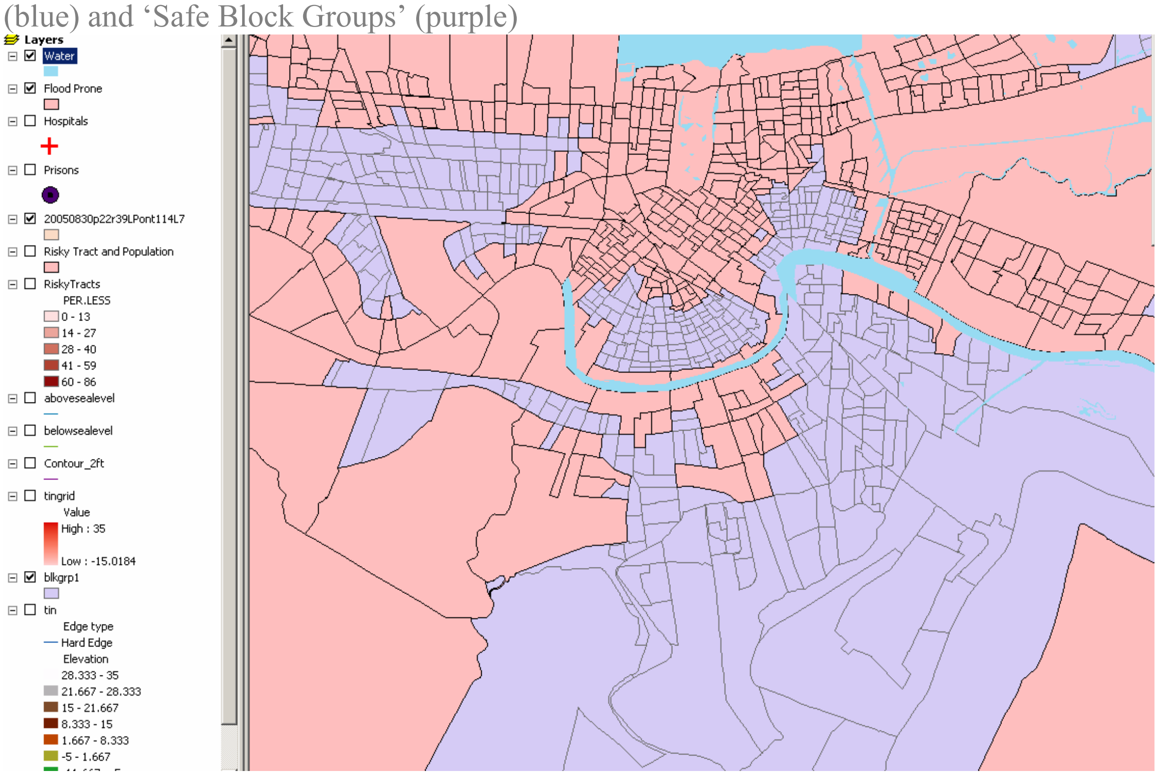
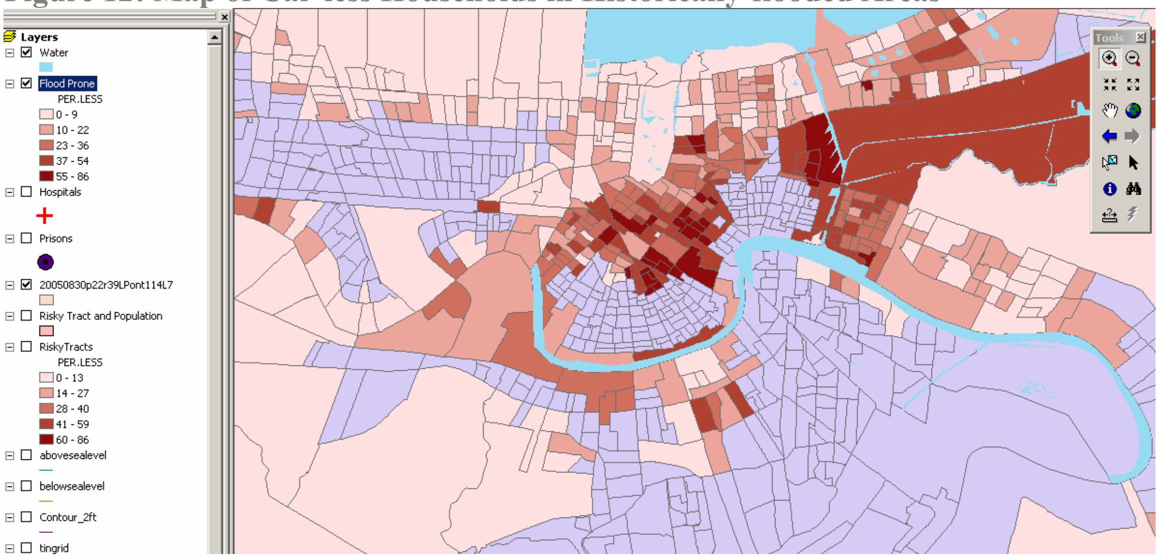


Figure 11: Map of 'Flood Prone' Block Groups (in pink), with existing water bodies (blue) and 'Safe Block Groups' (purple)



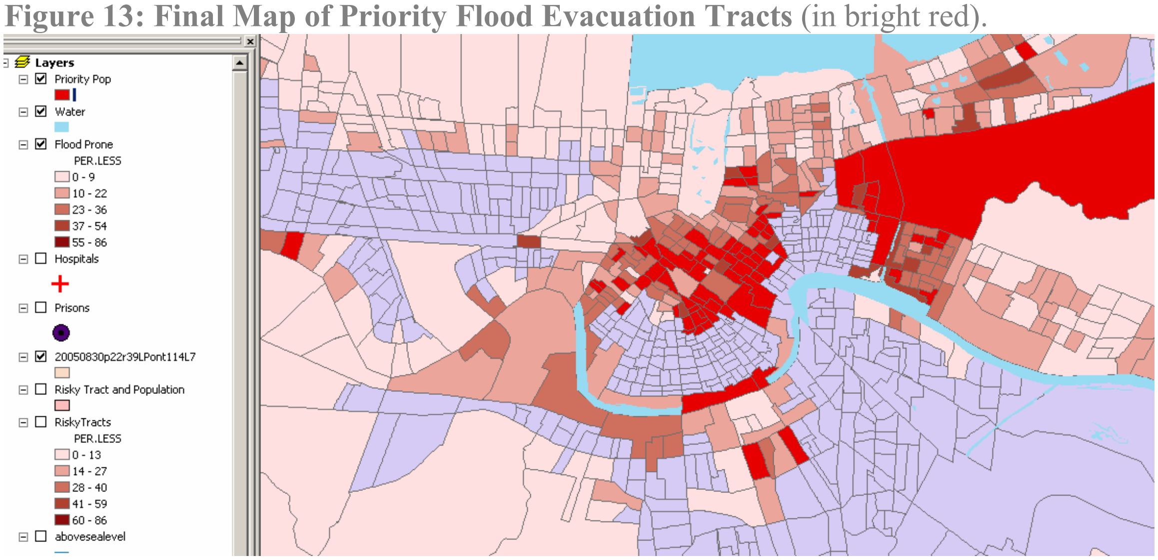
The map below was created by linking historic flood data to data on the car-less population. It shows the percentage of households in the high-risk flood areas that are in need of an alternate mode of evacuation.

Figure 12: Map of Car-less Households in Historically-flooded Areas



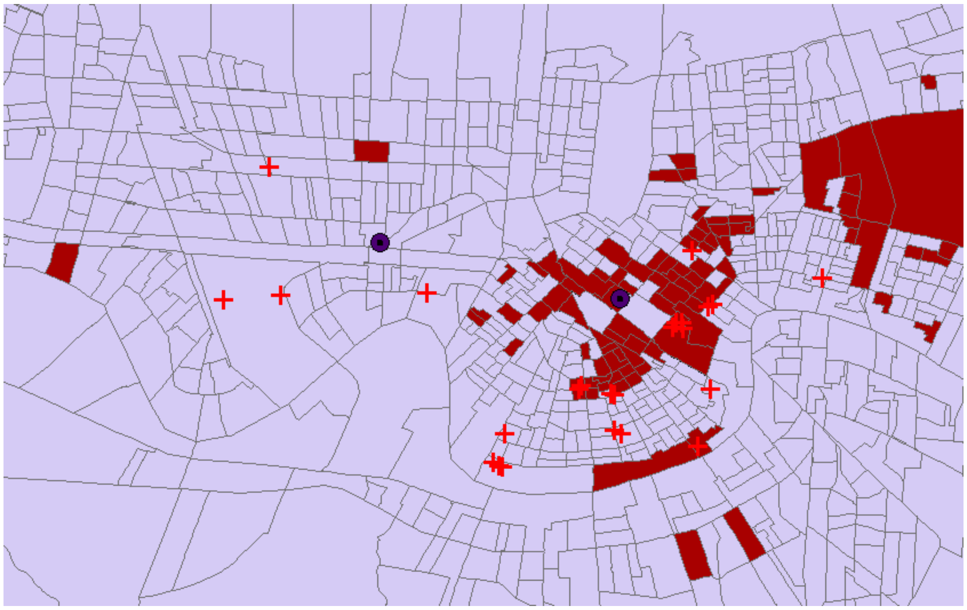
Block Groups with more than 40% car-less population were used to create a layer for the 'Needy Population' which resulted in:

Figure 13: Final Map of Priority Flood Evacuation Tracts (in bright red).



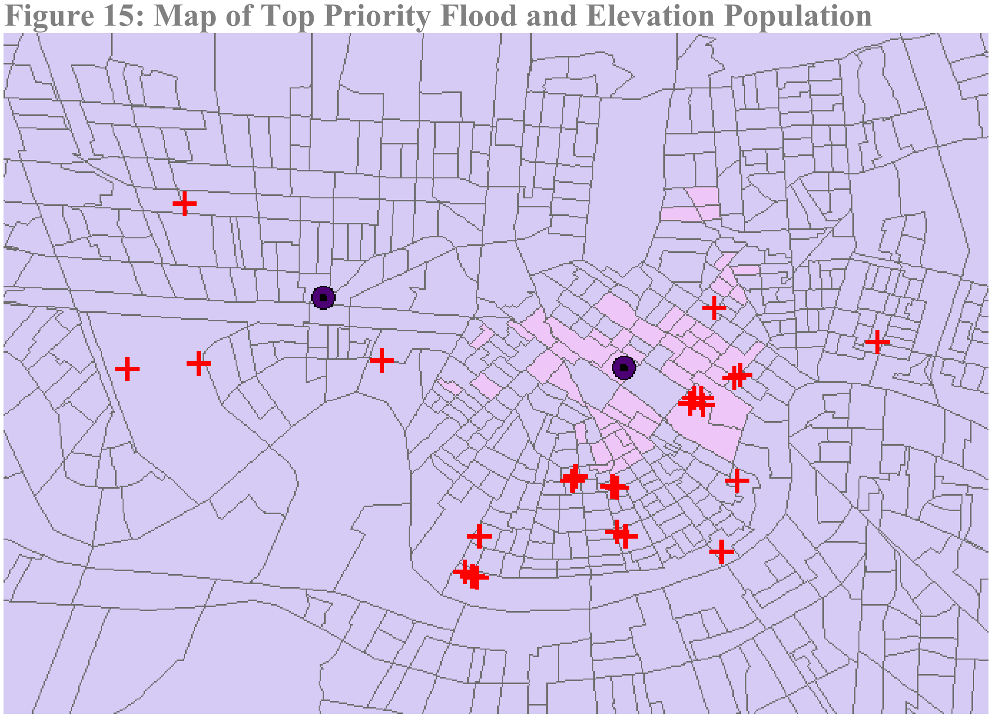
For our most <u>conservative</u> model the "Union" command was used with the Priority Flood and Priority Elevation maps and overlaid with the institutional locations (see map below) to create the most expansive map.

Figure 14: Map of Conservative Priority Flood and Elevation Population



And then for a less-conservative model, the "Intersect" command was used on the Priority Flood with Priority Elevation maps to get only those areas that are BOTH below sea level AND were flooded during Hurricane Katrina. With the institutions overlaid, this map indicates the Top priority locations for mass-transit/publicly available evacuation.

Figure 15: Map of Top Priority Flood and Elevation Population



B. How are the Evacuees going to get out?

Mode/Route Assumptions

Evacuation of New Orleans during Katrina was done almost completely using the road network, and primarily by private vehicle. However, New Orleans has extensive rail infrastructure, including separate bridges over the east and west ends of Lake Pontchartrain. Also, busses could be used more efficiently if they were allowed to make multiple trips into the city, and if their speeds were increased.

Bus Transit Evacuation Modeling

The Mardi Gras Index reported that at the time Katrina hit, there were 150,000 residents of New Orleans living in car-less households. Additionally, there are a large number of tourists in New Orleans at any given time, and also a number of individuals with cars who are not able to evacuate due to financial constraints. This population could be evacuated by a large-scale bus evacuation.

With the numbers needing evacuation so high, an evacuation scheme that did not send each bus on multiple trips would require an enormous amount of busses. Thus, the key to a bus based evacuation is to minimize the delay and the distance that each bus must travel, and maximize the number of trips each bus can take into and out of the city in a given evacuation time period.

New Orleans has 33,000 hotel rooms and 9000 rental cars. However, many tourists have their own cars or rent cars and thus have the ability to self evacuate. Assuming 1.5 persons per hotel room, 60% occupancy and that 50% drive their own car, 11,200 tourists will require evacuation.

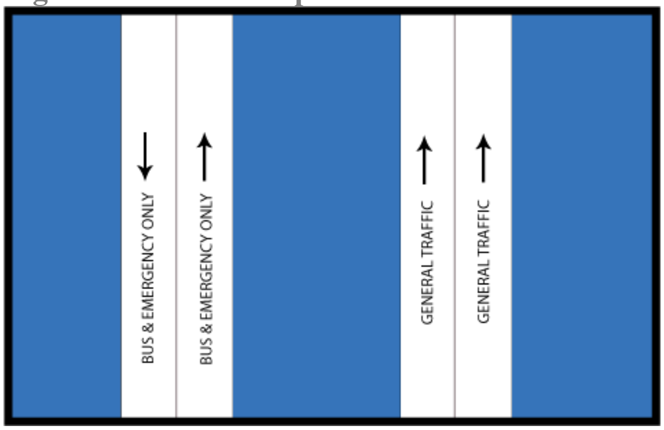
A survey by the Gulf Coast Reconstruction Watch of the 270,000 people living in shelters during Hurricane Katrina found that 23% in shelters were physically unable to evacuate while an additional 55% were from car-less households. Thus, there are 59,000 and 150,000 from each group respectively.

This leaves a total of 262,300 evacuees, when prison and hospital populations are included. The prison, hospital and physically disabled populations will be dealt with in the next section detailing a rail-based evacuation. When these special populations are removed, 182,000 people remain to be evacuated via bus.

New Orleans has an existing fleet of busses. The school district of New Orleans has 324 school busses and the transit agency has 364 busses (Infrastructure Final, 2006). The average bus capacity is 72-52 passengers, however the lower-end was used as a conservative capacity assumption.

To maximize the number of trips each bus can make, the inbound lanes on the Lake Pontchartrain Causeway will be utilized. One will be converted to outbound busses and emergency vehicles only, while one remain open to inbound traffic. This should allow busses to bypass the severe congestion that will occur at every bottleneck leaving the city.

Figure 16: Bus lane operations on the Lake Pontchartrain Causeway



Each bus will pick up passengers at designated pick up locations and shuttle them across the causeway to transshipment points in safe areas, approximately 60 miles away. The process for locating these shelters is discussed later in the paper.

If 100 busses per hour both inbound and outbound use the dedicated busway, average speeds for the entire journey could be 30 miles per hour. This includes the congested segment within the city of New Orleans, the relatively quick segment across the causeway, and another congested segment to the designated transshipment points. This will allow busses to make the 120 mile round trip in 5 hours, with one hour for loading and unloading.

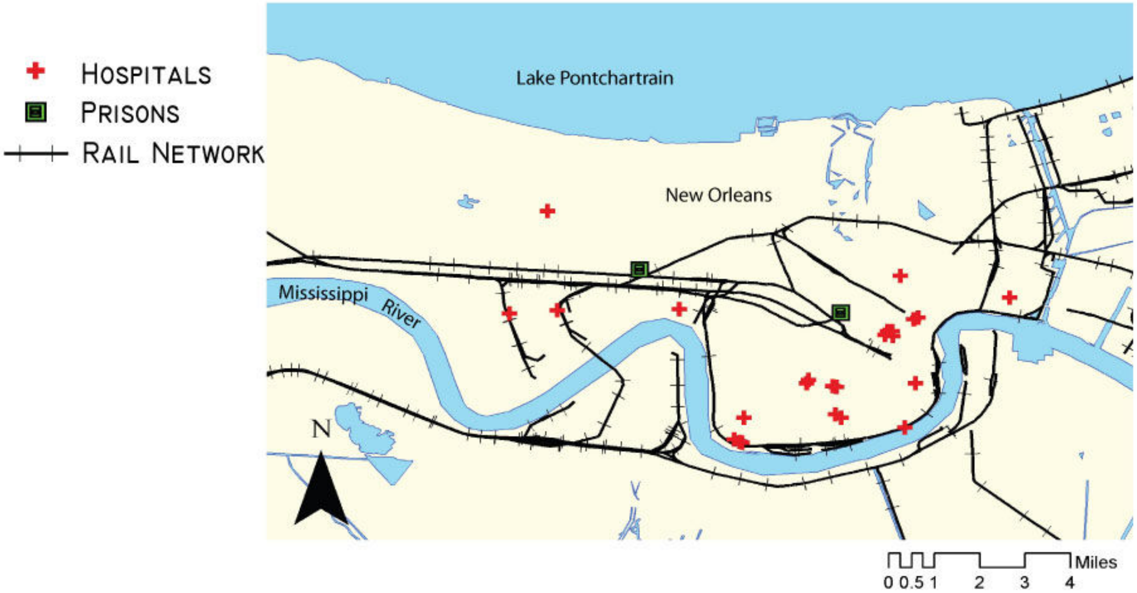
3,500 busloads of people will need to be evacuated. However, the evacuation is possible given New Orleans current fleet of 688 busses. If each bus makes the round trip in 5 hours, the total evacuation time will be 26 hours, with most busses taking 5 trips. This is a very feasible solution to evacuating huge numbers of people, but it relies advanced planning and coordination to open up the dedicated bus lanes across the causeway, assemble car-less households at convenient pickup points around the city, and obtaining enough divers to operate almost 18,000 vehicle-hours of bus operations.

Rail Transit Evacuation Modeling

Evacuation by rail could be arranged for the most vulnerable populations such as prisoners and hospital patients. These populations need specialized attention or care by professionals, as well as specialized vehicles. Much advanced planning would be necessary for a rail-based evacuation to occur. First, old rolling stock from Amtrak and other rail companies would need to be obtained and retrofitted into prison and hospital transport cars. They would then need to be stored somewhere that they could be brought to New Orleans, or other Gulf coast cities rapidly when evacuation was decided.

New Orleans is currently served by three Amtrak routes and many spur lines cross the city. There are six rail routes out of New Orleans, two to the east and four to the west. Amtrak. A typical Amtrak car has 82 seats, with spacious amounts of leg room. These cars could be reconfigured to hold 150 passengers per car, which is the capacity of one commuter rail car in New York (Rail Capacity, 1996).

Figure 17: New Orleans Rail Map with Institutions Overlaid



Prison Evacuation

New Orleans has one of the highest prisoner-to-population ratio of any city in the United States. The Mardi Gras Index cited that 6,100 prisoners were eventually evacuated during Hurricane Katrina (Hurricane Katrina, 2006). However, stories about prisoners being kept in makeshift shelters exposed to the elements or locked into flooding cells point out the lack of preparedness for a full-scale prison evacuation. As shown on the map above, both prisons in New Orleans are very close to rail spurs. Using 6 trains made up of 10 specially configured prison cars each, New Orleans prison population could be fully evacuated. This assumes 100 prisoners per car, which is a manageable number well below the capacity of most commuter rail cars. These prison trains can be sent to other prisons across the country that have the capacity to house the prisoners. Each car can carry a different class of prisoners and can be dropped off at different facilities along the route. These trains would not make multiple trips into and out of New Orleans.

To facilitate moving the prisoners to the train, 10 prison busses holding 50 passengers each can make trips between the prison and the train. With an assumption of a 1-hour round trip, including loading and unloading time, these 10 busses can fill a train in 1.5 hours. This could allow for a prison train to depart every two hours, thus the total prison evacuation will take 12 hours.

Hospital Evacuation

An article by Quigley suggested that the total number of hospital patients, workers, and family members that needed evacuation from New Orleans hospitals was 36,000. This can also be accomplished using rail. Specialized rail cars for hospitals were widely used during WWI and WWII. Using old rolling stock, a set of hospital evacuation train cars could be stockpiled. These would have beds, room for medical equipment and space for patients who are able to sit up as well. These trains car have ten cars each with a capacity of 50 passengers. Under these assumptions, it would require 72 trains to fully evacuate New Orleans hospital population.

Using busses and ambulances (with 25 passengers per bus), and assuming a 1-hour round trip from hospital to rail transshipment point, 35 busses would be required to fully evacuate New Orleans hospitals. This would allow one train to be fully loaded every 35 minutes. Under these assumptions, the total evacuation would require 42 hours.

Houston, Jackson, Montgomery and Tallahassee are possible locations for hospital patients to be evacuated to. Each city is no more than 400 miles away via rail. They could be sent to various hospitals based on their conditions and the capacity of each cities hospitals to accommodate additional patients. If trains move an average of 40 mph, then each train could make 3 round trips in a 40-hour period. This reduces the total number of emergency trains and specialized rail cars needed.

Evacuation of the Physically Disabled

In a similar design to the rail-based evacuation of the hospitals, the physically disabled can be evacuated by rail. These can include nursing home residents and physically handicapped residents. Quigley estimated that there are 38,000 physically-disabled residents in New Orleans requiring evacuation. Because they are more disperse around the city, a bus with a capacity of 25 passengers could make round trips to the rail transshipment points every 2 hours. This increases the number of busses needed to 80, and allows for a train to depart every half hour; this evacuation would take 38 hours. In the same fashion as the hospital trains, it was estimated that each train could make 3 round trips in 40 hours, greatly reducing the infrastructure required for a full-scale evacuation.

The entire mass transit-based evacuation for these two institutional populations will require the following infrastructure to be available prior to an evacuation:

10 Specialized prison busses
25 busses for evacuating hospital patients
80 busses for evacuating the physically disabled
Numerous ambulances
60 prison grade rail cars
240 hospital grade rail cars
270 rail cars for the physically disabled
57 locomotives and staff for operating trains and track for 50 hours continuously

C. Where are the Evacuees going?

Locating the 'Safe-Haven' Trans-shipment points

Assumptions:

This model considers not only the collection locations and mode of escape, but also the equally important destination points for the evacuees. Because of the unique geography of low-lying, levied New Orleans and the fact that only 5 main evacuation routes exist, a series of transshipment points were identified outside of the city. These sites were located in counties that were undamaged in the recent disaster, sufficiently above sea level, and beyond the bottlenecks out of the city to ensure that they would provide initial safety to the evacuees as well as access to medical supplies and food diverted from the rest of the state and country. Additionally, their proximity to New Orleans will allow busses used in evacuation to make multiple trips, greatly reducing the number of busses required for a full evacuation. These trans-shipment locations will offer only temporary shelter and should be thought of as 'jumping off points' for more permanent settlements outside of the region.
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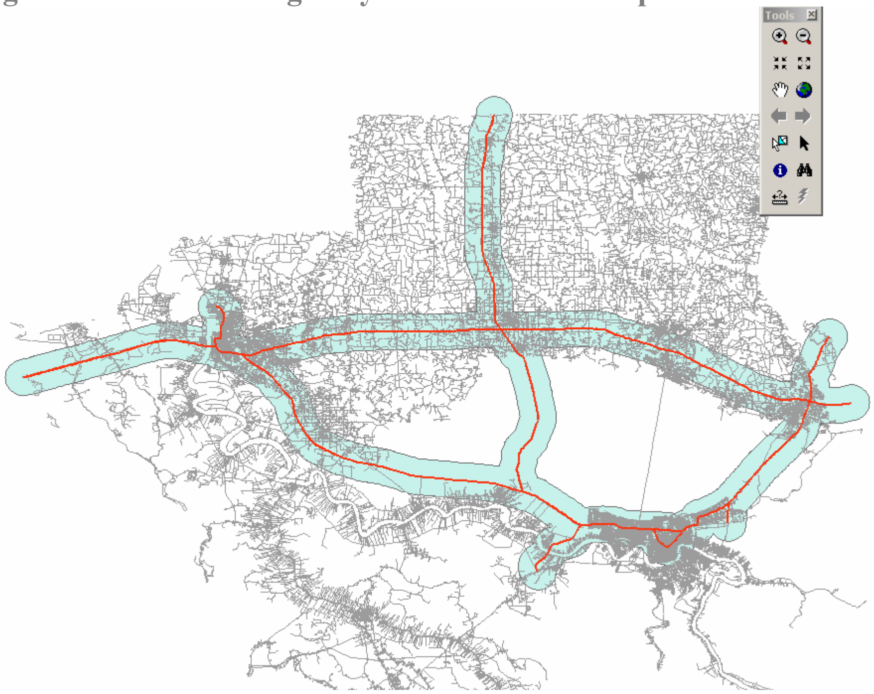
As an additional constraint, a three-mile buffer of freeways was used to ensure that the Safe-Havens be close enough to a major roadway to allow for ease and speed of evacuation trips. Because they will be used for trans-shipment of evacuees, it would be necessary for many vehicles to both arrive and depart these locations. One type of common existing location, which has the space for evacuation, is public school gymnasiums, particularly at large high schools. Selected gyms could be retrofitted to be structurally sound against a hurricane and could be stocked with emergency food and medical supplies. They have a lot of open space which can be configured as needed during an evacuation situation. Most importantly, they are plentiful in the suburbs of Baton Rouge.

Model Process:

To start with, the geography of safety was considered. School locations were only considered if they were located in counties that experienced no damage in the last hurricane. Next, as stated in the assumptions, these trans-shipment school locations should be located in close proximity to the freeway network to allow supplies and evacuees to arrive quickly and easily.

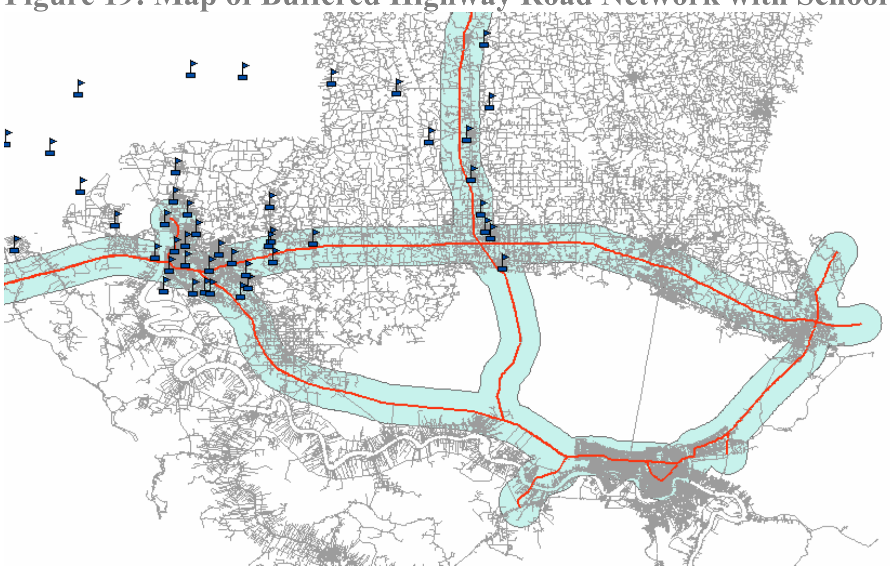
First, the road network of southern Louisiana was categorized by class and a 3-mile buffer was created around the Type-1/Major roads (See map below).

Figure 18: Buffered Highway Road Network Map



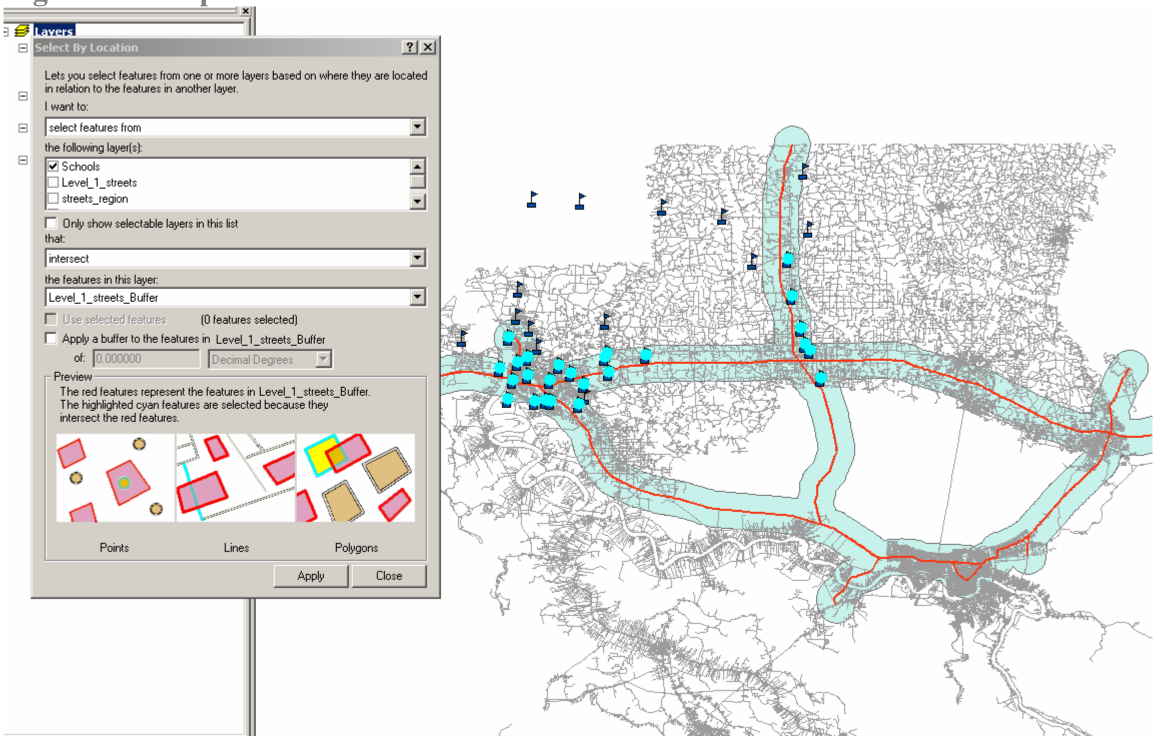
After the basic geography was determined, the schools layer was added.

Figure 19: Map of Buffered Highway Road Network with School Location



And schools that were located within a 3-mile buffer of the regional freeway network were selected (see below).

Figure 20: Map of Buffered-School Selection Process



Lastly, a layer of the selected schools was created to indicate those that would be included in the final model. The red schools below were included, the blue were excluded.

Figure 21: Map of 'Safe Have' School Selection

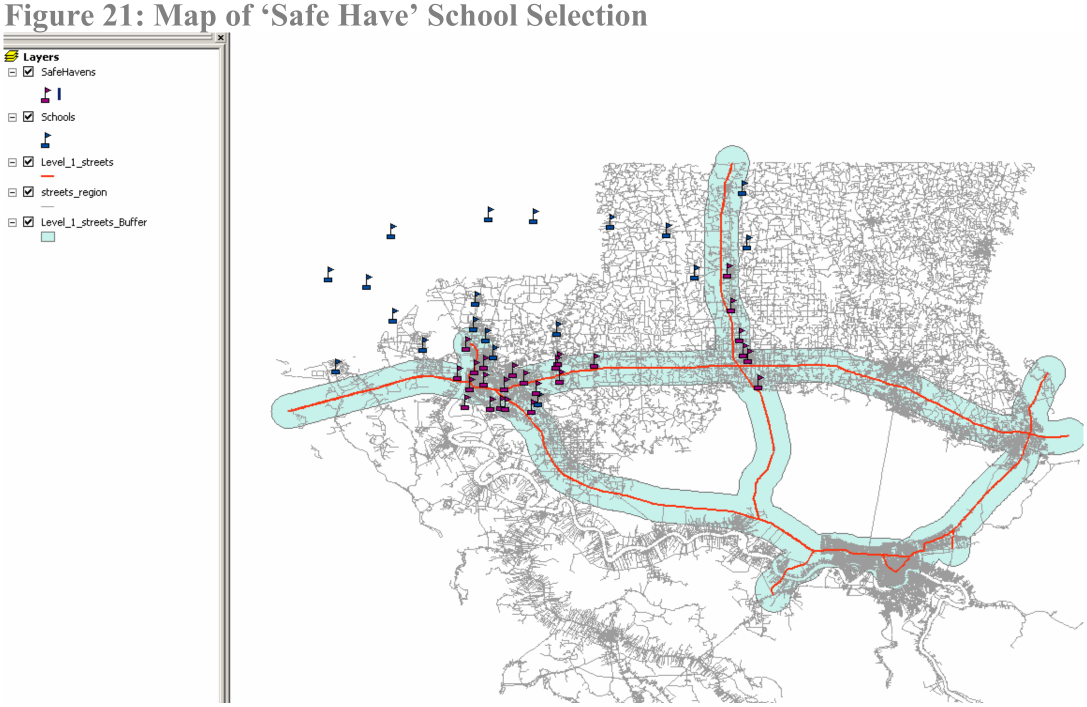
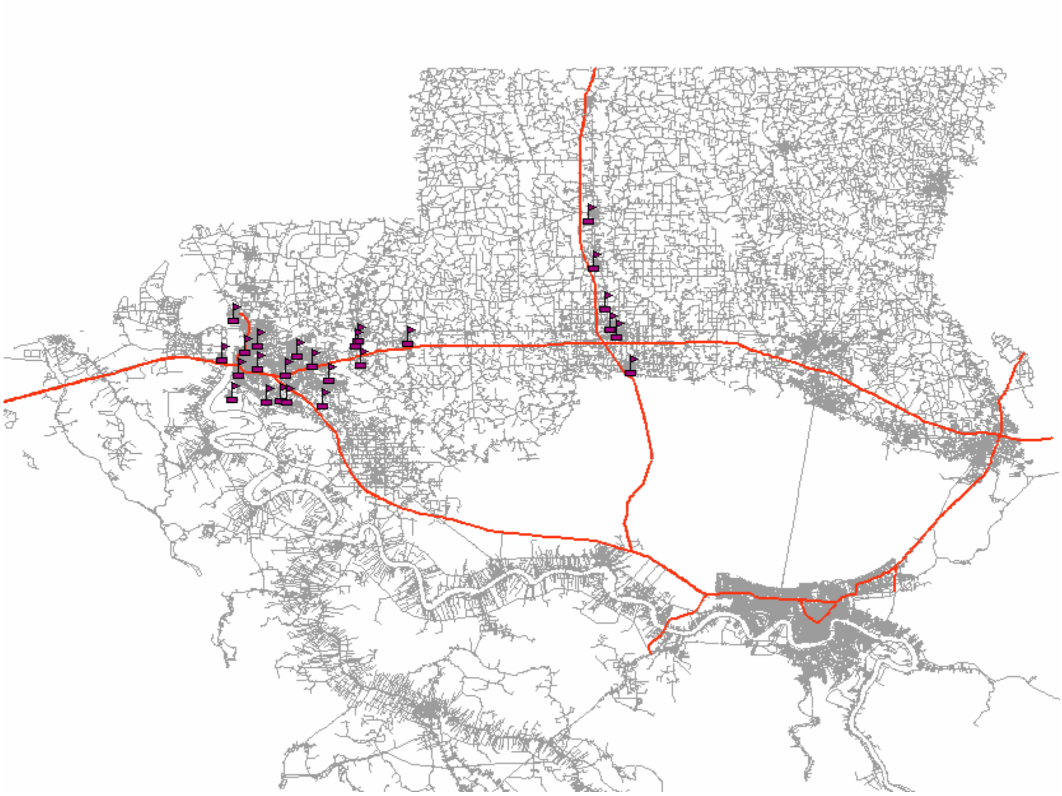


Figure 22: Final Map of 'Safe-Haven' Schools



Determining 'Safe Haven' Capacity

Once the school locations were defined it was necessary to determine the evacuee capacity of each school's facilities.

Assumptions:

As this paper is focusing on the methodology of the model, only one schools gymnasium capacity was estimated. If this model were actually used to develop a full evacuation plan, more exact data on school facilities, structural condition and locations for emergency supplies would be needed. This model assumes perfect data for the example presented below and indicates the process that could be used on a larger scale to build a complete evacuation model.

Model Process:

First an aerial photo of a neighborhood outside of New Orleans was loaded. This contained the location of one of the potential 'Safe-Haven' schools. The street grid was overlaid but at this point the image was not geo-referenced.

Figure 23: Aerial Photo and Street-Grid Overlay

Using the Geo-referencing function, the image was rotated, shrunk and lined-up to the street grid. The red 'x's on the map below indicate points on the map that were 'referenced' to the street grid.

Figure 24: Aerial Photo Geo-coding Process

A few more reference points were added to ensure that the least distortion in the geo-referencing was near the 'safe haven' school, thereby ensuring better accuracy for calculation.

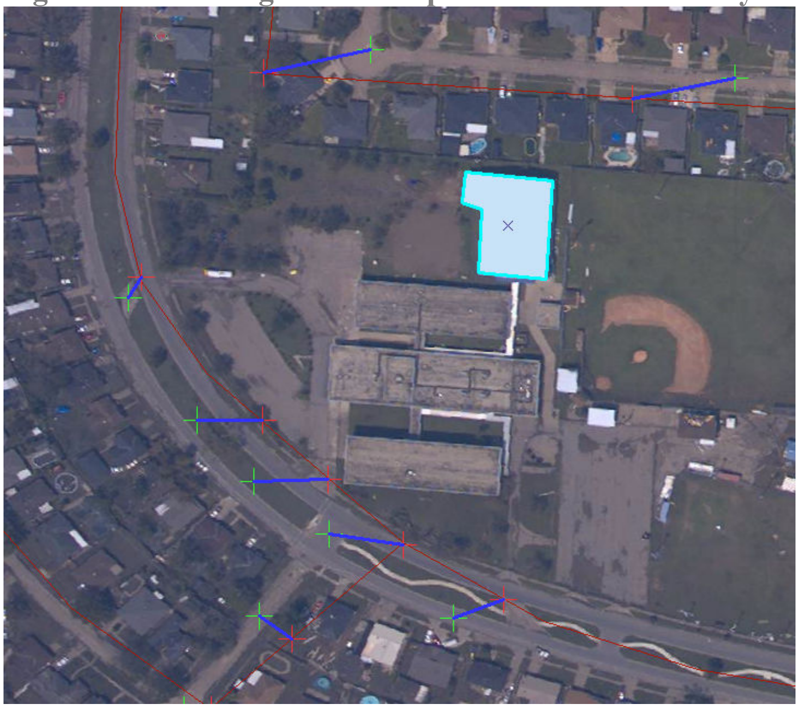
Figure 25: Fine-Grained Aerial Photo Geo-coding Process

Next the gymnasium was located (large white shed-roof).

Figure 26: Map of the Gym

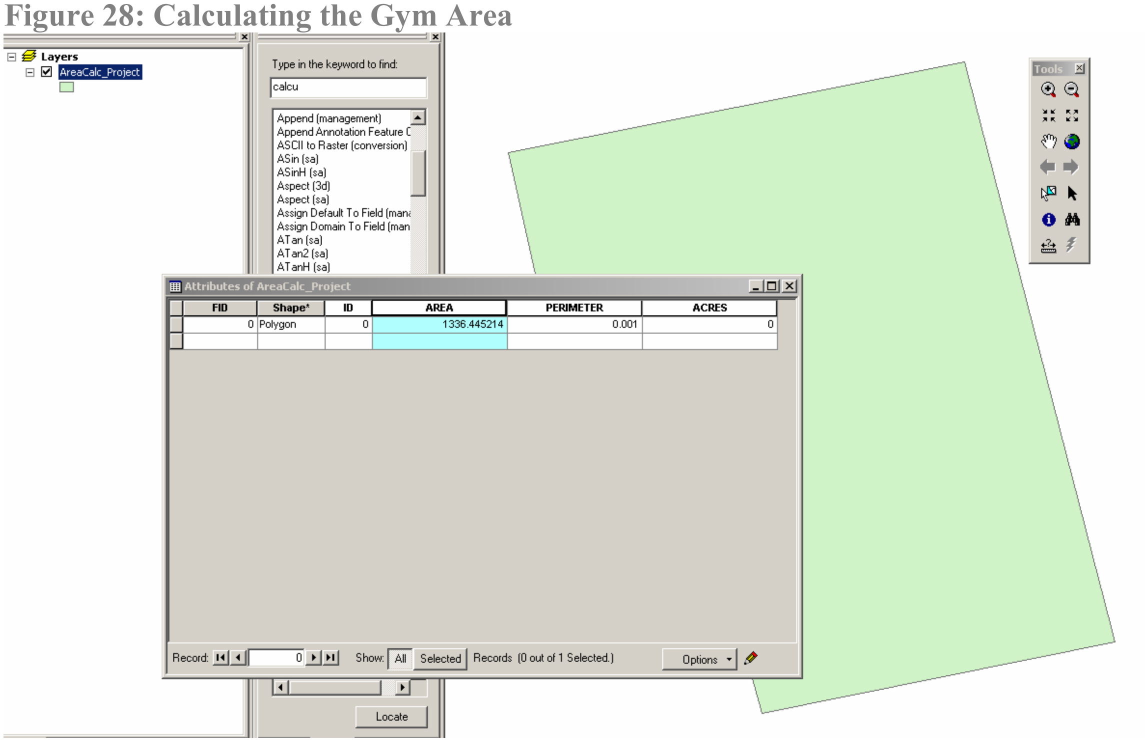
To calculate the area of the gym (to eventually determine its capacity) a new shapefile was created in ArcCatalogue. After loading the new layer 'AreaCalc', the editor was used to create a new polygon over the gym roof (see selected polygon below).

Figure 27: Creating a New Shapefile of the Selected Gym



Once the new shapefile was created, it was re-projected into UTM (meter) units. The area of the polygon was calculated as 1336.4 sq meters, or 14284.9 sq feet.

Figure 28: Calculating the Gym Area



It was estimated that an emergency shelter can accommodate one person per 10 square feet. Using this equation, it was calculated that a school with a gym of 14,385 sq ft could accommodate 1,439 people.

Standard Emergency Shelter Capacity: 10sq ft = 1 person
Gym = 14384.9 sq ft
GYM capacity = 1,439 people

IV. Our Process and its Purpose and Limitations

Is this model useful? This paper focuses less on the results of the evacuation model and more on the process and methodology. It represents an example of the procedure that could be used by City of New Orleans or state of Louisiana to create a more comprehensive, staged evacuation plan. It can also be used by other cities that have limited evacuation routes. Thus, while the actual results of the numbers should not be used directly, the methodology developed in this model could be applied to other evacuation modeling situations.

Many assumptions were included in the model and are documented throughout this paper. However, many of them are not trivial. First, this model assumes that there would be perfect coordination and communication between dozens of governmental and non-governmental agencies on all levels. This includes Amtrak, dozens of city and parish governments, various transportation authorities, school districts, transit agencies, prisons and hospitals around the country and the highway patrol to name a few. It is very unlikely that perfect cross-agency coordination could exist. However, to allow for effective evacuation to occur, the coordination between agencies needs to occur well before disaster strikes.

VI. References

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