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Research article

Quantitating Three Dimensional Impervious Surface Fractions Employing Geo-Schematic Layout algorithms, Isarithmic Maps and Non-Contiguous Cartograms for Identifying Hydrodynamic Catchment Flood Vulnerable Basins of High-Priority Hurricane Evacuation Routes and Levee Construction Sites in Hillsborough County, Florida

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Abstract: This research demonstrated the use of Remote Sensing technique and GIS for flood evacuation mapping in Hillsborough County, Florida. The data from a Digital Elevation Model (DEM) was obtained to extract isopleths (i.e, a cross-section of the three-dimensional graph of the function $f(x, y)$ parallel to the x, y plane) and other topological statistics. Landsat^{TM} imagery was employed for classification purposes. The DEMs generated provided flood evacuation routes during several levels of flooding in the county. Remote Sensing incorporated with GIS techniques can be employed to determine probable flood affected areas in Hillsborough County.

Keywords: Remote Sensing, GIS, Hillsborough, Landsat, Digital Elevation Models.

Introduction

Flood-vulnerability, disaster management, emergency evacuation strategy and arrangement in the event of a hurricane, or severe tropical weather represent significant public health and legislative issues in coastal locations of humid subtropical climate, such as Florida. A cursory evaluation of current procedures and resources for hurricanes and flooding in Hillsborough County reveals an immediate necessity for improvement in evacuation prioritization and flood vulnerability maps for the county. Data were drawn from the 2010 Census estimate [www.hillsborough.communityatlas.usf.edu/demographics]which revealed that there are approximately 1,862 persons per square mile (mi^2) inhabiting the city of Tampa and 1,082 persons/mi^2 in Hillsborough County.As they currently stand however, these population density estimates, when compared with Florida's overall estimation of 321 persons/mi^2, demonstrate how imperative it is to have proper protocols regarding natural disasters in place. Expanding upon what is already understood concerning important crisis regions will allow first responders, legislators and other stakeholders to make informed critical and time-sensitive decisions with potentially limited resources. Financialinvestment and time spent toward disaster mitigation and preparedness may significantly reduce injury, personal hardship, and mortality, as well as property damage and economic strain in a potential disaster scenario.

Hillsborough County currently employs the Hurricane Evacuation Assessment Tool (HEAT) to view evacuation prioritization. This tool, updated last in 2002 and developed with the Federal Emergency Management Agency (FEMA), utilizes geographic information systems (GIS) technology only for a fraction of its predictions and spatial representation potential, applying only elevation and basic street-level maps to the decision-making process. In addition, HEAT does not take into consideration residential or commercial zoning when evaluating evacuation protocols. Misrepresentation of priority flood areas may lend a false sense of security in zones that are actually at a heightened risk, as well as less than thejudicious allocation of public funds to low-risk zones.

Currently there are no contributions in literature for Hillsborough County or any of the surrounding counties in the Tampa Bay area that illustrates flooding and hurricane scenarios employing updated GIS methods and three-dimensional (3-D) modelling. Remotely sensed, 3-D, geomorphological models applying free, publiclyavailable, satellite imagery from the United States Geological Survey (USGS) can be used to forecast flood-vulnerable locations that go beyond the elevation models that are presently in use (www.usgs.gov). Municipality road class capacity data and census population density zones may be employable to construct models, which may indicate priority areas for emergency management services and evacuation in Hillsborough County. Combining these data in GIS may provide greater clarity of Hillsborough county vulnerability to flooding and indicate the best intervention,or set of interventions, to lessen the scope of, or avert altogether, a probable disaster situation. These 3-Dmodels may exhibit the use of remote-sensing techniques to decide potential locations for levee construction and flood management.

Updated GIS models can be readily incorporated into the current systems that assist policy makers and emergency management personnel in the appropriate use of public funds, as well as fulfill FEMA mandates for disaster planning[2]. GIS 3-D mapping tools may plan evacuation routes, ensuring that these routes are cartographically precise in the event of a disaster, for averting property damage and loss of life in Hillsborough County. Further, these models may be expanded for use in countywide studies or, with high-resolution data, which may besubsequently narrowed down to target specific neighborhoods and municipalities in the county.

Methods

Resources

Landsat 8 ^{TM}30-meter satellite data was used for generating base texture maps in ArcMap. National Elevation Data (NED) >3 meters were employed to create the elevation models used for this study.Both datasets were obtained from the USGS.The Landsat8 ^{TM}has multispectral products with 16-bit pixel depth.

Landsat 8 carries two push-broom instruments: The Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS).The spectral bands of the OLI sensor provides enhancement from prior Landsat instruments, with the addition of two additional spectral bands: a deep blue visible channel (band 1) specifically designed for water resources and coastal zone investigation, and a new shortwave infrared (SWIR) channel (band 9) for the detection of cirrus clouds (https://landsat.gsfc.nasa.gov/). The TIRS instrument collects two spectral bands for the wavelength covered by a single band on the previous TM and ETM+ sensors

Landsat 8 OLI and TIRS images consist of nine spectral bands with a spatial resolution of 30 meters for Bands 1 to 7 and 9. The ultra-blue Band 1 is useful for coastal and aerosol studies. Band 9 is useful for cirrus cloud detection. The resolution for Band 8 (panchromatic) is 15 meters. Thermal bands 10 and 11 are useful in providing more accurate surface temperatures and are collected at 100 meters https://landsat.gsfc.nasa.gov/). The approximate scene size tile for Hillsborough County was 170 km north-south by 183 km east-west (106 mi by 114 mi). Band designations for the Landsat satellite are provided in Table 1.

Table 1 OLI and TIRS data from Landsat 8 for imaging Hillsborough County

Bands	**Wavelength (micrometers)**	**Resolution (meters)**
Band 1 - Ultra Blue (coastal/aerosol)	0.43 - 0.45	30
Band 2 - Blue	0.45 - 0.51	30
Band 3 - Green	0.53 - 0.59	30
Band 4 - Red	0.64 - 0.67	30
Band 5 - NIR	0.85 - 0.88	30
Band 6 - SWIR	1.57 - 1.65	30
Band 7 SWIR 2	2.11 - 2.29	30
Band 8 - Panchromatic	0.50 - 0.68	15
Band 9 - Cirrus	1.36 - 1.38	30
Band 10 TIRS 1	10.60 - 11.19	100 * (30)
Band 11 - TIRS 2	11.50 - 12.51	100 * (30)

* TIRS bands are acquired at 100 meter resolution, but were resampledto 30 meter

We generated multiple vegetation Indices for the Hillsborough County study site in the Image Analysis Window in ArcGIS. Vegetation Indices (VIs) are combinations of surface reflectance at two or more wavelengths designed to highlight a particular property of vegetation. A VI is a simple measure of some vegetation property calculated from reflected solar radiation measurements made across the optical spectrum (www.esri.com). Here these indices were derived using the reflectance properties of vegetation land cover in the Hillsborough County Landsat scene. Classifying urban landscape vegetation employing remotely sensed data requires knowledge of the structure and function of vegetation and its reflectance properties [1]. Vegetation interacts with solar radiation differently from other natural materials, such as soils and water bodies [2]. The absorption and reflection of solar radiation is the result of many interactions with different plant materials, which varies considerably by wavelength (www.esri.com).

The solar-reflected optical spectrum routinely spans a wavelength range of 400 nm to 3000 nm. Of this range, the 400 nm to 2500 nm region was measured employing optical sensors from the multispectral Landsat ™ data for the Hillsborough County study site. Water, pigments, nutrients, and carbon are each expressed in the reflected optical spectrum from 400 nm to 2500 nm, with often overlapping, but spectrally distinct, reflectance behaviors [1]. Our assumption was that interpolated VI signatures may allow GIS scientists to combine reflectance measurements at different wavelengths to enhance specific vegetation landscape characteristics by defining VIs for constructing flood vulnerability models for Hillsborough County

Jacob et al. [1] employed VI signatures [Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index (SAVI) to construct an urban ecohydrological model to determine landscape areas where bare soil interacted with moderately vegetated terrain in Cook County in northern Illinois. The NDVI is a standardized index allowing you to generate an image displaying greenness (relative biomass) [https://earthobservatory.nasa.gov]. This index takes advantage of the contrast of the characteristics of two bands from a multispectral raster dataset—the chlorophyll pigment absorptions in the red band and the high reflectivity of plant materials in the NIR band [2]. The value of urban NDVI value may depend on the particular anisotropy of the target and on the angular geometry of illumination and observation at the time of the measurements, and hence on the position of the target of interest within the swath of the instrument or the time of passage of the satellite over an urban site[1]. The soil-adjusted vegetation index (SAVI) and its later revision, modified SAVI (MSAVI), seek to address some of the limitation of NDVI when applied to areas with a high degree of exposed soil surface [2]. SAVI can account for the differential red and NIR extinction through the vegetation canopy(www.esri.com).

The image analysis tool enabledcreating a composite band with a TIF extension from the acquired Landsat multispectral bands. The NIRand Red spectral bands of the composite raster image were subsequently utilized in constructing the NDVI model for Hillsborough County.NDVI is the ratio of the reflected radiance (the difference between NIR and Red divided by its sum) required to normalize illumination and topographic variation within the model [2, 3]. The value ranged from -1.0 to 1.0 from Landsat reflectance. The following equations were derived in calculating NDVI for the Hillsborough study site:

$$\frac{P_{NIR} - P_R}{P_{NIR} + P_R} \quad (1.1)$$

$$\mu_{cal}^2\,(NDVI) = \left(\frac{\partial NDVI}{\partial \rho_{NIR}}\right)^2 \mu_{cal}^2\,(\partial \rho_{NIR}) + \left(\frac{\partial NDVI}{\partial \rho_R}\right) \quad (1.2)$$

$$\mu_{cal}^2\,(\partial P_R) + 2\,\frac{\partial NDVI}{\partial P_{NIR}}\frac{\partial NDVI}{\partial P_R}.\mu_{cal}^2\,(P_{NIR}, P_R) \quad (1.3)$$

$$\frac{\partial NDVI}{\partial P_{NIR}} = \frac{2\rho_R}{(\rho_{NIR}+P_R)^2} \quad (1.4)$$

$$\frac{\partial NDVI}{\partial P_R} = \frac{-2\rho_{NIR}}{(\rho_{NIR}+P_R)^2} \quad (1.5)$$

$$\frac{\partial NDVI}{\partial P_{NIR}}\frac{\partial NDVI}{\partial P_R} = \frac{-4\rho_{NIR}\rho_R}{(\rho_{NIR}+\rho_R)^2} (1.6)$$

We corrected for the changes in soil brightness by calculating SAVI in ArcMap, applying an adjustment factor (L) of 0.5 commonly used in research. The adjustment factor L ranges from 0.0 to 1(where0.0=high vegetation cover, 1.0=low vegetation cover) is necessary to remove soil background noise [1].The equation of SAVI was expressed as:

$$SAVI = (1 + L)\,\frac{\rho_{NIR}-\rho_R}{\rho_{NIR}+\rho_R+L} \,(2.1)$$

$$\mu_{cal}^2\,(SAVI) = \left(\frac{\partial SAVI}{\partial \rho_{NIR}}\right)^2 \mu_{cal}^2\,(\rho_R) \quad + \left(\frac{\partial SAVI}{\partial \rho_R}\right)^2 (2.2)$$

$$\mu_{cal}^2\,(\rho_R) + 2\,\frac{\partial SAVI}{\partial \rho_{NIR}}\frac{\partial SAVI}{\partial \rho_R}\,.\mu_{cal}(P_{NIR}, P_R)(2.3)$$

where

$$\frac{\partial SAVI}{\partial \rho_{NIR}} = (1 + L)\,\frac{2\rho_R+L}{(\rho_{NIR}+\rho_R+L)^2} (2.4)$$

$$\frac{\partial SAVI}{\partial \rho_R} = (1 + L)\,\frac{2\rho_R+L}{(\rho_{NIR}+\rho_R+L)^2} (2.5)$$

The road class shapes were obtained from the Diva-GIS online database. Census data was obtained from the United States Census Bureau. Comparison evacuation zone maps were obtained from Hillsborough county evacuation procedures publications. Hillsborough County building layouts and zoning information were both obtained from the Hillsborough CountyArcGIS database. All resources were last referenced in July 2015.

Remote sensing techniques have been employed in flood vulnerable geographic landscapes [www.esri.com]. We compartmentalized Hillsborough County into a 5km by 5 km gridin Arc Map and subsequently overlaid on the Landsat8 imagery. Numeric place-markers/sampling points on the grid cells allow for identification sampled territories andalso allow for assessment of potential flood damage[2].

Population Density Model

Landsat 8 TM data were overlaid with the census bureau tracts. These residential tracts were scored based on their household density from low to high. The lowest tracts had a household density of 0 and were considered industrial or commercial tracts and therefore omitted from the recommendations. Tracts with density >0 were highlighted to display the residential zones, from green (low population density) to red (high population density). However, we utilized Hillsborough administrative shapefiles from Diva-GIS in constructing the population density maps.

The evolution of urban morphology in the process of urban growth is one of the theoretical frontier issues, while the spatial-temporal structure of the distribution of urban populationdensity which is one of the important contents of urban growth [2]. Combining data of the previous Cook County, Illinois censuses Jacob et al. [1] constructed multiple ArcGIS models of spatial distributionof population density and its evolution for more than 10 years systematically. The authors transformed data of population census into spatial data by using the map of Cook County and extracted data of urban population density distribution of different years in ArcGIS .Then multiple models were tested, including the linear ,exponential logarithmic ,the log-normal, the power-exponential and ansecond degree exponentialone. With a viewpoint of the whole tendency, the power-exponential model, as an amended form of the negative exponential model, described spatial distribution of urban population density of Cook County.The parameter σ reflected the tendency of changes of information entropy of an urban geographic system. The parameter σfluctuated, increasing as the model forecast approached 1, indicating that the power-exponential distribution of urban population density evolved into the ideal Clark (negative exponential) with the lapse of time. The authors revealed that an ArcGIS analysis of urban growth and its spatial dynamics can reveal the spatial complexity and the utility of function unit increases, and that urban spatialstructure tends to be in a new order with the increase of urban ability as a self-organization with the development of suburbanization.

Grid cells were generated in ArcMap which were employed to quantitate the relationship between floodwater volumes and flood water level. A data grid is an architecture or set of services that gives individuals or groups of users the ability to access, modify and transfer extremely large amounts of geographically distributed data for research purposes (www.esri.com).

Grid algorithmic matrices make it possible through a host of ArcGIS applications to precisely map impervious surface (IS) [1]. IS defined as man-made sealed surfaces through which water cannot infiltrate typically dominate urban environments and may be used as a proxy for many aspects of urbanization [4]. IS are a key indicator of environmental quality as they have important implications for many bio-physical processes at the regional and local scale [5]. For urban areas, these processes are primarily linked to the hydrological cycle (run-off volumes and velocity, transport of non-point pollutants, groundwater recharge), the surface energy budget (reflective properties of surfaces, changing heat fluxes, urban heat islands) and biological functions (flora and fauna distribution, biodiversity) [2]. Therefore, we designed the IS grid cells from low to high elevation: since water gravitates towards a higher plain.

GeoSchematic layout algorithms were used in ArcMap to separate landscape elements in Hillsborough County study site that were visually close which preserved the position of the elements in the Landsat scene. The relative spatial positions of landscape features were maintained, although the reference system was dropped. Detailed information were displayed in ArcMap of the County without zooming in and out. The desired effect of a GeoSchematic layout algorithm in an urban environment is to normalize the spacing of the node features while maintaining some of the original spatial relationship between the facilities [1].Local grid improvements require moving each node to a new grid location while global improvement is based on constrained quadratic

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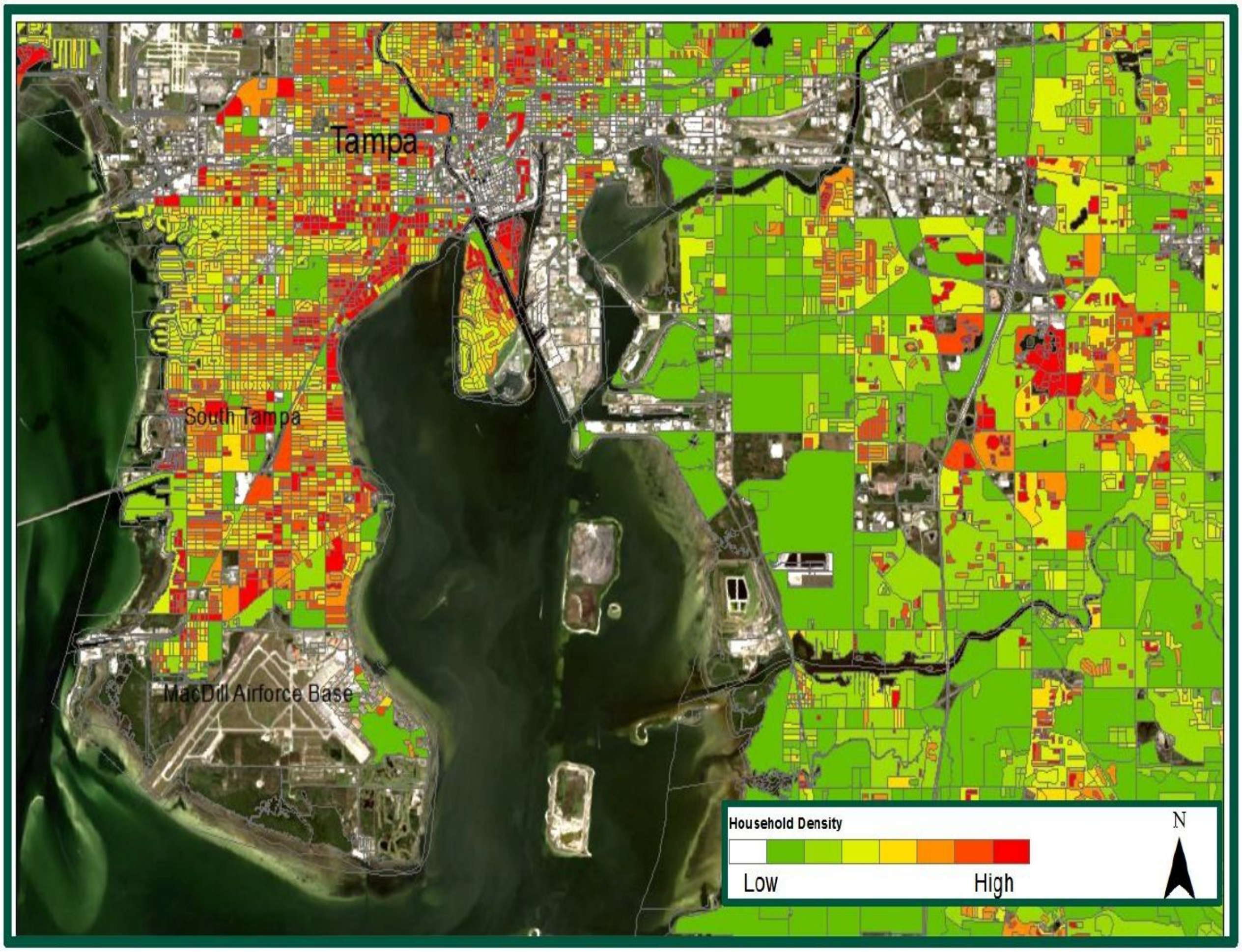
Figure 3. Household densities for Hillsborough County.



programming approach that minimizes the total edge length while keeping node in relative positions[3].Because they take the current position of the elements during their execution, GeoSchematic layout algorithms were applied to the Hillsborough Countysatellite data.The problem of computing urban orthogonal and quasi-upward drawings with vertices of prescribed size may be resolved in ArcMap [www.esri.com].

The stratified gridded data of population densityforthe Hillsborough County indicated latent fractal structures at the study site. Fractal structure of a system suggests the optimal way in which parts arranged or put together to form a whole. The ideas from fractals have a potential application to flood vulnerability research on urban sustainable development [3]. To characterize fractal locations, a measure of fractional dimension may be required [2]. However, if the fractal organization is concealed in the complex spatial distributions of geographical phenomena, the common methods of evaluating fractal parameters in GIS will be disabled. Hence, we proposed a model to describe urban density and estimate fractal dimension of urban form for Hillsborough County.

According to Jacob et al. [1] if urban density takes on quasi-fractal patterns, or the self-similar pattern is hidden in the negative exponential distribution, a generalized gamma function may be employable to model urban landscape and estimate its latent fractal dimension in ArcGIS. As a case study, we assumed that the method may be applicable for localizing high population density areas in Hillsborough County. The results revealedthat urban landscapes in the study siteevolves from simple to complex structure as movement towards the county central business district occurs.

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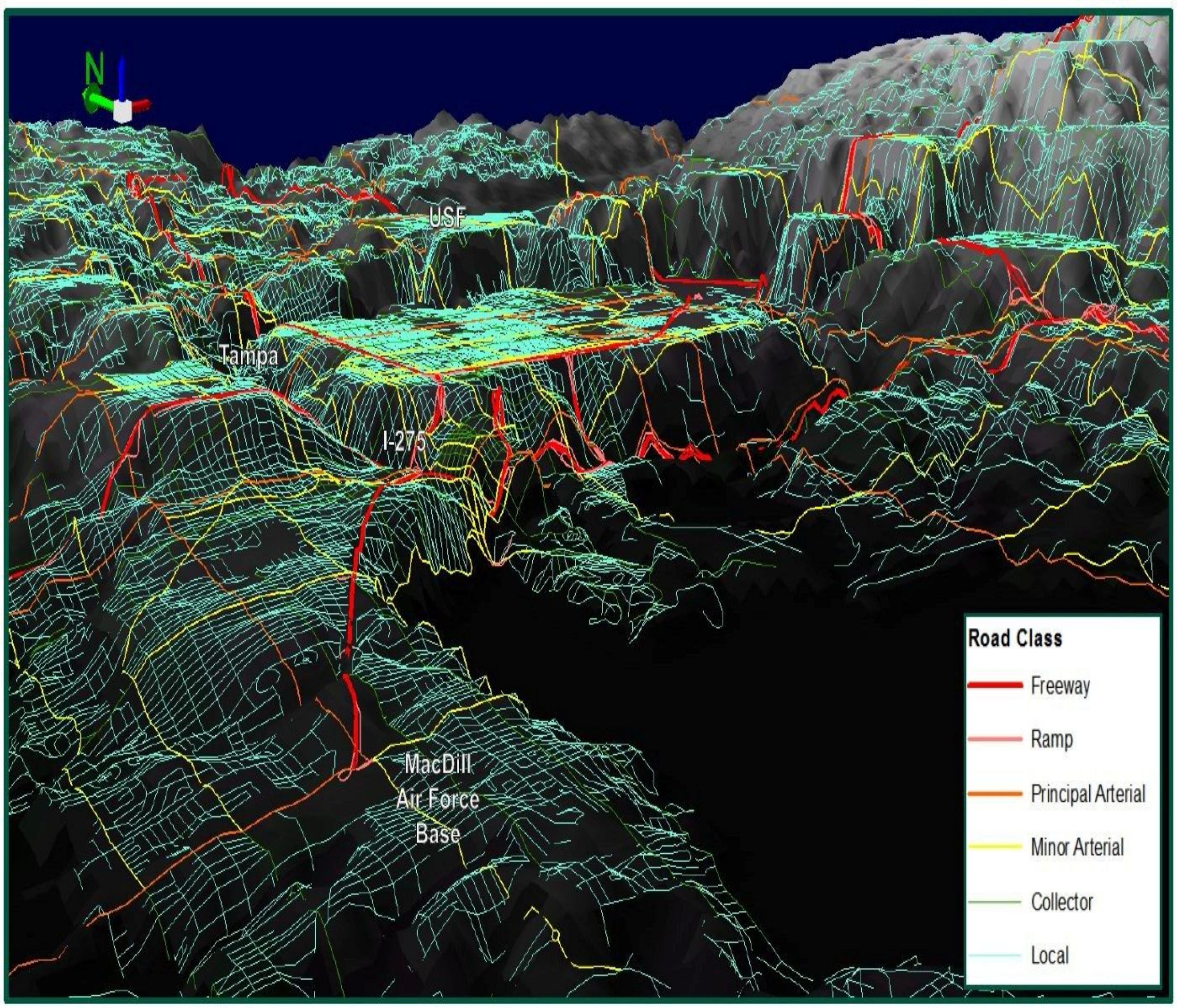
Digital 3D Elevation Model (Road Ranking)

The DEM for Hillsborough Countywas downloaded through GEOTIFF in Landsat8 TM and subsequently processed as a layer which was then imported into ArcGIS. This was projected in the default coordinate system for ArcGIS (WGS 1984 UTM Zone 48N). Additionally, in order to be precise with our outcome, we compared DEMs generated from Landsat8 point for point in Google Earth TMand found them to similar. Similarly, these products were radiometric and sensor corrected to minimize error.

NED >3 meter data were overlaid with the road plans for Hillsborough county and scored based on civil road planning capacity indicators. These "road class" indicators were used to isolate high-capacity roads available for evacuation out of high-priority evacuation zones. The indicators (in descending order) were 'freeway', 'freeway ramp', 'principal arterial', 'minor arterial', 'collector', and 'local' roads. A rasterization of the Hillsborough County DEM displays low elevation areas against road classes to illustrate potential problem areas in theevacuation.

Figure 4. Digital 3D Elevation Model with Significance Road Design



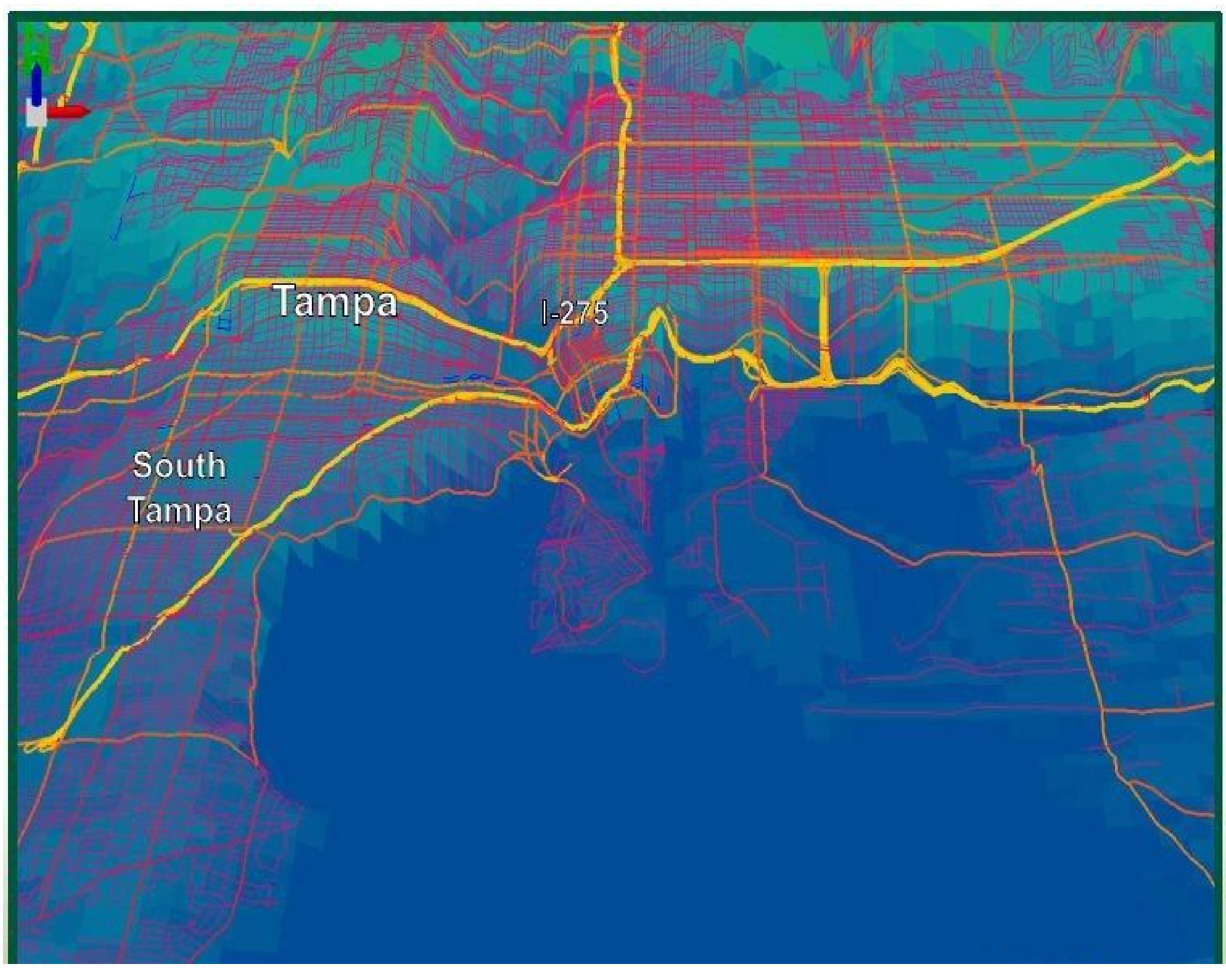
The Hillsborough countyDEM and the road ranking dataset were floated in Arc-scene as to generate a 3D elevation model. Likewise, the draped image over the terrain enabled us to visualize the geomorphologic features and other causal parameters (i.e. elevations, slope gradients, curvatures and water swell) associated with flooding susceptibility in Hillsborough County [3].

The aforementioned Hillsborough CountyDEM was exaggerated 40x employing 3D analyst tool in ArcGIS. The geographic landscapes were vertically exaggerated to show case some of the inconspicuous features within the terrain. We observed in similar studies, that elevation levels and slopes are important variables for flood vulnerability [4 and 5]. Two sets of models were created, one with the dereferenced flood plains for the entire county, and the other with roads only, both overlaid on the exaggerated DEM. Water swells were represented by extruding a calibrated 3D layer into the model. These water swell models were adjusted at different standardized heights, from 8 feet to 34 feet, according to guidelines already used in evacuation levels in Hillsborough County and extended slightly to encompass swell heights recorded from New Orleans after Hurricane Katrina (33 feet to 34 feet).

Results

A comparison of Hillsborough Countyevacuation maps with the population density model created in this study indicated the need for a reevaluation of priority evacuation zones.The current maps only indicate zones based on elevation and water swell levels only. Large swathes of the highest-priority evacuation zones are largely industrial or commercial zones, which bear a relatively small burden of evacuation priority in a real-life scenario [4]. The typical hurricane evacuations, which have ample warning, take place from residences [2].

Figure 5: Vertically Exaggerated Digital Elevation Model by a factor of 40.



The Figures 5 above and 6 below were DEMS vertically exaggerated by a factor of 40 and 80 respectively to demonstrate elevation and depression points on major evacuation routes in Hillsborough County. These models were used to identify similar depression points and high-risk areas for water run-off accumulation in the study site

Figure 6: Vertically Exaggerated Digital Elevation Model by a factor of 80.

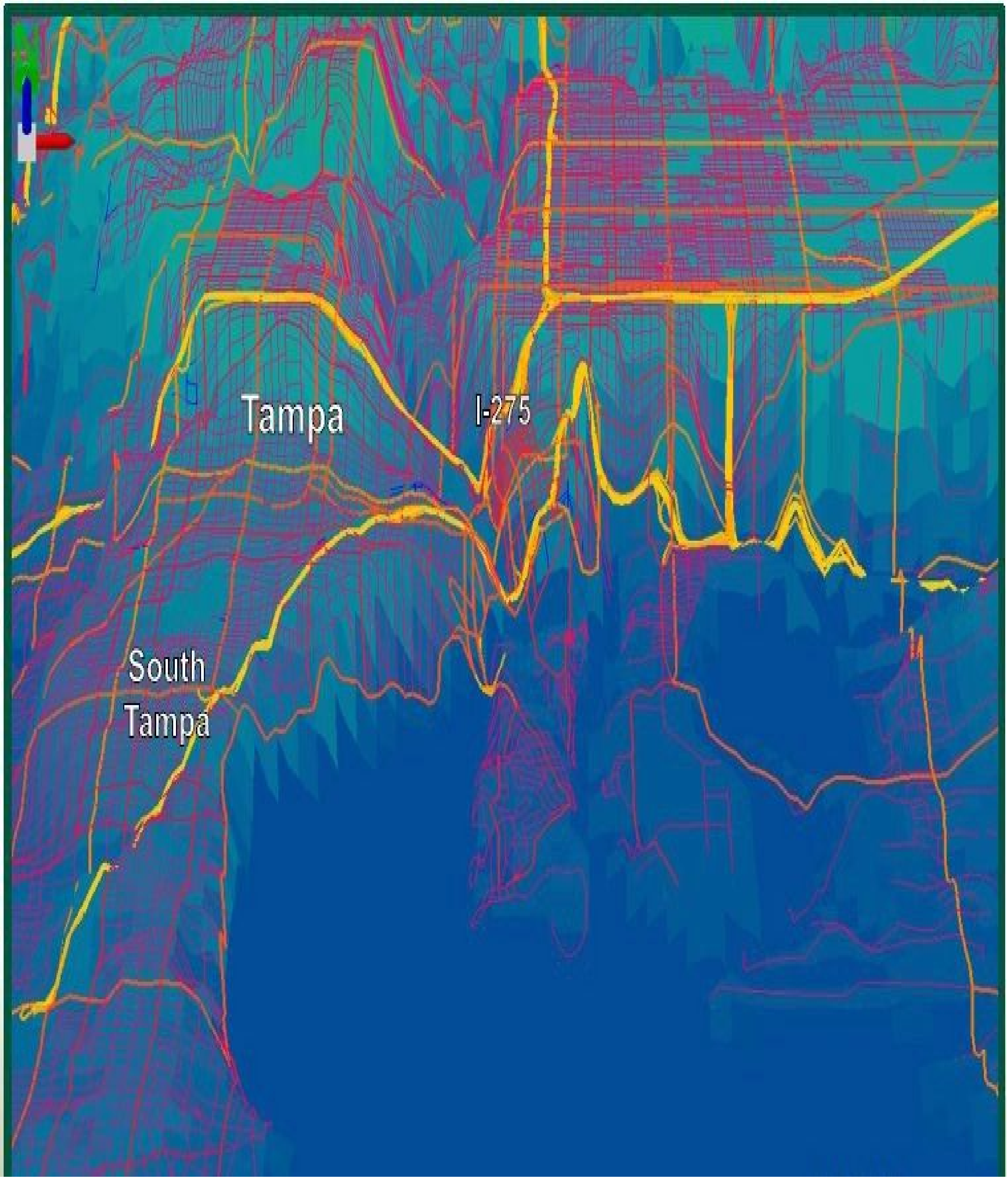


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Figure 7. Digital 3D Remotely Sensed Levee Recommendations on Interstate 275

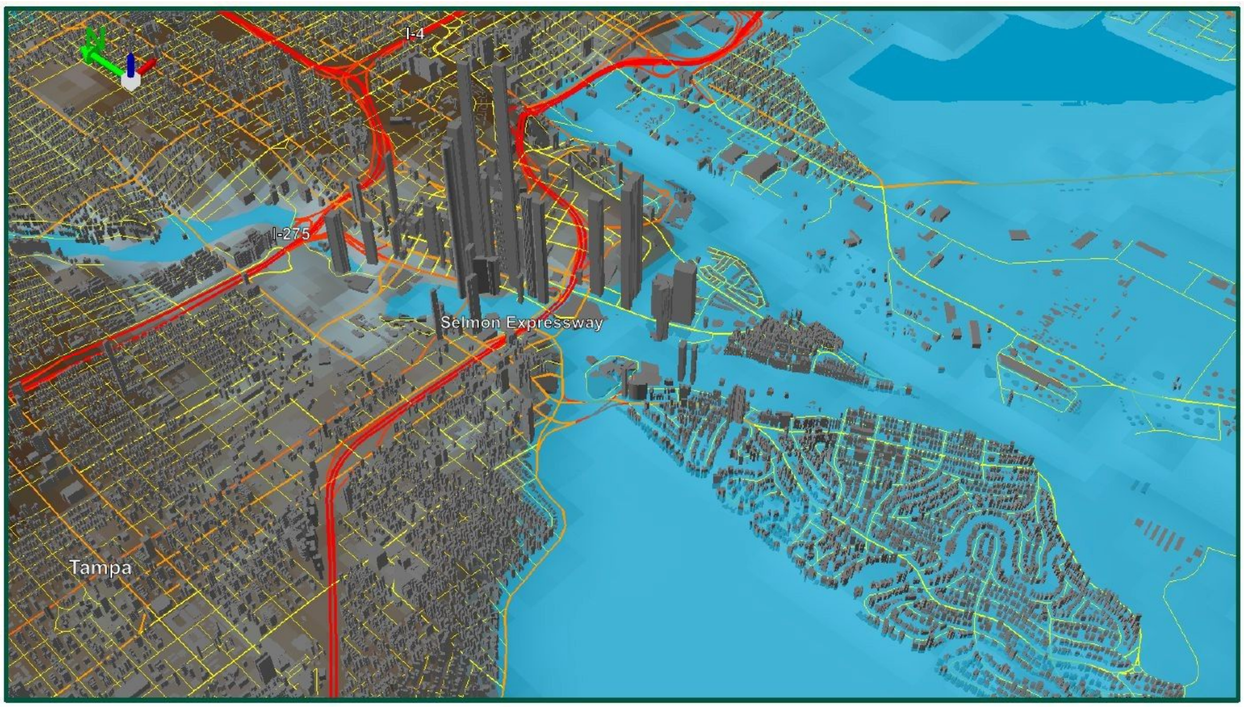
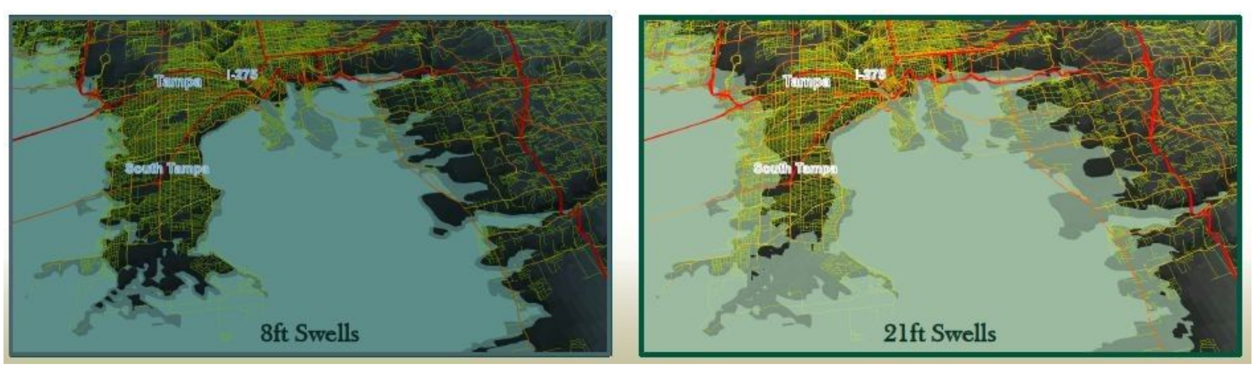


Figure 8. Digital 3D Elevation Models with major evacuation roads assuming 34 ft. (top), 8ft. (bottom left), and 21 ft. (bottom right) swells



The 3D models created provided an easy assessment of significant roads as well as locations of concern in a sizeable storm. The two major freeways out of Tampa (to be used by first responder vehicles and evacuees), are Interstate275 and the Selmon Expressway.The models predict each to have portions of theroad with either ramps or parts of the roads at risk of flooding with swells as small as 8 feet.

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Figure 9. Digital 3D Elevation Models with major evacuation roads in Hillsborough County

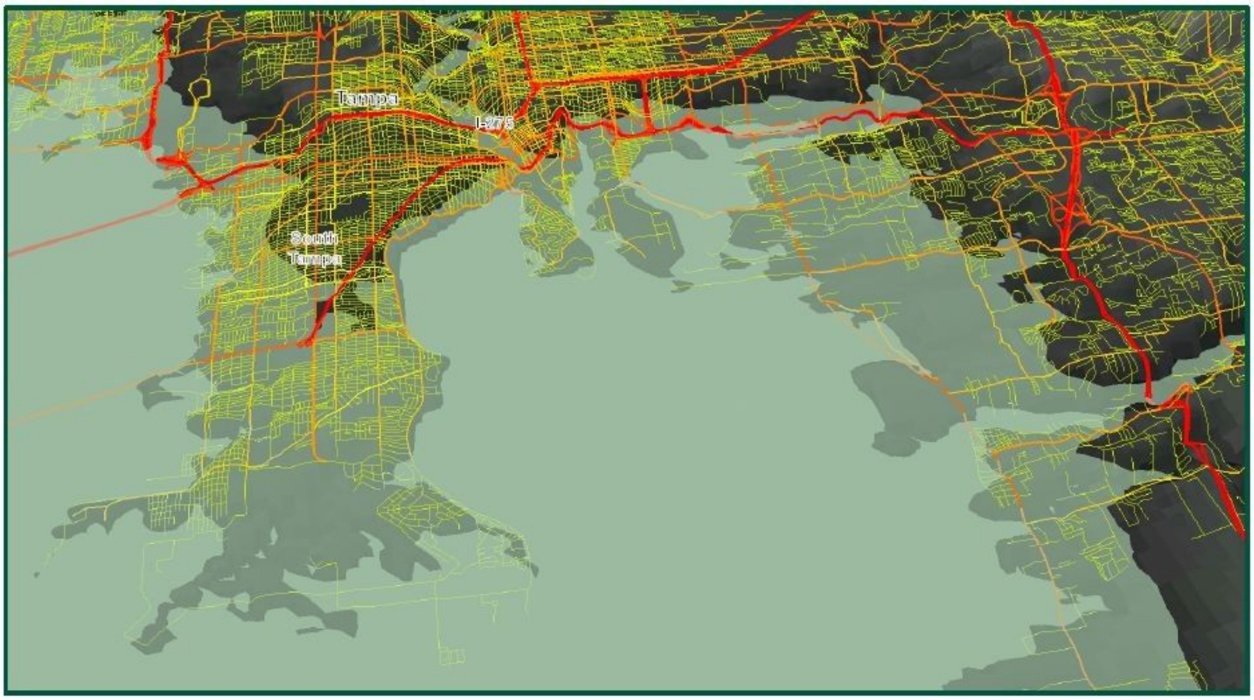
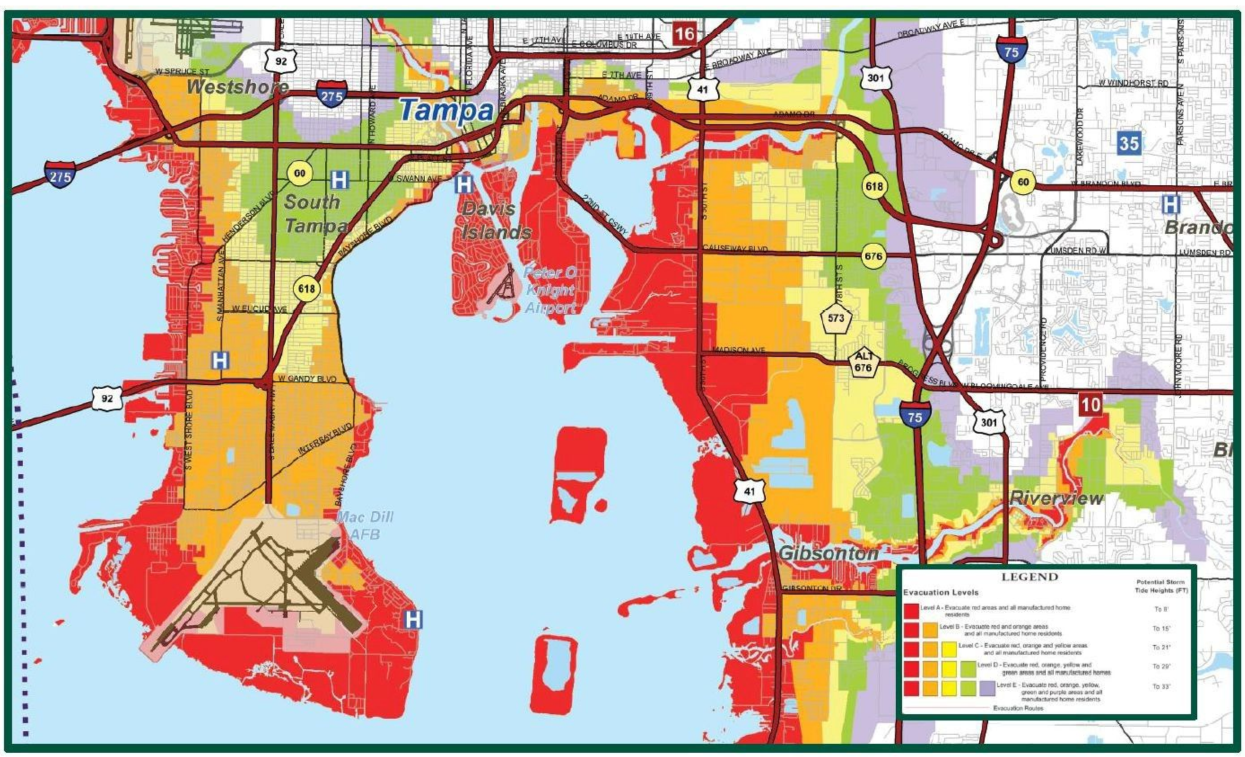


Figure 10. Prioritized areas for evacuation in the event of flooding in Hillsborough County.



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Conclusions & Recommendations

Though often considered a “flat” area, Hillsborough County could benefit immensely from improvements to current evacuation planning maps that more thoroughly address regional population density and residential areas. Future protective developments, such as levees and other flood-preparation structures,mayalso be better specified using ArcGIS models at high-risk sites, such aslow elevation points on I-275 and theSelmon Expressway. Further,ArcGIS modelling may be used to forecast water runoff and high-risk flow accumulation within the study site.

The economic impact may seem obvious in commercial districts, but residential areas in Hillsborough County could also be negatively affected by flooding due to property damage. Prospective renters, as well as those considering investing in residential properties, may well avoid looking in areas negatively impacted by flooding, and these properties may be withdrawn from active listings by the sellers during the immediate aftermath of a disaster. This could compound negative impacts on the commercial economy in these areas in the longer term.

The models created in this study represent the potential of ArcGIS to better illustrate possible weak points in infrastructure when preparing for disaster scenarios. With higher resolution data, these models can be made with optimal geographic specificity, allowing for a more rigorous evaluation of localized neighborhoods, as well as enabling procedural implementation to be communicated with precision in Hillsborough County.

Daily, or more frequent, ArcGIS maps of surface water have important applications in environmental and water resource management in Hillsborough County. In particular, surface water maps derived from remote sensing imagery in an ArcGIS can play a useful role in the derivation of spatial inundation patterns over time and in calibrating and validating hydrological and hydrodynamic models. While coarse resolution data can provide realistic means to achieve this, cloud cover often limits them during flooding events, and their spatial resolutions (e.g., 250 – 1000 m pixel) are not always suited to small river catchments. The Landsat ™ data can provide daily 3-D surface water maps, both spatially and temporally, across a range of catchments.

Due to the larger calibration uncertainty associated with TIRS band 11, it is recommended that county-level flood water mappers refrain from relying on band 11 data in quantitative analysis of the TIRS data, such as the use of split window techniques for atmospheric correction and retrieval of surface temperature values in ArcMap. We suggest that Band 10 be used in conjunction with an atmospheric model to estimate surface brightness temperature. We found that with current processing these surface brightness temperatures are accurate to within ~±1 K for many 15 – 35° C targets, e.g., growing season vegetated targets.

The Green Vegetation Index (GVI) was originally designed from Landsat MSS imagery and has been modified for Landsat TM imagery which may be applicable for optimally quantitating vegetation levels in urban zones for creating precise flood evacuation maps. It is also known as the Landsat TM Tasseled Cap green VI. This VI signature may be used for flood vulnerability mapping with imagery whose bands share the same spectral characteristics employing GVI=-0.2848*Band1-0.2435*Band2 0.5436*Band3+0.7243*Band4+0.0840*Band5-1.1800*Band7.This index outputs values between -1 and 1.

This study revealed that Landsat ™ data is suitable for capturing both medium and large flood eventswhilecartographically precisely detailing around the edge of a flood or along narrow water features where coarse resolution (MODIS) tends to underestimate water extent. Compared to a coarse resolution water map, the Landsat ™ hydrological maps can detail a strong-to-moderate statistical agreement between flood vulnerable locations. Terrain–related geomorphological land cover can be mapped with moisture in the soil-based on soil color. Flooding under dense vegetation is often invisible to MODIS or any other optical remote sensor[www.esri.com]. The view angle, or range distance from thesensor to thepixel, influences the amount of water that can be mapped, as is demonstrated with a permanent water body [2]. On a temporal scale, cloud cover often inhibits the use of MODIS imagery at the start and lead-up to the peak of a flood event. Landsat ™ 3-D surface water maps are sensitive to the dynamics of water movement when compared to flow gauge data. Given their temporal and spatial characteristics, the Landsat TM sensors can provide useful information for hydrodynamic modelling, and do appear to be the best available product for mapping inundation extent and its change dynamics at large county-level /basin scales.

References

1. Jacob, B.G., et al., Developing operational algorithms using linear and non-linear squares estimation in Python® for the identification of *Culex pipiens* and *Culex restuans* in a mosquito abatement district (Cook County, Illinois, USA). Geospatial health, 2009. **3**(2): p. 157-176.

2. Khan, S., A. Ahmad, and B. Wang, *Quantifying Rainfall and Flooding Impacts on Groundwater Levels in Irrigation Areas: GIS Approach.* Journal of Irrigation & Drainage Engineering, 2007. **133**(4): p. 359-367.

3. Theilen-Willige, B., et al., *Remote Sensing and Geographic Information Systems (GIS) Contribution to the Inventory of Infrastructure Susceptible to Earthquake and Flooding Hazards in North-Eastern Greece.* Geosciences, 2012. **2**(4): p. 203.

4. Liu, R., et al., *Assessing spatial likelihood of flooding hazard using naïve Bayes and GIS: a case study in Bowen Basin, Australia.* Stochastic Environmental Research and Risk Assessment, 2016. **30**(6): p. 15751590.

5. Eves, C. & Wilkinson, S. (2014) *Assessing the immediate and short-term impact of flooding on residential property participant behaviourNat Hazards* 71: 1519. doi:10.1007/s11069-013-0961-y