GIS Analysis: A Flood Vulnerability Assessment of Major Municipalities in Miami-Dade County

GEOB 270: Introduction to Geographic Information Science

Final Project Report

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Sean Coulter

22363148

Hyun Soo Kanyamuna

15598148

Halina Rachelson

13813143

Stella Zhou

48181127

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Abstract

It has been established that climate change will impact sea level height and increase the possibility of severe flooding events in the coming decades. How rising sea levels and severe floods impact coastal cities is of foremost concern. This report will examine the effects of a rising sea level and potential flooding in three major municipalities of Miami-Dade County in the State of Florida, United States. Three vulnerability assessment maps were created to visualize how flooding will interact with land use, infrastructure, and population density. Data on land use, infrastructure and 2010 U.S. Census tracts was gathered online from the Miami-Dade Government's GIS website, and the 2009 flood model data was obtained from the Federal Emergency Management Agency (FEMA). According to FEMA, 'flood hazard' areas are defined as the areas that will be inundated by a flood event having a 1-percent chance of being equaled or exceeded in any given year. The '1-percent annual chance flood' is also referred to as the 'base flood' or '100-year flood.' The flood model predicts the extent of seawater in the next 100 years. From these three maps, interpretations are drawn and discussions are made regarding the possible impacts that flooding will have over these three areas of focus. From our analysis we discover that Miami Beach and Downtown Miami are the most susceptible to being flooded. We make suggestions for mitigating damage and allocating resources based on our findings.

Description of Project, Study Area, and Data

Miami-Dade County remains one of the most vulnerable locations for the effects of sea level rise and the single most vulnerable in terms of monetary value of affected assets (Gore, 2016). This vulnerability assessment is based on the FEMA 100-year flood scenario for the county. Our GIS analysis determines severe flood vulnerability of three coastal municipalities within Miami-Dade County, the City of Miami, City of Miami Beach, and City of Coral Gables. Our criteria for assessing vulnerability to flooding included population density, land use type, and infrastructure driving urban economic development and basic urban functioning such as health care and education facilities, transportation infrastructure, (i.e., sea ports, major streets), and sewer pump stations. We retrieved our data from the official Miami-Dade County Self-Service GIS website and the U.S. Census Bureau. As city planners, we will use this analysis to determine which areas may require more attention from adaptation efforts. For example, the identification of road networks that would be submerged in the event of a flood or sea level rise may demand infrastructural improvements such as the raising of roads. Likewise, knowing which affected coastal areas contain higher population densities may help the County and City planning departments allocate adaptation efforts more effectively.

Methodology of Analysis

We based our analysis on the FEMA 100-year flood, which the Miami-Dade County Sea Level Rise Taskforce uses as an indicator for sea level rise vulnerability (Miami-Dade County, n.d.c).

To create this base map, we retained only the categories that represent areas where purchasing flood insurance is mandatory (A, AE, AH, and VE). With the merging, we created a new layer indicating areas where flooding would be most severe. We narrowed the scope of our analysis by scaling the county map down to coastal municipalities and three municipalities (City of Coral Gables, City of Miami, and City of Miami Beach), using *select by attribute* to create the *Municipalities 123* layer. In addition, we clipped major roads from a county-wide level to the tri-municipality layer and used *select by attribute* to retain only categories 1, 2, 3 of our *Road Network* layer: expressways, highways, and major roads. This way we could identify major roads within these municipalities that are at risk of flooding. In addition, we viewed the attribute table to record the total shape length of the severe flood zone within the municipalities. This served as the base map for three other analyses performed: population density, land use, and facilities/infrastructure vulnerability.

Please note that all layers were in US measurements (i.e. feet) as set by the coordinate system *NAD_1983_StatePlane_Florida_East_FIPS_0901_Feet*. For the purpose of our analysis, we changed each layer used in the maps to the corresponding coordinate system based on metric units.

For the population density map, we aimed to determine which census tracts of high population density within these three municipalities lie within the severe flood zone. We obtained 2010 U.S. Census data indicating population by census tract, clipped it to the boundary of the three municipalities of focus, classified its population per census tract by natural breaks, and normalized it by census tract area to reveal population density (per square kilometre) of individual census tracts. An extra field was added to the attribute table and we used the *Calculate Geometry* function to calculate shape area of census tracts in square kilometres. For our analysis, we looked at areas where higher density and the severe flood zone overlap and used proximity analysis (*select by location*) to calculate the number of census tracts (target layer) that would overlap with the flood zone (source layer).

For the land use component of the analysis, we parsed a list of Miami-Dade County zoning categories (i.e., urban core 1, 2, 3) using the *Merge* tool to simplify our analysis to six land use categories: residential, parks and recreation, business and commercial, government and public services, industrial, and educational institutions. We then used the *Clip* tool to reveal land use layers vulnerable to severe flood. We calculated the shape areas for each of the six categories.

For the infrastructure map, we used proximity analysis (*select by location*) to create layers of facilities (features such as hospitals, public works, bridges, and ports) to indicate potential economic assets that may be affected within the severe flood zone. In addition, we calculated the shape length for the major roads affected (under *Statistics* in the layer's attribute table).

Discussion and Results

Base Map of 100 Year Flood Zone:
We discovered that 9049.47 hectares out of the total land area (27605.43 hectares) of the three municipalities would be severely affected by sea level rise based on the 100 year flood zone (Appendix A). This means that at least 32.78% of these three municipalities are at major risk if a 100 year flood were to occur.

Population and Land Use:

Discussion
Within the three municipalities of focus, residential areas and parks & recreation are the two most vulnerable land use categories at risk from potential severe flooding. This is of concern to city planners because a number of households may be displaced in an emergency scenario. Analyzed in conjunction with the population map, which displays that areas of higher density within the severe flood zone, we have determined that the city must prioritize neighbourhoods in South and North Miami Beach, Downtown, and Brickell neighbourhoods for adaptation efforts. In addition, parks and recreation areas would be affected such as Virginia Key, a barrier island consisting of historic beaches, natural dunes and forests, and trails. This land use type is a valuable asset to the local economy, natural environment, and the livability of the region. Thus, city planners should allocate funding and capacity to protect these areas through various flood mitigation efforts. In addition, the south-eastern strip of City of Miami Beach known as South Beach, which is identified under the parks and recreation land use category, would be at risk. This has severe implications for the tourism industry, as this beach draws hundreds of tourists as well as new residents to the region every year (Tompkins and Deconcini, 2014).

I. Population Map
Our population density map (Appendix B) indicates that 141 census tracts in total would be somewhat affected by flooding. In addition, census tracts of higher population density affected include north and southern tips of the City of Miami Beach, the Downtown district within the City of Miami, and coastal parts of the City of Coral Gables.

II. Land Use Map
After simplifying our analysis to distinct land use categories and calculating the areas for each categories within the severe flood zone, we identified six categories that were to be affected (Appendix C).

Facilities:

Discussion
It has been said that no U.S. metropolitan area is as vulnerable in terms of assets potentially lost to sea level rise as Miami-Dade County (Cox and Cox, 2015). Based on our analysis, it is clear that the City of Miami Beach would stand to lose many of its valuable economic assets. As Miami is a major coastal city, the impacts to urban infrastructure listed above in three of the county's coastal municipalities hold severe implications locally, as well as for economic development and trade relations on both national and global scales. We chose to analyze sewer facilities, keeping in mind their necessity in upholding basic urban functions. In addition, we considered infrastructure imperative for international trade and tourism—two of Miami's major economic drivers—such as ports and major roads, as well as facilities needed to drive local economic development such as hospitals and higher education institutions.

III. Facility Map
Our facilities and infrastructure vulnerability analysis (Appendix A) indicates that a total of 5 hospitals (Appendix E), 20 higher education institutions (Appendix F), 155 sanitary pump stations, and 2 ports (Appendix G), would be affected in the case of severe flooding and sea level rise projections. In addition, 1,152,544.72 ft. (1.15 million ft.) of major roads would be at risk.

i. Hospitals
As a hub for cutting-edge medical research, the city must consider the impact it would have on public health, research and development, and employment if five major hospitals (Appendix E) would be affected. For example, University of Miami Hospital, one such affected facility, functions as a teaching hospital and general medical and surgical facility, consisting of 1200 physicians and 525 hospital beds to support patient care. Medical equipment and jobs must be considered among the losses.

ii. Higher Education Institutions
In addition, our map displays 20 higher education institutions at risk. This has implications for the local economic development. In addition, many of these are highly specialized training and research centers in the field of medicine (i.e., UM ALS Clinical and Research Center). Some of these higher education institutions enroll very large student populations, such as the Medical Campus part of Miami Dade College, the second largest higher education institution in the United States. These institutions support various sectors upholding the local economy including healthcare, business, entertainment, arts and technology, and education. Losing these assets could lead to thousands of job losses.

iii. Major Roads

A total of 1.15 million feet (351,295.63m) of major roads are at risk of severe flooding in the case of sea level rise. Not only would damages to this infrastructure incur enormously high costs to repair and replace these, but it could affect the flow of resources (i.e., transporting goods on major highways), upset traffic patterns in a city fundamentally dependent on automobile transport, and lead to environmental damage due to runoff from road pollutants (Flechas and Staletovich, 2015). This also has implications socially, economically, and environmentally.

iv. Pump Stations

Operating "twenty-three hundred miles of canals, sixty-one pump stations, and more than two thousand "water control structures," the South Florida Water Management District reports "that it operates the 'world's largest water control system'" (Kolbert, 2015). As the state's most populous county, the magnitude of Miami-Dade County's water network makes it a salient concern in light of coastal flooding and sea level rise. The system is responsible for keeping the state afloat, redirecting water as a way of preventing the flooding of the landscape. Due to the height of the water table, residences in Florida are generally prohibited from constructing basement suites.

In addition to redirecting water, the system is tasked with providing sanitary water to the residents of Miami-Dade County. Our analysis shows that 155 sanitary pump stations are within the flood zone, therefore at risk of being inundated by sea level rise. The risk of inland flooding is also increased as "rainwater… has nowhere to go" (Kolbert, 2015) during storm events, informing us on the wide-ranging spatiality of the affected pump stations. This raises issues related to public health, stemming from the permeation of salt water into the freshwater system. In fact, Hallandale Beach, a city north of Miami, has been forced to "close most of its drinking wells because the water is too salty (Kolbert, 2015). It appears inevitable that this fate will extend to other municipalities in the near future.

v. Ports

Situated along the Eastern Seaboard of the United States, Miami-Dade County is a key hub for economic activity on both the state and national levels. The region ranks among the nation's leading exporters by gross metropolitan product (GMP), preceded only by the New York, Houston, Los Angeles, and Detroit metropolitan areas (IHS Global Insight, 2012).

In accordance with the Miami-Dade County's geographic positioning as a coastal city, marine-based transport activities predominate the region's economic landscape. Our geospatial analysis has identified two seaports that are vulnerable to impending sea level rise. These facilities are the Dante B. Fascell Port of Miami and the Miami Seaplane Base, both of which serve as major generators of revenue and employment.

A distinctive feature of the Dante B. Fascell Port of Miami and the publicly-owned Miami Seaplane Base is the diverse nature of the economic activities it hosts. Functioning as both a terminal for cruise ships and a hub for containerized cargo, the port is marketed as a "global gateway for trade, commerce and tourism" (Miami-Dade County, n.d.b). The Dante B. Fascell Port of Miami has undergone extensive development over the past decade. Upwards of $1 billion had been invested in structural restorations, including the improvement of the freight rail system, cranes, and the construction of the PortMiami tunnel which provides "direct access to the U.S. Interstate Highway System" (Miami-Dade County, n.d.b). Further, in 2011, the Miami-Dade County had announced an additional $2 billion in investment over the course of twenty-five years for the completion of the Port of Miami 2035 Master Plan (Miami-Dade County, n.d.b). Alongside substantial investiture, the annual economic output of the Dante B. Fascell Port of Miami is $28 billion (Miami-Dade County, n.d.b). Upwards of 207,000 jobs are generated by the operations of the port (Miami-Dade County, n.d.b), granting credence to its socio-economic importance within the Miami-Dade County and the United States as a whole.

Hazard assessments conducted by the Natural Hurricane Center, a subdivision of the National Oceanic and Atmospheric Administration, indicate that the entirety of the State of Florida is at risk for hurricane damage. The Miami-Dade County is susceptible to phenomenon such as storm surges and tides, heavy rainfall, inland flooding, high winds, rip currents, and tornadoes (Natural Hurricane Center, n.d.). Climate change is attributed to the aggravation of such natural events, a trend that founds the basis our analysis. The Port of Miami and the Miami Seaplane Base's proximity to the Atlantic coastline render these facilities particularly vulnerable to infrastructural damage and a wide range of socio-economic consequences.

Error and Uncertainty

Much of the error and uncertainty we have identified does not stem from the data itself (i.e. its reliability), but instead is rooted in our interpretation of the data. In other words, there is no question that the data we used is spatially accurate, but there are factors and attributes that are not included in the data whose exemption causes uncertainty in predicting the effects of sea level rise. For example, the data we used to display the flood zone layer is reliable in the sense that it is extracted from a government database. However, this model is based on current trends in sea level rise and thus is not necessarily accurate in its predictions of what may actually happen in the future.

Further, climate change is recognized as a threat whose impacts are notoriously difficult to foresee. There are many factors involved in the changing of the climate and these factors vary

with the changing years. Considering this, it must be understood that there is a large degree of uncertainty that comes with the creation of a flood-model based off of projected sea level rise.

The flood-model data is based on data gathered by FEMA in 2009. In the seven years that have passed since this data was compiled, the parameters of the actual (i.e. modern) flood zone may have changed. It may then be inappropriate to apply this dated dataset to our analysis, as interpretations drawn from our map may lead to inaccurate conclusions about reality. This is perhaps the most prominent error in our project. Also, the data that FEMA gathered was based off of historic flood statistics from NOAA (National Hurricane Center, 2010), going back to 1979. Given that records only exist back to 37 years, the lack of long-term data trends must be taken into account. It is difficult to come to an undeniable conclusion about sea-level rise in Miami given that the data used in analysis is restricted to only 37 years. To re-emphasize a previous point about uncertainty, this lack of long-term data results in uncertainty in the flood-model's application and relevance to today.

Also, the resilience of infrastructure such as bridges and hospitals against flooding was not accounted for in this analysis. Error could therefore result, as a structure labelled or interpreted as 'at risk' of damage by flooding could in reality be safe due to its design features.

Our classification of census tracts was colour-coded based on population density. However, Miami-Dade County's census tracts are nearly uniform in their population densities. This created issues in breaking tracts into colour-classes based on population densities. To combat this issue we decided to make over 30 classes for population density so that differences in densities between tracts could be more easily visualized. In doing this, however, we had to exempt 'outliers' in the data that were causing issues. Doing this effectively compromised the integrity of our map's representation of census tract population densities, as very dense outliers were grouped in with relatively much less dense counterparts.

Small islands dot the east coast of the county. These sparsely-inhabited islands are clustered along the coast and are grouped into their own large census tracts. These tracts cover big areas of seawater and are all at risk of flooding. However it is clearly not possible for seawater to flood. In calculating total area affected by flooding based on census tract area, open seawater is accounted for due to the islands' position in the water. The fact that seawater and not just the islands is defined as 'land area' for the purpose of this calculation is erroneous.

Further Research and Recommendations

Considering that some of the more populated areas of Miami-Dade County—namely Downtown and Miami Beach—will be heavily affected by the flooding, it is paramount that emergency management plans are formulated to protect local citizens and their homes as well as commercial development in the event of a disaster. Population density reaches its highest levels in the central downtown area, according to the map. Likewise, the entirety of Miami Beach is at risk of being submerged by flooding. Of particular concern, the southern part of that landscape contains high population density. On a broad scale, highly populated neighbourhoods throughout much of the county are at risk. So, we recognize that there are two possible directions for the City to take in order to protect the majority. First, the city can invest in new infrastructure to combat the rising tide-- for example, levees and/or dams or 'softer' green infrastructure approaches (i.e., wetland restoration) along the coast. Alternatively, efforts can be made to plan for relocation of citizens and infrastructure away from any at-risk areas. However, both methods are costly and are bound to face public opposition. This is why we suggest that a balance is struck between infrastructure investment and relocation.

It appears that the inland neighbourhood of northern Coral Gables is largely safe from flooding. In this area, we find fewer sewer stations and hospitals than other neighbourhoods. This area could then be a potential site for infrastructure relocation, whereby sewers are rerouted away from the flood zones and installed in Coral Gables.

We recommend that further research is undertaken by the City's higher education facilities in conjunction with those of other cities facing similar flooding risks, such as Amsterdam or New Orleans. Amsterdam has long been famed for its resilience against rising sea levels, employing civil engineering and technological innovation against such hazards. Fortunately, Dutch consultancy firms, such as ARCADIS, have already been hired by the city to do some of the basic infrastructure planning work (Goodell, 2013), but municipal and state support must be provided to continue such partnerships.

A combination of research into disaster mitigation, the relocation of citizens, and converting essential facilities into safer areas is politically and economically reasonable and necessary in order to ensure Miami's preparation for the future impacts of a flood.

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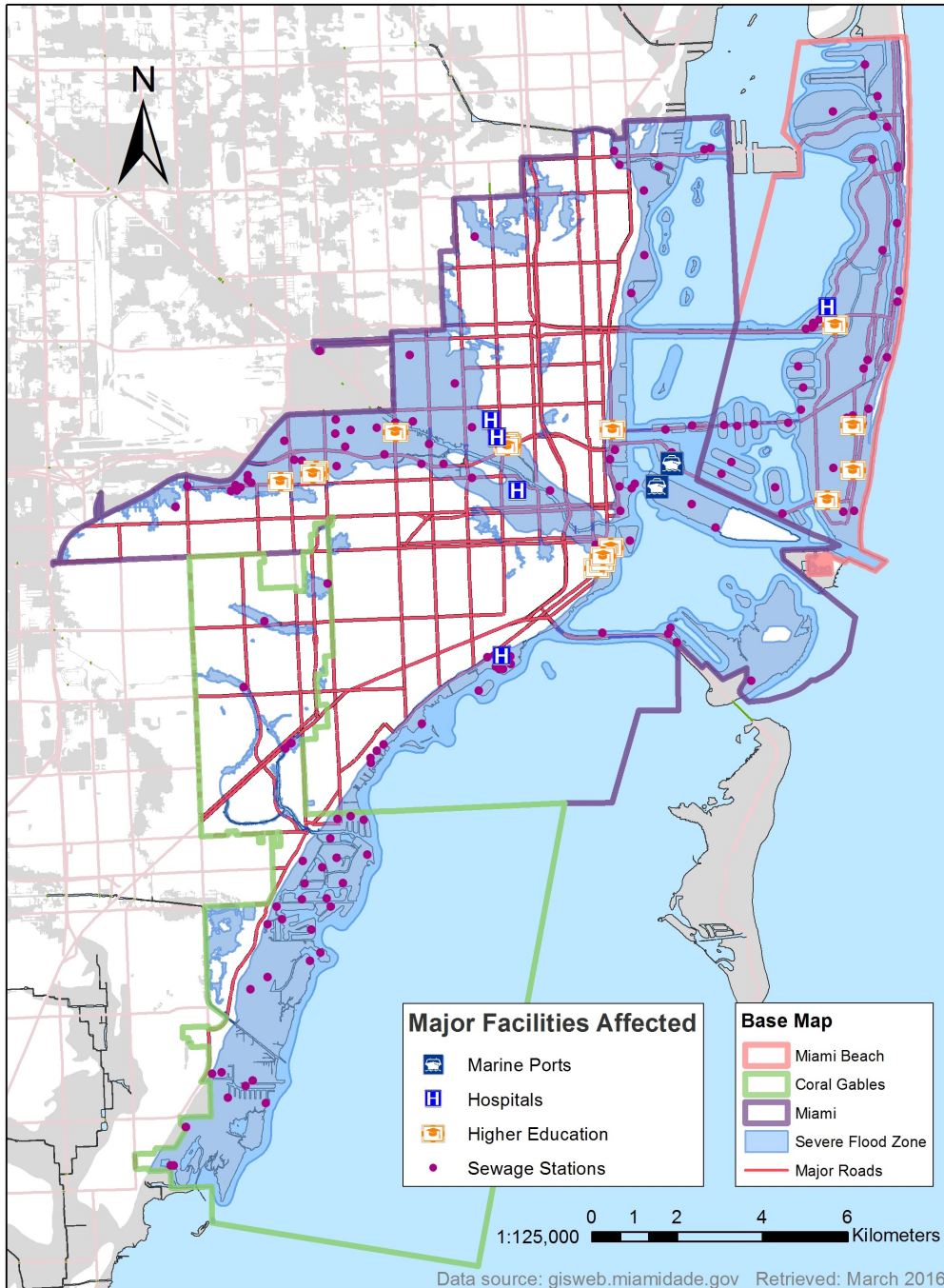
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Appendix

Appendix A: Facility Map

100 Year Flood Zone Risk Assessment of Miami-Dade County

Major Facilities Affected

- 🚢 Marine Ports
- Ⓗ Hospitals
- 🏛 Higher Education
- • Sewage Stations

Base Map

- Miami Beach
- Coral Gables
- Miami
- Severe Flood Zone
- Major Roads

1:125,000

0 1 2 4 6 Kilometers

Data source: gisweb.miamidade.gov   Retrieved: March 2016

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100 Year Flood Zone Risk Assessment of Miami-Dade County

**Population Density
US Census Tract 2010**

people per km square
classification: natural breaks

	0 - 2160
	2161 - 4267
	4268 - 7529
	7530 - 12999
	13000 - 29295

Base Map

	Miami Beach
	Coral Gables
	Miami
	Severe Flood Zone
	Major Roads

0 1 2 4 6 Kilometers

1:125,000

Data source: gisweb.miamidade.gov   Retrieved: March 2016
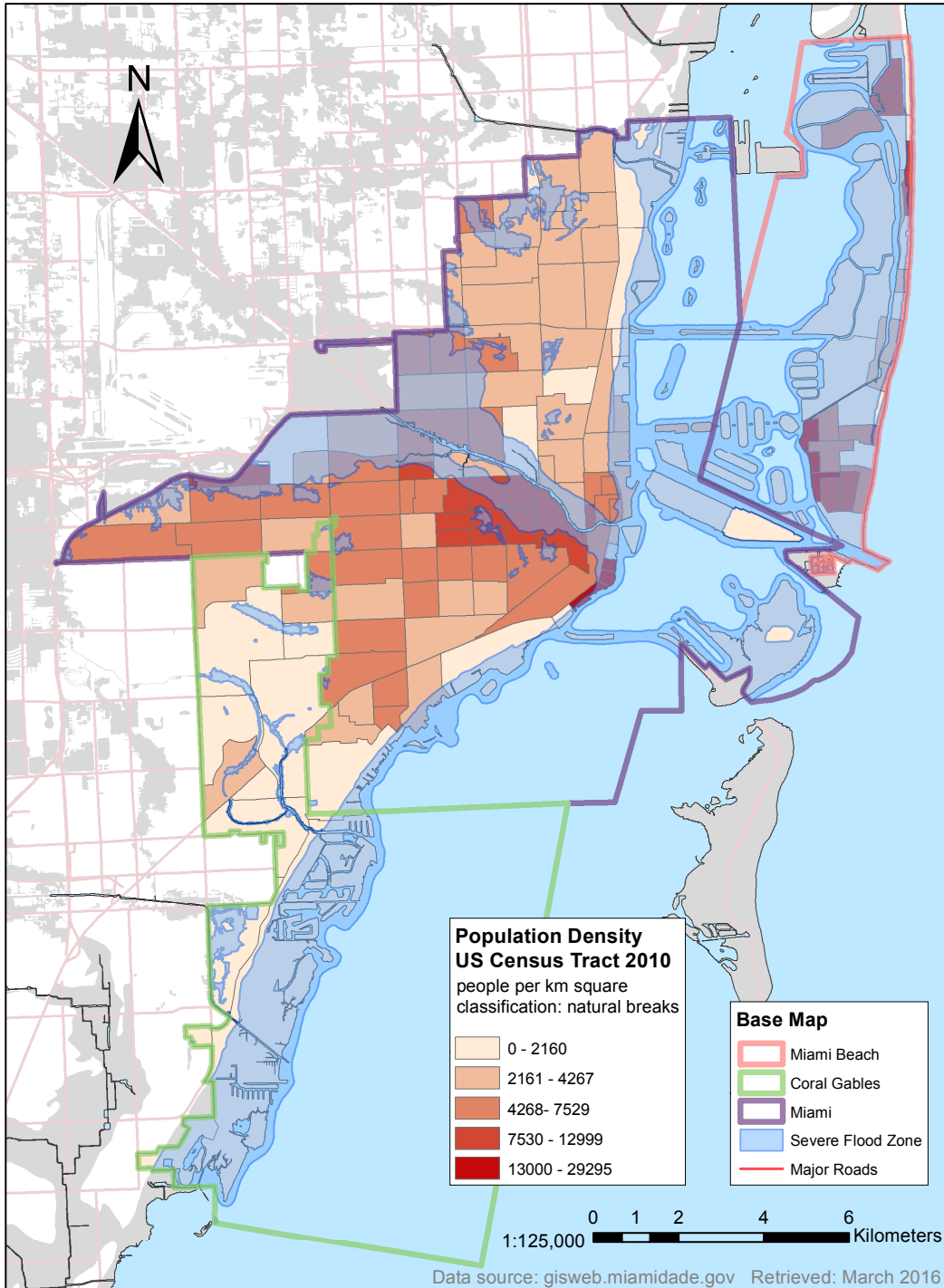
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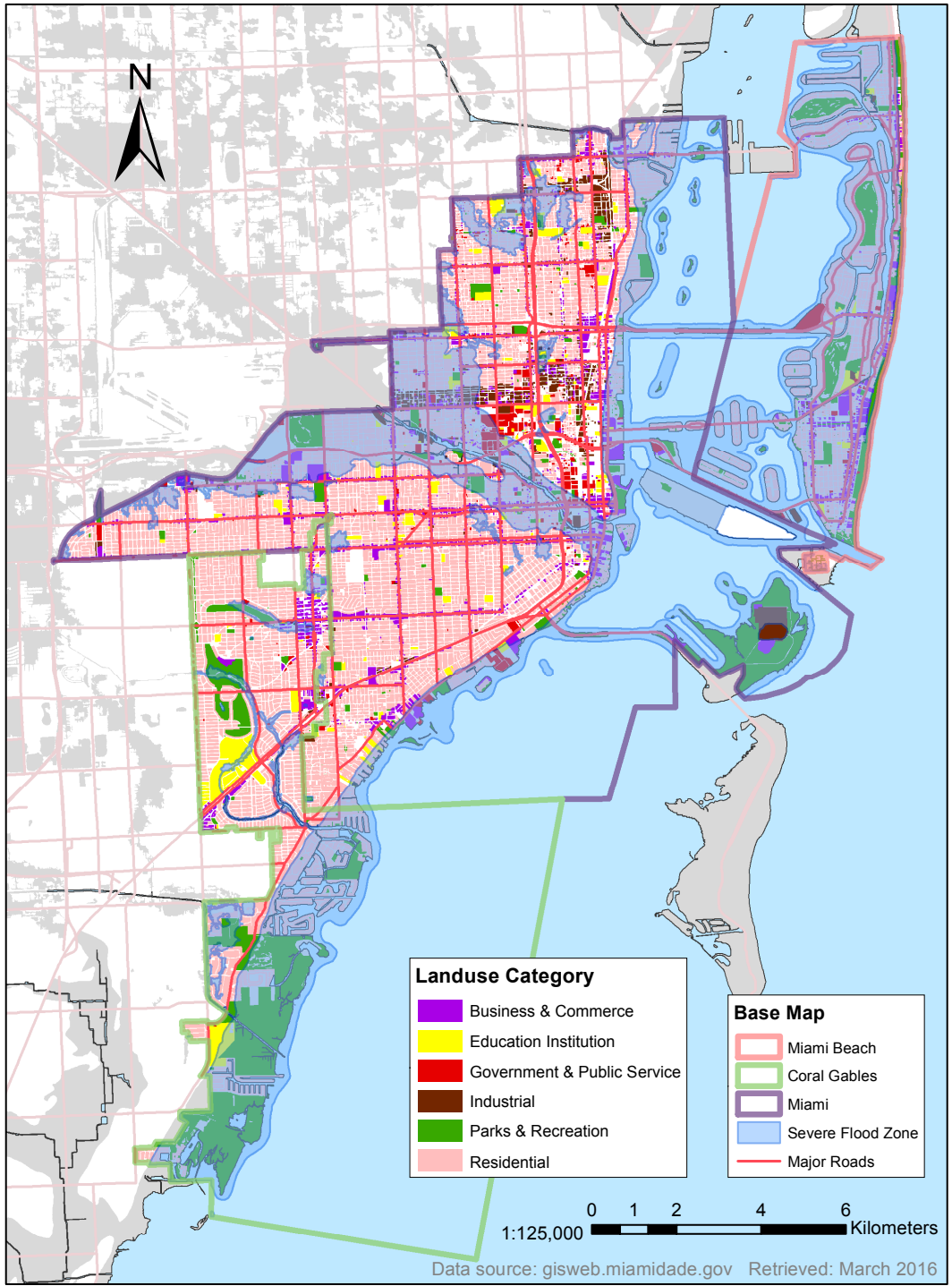
Appendix C: Land Use Map

100 Year Flood Zone Risk Assessment of Miami-Dade County

Landuse Category
- Business & Commerce
- Education Institution
- Government & Public Service
- Industrial
- Parks & Recreation
- Residential

Base Map
- Miami Beach
- Coral Gables
- Miami
- Severe Flood Zone
- Major Roads

0 1 2 4 6 Kilometers
1:125,000

Data source: gisweb.miamidade.gov   Retrieved: March 2016

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Appendix D: Land use categories

Land Use Category (6)	Area Affected (hectares)
Residential	2333.51 hectares
Parks & Recreation	1544.35 hectares
Business & Commercial	426.10 hectares
Government & Public Services	132.70 hectares
Industrial	124.64 hectares
Education Institutions	89.97 hectares

Appendix E: Hospitals within flood zone

Hospitals Affected (5)
Department of Veteran's Affairs Medical Center
Mount Sinai Medical Center
Mercy General Hospital
Select Specialty Hospital
University of Miami Hospital

Appendix F: Higher education institutions within flood zone

Higher Education Institutions Affected (20)
Talmudic College of Florida
Open Hearts Language Academy
UM ALS Clinical and Research Center
UM Center for Complementary and Integrated Medicine
UM Ear Institute
UM Epidemiology and Public Health
Florida International University Brickell
Florida International University Wolfsonian
Beauty Schools of America

Higher Education Institutions Affected (20)
Olga P Gonzalez Sewing School
UM Clinical Enterprise Technologies
UM Otolaryngology Department
Miami International University of Art & Design
TALK International School of Languages
Key Power Tech. Inst. Comm. Truck Driving School
Center of Cinematography Arts & Television
Strayer University - Brickell Campus
Florida International University Miami Beach
Dade Medical College - Miami Campus
Inlingua Language Center Brickell Avenue

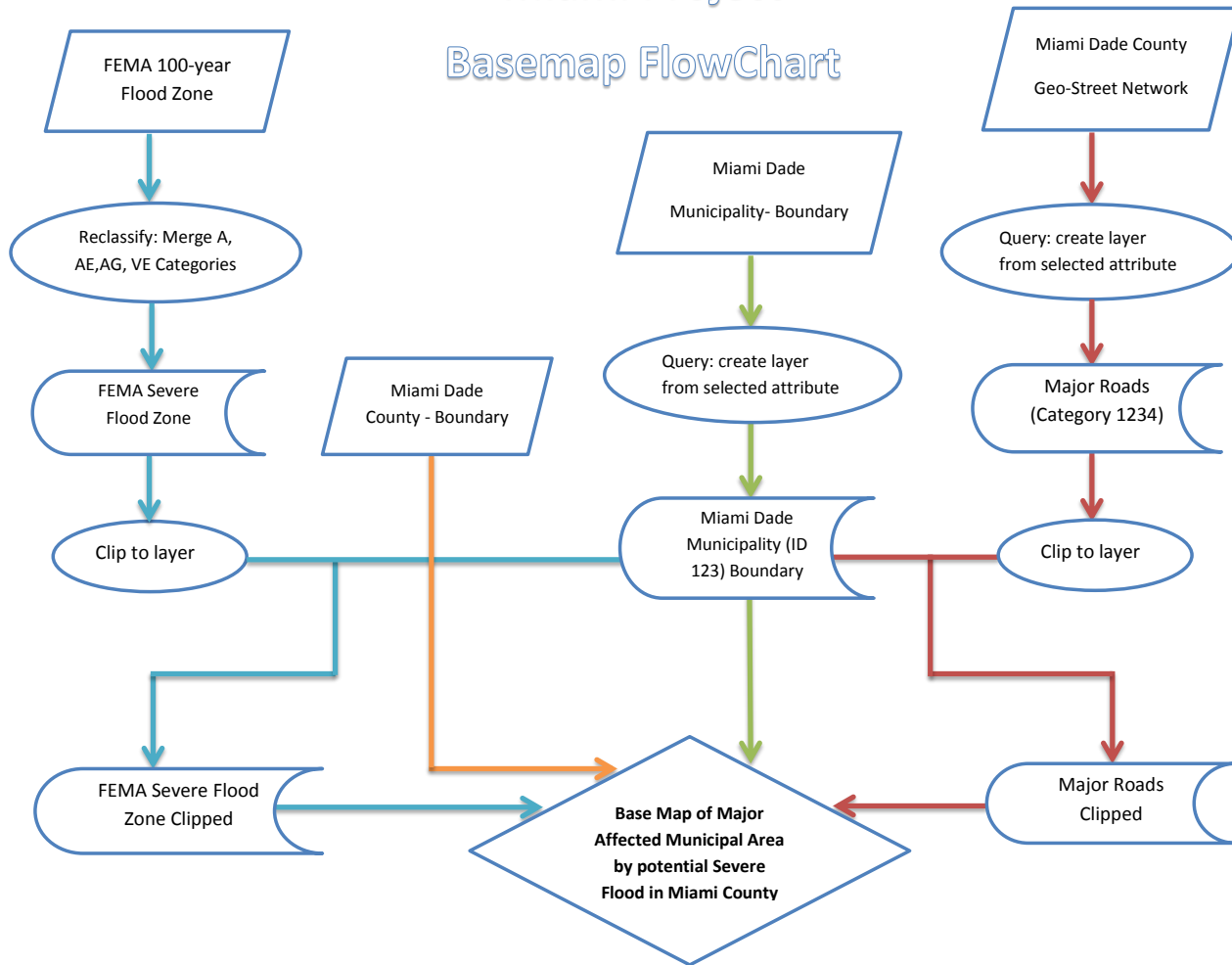**Appendix G:** Ports within flood zone

Ports Affected (2)
Seaplane Base
Port of Miami

Flowchart for Basemap

Miami Project
Basemap FlowChart

Flowchart for *Land Use, Facility,* and *Population Density* Maps