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Development and evaluation of a geographic information system based method to estimate flooding susceptibility in an area of Broward County, Florida

Carolyn J. Anderson
Florida International University

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FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

DEVELOPMENT AND EVALUATION OF A GEOGRAPHIC INFORMATION SYSTEM BASED METHOD TO ESTIMATE FLOODING SUSCEPTIBILITY IN AN AREA OF BROWARD COUNTY, FLORIDA

A thesis submitted in partial fulfillment of the
requirements for the degree of
MASTER OF SCIENCE
in
ENVIRONMENTAL AND URBAN SYSTEMS
by
Carolyn J. Anderson

2004

To: Dean Vish Prasad
College of Engineering

This thesis, written by Carolyn J. Anderson, and entitled Development and Evaluation of a Geographic Information System Based Method to Estimate Flooding Susceptibility in an Area of Broward County, Florida, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this thesis and recommend that it be approved.

Keqi Zhang

Dean Whitman

Stephen P. Leatherman

Hector R. Fuentes, Major Professor

Date of Defense: March 10, 2003

The thesis of Carolyn J. Anderson is approved.

Dean Vish Prasad
College of Engineering

Dean Douglas Wartzok
University Graduate School

Florida International University, 2004

DEDICATION

I dedicate this thesis to my parents. Without their constant encouragement and patience, the completion of this work would not have been possible.

ACKNOWLEDGMENTS

I wish to thank the members of my committee for their constant guidance and priceless time. I am greatly appreciative toward my major professor, Dr. Hector R. Fuentes, for providing his wisdom and guidance throughout the duration of my graduate studies at Florida International University (FIU). I would also like to express my gratitude towards my committee members Dr. Stephen Leatherman, Dr. Dean Whitman, and Dr. Keqi Zhang for sharing their vast knowledge and technical expertise. I also acknowledge the International Hurricane Research Center (IHRC) and College of Engineering for their support and cooperation.

Finally I would like to thank my family (Andersons and Robertsons) for their constant encouragement and "loving pushes" towards my goals. Most of all, my love and gratitude goes to Quin, whom by the end of this long journey became my husband. If it were not for his constant reality checks, pep talks, ego boosts, and loving threats this thesis would not have been possible.

ABSTRACT OF THE THESIS

DEVELOPMENT AND EVALUATION OF A GEOGRAPHIC INFORMATION SYSTEM BASED METHOD TO ESTIMATE FLOODING SUSCEPTIBILITY IN AN AREA OF BROWARD COUNTY, FLORIDA

by

Carolyn J. Anderson

Florida International University, 2004

Miami, Florida

Professor Hector R. Fuentes, Major Professor

The objective of this study was to develop a GIS-based multi-class index overlay model to determine areas susceptible to inland flooding during extreme precipitation events in Broward County, Florida. Data layers used in the method include Airborne Laser Terrain Mapper (ALTM) elevation data, excess precipitation depth determined through performing a Soil Conservation Service (SCS) Curve Number (*CN*) analysis, and the slope of the terrain. The method includes a calibration procedure that uses "weights and scores" criteria obtained from Hurricane Irene (1999) records, a reported 100-year precipitation event, Doppler radar data and documented flooding locations. Results are displayed in maps of Eastern Broward County depicting types of flooding scenarios for a 100-year, 24-hour storm based on the soil saturation conditions. As expected the results of the multi-class index overlay analysis showed that an increase for the potential of inland flooding could be expected when a higher antecedent moisture condition is experienced. The proposed method proves to have some potential as a predictive tool for flooding susceptibility based on a relatively simple approach.

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LIST OF ACRONYMS

ALTM	Airborne Laser Terrain Mapper
AMC	Antecedent Moisture Condition
BFE	Base Flood Elevation
C&SF	Central & Southern Florida Project
cfs	cubic feet per second
CN	Curve Number
DCA	Department of Community Affairs
DEM	Digital Elevation Model
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Maps
FIS	Flood Insurance Studies
FLDOT	Florida Department of Transportation
FLUCCS	Florida Land Use and Cover Classification System
ft	feet
GIS	Geographic Information System
GPS	Global Positioning System
IDF	Intensity-Duration-Frequency
IHRC	International Hurricane Research Center
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
in	inches
LEC	Lower East Coast Service

LIDAR	Light Detection and Ranging
NCDC	National Climatic Data Center
NEXRAD	Next Generation Weather Radar
NHC	National Hurricane Center
nmi	nautical miles
NRCS	National Resource Conservation Service
NWS	National Weather Service
QPE	Quantitative Precipitation Estimation
QPF	Quantitative Precipitation Forecast
RMSE	Root Mean Square Error
ROT	Rule of Thumb
SCS	Soil Conservation Service
SFHA	Special Flood Hazard Areas
SFWMD	South Florida Water Management District
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
STP	Storm Total Precipitation
TC	Tropical Cyclone
TIN	Triangulated Irregular Network
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
UTC	Universal Time Coordinated
UTM	Universal Transverse Mercator
WCA	Water Conservation Area

WSR-88D	Weather Surveillance Radar, 1988-Doppler
yr	year

Chapter 1. Introduction & Objective

Coastal regions are susceptible to a wide range of natural disasters, among which tropical cyclones are the most well known. Historically, tropical cyclones have caused widespread damage and death in the United States, Central America, South America, and the Caribbean. While tropical cyclones are multi-dimensional hydrometeorological phenomena, residents often prepare for only one aspect of the storm -- wind. In the last few decades the public and researchers have come face to face to the damaging affects of other hurricane hazards, specifically inland flooding caused by extreme rainfall. According to recent findings by Rappaport et al. (1998), inland flooding has been responsible for more than half the deaths associated with tropical cyclones in the United States for the last three decades.

Minimal strength storms can cause a major hazard due to flooding as illustrated by Hurricane Irene (1999) in South Florida and Tropical Storm Allison (2001) in the Houston, Texas area. As a result of Hurricane Irene, more than 18 inches of rain fell in sections of South Florida. This contributed to the deaths of 8 Florida residents and caused $800 million in water damage (Aliva and Abtew 1999). Flooded roadways made it impossible for residents to escape, leaving entire communities cut off by flooded waters. Over 30,000 families were displaced and 50 people died as Tropical Storm Allison swamped 70 counties in 5 states. Losses due to water damage caused by this storm exceeded $6 billion (Franklin and Brown 2000).

Inland flooding continues to be one of South Florida's most costly hazards and has long been recognized as a problem, especially in urban areas. Currently there is little documentation on the prediction of potential inland flooding due to the extreme rainfall associated with these storms. The Federal Emergency Management Agency (FEMA) National Flood Insurance Rate Maps (FIRMs) are the most commonly used tool among residents to determine whether their property or surrounding neighborhoods have a higher potential for flooding (FEMA 2001). However, the majority of these maps are based on Flood Insurance Studies (FIS), which were conducted in the late 1970's and early 1980's. These maps are out-dated and therefore do not take into account rapid urbanization.

Due to the lack of information on flood potential, the severity of past problems with property damage and the death toll attributed to inland flooding, new models are needed that incorporate the latest technology. The Geographic Information System (GIS) provides a perfect platform to perform an analysis using various types of spatially referenced data to determine the possible potential for inland flooding in a particular area.

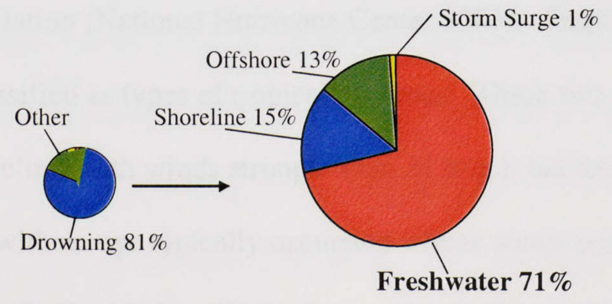
The objective of this project is to develop and evaluate the effectiveness of a method that performs a multi-class index overlay analysis to determine areas susceptible to inland flooding within eastern Broward County. The method is based on several factors including: flat low-lying topography, soil type, land use, percentage of impervious areas, and antecedent moisture conditions. Data layers used in the analysis include highly accurate Airborne Laser Terrain Mapper (ALTM) elevation data, the excess precipitation depth for the subject areas through performing a Soil Conservation Service (SCS) Curve Number (*CN*) analysis, and the slope of the terrain. A calibration analysis is performed, using archived radar measurements and reported flooding locations for Hurricane Irene (1999), to determine the weights and scores used in the analysis. These weights and scores are then applied in the final analysis using a 100-year, 24-hour storm event determined from an intensity-duration-frequency curve. The final graphical output delineates areas most susceptible to inland flooding within Broward County based a 100-year storm event. It is hoped that the development of this tool will be an initial stepping block to assist with the implementation of mitigation and evacuation strategies during extreme precipitation events.

Chapter 2. Background

2.1 Inland Flooding Associated with Extreme Precipitation Events

Along the Atlantic and Gulf Coasts of the United States, the most severe floods are usually caused by tropical cyclones. These floods can pose a serious threat to communities. Pielke and Pielke (1997) stated that during flooding situations people might create their own vulnerabilities due to certain actions and choices. One of the problems associated with inland flooding in flat low-lying areas is that residents can easily overlook the severity of the hazard, especially after tropical cyclone winds diminish. Inland flooding can become a dangerous situation if residents are required to evacuate the coastline due to the threat of wind and/or storm surge. Driving through flooded neighborhoods and roadways could be costly, including damaged property and/or life threatening situations. According to recent findings conducted by Rappaport et al. (1998), 81 percent of U.S. tropical cyclone deaths between 1970 and 1998 were the result of drowning; 71 percent of these deaths occurred due to freshwater inland flooding incidents as shown in Figure 1.

Figure 1. U.S. Tropical Cyclone deaths between 1970 and 1998 (Rappaport et al. 1998).



In many cases citizens rely on past knowledge and historical documentation when trying to avoid areas prone to flooding. Unfortunately, historical documentation cannot always be relied upon when determining areas prone to flooding because of the rapid urbanization and change of land use configuration.

Tropical Cyclones

According to Hirschboeck et al. (2000), there are two types of atmospheric precipitation processes that can cause flooding. The mesoscale/storm scale system is a process that is short lived and produces extreme amounts of rainfall over very localized areas within a few hours. An example of this phenomenon would be an intense but short duration storm as often witnessed during the rainy season in South Florida. The second process is classified as a macroscale/synoptic scale system that generally produces floods developing over tens of hours to days and affects large geographical regions, such as a tropical cyclone.

Tropical cyclones can be defined as warm-core, nonfrontal low-pressure systems of synoptic scale that develop over tropical or subtropical waters and have a definite organized surface circulation (National Hurricane Center 2001). Tropical storms and hurricanes are both classified as types of tropical cyclones. These two phenomena are defined as a tropical cyclone with winds stronger than 31 m.p.h but less than 74 m.p.h. and a tropical cyclone with an eye typically occurring whose winds speeds are 74 m.p.h. or greater, respectively (Pielke 1990). Hurricanes can be further classified by their potential damage according to the Saffir/Simpson Scale, which was developed by the

National Weather Service (NWS). Table 1 shows the scale and corresponding classifications.

Table 1. The Saffir-Simpson Hurricane Scale.

Category	Winds (mph)	Storm Surge	Damage
1	74-95	4-5 ft above normal	No real damage
2	96-110	6-8 feet above normal	Some roofing material, door, and window damage of buildings
3	111-130	9-12 ft above normal	Some structural damage to small residences
4	131-155	13-18 ft above normal	More extensive failures with some complete roof structure failures on small residences
5	greater than 155 mph	greater than 18 ft above normal	Complete roof failure on many residences and industrial buildings.

The Florida peninsula is affected by one named storm a year and by a hurricane every two to three years (National Hurricane Center 2001).

As defined by Freidman (1984) four factors interact to determine the impact that a tropical cyclone will have on a population. The first factor is the consideration of the geographical pattern of wind, storm surge, and rainfall severity associated with the passage of the tropical cyclone. The second factor is the local condition that could modify the storm severity. For the flooding hazard, the shape of the land, soil characteristics, duration of the storm, urban landscape, and the period of time between previous storms could affect the inundation of coastal regions. The third factor is the spatial distribution and clustered densities of buildings and other property that are considered to be insured elements at risk. The fourth factor would be the vulnerability of insured physical elements when subjected to given hurricane winds, storm surge, and rainfall. The interaction between the various parameters of these four factors can determine the damage potential of a specific storm towards residential and commercial buildings during a tropical cyclone event. There are two types of "destructive" flooding impacts associated with tropical cyclones including, storm surge and flooding induced by rainfall.

Storm Surge

Flooding caused by storm surge refers to the rapid rise of sea level that occurs as a storm approaches a coastline, the greatest inundation occurring during a high tide (Pielke and Pielke 1997). The most negative effect of a storm surge is felt on beaches, off shore islands and low-lying coastlines. The destructiveness of a storm surge is related to the wind speeds and the aerial extent of the tropical cyclone's maximum winds. A tropical cyclone does not need to make landfall in order for a community to feel the devastating affects of a storm surge. According to 2000 U.S. Census data, coastal populations have risen 20 percent in the states most vulnerable to hurricanes. More than 11 million people could be affected by storm surge flooding. During the 1900 Hurricane, 6,000 people were swept away to their deaths on Galveston, Texas due to the storm surge, making this storm the deadliest hurricane in United States history (Herbert et al. 1997). The SLOSH model (Sea, Lake, and Overland Surges from Hurricanes) is the model used by NWS to define flood prone areas along the Atlantic Coast and the US Gulf of Mexico.

Inland Flooding

Flooding from heavy rains can be the most devastating aspect of tropical storms and hurricanes. The threat of inland flooding is a function of several atmospheric and land processes interacting at various spatial and temporal scales affecting the type of hazard presented. Dunn and Miller (1964) found that for heavy rains to persist for any length of time during a tropical cyclone, there must be a continued flow of moist air into the center of the storm or along the upslope of a mountain range, frontal surface, or other mechanism for lifting air. Precipitation in a tropical cyclone can be separated into two systems: convective and stratiform. Convective precipitation refers to the vertical transport of heat and moisture by the movement of a fluid. The terms "convection" and "thunderstorms" often are used interchangeably, although thunderstorms are only one form of convection. Stratiform precipitation, in general, is relatively continuous and uniform in intensity and is defined as a system that has extensive horizontal development (i.e., steady rain versus rain showers).

Observations made by Marks and Shay (1998) based on radar studies suggest that in just a few hours of tropical cyclone development the inner core produces a large amount of precipitation over a relatively small area. However, inland flooding is a complicated phenomenon dependent on various factors. The flood producing potential of an area is dependent upon its natural setting (climate, soils, geology, steepness), land cover (forests, crops, roads, buildings), land use (agriculture, forestry, towns and cities), total accumulation of precipitation, and the river/canal stages at the time the rains begin (Dunn and Miller 1960). After landfall orographic forcings, caused by physical geography, can sometimes anchor heavy precipitation to a local area for an extended period of time. This often occurs in mountainous regions such as the Carolinas, Virginia, West Virginia, and Pennsylvania. The total accumulation of rainfall at a given area is also greatly dependent upon the forward speed of the tropical cyclone and the stage of development of the storm. Simply stated, in slower-moving storms the rain has been observed to last longer. One technique used to determine expected precipitation accumulation for tropical cyclones is Ray Kraft's "Rule of Thumb" (ROT) first proposed in the late 1950s (Swartz 2000). The potential rainfall amounts of an approaching tropical storm are calculated using the following equation:

$$\text{Maximum rainfall} = 100/\ \text{forward speed (knots)} \qquad (1)$$

This simple estimation can give a general idea of the potential maximum rainfall for an approaching storm, but it provides no information about the distribution of rain in space or time. There is also no adjustment in the rule for storm intensity, topography, or other dynamical or microphysical parameters

Inland flooding arises when weather, hydrology, and the local landscape combine in ways that produce excessive amounts of run-off. Excess precipitation is defined as water that cannot be accommodated by a watershed, streams, channels, canals, drainage basins, or other man-made structures. According to Roberson et al. (1998), physical law dictates that all other things being equal, steep slopes will produce more excess precipitation than flat slopes; vegetated drainage areas will yield less excess precipitation than bare areas; and areas where clay/silty soils are impermeable will produce more excess precipitation than sandy soils with high permeability. Excess precipitation usually flows as a thin sheet overland where it eventually reaches a channel where the flow concentrates. The flow rate of this channel increases as it connects with other flow channels. Eventually the surface excess precipitation will either connect with a river, canal, detention pond, or will accumulate in a low-lying area. Flooding occurs when a volume of water exceeds a river/canal channel or due to ponding water as a result of high water table and/or poor drainage in a low-lying area.

For prediction and warning purposes, river/canal floods are classified by the National Weather Service (NWS) into two types of events, floods and flash flood. Floods are those that develop and crest over a period of approximately six hours or more and flash floods are those that crest more quickly (White et al. 1975). Flash flooding events most commonly are examined due to their serious nature and abruptness. In response to the threat of such events, flood control devices have been constructed such as levees, channels, canals, and dams. However these flood control structures can create a misleading sense of security when communities assume that flooding due to heavy rain will no longer occur.

Although river/canal flooding often receive the most attention, flooding due to accumulating water in low-lying areas has also become a serious threat. The ponding of water can occur in large or small areas. Large area floods are defined as floods that arise from storms of low intensity having the duration of a day or two, usually occurring during the fall in Florida (Finkl 1996). Small-area floods are a result of high-intensity storms having a short duration, as seen during the short and intense storms during the summer rainy seasons. Inland flooding events caused by ponded water are sometimes overlooked by governmental and local agencies and are not considered as harmful as flash flood or canal/river flooding events.

2.2 South Florida Flooding: A Historical Perspective

When a tropical cyclone is accompanied by copious amounts of rainfall, extensive flooding can result, especially in low-lying, low relief coastal plains. Due to the relatively flat terrain found across South Florida, the drainage of ponded water tends to occur slowly and is a complicated manner. In the past 50 years, many of the heaviest rainfalls have been caused by tropical cyclones (Abtew and Huebner 2000; Franklin and Brown 2000; Herbert et al. 1997). Table 2 depicts selected Florida rainfall totals for tropical cyclones.

Quite often minimal strength storms cause a major hazard due to flooding, as illustrated by Hurricane Irene (1999). Hurricane Irene began over the southwestern Caribbean Sea in early October. Signs of the strengthening system were not apparent until October 11, 1999. As the storm moved over Cuba, it finally reached hurricane status over the Florida Straits on October 15. The hurricane made landfall on the mainland of Florida at Flamingo by late afternoon October 15. As the storm crossed South Florida and approached North Carolina it continued to intensify while depositing copious amounts of rainfall. After the hurricane made landfall in North Carolina it

Table 2. Selected Florida rainfall totals in connection with tropical cyclones (Abtew and Huebner 2000; Franklin and Brown 2000; Herbert et al. 1997).

Storm Name/Year	Rainfall (inches)	Path	Remark
Hurricane King (1950)	14.19	Miami to Georgia through Central Florida	Rainfall observed in Orlando
Tropical Storm (1951)	15.72	Fort Myers to Vero Beach	Rainfall observed in Bonita Springs
Hurricane Betsy (1965)	10.89	Florida Keys and the tip of Florida	Rainfall observed at Homestead AFB
Tropical Storm Dennis (1981)	20.38	Cape Sable to Cape Canaveral	Rainfall observed in Kendall
Tropical Storm Marco (1990)	4.78	Keys to Cedar Key along the west coast	Rainfall observed at McDill AFB
Hurricane Andrew (1992)	6.9	Homestead to Everglades City	Estimated at Homestead
Tropical Storm Gordon (1994)	16.0	Key West to Cape Canaveral	Rainfall observed in Naples
Hurricane Erin (1995)	8.81	Vero Beach to North Tampa	Rainfall observed in Melborne
Tropical Storm Jerry (1995)	16.18	Jupiter to Cedar Key	Rainfall observed in Naples
Hurricane Irene (1999)	17.46	Flamingo to Jupiter	Rainfall observed in Boynton Beach
No-Name Storm/ Tropical Storm Leslie (2000)	17.50	Florida Keys to Daytona Beach	Rainfall observed in South Miami
Tropical Storm Barry (2001)	4.22	Santa Rosa Beach to Georgia	Rainfall observed in Sawgrass Mills

continued in a northeast direction where it finally became absorbed by a much larger extratropical low near Newfoundland (Avila 1999). By October 18 all warnings where discontinued everywhere they had still been affect.

Hurricane Irene caused large amounts of damage for Southern Florida due to torrential rains. Flooding lasted for a week in many areas of South Florida including a maximum rainfall total reaching 14.08 inches over a three-day period in Broward County. Refer to Appendix A for a listing of all 24-hour rainfall accumulations for rain gauges in Broward County. Many areas within Broward and Miami-Dade Counties received the 100-year, 24-hour, 48-hour, and 72-hour rainfall during this particular storm, as depicted in Table 3 (Abtew and Huebner 2000). Water levels in canals and water conservation areas rose dramatically. Flows through water control structures located throughout the South Florida Water Management District (SFWMD) showed significant increase. The S9 pump, whose purpose is to pump excess precipitation via the South New River Canal into Water Conservation Area 3A, achieved a historical maximum pumping daily average of 2,539 cubic feet per second (cfs) on October 16, 1999 (Abtew and Huebner 2000). Ponded water in many areas of Broward County caused a major disruption in resident's lives. Severely flooded areas located in Broward County are depicted in Figure 2. Although flooding did occur in parts of the Broward County SFWMD, it was determined that all primary systems including the C-11 (South New River Canal) performed as designed, and flooding was attributed to excess rain (Shweigart 1999).

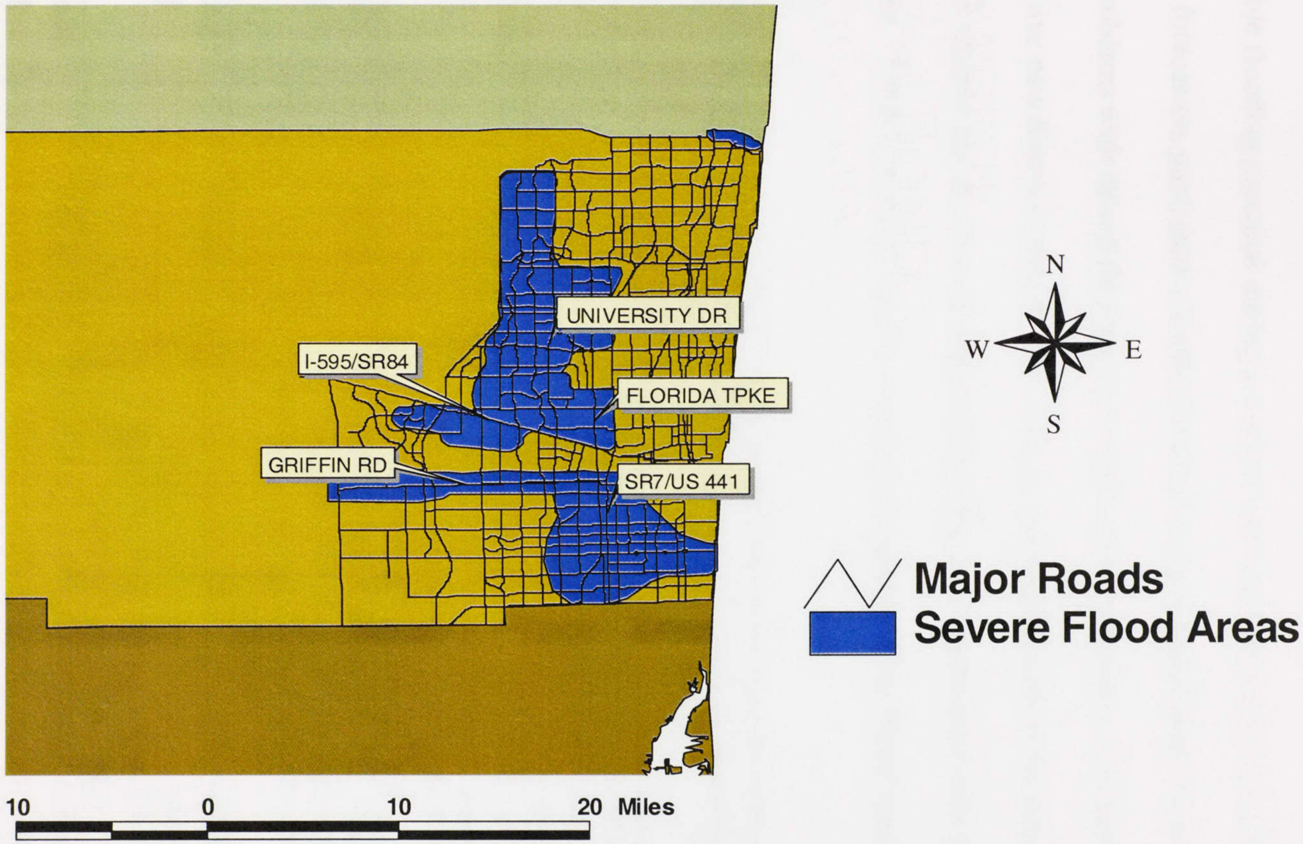
A total amount of damage for Florida has been estimated at $800 million; $600 million of that alone is a result of damages in Miami-Dade, Broward, and Palm Beach Counties (Aliva 1999). Hurricane Irene generated flood insurance claims from 6,200 people totaling $100 million (DCA 2001). Inland flooding lasted for almost a week in some residential communities, displacing several hundred persons and isolating thousands.

In October 2000, a no-named tropical storm that later developed into Tropical Storm Leslie, caused major flooding in South Florida. As the tropical disturbance made its way north through Florida, it became stalled on October 3 and a broad band of heavy rainfall became stationary across Southeast Florida. Accumulations of 12 to 18 inches extended from Southeast Miami-Dade to Southeast Broward County (Franklin and Brown 2000). Southeast Broward County sustained an average of 10 to 12 inches of rain over a 24-hour period. At the same time, northern sections of Broward County received 4 to 6 inches of rain. Enormous amounts of property damage resulted during the pre-depression stage of the No-Name Storm. Total damage for South Florida was estimated at $700 million with $500 million in agricultural damage (Franklin and Brown 2000). A State of Emergency was declared on Thursday following the dissipating rains. Emergency Management Officials noted problem areas in Broward County at the following locations: Hallandale Beach, Hollywood, and Pembroke Park (Click10.com 2000). Flooded roadways made it impossible to drive, leaving entire communities stranded in cars or wading through potentially harmful flooded areas.

Table 3. Maximum 24, 48, and 72-hour rainfall totals at county stations and the corresponding reported return period for Hurricane Irene (Abtew and Huebner 2000).

County	Station	24-hour Total (in)	Return Period (yr)	Station	48-hour Total (in)	Return Period (yr)	Station	72-hour Total (in)	Return Period (yr)
Broward	3A-SW	8.97	100	MIRAMAR	12.97	100	FTL	14.08	100
Miami-Dade	COOPER	10.30	100	COOPER	14.87	100	COOPER	15.17	100
Palm Beach	WPBFS	10.35	25	S41	16.25	100	S41	17.46	100
Martin	S80	6.82	10	JDWX	9.42	10	JDWX	10.72	25

Figure 2. Map depicting severe flood areas with in Broward County following Hurricane Irene (1999). Data provided by the South Florida Water Management District.



According to a poll conducted by Florida International University in conjunction with the International Hurricane Research Center in the spring of 2000, 90 percent of South Florida residents responded that they would like to see a rainfall index created to warn of possible flooding potential during a tropical cyclone (Leatherman and Anderson 2000). Local forecasters published a South Florida Hurricane Flood Index in response to the ensuing problems with inland flooding and a demand for solutions. The scale is comprised of five new South Florida flood-warning categories based on the amount of rainfall and the degree and duration of expected flooding to be associated with the tropical cyclone. Table 4 explains the five warning categories of the Flood Index (Merzer 2000).

Table 4. South Florida Hurricane Flood Index.

Category	Expected Flooded Area (Inches)	Description
Minor/Urban Advisory	2-4	Side street, parking lot, isolated structural flooding, minor agricultural damage; lasting 8 hours metro, 1 day inland
Moderate Flood Warning	5-9	A few main roads impassable, widely scattered structural flooding, moderate agricultural damage; lasting 8-24 hours metro, 2-6 days inland
Major Flood Warning	10-15	A few major roads impassable, scattered structural flooding, major agricultural damage; lasting 1-3 days metro, 1-2 weeks inland
Severe Flood Warning	16-20	Some major roads impassable, widespread inland structural flooding, severe agricultural damage; lasting 4-6 days metro, 2-3 weeks inland
Extreme Flood Warning	20- +	Many major roads impassable, widespread metro structural flooding, catastrophic agricultural damage; lasting 1-2 weeks metro, 1+ month inland

The purpose of this index was to relay to the public the dangers of flooding during a hurricane event. Although this is a step in the right direction, discrete information relaying specific areas susceptible to inland flooding is still lacking. Residents along the Broward County coast must deal with storm surge and extreme rainfall events, making them vulnerable to inland flooding. Current flood maps in many areas such as South Florida lack the accuracy necessary to predict urban flooding inland.

2.3 Flood Protection

In 1948, Congress authorized the Central and Southern Florida (C&SF) Project, the predecessor to the South Water Management District (SFWMD). The major purpose of this project was to provide flood control and water supply for municipal, industrial, and agricultural uses. Although the C&SF project network can be found throughout SFWMD, the system is mainly concentrated in Broward, Miami-Dade, and Palm Beach Counties. Broward County is found in the Lower East Coast Service (LEC). Currently, this system occupies three Water Conservation Areas (WCA), 1,800 miles of canals and levees, 25 major pumping stations and 200 large and 2,000 small water control structures.

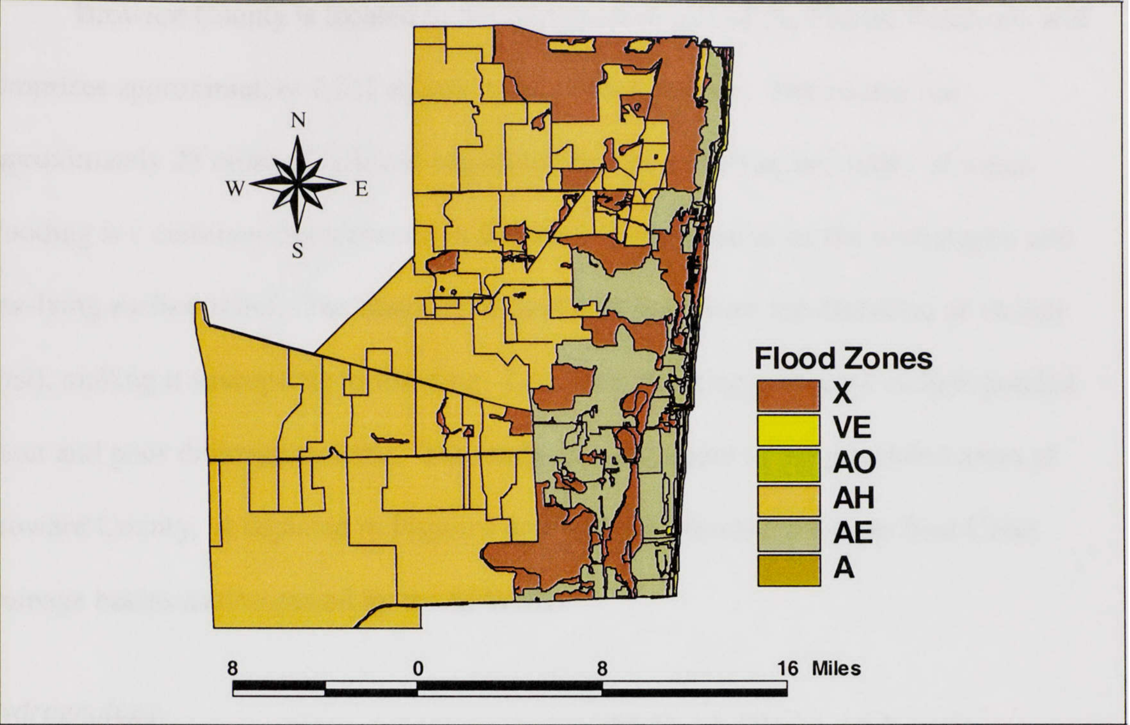
Through the wet season, this system maintains the low water levels in the canals in anticipation of hurricane storm surge and runoff from excess precipitation. Flood control is enhanced with a network of pumping stations that allow the transfer of excess water from canals into the WCA. During drought, water stored in impoundment areas is re-routed into the canal systems where the water helps maintain groundwater levels in the Biscayne aquifer. During the past five years, SFWMD has witnessed the effects of inland flooding associated with hurricanes and how the current network can handle excess precipitation. Since Hurricane Irene, millions of dollars have been reinvested into the C&SF project with the creation of several new pumping stations that can handle the excessive water in avoidance of a dire flooding situation. However, complete flooding prevention is probably not possible in South Florida. Even when canals are brought to levels that will enhance the ability of local drainage facilities to drain excessive excess precipitation to the primary canal, backup will still occur in low-lying areas or in areas with poor connections to drainage systems.

The purpose of this program is not to prevent but to reduce flooding levels and shorten the duration of standing floodwaters. Not only does the C&SF project include flood protection facilities, but also identifies areas within SFWMD where flooding is a problem and non-structural approaches are necessary. These areas would include floodplains and flood prone areas. SFWMD defines a floodplain as "land area that may be submerged by floodwaters from a river, lake, or coastal waters; but should not include isolated low-lying areas which may be inundated due to a lack of drainage" (SFWMD 1995).

Currently, the major method used to determine the probability of flooding for a particular property is the use of the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMs). FIRM maps are limited to riverine and coastal flooding only. These maps were developed for the purposes of regulating land use development and delineating flood-prone areas; more specifically the special flood hazard areas and the flood risk premium zones applicable to a community, and establishing flood insurance premium rates. FIRM maps were created after detailed Flood Insurance Studies (FIS) were conducted in the late 1970's and early 1980's. Special Flood Hazard Areas (SFHAs) identify an area with a one-percent chance of being flooded in any given year; hence the property is in the 100-year floodplain (FEMA 2001). Information relayed on these maps is based on historic, meteorologic, and FIS using hydrologic and hydraulic data as well as open-space conditions, flood control works, and development. The Broward County Flood Zones are shown in Figure 3. South Florida does not generally experience riverine/canal flooding problems due to the controlled nature of the surface water system. Most often flooding is the result of ponding caused by the low-lying topography and antecedent moisture conditions of the soils after heavy rains.

Areas prone to flooding caused by ponding can be identified through flood studies and storm reports conducted by the SFWMD. These types of reports provide a historical record of areas with continuous problems with flooding. Specific areas are identified, peak flood elevations are recorded, meteorological factors that caused the storm are recorded, and the performance of the C&SF system is noted. Unfortunately this information tends to be poorly organized and is not readily available to the public for decision-making purposes.

Figure 3. Map depicting the FEMA flood zones for Broward County. Zones are defined in the preceding table (FEMA 2001).



Zone Label	Description
A	Zone A is the flood insurance rate zone that corresponds to the 100-year floodplains that are determined in the Flood Insurance Study (FIS) by approximate methods. Because detailed hydraulic analyses are not performed for such areas, no base flood elevations (BFEs) or depths are shown within this zone. Mandatory flood insurance purchase requirements apply.
AE and A1-A30	Zones AE and A1-A30 are the flood insurance rate zones that correspond to the 100-year floodplains that are determined in the FIS by detailed methods. Mandatory flood insurance purchase requirements apply.
AH	Zone AH is the flood insurance rate zone that corresponds to the areas of 100-year shallow flooding with a constant water-surface elevation (usually areas of ponding) where average depths are between 1 and 3 feet. Mandatory flood insurance purchase requirements apply.
AO	Zone AO is the flood insurance rate zone that corresponds to the areas of 100-year shallow flooding where average depths are between 1 and 3 feet. Average flood depths derived from the detailed hydraulic analyses are shown within this zone. In addition, alluvial fan flood hazards are shown as Zone AO on the FIRM. Mandatory flood insurance purchase requirements apply.
VE	Zone VE is the flood insurance rate zone that corresponds to the 100-year coastal floodplains that have additional hazards associated with storm waves. Mandatory flood insurance purchase requirements apply.
B, C, X	Zones B, C, and X are the flood insurance rate zones that correspond to areas outside the 100-year floodplains, areas of 100-year sheet flow flooding where average depths are less than 1 foot, areas of 100-year stream flooding where the contributing drainage area is less than 1 square mile, or areas protected from the 100-year flood by levees. No BFEs or depths are shown within this zone.

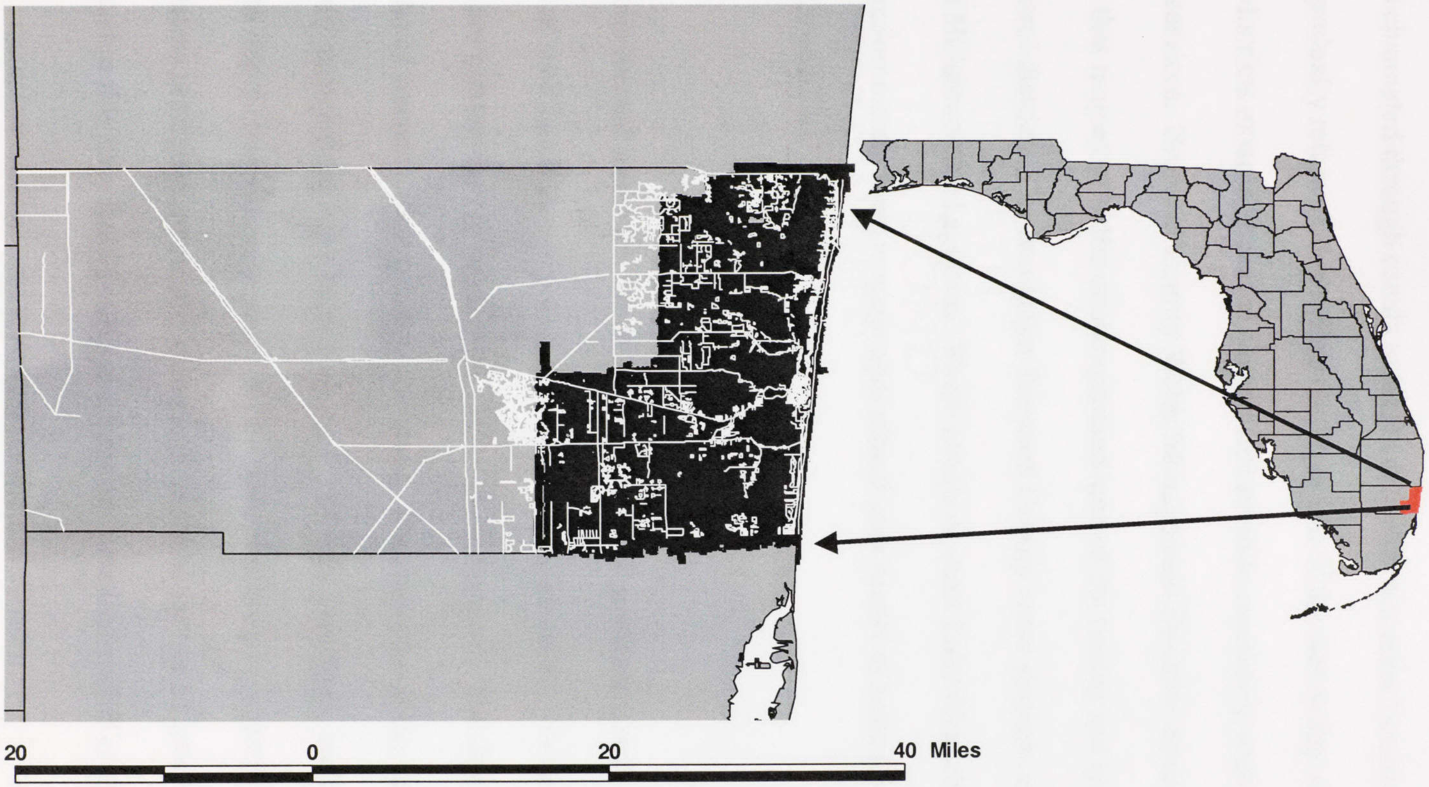
2.4 Subject Area

Broward County is located in the southeastern part of the Florida Peninsula and comprises approximately 1,211 square miles of land surface. The county has approximately 23 miles of Atlantic coastline beaches and 10 square miles of water. Flooding is a common phenomenon in Broward County due to its flat topography and low-lying surface relief. The majority of land area lies below the elevation of 16 feet (msl), making it susceptible to flooding. Localized flooding problems include ponded water and poor drainage systems. The study area is located in the populated areas of Broward County, as depicted in Figure 4 and will encompass the Lower East Coast drainage basins as designated by the SFWMD.

Hydrogeology

South Florida contains two principal aquifer systems: the Surficial Intermediate, and Floridian Aquifer systems. The Floridian Aquifer's groundwater is contained in a confined aquifer that allows it to be used in artificial storage and recovery programs. The principal aquifer system of Broward County is the Biscayne aquifer, which is considered a part of the Surficial Intermediate aquifer system. The Biscayne aquifer is a surficial aquifer composed of lightly permeable limestone and less-permeable sandy limestone formed during the Pleistocene age (Miller 1997). The limestone and other carbonate rocks tend to dissolve over time in water making the aquifer extremely porous. This aquifer has a direct hydraulic connection with streams, canals, and other man-made surface water bodies, and is therefore continually monitored by SFWMD.

Figure 4. The project subject area (shown in black). Areas shown in white represent the major canals throughout Broward County, Florida.



The canals constructed in Broward County were created for the purpose of draining the land for agricultural and settlement purposes. Excess precipitation caused by rainfall is channeled through canals to large impoundment areas bounded by levees. The water is gradually released, depending on the extent of the wet or dry season. Special drainage districts exist in Broward County that provide secondary water management and drainage services. Broward County Water Management Division deals with flooding problems that may exist in the unincorporated area of the county not lying within a local water control district. The two major Broward County canal systems are the North New River and Hillsboro canal systems. These canals connect Lake Okeechobee to WCA2 and are predominately used to route agricultural area runoff to Lake Okeechobee and WCA1, 2A and 3A

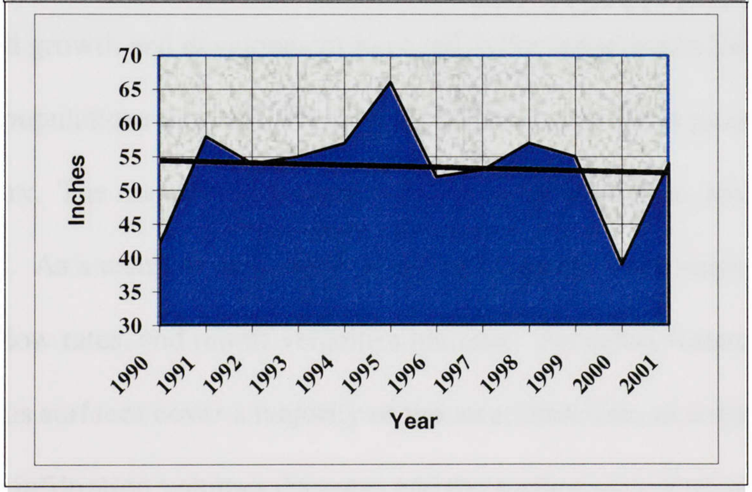
Soils

Soils located along the South Florida Coast are generally sandy and can be classified as well to excessively well drained when undisturbed. Natural surface materials are predominately sand, marl, and organic material. The dominant soils in this area consist of Arents-Urban Land Association. The majority of the study areas located in these soil associations have been built up with roads, buildings, and parking lots, creating an impervious drainage area. When water infiltration is restricted, ponding or surface excess precipitation usually ensues. Due to the increased urban complex, the soils located in this area drain poorly and have an increased runoff capacity.

Climate

South Florida is a semi-tropical climate with wet and dry seasons. The average January temperature is 68.6 degrees Fahrenheit and the average August temperature is 82 degrees Fahrenheit. The source of all fresh water in Florida is through precipitation. Much of the area, including Broward County, can receive more than 75 percent of its annual rainfall during the rainy season, (June through September), which coincides with hurricane season (SFWMD 1995). Rainfall during this period is attributed to daily convective thunderstorms and other weather systems such as tropical storms, depressions, and hurricanes On average, South Florida has received 52 inches of rainfall a year over the last decade. Figure 5 depicts the annual rainfall for Southern Florida during the past decade (SFWMD 2000).

Figure 5. Graph depicting the annual rainfall for South Florida with an average of 52 inches per year.



South Florida water resources rely heavily upon rainfall associated with tropical cyclones. During the rainy season, the local water table level is usually between 2 to 4 feet below the ground surface. However, drought conditions can drop the water table to 7 feet below the ground surface. Due to its shallow water table, the rate of runoff generation in South Florida is considered to be extremely high when compared to other parts of the country.

Land Use and Development Trends

Broward County has experienced pronounced land cover changes in the past 20 years, depicting a rapid urbanization. Broward County is being subjected to rapid development and population increase, and has the second largest population among counties located in Southern Florida reaching approximately 1.5 million people. This measures to approximately 1,088 persons per square mile. It has been estimated that 88 percent of Broward County's population is located in incorporated areas; Fort Lauderdale, Hollywood, and Coral Springs having the greatest population.

Increased growth and development have led to the reduction in the natural floodplain. As populations increase, the pressure to develop in flood prone areas has become necessary. The majority of landuse is commercial, industrial, and dense residential areas. As a result of man-made modifications to the landscape, runoff volumes, peak flow rates, and runoff velocities increase. An urban watershed is one in which impervious surfaces cover a majority of the area; therefore, as urbanization increases, water infiltration volumes decrease and the surface excess precipitation volumes increase; all of which may lead to increased flooding.

Chapter 3. Methodology

Geographic Information Systems (GIS) have become a staple technology in the use of managing and analyzing spatial operations and data. It is a database system that was designed to allow users to work with data referenced by spatial and/or geographic coordinates allowing for complex spatial relationships to be assessed and studied. GIS was used as the main platform for the multi-class index overlay analysis herein presented.

This method of analysis was chosen because it is predominately used to analyze map layers in a weighted combination and allows for more flexibility when compared to other models such as a Boolean operation. The multi-class index overlay model is based on subjective empirical models, where the researcher assigns the weights and scores. Both ArcView and ArcGIS software programs were implemented to complete the various tasks required to perform the multi-index overlay analysis defined by the following equation:

$$S = (\sum_{i}^{n} SiWi)/(\sum_{i}^{n} Wi) \qquad (2)$$

where S is the weighted score for an area object (polygon, pixel), Wi is the weight for the I-th input layer, and Si is the score for the classes in the I-th layer, (Bonham-Carter 1994). As defined by the equation, classes occurring on each input layer (in this case: excess precipitation, elevation, and slope) are assigned a range of scores and the map layers themselves receive different weight. The original class values for each input layer are reclassified using a chosen range of scores; the researcher defines the range of the score. There is no limit on the numerical range of the scores; the only condition being that the scores be real numbers chosen according to a similar scheme for each input layer. For example, the class (pixel) scores can range from 1 (the worst case scenario) to 9 (the best case scenario) for each input layer. Scores are then multiplied by the input layer weight, as shown in the above equation.

This analysis allows for different flooding scenarios to be tested by modifying the class scores and layer weights, reflecting the judgment of the user. As such, the output of the model can be tested against known events and the scores and weights can be adjusted accordingly until the output matches the known events. Figure 6 demonstrates the framework of the methodology used in this study. There are three main components to this framework including the acquisition and development of data layers, the calibration of scores and weights, and performing the final multi-class index overlay method using a predictive 100-year, 24-hour storm event.

3.1 Data Layers

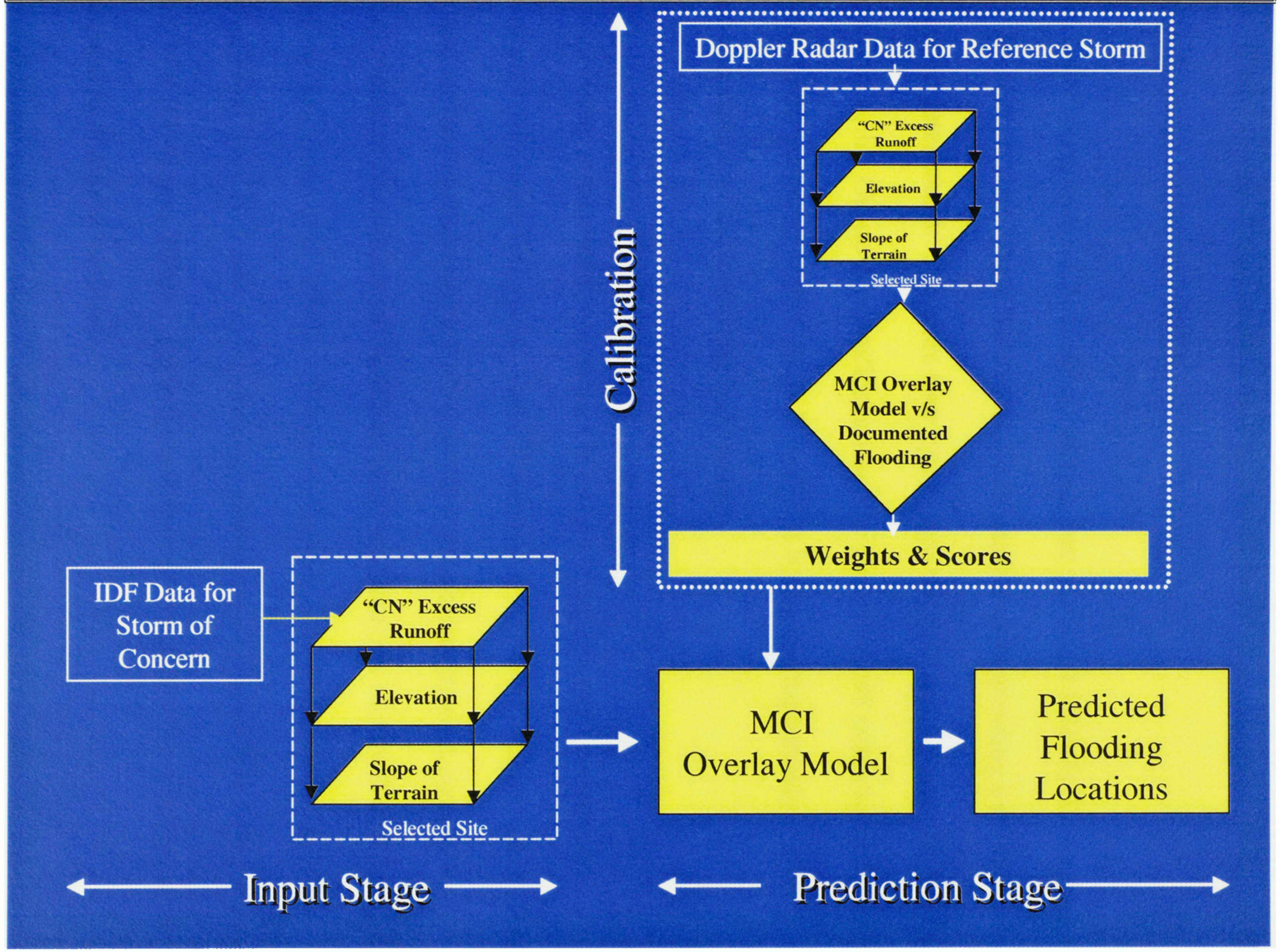
The multi-class index overlay model to be used in this analysis is composed of three data layers: excess precipitation depth, elevation, and slope. The following is a detailed description of the three data layers and their importance in this analysis.

Excess Precipitation Depth: The SCS Curve Number Method

An important aspect of determining the freshwater flooding potential of an area is the determination of the depth of rainfall to be expected at a particular location. Surface runoff, also known as excess rainfall or excess precipitation, is the part of precipitation greater in volume than the combined interception, depression-storage, evaporation, and infiltration volumes (Roberson et al. 1998). The U.S. Soil Conservation Service (SCS) Curve Number (CN) method, developed by hydrologists over four decades, is a widely accepted method used to determine runoff. Precipitation values used in combination with a CN analysis allow researchers to estimate probable excess precipitation.

The USDA Natural Resources Conservation Services (formerly the Soil Conservation Service) created soil survey maps for most of the United States. For decades this organization has developed equations and conducted experiments to determine reliable models for predicting peak volume and surface water discharges during storm events. The SCS excess precipitation Curve Number *(CN)* was developed for the United States as an index that represents the combination of a hydrologic soil group, antecedent moisture conditions, and land use of a watershed (McCuen 1998). The CN method attempts to account for the initial abstraction (Ia) of rainfall and the infiltration rate after excess precipitation begins (Roberson et al. 1998). Initial abstraction can be defined as the interception and depression storage plus the amount of infiltration that occurs before excess precipitation begins.

Figure 6. Framework of the methodology used for the analysis.



In the scientific literature, many models exist that use a CN analysis as a component for research (Zhang et al. (1999), Zheng and Baetz (1999), Tao and Kowen (1989)). In each hydrologic model, excess precipitation depth was determined through using the CN Analysis. Currently the CN method is used by the FLDOT and various engineering firms to perform drainage studies in Florida.

In order to perform a CN analysis a researcher must first identify the varying soil types for the subject area. Once the soil is identified, the corresponding hydrologic soil group must be determined. There are four hydrologic soil groups based on the infiltration capacity of the soils. Group A classification has the lowest runoff potential and Group D the highest runoff potential, with Groups B and C in between; respectively. Table 5 lists a detailed description of the hydrologic soil groups.

A CN table is then used to select a CN value for a particular landuse and corresponding hydrologic soil group. The CN method is empirical and estimated from the various land surface characteristics including land use, soil hydrologic condition, antecedent moisture condition, and based on observed behavior of runoff as a function of precipitation (Roberson et al. 1998). The curve number is a dimensionless number defined such that $0 \leq CN \leq 100$, for impervious and water surfaces $CN = 100$; for natural surfaces $CN < 100$ (Mays 2001). Table 6 provides curve numbers for selected urban, suburban, and agricultural land use.

Table 5. Hydrologic Soil Group Descriptions (Roberson et al. 1998; McCuen 1998; Mays 2001).

Group	Minimum Infiltration rate (in/hr)	Description
A	0.30-0.45	Soils having a high infiltration rate. Well-drained sand and gravel; Deep loess; aggregated silts. Low runoff potential
B	0.15-0.30	Soils having a moderate infiltration rate. Moderate to well drained soils; moderately fine to moderately coarse texture such as shallow loess and sandy loam.
C	0.50-0.15	Soils having a slow infiltration rate when wet. Poor to moderately well-drained soils; moderately fine to fine texture such as clay loams; shallow sand, loam; soils in low organic content; and soils usually high in clay content.
D	0.00-0.05	Soils having a very slow infiltration rate. Poorly drained, clay soils with high swelling potential, permanent high water table, claypan, heavy plastic clays; certain saline soils; or shallow soils over nearly impervious layer(s). High runoff potential.

Table 6. Runoff Curve Numbers (Roberson et al. 1998; McCuen 1998; Mays 2001).

		Curve Numbers for Hydrologic Soil Group			
Land Use Description		**A**	**B**	**C**	**D**
Fully developed urban areas[a] (vegetation established)					
Lawns, open spaces, parks, golf courses, cemeteries, ect.					
Good condition; grass cover on 75% or more of the area		39	61	74	80
Fair Condition; grass cover on 50% to 75% of the area		49	69	79	84
Poor condition; grass cover on 50% or less of the area		68	79	86	89
Paved Parking lots, roofs, driveways, ect.		98	98	98	98
Streets and Roads					
Paved with curbs and storm sewers		98	98	98	98
Gravel		76	85	89	91
Dirt		72	82	87	89
Paved with open ditches		83	89	92	93
	Average % impervious[b]				
Commercial and business area	85	89	92	94	95
Industrial districts	72	81	88	91	93
Row houses, town houses, and residential with lot sizes 1/8 acre lot size	65	77	85	90	92
Residential: average lot size					
¼ acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
½ acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acre	12	46	65	77	82
Developing urban areas[c] (no vegetation established)					
Newly graded area		77	86	91	94

[a] For land uses with impervious areas, numbers are computed assuming that 100% of runoff from impervious areas is directly connected to the drainage system. Pervious areas (lawns) are considered to be equivalent to lawns in good condition and the impervious areas have a *CN* of 98.

[b] Includes paved streets.

[c] Use for the design of temporary measures during grading and construction. Impervious areas as percent for urban areas under development vary considerably. The user will determine the percent impervious and then recalculate the *CN*.

An accumulated precipitation volume must be selected for the calculation. This can be determined in several ways; either known precipitation values or probable precipitation values. For this analysis two types of precipitation values will be input into the CN equation: known precipitation values in the form of Doppler radar data will be used during the "calibration stage" of the analysis and probable precipitation totals in the form of values extracted from IDF curves will be used during the "prediction stage" of the analysis.

Once the CN and precipitation variables have been identified, the analysis can be performed. The following equations are the basis of the SCS CN method:

$$S = (1000/CN) - 10 \qquad (3)$$

$$Ia = 0.2*S \qquad (4)$$

$$Q = [(P-Ia)^\wedge 2]/[(P-Ia)+S] \qquad (5)$$

where:
S = potential maximum retention after runoff begins (in)
CN = runoff curve number
Ia = initial abstraction (in)
P = rainfall (in)
Q = runoff (in)

If a land surface receives a CN value of 100 then excess precipitation will be equivalent to the total amount of precipitation experienced during the storm. If a land surface receives a CN value of less than 100, the depth of excess precipitation is always less than the total amount of precipitation experienced. Further adjustments can be made to the CN based on the existing soil condition, also known as the antecedent moisture condition

(AMC) at the time of the storm. The SCS developed three AMCs, labeled I, II, III. McCuen (1998) defined the conditions as follows:

Condition I: Soils are dry but not to wilting point; satisfactory cultivation has taken place. AMC-I is the lower limit of the moisture or the upper limit of S.
Condition II: Average conditions
Condition III: Heavy rainfall, or light rainfall and low temperatures have occurred within the last five days; saturated soil. AMC-III is the upper limit of moisture or the lower limit of S.

AMC transformations can be viewed in Table 7.

The conditions of soil is an important consideration because in many past flooding situations, pre-existing conditions such as saturated soil, contributed heavily to the inland flooding experienced. For example in connection with Hurricane Diane (1955), also known as the “first-billion dollar hurricane”, approximately 200 deaths and $1 billion in flood damages located in Virginia and New England were the result of rainfall estimates of 10 inches in a 24-hour period. Upon Diane’s arrival, soils in the areas were already completely saturated due to Hurricane Connie (1955). Although heavy rainfall was recorded during Hurricane Diane, the pre-existing soil conditions also contributed to the observed inland flooding. The devastation caused by Hurricane Diane could not have occurred without the extreme importations of moisture to the area carried by the previous storm.

An estimation of *CN* values for urban land use has also been developed by the SCS and is based on a specific percent of imperviousness for the given area. According to McCuen (1998), for urban land uses with percentages of imperviousness different than those shown on already established SCS *CN* Tables, curve numbers can be estimated using a weighted *CN* approach. *CN* values of 39, 61, 74, and 80 are used for hydrologic soil groups A, B, C, and D, respectively.

$$CN_w = CN_p(1-f) + f(98) \qquad (6)$$

where:
f = the fraction (not percentage) of imperviousness
CN_p = the curve number for the pervious portion

An area of increased urbanization usually leads to increased impervious surfaces; thereby effecting the direct excess precipitation within that area.

The *CN* method is widely used and accepted throughout the United States in which to assess excess precipitation quantitatively. This method predominately was chosen for this analysis because parameters include combinations of soil type, soil cover, land use, hydrologic condition, and AMC. Another important variable for the CN analysis is precipitation volume. Varying precipitation values can greatly affect the predicted value of excess precipitation.

Table 7. Transformation of Curve Number (CN) in terms of antecedent moisture condition (NRCS 1964).

CN for condition	Corresponding CN for condition	
AMC II	AMC I	AMC III
100	100	100
99	97	100
98	94	99
97	91	99
96	89	99
95	87	98
94	85	98
93	83	98
92	81	97
91	80	97
90	78	96
89	76	96
88	75	95
87	73	95
86	72	94
85	70	94
84	68	93
83	67	93
82	66	92
81	64	92
80	63	91
79	62	91
78	60	90
77	59	89
76	58	89
75	57	88
74	55	88
73	54	87
72	53	86
71	52	86
70	51	85
69	50	84
68	48	84
67	47	83
66	46	82
65	45	82
64	44	81
63	43	80
62	42	79
61	41	78
60	40	78
59	39	77
58	38	76
57	37	75
56	36	75
55	35	74
54	34	73
53	33	72
52	32	71
51	31	70
50	31	70
49	30	69
48	29	68
47	28	67
46	27	66
45	26	65
44	25	64
43	25	63
42	24	62
41	23	61
40	22	60
39	21	59
38	21	58
37	20	57
36	19	56
35	18	55
34	18	54
33	17	53
32	16	52
31	16	51
30	15	50
25	12	43
20	9	37
15	6	30
10	4	22
5	2	13
0	0	0

Precipitation Data

The potential for inland flooding to occur is dependent upon various factors such as the rate of rainfall, the duration of the storm, and the total accumulation of water. The CN Analysis considers rainfall in inches as the necessary component to determining storm excess precipitation. According to his article, Marks (2000) stated that the varied nature of rainfall makes Quantitative Precipitation Forecasting (QPF) and Quantitative Precipitation Estimation (QPE) in tropical cyclones very complex. However the determination of probable rainfall quantities for a given storm is a necessary component of this analysis. In order to describe rainfall quantitatively, it is necessary to consider the four characteristics of rainfall: duration, volume/depth, frequency, and intensity. Duration is defined as the length of time over which a precipitation event occurs, volume/depth is the amount of precipitation over the storm duration, frequency is the frequency of occurrence of events having the same volume and duration, and the intensity is the volume of the rainfall divided by the duration of the storm (McCuen 1998). Several technologies and analysis exist to determine a probable rainfall amount for an area including: radar, satellite, in-situ observations of the rainfall rate from gages and disdrometers, and frequency analysis.

Intensity-Duration-Frequency Curves

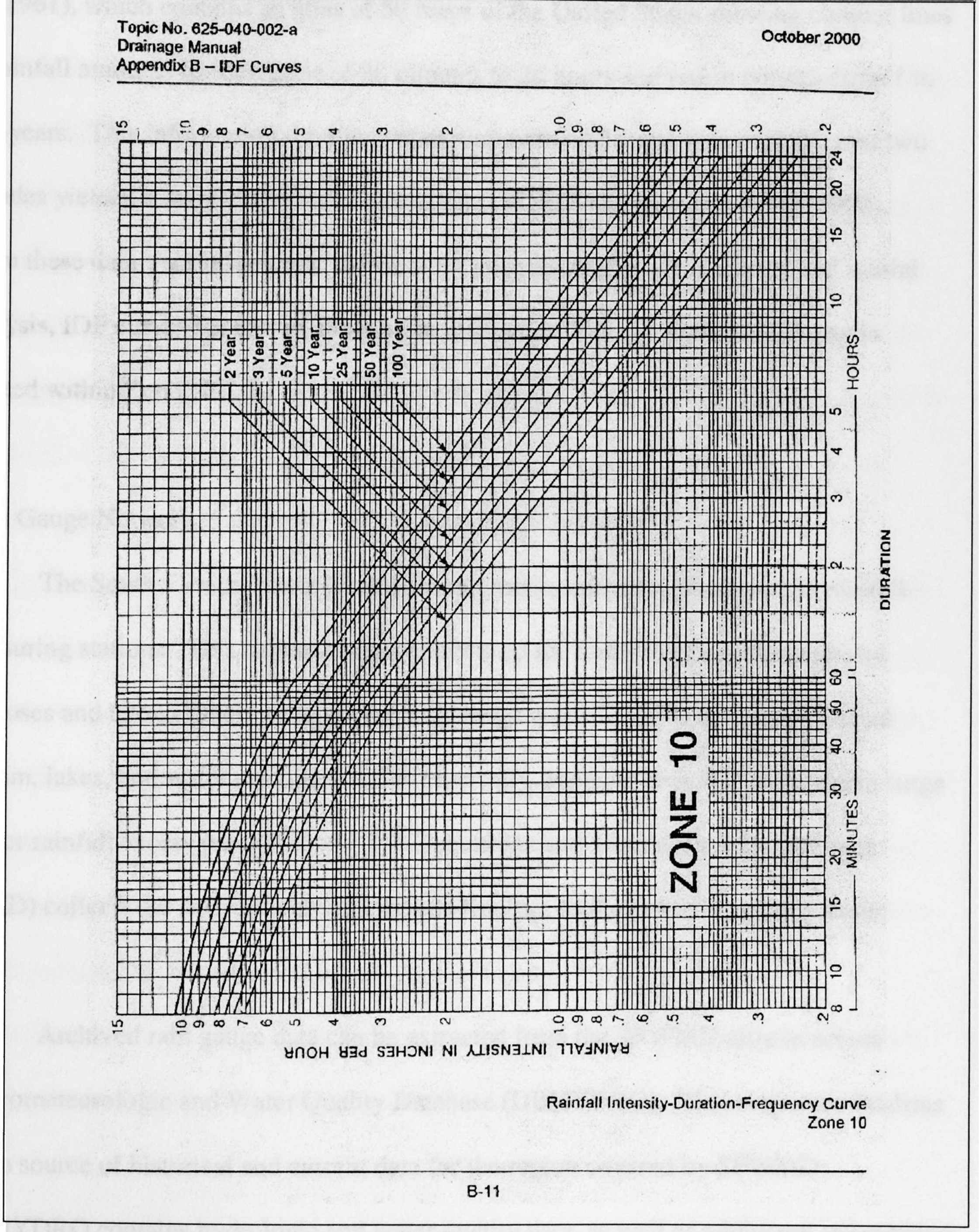
Intensity-Duration-Frequency (IDF) curves are a common tool used by researchers and practitioners for extracting information conveying the characteristics of design storms and as a form of establishing a probable amount of rainfall for a given location. These curves are used as inputs in most hydrologic design models; and are therefore readily available for the entire United States. As depicted in Figure 7, IDF curves display the average rainfall intensity for a given storm duration and return period. The return period can be defined as the average length of time between events having the same depth and duration. The return period and rainfall intensities of excessive storms are needed for the planning and design of drainage systems and other projects that need to consider storm excess precipitation (Wanielista et al. 1996). Information from the IDF curves is determined by finding the intersection of the characteristics for a particular storm.

From IDF curves, the depth of rainfall can be determined through the simple equation:

$$\text{intensity} = \text{depth}/\text{duration} \tag{7}$$

In this type of analysis, depth is assumed to occur uniformly over a particular area. The specified total depth of precipitation resulting from a storm may occur from different combination of intensities and durations. For example a storm with an intensity of 12 in/hr and duration of 0.25 hours would have the same rainfall depth of 3 inches as a storm with an intensity of 1.5 in/hr and duration of 2 hours. Information extracted from the IDF curve gives a researcher an idea of the probable precipitation amount for a given storm frequency commonly expressed in terms of 2, 5, 10, 25, 50, and a 100-year storm.

Figure 7. Intensity-Duration-Frequency Curve for Broward County, Florida. IDF Curves can be located in Chapter 5, Volume 2 of the 1987 "Drainage Manual", in Appendices B and C of the "Handbook for Drainage Connection Permit", and in Appendix B in the October 2000 "Drainage Manual".



Topic No. 625-040-002-a
Drainage Manual
Appendix B – IDF Curves

October 2000

Rainfall Intensity-Duration-Frequency Curve
Zone 10

B-11

The IDF curves for the zones within Florida were developed by the Department of Transportation (FDOT) using depth-duration-frequency data from TP-40 and HYDRO–35 models (FDOT 1987). TP-40 refers to the U.S. Weather Bureau Technical Paper No. 40 (1961), which contains an atlas of 50 maps of the United States showing contour lines of rainfall amounts for durations of 30 minutes to 24 hours and return periods from 1 to 100 years. This information used in conjunction with additional data over the past two decades yielded a supplement to TP-40 called HYDRO-35 (Wanielista et al. 1996). From these data, rainfall records, distribution analysis, regression analysis, and spatial analysis, IDF curves for eleven zones were created for Florida. Broward County is located within Zone 10.

Rain Gauge Network

The South Florida Water Management District currently contains 138 rainfall-measuring stations. This network is generally used for water resource management purposes and allows District employees to manage water levels in the primary canal system, lakes, and water catchment areas especially during events that cause storm surge and/or rainfall excess precipitation. The Operations and Maintenance Department (OMD) collects the network data and reports findings to the public on a daily basis.

Archived rain gauge data can be extracted from the SFWMD remote access Hydrometeorologic and Water Quality Database (DBHYDRO). This corporate database is the source of historical and current data for the region covered by SFWMD. DBHYDRO contains hydrologic and water quality data, as well as additional information about sites, structures, and stations. An Oracle Form application entitled HYDRO_PREP allows users to retrieve data and reports in the desired field.

Doppler Radar

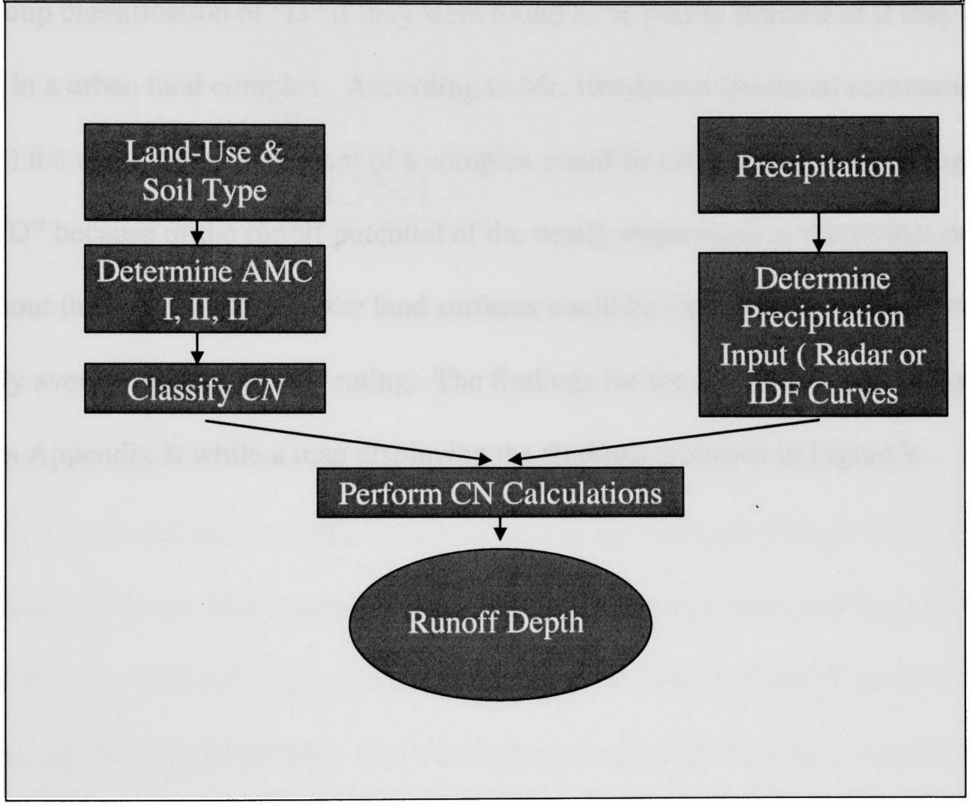
The Next Generation Weather RADar (NEXRAD) program is a joint effort of the Department of Commerce, the Department of Defense, and the Department of Transportation. The effort of these agencies has resulted in a network of Doppler radars referred to as The Weather Surveillance Radar, 1988-Doppler (WSR-88D). The NEXRAD system is a network consisting of 160 WSR-88D radar systems distributed across the continental United States. This system is advanced weather radar that uses the "Doppler effect" to measure motion of clear air and atmospheric phenomena within storms, up to a maximum distance of 230 km from the radar (NERAD Panel 1995). NEXRAD systems obtain weather information based on returned energy. Data readings are determined by the strength of the returned pulse, the time it took the pulse to travel, and the phase shift of the pulse. This system has an increased emphasis on automation, including the use of algorithms and automated volume scans operating in three-dimensional space enabling the user to better identify areas of potential severe weather and analyze the vertical structure of the system. The NEXRAD is about 10 times more sensitive than any of the previous radars and can predict precipitation within approximately 80 nmi of the radar and 140 nmi during intense rain and/or snow storms (NERAD Panel 1995).

There are many advantages in using WSR-88D network radar over conventional radar. The WSR-88D not only provides reflectivity and velocity products, but also numerous derived products. The increased sensitivity of the Dopplers allow the user the ability to view atmospheric conditions, such as cold fronts, dry lines, and thunderstorm gust fronts, that were never before visible within the storms. Also their volume scanning function displays a three-dimensional view of the weather, enabling the user to better identify areas of potential severe weather. Another major advantage of using radar technology for the measurement of precipitation is the ability to cover a large area with high spatial and temporal resolution. However, as discussed by Wilson and Brandes (1979), the precipitation observed at radar beam height may not be representative of the rainfall reaching the ground level due to the radar reflectivity being affected by precipitation growth and evaporation.

The National Climatic Data Center (NCDC) disseminates archived Level III radar data for a number of parameters including, but not limited to, 24-hour rainfall accumulation, 1-hour rainfall accumulation, base reflectivity, and composite reflectivity. There are a total of 24 Level III products routinely available from NCDC that include 7 graphic products in clear-air mode, 11 in precipitation mode, 5 graphic overlays and 1 alphanumeric product. Each product includes state, county & city background map. Storm Total Precipitation (STP) are maps of estimated storm total precipitation accumulation updated hourly over the entire scope. This product is used to locate flood potential over urban or rural areas, estimate total basin excess precipitation and provide rainfall data 24 hours a day.

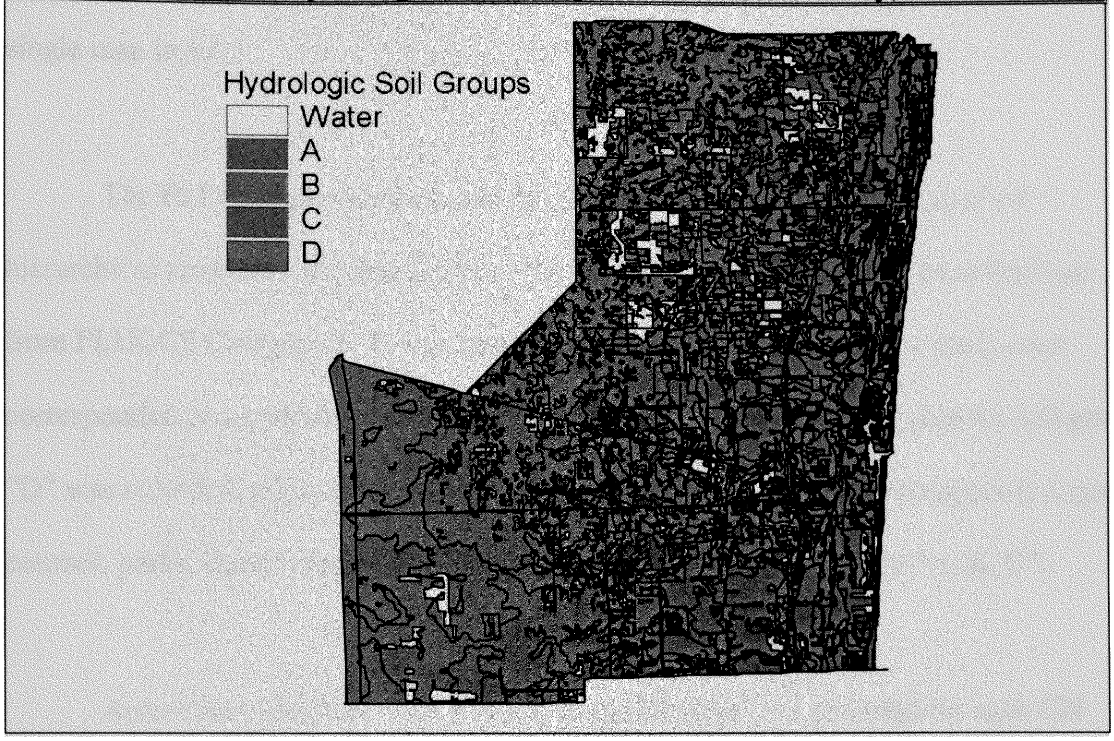
Two major steps are necessary in order to perform the SCS Curve Number analysis – the determination of the Curve Number for a given landuse and the determination of precipitation values to be used in the analysis. Figure 8 depicts the process needed to determine excess precipitation depth using the SCS Curve Number analysis.

Figure 8. Steps necessary to perform a SCS Curve Number analysis.



The first step in performing a SCS CN Analysis within an ArcView platform is to determine the soil coverage for the selected area. Soil coverage data were obtained from the South Florida Water Management District (SFWMD) in the form of ArcInfo export files in vector format. Hydrologic Soil Groups were designated to soil types based on soil information obtained from the U.S. Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS). The hydrologic soil groups for the soils found in Broward were determined by examining the USDA-NRCS Official Soil Series, comparing published soil survey conducted for neighboring counties, and through a correspondence with Warren Henderson, a soil scientist with USDA-NRCS located in Florida. During classification, particular attention was paid to the permeability, drainage, and excess precipitation potentials of the soils. Soils were designated with a Hydrologic Soil Group classification of "D" if they were found to be poorly drained or if they were located in a urban land complex. According to Mr. Henderson (personal communication 9/26/01) the urban land component of a complex could be categorized as hydrologic soil group "D" because of the runoff potential of the nearly impervious surfaces that occur throughout the areas. Although the land surfaces could be variable, the surfaces would probably average an overall "D" rating. The findings for the hydrologic soil groups are found in Appendix B while a map displaying the findings is shown in Figure 9.

Figure 9. Assigned Hydrologic Soil Groups for Broward County, Florida.

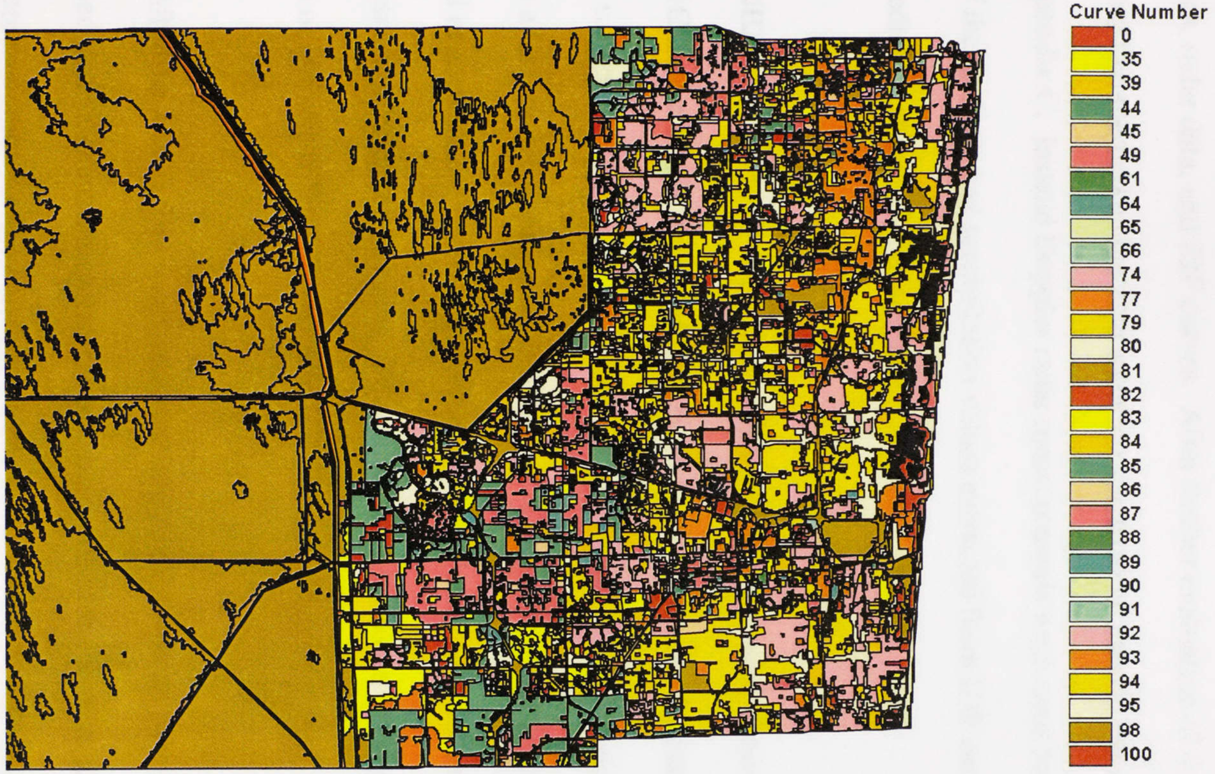


Once the soil types were categorized into the respective hydrologic soil groups, attention was directed to land use coverage. Land cover describes the features, predominately vegetation, that exists over the unit of area delineated at the time of interpretation. Land use describes the activities, management practices or cultural importance of a given area. Land use shapefiles that were digitized and categorized from 1994, 1995, and 1996 aerial photographs were obtained from the South Florida Water Management District (SFWMD). The GIS information was received in vector format, and depicted land use of Broward County in 1995. Using the Florida Land Use and Cover Classification System (FLUCCS) developed by the FDOT (most recently revised in 1999), the land use data were reclassified to correspond with SCS CN Analysis classifications as described in the National Engineering Handbook (NRCS, 1964). This classification is used throughout Florida for mapping both land use and cover into a single map layer.

The FLUCCS provides a broad range of potential classes in a three level hierarchical structure. For this project a curve number was assigned to each land use from FLUCCS Category 2. It was first assumed that all land uses in the study area corresponded to a hydrologic soil group rating of "D". After the CN value for soil group "D" was recorded, adjustments were made for areas outside an urban complex (i.e. golf courses, parks, cemeteries) that were located in hydrologic soil groups "A, B, C".

Antecedent Moisture Conditions I, II and III were also recorded for each CN value. Please refer to Appendix C for a listing of all classifications. A new shapefile was created using the established CN data were for AMC I, AMC II, and AMC III within the subject area. This coverage was then gridded to the same extents as the other data layers used in the analysis (cell size 100 feet, rows 1,433, and columns 1,066). Figure 10 shows a map of CN values for AMC II, the average soil moisture conditions in Broward County, Florida.

Figure 10. Curve Number values for Antecedent Moisture Condition II, the average soil moisture conditions in Broward County, Florida.



The second step in the CN Analysis is the development of precipitation data. Precipitation data is a very important component of the CN Analysis. As part of this analysis three types of precipitation values were examined in the CN Analysis – rain gauge data, radar data, and IDF curves. After further evaluation of the data sets it was determined that the rain gauge data were too sparse to be used in the analysis as referred to in Appendix C. Instead Doppler radar measurements were used for the "calibration stage" of the analysis and precipitation values extracted from IDF curves were used in the final "prediction stage" of the analysis.

NEXRAD Level III radar data for Hurricane Irene were obtained from the National Climatic Data Center (NCDC) in the form of raw binary data files. A software program was created by the IHRC in order to read these Storm Total Precipitation (NTP) files into a GIS environment as an ASCII file. The Storm Total Precipitation data consisted of accumulated precipitation data for every hour on a 1.1 nmi by 1 degree grid with a maximum range of 124 nmi. These data were based on a 0 degree longitude meridian or Universal Time Coordinated (UTC) system.

After the ASCII files were imported into ArcView as an event theme, it was determined that an exact interpolator would be needed for converting the points into an area of representation for the Hurricane Irene storm event. It was decided that a Triangulated Irregular Network (TIN) method would be used because the data points were evenly distributed over a large area. This method created a continuous surface where the space was partitioned into a set of non-overlapping triangles. After the continuous surface was created, the layer was re-gridded to the same extents as the Curve Number data layer to be used in the analysis (cell size 100 feet, rows 1,433, and columns 1,066). Figure 11 shows the radar readings.

Precipitation values for a 100-year storm event were obtained from the FDOT IDF Curves for Zone 10, including St. Lucie, Martin, Palm Beach, Broward, and Miami-Dade Counties. FDOT use the curves when designing flood control and pollution control structures within the various counties. The IDF Curve is located in Figure 7. Rainfall frequencies for 1, 2, 5, 10, 25, 50, and 100-year return periods for 12 and 24-hour storm were examined. By using the rainfall intensity and duration information found on the curves the depth of precipitation could be found. The results for the rainfall depths are indicated in Table 8. This precipitation data would be used in the CN calculations during the final prediction stage of the analysis.

Figure 11. August 14, 15, and 16-rainfall accumulation for Hurricane Irene. Rainfall accumulation has been superimposed over digital orthophotographs for Broward County.

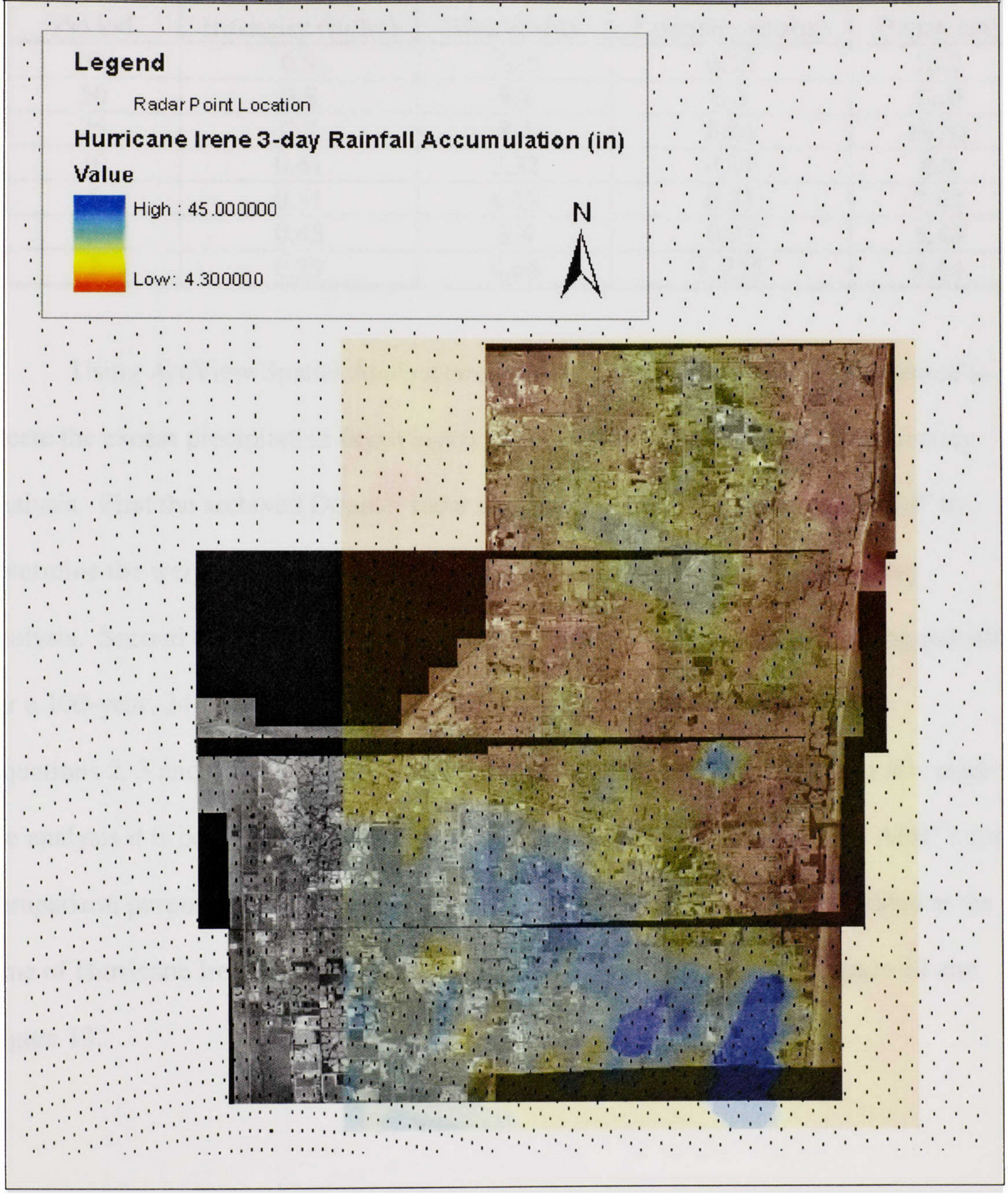


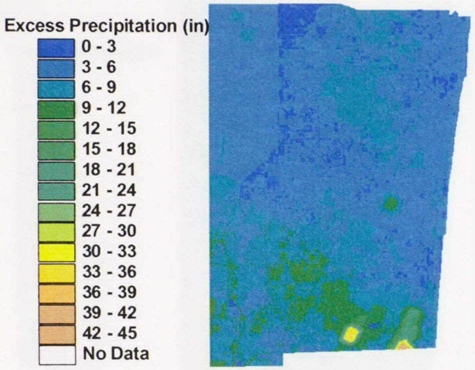
Table 8. Broward County Rainfall Frequencies obtained from an Intensity-Duration-Frequency Curve.

	12 Hour Design Storm		24 Hour Design Storm	
Return Period	**Rainfall Intensity (in/hr)**	**Rainfall Depth (in)**	**Rainfall Intensity (in/hr)**	**Rainfall Depth (in)**
100	0.9	**10.8**	0.55	**13.2**
50	0.8	**9.6**	0.5	**12.0**
25	0.7	**8.4**	0.43	**10.32**
10	0.61	**7.32**	0.37	**8.8**
5	0.51	**6.12**	0.31	**7.44**
3	0.45	**5.4**	0.27	**6.48**
2	0.39	**4.68**	0.235	**5.64**

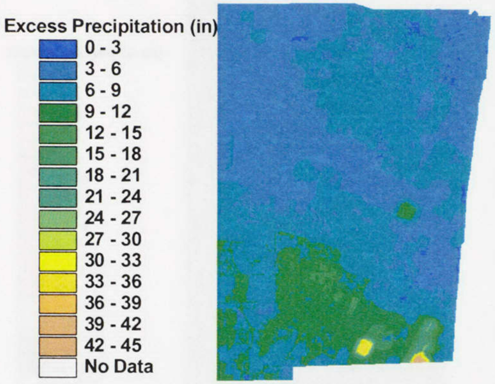
Using ArcView Spatial Analyst two types of CN analyses were implemented to create the excess precipitation depth layers to be used in the multi-class index overlay analysis. First the archived Doppler radar data were used to "calibrate the model" to determine the weights and scales to be used in the final multi scale index overlay analysis. Second the IDF precipitation data were used to determine the flooding potential for a 100-year, 24-hour storm event in the final prediction stage of the analysis. Equations 2, 3 and 4 were used to perform the analysis in map calculator. At this stage in the analysis it is beneficial to create excess precipitation outputs for all three AMC's for comparison purposes, even though Broward County soil was extremely saturated at the time of Hurricane Irene. The outputs for these data layers are shown in Figure 12 and Figure 13.

Figure 12. Curve Number excess precipitation results for Antecedent Moisture Conditions I, II, and III using October 14, 15, 16, 1999 24-hour Doppler radar data. The map data layers are used for calibration purposes for the model.

AMC I



AMC II



AMC III

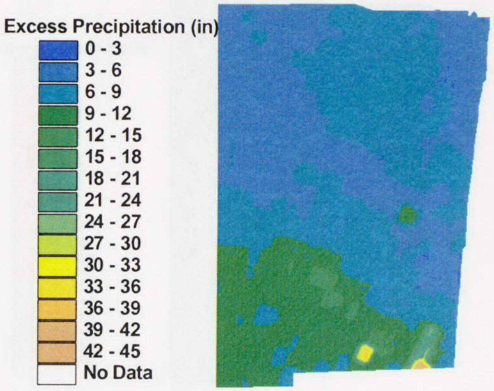
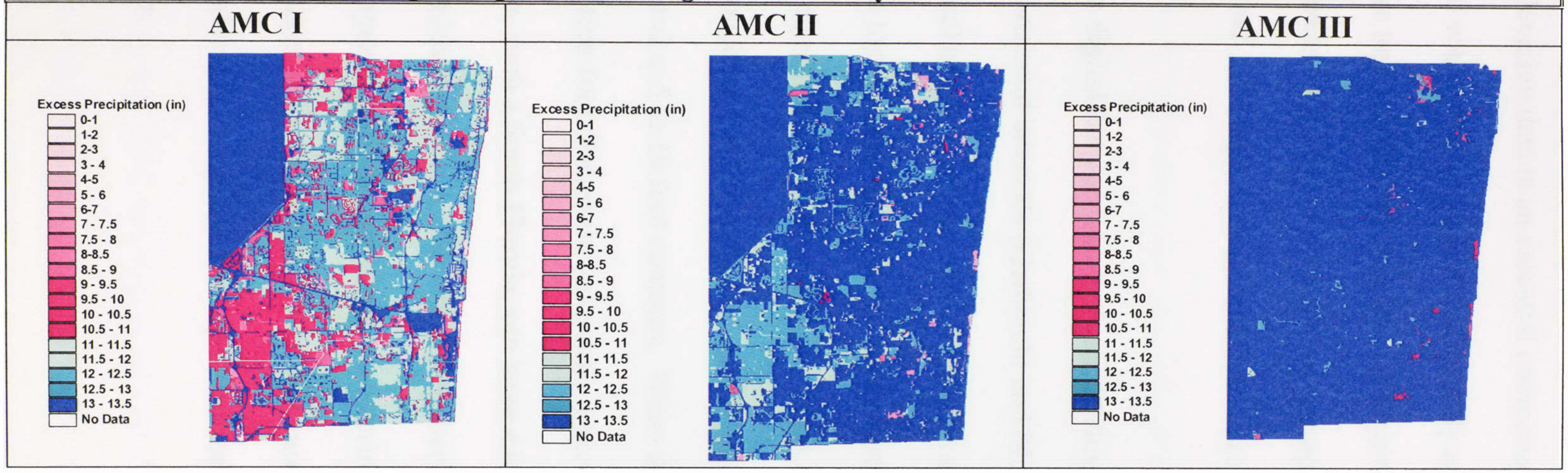


Figure 13. Curve Number excess precipitation results for Antecedent Moisture Conditions I, II, and III using IDF Curve information for a 100-year, 24-hour storm event. The map data layers are used to determine areas susceptible to flooding during the "prediction stage" of the analysis..



Digital Elevation Data

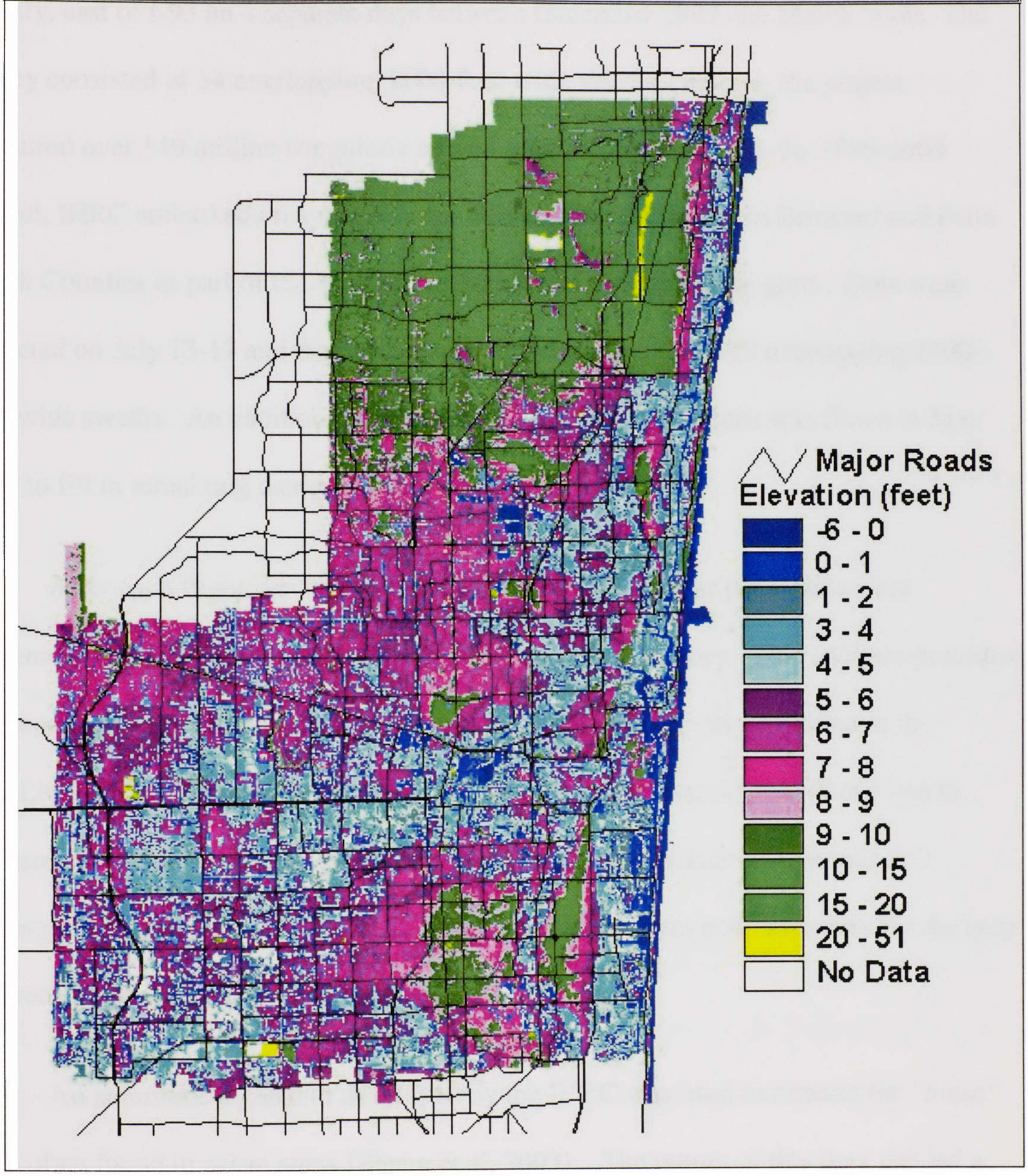
Accurate elevation data is an essential component in the prediction of inland flooding associated with tropical cyclones. Currently many GIS systems are being developed that store topographic information as the primary data for analyzing water resources. Most researchers rely on published topographic maps or Digital Elevation Models (DEMs) when creating a GIS system to analyze hydrological processes.

DEMs are a digital file consisting of terrain elevations for ground positions at regularly spaced horizontal intervals (Garbrecht and Martz 2000). A DEM is based on a grid where each pixel has X Y coordinates and an elevation Z. Researchers have found that high-resolution topographic data is a necessary component when identifying possible flood hazards (Blomgren 1998; Marks and Bates 2000; Garbrecht and Martz 2000). In many locations throughout the United States, topographic information is based upon USGS maps produced at 5 to 10 foot contours. When dealing with low-lying areas such as South Florida, a five-foot discrepancy provides a very large error. Typical DEMs of low relief landscape, such a South Florida, can have a limited vertical resolution resulting in inaccurate determinations of possible drainage patterns. The Airborne Laser Terrain Mapping (ALTM) system provides solutions to receiving more accurate elevation data for many areas. Recent advances in the technology known as ALTM or LIght Detection and Ranging (LIDAR) allows rapid and inexpensive measurement of topography with very high resolution.

The ALTM is an advanced electro-optical instrument designed for the high-speed acquisition of accurate digital elevation information from an airborne platform (Optech 1998). The system consists of high-accuracy laser rangefinder and programmable precision scanners that work in tandem with a high frequency inertial measurement instrument (IMU), and global positioning system (GPS). The rangefinder scans beneath the aircraft, producing a wide swath over which the distance to the ground and angle at which the laser is scanned are measured. The IMU corrects for the aircraft's movements while the GPS receiver, located on the aircraft, records the aircraft's position at fixed intervals. Several ground-based receivers provide differential corrections for a more accurate position estimate. The combination of these three sophisticated technologies into a single instrument mounted onto a twin engine Cesssna 337 airplane allows for measuring of X, Y, Z (elevation), and sometimes I (intensity) coordinates of irregularly spaced ground points on a 200-1000 m-wide swath beneath the flight path (Zhang et al. 2000a; 2000b). This system is capable of producing up to 33,000 measurements per second with a vertical accuracy up to 5.9-7.8 in and nominal horizontal resolution up to 1.6 ft.

The International Hurricane Research Center (IHRC) at Florida International University (FIU) and University of Florida (UF) Geomatics Program were the first educational centers to co-purchase an ALTM OPTECH 1210 system in 1999. Since the purchase of the system, the IHRC has performed various LIDAR studies in the South Florida region, including data acquisition of Broward and Palm Beach County, Florida. Figure 14 shows the current LIDAR coverage for Broward County. The county predominately consists of flat low-lying terrain except for the coastal ridge that runs parallel to the coast and has an elevation of approximately 14 ft. The northwestern section of the county is also slightly elevated, averaging 3.2 ft higher than the remainder of the county. The majority of the low elevation areas are concentrated along the east coast of Broward County and in the center of the study area. It could be speculated that during an extreme precipitation event increased inland flooding would most likely occur in low elevation areas, such as the southwestern portion of the study area.. Areas located below sea-level are predominately canals, water detention areas, or other types of waterways.

Figure 14. Areas currently covered by LIDAR data for Broward County, Florida.



Data Acquisition & Development

In a pilot project, IHRC researchers collected LIDAR data in regions of Broward County, east of I-95 on 4 separate days between December 1999 and March 2000. The survey consisted of 34 overlapping, 2000-foot-wide swaths. In total, the project measured over 140 million irregularly spaced points. Continuing on the 1999-2000 project, IHRC embarked on a much larger data acquisition project in Broward and Palm Beach Counties as part of the Windstorm Simulation and Modeling grant. Data were collected on July 13-17 and August 6- 7, 2001 and consisted of 128 overlapping 2000-foot-wide swaths. An additional deployment consisting of 3 swaths was flown in May 2002 to fill in remaining data gaps.

After each flight, aircraft and ground station GPS carrier phase data were differentially processed to produce a kinematic aircraft trajectory. This analysis provides the geodetic height of the aircraft. The trajectory information was combined in the REALM software with the range, scan, and Inertial Navigation System (INS) data to produce laser return coordinates for each data swath. Swath data were output as 9 column ASCII text files containing the time, x,y,z coordinates and intensities for the laser first return and the second laser pulse return.

An automatic algorithm developed by the IHRC was used to remove the "noise" quite often found in urban areas (Zhang et al. 2003). The output of this data yielded a continuous elevation field absent of trees and buildings. Horizontal coordinates were transformed to NAD83, State Plane, FL East zone feet and elevations were converted from GPS ellipsoidal heights to NAVD88 orthometric heights with the NGS GEOID99 model. For this analysis data gridded at a 100 foot resolution was used.

In total, FIU collected over 700 million LIDAR measurements in Broward and Palm Beach Counties between 1999-2002. The accuracy of the DEMs was tested with an independent dataset consisting of approximately 480 control points. Accuracy was calculated using the Root Mean Square Error (RMSE). The RMSE is the square root of the average of the squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy. Accuracy is reported in measurement units at the 95% confidence level. A 95% confidence level means that 95% of the measurements will have an error of less than or equal to the reported accuracy. If the error is normally distributed with zero mean, the 95% vertical accuracy is equal to 1.96 times the $RMSE_z$ After further analysis it was determined that the Broward County LIDAR data had a reported accuracy of less than 4.7 in (Whitman et al. 2003).

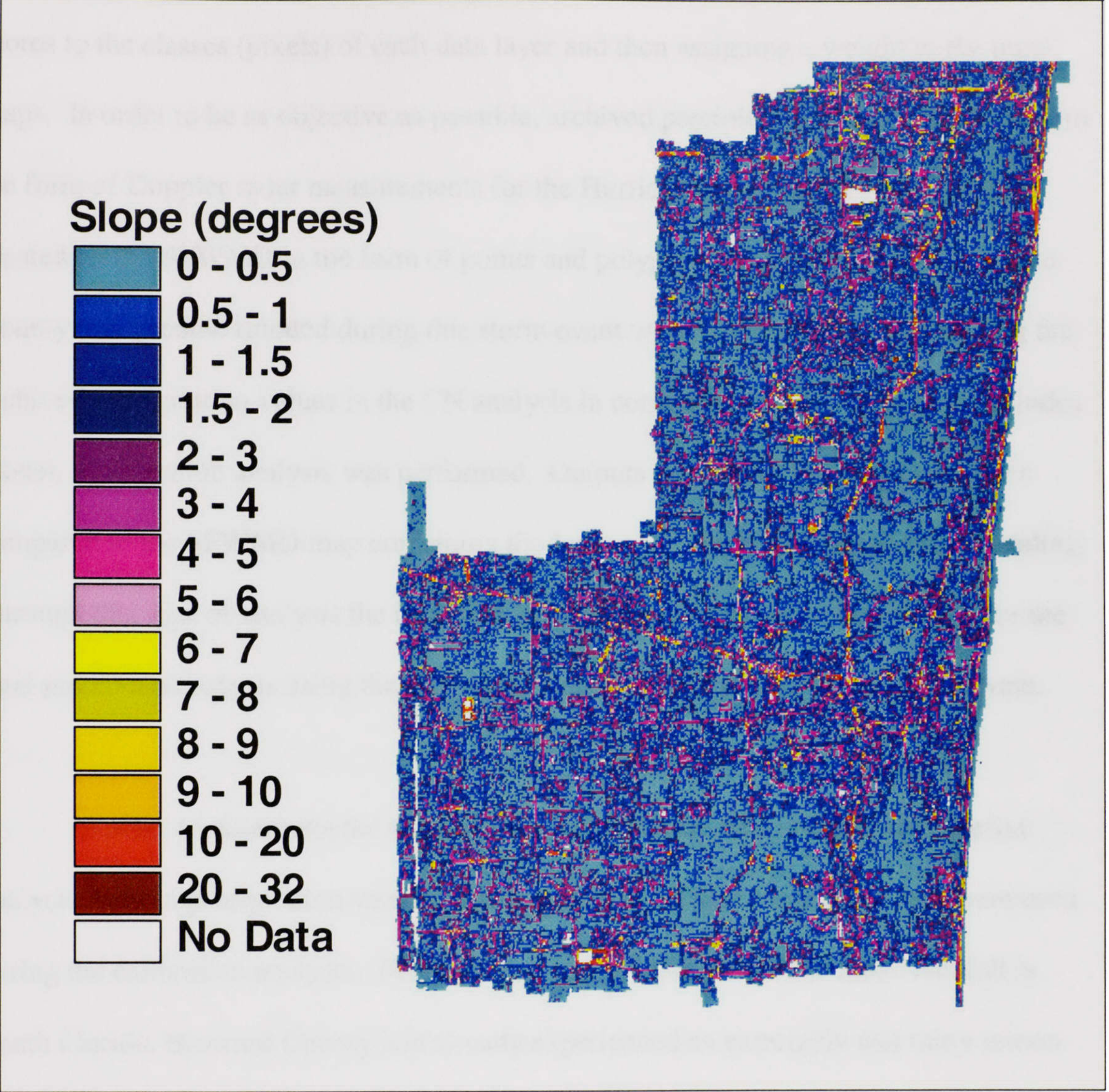
Slope

An important aspect of determining surface excess precipitation or potential flooding in an area is the slope of the terrain. Slope is a major factor that will determine the hydraulic and hydrologic character of a localized area (Mays 2001). After a rainstorm, when the local abstractions have been accomplished, as indicated in the CN analysis, water will begin to accumulate or flow overland. The steepness and length of a slope can greatly contribute to the momentum of excess precipitation affecting the potential flooding conditions (McCuen 1998). The slope reflects the rate of change of elevation with respect to the distance along the ground surface.

Data Acquisition & Development

From the acquired filtered elevation data, the slope of terrain can be easily established using spatial analyst extension within ArcView. Deriving the slope identifies the maximum rate of change from each cell to its neighbors. The output grid theme represents the degree of slope for each cell location. If a greater slope is indicated it is assumed that excess precipitation will travel away from that cell, resulting in a less potential for flooding. Areas where there is little or no slope present are assumed to contribute to the ponding effect resulting in a greater likelihood of freshwater flooding. The slope of the terrain data can be viewed in Figure 15. The majority of land surface throughout Broward County is flat with little or no slope. Areas with a high degree of slope usually correspond to canals, roadways, or other man-made features and areas along the coastal ridge.

Figure 15. Broward County slope of the terrain data.



3.2 Calibration

A key component of the multi-class index overlay analysis is the assigning of scores to the classes (pixels) of each data layer and then assigning a weight to the input maps. In order to be as objective as possible, archived precipitation data were gathered in the form of Doppler radar measurements for the Hurricane Irene storm event. Data created by the SFWMD in the form of points and polygons indicating areas in Broward County that became flooded during this storm event were also obtained. Upon using the archived precipitation values in the CN analysis in conjunction with the multi-class index model, a calibration analysis was performed. Outputs from these test trials were then compared to the SFWMD map containing the location of areas that experienced flooding. Through this type of analysis the best fit scales and weights could be determined for the final prediction analysis using the IDF curve data for a 100 year, 24-hour storm event.

In order to determine the weights and scores for the multi-class index overlay analysis, known precipitation values from acquired Hurricane Irene radar data were used during the calibration analysis. During the time that Hurricane Irene made landfall in South Florida, Broward County had already experienced an extremely wet rainy season. As a result the soil was very saturated. For this reason the archived radar data implemented in the CN analysis was only for Antecedent Moisture Conditions II and III; AMC II only being used for comparison purposes. As discussed in a previous section flood locations provided by SFWMD covered a three-day period of accumulating rainfall. For this reason it was decided that the radar data used in the calibration analysis would also cover a three-day period. Therefore radar data from October 14, 15, and 16, 1999 were added together.

The excess precipitation (derived from archived Hurricane Irene radar data), elevation, and slope input layers were placed into a uniform range by being re-gridded to have the same extent as the filtered elevation data. For a multi-class index model analysis it is important that all pixels, rows, and columns be equivalent for each input map.

When performing this type analysis it is important to note that class scores should not be normalized for each map layer. By selecting the same range of scores for the three map layers increased variability in the analysis can be avoided. For this analysis each class value for the three maps was assigned an integer ranging from 1-9 (a factor of three). As a result the susceptibility of inland flooding in a given area was classified into three categories, high susceptibility (range score 1-3), moderate susceptibility (range score 4-6), and low susceptibility (range score score 5-9). Given the range of original class values, excess precipitation using radar data and the elevation map layers were categorized into 9 classes (range score 1-9) and the slope of the terrain and excess precipitation using IDF curve data were categorized into 3 classes (scores 1, 5, and 9). The ranking ranged from the best case scenario (a high rating of 9) to the worst case scenario (a low rating of 1). For instance, an area with a high elevation, containing a steep slope, with little excess precipitation would be a best case scenario for that location not to flood during a precipitation event. However, an area located in a low elevation with little to no slope and extreme excess precipitation would hold the qualities for the potential to flood. Table 9 shows the score values for each class among the three input maps.

Table 9. Class scores used for data layer reclassification for the Multi-class index overlay analysis.

	Assigned Score	100 foot DEM	Direct Runoff (radar data, inches)	Direct Runoff (IDF data, inches)	Slope
Worst Case Scenario	1	-6-2	11-45	11-13.2	0-0.5
	2	2-4	9-11		
	3	4-5.5	8-9		
	4	5.5 –7	7-8	9-11	0.5 – 2
	5	7-9	6-7		
	6	9-11	5.5 –6		
Best Case Scenario	7	11-13	5-5.5	0-9	2-32
	8	13-15	4-5		
	9	15-51	0-4		

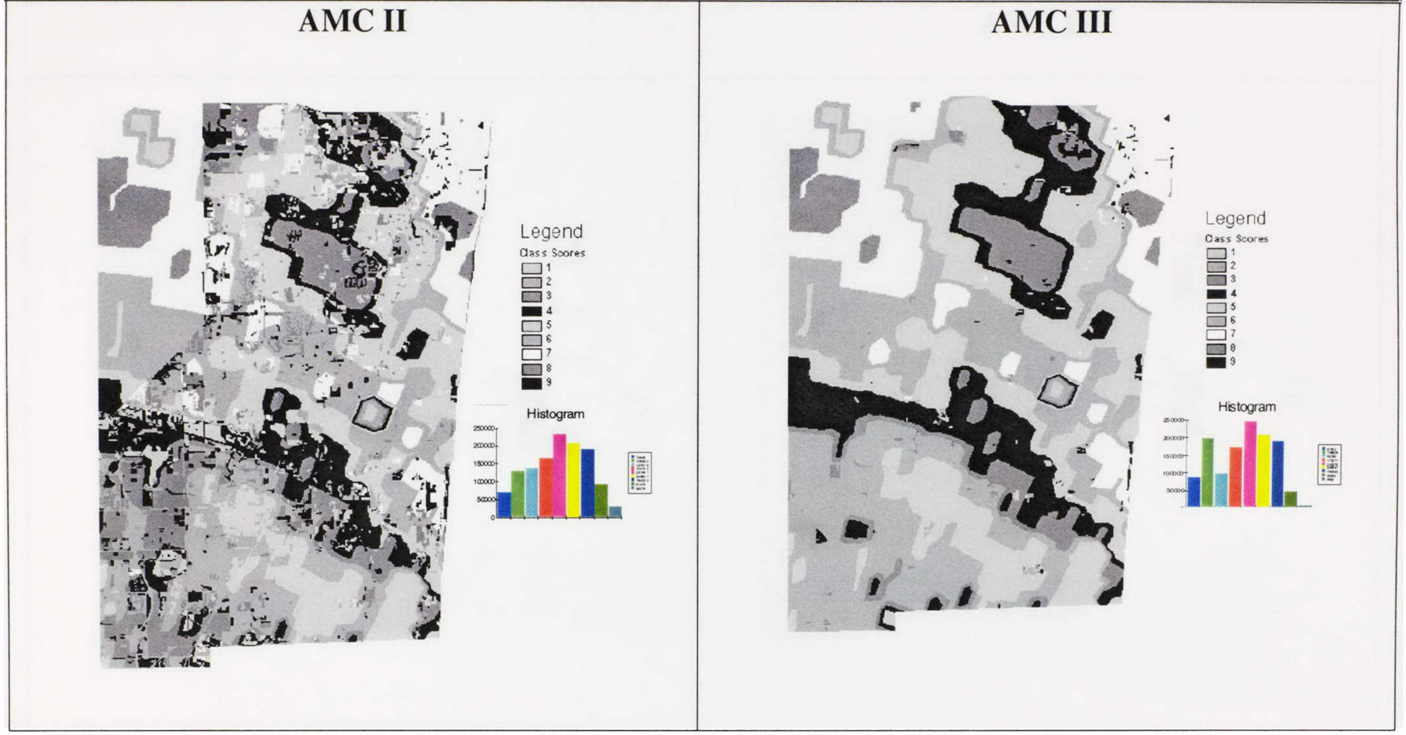
The ranges of scores were determined from histogram distribution charts for each map layer. By initiating the histogram command in ArcView a comparison was made of the number of cells within the assigned values. For this analysis, the original cell values for each map layer were recategorized with the corresponding range 1-9 until the values were normally distributed for each map layer (i.e., the bell curve). The reclassified data layers with the corresponding histogram charts can be viewed in Figures16 through 19

Weights for the individual map layers were determined subjectively based on the researchers knowledge and the results of the calibration analysis. The sums of the weights for the three variable maps were equivalent to one. Several calibration trials were performed using the elevation, slope and excess precipitation input maps. By using the map calculator in Spatial Analyst, several analyses were performed using various weights for each variable in order to determine the best fit for the model. The outputs for the calibration analysis were then compared to a map produced by the SFWMD that documented flooded areas during the Hurricane Irene storm event, as shown in Figure 20. An ArcView script entitled GridSpot was used to extract the results. The results were then imported into an excel spreadsheet, as shown in Appendix D. Areas that would be assumed to flood are those that received a rating of less than three. The percentage of areas that received flooding as a result of using the multi-class index overlay model with Hurricane Irene precipitation data were then calculated. Based on these percentages the best weights for the final analysis using the IDF Curve data were determined. The results are included in Table 10.

Table 10. Multi-class index overlay weight results obtained during the calibration analysis.

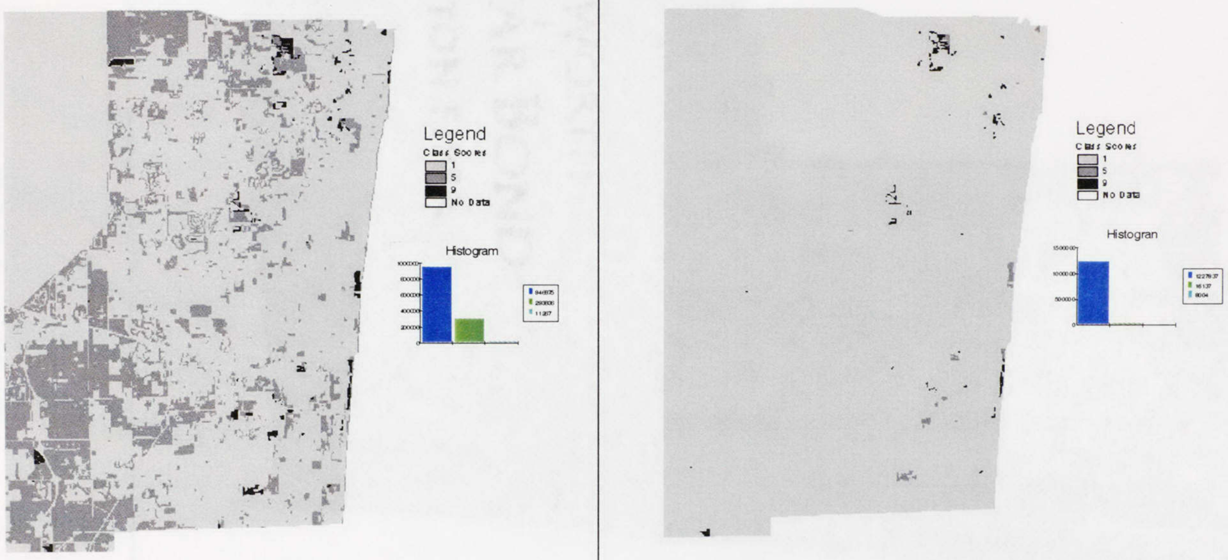
Weights (DEM/CN/Slope)	**Percentage of Hits (AMC2)**	**Percentage of Hits (AMC3)**
0.5/0.3/0.2	28%	28%
0.8/0.1/0.1	27%	28%
0.6/0.2/0.2	29%	30%
0.2/0.6/0.2	33%	35%
0.333/0.333/0.333	27%	28%
0.5/0.5/0.0	33%	36%
0.0/1.0/0.0	27%	32%

Figure 16. Reclassification of class scores for the excess precipitation map layer using Doppler radar data. This map layer is to be used in the “calibration stage of the analysis.


AMC II

AMC III

Figure 17. Reclassification of class scores for the excess precipitation map layer using IDF curve precipitation data. This map layer is to be used in the “prediction stage of the analysis.



AMC II

AMC III

Figure 18. Reclassification of class scores for the elevation map layer.

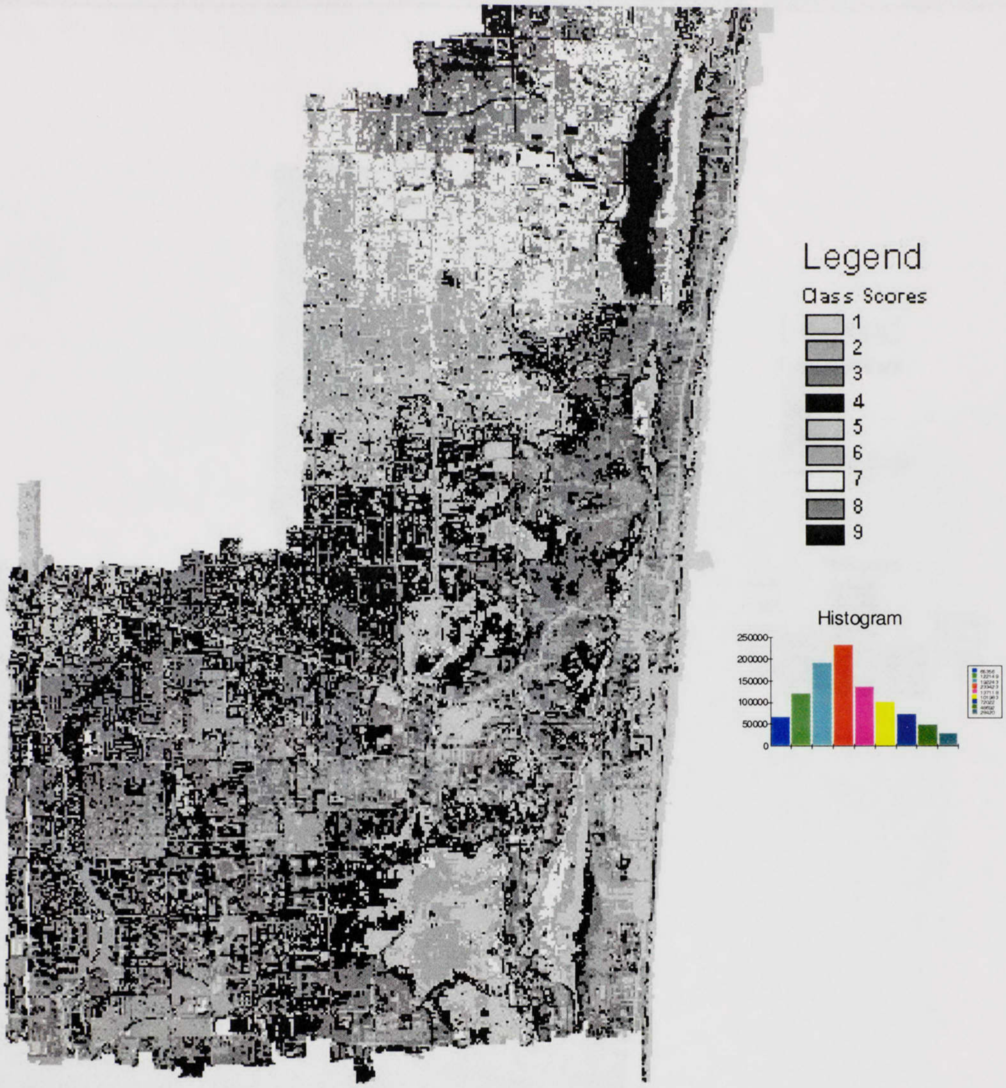


Figure 19. Reclassification of class scores for the slope map layer.

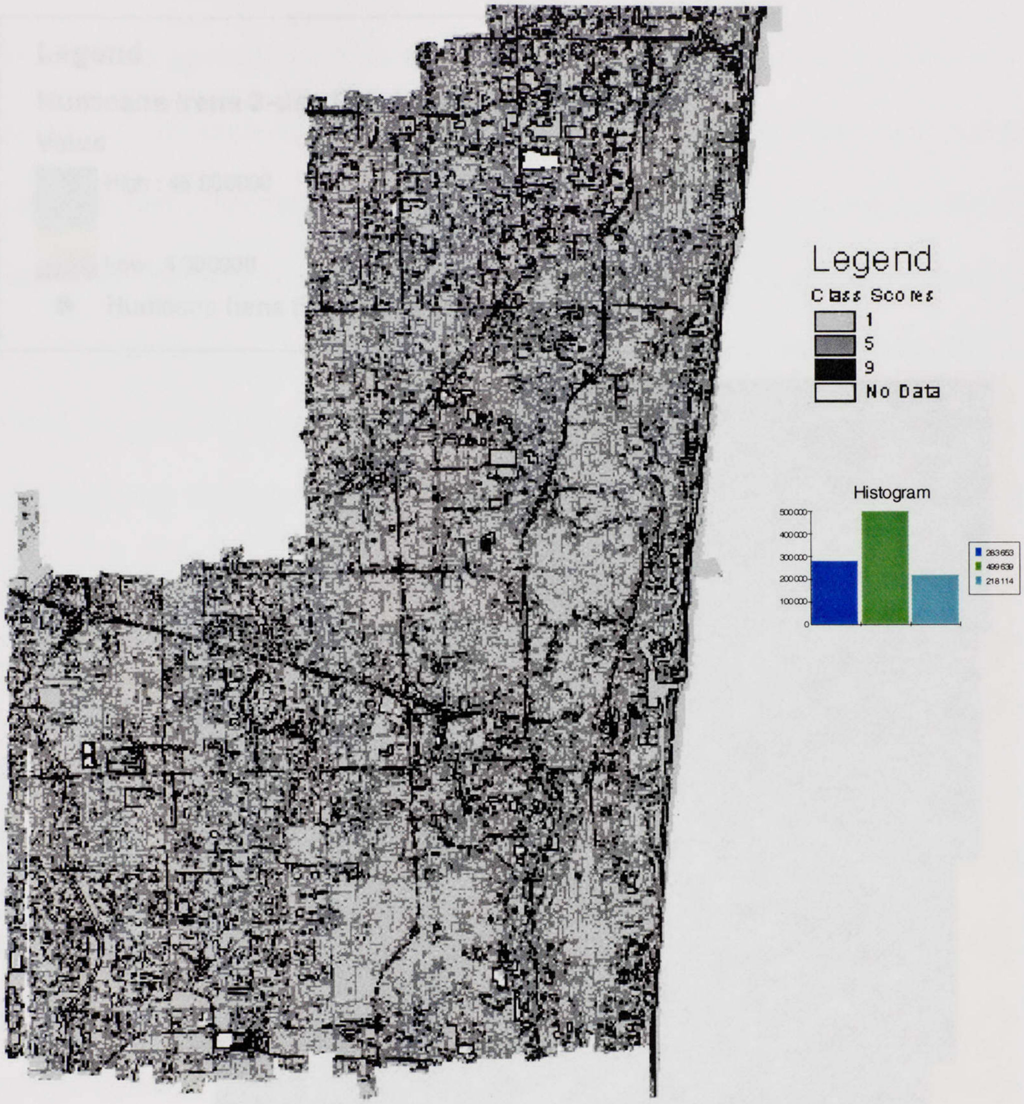
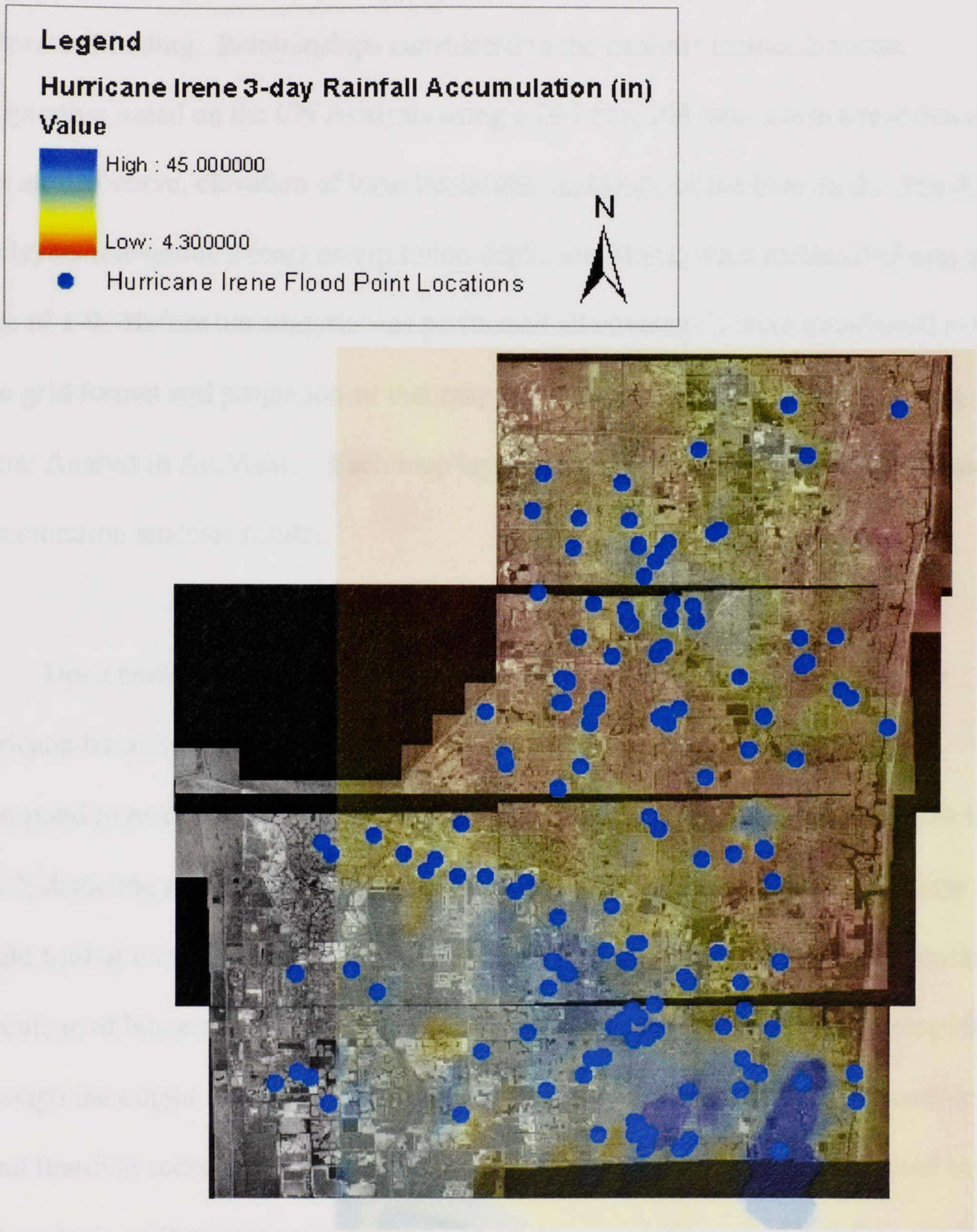


Figure 20. Address locations in Broward County Florida that reported flooding during the Hurricane Irene storm event.



3.3 Application

A GIS-based multi-class index overlay model was used to perform a susceptibility analysis to establish areas within Broward County that have a greater potential for freshwater flooding. Relationships considered in the analysis included excess precipitation based on the CN Analysis using a 24-hour, 100-year storm event derived from an IDF curve, elevation of local landscape, and slope of the bare earth. The three data layers (elevation, excess precipitation depth, and slope) were reclassified into a class range of 1-9. Before the analysis was performed all coverage's were transferred to the same grid format and projection so that map calculations could be performed using Spatial Analyst in ArcView. Each map layer was assigned a different weight based on the calibration analysis results.

Upon performing the calibration analysis using the archived radar data for Hurricane Irene, two weight trials received the same percentage of "hits". Hits correspond to results at the documented flooding locations that received a score of less than 3; depicting a high susceptibility of flooding. During the calibration phase the weight trial of elevation 0.2, excess precipitation 0.6, and slope 0.2, received similar percentage of hits as the trial with elevation 0.5, excess precipitation 0.5 and slope 0.0. Although the output flooding maps for AMC III showed two very different possible inland flooding scenarios, it was decided that all three map layers should be used in the final analysis, with excess precipitation having the most influence. Therefore, the best weights to be used in the final analysis were elevation, 0.2, excess precipitation depth 0.6; and slope, 0.2.

By using the map calculator in Spatial Analyst the flood potential was estimated using a multi-class index overlay model defined by Equation 1 for AMC II and AMC III. Colors for the analysis were chosen to depict areas of high, moderate and low susceptibility to inland flooding. Figure 21 depicts a graphical representation of how the weights and scores were used in the final analysis. Two maps for the study area were created as a result of the proposed analysis, one for Antecedent Moisture Condition II and III, Figures 22 and 23. For each map, susceptibility of inland flooding in a given area were classified into three categories, high susceptibility (score range of 0-3; red), moderate susceptibility (score range of 3-6; purple), and low susceptibility (score range of 6-9; green).

The established methodology can be used as a platform to determine inland flooding caused by various types of storms. Figure 24 shows areas susceptible to flooding based on a 24- hour, 50-year storm event. In this particular case the weights and scores are based on those determined during the "calibration stage", which used archived rainfall data from the 100-year storm event. According to this output, Broward County would not receive severe flooding during a 50-year storm. To achieve more accurate result for other type of storm events a new calibration analysis would need to be developed; however for illustration purposes the same results were used.

Figure 21. A graphical representation of the final analysis. After the classes for the individual data layers were assigned scores ranging from 1-9 each class was multiplied by a corresponding weight. The results were then tabulated and any class receiving a score of less than 3 was considered susceptible to flooding.

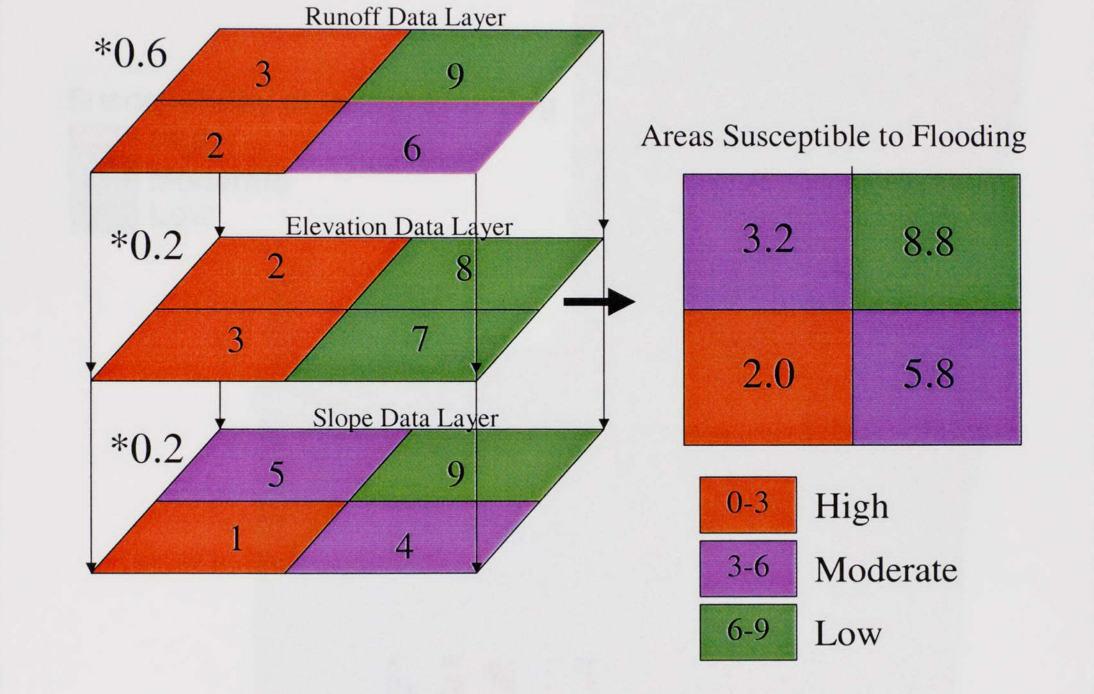


Figure 22. Broward County Potential for inland flooding as a function of Antecedent Moisture Condition II during a 100-year, 24-hour storm event (weights: elevation 0.2, runoff 0.6, slope 0.2).

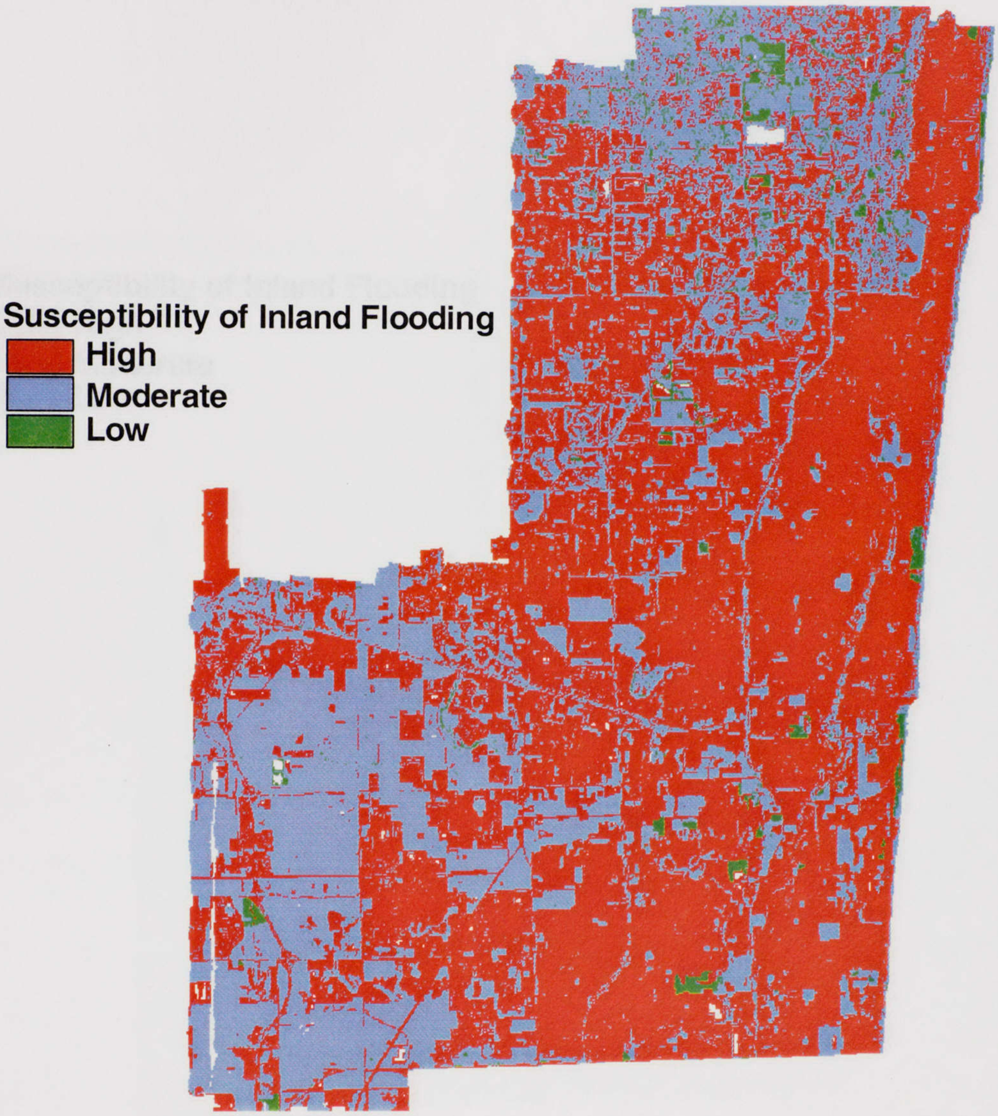


Figure 23. Broward County Potential for inland flooding as a function of Antecedent Moisture Condition III during a 100-year, 24-hour storm event (weights: elevation 0.2, runoff 0.6, slope 0.2).

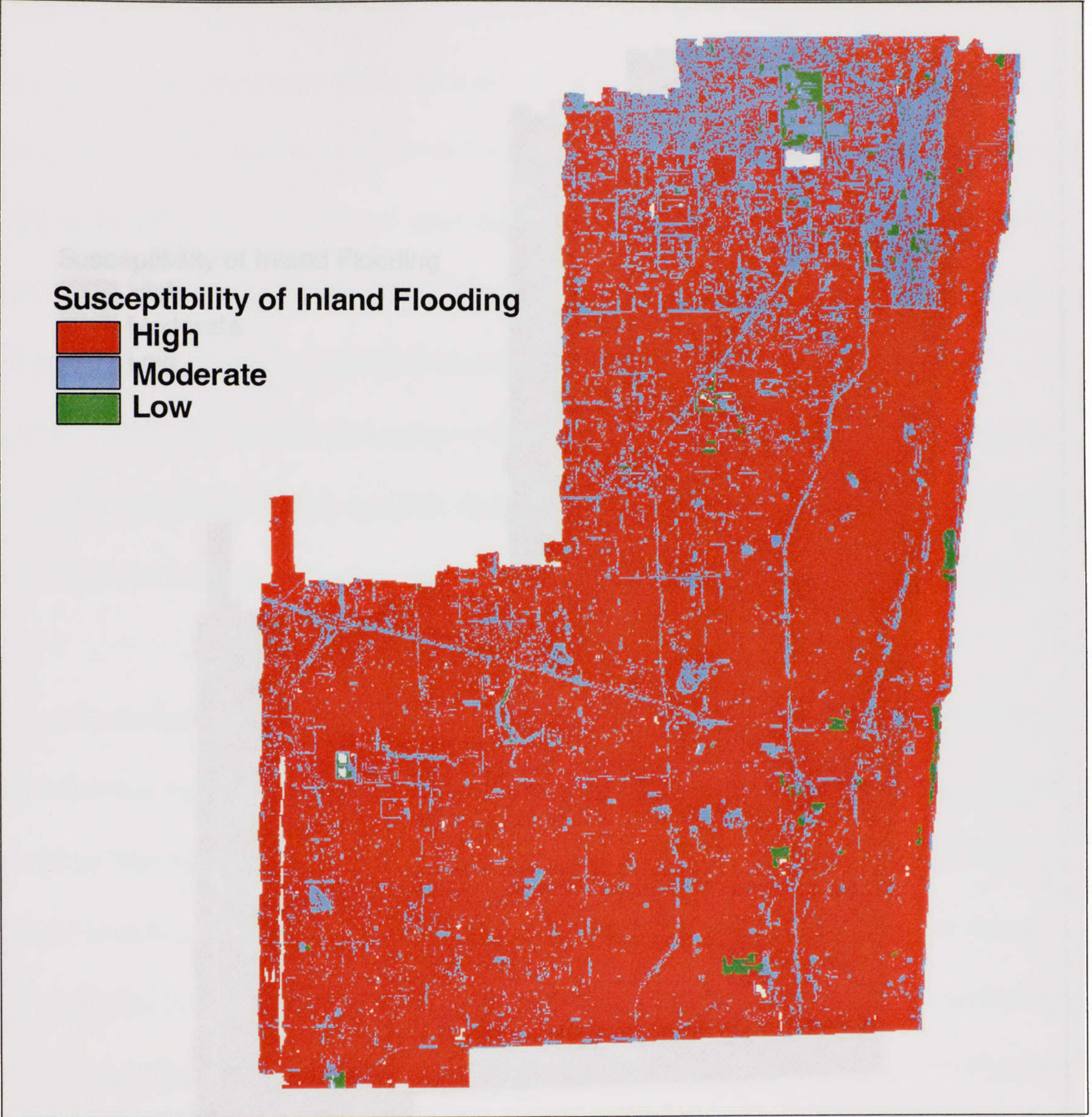
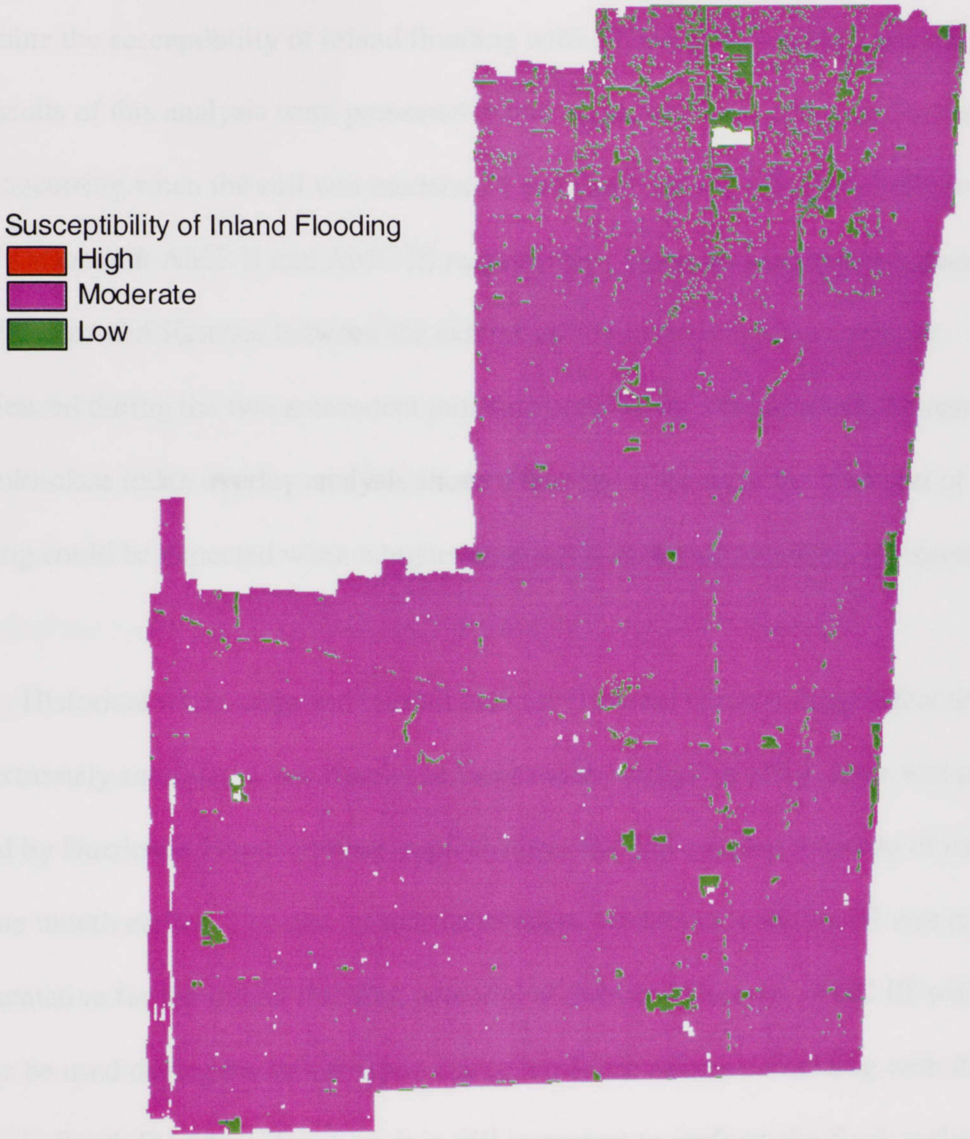


Figure 24. Broward County Potential for inland flooding as a function of Antecedent Moisture Condition III during a 50 year, 24-hour storm event (weights: elevation 0.2, runoff 0.6, slope 0.2).



Chapter 4. Results & Discussion

The use of a multi-class index overlay model enables researchers to analyze the combination of various map layers. This research used three weighted map layers to determine the susceptibility of inland flooding within Eastern Broward County, Florida. The results of this analysis were presented in two maps, one for a 100-year 24-hour storm event occurring when the soil was moderately saturated and the other when the soil was heavily saturated; AMC II and AMC III respectively. Upon viewing the two maps there is a pronounced difference between the extents of inland flooding that could be experienced during the two antecedent moisture conditions. As expected, the results of the multi-class index overlay analysis showed that an increase for the potential of inland flooding could be expected when a higher antecedent moisture condition is experienced.

Historical water table and rainfall data for Broward County suggest that the soil was extremely saturated when Hurricane Irene made landfall in 1999. This was partially caused by Hurricane Floyd, another tropical storm that left copious amounts of rainfall just one month earlier. For this reason, Antecedent Moisture Condition III was more representative for the inland flooding potential of Broward County. AMC III will almost always be used during the this analysis due to hurricane season coinciding with the rainy season in South Florida. However, it is still important to perform the final analysis using various antecedent moisture conditions for comparison purposes.

Areas that received a rating for a high susceptibility of inland flooding are located throughout the study area. Areas shown in purple are predominately located in northern

Broward County and along raised roadways. Areas in green include undeveloped land, golf courses, and parks. According to this analysis most urban areas in Broward County would experience flooding during a 100-year 24-hour storm event during the rainy season.

It is important to keep in mind that when using the IDF precipitation data in the final analysis, it is assumed that the same rainfall accumulation would be experienced throughout an entire area. Unfortunately this rarely happens. During an extreme rainfall event various rain cells or bands usually cause varied levels of rainfall accumulation; it is rarely uniform. Two types of archived rainfall data were examined in this analysis: rain gauge and radar. Discrepancies can exist between radar rainfall estimates and actual rainfall of the Earth's surface measured in rainfall gauges. Unfortunately for Broward County the number of gauges within the study area was limited and therefore not used as part of the analysis. The methodology presented in this research could be greatly enhanced if radar data and rain gauge data were used in concert during the calibration phase of the analysis. Unfortunately the IDF curve is the only type of precipitation data that can be sued during the predictive phase of the analysis; and this data will always be evenly distributed throughout an area.

The weight and scores used in the analysis may not have been ideal. Although the weights and scores were "calibrated" using the archived Doppler radar measurements and inland flooding documentation data for Hurricane Irene, the percentages obtained did not have statistically significant results to objectively determine the weights and scores. The weights of 0.2 for elevation, 0.6 for excess precipitation depth, and 0.2 for the slope of the terrain were chosen because the results obtained during the calibration phase yielded the highest return using all three maps; however each was below 40 percent for AMC II and III. As depicted in Table 10, the results for all "trial runs" had between 17 percent to 36 percent return when compared to the documented flooding data layer.

The methodology used in this analysis is dependent upon the calibration of the model using flood documentation. The only available documentation for flooding locations experienced in Broward County during Hurricane Irene were obtained from SFWMD. Little metadata accompanied the flood location map and the estimated accuracy was not recorded, it was assumed for the purposes of this study that the accuracy was within reason considering the data was created and distributed by SFWMD. However we are cautioned to remember that the quality of this data set may have affected the overall analysis; remembering also it was the only documented database containing the location for inland flooding during the Hurricane Irene storm event in Broward County. Hopefully flooding location documentation will be recorded using higher standards during future inland flooding events.

Possible address matching errors for the flood location map could also contribute to the based weighting. Address locations were placed on the map using Address Geocode in ArcView. When an address is imported into an ArcView map containing street locations, ArcView will locate the address along the correct side of the street by looking at whether house number is even or odd. A point is placed at the appropriate spot along the street by interpolating where the number falls along the range. The range is usually one street block. The coordinates of the point are based on the location of the matching feature. By default, ArcView applies a 2.5 percent "squeeze" factor to the interpolated location by shifting the address location 2.5 percent distance from each end inward of a street segment defined by its two ending intersections. This option is intended to prevent the Address Geocode function from placing addresses at the end of a block as opposed to being placed on top of an intersection. Human errors may have also occurred as SFWMD staff was inputting the address locations into a spreadsheet. If an address were incorrectly matched on the flood location map, the overall calibration analysis would be affected.

The results depict two types of possible inland flooding scenarios based on precipitation measurements, antecedent moisture conditions of the soil, percent of impervious areas, soil type, topography and slope of the terrain. Although many limitations were found when creating this analysis it is hoped that the established methodology will be a first step for future inland flooding susceptibility models.

Chapter 5. Conclusions & Recommendations

A method that performs a GIS-based multi-class index overlay analysis to determine areas susceptible to inland flooding within eastern Broward County was developed and evaluated. Three data layers including highly accurate Airborne Laser Terrain Mapper (ALTM) elevation data, the total excess precipitation depth through performing a Soil Conservation Service (SCS) Curve Number (*CN*) analysis, and the slope of the terrain were merged to yield possible flooding scenarios. A calibration analysis was also performed, using archived radar measurements of a 100-year, 72-hour storm event and documented flooding locations for Hurricane Irene (1999), to determine the weights and scores used in the analysis. The maps created as a result of this method show three ranges of inland flooding severity as a function of the antecedent moisture condition of the soil during a 100-year, 24-hour precipitation event derived from Intensity-Frequency-Duration Curves.

There are several advantages presented with this method. The majority of existing flood maps are currently paper based, making it very difficult and expensive to update, manage, and distribute. The majority of these maps are approximately 30 years old. The information they contain often does not reflect the reality of the rapidly changed urban environment for most flood vulnerable communities. Performing a multi-class index overlay analysis within a GIS platform provides a way of examining the relationships of various types of spatial data layers that contribute to inland flooding in a digital format. The results of this analysis can be readily updated with new information and technology.

Successful predictions using this model highly depend on the quality of available data. Due to the availability of readily accessible data, it was necessary to calibrate the model using a 72-hour storm event and use a 24-hour storm event in the final "prediction stage" of the analysis. Ideally the storm duration should be equivalent for both the calibration and prediction phase. All data layers were acquired from various reputable agencies, such as the International Hurricane Research Center, Florida Department of Transportation, South Florida Water Management District, and the National Climatic Data Center. However, several improvements regarding the types of data sets used in the analysis could be made.

For instance the LIDAR data, which was used as a means to determine elevation, could also be used as a means of determining the percent of impervious area based on the intensity return of the laser. The infrared laser provides a fast and accurate way of determining current land uses as opposed to the current method of interpreting aerial photographs by hand. Concrete and pavement, defined as impervious layers, have a low spectral response to infrared. As such, the dark areas on a LIDAR intensity map would correspond to impervious areas. This technology could offer a new way of reclassifying current landuse areas.

Photography taken from aircraft and satellites after an extreme precipitation event has taken place would offer an additional way to determine where flooding has occurred. One of the major problems with using the documented flooding locations dataset provided by SFWMD is 1) not every resident of Broward County reported flooding problems and 2) the data offers no incite as to the severity of flooding experienced by the residents. Depending on the perception of the resident, severe flooding may have been 2 cm compared to 2 m; it is based on personal interpretation. Satellite images such as SPOT or LANDSAT could offer insight as to the span of inland flooding. Both of these types of data offer images in digital format with good spatial resolution and provide long-term repetitive coverage. Additional field studies could then determine the actual depth of flooding. This type of detailed information would allow for a more accurate calibration of the model.

One major limitation to this analysis is that it does not account for how the water may move through localized areas nor does the analysis take into account how primary, secondary, or tertiary drainage systems may affect the analysis. In the future, improvements on this model should consider the primary canal system, especially how canal pumping would affect the span and duration of ponded water. After the Hurricane Irene (1999) flooding event, many improvements were made to the South Florida primary canals systems by SFWMD. In areas where pumps have been improved or implemented, inland flooding has seized to be a problem during recent extreme precipitation events. A more complex model should consider canal pumping as a major factor contributing to the flooding problems.

To create a more dynamic flood prediction model, ALTM data in conjunction with established hydrologic and hydraulic models should be explored. Currently the U.S. Army Corps of Engineers uses a Hydrologic Modeling System (HEC-HMS) for precipitation-runoff simulation of natural and urban watershed systems. An examination into the programming language should take place to determine whether or not a rasterized data set could be implemented into the computer program. Highly accurate elevation data integrated with hydrologic analysis components would result in a very powerful flood prediction tool.

Although this study provides a basic foundation to examine the relationship of various and key factors affecting the inland flooding potential of an urban area, it is evident that additional evaluations, and an advanced version of this study is needed before conclusions about the flooding potential of an area can be drawn. In the future this method, as it is developed, could provide communities with a better way to access data and an easier way to compare spatial layers of complexity. The use of this technique in conjunction with other storm events would require additional testing to show that the method is truly successful.

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Appendix A. Broward County Rain Gauge Data

Two types of archived rainfall data were assessed to determine the scale and weights for the multi-class index overlay analysis. The data included Broward County rain gauge data and Doppler radar data. Rainfall gauge data were retrieved from the SFWMD remote access Hydrometeorologic and Water Quality Database (DBHYDRO). Information retrieved included: station name, station latitude and longitude, and 24-hour rainfall accumulation depths. The 24-hour rainfall totals ended at approximately 7am Eastern Standard Time (EST) on the designated day for October 13-17. The data were presented in table format with information including station name and station location in decimal degree minutes seconds (DDMMSS). The gauge locations were converted into decimal degrees. A detailed record of the daily precipitation amounts for each rainfall measuring station in the study area was compiled into a comma delimited text file that could then be imported into ArcView. Please refer to Table 11 for a listing of stations used. 24-hour rainfall accumulations for Hurricane Irene were interpolated using a TIN method. After the continuous surface was created, the layer was re-gridded to be used in the analysis.

When compared to the radar datasets, as disused in Chapter 5, it was decided that the rain gauge dataset should not be used in the analysis due to the sparse gauge station data in the study area. After further examination of the rain gauge data for the days during the storm event, it was observed that many stations were either located outside the study area or did not recorded sufficient data for the days in question. For this reason it was decided that the radar data would be more sufficient based on the density of point data. Figure 25 compares the data density of the rain gauge data versus Doppler radar data for Broward County.

Table 11. 24-hour rainfall accumulations during Hurricane Irene.

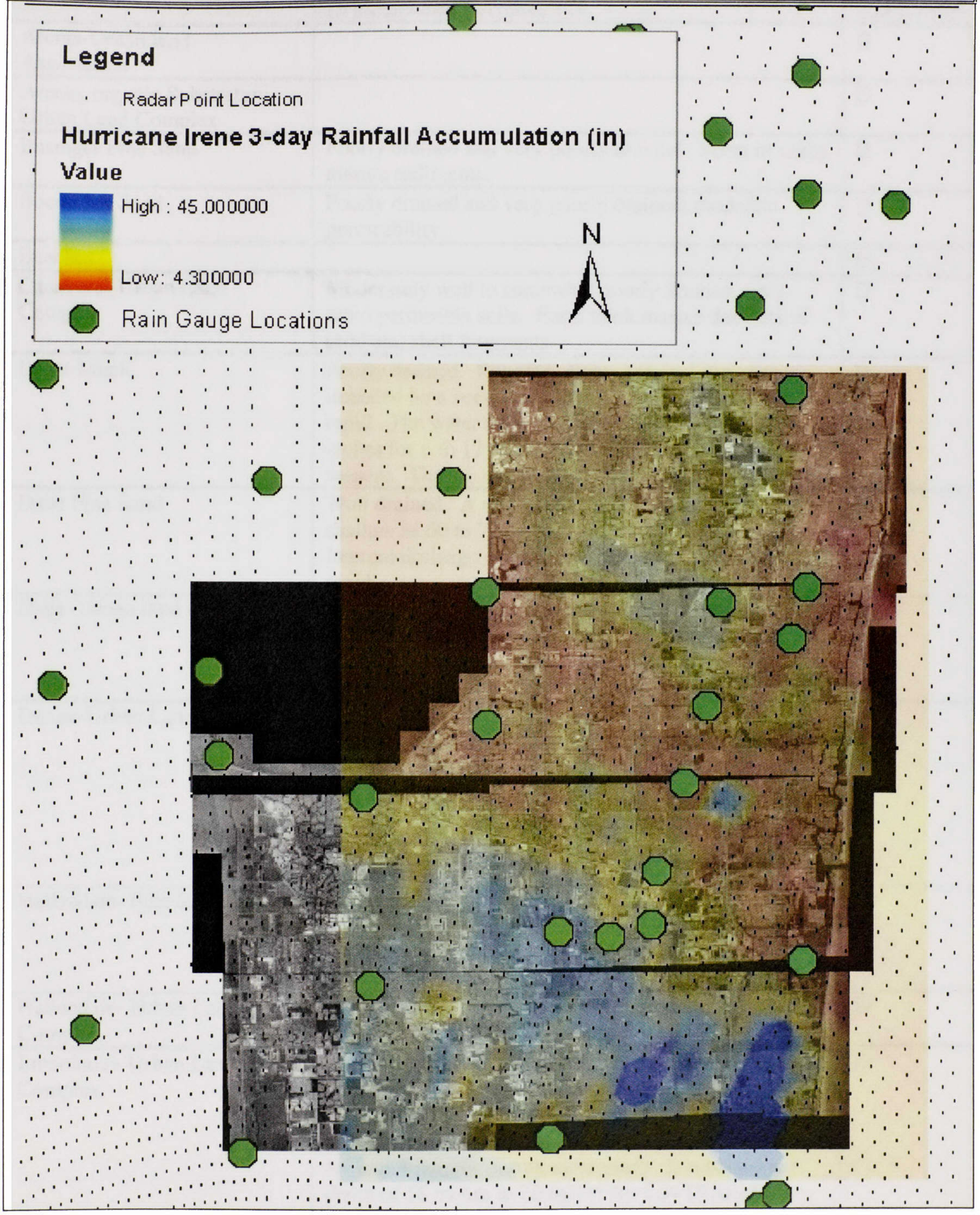
Rain Gauge Station	Location (DD)		24-hour Totals (in)					Storm Total (in)
	Lat	Long	10/13/99	10/14/99	10/15/99	10/16/99	10/17/99	
3A_36_R	26.191389	-80.449167	0.1	4.63	7	0.9	0	12.63
3A_NE_R	26.278611	-80.605	0.03	3.85	2.34	0	0	6.22
3A_S_R	26.083333	-80.684444	0.4	1.59	6.52	0	0	8.51
ANDYTOWN_W	26.183611	-80.533056	0.03	0.23	1.65	5.14	0.7	7.75
CORAL_SP	26.283611	-80.316389	0.13	0	3.04	7.86	0.33	11.36
CORAL_SP_W	26.283611	-80.416389	0.26	0.48	2.18	5.07	0.32	8.31
FTL	26.092778	-80.206389	-999	1.3	5.19	7.59	0	14.08
G57_R	26.231111	-80.124167	0.2	3.42	5.78	0.2	0.01	9.61
GILL_REA_R	26.060278	-80.231667	0.53	1.78	5.75	-999	-999	8.06
HOLLYWOOD	26.048333	-80.1275	0.7	0.62	4.82	7.69	-999	13.83
MIRAMAR_R	26.016944	-80.516389	0	0.48	5.45	7.52	0	13.45
S124_R	26.129167	-80.365556	0.05	1.15	3.71	4.98	0.04	9.93
S125_R	26.164167	-80.2975	0.4	3.47	3.48	0	0	7.35
S33_R	26.135556	-80.190833	0.21	1.42	2.67	5.05	0	9.35
S34_R	26.150278	-80.443333	0.12	1.18	3.38	2.26	0.04	6.98
S37A_R	26.205833	-80.132222	0.42	1.26	6.36	5.26	0.32	13.62
S37B_R	26.223889	-80.170833	0.26	0.24	2.23	2.63	0.26	5.62
S38_R	26.229722	-80.298333	0.51	0.99	2.77	5.02	0.22	9.51
LWD.RAN	26.3875	-80.204722	0.37	1.05	2.15	-999	-999	3.57
LWD.POW	26.368889	-80.153889	0.51	1.66	3.87	-999	-999	6.04
LWD.L38M	26.423889	-80.122222	0.16	1.18	4.53	-999	-999	5.87
LWD.L39R	26.416667	-80.203889	0.77	1.49	2.65	-999	-999	4.91
LWD.MIL	26.520833	-80.123889	0.06	2.52	4.36	-999	-999	6.94
LWD.E2_F	26.528333	-80.170278	0.04	1.71	2.84	-999	-999	4.59
LWD.L28	26.495556	-80.202778	0.15	0.34	2.6	-999	-999	3.09
LWD.HQ	26.483056	-80.123056	0.37	0.74	3.33	-999	-999	4.44
LWD.E2.2	26.454444	-80.171111	0.38	1.35	2.65	-999	-999	4.38
LWD.L32	26.470556	-80.205	0.23	1.34	3.15	-999	-999	4.72
SBDD	26.037778	-80.362222	0.15	4.34	8.71	0	0	13.2
MIAMI AP	25.816944	-80.283056	0	2.36	3.07	5.56	0	10.99
N DADE_F	25.8	-80.240278	0	0.8	3.14	4.41	0	8.35
S29_R	25.928333	-80.150833	0	1.73	2.28	4.25	0	8.26
DELRAY B	26.500278	-80.216389	0.13	0	2.94	9.25	0.01	12.33
MIAMI 2_R	25.783333	-80.133333	0	1.8	2.13	3.48	0	7.41
S36_R	26.173333	-80.178333	0.24	0.76	3.2	2.76	0	6.96
FT. LAUD	26.063611	-80.259444	0.07	2.2	4.1	6.95	0	13.32

Table 11. 24-hour rainfall accumulations during Hurricane Irene (Cont.).

Rain Gauge Station	Location (DD)		24-hour Totals (in)					Storm Total (in)
	Lat	Long	10/13/99	10/14/99	10/15/99	10/16/99	10/17/99	
SWEETWATER	25.883611	-80.599722	0.01	0.52	2.94	8.42	0	11.89
COOPER_	25.816944	-80.716389	-999	0.3	4.57	10.3	0	15.17
WCA1ME	26.510556	-80.310278	0.01	1.67	8.35	0.02	0	10.05
MIAMI.FS	25.826944	-80.344167	0.71	4.35	8.58	0	0.01	13.65
LOXWS	26.498889	-80.222222	0	2.93	9.46	0.02	0	12.41
EAA5	26.436389	-80.615	0	1.4	7.2	0.07	0	8.67
S28Z_R	25.913333	-80.293056	0.18	3.61	3.87	0	0	7.66
S29_R	25.911667	-80.150833	0.26	3.04	4.96	0	0	8.26
S29Z_R	25.961944	-80.264444	0.16	3.7	4.4	0	0	8.26
G201_R	26.337778	-80.636111	0	2.26	4.73	0.04	0	7.03
G56_R	26.327778	-80.130833	0.03	4.19	2.5	0.11	0	6.83
S13_R	26.066111	-80.208611	0.5	5.73	4.42	0.01	0	10.66
S30_R	25.956667	-80.431389	0.05	4.41	2.79	0	-999	7.25
S335_R	25.776111	-80.482778	0.65	2.57	8.38	0	0.01	11.61
S26_R	25.808056	-80.260833	0.73	2.98	6.54	0.01	0	10.26
S27_R	25.848611	-80.188889	0.45	2.19	6.9	0.01	0	9.55
S39_R	26.356111	-80.2975	0.08	2.43	3.37	0.04	0.01	5.93
S40_R	26.418611	-80.074167	0	3.65	2.8	0.09	0	6.54
S41_R	26.531111	-80.059167	0	10.29	7.15	0.02	0	17.46
S46_R	25.934167	-80.141667	0	4.37	1.96	0.11	0	6.44
S6_R	26.472222	-80.445556	0.06	1.55	2.98	0.03	0	4.62
S7_R	26.335833	-80.536667	0	2.47	0.85	0.03	0.02	3.37

*-999 is the designated number if rainfall data were not recorded

Figure 25. Data density comparison between the rain gauge data versus Doppler radar data for Broward County, Florida.



Appendix B. Broward County study area Hydrologic Soil Classification.

Soil Type	USDA-NRCS Official Soil Series Descriptions for Drainage and Permeability	Hydrologic Soil Group
Arents-Urban land Association		D
Arents, organic Substratum Urban Land Complex		D
Basinger Fine Sand	Poorly drained and very poorly drained. Form in sandy marine sediments.	D
Boca Fine Sand	Poorly drained and very poorly drained; moderate permeability.	D
Beaches		D
Canaveral-Urban Land Complex	Moderately well to somewhat poorly drained, very rapid permeable soils. Form thick marine deposits of sand and shell fragments.	D
Dania Muck	Poorly drained. Runoff is slow. Internal drainage is impeded by a very shallow water table. Permeability is rapid. The water table is at depths of less than 10 inches for 6 to 12 months except during extended dry seasons. During wet seasons these soils are flooded.	D
Dade Fine Sand	Well drained. A water table begins at depths as shallow as 60 to 72 inches for 1 to 2 months annually. Internal drainage is rapid and permeability is very rapid.	A
Dade- Urban land Complex	Well drained. A water table begins at depths as shallow as 60 to 72 inches for 1 to 2 months annually. Internal drainage is rapid and permeability is very rapid.	D
Duette-Urban Land-Complex	Moderately well drained; runoff is very slow. Permeability is moderately rapid in the Bh horizon. The water table is usually at depths of 4 to 6 feet from 1 month to 4 months during the summer and fall months. It is below these depths most of the rest of each year. After heavy or prolonged rain it rises above these depths briefly.	D
Hallendale- Fine Sand	Poorly to very poorly drained; slow to ponded runoff; rapid permeability. In drained areas, the water table fluctuates with the water level in canals and ditches through the solution holes in the limestone.	D
Hallendale- Urban Land Complex	Poorly to very poorly drained; slow to ponded runoff; rapid permeability.	D
Immokalee-Urban Land Complex	Poorly drained or very poorly drained. Runoff is slow or ponded. Permeability is rapid or very rapid in A and E horizons and moderate or moderately rapid in the Bh horizon. The water table is at depths of 6 to 18 inches for 1 to 4 months during most years. It is between a depth of 18 inches to 36 inches for 2 to 10 months during most years. It is below 60 inches during the dry periods of most years. Depressional areas are covered with standing water for periods of 6 to 9 months or more in most years.	D

Appendix B. Broward County study area Hydrologic Soil Classification (Cont.).

Soil Type	USDA-NRCS Official Soil Series Descriptions for Drainage and Permeability	Hydrologic Soil Group
Immokalee Fine Sand	Poorly drained or very poorly drained. Runoff is slow or ponded. Permeability is rapid or very rapid in A and E horizons and moderate or moderately rapid in the Bh horizon. The water table is at depths of 6 to 18 inches for 1 to 4 months during most years. It is between a depth of 18 inches to 36 inches for 2 to 10 months during most years. It is below 60 inches during the dry periods of most years. Depressional areas are covered with standing water for periods of 6 to 9 months or more in most years.	D
Immokalee-, Limestone Substratum -Urban Land Complex	Poorly drained or very poorly drained; runoff is slow or ponded	D
Lauderhill Muck	Very poorly drained; rapid permeability. In natural areas the water table is at or above the surface for much of the year; in other areas the water table is controlled by man.	D
Margate Fine Sand	Poorly drained; very slow runoff; rapid permeability. In undrained areas, the water table is within 10 inches of the soil surface for 2 to 4 months or shallow water covers the soil for 1 to 4 months during most years. In drained areas, the water table fluctuates with the canals and ditches through the solution holes in the limestone.	D
Okeelanta Muck	Very poorly drained; rapid permeability.	D
Palm Beach-Urban Land Complex	Well to excessively drained. Surface runoff is slow to very slow. Internal drainage and permeability are very rapid.	D
Palm Beach Sand	Well to excessively drained. Surface runoff is slow to very slow. Internal drainage and permeability are very rapid.	A
Paola Fine Sand	Excessively drained; slow runoff; rapid internal drainage; very rapid permeability. Water table is deeper than 72 inches.	A
Paola-Urban Land Complex	Excessively drained; slow runoff; rapid internal drainage; very rapid permeability. Water table is deeper than 72 inches.	D
Pennsuco Silty Clay Loam, Drained	Poorly and very poorly drained; very slow to ponded runoff. Permeability is moderately slow to moderate. The water table is within 10 inches of the surface for 4 to 6 months.	D
Pennsuco Silty Clay, Tidal	Poorly and very poorly drained; very slow to ponded runoff. Permeability is moderately slow to moderate. The water table is within 10 inches of the surface for 4 to 6 months. Tidal areas are flooded by daily or seasonal tides.	D
Perrine Silty clay Loam, drained	Poorly drained. Permeability is moderately slow to moderate. Runoff is very slow. The water table is within 10 inches of the surface about 30 to 50 percent of the time with highest probably from June to November.	D

Appendix B. Broward County study area Hydrologic Soil Classification (Cont.).

Soil Type	USDA-NRCS Official Soil Series Descriptions for Drainage and Permeability	Hydrologic Soil Group
Perrine Variant Silt Loam	Poorly drained. Permeability is moderately slow to moderate. Runoff is very slow. The water table is within 10 inches of the surface about 30 to 50 percent of the time with highest probably from June to November.	D
Plantation Muck	Very poorly drained; slow runoff; rapid permeability. Shallow water stands on soil surface for 1 to 2 months in most years. The water table is within 10 inches of the surface for 2 to 6 months and within 20 inches the remainder of the year during most years.	D
Pomello Fine Sand	Moderately well and somewhat poorly drained. Moderately rapid permeability. The seasonally high water table is at depths of about 24 to 42 inches for 1 to 4 months.	C
Pompano Fine Sand	Poorly to very poorly drained. Runoff is slow. Permeability is rapid or very rapid, but internal drainage is impeded by a very shallow water table. The water table is at depths of less than 10 inches for 2 to 6 months each year. Even during the drier months it is within depths of 30 inches for more than 9 months each year. In depressed areas the water table is above the soil surface for more than 3 months each year.	D
Sanibel Muck	Very poorly drained sandy soils with organic surfaces. Form in rapidly permeable marine sediments.	D
St. Lucie Fine Sand	Excessively drained. Internal drainage and permeability are very rapid, but there is little or no surface runoff. Depth to the seasonal water table is 72 to 120 inches.	B
Terra Ceia Muck, Tidal	Poorly drained; slow to ponded runoff. Internal drainage and permeability are rapid. In drained areas, water control systems regulate the level of the water tablet o depths of 12 to 48 inches, depending on the need of the crop grown. In undrained areas, the water table is at or above the soil surface except during extended dry periods, and areas on flood plains are flooded for long duration.	D
Udorthents		A
Udorthents, Marly Substratum-Urban land Complex		D
Udorthents, Shaped		A
Udorthents-Urban Land Complex		D
Urban Land		D
Water		N/A

Appendix C. Curve Number classification for the Florida Land Use and Cover Classification Systems (FLUCCS).

		Hydrologic Group A			Hydrologic Group B			Hydrologic Group C			Hydrologic Group D		
Lu-code	Classification	AMC I	AMC II	AMC III	AMC I	AMC II	AMC III	AMC I	AMC II	AMC III	AMC I	AMC II	AMC III
100	Developing Areas (20% impervious)	31	51	70	48	68	84	62	79	91	68	84	93
110	Residential Low Density (38% impervious)	41	61	78	57	75	88	67	83	93	73	87	95
120	Residential Medium Density (65% impervious)	59	77	89	70	85	94	78	90	96	81	92	97
130	Residential High Density (75% impervious)	70	85	94	78	90	96	83	93	98	85	94	98
140	Commercial and Service (85% impervious)	76	89	96	81	92	97	85	94	98	87	95	98
148	Cemetery	30	49	69	50	69	84	62	79	91	68	84	93
150	Industrial (72% impervious)	64	81	92	75	88	95	80	91	97	83	93	98
160	Extractive	67	83	93	76	89	96	81	92	97	83	93	98
170	Institutional	64	81	92	75	88	95	80	91	97	83	93	98
180	Recreational	30	49	69	50	69	84	62	79	91	68	84	93
190	Open Land	21	39	59	41	61	78	55	74	88	63	80	91
192	Inactive land with street pattern	48	68	84	62	79	91	72	86	94	76	89	96
210	Cropland and pastureland	44	64	81	57	75	88	66	82	92	70	85	94
220	Tree Crops	47	67	83	60	78	90	70	85	94	76	89	96
230	Feeding operation	30	49	69	50	69	84	62	79	91	68	84	93
240	Nurseries and vineyards	25	44	64	45	65	82	58	76	89	66	82	92
250	Specialty Farms	39	59	77	55	74	88	66	82	92	72	86	94
260	Other open land	30	49	69	50	69	84	62	79	91	68	84	93
310	Herbaceous	N/A	N/A	N/A	63	80	91	73	87	95	83	93	98
320	Shrub and Brush land	18	35	55	36	56	75	51	70	85	59	77	89

Appendix C. Curve Number classification for FLUCCS (Cont.).

		Hydrologic Group A			Hydrologic Group B			Hydrologic Group C			Hydrologic Group D		
330	Mixed Rangeland	30	49	69	50	69	84	62	79	91	68	84	93
410	Upland Coniferous Forests	26	45	65	46	66	82	59	77	89	67	83	93
420	Upland Hardwood Forests	45	26	65	66	46	82	77	59	89	83	67	93
430	Upland Hardwood Forests	45	26	65	66	46	82	77	59	89	83	67	93
440	Tree Plantations	67	47	83	78	60	90	85	70	94	89	76	96
510	Streams and Waterways	100	100	100	100	100	100	100	100	100	100	100	100
520	Lakes	100	100	100	100	100	100	100	100	100	100	100	100
530	Reservoirs	100	100	100	100	100	100	100	100	100	100	100	100
540	Bays and Estuaries	100	100	100	100	100	100	100	100	100	100	100	100
550	Major Springs	100	100	100	100	100	100	100	100	100	100	100	100
560	Slough Waters	100	100	100	100	100	100	100	100	100	100	100	100
610	Wetland Hardwood Forests	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
620	Wetland Coniferous Forests	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
630	Wetland Forested Mixed	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
640	Vegetated Non-Forested Wetlands	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
650	Non-vegetated	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
710	Beaches other than swimming beaches	21	39	59	41	61	78	55	74	88	63	80	91
720	Sand other than beaches	21	39	59	41	61	78	55	74	88	63	80	91
730	Exposed Rock	94	98	99	94	98	99	94	98	99	94	98	99
740	Disturbed Lands	59	77	89	72	86	94	80	91	97	85	94	98
810	Transportation	94	98	99	94	98	99	94	98	99	94	98	99
815	Port Facilities	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
816	Canals and Locks	100	100	100	100	100	100	100	100	100	100	100	100

Appendix C. Curve Number classification for FLUCCS (Cont.).

		Hydrologic Group A			Hydrologic Group B			Hydrologic Group C			Hydrologic Group D		
820	Communications	64	81	92	70	85	94	80	91	97	83	93	98
830	Utilities	64	81	92	75	88	95	80	91	97	83	93	98

Appendix D. Antecedent Moisture Condition II point results for the multi-class index overlay analysis using Doppler radar for the Hurricane Irene storm event compared to documented flooding locations. Points were extracted using the ArcView script GridSpot. Ratings from 0-3 indicate a high probability of flooding, 3-6 indicate a moderate probability of flooding and 6-9 indicate a low probability of flooding.

Calibration Analysis for Antecedent Moisture Condition II						
Ratings below 3 indicate a greater flood potential						
Flooding Location Address	Multi-Class Index Analysis Weights (elevation_excess precipitation_slope)					
	Radar					
	0.5_0.3_0.2	0.6_0.2_0.2	0.8_0.1_0.1	0.2_0.6_0.2	0.3_0.3_0.3	0.5_0.5_0
2400 Kensington Blvd.	4.25	4.40	4.45	3.80	4.34	5.00
4151 SW 100th Terrace	2.22	2.37	2.46	1.75	2.25	1.75
101 Royal Park Dr	2.72	2.42	2.21	3.61	2.68	1.21
104 Thomas Rd.	2.15	2.35	2.67	1.55	1.91	1.55
105 Allen Rd	2.55	2.85	3.43	1.65	2.09	1.65
1145 NW 69th Ave	5.66	5.96	5.96	4.77	5.94	3.57
11570 SW 13th Place	3.38	3.46	3.17	3.11	3.85	2.51
121 NE 56th Ct	4.00	3.80	3.90	4.60	3.66	1.60
12577 Sw 14th St	2.78	2.72	2.86	2.96	2.53	3.80
1300 SW 125th Ave.	3.33	3.36	3.19	3.25	3.58	3.10
131 N. 68th St.	3.20	3.00	3.00	3.80	3.00	1.40
13731 Roanoke St	4.39	4.43	4.41	4.27	4.45	2.47
1401 SW 17th St.	3.95	3.58	2.95	5.06	4.43	2.06
14620 Shotgun Rd	4.09	4.18	4.50	3.85	3.74	2.05
1473 NW 10th St	4.97	4.67	3.84	5.87	5.78	2.87
1473 NW 10th St	4.97	4.67	3.84	5.87	5.78	2.87
1560 SW 100 Terr	3.07	3.25	3.55	2.51	2.84	1.91
1561 NW 33rd Terrace	4.94	4.71	4.21	5.62	5.37	2.62
15705 W. Waterside Circle	4.90	4.93	4.64	4.79	5.31	2.99
1605 SW 5th Place	4.00	3.80	3.40	4.60	4.33	2.20
1630 NW 118 Ave.	3.34	3.54	3.77	2.74	3.24	2.14
1631 SW 3rd. Ave.	4.85	4.55	3.78	5.75	5.58	2.75
16611 SW 48th St	2.70	2.70	2.85	2.70	2.50	3.90
1695 NW 66th Ave.	4.90	5.20	5.60	4.00	4.66	2.80
1841 SW 105th Ave	2.93	2.93	2.46	2.93	3.54	2.33
191 NW 49th Ave.	4.47	4.37	4.18	4.78	4.62	2.38
1960 SW 68th Terrace	4.33	4.33	4.67	4.33	3.89	1.93
2100 NW 82nd Terr	4.15	4.05	4.02	4.45	4.07	2.05
2110 NW 2nd Ave.	3.38	3.14	2.89	4.09	3.48	1.69
2200 SO Ocean Blvd	2.52	2.42	2.21	2.82	2.69	1.62
2270 Sunshine Blvd	2.01	2.21	2.60	1.41	1.68	1.41
2305 SW 82nd Terrace	4.87	4.77	4.91	5.16	4.59	2.16
2515 NW 53rd St.	5.20	5.40	5.70	4.60	4.99	2.80
2555 N. 40th Ave.	4.52	4.62	4.79	4.23	4.38	2.43

Calibration Analysis for Antecedent Moisture Condition II (Cont.).

Ratings below 3 indicate a greater flood potential

Flooding Location Address	**Multi-Class Index Analysis Weights (elevation_excess precipitation_slope)**					
	Radar					
	0.5_0.3_0.2	0.6_0.2_0.2	0.8_0.1_0.1	0.2_0.6_0.2	0.3_0.3_0.3	0.5_0.5_0
2604 SW 55th St	2.94	2.84	2.92	3.24	2.72	1.44
2605 NW 98th Terrace	5.80	5.80	5.90	5.80	5.66	5.20
2611 NW 21st	4.01	3.81	3.42	4.60	4.34	2.20
2614 Sherman St.	2.95	2.86	2.48	3.22	3.36	2.02
2713 Utopia Dr.	2.04	2.05	2.12	1.98	1.97	1.38
2714 Coolidge	3.70	3.60	2.80	4.00	4.66	2.80
2729 Cayenne Ave	3.60	3.80	3.90	3.00	3.66	2.40
2729 Sunshine Blvd	2.84	3.01	2.84	2.34	3.23	2.34
2736 Sunshine Blvd	2.77	2.93	2.78	2.28	3.12	2.28
2741 North 72nd Way	3.18	3.39	3.23	2.56	3.60	2.56
2741 SW 7th St.	3.51	3.21	3.10	4.41	3.34	1.41
300 N. 29th Ave.	4.99	5.31	5.25	4.04	5.39	3.44
305 N. 31st Ave.	2.59	2.69	2.84	2.29	2.48	1.69
3099 Perwinkle Circle	3.79	3.97	3.88	3.25	4.08	2.65
3100 North 72nd Way	2.72	2.94	3.09	2.05	2.74	2.05
3171 N. 34th St.	3.07	2.98	3.03	3.34	2.90	1.54
319 SW 34 Ave.	6.19	6.59	7.30	4.99	5.65	3.19
3249 Grant St.	2.30	2.40	2.70	2.00	2.00	1.40
3260 SW 44th St	3.20	3.00	2.50	3.80	3.66	2.00
3260 SW 44th St	3.20	3.00	2.50	3.80	3.66	2.00
331 NE 57th Court	4.46	4.22	3.93	5.17	4.61	2.17
3333 NE 32nd St	4.00	3.80	3.40	4.60	4.33	2.20
3430 Pine Walk Dr. N.	5.33	5.46	5.38	4.94	5.56	3.14
3501 NW 47th Ave.	5.61	5.11	4.56	7.11	5.85	4.71
3520 SW 59th Ter	2.58	2.78	2.89	1.98	2.63	1.98
3941 NW 39th St.	4.65	4.46	4.24	5.24	4.73	2.24
4011 SW 72nd Drive	2.52	2.66	3.05	2.09	2.14	1.49
4020 Riverside Dr.	5.63	5.83	6.41	5.03	5.04	2.63
4100 SW 52nd Ct	2.15	2.05	2.04	2.44	2.06	1.24
4109 SW 61 Ave.	4.02	4.02	4.01	4.02	4.03	2.22
421 NE 57th Ct.	4.13	3.83	3.41	5.03	4.38	2.03
4220 NW 41st Terrace	4.83	4.62	4.26	5.46	5.09	2.46
4251 NW 74th	4.86	4.75	4.84	5.18	4.63	2.18
4410 NE 19th Terrace	3.91	3.74	3.53	4.42	4.02	2.02
4461 NW 73rd Ave.	4.78	4.67	4.78	5.11	4.51	2.11
4485 Cordia Circle	5.70	6.00	6.50	4.80	5.33	3.00
451 South 19th Ave	3.62	3.98	4.31	2.53	3.54	2.53
4610 SW 65th Ave	3.10	3.20	3.10	2.80	3.33	2.20
4631 NW 74th Ave.	4.30	4.12	4.14	4.86	4.09	1.86
4720 NW 41st St.	4.80	4.60	4.30	5.40	4.99	2.40
4748 NE 16th Ave	3.52	3.32	3.16	4.12	3.53	1.72
4766 NW 22nd	6.17	6.41	6.38	5.47	6.44	3.67

Calibration Analysis for Antecedent Moisture Condition II (Cont.).

Ratings below 3 indicate a greater flood potential

Flooding Location Address	Multi-Class Index Analysis Weights (elevation_excess precipitation_slope)					
	Radar					
	0.5_0.3_0.2	0.6_0.2_0.2	0.8_0.1_0.1	0.2_0.6_0.2	0.3_0.3_0.3	0.5_0.5_0
4850 SW 63rd Terr	3.79	3.74	3.20	3.93	4.46	5.05
4928 NW 39th St.	5.27	5.07	4.53	5.87	5.77	2.87
4980 SW 100th Ave	3.63	3.73	3.86	3.34	3.56	4.54
505 Brainwood Circle	2.50	2.80	3.40	1.60	2.00	1.60
5053 SW 87th Terr	2.60	2.82	2.99	1.95	2.58	1.95
5060 NW 120th Way	5.10	5.60	6.80	3.60	4.00	2.40
5116 SW 87th Ave	2.97	3.14	2.88	2.49	3.48	2.49
5116 SW 87th Ave	2.97	3.14	2.88	2.49	3.48	2.49
5140 SW 85th Ter	2.41	2.61	2.81	1.81	2.35	1.81
5201 Lancelot Lane	4.11	4.29	4.06	3.55	4.59	2.95
5221 SW 6th St.	4.59	4.89	5.44	3.69	4.14	2.49
5242 NW 51st	6.50	6.80	7.40	5.60	5.99	3.20
5300 SW 40th Ave	4.39	3.84	3.08	6.03	4.86	5.78
5356 Redwood Rd.	3.81	3.67	3.65	4.22	3.70	1.82
5702 Jefferson	3.11	3.51	4.26	1.91	2.52	1.91
5875 SW 41st Street	3.65	3.43	2.63	4.30	4.49	2.50
6231 SW 5th St.	4.72	5.08	5.84	3.64	4.06	2.44
632 SW 16th Ave	4.03	3.82	3.42	4.65	4.36	2.20
6400 NW 20th St.	5.44	5.74	6.37	4.54	4.90	2.74
641 NE 56th	3.74	3.44	3.22	4.64	3.74	1.64
6410 Kimberly	4.90	5.20	5.60	4.00	4.66	2.80
6450 Perry St.	3.00	3.14	3.24	2.60	2.99	2.00
6450 Sheridan St.	3.60	3.80	3.90	3.00	3.66	2.40
6611 SW 17th St.	5.19	5.28	5.58	4.92	4.87	2.52
6611 SW 17th St.	5.19	5.28	5.58	4.92	4.87	2.52
6670 Scott Street	3.05	3.28	3.26	2.38	3.30	2.38
673 Vista Isle Dr	4.91	4.94	4.62	4.82	5.36	3.02
6745 SW 27th Ct.	2.01	2.21	2.60	1.41	1.68	1.41
6803 SW 19th St	4.70	4.61	4.34	4.98	4.96	2.58
6880 Greene	2.50	2.80	3.40	1.60	2.00	1.60
6925 SW 35th Street	2.59	2.86	3.28	1.78	2.30	1.78
700 S Park Road	3.24	3.21	2.78	3.34	3.79	3.92
7000 Nova Dr.	3.67	3.58	3.29	3.94	3.96	3.28
7000 Park St.	3.30	3.60	3.80	2.40	3.33	2.40
708 SE 4th St	4.71	4.41	4.21	5.61	4.68	2.01
7110 Plantation Blvd	2.00	2.20	2.60	1.40	1.66	1.40
713 SW 79th Ave.	5.43	5.53	5.76	5.13	5.21	2.73
714 Hollywood Blvd	2.64	2.24	1.62	3.84	3.07	1.44
7301 NW 44th Place	5.08	4.73	4.10	6.14	5.56	3.34
7301 NW 44th Place	5.08	4.73	4.10	6.14	5.56	3.34
7305 NW 5th Place	5.36	5.75	6.34	4.18	4.97	2.98
732 SW 7th Avenue	3.11	3.41	3.71	2.21	3.01	2.21

Calibration Analysis for Antecedent Moisture Condition II (Cont.).

Ratings below 3 indicate a greater flood potential

Flooding Location Address	**Multi-Class Index Analysis Weights (elevation_excess precipitation_slope)**					
	Radar					
	0.5_0.3_0.2	0.6_0.2_0.2	0.8_0.1_0.1	0.2_0.6_0.2	0.3_0.3_0.3	0.5_0.5_0
7371 NW 44th Ct.	4.89	4.70	4.44	5.43	5.05	2.43
7410 Farragut St.	2.80	3.00	3.00	2.20	3.00	2.20
750 NW 134th Terrace	3.60	3.60	3.80	3.60	3.34	1.80
7501 Farragate St.	2.44	2.65	2.87	1.81	2.35	1.81
751 NW 42 Court	4.50	4.40	4.20	4.80	4.66	2.40
7560 NW 35th St.	4.34	4.18	4.31	4.80	4.00	1.80
7606 NW 18th Ct	4.80	4.91	4.55	4.44	5.39	3.24
7618 N 18th Ct	5.58	5.86	5.81	4.75	5.92	3.55
7745 Tamoshanter Blvd	5.30	5.36	5.48	5.12	5.20	2.72
7771 NW 13th St.	2.00	2.20	2.60	1.40	1.66	1.40
7801 NW 13th St.	2.39	2.59	2.80	1.79	2.32	1.79
7811 NW 13th St	2.79	2.99	3.00	2.19	2.99	2.19
7820 SW 9th St.	4.76	4.87	4.99	4.42	4.70	2.62
7920 NW 13th St.	2.27	2.47	2.73	1.67	2.11	1.67
8110 NW 13th Street	2.77	2.96	2.95	2.19	2.98	2.19
8110 NW 13th	2.77	2.96	2.95	2.19	2.98	2.19
8113 NW 71st. Ave.	4.84	4.94	5.47	4.54	4.23	2.14
8260 27th St	5.46	5.71	6.11	4.70	5.17	2.90
8360 NW 4th St.	3.09	3.29	3.64	2.49	2.81	1.89
8948 SW 49th Court	2.26	2.45	2.66	1.70	2.17	1.70
8952 SW 49th	2.00	2.20	2.60	1.40	1.66	1.40
8962 SW 49th St	2.00	2.20	2.60	1.40	1.66	1.40
9120 SW 53rd	1.68	1.79	1.95	1.34	1.57	1.34
948 Pennsylvania Ave	4.37	4.29	4.28	4.58	4.30	2.18
9560 SW 3rd Ct	3.12	3.12	2.52	3.15	3.91	2.55
995 SW 50th Way	4.81	5.11	5.56	3.91	4.51	2.71
5011 SW 13 Ct	5.00	5.10	5.55	4.70	4.50	4.70
6450 Perry St	3.00	3.14	3.24	2.60	2.99	2.00
4511 NW 74 Ave	4.69	4.51	4.33	5.25	4.74	2.25
5011 SW 13 Ct	5.00	5.10	5.55	4.70	4.50	4.70
4251 NW 74th Ave	4.86	4.75	4.84	5.18	4.63	2.18
521 NE 43rd St	3.89	3.67	3.22	4.56	4.25	2.16
6610 NW 25th	4.47	4.21	3.78	5.27	4.78	2.27
1113 NW 29th Ave	4.30	4.00	3.50	5.20	4.66	2.20
550 E Campus Circle	4.66	4.59	4.45	4.86	4.77	2.46
4930 NW 53rd St	5.18	5.08	5.04	5.48	5.12	2.48
12305 Paseo Way	3.46	3.64	3.74	2.90	3.50	2.30
3050 NW 10th Ct	3.86	3.48	2.80	5.03	4.37	2.03
4565 SW 33rd Ave	3.09	2.92	2.46	3.57	3.54	2.00
4704 NE 2nd Ave	4.54	4.29	3.89	5.30	4.82	2.30
1810 NW 91 Terrace	2.91	3.11	3.05	2.31	3.17	2.31
4521 NW 74th Ave	4.83	4.66	4.47	5.35	4.90	2.35

Calibration Analysis for Antecedent Moisture Condition II (Cont.).						
Ratings below 3 indicate a greater flood potential						
Flooding Location Address	**Multi-Class Index Analysis Weights (elevation_excess precipitation_slope)**					
	Radar					
	0.5_0.3_0.2	0.6_0.2_0.2	0.8_0.1_0.1	0.2_0.6_0.2	0.3_0.3_0.3	0.5_0.5_0
4710 NE 2nd Ave	4.51	4.25	3.84	5.28	4.80	2.28
7411 SW 39th St	2.71	2.81	2.90	2.41	2.68	1.81
13031 SW 7th Ct	3.80	3.80	3.90	3.80	3.67	2.00
119 Essex Rd	2.23	2.44	2.75	1.61	2.02	1.61
10671 NW 22nd	3.10	3.20	3.10	2.80	3.33	2.20
1951 NW 44th St	5.60	6.10	7.05	4.10	4.84	2.90
2401 SW 84th Ave	4.24	4.25	4.17	4.22	4.36	4.82
500 NE 58th Ct	3.50	3.20	3.10	4.40	3.33	1.40
7450 Roosevelt St	2.29	2.51	2.86	1.62	2.03	1.62
2664 73rd Ave	4.03	3.83	3.43	4.62	4.37	2.22
5800 NW 74th Place	6.29	6.39	6.19	6.00	6.66	6.00
1144 SW 149th	4.70	4.80	4.90	4.40	4.66	2.60
10361 Iris Court	2.57	2.67	2.86	2.26	2.42	1.66
1635 East Lake Way	3.09	2.79	2.39	3.99	3.31	1.59
2920 Nw 11th Place	4.30	4.00	3.50	5.20	4.66	2.20
6424 Oak Street	2.97	3.13	3.34	2.51	2.84	1.91
5300 Nw 52nd St	6.45	6.74	6.82	5.58	6.62	3.78
8468 Windsor Dr	2.70	2.86	3.24	2.21	2.35	1.61
8468 Windsor Dr	2.70	2.86	3.24	2.21	2.35	1.61
7830 NW 33rd St Apt 204	2.39	2.61	2.93	1.72	2.20	1.72
1120 NW 83rd Way	2.66	2.78	2.98	2.31	2.51	1.71
10361 Iris Court	2.57	2.67	2.86	2.26	2.42	1.66
2800 NW 47ty Terrace	5.13	5.00	4.83	5.53	5.22	2.53
8841 NW 3rd	3.32	3.42	3.21	3.02	3.69	2.42
3777 NW 78th Ave	3.03	3.19	3.18	2.52	3.21	2.23
3333 SW 15th St	3.53	3.43	3.21	3.83	3.71	2.03
2641 SW 137th Terrace	4.23	4.23	4.14	4.21	4.35	4.81
4920 NW 73rd Ave	5.28	5.08	5.04	5.88	5.13	2.28
320 NE 58th St	4.22	3.94	3.61	5.03	4.38	2.03
5730 Farragut St	2.83	2.87	3.13	2.71	2.52	1.51
7028 NW 49th Ct	5.84	5.45	5.23	6.99	5.75	4.55
8645 Beekman Dr	3.60	3.80	3.90	3.00	3.66	2.40
15904 W Wind Circle	4.44	4.45	4.29	4.40	4.65	2.60
3548 Jackson Blvd	3.76	3.61	3.53	4.22	3.70	1.82
7420 NW 37th Ct	4.58	4.48	4.74	4.88	4.13	1.88
14700 Madison Place	4.68	4.77	4.86	4.39	4.65	2.59
5012 SW 88th Terrace	2.71	2.91	2.95	2.11	2.84	2.11
827 Ne 14th Ct	3.48	3.08	2.56	4.66	3.77	1.66
3371 SW 15th St	3.01	2.92	3.01	3.29	2.81	1.49
7130 Coral Blvd	2.30	2.40	2.70	2.00	2.00	1.40
6862 Broadmoor	5.11	5.13	5.17	5.04	5.07	2.64
6270 Sherman St	2.84	3.04	3.56	2.21	2.35	1.61

Calibration Analysis for Antecedent Moisture Condition II (Cont.).

Ratings below 3 indicate a greater flood potential

Flooding Location Address	Multi-Class Index Analysis Weights (elevation_excess precipitation_slope)					
	Radar					
	0.5_0.3_0.2	0.6_0.2_0.2	0.8_0.1_0.1	0.2_0.6_0.2	0.3_0.3_0.3	0.5_0.5_0
6901 SW 22nd Ct	2.53	2.70	2.68	2.03	2.72	2.03
8524 SW 17th Ct	2.90	2.80	2.90	3.20	2.66	1.40
2421 SW 49th Ct	3.78	3.68	3.34	4.08	4.12	2.28
1221 Silverado	4.40	4.60	5.30	3.80	3.66	2.00
1741 NW 104th Ave	3.22	3.35	3.29	2.85	3.41	2.25
7570 Juniper St	2.60	2.60	2.80	2.60	2.33	1.40
7111 NW 46th Court	4.20	4.04	4.21	4.68	3.79	1.68
7028 NW 49th Ct	5.84	5.45	5.23	6.99	5.75	4.55
14620 Shot Gun Road	4.09	4.18	4.50	3.85	3.74	2.05
3100 Canal Rd	3.69	3.74	3.66	3.51	3.85	2.31
3301 Lee St	3.40	3.40	3.20	3.40	3.66	2.20
6300 SW 9th Place	4.87	5.17	5.59	3.97	4.62	2.77
7432 NW 34th St	5.00	5.00	5.00	5.00	4.99	2.60
4901 NW 72nd Terrace	5.31	5.08	4.93	5.97	5.28	2.37
7380 NW 38th St	2.11	2.31	2.66	1.51	1.86	1.51
7451 Branch St	2.41	2.67	3.13	1.64	2.06	1.64
7130 NW 46th St	4.50	4.40	4.70	4.80	3.99	1.80
331 Delaware Ave	4.12	4.02	4.02	4.41	4.02	2.01
5259 SW 40th Ave	3.71	3.33	2.67	4.84	4.21	4.19
6701 Park St	2.29	2.49	2.74	1.69	2.15	1.69
6601 Scott St	2.66	2.79	3.04	2.28	2.46	1.68
8501 NW 7th Court	3.44	3.63	3.75	2.88	3.46	2.28
2654 Nassau Dr	2.68	2.69	2.93	2.63	2.38	1.43
5523 NW 53 Ct	6.37	6.64	6.69	5.55	6.57	3.75
3220 W Quayside Dr	3.60	3.80	3.90	3.00	3.66	2.40
3371 SW 15th St	3.01	2.92	3.01	3.29	2.81	1.49
5800 NW 74th Pl	6.29	6.39	6.19	6.00	6.66	6.00
137 Essex Road	2.01	2.21	2.61	1.41	1.68	1.41
119 Essex Rd	2.23	2.44	2.75	1.61	2.02	1.61
8231 NW 20th St	4.93	5.23	5.61	4.06	4.71	2.81
551 Fairfx	4.20	4.20	4.10	4.20	4.33	2.40
5515 SW 44 Ave	3.06	2.96	2.98	3.36	2.93	1.56
165 SW 125 Ave	4.20	4.23	4.22	4.14	4.23	2.34
16233 Nw 24 St	2.38	2.32	2.16	2.56	2.53	2.33
4720 NW 41st St	4.80	4.60	4.30	5.40	4.99	2.40
107 Newton Road	2.01	2.21	2.61	1.41	1.69	1.41
4702 SW 66th Terrace	2.33	2.43	2.72	2.03	2.05	1.43
267 NW 7th Street	6.22	6.47	6.95	5.49	5.81	3.09
1233 SW 87th Terrace	4.72	4.69	4.18	4.82	5.37	3.02
5220 SW 91st St Avenue	2.05	2.16	2.12	1.72	2.20	1.72
8401 NW 7th Ct	3.14	3.28	3.34	2.71	3.19	2.11
5805 NW 43rd Ave	3.90	4.00	4.50	3.60	3.33	1.80

Calibration Analysis for Antecedent Moisture Condition II (Cont.).

Ratings below 3 indicate a greater flood potential

Flooding Location Address	**Multi-Class Index Analysis Weights (elevation_excess precipitation_slope)**					
	Radar					
	0.5_0.3_0.2	0.6_0.2_0.2	0.8_0.1_0.1	0.2_0.6_0.2	0.3_0.3_0.3	0.5_0.5_0
7200 NW 46 Ct	4.06	3.86	3.93	4.66	3.76	1.66
6516 Harbor Rd	4.68	4.94	5.25	3.91	4.52	2.71
B316 Sw 15th St	4.67	4.50	4.44	5.15	4.59	2.15
2825 Morning Glory Ln	2.97	2.93	2.30	3.07	3.77	2.47
1143 Wyoming Avenue	3.70	3.60	3.80	4.00	3.33	1.60
3321 NW 7th Tr	4.29	4.11	3.68	4.82	4.69	2.42
5383 NW 55th Terrace	5.40	5.80	6.90	4.20	4.33	2.40
3551 SW 130th Avenue	2.64	2.57	2.44	2.84	2.74	4.04
317 NE 28th Street	4.50	4.40	4.20	4.80	4.66	2.40
151 Commodore Dr	4.02	3.82	3.91	4.62	3.69	4.02
10030 NW 35th St	3.61	3.66	3.54	3.49	3.81	4.69
4050 SW 102 Ave	2.91	2.93	2.53	2.87	3.45	2.27
7435 North W 34th St	5.00	5.00	5.00	5.00	4.99	2.60
4461 NW 73rd Ave	4.78	4.67	4.78	5.11	4.51	2.11
4475 SW 54 Court	2.50	2.30	2.17	3.09	2.48	1.29
5411 SW 43rd Terrace	2.54	2.44	2.35	2.84	2.54	1.47
4550 NW 12th Ave	3.43	3.44	3.75	3.41	3.02	1.61
2817 SW 5th St	4.62	4.43	4.24	5.21	4.68	2.21
2681 Regalia Place	3.37	3.57	3.79	2.77	3.28	2.17
5503 NW 55th Terrace	6.54	7.00	7.84	5.13	5.88	3.33
5415 SW 43rd Terrace	2.67	2.57	2.46	2.97	2.71	1.56
7301 NW 44th Pl	5.08	4.73	4.10	6.14	5.56	3.34
5270 SW 48th St	3.20	3.00	2.50	3.80	3.66	4.40
8510 NW 4th St	3.11	3.23	3.26	2.72	3.20	2.12
10681 SW 47th St	2.86	2.97	3.02	2.54	2.90	4.34
9631 Ridge Side Ct	3.79	3.87	3.33	3.56	4.59	2.96
9362 Arbor Wood Cir	3.31	3.51	3.76	2.71	3.19	2.11
4821 N 31st Ct	3.75	3.74	3.83	3.78	3.62	1.98
8511 NW 4th St	3.11	3.23	3.26	2.72	3.20	2.12
1770 NW 107th Ave	2.97	3.07	3.03	2.67	3.11	2.07
4475 54th Ct SW	2.50	2.30	2.17	3.09	2.48	1.29
3790 NW 58th St	5.76	6.06	6.56	4.85	5.41	3.05
6880 Green St	2.50	2.80	3.40	1.60	2.00	1.60
6410 Harding	2.73	2.87	3.10	2.33	2.55	1.73
1365 W 3rd Ave	6.52	6.81	7.41	5.64	6.01	3.24
9611 Ridgeside Ct	2.94	2.93	2.41	2.98	3.62	2.38
1920 NW 42nd St	4.25	4.10	3.31	4.70	5.16	2.90
1360 NE 40th Ct	2.40	2.20	2.10	3.00	2.33	1.20
14481 Hickory Ct	4.36	4.31	3.89	4.52	4.86	2.72
5307 NW 44th Ave	5.16	5.06	4.53	5.46	5.77	3.06
4801 SW 55th Terr	3.72	3.72	3.36	3.72	4.19	2.52
3324 SW 50th Rd	4.21	4.05	3.23	4.68	5.13	2.88

Calibration Analysis for Antecedent Moisture Condition II (Cont.).

Ratings below 3 indicate a greater flood potential

Flooding Location Address	**Multi-Class Index Analysis Weights (elevation_excess precipitation_slope)**					
	Radar					
	0.5_0.3_0.2	0.6_0.2_0.2	0.8_0.1_0.1	0.2_0.6_0.2	0.3_0.3_0.3	0.5_0.5_0
600 SW 133rd	3.40	3.40	3.70	3.40	3.00	1.60
2119 NW 27th Terr	3.60	3.30	3.18	4.48	3.46	1.48
3370 SW 15th St	3.01	2.92	3.01	3.29	2.81	1.49
2920 NW 11th Pl	4.30	4.00	3.50	5.20	4.66	2.20
11300 SW 22nd St	3.01	2.93	2.57	3.24	3.40	4.44
5393 NW 55th Terr	5.40	5.80	6.90	4.20	4.33	2.40
14641 Poplar Hill Rd	4.43	4.53	4.77	4.13	4.22	2.33
7760 NW 47th Ct	5.39	5.15	4.86	6.12	5.52	2.52
2849 S. Belmont Ln	3.71	3.87	3.75	3.22	4.03	2.62
13350 Luray Rd	2.44	2.25	2.17	3.02	2.36	3.62
11280 Renaisance Rd	2.78	2.98	3.47	2.19	2.32	1.59
5800 NW 74th	6.29	6.39	6.19	6.00	6.66	6.00
5333 NW 48th St	6.48	6.88	7.44	5.28	6.14	3.48
14740 Highland Spring Ct	4.16	4.24	4.49	3.94	3.90	2.14
5551 NW 50th Ave	6.25	6.66	7.38	5.02	5.70	3.22
3451 SW 130th Ave	2.40	2.30	2.15	2.70	2.50	3.90
5760 NW 7th	5.47	5.89	6.51	4.23	5.04	3.03
5654 NE 54th Avenue	5.09	4.85	4.23	5.80	5.66	2.80
470 Greaton Ave	3.79	3.82	4.05	3.71	3.51	1.91
5654 NE 5th Ave	5.09	4.85	4.23	5.80	5.66	2.80
123 Bedford Ave	2.80	3.00	3.00	2.20	3.00	2.20
14721 Madison Place	4.70	4.80	4.90	4.40	4.66	2.60
4730 NE 2nd Avenue	7.56	7.76	8.36	6.97	6.94	3.37
5551 NW 50th Ave	6.25	6.66	7.38	5.02	5.70	3.22
5170 SW 40th Avenue	3.41	3.14	2.57	4.23	3.90	3.37
3450 SW 130th Ae	2.10	2.00	2.00	2.40	2.00	3.60
5383 NW 55 Terrace	5.40	5.80	6.90	4.20	4.33	2.40
5800 NW 74th Place	6.29	6.39	6.19	6.00	6.66	6.00
1136 Wyoming Ave	4.10	4.00	4.00	4.40	4.00	2.00
1550 SW 15 Ave	3.75	3.26	2.68	5.23	4.02	2.84
11251 Renaissance Rd	2.81	3.01	3.49	2.23	2.37	1.63
5800 NW 74th Place	6.29	6.39	6.19	6.00	6.66	6.00
11201 SW 52nd St	3.31	3.45	3.43	2.88	3.47	4.68
11555 SW 21st Ct	3.17	3.20	3.29	3.05	3.08	4.25
3410 NW 33rd Court	4.56	4.53	4.60	4.66	4.43	2.26
3001 SW 23rd Street	3.41	3.46	2.97	3.27	4.12	2.67
5800 NW 74th Place	6.29	6.39	6.19	6.00	6.66	6.00
11201 SW 52nd Street	3.31	3.45	3.43	2.88	3.47	4.68
14740 Highland Springs	4.16	4.24	4.49	3.94	3.90	2.14
12305 Paseo Way	3.46	3.64	3.74	2.90	3.50	2.30
3230 NW 18th Street	4.54	4.34	4.17	5.14	4.56	2.14

Antecedent Moisture Condition III point results for the multi-class index overlay analysis using Doppler radar for the Hurricane Irene storm event compared to documented flooding locations. Points were extracted using the ArcView script GridSpot. Ratings from 0-3 indicate a high probability of flooding, 3-6 indicate a moderate probability of flooding and 6-9 indicate a low probability of flooding.

Calibration Analysis for Antecedent Moisture Condition III						
Ratings below 3 indicate a greater flood potential						
Flooding Location Address	Multi-Class Index Analysis Weights (elevation_excess precipitation_slope)					
	Radar					
	0.5_0.3_0.2	0.6_0.2_0.2	0.8_0.1_0.1	0.2_0.6_0.2	0.3_0.3_0.3	0.5_0.5_0
2400 Kensington Blvd.	3.95	4.20	4.35	3.20	4.00	2.60
4151 SW 100th Terrace	2.22	2.37	2.46	1.75	2.25	1.75
101 Royal Park Dr	2.72	2.42	2.21	3.61	2.68	1.21
104 Thomas Rd.	2.15	2.35	2.67	1.55	1.91	1.55
105 Allen Rd	2.55	2.85	3.43	1.65	2.09	1.65
1145 NW 69th Ave	5.66	5.96	5.96	4.77	5.94	3.57
11570 SW 13th Place	3.38	3.46	3.17	3.11	3.85	2.51
121 NE 56th Ct	4.00	3.80	3.90	4.60	3.66	1.60
12577 Sw 14th St	2.30	2.40	2.70	2.00	2.00	1.40
1300 SW 125th Ave.	3.11	3.21	3.11	2.80	3.33	2.20
131 N. 68th St.	3.20	3.00	3.00	3.80	3.00	1.40
13731 Roanoke St	4.39	4.43	4.41	4.27	4.45	2.47
1401 SW 17th St.	3.95	3.58	2.95	5.06	4.43	2.06
14620 Shotgun Rd	4.09	4.18	4.50	3.85	3.74	2.05
1473 NW 10th St	4.97	4.67	3.84	5.87	5.78	2.87
1473 NW 10th St	4.97	4.67	3.84	5.87	5.78	2.87
1560 SW 100 Terr	3.07	3.25	3.55	2.51	2.84	1.91
1561 NW 33rd Terrace	4.94	4.71	4.21	5.62	5.37	2.62
15705 W. Waterside Circle	4.90	4.93	4.64	4.79	5.31	2.99
1605 SW 5th Place	4.00	3.80	3.40	4.60	4.33	2.20
1630 NW 118 Ave.	3.34	3.54	3.77	2.74	3.24	2.14
1631 SW 3rd. Ave.	4.85	4.55	3.78	5.75	5.58	2.75
16611 SW 48th St	2.40	2.50	2.75	2.10	2.17	1.50
1695 NW 66th Ave.	4.90	5.20	5.60	4.00	4.66	2.80
1841 SW 105th Ave	2.93	2.93	2.46	2.93	3.54	2.33
191 NW 49th Ave.	4.47	4.37	4.18	4.78	4.62	2.38
1960 SW 68th Terrace	4.33	4.33	4.67	4.33	3.89	1.93
2100 NW 82nd Terr	4.15	4.05	4.02	4.45	4.07	2.05
2110 NW 2nd Ave.	3.38	3.14	2.89	4.09	3.48	1.69
2200 SO Ocean Blvd	2.52	2.42	2.21	2.82	2.69	1.62
2270 Sunshine Blvd	2.01	2.21	2.60	1.41	1.68	1.41
2305 SW 82nd Terrace	4.87	4.77	4.91	5.16	4.59	2.16
2515 NW 53rd St.	5.20	5.40	5.70	4.60	4.99	2.80
2555 N. 40th Ave.	4.52	4.62	4.79	4.23	4.38	2.43
2604 SW 55th St	2.94	2.84	2.92	3.24	2.72	1.44

Calibration Analysis for Antecedent Moisture Condition III (Cont.).						
Ratings below 3 indicate a greater flood potential						
Flooding Location Address	Multi-Class Index Analysis Weights (elevation_excess precipitation_slope)					
	Radar					
	0.5_0.3_0.2	0.6_0.2_0.2	0.8_0.1_0.1	0.2_0.6_0.2	0.3_0.3_0.3	0.5_0.5_0
2605 NW 98th Terrace	5.50	5.60	5.80	5.20	5.33	2.80
2611 NW 21st	4.01	3.81	3.42	4.60	4.34	2.20
2614 Sherman St.	2.95	2.86	2.48	3.22	3.36	2.02
2713 Utopia Dr.	2.04	2.05	2.12	1.98	1.97	1.38
2714 Coolidge	3.70	3.60	2.80	4.00	4.66	2.80
2729 Cayenne Ave	3.60	3.80	3.90	3.00	3.66	2.40
2729 Sunshine Blvd	2.84	3.01	2.84	2.34	3.23	2.34
2736 Sunshine Blvd	2.77	2.93	2.78	2.28	3.12	2.28
2741 North 72nd Way	3.18	3.39	3.23	2.56	3.60	2.56
2741 SW 7th St.	3.51	3.21	3.10	4.41	3.34	1.41
300 N. 29th Ave.	4.99	5.31	5.25	4.04	5.39	3.44
305 N. 31st Ave.	2.59	2.69	2.84	2.29	2.48	1.69
3099 Perwinkle Circle	3.79	3.97	3.88	3.25	4.08	2.65
3100 North 72nd Way	2.72	2.94	3.09	2.05	2.74	2.05
3171 N. 34th St.	3.07	2.98	3.03	3.34	2.90	1.54
319 SW 34 Ave.	6.19	6.59	7.30	4.99	5.65	3.19
3249 Grant St.	2.30	2.40	2.70	2.00	2.00	1.40
3260 SW 44th St	3.20	3.00	2.50	3.80	3.66	2.00
3260 SW 44th St	3.20	3.00	2.50	3.80	3.66	2.00
331 NE 57th Court	4.46	4.22	3.93	5.17	4.61	2.17
3333 NE 32nd St	4.00	3.80	3.40	4.60	4.33	2.20
3430 Pine Walk Dr. N.	5.33	5.46	5.38	4.94	5.56	3.14
3501 NW 47th Ave.	4.71	4.51	4.26	5.31	4.85	2.31
3520 SW 59th Ter	2.58	2.78	2.89	1.98	2.63	1.98
3941 NW 39th St.	4.65	4.46	4.24	5.24	4.73	2.24
4011 SW 72nd Drive	2.52	2.66	3.05	2.09	2.14	1.49
4020 Riverside Dr.	5.63	5.83	6.41	5.03	5.04	2.63
4100 SW 52nd Ct	2.15	2.05	2.04	2.44	2.06	1.24
4109 SW 61 Ave.	4.02	4.02	4.01	4.02	4.03	2.22
421 NE 57th Ct.	4.13	3.83	3.41	5.03	4.38	2.03
4220 NW 41st Terrace	4.83	4.62	4.26	5.46	5.09	2.46
4251 NW 74th	4.86	4.75	4.84	5.18	4.63	2.18
4410 NE 19th Terrace	3.91	3.74	3.53	4.42	4.02	2.02
4461 NW 73rd Ave.	4.78	4.67	4.78	5.11	4.51	2.11
4485 Cordia Circle	5.70	6.00	6.50	4.80	5.33	3.00
451 South 19th Ave	3.62	3.98	4.31	2.53	3.54	2.53
4610 SW 65th Ave	3.10	3.20	3.10	2.80	3.33	2.20
4631 NW 74th Ave.	4.30	4.12	4.14	4.86	4.09	1.86
4720 NW 41st St.	4.80	4.60	4.30	5.40	4.99	2.40
4748 NE 16th Ave	3.52	3.32	3.16	4.12	3.53	1.72
4766 NW 22nd	6.17	6.41	6.38	5.47	6.44	3.67
4850 SW 63rd Terr	3.45	3.51	3.08	3.25	4.08	2.65

Calibration Analysis for Antecedent Moisture Condition III (Cont.).						
Ratings below 3 indicate a greater flood potential						
Flooding Location Address	Multi-Class Index Analysis Weights (elevation_excess precipitation_slope)					
	Radar					
	0.5_0.3_0.2	0.6_0.2_0.2	0.8_0.1_0.1	0.2_0.6_0.2	0.3_0.3_0.3	0.5_0.5_0
4928 NW 39th St.	5.27	5.07	4.53	5.87	5.77	2.87
4980 SW 100th Ave	3.33	3.53	3.76	2.74	3.23	2.14
505 Brainwood Circle	2.50	2.80	3.40	1.60	2.00	1.60
5053 SW 87th Terr	2.60	2.82	2.99	1.95	2.58	1.95
5060 NW 120th Way	5.10	5.60	6.80	3.60	4.00	2.40
5116 SW 87th Ave	2.97	3.14	2.88	2.49	3.48	2.49
5116 SW 87th Ave	2.97	3.14	2.88	2.49	3.48	2.49
5140 SW 85th Ter	2.41	2.61	2.81	1.81	2.35	1.81
5201 Lancelot Lane	4.11	4.29	4.06	3.55	4.59	2.95
5221 SW 6th St.	4.59	4.89	5.44	3.69	4.14	2.49
5242 NW 51st	6.50	6.80	7.40	5.60	5.99	3.20
5300 SW 40th Ave	3.43	3.21	2.76	4.12	3.80	3.87
5356 Redwood Rd.	3.81	3.67	3.65	4.22	3.70	1.82
5702 Jefferson	3.11	3.51	4.26	1.91	2.52	1.91
5875 SW 41st Street	3.65	3.43	2.63	4.30	4.49	2.50
6231 SW 5th St.	4.72	5.08	5.84	3.64	4.06	2.44
632 SW 16th Ave	4.03	3.82	3.42	4.65	4.36	2.20
6400 NW 20th St.	5.44	5.74	6.37	4.54	4.90	2.74
641 NE 56th	3.74	3.44	3.22	4.64	3.74	1.64
6410 Kimberly	4.90	5.20	5.60	4.00	4.66	2.80
6450 Perry St.	3.00	3.14	3.24	2.60	2.99	2.00
6450 Sheridan St.	3.60	3.80	3.90	3.00	3.66	2.40
6611 SW 17th St.	5.19	5.28	5.58	4.92	4.87	2.52
6611 SW 17th St.	5.19	5.28	5.58	4.92	4.87	2.52
6670 Scott Street	3.05	3.28	3.26	2.38	3.30	2.38
673 Vista Isle Dr	4.91	4.94	4.62	4.82	5.36	3.02
6745 SW 27th Ct.	2.01	2.21	2.60	1.41	1.68	1.41
6803 SW 19th St	4.70	4.61	4.34	4.98	4.96	2.58
6880 Greene	2.50	2.80	3.40	1.60	2.00	1.60
6925 SW 35th Street	2.59	2.86	3.28	1.78	2.30	1.78
700 S Park Road	3.05	3.08	2.71	2.94	3.57	2.34
7000 Nova Dr.	3.40	3.40	3.20	3.40	3.66	2.20
7000 Park St.	3.30	3.60	3.80	2.40	3.33	2.40
708 SE 4th St	4.71	4.41	4.21	5.61	4.68	2.01
7110 Plantation Blvd	2.00	2.20	2.60	1.40	1.66	1.40
713 SW 79th Ave.	5.43	5.53	5.76	5.13	5.21	2.73
714 Hollywood Blvd	2.64	2.24	1.62	3.84	3.07	1.44
7301 NW 44th Place	4.78	4.53	4.00	5.54	5.22	2.54
7301 NW 44th Place	4.78	4.53	4.00	5.54	5.22	2.54
7305 NW 5th Place	5.36	5.75	6.34	4.18	4.97	2.98
732 SW 7th Avenue	3.11	3.41	3.71	2.21	3.01	2.21
7371 NW 44th Ct.	4.89	4.70	4.44	5.43	5.05	2.43

Calibration Analysis for Antecedent Moisture Condition III (Cont.).

Ratings below 3 indicate a greater flood potential

Flooding Location Address	Multi-Class Index Analysis Weights (elevation_excess precipitation_slope)					
	Radar					
	0.5_0.3_0.2	0.6_0.2_0.2	0.8_0.1_0.1	0.2_0.6_0.2	0.3_0.3_0.3	0.5_0.5_0
7410 Farragut St.	2.80	3.00	3.00	2.20	3.00	2.20
750 NW 134th Terrace	3.60	3.60	3.80	3.60	3.34	1.80
7501 Farragate St.	2.44	2.65	2.87	1.81	2.35	1.81
751 NW 42 Court	4.50	4.40	4.20	4.80	4.66	2.40
7560 NW 35th St.	4.34	4.18	4.31	4.80	4.00	1.80
7606 NW 18th Ct	4.80	4.91	4.55	4.44	5.39	3.24
7618 N 18th Ct	5.58	5.86	5.81	4.75	5.92	3.55
7745 Tamoshanter Blvd	5.30	5.36	5.48	5.12	5.20	2.72
7771 NW 13th St.	2.00	2.20	2.60	1.40	1.66	1.40
7801 NW 13th St.	2.39	2.59	2.80	1.79	2.32	1.79
7811 NW 13th St	2.79	2.99	3.00	2.19	2.99	2.19
7820 SW 9th St.	4.76	4.87	4.99	4.42	4.70	2.62
7920 NW 13th St.	2.27	2.47	2.73	1.67	2.11	1.67
8110 NW 13th Street	2.77	2.96	2.95	2.19	2.98	2.19
8110 NW 13th	2.77	2.96	2.95	2.19	2.98	2.19
8113 NW 71st. Ave.	4.84	4.94	5.47	4.54	4.23	2.14
8260 27th St	5.46	5.71	6.11	4.70	5.17	2.90
8360 NW 4th St.	3.09	3.29	3.64	2.49	2.81	1.89
8948 SW 49th Court	2.26	2.45	2.66	1.70	2.17	1.70
8952 SW 49th	2.00	2.20	2.60	1.40	1.66	1.40
8962 SW 49th St	2.00	2.20	2.60	1.40	1.66	1.40
9120 SW 53rd	1.68	1.79	1.95	1.34	1.57	1.34
948 Pennsylvania Ave	4.37	4.29	4.28	4.58	4.30	2.18
9560 SW 3rd Ct	3.12	3.12	2.52	3.15	3.91	2.55
995 SW 50th Way	4.81	5.11	5.56	3.91	4.51	2.71
5011 SW 13 Ct	4.40	4.70	5.35	3.50	3.84	2.30
6450 Perry St	3.00	3.14	3.24	2.60	2.99	2.00
4511 NW 74 Ave	4.69	4.51	4.33	5.25	4.74	2.25
5011 SW 13 Ct	4.40	4.70	5.35	3.50	3.84	2.30
4251 NW 74th Ave	4.86	4.75	4.84	5.18	4.63	2.18
521 NE 43rd St	3.89	3.67	3.22	4.56	4.25	2.16
6610 NW 25th	4.47	4.21	3.78	5.27	4.78	2.27
1113 NW 29th Ave	4.30	4.00	3.50	5.20	4.66	2.20
550 E Campus Circle	4.66	4.59	4.45	4.86	4.77	2.46
4930 NW 53rd St	5.18	5.08	5.04	5.48	5.12	2.48
12305 Paseo Way	3.46	3.64	3.74	2.90	3.50	2.30
3050 NW 10th Ct	3.86	3.48	2.80	5.03	4.37	2.03
4565 SW 33rd Ave	3.09	2.92	2.46	3.57	3.54	2.00
4704 NE 2nd Ave	4.54	4.29	3.89	5.30	4.82	2.30
1810 NW 91 Terrace	2.91	3.11	3.05	2.31	3.17	2.31
4521 NW 74th Ave	4.83	4.66	4.47	5.35	4.90	2.35
4710 NE 2nd Ave	4.51	4.25	3.84	5.28	4.80	2.28

Calibration Analysis for Antecedent Moisture Condition III (Cont.).

Ratings below 3 indicate a greater flood potential

Flooding Location Address	Multi-Class Index Analysis Weights (elevation_excess precipitation_slope)					
	Radar					
	0.5_0.3_0.2	0.6_0.2_0.2	0.8_0.1_0.1	0.2_0.6_0.2	0.3_0.3_0.3	0.5_0.5_0
7411 SW 39th St	2.71	2.81	2.90	2.41	2.68	1.81
13031 SW 7th Ct	3.80	3.80	3.90	3.80	3.67	2.00
119 Essex Rd	2.23	2.44	2.75	1.61	2.02	1.61
10671 NW 22nd	3.10	3.20	3.10	2.80	3.33	2.20
1951 NW 44th St	5.60	6.10	7.05	4.10	4.84	2.90
2401 SW 84th Ave	3.64	3.85	3.97	3.02	3.69	2.42
500 NE 58th Ct	3.50	3.20	3.10	4.40	3.33	1.40
7450 Roosevelt St	2.29	2.51	2.86	1.62	2.03	1.62
2664 73rd Ave	4.03	3.83	3.43	4.62	4.37	2.22
5800 NW 74th Place	5.99	6.19	6.09	5.40	6.32	3.60
1144 SW 149th	4.70	4.80	4.90	4.40	4.66	2.60
10361 Iris Court	2.57	2.67	2.86	2.26	2.42	1.66
1635 East Lake Way	3.09	2.79	2.39	3.99	3.31	1.59
2920 Nw 11th Place	4.30	4.00	3.50	5.20	4.66	2.20
6424 Oak Street	2.97	3.13	3.34	2.51	2.84	1.91
5300 Nw 52nd St	6.45	6.74	6.82	5.58	6.62	3.78
8468 Windsor Dr	2.70	2.86	3.24	2.21	2.35	1.61
8468 Windsor Dr	2.70	2.86	3.24	2.21	2.35	1.61
7830 NW 33rd St Apt 204	2.39	2.61	2.93	1.72	2.20	1.72
1120 NW 83rd Way	2.66	2.78	2.98	2.31	2.51	1.71
10361 Iris Court	2.57	2.67	2.86	2.26	2.42	1.66
2800 NW 47ty Terrace	5.13	5.00	4.83	5.53	5.22	2.53
8841 NW 3rd	3.32	3.42	3.21	3.02	3.69	2.42
3777 NW 78th Ave	3.03	3.19	3.18	2.52	3.21	2.23
3333 SW 15th St	3.53	3.43	3.21	3.83	3.71	2.03
2641 SW 137th Terrace	3.93	4.03	4.04	3.61	4.01	2.41
4920 NW 73rd Ave	5.28	5.08	5.04	5.88	5.13	2.28
320 NE 58th St	4.22	3.94	3.61	5.03	4.38	2.03
5730 Farragut St	2.83	2.87	3.13	2.71	2.52	1.51
7028 NW 49th Ct	4.99	4.89	4.94	5.29	4.81	2.29
8645 Beekman Dr	3.60	3.80	3.90	3.00	3.66	2.40
15904 W Wind Circle	4.44	4.45	4.29	4.40	4.65	2.60
3548 Jackson Blvd	3.76	3.61	3.53	4.22	3.70	1.82
7420 NW 37th Ct	4.58	4.48	4.74	4.88	4.13	1.88
14700 Madison Place	4.68	4.77	4.86	4.39	4.65	2.59
5012 SW 88th Terrace	2.71	2.91	2.95	2.11	2.84	2.11
827 Ne 14th Ct	3.48	3.08	2.56	4.66	3.77	1.66
3371 SW 15th St	3.01	2.92	3.01	3.29	2.81	1.49
7130 Coral Blvd	2.30	2.40	2.70	2.00	2.00	1.40
6862 Broadmoor	5.11	5.13	5.17	5.04	5.07	2.64
6270 Sherman St	2.84	3.04	3.56	2.21	2.35	1.61
6901 SW 22nd Ct	2.53	2.70	2.68	2.03	2.72	2.03

Calibration Analysis for Antecedent Moisture Condition III (Cont.).						
Ratings below 3 indicate a greater flood potential						
Flooding Location Address	Multi-Class Index Analysis Weights (elevation_excess precipitation_slope)					
	Radar					
	0.5_0.3_0.2	0.6_0.2_0.2	0.8_0.1_0.1	0.2_0.6_0.2	0.3_0.3_0.3	0.5_0.5_0
8524 SW 17th Ct	2.90	2.80	2.90	3.20	2.66	1.40
2421 SW 49th Ct	3.78	3.68	3.34	4.08	4.12	2.28
1221 Silverado	4.40	4.60	5.30	3.80	3.66	2.00
1741 NW 104th Ave	3.22	3.35	3.29	2.85	3.41	2.25
7570 Juniper St	2.60	2.60	2.80	2.60	2.33	1.40
7111 NW 46th Court	4.20	4.04	4.21	4.68	3.79	1.68
7028 NW 49th Ct	4.99	4.89	4.94	5.29	4.81	2.29
14620 Shot Gun Road	4.09	4.18	4.50	3.85	3.74	2.05
3100 Canal Rd	3.69	3.74	3.66	3.51	3.85	2.31
3301 Lee St	3.40	3.40	3.20	3.40	3.66	2.20
6300 SW 9th Place	4.87	5.17	5.59	3.97	4.62	2.77
7432 NW 34th St	5.00	5.00	5.00	5.00	4.99	2.60
4901 NW 72nd Terrace	5.31	5.08	4.93	5.97	5.28	2.37
7380 NW 38th St	2.11	2.31	2.66	1.51	1.86	1.51
7451 Branch St	2.41	2.67	3.13	1.64	2.06	1.64
7130 NW 46th St	4.50	4.40	4.70	4.80	3.99	1.80
331 Delaware Ave	4.12	4.02	4.02	4.41	4.02	2.01
5259 SW 40th Ave	3.15	2.96	2.48	3.73	3.60	3.08
6701 Park St	2.29	2.49	2.74	1.69	2.15	1.69
6601 Scott St	2.66	2.79	3.04	2.28	2.46	1.68
8501 NW 7th Court	3.44	3.63	3.75	2.88	3.46	2.28
2654 Nassau Dr	2.68	2.69	2.93	2.63	2.38	1.43
5523 NW 53 Ct	6.37	6.64	6.69	5.55	6.57	3.75
3220 W Quayside Dr	3.60	3.80	3.90	3.00	3.66	2.40
3371 SW 15th St	3.01	2.92	3.01	3.29	2.81	1.49
5800 NW 74th Pl	5.99	6.19	6.09	5.40	6.32	3.60
137 Essex Road	2.01	2.21	2.61	1.41	1.68	1.41
119 Essex Rd	2.23	2.44	2.75	1.61	2.02	1.61
8231 NW 20th St	4.93	5.23	5.61	4.06	4.71	2.81
551 Fairfx	4.20	4.20	4.10	4.20	4.33	2.40
5515 SW 44 Ave	3.06	2.96	2.98	3.36	2.93	1.56
165 SW 125 Ave	4.20	4.23	4.22	4.14	4.23	2.34
16233 Nw 24 St	2.20	2.20	2.10	2.20	2.33	1.60
4720 NW 41st St	4.80	4.60	4.30	5.40	4.99	2.40
107 Newton Road	2.01	2.21	2.61	1.41	1.69	1.41
4702 SW 66th Terrace	2.33	2.43	2.72	2.03	2.05	1.43
267 NW 7th Street	6.22	6.47	6.95	5.49	5.81	3.09
1233 SW 87th Terrace	4.72	4.69	4.18	4.82	5.37	3.02
5220 SW 91st St Avenue	2.05	2.16	2.12	1.72	2.20	1.72
8401 NW 7th Ct	3.14	3.28	3.34	2.71	3.19	2.11
5805 NW 43rd Ave	3.90	4.00	4.50	3.60	3.33	1.80
7200 NW 46 Ct	4.06	3.86	3.93	4.66	3.76	1.66

Calibration Analysis for Antecedent Moisture Condition III (Cont.).						
Ratings below 3 indicate a greater flood potential						
Flooding Location Address	Multi-Class Index Analysis Weights (elevation_excess precipitation_slope)					
	Radar					
	0.5_0.3_0.2	0.6_0.2_0.2	0.8_0.1_0.1	0.2_0.6_0.2	0.3_0.3_0.3	0.5_0.5_0
6516 Harbor Rd	4.68	4.94	5.25	3.91	4.52	2.71
B316 Sw 15th St	4.67	4.50	4.44	5.15	4.59	2.15
2825 Morning Glory Ln	2.97	2.93	2.30	3.07	3.77	2.47
1143 Wyoming Avenue	3.70	3.60	3.80	4.00	3.33	1.60
3321 NW 7th Tr	4.29	4.11	3.68	4.82	4.69	2.42
5383 NW 55th Terrace	5.40	5.80	6.90	4.20	4.33	2.40
3551 SW 130th Avenue	2.34	2.37	2.34	2.24	2.40	1.64
317 NE 28th Street	4.50	4.40	4.20	4.80	4.66	2.40
151 Commodore Dr	3.72	3.62	3.81	4.02	3.36	4.02
10030 NW 35th St	3.31	3.46	3.44	2.89	3.47	2.29
4050 SW 102 Ave	2.91	2.93	2.53	2.87	3.45	2.27
7435 North W 34th St	5.00	5.00	5.00	5.00	4.99	2.60
4461 NW 73rd Ave	4.78	4.67	4.78	5.11	4.51	2.11
4475 SW 54 Court	2.50	2.30	2.17	3.09	2.48	1.29
5411 SW 43rd Terrace	2.54	2.44	2.35	2.84	2.54	1.47
4550 NW 12th Ave	3.43	3.44	3.75	3.41	3.02	1.61
2817 SW 5th St	4.62	4.43	4.24	5.21	4.68	2.21
2681 Regalia Place	3.37	3.57	3.79	2.77	3.28	2.17
5503 NW 55th Terrace	6.54	7.00	7.84	5.13	5.88	3.33
5415 SW 43rd Terrace	2.67	2.57	2.46	2.97	2.71	1.56
7301 NW 44th Pl	4.78	4.53	4.00	5.54	5.22	2.54
5270 SW 48th St	2.90	2.80	2.40	3.20	3.33	2.00
8510 NW 4th St	3.11	3.23	3.26	2.72	3.20	2.12
10681 SW 47th St	2.56	2.77	2.92	1.94	2.56	1.94
9631 Ridge Side Ct	3.79	3.87	3.33	3.56	4.59	2.96
9362 Arbor Wood Cir	3.31	3.51	3.76	2.71	3.19	2.11
4821 N 31st Ct	3.75	3.74	3.83	3.78	3.62	1.98
8511 NW 4th St	3.11	3.23	3.26	2.72	3.20	2.12
1770 NW 107th Ave	2.97	3.07	3.03	2.67	3.11	2.07
4475 54th Ct SW	2.50	2.30	2.17	3.09	2.48	1.29
3790 NW 58th St	5.76	6.06	6.56	4.85	5.41	3.05
6880 Green St	2.50	2.80	3.40	1.60	2.00	1.60
6410 Harding	2.73	2.87	3.10	2.33	2.55	1.73
1365 W 3rd Ave	6.51	6.81	7.40	5.62	6.00	3.24
9611 Ridgeside Ct	2.94	2.93	2.41	2.98	3.62	2.38
1920 NW 42nd St	4.25	4.10	3.31	4.70	5.16	2.90
1360 NE 40th Ct	2.40	2.20	2.10	3.00	2.33	1.20
14481 Hickory Ct	4.36	4.31	3.89	4.52	4.86	2.72
5307 NW 44th Ave	5.16	5.06	4.53	5.46	5.77	3.06
4801 SW 55th Terr	3.72	3.72	3.36	3.72	4.19	2.52
3324 SW 50th Rd	4.21	4.05	3.23	4.68	5.13	2.88
600 SW 133rd	3.40	3.40	3.70	3.40	3.00	1.60

Calibration Analysis for Antecedent Moisture Condition III (Cont.).

Ratings below 3 indicate a greater flood potential

Flooding Location Address	Multi-Class Index Analysis Weights (elevation_excess precipitation_slope)					
	Radar					
	0.5_0.3_0.2	0.6_0.2_0.2	0.8_0.1_0.1	0.2_0.6_0.2	0.3_0.3_0.3	0.5_0.5_0
2119 NW 27th Terr	3.60	3.30	3.18	4.48	3.46	1.48
3370 SW 15th St	3.01	2.92	3.01	3.29	2.81	1.49
2920 NW 11th Pl	4.30	4.00	3.50	5.20	4.66	2.20
11300 SW 22nd St	2.71	2.73	2.47	2.64	3.07	2.04
5393 NW 55th Terr	5.40	5.80	6.90	4.20	4.33	2.40
14641 Poplar Hill Rd	4.43	4.53	4.77	4.13	4.22	2.33
7760 NW 47th Ct	5.39	5.15	4.86	6.12	5.52	2.52
2849 S. Belmont Ln	3.71	3.87	3.75	3.22	4.03	2.62
13350 Luray Rd	2.14	2.05	2.07	2.42	2.03	1.22
11280 Renaisance Rd	2.78	2.98	3.47	2.19	2.32	1.59
5800 NW 74th	5.99	6.19	6.09	5.40	6.32	3.60
5333 NW 48th St	6.48	6.88	7.44	5.28	6.14	3.48
14740 Highland Spring Ct	4.16	4.24	4.49	3.94	3.90	2.14
5551 NW 50th Ave	6.25	6.66	7.38	5.02	5.70	3.22
3451 SW 130th Ave	2.10	2.10	2.05	2.10	2.17	1.50
5760 NW 7th	5.47	5.89	6.51	4.23	5.04	3.03
5654 NE 54th Avenue	5.09	4.85	4.23	5.80	5.66	2.80
470 Greaton Ave	3.79	3.82	4.05	3.71	3.51	1.91
5654 NE 5th Ave	5.09	4.85	4.23	5.80	5.66	2.80
123 Bedford Ave	2.80	3.00	3.00	2.20	3.00	2.20
14721 Madison Place	4.70	4.80	4.90	4.40	4.66	2.60
4730 NE 2nd Avenue	7.56	7.76	8.36	6.97	6.94	3.37
5551 NW 50th Ave	6.25	6.66	7.38	5.02	5.70	3.22
5170 SW 40th Avenue	3.07	2.91	2.46	3.54	3.52	2.69
3450 SW 130th Ae	1.80	1.80	1.90	1.80	1.67	1.20
5383 NW 55 Terrace	5.40	5.80	6.90	4.20	4.33	2.40
5800 NW 74th Place	5.99	6.19	6.09	5.40	6.32	3.60
1136 Wyoming Ave	4.10	4.00	4.00	4.40	4.00	2.00
1550 SW 15 Ave	3.44	3.05	2.58	4.61	3.68	1.61
11251 Renaissance Rd	2.81	3.01	3.49	2.23	2.37	1.63
5800 NW 74th Place	5.99	6.19	6.09	5.40	6.32	3.60
11201 SW 52nd St	3.01	3.25	3.33	2.28	3.13	2.28
11555 SW 21st Ct	2.87	3.00	3.19	2.45	2.75	1.85
3410 NW 33rd Court	4.56	4.53	4.60	4.66	4.43	2.26
3001 SW 23rd Street	3.41	3.46	2.97	3.27	4.12	2.67
5800 NW 74th Place	5.99	6.19	6.09	5.40	6.32	3.60
11201 SW 52nd Street	3.01	3.25	3.33	2.28	3.13	2.28
14740 Highland Springs	4.16	4.24	4.49	3.94	3.90	2.14
12305 Paseo Way	3.46	3.64	3.74	2.90	3.50	2.30
3230 NW 18th Street	4.54	4.34	4.17	5.14	4.56	2.14