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Hurricane Floyd Flood Mapping Integrating Landsat 7 TM Satellite Imagery and DEM Data

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ABSTRACT

Capturing the extent of flooding during an extreme event in an efficient manner is essential for response, recovery, and mitigation activities. An efficient and economical method for mapping flood extent in a coastal floodplain is described in this paper. The method was based on classifying water and non-water features on two Landsat 7 thematic mapper (TM) images (acquired before and during the flood event), then performing a change detection analysis to identify floodwaters. Digital elevation model (DEM) data were also integrated into the analysis to model floodplain inundation and identify flooded areas underneath forest canopies. Within Pitt County, North Carolina, the primary land cover types most affected by flooding were bottomland forest/hardwood swamps, southern yellow pine, and cultivated land. The method proved to be reliable and could be applied quickly using data that are relatively inexpensive, easy to

obtain, and easy to analyze. This method should work well in similar areas of large spatial extent and flat terrain.

INTRODUCTION

It is important to be able to quickly determine the extent of flooding and the land use/land cover types under water during an extreme event, such as in the aftermath of a hurricane. Access to this type of information can greatly assist comprehensive relief efforts (Corbley, 1993). This research sought to develop a method for mapping flood extent using data that would be relatively easy to process, easily accessible, and inexpensive. Remotely sensed data can provide valuable mapping capabilities and information during flooding events. However, obtaining remotely sensed data for analysis that represents an ideal combination of fine temporal and spatial sampling with the ability to see through clouds and to discriminate flooding under forest cover, is difficult. Developing an integrated method incorporating other digital spatial data, such as digital elevation model (DEM) data, into the analysis process can provide additional information not available from remotely sensed data alone.

September 2, 1999, Hurricane Dennis visited the Outer Banks of North Carolina. It then returned as a tropical storm on September 5, spreading significant precipitation across eastern North Carolina, leaving the ground saturated. September 15, 1999, Hurricane Floyd made landfall near the South Carolina - North Carolina border and proceeded to churn through eastern North Carolina, dumping 25 - 46 cm of rain in many areas in less than 72 hours. The damage due to the floodwaters, which covered over 50,000 km^2, was immense causing an unprecedented disaster in the eastern region of state. In addition to the loss of over fifty lives, more than 6,000 homes were destroyed and some 44,000 were damaged. Estimated losses could exceed $6 billion (Gares, 1999).

METHODOLOGY

Study Area and Ground Observation

Pitt County is located at approximately the center of the eastern coastal plain of North Carolina. The elevation of the region drops only about 60 meters as it extends for approximately 120-160 km from the Piedmont region to the coast. The population of Pitt County is about 126,000 (estimated in 1998). Greenville, which is the largest city, is centrally located and has a population of approximately 60,000 (estimated in 1998). Additional residents in the county are spread throughout rural towns. In Pitt County the majority of the 1999 flooding occurred north of the Tar River. North of Greenville and immediately adjacent to the Tar River is an area that is currently defined as conservation/open space land use in the city of Greenville (Figure 1). This conservation/open space land use zone grades into low- and medium-density residential, industrial, and mixed land uses. The city of Greenville suffered flooding to its water treatment facility, airport, power transmission substation, and numerous residential and industrial areas that are nearby or currently within open space land use zones. Some 6,000 homes were flooded in Pitt County. The majority of these homes were uninsured. Of the 50,000 or so people who were displaced, more than 6,000 were housed in emergency shelters, many for weeks.

Ground truth information was gathered in the field once the floodwaters had completely subsided, but before high water marks had faded. Areas to the south and north of the Tar River were examined for the depth and extent floodwaters. The aerial photo in Figure 1 was taken on September 23, 1999, during the flood event. Floodwaters extend into the student housing district seen in the southeastern section of the photo and throughout the entire area shown north of the river. Areas of extensive tree canopy north of the river in the primary and secondary floodplains were completely flooded.

Flood Mapping Using TM Images

Two remotely sensed Landsat images were acquired for this project. One was obtained on the 28th of July (pre-flood); another was obtained on September 30th (during the flooding). The Tar River reached peak flood stage in the area of

Pitt County on the September 21, 1999. Due to the 16-day repeat orbiting of the Landsat 7 satellite, no other Landsat 7 satellite images were obtained during the flooding. We geo-referenced both images and were able to determine the extent of flooding in Pitt County using the non-flood July 28 image as a reference.

There were two steps involved in identifying flooded vs. non-flooded areas using the TM imagery: 1) identify water vs. non-water areas on both of the TM images, and 2) compare the areas classified as water vs. non-water on the TM images to determine which areas represented flooding.

After investigating a number of approaches to identify the water vs. non-water areas, we determined that best method consisted of an addition of two TM bands (TM4 + TM7). TM4 (0.76 to 0.90 µm, reflective infrared) is responsive to the amount of vegetation biomass and is useful in identifying land and water boundaries. However, it is possible to confuse water and asphalt areas (road pavements and rooftops of buildings) in the developed areas such as downtown, commercial/industrial areas, etc., as they appear black on the TM 4 image or they reflect little back to the sensor. On the TM 7 (2.08 to 2.35 µm, mid-infrared) image, the reflectance from water, paved road surfaces, and rooftops differs. Therefore, we could identify the water (flooded) and non-water (non-flooded) areas, by including TM 7 in the analysis. Ground truthing was an important component in determining the cut-off value to separate water from non-water on the images. These observations were made in the field in early October of 1999, and through the analysis of aerial photos taken during the flood event.

Determining the areas that were flooded was the next step and was performed on a pixel-by-pixel basis. After performing a change detection analysis between the two images there were four possible results for each pixel.

1. If an area was classified as water before and during the flooding, it was considered to be a permanent water feature (e.g., river channel, ponds, lakes).
2. If an area was classified as non-water on the July (pre-flood) image, and the area was classified as water on the September (flood) image, the area was considered to be flooded.
3. If an area was dry on both the July and September images, the area was not flooded.
4. Areas that were classified as water in July and classified as non-water in September were usually caused by cloud shadows on the image or by land use change between the two dates.

Using the method described above, a map representing flooded areas in Pitt County on September 30, 1999, was created. Inspection of this map indicated that the TM imagery did a good job of delineating the extent of flooding; however, due to the inability of the imagery to penetrate forest canopy, large gaps appeared in flooded areas where forests were present.

Integration of the DEM Data into the Flood Mapping Analysis

One method to overcome the lack of canopy penetration by the TM imagery is to incorporate digital elevation model (DEM) data into the analysis. There are several advantages to this integration. In the U.S., the DEM data are widely available. The DEM data are invariable year to year or seasonally. Also, most of the bottomland forest and hardwood swamps, which were heavily flooded, are located in the floodplain of the river. By inundating the DEM according to river gage readings flooding that occurred underneath tree canopies in the floodplain could be identified. The DEM data works well for flood mapping in this area of relatively flat terrain, and may work well in other areas such as the coastal floodplains along the East Coast and the Gulf of the Mexico.

Four 7.5-minute quadrangles of USGS DEM data were selected for the Greenville area, which covers most of the Tar River in Pitt County. The TM imagery were also subset for this area. We proceeded to inundate the DEM based on the river gage reading during the flood event on September 30, 1999. The river gage is located near the center of the four quads (Figure 1). Similar to the TM imagery analysis, using the DEM data a distinction was made between permanent water features and areas that were flooded, and the DEM was classified into water bodies/rivers, flooded areas, and non-flooded areas.

The final flood map for the Greenville area was derived by combining the flood maps from both the TM and DEM data in a standard geographic information system (GIS) procedure by using the logical "OR" operator. If flooded areas were identified in the TM flood map or the DEM flood map they were included in the final map (Figure 2). This "OR" logic allowed us to extract the best of the TM and DEM data in the flood mapping analysis and overcame some of the deficiencies of using the TM data or the DEM data alone. This integration of the TM and DEM data in flood mapping was straightforward and efficient.

Flooded areas for land use and land cover types within the four-quadrangle area were calculated separately using the TM and DEM flood delineations and for the combined map. The land use and land cover types and amount of area inundated within the categories most affected by flooding are recorded in Table 1 (below). From Table 1 we can see that the category most affected by flooding was bottomland forest and hardwood swamps. The southern pine category was not heavily flooded according to the DEM data because this type of forest is generally found above the floodplain.

Table 1

Primary flooded land use/land cover categories within the study site (four topographic quadrangle area).

(The final flooded area is derived through the logical "OR" operation from the TM data and DEM data.)

	Flooded TM Data (km^2)	Flooded DEM Data (km^2)	Flooded TM & DEM Data (km^2)
Cultivated	15.129	8.515	19.138
Bottom Land Forest/Swamp	23.217	22.557	32.694
Southern Yellow Pine	28.198	1.969	28.816

CONCLUSION

A simple and efficient method for mapping flood extent in a coastal floodplain was developed. The method was based on classifying water and non-water areas on two Landsat 7 TM images, performing a change detection analysis to determine flooded areas, and incorporating the representation of flooding according to the inundation of a DEM. Inclusion of the DEM data into the analysis overcame the limitation of the TM data in being able to distinguish between flooded areas and forest canopy. Assessment of the flooded and non-flooded areas was undertaken using ground verification and interpretation of aerial photography taken during the flooding. The land use and land cover categories most affected by the flood were: bottomland forest/hardwood swamps, southern yellow pine, and cultivated land.

The objective of this research was to develop a method for mapping flood extent using data that was accessible, inexpensive, and relatively easy to process. The method developed here has been shown to be reliable and could be used in the other coastal floodplains (such as the East Coast, and the Gulf Coast of the U.S.), using similar TM images, DEM data, and river stage data.

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