Comparison of Light Detection and Ranging and National Elevation Dataset Digital Elevation Model on Floodplains of North Carolina

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Abstract: USGS national elevation dataset (NED) digital elevation model (DEM) data and four sets of light detection and ranging (LIDAR) DEMs were compared for Pitt County, North Carolina. The NED DEM has a spatial resolution of 30×30 m. Two sets of the LIDAR DEMs have a spatial resolution of 6.1×6.1 m and 15.2×15.2 m, respectively. To compare the DEMs spatially, two LIDAR DEMs were resampled into 30×30 m resolution. Statistically, the LIDAR DEMs were very similar to each other, and there was some difference with the LIDAR DEMs versus NED DEM. All five DEMs covering the floodplains between the cities of Greenville and Washington were then utilized to map a flood extent. The spatial patterns of individual categories on the maps agreed 87.4–95.0%. Finally, modeled inundation extents were examined against the 1999 flood event. The overall accuracy for selected flooded and nonflooded sites ranged 92.5–96.1%.

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CE Database subject headings: Floodplains; Floods; Hurricanes; North Carolina; Digital techniques; Recovery planning.

Introduction

After the massive 1999 flood caused by Hurricane Floyd in eastern North Carolina, critical weaknesses have been identified regarding rescue, recovery, and mitigation efforts in order to reduce the risk of similar damages in the future (FEMA 2000; USACE and FEMA 2000; Maiolo et al. 2001). One of the weaknesses is that the original FEMA flood insurance rate maps (FIRMs) that only delineate the 100-year floodplains are out of date and are of limited utility during a flood. Since the 1999 flood, there have been two major developments. First, the multiyear/phase and multimillion dollar statewide North Carolina Floodplain Mapping Program (NCFMP) started in 2001 (http://www.ncflodmaps.com). The collection of statewide light detection and ranging (LIDAR) digital elevation models (DEMs) is a major component and cost in the NCFMP. The LIDAR DEMs have been created for many counties now, and eventually for all North Carolina counties (http://www.ncfloodmaps.com/Status). The LIDAR DEMs are of 6.1×6.1 m (20×20 ft) and 15.2×15.2 m (50×50 ft) spatial resolutions. The other development is the completion of the national elevation dataset (NED) by the United States Geological Survey (USGS). The NED DEMs are developed by combining the highest-resolution and best-quality elevation data available in the United States (Gesch et al. 2002). The NED DEMs have spatial resolution of 30×30 m, and are free for downloading.

The availability of LIDAR and NED DEMs not only provides the basis for creating updated and accurate flood extent maps, but also presents a unique opportunity for intercomparison. Are the DEMs on floodplains of North Carolina similar or different? We will compare the LIDAR and NED DEMs for our case study—Pitt County, North Carolina—and then compare the flood extents derived from the DEMs on the coastal floodplains between the cities of Greenville and Washington. Finally, we will quantify the accuracy of the modeled extents with a real flood event documented with aerial photographs and satellite images, as well as with ground observation. It should be noted that the DEM comparisons and comparisons of the flood extent maps are not a part of the NCFMP, whose primary goal is to conduct flood hazard analysis and to produce updated and static digital flood insurance rate maps (DFIRMs) (http://www.ncfloodmaps.com). Also, the authors are trying to mimic the situation wherein a user gets and uses the data that have been through the quality control/quality assurance (QC/QA) process conducted by the data providers (i.e., the NCFMP and USGS). Therefore, the accuracy assessments of the LIDAR and USGS DEMs themselves in the study area are not sought even though the errors in the DEMs can influence the outcomes of terrain and inundation modeling (USACE 1986; Kenward et al. 2000; Holmes et al. 2002; Tate et al. 2002; Hodgson et al. 2003).

Approach

Study areas

Pitt County and the westernmost part of Beaufort County, North Carolina, are the study area. The area belongs to the Tar/Pamlico and Neuse river basins. LIDAR DEM of 15.2×15.2 m resolution, as an example, shows the elevation of Pitt County in gray

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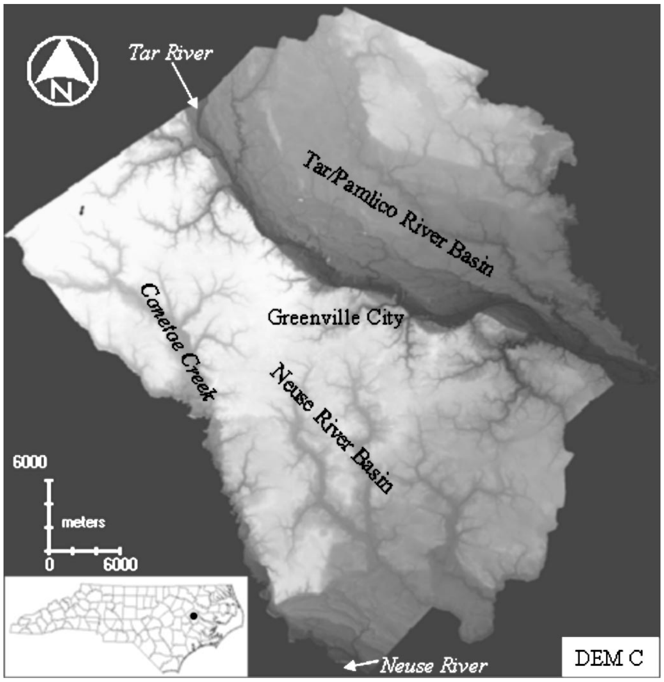

Fig. 1. The light detection and ranging digital elevation model (DEM) of 15.2×15.2 m spatial resolution (DEM C) shows Pitt County, North Carolina. The county is about 1697 km^2. Beaufort County is adjacent to Pitt on the east.

scale—the brighter the tone, the higher the elevation (Fig. 1). Greenville, with a residential population of 60,000 and an additional 20,000 college students, is located in the middle of Pitt County and is the hub of educational, medical, financial, and retail services in eastern North Carolina. Agriculture and forestry are the major activities on the floodplain between Greenville and Washington (Fig. 2). The Tar/Pamlico River is also a recreational resource for sailing and fishing. The study area was selected due to the flooding caused there by Hurricane Floyd in 1999. The flooding has greatly affected eastern North Carolina, and millions

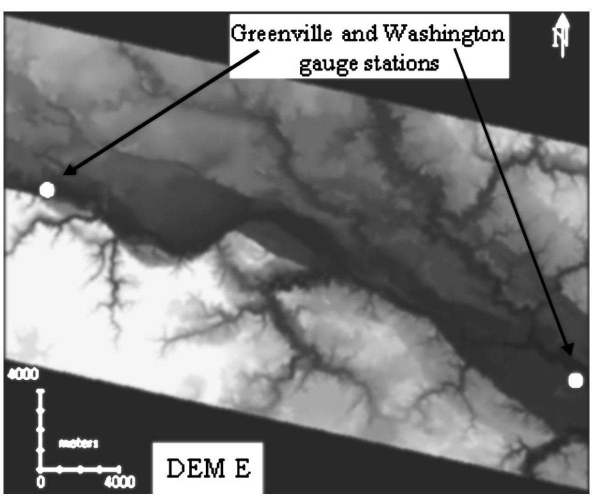

Fig. 2. The USGS national elevation dataset digital elevation model (DEM E) illustrates the inundation study areas between Greenville, in Pitt County, and Washington, in Beaufort County. The total area is about 518 km^2.

Table 1. Surface Water Height (m) above Mean Sea Level at Two USGS Gauge Stations on the Tar/Pamlico River, North Carolina

Date and conditions	Greenville gauge station	Washington gauge station
June 6, 2003 (at normal river flow condition)	1.05	0.35
September 21, 1999 (at extremely high flow condition)	8.32	1.68
September 23, 1999 (at high flow condition)[a]	7.96	1.60

[a]Aerial photographs and Landsat 7 EMT+ data were acquired on September 23, 1999.

of dollars of federal and state money have been spent in recovery and mitigation activities (USACE and FEMA 2000; Maiolo et al. 2001). LIDAR and NED DEM data of this area are available. Ground observations and remotely sensed data are also collected, and they can be used to investigate the accuracy of a modeled flood extent derived from the inundation of the DEMs.

Datasets

The NCFMP DEMs are developed using an airborne LIDAR that transmits laser pulses pointing toward the ground and detects the echoes of the pulses. Because of different delays of the echoes, the elevation of earth surface can be measured (Lillesand et al. 2004). To minimize the vegetation influence on the elevation measurement (of bare earth), the LIDAR data of the Tar/Pamlico and Neuse river basins were acquired between January and March 2001, when deciduous vegetation was at a leaf-off stage. LIDAR DEMs of 6.1×6.1 m and 15.2×15.2 m spatial resolutions are created and are downloadable (http://www.ncfloodmaps.com). The data are organized in tiles, and each tile covers 3,048.0 ×3,048.0 m (10,000.0×10,000.0 ft). Hundreds of DEM tiles of two spatial resolutions are assembled to cover the study area, respectively. Also, the 15.2×15.2 m DEMs have been hydrocorrected so that all flow directions in a basin are accounted for—that is, all large and small rivers and creeks are identified and connected accordingly (S. Wray, NCFMP, personal communication, 2003). The hydrocorrection is not applied to the 6.1 ×6.1 m DEMs.

The NED DEMs and metadata are downloaded at http://gisdata.usgs.gov/NED/default.asp. The DEM data are a seamless mosaic of the best-available elevation data the USGS has and are mainly derived from the individual DEMs of USGS 7.5-min quadrangles and updated with aerial photographs, satellite images, and ground surveys. The DEM is 1.0×1.0 arcsec (about 30.0×30.0 m) in the latitude and longitude coordinate system. The elevation is in meters. The NED DEMs for the study area should be similar to the previous level-two USGS DEMs.

Surface water heights measured at the USGS river gauge stations (http://waterdata.usgs.gov/nc/nwis/measurements) are additional data needed to model the inundation extent on floodplains using the simple DEM-inundation method (Wang et al. 2002). Two stations exist, one in the City of Greenville (Pitt County) and the other in the City of Washington (Beaufort County). Floodplains of Tar/Pamlico River, in a parallelogram shape between the two stations, are extracted and used for the inundation modeling. The parallelogram area covers most of the floodplains of the river and its tributaries between the two stations (Fig. 2). Surface water heights at a normal river flow and a flood flow are tabulated (Table 1). The use of the surface water height at the normal flow

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Table 2. Descriptive Summary of the Digital Elevation Models (DEMS) of Pitt County, North Carolina

Parameter	DEM A	DEM B	DEM C	DEM D	DEM E
Minimum elevation	−39.909	−39.809	−37.938	−36.945	−3.390
Mode	13.259	13.359	13.375	13.311	11.140
Median	13.615	13.359	13.375	13.311	13.340
Maximum	47.640	47.640	47.564	47.564	38.360
Mean	14.573	14.569	14.481	14.481	14.284
One standard deviation	6.753	6.752	6.808	6.808	6.721
Negative area	6.034	6.052	10.826	10.895	0.020
Zero elevation area	0.008	0.011	0.000	0.000	0.224
Positive area	1,691.075	1,691.060	1,686.253	1,686.227	1,696.879
Negative volume	−0.005	−0.005	−0.013	−0.013	0.000
Positive volume	24.740	24.730	24.589	24.589	24.241
n (no. of cells or samples)	45,665,127	1,885,692	7,306,880	1,885,692	1,885,692

Note: Elevation (m) is above mean sea level; area = km^2, volume = km^3.

to flood the DEMs allows for identification of the regular river and stream channels.

To verify modeled inundation extents, aerial photographs and Landsat 7 ETM+ images (acquired on September 23, 1999, during the flood event), as well as ground observation (made in early October 1999, after the flood) are used. The Tar/Pamlico River crested on September 21, 1999, and the floodwater dropped 0.36 m and 0.08 m on September 23 at the Greenville and Washington gauge stations, respectively (Table 1). With the combined use of the aerial photographs, ETM+ data, and USGS color infrared digital orthorectified quarter quadrangle (DOQQ) data acquired in 1998, 14 flooded forest sites (with a total area of 5.9 km^2), 12 flooded fields (3.8 km^2), 9 flooded developed areas (1.2 km^2), 12 nonflooded forest sites (2.5 km^2), 20 nonflooded fields (6.1 km^2), and 9 nonflooded developed areas (1.9 km^2) are selected. The sites scatter over the floodplains. The forest sites consist of mainly bottomland forests, hardwood swamps, southern yellow pines, and mixed hardwoods and conifers. The fields include cultivated areas, managed and unmanaged herbaceous covers, and shrub lands. The developed areas are made of residual, commercial, and industrial areas, and are mainly near the cities of Greenville and Washington.

Analyses

Since the data sets come from different sources, georeferencing them into a common coordinate system through reprojection is the initial step. The spatial resolutions of the DEMs are the same before and after the reprojection. The nearest neighbor method is employed when resampling *x*, *y*, and *z* is needed. For the horizontal values (*x* and *y*), World Geodetic System 84 (WGS 84) is used as the spheroid and datum, and Universal Transverse Mercator (UTM) as the projection. For the vertical value (*z*), the datum is NAVD 88.

To compare the LIDAR and NED DEMs spatially or on the cell-by-cell basis, the DEMs involved have to have the same spatial resolution. Thus, the high-resolution LIDAR DEMs have been resampled through the nearest neighbor method to match the 30 $\times$ 30 m resolution of the NED DEMs. (One can alternatively resample the 30 $\times$ 30 m NED data and 15.2 $\times$ 15.2 LIDAR data into 6.1 $\times$ 6.1 m spatial resolution and then perform the spatial comparisons.) In summary, there are five sets of DEMs of different resolutions and coming from different sources. To simplify the presentation, DEMs A–E are used (Appendix). Then the following analyses are carried out.

Comparison of the Digital Elevation Models

The first comparison utilizes five DEMs of Pitt County. Visual examination and descriptive statistics are used, and a t-test on mean elevation is done among the DEMs. Next, three difference operations of DEM B − DEM D, DEM B − DEM E, and DEM D − DEM E are performed on a cell-by-cell basis. The absolute elevation difference ($|\Delta z|$) in 0.1 m interval is tabulated.

Comparison of Inundation Extents

Even though the comparison of DEMs provides valuable information about the similarity and difference of the DEMs, the use of the DEMs to create inundation maps will further offer insight about the DEMs on the floodplain mapping. After all, one major reason to create the LIDAR DEMs is to have accurate and updated flood maps (http://www.ncfloodmaps.com). Thus, it will be of great interest to use the same river's surface water height and the same DEM-inundation method to flood the five DEMs, to investigate the degree of agreement of the derived flood extents, and to verify the extents with a real flood event. A simple algorithm using surface water heights at two river gauge stations is employed, linearly interpolating the water height along the stream channel between the stations, and then comparing the DEM cell value with the interpolated water height at each cross section of the channel to determine whether the cell or location is under or above the water (Wang et al. 2002). Using the surface water heights at the normal and flood flow conditions (Table 1), three categories—water (regular river and stream channels, etc.), flooded area, and nonflooded area—can be derived. Descriptive statistics of the five inundation extents are then computed. Using the simple inundation method should allow one to focus on the comparative study of the LIDAR and NED DEMs but not to be bogged down by the complicity of and uncertainty of input parameters to a sophistical floodplain mapping model such as the HEC-RAS model (USACE 2002). (One could input the LIDAR or NED DEMs into the HEC-RAS model once the locations of cross sections, land cover data, discharge, and surface water height are determined. However, this modeling alternative may be beyond the scope of this comparative study.) Next, spatial comparisons of the modeled inundation extents of DEM C versus DEM D, DEM C versus DEM E, and DEM D versus DEM E are conducted. Finally, using the selected flooded and nonflooded forest, field, and developed sites, the accuracy of the inundation extents on September 23, 1999, is examined.

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Results

DEMs A–E of Pitt County clearly show the division of the county into the Tar/Pamlico and Neuse river basins. Descriptive statistics of the elevation are summarized (Table 2). DEMs A, B, C, and D are very similar, whereas DEM E differs slightly. t-tests on the means indicate the means of DEM A versus DEM B and DEM C versus DEM D are statistically identical as indicated by t-test, but the means of the rest of the 10 pairs (DEM A versus DEM C, etc.) differ. Even though the difference in the means is very small, the inequality of mean values for the 10 t-tests is caused by the very large number of samples (Table 2). It should be noted that three digits after the decimal points are used in the table, but the DEMs themselves do not have accuracy to the millimeters.

Table 2 also summarizes areas (km^2) and volumes (km^3) within the county having a negative, zero, or positive elevation. The negative, zero, and positive areas range from 0.02 to 10.90 km^2, 0.00 to 0.22 km^2, and 1686.23 to 1696.88 km^2, respectively. The range negative (positive) volume is from −0.01 to 0.00 (24.24 to 24.74) km^3. DEMs A, B, C, and D differ slightly, but comparison of DEM E with DEM A, B, C, or D exhibits an intermediate difference.

So far, the comparisons are nonspatial. To compare the DEMs on a cell-by-cell basis, difference operations of DEM B − DEM D, DEM B − DEM E, and DEM D − DEM E are done. Fig. 3 shows the result of absolute difference |DEM B − DEM D| in gray scale. The brighter the tone, the larger the absolute difference. Almost all of the highlighted areas are river, streams, and creeks, which is attributed to the fact that DEM D is resampled from DEM C, and DEM C is hydrologically corrected. No hydrocorrection has been done to DEM B or DEM A. The absolute difference image of |DEM D − DEM E| (Fig. 4) shows three major things. The difference scatters over the entire county. There are large differences in the low and high elevation areas (cf. Fig. 1), specified by arrows. The difference patterns (of river, stream, and creek) noticed in Fig. 3 disappear totally. Similar difference patterns as shown in Fig. 4 have been noticed on the |DEM B − DEM E| image.

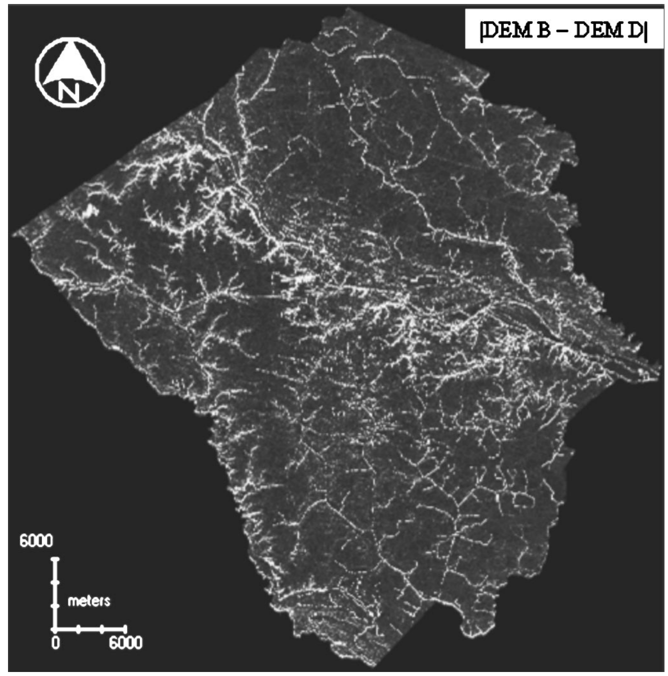

Fig. 3. |DEM B—DEM D| of Pitt County

To quantify the differences, absolute difference of elevation (|Δz|) is tabulated in 0.1 m increments (Table 3). When |Δz| reaches 0.7 m, DEM B and DEM D agree 90.9%. In order to have ⩾90% agreement, |Δz| has to be 1.6 m for the DEM B and DEM E pair, and 1.7 m for DEMs D and E. The value of 1.6 or 1.7 m is about 11.0–12.0% of the mean elevation (14.3 to 14.6 m, Table 2), and could be significant in a county of low elevation and flat terrain.

Next, five DEMs are used to study the inundation extents. The study area is between the cities of Greenville on the west and Washington on the east (Fig. 2), encompassing about 517.7 km^2 of dominantly cultivated lands, bottomland forests/swamp forests,

Table 3. Absolute Elevation Difference (|Δz|) of Digital Elevation Model (DEM) Pairs up to 90% Cumulative Frequency

	|DEM B − DEM D|		|DEM B − DEM E|		|DEM D − DEM E|	
|Δz| (m)	Frequency (%)	Cumulative (%)	Frequency (%)	Cumulative (%)	Frequency (%)	Cumulative (%)
0.0–0.1	36.9	36.9	9.1	9.1	9.2	9.2
0.1–0.2	22.9	59.8	8.9	18.0	9.0	18.2
0.2–0.3	13.1	73.0	8.6	26.6	8.6	26.8
0.3–0.4	7.7	80.7	8.2	34.8	8.2	35.0
0.4–0.5	4.9	85.6	7.8	42.6	7.6	42.8
0.5–0.6	3.2	88.8	7.2	49.8	7.2	50.0
0.6–0.7	2.2	90.9	6.6	56.3	6.6	56.6
0.7–0.8	—	—	6.0	62.3	6.0	62.5
0.8–0.9	—	—	5.4	67.7	5.3	67.9
0.9–1.0	—	—	4.8	72.5	4.7	72.5
1.0–1.1	—	—	4.2	76.7	4.1	76.6
1.1–1.2	—	—	3.6	80.3	3.5	80.1
1.2–1.3	—	—	3.1	83.3	3.0	83.1
1.3–1.4	—	—	2.6	85.9	2.5	85.5
1.4–1.5	—	—	2.2	88.1	2.1	87.6
1.5–1.6	—	—	1.8	90.0	1.8	89.3
1.6–1.7	—	—	—	—	1.4	90.8

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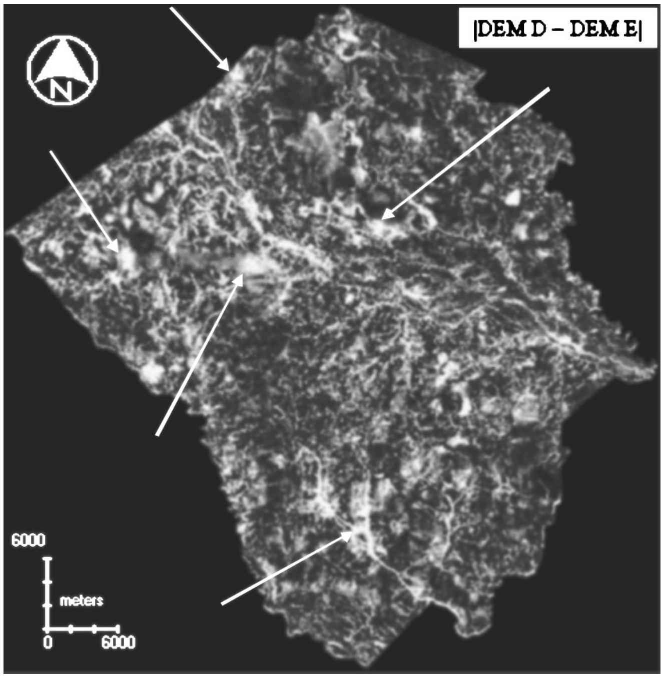

Fig. 4. |DEM D—DEM E| of Pitt County. Several areas of large absolute differences are specified by arrows

and southern yellow pines. Based on the DEMs, the mean elevation ranges from 8.6 to 8.8 m, with one standard deviation between 5.4 and 5.7 m. Using the simple DEM-inundation method (Wang et al. 2002) and the river's surface water heights at normal river flow and extremely high flow conditions between two river gauge stations (Table 1), we model the area into water, flooded area, and nonflooded area, and show them as dark gray, gray, and white, respectively. Again, the inundation patterns derived from DEMs A–D are very similar to each other. The similarity indicates the internal consistency of the LIDAR DEMs. There are differences among the inundation extents derived from DEMs A–D and DEM E. For example, one can easily notice that there is more water area in Fig. 5(a) than in Fig. 5(b). The water area (or river channel) is disconnected, as indicated by an arrow [Fig. 5(b)]. Comparison of the water area (12.1 km^2) and flooded area (129.6 km^2) from DEM E with their respective counterparts from DEM A, B, C, or D quantifies the differences (Table 4). The differences could vary if different river flow conditions for the normal flow or flood flow are used.

Next, three pairs of extents derived from DEMs B, D, and E are compared on a cell-by-cell basis to investigate the spatial agreement. That is, for each cell or location on two inundation layers, if the same category exists, there is one agreement; otherwise, there is one disagreement. Adding all the agreements (of

Table 4. Inundation Extents (km^2) Derived from the Digital Elevation Models (DEMs) and River Surface Water Height on June 6, 2003, and on September 21, 1999

Category	DEM A	DEM B	DEM C	DEM D	DEM E
Water	42.87	42.85	47.01	47.00	12.07
Flooded area	90.56	90.63	90.59	90.79	129.60
Subtotal	133.43	133.48	137.6	137.79	141.67
Nonflooded area	383.77	384.27	379.85	379.92	376.05

Note: Total area is 517.7 km^2.

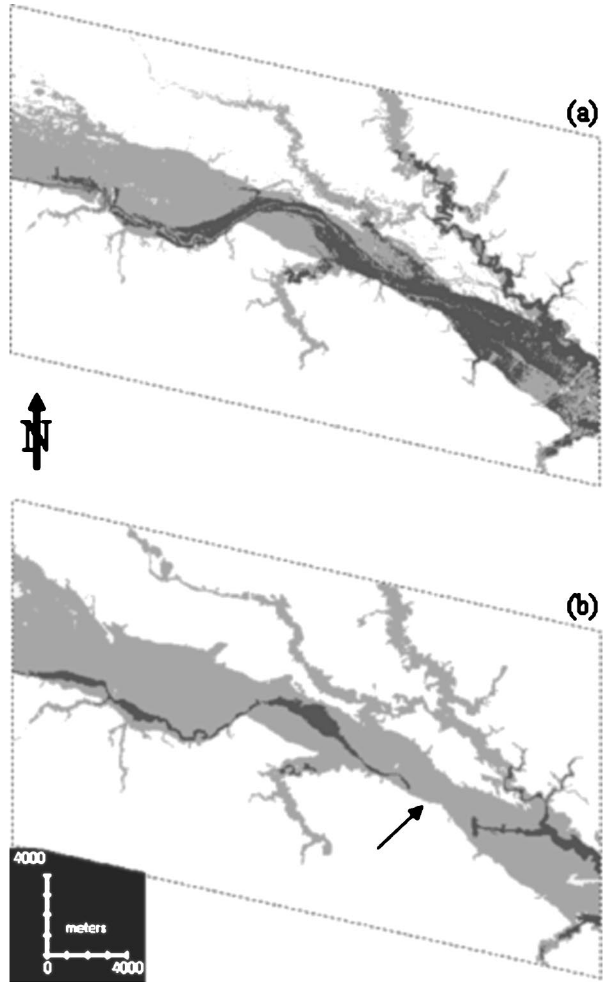

Fig. 5. Derived inundation extents from DEM B (a) and DEM E (b) (white is the nonflooded area; gray is the flooded area, and dark gray is water)

water, flooded area, and nonflooded area on both layers), one can obtain the total agreement (Table 5). Then the degree of the agreement can be computed as the ratio of the total area in agreement divided by the total study area. Of a total study area 517.7 km^2, the water, flooded area, and nonflooded area in agreement on the extents derived from DEM B and DEM D are 38.72, 78.18, and

Table 5. A Cell-by-Cell Comparison of the Derived Inundation Extents (km^2) from Digital Elevation Models (DEMs) B, D, and E

Description	DEM B versus DEM D	DEM B versus DEM E	DEM D versus DEM E
W→water	38.72	8.95	9.14
W→FA	4.00	33.59	36.82
W→NFA	0.10	0.28	1.05
FA→W	7.67	3.10	2.92
FA→F	78.18	80.31	77.99
FA→NFA	4.79	7.22	9.89
NFA→W	0.62	0.02	0.01
NFA→FA	8.61	15.70	14.80
NFA→NFA	375.04	368.55	365.11
Total agreement	491.94	475.81	452.24
Degree of agreement (ratio)	95.0%	88.4%	87.4%

Note: W=water; FA=flooded area; and NFA=nonflooded area.

Table 6. Error Matrix and Classification Accuracy Derived by DEM B, DEM D, and DEM E at Selected Forested Areas, Open Fields, and Developed Sites. Within Producer's and User's Accuracy Sections, Omission and Commission Errors are in parentheses and square brackets, respectively.

a. Forested Areas: *Reference Data*

Classification		Flooded (km^2)	Non-flooded (km^2)	*Total (km^2)*
DEM B	Flooded	5.61	0.24	*5.85*
	Non-flooded	0.27	2.26	*2.53*
	Total	*5.88*	*2.50*	*8.38*
DEM D	Flooded	5.60	0.29	*5.88*
	Non-flooded	0.28	2.22	*2.50*
DEM E	Flooded	5.57	0.21	*5.78*
	Non-flooded	0.31	2.29	*2.60*

	Producer's accuracy (%)			User's accuracy (%)		
	DEM B	DEM D	DEM E	DEM B	DEM D	DEM E
Flooded	95.4 (4.6)	95.2 (4.8)	94.7 (5.3)	95.8 [4.2]	95.1 [4.9]	96.3 [3.7]
Non-flooded	90.3 (9.7)	88.6 (11.4)	91.5 (8.5)	89.3 [10.7]	88.8 [11.2]	88.0 [12.0]

Overall accuracy: 93.9% of DEM C, 93.2% of DEM D, or 93.8% of DEM E.

b. Open Fields: *Reference Data*

Classification		Flooded (km^2)	Non-flooded (km^2)	*Total (km^2)*
DEM B	Flooded	3.51	0.10	*3.61*
	Non-flooded	0.29	5.97	*6.26*
	Total	*3.81*	*6.06*	*9.87*
DEM D	Flooded	3.50	0.14	*3.64*
	Non-flooded	0.31	5.92	*6.23*
DEM E	Flooded	3.49	0.19	*3.68*
	Non-flooded	0.32	5.87	*6.19*

	Producer's accuracy (%)			User's accuracy (%)		
	DEM B	DEM D	DEM E	DEM B	DEM D	DEM E
Flooded	92.3 (7.7)	91.9 (8.1)	91.5 (8.5)	97.4 [2.6]	96.1 [3.9]	94.8 [5.2]
Non-flooded	98.4 (1.6)	97.7 (2.3)	96.8 (3.2)	95.3 [4.7]	95.1 [4.9]	94.8 [5.2]

Overall accuracy: 96.1% of DEM C, 95.5% of DEM D, or 94.8% of DEM E.

c. Developed Sites: *Reference Data*

Classification		Flooded (km^2)	Non-flooded (km^2)	*Total (km^2)*
DEM B	Flooded	1.05	0.02	1.07
	Non-flooded	0.11	1.92	2.03
	Total	*1.16*	*1.95*	*3.10*
DEM D	Flooded	1.05	0.04	1.09
	Non-flooded	0.11	1.91	2.01
DEM E	Flooded	1.06	0.13	1.19
	Non-flooded	0.10	1.81	1.91

	Producer's accuracy (%)			User's accuracy (%)		
	DEM B	DEM D	DEM E	DEM B	DEM D	DEM E
Flooded	90.5 (9.5)	90.6 (9.4)	91.5 (8.5)	97.9 [2.1]	96.2 [3.8]	88.7 [11.3]
Non-flooded	98.8 (1.2)	97.9 (2.1)	93.1 (6.9)	94.6 [5.4]	94.6 [5.4]	94.9 [5.1]

Overall accuracy: 95.7% of DEM C, 95.2% of DEM D, or 92.5% of DEM E.

375.04 km^2, respectively. The total area in agreement is 491.94 km^2, and the ratio is 95.0% (Table 5). The other two total areas in agreement including (ratios) are also given in Table 5. All the inundation extent pairs agree spatially between 87.4 and 95.0%.

The final analysis of the DEMs is to use them to map a real flood extent, and use the selected flooded and nonflooded forest, field, and developed sites to verify the flood map. As described previously, the flood extent between the cities of Greenville and Washington is modeled based on the river's surface water heights on September 23, 1999, at Greenville and Washington gauge stations, and DEM B, DEM D, and DEM E. The error matrix and classification accuracy for each category is given in Table 6. In the table, three major sections are used to summarize the results of forested areas, open fields, or developed areas, respectively. The results show that for the three categories the producer's accuracies are between 88.6–98.8%, user's accuracies are 88.0–97.9%, and overall accuracies are 92.5–96.1%. All three DEMs work well in the flood extent mapping.

Concluding Remarks

To broaden the scope of comparing DEMs on floodplains, and eventually to link this study to one of general goals—to create a better, updated, and accurate flood insurance map of the NCFMP—one has to address the issue of flood extent accuracy vertically and horizontally. Even though modeled flooded extents have been verified by selected flooded and nonflooded sites on the floodplains and the accuracy is high, the accuracy of the flooded/nonflooded boundaries on the flood maps have not been verified in this study. The horizontal extent of flooding is of primary concern during a flood event and in floodplain studies for determining required flood insurance coverage. In other words, the location of the boundaries on the new digital flood insurance rate maps (DFIRMs) and the enforcement of these boundaries by governmental agencies has the utmost importance. If a property is within the 100-year floodplain delineated by the DFIRMs, then flood insurance is required; otherwise, no insurance is needed. However, it should be noted that when the 100-year and 500-year floodplain delineations on the DFIRMs were applied to map two flood events that occurred in and around the city of Wilson, NC, the delineations missed significant portions of the flooded areas (Aycock and Wang 2004). Furthermore, most assessments for determining accuracy of the flooded extent and locating the flooded/nonflooded boundaries rely on base flood elevation profiles (USACE 1986). Data for the evaluation is derived from ground surveys, and the evaluated accuracy is based on vertical profiles, but the accuracy of the horizontal extent of a flood is not examined. Moreover, standard methods do not exist for comparing and assessing the horizontal accuracy of water surface profile boundaries derived for flood insurance studies, flood control projects, highway stream crossings, and real-time monitoring of flood events. For determining horizontal accuracy of a flood extent FEMA relies on miscellaneous data sources, high water marks, anecdotal evidence, and comparison to aerial photographs. Therefore, future research should focus on the development of the quantitative methods that address the horizontal accuracy of the flooded/nonflooded boundaries of a flood extent and on floodplain maps derived from different elevation data sources. In addition, the potential should exist for establishing a quantitative relationship between the horizontal and vertical accuracy of water surface profiles. These will be our major goals to pursue in subsequent studies.

Appendix.

Simplified DEM names

DEM A: LIDAR DEM of 6.1×6.1 m spatial resolution
DEM B: 30.0×30.0 m DEM resampled from DEM A
DEM C: LIDAR DEM of 15.2×15.2 m spatial resolution
DEM D: 30.0×30.0 m DEM resampled from DEM C
DEM E: USGS NED 30.0×30.0 m DEM

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