Effects of Uncertainty of Drainage Area on Low-Gradient Watershed Hydrology

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ABSTRACT. An accurate estimate of a watershed drainage area contributing to stream flow is critical for reliable estimates of storm event hydrograph characteristics e.g., peak flow rate, outflow depth, runoff coefficient (proportion of rainfall as runoff) as well as water balance and pollutant load estimates. Peak flow rate, a hydrologic parameter widely used in stormwater management, design of channels and cross drainage structures and other BMPs, is calculated as a function of watershed drainage area and other parameters. However, in contrast with the upland watersheds with high gradient, currently available topographic maps and DEMs used to estimate the watershed drainage area are not adequate for flat, low-gradient landscape, which may even likely result in "imbalance" of water. Furthermore, with the construction of new roads and culverts (after the DEM is developed) in the watersheds, the runoff flow path is often changed and thus inaccurate runoff calculation. Above all, the low resolution digital elevation models (DEMs) are not accurate and they do not reflect the present ground reality as they are developed earlier and through other sources like Shuttle Radar Thematic Mapper (SRTM) data and surveying information. However, Light Detection and Ranging (LiDAR) based DEMs are more accurate for identifying actual topographic conditions. For coastal flat watersheds, recent high resolution, and accurate DEMs are very essential for hydrologic analysis. In this presentation, we explore a case study of a 3rd order Lower Coastal Plain (LCP) watershed (Turkey Creek) at US Forest Service Santee Experimental Forest at headwaters of east branch of Cooper River draining to Charleston Harbor, SC to address potential errors in estimating the streamflow as area-based depth and water balance as a result of uncertainty in watershed drainage area estimated based on various methods since it was established in 1963. The results demonstrate a need for very high resolution DEMs developed with high resolution LiDAR data, with field verification to reduce errors and uncertainties in hydrologic studies of the LCP systems.

INTRODUCTION

Watersheds in lower coastal plain (LCP) region are generally characterized by flat, low-gradient landscapes with less than 1% slope. The region is dominated by a humid climate with long-term average precipitation exceeding potential evapotranspiration (PET) and thus the surplus soil moisture. About 60 percent (%) of the region is covered by forest ecosystems, including wetlands (Sun et al., 2002), where the regional long-term water balance includes 70-75% of average annual precipitation lost as evapotranspiration (ET). The remaining balance primarily as runoff occurs due to shallow surface and subsurface drainage. Water yield of this region generally depends on the precipitation and ET.

Reliable and sustainable water yield from watersheds in the Southeastern Coastal Plain have become an area of concern in recent years because of changing population growth, land use, and potential climate change. To address this concern, there is a need for a reliable understanding of hydrologic processes and water balance of less disturbed, forested watersheds on low-gradient coastal plain (LCP) lands (Williams et al., 2012; Amatya and Skaggs, 2011; Callahan et al., 2011; Garrett et al., 2011; La Torre Torres et al., 2011; Amatya et al., 2009; Bosch et al., 1999). This reference water balance could be used to quantify the magnitude and potential change to water balance in the LCP due to the impacts of human and natural disturbances, which is important for economic development and land management practices. Monitoring and modeling approaches are often used to understand the processes and quantify the runoff, water balance, and pollutant loads (Amatya and Jha, 2011). However, there are challenges in accurately quantifying the runoff and subsequently the water balance of these LCP systems, which are often impacted by hurricanes and tropical storms, tidal surges, submergence of flow measuring structures, and backwater flows. Furthermore, much of the freshwater runoff carrying the pollutant loads in the LCP may occur during the summer-fall tropical storms potentially impacting the nearby nutrient-sensitive estuarine ecosystem. Such problems will be exacerbated by potential impacts of climate change and sea level rise (Scavia et al., 2002; Nuttle and Portnoy, 1992). Scavia et al (2002) forecasted that the increasing rates of sea-level rise and intensity and frequency of coastal storms and hurricanes over the next decades will increase threats to ecological integrity of shorelines, wetlands and coastal development.

The literature in quantifying uncertainty in stream flow measurements at gauging stations in freely draining upland watersheds are well documented (Pelletier, 1988; Sauer and Meyer, 1992; Harmel et al., 2006; 2009). However, there are only limited studies done on the effects of uncertainty in measurements of runoff in these LCP systems affected by submergence and backwater flows (Amatya and Skaggs, 2011; Amatya et al., 1998).

Another major area of concern in accurate quantification of watershed water balance in the LCP is the watershed area-based runoff depth that is estimated using drainage area. The drainage area can be estimated with a reasonable accuracy for high-gradient upland watersheds with regularly available U.S. Geological Survey (USGS) topographic quad maps (Scale 1"= 1 mi with 2-ft contour intervals. However, more accurate topographic maps or digital elevation models (DEMs) may be needed to obtain an accurate estimate of the drainage area in the LCP where the land slope is very flat with a few contours. For example, recently Panda et al. (2012) found huge discrepancies in the elevation data of Interstate (I-95) obtained by 10 m DEM created from 10 m contours developed by hand digitization of USGS 1:24,000 scale topo maps and the DEM developed from 2010 LiDAR data. The older 10 m DEM and the latest LiDAR-DEM provided an average difference of 0.9 m on randomly selected locations on the I-95. They converted the 10 m DEM for the study area (Camden County, GA, a coastal county) using the algorithm developed with differentiation values of both. Similarly, Renschler and Flanagan (2008) reported that the USGS topomaps are considered insufficiently accurate in their topographical representation of watershed boundaries, slopes, and upslope contributing areas to meaningfully apply detailed process-based soil erosion assessment tools at the field scale. However, the authors also concluded that DEMs based on USGS 10-ft contour lines from publicly available data can be as good as the most accurate datasets obtained from real-time kinematic differential GPS (RTK-DGPS) in estimating average annual off-site runoff (-18.3% error) and sediment yield using the WEPP model within a 30-ha upland watershed. Most recently, Aziz et al. (2012) reported the effects of uncertainty in estimating elevations from various DEM types on erosion rates. Depending on data sources, methods and procedures used to generate field DEMs, the DEM estimates contain errors (Wechsler, 2007). Furthermore, the DEMs created using the topographic elevations may often be altered by construction of roads and cross-drainage structures, more so in flat LCP. In these flat lands such a road bed may serve as a boundary of the watershed that may not have been reflected in the developed DEMs. If not field verified for those road infrastructures, the actual estimated drainage area as well as drainage network may well be different from that developed using the available DEMs. This clearly suggests a necessity of having accurate high resolution DEM for such hydrologic analysis, especially drainage area calculation, particularly in coastal plains.

There is almost no study conducted on the effects of errors in DEMs in estimating drainage area of watersheds in low-gradient coastal landscapes. Therefore, the main objective of this paper is to summarize the effects of various DEM resolutions and topographic maps used in estimating drainage area on average annual runoff coefficient for a forested watershed (Turkey Creek) in Lower Coastal Plain. Furthermore, the effect of roads and road culverts on the estimated actual effective drainage area using the available DEM is discussed.

MATERIALS AND METHODS

Site Description

Turkey Creek watershed is located in the Francis Marion National Forest on the coastal plain of South Carolina (Fig. 1). The U.S. Forest Service established a stream gauging station in Turkey Creek in 1964 and monitored the watershed until 1984.

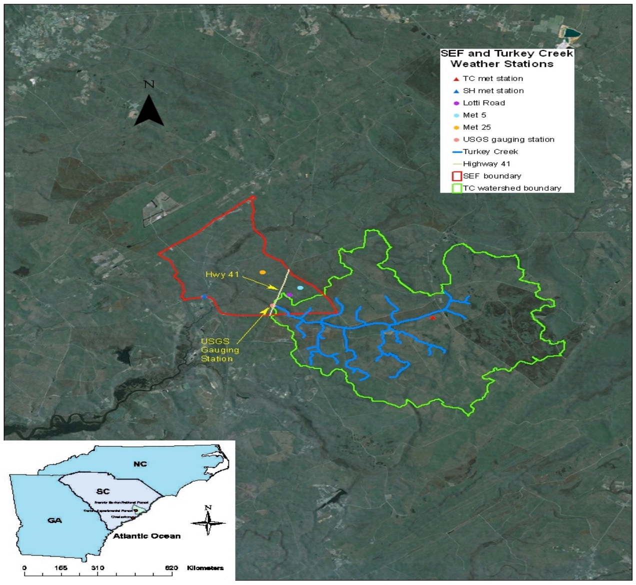

Figure 1. Location of the Turkey Creek watershed in the Francis Marion National Forest, coastal South Carolina. Also shown are the monitoring stations in and around the watershed.

Nevertheless, researchers recognized the importance of stream gauging and other hydro-meteorological data from a forested coastal watershed as a reference in a rapidly changing coastal environment. As a result, in 2004, the U.S. Forest Service, in cooperation with the College of Charleston and the USGS, reinstalled a real-time streamflow gauging station, including a rain gauge (http://waterdata.usgs.gov/sc/nwis/uv?site_no=02172035) approximately 800 m upstream of the historic gauging station (Amatya and Trettin, 2007).

The study watershed is located within the USGS quadrangle maps of Huger (NE), Bethera (SE), Shulerville (SW and SE), and Ocean Bay (NW and NE) with the approximate coordinate ranges of 610400 to 628600 easting and 3658500 to 3670500 northing (Amatya and Jha, 2011). Located within a 12-digit hydrologic unit code (HUC 030502010301) of the Catawba-Santee basin (Eidson et al., 2005) at the headwaters of East Cooper River, a major tributary of the Cooper River, which drains to the Charleston harbor system, Turkey Creek (WS 78) is typical of other watersheds in the south Atlantic coastal plain, where rapid urban development is taking place. Technically, Turkey Creek is a 6th level hydrologic unit that qualifies only as a subwatershed although we refer to it as a "watershed" in this paper. The topographic elevation of the watershed varies from about 2.0 m at the stream gauging station to 14 m above mean sea level.

Evolution of Drainage Areas

The estimation of drainage area of the Turkey Creek watershed changed as more accurate maps and associated DEMs were available in the course of this 48-year (1964-2012) period. When the watershed was established in 1964, the drainage area boundary was approximated using the then available USGS topomap with a scale of 1"=2 miles. Later on in early 1969 the 1"=1 mi scale USGS map was used to obtain a new boundary and watershed area. Although flow data on the watershed was continued to be collected until 1984 no analysis or publication was done with this historic data, except for the internal station reports. After discontinuation of flow measurements in 1984, it was not again revitalized until late 2004. So there was no need for update or interest in drainage area of the watershed as new DEMs continued to become available in late 80s and 90s.

The first literature search on the recent DEMs in 2004 when the Turkey Creek watershed was revitalized showed a 1999 publication for 14-digit hydrologic unit code (HUC) development for South Carolina (Bower et al., 1999) who used the 1:24,000-scale 7.5-minute series topographic maps as the source maps and the base maps from 1:100,000-scale Digital Line Graphs; however, the data were published at a scale of 1:500,000. In the 2005 Hydrologic Unit Code (HUC) map for South Carolina (Eidson et al., 2005), Turkey Creek area is listed as 6,685 ha (16,508 ac) to its confluence with Nicholson Creek (Hansen, 2007), which is further downstream from the current gauging station. The source maps for the basin delineations using the HUCs are 1:24,000-scale 7.5-minute series topographic maps, and 1:24,000-scale digital raster graphics. Similarly, DEMs with 30m horizontal resolution and 1 m vertical resolution were also available from SC Department of Natural Resources. Later in 2006, USGS Enhanced 1:24,000 True 10-meter horizontal 1-meter vertical DEM were obtained from the USGS (Haley, 2007). The cross-drainage structures on forest roads in and around the Turkey Creek watershed were also surveyed using 2002, 3-D Delorme topo quad maps with a scale of 1:25,000 and a 1988 Forest Service Francis Marion National Forest map with a scale of 1:126,720 that showed perennial streams, bridges, and road names. The field equipment included a GPS unit-Garmin GPS V personal navigator (with an accuracy of 6-9 m), a digital camera, a 50 m measuring tape, and a compass during December 2006 – April 2007 period. The details of the field survey results of cross-drainage structures (44 culverts) are given by Haley (2007).

By 2006 when the data using Light Detection and Ranging (LiDAR) technology was obtained for Santee Experimental Forest (Trettin et al., 2008), part of the downstream portion of the Turkey Creek watershed adjacent to the Forest was also available in very high resolution DEMs (at a 2 m point spacing or better, and gridded with a 1m resolution and a vertical accuracy of 0.07 - 0.15 m). The estimate of the drainage area was updated using DEMs from that smaller area with LiDAR data. Finally, by August 2011 similar high resolution LiDAR data for the Berkeley County, SC that contains the Turkey Creek watershed was obtained from the SC DNR (Scurry, 2011).

The data specifications for LiDAR elevation data acquired as point cloud (".LARS") for the Turkey Creek watershed included a nominal point spacing of 1.5 meter and vertical root mean square error (RMSE) of 18.4 cm (Fig. 2). The Vertical RMSE suggests that there is a possibility of 18.4 cm average error in elevation in the DEM created from the LiDAR data.

Quick Terrain Modeler® x64 (QTM, 2012) was used to generate the Bare Earth ground and Water surface raster DEM with a cell size of 1.5 m. Although, the LiDAR data resolution was of 0.3 m, the DEM of 1.5 m resolution was developed from it to reduce the file size for the watershed to conduct smooth and faster analysis. The generated DEM was then exported as an ERDAS IMAGINE image (Civco, 1994) and projected to the State Plane-NAD 83-South Carolina FIPS 3900 feet, using ESRI® ArcGIS 9.3.1(ESRI, 2009).

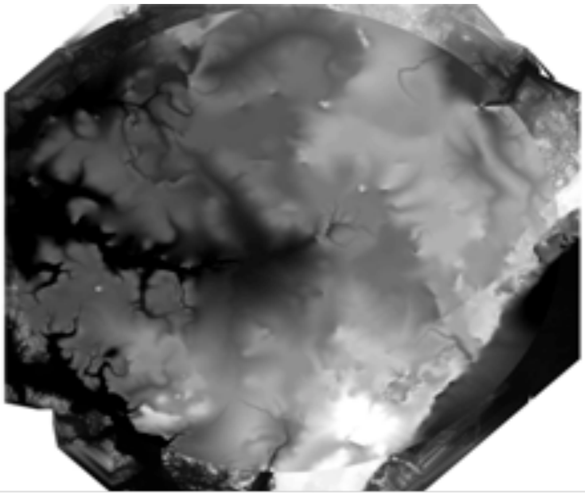

Figure 2. LiDAR-based DEM of 1.5mx1.5m horizontal and 0.18m vertical resolution.

LiDAR DEM reconditioning for Culverts

The DEM was further pre-processed to minimize generation of discontinuous streams due to presence of bridges and culverts. This was achieved by reconditioning the DEM (Burning-in-Streams) with flowlines at bridge and culvert crossings using ArcHydro Tools by ESRI®. The flowlines (culverts and bridges) were created based on their respective spatial orientation. Bridges were identified and validated as intersections of roads and streams using aerial imagery acquired from the National Agricultural Imagery Program (NAIP). Total of 138 culverts were identified by examination of Bare Earth LiDAR DEM, followed by field visits that were made in July 2010 (18 more culverts) and August 2011 (76 additional culverts) as shown in Figure 3. The burning-in-streams located the culverts and the width of it. The depth of culvert was used to recondition the DEM on the locations of the culverts through the ArcHydro DEM reconditioning function. Thus, the elevation at those culverts locations become accurate (lower than the one obtained from LiDAR data based DEM as LiDAR data cannot locate the culverts opening as they are buried below the roads).

The automated watershed delineation processes of programs such as ArcSWAT (Luzio et al., 2002; Arnold et al., 1998) or BASINS model (US EPA, 2009) use the Deterministic 8-neighbor (D8) algorithm for flow direction (O'Callaghan and Mark, 1984) based on the concept of steepest slope. Some of the documented weaknesses of D8-algorithm include tendency to generate parallel flow paths in flat areas, high sensitivity to inherent DEM errors, and inaccurate flow direction on convex slopes (e.g., Jones, 2002; Paz et al., 2008; and Wilson et al., 2007). Other algorithms such as multiple flow direction (MFD), Deterministic-Infinity (D∞), Random-Eight Neighbor (Rho8), and Digital Elevation Model networks (DEMON) have been used to address the above challenges (Crombez, 2008).

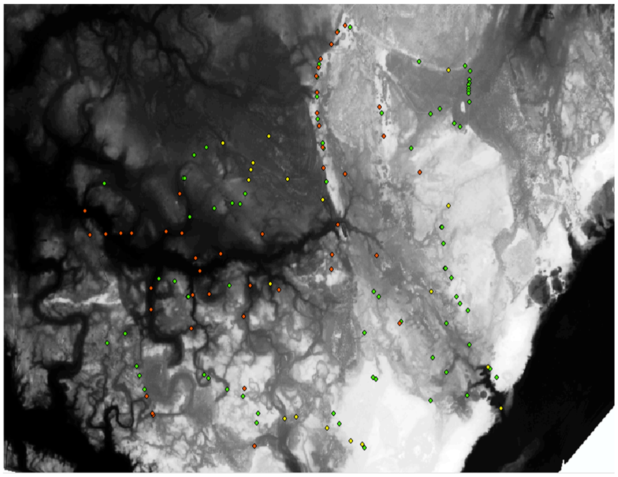

Figure 3. Location of culverts identified in LiDAR-DEM.

This presentation does not address the effect of algorithm used to automatically delineate watersheds from DEM, but concentrates on effects of DEM resolution using ArcSWAT that implements the D8 algorithm. Additional challenges of working with low relief and very low slope watersheds such as Turkey Creek are such that wide areas can have a slope of near zero and also the area is covered by a network of raised and compressed logging and forest service road beds. These effectively act as runoff barriers or miniature dams. To address some of the above challenges, a comprehensive culvert survey of the study area was carried out using a combination of identifiers to predict the likely locations of culverts.

First, the National Hydrography Dataset (NHD; Simley and Carswell, 2009) was used to locate where confirmed water vectors intersect the roads. NAIP orthoimagery was used to identify where denser brighter green vegetation common to riparian zones and wetlands (areas where water accumulates for extended periods of time) approach roads. Lastly, the elevation data was used to identify where roads span across depressions where water can collect. These points were plotted at these locations and the data was used during field surveys as coordinate lists and maps. Each location was driven to and searched. If a culvert was confirmed, its GPS coordinates and orientation were noted. Any additional culverts that were identified in the field were also recorded. Ideally, each feature would include location, orientation, width, length and depth. However, the three later parameters were limited by the raster resolution, meaning that the dimensions were measured as multiples of pixels. For the purpose of processing the latest elevation data available for Turkey Creek, all culverts were represented by three-pixel wide (4.5m) V-channels. This was done using the Agree Streams capability of the ArcHydro extension for ArcGIS. The process lowers the pixel values that coincide with the chosen polyline shapefile by a pair of defined depth values for a given width in pixels. Figure 4 shows where a culvert line was drawn along Forest Route 167 at a GPS point where the culvert was identified in a 120m wide depression area just 15m from the NHD location of Kutz Creek. The channels for bridges had previously been inserted by the agency that collected and processed the LiDAR.

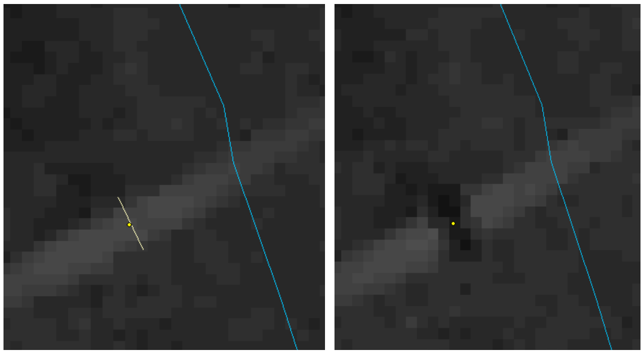

Figure 4. Before and After - Making Channels at Culvert Locations Using ArcHydro Agree Streams

The new DEM obtained after reconditioning for all culvert elevations was used to generate a new Turkey Creek watershed boundary and subwatersheds with ArcSWAT. Through the watershed delineation process, DEM-based stream network, inlets and outlets, watershed and subwatersheds and their corresponding topographic parameters were established

Hydrologic Analysis with Changed Watershed Boundary and Area

The historic stream flow data obtained by using the measured stage data with the stage-discharge relationship established in the early period (Young, 1967) were archived in Forest Service data base (Amatya and Trettin, 2007). No studies, however, were conducted or published using these flow data from this watershed for this period.

The daily streamflow data was processed to obtain volume of water in cubic meters discharged in each year by multiplying by the drainage area with the given DEM method and conversion factors. The mean annual outflow volume of 16.5 mil cum for the 13-year period calculated was then divided by the calculated drainage area of the watershed obtained by each of the DEM methods since mid-1960s to obtain the depth-based outflow. The 50-year (1951-2000) average annual rainfall of 1370 mm obtained from the data collected at a nearby weather station at Santee Experimental Forest (SEF) headquarters (Amatya and Jha, 2011) was used to calculate the average annual runoff coefficient (ROC), as the proportion of average annual depth-based outflow (mm) and average annual rainfall (mm) for each of the DEM methods to assess the uncertainty in the average annual ROC, for that matter the overall average annual water balance of the watershed. The average annual ROC obtained using the drainage area based on the recent high resolution DEM from the LiDAR data was considered as a reference for comparison with the historic results.

RESULTS AND DISCUSSION

The watershed drainage area delineated in 1964 using the USGS topomap with 1”=2 miles scale is shown in Figure 5. Based on this the preliminary drainage area at that time was reported as 3,240 ha (8,000 ac) (Young, 1965). Some of the boundary followed the existing road. This drainage area resulted in the average annual ROC of 0.37. Such a value generally observed for mountainous upland conditions (Sun et al., 2002) is considered high for predominantly forested low-gradient watersheds in the humid coastal region.

Figure 5. Watershed boundary using 1”=2 mile USGS topomap.

The second estimated drainage area of the Turkey creek watershed in 1970s was based on the USGS topomap of 1”=1 mile scale (Fig. 7). The area of the watershed using this map was estimated at 4,575 ha (11, 300 acres) (Laseter, 2008), which was about 41% higher than the initial estimate of 3,240 ha. As a result, the calculated average annual ROC for this DEM was 0.26 only, which is in the range of values obtained for similar coastal forested watersheds (Amatya et al., 2006).

Figure 6. Watershed boundary using 1”=1 mile USGS topomap.

Later when the watershed gauging station was revitalized in late 2004 for conducting multi-collaborative hydrologic studies on this and adjacent 1st and 2nd order watersheds, a need of more reliable drainage area estimate was perceived. Accordingly, the new DEMs with 30m horizontal and 1 m vertical resolution available in 2004 from SC Department of Natural Resources (SC DNR) were used to delineate the watershed using the ArcView GIS software tools (Fig. 7).

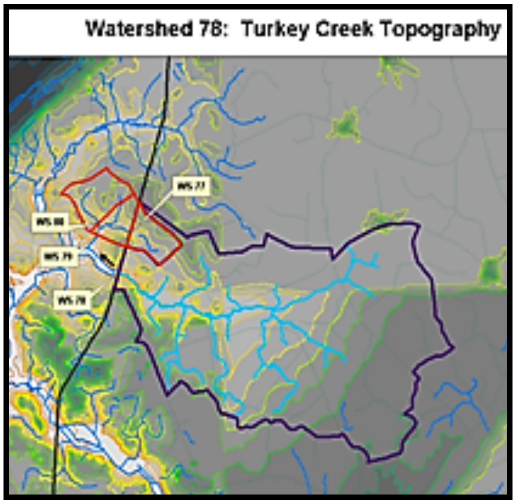

Figure 7. Watershed boundary using 30m horizontal and 1-m vertical resolution DEM (SC DNR, 2005).

The new watershed boundary shown in Figure 7 yielded the drainage area approximately at 4,920 ha. This was an increase of 7.5% compared to 4,575 ha using the 1”=1 mile USGS map and a 52% increase from the first initial estimate. Thus the drainage area continued to increase. Accordingly, the calculated average annual ROC continued to decrease to 0.24, which is also in the range of published data for this type of coastal forested watersheds (Amatya et al., 2006). Amatya and Radecki-Pawlik (2007) used these data to compare the streamflow dynamics of this watershed with the two adjacent 1st and 2nd order watersheds. No field verification was done.

Later USGS obtained an estimate of 5,880 ha (22.7 sq. mi.) as the drainage area at the outlet of the current gauging station (Fig. 8, green color) using the SC 14-digit HUC with the 1:24,000-scale 7.5-minute series topographic maps as the source maps and 1:100,000-scale Digital Line Graphs as base maps (Bower et al., 1999). This was still a 19.5% increase from the previous SC DNR2005 based DEM result. No field checking for the road boundaries as well as cross drainage structures like culverts was done for this estimate although these may have dramatic effects on the reconditioned DEMs and the derived drainage area. Accordingly, the average annual ROC was found to be 0.20 for this area, which is also in the range of the published data for the coastal forested watersheds.

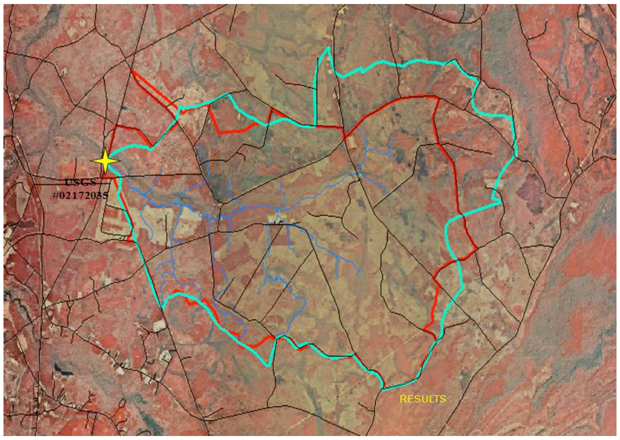

Figure 8. Watershed boundary using SC14-digitHUC (green) overlaid on SC DNR2005 boundary (red).

In 2005, new DEMs obtained from the USGS Enhanced 1:24,000 true 10-meter horizontal 1-meter vertical DEM became available to update the watershed boundary. In this case the ArcSWAT extension in GIS platform (Luzio et al., 2002) was used to delineate the watershed as shown in Figure 9. The delineation also considered the drainage pathways due to forest roads and 44 culverts surveyed during the 2006-07 period (Haley, 2007). The ArcSWAT delineation yielded the highest drainage area so far of 7,260 ha. This was 124% higher than the initial estimate of 3,240 ha and 47.6% higher than the estimate using the 30mx30m DEM. This was possibly due to errors in the 10-m enhanced DEM as reported recently by Panda et al. (2012).

This new drainage area resulted in the lowest average annual ROC value of 0.17, as expected. Ongoing studies on the Turkey Creek watershed at that time used this drainage area to calculate the new depth-based outflow in estimating field water balance (Amatya et al., 2009), assessing the rainfall-runoff storm event dynamics (La

Torre Torres et al., 2011), as well as validating a SWAT model (Amatya and Jha, 2011; Haley, 2007).

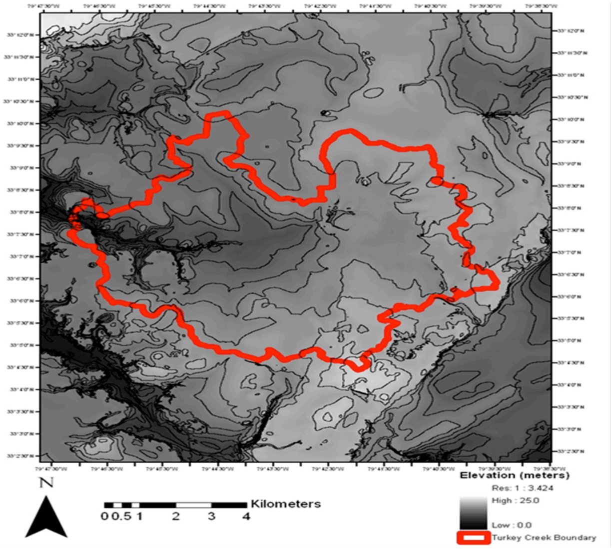

Figure 9. Watershed boundary using 2005 USGS enhanced 1:24,000 scale 10mx10m and 1m-vertical DEM

Later in 2010 using a partial LiDAR data for the lower part of the Turkey Creek watershed which is within the Santee Experimental Forest a new drainage area of 6,510 ha was obtained, which was 10.3% lower than the ArcSWAT computed area of 7,260 ha and 10.7% higher than the SC 14-digit HUC generated area of 5980 ha. The average annual ROC was 0.18 based on this area of 6,510 ha and is lower compared to similar watersheds.

Finally, in 2011 the most updated high resolution 1.5mx1.5m and 0.18 m vertical resolution DEM based on the complete LiDAR data for the watershed was used to redefine the boundary and corresponding area using the ArcGIS-SWAT model as shown in blue color in Figure 10. The area calculated by this method as a reference was 5,240 ha with a corresponding calculated average annual ROC of 0.23, which was very close to the similar other forested watersheds in the coastal plain (Amatya et al., 2006; Chescheir et al., 2003).

The area of 5,240 ha by the LiDAR-based DEM is just about 6.5% higher than the previously estimated area of 4,920 ha by SC DNR2005 method, indicating that the 30mx30m horizontal and 1 m vertical resolution DEM was well within the water balance errors. The USGS defined drainage area of 5,880 ha based on 14-digit HUC was 12.2 % higher than this LiDAR-based DEM as a reference. Interestingly, if the areas that were drained by the road culverts (based on DEM reconditioning and field verification) outside of the watershed boundary are not considered (or included as if there were no culverts) then the LiDAR-based DEM (brown color) also provides exactly the same drainage area (5,880 ha) as the one obtained by the14-digit HUC. This indicates that for areas without culverts the DEM based on the 14-digit HUC may be as accurate as the LiDAR based DEM for these LCP watersheds.

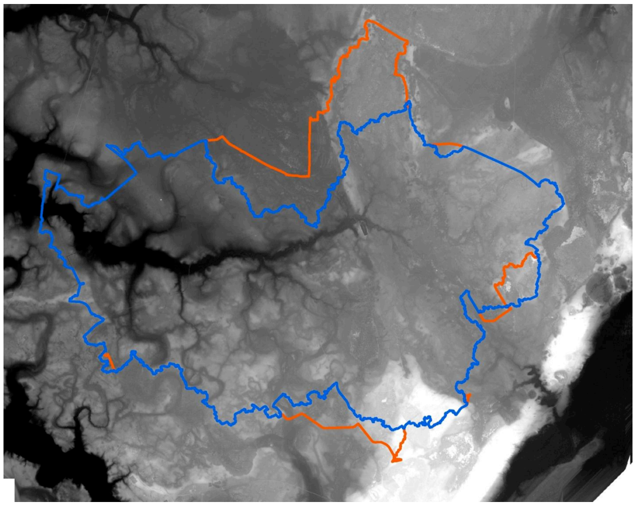

Figure 10. Watershed boundary using 1.5m horizontal and 0.18 m vertical resolution DEM from the 2011 LiDAR data (Blue color with and brown color without accounting for culverts).

Data in Figure 11 shows the uncertainty in average annual runoff coefficients as a result of variability in the corresponding estimated drainage areas of the Turkey Creek watershed for various DEM types used since 1960s. Clearly, a highest ROC of 0.37 was obtained for the lowest area estimated using very first initial USGS topomap of 1”= 2mi scale in 1960s. The lowest ROC of 0.17 was obtained for the largest estimated area of 7,260 ha by using ArcSWAT delineation with the 1:24,000 scale true 10m horizontal and 1m vertical resolution DEMs. We believe both of these DEMs produced larger errors in estimating average annual ROCs, as a result of errors in drainage areas.

The effects of uncertainty in drainage areas obtained by various DEM types can be propagated in many hydrologic studies including water and nutrient balances, spatially distributed modeling (SWAT, MIKESHE, HSPF, DRAINWAT, WEPP etc.) and engineering designs for water resources structures involving Rational Method, USGS regional flood discharge formula (Guimares and Bohan, 1992), peak discharge estimates (Sheridan, 2002), pollutant export coefficients, designing the best management practices and Total Maximum Daily Load (TMDL) Estimates.

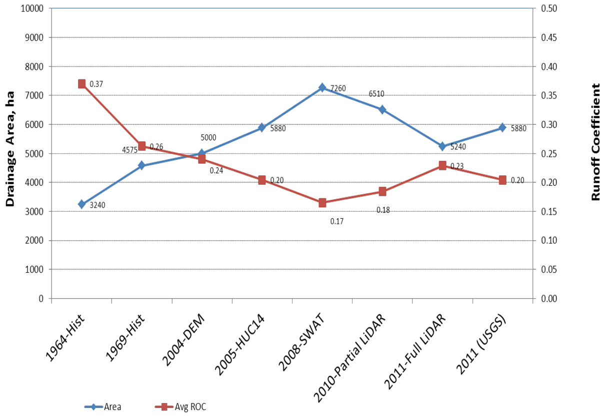

Figure 11. Estimated drainage areas of the Turkey Creek watershed using various DEM types and the corresponding average annual runoff cofficients.

While the importance of high resolution LiDAR-based DEM for watershed area was demonstrated here it may have other applications also as shown by Trettin et al. (2008) for the Santee Experimental Forest. The authors reported that the improvements in hydrologic functions and pathways used in hydrologic models and assessments can be achieved by using these high resolution DEMs that are capable to identify the remnants of legacy water managements structures left from rice planting in 1700s in the SC lower coastal plain, which otherwise were not identified using the regular and enhanced DEMS. Similarly, Amoah et al. (2011) used DEM-based approach including LiDAR data to quantify the surface depressional storage parameter widely used in hydrologic models for predicting the peak flow rates.

CONCLUSIONS

DEMs based on high resolution topographic data such as LIDAR with field verification for cross drainage structures and roadbeds of the study watershed should be used for estimating more reliable boundary/drainage area often used in hydrologic studies in the flat, low-gradient coastal plain landscapes. The area delineated by using the 14-digit HUC may be as accurate as the one obtained by the LiDAR-based DEM for these LCP watersheds as long as the culverts and roads are not existent. The drainage area estimated using the 30m horizontal and 1 m vertical resolution DEM was found to be much more accurate than the USGS enhanced 1:24,000 True 10-meter horizontal 1-meter vertical DEM when compared to the LiDAR-based DEM in this study. Although the high resolution LiDAR-based DEM was considered as the most accurate for use as a reference in this study, we should still acknowledge some uncertainties and errors in the LiDAR data processing also as various software used to process them have some limitations and potential errors (e.g., errors due to inherent structure of algorithms for automatic watershed delineation).

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