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Assessing resolution and source effects of digital elevation models on automated floodplain delineation: A case study from the Camp Creek Watershed, Missouri

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ABSTRACT

Digital elevation models (DEMs) have been widely used in automated floodplain modeling to determine floodplain boundaries. However, the effects of DEM resolution and data source on floodplain delineation are not well quantified. This paper presents a case study to assess these effects from the Camp Creek Watershed, Missouri, using two sets of DEMs. One is the Light Detection and Ranging (LiDAR) DEMs re-sampled from 1-m to 3, 5, 10, 15, and 30-m resolutions. The other is 5, 10, and 30-m DEMs obtained from the U.S. Geological Survey (USGS). Floodplain boundaries are delineated using a combination of hydrological, hydraulic and floodplain delineation models under the Federal Emergency Management Agency's (FEMA) guideline. Model outputs including stream network, watershed and floodplain boundaries are compared to 1-m LiDAR DEM outputs (as the reference) to assess the uncertainty. Results indicate that re-sampled 3 or 5-m LiDAR DEMs produce similar streams and floodplain boundaries within 10% difference of the reference. In contrast, coarser LiDAR DEMs (such as the 10-m resolution) are more appropriate for watershed boundary delineation because higher DEM resolutions are likely more sensitive to minor topographic changes and may introduce erroneous boundaries. For different data sources, uncertainties introduced by USGS DEMs are much higher than LiDAR DEMs with a distinct relationship between uncertainties and DEM resolutions. Uncertainties of LiDAR DEMs consistently increase with decreasing resolutions, whereas similar levels of uncertainty are observed for different USGS DEM resolutions. This difference is probably due to the inherited difference in their original data source resolutions to make these two types of DEMs.

Introduction

Water is essential to life on Earth, but it can also cause disasters. Water-related disasters, such as flooding, hurricanes, cyclones, tsunamis, mudslides, and blizzards, account for approximately 60% of all disasters worldwide (Frech, 2006; Ibarra, 2011; Vinet, 2008). Flooding itself is the largest natural disaster (about 40% of all disasters) in the United States with an estimated property damage of about $4 billion and approximate 200 deaths each year (Pielke, Downton, & Miller, 2002). Therefore, understanding the extent of flooding is critical to prevent property damage and life loss. Since the 1970s, the Federal Emergency Management Agency (FEMA) of the United States has conducted considerable effort to map nationwide floodplain areas, especially for the 100 year flooding event (Blanchard-Boehm, Berry, & Showalter, 2001). Early methods to delineate floodplain boundaries are primarily manual and require considerable amount of time and effort (Norman, Nelson, & Zundel, 2001). With the development of numerical modeling, geographic information systems (GIS), and digital elevation models (DEMs), automated techniques and methods become available and have been widely used in floodplain delineation.

The automated method significantly reduces the time and improves the accuracy of the floodplain delineation. However, uncertainties still exist. First, automated floodplain modeling usually includes a combination of hydrological, hydraulic, and floodplain delineation models (FEMA, 2005) and each model can have different choices with strengths and weaknesses (Norman et al., 2001). Therefore, uncertainties can be introduced due to different combinations of models and/or parameters (Wheater, 2002; Yang, Townsend, & Daneshfar, 2006). Second, automated floodplain modeling requires a DEM to represent topography, calculate flood elevation, and delineate floodplain boundaries. The

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source and resolution of the DEM would affect many steps of the floodplain modeling. With technological advances, DEMs can be created at much higher resolutions. For example, the use of Light Detection and Ranging (LiDAR) allows for the creation of <1-m resolution DEMs (National Academy of Sciences, 2009; Tate, Maidment, Olivera, & Anderson, 2002). Higher resolution DEMs provide more accurate terrain representation and would result in more accurate floodplain delineation. However, gathering higher resolution DEMs can be expensive and require considerable demands of data storage space and computation ability. In addition, DEMs can be created using different data sources such as synthetic aperture radar, topographic maps, LiDAR, and field surveys. As all DEMs introduce errors, examining the effects of DEM resolution and data source on floodplain delineation is critical to flood management and disaster prevention.

The effects of DEM resolution and data source have been examined for many processes such as soil erosion (Zhang, Chang, & Wu, 2008), landslide (Claessens, Heuvelink, Schoorl, & Veldkamp, 2005), solar radiation (Cebecauer, Huld, & Suri, 2007), watershed, and hydrological (Chaubey, Cotter, Costello, & Sorens, 2005; Vazquez & Feyen, 2007; Wu, Li, & Huang, 2006) models to test if an optimum DEM resolution exists so the model output can be accurate enough without the need to significantly increase data storage space and computation ability. The goal of this paper is to assess the effects of DEM resolution and data source on automated floodplain delineation through a case study from the Camp Creek Watershed, Missouri. The results of this study would provide insights into the determination of an optimum DEM resolution needed for accurate floodplain modeling.

Study area and datasets

The Camp Creek Watershed is located in Saline County, Missouri, with a drainage area of about 46 km^2 (Fig. 1A). The portion of the Camp Creek used for this study consists of approximately 19.3 km of the stream flowing from its headwaters southward to about 1.5 km upstream from the Salt Fork River. The watershed belongs to a relatively flat topography (<10% in slope) and consists of silt loam soils. The land use of the watershed is dominated by agricultural land (66%), grassland (18%), and forest (15%) (Fig. 1B).

Two sets of DEMs are used for this study. One is a set of DEMs derived from an original 1-m LiDAR dataset obtained by a joint project between the United States Army Corps of Engineers, Kansas City District, and United States Department of Agriculture, Natural Resource Conservation Service (USDA-NRCS) in 2007. The original dataset covers four counties in Missouri (Lafayette, Saline, Carroll, and Chariton) and was verified using 304 ground control points (17 points from forest covered areas) with a vertical accuracy of <0.13 m. To examine the effect of DEM resolution on floodplain delineation, this original dataset is re-sampled to a set of DEMs with resolutions of 3, 5, 10, 15, and 30 m. The other is USGS DEMs with resolutions of 5, 10 and 30 m. The 30-m DEM is retrieved from the Missouri State Data Repository (MSDIS, http://misdisweb.missouri.edu) and was developed for the USGS in 1998 by the Geographic Resource Center (GRC) at the University of Missouri using 7.5 min quadrangle topographic maps. The 5 and 10-m DEMs were developed for the USGS by the Center for Applied Research and Environmental Systems (CARES) at the University of Missouri in 2005. These DEMs were developed based on 1:24,000 topography maps and are obtained directly from CARES with the permission of the USGS.

Methods

Automated floodplain modeling

Following the FEMA guidelines, the floodplain model used in this study includes three portions: hydrological, hydraulic, and floodplain delineation models (Fig. 2). The hydrological portion determines the discharge of a flooding event at a stream cross section. The hydraulic portion calculates the flood elevation corresponding to the discharge at each cross section. The final portion delineates floodplain boundaries based on calculated flood elevation at each cross section and the DEM.

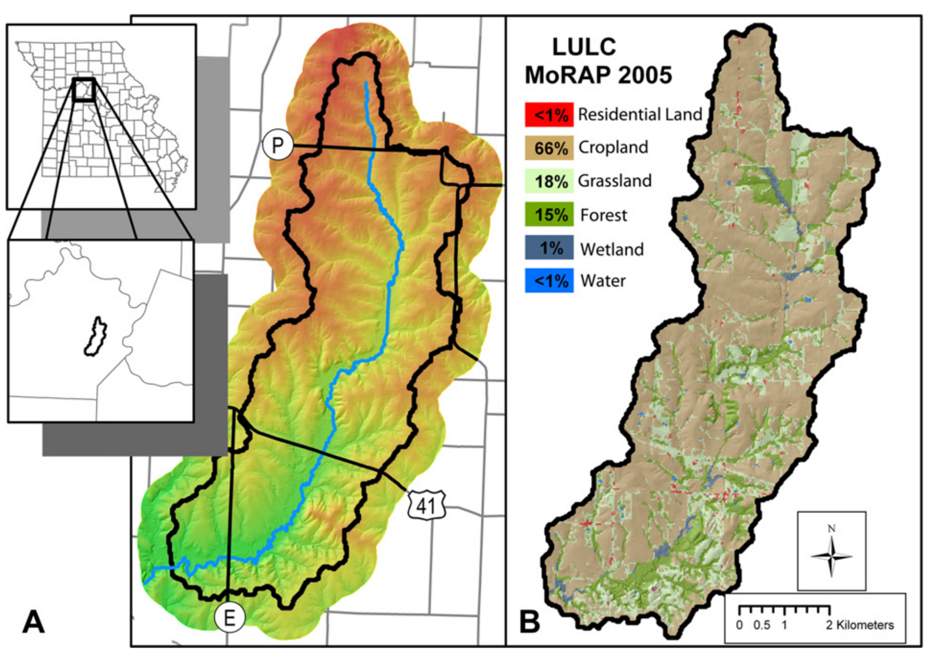

Fig. 1. (A) The shaded relief map of the Camp Creek Watershed. (B) The land use/land cover (LULC) map of the study area (based on Missouri Resource Assessment Partnership (MoRAP) 2005 data).