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Research article

Conservation Reserve Program effects on floodplain land cover management

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ABSTRACT

Growing populations and industrialized agriculture practices have eradicated much of the United States wetlands along river floodplains. One program available for the restoration of floodplains is the Conservation Reserve Program (CRP). The current research explores the effects CRP land change has on flooding zones, utilizing Flood Modeller and HEC-RAS. Flood Modeller is proven a viable tool for flood modeling within the United States when compared to HEC-RAS. Application of the software is used in the Nodaway River system located in the western halves of Iowa and Missouri to model effects of introducing new forest areas within the region. Flood stage during the conversion first decreases in the early years, before rising to produce greater heights. Flow velocities where CRP land is present are reduced for long-term scopes. Velocity reduction occurs as the Manning's roughness increases due to tree diameter and brush density. Flood zones become more widespread with the implementation of CRP. Future model implementations are recommended to witness the effects of smaller flood recurrence intervals.

1. Introduction

Floods account for approximately fifty percent of all water related natural disasters across the world. 196 million people from more than 90 nations are annually subjected to disastrous flooding (United Nations Development Programme, 2004). Flooding occurs when the surface runoff volumes routed to stream channels surpasses the capacity of the stream. The runoff is unable to be routed downstream to the watershed outfall point, causing inundation of urban and rural areas (O'Connell et al., 2007). Many in the scientific community have proposed that a boosted hydrological cycle has led to the increased precipitation and subsequent flooding trends since 1895 (Andresen et al., 2012) (Pielke et al., 2000). Inundation cases of floodplain lands have become more numerous as artificially erected systems have scrupulously imposed on natural habitats, disregarding their effects on hydrologic systems (De Laney, 1995). In particular, the shrinking of floodplains has resulted in higher flood stages and increased sedimentation (Asselman and van Wijngaarden, 2002). Heavy demands placed on farmers since World War II have seen the landscape near rivers dramatically change with deforestation, unchecked runoff from bare soils, desolation of buffer zones, and deeper compaction of soils (O'Connell et al., 2007). The American Midwest, also known as the "breadbasket," is land within the Mississippi River basin where 65% is farmland and another 25% is harvestable (Turner and Rabalais, 2003). Working to solve the present flood control problems, engineers are turning towards sustainable methods by integrating natural restoration techniques for floodplain control (Werner et al., 2005).

Agricultural programs not limited to: Agricultural Act of 1933, Agricultural Act of 1956, and Food Security Act of 1985; have been enacted by the United States Government to authorize the reservation of crop lands to be assigned for rehabilitation (Yuan et al., 2015). Most recently these programs have brought forth the Conservation Reserve Program (CRP) facilitated by the United States Department of Agriculture (USDA). Originally organized by the USDA, the CRP was intended to pay farmers subsidies to rent their land and cease crop production to lower supply and therefore raise market prices. This practice is still ongoing today, but the program also focuses on floodplain restoration and wetland habitat rehabilitation. Forest management of mixed-species timber and plants is a growing trend worldwide, working towards natural landscapes (Zhao et al., 2004). Research has been conducted to quantify the growth of a forest, but the necessary physiological processes

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needed for calculations is complicated and the multi-variable models involve large volumes of information input. One physical experiment, the Coalburn Research Catchment, has been executed to study forest growth and its effect on hydrologic parameters (Robinson et al., 1998).

Wetlands provide areas of flat landscape housing vegetation that hold soil stabilizing streambanks and boost sediment retention. Restoring cultivated fields into natural forest has multiple effects, though their consequence on flood control is scattered according to the age of the forest. Interception losses in young forests are minimal but increase over time as timber stands grow. The lower interception losses are visible in the Coalburn experiment where peak discharges exiting the test catchment increased by 20% during the first five years of forestation, before reducing the peak flows twenty years after forest planting (Robinson et al., 1998). Multiple studies have been conducted comparing peak flows to wetland areas, and a relationship for an Illinois stream found the peak discharge decreased 3.7–1.4 percent for every one percent increase of wetlands in the basin (Demissie and Khan, 1993). Another study found watershed basins that include 5–10 percent wetlands could deliver up to a 50% peak flow reduction compared to basins without (De Laney, 1995). Placement of wetlands also affects their usefulness, not just the amount of area covered. Studies prove that several small marshes dispersed in the upper reaches of a catchment are better at reducing total runoff than a singular large marsh downstream. The smaller dispersed marshes neutralize meteorological storms, as the surface runoff is reduced in volume and unable to become organized as a large flow (Mitsch and Gosselink, 2000) (Loucks, 1990). However, though numerous smaller wetlands upstream may be better at reducing flow reaching the stream, wetlands downstream are have been shown to be more efficient at attenuating flood events (Ogawa and Male, 1983).

The Manning Equation is common for open channel hydraulics and built for uniform flow when the energy gradient is equal to the water surface and streambed slope (Chow, 1959) (Marcus et al., 1992). Manning's n value is widely used for flows with larger Reynold's numbers (Sellin et al., 2003). United States Geological Survey (USGS) has published a guide that includes approximate ranges for surface roughness coefficients for multiple open channel flow scenarios, including natural channels and floodplains (Arcement and Schneider, 1989). Studies have modeled water-surface interactions pertaining to overland flow on floodplains and forests, finding average n values of cultivated crops (Li and Zhang, 2001). Farmland crops have been reported to decrease from damage as much as 15–20 percent derived from the impact of flooding (Mani et al. 2013). Focusing on forested areas, mature trees with scattered undergrowth have been studied to maintain certain roughness factors after ten years of growth (Phillips and Tadayon, 2006). Flow roughness factors are main inputs for both one and two-dimensional models. Meandering channels are complex with shear layer interactions between channel and floodplain during out-of-bank flows (Knight and Shiono, 1997). Flood simulations in two-dimensional models transform exceedance probabilities into useful information as depth and velocity. These parameters are then used to rank flood events across a hazard index, with the depth of flooding being the most common factor analyzed (Mani et al. 2013).

This study focuses on modeling a river reach and designating certain areas of existing farmland for the Conservation Reserve Program, to be reverted to a more natural state, and recording its effect during a flood event. The study is prepared to investigate the effects of flooding attenuation parameters over the simulated length of a CRP land contract. River models were prepared with both Flood Modeller and Hydrologic Engineering Center River Analysis System (HEC-RAS) programs simulating peak flow for one and two-dimensional modeling. In the models the Manning's roughness coefficient was altered to represent the land cover present at a particular time in the supposed CRP contract. The intent of the current study is to explore the capabilities of Flood Modeller within the United States for CRP land change, and provide a comparison with extensively used hydraulic model HEC-RAS. The results of two program results from both one and two-dimensional simulations will provide a better guideline for future CRP land contract durations. The combination of various land cover scenarios is modeled to represent CRP land over a single length of the government contract. These findings along with others mentioned above present the starting point for determining how CRP land interacts with flooding characteristics compared to the existing farmland. Through this research, it is hopeful to determine if the existing CRP land contracts are of adequate length to successfully act as a viable option towards natural flood control, and to quantify the effects that wetland restoration produces during a flood event.

2. Materials and methods

2.1. Study area and data

The Nodaway River is a sixth order river located in the western halves of Iowa and Missouri. It starts in Iowa for the first 68% and then flows south into Missouri for the final 32%, before discharging into the Missouri River north of Kansas City as seen from Fig. 1. The river flows through predominantly agricultural areas with small townships spread along the reach. The floodplain of the Nodaway River has been almost exclusively converted to agricultural fields, clearing brush and forest capable of growing cultivatable crops.

The Nodaway River is prone to flooding further downstream because of its extreme top-heavy shape and poor land use managements. The watershed basin is 4714 km^2, and the top-heavy shape is visible through its maximum width of 56 km upstream, compared to the average width of the lower two-thirds at only 19 km. It is this narrowing dendritic watershed basin shape that causes frequent flooding in the lower reaches of the river. In the lower 103 km of the river, the channel gradient is nearly constant at 0.38 m per kilometer (Horton and Kerns, 1998) (Smith et al., 2013). The increased pressure on agriculture communities to produce even greater capacities of food then before is leading to the reduction of natural wetlands within the floodplain.

Focusing on a 16.9 km stretch of the Nodaway River in rural Missouri in Fig. 2, this study utilizes USGS station 06817500 near Burlington Junction, MO for historic discharge and stage readings. Annual peak discharge and stage data are available for a combined 74 years, from 1922 to 1993 and 2015–2016. Manipulating the discharge values into Log-Pearson Type III distribution, a 100-year flood discharge was calculated at 1440 m^3/sec. Log-Pearson Type III is widely accepted for determining flood frequency intervals, and 100-year return period is the standard set by the Federal Emergency Management Agency for flood mapping. Floodplain and river channel cross sections were determined from digital elevation model (DEM) n41w096, downloaded from USGS TNM Map Viewer. The location of this study was picked for its agricultural landscape and frequent flooding. Utilizing tools in Ersi ArcMap 10.2, the original DEM was interpolated to a 1 m DEM. Inverse Distance Weighted (IDW) interpolation was chosen for its commonality and more accurate results compared to methods like Spline that create smooth surfaces. Riverbanks and floodplains are not necessarily smooth, and IDW takes a more advanced approach to interpolation, capturing the natural landscape of cliffs and more dramatic slope changes with better accuracy. Flood mapping and modeling is completed with the conversion of the DEM into a triangulated irregular network (TIN). TINs account for better representation of