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Characteristics of river flood and storm surge interactions in a tidal river in Rhode Island, USA

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Abstract

During a hurricane event, heavy rainfall can cause storm runoff and river flood. In tidal rivers, hurricane induced storm surge can increase the river downstream boundary water levels. The interactions of storm-induced rainfall runoff and storm surge in tidal rivers may cause more severe flood during hurricane events. In this study, hydrodynamic model simulations were conducted to characterize the interactions of rainfall runoff and storm surge in a tidal river in Rhode Island, USA. River floods under scenarios with and without storm surge were compared.

Keywords: rainfall runoff; tidal river; storm surge; flood

1. Introduction

The Woonasquatucket River (Fig. 1) is a tidal river located in Rhode Island, U.S.A. The Woonasquatucket River's headwaters are 300 feet above sea level at Primrose, in the town of North Smithfield. From several ponds there the river flows 19 miles south and east to downtown Providence, at sea level, where it joins the Moshassuck River to form the Providence River, which in turn flows into Narragansett Bay. The lower reaches of the river, up to the Rising Sun Dam near Donigian Park in Olneyville, rise and fall with the tide in Narragansett Bay.

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During the hurricane event, the interactions of rainfall runoff and storm surge affect the water levels along the river. In this study, a storm event in 2010 was selected to characterize the interactions of the rainfall runoff and storm surge in the river. A HEC-RAS river hydrodynamic model for Woonasquatucket River was previously developed under steady flow conditions for river flood analysis by USGS (Fig. 2). The USGS's HEC-RAS model was modified for unsteady flow simulations to simulate interactions of rainfall runoff and storm surge.

Fig. 1. Woonasquatucket River in Rhode Island, USA

2. Governing Equations of HEC-RAS Hydrodynamic Model

The basic dynamics of the shallow river flow can be described by the one-dimensional Saint Venant equation[1], which has been used in the popular river hydrodynamic model HEC-RAS [2]. Saint Venant equation gives a good balance between accuracy and numerical cost. The Saint Venant equation for one-dimensional river flow consists of the conservation equations for mass and momentum as given below[2]:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - q_l = 0 \tag{1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial (uQ)}{\partial x} + gA\left(\frac{\partial z}{\partial x} + S_f\right) = 0 \tag{2}$$

where x is horizontal distance along a river (m), t is time (s), A is wetted cross-sectional area (m^2), Q is discharge (m^3/s), u is depth-averaged flow velocity (m/s), q_l is lateral inflow discharge per unit distance (m^2/s), z is water surface level (m), S_f is friction slope and g is acceleration due to gravity (m^3/s). For the friction slope

$$S_f = \frac{n^2 Q^2}{A^2 R^{4/3}} \tag{3}$$

where R (m) is hydraulic radius.

3. Model Setup

The basic HEC-RAS model for Woonasquatucket River was set up and calibrated by Zarriello et al. [3] for steady flow simulations, and was provided for this study from USGS. The model was modified for unsteady flow simulations to simulate interactions of river flood and storm surge.