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Assessment of salinity intrusion in the James and Chickahominy Rivers as a result of simulated sea-level rise in Chesapeake Bay, East Coast, USA

Karen C. Rice [a], Bo Hong [b,*], Jian Shen [b]

[a] U.S. Geological Survey, P.O. Box 400123, University of Virginia, Charlottesville, VA 22904-4123, USA
[b] Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA 23062, USA

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ABSTRACT

Global sea level is rising, and the relative rate in the Chesapeake Bay region of the East Coast of the United States is greater than the worldwide rate. Sea-level rise can cause saline water to migrate upstream in estuaries and rivers, threatening freshwater habitat and drinking-water supplies. The effects of future sea-level rise on two tributaries of Chesapeake Bay, the James and Chickahominy (CHK) Rivers, were evaluated in order to quantify the salinity change with respect to the magnitude of sea-level rise. Such changes are critical to: 1) local floral and faunal habitats that have limited tolerance ranges to salinity; and 2) a drinking-water supply for the City of Newport News, Virginia. By using the three-dimensional Hydrodynamic-Eutrophication Model (HEM-3D), sea-level rise scenarios of 30, 50, and 100 cm, based on the U.S. Climate Change Science Program for the mid-Atlantic region for the 21st century, were evaluated. The model results indicate that salinity increases in the entire river as sea level rises and that the salinity increase in a dry year is greater than that in a typical year. In the James River, the salinity increase in the middle-to-upper river (from 25 to 50 km upstream of the mouth) is larger than that in the lower and upper parts of the river. The maximum mean salinity increase would be 2 and 4 ppt for a sea-level rise of 50 and 100 cm, respectively. The upstream movement of the 10 ppt isohaline is much larger than the 5 and 20 ppt isohalines. The volume of water with salinity between 10 and 20 ppt would increase greatly if sea level rises 100 cm. In the CHK River, with a sea-level rise of 100 cm, the mean salinity at the drinking-water intake 34 km upstream of the mouth would be about 3 ppt in a typical year and greater than 5 ppt in a dry year, both far in excess of the U.S. Environmental Protection Agency's secondary standard for total dissolved solids for drinking water. At the drinking-water intake, the number of days of salinity greater than 0.1 ppt increases with increasing sea-level rise; during a dry year, 0.1 ppt would be exceeded for more than 100 days with as small a rise as 30 cm.

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1. Introduction

The threat of climate change to the environment has become a prominent focus for both government and industry. Observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly affected by sea-level rise, with wide-ranging consequences for human societies and ecosystems (IPCC, 2007). Sea-level rise can cause saline water to migrate upstream to points where freshwater existed previously (e.g., National Research Council, 1987; Grabemann et al., 2001; Poff et al., 2002). Several studies indicate that sea-level rise will increase the salinity in estuaries (e.g., Hull and Tortoriello, 1979; Hilton et al., 2008; Bhuiyan and Dutta, 2011), which will result in changes in stratification and estuarine circulation (Hong and Shen, 2012). Such salinity migration could cause shifts in salt-sensitive habitats, thereby affecting the distribution of flora and fauna, and affect water availability for municipal supply, irrigation, and industrial uses.

Analyses of long-term tide-gauge data indicate that the relative sea level in the Chesapeake Bay, on the East Coast of the USA, has been rising for decades (Barbosa and Silva, 2009). The linear trend in relative sea level of the lower Chesapeake Bay is 4.4501 ± 0.1850 mm/year (Boon et al., 2010). Based on data from 1949 to 2006, Hilton et al. (2008) conclude that sea-level rise largely has been responsible for salinity increases in most parts of the Bay. Hong and Shen (2012) demonstrate that average salinity, salt intrusion distance, and stratification in Chesapeake Bay will increase as sea level rises. All of these studies focus on the main channel of Chesapeake Bay. To date, no studies have addressed salinity change in the Bay's tributaries and how such changes may affect floral and faunal habitats or municipal water supply.

* Corresponding author. Tel.: +1 804 684 7184.
E-mail address: andyhong@vims.edu (B. Hong).

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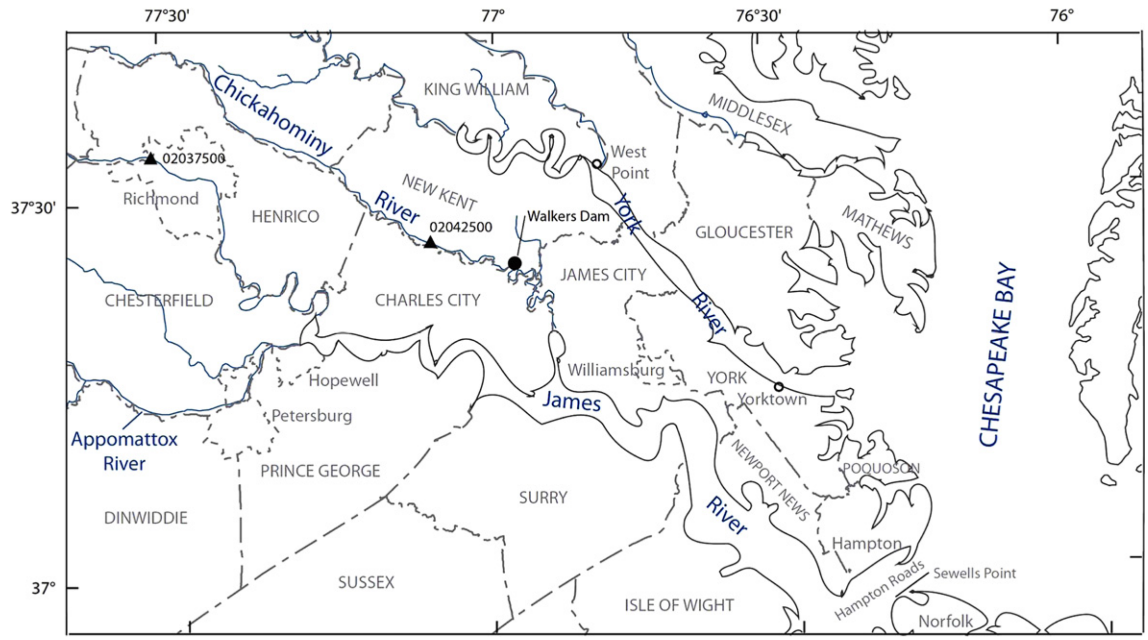

Fig. 1. Location map of the James River and the Chickahominy River.

The James River is the southernmost tributary of Chesapeake Bay (Fig. 1). Salinity in the estuarine part of the James River varies seasonally, which is a common characteristic of estuaries in the mid-latitudes. Near the river mouth, the channel is more than 15 m deep, and salinity typically is around 25 parts per thousand (ppt). The horizontal salinity gradients are usually larger near the head of the river where the freshwater and saltwater converge, referred to, in this paper, as the salinity front. The denser, saline, bottom water enters the James River from Chesapeake Bay and flows upstream, while the less dense surface waters, dominated by freshwater inflow, flow downstream toward the Bay (Pritchard, 1956; Shen and Lin, 2006).

The Chickahominy (CHK) River is one of the main tributaries of the James River near the coast (Fig. 1) and enters the James River approximately 73 km upstream of its mouth. A lake formed by Walkers Dam on the CHK serves as a drinking-water supply for the City of Newport News, Virginia (Fig. 1). Newport News Waterworks is a regional drinking-water utility located on the Virginia Lower Peninsula and serves about 415,000 people, including eight Federal installations. The drinking-water supply intake at Walkers Dam supplies anywhere from 30 to 70 percent of the region's drinking water, depending on the availability of other sources. When freshwater discharge is low, saline water from the James River can

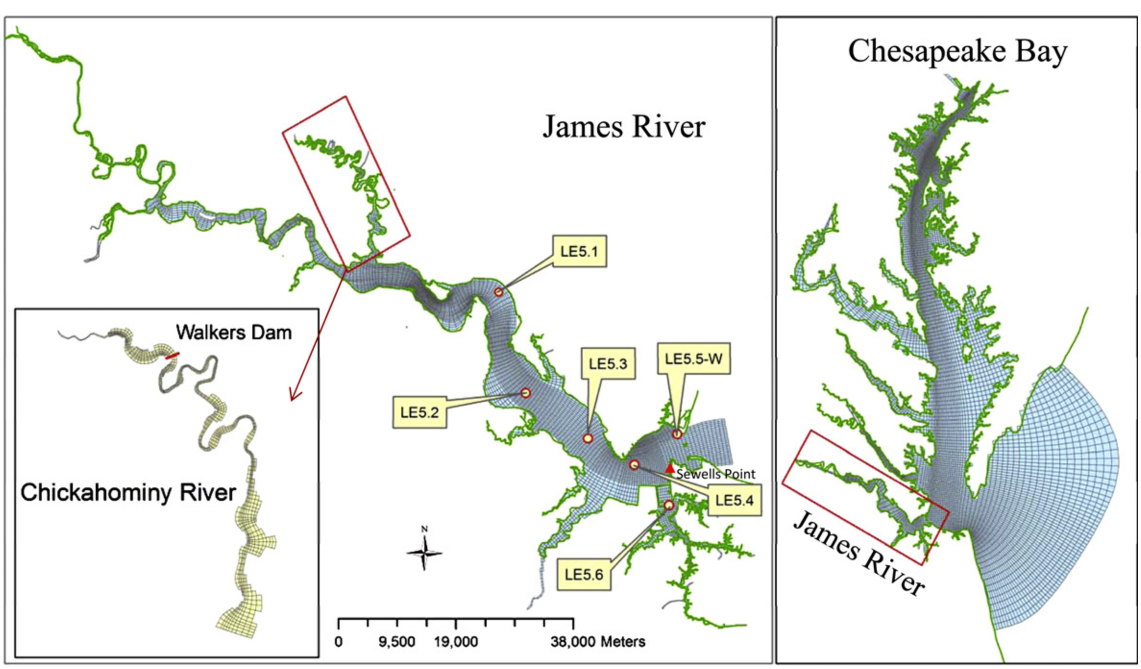

Fig. 2. Diagram of the numerical model grids. Salinity and water level monitoring stations in the James River also are shown.

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