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Development of a storm surge driven water quality model to simulate spills during hurricanes

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ABSTRACT

Hurricanes can cause widespread environmental pollution that has yet to be fully articulated. This study develops a predictive water quality model to forecast potential contamination resulting from buckled or ruptured storage tanks in coastal industrialized areas when subjected to storm surge. The developed EFDC-Storm Surge model (EFDC-SS) couples EPA's EFDC code with the SWAN-ADCIRC hurricane simulation model. EFDC-SS is demonstrated using the Houston Ship Channel in Texas as a testbed and hurricane Ike as a model hurricane. Conservative and decaying dye runs evaluated various hurricane scenarios, combined with spills released at different locations and release times. Results showed that tank locations with shorter distances to the main waterbody and lower ground elevations have a higher risk of inundation and rapid spill mass transport. It was also determined that hurricane strength and landfall location, the location of the spill, and the spill release time relative to peak surge were interdependent.

1. Introduction

The United States has had a long history of hurricane strikes. Over 290 hurricane events have made landfall since 1851 with 12 events occurring in the last 10 years (Blake et al., 2011). In addition to destruction and damage to infrastructure, hurricanes can cause widespread environmental pollution and chemical and petrochemical spills with devastating long term effects to water quality and ecological resources. Hurricane Sandy, for instance, in New York City, damaged industrial areas, waste water treatment facilities and superfund sites and caused oil spills along with the release of toxic chemicals, raw sewage, and hazardous substances (Wilson, 2014). Additionally, significant changes in sediment chemistry and sediment toxicity were reported by Romanok et al. (2016) after Sandy. Paerl et al. (2006), Milbrandt et al. (2006), and Frazier et al. (2013) all reported the deleterious effect of hurricanes on ecosystems. Mallin and Corbett (2006) described massive nutrient loading, algal blooms, significant changes in dissolved oxygen (DO), and chemical pollutants as common effects of hurricanes on water quality. Pardue et al. (2005) discussed the immediate effects and potential deposition of contaminants by Hurricane Katrina and found high levels of toxic metals and depleted DO in New Orleans, Louisiana. Hagy et al. (2006) compared water quality surveys 20 and 50 days after Hurricane Ivan to a survey done 14 days before landfall and reported significant changes in salinity, phytoplankton, and DO levels after Ivan.

The aforementioned studies are all retrospective and report on environmental and ecological impacts after a hurricane has occurred. Additionally, damage assessments from hurricanes typically focus on residential and infrastructure losses but almost never elucidate explicitly the damages associated with environmental pollution and chemical and petrochemical releases. Burleson et al. (2015), in the first work of this type, calculated losses due to the direct effect of inundation caused by storm surge in industrialized areas. The authors estimated the number of storage tanks at industrial facilities in the Houston Ship Channel (HSC) in Texas that would be inundated and the corresponding spill volumes for different storm surge levels and estimated total losses using a fixed cost per gallon of spilled material. While novel and important, Burleson et al. (2015) did not rigorously address the impact of a hurricane event on water quality and the potential for ecological damage in coastal environments.

Additionally, and while the literature is replete with studies that have simulated pollutant transport in coastal environments associated mainly with oil spills (Yapa et al., 1992, Lee and Page, 1997, Beegle-Krause, 1999, Korotenko et al., 2000, Colombo et al., 2005, Kabdasli et al., 2010, Olita et al., 2012, Chen et al., 2017, Durgut and Reed, 2017), none have included the effect of storm surge. As storm surge

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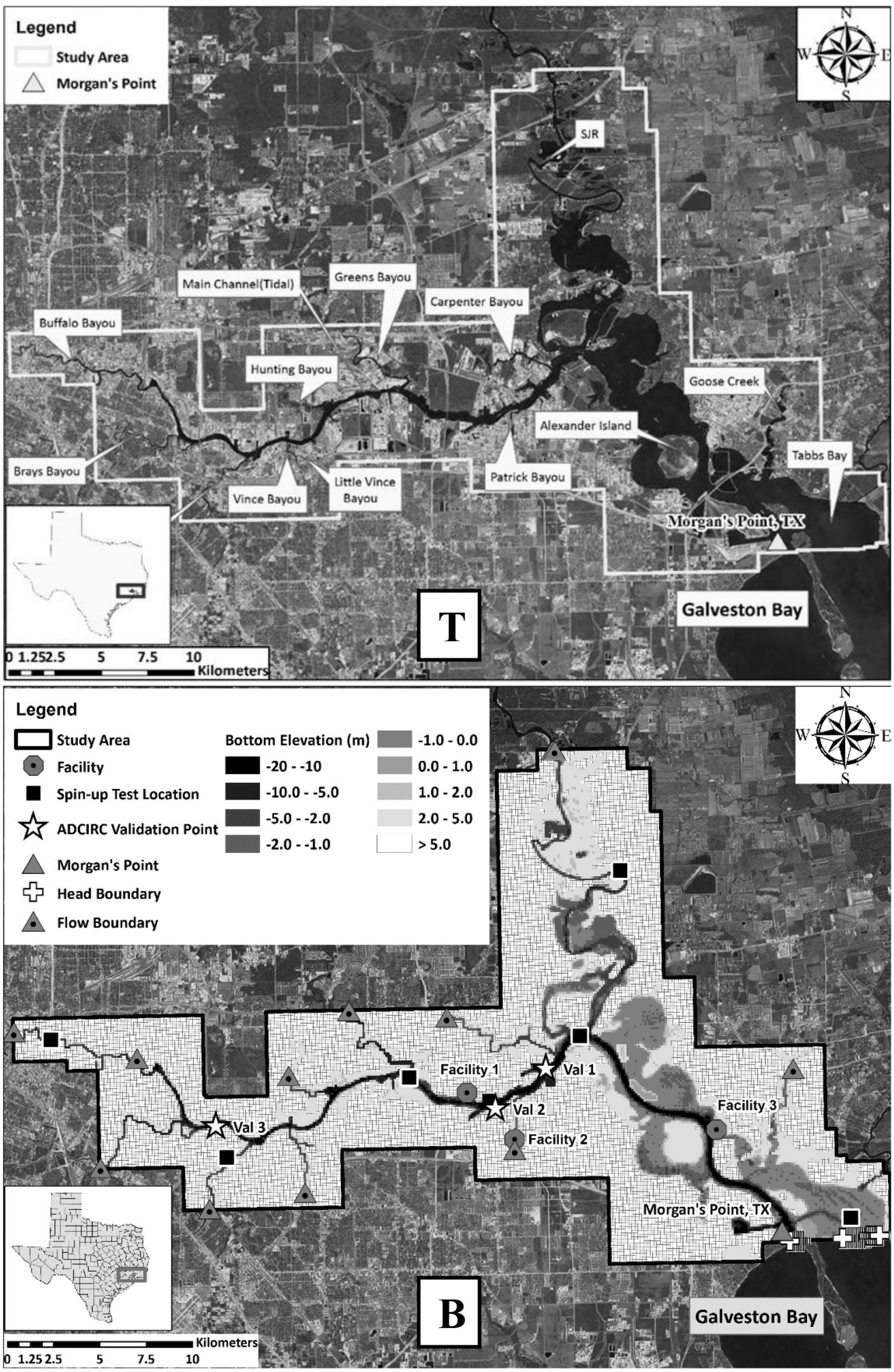

Fig. 1. (T) Modeled Houston Ship Channel System; (B) EFDC-SS grid cells with bottom elevation (NAD83), conservative tracer release locations, and other key locators along the Channel.

pushes ocean water inland, it can potentially cause damage to environmental infrastructure (e.g., storage tanks, water and wastewater networks, treatment plants, and hazardous waste facilities) and cause releases that can get further distributed in the environment as the surge recedes. The potentially significant rainfall events that accompany hurricanes can also contribute to further spreading of the spilled material.

The research presented in this study addresses the aforementioned gaps and develops a predictive water quality model that is driven by surge at its boundary in order to forecast the potential environmental pollution that accompanies a hurricane as it approaches the coast, makes its landfall and recedes. The model is based on the EPA EFDC code (Hamrick, 2007) coupled to a hurricane simulation model (SWAN-ADCIRC, Hope et al., 2013). The resulting model, referred to as EFDC-Storm Surge or EFDC-SS, can be used to: 1) investigate the transport, and predict the trajectory of spills from industrial facilities during a hurricane event as a function of the location and timing of the spill relative to storm surge; 2) quantify the importance of local rainfall