Compound Urban Coastal Flood Modeling: Integrating Tide, Waves, Precipitation and Hydraulic Infrastructure

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INTRODUCTION

Compound coastal flooding considers the joint impacts of marine and hydrologic interactions and has recently been identified as an international research priority. Along the US West Coast, winter storms often bring high marine water levels along with energetic waves and precipitation. Hydrodynamic models have been widely used to estimate flood impacts, including extreme estuarine water levels in compound events (e.g., riverine discharge-tide-storm surge interactions), and produced satisfactory results. However, few studies further consider overland flow routing and high-resolution flood mapping in highly urbanized, low-lying coastal areas. Here, an integrated Delft3D-FM based numerical modeling framework is used to explicitly resolve multi-pathway flood processes (i.e., high marine water levels, waves overtopping, precipitation) and infrastructure (e.g., seawalls, storm drains, artificial dunes).

MODELING APPROACH

Delft3D-FM (http://oss.deltares.nl/web/delft3dfm), an open-source 2D hydrodynamic flexible-mesh numerical model is utilized to quantitatively characterize future compound flood risk considering infrastructure and coastal management interventions. Here, an integrated Delft3D-FM based numerical modeling framework is used to concomitantly resolve multi-source flood processes (i.e., high marine water levels, waves precipitation) and infrastructure (e.g., seawalls, storm drains, dunes). Hydrodynamic model results are validated with a leveled RBR pressure sensor data and photographic observations from historical events (Figure 1). Hydraulic infrastructure (i.e., storm drains, seawalls) were surveyed using RTK-GPS. Grid nodes representing seawalls or other key hydraulic features were snapped to the seawall location and their elevation were assigned from RTK survey data. Storm drains were resolved in the model using a sink function, multiple storm drain characterizations are presented and evaluated. Tide valve closures were represented by setting drainage flows to zero during valve closure periods (embayment water level higher than catch basin of 1.68 m NAVD88). Sacrificial dunes are resolved from analysis of over two decades of LiDAR data. Lidar derived profiles are modeled in XBeach (Roelvink et al., 2009) and loosely coupled to the Delft3D model as source points landward of the dune crest.

RESULTS

The dominate flooding source in this site results from precipitation during tide valve closure periods. Results suggest that precipitation and water level phasing is critical to accurate compound flood prediction. If a compound flood is simulated where the tide valves are closed and the storm system is unable to drain precipitation to the bay (water level >1.68 m), flooding depends entirely on the precipitation timing relative to the high tide. The 100-year water level is expected to become annual in this century (Tebaldi et al., 2012; Taherkhani et al., 2020). Increasing sea levels will necessitate elevated seawalls to mitigate tidal flooding. Critically however, the seawall may retain tidal overflow and interact with precipitation potentially exacerbating both marine and pluvial flooding. Given the current seawall elevation tidal overflow begins at ~2.35 m NAVD88 (essentially, the current 100-year return period), resulting in a relatively small maximum flood extent of 18,256 m2 (Figure 8A). A 10 cm increase in water level to 2.45 m results in a four-fold increase in a flooded area of 77,100 m2, whereas a 2.55 m water level results in a six-fold increase of flooded area of 108,887 m2 (Figure 8A). From a volume perspective, a 2.35 m tide produces a relatively small maximum inundation of 1,984 m3 (Figure 8C). A 10 cm increase in water level to 2.45 m results in a nearly six-fold increase in inundation (11,603 m3), whereas a 2.55 m water level results flooded area of 24,800 m3, more than an order of magnitude compared to the current 100-year water level (Figure 8C). Elevating the seawall to a uniform 2.5 m prohibits tidal overflow for marine water levels below this threshold (Figure 8B, D). However, the elevated seawall may offer only limited protection for future extreme tides. In this case, a high tide 5 cm over the elevated wall (2.55 m) essentially fills the backshore (Figure 8D) and provides only a marginal benefit when compared to the current seawall (20,592 vs. 24,800 m3, respectively).

Seawall impacts on pluvial flooding are shown in Figure 8E and F, with (solid lines) and without drainage (dashed lines). Here, only total inundation volume for the sub-basin adjacent to the wall is considered since uniform precipitation causes isolated non-hydraulically connected low spots to accumulate water. No drainage scenarios (dashed lines) represent situations when tidal values are closed during a compound event. Although peak flood volumes for a given return period with the current seawall are identical with and without drainage (Figure 8E), flood duration is substantially decreased with drainage (solid lines). Simply elevating the seawall to a constant 2.5 meters results in substantial pluvial flooding increases (Figure 8F). The average inundation volume for the 25-year return period with the 2.5 m seawall is similar to the 100-year inundation volume with the current seawall (Figure 8E, F). More extreme events showed flood volumes converge to the sub-basin volumes constrained by the seawall, suggesting the overflow sub-basin saturates. For example, the 100-year precipitation event produces only a marginally higher flood peak than the 50-year, though the peak timing is shifted by approximately one hour (Figure 8F). These results suggest that elevating seawalls to mitigate marine flooding may exacerbate pluvial flooding. Notably, as sea levels rise, storm drains will be closed more frequently and over longer periods substantially increasing both future flood extent and duration.

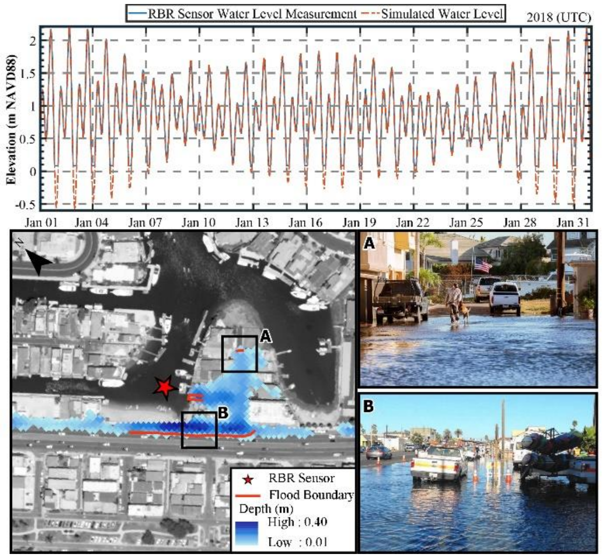

Figure 1 – Model validation results.

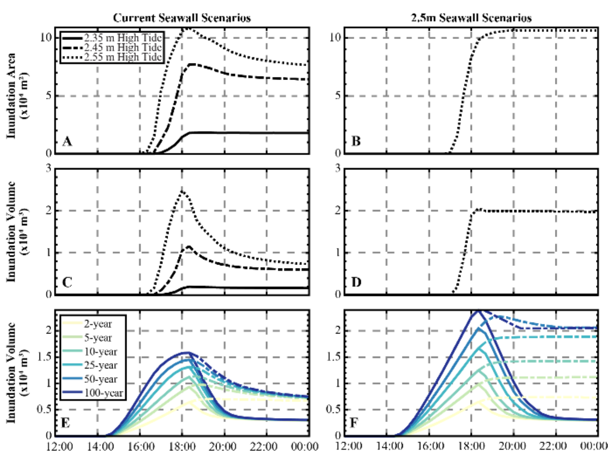

Figure 2 – Tidal overflow flooding extent and volume for the current seawall (A,C) and the 2.5 m seawall (B,D). Compound flood dynamics for various precipitation return periods with drainage (solid lines) and without (dashed lines) drainage for the current seawall (E), and the 2.5 m seawall (F).

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