Applying a Multi-Scale, Decoupled Modeling Approach to Evaluation of New Orleans Flood Defenses

Haydel Collins[1], Maria Sklia[2], Max Agnew[1], David Fertitta[1], Aggelos Dimakopoulos[2], Matt Halso[1], Chris Kees[3]

[1] USACE MVN, [2] HR Wallingford, [3] US Army Coastal Hydraulics Lab

Introduction

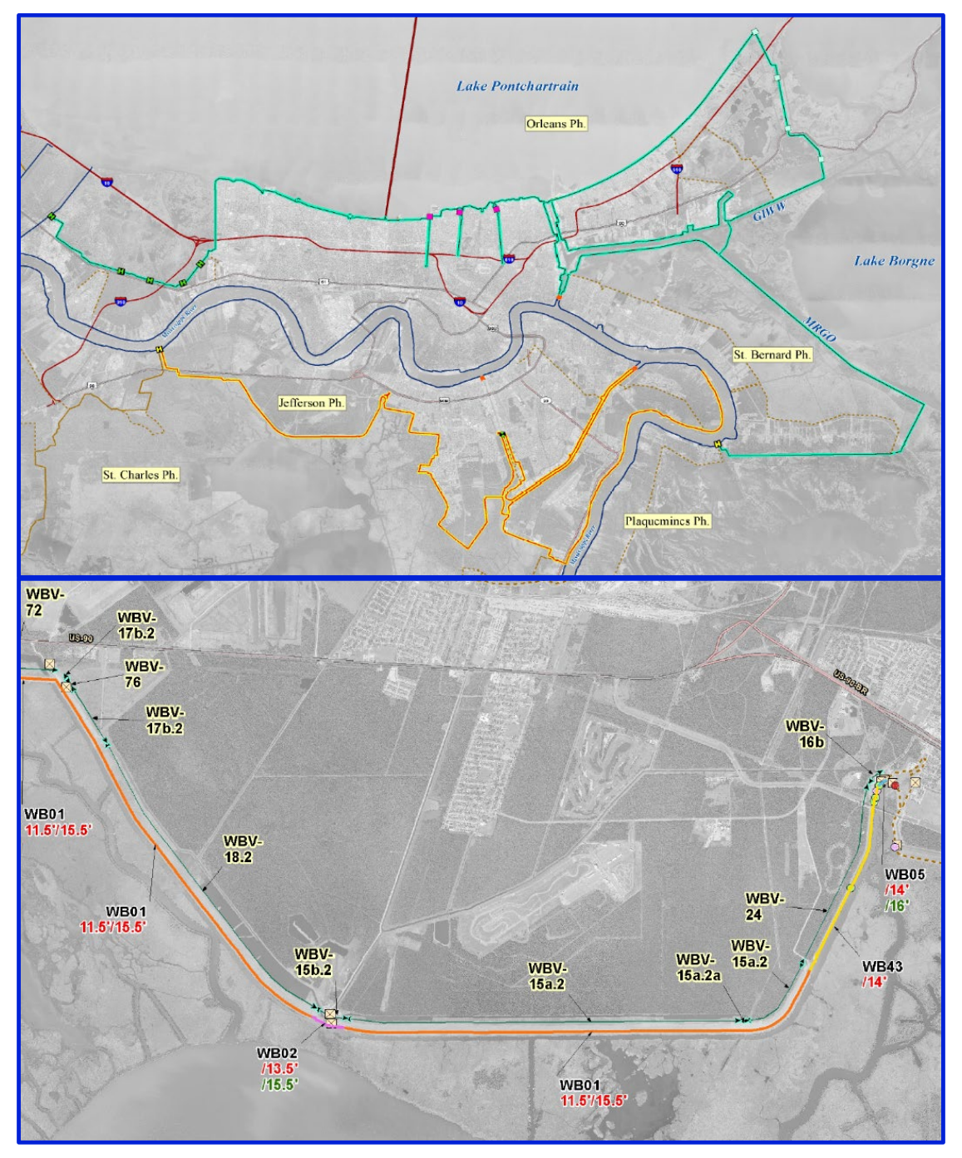


Figure 1. Location of New Orleans flood defenses. GNO-HSDRRS (top) and Jefferson WBV reach (bottom).

The Greater New Orleans Hurricane and Storm Damage Risk Reduction System (GNO-HSDRRS) is the comprehensive flood defense system constructed in response to Hurricane Katrina. The GNO-HSDRRS is divided into two sub polders which are the Lake Pontchartrain and Vicinity (LPV) and the West Bank and Vicinity (WBV) projects (Figure 1). In order for the system to meet the allowable overtopping criterion throughout the design life, continual evaluation and costly maintenance is required to combat deficiencies resulting from subsidence and sea level rise. This analysis aims to test a multi-scale decoupled modeling approach to evaluating the health of the GNO-HSDRRS using ADCIRC output (regional scale) and Proteus (local scale).

Using statistical surge elevations and wave characteristics extracted from 446-synthetic storms (ADCIRC)[1,2] ,overtopping of floodwalls and levees were calculated with empirical relationships from the EurOtop guidance[3]. For a more in-depth evaluation of the localized hydraulic processes involved with overtopping of the GNO-HSDRRS structures, the study will be supplemented with computational fluid dynamics (CFD) simulation by imposing identical conditions in Proteus. **Primarily, this will serve as an evaluation of the Proteus code's ability to produce accurate overtopping rates for the New Orleans coastal defenses. Secondly, overtopping rates for more complex levee and floodwall geometries will be evaluated by using Proteus as a design tool.** The goal is to identify and optimize potential cross-sections that could reduce flood risk more efficiently.

A hypothetical future scenario was applied to the two reaches located in the Jefferson sector of the WBV (Figure 1): WB01 (earthen levee) and WB43 (concrete floodwall). For WB01, three alternative cross sections were analyzed for comparative efficiency against the no action scenario: a simple raise, a crown wall, and a crown recurved wall. For WB43, a bull nose attachment alternative was compared against the no action scenario.

Modeling Background

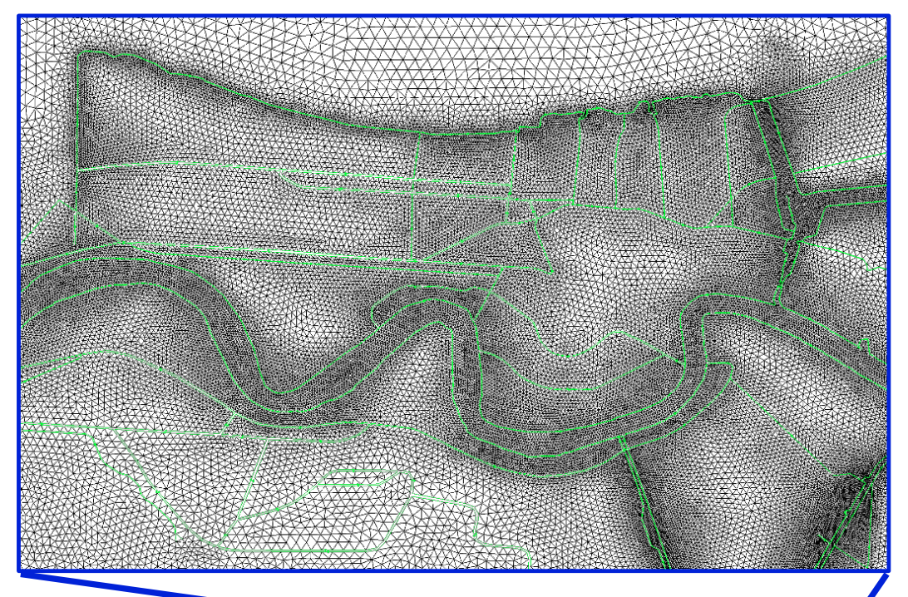


Figure 2.1 Unstructured ADCIRC mesh GNO-HSDRRS.

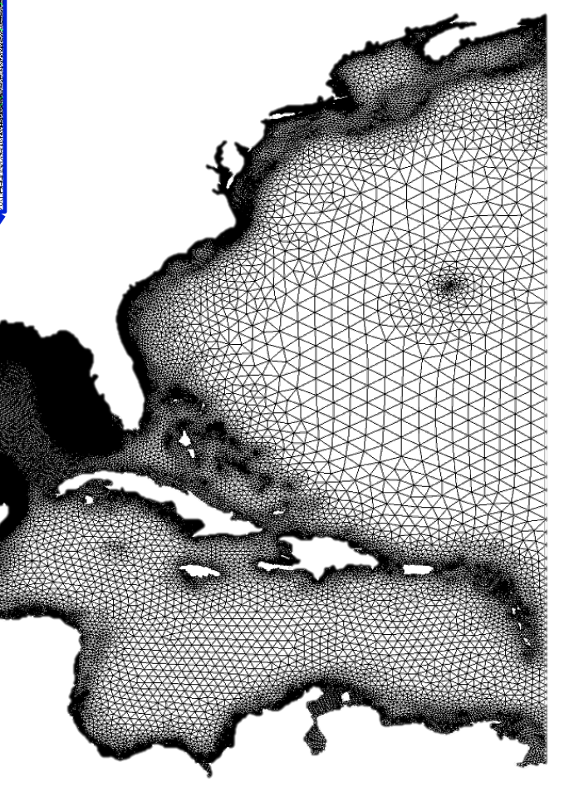
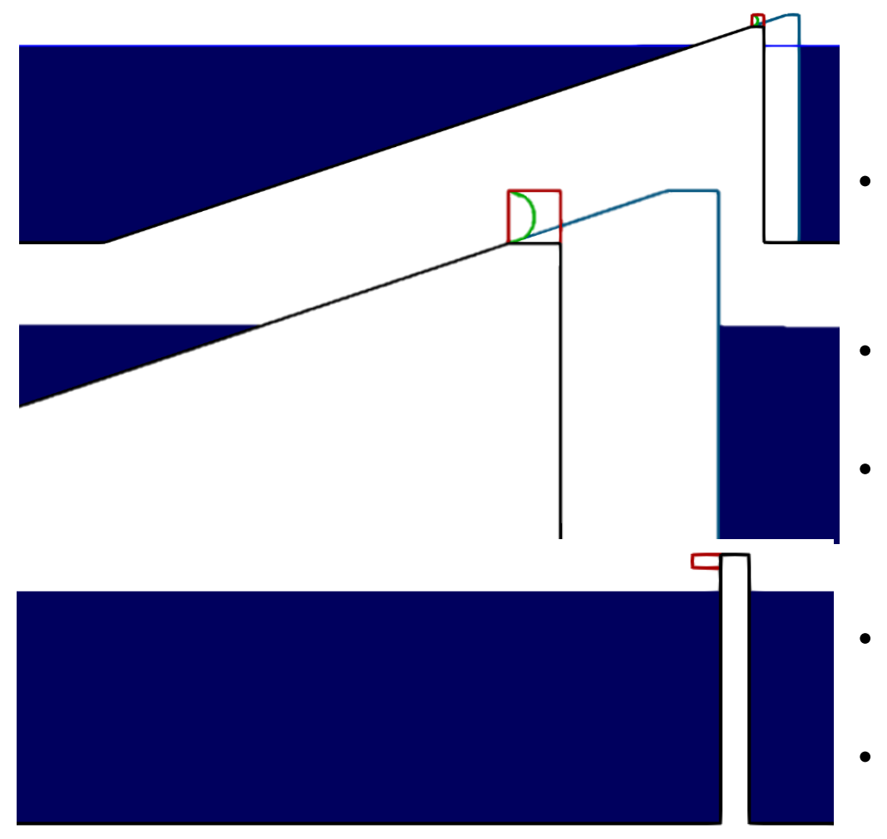


Figure 2.2 Unstructured ADCIRC mesh of the full domain.

- The ADCIRC storm surge modeling was conducted by Coastal Protection and Restoration Authority (CPRA) as part of 2017 Coastal Master Plan. [1,2]
- ADCIRC is capable of modeling continental -> local scales using a spatially varying unstructured mesh. (figures 2.1 and 2.2)
- ADCIRC modeling includes validation of past storms including Hurricanes Katrina, Rita, Gustav, Ike and Isaac. [1,2]
- The surge hazard was computed through simulation of 446 synthetic storms for coastal Louisiana. [1,2]
- The still water level, wave height, and wave period statistics were produced for entire Louisiana coast using USACE statistical code.

Extract results from a suite of 446 synthetic storms using ADCIRC + SWAN

Input extracted water surface elevations and wave characteristics into Proteus



- Proteus is an open source, multifaceted toolkit for solving PDE's. In this case, the multiphase Navier-Stokes solver is used in conjunction with the built-in WaveTools[4] library to simulate the hydraulic processes involved with overtopping coastal structures.
- The multiphase solver models the air and water phase together using a conservative level-set approach described by Kees et al (2011)[5].
- The 2-D domains (Figure 2.3) are simulated as numerical wave tanks with the structures located three wavelengths away from a wave generation zone. On the leeward side of each structure is a catchment basin that returns excess volume to the windward side.
- Extracted wave characteristics (100-year Hs & Tp) and water elevations (100-year + 1.5 ft) are applied as boundary conditions to create a hypothetical deficient future scenario.
- Overtopping discharges are measured by calculating the flux of the water phase in the +x direction at the crown of each structure.

Figure 2.3 Array of levee and flood wall cross sections. Top: No action (black), raise (blue), crown wall (red), crown recurve (green). Bottom: No action (black), bull nose (red) .

Open Source:
https://github.com/erdc/proteus.git

Prior Validation

- To evaluate the ability of Proteus to accurately replicate the hydraulic processes involved in overtopping of coastal structures, a validation study was conducted comparing modeled results vs a set of physical experiments from the CLASH[6] database.
- The CLASH Project is a European research effort focused on accumulation of data from over a wide range of physical experiments involving overtopping[3,6].
- The Proteus validation analysis consists of eight cases (listed below)[7]. Each structure has a 4:1 slope with a crest elevation of 4.31 ft. The wave conditions are produced with a randomized time series built from JONSWAP spectrum. Spectral parameters ranging from 0.79 ft to 1.80 ft for significant wave height and 1.67s to 3.27s for peak wave period.
- Figure 3.1 depicts the modeled vs observed discharges for the eight CLASH cases.

CLASH Datasets: 042-044, 042-181, 042-200, 042-194, 042-201, 042-196, 042-192, 042-187 [7]
This work was performed by Maria Sklia and Aggelos Dimakopolous at HR-Wallingford Oxfordshire, UK

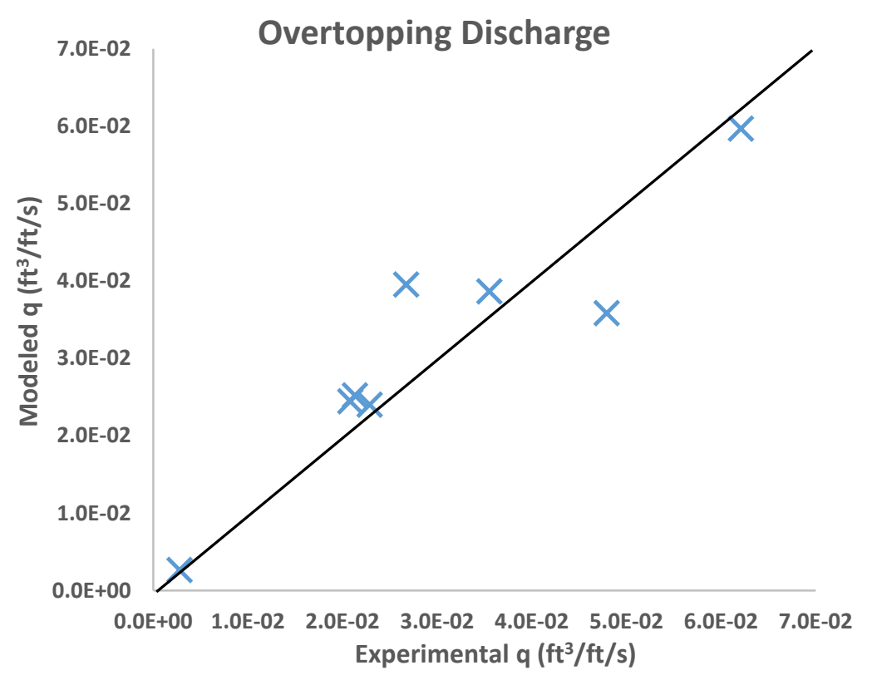


Figure 3.1 Comparison of modeled vs observed.

Comparative Overtopping for Levee and Flood Wall Alternatives

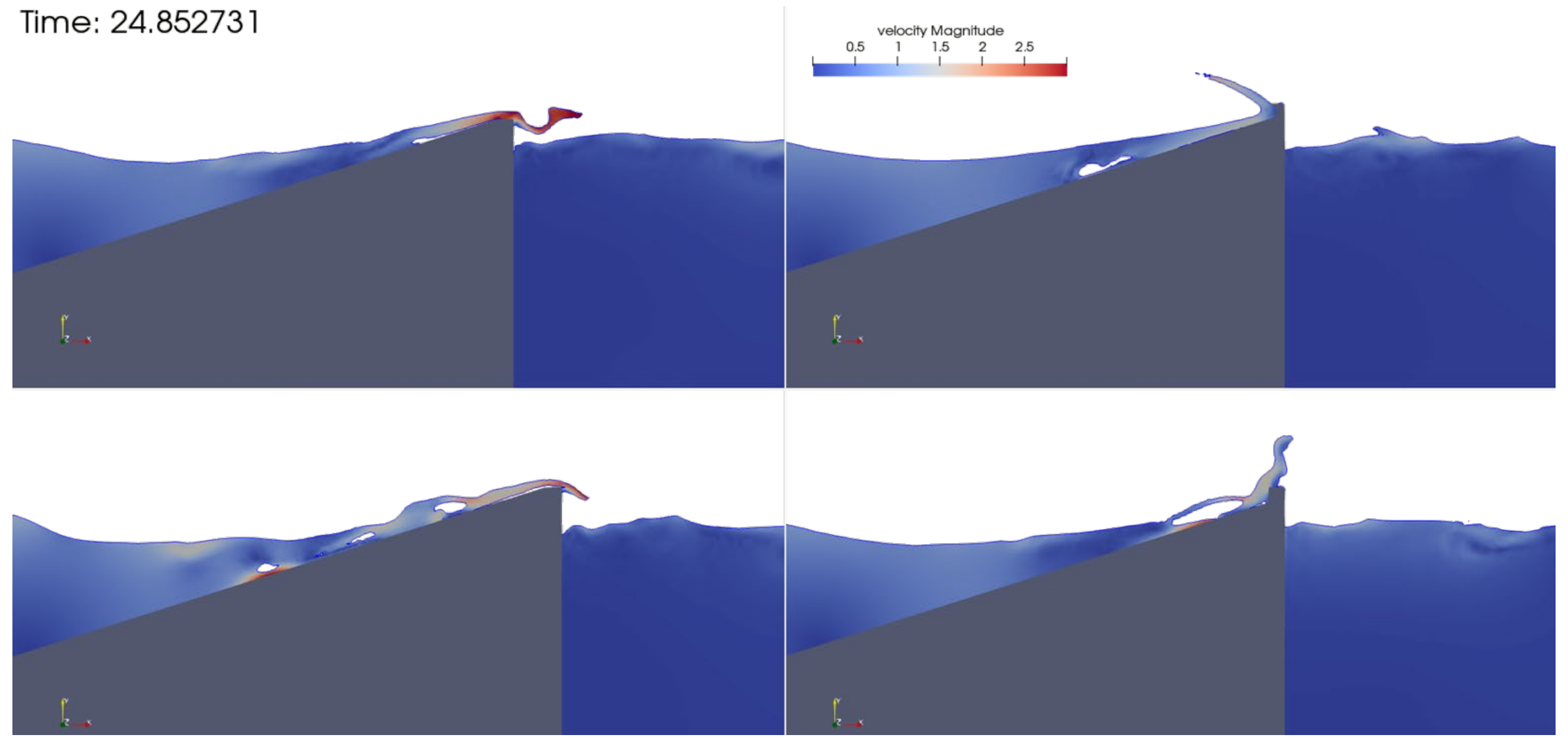


Figure 4.1 Comparative overtopping of WB01 reach: No Action (top left), Recurve (top right), Raise (bottom left), Wall (bottom right)

Boundary Conditions

The still water level applied to these simulations is 8.2ft. This was based on the extracted statistical 100-year water elevation raised by 1.5ft to create hypothetical future deficiencies. The statistical 100-year significant wave height is 1.5ft and peak period is 2.2s.

Structures

The levee sections are based on the WB01 reach of WBV. The slope is 1:3 with a crest elevation of 9ft. The alternatives increase the crest elevation by 0.5ft with a raise, a crown wall, and a recurve wall. The flood wall sections are based on the WB43 reach of WBV. The vertical wall has crest elevation of 9.5ft. The bull nose attachment extends 1ft over the windward face of the wall.

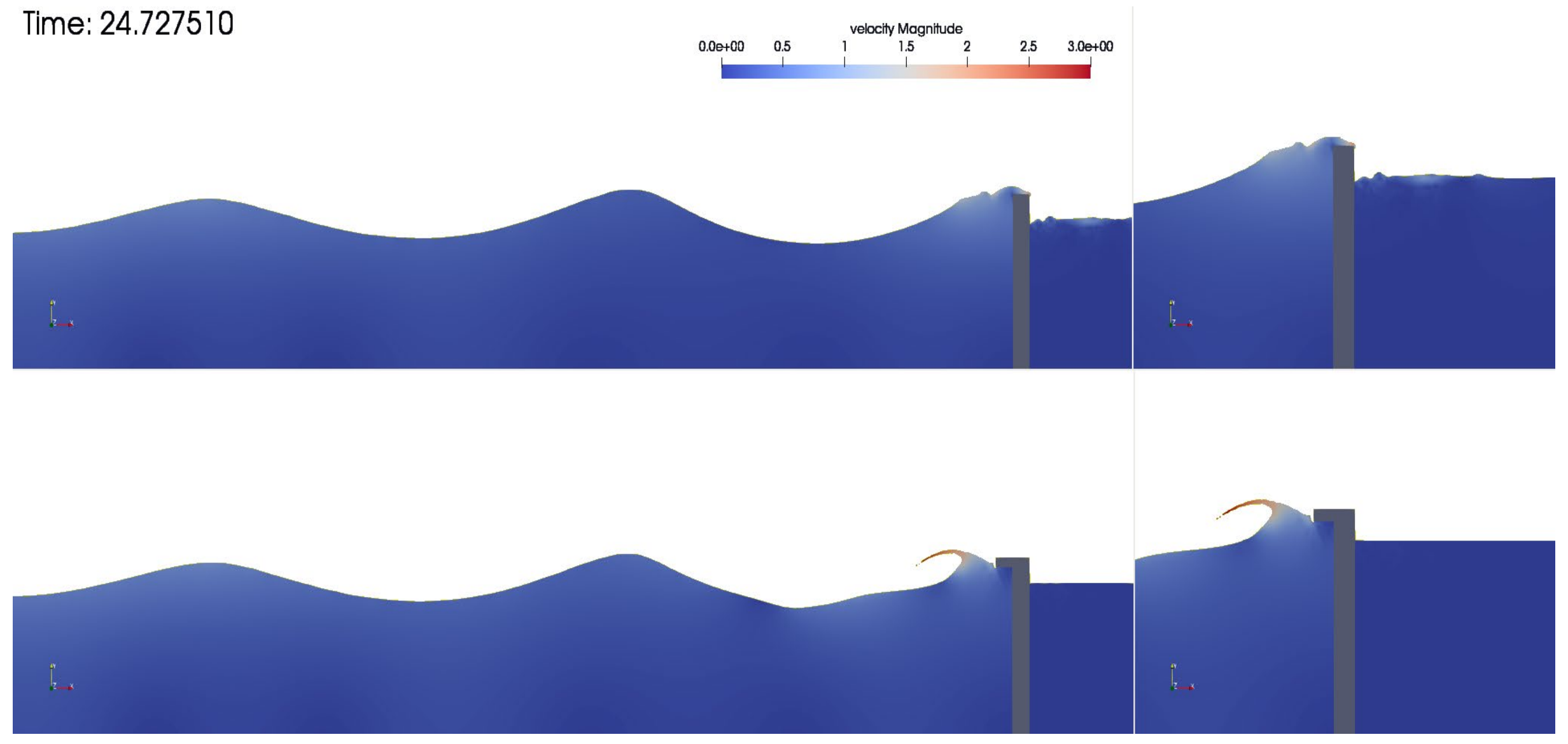


Figure 4.1 Comparative overtopping of WB43 reach: No Action (top), Bull Nose (bottom). Zoomed view (right)

Monochromatic Results for Levee

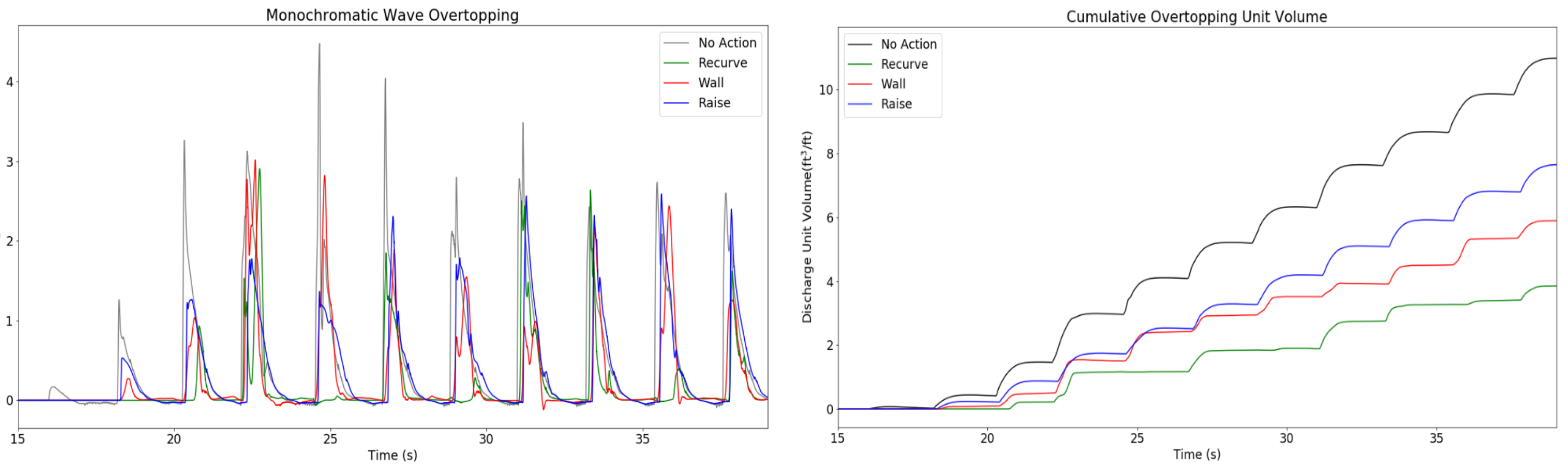


Figure 5.1 Instantaneous discharge rates (left) and cumulative discharge volume (right).

A monochromatic set of 11 waves were simulated with a height of 1.5 ft and a period of 2.2 s. The recurve wall attached at the crown out-performs the standard crown wall and the raise of an equivalent height.

Monochromatic Results for Flood Wall

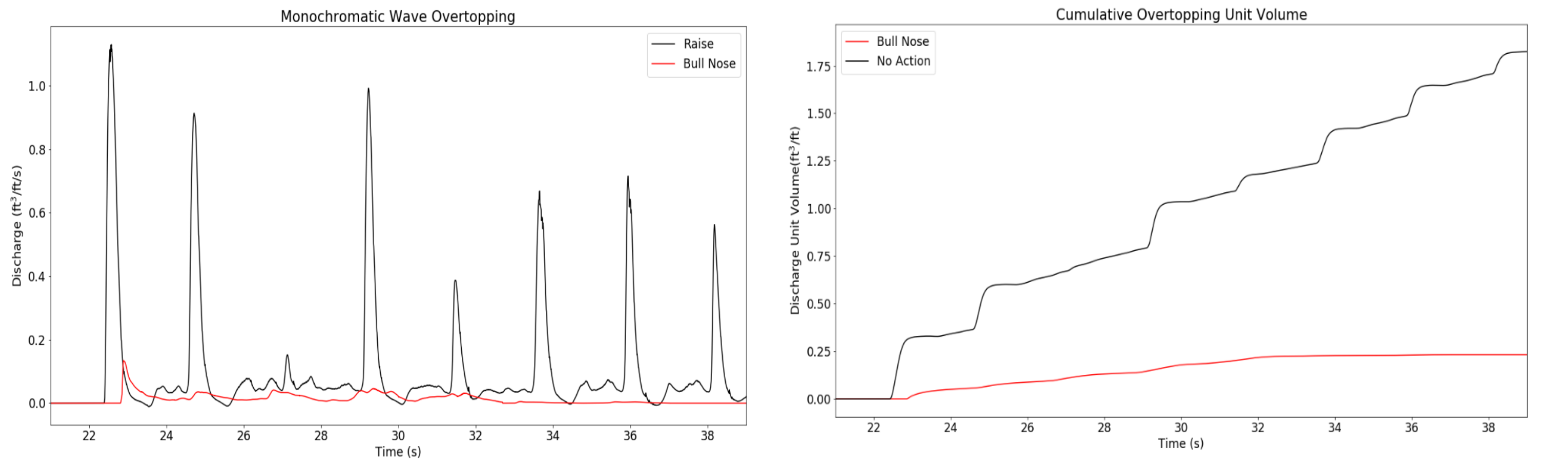


Figure 6.1 Instantaneous discharge rates (left) and cumulative discharge volume (right).

A monochromatic set of 8 waves were simulated with a height of 1.5 ft and a period of 2.2 s. The bull nose attachment significantly improves the efficiency of the standard vertical wall without increasing the crest elevation.

Random Time Series Results for Levee

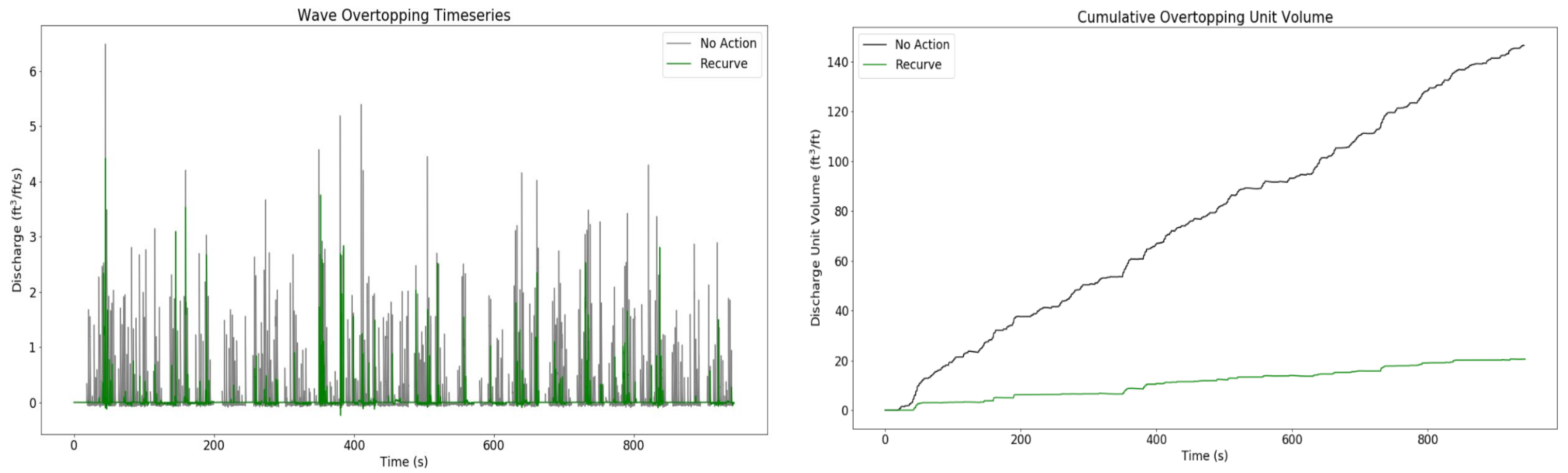


Figure 7.1 Instantaneous discharge rates (left) and cumulative discharge volume (right).

A time series of random waves was generated using the WaveTools.RandomWavesFast[4] class which simulates the sea states produced in storm like conditions. The cumulative overtopping volume was measured for both the no action and recurve scenarios. The modeled overtopping discharge rate was 1.6e-1 ft^3/ft/s for the no action levee; The EurOtop estimate using equation 5.10[3] was 1.9e-1 ft3/ft/s. The recurve wall significantly improves the efficiency, yielding a modeled overtopping discharge rate of 2.2e-2 ft^3/ft/s.

Random Time Series Results for Flood Wall

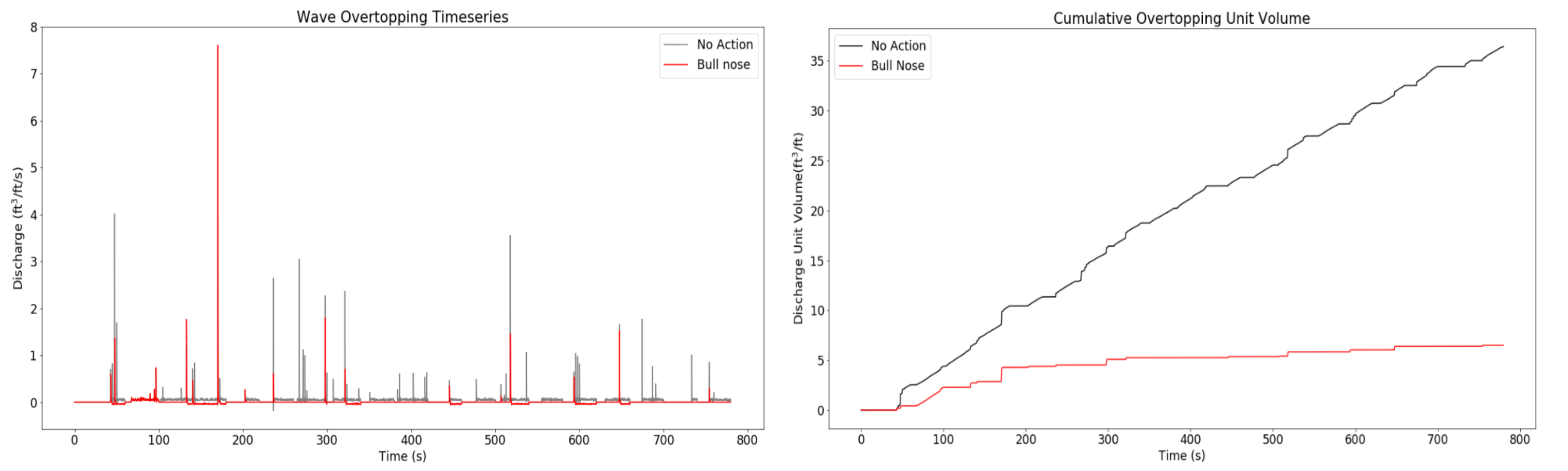


Figure 8.1 Instantaneous discharge rates (left) and cumulative discharge volume (right).

The time series generated from the WB01 simulations was applied for the WB01 flood wall scenarios. The cumulative overtopping volume was measured for both the no action and bull nose scenarios. The modeled overtopping discharge rate was 4.4e-2 ft^3/ft/s for the no action levee; The EurOtop estimate using equation 7.1[3] was 3.9e-2 ft3/ft/s. The addition of the bull nose significantly improves the efficiency, yielding a modeled overtopping discharge rate of 7.6e-3 ft^3/ft/s.

Conclusions and Future Work

1. Evaluating the New Orleans flood defenses with a regional -> local scale modeling approach can assist in improving the efficiency and effectiveness of the system as a whole.
2. Proteus performs well compared to observed experimental overtopping results from the CLASH dataset and EurOtop.
3. In regards to performance as a design tool, Proteus successfully provided a reliable means to compare efficiencies of non-primitive geometric cross sections.

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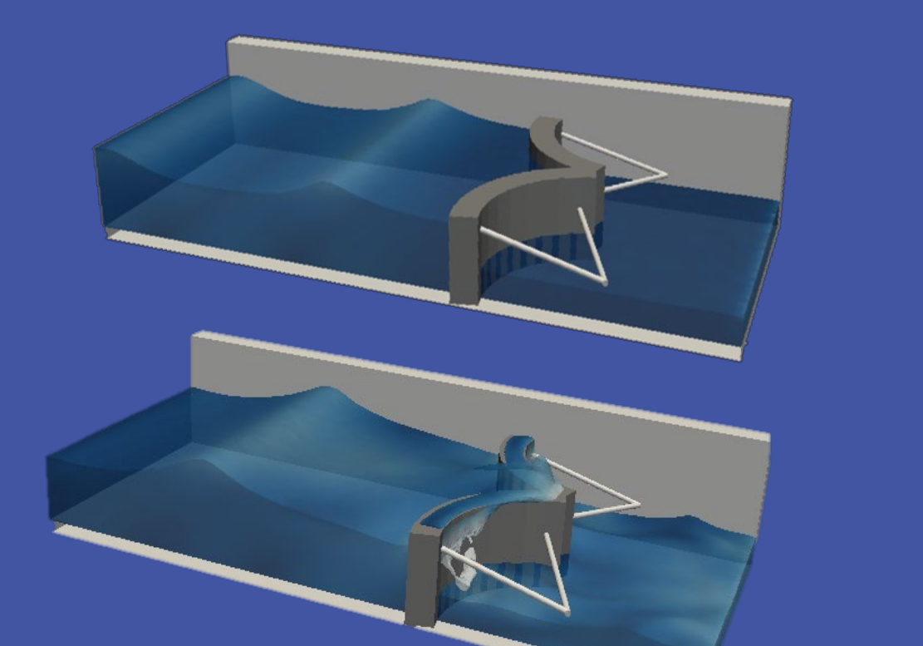
1. Further evaluate the performance of Proteus as a design tool for 3-Dimensional applications.
2. Test and implement ways to reduce computational cost of running full storm event time series using the New Wave theory[8].



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