Evaluation of Substations Vulnerability of Flooding in Current and Climate Change Scenarios

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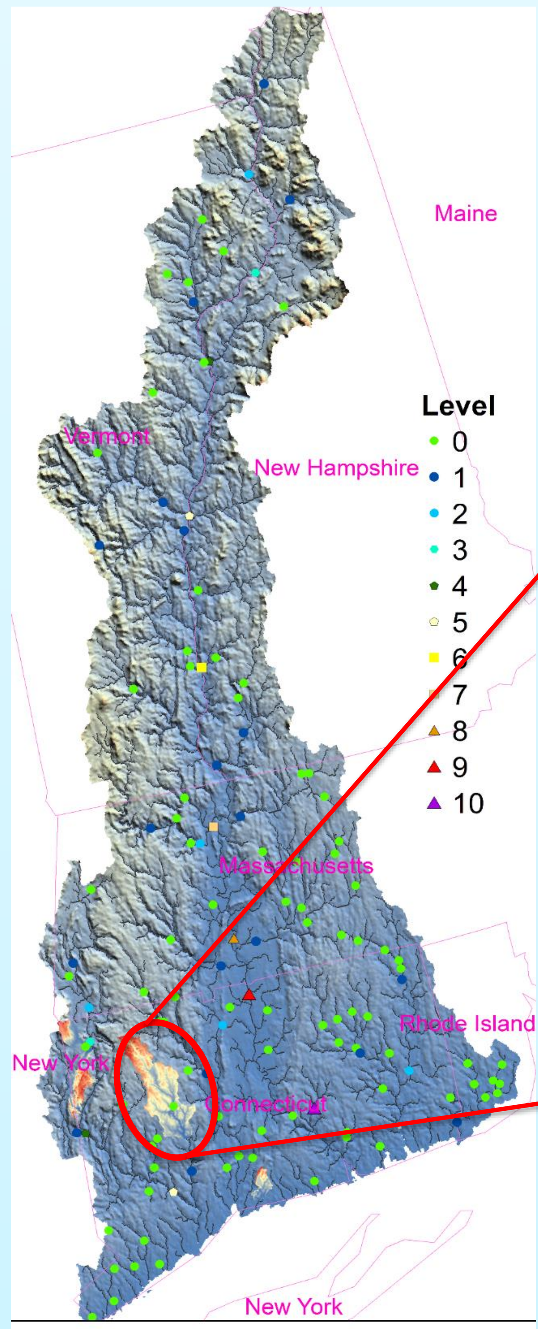
I Abstract

Many utilities have critical infrastructure located within floodplain areas that are vulnerable to extreme events. Early warning systems have the potential to predict flooding impacts and allow for better emergency response and mitigation efforts. This research topic focuses on estimating flood frequency using long-term hydrological simulations forced by reanalysis meteorological data. The estimated extreme flood events are then ingested into a hydraulic model to: 1) estimate the risk of failure (ROF) of hydraulic structures near substations; 2) evaluate the inundation risk over substation areas during flood events and 3) design management strategies that reduce the ROF of hydraulic structures and inundation risk of substations.



The Housatonic, Connecticut and Thames river basins

II Problem Statement

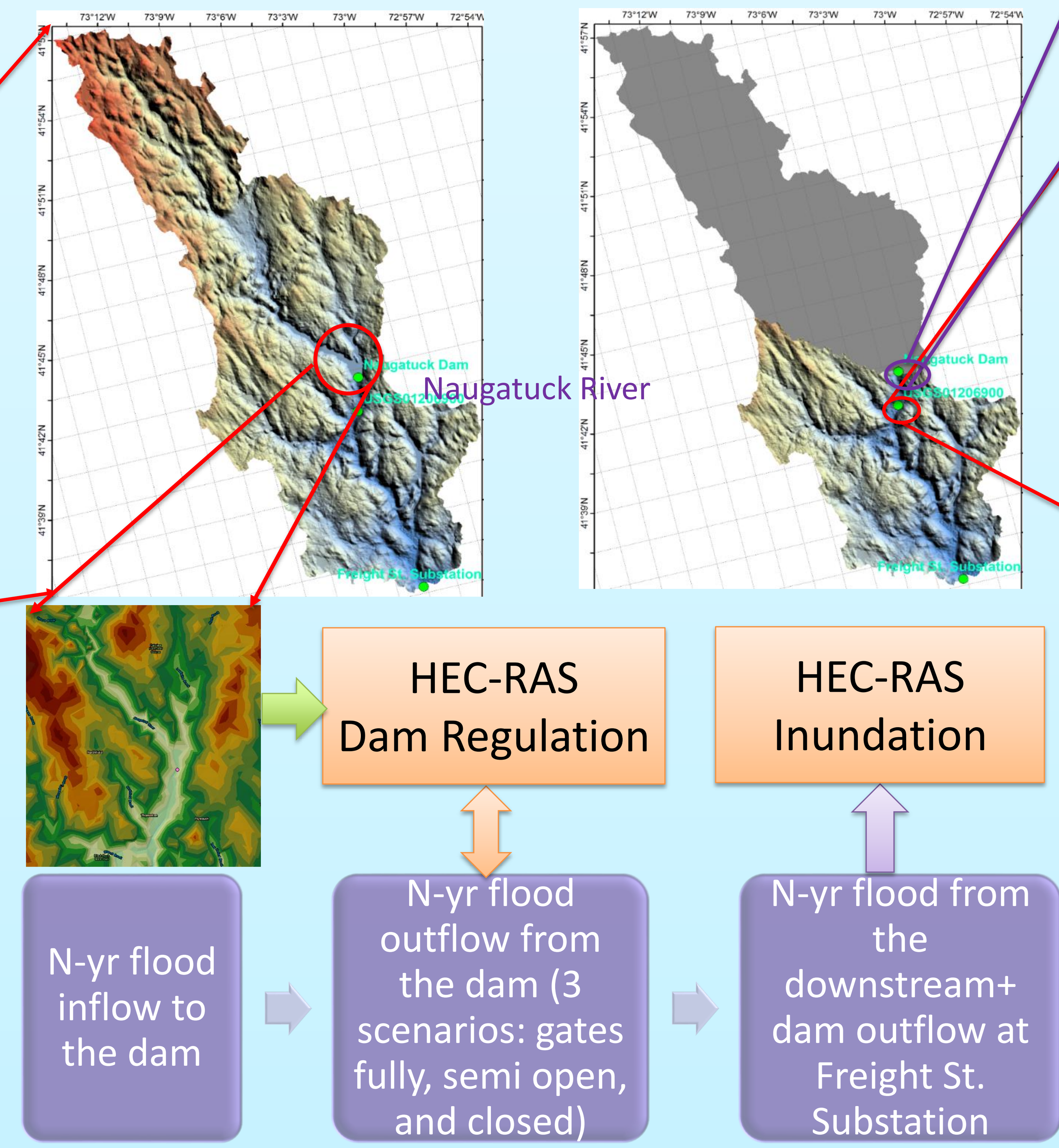
Eversource Energy has substations located within floodplain areas that are vulnerable to extreme events and climate change effects. One of the two substations and associated resilience has been investigated in this study

- Freight St. Substation; Located at 250 Freight St, Waterbury. This substation is bordered on the west by the Naugatuck River. As a result of the great flood of 1955 the Army Core of Engineers have put in place several structures to mitigate flooding in downtown Waterbury. Presently FEMA is stating that this location is not affected by a 100-yr flood event due to the constructed dams. The need is to verify that indeed a 100 or 200-yr flood event would not impact the Evesource substation at this location. The study will account for the Army Core structures that were put in place to minimize the effect of the Naugatuck River flooding in extreme climatic event scenarios such as a cat 3 hurricane. In addition, there is need for evaluating the substation vulnerability to a potential dam breakage.

The major challenge comes from the long distance (~15km) between the Thomaston dam which modulates the upstream flow during floods and the Freight St. substation where critical property and transformers are. To assess the flood risk climate scenario, i.e., flood of 100 and 200-yr return period, long term hydrological simulation over this large drainage is needed which cannot obtainable by a hydrodynamic model. On the other hand, to mapping the inundation risk at the substation with taking the dam alleviation into consideration, a hydrological model cannot work alone too. A framework needs to be reasonably designed to combine the flood frequency analysis (FFA) information over a large area and the detailed hydraulic regulation and inundation simulation kills at high resolution.

II Method

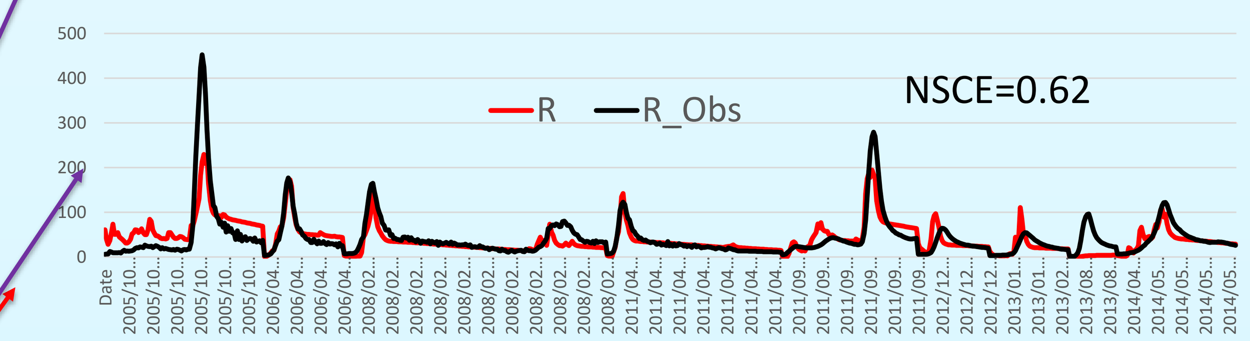
The Framework of combining long-term hydrological and short-term hydraulic modelling skills



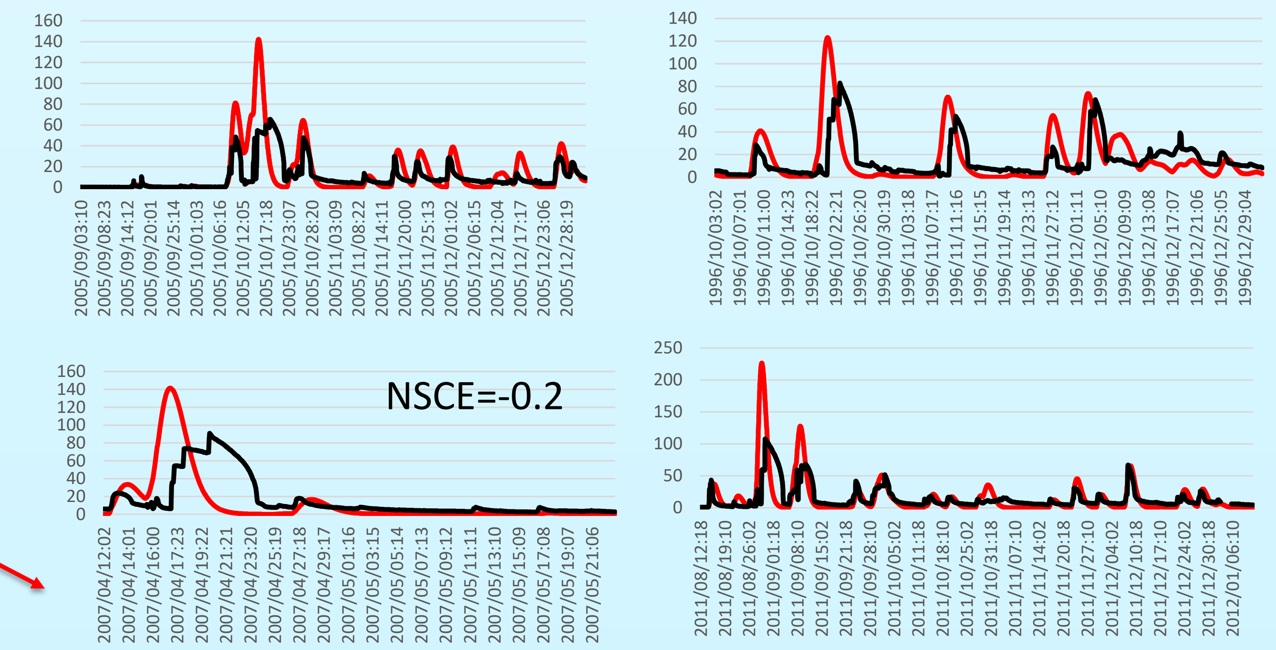
Step A Scalable long term hydrological simulation
Step B Flood frequency estimation
Step C Construction of synthetic event hydrograph of N-yr
Step D Thomaston Dam regulation simulation and ROF assessment
Step E Combination of upstream and downstream hydrograph
Step F Inundation mapping at Freight Street Substation

We developed the CREST-SVAS model (Shen et al., 2016; Shen and Anagnostou, 2017) to compute precipitation-runoff generation are computed at 500 m resolution and the routing at 30 m resolution. The snow accumulating and ablation process is accurately taken into consideration as well as the small scale of the basin.

Dam operations significantly reduce and delay the flow peak as shown in the hydrograph of events at USGS 01206900. Such impact must be considered in modelling the substation inundation problem. We carried out steps A-D to account the dam impact. CREST output flow rate at the inlet instead of the outlet of the Thomaston Dam.



Flow rate validation at the inlet of the Thomaston Dam



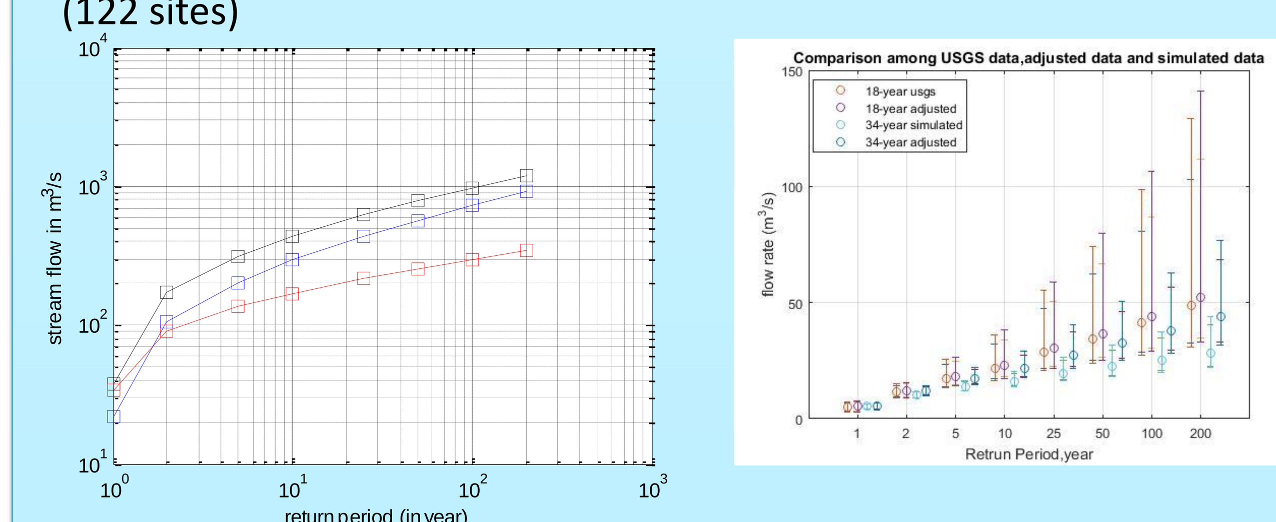
Flow rate validation at USGS 01206900 during 4 events assuming no dam

FFA by Synthesizing Long-term Modelling Skills and Observed Information

The model provides reanalysis-forced long-term simulations that reduce estimation uncertainty of flood frequency Analysis (FFA) compared to short-term USGS hourly streamflow observations. We developed a power-law relationship to remove the bias of peak flows. The power-law relationship is established based on the Q-Q matching between simulation and observation.

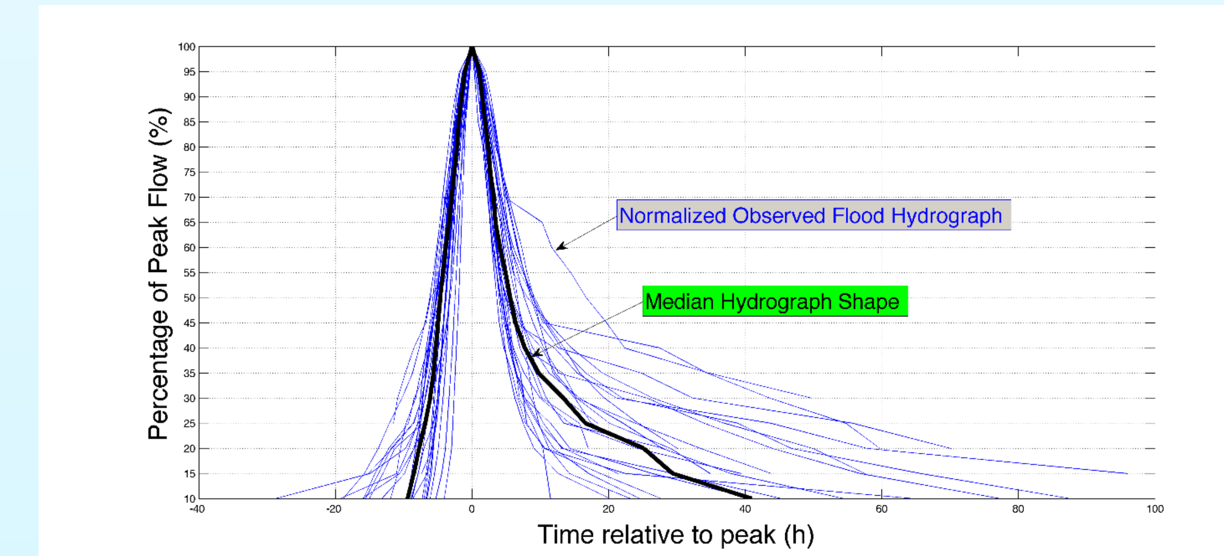
$$Q^{obs}(p\%) = a\left[Q^{sim}(p\%)\right]^b p \geq p_0$$

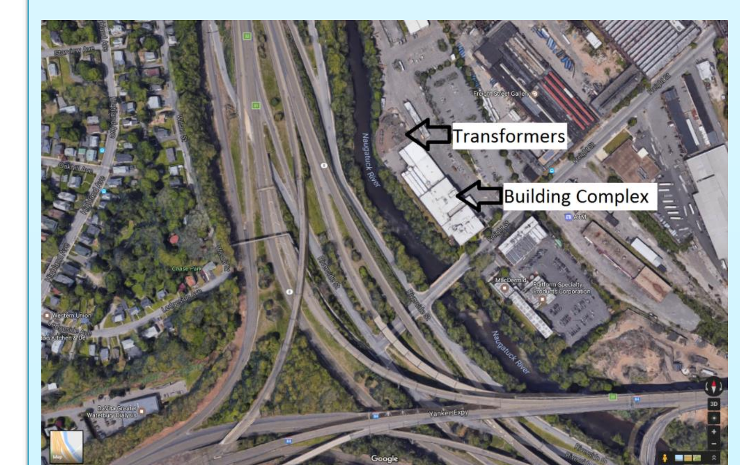
The removal gives unexceptionally high quality FFA results across all (122 sites)

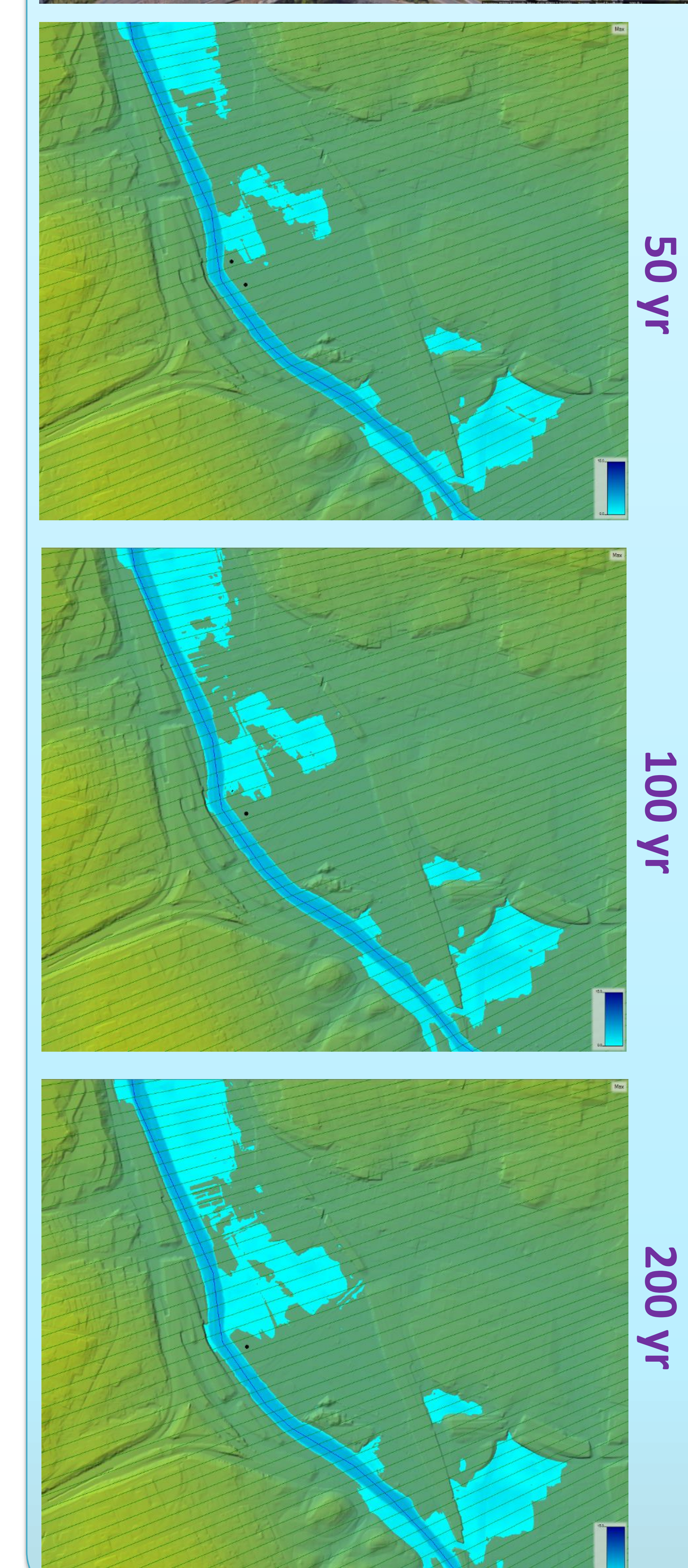


Synthetic event hydrograph

FFA only gives flood peak magnitude info. HEC-RAS needs the entire hydrograph to estimate the dam outflow and inundation of the substation. We employed an novel method (Archer et. al., 2000) to construct synthetic hydrograph of flood events at 50, 100 and 200-yr return period. The methods combines the timing (to and from peak) info averaging from historic events and the peak magnitude from the FFA result.







DAM ROF Estimation

HEC-RAS shows that even at the presence of 200-yr floods, the dam is far from overtopping and breakage.

Inundation Mapping by HEC-RAS

A group of undergraduates participated the hydrodynamic modelling parts of this project as their senior design. They collected the regulation behavior and flow records (available from 2005-2015), and the geometric characteristics of the Thomaston dam. These data are finally used to calibrate CREST-SVAS and run the HEC-RAS to model dam control and inundation at the Freight St. substation during 50, 100, 200yr floods. Three scenarios (gate fully-open, semi-open and fully closed) have been simulated. The left figures gives the most realistic operation according to the records, i.e., semi open during floods.

Acknowledgement

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