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Large discrepancies between event- and response-based compound flood hazard estimates

Sara Santamaria-Aguilar et al.

Correspondence to: Sara Santamaria-Aguilar (sara.santamariaaguilar@ucf.edu)

Table S1. Datasets, authors, and sources of the data used to setup the SFINCS model for Gloucester City (NJ).

Name	Authors	Source
Hydrologic Units	NJDEP Bureau of GIS	https://gisdata-njdep.opendata.arcgis.com/datasets/02599a9424254a4ea33e689941559e3c_17/explore
DEM CoNED	U.S. Geological Survey NOAA	https://www.usgs.gov/special-topics/coastal-national-elevation-database-applications-project/data
Landcover classes	NJDEP Bureau of GIS	https://gisdata-njdep.opendata.arcgis.com/documents/njdep::land-use-land-cover-of-new-jersey-2015-download/about

Table S2. Datasets searched and used for the SFINCS flood model validation.

	Database	Source	Resolution	# Events
1	Global Flood Database	https://global-flood-database.cloudtostreet.ai/#interactive-map	500-250m	1 in 2001
2	USGS HWMs	https://stn.wim.usgs.gov/fev/	Point	None
3	NOAA Storm Events	https://www.ncdc.noaa.gov/stormevents/ Keywords search: Coastal Flood, Flood, Heavy rain, Hurricane, Storm surge/tide, Tropical Storm, Tropical Depression, Winter Storm, Winter weather Region: Camden County	Narrative	None
4	FEMA	Flood Risk Map: https://map1.msc.fema.gov/data/FRP/FRM_Coastal_34007_20170424.pdf?LOC=f509865d8cfc4b3f81267fa59019847d	Point	1 in 2009
5	Local News	https://www.courierpostonline.com/story/news/local/south-jersey/2019/06/20/floodwaters-ruin-artifacts-gloucester-city-historical-society/1514980001/ https://www.courierpostonline.com/story/news/local/south-jersey/2019/06/21/westville-gloucester-city-clean-whats-left-after-flooding/1529203001/	Point	1 in 2019
6	Global Flood Monitor	https://www.globalfloodmonitor.org/ Tweet: https://twitter.com/stormchaser0026/status/1281677885124771840	Point	9 events, 1 with photo
7	MyCoast: New Jersey	https://mycoast.org/nj/high-water	Point	None

8	Local Authorities	Camden County Municipal Utilities Authority (CCMUA) Regional Flooding Study. Phase 1 Final Report. CDM Smith, 2023	Areas, points	6 regions identified as frequently flooded

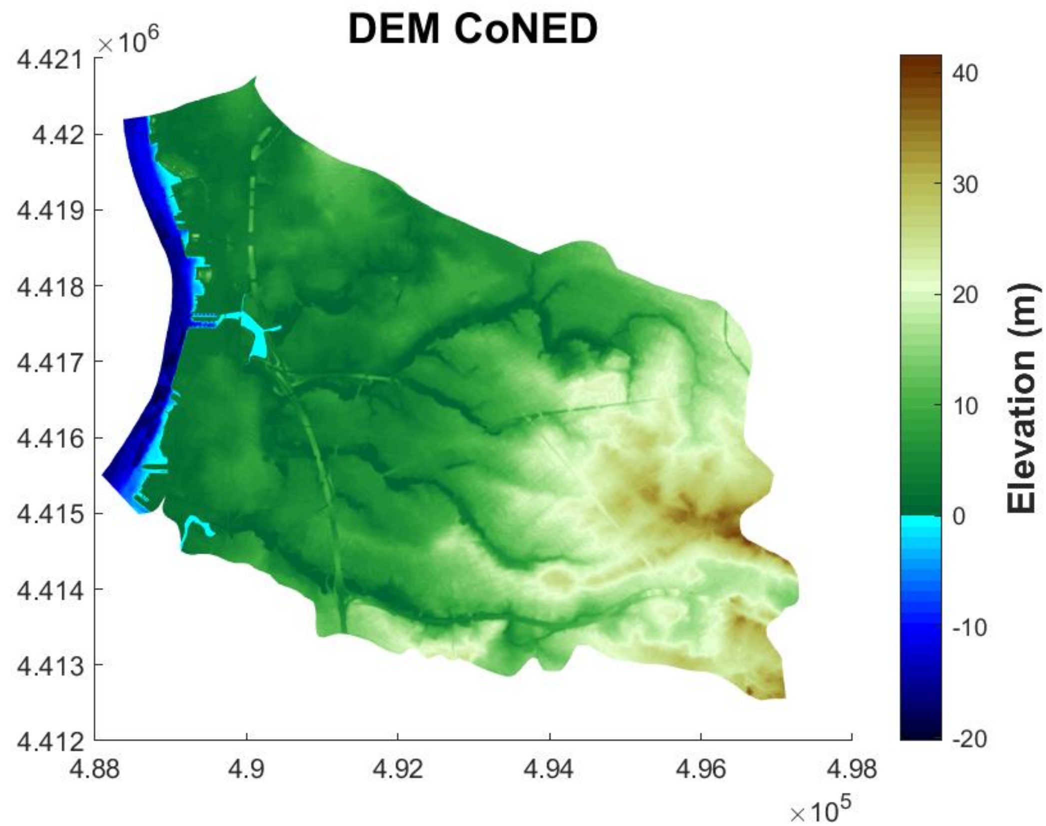


Figure S1 Topobathy from CoNED (NAD83/UTM18N)

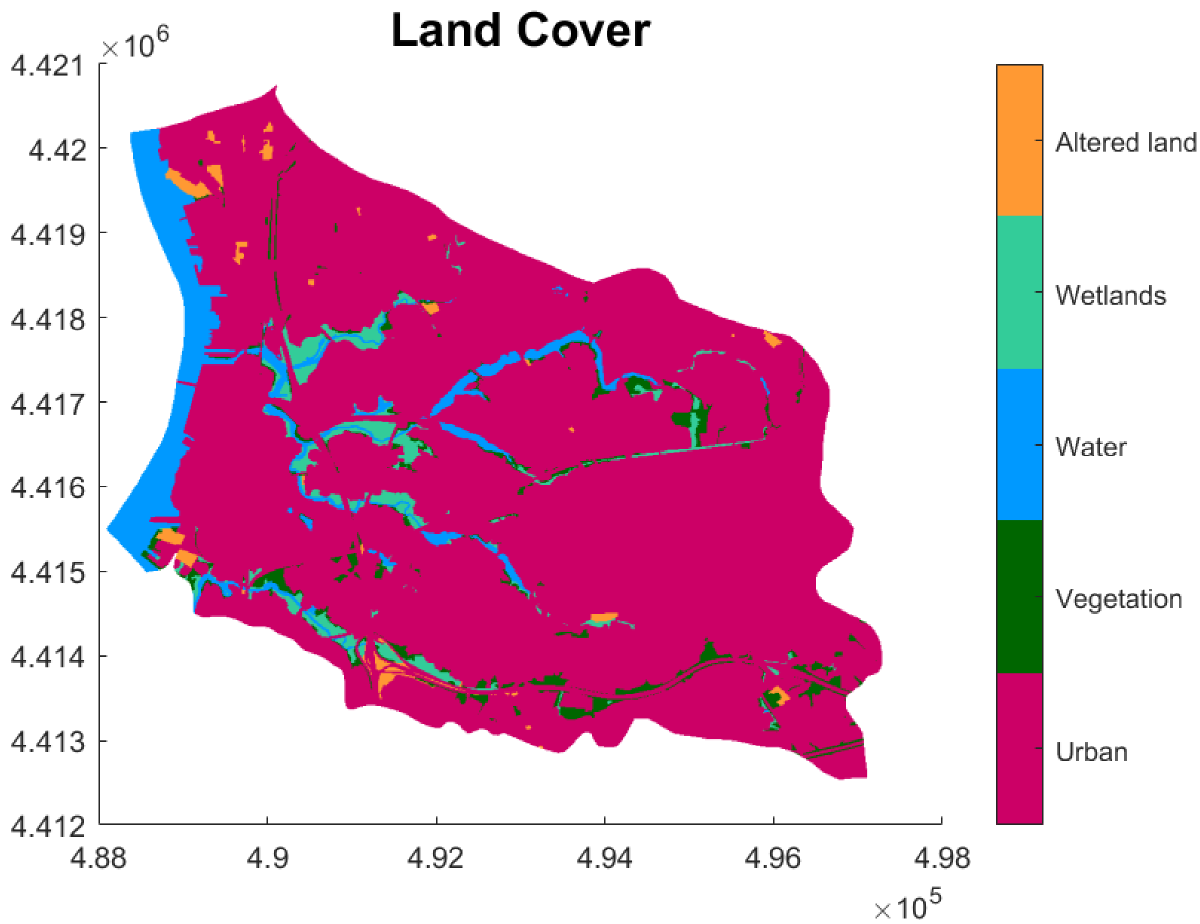


Figure S2 Land Cover of the study site. Note that the land cover classes have been grouped in these main classes for plotting purposes, but the original dataset contains a larger number of classes (NAD83/UTM18N)

Flood Model Validation

Different types of observations can be used to validate and calibrate flood extent and water depths, such as high-water marks and satellite images. In Table S2, we list the different sources we considered in this study to validate the flood model; it shows that little information is available about historical flooding in Gloucester City. Satellite images (or aerial images) are the only type of observed data that can measure the flood extent (Bates, 2004), and although these can be very useful for validating and calibrating large-scale flood models against large flood events (Tellman et al., 2021), for small-scale applications their resolution is too coarse (Table S2, row 1). For validating and calibrating water depth outputs of flood models, high-water marks are commonly used. In the U.S., the U.S. Geological Survey, in partnership with FEMA, is the agency responsible for collecting high-water marks after major flood events (Table S2, row 2). However, no high-water marks from USGS are available for Gloucester City. Another source of flood-related information is the NOAA Storm Event dataset, which documents significant weather events from 1950 onwards. However, no flood events have been recorded for Gloucester City (Table S2, row 3). Comparison against FEMA

Special Flood Hazard Areas (SFHA) has also been used as a measure of flood model performance (Bates et al., 2021). However, we are including pluvial flooding, which is neglected when delineating the FEMA SFHA, and thus the comparison of our 1% AEP flood map to the FEMA SFHA will not provide a suitable measure of model performance. In addition, some studies have pointed to inaccuracies in the 1% AEP FEMA SFHA (Flores et al., 2023; National Academies of Sciences, 2019). Nevertheless, we found useful information for one particular flood in Gloucester City in the Flood Risk Map of FEMA (FEMA, 2016b; Table S2, row 4). This map is paired with a photo of a flooded intersection that is located outside of the SFHA and marked on the map with a star (Fig. S2). This flood happened in 2009, and based on the water level records and precipitation data, the flooding occurred due to a short but heavy rainfall event, with a maximum precipitation of 33.5 mm/h. We simulated this event using two approaches: one neglecting infiltration and another accounting for infiltration based on the Curve Number method included in SFINCS. We find that including infiltration underestimates flooding since the simulation results in no flooding in the intersection where flooding was documented (see Pollack et al., 2024 for further details). This, combined with the highly urbanized nature of the catchment (characterized by extensive impervious surfaces) and the inadequate stormwater system performance reported by the CCMUA, led us to exclude infiltration in the SFINCS model configuration used for all simulations in this study. At the time this study was conducted, the Curve Number method was the most advanced infiltration approach available in SFINCS (the latest release has since added the Green-Ampt method). However, as noted by (Nederhoff et al., (2024), assuming that the initial soil moisture is at 50% of its total capacity can lead to an overestimation of infiltration. Neglecting infiltration, the average water depth resulting from the simulation of that event in the intersection is 36 cm, a value similar to the water depth (approx. height of the curbside) shown in the FEMA Flood Risk Map (FEMA, 2016b; Fig. S21). We also searched for reported flooding in Gloucester City in local news, finding a couple of articles regarding a flood event that occurred in June of 2019 (Table S2, row 5). That event flooded a few areas of the city and led to power outages. In one of the articles, flooding of ~91 cm (3 feet) was reported in the basement of the Historical Society Museum. We simulated this event, finding that our flood model results in flooding of the area where the museum is located with average water depths of 68 cm (2.23 feet).

Since almost no information about historical flood hazards was found in the most commonly used sources, we also considered crowd-sourced platforms such as social media and the citizen science platform MyCoast: New Jersey. Crowd-sourced observed flood data such as photos and geo-localized tweets have been shown to be useful for flood model validation as they often include information about the location of the flood and water depth levels can be extracted from photos (de Bruijn et al., 2019; Wang et al., 2018). We checked the Global Flood Monitor dataset (de Bruijn et al., 2019), which has an algorithm that automatically searches for flood keywords within tweets posted in any location of the world. In this database, we found nine tweets reporting flooding within the region of interest. However, only one of them (which occurred in 2020) contained photos and information about the exact location of the flooding reported (Table S2, row 6). In one of these photos, a traffic barrel is shown in reference to the flooding, which allows us to estimate a flood depth of approx. 60 cm based on standard traffic barrels of 5 sheeting of 15.24 cm each. We simulated that flood event and obtained average water depths of 72 cm around the streets and intersections reported as flooded in the tweet (Fig. S3). The citizen science platform MyCoast (Table S2, row 7) allows citizens to upload photos of flooding anywhere in New Jersey, but it does not have any photos of flooding in Gloucester City. We also contacted local authorities to obtain any information available about historical floods in Gloucester City. In this context, the Camden County Municipal Utilities Authority (CCMUA) has recently identified flood-prone locations in Gloucester City as part of the first phase of a regional flood study to design flood mitigation measures for the region (Table S2, row 8 and Fig. S4). We compared the 10-year return period flood map to these geo-located regions to evaluate whether these known flood-prone locations experience flooding from events with a relatively short return period. We found that the 10-year return period flood map captures those flood-prone locations well (Fig. S4). Although the limited observed flood data for Gloucester City did not allow for a quantitative flood model validation, we believe that the qualitative validation performed based on the simulation of the events of 2009, 2019, and 2020, together with the evaluation of the known flood-prone regions represented in the 10-year flood hazard map, provides the best possible flood model validation for our study site.

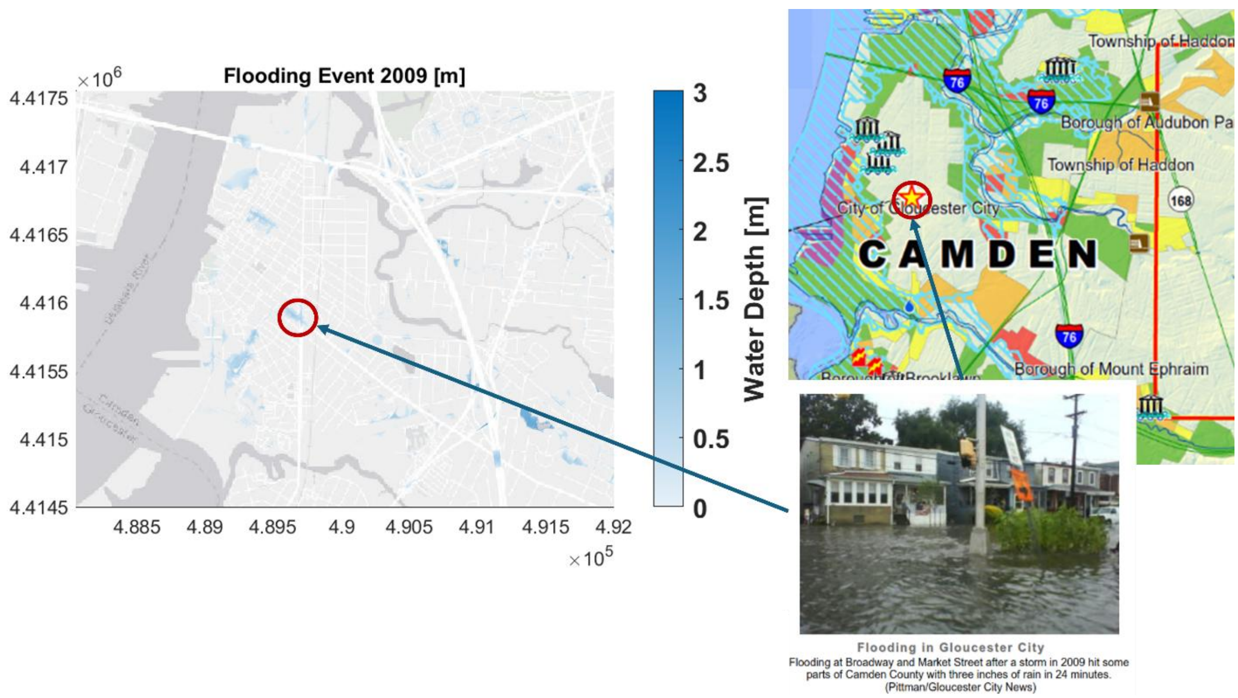


Figure S3. Flood map resulting from the simulation (neglecting infiltration) of the 2009 flood event reported in the FEMA Risk Map. Average water depths of 36cm are estimated for the intersection shown in the photo (red circle). Figure from Pollack et al., (2024). [NAD83/UTM18N. Source: Esri | Powered by Esri]

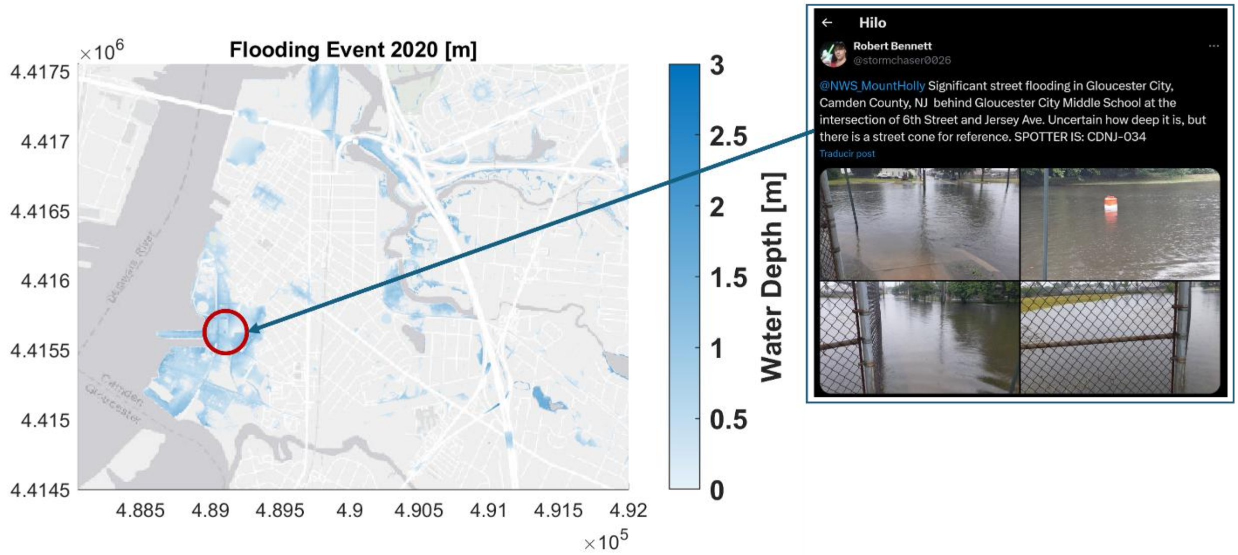


Figure S4. Flooding resulting from the simulation of the flood event in 2020 reported via Twitter and corresponding tweet showing flooding in the region marked with a red circle. Average water depths estimated by the SFINCS model are of 72 cm. Figure from Pollack et al., (2024). [NAD83/UTM18N. Source: Esri | Powered by Esri]

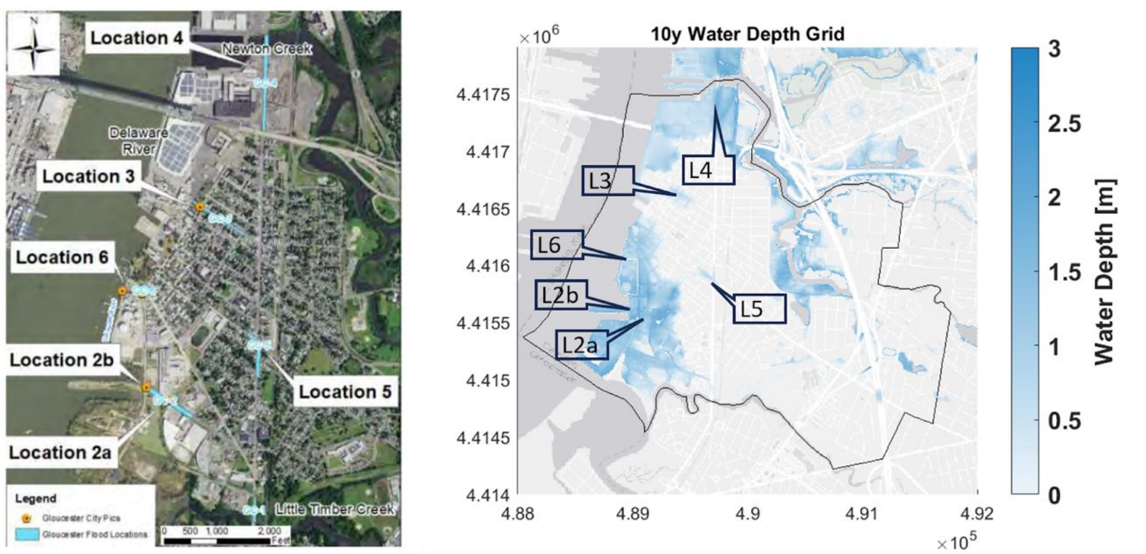
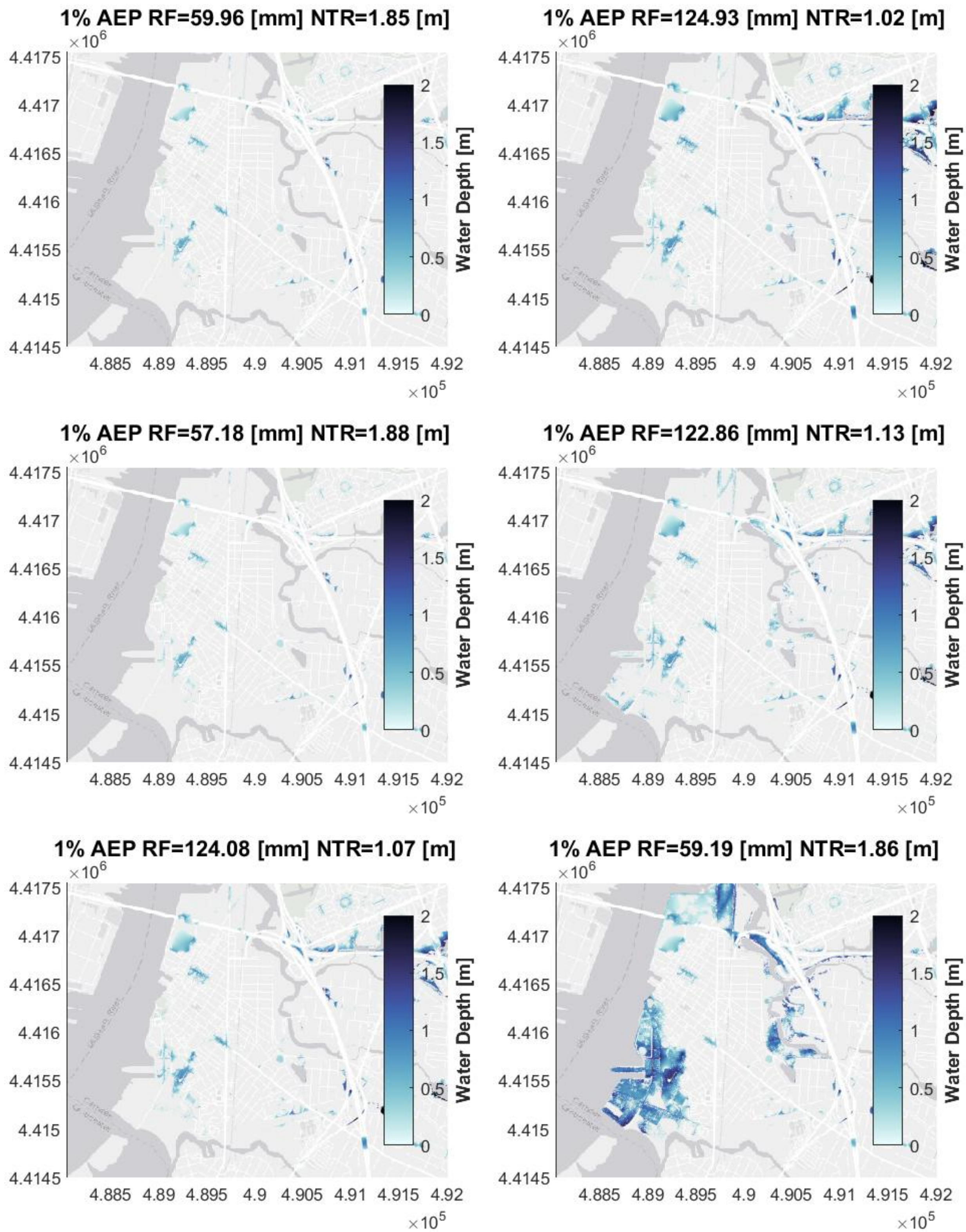


Figure S5. Left panel shows the locations in Gloucester City where flooding is frequently reported by the Camden County Municipal Utilities Authority (CCMUA) (source: Regional Flooding Study. Phase 1 Final Report. CDM Smith, 2023). Right panel shows the water depths from the simulation of the 10- year event, highlighting the flood prone areas identified by CCMUA. Figure from Pollack et al., (2024). [NAD83/UTM18N. Source: Esri | Powered by Esri]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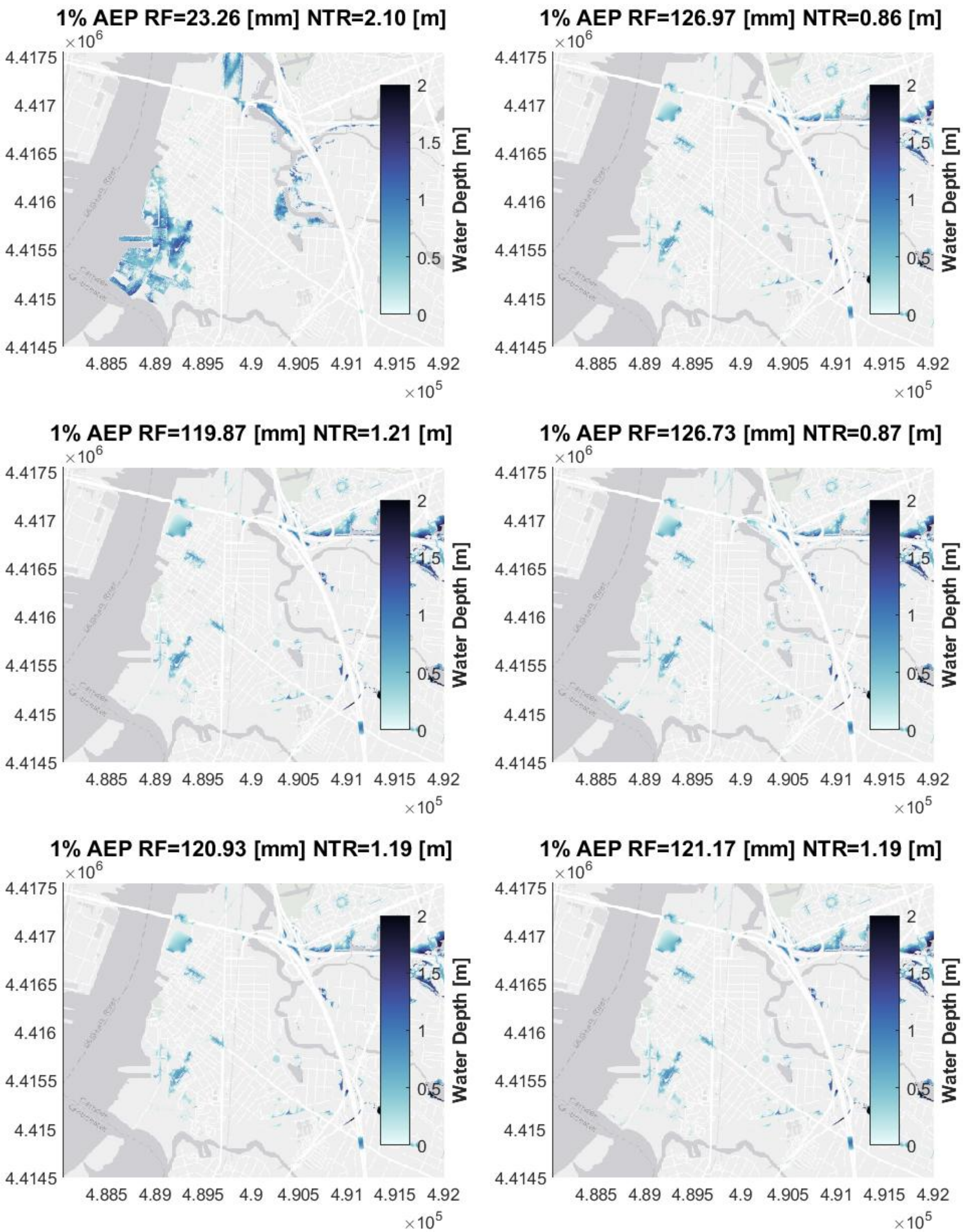
1% AEP RF=124.93 [mm] NTR=1.02 [m]
1% AEP RF=57.18 [mm] NTR=1.88 [m]
1% AEP RF=122.86 [mm] NTR=1.13 [m]
1% AEP RF=124.08 [mm] NTR=1.07 [m]
1% AEP RF=59.19 [mm] NTR=1.86 [m]
×10^6
4.4175
4.417
4.4165
4.416
4.4155
4.415
4.4145
4.885 4.89 4.895 4.9 4.905 4.91 4.915 4.92
×10^5
Water Depth [m]
0
0.5
1
1.5
2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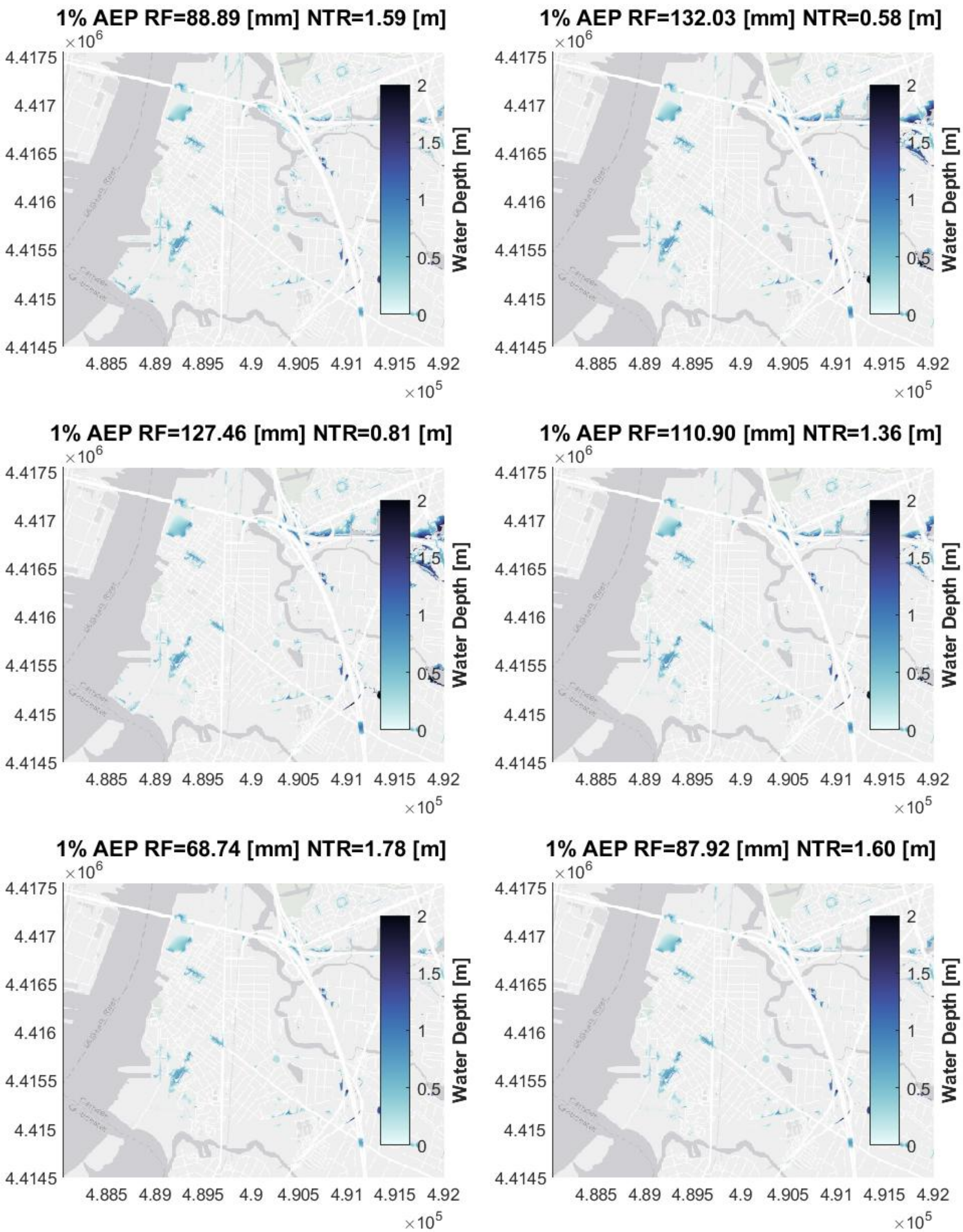
1% AEP RF=120.93 [mm] NTR=1.19 [m]
1% AEP RF=121.17 [mm] NTR=1.19 [m]
×10^6
4.4175
4.417
4.4165
4.416
4.4155
4.415
4.4145
4.885 4.89 4.895 4.9 4.905 4.91 4.915 4.92
×10^5
Water Depth [m]
0
0.5
1
1.5
2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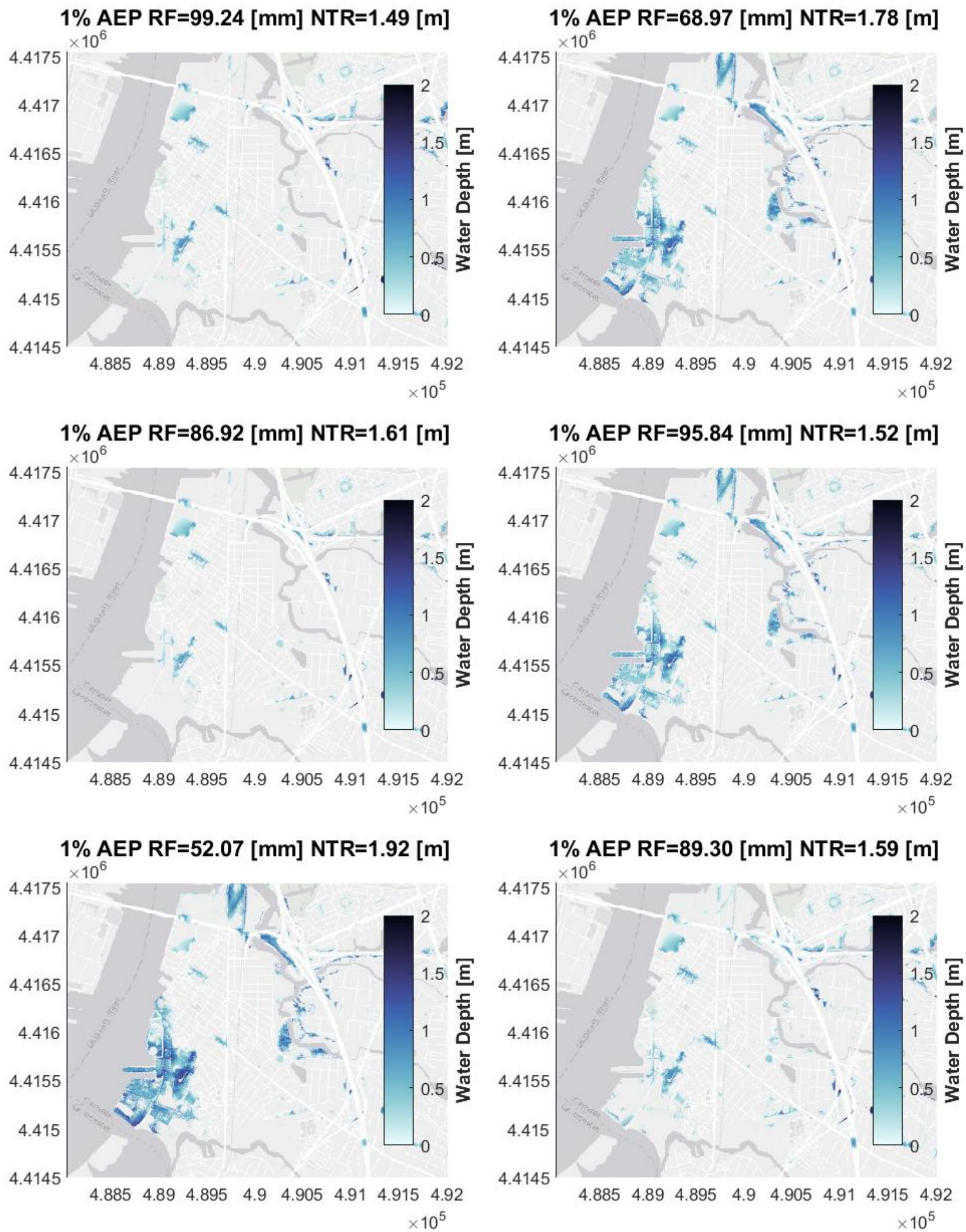
1% AEP RF=87.92 [mm] NTR=1.60 [m]
×10^6
4.4175
4.417
4.4165
4.416
4.4155
4.415
4.4145
4.885
4.89
4.895
4.9
4.905
4.91
4.915
4.92
×10^5
Water Depth [m]
0
0.5
1
1.5
2


1% AEP RF=99.24 [mm] NTR=1.49 [m]
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1% AEP RF=86.92 [mm] NTR=1.61 [m]
1% AEP RF=95.84 [mm] NTR=1.52 [m]
1% AEP RF=52.07 [mm] NTR=1.92 [m]
1% AEP RF=89.30 [mm] NTR=1.59 [m]
Water Depth [m]
0
0.5
1
1.5
2
×10^6
4.4175
4.417
4.4165
4.416
4.4155
4.415
4.4145
4.885
4.89
4.895
4.9
4.905
4.91
4.915
4.92
×10^5

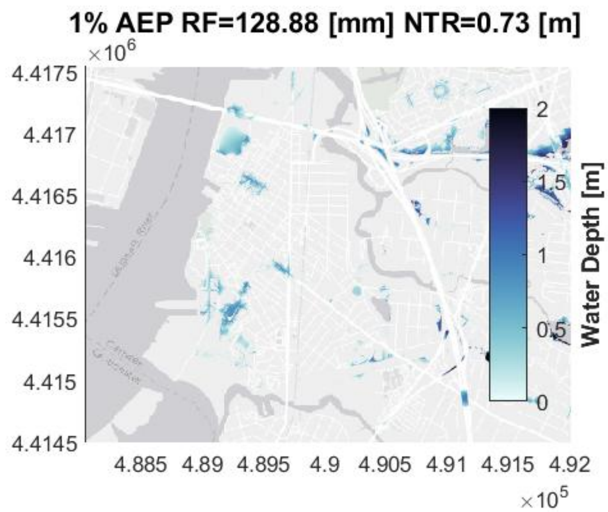

Figure S6. 1% AEP event flood hazard map for all the 1% AEP compound events [NAD83/UTM18N. Source: Esri | Powered by Esri]

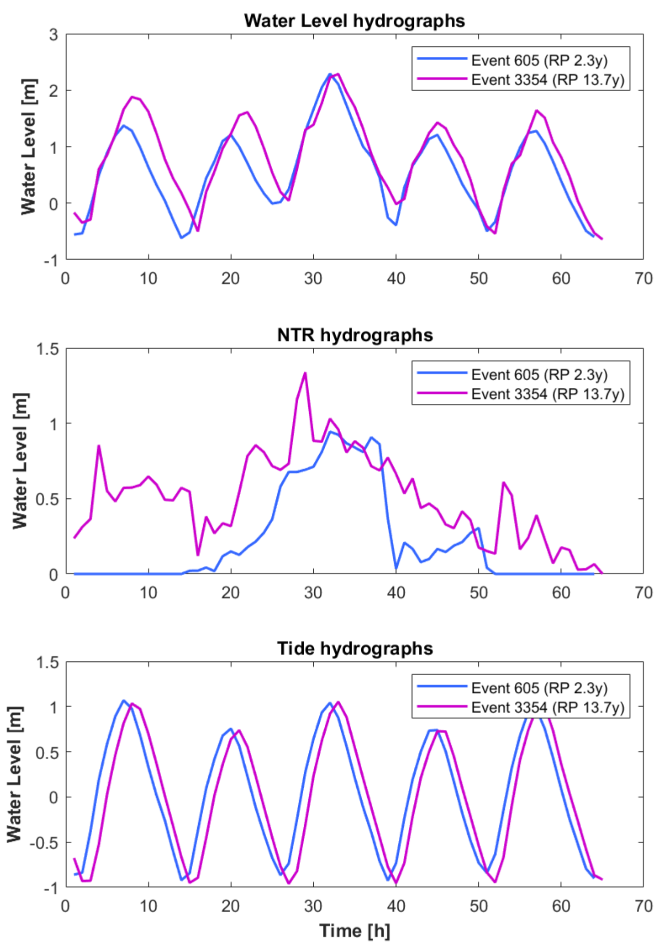

Figure S7. Time series of water levels, NTR, and Tide of the synthetic events that produce the 1% AEP water depth from the response approach.

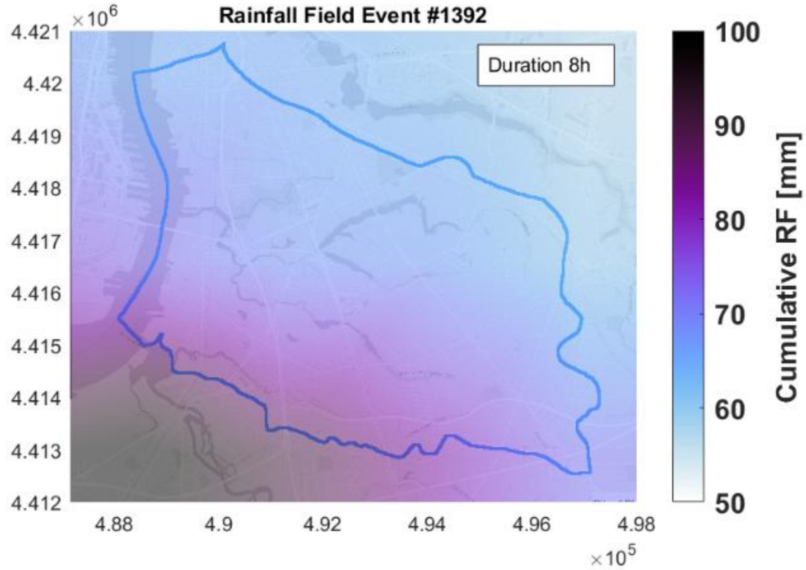

Figure S8. Accumulated rainfall field (over the event duration) of one of the events that produces the 1% AEP water depth in the pluvial hotspots of the study site. The return period of this event is 8.26 years. [NAD83/UTM18N. Source: Esri | Powered by Esri]

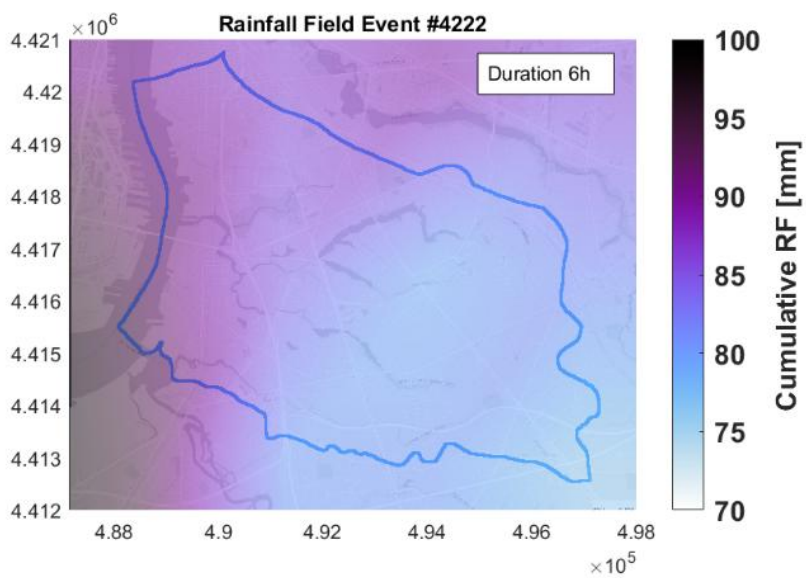

Figure S9. Accumulated rainfall field (over the event duration) of the other event that produces the 1% AEP water depth in the pluvial hotspots of the study site. The return period of this event is 8.85 years. [NAD83/UTM18N. Source: Esri | Powered by Esri]