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Current and future rainfall-driven flood risk from hurricanes in Puerto Rico under 1.5 and 2 °C climate change

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Supplement

Contents

Text S1

Table S1

Figures S1-S2

Introduction

In this Supporting Information file, further information on the assessment of the High Water Mark (HWM) data is provided in accompaniment to Section 2.4 and 3.1.

Additional Description of the High Water Mark Selection – Text S1

The LiDAR 1m ground elevation, plus the USGS-measured flood water depth for each HWM were taken to calculate the observed water surface elevation. The original USGS-measured HWM ground elevation was not used, as on assessment these values were considerably different to the LiDAR heights. One reason for this could be that the dominant method of terrain elevation measurement was handheld GPS or the use of map contours, leading to lower accuracy, although this will not affect the absolute water depths. The original USGS-measured HWM height was converted to metres and to the EGM96 geoid to match the flood model datum using VDatum.

When all riverine HWMs (n=149) were included in the analysis comparing all events with the HWMs, there were 24 (16%) extreme outliers (>+-4m) identified across the four climate models. Two main reasons for this were found on inspection of the satellite imagery and the 1m and 20m LiDAR elevations at each HWM location. The satellite imagery used was (ESRI, 2023) (ArcGIS/World Imagery) at 0.5m resolution, as this was readily available for comparison with the HWMs in GIS applications. First, as a result of LiDAR resampling from 1m to 20m, the elevation of areas which were on the boundary of high/low topographic areas and near riverbeds were aggregated during the resampling. This led to different elevations in the 20m LiDAR compared to the 1m LiDAR and thus an over or under prediction of water surface elevation. If the event set was run again at a finer resolution, model performance at these locations would be likely to improve, as has previously been noted in other studies (Fewtrell et al., 2011; Neal et al., 2009). Secondly, the model both under- and over-predicted water surface elevations compared to the HWMs in areas close to bridges. In some locations bridges had been removed from the LiDAR, whilst other points still had bridges evident in the terrain data. Future analysis could investigate how the inclusion or removal of bridges leads to under or over prediction in the model.

High Water Mark Error Assessment – Table S1

Point ID	Model prediction	HWM ground elevation (m)	LiDAR 1m elevation (m)	LiDAR 20m model elevation (m)	Check against satellite imagery	Reasons for outliers
5	Under	49.52	48.17	46.04	No clear reason	High Water Mark quality marked as 'fair'. Due to DEM resampling, the 20m LiDAR includes higher areas whereas the point is just on the boundary of a higher/lower area.
8	Under	4.71	3.37	3.88	Near river	Due to DEM resampling, the 20m LiDAR includes lower values associated with the riverbed.
9	Under	5.57	5.13	5.48	No clear reason	No clear reason.
27	Under	44.05	53.59	53.57	Near bridge	High Water Mark quality marked as 'fair'. Near bridge.
39	Under and some over	200.21	199.18	198.87	Near bridge and river	High Water Mark quality marked as 'fair'. Near bridge.
52	Over	8.45	6.49	5.35	Near bridge and stream	Due to DEM resampling, the 20m LiDAR includes lower values associated with the riverbed. Near bridge.
57	Over	182.57	180.97	181	No clear reason	High Water Mark quality marked as 'fair'.
59	Over	182.71	181.09	179.6	No clear reason	No clear reason.
62	Over and some under	13.91	12.09	18.36	No clear reason	Due to DEM resampling, the 20m LiDAR includes higher areas whereas the point is just on the boundary of a higher/lower area.

63	Over and some under	13.75	11.40	18.36	No clear reason	Due to DEM resampling, the 20m LiDAR includes higher areas whereas the point is just on the boundary of a higher/lower area.
76	Under	194.54	192.36	192.29	Near bridge and river	High Water Mark quality marked as ‘fair’. Due to DEM resampling, the 20m LiDAR includes lower values associated with the riverbed. Near bridge.
79	Under	12.07	9.67	9.98	No clear reason	HWM elevation higher than LiDAR.
81	Under and some over	12.96	13	14.51	No clear reason	High Water Mark quality marked as ‘poor’. Due to DEM resampling, the 20m LiDAR includes higher areas whereas the point is just on the boundary of a higher/lower area.
83	Over	188.82	187.06	187.59	Near bridge	Near bridge.
84	Under	181.45	179.85	178.48	Close to bridge	High Water Mark quality marked as ‘fair’.
89	Over	150.60	150.12	147.98	Proximity to river.	Due to DEM resampling, the 20m LiDAR includes lower values associated with the riverbed.
115	Under	36	33.72	32.68	No clear reason	No clear reason.
124	Under	14.27	11.59	11.22	Near bridge and river	Near bridge.
125	Under	15.64	13.83	14.53	No clear reason	High Water Mark quality marked as ‘fair’.
129	Over	57.35	56.05	55.71	Near bridge and small stream	Near bridge.
132	Under	10.83	10.14	10.11	Near bridge	Near bridge.
138	Over	61.78	60.93	60.81	Near river	Due to DEM resampling, the 20m LiDAR includes lower values associated with the riverbed.
143	Over	14.23	13.12	13.65	No clear reason	No clear reason.
147	Under	13.29	11.77	12.52	Near pond	Due to DEM resampling, the 20m LiDAR includes lower values associated with the nearby pond.

Table S1. Table showing the outliers with error >+-4m comparing observed High Water Mark water surface elevations for Hurricane Maria with modelled water surface elevations. For each outlier, the elevations of the original USGS ground elevation, and the LiDAR ground elevations at 1m and 20m, are compared. Satellite imagery is also used to identify any features in the surrounding area which may lead to error, such as bridges and other topographical features. For each outlier point, the key reason leading to error is identified and noted in the table.

High Water Mark Locations – Figure S1

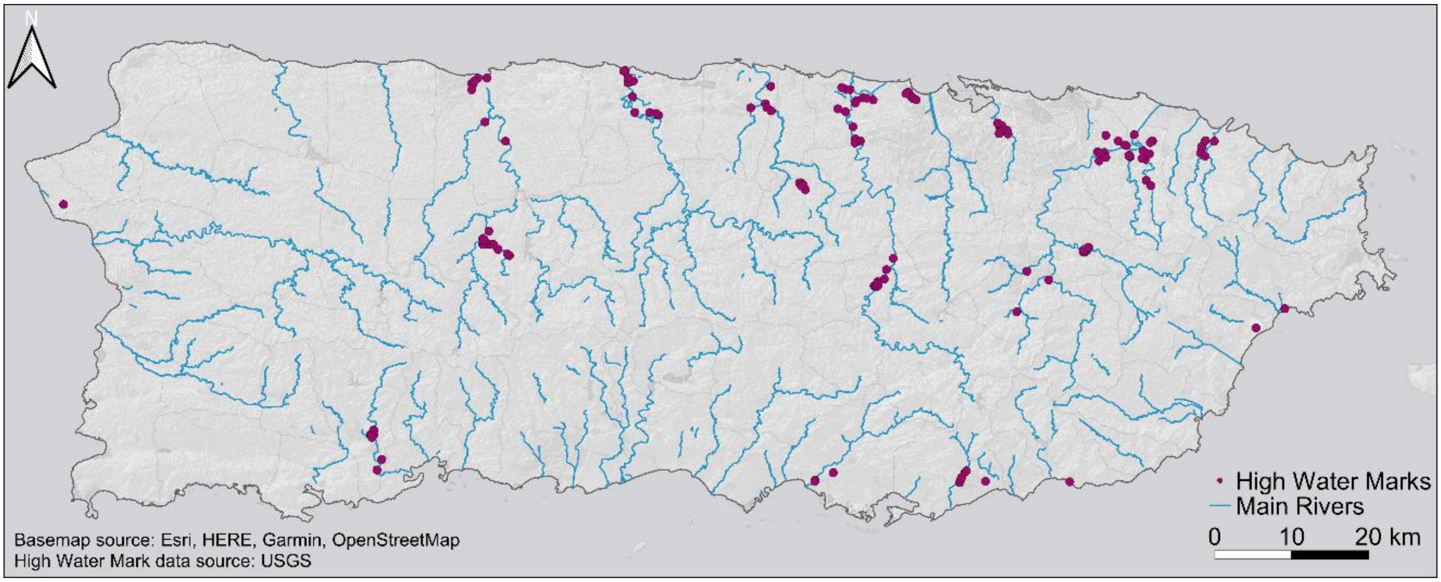

Figure S1. Figure showing the location of all riverine High Water Mark locations associated with Hurricane Maria (n=149), collected by USGS and available here: https://stn.wim.usgs.gov/FEV/#MariaSeptember2017

Hurricane Maria-like Events Track Locations – Figure S2

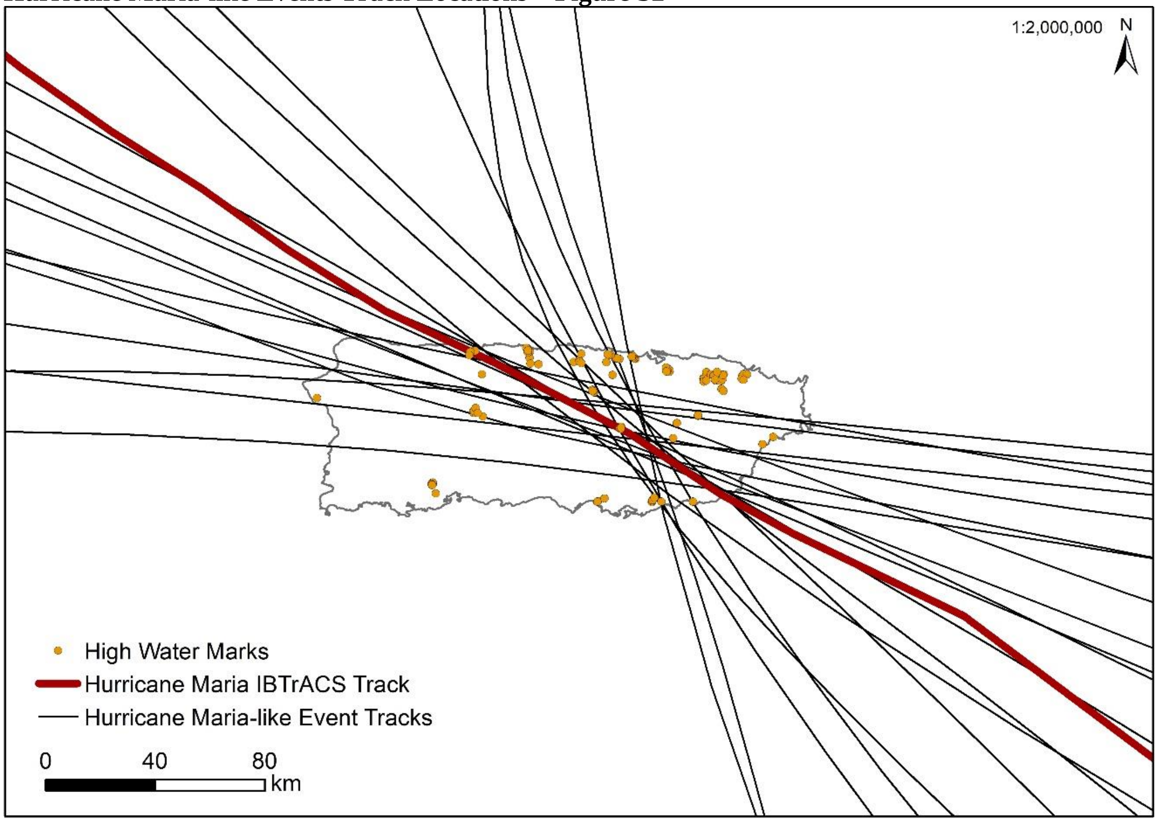

Figure S2. Figure showing the track locations of the events selected as Maria-like in the event set (20 events) in comparison to the Hurricane Maria track from IBTrACS across Puerto Rico. The map also shows the locations of the High Water Marks from Hurricane Maria, which the flood depths in each event are compared to.

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