Rainfall Analysis for the August 5, 2017, New Orleans Flash Flood Event

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ABSTRACT

On the afternoon of 5 August, 2017, a nearly stationary thunderstorm caused flash flooding in portions of the New Orleans, Louisiana, metropolitan area. Rising water resulted in flooding of numerous vehicles, highway underpasses, and the lowest levels of several homes and businesses. Real-time National Weather Service (NWS) rainfall estimates suggested a storm total rainfall maximum of about 6.0 inches (dual-polarization radar method) and about 7.0 inches (official bias-corrected method). Gauge observations collected after the event indicated even higher rainfall amounts; an isolated portion of New Orleans known as Mid-City received over 9.0 inches in a 3-to-6-hr period.

This report presents an analysis of rainfall observations from the New Orleans area and an updated gridded rainfall estimate using all available gauge reports. To begin the process, additional rainfall observations were collected from CoCoRaHS and private weather station networks. These reports were used to bias-correct radar-only rainfall estimates using techniques utilized by NWS River Forecast Centers (RFCs) to produce hourly Quantitative Precipitation Estimate (QPE) grids. This bias-corrected rainfall was then used to run a hydrologic model to compare runoff values to that of other New Orleans flood events. Using the updated rain gauges, it was determined that an isolated portion of New Orleans (Mid-City) experienced 3-hr rainfall greater than the 1-in-100 annual chance. Using the hydrologic model it was determined that runoff from the August 2017 event exceeded that of other events with minimal flood impact, but did not come close to reaching the magnitude produced by the May 1995 flood event.

1.0 Introduction

On the afternoon of 5 August, 2017, a nearly stationary thunderstorm caused flash flooding in portions of the New Orleans metropolitan area. Within a span of only three hours, a small portion of New Orleans' Mid-City neighborhood recorded at least 9-in of rainfall, an event with a less than 1-in-100 chance of occurring in a given year, according to NOAA Atlas 14 (National Weather Service, 2013) from the National Weather Service (NWS) Hydrologic Design Studies Center (HDSC). This significant rainfall event led to numerous roadways becoming flooded to impassable depths, numerous flooded vehicles, and a few flooded structures (Figure 1).

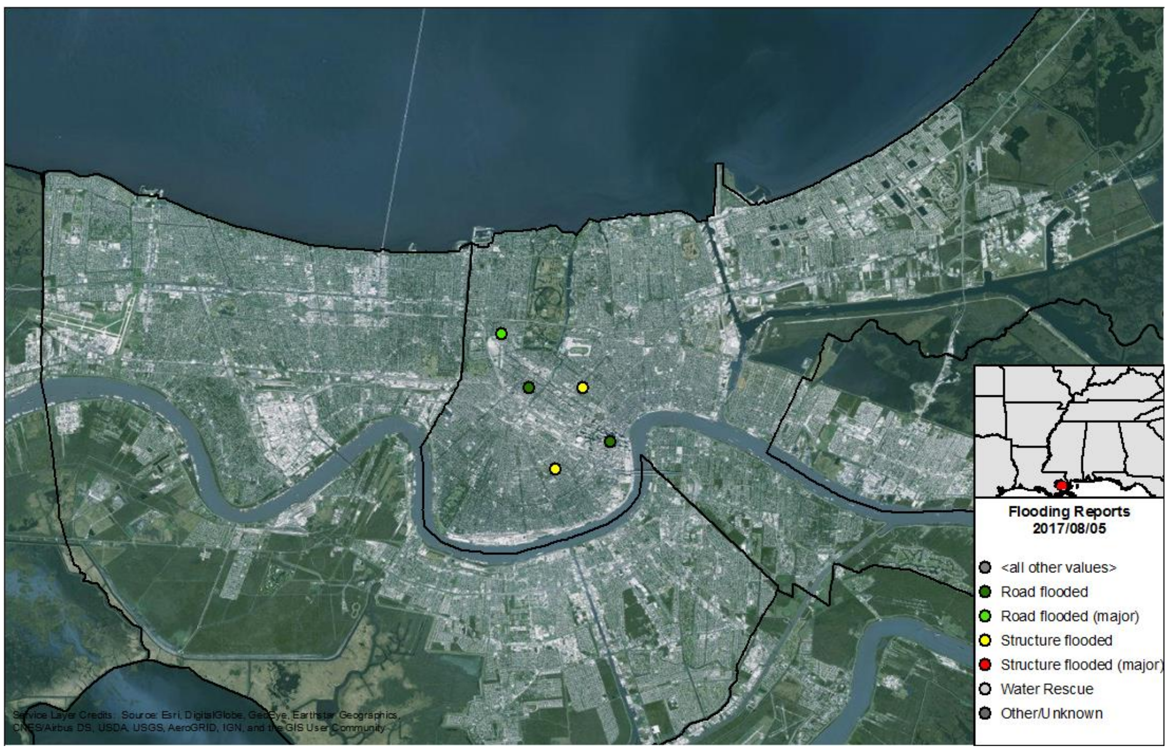

Figure 1. Map of storm reports sent to the NWS (LSRs) for 5 August, 2017, for the New Orleans area. Reports are colored based upon relative severity.

Due to the unique hydrology of New Orleans, all rain that falls on the city must be pumped out if not removed through evaporation (Schlotzhauer & Lincoln, 2016). Unlike natural watersheds which have a downstream outlet, New Orleans consists of several artificial hydrologic areas known as polders; each polder is hydrologically isolated from the others and has no downstream outlet. The main polder, which contains the majority of New Orleans proper including the Central Business District (CBD), has elevations (NAVD88 datum) ranging from less than -10.0 feet to approximately 20.0 feet at the periphery. Rain that falls on these locations moves into a storm drain, then into the underground drainage system where it is conveyed to a pumping station, and then is lifted into an outfall canal connected to Lake Pontchartrain (Figure 2). The drainage and pumping system is operated by the Sewerage and Water Board of New Orleans (SWBNO). SWBNO indicates that the drainage capacity is 1.0-in in the first hour of an event, followed by 0.5-in for each additional hour of rainfall.

The weather pattern of 5 August, 2017, was not particularly indicative of a significant flash flood event. Slow-moving, afternoon thunderstorms are common across the gulf coast during summer. Precipitable water values from upper air observations at the NWS Weather Forecast Office (WFO) New Orleans/Baton Rouge (LIX) located in Slidell, Louisiana, showed atmospheric moisture values above average but not particularly rare. At 1200 UTC, the LIX upper air observation showed a precipitable water value of 2.10 inches. The value ranked between the 75th and 95th percentile for 5 August (Figure 3). The upper air sounding also showed that atmospheric wind fields were weak; without significant winds in the mid and upper levels of the atmosphere, thunderstorms which developed were slow moving. These atmospheric conditions allowed intense rainfall rates to remain nearly stationary over the urban, runoff-conducive landscape of New Orleans for an extended duration of time.

This report presents the results of a re-evaluation of rainfall estimates 5 August, 2017, using additional rainfall data based upon the methodology of Lincoln et al. (2017). The report will present the methodology used and then will present the updated bias-corrected rainfall grid incorporating the higher rainfall observations found in the Mid-City neighborhood. Then, using the model developed for Schlotzhauer and Lincoln (2016), storm runoff sent to the pumping system will be estimated using revised rainfall estimates.

Figure 2. The drainage network of New Orleans. Areas below sea level (the average elevation of Lake Pontchartrain) are shaded in gray. Major underground drainage pipes and canals indicated by dashed blue lines. Approximate contributing areas to each pumping station delineated by dashed black lines. Based upon information from Schlotzhauer & Lincoln (2016).

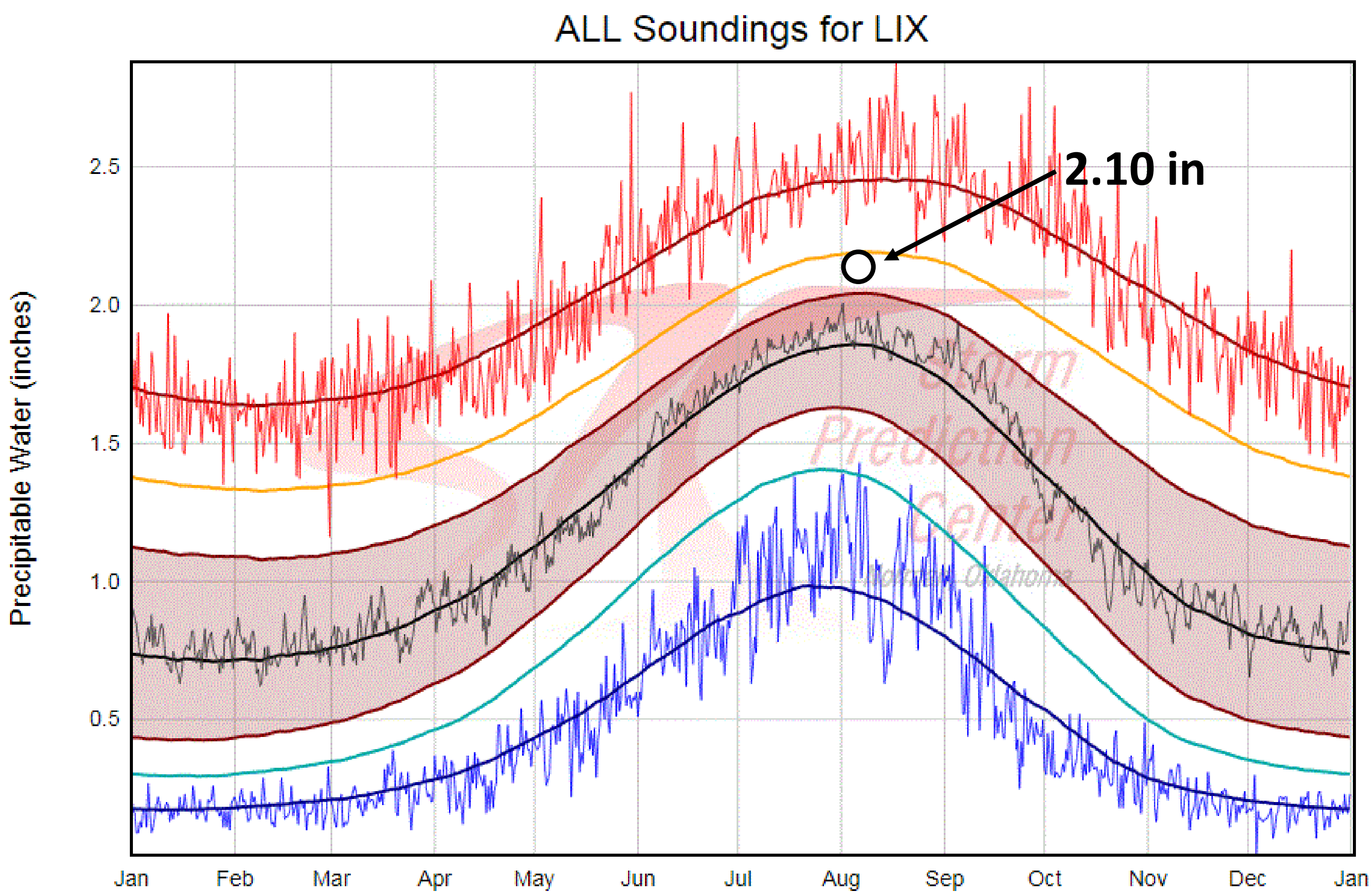

Figure 3. Precipitable water climatology values from soundings at NWS WFO Slidell, Louisiana. Observed precipitable water value for 1200 UTC 5 August 2017 is indicated by the white circle. This precipitable water value was between the 75th and 90th percentile for that day in August.

2.0 Methodology

2.1 Rainfall estimation

To refine the rainfall analysis, additional point rainfall data was collected from multiple sources. Once compiled, the rainfall observations were put through a simple QC technique to remove questionable data. Once verified, these observations were used to bias-correct radar-only rainfall estimates.

2.1.1 POINT RAINFALL DATA

Data obtained from official sources include the Automated Surface Observing System (ASOS; automated stations typically located at airports), NWS/National Oceanic and Atmospheric Administration (NWS/NOAA; manual-reporting daily stations used for NWS climate records), and United States Geological Survey (USGS; automated stations co-located with stream gauges). Data obtained from private sources include Community Collaborative Rain Hail and Snow network (CoCoRaHS; manual-reporting stations monitored by a volunteer observer network), Weather Underground Personal Weather Station network (WU PWS; automated stations of varying quality and reliability operated by private persons), and GroundTruth (formerly known as Earth Networks and AWS) WeatherBug (WB; automated stations of varying quality and reliability operated by private persons).

2.1.2 GRIDDED RAINFALL DATA

Raw gridded rainfall estimates for this reanalysis were the radar-only estimates obtained from the National Severe Storms Laboratory (NSSL) Multi-Radar Multi-Sensor (MRMS) system. MRMS creates a national mosaic of radar reflectivity by seamlessly mosaicking all NWS radars across the country. Hourly MRMS data was retrieved from the Iowa Environmental Mesonet's rainfall archive (www.mesnet.argron.iastate.edu/rainfall). These hourly estimates were then accumulated from 1800 UTC 5 August through 0000 UTC 6 August to provide a 6-hr storm total. The MRMS radar rainfall estimates were then bias corrected against the point rainfall data.

To complete the rainfall reanalysis, this 6-hr MRMS radar rainfall estimate was then bias corrected using the verified point rainfall data. The bias correction technique is very similar to the process utilized operationally by the NWS RFCs. For each gauge location, the bias correction factor was calculated by dividing the gauge value by the raw radar rainfall estimate. These bias correction factor point values were then interpolated to a bias correction grid using the kriging method. The kriging method assumed an exponential relationship between distance from observation and bias correction factor. As a final step, the radar rainfall estimate is then multiplied by the bias correction grid to produce a bias-corrected rainfall estimate.

2.1.3 GRIDDED RAINFALL DATA

To determine the annula exceedance probability, or AEP, the 6-hr bias-corrected rainfall was then compared to rainfall frequency data from NOAA Atlas 14 (National Weather Service, 2013). The AEP is equal to one divided by the average recurrence interval (ARI). The

AEP provides a climatological context for a particular rainfall event. Because the same amount of rainfall may be more or less common depending on the location where it occurs, determining the AEP provides a way of estimating the rainfall severity based upon local climatology.

2.2 Hydrologic modeling

This study used the methodology outlined in Schlotzhauer & Lincoln (2016) where the authors created a hydrologic model to estimate what portion of rainfall during Hurricane Isaac infiltrated into the soil and what portion became runoff sent to the pumping stations. The model developed for that study was used to estimate the amount of runoff generated by the 5 August, 2017, event as well as several other events of different magnitudes. The chosen events included a major flood event (May 1995), a null event (Hurricane Isaac, August 2012), and a marginal flood event (July 2017). The May 1995 rainfall event was one of the largest non-tropical rainfall events in New Orleans history and led to major, widespread flooding impacts (Lincoln, 2014; Ricks, et al., 1997). More recent events such as Hurricane Isaac and rains from a summer thunderstorm on 22 July, 2017, each caused minimal flood impacts. To perform the model analysis, hourly rainfall data for each event was averaged by SWBNO drainage basin (Figure 2) to create a basin-averaged time series. Model infiltration parameters were kept the same as in Schlotzhauer & Lincoln (2016). Pumping records were available from SWBNO for the August 2012, July 2017, and August 2017 events. It is hypothesized that modeling results for each of these events may illustrate differences which could be used to better characterize future flood events as they develop.

The analysis by Schlotzhauer & Lincoln (2016) provided the average flow rate capacity (approximately 20,000 cfs) of all of the pumps combined in the main polder of the city (also known as the "nominal" pumping capacity) based upon a post-Katrina analysis of the pumping system by the Interagency Performance Evaluation Task Force, or IPET (2006). Pump capacity does vary, however, based upon the vertical distance water is being pumped, ranging from approximately 13,000 cfs to 23,000 cfs. Another consideration is that capacity values also assume that water is not impeded in movement to the pumping stations. This assumption is an important one and one that is likely not entirely accurate due to the finding in Schlotzhauer & Lincoln (2016) of the pumping capacity rarely being fully utilized even though pumping stations were working as expected.

3.0 Results and Discussion

3.1 Point rainfall observations

Approximately 39 rain gauge reports were collected. Of these, 4 came from official sources (which would have been available to NWS warning forecasters in real time) and 35 came from private observers (Table 1). The heaviest rainfall generally fell between official gauge locations (Figure 4). Numerous private rainfall observations were higher than official observations.

Table 1. Gauge data collected for this analysis. The rainfall observations collected for this analysis include official gauges (ASOS and USGS), and private weather observations (CoCoRaHS, WB, and WU PWS).

	Observations Collected for This Analysis
ASOS	3
USGS	1
CoCoRaHS	3
WB	12
WU PWS	20
TOTAL	39

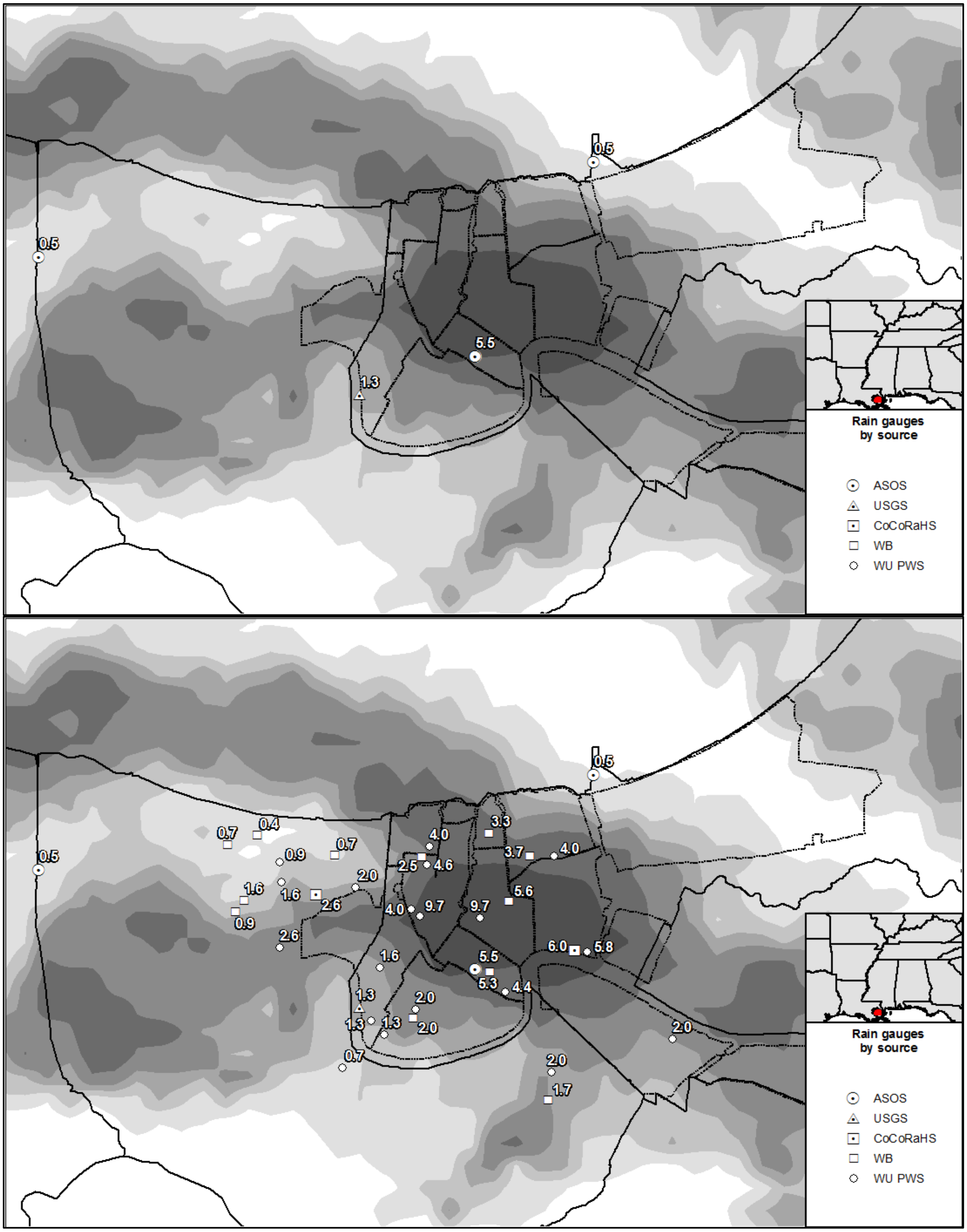

Figure 4. Rainfall reports collected from official sources only (top) and a combination of official sources, CoCoRaHS reports, and private weather station networks. Relative rainfall totals are indicated with gray shading. The area of heaviest rainfall generally occurred between official reporting stations.

3.2 Radar rainfall estimates

Although this reanalysis utilizes radar-derived rainfall data obtained through MRMS, real-time radar-derived rainfall estimates were available to warning forecasters from the KLIX WSR-88D radar station located northeast of New Orleans in Slidell, Louisiana. Radar-derived rainfall estimates are beneficial because they are available almost immediately. However the trade-off for their near real-time availability is that the estimates do not benefit from the bias correction processes using point observations. For the 5 August event, radar-derived rainfall estimates using the dual polarization algorithm were substantially higher (and closer to gauge values) than the legacy algorithm. The MRMS estimates were also similar to the dual-polarization estimates. A comparison of the three different radar rainfall estimates is shown by Figure 5. All three of these estimation algorithms indicated a rainfall maximum near the Mid-City neighborhood of New Orleans, just northwest of the CBD.

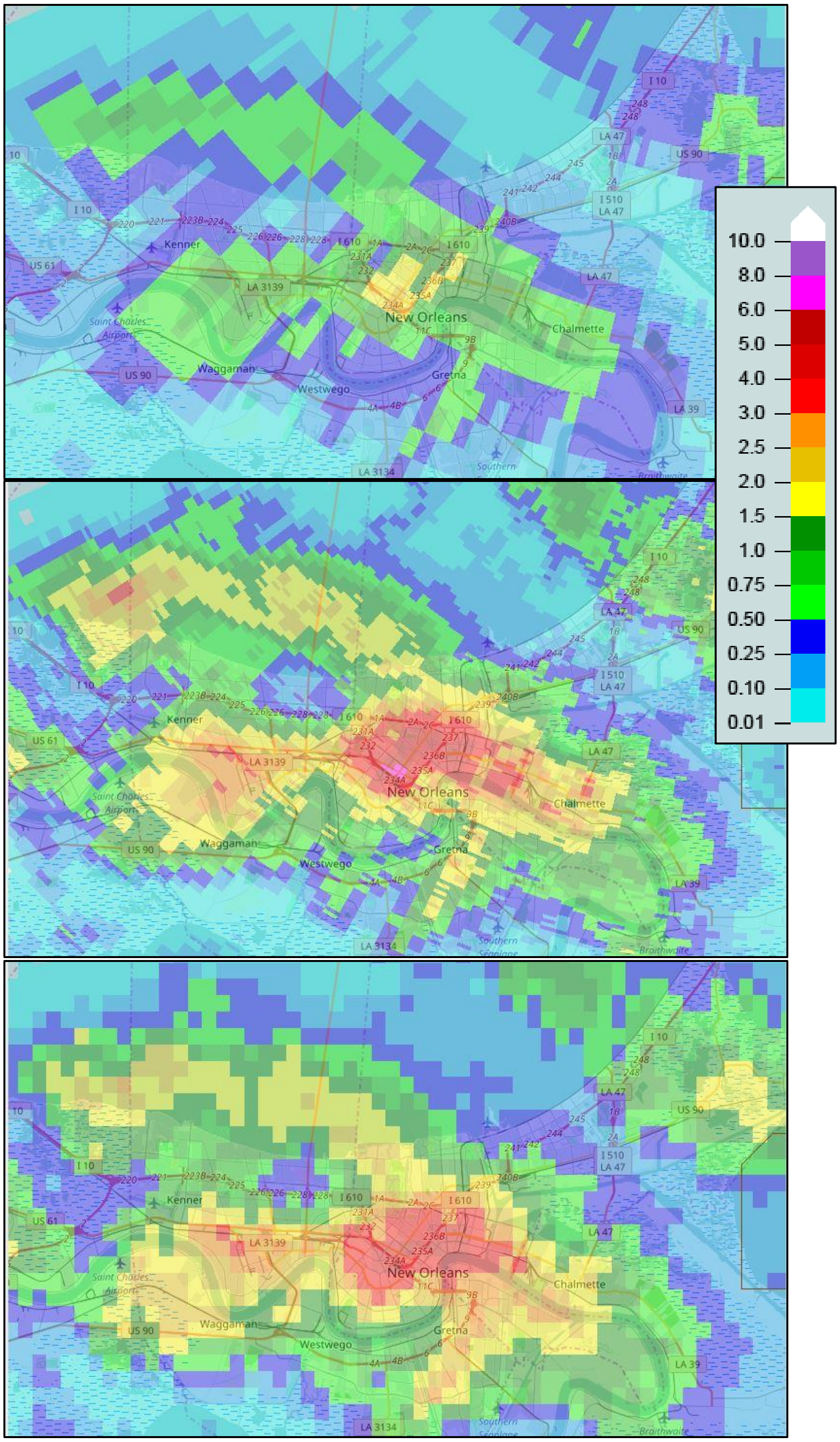

Figure 5. Raw radar-derived rainfall estimates from KLIX NEXRAD using the legacy rainfall algorithm (top) and the dual-polarization algorithm (middle), along with the multi-radar mosaicked rainfall estimates from MRMS (bottom).

3.3 Bias-corrected radar rainfall estimates

Utilizing bias correction, it was found that raw radar rainfall estimates were too low for most portions of New Orleans (Figure 6). For a few areas west of the CBD and into the suburbs of Metairie and Kenner, raw radar rainfall estimates were too high. For areas with the largest rainfall totals, a bias correction of 2.0 was applied to the radar estimate. This meant that radar rainfall estimates were doubled in order to match radar estimates to gauge observations in those locations. After this bias correction process, the reanalysis showed that the storm total rainfall maximum increased to 9.8 inches and moved about 2-3 miles east into the French Quarter neighborhood (Figure 7). Compared to the NWS RFC bias-corrected rainfall estimate, this rainfall reanalysis indicated increased rainfall values over the portions of New Orleans that experienced the highest storm totals, but decreased rainfall values just a few miles to the west (Figure 8). In both areas, the changes to the rainfall estimates were on the order of 2.0 inches or less.

The AEP for the 6-hr bias-corrected rainfall indicated a very small area (approximately 6 miles by 4 miles in size) exceeding the 1-in-2 annual chance event. Rainfall with only a 1-in-50 annual chance occurred over an area of less than 1 mi^2. Although the entire rainfall event lasted over 6 hours, the heaviest rainfall occurred over a roughly 3-hr period (ending at 2300 UTC), and this accounted for at least 80% of the storm total. The bias correction factor for the entire event was downscaled to the 3-hr estimates, and the AEP re-calculated. Over the 3-hr period, rainfall reached 1% AEP magnitude for a very isolated area (less than 0.5 mi^2) near the French Quarter (Figure 9). A majority of the city of New Orleans experienced rainfall less than a 1-in-2 annual chance event.

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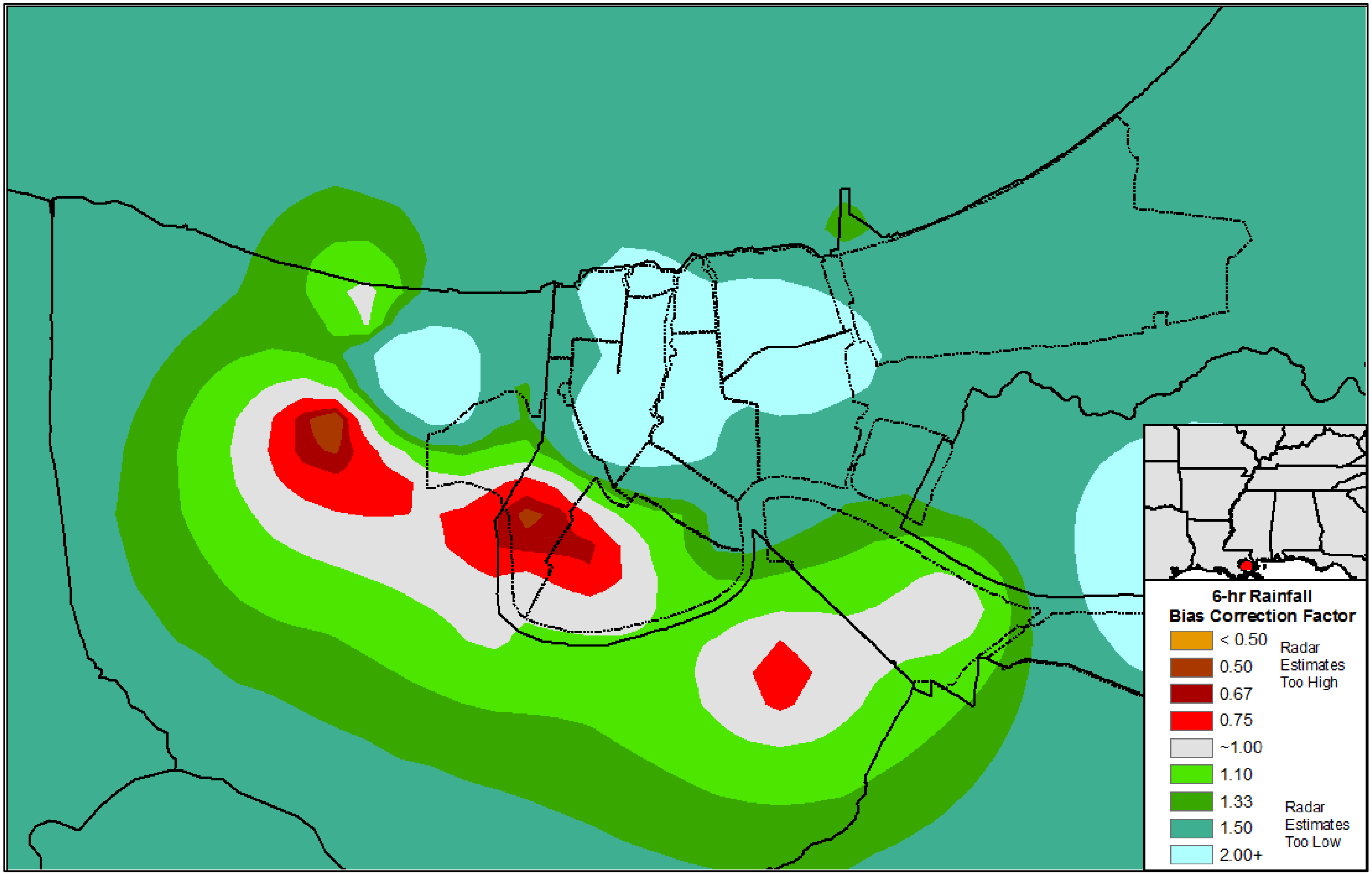

243 Figure 6. The bias correction factor for the 6-hr rainfall ending at 0000UTC 06 August, 2017. Values less than 1.0 correspond to gauge values lower than raw radar values and vice versa.

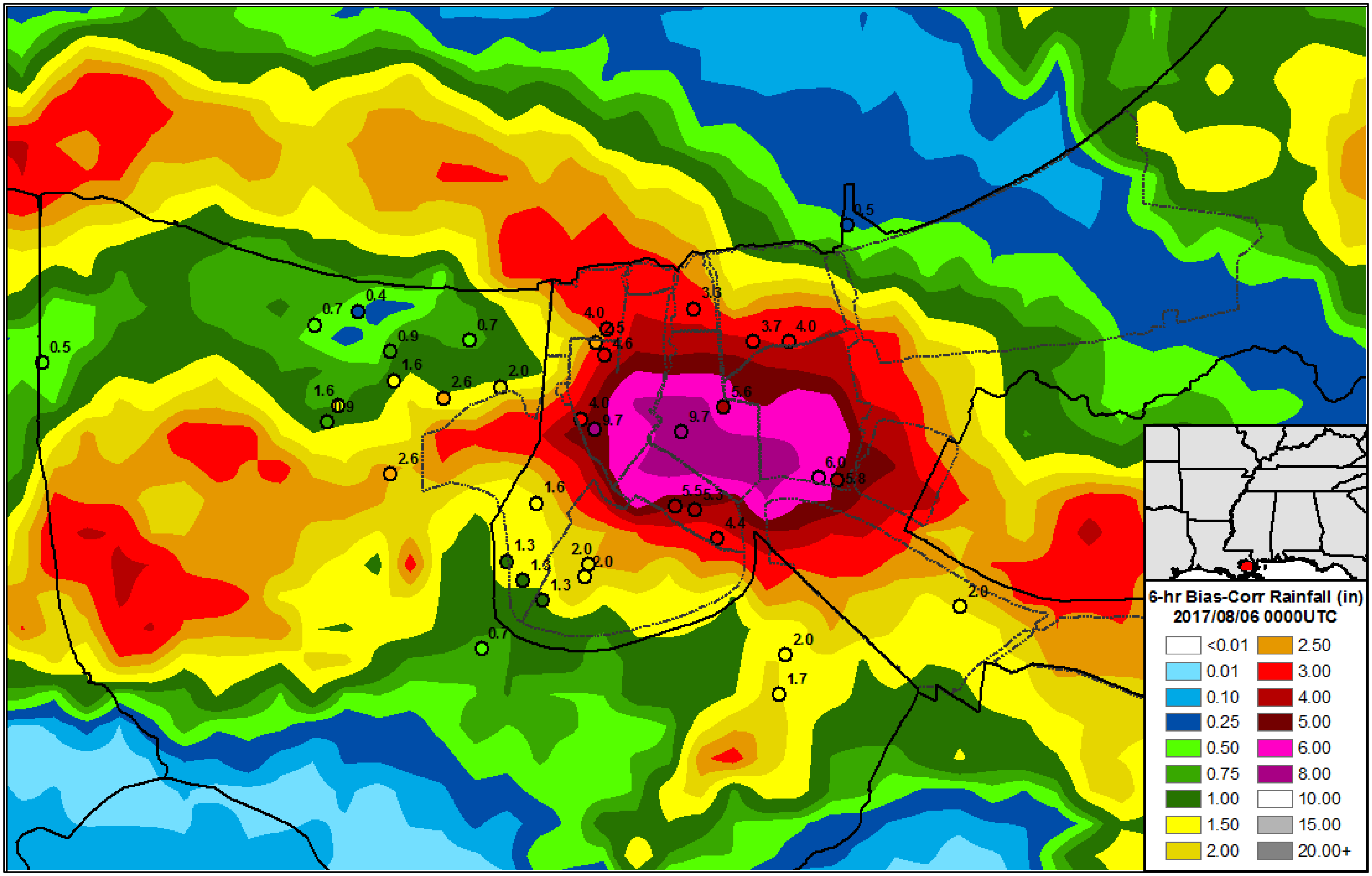

Figure 7. Bias corrected rainfall estimates for the 6-hr period ending at 0000UTC 06 August, 2017.

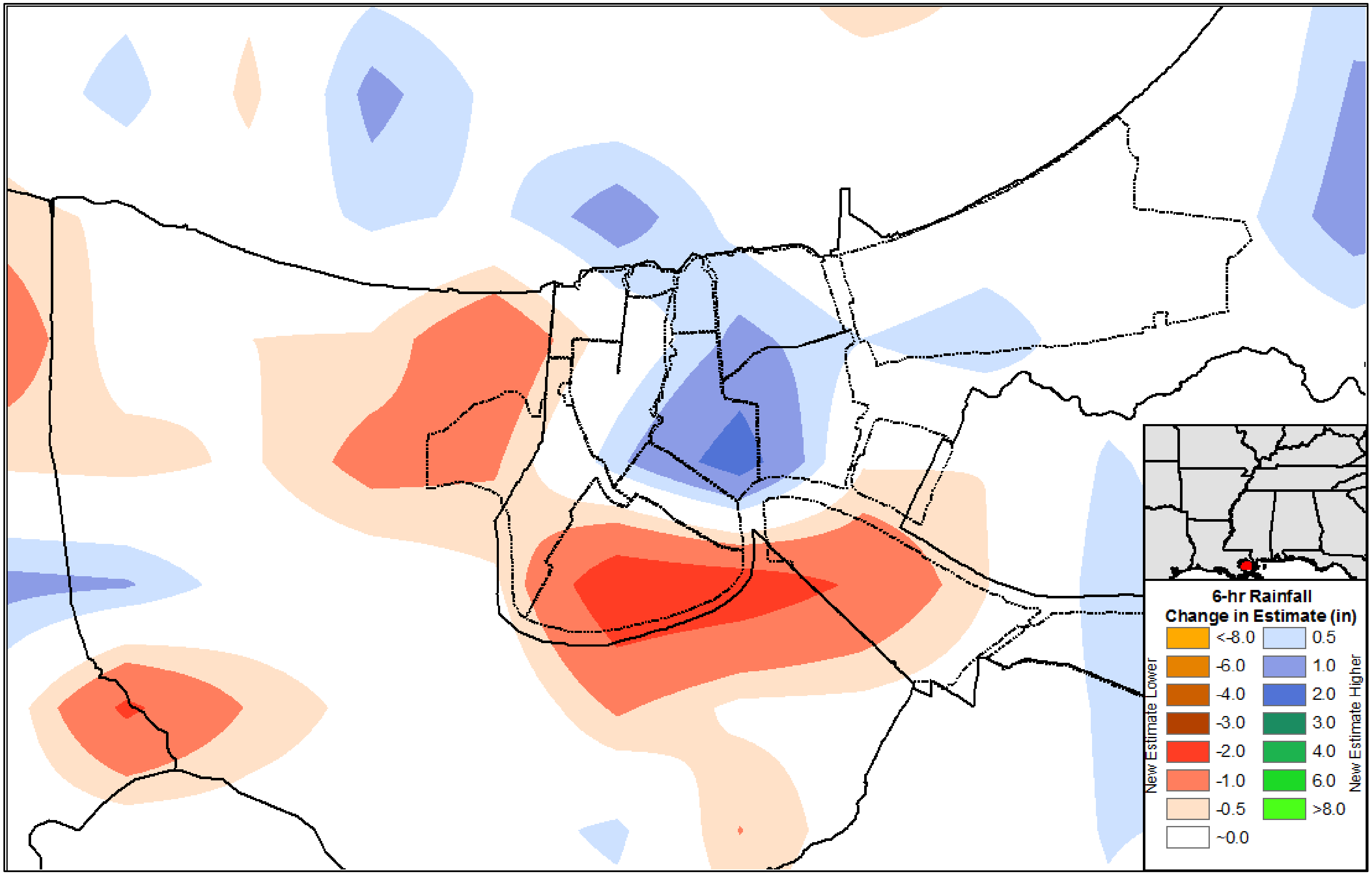

Figure 8. Difference between the rainfall estimate produced by this analysis and the traditional rainfall estimate produced by the NWS RFCs. Blue and green areas indicate a rainfall estimate that increased due to the additional gauges. Red and brown areas indicate a rainfall estimate that decreased due to the additional gauges.

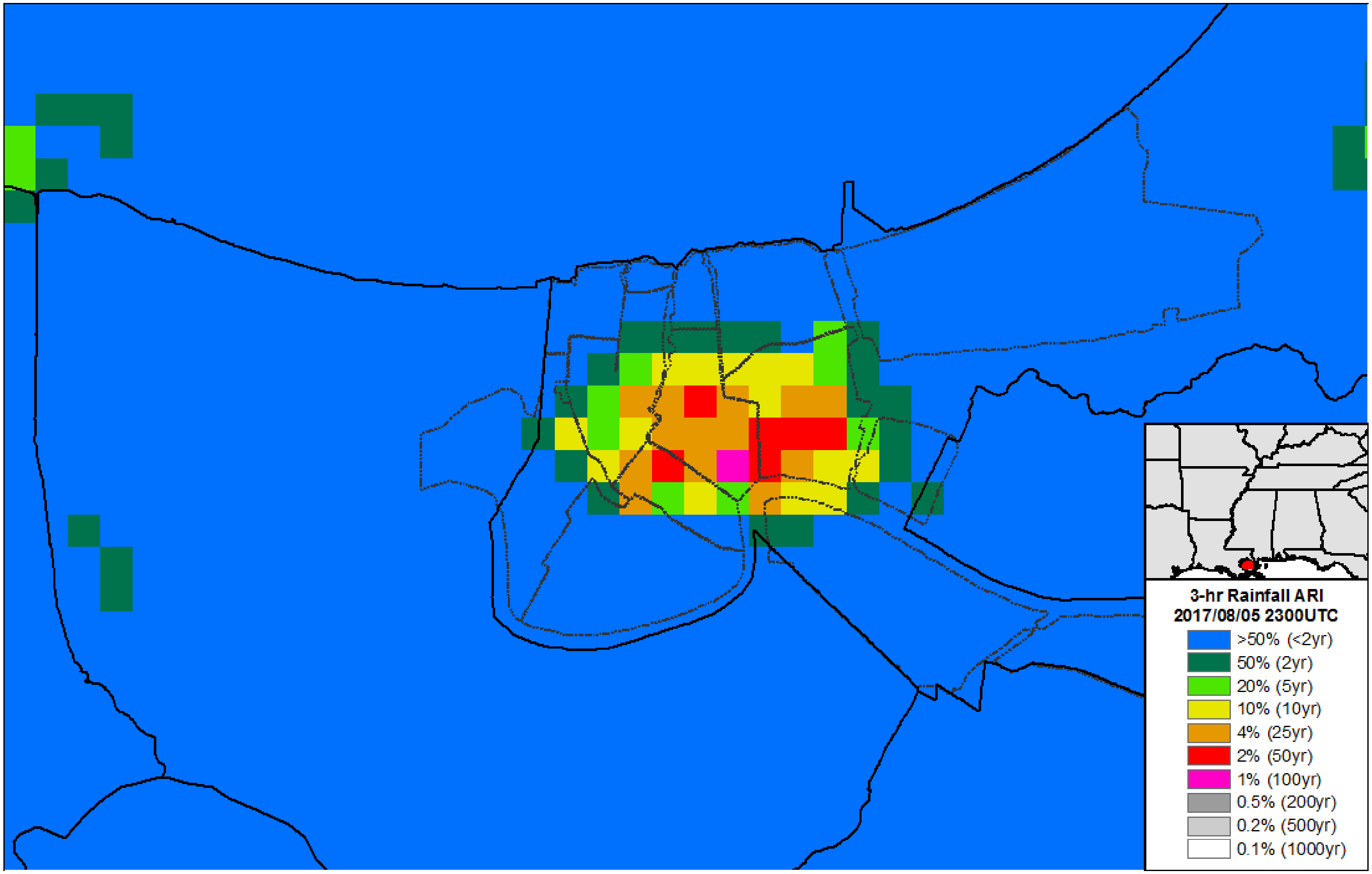

Figure 9. The ARI/AEP for the 3-hr bias corrected rainfall estimates ending at 2300UTC 05 August, 2017.

3.4 Hydrologic modeling

Peak flow rates produced by the hydrologic model varied significantly between events (Figure 10, top). For the major flood event (May 1995), flow rates reached almost 5 times the assumed pumping capacity, while the two marginal events (Hurricane Isaac in 2012 and July 2017) just barely exceeded pumping capacity. The event flow exceeding average, or nominal, pumping capacity was also calculated based upon the estimated capacities from IPET (2006). The 5 August 2017 event was more than double the peak flow of the marginal events (about 1.5x assumed capacity) but not even close to the magnitude of the 1995 event. The New Orleans Advocate on 15 August, 2017, documented available pumping capacity for 5 August, 2017 (http://www.theadvocate.com/new_orleans/news/article_10a26648-8215-11e7-b748-67c91e24fa7e.html); this capacity was lower than the published nominal values. To account for this reduced level of pumping capacity the author reduced pumping capacity by 1000 cfs and 5100 cfs for the July 2017 and August 2017 events, respectively. The reduction in pumping capacity was not enough to change the rankings of the events or drastically alter the results. To calculate excess flow, the 2006 pumping capacity was used with the caveat that pumping capacity was likely lower in prior years, including the May 1995 event. For the 1995 event in particular, even a significant reduction in pumping capacity would have had minimal impact on the resulting excess flow; with the entire pumping system offline, excess flow for May 1995 would increase by only a maximum of 20%.

For the 22 July 2017 and 5 August 2017 events, pumping records from SWBNO were made available publicly on the web (SWBNO, 2017). Records for Hurricane Isaac (August into September 2017) were already available from Schlotzhauer & Lincoln (2016). Although total rainfall was highest during Hurricane Isaac, rainfall rates were much higher during the summer

2017 events, exceeding the assumed pumping capacity on both occasions (Figure 11). In contrast, when looking at storage values of runoff, defined as the amount of runoff that has yet to be pumped out of the city, Hurricane Isaac in 2012 exceeds the hypothetical drainage system storage capacity by more than the other events (Figure 12). One difference between Hurricane Isaac and the summer 2017 events is the distribution of heavy rainfall; rainfall during Isaac generally affected all portions of the city while the 22 July 2017 event and the 5 August 2017 event were caused by very isolated, intense thunderstorms. To evaluate smaller-scale differences between these rainfall events, hydrologic model results were compared for a single interior pumping station, DPS 03, which services a small portion of central New Orleans (about 11% of the main polder). The rainfall and runoff rate differences illustrated by Figure 11 became much more dramatic when looking at the smaller area. Runoff rates for the 5 August 2017 event at DPS 03 far exceeded the runoff rates of the other events as well as the local pumping capacity (Figure 13).

The differences in runoff rates estimated by the hydrologic model provide some insights into which events had flood impacts, and which events did not have flood impacts, however this type of model is not available to NWS warning forecasters in real time warning operations. A more readily-available indicator of flash flood potential may be something as simple as the rain rate itself, as runoff is typically not variable in New Orleans due to the urban landscape and its high percentage of impervious surface. A comparison of maximum 3-hour rainfall rates for any pump station's service area is shown by Figure 14. Increased rainfall rates generally are correlated with worse flood impacts. Overall, these rainfall estimates and modeled runoff estimates seem plausible based upon the relative severity of flash flood impacts which were reported.

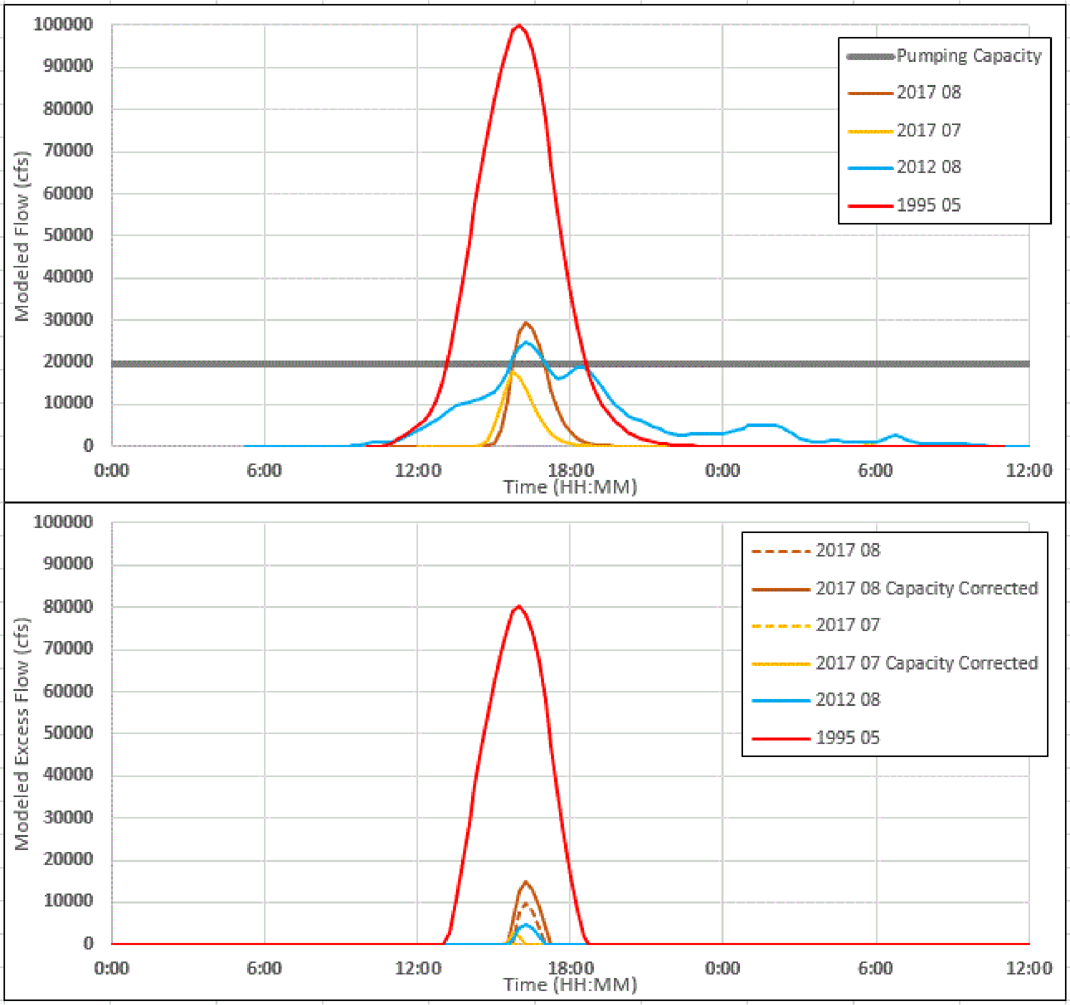

Figure 10. Comparison of peak flow rates generated by the hydrologic model for several New Orleans rainfall events (top). The 5 August 2017 event produced more runoff than the marginal flood events (Hurricane Isaac in 2012 and July 2017) but was not close to the magnitude of the May 1995 event. Excess flow rates (flow rate minus assumed pumping capacity; bottom) was also calculated. Due to a reduction in pumping capacity during the summer 2017 events, "capacity-corrected" values are also indicated.

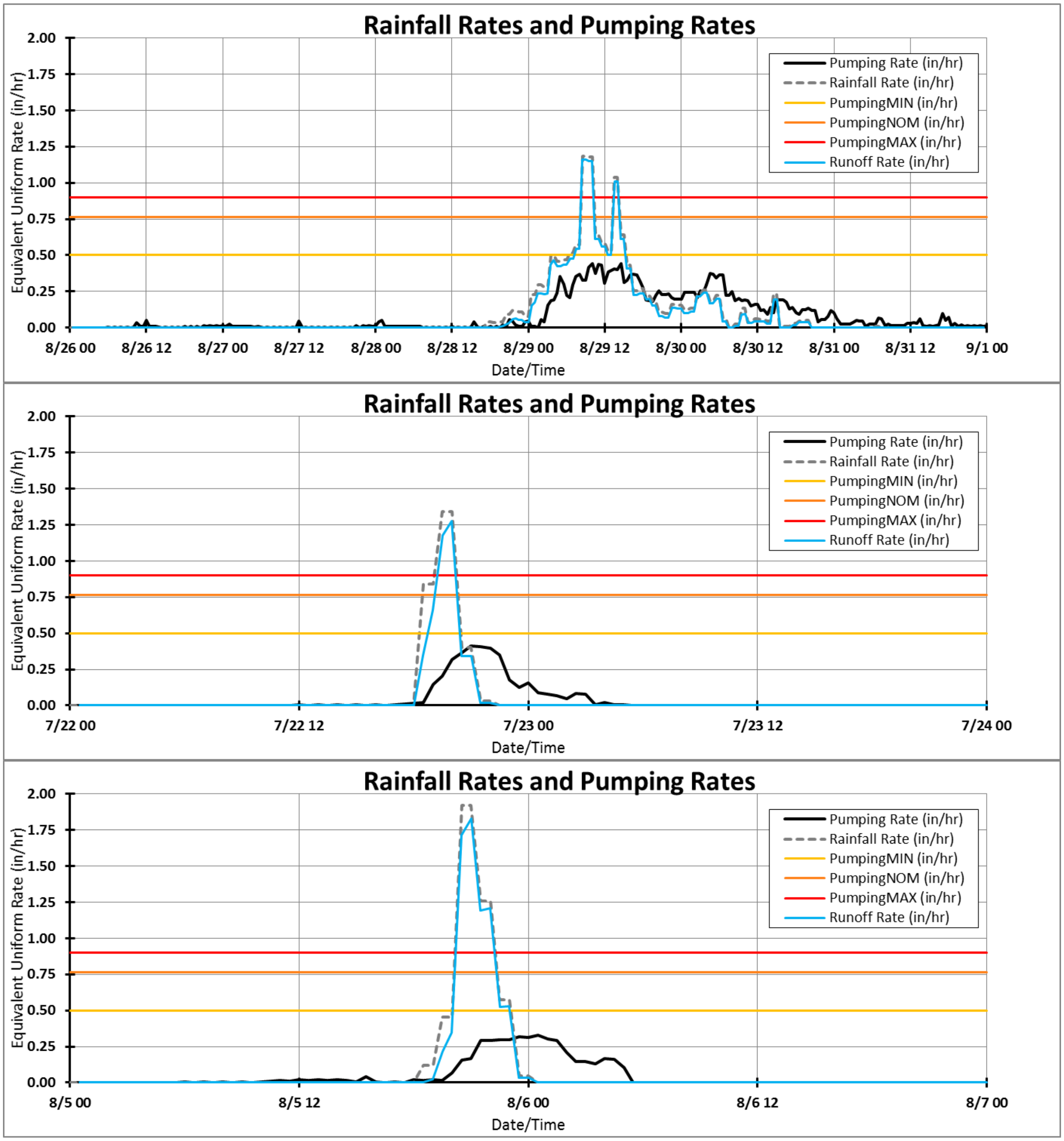

Figure 11. A comparison between hydrologic model results for 3 different rainfall events occurring in the main polder of New Orleans - August 2012 (top), July 2017 (middle), and August 2017 (bottom). In all three events, pumping rates never reached the assumed capacity of the pumping system. This does not necessarily mean a pumping malfunction and is likely due to multiple factors including the delay between rainfall and subsequent runoff moving through the drainage system to a pumping station.

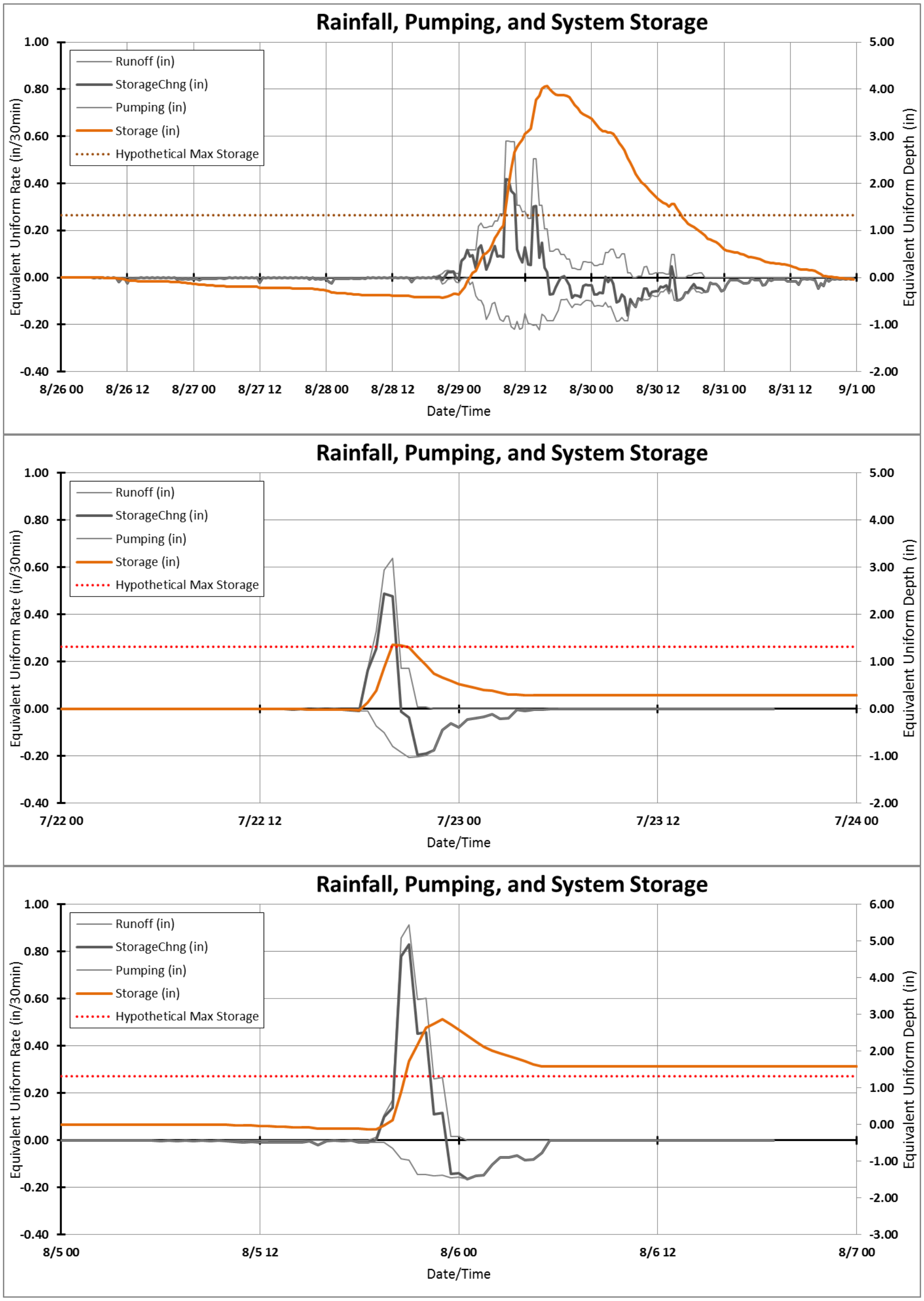

Figure 12. A comparison between hydrologic model results for 3 different rainfall events occurring in the main polder of New Orleans - August 2012 (top), July 2017 (middle), and August 2017 (bottom). Cumulative system storage is shown compared to the hypothetical maximum storage (volume of space in underground drainage pipes and canals to store water waiting to be pumped). Note that pumping records ended early for the July 2017 and August 2017 events.

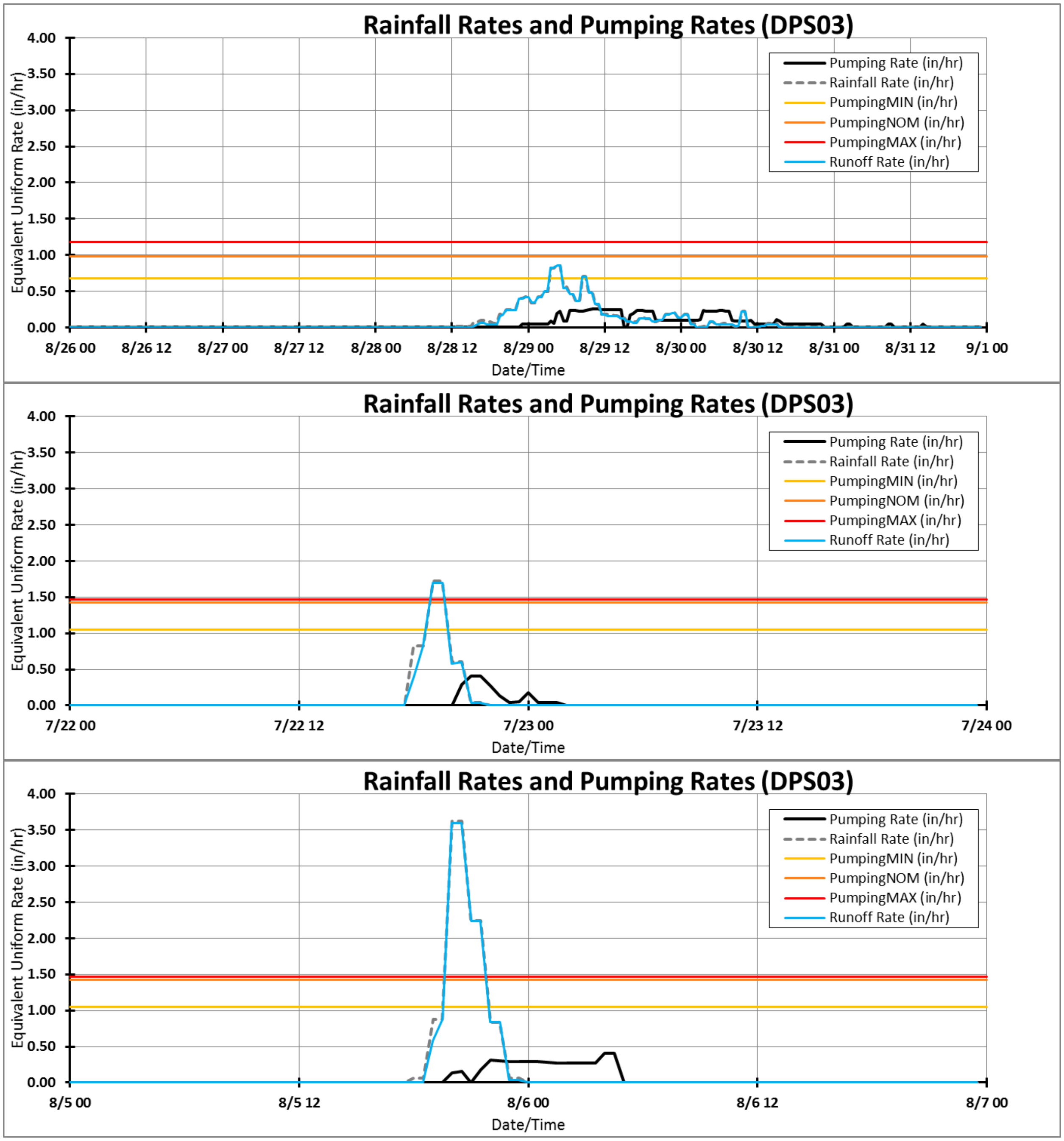

Figure 13. A comparison between hydrologic model results for 3 different rainfall events occurring in the service area for DPS 03 in the main polder of New Orleans - August 2012 (top), July 2017 (middle), and August 2017 (bottom). Runoff rates greatly exceeded the average pumping capacity for the 5 August 2017 event.

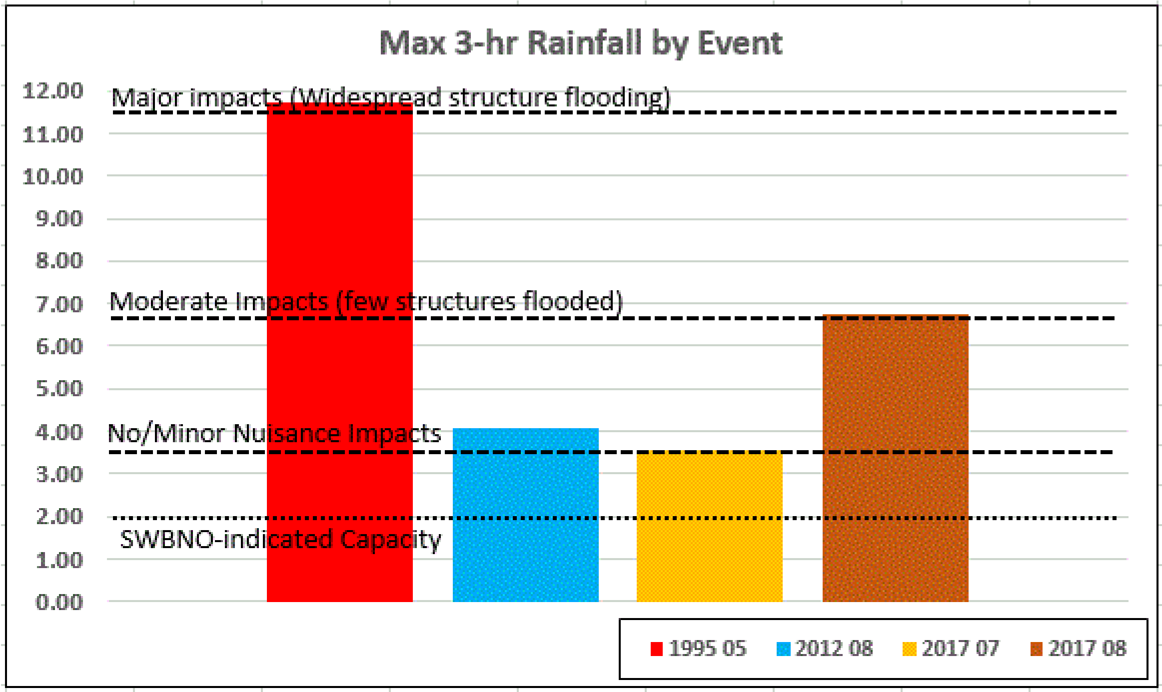

Figure 14. Comparison of maximum 3-hour rainfall totals for several New Orleans rainfall events. The general magnitude of flash flood impacts produced by each event is indicated. Colors were chosen to match those used in Figure 10.

5.0 Conclusions

Excessive rainfall from a nearly stationary thunderstorm caused significant flash flooding in areas of New Orleans, Louisiana, on 5 August, 2017. The heaviest rainfall occurred away from most official gauge locations operated by federal agencies including the NWS. Utilizing additional rainfall reports from CoCoRaHS and private observing networks, the bias-corrected rainfall estimate increased significantly for a portion of New Orleans, specifically the Mid-City neighborhood. This isolated afternoon thunderstorm produced a maximum estimated rainfall that had only a 1-in-100 chance of occurring annually. This event and subsequent reanalysis illustrates the importance of assembling numerous point rainfall observations from rain gauges to increase the accuracy of bias-corrected rainfall estimates.

Although a hydrologic model is necessary to estimate the amount of runoff generated and the flow rate headed toward the pumping stations, the urbanized nature of the impacted area reduces the variability in runoff due to soil moisture. This fact highlights a potential area of research into increasing NWS predictive capabilities for flash flood impacts in the New Orleans area. Utilizing maximum 3-hr rainfall rates, forecasts may be able to determine the onset of flash flood conditions and the severity of impacts from a given event.

6.0 Acknowledgements

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7.0 Works Cited

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