Combining the best of both worlds, using detailed flood analyses to inform rainfall accumulation characteristics for the World-Record July 1942 “Smethport” Storm – Supporting PMP and flood frequency analyses

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Overview:

The Division of Dam Safety, Pennsylvania Department of Environmental Protection (PA DEP), completed a Probable Maximum Precipitation (PMP) Study for the Commonwealth of Pennsylvania. The work was led by Applied Weather Associates with support from Aterra Solutions. The PMP depths for Pennsylvania, particularly along the western edge of the Allegheny Mountains, are greatly influenced by the exceptional magnitude of a world-record-setting storm that occurred in July 1942 in the north-central region of Pennsylvania. (See Figure 1.) The July 1942 storm is critical for PMP development in the region. However, there are uncertainties related to the quality of the rainfall data collected in this rural region of Pennsylvania. Therefore, a critical component of the study is a hydrologic and hydraulic simulation of the watershed’s response to the July 1942 rainfall event, using a combination of lumped and distributed (2D) techniques. The purpose of the flood analysis was to substantiate the recorded rainfall or identify, isolate, and quantify observational uncertainties in the recorded rainfall and develop rainfall depth, spatial, and/or temporal patterns that better match observed flood data. This presentation describes the approach taken to develop and calibrate the flood models, comparisons between modeled and observed flood data, and results of iterations to refine our understanding of the rainfall magnitude, spatial patterns, and/or temporal patterns.

Storm Description:

According to NOAA, the “Smethport” Storm of July 18, 1942, was a world-record setting event for the 3- and 4.5-hour durations at 28.5 and 30.8 inches, respectively. While the Borough of Smethport is the name associated with this storm, the record rainfall and storm center actually occurred in the Borough of Port Allegany PA. A significant number of rainfall observations were reported; however, most were unofficial “bucket surveys” that have uncertainties in the total reported rainfall and limited temporal information. See Figures 2 and 3 for the locations of the hourly gauges and other observation points (including bucket surveys). As shown in Figure 4, the hourly gauges show an initial intense burst of rain near midnight of July 18, 1942 followed by lower intense rainfall then a second significant rainfall period. (Note that midnight of July 18, 1942 corresponds to the end of Index Hour 47 on the hyetographs.) While a significant number of total rainfall depths were recorded, only the scattered hourly gauges were available to provide temporal information (none of which recorded more than 9 inches of rainfall). HMR-56 timed the storm between Coudersport and Port Allegany as shown in Figure 5.

Transposition Limits:

The Smethport storm is one of the few storms used in the series of HMRs where the NWS provided explicit discussions and an image of the transposition limits. Therefore, the limitations of where this storm was intended to be used are known. See Figure 6 from HMR 52. This image shows that the NWS only intended for this storm to effect areas along and immediately to the west of the Appalachian Mountains where topographical and meteorological patterns are similar to the storm center location. However, the Smethport storm implicitly influenced PMP depths throughout the HMR 51 region, far beyond the intended areas of influence as set by the NWS and limits of where it could meteorologically occur. Because of this, the majority of infrastructure with contributing drainage areas less than 500 mi^2 and have PMP values from HMR 51/52 for the inflow design flood are influenced by this storm’s values. During numerous site-specific, statewide, and regional PMP studies, updated transposition limits have been developed. These are based on a more accurate understanding of the meteorological and topographical interactions associated with the storm and the other areas in the region where the same combinations could occur. Use of these more accurate transposition limits have resulted in a more restricted influence of the Smethport storm. However, it still covers a significant region with critical infrastructure. The area of influence follows the western side of the Appalachian and Allegheny Mountains in southwestern NY, western PA, central WV, and eastern parts of KY and TN. See Figure 6.

Figure 1. Location Map.

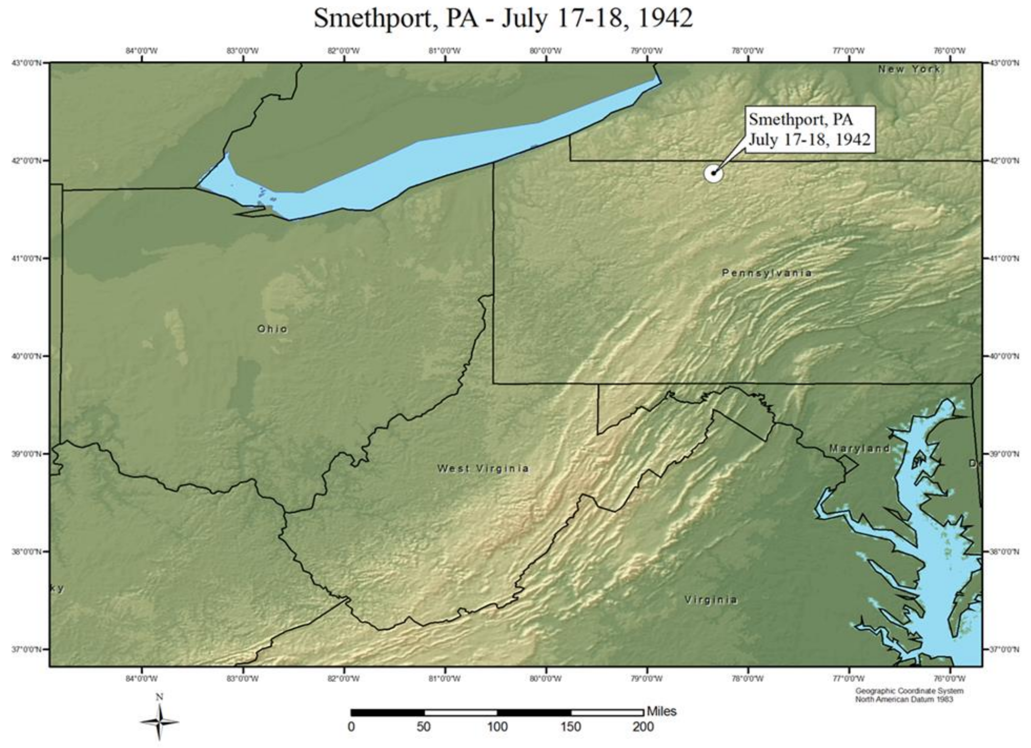


Figure 2. All Rain Gages in Study Area and Vicinity of Storm Center.

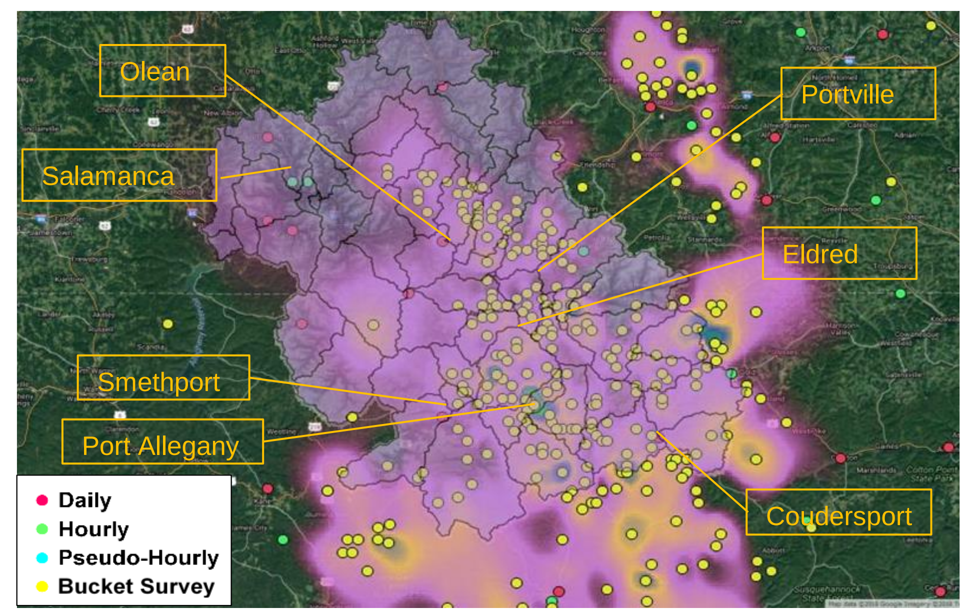


Figure 3. Location of Hourly Gages

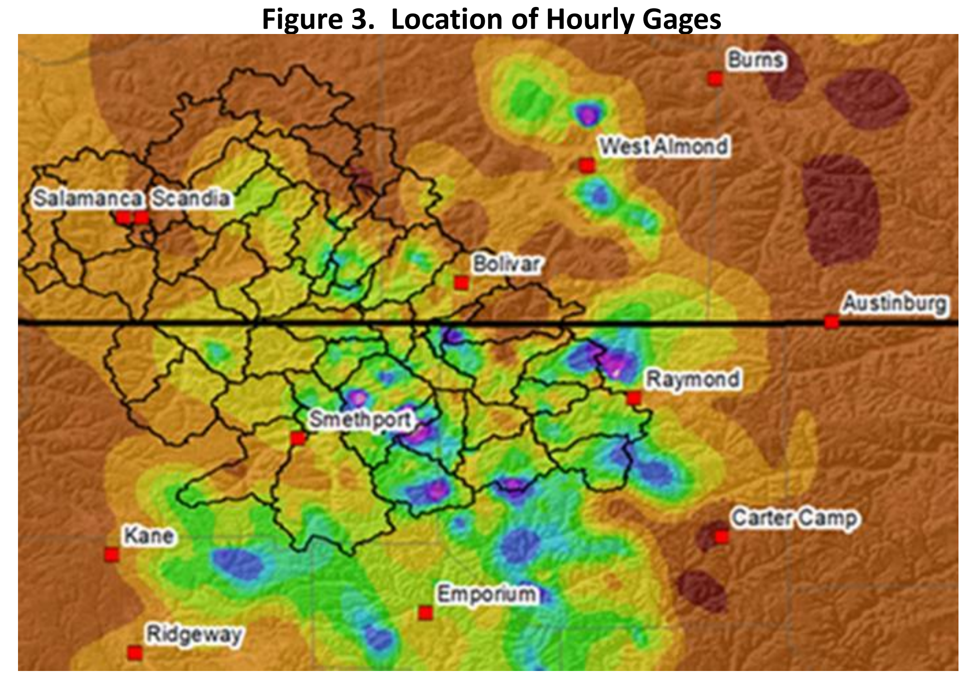


Figure 4. Temporal Pattern of Rainfall (based on Bolivar Gage)

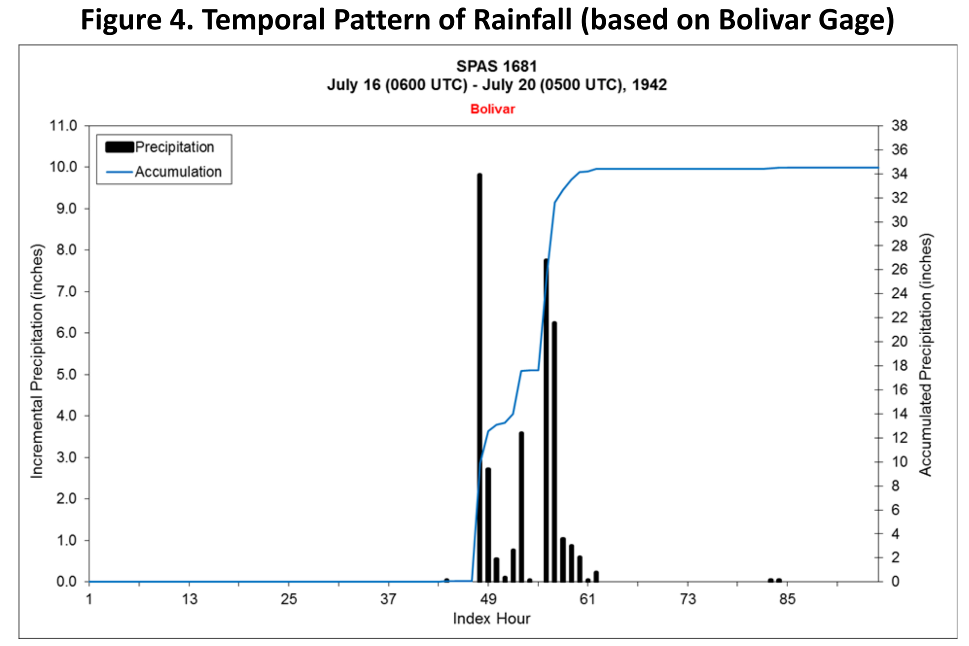


Figure 5. Temporal Pattern of Rainfall (based on HMR-56)

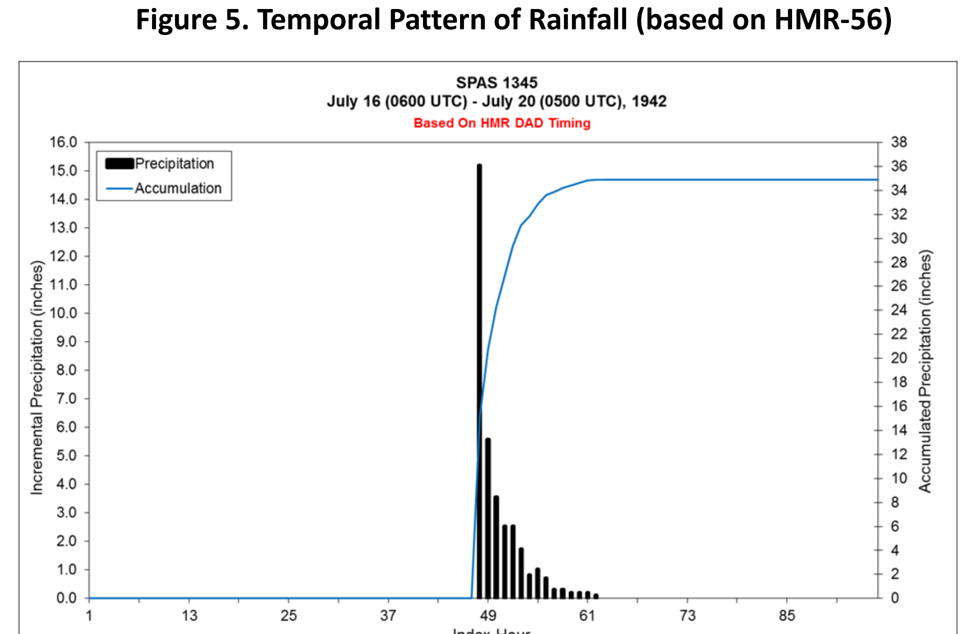


Figure 6. Transposition Limits of the Smethport

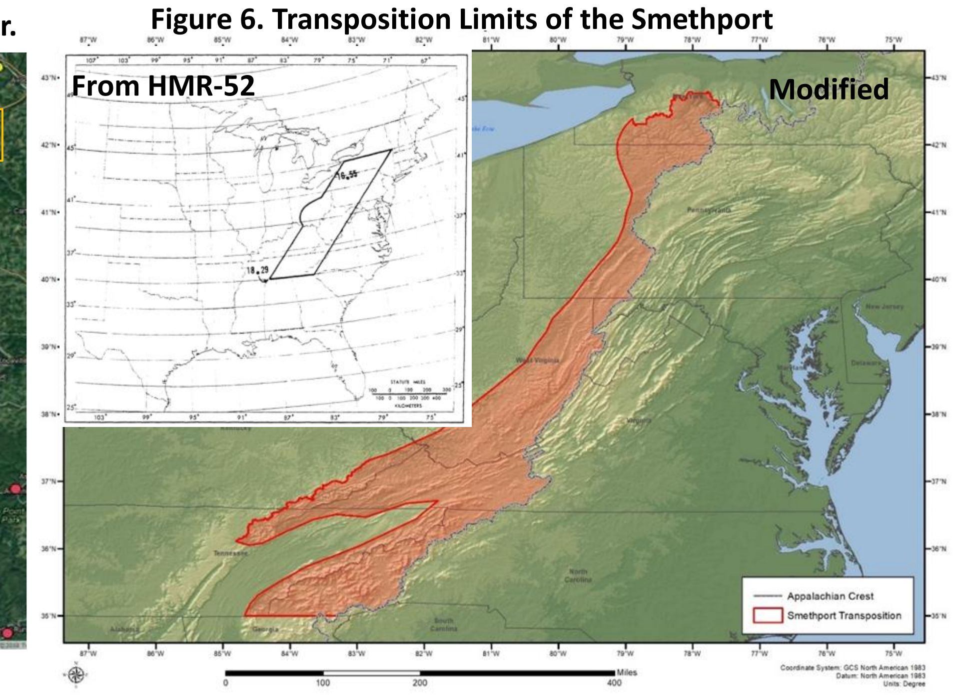


Figure 7. Model Domains

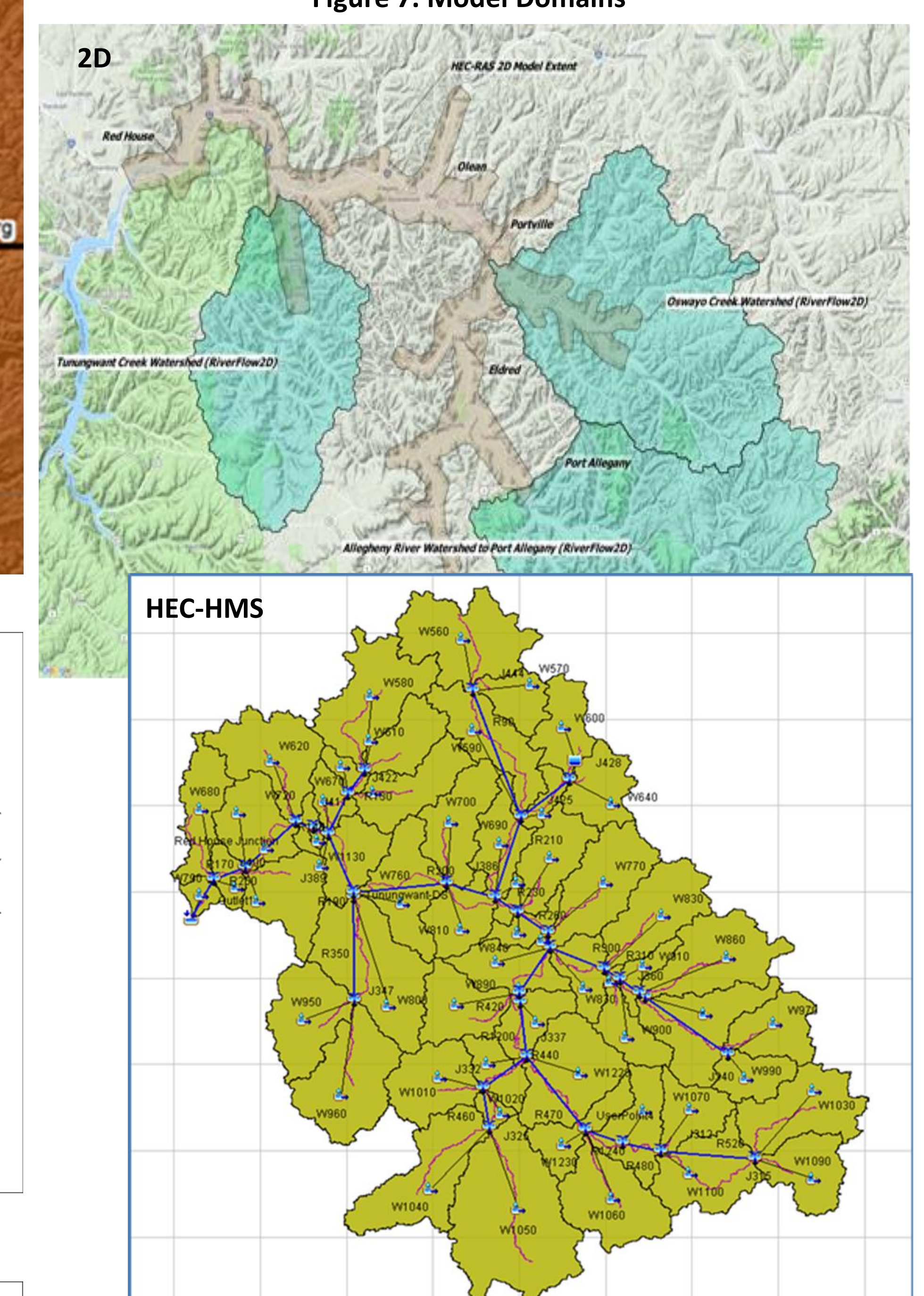


Figure 8. Allegheny River Hydrographs at Red House/Salamanca NY

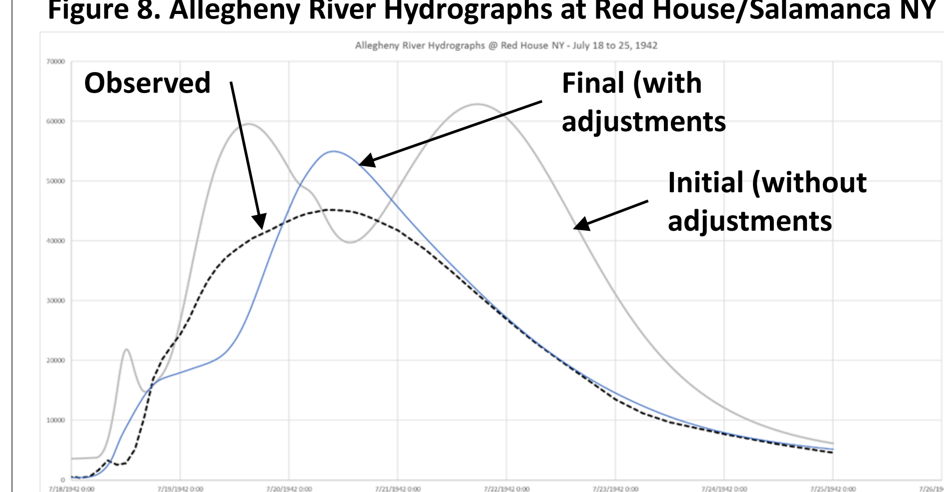
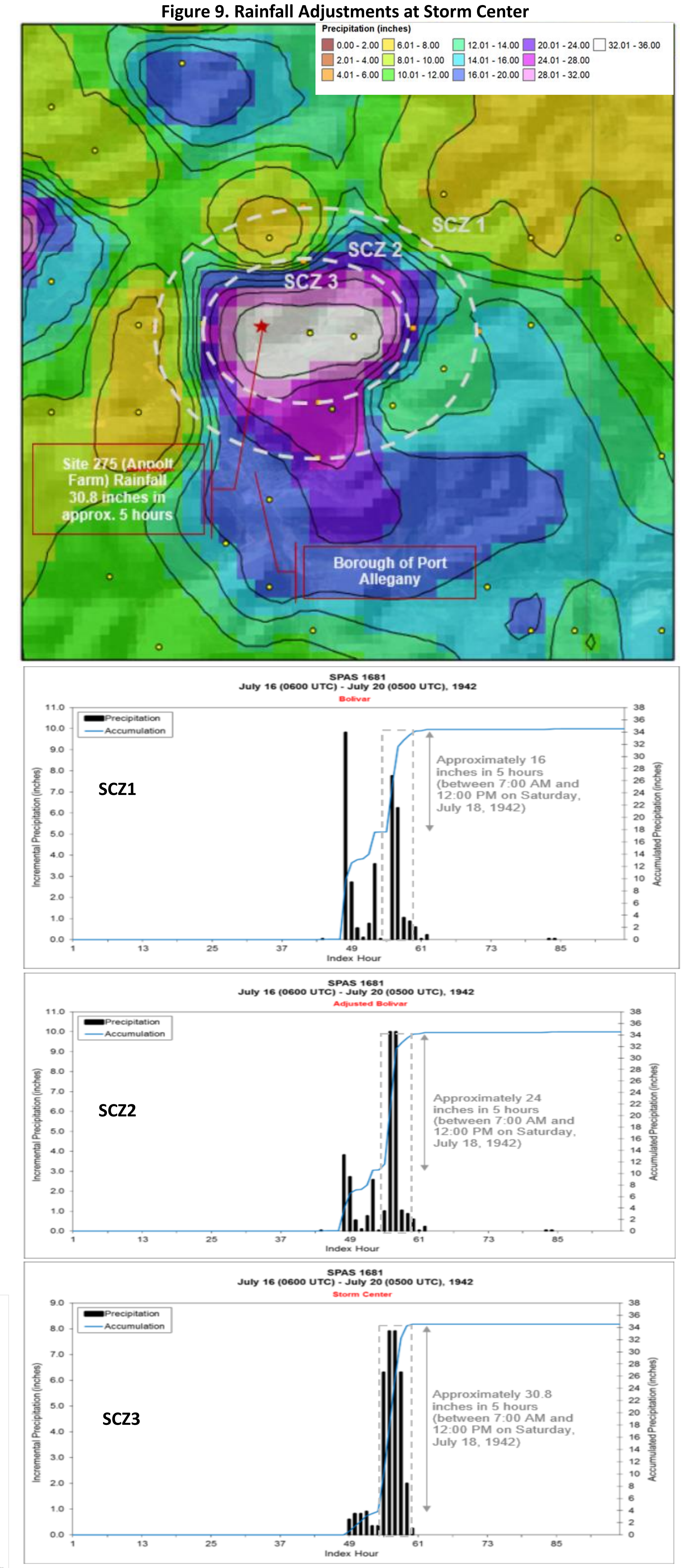


Figure 9. Rainfall Adjustments at Storm Center



Flood Model Development & Calibration:

The July 1942 storm produced the largest discharges on record at several locations in the upper portions of the Allegheny River, Clarion River, and Sinnemahoning Creek watersheds. Discharges diminished in the lower reaches of major streams. Review of streamflow gauge records in the region indicate that the July 1942 flood was particularly significant for watersheds less than 500 mi^2, approximately corresponding to the Borough of Eldred, PA along the Upper Allegheny River. The flooding analysis of the 1,780 mi^2 watershed was accomplished using complementary models designed to make optimal use of computational capacity (at the time). The entire study domain was modeled with the USACE’s HEC-HMS software using the RCN approach for loss/retention estimation and the Snyder Unit Hydrograph (UH) for runoff transformation. The UH in the HEC-HMS model was adjusted to reconcile the hydrograph from the 2D models and account for a non-linear watershed response in the calibration events. 2D watershed models were developed for 3 sub-watersheds within the study domain: Upper Allegheny River at Port Allegany, PA (250 mi^2); Oswayo Creek to its confluence with the Allegheny River (248 mi^2); and Tunungwant Creek to its confluence with the Allegheny River (169 mi^2). A 2D modeling approach has advantages over conventional methods in that it is more physically-based, making it flexible in modeling flood responses to rainfall events of various magnitudes, intensities, and spatial and temporal distributions. The 2D approach also reduces concerns over the application of generic non-linearity UH adjustments in HEC-HMS, which introduces an unknown level of inaccuracy. Mesh sizes were kept relatively small to maintain accuracy, particularly to limit artificial retention of runoff in the watershed. This mesh size limitation made the 2D model computationally impractical for the entire 1,780 mi^2 watershed. The computer software chosen to provide the 2D watershed simulation was RiverFlow2D, which solves the shallow water equations (depth averaged/vertical integration of the Navier-Stokes equations) using a finite-volume scheme. Each triangulated mesh element is assigned individual parameters (rather than homogenous parameters for each sub-basin). Downstream of Port Allegany, 2D hydraulic modeling was performed along the main-stem Allegheny River using the USACE HEC-RAS, which allowed for dynamically linking hydrographs from HEC-HMS DSS files. HEC-HMS parameters, specifically RCN and Snyder Parameters, were adjusted in the Oswayo Creek and Tunungwant Creek watershed models to achieve a good hydrologic match with RiverFlow2D. See Figure 7. The models were calibrated using three warm-season flood events in months with full vegetative growth to simulate canopy coverage comparable to July 1942. The September 2004 “Ivan” flood and June 2014 storms were selected for warm-season candidates and run through AWA’s SPAS program to produce the hourly gridded rainfall data. Using post-1996 storm events allows the use of the NEXRAD data, providing a more reliable and comprehensive understanding of the spatial and temporal distribution for the calibration storms. The 1972 “Tropical Storm Agnes” flood was also selected for calibration due to its significant effect on the region and the SPAS analysis that utilized a substantial amount precipitation data. Since some conditions differed between the calibration and July 1942 storms (e.g., dams, levees, land use, etc.), post-calibration adjustments were made prior to applying the July 1942 rainfall. These adjustments were made to reduce concerns that flow discrepancies can be attributed to factors other than uncertainties in the rainfall data.

Rainfall Adjustments:

The evaluation of model and observed flood data led to adjustments to the SPAS-generated rainfall data. These included adjustments to the timing, magnitude, and spatial patterns of the rainfall accumulation between observed data points. Most of the flood observations and records were at flood peaks. While peak flood data was helpful in corroborating or adjusting rainfall, a time-distributed representation of the flood was only available at two USGS gauge locations along the Allegheny River; Eldred (PA) and Red House (NY). Because the Red House watershed encompassed the entire study domain and key rainfall locations, it represented a key comparison point in judging acceptance (Figure 8). While not comprehensive, the following summarizes the key rainfall adjustments:

- Revised the rainfall temporal pattern in the sub-watersheds between Coudersport and Port Allegany, deviating from the HMR-56 timing, to a pattern more consistent with the surrounding hourly gauges. See Figures 4 and 5.
- The spatial extent of the "Bradford 2A" gauge in the Tunungwant Creek Watershed was reduced due to sparse rainfall collection. Spatial extent of other high-rainfall gauges show a tighter spatial distribution.
- Re-distributed the 2 hours for the second peak over 4 hours in sub-watershed W830 and resolved high “ΔP’s” (difference between the SPAS generated rainfall with observed).
- The record Appolt Farm observation (30.8” in 5 hours between 7:00 AM and 12:00 PM on 7/18/42) at the storm center was not represented by nearby hourly gages. Applying the Appolt Farm rainfall pattern too broadly in the flood model led to significantly higher flood data observed in the area. Therefore, the rainfall pattern was iteratively adjusted into 3 Storm Center Zones (SCZs); SCZ1 represented the outer-most zone that was timed to nearby hourly gages; SCZ3 was the inter-most zone that was timed to the Appolt Farm observation; and the intermediate zone (SCZ2) represented a transition between SCZ1 and SCZ3. See Figure 9.
- The Appolt Farm record also identified flow estimates at small, unnamed tributaries upstream of the farm. Using the Rational Method, peak rainfall intensities were computed to generate these observed flows; with a maximum intensity of 45 in/hr. This intensity likely occurred for a short period of time (5 minutes +/-). See Figure 10.

Figure 10. Peak Intensity Estimates at Storm Center

Watershed	Point #	Rational Runoff Coef (C)	Peak Intensity (in/hr)	Drainage Area (acres)	Peak Flow (cfs)	Flow per Sq Mile (cfs/mi^2)
Port Allegany	016.16	0.35	16.1	250	1,406	3,606
Two Mile Run	016.20	0.42	23.2	20	200	6,236
Two Mile Run	016.21	0.42	45.0	34	641	12,096
Two Mile Run	016.22	0.42	17.1	56	400	4,596
Sartwell Creek	016.10	0.32	16.1	60	310	3,297