PMPs NEVER HAPPEN – OR DO THEY?

John Harrison, P.E.
Schnabel Engineering Associates, Inc.

Abstract: This paper explores extreme precipitation events in the eastern United States that have approached or exceeded the Probable Maximum Precipitation (PMP) estimates as defined by Hydrometeorological Report 51 (HMR 51). PMP estimates from HMR 51 are compared to world record point rainfalls, and correlation of latitude with world record events occurring in the US is discussed. Extreme events are graphed with respect to area and duration for assessment of percent of PMP. The apparent greater percentage of extreme 12 hour precipitation values in the Mid Atlantic states is discussed.

PMP Methodology

PMP is defined as "the theoretically greatest depth of precipitation for a given duration that is physically possible over a particular drainage area at a certain time of the year" (American Meteorological Society 1959). A three step process was developed by the World Meteorological Organization, and was followed by the National Weather Service in developing the PMP estimates for the United States: moisture maximization, transposition, and envelopment.

Moisture maximization consists of increasing *observed* storm precipitation (from a major historic event) by a factor that reflects the maximum amount of moisture that *could* have existed in the atmosphere for the same location and time of year as the historic event. This is done by using the maximum 12-hour dew point from the storm event, and the maximum 12-hour dew point ever recorded for the same location and time of year. The maximization process is expressed mathematically as:

$$P(max) = P(storm) \times \frac{w_p\,(max)}{w_p\,(storm)}$$

Where:
P(max) = moisture-maximized rainfall
P(storm) = observed storm rainfall
w_p (max) = precipitable water, from highest 12-hr dewpoint ever observed at site
w_p (storm) = precipitable water, from highest 12-hr dewpoint from storm
(both dew points for same location, time of year)

Transposition is the process of applying a storm pattern from the location it occurred to a topographically and meteorologically similar region.

Envelopment involves drawing smooth curves that envelop precipitation maxima for various durations and area sizes to compensate for data gaps.

The NWS' methodology is standard methodology for performing PMP studies, yet concedes that that there is still a margin of error. HMR 51 states: "In consideration of our limited knowledge of the complicated processes and interrelationships in storms, PMP values

Figure 1: 100 Yr 24 Hr Rainfall (TP40)

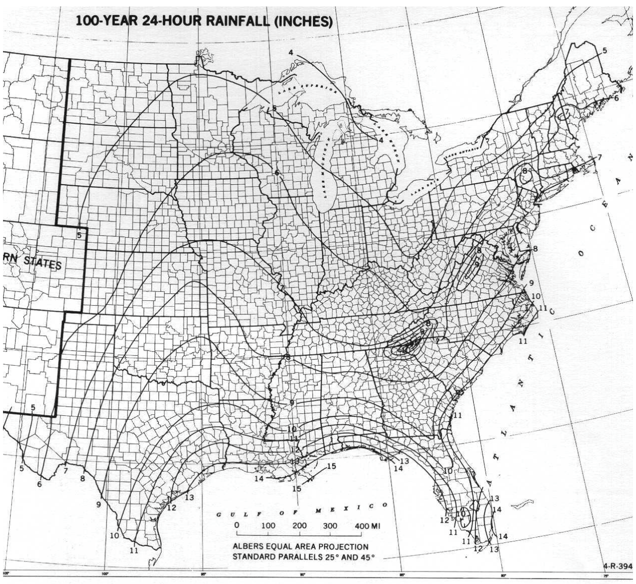
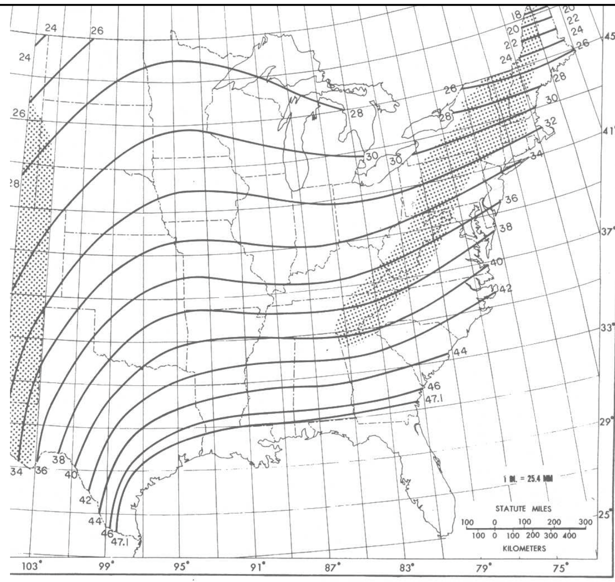


Figure2: 24 Hr 10 Sq.Mi. PMP (HMR 51)

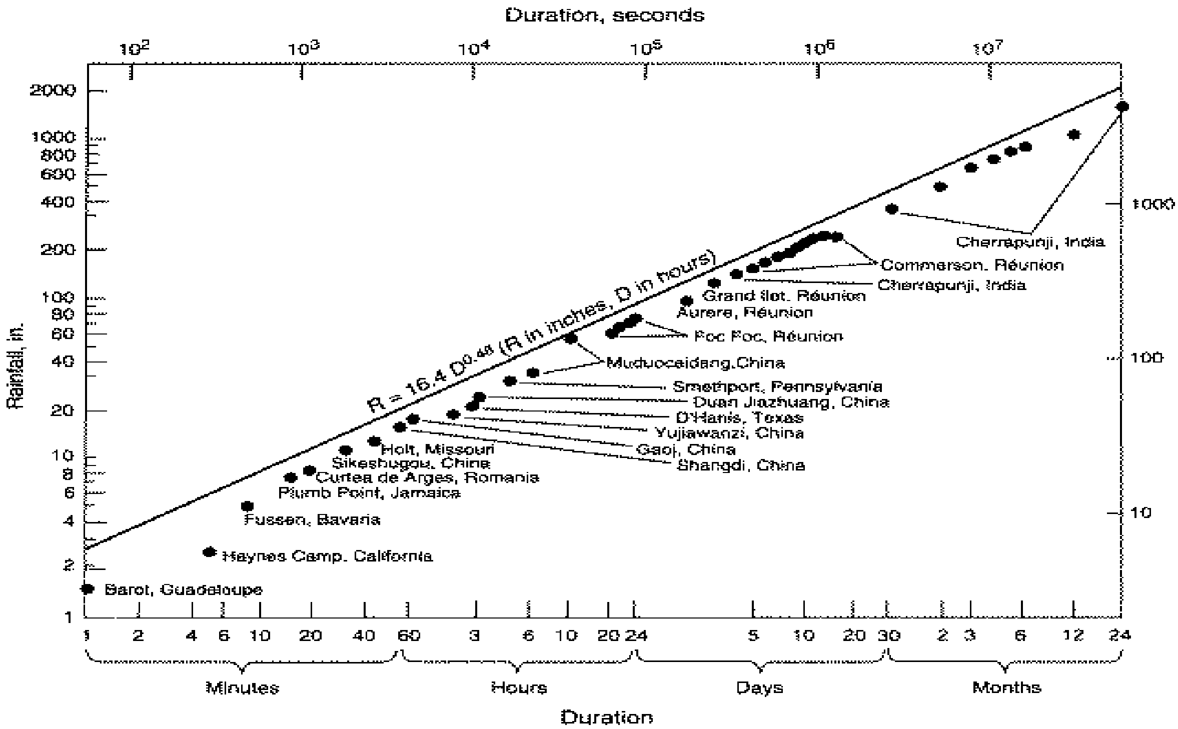


are identified as estimates." Review of the eastern portion of the United States in a generalized PMP map (Figure 2) demonstrates the primary role of latitude in setting the PMP depths in HMR51. In general, the more northerly the latitude, the less moisture the atmosphere typically holds. Comparing this with Figure 1, it is readily apparent that HMR51 does not reflect the greater probability of higher rainfall along the east coast and Appalachian Mountains. To account for this, HMR 51's generalized PMP maps are *stippled* in two regions: the Appalachian Mountains extending from Georgia to Maine; and, a strip between the 103rd and 105th meridian (see Figure 2). These stippled regions are two areas where "the generalized PMP estimates might be deficient because detailed terrain effects have not been evaluated. We expect future studies of the Hydrometeorological Branch will involve detailed generalized studies covering the stippled regions" (HMR51). These statements lead the reader to question whether PMPs (as defined by HMR51) have occurred, and if so, how do they relate to the estimates provided in HMR 51?

World Record Point Rainfalls

The World Meteorological Organization maintains records of the greatest precipitation depths throughout the world. Figure 3 shows world record point rainfalls. Two things are notable about the figure. The obvious point is that there is a definite logarithmic correlation

Figure 3



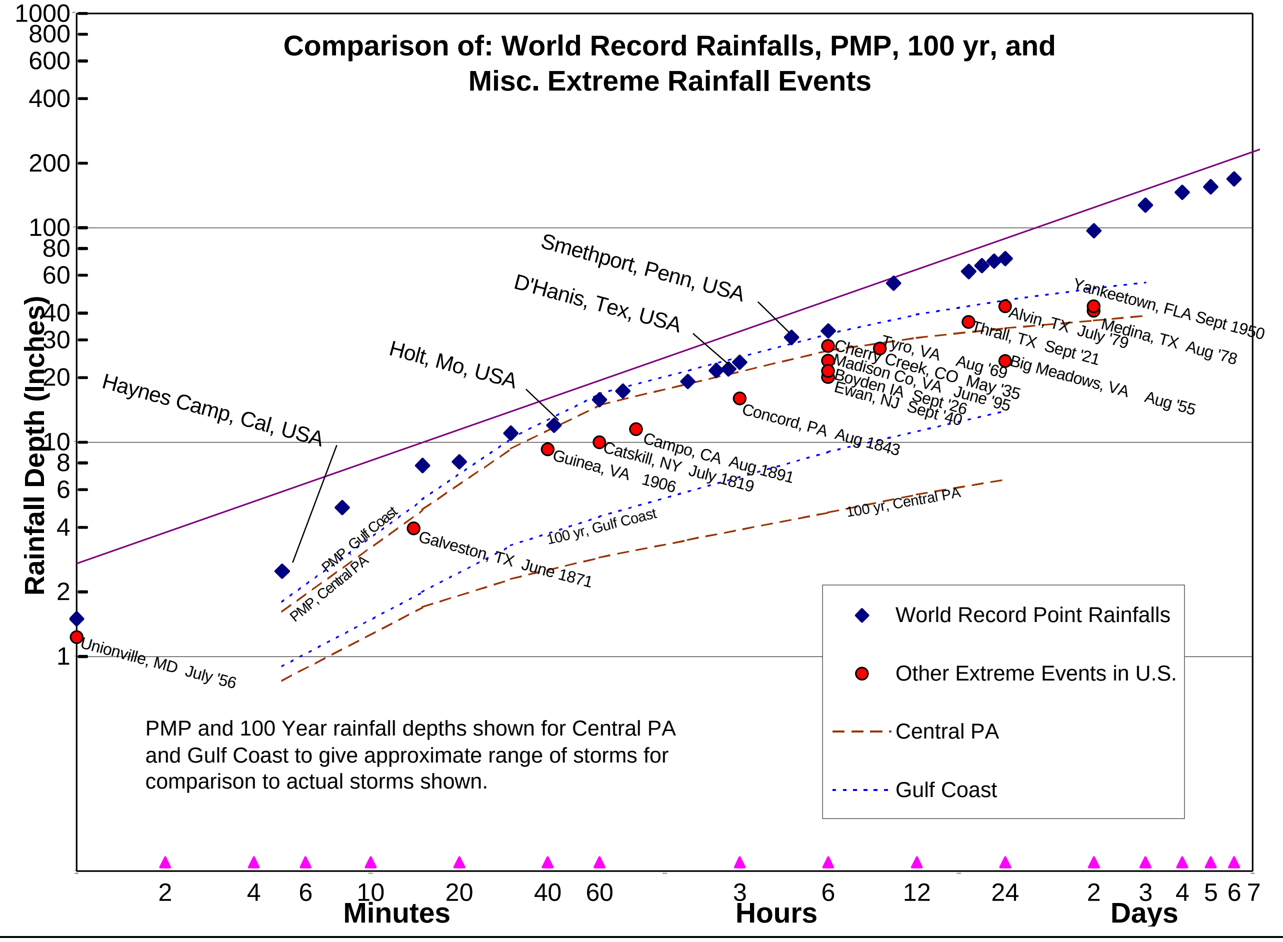
Maximum observed point rainfalls as a function of duration.

Source: World Meteorological Organization WMO 332, Modified by NWS 1992.

between depth and duration. The second notable feature is that the majority of the greatest known observed point rainfalls of 10-hour duration *or less* have occurred in the temperate regions of the world. For durations *longer* than 10 hours, most of the greatest observed point rainfalls indicated in Figure 3 have occurred in the tropics, in particular the Department of Reunion, an island country (east of Madagascar) having over 10,000 ft of relief in an area the size of Rhode Island, and in Cherrapunji, India, in the Himalayan region of India. Focusing on the shorter duration storms, it is interesting that there are four events from the U.S., with two of them (Smethport, PA and Holt, MO) occurring in the relatively northerly latitudes of the U.S. One might suspect, as I originally did, that all of the world's record rainfalls would occur in the tropic zones, rather than the higher latitudes indicated by Figure 3. Thus, there appears to be some correlation of extreme rainfall depth/duration with latitude, with short-duration world-record events occurring in the temperate regions, and long duration world-record events occurring in the tropical regions.

The four events occurring in the U.S. are highlighted in Figure 4, along with 100-year floods and PMPs for points in Pennsylvania and the Gulf Coast. These lines are shown to illustrate the approximate range of geographical area of the storms evaluated in this paper. The line marked PMP, Central PA is also representative of the PMP in the area of Holt, Missouri.

Figure 4



Based on review of Figure 4, it is apparent that point rainfalls in excess of the 10-square mile, 6-hour PMP values in HMR 51 have been equaled or exceeded. Also, several other recorded point rainfalls have come very close to exceeding the PMP values. HMR 51 and 52 do not develop rainfall distributions for areas less than 10 square miles. Concerning this point, HMR 51 notes: “The question may be raised as to whether PMP for areas less than 10 mi^2 would be greater than the 10 mi^2 values of this report. This is answered by the fact that with few exceptions the critical values establishing the PMP magnitude for 10 mi^2 came from 10 mi^2 average rainfalls rather than single station amounts. This indicates that PMP for areas smaller than 10 mi^2 would be greater than the 10 mi^2 values in this report.”

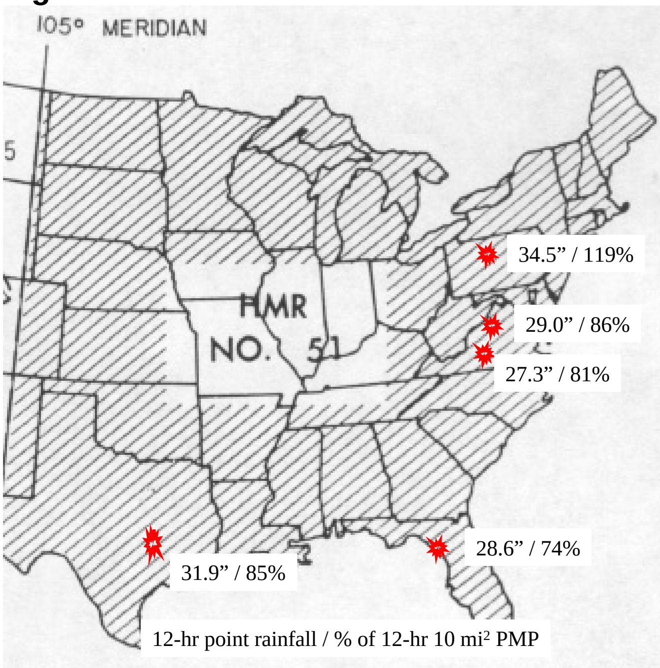
It is interesting to note that many of the greatest rainfalls were not captured by official weather stations or rain gage locations. Typically, surveys made after extreme storm events uncover greater rainfall depths than those recorded at official stations. This is due to the fact that there is little chance that the most intense rainfall in a storm will occur over a particular rain gage (Riedel and Schreiner, 1980). In fact, many of the greatest rain catches used in depth-area-duration studies are from postflood surveys.

Further review of Figure 4 indicates an additional interesting feature: the point of tangency of PMP lines with the best-fit upper limit line of world record rainfalls. This tangency point occurs at a duration of about one hour, and appears to further support the greater potential for short-duration extreme rainfall in the temperate regions of the world.

Mid-Atlantic Region – Conducive to Extreme Precipitation?

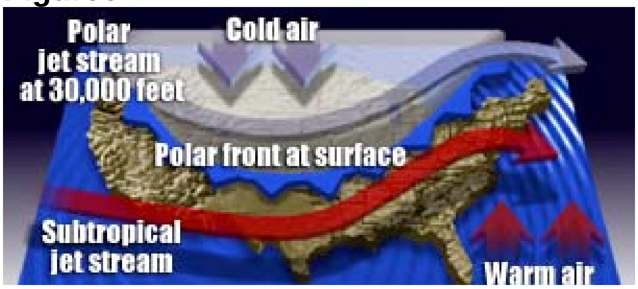
Three of the top five most intense 12-hr rainfall events in the United States have occurred in the Mid-Atlantic Region (Figure 5). The record 12-hour intense rainfall in the U.S. occurred in Smethport, PA. Figure 5 shows these events and their approximate locations. The other two Mid-Atlantic extreme events occurred in Virginia: Hurricane Camille (1969) and Madison County Flood (1995). Both states are relatively far from the moisture-laden air of the Gulf of Mexico, where you might expect the most intense rainfall. And indeed, rainfall atlases like TP-40 definitely indicate a greater probability of higher rainfall intensities along the Gulf Coast for all durations. Why then have some of the most intense short-duration rainfalls occurred in the Mid-Atlantic States? It should first be noted that the storms noted above were summer phenomena. It is only during the warm months of the year that the air can hold (and precipitate) such massive amounts of moisture.

Figure 5: Heaviest 12-Hr Rainfalls in U.S.



According to the Virginia State Climatologist’s Office (VSCO), two factors that contribute to the potential for extreme rainfall in the Mid-Atlantic region are the *topographic relief* and the right *latitude*. The steep mountains lift moisture-laden air, increasing rainfall, while the relatively northerly latitude prolongs the life of frontal systems. In the southern states, the heat of the sun warms up the air mass behind the front, making it less distinguishable from the tropical air to the south. The front then tends to disappear, along with the heavy rain.

Figure6

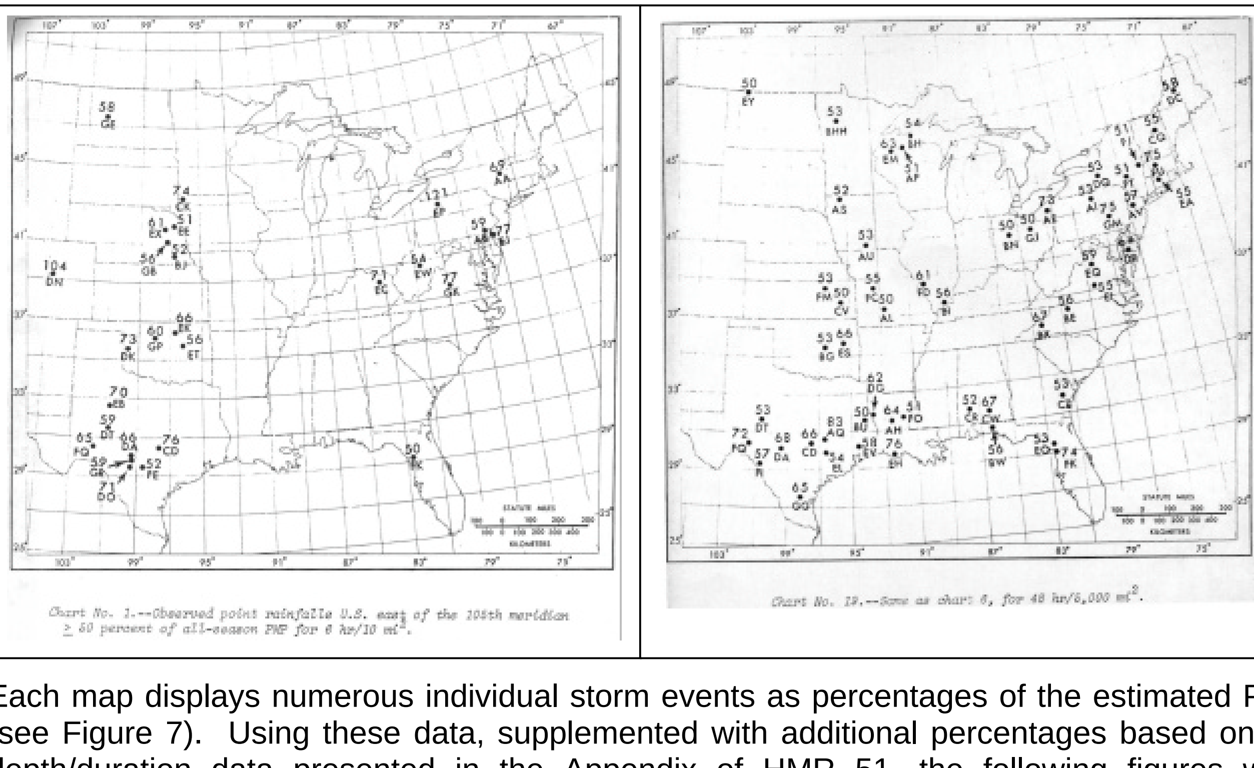


In addition, with the Mid-Atlantic states often being at the southern edge of the jet steam in the summer, fronts often stall in the region, further enhancing rainfall (Figure 6). Tropical moisture, already precipitating as it runs up against the mountains, is further wrung out as it is forced over the stationary front (VSCO).

Comparison of PMP w/ Actual Storms > 10mi^2

The rainfalls presented above are point rainfalls, but PMPs are defined in relation to a specific area and duration. How do actual rainfall events of various sizes and durations compare with the PMP estimates from HMR 51? Riedel and Schreiner (1980) addressed this question with their publication “Comparison of Generalized Estimates of Probable Maximum Precipitation with Greatest Observed Rainfalls.” They compare PMP estimates with observed storm depths greater than 50 percent of the PMP, displayed as a series of maps corresponding to the various combinations of depths and durations presented in HMR 51.

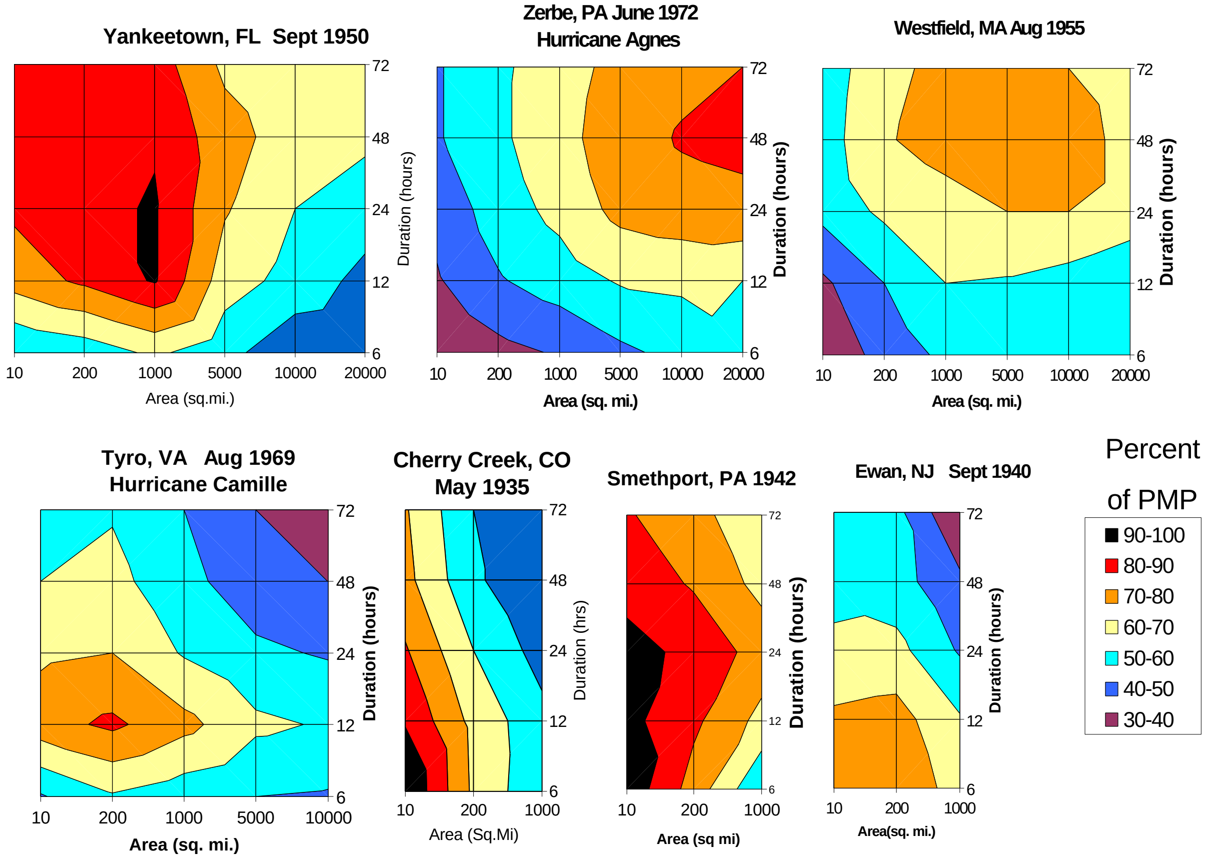
Figure 7: Sample Charts from NOAA Tech. Rpt. NWS 25



Each map displays numerous individual storm events as percentages of the estimated PMP (see Figure 7). Using these data, supplemented with additional percentages based on the depth/duration data presented in the Appendix of HMR 51, the following figures were developed to highlight several extreme events in the eastern US. Each highlighted event is presented as a contour plot to enable easy comparison of the relative size, duration, and intensity of the events.

Figure 8

Percent of PMP vs. Area & Duration



These graphs highlight the importance of defining the area and duration of a storm when comparing it to the PMP. For example, the Cherry Creek, Smethport and Ewan, NJ storms are representative of thunderstorm phenomena, with intense rainfall over relatively small areas. Alternatively, the June 1972 Hurricane known as Agnes was an 80% PMP for an area of 20,000 square miles and a duration of 72 hours, centered over Zerbe, Pennsylvania. However, Agnes' percent of PMP for smaller areas and shorter durations were comparatively lower (e.g., the 6 hr, 10 sq.mi. value was "only" 30 percent of the PMP.) Still, Agnes' great areal extent produced record floods on more streams than any other single event in Pennsylvania. Hurricanes Agnes and Connie exemplify the typical hurricane experienced in the eastern US, which is more likely to approach a PMP for large areas and long durations. One exception to the pattern is Hurricane Camille, which advanced northward from Mississippi and then turned due east through Kentucky. As the hurricane passed over the Blue Ridge, it drew tropical moisture up the steep mountain slopes, rapidly condensing the moisture-laden air in a string of intense thunderstorms on the east slope of the Blue Ridge. Another less common hurricane pattern is exemplified by the storm centered over Yankeetown, Florida in 1950. The extreme rainfall of this storm is attributed to the looping track (double loop) of the hurricane, causing the downpour to be concentrated in space. Tropical Storm Alberto similarly caused extreme downpours in southern Georgia in 1994 with its looping (single loop) track. HMR 51 notes that if other major tropical storms had looped or recurved while crossing the coast, the resulting areal rainfall would have been much more concentrated. This assumption played an important role in the development of PMP values for the Gulf Coast and eastern seaboard of the U.S.

Conclusion

In summary, it is evident that extreme precipitation events approaching the PMP estimates of HMR 51 have occurred, and in the case of point rainfalls, have exceeded the 10 mi^2 values of HMR 51. For small areas less than about 200 sq. mi., it appears that thunderstorm phenomena would be the most likely cause of a PMP. However, hurricanes with looping tracks can also cause extreme rainfall approaching PMPs for small areas. For larger areas, hurricanes and other tropical storms would be the most likely source of a PMP. Given the low probability of anyone "catching" the most intense point rainfall of any given storm, it is likely that many extreme events have higher point values than we are able to identify. The extremely low probability of a PMP has less to do with whether they ever occur, and more to do with whether they will ever occur at one specific location and reasonably match the basin size of interest.

References

National Weather Service, National Oceanic and Atmospheric Administration, 1980: *NOAA Technical Report NWS 25, Comparison of Generalized Estimates of Probable Maximum Precipitation with Greatest Observed Rainfalls*, Silver Spring, MD.

Schreiner, L.C., and Riedel, J.T., 1978: *Probable Maximum Precipitation Estimates, Eastern United States East of the 105th Meridian. Hydrometeorological Report No. 51*, National Weather Service, National Oceanic and Atmospheric Administration, Silver Spring, MD.

US Army Corps of Engineers, Hydrologic Engineering Center, 1984: *HMR52, Probable Maximum Storm (Eastern United States), Users Manual*, Davis, CA.

Virginia State Climatology Office Homepage

World Meteorological Organization, 1986: *Manual for Estimation of Probable Maximum Precipitation. WMO No. 332, Operational Hydrology Report No. 1*, Geneva, Switzerland.