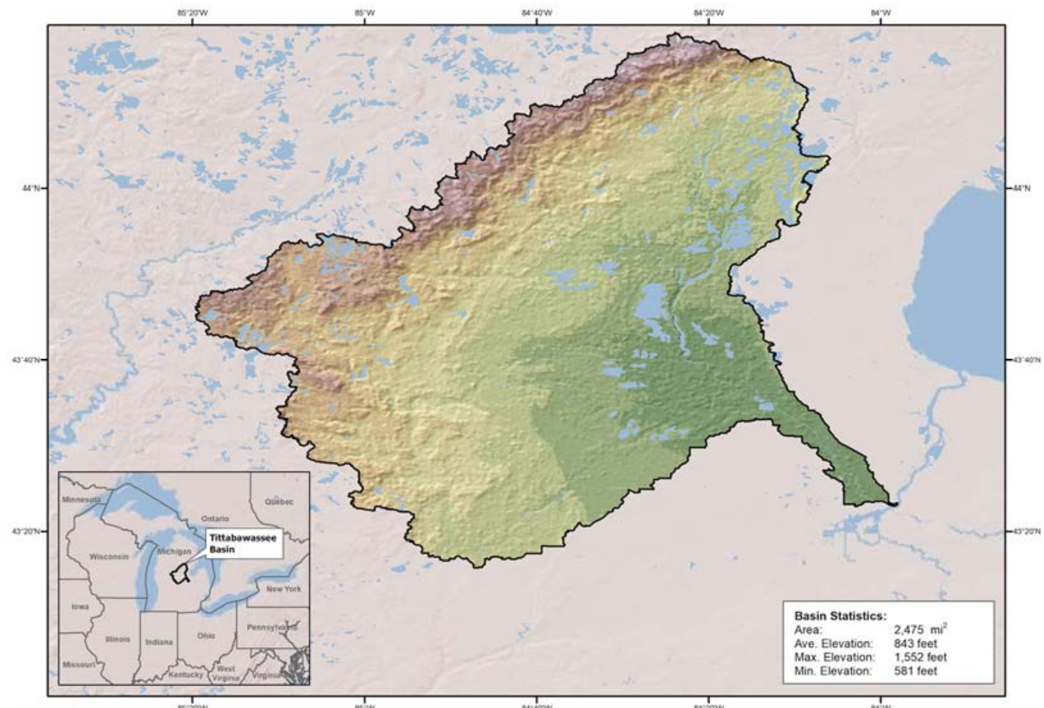
# Site-Specific Probable Maximum Precipitation Study
# For Tittabawassee River Basin, Michigan
# Final Report

Prepared for:

Four Lake Task Force
in coordination with Spicer Group, Ayres Associates, GEI Consultants





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Bill Kappel, President/Chief Meteorologist, Applied Weather Associates

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The following staff of Applied Weather Associates participated in this PMP development:

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# Executive Summary

This study produced gridded PMP values for the project domain for the Tittabawassee River basin including the Pine River basin and the Four Lake Region above Sanford Dam. Gridded PMP depths were provided at a spatial resolution of 90 arc-seconds, or approximately 2.2-square miles over the entire domain. Variations in topography, climate and storm types across the region were explicitly considered. PMP depths were calculated utilized the storm-based approach and included a large storm data representing PMP-type storms events over the basin and within the region conserved for PMP development. These updated PMP depths replace those provided in Hydrometeorological Reports (HMR) 51 and EPRI Michigan Wisconsin Regional PMP (EPRI) study. Results of this analysis reflect the most current practices used for defining PMP, including comprehensive storm analyses procedures, extensive use of geographical information systems (GIS), explicit quantification of transposition limits and topography, updated maximum dew point climatologies for storm adjustments, and improved understanding of the weather and climate related to extreme rainfall throughout the region.

The approach used in this study followed the same philosophy used in the numerous site-specific, statewide, and regional PMP studies that AWA has completed, including several in this region. PMP development follows the storm-based approach and the same general procedures used by the National Weather Service (NWS) in the development of the HMRs. The World Meteorological Organization (WMO) Manual on Estimation of PMP recommends this same approach. The storm-based approach identified extreme rainfall events that have occurred in regions considered transpositionable to the basin or any portion of the basin. These are storms that had meteorological and topographical characteristics similar to extreme rainfall events that could occur over any location within the project domain and were deemed to be PMP-type storm events. Detailed storm analyses were completed for the largest of these rainfall events.

Data, assumptions, and analysis techniques used in this study have been reviewed and accepted by numerous review boards including the Federal Energy Regulatory Commission, the Natural Resource Conservation Service, the US Army Corps of Engineers, and various private consultants and individual state dam safety offices. During the course of this project significant input was provided by other study participants.

Although this study produced deterministic values, it must be recognized that there is some variability associated with the PMP development procedures. Examples of decisions where meteorological judgment was involved included determining which storms are used for PMP, determination of storm adjustment factors, and storm transposition limits. For areas where uncertainties in data were recognized, conservative assumptions were applied unless sufficient data existed to make a more informed decision. All data and information supporting decisions in the PMP development process have been documented in this report so that results can be checked, reproduced, and verified.

Thirty-four rainfall events were identified across the storm search area as having similar characteristics to rainfall that could potentially control PMP depths at various locations with the study domain. These include 16 local storm rainfall centers, 12 general storm rainfall centers, and

six hybrid storm centers which exhibited characteristics of both storm types and were therefore evaluated as general and local storms in the PMP determination process.

Each storm utilized for PMP development was analyzed using the Storm Precipitation Analysis System (SPAS), which produced several standard products including DAD values, storm center mass curves, and total storm isohyetal patterns. National Weather Service Next Generation Weather Radar (NEXRAD) data were used in storm analyses when available (generally for storms which occurred after the mid-1990's).

Standard procedures were applied for in-place maximization adjustments (e.g., HMR 51 Section 2.3). New techniques and new datasets were used in other procedures to increase accuracy and reliability when justified by utilizing advancements in technology and meteorological understanding, while adhering to the basic approach used in the HMRs and in the WMO PMP Manual. Updated precipitation frequency analyses data available from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 were used for this study. These were used to calculate the Geographic Transposition Factors (GTFs) for each storm. The GTF procedure, through its correlation process, provided quantifiable and reproducible analyses of the effects of terrain and all other precipitation processes, to quantify the difference between two locations. Results of these factors (in-place maximization and geographic transposition) were calculated for each storm at each grid point for each of the area sizes and durations used in this study to define the PMP depths.

In-place maximization factors were computed for each of the analyzed storm events using updated dew point climatologies representing the maximum moisture equivalent to the 100-year recurrence interval for dew points that were associated with each rainfall event. The dew point climatology included the maximum average 6-, 12-, and 24-hour 100-year return frequency values. The most appropriate duration consistent with the duration of the storm rainfall was used. HYSPLIT model output, which represent model reanalysis fields of air flow in the atmosphere, and NWS synoptic weather maps were used as guidance in identifying the storm representative moisture source regions.

PMP calculation information was stored and analyzed in individual Excel spreadsheets and a GIS database. This combination of Excel and GIS was used to query, calculate, and derive PMP depths for each grid point for each duration for each storm type. The database allowed PMP to be calculated at any area size and/or duration available in the underlying SPAS data from 1/3rd-square mile through the total basin area size.

When compared to previous PMP depths provided in HMR 51 and the EPRI study the updated values from this study resulted in a wide range of reductions at most area sizes and durations, with minor increases at 12- and 24-hours when compared to the EPRI study. Providing PMP depths down to area sizes at 1/3rd-square miles and temporal accumulation patterns at 1-hour increments was a significant improvement for dam safety evaluations and design over what was previously available in the HMRs and the EPRI study.

Tables E.1-E.4 provide the basin average PMP depths for each of the four overall basins. The PMP depths are at the specific area size noted and are provide by storm type, local and general

**Table E.1: Overall Tittabawassee basin PMP depths, with controlling storms noted**

| General Storm 2475 mi² Basin Average PMP | | | | | |
|---|---|---|---|---|---|
| 1 | 6 | 12 | 24 | 48 | 72 |
| 2.1 | 7.4 | 12.8 | 14.1 | 15.7 | 16.6 |
| SPAS 1286_1<br>Aurora College, IL | SPAS 1286_1<br>Aurora College, IL<br>SPAS 1699_1<br>Hayward, WI | SPAS 1628_1<br>Jefferson, OH | SPAS 1628_1<br>Jefferson, OH | SPAS 1628_1<br>Jefferson, OH | SPAS 1628_1<br>Jefferson, OH |

| Local Storm 2475 mi² Basin Average PMP | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 12 | 24 |
| 2.3 | 3.8 | 4.9 | 6.1 | 6.9 | 7.5 | 10.3 | 11.7 |
| SPAS 1286_1<br>Aurora College, IL | SPAS 1286_1<br>Aurora College, IL | SPAS 1286_1<br>Aurora College, IL | SPAS 1699_1<br>Hayward, WI | SPAS 1699_1<br>Hayward, WI | SPAS 1699_1<br>Hayward, WI | SPAS 1699_1<br>Hayward, WI | SPAS 1699_1<br>Hayward, WI |

**Table E.2: Tittabawassee basin above the Pine River basin PMP depths, with controlling storms noted**

| General Storm 1447 mi² Basin Average PMP | | | | | |
|---|---|---|---|---|---|
| 1 | 6 | 12 | 24 | 48 | 72 |
| 2.4 | 8.0 | 13.1 | 14.3 | 16.1 | 17.1 |
| SPAS 1286_1<br>Aurora College, IL | SPAS 1699_1<br>Hayward, WI | SPAS 1628_1<br>Jefferson, OH | SPAS 1628_1<br>Jefferson, OH | SPAS 1628_1<br>Jefferson, OH | SPAS 1628_1<br>Jefferson, OH |

| Local Storm 1447 mi² Basin Average PMP | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 12 | 24 |
| 2.6 | 4.3 | 5.6 | 6.6 | 7.4 | 8.0 | 10.9 | 12.4 |
| SPAS 1286_1<br>Aurora College, IL | SPAS 1286_1<br>Aurora College, IL | SPAS 1286_1<br>Aurora College, IL | SPAS 1286_1<br>Aurora College, IL | SPAS 1699_1<br>Hayward, WI | SPAS 1699_1<br>Hayward, WI | SPAS 1699_1<br>Hayward, WI | SPAS 1699_1<br>Hayward, WI |

**Table E.3: Pine River basin PMP depths, with controlling storms noted**

| General Storm 1026 mi² Basin Average PMP | | | | | |
|---|---|---|---|---|---|
| 1 | 6 | 12 | 24 | 48 | 72 |
| 2.8 | 9.1 | 14.5 | 15.8 | 17.8 | 18.8 |
| SPAS 1286_1<br>Aurora College, IL | SPAS 1699_1<br>Hayward, WI | SPAS 1628_1<br>Jefferson, OH | SPAS 1628_1<br>Jefferson, OH | SPAS 1628_1<br>Jefferson, OH | SPAS 1628_1<br>Jefferson, OH |

| Local Storm 1026 mi² Basin Average PMP | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 12 | 24 |
| 3.1 | 5.1 | 6.7 | 7.8 | 8.5 | 9.2 | 12.5 | 14.2 |
| SPAS 1434_1<br>Holt, MO<br>SPAS 1286_1<br>Aurora College, IL | SPAS 1286_1<br>Aurora College, IL | SPAS 1286_1<br>Aurora College, IL | SPAS 1286_1<br>Aurora College, IL | SPAS 1286_1<br>Aurora College, IL | SPAS 1286_1<br>Aurora College, IL | SPAS 1699_1<br>Hayward, WI | SPAS 1699_1<br>Hayward, WI |

**Table E.4: Tittabawassee basin above Sanford Dam PMP depths, with controlling storms noted**

| General Storm 945 mi² Basin Average PMP | | | | | |
|---|---|---|---|---|---|
| 1 | 6 | 12 | 24 | 48 | 72 |
| 2.6 | 8.3 | 13.2 | 14.4 | 16.3 | 17.2 |
| SPAS 1286_1<br>Aurora College, IL | SPAS 1699_1<br>Hayward, WI | SPAS 1628_1<br>Jefferson, OH | SPAS 1628_1<br>Jefferson, OH | SPAS 1628_1<br>Jefferson, OH | SPAS 1628_1<br>Jefferson, OH |

| Local Storm 945 mi² Basin Average PMP | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 12 | 24 |
| 2.8 | 4.6 | 6.0 | 7.0 | 7.7 | 8.3 | 11.2 | 12.7 |
| SPAS 1434_1<br>Holt, MO<br>SPAS 1286_1<br>Aurora College, IL | SPAS 1286_1<br>Aurora College, IL | SPAS 1286_1<br>Aurora College, IL | SPAS 1286_1<br>Aurora College, IL | SPAS 1286_1<br>Aurora College, IL | SPAS 1286_1<br>Aurora College, IL | SPAS 1699_1<br>Hayward, WI | SPAS 1699_1<br>Hayward, WI |

# Glossary

**Adiabat:** Curve of thermodynamic change taking place without addition or subtraction of heat. On an adiabatic chart or pseudo-adiabatic diagram, a line showing pressure and temperature changes undergone by air rising or condensation of its water vapor; a line, thus, of constant potential temperature.

**Air mass:** Extensive body of air approximating horizontal homogeneity, identified as to source region and subsequent modifications.

**Cooperative station:** A weather observation site where an unpaid observer maintains a climatological station for the National Weather Service.

**Cyclone:** A distribution of atmospheric pressure in which there is a low central pressure relative to the surroundings. On large-scale weather charts, cyclones are characterized by a system of closed constant pressure lines (isobars), generally approximately circular or oval in form, enclosing a central low-pressure area. Cyclonic circulation is counterclockwise in the northern hemisphere and clockwise in the southern. (That is, the sense of rotation about the local vertical is the same as that of the earth's rotation).

**Depth-Area curve:** Curve showing, for a given duration, the relation of maximum average depth to size of area within a storm or storms.

**Depth-Area-Duration:** The precipitation values derived from Depth-Area and Depth-Duration curves at each time and area size increment analyzed for a PMP evaluation.

**Depth-Area-Duration values:** The combination of depth-area and duration-depth relations. Also called depth-duration-area.

**Depth-Duration curve:** Curve showing, for a given area size, the relation of maximum average depth of precipitation to duration periods within a storm or storms.

**Dew point:** The temperature to which a given parcel of air must be cooled at constant pressure and constant water vapor content for saturation to occur.

**Explicit transposition:** The movement of the rainfall amounts associated with a storm within boundaries of a region throughout which a storm may be transposed with only relatively minor modifications of the observed storm rainfall amounts. The area within the transposition limits has similar, but not identical, climatic and topographic characteristics throughout.

**Front:** The interface or transition zone between two air masses of different parameters. The parameters describing the air masses are temperature and dew point.

**General storm:** A storm event that produces precipitation over areas in excess of 500-square miles, has a duration longer than 6 hours, and is associated with a major synoptic weather feature.

**Geographic Transposition Factor:** A factor representing the comparison of precipitation frequency relationships between two locations which is used to quantify how rainfall is affected by physical processes related to location and terrain. It is assumed the precipitation frequency data are a combination of what rainfall would have accumulated without topographic affects and what accumulated because of the topography, both at the location and upwind of the location being analyzed.

**HYSPLIT:** Hybrid Single-Particle Lagrangian Integrated Trajectory. A complete system for computing parcel trajectories to complex dispersion and deposition simulations using either puff or particle approaches. Gridded meteorological data, on one of three conformal (Polar, Lambert, or Mercator latitude-longitude grid) map projections, are required at regular time intervals. Calculations may be performed sequentially or concurrently on multiple meteorological grids, usually specified from fine to coarse resolution.

**Implicit transpositioning:** The process of applying regional, areal, or durational smoothing to eliminate discontinuities resulting from the application of explicit transposition limits for various storms.

**Isohyets:** Lines of equal value of precipitation for a given time interval.

**Isohyetal pattern:** The pattern formed by the isohyets of an individual storm.

**Local storm:** A storm event that occurs over a small area in a short time period. Precipitation rarely exceeds 6 hours in duration and the area covered by precipitation is less than 500 square miles. Frequently, local storms will last only 1 or 2 hours and precipitation will occur over areas of up to 200 square miles. Precipitation from local storms will be isolated from general-storm rainfall. Often these storms are thunderstorms.

**Mass curve:** Curve of cumulative values of precipitation through time.

**Mesoscale Convective Complex:** For the purposes of this study, a heavy rain-producing storm with horizontal scales of 10 to 1000 kilometers (6 to 625 miles) which includes significant, heavy convective precipitation over short periods of time (hours) during some part of its lifetime.

**Mesoscale Convective System:** A complex of thunderstorms which becomes organized on a scale larger than the individual thunderstorms, and normally persists for several hours or more. MCSs may be round or linear in shape, and include systems such as tropical cyclones, squall lines, and MCCs (among others). MCS often is used to describe a cluster of thunderstorms that does not satisfy the size, shape, or duration criteria of an MCC.

**Moisture maximization:** The process of adjusting observed precipitation amounts upward based upon the hypothesis of increased moisture inflow to the storm.

**One-hundred year rainfall event:** The point rainfall amount that has a one-percent probability of occurrence in any year. Also referred to as the rainfall amount that has a 1 percent chance of occurring in any single year.

**Precipitable water:** The total atmospheric water vapor contained in a vertical column of unit cross-sectional area extending between any two specified levels in the atmosphere; commonly expressed in terms of the height to which the liquid water would stand if the vapor were completely condensed and collected in a vessel of the same unit cross-section. The total precipitable water in the atmosphere at a location is that contained in a column or unit cross-section extending from the earth's surface all the way to the "top" of the atmosphere. The 30,000 foot level (approximately 300mb) is considered the top of the atmosphere in this study.

**Persisting dew point:** The dew point value at a station that has been equaled or exceeded throughout a period. Commonly durations of 12 or 24 hours are used, though other durations may be used at times.

**Probable Maximum Flood:** The flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in a particular drainage area.

**Probable Maximum Precipitation:** Theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographic location at a certain time of the year.

**Pseudo-adiabat:** Line on thermodynamic diagram showing the pressure and temperature changes undergone by saturated air rising in the atmosphere, without ice-crystal formation and without exchange of heat with its environment, other than that involved in removal of any liquid water formed by condensation.

**Saturation:** Upper limit of water-vapor content in a given space; solely a function of temperature.

**Shortwave:** Also referred to as a shortwave trough, is an embedded kink in the trough / ridge pattern. This is the opposite of longwaves, which are responsible for synoptic scale systems, although shortwaves may be contained within or found ahead of longwaves and range from the mesoscale to the synoptic scale.

**Spatial distribution:** The geographic distribution of precipitation over a drainage according to an idealized storm pattern of the PMP for the storm area.

**Storm transposition:** The hypothetical transfer, or relocation of storms, from the location where they occurred to other areas where they could occur. The transfer and the mathematical adjustment of storm rainfall amounts from the storm site to another location is termed "explicit transposition." The areal, durational, and regional smoothing done to obtain comprehensive individual drainage estimates and generalized PMP studies is termed "implicit transposition" (WMO, 1986).

**Synoptic:** Showing the distribution of meteorological elements over an area at a given time, e.g., a synoptic chart. Use in this report also means a weather system that is large enough to be a major feature on large-scale maps (e.g., of the continental U.S.).

**Temporal distribution:** The time order in which incremental PMP amounts are arranged within a PMP storm.

**Transposition limits:** The outer boundaries of the region surrounding an actual storm location that has similar, but not identical, climatic and topographic characteristics throughout. The storm can be transpositioned within the transposition limits with only relatively minor modifications to the observed storm rainfall amounts.

# List of Acronyms

**AMS:** Annual maximum series

**AWA**: Applied Weather Associates

**DA:** Depth-Area

**DAD:** Depth-Area-Duration

**dd:** decimal degrees

**DND:** Drop number distribution

**DSD:** Drop size distribution

**EPRI:** Electric Power Research Institute

**F:** Fahrenheit

**FERC:** Federal Energy Regulatory Commission

**GCS:** Geographical coordinate system

**GIS:** Geographic Information System

**GRASS:** Geographic Resource Analysis Support System

**GTF**: Geographic Transposition Factor

**HMR**: Hydrometeorological Report

**HRRR:** High-Resolution Rapid Refresh Model

**HYSPLIT:** Hybrid Single Particle Lagrangian Integrated Trajectory Model

**IDW:** Inverse distance weighting

**IPMF**: In-place Maximization Factor

**LLJ:** Low-level Jet

**MADIS:** NCEP Meteorological Assimilation Data Ingest System

**mb:** millibar

**MCC:** Mesoscale Convective Complex

**MCS**: Mesoscale Convective System

**NCAR:** National Center for Atmospheric Research

**NCDC:** National Climatic Data Center

**NCEI:** National Centers for Environmental Information

**NCEP:** National Centers for Environmental Prediction

**NEXRAD:** Next Generation Radar

**NOAA**: National Oceanic and Atmospheric Administration

**NRC:** Nuclear Regulatory Commission

**NRCS**: Natural Resources Conservation Service

**NWS**: National Weather Service

**PMF:** Probable Maximum Flood

**PMP**: Probable Maximum Precipitation

**PRISM:** Parameter-elevation Relationships on Independent Slopes

**PW:** Precipitable Water

**SMC:** Spatially Based Mass Curve

**SPAS:** Storm Precipitation and Analysis System

**SPP:** Significant Precipitation Period

**TAF:** Total Adjustment Factor

**TAR:** Total Adjusted Rainfall

**USACE**: US Army Corps of Engineers

**USBR**: Bureau of Reclamation

**USGS:** United States Geological Survey

**WMO**: World Meteorological Organization

# 1. Probable Maximum Precipitation Development Background

This study provides Probable Maximum Precipitation (PMP) depths for the Tittabawassee River basin, including the Pine River basin and the basin above Sanford Dam (Figure 1.1). The PMP depths are used in the computation of the Probable Maximum Flood (PMF) for the design of high-hazard structures and as information for inflow design floods. PMP depths calculated in this study supersede PMP depths from Hydrometeorological Reports (HMR) 51 (Schreiner and Riedel, 1978) and the EPRI Michigan Wisconsin Regional PMP study (EPRI) (Tomlinson, 1993).

PMP is a deterministic estimate of the theoretical maximum depth of precipitation that can occur over a specified area, at a given time of the year, over a given duration. Parameters to estimate PMP utilized in this study were developed using the storm based, deterministic approach as discussed in the HMRs and subsequently refined in the numerous site-specific, statewide, and regional PMP studies completed since the early 1990's (e.g., Kappel et al. 2013-2021).

Methods used to derive PMP depths for this study included consideration of numerous extreme rainfall events that have been appropriately adjusted to each grid point covering the overall basin domain and representing each PMP storm type relevant for this basin, local and general storms. Hundreds of storms were considered, with 34 events used for final PMP estimation. The large number of storm events provided enough data from which to derive the PMP depths within an acceptable amount of uncertainty for use in developing the PMF. The process of combining maximized storm events by storm type into a hypothetical PMP design storm resulted in a reliable PMP estimation by combining the worst-case combination of meteorological factors in a physically possible manner.

During this calculation process, air masses that provide moisture to both the historic observed storm and the hypothetical PMP storm were assumed to be saturated through the entire depth of the atmosphere and contain the maximum moisture possible represented by surface dew point observation converted to an amount of precipitable water. This saturation process used moist pseudo-adiabatic temperature profiles for both the historic storm and the PMP storm to derive precipitable water value for the observed storm and the PMP storm.

The storm based method assumed that the period of record available covering a large region included enough extreme rainfall events so that at least a few storms attained the maximum storm efficiency possible for converting atmospheric moisture to rainfall. PMP development processes assume that if surplus atmospheric moisture had been available, an individual extreme storm would have maintained the same efficiency for converting atmospheric moisture to rainfall and therefore produce more rainfall. The ratio of the maximized rainfall amounts to the actual rainfall amounts is represented by the ratio of the precipitable water in the observed storm versus the climatological maximum precipitable water in the atmosphere associated with each storm.

Current understanding of meteorology does not support an explicit evaluation of storm efficiency for use in PMP evaluation. To compensate for this, data is evaluated from the entire period of record (nearly 150 years for this study), along with an extended geographic region from which to choose storms. Using the long period of record and the large geographic region, the assumption is that at least one storm with dynamics (storm efficiency) that approached the maximum efficiency for rainfall production used in the PMP development has been included. In essence, the process is trading time for space to capture PMP processes.

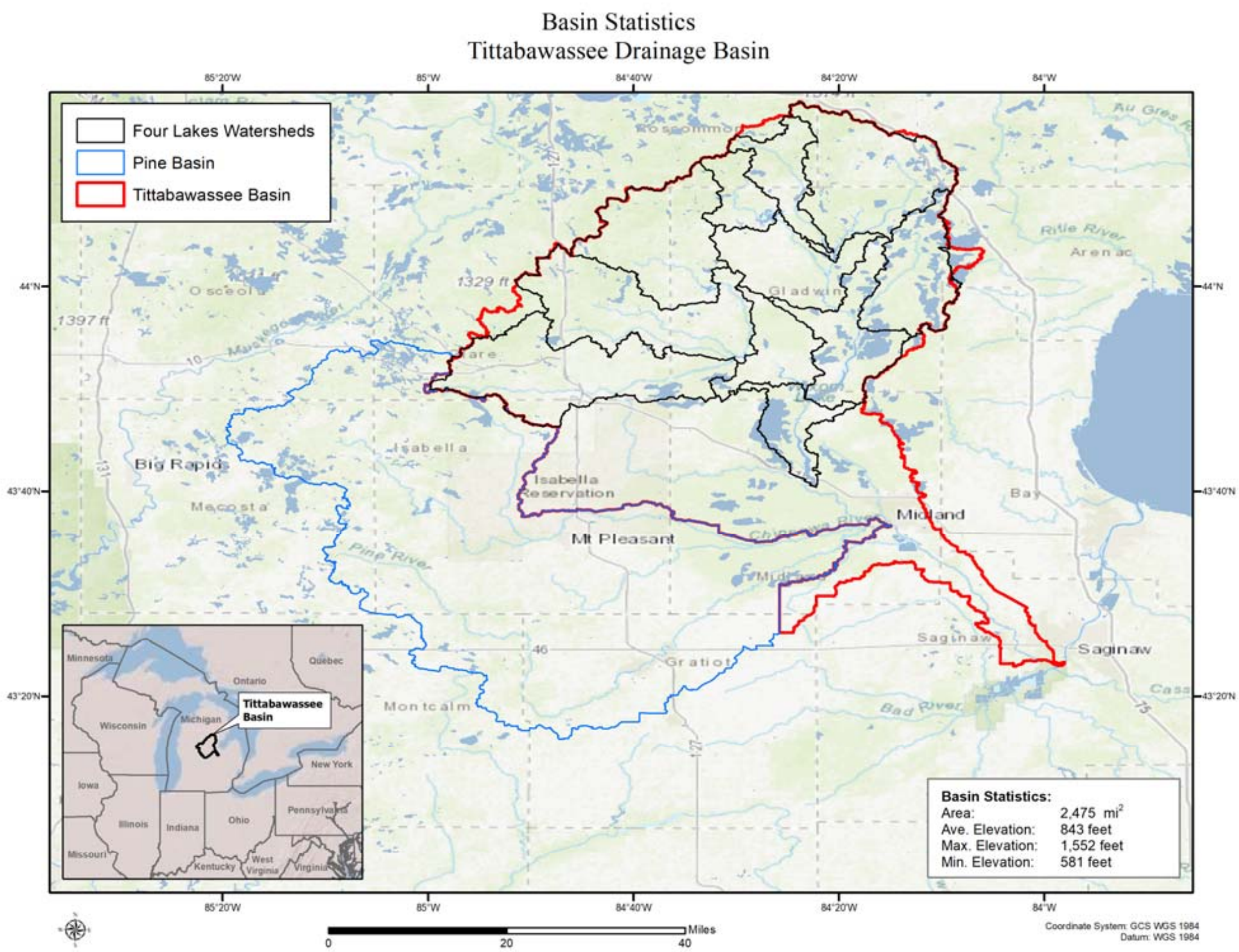


**Figure 1.1: Probable Maximum Precipitation study domain**

## 1.1 Background

Definitions of PMP are found in most of the HMRs issued by the National Weather Service (NWS). The definition used in the most recently published HMR is "theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location at a certain time of the year" (HMR 59, p. 5) (Corrigan et al., 1999). Since the early 1940s, several government agencies have developed methods to calculate PMP for various regions of the United States. The NWS (formerly the U.S. Weather Bureau), the U.S. Army Corps of Engineers (USACE), and the U.S. Bureau of Reclamation (USBR) have been the primary Federal agencies involved in this activity. PMP depths presented in their reports are used to calculate the PMF, which in turn, is often used for the design of high hazard hydraulic structures. It is important to remember that the methods used to derive PMP and the hydrological procedures that use the PMP depths need to adhere to the requirement of being "physically possible." In other words, various levels of conservatism and/or extreme aspects of storms that could not physically occur in a PMP storm environment over the location analyzed should not be used to produce combinations of storm characteristics that are not physically consistent in determining PMP for the hydrologic applications.

The generalized PMP studies currently in use in the contiguous United States include HMRs 49 (1977) and 50 (1981) for the Colorado River and Great Basin drainage; HMRs 51 (1978), 52 (1982), and 53 (1980) for the U.S. east of the 105th meridian; HMR 55A (1988) for the area between the Continental Divide and the 103rd meridian; HMR 57 (1994) for the Columbia River Drainage; and HMRs 58 (1998) and 59 (1999) for California (Figure 1.2).

In addition to these HMRs, numerous Technical Papers and Reports deal with specific subjects concerning precipitation (e.g., Technical Paper 1, 1946; Technical Paper 16, 1952; NOAA Tech. Report NWS 25, 1980; and NOAA Tech. Memorandum NWS HYDRO 40, 1984). Topics in these papers include maximum observed rainfall amounts for various return periods and specific storm studies. Climatological atlases (e.g., Technical Paper No. 40, 1961; NOAA Atlas 2, 1973; and NOAA Atlas 14, 2004-2018) are available for use in determining precipitation return periods such as the 100-year recurrence interval rainfall depth. A number of site-specific, statewide, and regional studies (e.g., Tomlinson 1993; Tomlinson et al., 2002-2013; Kappel et al., 2013-2021) augment generalized PMP reports for specific regions included in the large areas addressed by the HMRs. Recent site-specific PMP projects completed within the domain have updated the storm database and many of the procedures used to estimate PMP depths in the HMRs and the EPRI study. This study continued that process by applying the most current understanding of meteorology related to extreme rainfall events and updating the storm database through June of 2021. PMP results from this study provide values that replace those derived from HMR 51 and the EPRI study.

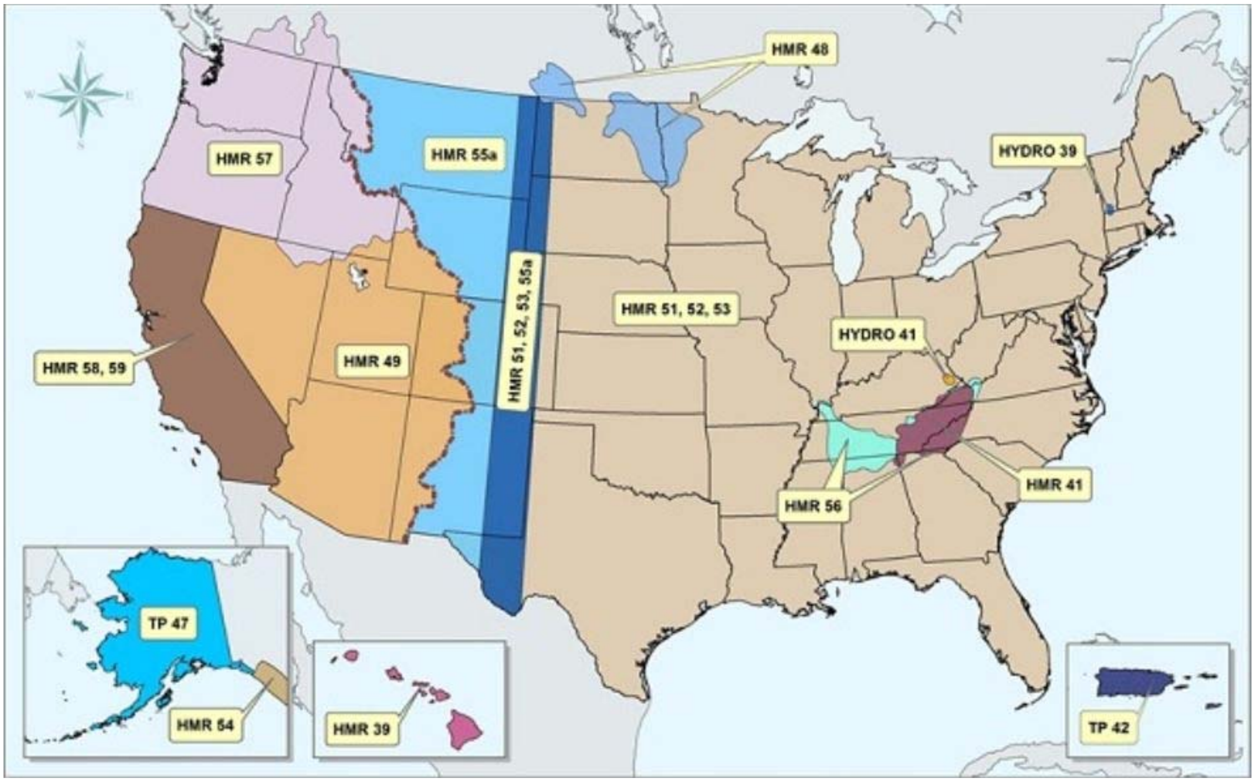


**Figure 1.2: Hydrometeorological Report coverages across the United States**

The Tittabawassee Basin is included within the domain covered by HMR 51 and HMR 52 (Figure 1.3). HMR 52 provided background information and hydrologic implementation guidelines for the storm data developed in HMR 51. These HMRs cover diverse meteorological and topographical regions. Although it provides generalized estimates of PMP depths for a large, climatologically diverse area, HMR 51 recognizes that studies addressing PMP over specific regions can incorporate more site-specific considerations and provide improved PMP estimates. Additionally, by periodically reviewing storm data and advances in meteorological concepts, PMP analysts can identify relevant new data and approaches for use in making improved PMP estimates.

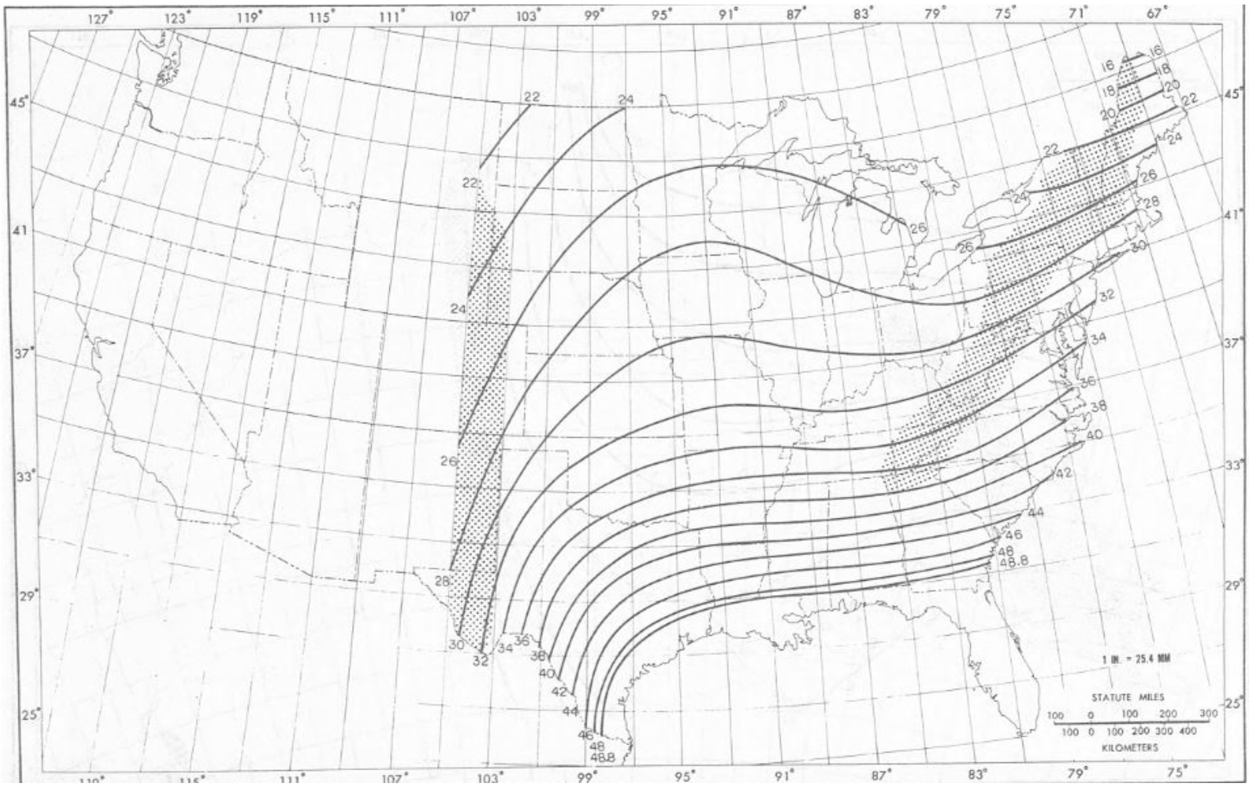


**Figure 1.3: Example of HMR 51 72-hour 200-square mile PMP map (from Schreiner and Riedel, 1978).**

The region analyzed in this study includes climate variations that include storms influenced by low-level jet (LLJ) interactions, thunderstorm complexes, and frequent passages of large-scale frontal systems (Figure 1.4). PMP depths must account for the complexity of the meteorology and terrain. Although the HMRs provided relevant data at the time they were published, the understanding of meteorology and effects of terrain on rainfall (orographic effects) have advanced significantly in the subsequent years. Limitations that can now be addressed include updates to the overall storm database, explicit calculation to address variation in elevation, improved documentation allowing for reproducibility, quantification of the probability of PMP depths, and the application of site-specific storm transposition limits. This project incorporated the latest methods, technology, and data to address these complexities. Each of these were addressed and updated where data and current understanding of meteorology allowed.

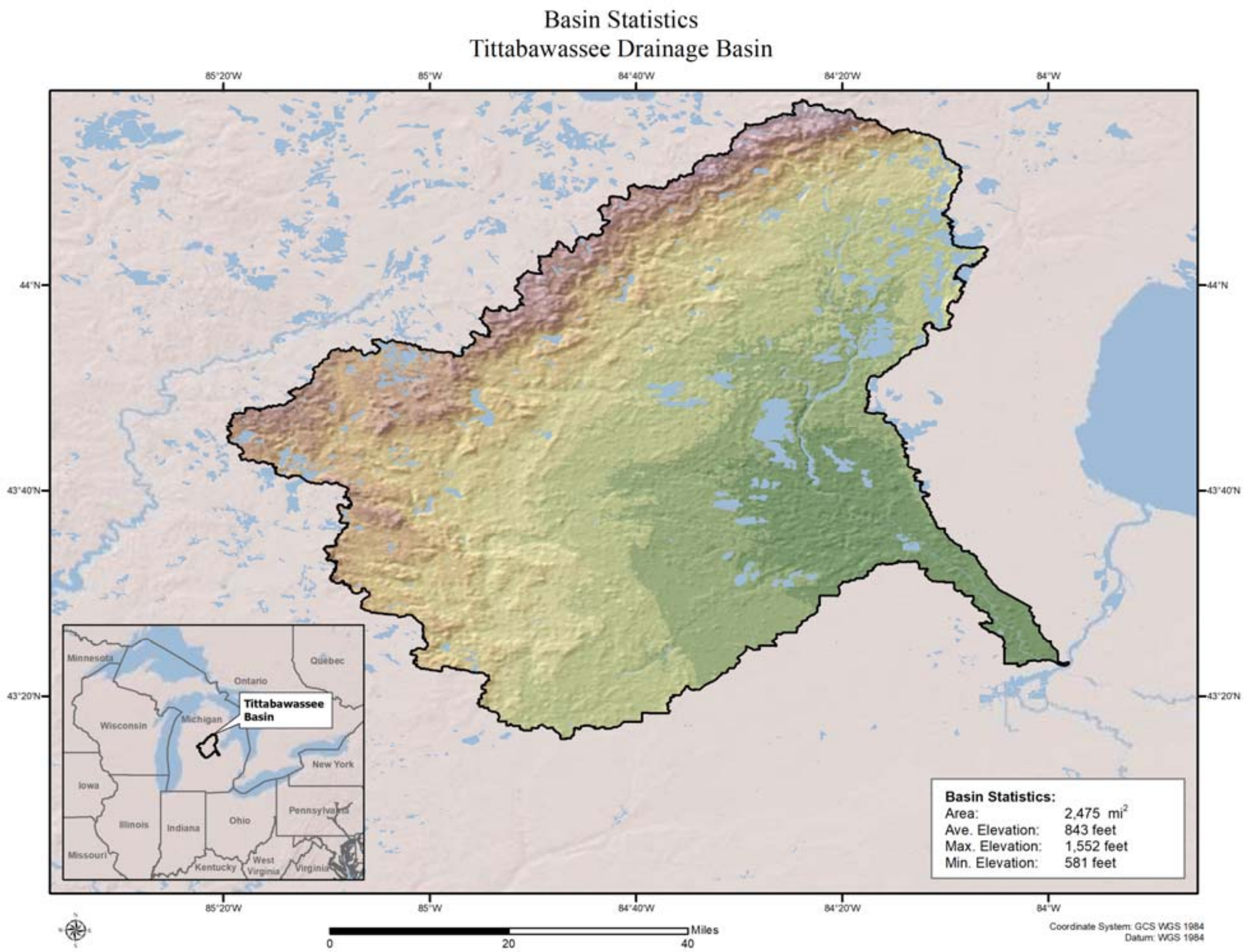


**Figure 1.4: Topography cross the overall PMP Domain**

Previous site-specific, statewide, and regional PMP projects completed by AWA provide examples that explicitly consider the unique topography of region and characteristics of historic extreme storms over similar regions surrounding the area. The procedures incorporate the most up-to-date data, techniques, and applications to derive PMP. AWA PMP studies have received extensive review and the results have been used in computing the PMF for the watersheds. This study follows similar procedures employed in those studies while making improvements where advancements in computer-aided tools and transposition procedures have become available.

Several PMP studies have been completed by AWA within the region covered by HMR 51 and the EPRI study, which are directly relevant to this study (Figure 1.5). Each of these provided PMP depths which updated those from HMR 51. These are examples of PMP studies that explicitly consider the meteorology and topography of the study location along with characteristics of historic extreme storms over climatically similar regions. Information, experience, and data from these PMP studies were utilized in this study. These included use of previously analyzed storm events using the SPAS program (Hultstrand and Kappel, 2017), previously derived storm lists, previously derived in-place storm maximization factors, climatologies, and explicit understanding of the meteorology of the region. In addition, comparisons to these previous studies provided sensitivity and context with results of this study.

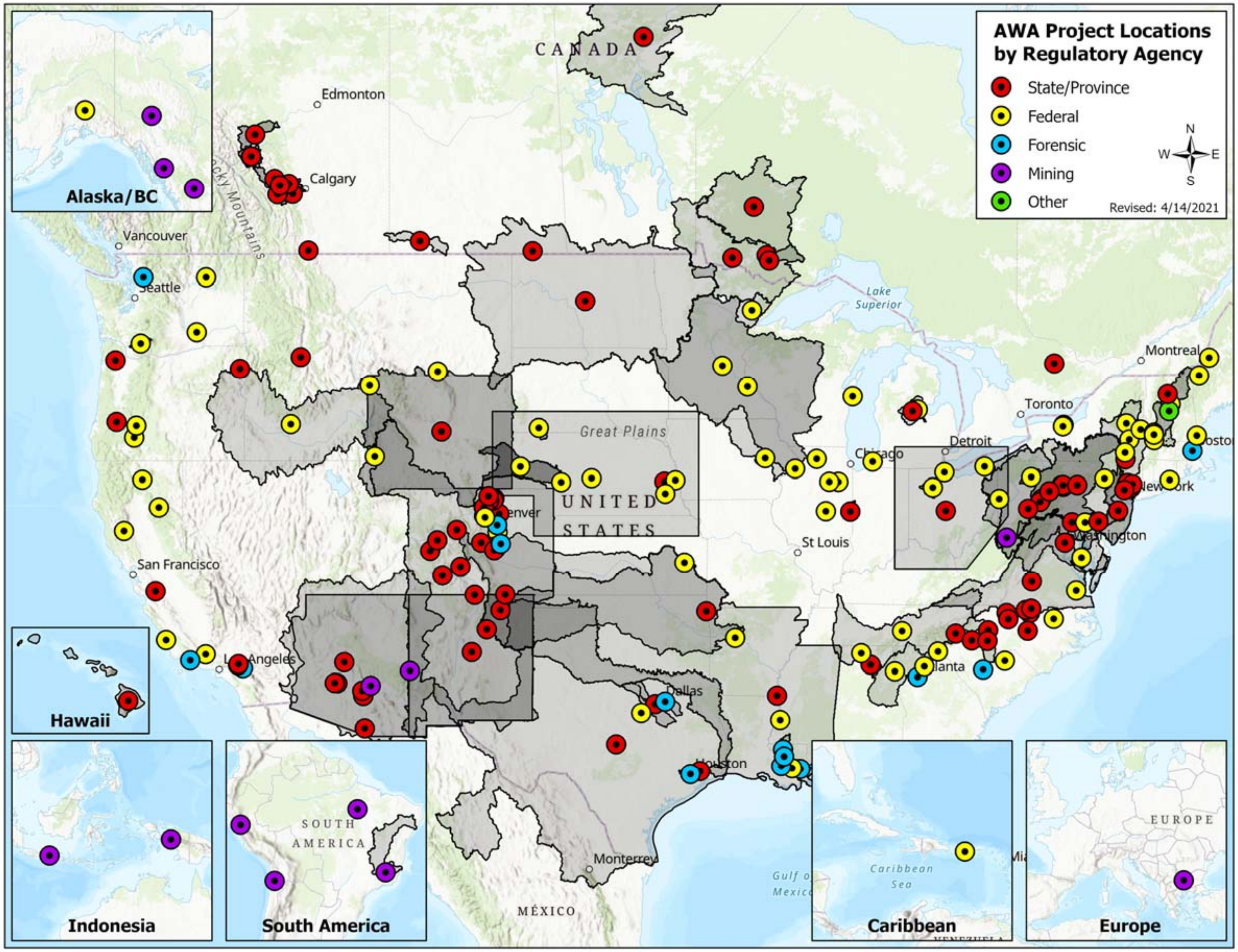


**Figure 1.5: Locations of AWA PMP studies as of April 2021**

## 1.2 Objective

This study determined estimates of PMP depths for use in computing the PMF for the Tittabawassee River basin and various watersheds within the overall project domain. Updates to methods and data used in HMRs and the EPRI were applied where appropriate.

## 1.3 PMP Analysis Domain

The project domain was defined to cover the Tittabawassee River basin, the Pine River basin, and the Four Lakes domain upstream of Stanford Dam. This study allows for gridded PMP depths to be determined for each grid cell within the project domain. The full PMP analysis domain is shown in Figure 1.1. Discussions with Four Lakes Task Force members and private consultants involved in the study helped refine the analysis to fully incorporate all potential aspects that may affect any portion of the study domain.

## 1.4 PMP Analysis Grid Setup

A uniform grid covering the PMP project domain provides a spatial framework for the analysis. PMP grid resolution for this study was 0.025 x 0.025 decimal degrees (dd), or 90 arc-seconds, using the Geographic Coordinate System (GCS) spatial reference with the World Geodetic System of 1984 (WGS 84) datum. This resulted in 1,273 grid cells with centroids within the domain. Each grid cell represents an approximate area of 2.2-square miles. The grid network placement is essentially arbitrary. However, the placement was oriented in such a way that the grid cell centroids are centered over whole number coordinate pairs and then spaced evenly every 0.025 dd. For example, there is a grid cell centered over 44.0°N and 84.5°W with the adjacent grid point to the west at 44.0°N and 84.525°W. As an example, the PMP analysis grid over the entire PMP domain is shown in Figure 1.6.

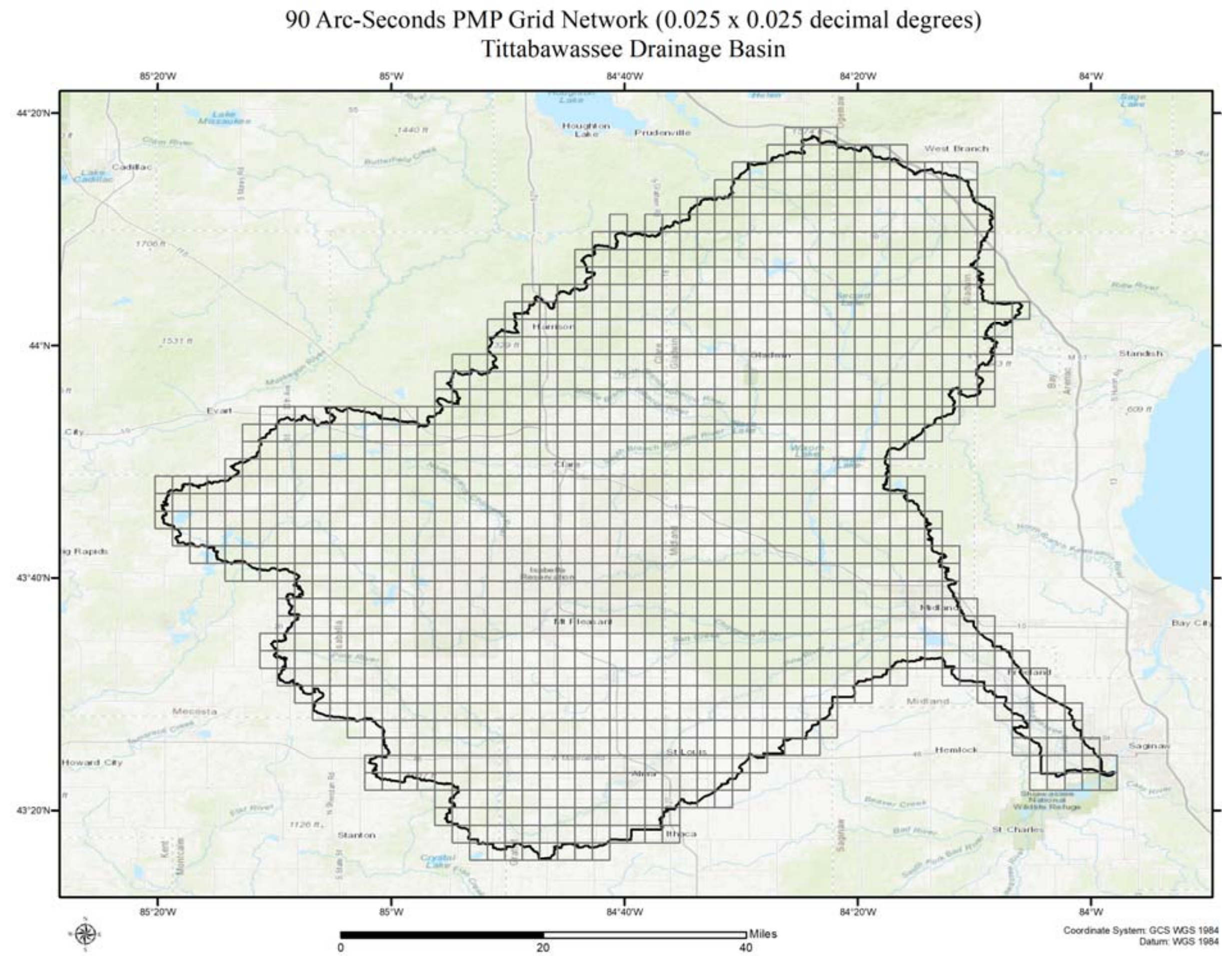


**Figure 1.6: PMP analysis grid placement over the Tittabawassee River basin**

# 2. Methodology

The storm-based approach used in this study is consistent with many of the procedures that were used in the development of the HMRs and as described in the World Meteorological Organization PMP documents (WMO, 2009). As part of this stie-specific study, AWA has applied updated procedures to improve on the processes and reduce uncertainty when support by data and improved understanding. Methodologies reflecting the current standard of practice were applied in this study considering the unique meteorological and topographical interactions within the region as well as the updated scientific data and procedures available. Figure 2.1 provides the general steps used in deterministic PMP development utilizing the storm-based approach.

This study identified major storms that occurred within the region considered transpositionable to any location within the overall basin. Each of the PMP storm types capable of producing PMP-level rainfall were identified and investigated. PMP storm types included local storms and general storms. The final short list of storms used for PMP calculations was extensively reviewed, quality controlled, and accepted as representative of all storms that could potentially effect PMP depths at any location or area size within the overall study domain. This short list of storms was utilized to derive the PMP depths for all locations.

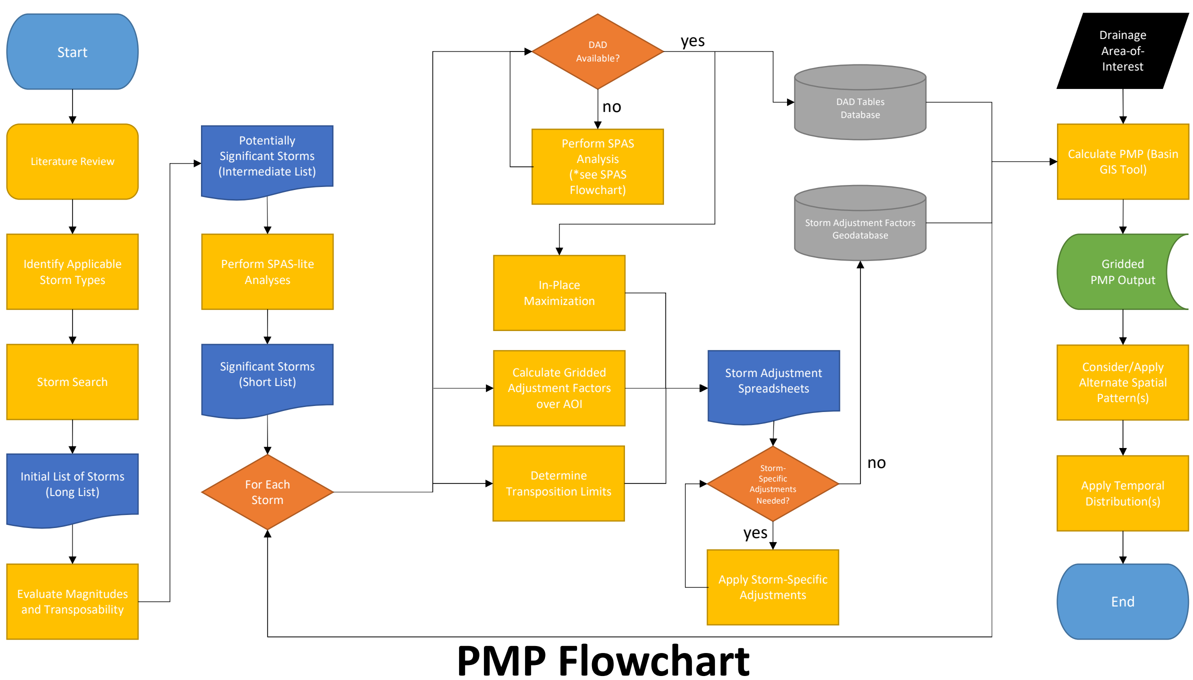


**Figure 2.1: Probable Maximum Precipitation calculation steps**

The moisture content of the short list storms was maximized to provide worst-case rainfall accumulation for each storm at the location where it occurred (in-place storm location). Storms were then transpositioned to each grid within the basin. Adjustments were applied to each storm as it was transpositioned to each grid point to calculate the amount of rainfall each storm would have produced at each grid point versus what it produced at the original location.

These adjustments were combined to produce the total adjustment factor (TAF) for each storm for each grid point for each duration. The TAF is applied to the observed precipitation depths at the area size of interest.

SPAS was utilized to analyze the rainfall associated with each storm used for PMP development. SPAS has been used to analyze more than 800 extreme rainfall events since 2002. SPAS analyses are used in PMP development as well as other meteorological applications including input for model calibration and validation. SPAS has been extensively peer reviewed and accepted as appropriate for use in analyzing precipitation accumulation by numerous independent review boards and as part of the Nuclear Regulatory Commission (NRC) software certification process (Hultstrand and Kappel, 2017). Appendix E provides a detailed description of the SPAS program.

The TAF is a product of the In-Place Maximization Factor (IPMF) and the Geographic Transposition Factor (GTF) (see Section 9.5). The governing equation used for computation of the Total Adjusted Rainfall (TAR), for each storm for each grid cell for each duration, is given in Equation 1.

$$TAR_{xhr} = P_{xhr} \times IPMF \times GTF \qquad \text{(Equation 1)}$$

where:

$TAR_{xhr}$ is the Total Adjusted Rainfall value at the x-hour (x-hr) duration for the specific grid cell at each duration at the target location;

$P_{xhr}$ is the x-hour precipitation observed at the historic in-place storm location (source location) for the basin-area size;

*In-Place Maximization Factor* (*IPMF)* is the adjustment factor representing the maximum amount of atmospheric moisture that could have been available to the storm for rainfall production;

*Geographic Transposition Factor (GTF)* is the adjustment factor accounting for precipitation frequency relationships between two locations. This is used to quantify all processes that effect rainfall, including terrain, location, and seasonality.

Note, the largest of these values at each duration becomes PMP at each grid point and the sum of those depths represents the basin average PMP depths. The data and calculations are run at the area size and duration(s) specified in coordination with the hydrologist and can extend from a single grid through the entire basin area size. The PMP output depths are then provided for durations required for Probable Maximum Flood (PMF) analysis at a given location by storm type and provided as a basin average. These data have various spatial patterns and temporal patterns associated with them for hydrologic modeling implementation. The spatial and temporal patterns are based on climatological patterns (spatial) and a synthesis of historic storm accumulation patterns (temporal) used in this study.

# 3. Weather and Climate of the Region

The region is influenced by several factors that can potentially contribute to extreme rainfall. First is the proximity to the Gulf of Mexico which allows for high amounts of moisture to move directly into the region (Figure 3.1). The lift required to convert these high levels of moisture into rainfall on the ground is provided in several ways over the basin.

Numerous large-scale weather systems with their associated fronts traverse the region. These fronts (boundaries between two different air masses) can be a focusing mechanism providing upward motion in the atmosphere. These are often locations where heavy rainfall is produced. A front typically will move through with enough speed that no given area receives excessive amounts of rainfall. However, some of these fronts will stall or move very slowly across the region, allowing heavy amounts of rainfall to continue for several days in the same general area, which can lead to extreme widespread flooding.

Another mechanism, which creates lift in the region, is heating of the surface and lower atmosphere by the sun. This creates warmer air below cold air resulting in atmospheric instability and leads to rising motions. This will often form ordinary afternoon and evening thunderstorms. However, in unique circumstances, the instability and moisture levels in the atmosphere can reach very high levels and stay over the same region for an extended period of time. This can lead to intense thunderstorms and very heavy rainfall. If these storms are focused over the same area for a long period, flooding rains can be produced. This type of storm produces some of the largest point rainfall recorded, but often does not affect larger areas with extreme rainfall amounts.


**Figure 3.1: Synoptic weather features associated with moisture from the Gulf of Mexico into the region**

## 3.1 Regional Climatological Characteristics Affecting PMP Storm Types

Weather patterns in the region are characterized by:

1. Areas of low pressure moving through the region from the west through the southwest or redeveloping along the lee slopes of the Rocky Mountains or over the warm water of the Gulf of Mexico (general storms) and moving into the region from the northwest, west, or southwest;
2. Isolated thunderstorms/Mesoscale Convective Systems (local storms). These generally form to the northwest or west of the region and follow the atmospheric steering current around high pressure to the east as they move through the region

General storms which produce PMP-type rainfall are most frequent in the summer and fall. Local storms which can produce PMP-type rainfall are most active from mid spring through early fall.

## 3.2 Storm Types

PMP storm types investigated during the study were local thunderstorms/Mesoscale Convective Systems (MCS) where the main rainfall occurs over short durations and small area sizes and general storms where main rainfall occurs over large areas sizes and longer durations and is associated with frontal system and strong areas of low pressure. The unique temporal patterns associated with each of these storm types was explicitly investigated. These patterns were based on the output from the adjacent Pennsylvania statewide PMP study. Detailed descriptions of the temporal patterns can be found in Section 12 of the report documentation from that study and can be downloaded at https://www.dep.pa.gov/Business/Water/Waterways/DamSafety/Pages/Probable-Maximum-Precipitation-Study-.aspx.

The classification of storm types, and hence PMP development by storm type used in this study, is similar to descriptions provided in several HMRs. Storms were classified by rainfall accumulation characteristics, while trying to adhere to previously used classifications. In addition, the storm classifications were cross-referenced with the storm typing completed as part of several other AWA PMP studies in the region (e.g., Tomlinson, 1993; Tomlinson et al. 2008; Tomlinson et al. 2013; Kappel et al., 2015; Kappel et al., 2019; Kappel et al., 2021) to ensure consistency between how storms were used in adjacent studies.

Local storms were defined using the following guidance:

- The main rainfall accumulation period occurred over a 6-hour period or less
- Was previously classified as a local storm in the EPRI study, by the USACE, or in the HMRs
- Was not associated with overall synoptic patterns leading to rainfall across a large (1000's of square miles) region
- Exhibited high intensity accumulations compared to general storms
- Occurred during the appropriate season, May through October

General storms were defined using the following guidance:

- The main rainfall accumulation period lasted for 24 hours or longer
- Occurred with a synoptic environment associated with a low-pressure system, frontal interaction, and/or regional precipitation coverage
- Was previously classified as a general storm int eh EPRI study, by the USACE, or in the HMRs
- Exhibited lower rainfall accumulation intensities compared to local storms

It should be noted that some of the storms exhibit characteristics of both storm types and therefore have been evaluated for PMP development as each storm type. These are classified as hybrid storms.

### 3.2.1 Local Storms

Localized thunderstorms and MCSs are capable of producing extreme amounts of precipitation for short durations and over small area sizes, generally 6 hours or less over area sizes of 500 square miles or less. During any given hour, the heaviest rainfall only covers very small areas, generally less than 100 square miles.

Many of the storms previously analyzed by the USACE and NWS Hydrometeorological Branch, in support of pre-1979 PMP research, have features that indicate they were most likely Mesoscale Convective Complexes (MCCs) or MCSs. However, this nomenclature had not yet been introduced into the scientific literature, nor were the events fully understood. It is important to note that an MCC is a subset of the broader MCS category of mesoscale atmospheric phenomena. Another example of an MCS is the derecho, an organized line of thunderstorms that are notable for strong winds and resultant significant wind damage.

A mesoscale convective complex (MCC) is a mesoscale convective system that satisfies all of the following criteria:

- The spatial extent of the cloud shield with cloud-top temperatures less than or equal to -32 degrees Celsius (-26 degrees Fahrenheit) must be at least 100,000 square kilometers, roughly two-thirds of the state of Iowa;
- The spatial extent of the coldest cloud tops with temperatures less than or equal to -52 degrees Celsius (-62 degrees Fahrenheit) must be at least 50,000 square kilometers;
- These size criteria must persist for at least six hours;
- Around the time of maximum extent, the cloud shield must be roughly circular in shape...refers to the cloud shield of cold cloud tops (temperatures less than or equal to -32 degrees Celsius) reaches its maximum size.

A typical MCC begins as an area of thunderstorms over the western High Plains or Front Range of the Rocky Mountains. As these storms begin to form early in the day, the predominantly westerly winds aloft move them in a generally eastward direction. As the day progresses, the rain-cooled air below and around the storm begins to form a mesoscale high-pressure area. This mesoscale high moves along with the area of thunderstorms. During nighttime hours, the MCC undergoes rapid development as it encounters increasingly warm and humid air from the Gulf of Mexico, usually associated with the low-level jet (LLJ) 3,000-5,000 feet above the ground. In the most extreme cases, this can be associated with the "Maya Express" pattern, where the moisture advecting into the region is enhanced significantly. This feed of moisture at a similar level at the LLJ over the Great Plains, can result in extreme rainfall accumulations when it is focused on the same areas for several days (Dirmeyer and Kitner, 2007).

The area of thunderstorms will often form a ring around the leading edge of the mesoscale high and continue to intensify, producing heavy rain, damaging winds, hail, and/or tornadoes. An MCC will often remain at a constant strength as long as the LLJ continues to provide an adequate supply of moisture. Once the mesoscale environment begins to change, the storms weaken, usually around sunrise, but may persist into the early daylight hours (Maddox, 1980).

Separate from MCC and MCS storm types, individual thunderstorms can be isolated from the overall general synoptic weather patterns and fueled by localized moisture sources. The local storm type in the region has a distinct seasonality, occurring during the warm season when the combination of moisture and atmospheric instability is at its greatest. This is the time of the year when convective characteristics and moisture within the atmosphere are adequate to produce lift and instability needed for thunderstorm development and heavy rainfall. Note that because of the relatively large size of each of the basins investigated in this study, the general storm type and storms with hybrid characteristics are most important for PMP development.

#### 3.2.2 General Storms

General storms occur in association with frontal systems along boundaries between sharply contrasting air masses. Precipitation associated with frontal systems is enhanced when the movement of weather patterns slow or stagnates, allowing moisture and instability to affect the same general region for several days. In addition, when there is a larger than normal thermal contrast between air masses in combination with higher-than-normal moisture, PMP-level precipitation can occur. Intense regions of heavy rain can also occur along a front as a smaller scale disturbance moving along the frontal boundary, called a shortwave, creating a region of enhanced lift and instability. These shortwaves are not strong enough to move the overall large-scale pattern, but instead add to the storm dynamics and energy available for producing precipitation.

This type of storm will usually not produce the highest rainfall rates over short durations, but instead cause widespread flooding as moderate rain continues to fall over the same region for an extended period of time, such as occurred during May 2020.

# 4. Data Description and Sources

An extensive storm search was conducted as part of adjacent studies and updated during this study to derive the list of storms to use for PMP development. This included investigating the storm lists from previous relevant studies in the region (e.g., statewide studies in Nebraska, Ohio, Texas, regional PMP study for the Tennessee Valley Authority, Pennsylvania, regional PMP study for Oklahoma-Arkansas-Louisiana-Mississippi, North Dakota, and several site-specific studies within the region). The storm list and the updated storm search completed to augment those previous storm lists utilized data from the sources below:

1. Hydrometeorological Reports 1, 33, 51, 52, 55A each of which can be downloaded from the Hydrometeorological Design Studies Center website at http://www.nws.noaa.gov/oh/hdsc/studies/pmp.html
2. Cooperative Summary of the Day / TD3200 through 2021. These data are published by the National Center for Environmental Information (NCEI), previously the National Climatic Data Center (NCDC). These are stored on AWA's database server and can be obtained directly from the NCEI.
3. Hourly Weather Observations published by NCEI, U.S. Environmental Protection Agency, and Forecast Systems Laboratory (now National Severe Storms Laboratory). These are stored on AWA's server and can be obtained directly from the NCEI.
4. NCEI Recovery Disk. These are stored on AWA's database server and can be obtained directly from the NCEI.
5. U.S. Corps of Engineers Storm Studies (USACE, 1973)
6. United States Geological Society (USGS) Flood Reports)
7. Other data published by NWS offices. These can be accessed from the National Weather Service homepage at http://www.weather.gov/.
8. Data from supplemental sources, such as Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS), Weather Underground, Forecast Systems Laboratories, RAWS, and various Google searches
9. Previous and ongoing PMP and storm analysis work (Tomlinson, 1993; Tomlinson et al., 2008-2013; Kappel et al., 2013-2021)
10. Peer reviewed journals articles

## 4.1 Use of Dew Point Temperatures

HMR and WMO procedures for storm maximization use a representative storm dew point as the parameter to represent available moisture to a given storm. Prior to the mid-1980s, maps of maximum 12-hour persisting dew point values from the *Climatic Atlas of the United States* (EDS, 1968) were the source for maximum dew point values. This study used the 100-year return frequency dew point climatology, which is updated every few years by AWA. Storm precipitation amounts were maximized using the ratio of precipitable water for the maximum dew point to precipitable water for the storm representative dew point, assuming a vertically saturated atmosphere through 30,000 feet. The precipitable water values associated with each storm representative value were taken from the WMO Manual for PMP Annex 1 (1986).

Use of the 100-year recurrence interval dew point climatology in the maximization process is appropriate because it provides a sufficiently rare occurrence of moisture level when combined with the maximum storm efficiency to produce a combination of rainfall producing mechanism that could physically occur. Recent research has shown that the assumption of combining the maximum storm efficiency with the maximum dew point value results in the most conservative combination of storm parameters and hence the most conservative PMP depths when considering all the possibilities of PMP development (Alaya et al., 2018).

An envelope of maximum dew point values is no longer used because in many cases the maximum observed dew point values do not represent a meteorological environment that would produce rainfall, but instead often represents a local extreme moisture value that can be the result of local evapotranspiration and other factors not associated with a storm environment and fully saturated atmosphere. Also, the data available has changed significantly since the publication of the maximum dew point climatologies used in HMR 51. Hourly dew point observations became standard at all first order NWS weather stations starting in 1948. This has allowed for a sufficient period of record of hourly data to exist from which to develop the climatologies out to the 100-year recurrence interval. These data were not available in sufficient quantity and period of record during the development of HMR 51.

Maximum dew point climatologies are used to determine the maximum atmospheric moisture that could have been available to a given storm events. Prior to the mid-1980s, maps of maximum dew point values from the *Climatic Atlas of the United States* (EDS, 1968) were the source for maximum dew point values. For the region covered by HMR 49, HMR 50 (Hansen and Schwartz, 1981) provided updated dew point climatologies. HMR 55A provided updated maximum dew point values for a portion of United States from the western High Plains through the Continental Divide. HMR 57 updated the 12-hour persisting dew points values and added a 3-hour persisting dew point climatology. The regional PMP study for Michigan and Wisconsin (EPRI study) produced dew point frequency maps representing the 50-year recurrence interval. The choice to use a recurrence interval and average duration was first determined to be the best representation of the intent of the process during the EPRI study (Section 2-1 and 7, Tomlinson, 1993). That study included original authors of HMR 51 on the review board.

The EPRI study was conducted using an at-site method of analysis with L-moment statistics. The Review Committee for that study included representatives from NWS, FERC, Bureau of Reclamation, and others. They agreed that the 50-year recurrence interval values were appropriate for use in PMP calculations. For the Nebraska statewide study (Tomlinson et al., 2008), the Review Committee and FERC Board of Consultants agreed that the 100-year recurrence interval dew point climatology maps were appropriate because their use added a layer of conservatism over the 50-year return period. This has subsequently been utilized in all PMP studies completed by AWA. This study is again using the 100-year recurrence interval climatology constructed using dew point data updated through 2018 (Figure 4.1).

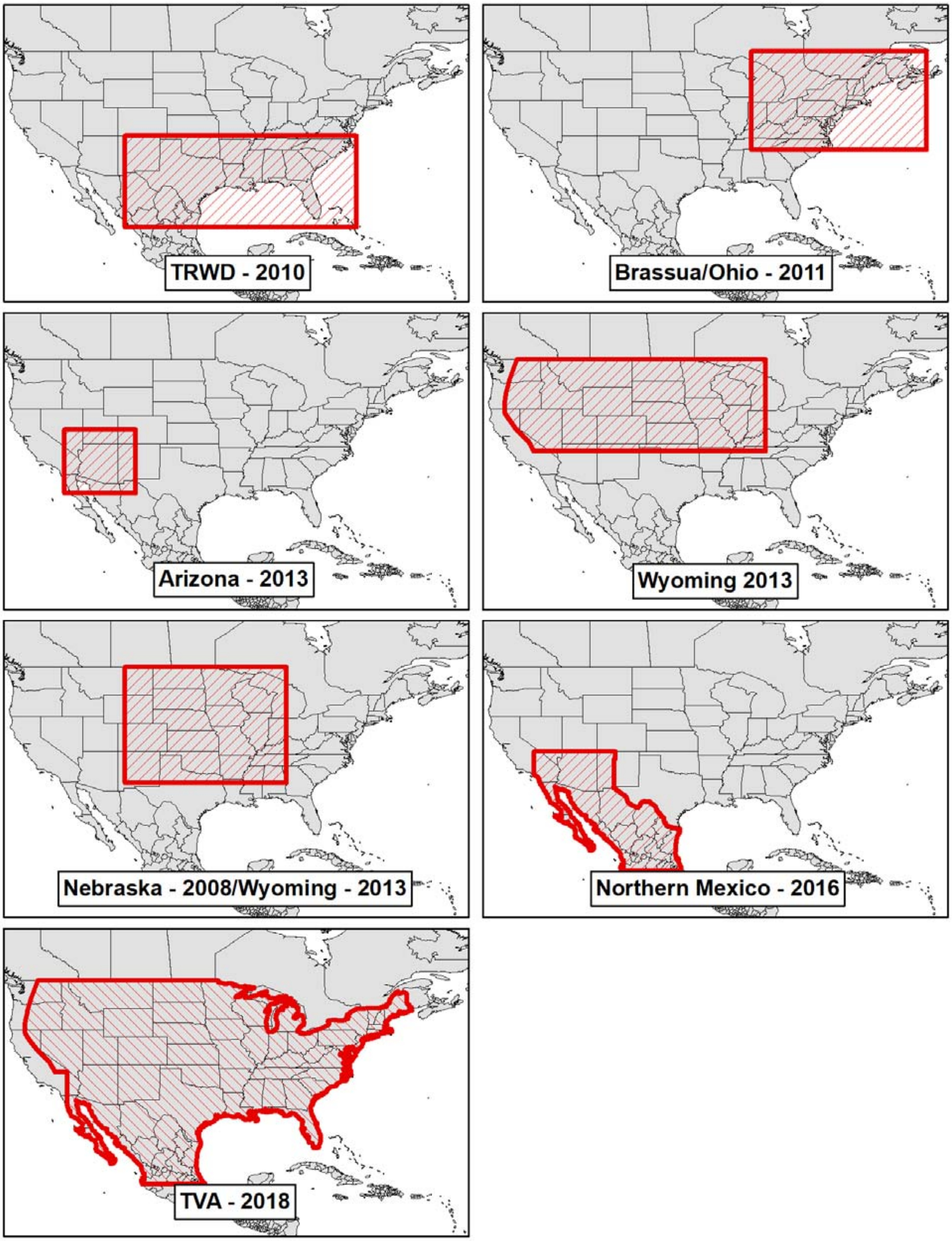


**Figure 4.1: Maximum dew point climatology development regions and dates**

# 5. Data Quality Control and Quality Assurance

During the development of the deterministic PMP values, quality control (QC) and quality assurance (QA) measures were in-place to ensure data used were free from errors and process followed acceptable scientific procedures. QC/QA procedures were in-place internally and externally from the other study participants.

The built in QA/QC checks that are part of the SPAS algorithms were utilized. These include gauge quality control, gauge mass curve checks, statistical checks, gauge location checks, co-located gauge checks, rainfall intensity checks, observed versus modeled rainfall checks, ZR relationship checks (if radar data are available). These data QA/QC measures help produce accurate precipitation reports, proper data analysis and compilation of values by duration and area size, and result in consistent output of SPAS results. For additional information on SPAS, the data inputs, modeled outputs, and QA/QC measures, see Appendix E.

For the storm adjustment process, internal QA/QC included validation that all IPMFs were 1.00 or greater, that upper (1.50) and lower (0.50) limits of the GTF were applied and consistent with adjacent studies.

Maps of gridded GTF values were produced to cover the PMP analysis domain (Appendix B). These maps serve as a tool to spatially visualize and evaluate adjustment factors. Spot checks were performed at various positions across the domain to verify adjustment factor calculations are consistent. Internal consistency checks were applied to compare the storm data used for PMP development against previous PMP studies completed by AWA, against HMR 51, EPRI study, and other data such as NOAA Atlas 14 precipitation depths, and world record rainfall depths.

Maps of PMP depths were plotted to ensure proper spatial continuity. Updates were applied to ensure reasonable gradients and depths based on overall meteorological and topographical interactions. Comparisons were completed against previous PMP from HMR and the EPRI study.

The other study participants completed external QA/QC on several important aspects of the PMP development. Storms used for PMP development were evaluated, the transposition limits of important storms were discussed in detail, the storm representative values for each storm were reviewed, and the PMP depths across the region reviewed and discussed. In addition, the study participants provided review and comment on the temporal accumulation pattern development, the GIS tool output, and report documentation.

# 6. Storm Selection

## 6.1 Storm Search Process

The initial search began with identifying storms that had been used in other PMP studies in the region covered by the storm search domain as mentioned in Section 4 (Figure 6.1). These storm lists were combined to produce a long list of storms for this study. These previous storms lists were updated with data through the course of this study and from other reference sources such as HMRs, the EPRI study, USGS, USACE, USBR, state climate center reports, and NWS reports. In addition, discussions with the other study participants were reviewed to identify dates with large rainfall amounts for locations within the storm search domain.

Storms from each of these sources were evaluated to see if they occurred within the overall region considered to be transpositionable to any locations within the overall basin and were previously important for PMP development. Next, each storm was analyzed to determine whether it was included on the short list for any of the previous studies, whether it was used in the relevant HMRs, the ERPI study, and/or whether it produced an extreme flood event. Storms included on the initial storm list all exceeded the 100-year return frequency value for specified durations at the station location. Each storm was then classified by storm type (e.g., local or general) based on their accumulating characteristics and seasonality as discussed in Section 3. Storm types were compared to adjacent relevant studies to ensure consistency. The storms were then grouped by storm type, storm location, and duration for further analysis to define the final short list of storms used for PMP development. These storms were plotted and mapped using GIS to better evaluate the spatial coverage of the events throughout the region by storm type to ensure adequate coverage for PMP development.

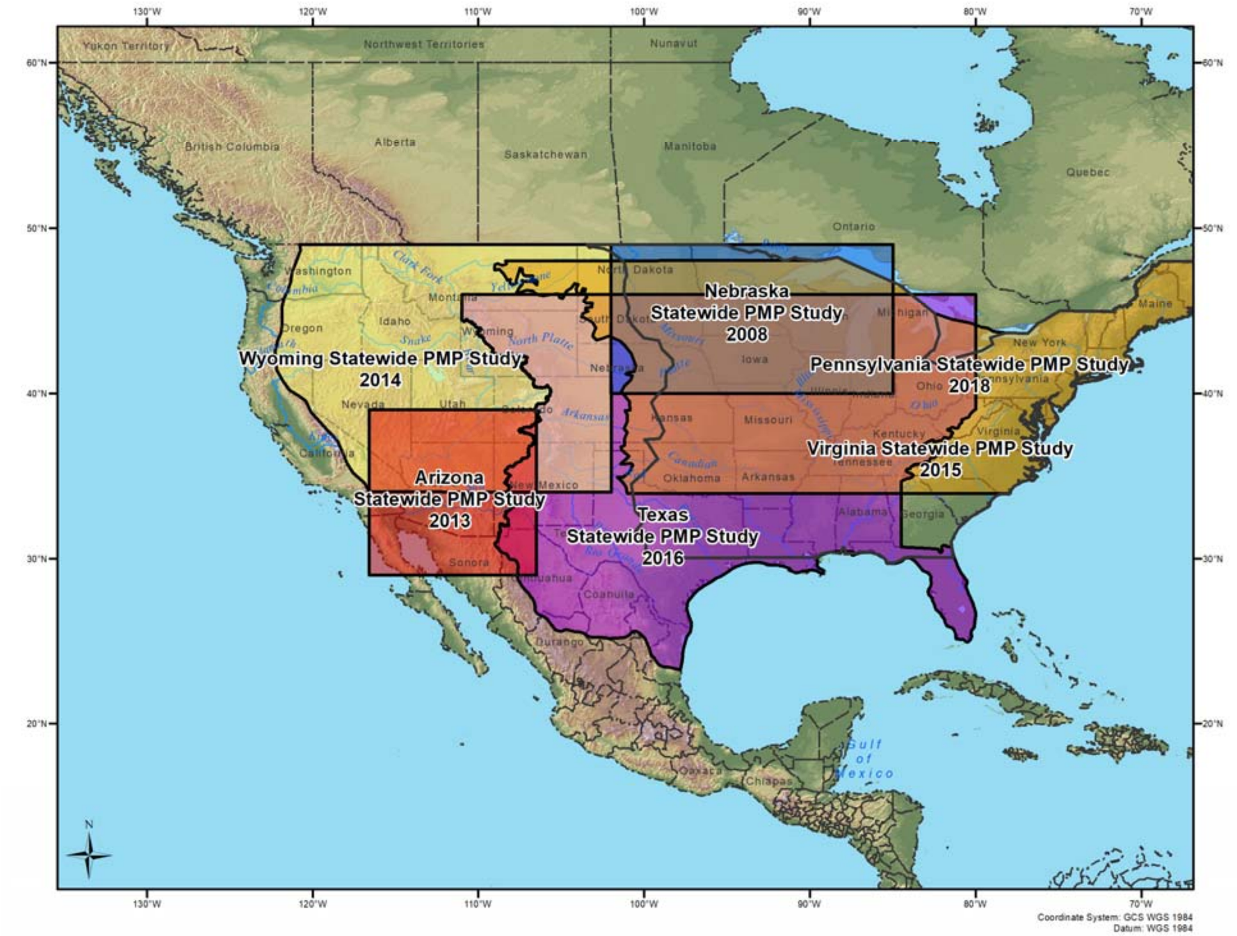


**Figure 6.1: Previous AWA PMP studies storm search domains**

## 6.2 Short Storm List Development

From the initial storm list, the storms to be used for PMP development were identified and moved to the short storm list. Each storm was investigated using both published and unpublished references described above and AWA PMP studies to determine its significance in the rainfall and flood history of surrounding regions. Detailed discussions about each important storm took place with the review board and other study participants. These included evaluations and comparisons of the storms, discussions of each storm's effects in the location of occurrence, discussion of storms in regions that were underrepresented, discussion of each storms importance for PMF development in previous design analyses, and other meteorological and hydrological relevant topics.

Consideration was given to each storm's transpositionability within the overall domain and each storm's relative magnitude compared to other similar storms on the list and whether another storm of similar storm type was significantly larger. In this case, what is considered is whether after all adjustments are applied a given storm would still be smaller than other storms used. To determine this, several evaluations were completed. These included use of the storm in previous PMP studies, comparison of the precipitation values at area sizes relevant to the basin, and comparison of precipitation values after applying a 50% maximum increase to the observed values.

## 6.3 Final PMP Storm List Development

The final short storm list used to derive PMP depths for this study considered each of the discussions in the previous sections in detail. Each storm on the final short storm list exhibited characteristics that were determined to be possible over some portion of the overall study domain. The storms that made it through these final evaluations were placed on the short storm list (Table 6.1 and Figure 6.2). Figure 6.3 and Figure 6.4 provide the short list storms by storm type with a callout providing the storm name and date that can be cross-referenced with the information provided in Table 6.1. Each of these storms were fully analyzed in previous PMP studies or as part of this study using the SPAS process. Ultimately, only a subset of the storms on the short list control PMP depth at a given location for a given duration, with most providing support for the PMP depths.

The short storm list contains 34 unique SPAS storm DAD zones, far more storms than were ultimately controlling of the PMP depths. This is one of the steps that helps to ensure no storms were omitted which could have affected PMP depths after all adjustment factors were applied. The conservative development of the short storm list is completed because the final magnitude of the rainfall accumulation associated with a given storm is not known until all total adjustment factors have been calculated and applied. In other words, a storm with large point rainfall values may have a relatively small total adjustment factor, while a storm with a relatively smaller rainfall value may end up with a large total adjustment factor. The combination of these calculations may provide a total adjusted rainfall value for the smaller rainfall event that is greater than the larger rainfall event after all adjustments are applied.

**Table 6.1: Short storm list**

| SPAS_ID | Storm Name | State | Latitude | Longitude | Year | Month | Day | Maximum Total Rainfall (in) | Elevation (feet) | PMP Storm Type | Storm Rep Analysis Duration | Storm Rep Dew Point | In Place Max Dew Point | In Place Maximization Factor | Storm Adjustment Date | Storm Representative Latitude | Storm Representative Longitude | Moisture Inflow Vector |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SPAS_1628_1 | JEFFERSON | OH | 41.8458 | -80.8375 | 1878 | 9 | 10 | 15.01 | 665 | General | 24 | 72.50 | 77.00 | 1.25 | 27-Aug | 40.00 | -84.00 | SW @ 210 |
| SPAS_1697_1 | IRONWOOD | MI | 46.4542 | -90.2064 | 1909 | 7 | 21 | 13.41 | 1443 | General | 24 | 72.00 | 80.50 | 1.50 | 15-Jul | 42.75 | -92.25 | SSW @ 275 |
| SPAS_1698_1 | BELLEFONTAINE | OH | 40.3670 | -83.7670 | 1913 | 3 | 23 | 11.20 | 1224 | General | 24 | 69.00 | 70.50 | 1.09 | 5-Apr | 33.36 | -87.22 | SSW @ 520 |
| SPAS_1311_1 | MCKENZIE | TN | 36.4375 | -87.9125 | 1937 | 1 | 17 | 19.86 | 566 | General | 24 | 65.50 | 69.00 | 1.18 | 1-Jan | 32.38 | -86.35 | SSE @ 295 |
| SPAS_1433_1 | COLLINSVILLE | IL | 38.6708 | -90.0042 | 1946 | 8 | 12 | 19.07 | 563 | General | 24 | 76.00 | 80.00 | 1.21 | 30-Jul | 35.71 | -91.60 | SSW @ 225 |
| SPAS_1583_1 | COUNCIL GROVE | KS | 38.6458 | -96.6208 | 1951 | 7 | 9 | 18.56 | 1430 | General | 24 | 75.00 | 80.50 | 1.30 | 15-Jul | 36.05 | -93.32 | SE @ 250 |
| SPAS_1527_1 | IDA GROVE | IA | 42.3625 | -95.4958 | 1962 | 8 | 30 | 12.67 | 1329 | General | 24 | 71.00 | 80.00 | 1.50 | 15-Aug | 38.60 | -96.65 | SSW @ 265 |
| SPAS_1630_1 | BOLTON | ONT | 43.8375 | -79.9792 | 1954 | 10 | 14 | 11.23 | 1250 | General | 24 | 68.00 | 71.50 | 1.19 | 1-Oct | 41.16 | -81.35 | SSW @ 200 |
| SPAS_1278_1 | MADISONVILLE | KY | 37.3458 | -87.4958 | 1964 | 3 | 8 | 11.67 | 445 | General | 24 | 70.00 | 73.50 | 1.19 | 25-Mar | 29.61 | -91.20 | SSW @ 575 |
| SPAS_1738_1 | HARLAN | IA | 41.7208 | -95.2125 | 1972 | 9 | 10 | 15.81 | 1368 | General | 24 | 74.50 | 78.00 | 1.19 | 27-Aug | 39.21 | -98.23 | SW @ 235 |
| SPAS_1206_1 | BIG RAPIDS | MI | 43.6125 | -85.3125 | 1986 | 9 | 9 | 13.18 | 987 | General | 24 | 70.50 | 78.50 | 1.48 | 25-Aug | 41.36 | -88.68 | SW @ 230 |
| SPAS_1277_1 | GILBERTSVILLE | KY | 36.9958 | -88.2625 | 1989 | 2 | 12 | 13.20 | 352 | General | 24 | 64.00 | 71.00 | 1.41 | 1-Mar | 29.70 | -96.00 | SW @ 670 |
| SPAS_1735_1 | COLDWATER | MI | 41.9625 | -85.0042 | 1989 | 5 | 30 | 9.2 | 960 | General | 24 | 72.00 | 78.50 | 1.38 | 14-Jun | 31.19 | -89.36 | SW @ 300 |
| SPAS_1244_1 | LOUISVILLE | KY | 38.1000 | -85.6700 | 1997 | 2 | 28 | 13.51 | 548 | General | 24 | 68.50 | 70.50 | 1.10 | 15-Mar | 30.80 | -85.70 | S @ 500 |
| SPAS_1297_1 | WARROAD | MN | 48.8750 | -95.0850 | 2002 | 6 | 9 | 14.62 | 1099 | General | 24 | 72.00 | 77.50 | 1.32 | 25-Jun | 43.55 | -99.55 | SSW @ 425 |
| SPAS_1275_1 | MONTGOMERY DAM | PA | 40.6450 | -80.3850 | 2004 | 9 | 18 | 8.79 | 1055 | General | 12 | 72.00 | 77.50 | 1.32 | 1-Sep | 40.64 | -82.30 | W @ 100 |
| SPAS_1048_1 | HOKAH | MN | 43.8125 | -91.3625 | 2007 | 8 | 18 | 18.26 | 1092 | General | 24 | 74.00 | 80.50 | 1.36 | 3-Aug | 38.91 | -93.85 | SSW @ 360 |
| SPAS_1208_1 | WARNER PARK | TN | 36.0611 | -86.9056 | 2010 | 4 | 30 | 19.71 | 622 | General | 12 | 75.00 | 77.00 | 1.10 | 15-May | 31.50 | -90.00 | SSW @ 360 |
| SPAS_1699_1 | HAYWARD | WI | 46.0130 | -91.4846 | 1941 | 8 | 28 | 15.00 | 1190 | Hybrid (G/L) | 24 | 73.00 | 80.00 | 1.40 | 15-Aug | 42.99 | -89.78 | SSE @ 225 |
| SPAS_1183_1 | EDGERTON | MO | 40.4125 | -95.5125 | 1965 | 7 | 18 | 20.76 | 915 | Hybrid (G/L) | 24 | 76.00 | 80.50 | 1.24 | 15-Jul | 39.22 | -96.58 | SW @ 100 |
| SPAS_1725_1 | LEONARD | ND | 46.5958 | -97.3375 | 1975 | 6 | 29 | 20.66 | 1061 | Hybrid (G/L) | 24 | 76.50 | 80.00 | 1.18 | 15-Jul | 44.12 | -93.53 | SE @ 250 |
| SPAS_1286_1 | AURORA COLLEGE | IL | 41.4575 | -88.0699 | 1996 | 7 | 16 | 18.13 | 636 | Hybrid (G/L) | 24 | 74.00 | 80.50 | 1.36 | 15-Jul | 38.63 | -92.24 | SW @300 |
| SPAS_1228_1 | FALL RIVER | KS | 37.6300 | -96.0500 | 2007 | 6 | 30 | 25.50 | 889 | Hybrid (G/L) | 24 | 76.50 | 81.00 | 1.24 | 15-Jul | 31.00 | -95.50 | S @ 460 |
| SPAS_1296_1 | DULUTH | MN | 47.0150 | -91.6650 | 2012 | 6 | 19 | 10.73 | 611 | Hybrid (G/L) | 12 | 76.00 | 81.50 | 1.30 | 5-Jul | 42.87 | -94.78 | SW @ 325 |
| SPAS_1426_1 | COOPER | MI | 42.3708 | -85.5875 | 1914 | 8 | 31 | 13.39 | 823 | Local | 6 | 75.00 | 82.00 | 1.40 | 15-Aug | 40.25 | -89.50 | SW @ 250 |
| SPAS_1427_1 | BOYDEN | IA | 43.1958 | -95.9958 | 1926 | 9 | 17 | 24.22 | 1435 | Local | 12 | 77.00 | 79.00 | 1.10 | 3-Sep | 40.85 | -94.75 | SSE @ 175 |
| SPAS_1736_1 | STANTON | NE | 41.8208 | -97.0292 | 1944 | 6 | 10 | 17.49 | 1571 | Local | 6 | 75.00 | 80.50 | 1.30 | 24-Jun | 35.00 | -100.00 | SSW @ 500 |
| SPAS_1434_1 | HOLT | MO | 39.4542 | -94.3292 | 1947 | 6 | 18 | 17.62 | 956 | Local | 6 | 79.00 | 81.50 | 1.13 | 5-Jul | 36.18 | -95.25 | SSW @ 230 |
| SPAS_1734_1 | THIEF RIVER FALLS | MN | 48.1625 | -96.2625 | 1949 | 5 | 27 | 9.96 | 1146 | Local | 6 | 69.00 | 77.00 | 1.49 | 11-Jun | 46.18 | -98.56 | SW @ 175 |
| SPAS_1226_1 | COLLEGE HILL | OH | 40.0854 | -81.6479 | 1963 | 6 | 3 | 19.39 | 974 | Local | 12 | 68.50 | 77.00 | **1.50** | 15-Jun | 39.20 | -83.00 | SW @ 95 |
| SPAS_1030_1 | DAVID CITY | NE | 41.2132 | -97.0710 | 1963 | 6 | 24 | 15.98 | 1627 | Local | 6 | 73.50 | 82.00 | **1.50** | 9-Jul | 39.41 | -94.83 | SE @ 175 |
| SPAS_1209_1 | WOOSTER | OH | 40.9146 | -81.9729 | 1969 | 7 | 4 | 14.95 | 1164 | Local | 24 | 76.00 | 79.00 | 1.16 | 15-Jul | 39.43 | -83.80 | SW @ 140 |
| SPAS_1035_1 | FOREST CITY | MN | 45.2394 | -94.5404 | 1983 | 6 | 20 | 17.00 | 1082 | Local | 12 | 72.00 | 81.00 | **1.50** | 6-Jul | 44.02 | -92.94 | SE @ 115 |
| SPAS_1210_1 | MINNEAPOLIS | MN | 44.8895 | -93.4021 | 1987 | 7 | 23 | 11.55 | 940 | Local | 6 | 78.00 | 82.50 | 1.24 | 15-Jul | 44.54 | -95.16 | WSW @ 90 |
| SPAS_1673_1 | HARROW | ONT | 42.0042 | -82.9375 | 1989 | 7 | 19 | 17.74 | 600 | Local | 12 | 71.00 | 78.50 | 1.43 | 15-Jul | 42.04 | -82.18 | E @ 40 |
| SPAS_1726_1 | TURTLE RIVER | ND | 47.9550 | -97.7550 | 2000 | 6 | 13 | 20.00 | 1224 | Local | 6 | 74.50 | 79.00 | 1.24 | 26-Jun | 47.97 | -97.40 | E @ 16 |
| SPAS_1220_1 | DUBUQUE | IA | 42.4400 | -90.7500 | 2011 | 7 | 27 | 15.14 | 902 | Local | 12 | 79.00 | 82.00 | 1.16 | 15-Jul | 40.95 | -90.27 | SSE @ 105 |
| SPAS_1727_1 | DRUMMOND | WI | 46.3150 | -91.4150 | 2018 | 6 | 14 | 17.33 | 1303 | Local | 6 | 77.00 | 80.50 | 1.18 | 30-Jun | 44.50 | -92.50 | SSW @ 135 |
| SPAS_1728_1 | CROSS PLAINS | WI | 43.1450 | -89.6150 | 2018 | 8 | 21 | 16.24 | 1006 | Local | 6 | 75.00 | 82.00 | 1.40 | 6-Aug | 38.47 | -88.70 | S @ 325 |
| SPAS_1729_1 | FOUNTAIN | MI | 44.0350 | -86.1850 | 2019 | 7 | 20 | 15.77 | 697 | Local | 12 | 79.50 | 82.50 | 1.15 | 15-Jul | 41.00 | -91.00 | SW @ 320 |

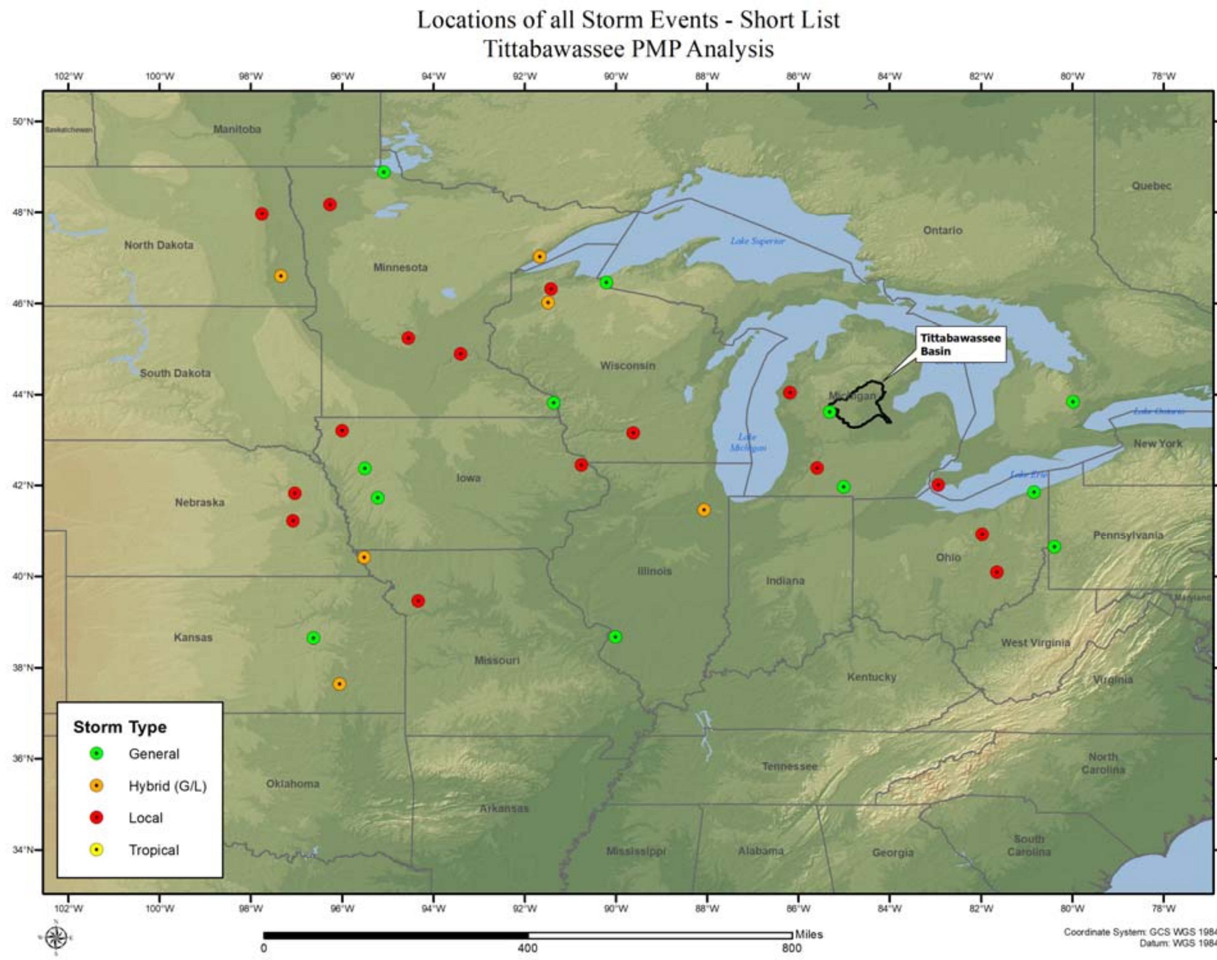


**Figure 6.2: Short storm list locations, all storms**

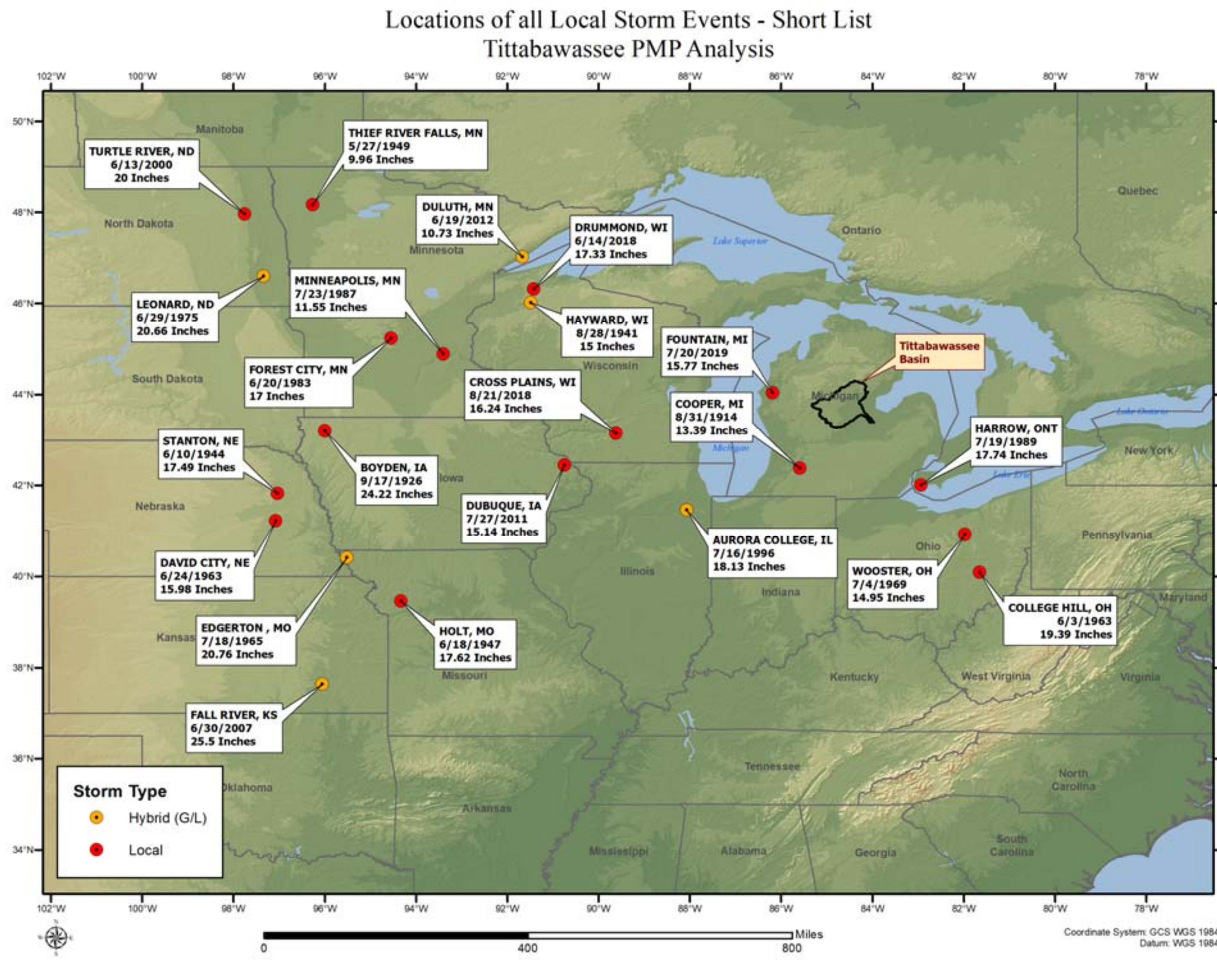


**Figure 6.3: Location of local storms on the short list**

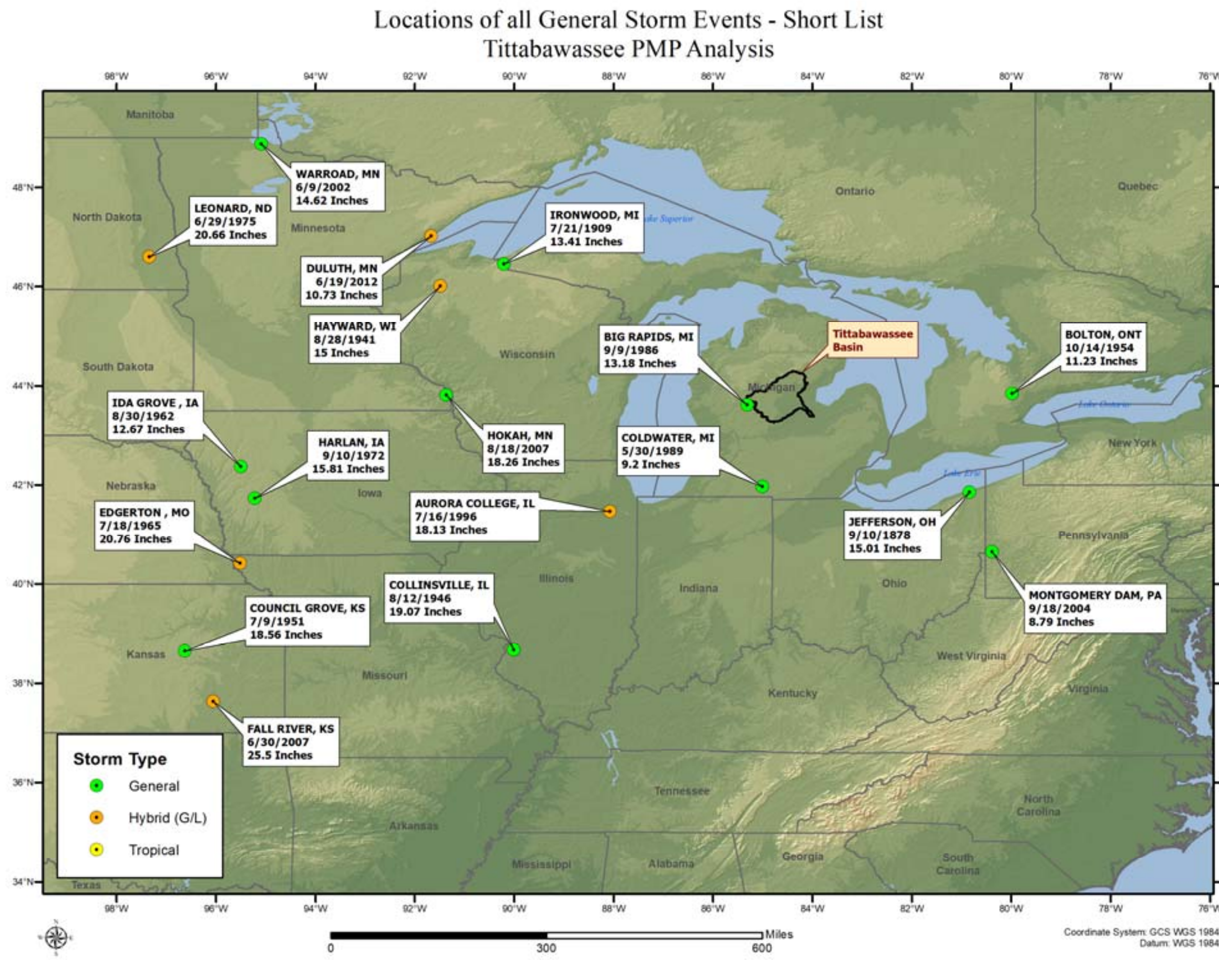


**Figure 6.4: Location of general storms on the short list**

# 7. SPAS Analysis Description

For all storms identified as part of this study, Depth-Area-Duration (DAD) and hourly gridded rainfall data were required for PMP development. Hourly gridded rainfall information was required for all storms for the GTF calculations to be completed and to calculate PMP depths. SPAS was used to compute DADs for all of the storms used in this study. Results of all SPAS analyses used in the study are provided in Appendix F. Appendix F includes the standard output files associates with each SPAS analysis, including the following:

- SPAS analysis notes and description
- Total storm isohyetal
- DAD table and graph
- Storm center mass curve (hourly and incremental accumulation)

There are two main steps in the SPAS DAD analysis: 1) The creation of high-resolution hourly rainfall grids and 2) the computation of Depth-Area (DA) rainfall amounts for various durations, i.e., how the depth of the analyzed rainfall varies with area sizes being analyzed. The reliability of the results from step 2) depends on the accuracy of step 1). Historically the process has been very labor intensive. SPAS utilizes GIS concepts to create spatially-oriented and accurate results in an efficient manner (step 1). Furthermore, the availability of NEXRAD (NEXt generation RADar) data allows SPAS to better account for the spatial and temporal variability of storm precipitation for events occurring since the early 1990s. Prior to NEXRAD, the NWS developed and used a method based on Weather Bureau Technical Paper No. 1 (1946). Because this process has been the standard for many years and holds merit, the DAD analysis process developed for this study attempts to follow the NWS procedure as much as possible. By adopting this approach, some level of consistency between the newly analyzed storms and the hundreds of storms already analyzed by the USACE, USBR, and/or NWS can be achieved. Appendix E provides a detailed description of the SPAS program with the following sections providing a high-level overview of the main SPAS processes.

## 7.1 SPAS Data Collection

The areal extent of a storm's rainfall is evaluated using existing maps and documents along with plots of total storm rainfall. Based on the storm's spatial domain (longitude-latitude box), hourly and daily rain gauge data are extracted from the database for the specified area, dates, and times. To account for the temporal variability in observation times at daily stations, the extracted hourly data must capture the entire observational period of all extracted daily stations. For example, if a station takes daily observations at 8:00 AM local time, then the hourly data needs to be complete from 8:00 AM local time the day prior. As long as the hourly data are sufficient to capture all of the daily station observations, the hourly variability in the daily observations can be properly addressed.

The daily database is comprised of data from NCDC TD-3206 (pre-1948) and TD-3200 (generally 1948 through present). The hourly database is comprised of data from NCDC TD-3240 and NOAA's Meteorological Assimilation Data Ingest System (MADIS). The daily supplemental database is largely comprised of data from "bucket surveys," local rain gauge networks (e.g., USGS, CoCoRaHS, etc.) and daily gauges with accumulated data.

## 7.2 SPAS Mass Curve Development

The most complete rainfall observational dataset available is compiled for each storm. To obtain temporal resolution to the nearest hour in the final DAD results, it is necessary to distribute the daily precipitation observations (at daily stations) into hourly bins. In the past, the NWS had accomplished this process by anchoring each of the daily stations to a single hourly station for timing. However, this may introduce biases and may not correctly represent hourly precipitation at locations between hourly observation stations. A preferred approach is to anchor the daily station to some set of nearest hourly stations. This is accomplished using a spatially based approach called the spatially based mass curve (SMC) process.

## 7.3 Hourly and Sub-Hourly Precipitation Maps

At this point, SPAS can either operate in its standard mode or in NEXRAD-mode to create high resolution hourly or sub-hourly (for NEXRAD storms) grids. In practice, both modes are run when NEXRAD data are available so that a comparison can be made between the methods. Regardless of the mode, the resulting grids serve as the basis for the DAD computations.

## 7.4 Standard SPAS Mode Using a Basemap Only

The standard SPAS mode requires a full listing of all the observed hourly rainfall values, as well as the newly created estimated hourly data from daily and daily supplemental stations. This is done by creating an hourly file that contains the newly created hourly mass curve precipitation data (from the daily and supplemental stations) and the "true" hourly mass curve precipitation. If not using a base map, the individual hourly precipitation values are simply plotted and interpolated to a raster with an inverse distance weighting (IDW) interpolation routine in a GIS.

## 7.5 SPAS-NEXRAD Mode

Radar has been in use by meteorologists since the 1960s to estimate rainfall depth. In general, most current radar-derived rainfall techniques rely on an assumed relationship between radar reflectivity and rainfall rate. This relationship is described by the Equation 2 below:

$$Z = aR^b \qquad \text{Equation 2}$$

where Z is the radar reflectivity, measured in units of dBZ, R is the rainfall rate, a is the "multiplicative coefficient" and b is the "power coefficient". Both a and b are related to the drop size distribution (DSD) and the drop number distribution (DND) within a cloud (Martner et al., 2005).

The NWS uses this relationship to estimate rainfall through the use of their network of Doppler radars (NEXRAD) located across the United States. A standard default Z-R algorithm of $Z = 300R^{1.4}$ has been the primary algorithm used throughout the country and has proven to produce highly variable results. The variability in the results of Z vs. R is a direct result of differing DSD and DND, and differing air mass characteristics across the United States

(Dickens, 2003). DSD and DND are determined by a complex interaction of microphysical processes in a cloud. They fluctuate hourly, daily, seasonally, regionally, and even within the same cloud (see Appendix E for a more detailed description).

Using the technique described above, NEXRAD rainfall depth and temporal distribution estimates are determined for the area in question.

## 7.6 Depth-Area-Duration Program

The DAD extension of SPAS runs from within a Geographic Resource Analysis Support System (GRASS) GIS environment and utilizes many of the built-in functions for calculation of area sizes and average rainfall depths. The following is the general outline of the procedure:

1. Given a duration (e.g., x-hours) and cumulative precipitation, sum up the appropriate hourly or sub-hourly precipitation grids to obtain an x-hour total precipitation grid starting with the first x-hour moving window.
2. Determine x-hour precipitation total and its associated areal coverage. Store these values. Repeat for various lower rainfall thresholds. Store the average rainfall depths and area sizes.
3. The result is a table of depth of precipitation and associated area sizes for each x-hour window location. Summarize the results by moving through each of the area sizes and choosing the maximum precipitation amount. A log-linear plot of these values provides the depth-area curve for the x-hour duration.
4. Based on the log-linear plot of the rainfall depth-area curve for the x-hour duration, determine rainfall amounts for the standard area sizes for the final DAD table. Store these values as the rainfall amounts for the standard sizes for the x-duration period. Determine if the x-hour duration period is the longest duration period being analyzed. If it is not, analyze the next longest duration period and return to step 1.
5. Construct the final DAD table with the stored rainfall values for each standard area for each duration period.

## 7.7 Comparison of SPAS DAD Output Versus Previous DAD Results

The SPAS process and algorithms have been thoroughly reviewed as part of many AWA PMP studies. The SPAS program was reviewed as part of the NRC software verification and validation program to ensure that its use in developing data for use in NRC regulated studies was acceptable (Hultstrand and Kappel, 2017). The result of the NRC review showed that the SPAS program performed exactly as described and produced expected results.

Comparisons were made of the SPAS DAD tables and previously published DAD tables developed by the USACE and/or NWS for many of the older storms. AWA evaluated these comparisons for important storms where previous DADs were available that covered the same domain as the SPAS analysis. As expected, the differences between SPAS DAD depths and previously published depths varied by area size and duration. The differences were a result of one or more of the following:

- SPAS utilizes a more accurate basemap to spatially distribute rainfall between known observation locations. The use of a climatological basemap reflects how rainfall has occurred over a given region at a given time of the year and therefore how an individual storm pattern would be expected to look over the location being analyzed. Previous DAD analyses completed by the NWS and USACE often utilized simple IDW or Thiessen polygon methods that did not reflect climatological characteristics as accurately. In some cases, the NWS and USACE utilized precipitation frequency climatologies to inform spatial patterns. However, these relied on NOAA Atlas 2 (Miller et al., 1973) patterns and data that are not as accurate as current data from PRISM (Daly et al., 1994 and Daly et al., 1997) and NOAA Atlas 14.

- In some cases, updated sources of data uncovered during the data mining process were incorporated into SPAS that were not utilized in the original analysis.
  SPAS utilizes sophisticated algorithms to temporally and spatially distribute rainfall. In contrast, the isohyetal maps developed previously were hand drawn. Therefore, they reflected the best guess of the analyst of each storm, which could vary between each analyst's interpretations. Also, only a select few stations were used for timing, which limited the variation of temporal accumulation patterns throughout the overall domain being analyzed. SPAS uses the power of all the rainfall observations that have passed QA/QC measures to inform patterns over the entire domain. These temporal and spatial fits are evaluated and updated on an hourly basis for the entire duration.

# 8. Storm Adjustments

## 8.1 In-Place Maximization Process

Maximization was accomplished by increasing surface dew points to a climatological maximum represented by the 100-year recurrence interval and calculating the additional rainfall amounts that could potentially be produced if the climatological maximum moisture had been available during the observed storm period. An additional conservatism is applied by choosing the climatological maximum dew point for a date two weeks towards the warm season when higher amounts of moisture could have been available versus the date that the storm actually occurred. This procedure assumes that the storm could have occurred with the same storm dynamics two weeks towards the time in the year when maximum dew points occur. This assumption follows HMR guidance and is consistent with procedures used to develop PMP values in all the current HMR documents (e.g., HMR 51 Section 2.3), the WMO Manual for PMP (WMO, 2009), as well as in all prior AWA PMP studies. The storm data Appendix F provides the individual analysis maps used for each storm adjustment analysis including the HYSPLIT model output (when available), the surface dew point observations, the storm center location, the storm representative location, and the IPMF for each storm.

Each storm used for PMP development was thoroughly reviewed as part of several adjacent PMP studies to confirm the reasonableness of the storm representative value and location used. As part of this process, AWA provided and discussed all the information used to derive the storm representative value for review, including the following:

- Hourly surface dew point observations
- Daily SST observations
- HYSPLIT model output
- Storm adjustment spreadsheets
- Storm adjustments maps with data plotted

These data allowed for an independent review of each storm. Results of this analysis demonstrated that the values AWA utilized to adjust each storm was reasonable for PMP development.

For storm maximization, average dew point values for the appropriate duration that are most representative of the actual rainfall accumulation period for an individual storm (e.g., 6-, 12-, or 24-hour) are used to determine the storm representative value. This value is then maximized using the appropriate climatological value representing the 100-year return interval at the same location moved two weeks towards the higher climatological maximum values.

The HYSPLIT model (Draxler and Rolph, 2013; Stein et al., 2015; and Rolph et al., 2017) provides detailed and reproducible analyses for assisting in the determination of the upwind trajectories of atmospheric moisture that was advected into the storm systems. Using these model trajectories, along with an analysis of the general synoptic weather patterns and available surface dew point temperature data, the moisture source region for candidate storms was determined. The procedure is followed to determine the storm representative location and is similar to the approach used in the HMRs. However, by utilizing the HYSPLIT model, much of the subjectivity found in the HMR analysis process was corrected. Further, details of each evaluation can be explicitly provided, and the HYSPLIT trajectory results based on the input parameters defined are reproducible. Available HYSPLIT model results are provided as part of Appendix F.

The process results in a ratio of observed moisture versus climatological maximum moisture. Therefore, this value is always 1 or greater. In addition, the intent of the process is producing a hypothetical storm event that represents the upper limit of rainfall that a given storm could have produced with the perfect combination of moisture and maximum storm efficiency (atmospheric processes that convert moisture to precipitation) associated with that storm (i.e., PMP). This assumes that the storm efficiency processes remain constant as more moisture is added to the storm environment. Therefore, an upper limit of 1.50 (50%) is applied to the IPMF with the assumption that increases beyond this amount would change the storm efficiency processes and the storm would no longer be the same storm as observed from an efficiency perspective.

This upper limit is a standard application applied in the HMRs (e.g., HMR 51 Section 3.2.2). Note, this upper limit was investigated further during the Colorado-New Mexico REPS study (Kappel et al. 2018) using the Dynamical Modeling Task and the HRRR model interface (Alexander et al., 2015). This explicitly demonstrated that storm efficiency changes as more moisture is added, often before the 50% moisture increase level for the storms investigated (Mahoney, 2016). Therefore, the use of 1.50 as an upper limit is a conservative application. During this study the 1.50 upper limit was applied against five storms:

- Ironwood, MI July 1909 (SPAS 1697)
- Ida Grove, IA August 1962 (SPAS 1527)
- David City, NE June 1963 (SPAS 1030)
- College Hill, OH June 1963 (SPAS 1226)
- Forest City, MN June 1963 (SPAS 1035)

## 8.2 Storm Representative Dew Point Determination Process

For storm maximization, average dew point values for the duration most consistent with the actual rainfall accumulation period for an individual storm (i.e., 6-, 12-, or 24-hour) were used to determine the storm representative dew point. To determine which time frame was most appropriate, the total rainfall amount was analyzed. The duration closest to when approximately 90% of the rainfall had accumulated was used to determine the duration used, i.e., 6-hour, 12-hour, or 24-hour.

Once the general upwind location was determined, the hourly surface observations were analyzed for all available stations within the vicinity of the inflow vector. From these data, the appropriate durational dew point value was averaged for each station (6-, 12-, or 24-hour depending on the storm's rainfall accumulation). These values were then adjusted to 1,000mb (approximately sea level) and the appropriate storm representative dew point and location were derived. The line connecting this point with the storm center location (point of maximum rainfall accumulation) is termed the moisture inflow vector. The information used and values derived for each storm’s moisture inflow vector are included in Appendix F.

HYSPLIT was used during the analysis of each of the rainfall events included on the short storm list when available (1948-present). Use of the trajectory model provides increased confidence in determining moisture inflow vectors and storm representative dew points. The HYSPLIT trajectories have been used to analyze moisture inflow vectors in other PMP studies completed by AWA over the past several years. During these analyses, the model trajectory results were verified, and the utility explicitly evaluated (e.g., Tomlinson et al., 2006-2012; Kappel et al., 2013-2021).

In determining the moisture inflow trajectories, HYSPLIT was used to compute the trajectory of the atmospheric moisture inflow associated with the storm's rainfall production, both location and altitude, for various levels in the atmosphere. HYSPLIT was run for trajectories at several levels of the lower atmosphere to capture the moisture source for each storm event. These included 700mb (approximately 10,000 feet), 850mb (approximately 5,000 feet), and storm center location surface elevation. For the majority of the analyses, a combination of all three levels was determined to be most appropriate for use in evaluation of the upwind moisture source location. It is important to note that the resulting HYSPLIT trajectories are only used as a general guide to evaluate the moisture source for storms in both space and time. The final determination of the storm representative dew point and its location was determined following the standard procedures used by AWA in previous PMP studies (e.g., Tomlinson, 1993; Tomlinson et al., 2006-2012; Kappel et al., 2013-2021) and as outlined in the HMRs (e.g., HMR 51 Section 2.3) and WMO Manual for PMP (Section 2.2).

The process involves deriving the average dew point values at all stations with dew point data in a large region along the HYSPLIT inflow vectors. Values representing the average 6-, 12-, and 24-hour dew points are analyzed in Excel spreadsheets. The appropriate duration representing the storm being analyzed is determined and data are plotted for evaluation of the storm representative dew point. This evaluation includes an analysis of the timing of the observed dew point values to ensure they occurred in a source region where they would represent the storm environment that resulted in rainfall analyzed.

Several locations are investigated to find values that are of generally similar magnitude (within a degree or two Fahrenheit). Once these representative locations are identified, an average of the values to the nearest half degree is determined and a location in the center of the stations is identified. This becomes the storm representative dew point, and the location provides the inflow vector (direction and distance) connecting that location to the storm center location. This follows the approach used in HMR 51 Section 2, HMR 55A Section 5, and HMR 57 Section 4, with improvements provided by the use of HYSPLIT and updated maximum dew point and SST climatologies. Appendix F of this report contains each of the HYSPLIT trajectories analyzed as part of this study for each storm (when used).

## 8.3 Storm Representative Dew Point Determination Example

As an example, Figure 8.1 shows the HYSPLIT model outputs used to analyze the inflow vector for the Aurora College, IL July 1996 (SPAS 1286) storm. HYSPLIT trajectories showed a general inflow from the Gulf of Mexico flowing north, then northeast into the storm and along and over a surface front. The turning of the moisture in a clockwise direction was around the western edge of the general high pressure located to the east of the Atlantic (the Bermuda High).

This is a common scenario for heavy rains over the region, where moisture is drawn up around the western edge of high pressure from the Gulf of Mexico and forced to lift over a frontal system stalled over the region and then further enhanced by topography of the Appalachian Mountains.

In this case, surface dew point values were analyzed for a region starting at the storm center and extending southward and to the southwest through the Central and Southern Plains region. All HYSPLIT inflow vectors showed a south to southwest inflow direction from the storm center over northern Illinois (the most common direction for this type of storm event in this region). The air mass source region supplying the atmospheric moisture for this storm was located over Missouri 24-36 hours prior to the rainfall occurring. Surface dew points were analyzed over this source region, ensuring that the dew point observations were located outside of the area of rainfall to avoid contamination of the dew points by evaporating rainfall and located within the area of high atmospheric moisture. Figure 8.2 displays the stations analyzed and their representative 24-hour average dew point values. The region circled in red is considered the moisture source region for this storm.

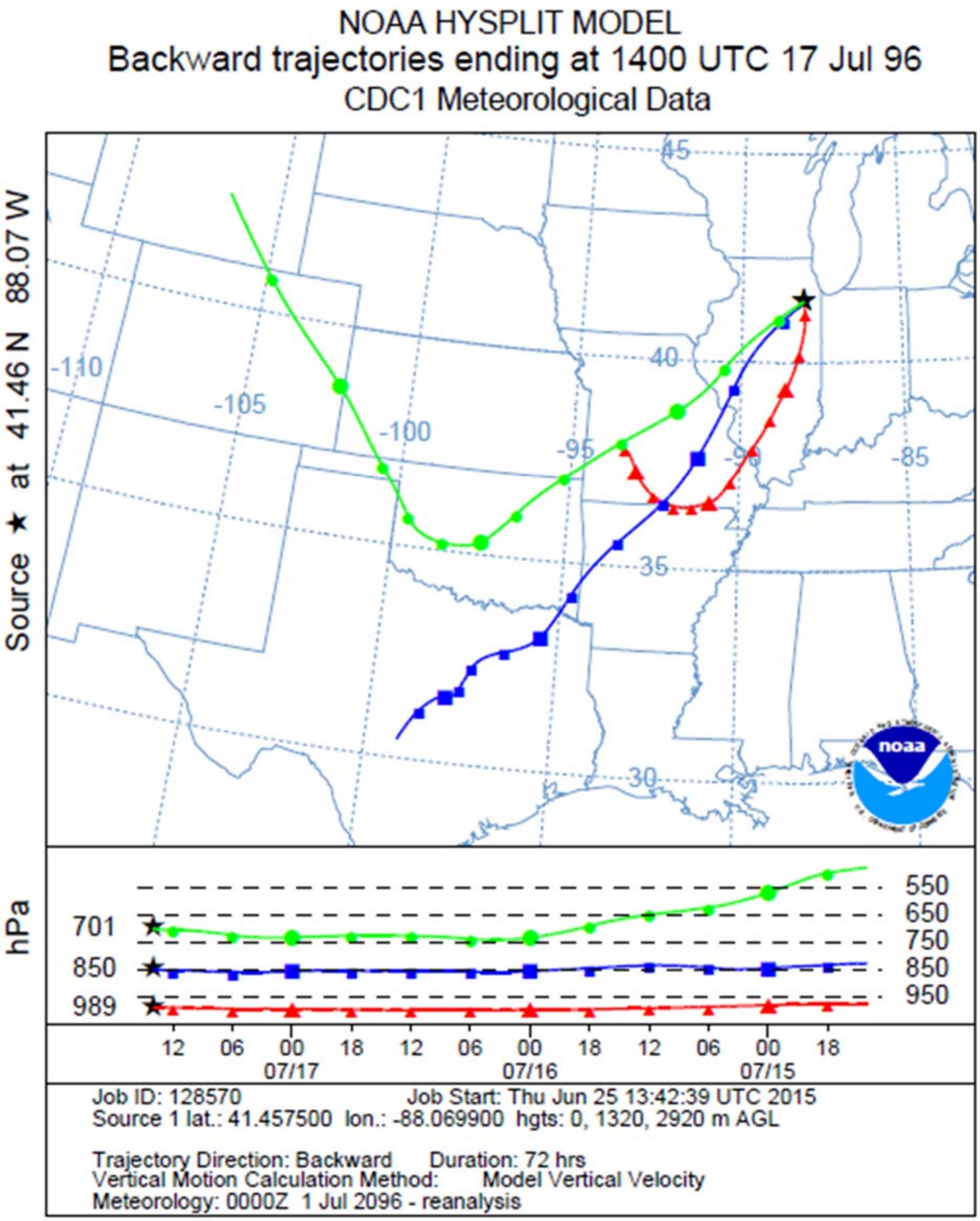


**Figure 8.1: HYSPLIT trajectory model results for Aurora College, IL July 1996 (SPAS 1286) storm**

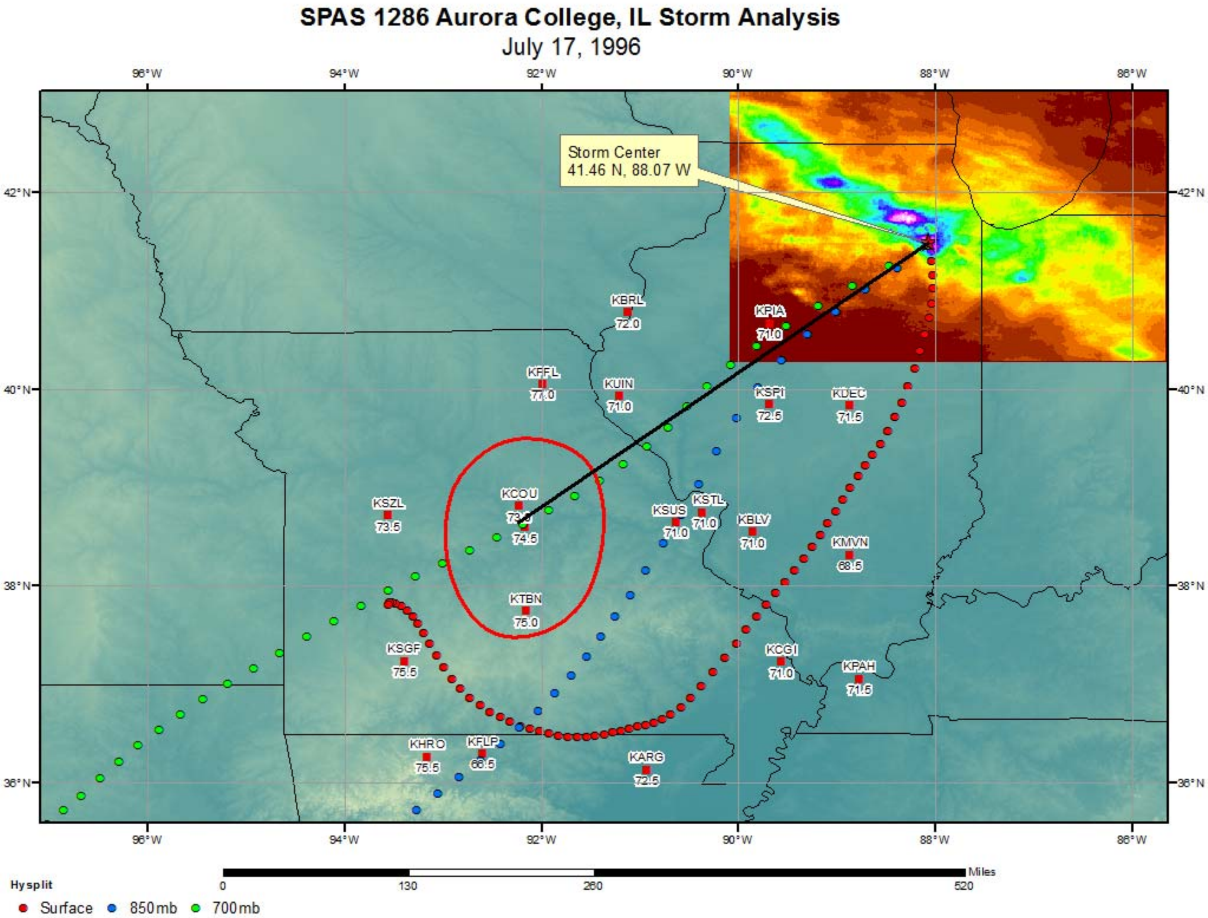


**Figure 8.2: Surface stations, 24-hour average dew points, and moisture source region, along with HYSPLIT trajectory model results for the Aurora College, IL July 1996 (SPAS 1286) storm**

## 8.4 In-Place Maximization Factor (IPMF) Calculation

Storm maximization is quantified by the IPMF using Equation 3.

$$IPMF = \frac{W_{p,max}}{W_{p,rep}} \qquad \text{Equation 3}$$

where,

| | | |
|---|---|---|
| $W_{p,max}$ | = | precipitable water for maximum dew point (in.) |
| $W_{p,rep}$ | = | precipitable water for representative dew point (in.) |

The available precipitable water, Wp, is calculated by determining the precipitable water depth present in the atmospheric column (from sea level to 30,000 feet) and subtracting the precipitable water depth that would not be present in the atmospheric column between sea-level and the surface elevation at the storm location using Equation 4.

$$W_p = W_{p,30{,}000'} - W_{p,elev} \qquad \text{Equation 4}$$

where,

$W_p$ = precipitable water above the storm location (in.)

$W_{p,30,000'}$ = precipitable water, sea level to 30,000′ elevation (in.)

$W_{p,elev}$ = precipitable water, sea level to storm surface elevation (in.)

## 8.5 Geographic Transposition Factor

The GTF process is used to not only capture the difference in terrain effects between two locations but also to capture all processes that result in precipitation reaching the ground at one location versus another location. The GTF is a mathematical representation of the ratio of the precipitation frequency climatology at one location versus another location. The precipitation frequency climatology is derived from actual precipitation events that resulted in the Annual Maximum Series (AMS) at a given station. Therefore, the assumption is made that the resulting 100-year recurrence interval depths are representative of all precipitation processes as observed during actual storms. Similar to the IPMF limits, an upper limit of 1.50 and a lower limit of 0.50 were applied to the GTF. This was done so that the storm being adjusted was not adjusted beyond reasonable limits, which would change the original storm characteristics in a manner that would violate the PMP process assumptions.

GTF values were calculated utilizing NOAA Atlas 14 precipitation frequency data at the 100-year recurrence interval. These data sets were used to ensure consistency in the climatological datasets and to ensure required coverage for all storm locations within the overall storm search domain. The storms used in NOAA Atlas 14 represent observed precipitation events that resulted in an AMS accumulation. Therefore, they represent all precipitation producing processes that occurred during a given storm event. In HMR terms, the resulting observed precipitation represents both the convergence-only component and any orographic component. The NOAA Atlas 14 gridded precipitation frequency climatology was produced using gridded mean annual maxima (MAM) grids that were developed with the PRISM (Daly et al., 1994). PRISM utilizes geographic information such as elevation, slope, aspect, distance from coast, and terrain weighting for weighting station data at each grid location.

The use of the precipitation frequency climatology grids should be reflective of all precipitation producing processes. Further, the use of the gridded precipitation climatology at the 100-year recurrence interval represents an optimal combination of factors, including representing extreme precipitation events equivalent to the level of rainfall utilized in AWA's storm selection process, and providing the most robust statistics given the period of record used in the development of the precipitation frequency climatologies.

Therefore, the GTF does not just represent the difference in topographic effects between two locations, but instead represents the difference in all precipitation processes between two locations. This is one reason it is very important to apply appropriate transposition limits to each storm during the PMP development process. As part of the GTF process the following assumptions are applied:

- NOAA Atlas 14 precipitation frequency climatologies represent all precipitation producing factors that have occurred at a location. This is based on the fact that the data are derived from AMS values at individual stations that were the result of an actual storm event. That actual storm event included both the amount of precipitation that would have occurred without topography and the amount of precipitation that occurred because of topography (if any).

- If it is accepted that the precipitation frequency climatology is representative of all precipitation producing processes for a given location, then comparing the precipitation frequency climatology at one point to another will produce a ratio that shows how much more or less efficient the precipitation producing processes are between the two locations. This ratio is called the GTF.
- If there is no orographic influence at either location being compared or between the two locations, then the differences should be a function of (1) storm precipitation producing processes in the absence of topography (thermodynamic and dynamic), (2) how much more or less moisture is available from a climatological perspective, and/or (3) elevation differences at the location.

## 8.6 Geographic Transposition Factor (GTF) Calculation

The GTF is calculated by taking the ratio of transposed 100-year rainfall to the in-place 100-year rainfall.

$$GTF = \frac{R_t}{R_s}$$ Equation 6

where,

$R_t$ = climatological 100-year rainfall depth at the target location

$R_s$ = climatological 100-year rainfall depth at the source storm center

The in-place climatological precipitation ($R_s$) was determined at the grid point located at the SPAS-analyzed total storm maximum rainfall center location. The corresponding transposed climatological precipitation ($R_t$) was taken at each grid point in the basin. The 100-year precipitation was used for each transposed location and also for the in-place location for storm centers. For this region, the 6-hour precipitation frequency climatologies were used for the local storm type. Conversely, the 24-hour precipitation frequency climatologies are used for the general storm type. Precipitation frequency data were taken from NOAA Atlas 14 volume 2 (Bonnin et al., 2006) and NOAA Atlas 14 volume 8 (Perica et al., 2013).

## 8.7 Total Adjustment Factor (TAF)

The TAF is a combination of the total moisture and terrain differences on the SPAS analyzed rainfall after being maximized in-place and then transpositioned to the target grid point.

$$TAF_{xhr} = P_{xhr} \times IPMF \times GTF$$ (from Equation 1)

The TAF, along with the other storm adjustment factors, is exported and stored within the storm's adjustment factor feature class to be accessed by the GIS PMP tool as described in the following section.

# 9. Development of PMP Values

## 9.1 PMP Calculation Process

To calculate PMP, the TAF for each storm must be applied to the storm's SPAS analyzed DAD value for the area size and duration of interest to yield a total adjusted rainfall value. The storm's total adjusted rainfall value is then compared with the adjusted rainfall values of every storm in the database transposable to the target grid point. The largest adjusted rainfall depth becomes the PMP for that point at a given duration. This process must be repeated for each of the grid cells intersecting the basin for each applicable duration and storm type. The gridded PMP is averaged over the basin of interest to derive a basin average and the accumulated PMP depths are temporally distributed.

A GIS-based PMP calculation tool was developed to automate the PMP calculation process. The PMP tool is a Python scripted tool that runs from a Toolbox in the ArcGIS desktop environment. The tool accepts a basin polygon feature or features as input and provides gridded, basin average, and temporally distributed PMP depths as output. These PMP output elements can be used with hydrologic runoff modeling simulations for PMF calculations. The PMP tool provides depths as an areal average for the basin area size or any other area size required by the hydrolgiist. The PMP tool can be used to calculate PMP depths for the following durations.

**Local Storm PMP Durations:**
1-, 2-, 3-, 4-, 5-, 6-, 12-, and 24-hour

**General Storm PMP Durations:**
1-, 6-, 12-, 24-, 48-, and 72-hour

### 9.1.1 Spatial Application Considerations

It is important to remember that the initial gridded PMP depths are spatially distributed closely following the NOAA Atlas 14 precipitation frequency patterns. This represents one possible spatial scenario and is generally considered a conservative application. However, other spatial patterns are possible that may result in a more severe flood response. For larger basins such as those investigation during this study, this may have a significant impact. It is recommended that other spatial patterns be tested. These could be based on HMR 52 guidance, the successive subtraction method, or previously observed storm patterns over the basin of interest. In all cases, it is important that the spatial pattern adhere to the caveat of producing a "physically possible" representation of the PMP design storm.

### 9.1.2 Alternative Temporal Patterns for PMP

Development of the site-specific temporal patterns utilized the output from the adjacent Pennsylvania statewide PMP study (Kappel et al., 2019). Several temporal patterns were provided for this study based on that work that were specifically relevant to the storms used for PMP development and are specifically relevant to the Tittabawassee basins. All storms utilized in this study were explicitly evaluated during the Pennsylvania statewide PMP study and therefore the temporal evaluations and patterns derived are directly relevant for this study.

Detailed descriptions of the data analyses and results are provided in the Pennsylvania statewide PMP study documentation. The documentation is publicly available at, https://www.dep.pa.gov/Business/Water/Waterways/DamSafety/Pages/Probable-Maximum-Precipitation-Study-.aspx or from Pennsylvania Department of Environmental Protection, Dam Safety.

### 9.1.3 Sample Calculations

The following sections provide sample calculations for the storm adjustment factors for the Aurora College, IL of July 1996 (SPAS 1286) general storm event when transposed to 43.325°N, 84.850°W (grid point ID #25). The target location is about 210 miles northeast of the storm location at an elevation of 791 feet within the southwest corner of the basin (Figure 9.1). Table 9.1 highlights the adjustment factors in the Storm Adjustment Factor feature class table for the storm at this target grid point location.

**Table 9.1: Aurora College, IL Adjustment Factors for Sample Target Location**

| ID | STORM | LON | LAT | ELEV_FT | IPMF | MTF | GTF | TAF |
|---|---|---|---|---|---|---|---|---|
| 25 | 1286_1_GEN | -84.850 | 43.325 | 791 | 1.36 | 1.00 | 0.78 | 1.06 |

July 1996 Aurora College, IL (SPAS 1286) Transposition to Grid Point #25 [43.325°, -84.850°]

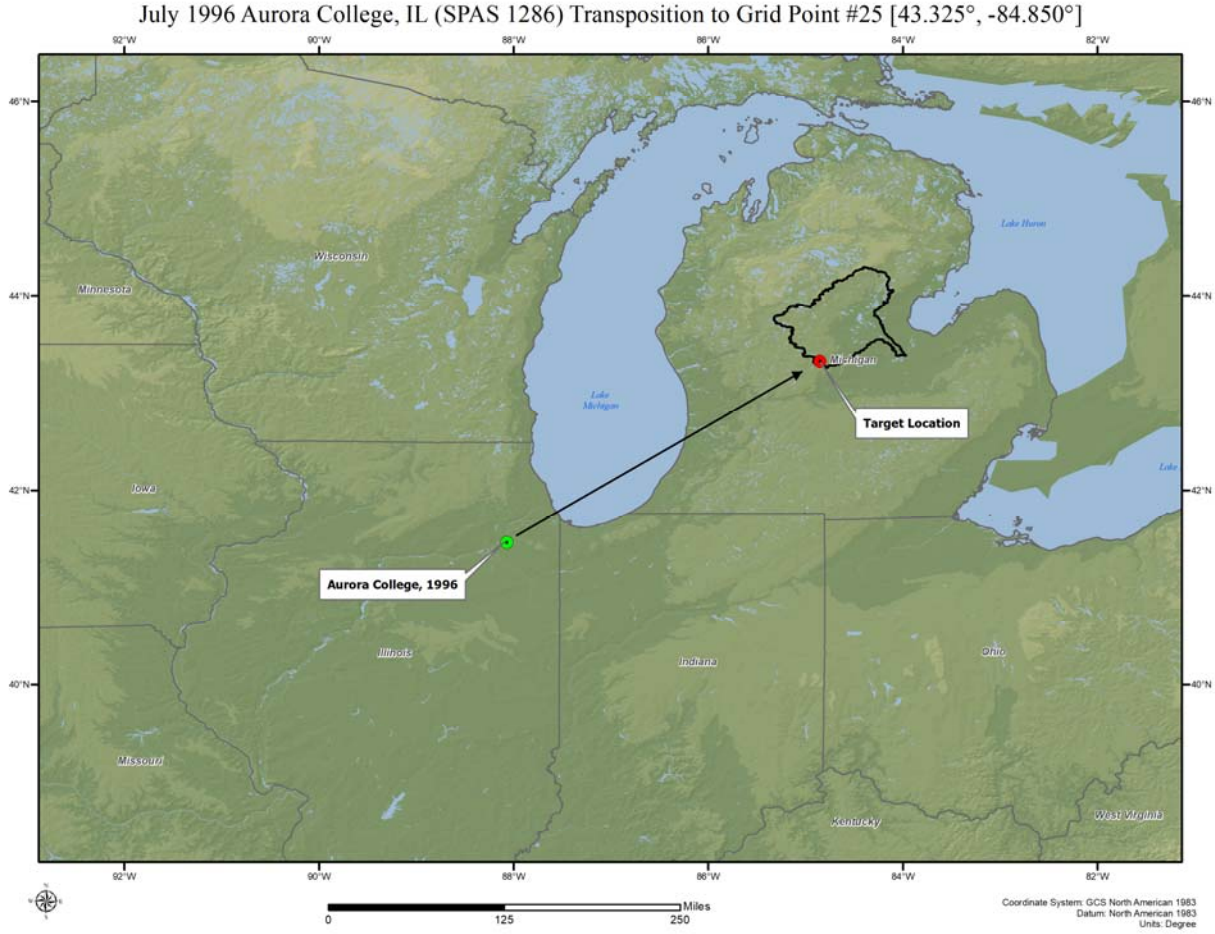


**Figure 9.1: Sample transposition of Aurora College, IL (SPAS 1286) to grid point #25**

### 9.1.4 Sample Precipitable Water Calculation

Using the storm representative dew point temperature and storm center elevation as input, the precipitable water lookup table returns the depth, in inches, used in Equation 4. The storm representative dew point temperature is 74°F at the storm representative dew point location 300 miles southwest of the storm center (see Appendix F for the detailed storm maximization and analysis information). The storm center elevation is approximated at 600 feet at the storm center location of 41.4575°N, 88.0699°W. The storm representative available moisture ($W_{p,\ rep}$) is calculated using Equation 4:

$$W_{p,rep} = W(@74.0°)_{p,30,000'} - W(@74.0°)_{p,600'}$$

or,

$$W_{p,rep} = 2.73'' - 0.15''$$

$$W_{p,rep} = 2.58''$$

The mid-July storm already occurred at a time when dewpoint values were highest, so no adjustment was needed towards the warm season. July 15th is used as the temporal transposition date. The July climatological 100-year maximum 24-hour average dew point at the storm representative dew point location is 80.61°F. The temperature is rounded to the nearest ½ degree to a climatological maximum dew point temperature of 80.50°F. The in-place climatological maximum available moisture ($W_{p,\ max}$) is calculated.

$$W_{p,max} = W(@80.50°)_{p,30,000'} - W(@80.50°)_{p,600'}$$

$$W_{p,max} = 3.68'' - 0.18''$$

$$W_{p,max} = 3.50''$$

### 9.1.5 Sample IPMF Calculation

In-place storm maximization is applied for each storm event using the methodology described in Section 7.2. Storm maximization is quantified by the IPMF using Equation 4:

$$IPMF = \frac{W_{p,max}}{W_{p,rep}}$$

$$IPMF = \frac{3.50''}{2.58''}$$

$$IPMF = 1.36$$

### 9.1.6 Sample GTF Calculation

The ratio of the 100-year 24-hour climatological precipitation depth at the target grid point #25 location to the Aurora College, IL 1996 storm center was evaluated to determine the storm's GTF at the target location. The 24-hour rainfall depth ($R_t$) of 6.09" was extracted at the grid point #25 location from the 100-year 24-hour NOAA Atlas 14 precipitation frequency climatology.

$$R_t = 6.09"$$

Similarly, the 24-hour rainfall depth ($R_s$) of 7.76" was extracted at the storm center location from the 100-year 24-hour NOAA Atlas 14 precipitation frequency climatology.

$$R_s = 7.76"$$

Equation 6 provides the climatological precipitation ratio to determine the GTF.

$$GTF = \frac{R_t}{R_s}$$

$$GTF = \frac{6.09"}{7.76"}$$

$$GTF = 0.78"$$

The GTF at grid #25 is 0.78, or a 22% rainfall decrease from the storm center location due to the differences captured within the precipitation climatology. The GTF is then considered to be a temporal constant for the spatial transposition between that specific source/target grid point pair, for that storm only, and can be applied to the other durations for that storm.

### 9.1.7 Sample TAF Calculation

$$TAF = IPMF \times GTF \qquad \text{(from Equation 1)}$$

$$TAF = 1.36 \times 0.78$$

$$TAF = 1.06$$

The TAF for Aurora College, IL 1996 when moved to the grid point at 43.325°N, 84.850°W, representing storm maximization and transposition, is 1.06. This is an overall increase of 6% from the original location and applied to the SPAS analyzed in-place rainfall. The TAF can then be applied to the storm's rainfall depth taken from the SPAS DAD table, at the basin area-size, to calculate the total adjusted rainfall. If the total adjusted rainfall is greater than the depth for all other transposable storms, it becomes the PMP depth at that grid point for that duration.

# 10. PMP Results

The PMP tool provides basin-specific PMP depths based on the area-size of each basin analyzed. For each storm type the tool provides output in ESRI file geodatabase format. The output also includes a basin average PMP table. If the sub-basin average option was checked, the tool provides averages for each sub-basin. The depths are calculated for the area-size of the basin, so no further areal reduction should be applied. The tool also provides a point feature class containing PMP depths and controlling storms listed by SPAS ID and storm name, date, and state, in addition to gridded raster PMP depth files. There are also temporally distributed accumulated rainfall tables for each temporal pattern applied to the basin. Finally, a basin average PMP depth-duration chart in the .png image format is also included in the output folder. An example depth-duration chart is shown in Figure 10.1.

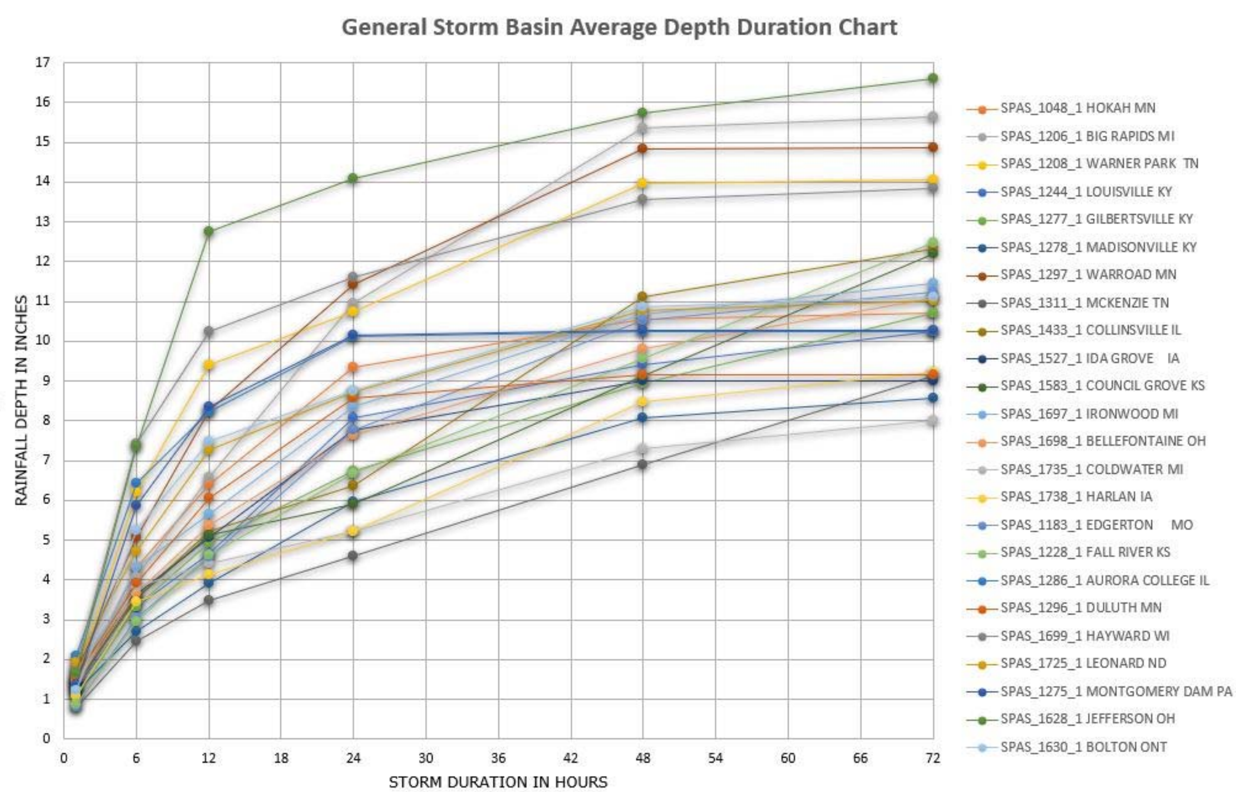


**Figure 10.1: PMP depth-area chart for the overall domain for the general storm type**

Gridded PMP depths were calculated for the entire study region at various index area-sizes for several durations as a visualization aid. The maps in Appendix A illustrate the depths for local storm PMP at 1-, 3-, 6-, 12-, and 24-hour durations and for general storm PMP at 6-, 24-, 48, and 72-hour durations.

# 11. Sensitivities and Comparisons

In the process of deriving PMP depths, various assumptions and meteorological judgments were made within the framework of state-of-the-practice processes. These parameters and derived values are standard to the PMP development process; however, it is of interest to assess the sensitivity of PMP depths to assumptions that were made and to the variability of input parameter values.

PMP depths and intermediate data produced for this study were rigorously evaluated throughout the process. ArcGIS was used as a visual and numerical evaluation tool to assess gridded values to ensure they fell within acceptable ranges and met test criteria. PMP depths were investigated by spatially, by storm type, and through duration as visual aids to help identify potential issues with calculations, transposition limits, DAD values, or storm adjustment values. Over the entire PMP analysis domain, different storms control PMP values at different locations for a given duration and area size.

## 11.1 Comparison of PMP Values to HMR Studies

This study employs a variety of improved methods when compared to previous HMR and EPRI studies. These methods include:

- A far more robust storm analysis system with a higher temporal and spatial resolution
- Improved dew point and precipitation climatologies that provide an increased reliability to maximize and transpose storms
- Gridded PMP calculations which result in higher spatial and temporal resolutions
- A greatly expanded storm record for PMP development

Unfortunately, working papers and notes from the HMRs are not available in most cases. Therefore, direct PMP comparisons between the calcinations and transposition adjustments utilized HMRs and this study are somewhat limited. Furthermore, due to the generalization of the regionally based HMR studies, comparisons to the detailed gridded PMP of this study can vary greatly over short distances. This is similar to the EPRI PMP maps, which produce widely spaced, low resolution PMP output. However, comparisons were made for sensitivity purposes where data allowed. PMP depths in this study resulted in a wide range of reductions as compared to the HMRs and both decreases and increases when compared to the EPRI study.

Gridded index PMP depths were available for HMR 51 allowing a direct gridded comparison with the depths produced for this study. A gridded percent change was calculated for each basin at the basin area size. The maximum PMP depth from the general storm and local storm types were used for the HMR 51 comparisons to account for differences in storm typing between the PMP from this study and HMR studies. Tables 11.1-11.4 provide the average percent difference (negative is a reduction) from HMR 51 and Table 11.5 provides an example of the average percent difference (negative is a reduction) from the EPRI study for the Four Lakes basin.

**Table 11.1: Basin average percent difference from HMR 51 PMP for the Four Lakes drainage basin.**

| Basin Average PMP (945 mi²) Comparison to HMR 51 - Four Lakes Basin | | | | | |
|---|---|---|---|---|---|
| | 6 Hour | 12 Hour | 24 Hour | 48 Hour | 72 Hour |
| HMR 51 | 12.9 | 15.3 | 16.8 | 19.4 | 21.4 |
| General Storm PMP | 8.3 | 13.2 | 14.4 | 16.3 | 17.2 |
| Percent Difference | -35% | -13% | -14% | -16% | -19% |

**Table 11.2 Basin average percent difference from HMR 51 PMP for the Pine drainage basin.**

| Basin Average PMP (1,026 mi²) Comparison to HMR 51 - Pine Basin | | | | | |
|---|---|---|---|---|---|
| | 6 Hour | 12 Hour | 24 Hour | 48 Hour | 72 Hour |
| HMR 51 | 12.6 | 14.8 | 16.5 | 19.1 | 21.2 |
| General Storm PMP | 9.2 | 14.5 | 15.8 | 17.8 | 18.8 |
| Percent Difference | -27% | -2% | -5% | -7% | -11% |

**Table 11.3 Basin average percent difference from HMR 51 PMP for the Tittabawassee drainage basin.**

| Basin Average PMP (1,447 mi²) Comparison to HMR 51 - Tittabawassee Basin | | | | | |
|---|---|---|---|---|---|
| | 6 Hour | 12 Hour | 24 Hour | 48 Hour | 72 Hour |
| HMR 51 | 12.4 | 14.7 | 16.2 | 18.8 | 20.8 |
| General Storm PMP | 8.0 | 13.1 | 14.3 | 16.1 | 17.1 |
| Percent Difference | -35% | -11% | -11% | -14% | -18% |

**Table 11.4 Basin average percent difference from HMR 51 PMP for the entire analysis domain.**

| Basin Average PMP (2,475 mi²) Comparison to HMR 51 - Overall Domain | | | | | |
|---|---|---|---|---|---|
| | 6 Hour | 12 Hour | 24 Hour | 48 Hour | 72 Hour |
| HMR 51 | 11.9 | 14.2 | 15.7 | 18.3 | 20.4 |
| General Storm PMP | 7.5 | 12.8 | 14.1 | 15.7 | 16.6 |
| Percent Difference | -37% | -10% | -10% | -14% | -18% |

**Table 11.5 Basin average percent difference from the 1993 EPRI report for the Four Lakes drainage basin.**

| Basin Average PMP (945 mi²) Comparison to EPRI PMP Study - Four Lakes Basin | | | | | |
|---|---|---|---|---|---|
| | 6 Hour | 12 Hour | 24 Hour | 48 Hour | 72 Hour |
| EPRI PMP (1,000 sqmi) | 11.4 | 12.4 | 14.3 | 16.8 | 18.1 |
| General Storm PMP | 8.3 | 13.2 | 14.4 | 16.3 | 17.2 |
| Percent Difference | -27% | 7% | 1% | -3% | -5% |

## 11.2 Comparison of PMP Values with Precipitation Frequency

The ratio of the PMP to 100-year return period precipitation amounts is generally expected to range between two and four, with values as low as 1.7 and as high as 5.5 for regions east of 117°W found in HMR 57 and HMR 59 (Hansen et al., 1994; Corrigan et al., 1999). Further, as stated in HMR 59 "…*the comparison indicates that larger ratios are in lower elevations where short-duration, convective precipitation dominates, and smaller ratios in higher elevations where general storm, long duration precipitation is prevalent*" (Corrigan et al., 1999, p. 207).

For this study, the maximum 1-square mile PMP was compared directly to the 100-year NOAA Atlas 14 precipitation frequency values on a grid-by-grid basis for the entire analysis domain using a GIS. The comparison was presented as a ratio of PMP to 100-year rainfall, and it was determined for each grid point. Figures 11.2 and 1.3 illustrate the PMP to 100-year rainfall ratios for 6-hour local storm PMP and 24-hour general storm PMP respectively. The PMP to 100-year return period rainfall ratios vary from 3.1 to 4.7. The values are in reasonable proportion expected for the study area and demonstrate the PMP values are at appropriately rare levels.

**Table 11.6: Ratio of 6-hour 1-square mile local storm PMP to 100-year precipitation**

| Local Storm Gridded Average | | | |
|---|---|---|---|
| 6-hr 1 mi² Local PMP (inches) | 100-yr 6-hr NOAA 14 Precip (inches) | Percent of PMP | Ratio of PMP to 100-yr 6-hr Precip |
| 20.2 | 4.3 | 21% | **4.7** |

**Table 11.7: Ratio of 24-hour 1-square mile general storm PMP to 100-year precipitation**

| General Storm Gridded Average | | | |
|---|---|---|---|
| 24-hr 1 mi² General PMP (inches) | 100-yr 24-hr NOAA 14 Precip (inches) | Percent of PMP | Ratio of PMP to 100-yr 24-hr Precip |
| 18.2 | 5.8 | 32% | **3.1** |

## 11.3 Annual Exceedance Probability of PMP

A final sensitivity was completed to determine the annual exceedance probability (AEP) of the PMP depths. This analysis allowed the deterministically derived PMP depths to be evaluated from a probabilistic perspective to better understand the recurrence interval of the PMP depths at two key durations, 24- and 72-hours. This analysis utilized both the regional L-moments approach and the stochastic storm transposition approach. The results of these analyses demonstrated that the PMP depths derived for the basin are appropriately rare, with AEP less than $10^{-6}$ (Table 11.8 and Figures 11.1 and 11.2). The detailed description of the AEP development and data analysis are provided in Appendix D.

**Table 11.8: 24-hour and 72-hour summary of Stochastic Storm Transposition method and Regional L-moment method for quantifying AEP of PMP**

| Four Lake Basin | AEP | AEP Upper | AEP Lower | Stochastic | Stochastic Upper | Stochastic Lower |
|---|---|---|---|---|---|---|
| 24-hr 945-$mi^2$ | $10^{-6}$ | $10^{-5}$ | $10^{-7}$ | $10^{-6}$ | $10^{-6}$ | $10^{-8}$ |
| 72-hr 945-$mi^2$ | $10^{-6}$ | $10^{-5}$ | $10^{-7}$ | $10^{-7}$ | $10^{-6}$ | $10^{-8}$ |

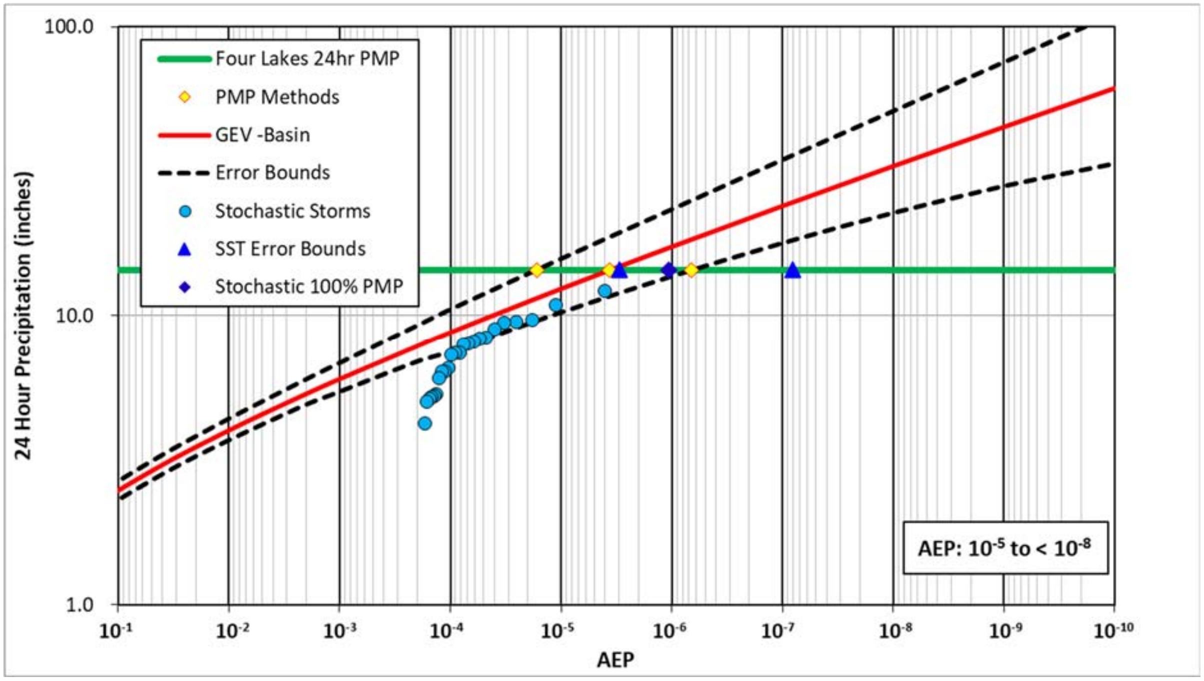


**Figure 11.1: Four Lake basin regional L-moment frequency curve and uncertainty bounds and the Stochastic Storm Transposition AEPs for 24-hour 945-mi2 PMP.**

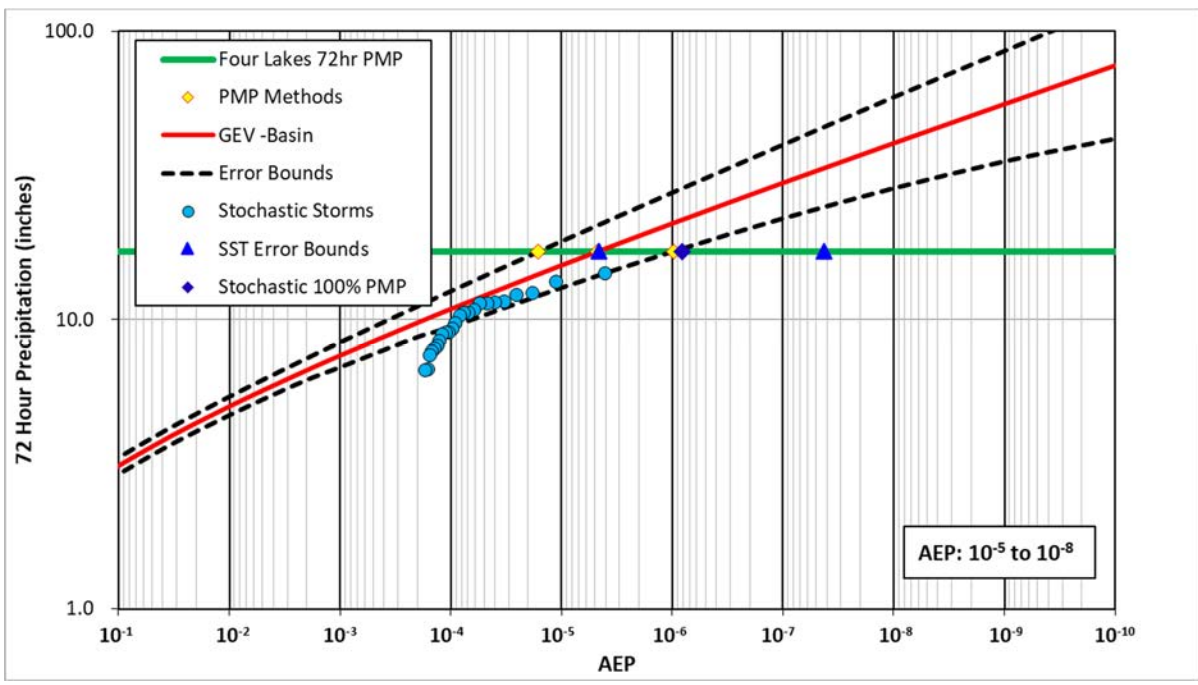


**Figure: 11.2: Four Lake basin regional L-moment frequency curve and uncertainty bounds and the Stochastic Storm Transposition AEPs for 72-hour 945-mi$^2$ PMP.**

# 12. SPAS Analyses for Model Calibration and Validation

AWA utilized SPAS to analyze rainfall over the Tittabawassee basin region. Four storm events were selected for calibration of the PMF hydrologic model (Table 12.1) through coordination with the hydrologist (Ellen Faulkner of Ayres Associates). AWA analyzed a sufficiently large storm domain that included hourly rain gauge observations to calibrate the NEXRAD data if available over a larger domain that included the region. Quality controlled NEXRAD data was acquired when available. In addition to the NEXRAD information, AWA utilized climatological basemaps to aid in the spatial distribution of precipitation. The rainfall analysis results were provided on a 1/3-$mi^2$ grid with a temporal frequency of 60 minutes. In addition to the rainfall grids, clipped to the basins, areal average rainfall statistics were provided for hydrologic modeling purposes.

**Table 12.1 Four storm events were selected for hydrologic model calibration**

Hydrologic Calibration Events Selected

| SPAS # | Date | Radar |
|---|---|---|
| 1773 | May 17-19, 2020 | Yes |
| 1790 | June 17-19, 1996 | Yes |
| 1791 | April 12-14, 2014 | Yes |
| 1792 | June 22-23, 2017 | Yes |

## 12.1 May 2020 Precipitation

The hourly precipitation grids derived from the May 2020 (SPAS 1773) analysis were used for the Four Lakes calibration. The SPAS 1773 analysis encompassed the 12 sub-basins of the Four Lake basin. The SPAS 1773 hourly grids were clipped to each of the Four Lake sub-basins, the sub-basin average statistics were calculated and added to an Excel spreadsheet used for hydrologic calibration. The calibration deliverables are based on the SPAS hourly precipitation data for 05/17/2020 - 05/19/2020. In general, between 3.00 and 6.00 inches of rain fell across the Four Lake basin (Figure 12.1).

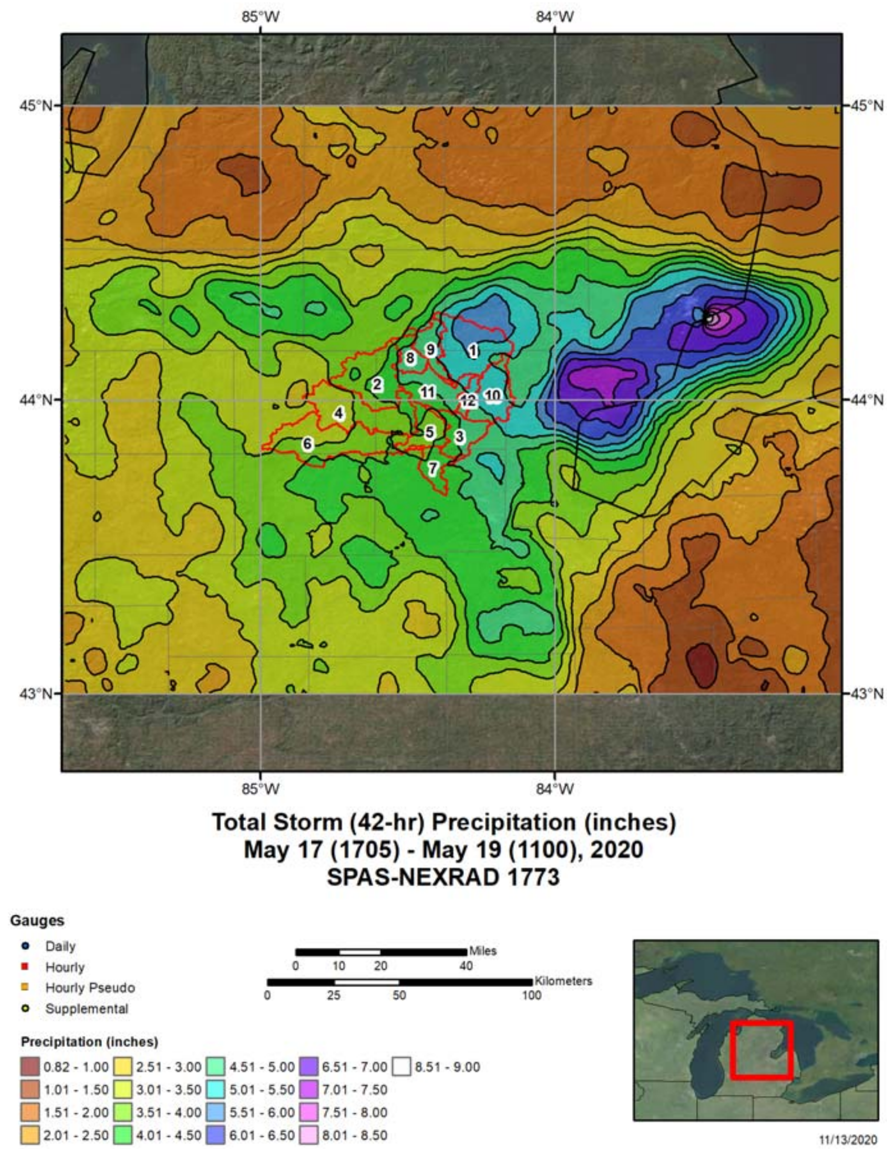


**Figure 12.1: Total storm rainfall for SPAS 1773 across Four Lake basin drainage. Note the numbers represent the sub basin numbers not precipitation values.**

## 12.2 June 1996 Precipitation

The hourly precipitation grids derived from the June 1996 (SPAS 1790) analysis were used for the Four Lakes calibration. The SPAS 1790 analysis encompassed the 12 sub-basins of the Four Lake basin. The SPAS 1790 hourly grids were clipped to each of the Four Lake sub-basins, the sub-basin average statistics were calculated and added to an Excel spreadsheet used for hydrologic calibration. The calibration deliverables are based on the SPAS hourly precipitation data for 06/17/1996 - 06/19/1996. In general, between 2.00 and 5.00 inches of rain fell across the Four Lake basin (Figure 12.2).

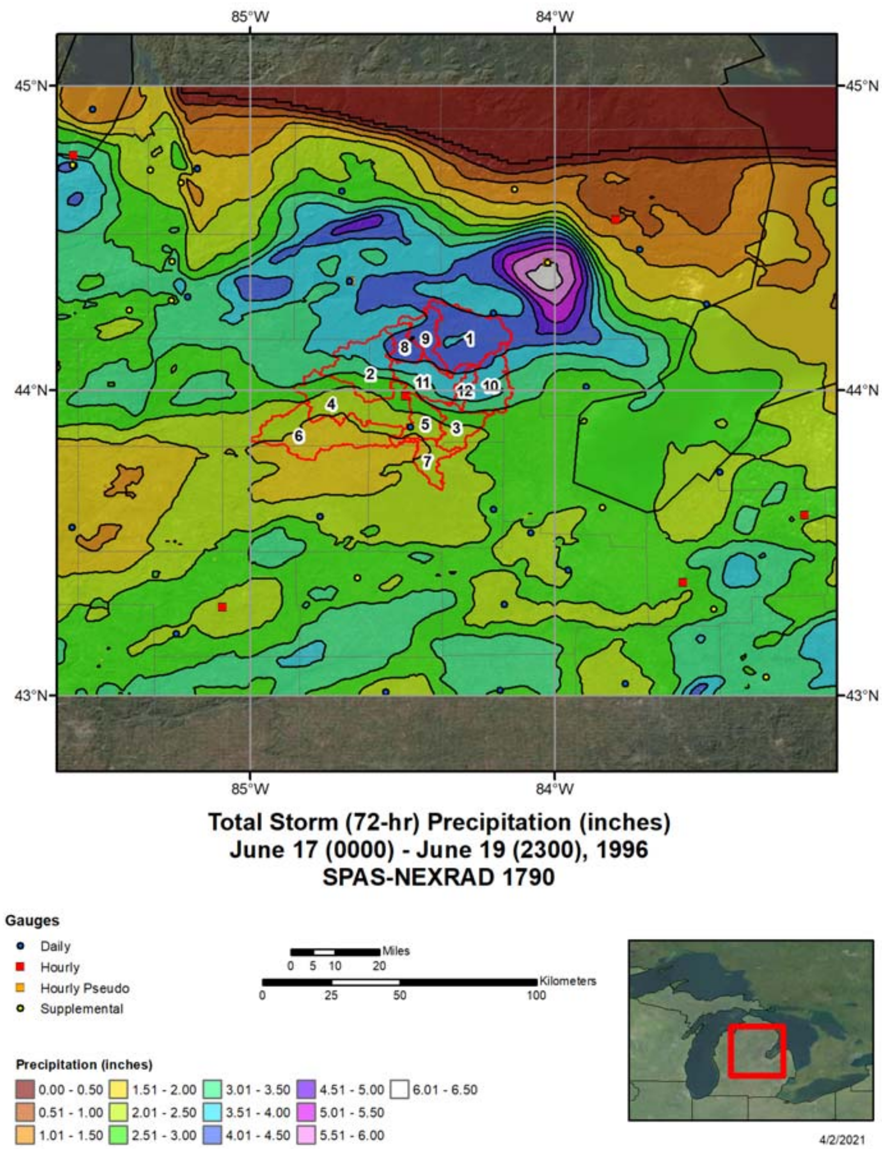


**Figure 12.2: Total storm rainfall for SPAS 1790 across Four Lake basin drainage. Note the numbers represent the sub basin numbers not precipitation values.**

## 12.3 April 2014 Precipitation

The hourly precipitation grids derived from the April 2014 (SPAS 1791) analysis were used for the Four Lakes calibration. The SPAS 1791 analysis encompassed the 12 sub-basins of the Four Lake basin. The SPAS 1791 hourly grids were clipped to each of the Four Lake sub-basins, the sub-basin average statistics were calculated and added to an Excel spreadsheet used for hydrologic calibration. The calibration deliverables are based on the SPAS hourly precipitation data for 04/12/2014 - 04/14/2014. In general, between 2.50 and 7.00 inches of rain fell across the Four Lake basin (Figure 12.3).

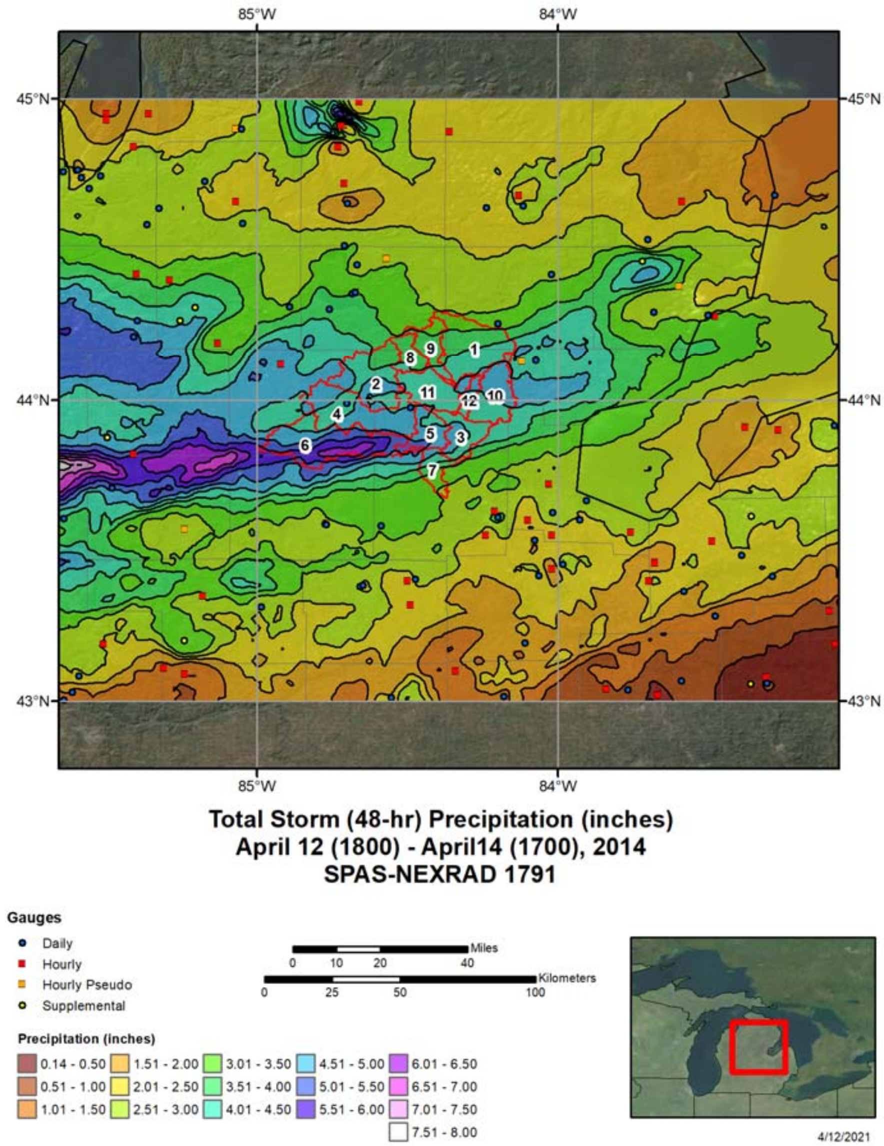


**Figure 12.3: Total storm rainfall for SPAS 1790 across Four Lake basin drainage. Note the numbers represent the sub basin numbers not precipitation values.**

## 12.4 June 2017 Precipitation

The hourly precipitation grids derived from the June 2017 (SPAS 1792) analysis were used for the Four Lakes calibration. The SPAS 1792 analysis encompassed the 12 sub-basins of the Four Lake basin. The SPAS 1792 hourly grids were clipped to each of the Four Lake sub-basins, the sub-basin average statistics were calculated and added to an Excel spreadsheet used for hydrologic calibration. The calibration deliverables are based on the SPAS hourly precipitation data for 06/22/2017 - 06/23/2017. In general, between 2.00 and 6.00 inches of rain fell across the Four Lake basin (Figure 12.4).

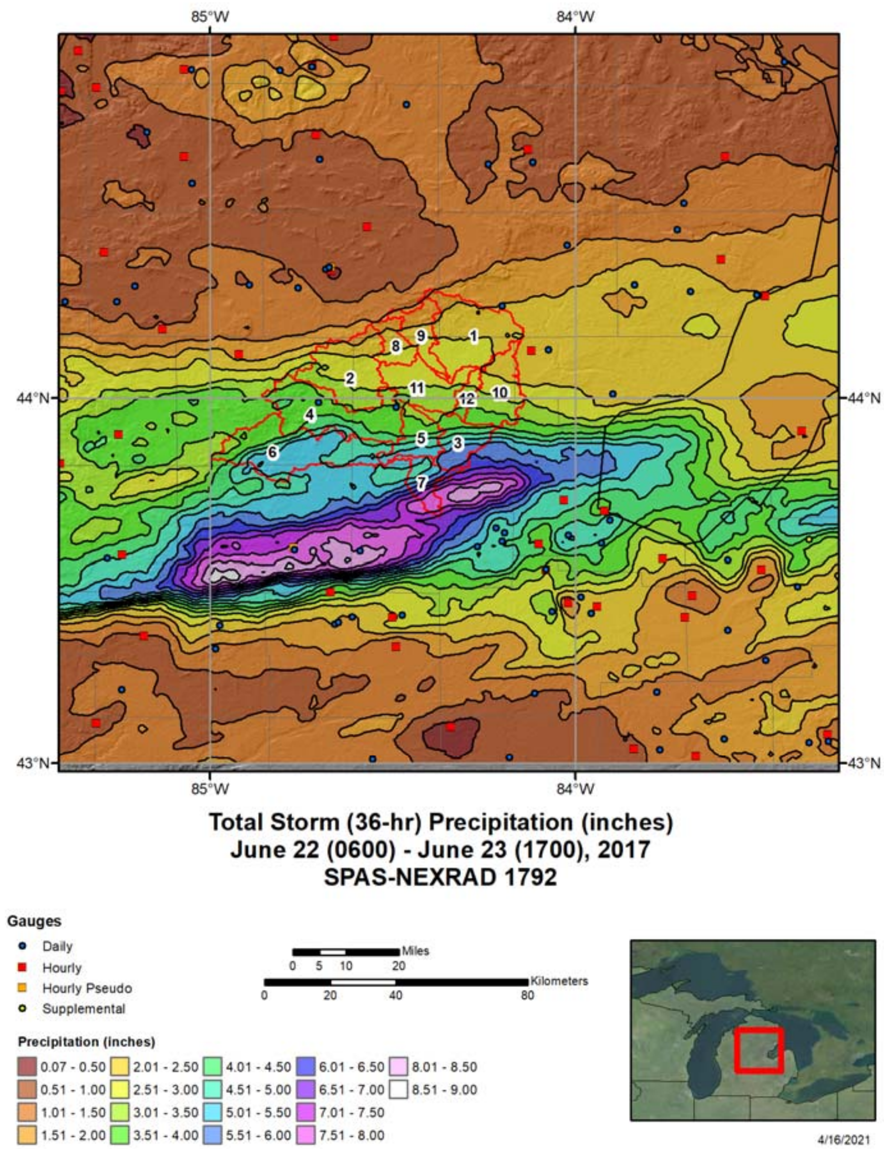


**Figure 12.4: Total storm rainfall for SPAS 1790 across Four Lake basin drainage. Note the numbers represent the sub basin numbers not precipitation values.**

# 13. Uncertainty and Limitations

## 13.1 Sensitivity of Parameters

In the process of deriving PMP depths, various assumptions and meteorological judgments were made. Additionally, various parameters and derived values were used in the calculations, which are standard to the PMP development process. It is of interest to assess the sensitivity of PMP values to assumptions that were made and to the variability of parameter values.

## 13.2 Saturated Storm Atmosphere

The PMP development process assumes that the atmosphere is saturated from the ground through the top of the atmosphere (30,000 feet or 300mb) for both the observed storm events and the hypothetical PMP storms. Applying this assumption, a moist pseudo-adiabatic temperature profiles is applied to both the historic storms and the hypothetical PMP storm to quantify the amount of atmospheric moisture available to the observed storm and the maximized (PMP storm). Initial evaluations of this assumption in the EPRI Michigan/Wisconsin PMP study (Tomlinson, 1993) and the Blenheim Gilboa study (Tomlinson et al., 2008) indicated that historic storm atmospheric profiles were generally not entirely saturated and contained somewhat less precipitable water than was assumed in the PMP procedure. This was also shown by Chen and Bradley (2006). More detailed evaluations were completed by Alaya et al., (2018) utilizing an uncertainty analysis and modeling framework. This again demonstrated that the assumption of a fully saturated atmosphere in conjunction with maximum storm efficiency may not be possible. However, recent work on a PMP storm, Hurricane Harvey utilized high resolution atmospheric profiles and showed that the atmosphere was fully saturated (Fernandez-Caban et al., 2019). This demonstrates that this assumption is possible when associated with a PMP-type storm event.

What is used in the storm maximization process during PMP development is the ratio of precipitable water associated with each storm. If the precipitable water values for each storm were both slightly overestimated, the ratio of these values would be essentially unchanged.

For example, consider the case where instead of a historic storm with a storm representative dew point of 70º F degrees having 2.25 inches of precipitable water assuming a saturated atmosphere, it actually had 90% of that value or about 2.02 inches. The PMP procedure assumed the same type of storm with similar atmospheric characteristics for the maximized storm but with a higher dew point, say 76º F degrees. The maximized storm, having similar atmospheric conditions, would have about 2.69 inches of precipitable water instead of the 2.99 inches associated with a saturated atmosphere with a dew point of 76º F degrees. The maximization factor computed using the assumed saturated atmospheric values would be 2.99″/2.25″ = 1.33. If both storms were about 90% saturated instead, the maximization factor would be 2.69″/2.02″ = 1.33. Therefore, potential inaccuracy of assuming saturated atmospheres (whereas the atmospheres may be somewhat less than saturated) should have a minimal impact on storm maximization and subsequent PMP calculations.

## 13.3 Maximum Storm Efficiency

The assumption is made that if a sufficient period of record is available for rainfall observations, at least a few storms would have been observed that attained or came close to attaining the maximum efficiency possible in nature for converting atmospheric moisture to rainfall for regions with similar climates and topography. The further assumption is made that if additional atmospheric moisture had been available, the storm would have maintained the same efficiency for converting atmospheric moisture to rainfall. The ratio of the maximized rainfall amounts to actual rainfall amounts would be the same as the ratio of precipitable water in the atmosphere associated with each storm.

There are two issues to be considered. First relates to the assumption that a storm has a rainfall efficiency close to the maximum possible. Unfortunately, state-of-the-science in meteorology does not support a direct calculation of storm efficiency. However, if the period of record is considered (generally over 100 years), along with the extended geographic region with transpositionable storms, it is accepted that there should have been at least one storm with dynamics that approached the maximum efficiency for rainfall production.

The other issue pertains to the assumption that storm efficiency does not change if additional atmospheric moisture is available. Storm dynamics could potentially become more efficient or possibly less efficient depending on the interaction of cloud microphysical processes with the storm dynamics. Offsetting effects could indeed lead to the storm efficiency remaining essentially unchanged. For the present, the assumption of no change in storm efficiency seems acceptable.

## 13.4 Storm Representative Dew Point and Maximum Dew Point

The maximization factor depends on the determination of storm representative dew points, along with maximum historical dew point values. The magnitude of the maximization factor varies depending on the values used for the storm representative dew point and the maximum dew point. Holding all other variables constant, the maximization factor is smaller for higher storm representative dew points as well as for lower maximum dew point values. Likewise, larger maximization factors result from the use of lower storm representative dew points and/or higher maximum dew points. The magnitude of the change in the maximization factor varies depending on the dew point values. For the range of dew point values used in most PMP studies, the maximization factor for a particular storm will change about 5% for every 1°F difference between the storm representative and maximum dew point values. The same sensitivity applies to the transposition factor, with about a 5% change for every 1°F change in either the in-place maximum dew point or the transposition maximum dew point.

## 13.5 Judgment and Effect on PMP

During the process of PMP development several decisions were based on meteorological judgment. These include the following:

- Storms used for PMP development
- Storm representative dew point value and location
- Storm transposition limits

- Use of precipitation frequency climatologies to represent differences in precipitation processes (including orographic effects) between two locations

Each of these processes were discussed and evaluated during the PMP development process internally within AWA, during previous review board discussions, and with others involved in the project. The resulting PMP depths derived as part of the PMP development reflect the most defensible judgments based on the data available and current scientific understanding. The PMP results represent reproducible, reasonable, and appropriately conservative estimates for use in the development of the PMF for high hazard and critical infrastructure.

## 13.6 Limitation of Applying the PMP Depths

This study focused on the development of PMP depths from 1-hour through 72-hours at areas sizes specific to each basin and sub basins and considering the specific meteorology and topography of the basins. Therefore, for rivers systems exceeding these bounds a separate site-specific PMP study may be required. In addition, no detailed analysis was completed regarding antecedent or subsequent precipitation or hydrologic conditions. These were investigated as part of the PMF development completed by Ayres Associates. Finally, PMP depths from this study are to be applied to a single basin or region assuming that PMP occurs in a worst-case, yet meteorologically possible scenario over a given location. Therefore, if concurrent precipitation depths are needed over adjoining or nearby locations, PMP should not be applied concurrently. Instead, other methods should be utilized to derive the concurrent rainfall. Examples would include running the PMP tool again at the overall larger area size and subtracting out the PMP volume over the basin of interest, utilizing precipitation frequency climatologies and appropriate areal reduction factors to distribute concurrent rainfall outside of the PMP region, or utilizing observed rainfall patterns to inform the spatial extent of a giving synoptic weather pattern. In all cases, care should be taken to not violate the requirement of the PMP design storm being "physically possible".

## 13.7 Climate Change and PMP

The effect of climate change on the number and intensity of extreme rainfall events is unknown as of the date of this report. With a warming of the atmosphere, there can potentially be an increase in the available atmospheric moisture for storms to convert to rainfall (e.g., Kunkel et al., 2013). However, storm dynamics play a significant role in that conversion process and the result of a warming climate on storm dynamics is not well understood. A warmer climate may lead to a change in the frequency of storms and/or a change in the intensity of storms, but there is no definitive evidence to indicate the trend or the magnitude of potential changes regarding PMP level rainfall (Herath et al., 2018). AWA has completed several detailed analyses of climate change projections on PMP (Kappel et al., 2020). These results are inconclusive and often show no significant change to PMP is likely, even under the most aggressive future emission scenarios. Based on these discussions, it is apparent that the current practice of PMP determination should *not* be modified in an attempt to address potential changes associated with climate change. This study has continued the practice of assuming no climate change, as climate trends are not considered when preparing PMP estimates (WMO 2009, Section 1.1.1).

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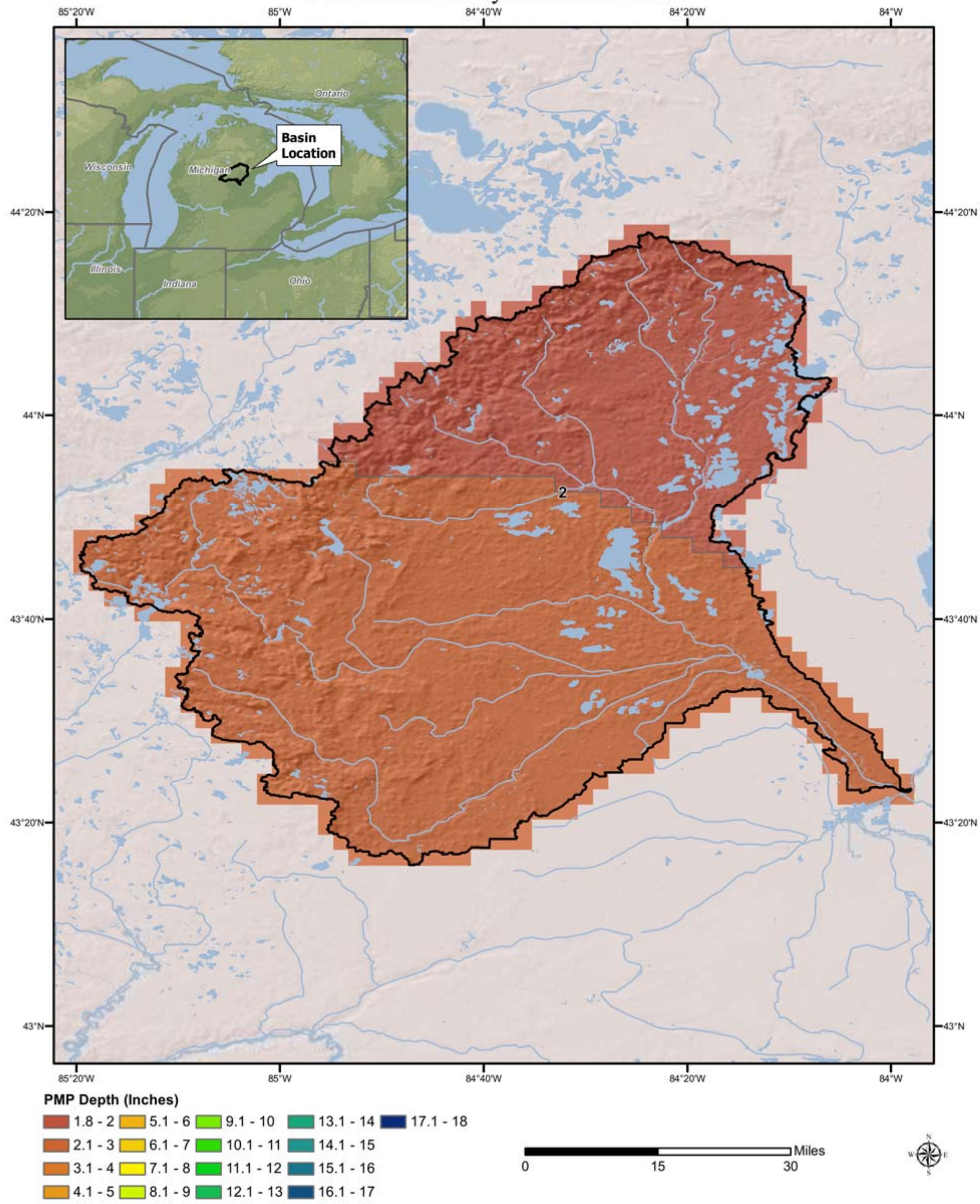
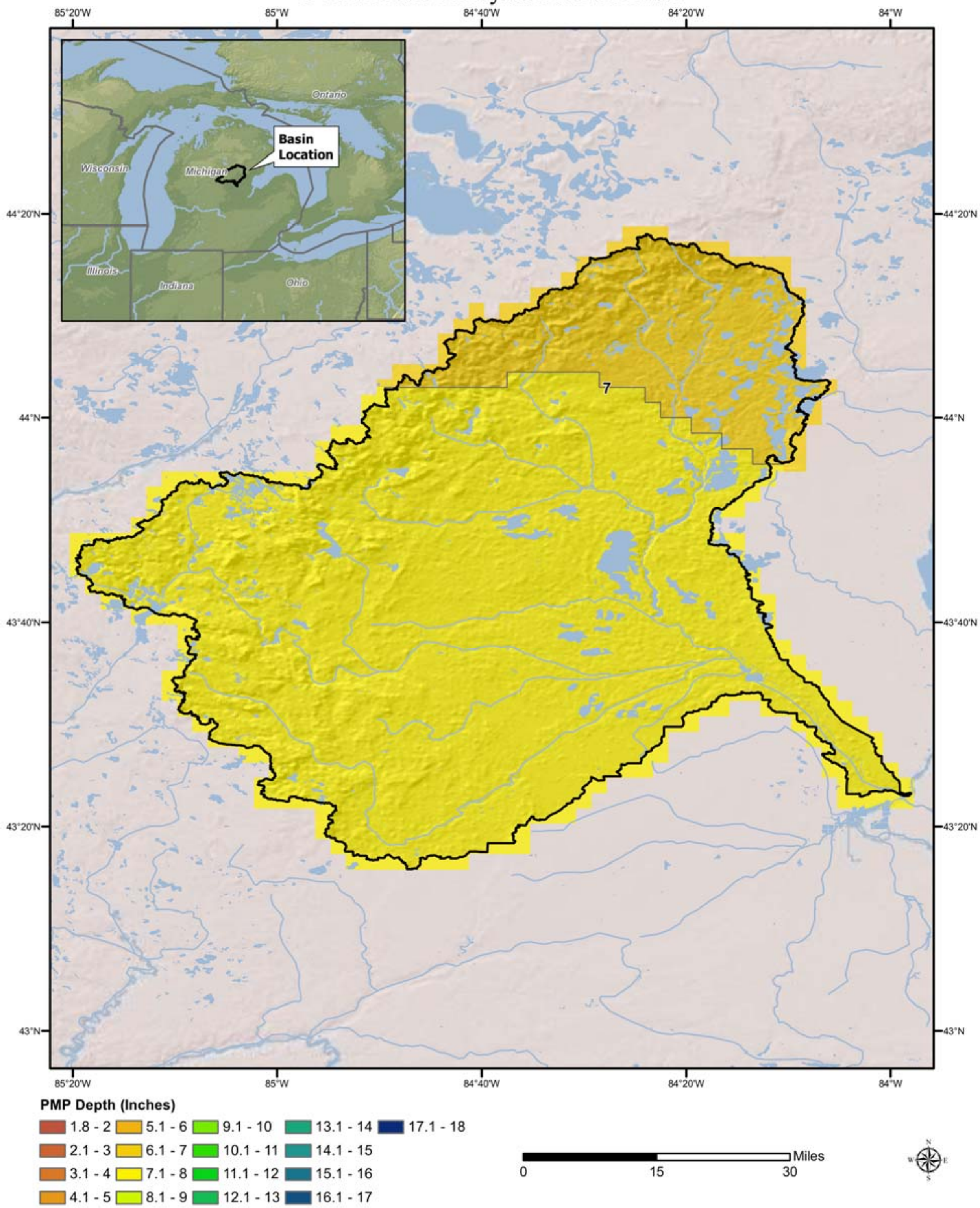
# Appendix A
## Probable Maximum Precipitation (PMP) Maps

# General Storms

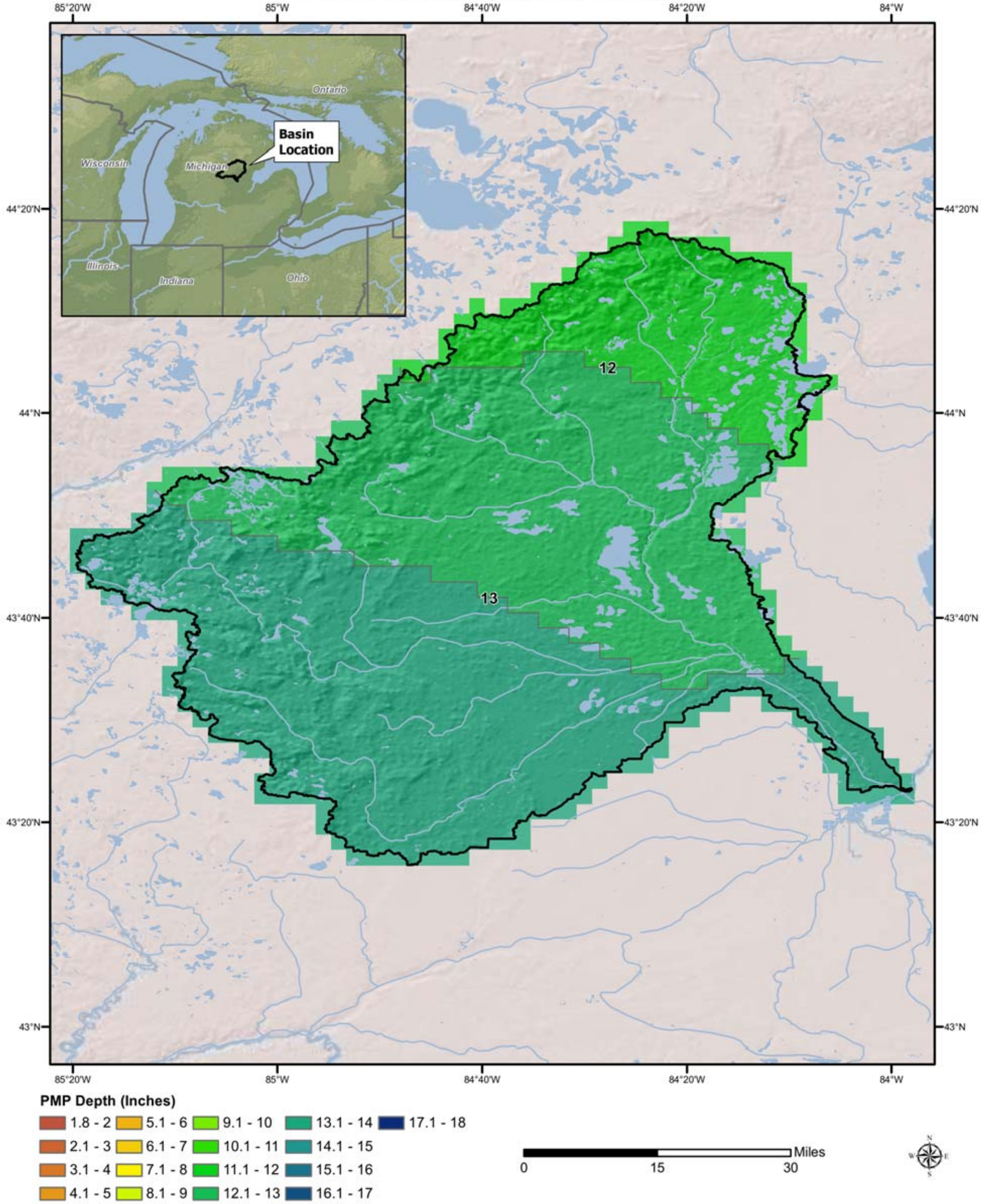
1-Hour General Storm Probable Maximum Precipitation (2,475 mi²)
Overall PMP Analysis Domain Basin



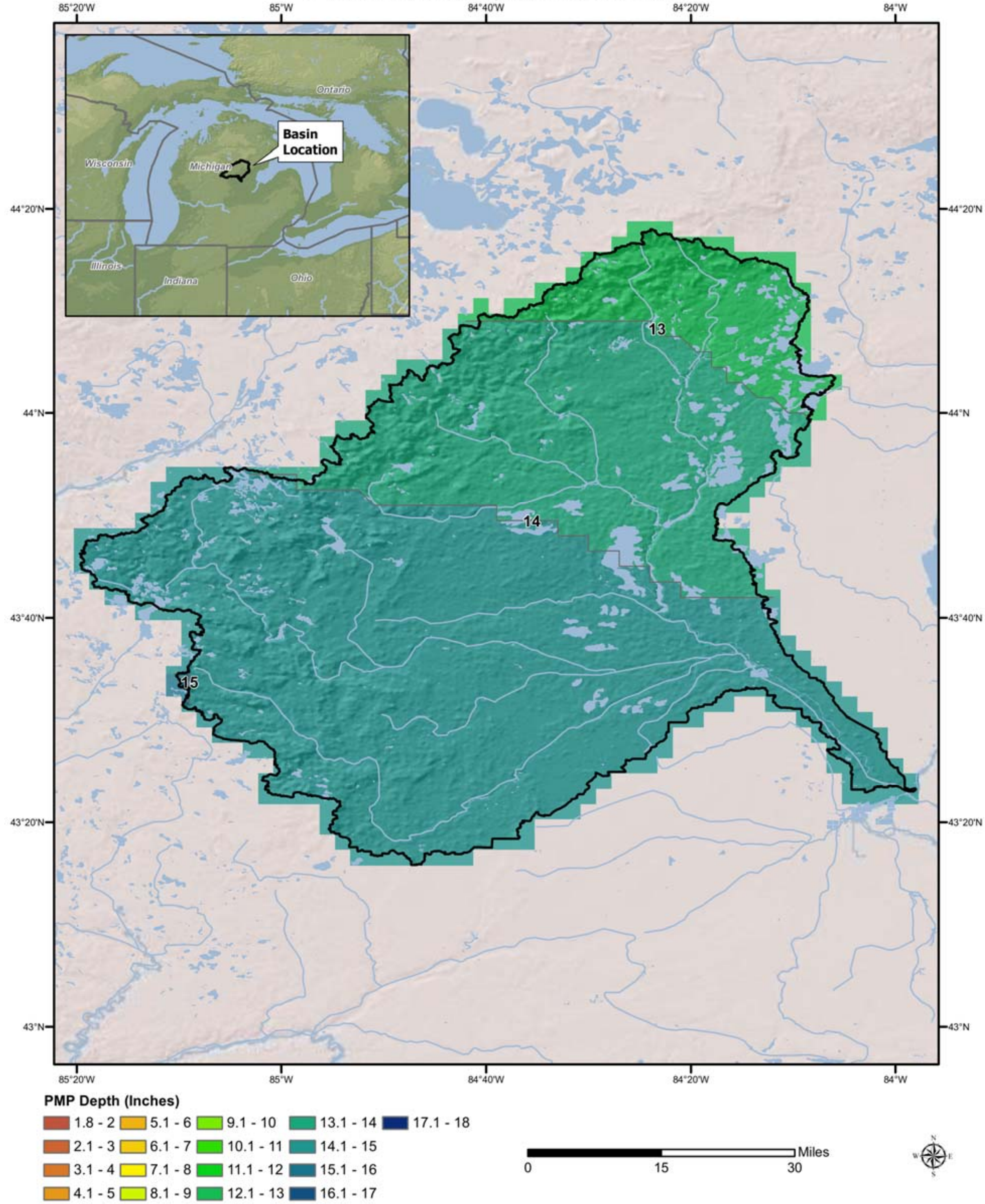
6-Hour General Storm Probable Maximum Precipitation (2,475 mi²)
Overall PMP Analysis Domain Basin



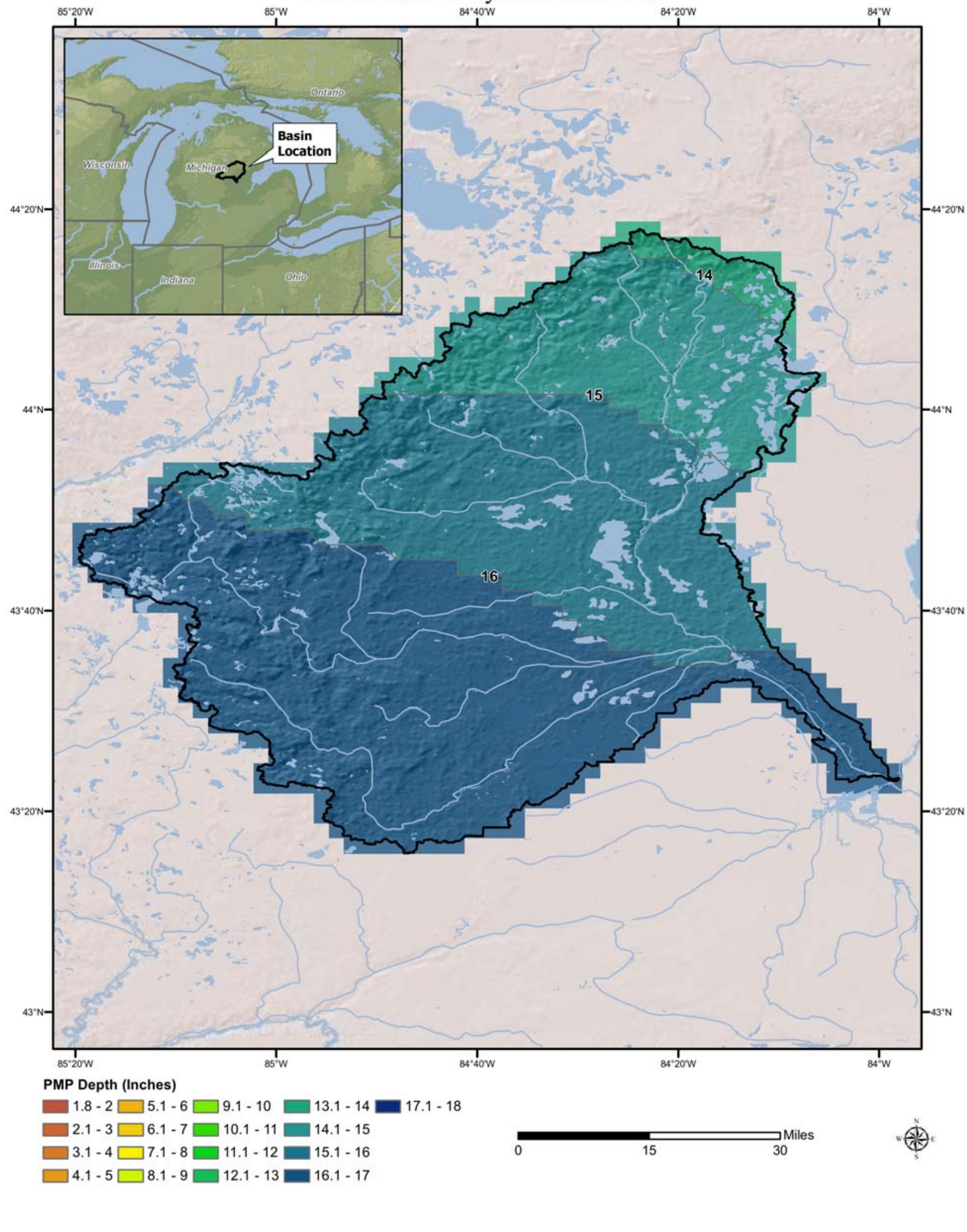
# 12-Hour General Storm Probable Maximum Precipitation (2,475 mi²)
# Overall PMP Analysis Domain Basin



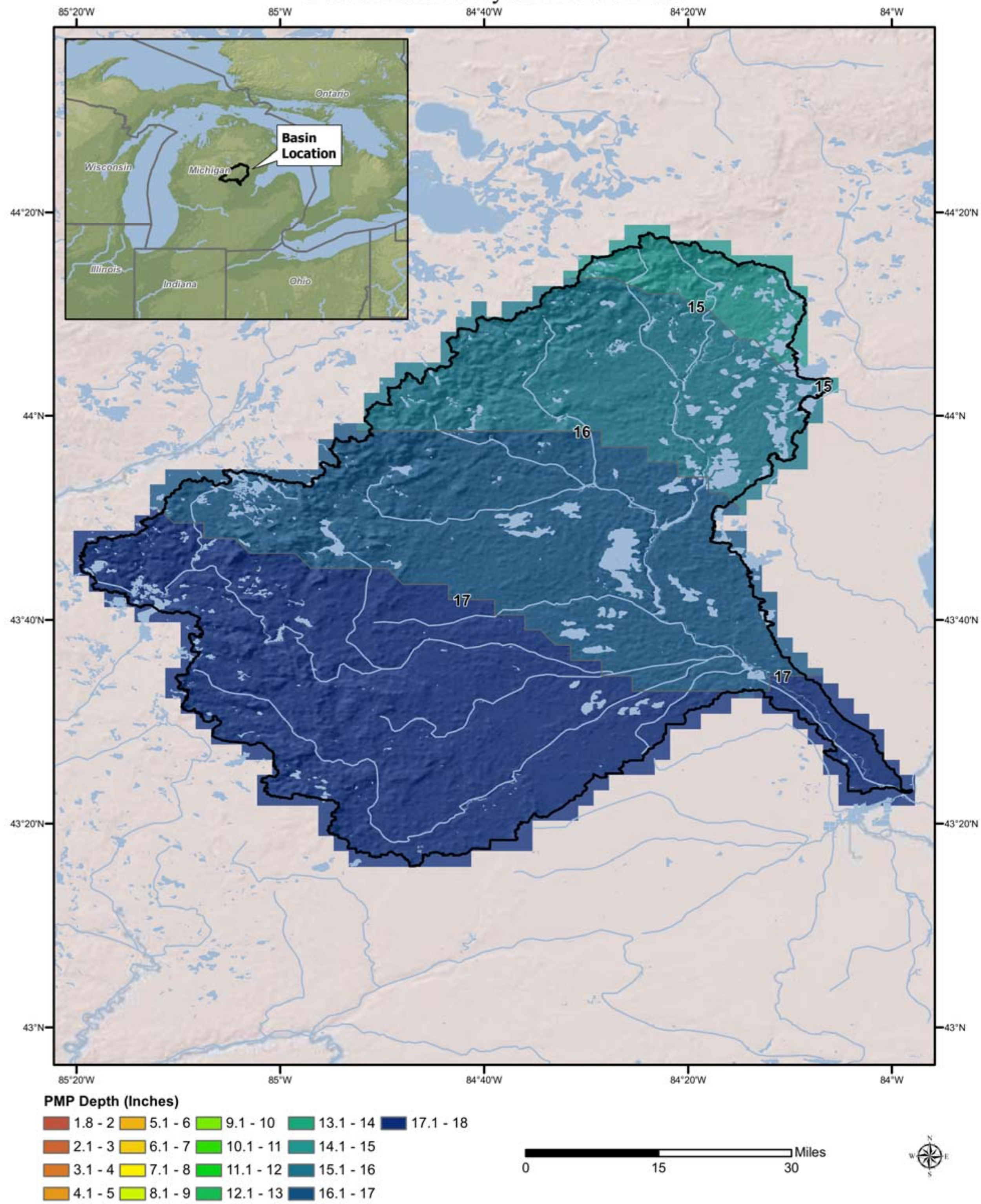
## 24-Hour General Storm Probable Maximum Precipitation (2,475 mi²)
## Overall PMP Analysis Domain Basin



# 48-Hour General Storm Probable Maximum Precipitation (2,475 mi²)
## Overall PMP Analysis Domain Basin

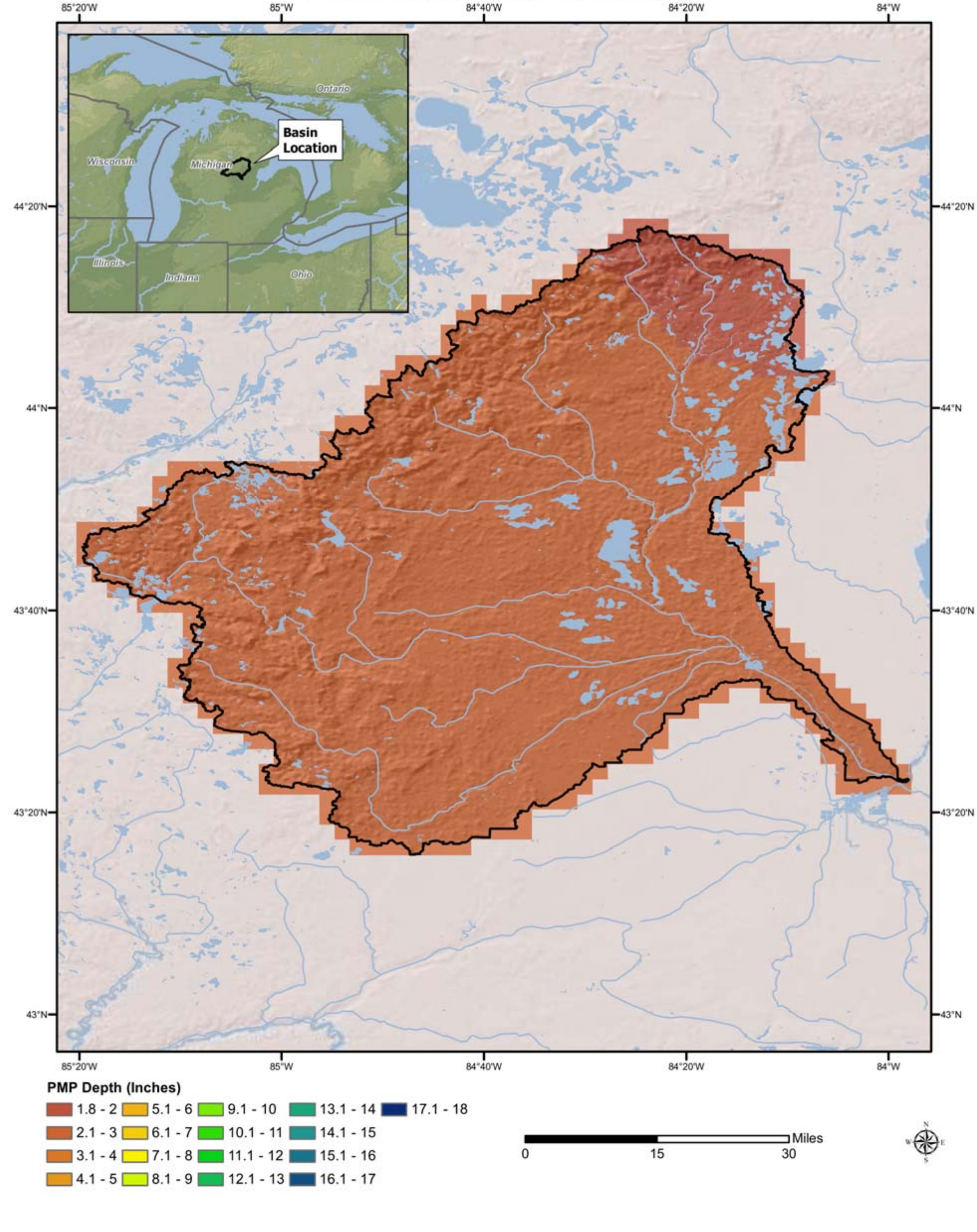


# 72-Hour General Storm Probable Maximum Precipitation (2,475 mi²)
## Overall PMP Analysis Domain Basin

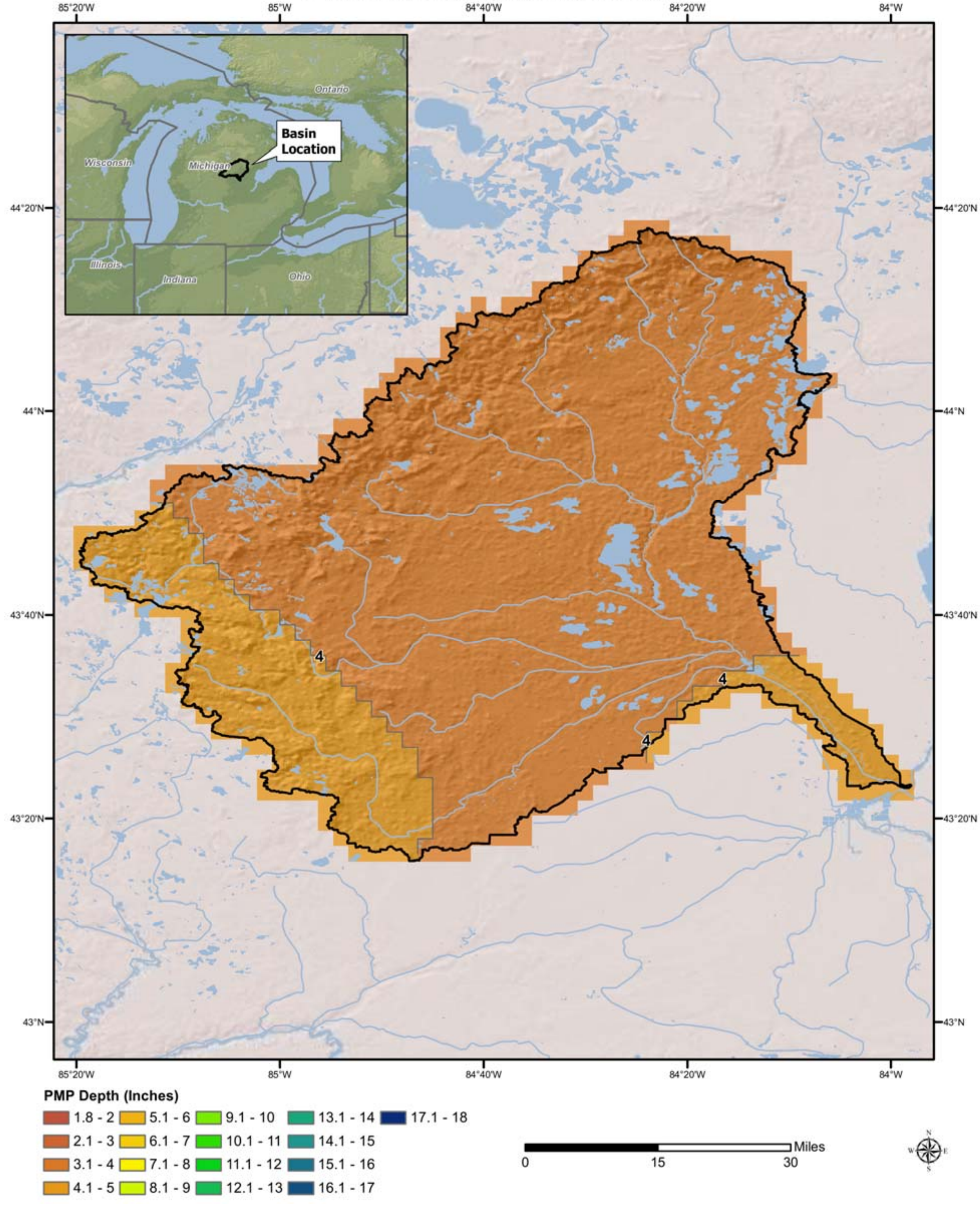


# Local Storms

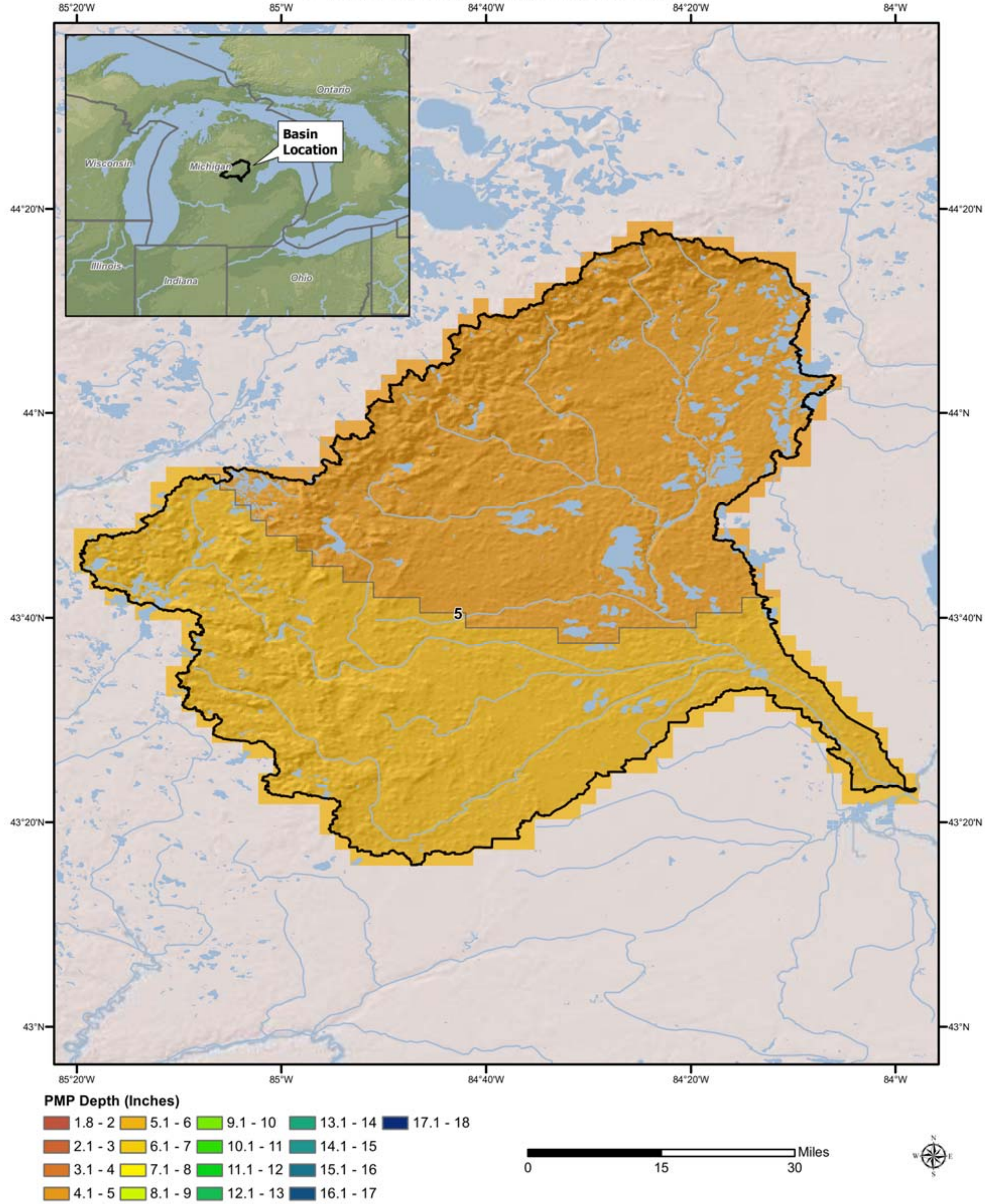
1-Hour Local Storm Probable Maximum Precipitation (2,475 mi²)
Overall PMP Analysis Domain Basin



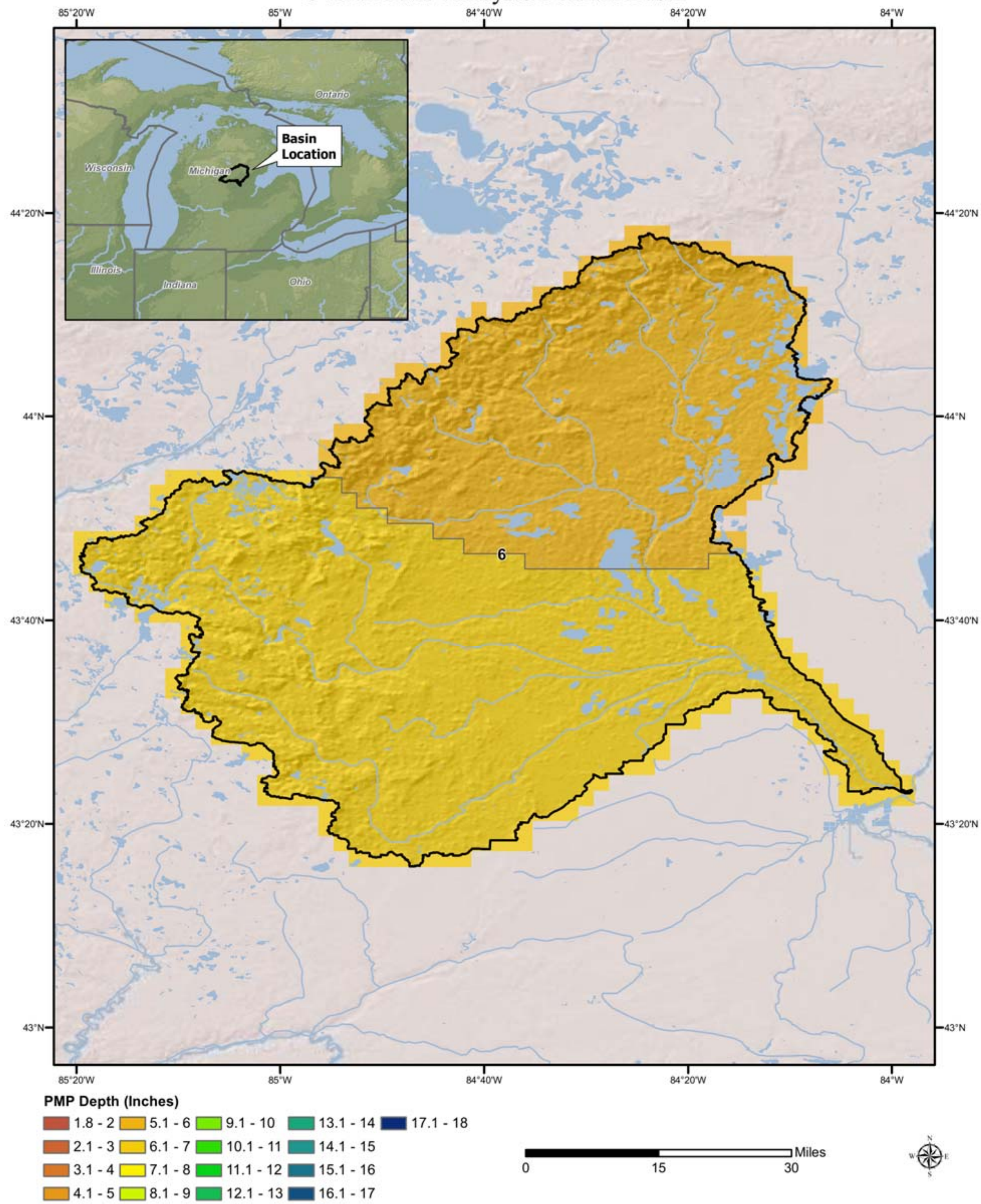
2-Hour Local Storm Probable Maximum Precipitation (2,475 mi²)
Overall PMP Analysis Domain Basin



# 3-Hour Local Storm Probable Maximum Precipitation (2,475 mi²)
# Overall PMP Analysis Domain Basin



# 4-Hour Local Storm Probable Maximum Precipitation (2,475 mi²)
## Overall PMP Analysis Domain Basin



# Tittabawassee Storm List Appendix F

This appendix contains all the storm data used to adjust each storm in-place. Information is provided representing the SPAS analyzed data, the information used to locate the storm representative dew point/SST location, and other pertinent information regarding the In-place storm representative dew point and rainfall. The adjustments applied to each storm to each grid point to calculate the TAF over the entire domain are contained in the PMP Tool database.

In this appendix, daily synoptic weather maps are provided for a period starting a few days before the storm and continuing to a few days after the storm. Daily weather maps covering the period from 1871 through 2002 are from the U.S. Daily Weather Maps Archive, NOAA Climate Database Modernization Program (CDMP), National Climatic Data Center, Asheville, NC, and the NOAA Central Library Data Imaging Project. Daily synoptic weather maps from 2002 through 2014 are from the NOAA Weather Prediction Center Daily Weather Maps web page, http://www.hpc.ncep.noaa.gov/dailywxmap/index.html.

For all storms which had a USACE Storm Studies analysis previously completed, those pertinent data sheet pages are included. These data came from the USACE Storm Rainfall in the United States, Depth-Area-Duration Data files (USACE, 1973). In addition, there are several storms which include a hand drawn transposition limit map complete by the NWS. These maps were recovered from the Hydrometeorological Design Studies Center office in Silver Spring, MD and are archived on AWA's server. Descriptions of transposition limits of key storms are contained in several HMRs (e.g. HMR 52 Figure 26 and HMR 53 Table 2 (Ho and Reidel, 1980)).

**Table F.1 Short storm list used for PMP Development-general storms. Maximum Total Rainfall is the location with the largest rainfall accumulation for the total storm duration.**

| SPAS_ID | Storm Name | State | Latitude | Longitude | Year | Month | Day | Maximum Total Rainfall (in) | Elevation (feet) | PMP Storm Type |
|---|---|---|---|---|---|---|---|---|---|---|
| SPAS_1628_1 | JEFFERSON | OH | 41.8458 | -80.8375 | 1878 | 9 | 10 | 15.01 | 665 | General |
| SPAS_1697_1 | IRONWOOD | MI | 46.4542 | -90.2064 | 1909 | 7 | 21 | 13.41 | 1443 | General |
| SPAS_1698_1 | BELLEFONTAINE | OH | 40.3670 | -83.7670 | 1913 | 3 | 23 | 11.20 | 1224 | General |
| SPAS_1311_1 | MCKENZIE | TN | 36.4375 | -87.9125 | 1937 | 1 | 17 | 19.86 | 566 | General |
| SPAS_1433_1 | COLLINSVILLE | IL | 38.6708 | -90.0042 | 1946 | 8 | 12 | 19.07 | 563 | General |
| SPAS_1583_1 | COUNCIL GROVE | KS | 38.6458 | -96.6208 | 1951 | 7 | 9 | 18.56 | 1430 | General |
| SPAS_1527_1 | IDA GROVE | IA | 42.3625 | -95.4958 | 1962 | 8 | 30 | 12.67 | 1329 | General |
| SPAS_1630_1 | BOLTON | ONT | 43.8375 | -79.9792 | 1954 | 10 | 14 | 11.23 | 1250 | General |
| SPAS_1278_1 | MADISONVILLE | KY | 37.3458 | -87.4958 | 1964 | 3 | 8 | 11.67 | 445 | General |
| SPAS_1738_1 | HARLAN | IA | 41.7208 | -95.2125 | 1972 | 9 | 10 | 15.81 | 1368 | General |
| SPAS_1206_1 | BIG RAPIDS | MI | 43.6125 | -85.3125 | 1986 | 9 | 9 | 13.18 | 987 | General |
| SPAS_1277_1 | GILBERTSVILLE | KY | 36.9958 | -88.2625 | 1989 | 2 | 12 | 13.20 | 352 | General |
| SPAS_1735_1 | COLDWATER | MI | 41.9625 | -85.0042 | 1989 | 5 | 30 | 9.2 | 960 | General |
| SPAS_1244_1 | LOUISVILLE | KY | 38.1000 | -85.6700 | 1997 | 2 | 28 | 13.51 | 548 | General |
| SPAS_1297_1 | WARROAD | MN | 48.8750 | -95.0850 | 2002 | 6 | 9 | 14.62 | 1099 | General |
| SPAS_1275_1 | MONTGOMERY DAM | PA | 40.6450 | -80.3850 | 2004 | 9 | 18 | 8.79 | 1055 | General |
| SPAS_1048_1 | HOKAH | MN | 43.8125 | -91.3625 | 2007 | 8 | 18 | 18.26 | 1092 | General |
| SPAS_1208_1 | WARNER PARK | TN | 36.0611 | -86.9056 | 2010 | 4 | 30 | 19.71 | 622 | General |

**Table F.2 Short storm list used for PMP Development-hybrid storms. Maximum Total Rainfall is the location with the largest rainfall accumulation for the total storm duration.**

| SPAS_ID | Storm Name | State | Latitude | Longitude | Year | Month | Day | Maximum Total Rainfall (in) | Elevation (feet) | PMP Storm Type |
|---|---|---|---|---|---|---|---|---|---|---|
| SPAS_1699_1 | HAYWARD | WI | 46.0130 | -91.4846 | 1941 | 8 | 28 | 15.00 | 1190 | Hybrid (G/L) |
| SPAS_1183_1 | EDGERTON | MO | 40.4125 | -95.5125 | 1965 | 7 | 18 | 20.76 | 915 | Hybrid (G/L) |
| SPAS_1725_1 | LEONARD | ND | 46.5958 | -97.3375 | 1975 | 6 | 29 | 20.66 | 1061 | Hybrid (G/L) |
| SPAS_1286_1 | AURORA COLLEGE | IL | 41.4575 | -88.0699 | 1996 | 7 | 16 | 18.13 | 636 | Hybrid (G/L) |
| SPAS_1228_1 | FALL RIVER | KS | 37.6300 | -96.0500 | 2007 | 6 | 30 | 25.50 | 889 | Hybrid (G/L) |
| SPAS_1296_1 | DULUTH | MN | 47.0150 | -91.6650 | 2012 | 6 | 19 | 10.73 | 611 | Hybrid (G/L) |

**Table F.3 Short storm list used for PMP Development-local storms. Maximum Total Rainfall is the location with the largest rainfall accumulation for the total storm duration.**

| SPAS_ID | Storm Name | State | Latitude | Longitude | Year | Month | Day | Maximum Total Rainfall (in) | Elevation (feet) | PMP Storm Type |
|---|---|---|---|---|---|---|---|---|---|---|
| SPAS_1426_1 | COOPER | MI | 42.3708 | -85.5875 | 1914 | 8 | 31 | 13.39 | 823 | Local |
| SPAS_1427_1 | BOYDEN | IA | 43.1958 | -95.9958 | 1926 | 9 | 17 | 24.22 | 1435 | Local |
| SPAS_1736_1 | STANTON | NE | 41.8208 | -97.0292 | 1944 | 6 | 10 | 17.49 | 1571 | Local |
| SPAS_1434_1 | HOLT | MO | 39.4542 | -94.3292 | 1947 | 6 | 18 | 17.62 | 956 | Local |
| SPAS_1734_1 | THIEF RIVER FALLS | MN | 48.1625 | -96.2625 | 1949 | 5 | 27 | 9.96 | 1146 | Local |
| SPAS_1030_1 | DAVID CITY | NE | 41.2132 | -97.0710 | 1963 | 6 | 24 | 15.98 | 1627 | Local |
| SPAS_1226_1 | COLLEGE HILL | OH | 40.0854 | -81.6479 | 1963 | 6 | 3 | 19.39 | 974 | Local |
| SPAS_1209_1 | WOOSTER | OH | 40.9146 | -81.9729 | 1969 | 7 | 4 | 14.95 | 1164 | Local |
| SPAS_1035_1 | FOREST CITY | MN | 45.2394 | -94.5404 | 1983 | 6 | 20 | 17.00 | 1082 | Local |
| SPAS_1210_1 | MINNEAPOLIS | MN | 44.8895 | -93.4021 | 1987 | 7 | 23 | 11.55 | 940 | Local |
| SPAS_1673_1 | HARROW | ONT | 42.0042 | -82.9375 | 1989 | 7 | 19 | 17.74 | 600 | Local |
| SPAS_1726_1 | TURTLE RIVER | ND | 47.9550 | -97.7550 | 2000 | 6 | 13 | 20.00 | 1224 | Local |
| SPAS_1220_1 | DUBUQUE | IA | 42.4400 | -90.7500 | 2011 | 7 | 27 | 15.14 | 902 | Local |
| SPAS_1727_1 | DRUMMOND | WI | 46.3150 | -91.4150 | 2018 | 6 | 14 | 17.33 | 1303 | Local |
| SPAS_1728_1 | CROSS PLAINS | WI | 43.1450 | -89.6150 | 2018 | 8 | 21 | 16.24 | 1006 | Local |
| SPAS_1729_1 | FOUNTAIN | MI | 44.0350 | -86.1850 | 2019 | 7 | 20 | 15.77 | 697 | Local |

# Table of Contents

# General Storms

# Storm Precipitation Analysis System (SPAS) For Storm #1628_1 SPAS Analysis

**General Storm Location**: Ohio (45.0,-84.0,37.0,-77.5)

**Storm Dates**: September 9-14, 1878

**Event**: Synoptic

**DAD Zone 1**

**Latitude**: 41.8458

**Longitude**: -80.8375

**Max. Grid Rainfall Amount**: 15.01”

**Max. Observed Rainfall Amount**: 15.00”

**Number of Stations**: 37

**SPAS Version**: 10.0

**Basemap:** USACE Isohyetal Image

**Spatial resolution:** 0.2498

**Radar Included:** No

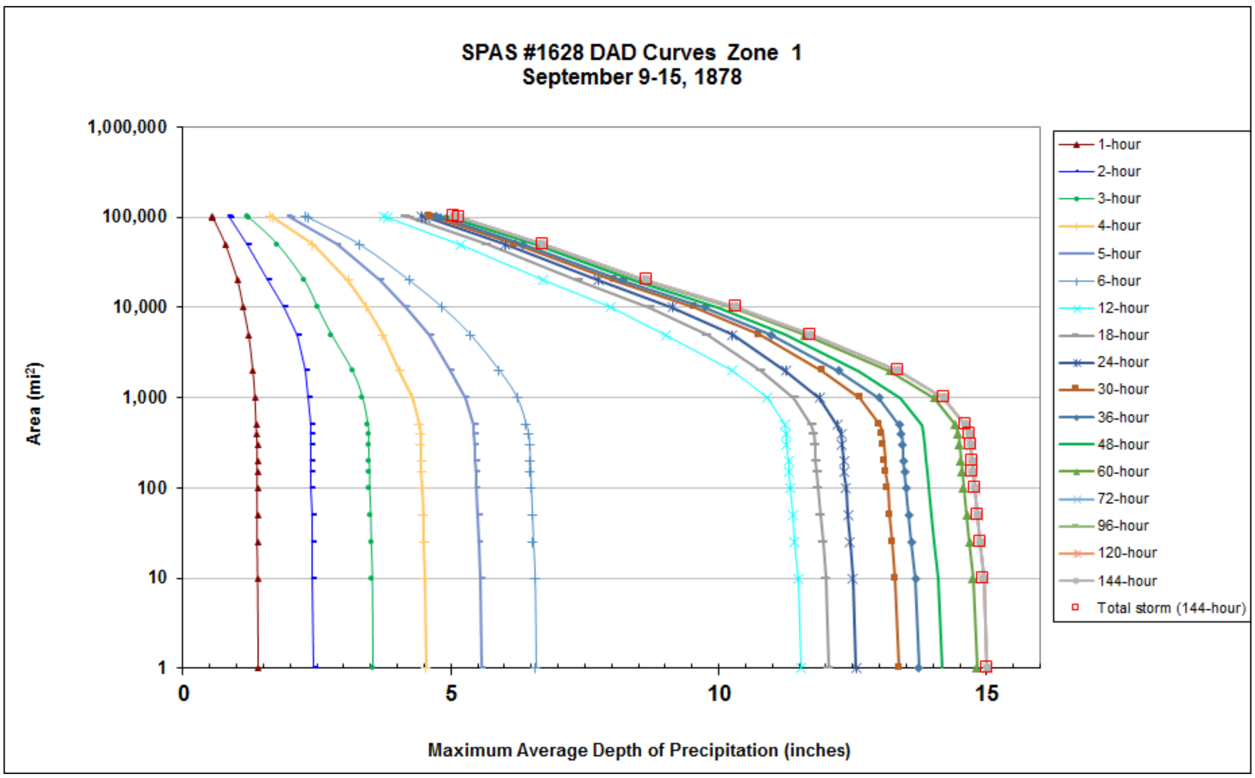
**Depth-Area-Duration (DAD) analysis**: Yes

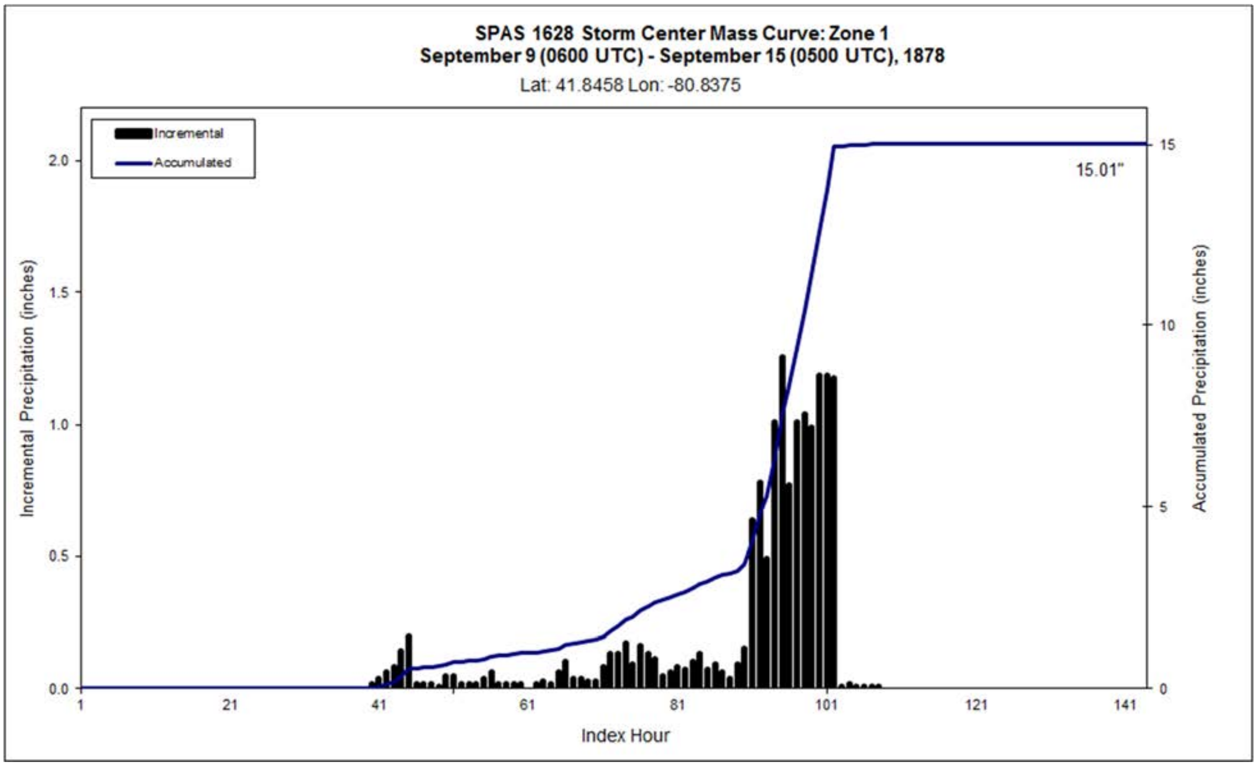
**Reliability of results:** This analysis was based on 37 hourly stations, daily data, and supplemental station data. We have a good degree of confidence for the station based storm total results. The spatial pattern is fully dependent on the basemap created from the USACE Isohyetal image. Timing is based on the three hourly pseudo stations. Several daily stations were moved to supplemental due to timing issues and to ensure data consistency.

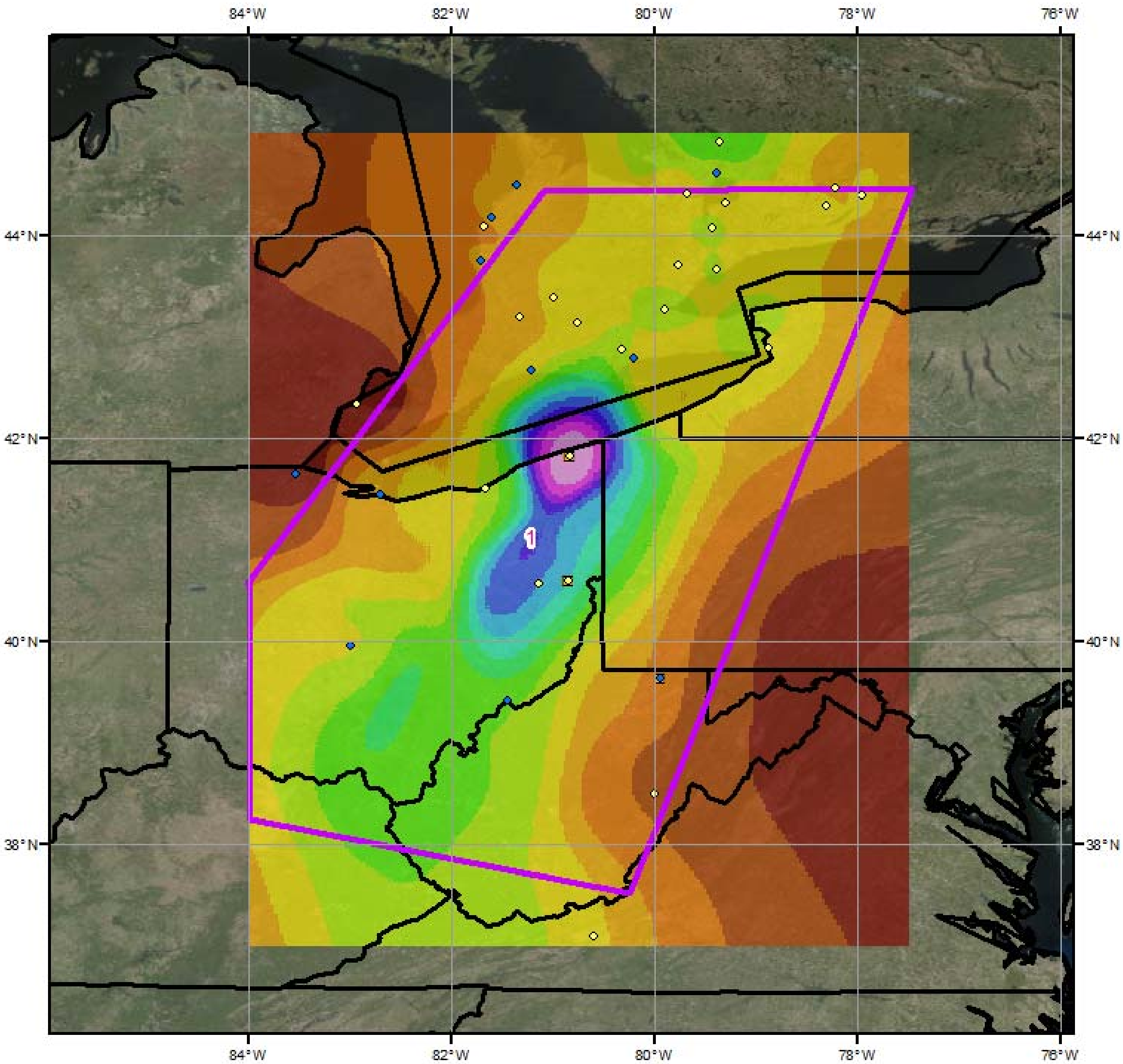
**Storm 1628 - September 9 (0600 UTC) - September 15 (0500 UTC), 1878**

**MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)**

| Area ($mi^2$) | Duration (hours) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 30 | 36 | 48 | 60 | 72 | 96 | 120 | 144 | Total |
| 0.4 | 1.41 | 2.44 | 3.54 | 4.53 | 5.57 | 6.58 | 11.54 | 12.05 | 12.56 | 13.37 | 13.73 | 14.16 | 14.82 | 15.01 | 15.01 | 15.01 | 15.01 | 15.01 |
| 1 | 1.41 | 2.44 | 3.54 | 4.53 | 5.57 | 6.58 | 11.54 | 12.05 | 12.56 | 13.37 | 13.73 | 14.16 | 14.82 | 15.01 | 15.01 | 15.01 | 15.01 | 15.01 |
| 10 | 1.40 | 2.41 | 3.53 | 4.51 | 5.55 | 6.56 | 11.48 | 12.00 | 12.50 | 13.30 | 13.67 | 14.09 | 14.75 | 14.95 | 14.95 | 14.95 | 14.95 | 14.95 |
| 25 | 1.39 | 2.41 | 3.51 | 4.49 | 5.52 | 6.53 | 11.42 | 11.94 | 12.45 | 13.24 | 13.60 | 14.02 | 14.68 | 14.88 | 14.88 | 14.88 | 14.88 | 14.88 |
| 50 | 1.39 | 2.40 | 3.50 | 4.48 | 5.50 | 6.51 | 11.38 | 11.90 | 12.41 | 13.19 | 13.55 | 13.97 | 14.63 | 14.83 | 14.83 | 14.83 | 14.83 | 14.83 |
| 100 | 1.39 | 2.39 | 3.48 | 4.46 | 5.47 | 6.49 | 11.34 | 11.85 | 12.37 | 13.15 | 13.50 | 13.92 | 14.57 | 14.78 | 14.78 | 14.78 | 14.78 | 14.78 |
| 150 | 1.39 | 2.39 | 3.48 | 4.45 | 5.46 | 6.48 | 11.31 | 11.83 | 12.34 | 13.12 | 13.47 | 13.89 | 14.54 | 14.75 | 14.75 | 14.75 | 14.75 | 14.75 |
| 200 | 1.39 | 2.39 | 3.47 | 4.44 | 5.45 | 6.47 | 11.30 | 11.81 | 12.33 | 13.11 | 13.45 | 13.87 | 14.52 | 14.73 | 14.73 | 14.73 | 14.73 | 14.73 |
| 300 | 1.39 | 2.38 | 3.46 | 4.43 | 5.44 | 6.46 | 11.27 | 11.79 | 12.30 | 13.08 | 13.43 | 13.85 | 14.49 | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 |
| 400 | 1.38 | 2.38 | 3.46 | 4.43 | 5.43 | 6.44 | 11.26 | 11.77 | 12.29 | 13.06 | 13.41 | 13.82 | 14.47 | 14.68 | 14.68 | 14.68 | 14.68 | 14.68 |
| 500 | 1.37 | 2.38 | 3.45 | 4.41 | 5.43 | 6.40 | 11.23 | 11.73 | 12.21 | 13.01 | 13.37 | 13.78 | 14.42 | 14.60 | 14.60 | 14.60 | 14.60 | 14.60 |
| 1,000 | 1.35 | 2.34 | 3.35 | 4.28 | 5.27 | 6.23 | 10.91 | 11.40 | 11.88 | 12.64 | 12.99 | 13.39 | 14.02 | 14.20 | 14.20 | 14.20 | 14.20 | 14.20 |
| 2,000 | 1.31 | 2.28 | 3.16 | 4.04 | 4.99 | 5.90 | 10.25 | 10.78 | 11.25 | 11.93 | 12.24 | 12.61 | 13.19 | 13.36 | 13.36 | 13.36 | 13.36 | 13.36 |
| 5,000 | 1.23 | 2.13 | 2.77 | 3.72 | 4.60 | 5.36 | 9.02 | 9.78 | 10.25 | 10.76 | 10.97 | 11.24 | 11.61 | 11.72 | 11.72 | 11.72 | 11.72 | 11.72 |
| 10,000 | 1.13 | 1.89 | 2.51 | 3.42 | 4.15 | 4.84 | 7.97 | 8.70 | 9.13 | 9.55 | 9.74 | 9.98 | 10.25 | 10.33 | 10.33 | 10.33 | 10.33 | 10.33 |
| 20,000 | 1.02 | 1.57 | 2.26 | 3.08 | 3.67 | 4.22 | 6.73 | 7.37 | 7.76 | 8.05 | 8.20 | 8.42 | 8.60 | 8.65 | 8.65 | 8.65 | 8.65 | 8.65 |
| 50,000 | 0.79 | 1.21 | 1.76 | 2.41 | 2.87 | 3.30 | 5.18 | 5.67 | 6.01 | 6.20 | 6.34 | 6.55 | 6.68 | 6.71 | 6.71 | 6.71 | 6.71 | 6.71 |
| 100,000 | 0.55 | 0.86 | 1.22 | 1.67 | 2.00 | 2.33 | 3.81 | 4.22 | 4.53 | 4.69 | 4.81 | 4.98 | 5.12 | 5.15 | 5.15 | 5.15 | 5.15 | 5.15 |
| 102,741 | 0.54 | 0.84 | 1.19 | 1.63 | 1.96 | 2.28 | 3.74 | 4.14 | 4.45 | 4.60 | 4.72 | 4.89 | 5.03 | 5.06 | 5.06 | 5.06 | 5.06 | 5.06 |




SPAS 1628 Storm Center Mass Curve: Zone 1
September 9 (0600 UTC) - September 15 (0500 UTC), 1878
Lat: 41.8458 Lon: -80.8375
Incremental
Accumulated
15.01"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
2.0
0
5
10
15
1
21
41
61
81
101
121
141




**Total Storm (144-hours) Precipitation (inches)**
**September 9-14, 1878**
**SPAS 1628 - Jefferson, OH**

**Gauges**

- Daily
- Hourly
- Hourly Pseudo
- Supplemental

Miles: 0, 45, 90, 180

Kilometers: 0, 90, 180, 360

**Precipitation (inches)**

- 0.58 - 1.00
- 1.01 - 2.00
- 2.01 - 3.00
- 3.01 - 4.00
- 4.01 - 5.00
- 5.01 - 6.00
- 6.01 - 7.00
- 7.01 - 8.00
- 8.01 - 9.00
- 9.01 - 10.00
- 10.01 - 11.00
- 11.01 - 12.00
- 12.01 - 13.00
- 13.01 - 14.00
- 14.01 - 15.00
- 15.01 - 16.00

4/3/2015

WAR DEPARTMENT — CORPS OF ENGINEERS, U. S. ARMY

# STORM STUDIES - PERTINENT DATA SHEET


Storm of Sept. 10 - 13, 1878
Assignment O R 9 - 19
Location Ohio, Pa. and W.Va.
Study Prepared by:
Ohio River Division
Pittsburgh District Office

Part I Reviewed by H. M. Sec. of Weather Bureau, 8/18/41
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 4/16/42
Remarks: Center at Jefferson, Ohio

## DATA AND COMPUTATIONS COMPILED

### PART I

Preliminary isohyetal map, in 5 sheet, scale vary

| Precipitation data and mass curves: | (Number of Sheets) |
|---|---|
| Form 5001-C (Hourly precip. data) | - |
| Form 5001-B (24-hour " " ) | 26 |
| Form 5001-D ( " " " " ) | 7 |
| Miscl. precip. records, meteorological data, etc. | 42 |
| Form 5002 (Mass rainfall curves) | 33 |

### PART II

Final isohyetal maps, in 1 sheet, scale 1 : 1,000,000

| Data and computation sheets: | |
|---|---|
| Form S-10 (Data from mass rainfall curves) | 2 |
| Form S-11 (Depth-area data from isohyetal map) | 1 |
| F,rm S-12 (Maximum depth-duration data) | 7 |
| Maximum duration-depth-area curves | 1 |
| Data relating to periods of maximum rainfall | 3 |

### MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

| Area in Sq. Mi. | Duration of Rainfall in Hours | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 12 | 18 | 24 | 30 | 36 | 48 | 60 | 66 | 84 |
| 10* | 5.9 | 11.2 | 11.7 | 12.2 | 13.0 | 13.4 | 14.3 | 14.9 | 15.0 | *15.0 |
| 100 | 5.8 | 10.9 | 11.6 | 12.1 | 12.7 | 13.2 | 14.1 | 14.6 | 14.7 | 14.7 |
| 200 | 5.8 | 10.8 | 11.4 | 11.9 | 12.5 | 12.9 | 13.9 | 14.4 | 14.5 | 14.5 |
| 500 | 5.6 | 10.5 | 11.1 | 11.5 | 12.2 | 12.6 | 13.4 | 13.9 | 14.0 | 14.0 |
| 1,000 | 5.3 | 10.1 | 10.6 | 11.0 | 11.7 | 12.1 | 12.9 | 13.4 | 13.5 | 13.5 |
| 2,000 | 4.9 | 9.4 | 10.0 | 10.4 | 11.1 | 11.5 | 12.2 | 12.6 | 12.7 | 12.7 |
| 5,000 | 4.1 | 8.0 | 8.8 | 9.2 | 9.9 | 10.3 | 10.9 | 11.3 | 11.3 | 11.3 |
| 10,000 | 3.5 | 6.8 | 7.5 | 8.1 | 8.8 | 9.0 | 9.7 | 9.9 | 10.0 | 10.0 |
| 20,000 | 2.8 | 5.4 | 6.1 | 6.7 | 7.2 | 7.5 | 8.1 | 8.4 | 8.4 | 8.4 |
| 50,000 | 1.9 | 3.5 | 4.1 | 4.6 | 4.9 | 5.2 | 5.8 | 6.1 | 6.1 | 6.1 |
| 70,000 | 1.6 | 2.8 | 3.4 | 3.8 | 4.0 | 4.3 | 4.9 | 5.1 | 5.2 | 5.2 |
| 90,000 | 1.3 | 2.2 | 2.9 | 3.2 | 3.4 | 3.7 | 4.1 | 4.4 | 4.5 | 4.5 |

* Extrapolated

Form S-2

WAR DEPARTMENT CORPS OF ENGINEERS, U. S. ARMY

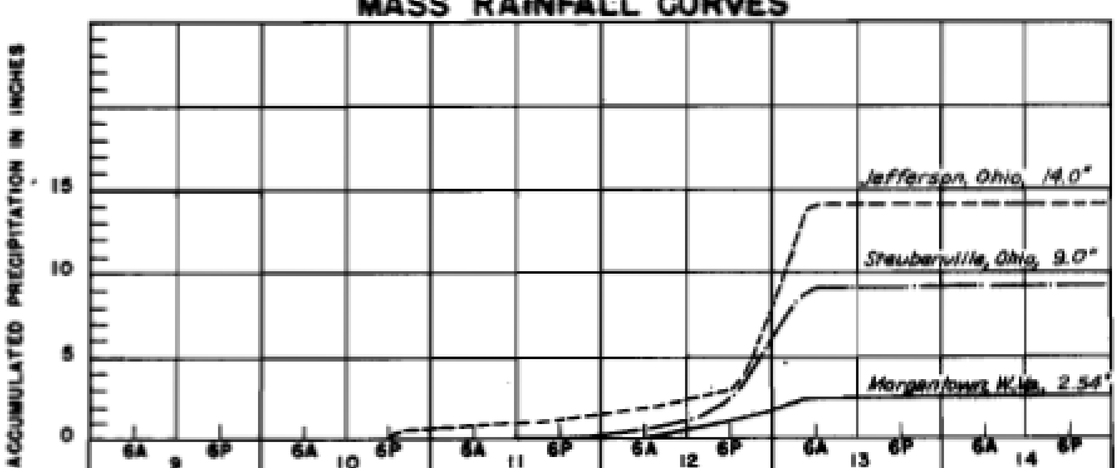
# STORM STUDIES – ISOHYETAL MAP

Storm of *September 10-13, 1878* Assignment *OR 9-19*

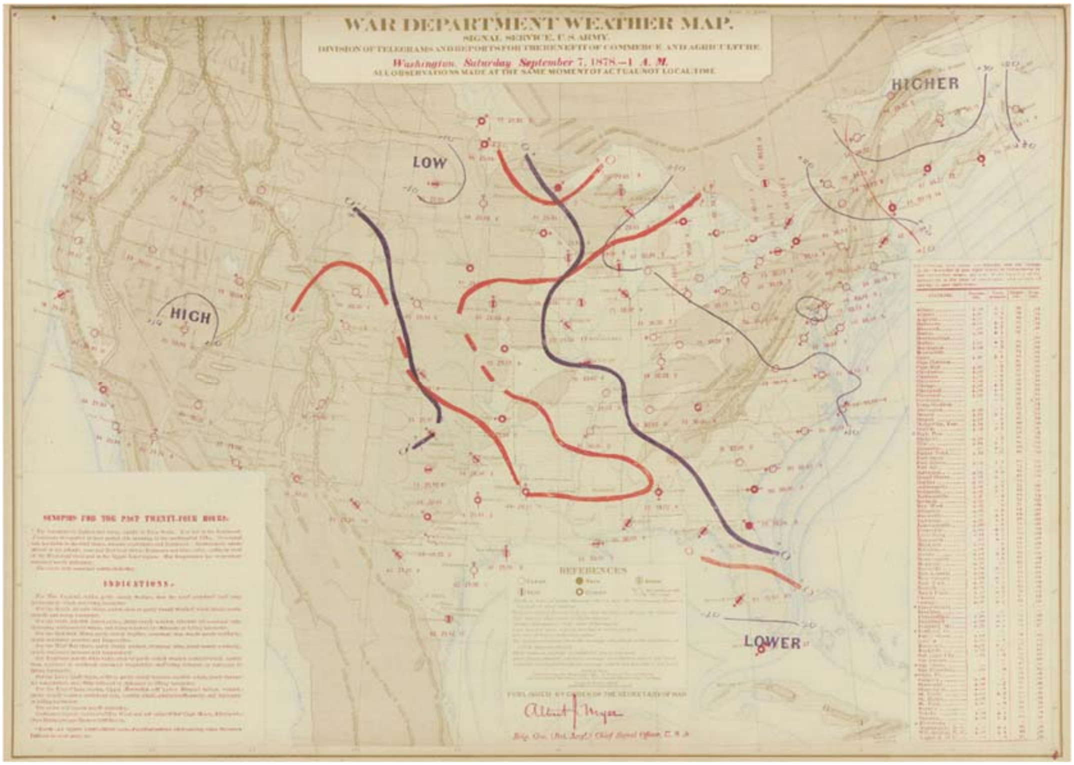
Study Prepared by: *Pittsburgh, Penna. District*
*Ohio River Division*

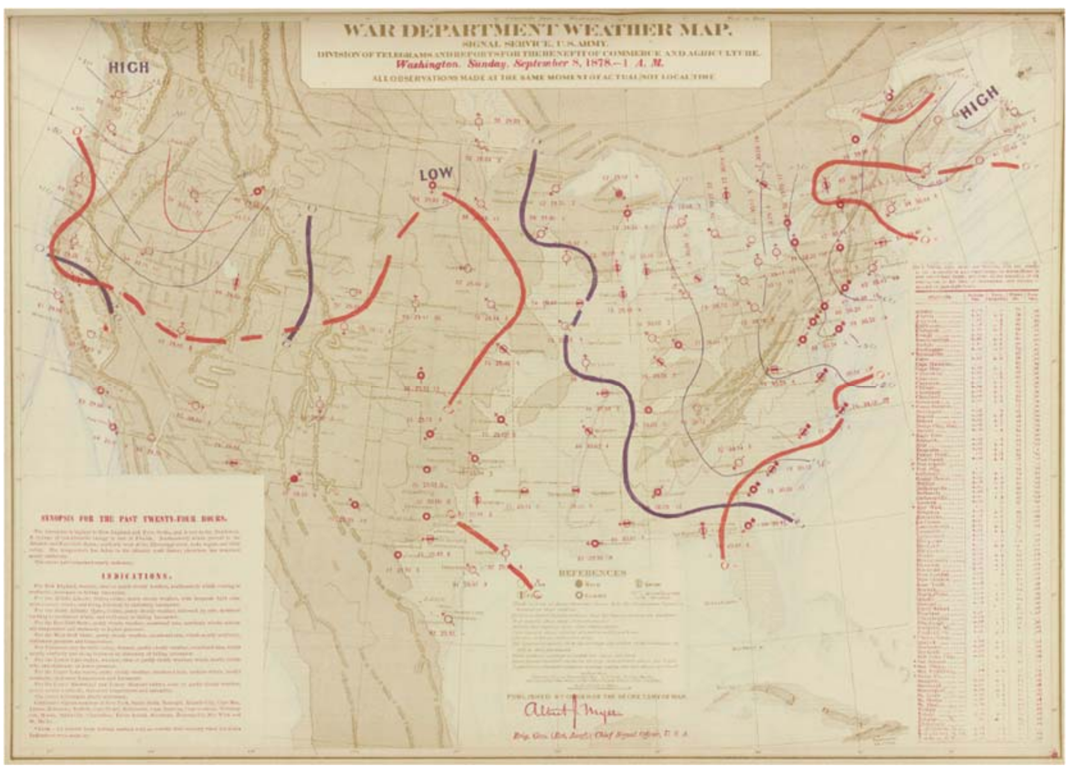

Storm Period *84* hours
from *12 M Sept. 9*
to *12 N Sept. 13*

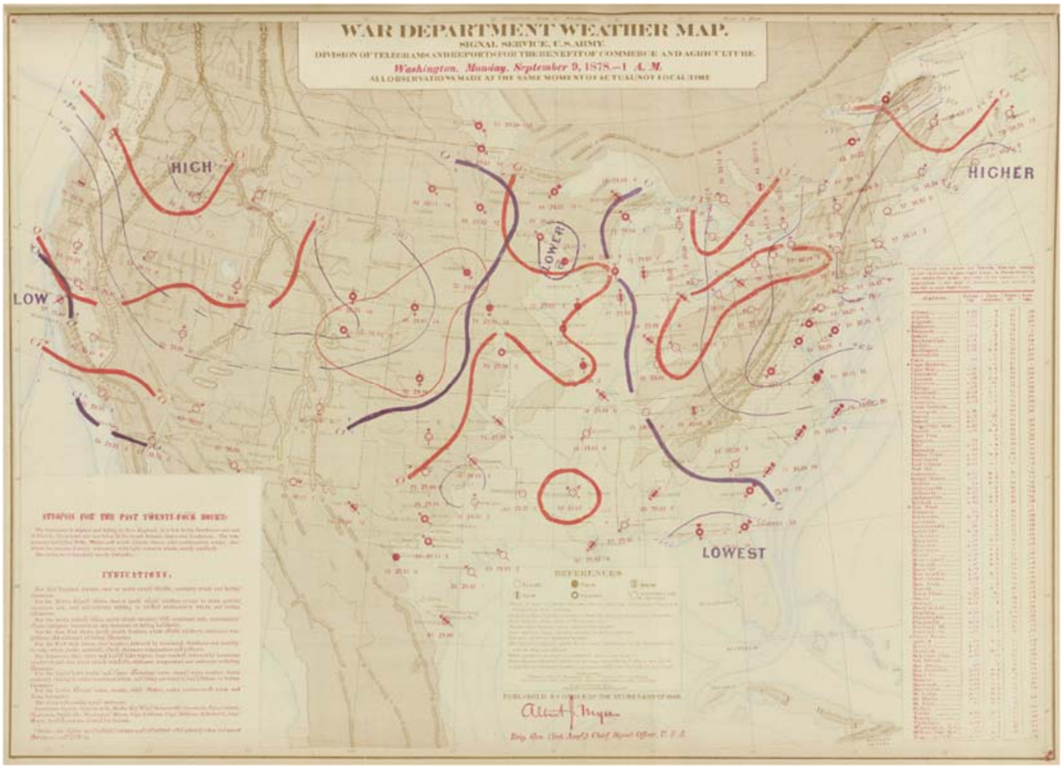
## MASS RAINFALL CURVES

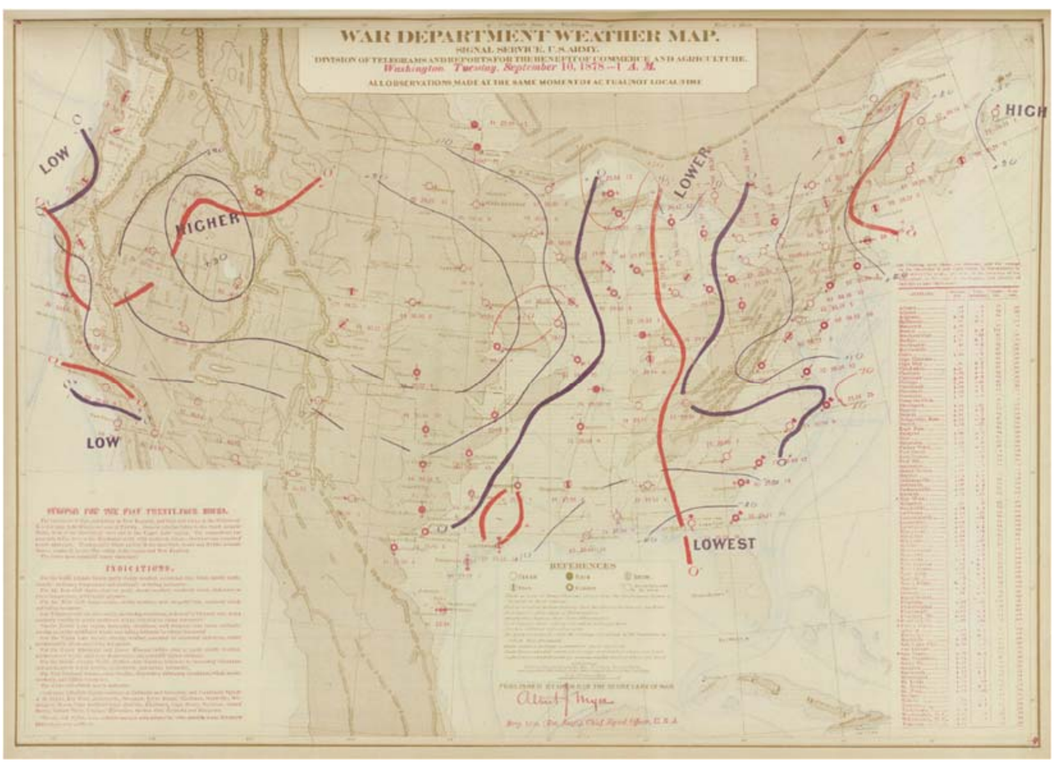


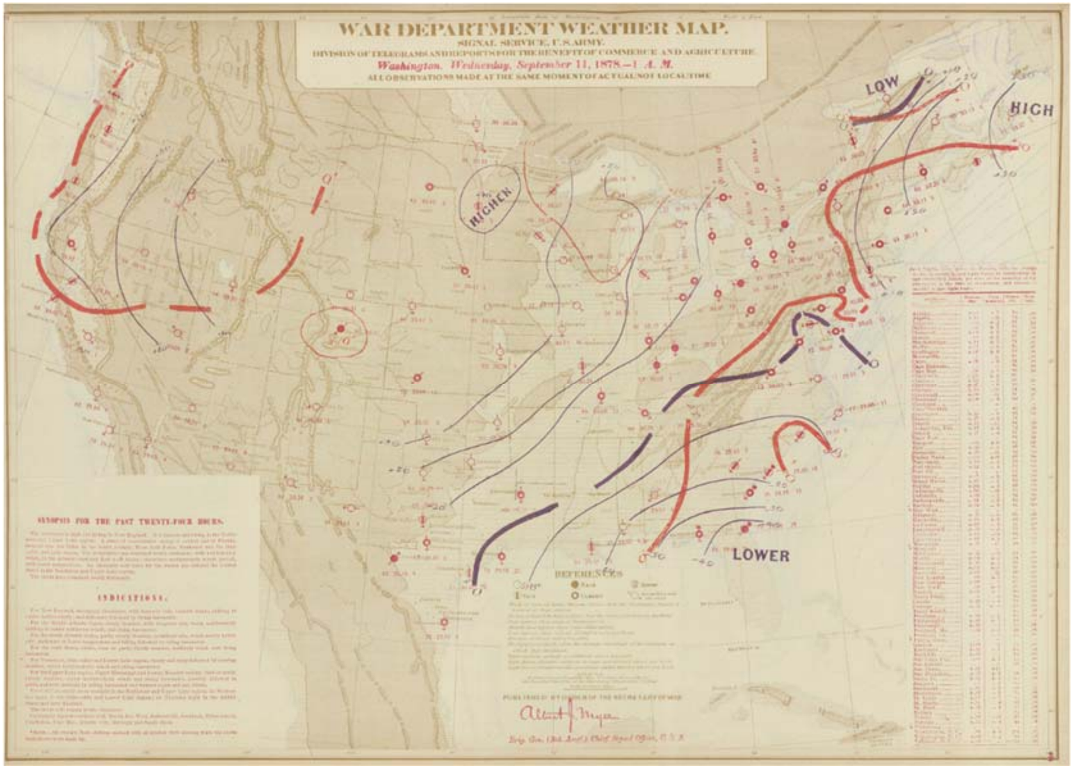

FORM S-3E

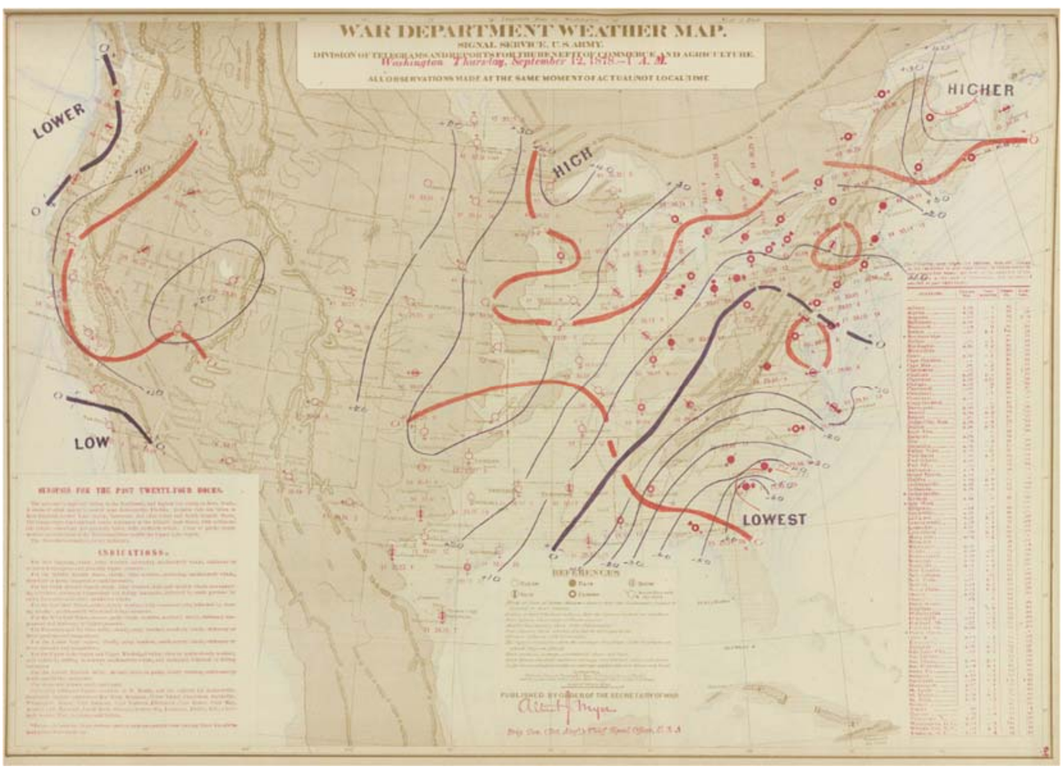

WAR DEPARTMENT WEATHER MAP.
SIGNAL SERVICE, U.S. ARMY.
DIVISION OF TELEGRAMS AND REPORTS FOR THE BENEFIT OF COMMERCE AND AGRICULTURE.
Washington, Saturday September 7, 1878.—1 A. M.
ALL OBSERVATIONS MADE AT THE SAME MOMENT OF ACTUAL NOT LOCAL TIME.
HIGHER
LOW
HIGH
LOWER
SYNOPSIS FOR THE PAST TWENTY-FOUR HOURS.
INDICATIONS.
REFERENCES

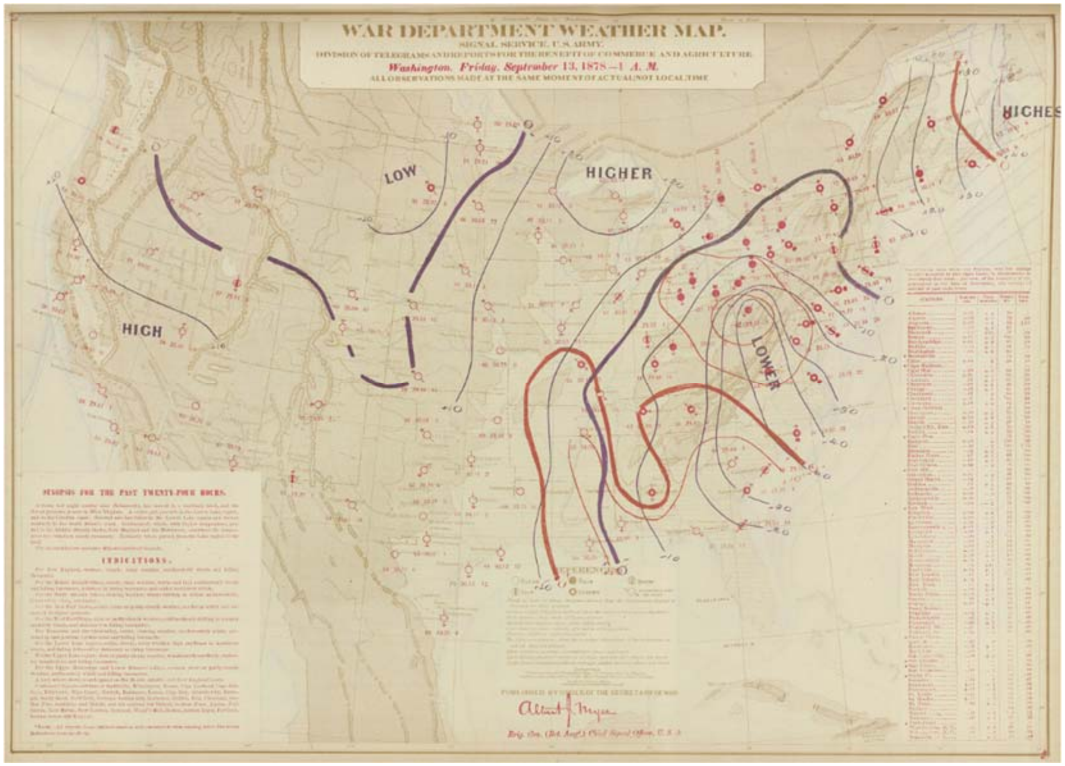

WAR DEPARTMENT WEATHER MAP.
SIGNAL SERVICE, U.S. ARMY.
DIVISION OF TELEGRAMS AND REPORTS FOR THE BENEFIT OF COMMERCE AND AGRICULTURE.
Washington, Sunday, September 8, 1878.—1 A. M.
ALL OBSERVATIONS MADE AT THE SAME MOMENT OF ACTUAL NOT LOCAL TIME.
HIGH
LOW
HIGH
SYNOPSIS FOR THE PAST TWENTY-FOUR HOURS.
INDICATIONS.
REFERENCES

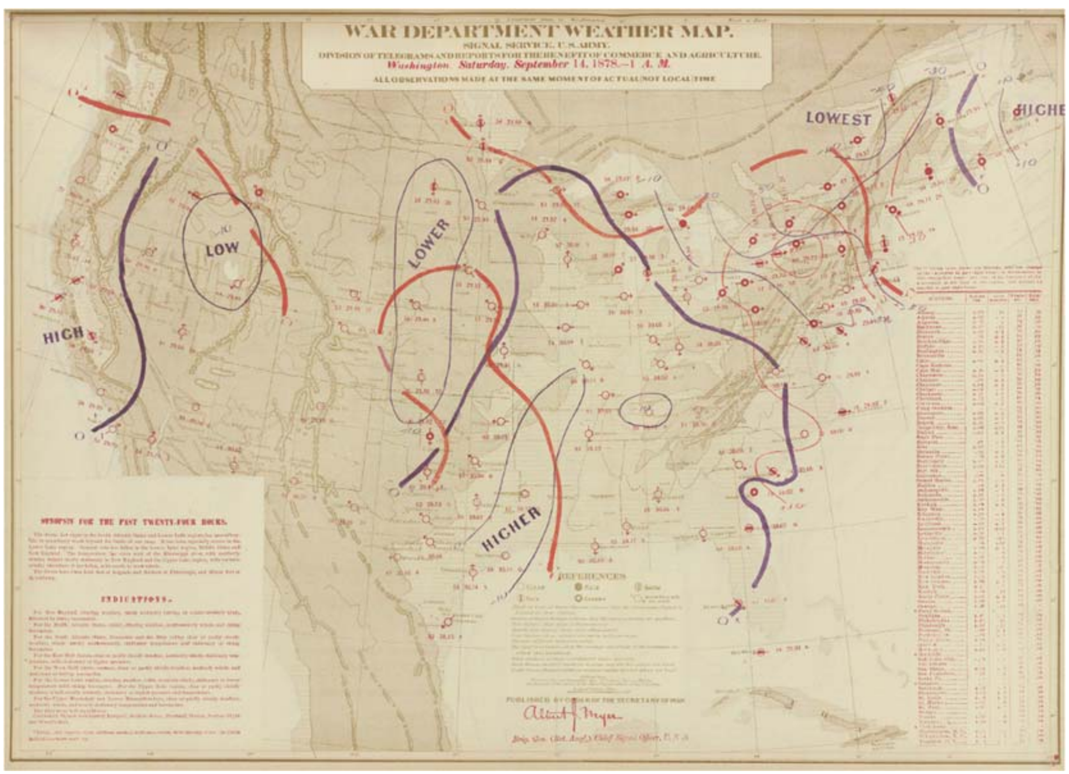

WAR DEPARTMENT WEATHER MAP.
SIGNAL SERVICE, U.S. ARMY.
Washington, Monday, September 9, 1878.—1 A. M.
HIGH
LOW
LOWER
HIGHER
LOWEST
INDICATIONS.
REFERENCES

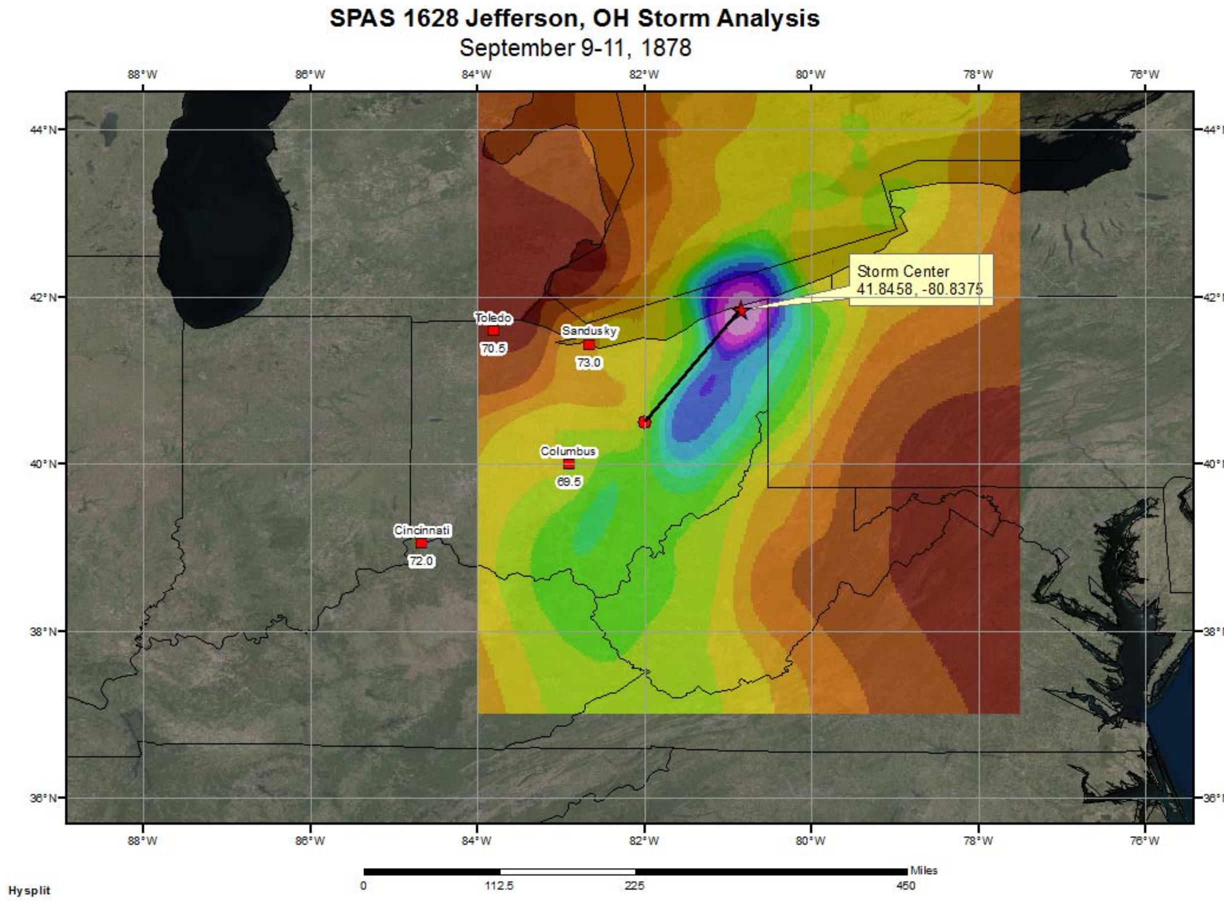

WAR DEPARTMENT WEATHER MAP.
SIGNAL SERVICE, U.S. ARMY.
Washington, Tuesday, September 10, 1878.—1 A. M.
LOW
HIGHER
LOWER
HIGH
LOW
LOWEST
INDICATIONS.
REFERENCES


WAR DEPARTMENT WEATHER MAP.
SIGNAL SERVICE, U.S. ARMY.
DIVISION OF TELEGRAMS AND REPORTS FOR THE BENEFIT OF COMMERCE AND AGRICULTURE.
Washington, Wednesday, September 11, 1878.—1 A.M.
ALL OBSERVATIONS MADE AT THE SAME MOMENT OF ACTUAL NOT LOCAL TIME
LOW
HIGH
HIGHER
LOWER
SYNOPSIS FOR THE PAST TWENTY-FOUR HOURS.
INDICATIONS.
REFERENCES


WAR DEPARTMENT WEATHER MAP.
SIGNAL SERVICE, U.S. ARMY.
DIVISION OF TELEGRAMS AND REPORTS FOR THE BENEFIT OF COMMERCE AND AGRICULTURE.
Washington, Thursday, September 12, 1878.—1 A.M.
ALL OBSERVATIONS MADE AT THE SAME MOMENT OF ACTUAL NOT LOCAL TIME
HIGHER
LOWER
HIGH
LOW
LOWEST
SYNOPSIS FOR THE PAST TWENTY-FOUR HOURS.
INDICATIONS.
REFERENCES


WAR DEPARTMENT WEATHER MAP.
SIGNAL SERVICE, U.S. ARMY.
DIVISION OF TELEGRAMS AND REPORTS FOR THE BENEFIT OF COMMERCE AND AGRICULTURE.
Washington, Friday, September 13, 1878.—1 A. M.
ALL OBSERVATIONS MADE AT THE SAME MOMENT OF ACTUAL (NOT LOCAL) TIME
LOW
HIGHER
HIGH
LOWER
HIGHES
SYNOPSIS FOR THE PAST TWENTY-FOUR HOURS.
INDICATIONS.


WAR DEPARTMENT WEATHER MAP.
SIGNAL SERVICE, U.S. ARMY.
DIVISION OF TELEGRAMS AND REPORTS FOR THE BENEFIT OF COMMERCE AND AGRICULTURE.
Washington, Saturday, September 14, 1878.—1 A. M.
ALL OBSERVATIONS MADE AT THE SAME MOMENT OF ACTUAL (NOT LOCAL) TIME
LOWEST
HIGHE
LOW
LOWER
HIGH
HIGHER
SYNOPSIS FOR THE PAST TWENTY-FOUR HOURS.
INDICATIONS.



SPAS 1628 Jefferson, OH Storm Analysis
September 9-11, 1878
88°W
86°W
84°W
82°W
80°W
78°W
76°W
44°N
42°N
40°N
38°N
36°N
Storm Center
41.8458, -80.8375
Toledo
70.5
Sandusky
73.0
Columbus
69.5
Cincinnati
72.0
Hysplit
0
112.5
225
450
Miles

# Storm Precipitation Analysis System (SPAS) For Storm #1697_1 SPAS Analysis

**General Storm Location**: Ironwood, MI

**Storm Dates**: July 19-23, 1909

**Event**: Synoptic

**DAD Zone 1**

> **Latitude**: 46.4542
>
> **Longitude**: -90.2064
>
> **Max. Grid Rainfall Amount**: 13.41”
>
> **Max. Observed Rainfall Amount**: 13.21”

**Number of Stations**: 128

**SPAS Version**: 10.0

**Base Map Used:** PRISM_ppt_basemap_full

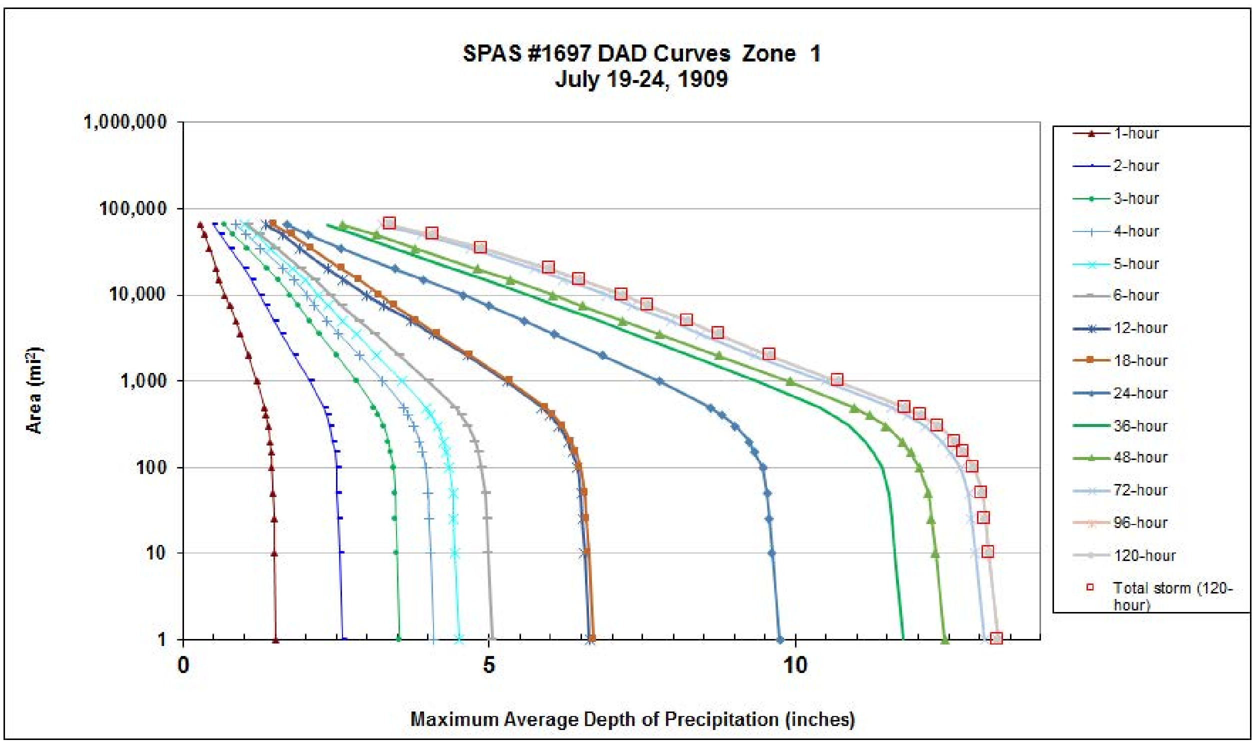
**Spatial resolution:** 0.2293

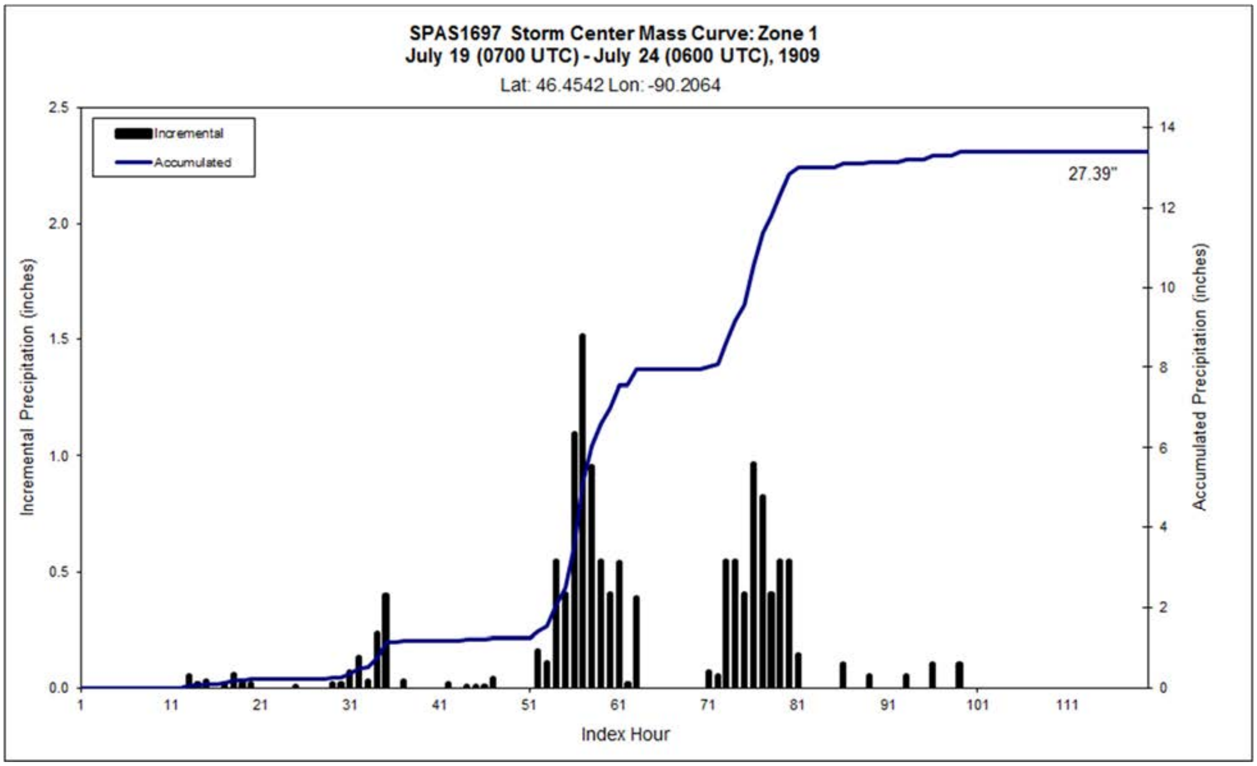
**Radar Included:** No

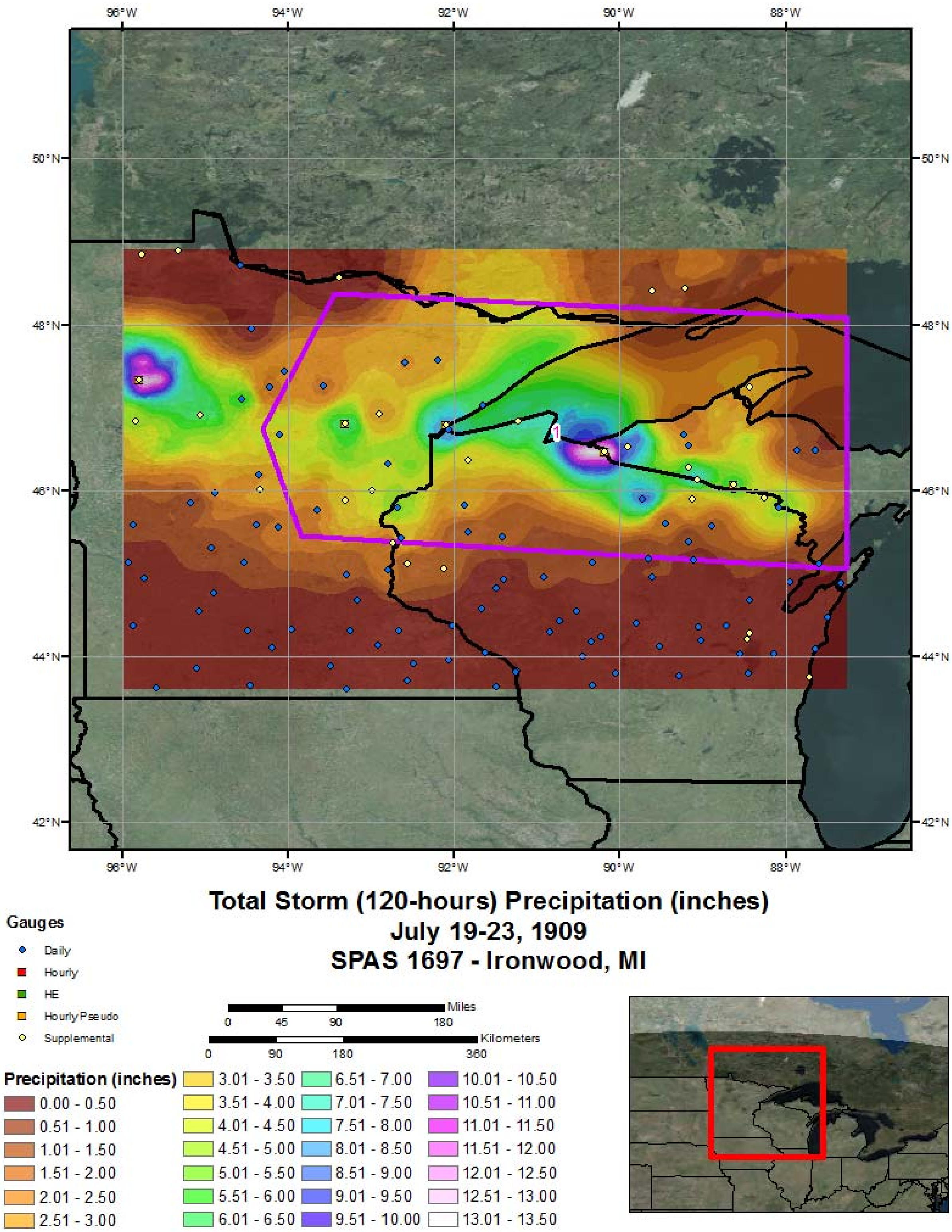
**Depth-Area-Duration (DAD) analysis:** Yes

**Reliability of Results:** This analysis was based on 128 hourly pseudo stations, daily data and supplemental station data. We have a good degree of confidence for the station based storm total results. The spatial pattern is dependent on the PRISM basemap. Timing is based on the hourly pseudo stations. Several daily stations were moved to supplemental due to timing issues and to ensure data consistency.

| Storm 1697 - July 19 (0700 UTC) - July 24 (0600 UTC), 1909 | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | | | | |
| Area (mi²) | Duration (hours) | | | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | 96 | 120 | Total |
| 0.4 | 1.51 | 2.61 | 3.55 | 4.11 | 4.51 | 5.06 | 6.67 | 6.73 | 9.79 | 11.81 | 12.49 | 13.14 | 13.37 | 13.37 | 13.37 |
| 1 | 1.51 | 2.59 | 3.53 | 4.09 | 4.50 | 5.04 | 6.63 | 6.70 | 9.74 | 11.76 | 12.44 | 13.08 | 13.31 | 13.31 | 13.31 |
| 10 | 1.49 | 2.55 | 3.49 | 4.04 | 4.44 | 4.98 | 6.55 | 6.62 | 9.62 | 11.62 | 12.28 | 12.93 | 13.16 | 13.16 | 13.16 |
| 25 | 1.49 | 2.53 | 3.47 | 4.01 | 4.42 | 4.96 | 6.52 | 6.59 | 9.57 | 11.57 | 12.22 | 12.87 | 13.10 | 13.10 | 13.10 |
| 50 | 1.47 | 2.52 | 3.46 | 4.00 | 4.41 | 4.94 | 6.50 | 6.57 | 9.54 | 11.53 | 12.17 | 12.83 | 13.05 | 13.05 | 13.05 |
| 100 | 1.45 | 2.51 | 3.43 | 3.96 | 4.34 | 4.87 | 6.44 | 6.48 | 9.46 | 11.40 | 12.02 | 12.69 | 12.91 | 12.91 | 12.91 |
| 150 | 1.44 | 2.48 | 3.38 | 3.91 | 4.30 | 4.82 | 6.36 | 6.41 | 9.33 | 11.26 | 11.88 | 12.53 | 12.75 | 12.75 | 12.75 |
| 200 | 1.42 | 2.45 | 3.35 | 3.86 | 4.24 | 4.76 | 6.29 | 6.33 | 9.24 | 11.13 | 11.74 | 12.39 | 12.61 | 12.61 | 12.61 |
| 300 | 1.39 | 2.39 | 3.27 | 3.77 | 4.15 | 4.65 | 6.14 | 6.19 | 9.01 | 10.88 | 11.47 | 12.11 | 12.33 | 12.33 | 12.33 |
| 400 | 1.35 | 2.34 | 3.19 | 3.68 | 4.05 | 4.54 | 5.99 | 6.04 | 8.80 | 10.62 | 11.20 | 11.83 | 12.04 | 12.04 | 12.04 |
| 500 | 1.33 | 2.29 | 3.12 | 3.60 | 3.96 | 4.44 | 5.86 | 5.91 | 8.61 | 10.38 | 10.95 | 11.57 | 11.79 | 11.79 | 11.79 |
| 1,000 | 1.20 | 2.07 | 2.83 | 3.26 | 3.58 | 4.01 | 5.29 | 5.34 | 7.78 | 9.40 | 9.91 | 10.49 | 10.69 | 10.69 | 10.69 |
| 2,000 | 1.06 | 1.82 | 2.50 | 2.87 | 3.17 | 3.54 | 4.65 | 4.70 | 6.86 | 8.29 | 8.74 | 9.33 | 9.58 | 9.58 | 9.58 |
| 3,500 | 0.94 | 1.61 | 2.23 | 2.54 | 2.83 | 3.14 | 4.08 | 4.15 | 6.07 | 7.36 | 7.78 | 8.46 | 8.73 | 8.74 | 8.74 |
| 5,000 | 0.86 | 1.48 | 2.06 | 2.34 | 2.61 | 2.88 | 3.72 | 3.81 | 5.57 | 6.78 | 7.17 | 7.96 | 8.23 | 8.23 | 8.23 |
| 7,500 | 0.76 | 1.35 | 1.88 | 2.14 | 2.37 | 2.60 | 3.28 | 3.45 | 5.00 | 6.11 | 6.52 | 7.33 | 7.60 | 7.60 | 7.60 |
| 10,000 | 0.68 | 1.25 | 1.75 | 2.01 | 2.21 | 2.41 | 2.99 | 3.21 | 4.58 | 5.62 | 6.04 | 6.92 | 7.18 | 7.18 | 7.18 |
| 15,000 | 0.58 | 1.12 | 1.55 | 1.81 | 2.00 | 2.15 | 2.61 | 2.87 | 3.92 | 4.90 | 5.33 | 6.21 | 6.47 | 6.47 | 6.47 |
| 20,000 | 0.54 | 1.00 | 1.38 | 1.63 | 1.80 | 1.94 | 2.36 | 2.59 | 3.46 | 4.42 | 4.80 | 5.74 | 5.97 | 5.99 | 5.99 |
| 35,000 | 0.43 | 0.76 | 1.05 | 1.26 | 1.42 | 1.52 | 1.90 | 2.08 | 2.57 | 3.43 | 3.78 | 4.68 | 4.87 | 4.88 | 4.88 |
| 50,000 | 0.34 | 0.61 | 0.82 | 1.03 | 1.20 | 1.26 | 1.63 | 1.78 | 2.05 | 2.84 | 3.17 | 3.91 | 4.07 | 4.08 | 4.08 |
| 65,546 | 0.28 | 0.49 | 0.68 | 0.85 | 1.00 | 1.06 | 1.36 | 1.48 | 1.70 | 2.36 | 2.61 | 3.24 | 3.37 | 3.38 | 3.38 |




SPAS1697 Storm Center Mass Curve: Zone 1
July 19 (0700 UTC) - July 24 (0600 UTC), 1909
Lat: 46.4542 Lon: -90.2064
Incremental
Accumulated
27.39"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
2.5
2.0
1.5
1.0
0.5
0.0
14
12
10
8
6
4
2
0
1
11
21
31
41
51
61
71
81
91
101
111




**Total Storm (120-hours) Precipitation (inches)**
**July 19-23, 1909**
**SPAS 1697 - Ironwood, MI**

DEPARTMENT OF THE ARMY — CORPS OF ENGINEERS

# STORM STUDIES - PERTINENT DATA SHEET (REV.)


Storm of 18-23 July 1909
Assignment UMV 1-11 (b)
Location Northern Minn. & Wis.
Study Prepared by:
Upper Mississippi Valley Division
St. Paul District Office

Part I Reviewed by H. M. Sec. of Weather Bureau, 6/7/39
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 5/24/41
Remarks: Rainfall Data only for Ironwood, Mich. center
Dewpt. 70° - Ref. Pt. 275 SSW
Grid B-12

## DATA AND COMPUTATIONS COMPILED

### PART I

Preliminary isohyetal map, in 1 sheet, scale 1: 1,000,000

Precipitation data and mass curves: (Number of Sheets)

- Form 5001-C (Hourly precip. data) — 4
- Form 5001-B (24-hour " " ) — -
- Form 5001-D (" " " " ) — 8
- Miscl. precip. records, meteorological data, etc. — 1
- Form 5002 (Mass rainfall curves) — 24

### PART II

Final isohyetal maps, in 1 sheet, scale 1: 1,000,000

Data and computation sheets:

- Form S-10 (Data from mass rainfall curves) — 4
- Form S-11 (Depth-area data from isohyetal map) — 2
- Form S-12 (Maximum depth-duration data) — 8
- Maximum duration-depth-area curves — 2
- Data relating to periods of maximum rainfall — 2

### MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

| Area in Sq. Mi. | Duration of Rainfall in Hours | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 12 | 18 | 24 | 30 | 36 | 48 | 60 | 72 | 96 | 108 |
| 10 | 5.2 | 6.3 | 6.7 | 9.6 | 11.1 | 11.7 | 12.1 | 12.8 | 13.2 | 13.2 | 13.2 |
| 100 | 5.1 | 6.2 | 6.6 | 9.4 | 10.8 | 11.4 | 11.8 | 12.5 | 12.9 | 12.9 | 12.9 |
| 200 | 4.6 | 6.0 | 6.3 | 9.0 | 10.5 | 11.1 | 11.5 | 12.1 | 12.5 | 12.5 | 12.5 |
| 500 | 3.9 | 5.5 | 5.8 | 7.9 | 9.8 | 10.1 | 10.7 | 11.2 | 11.5 | 11.5 | 11.5 |
| 1,000 | 3.2 | 5.0 | 5.3 | 6.9 | 9.0 | 9.3 | 9.7 | 10.3 | 10.5 | 10.5 | 10.5 |
| 2,000 | 2.8 | 4.4 | 4.6 | 6.0 | 7.9 | 8.2 | 8.7 | 9.2 | 9.5 | 9.5 | 9.5 |
| 5,000 | 2.3 | 3.6 | 3.8 | 5.0 | 6.5 | 6.8 | 7.2 | 7.8 | 8.0 | 8.0 | 8.0 |
| 10,000 | 2.1 | 3.2 | 3.4 | 4.2 | 5.4 | 5.6 | 6.0 | 6.5 | 6.7 | 6.9 | 6.9 |

Form S-2

DEPARTMENT OF THE ARMY — CORPS OF ENGINEERS

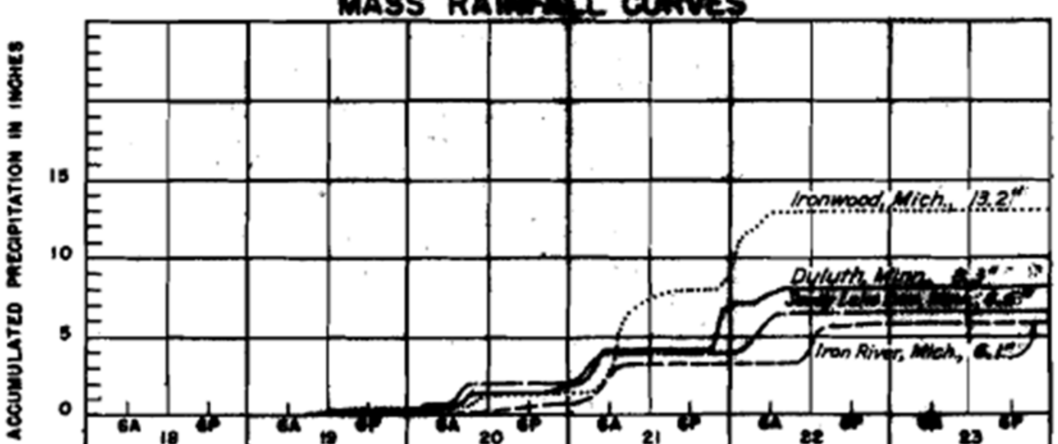
# STORM STUDIES - ISOHYETAL MAP

Storm of *July 18-23, 1909* Assignment *UMV 1-11 (b)*

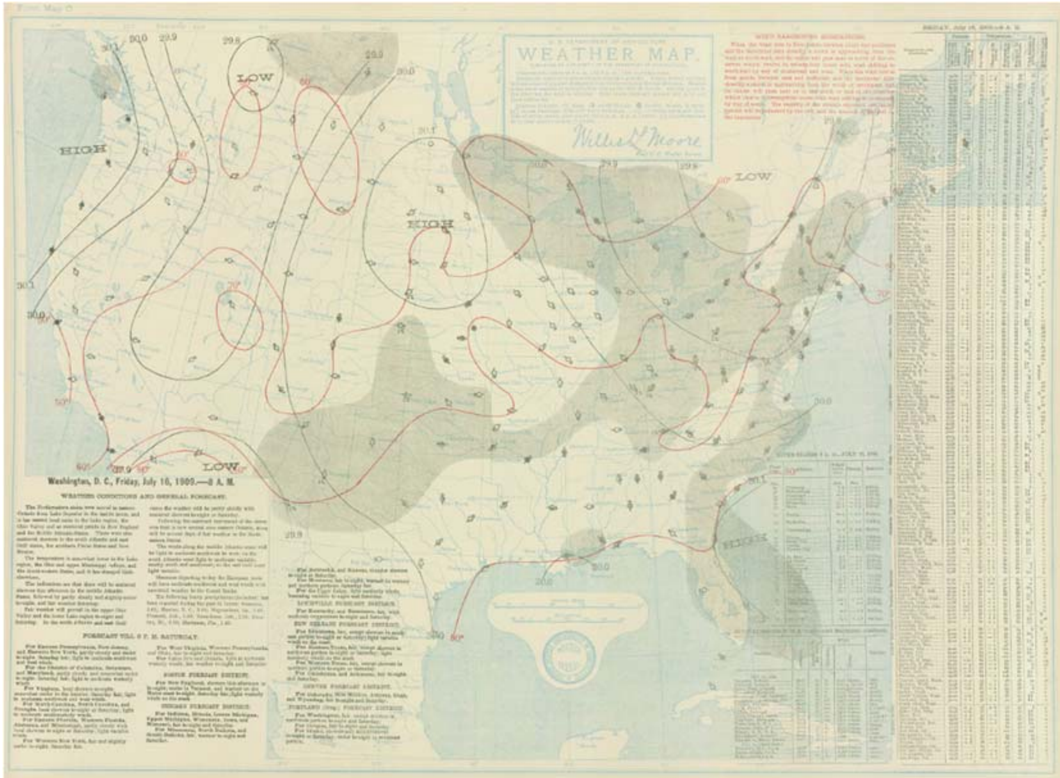
Study Prepared by: *St. Paul, Minn. District*
*Upper Mississippi Valley Division*

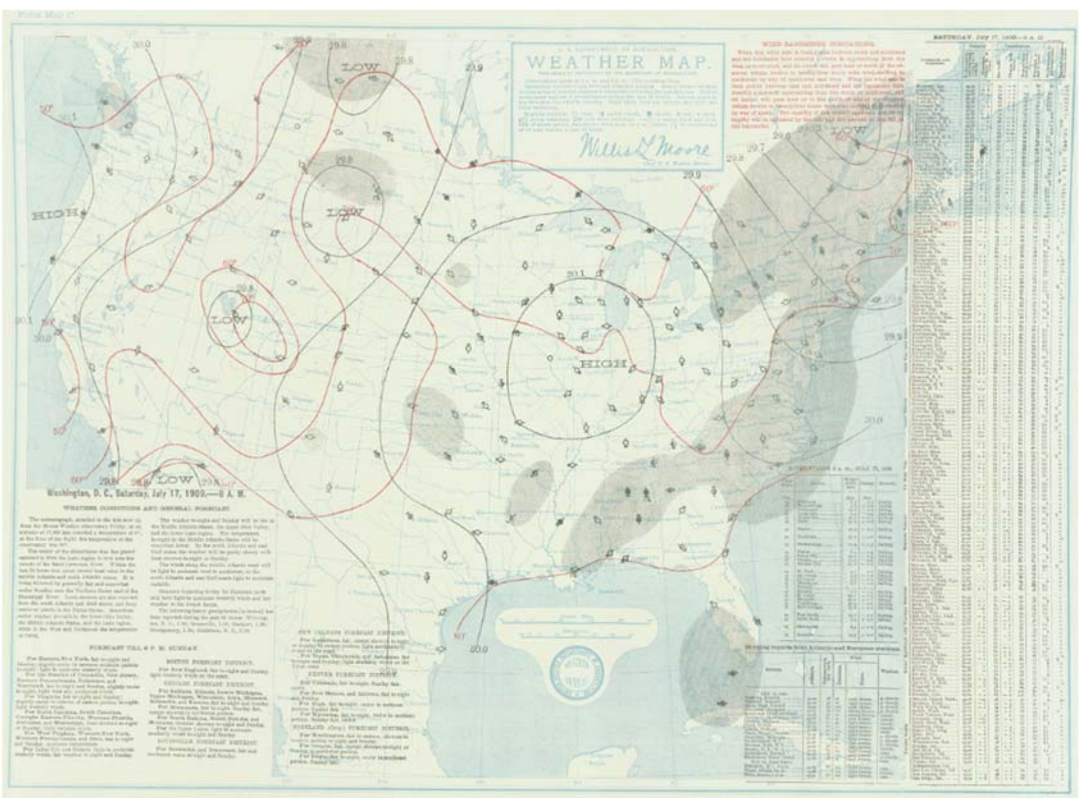

Storm Period *108* hours
from *1PM July 18*
to *1AM July 23*

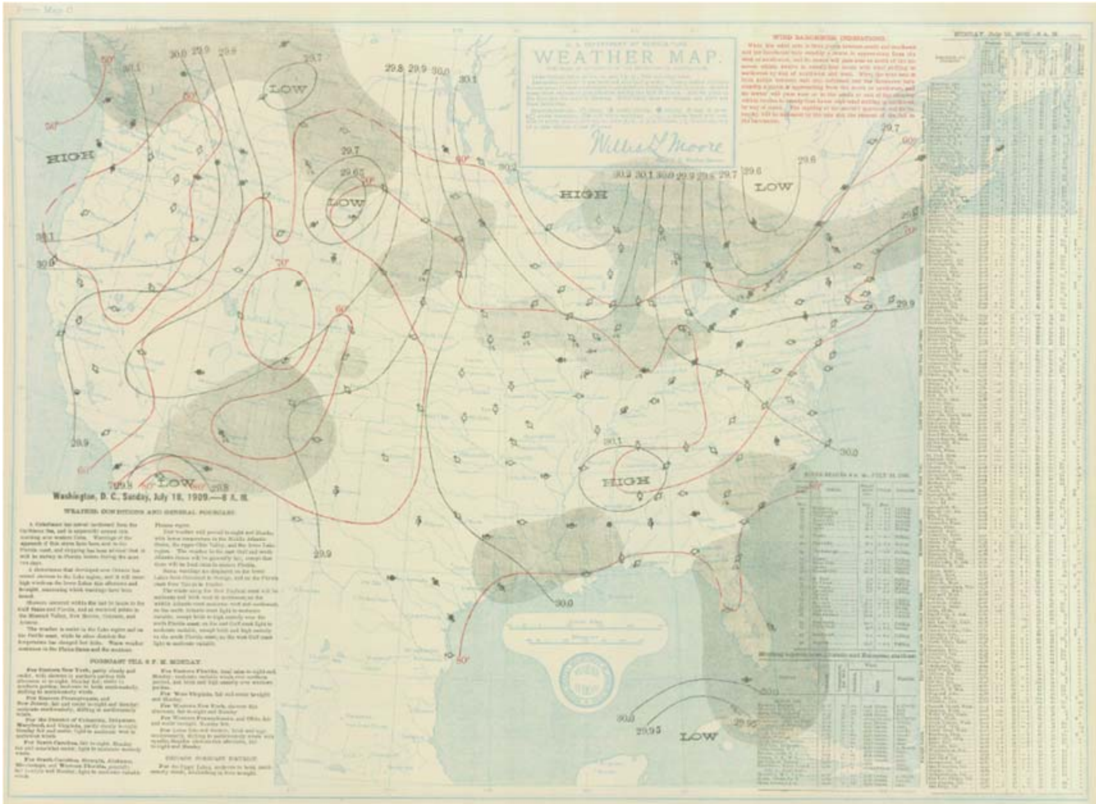
## MASS RAINFALL CURVES



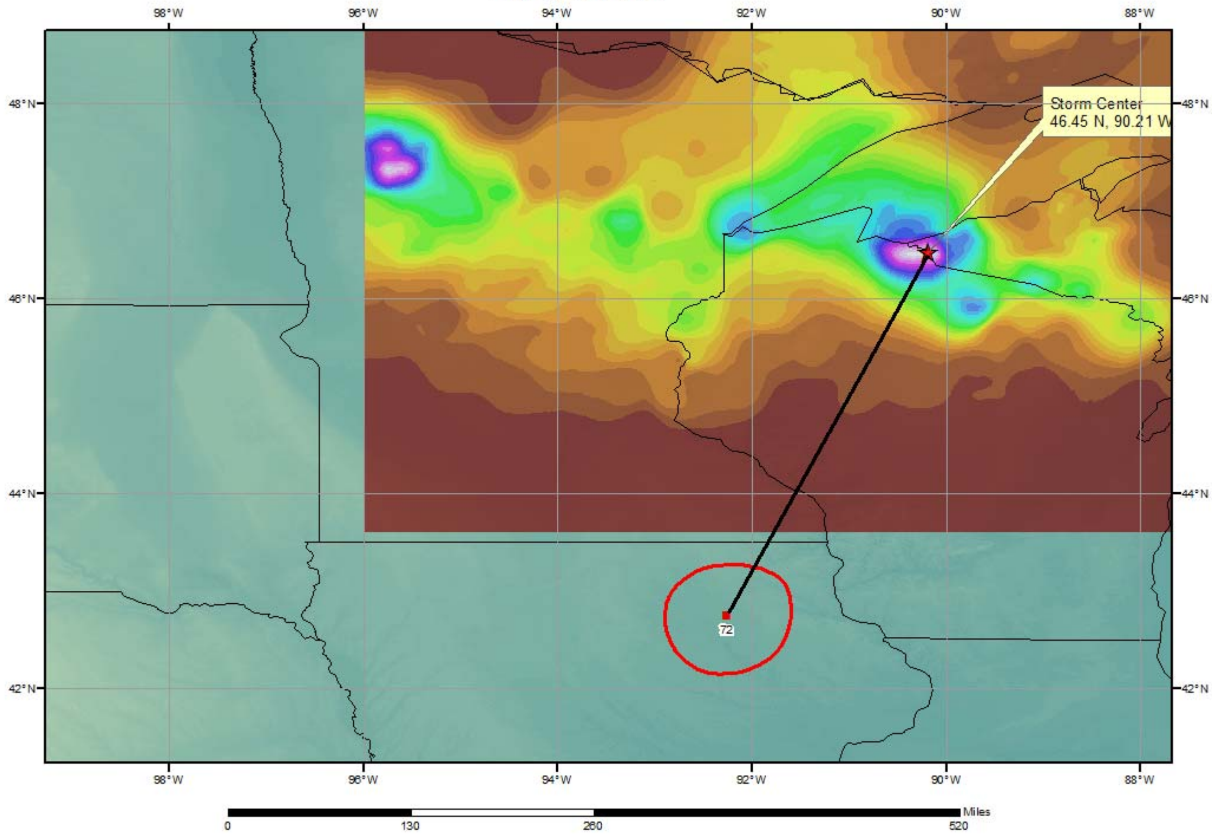

FORM S-3E


WEATHER MAP.
Willis L. Moore
HIGH
LOW
HIGH
LOW
LOW
Washington, D. C., Friday, July 16, 1909.—8 A. M.


WEATHER MAP.
Willis L. Moore
HIGH
LOW
LOW
LOW
HIGH
LOW
Washington, D. C., Saturday, July 17, 1909.—8 A. M.


WEATHER MAP.
HIGH
LOW
HIGH
LOW
HIGH
LOW
LOW
Washington, D. C., Sunday, July 18, 1909.—8 A. M.

**SPAS 1697 Ironwood, MI Storm Analysis (UMV 1-11B)**
July 18-23, 1909



# Storm Precipitation Analysis System (SPAS) For Storm #1698_1 SPAS Analysis

**General Storm Location**: Bellefontaine, OH

**Storm Dates**: March 22-27, 1913

**Event**: Synoptic

**DAD Zone 1**

**Latitude**: 40.3625

**Longitude**: -83.7125

**Max. Grid Rainfall Amount**: 11.44”

**Max. Observed Rainfall Amount**: 11.19”

**Number of Stations**: 1105

**SPAS Version**: 10.0

**Base Map Used:** Blend of isohyetal and us_ppt_in_map_1691_1990_usda_NA

**Spatial resolution:** 0.2565

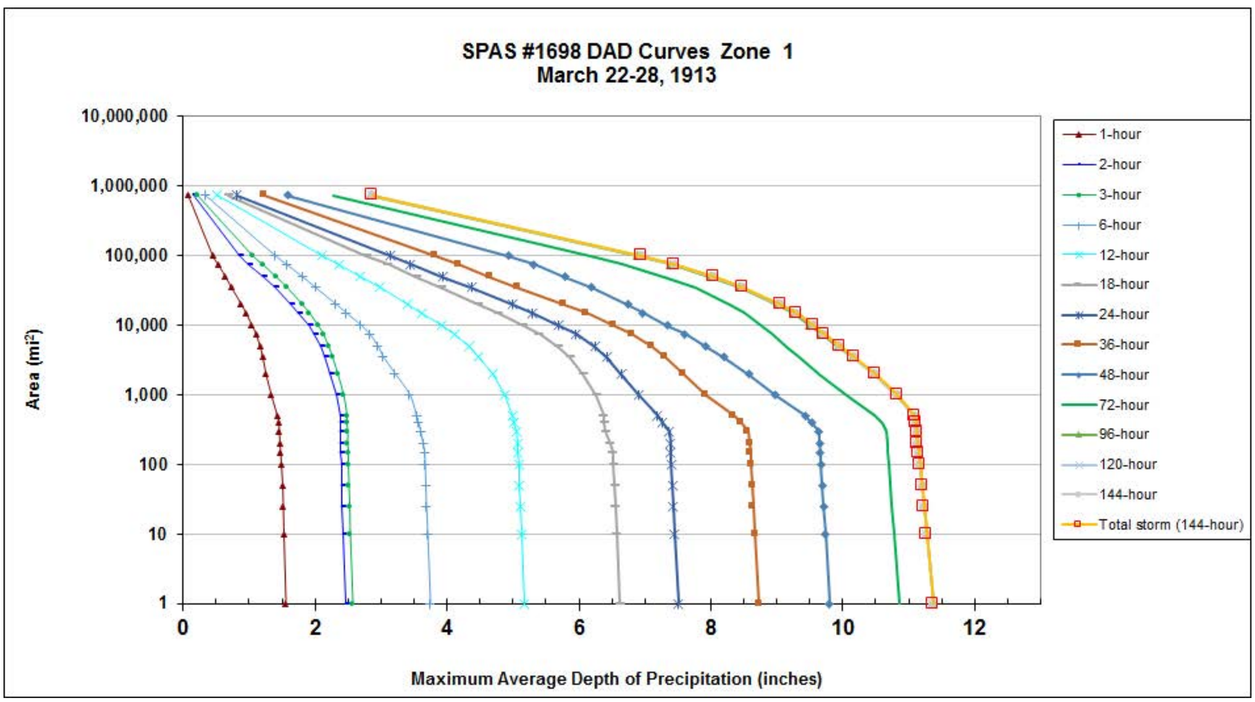
**Radar Included:** No

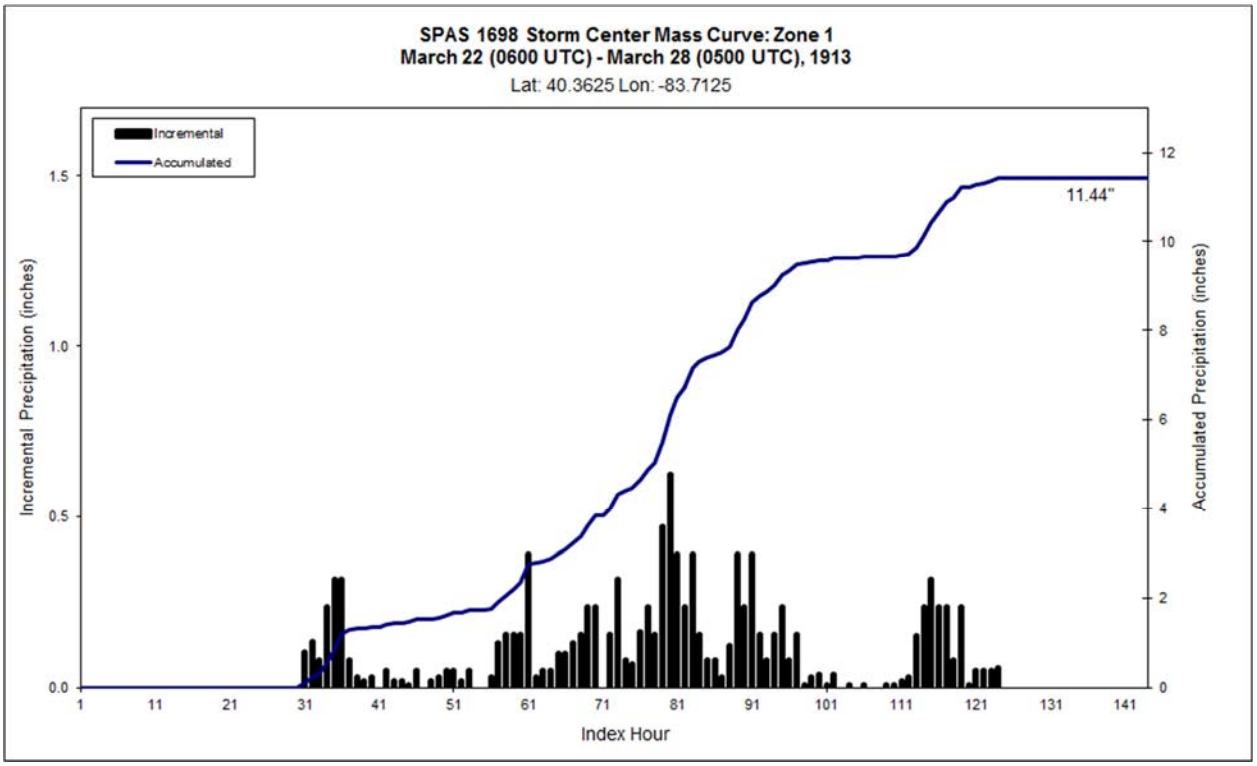
**Depth-Area-Duration (DAD) analysis:** Yes

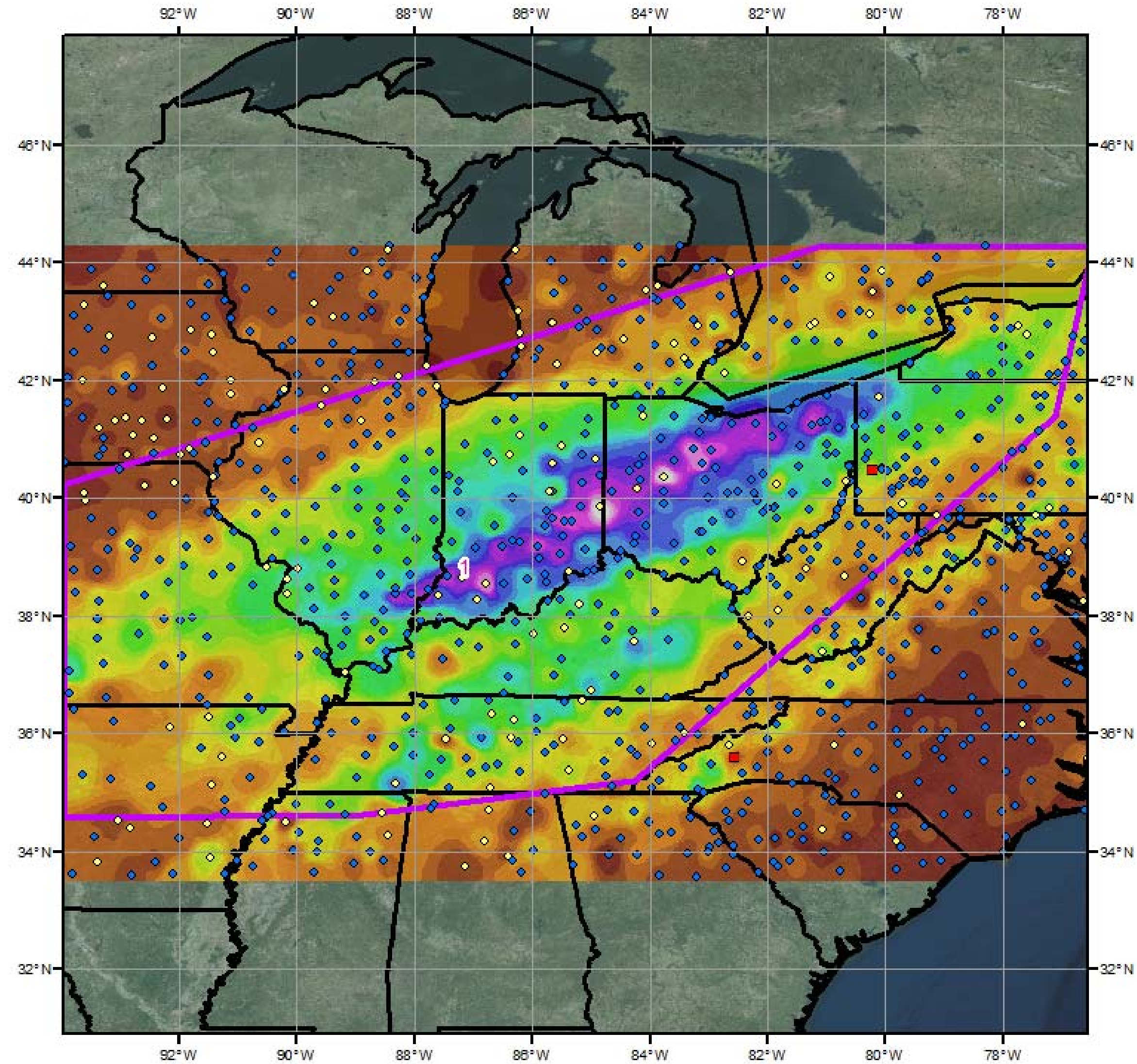
**Reliability of Results:** This analysis was based on 1105 hourly, hourly estimated pseudo stations, daily data and supplemental station data. We have a good degree of confidence for the station based storm total results. The spatial pattern is dependent on the blended basemap. Timing is based on the hourly and hourly estimated pseudo stations. Several daily stations were moved to supplemental due to timing issues and to ensure data consistency.

**Storm 1698- March 22 (0600 UTC) - March 28 (0500 UTC), 1913**
**MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)**

| Area ($mi^2$) | Duration (hours) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | 96 | 120 | 144 | Total |
| 0.4 | 1.56 | 2.47 | 2.58 | 3.75 | 5.20 | 6.65 | 7.53 | 8.75 | 9.83 | 10.88 | 11.41 | 11.41 | 11.41 | 11.41 |
| 1 | 1.55 | 2.46 | 2.57 | 3.74 | 5.18 | 6.62 | 7.51 | 8.73 | 9.80 | 10.85 | 11.37 | 11.37 | 11.37 | 11.37 |
| 10 | 1.52 | 2.43 | 2.53 | 3.70 | 5.13 | 6.57 | 7.45 | 8.67 | 9.74 | 10.77 | 11.27 | 11.27 | 11.27 | 11.27 |
| 25 | 1.51 | 2.41 | 2.52 | 3.68 | 5.11 | 6.55 | 7.43 | 8.64 | 9.71 | 10.74 | 11.23 | 11.23 | 11.23 | 11.23 |
| 50 | 1.50 | 2.41 | 2.51 | 3.67 | 5.10 | 6.54 | 7.42 | 8.63 | 9.69 | 10.72 | 11.20 | 11.20 | 11.20 | 11.20 |
| 100 | 1.48 | 2.40 | 2.50 | 3.66 | 5.09 | 6.52 | 7.40 | 8.61 | 9.67 | 10.69 | 11.17 | 11.17 | 11.17 | 11.17 |
| 150 | 1.47 | 2.39 | 2.50 | 3.65 | 5.08 | 6.51 | 7.39 | 8.60 | 9.66 | 10.68 | 11.15 | 11.15 | 11.15 | 11.15 |
| 200 | 1.46 | 2.39 | 2.49 | 3.63 | 5.07 | 6.47 | 7.39 | 8.59 | 9.65 | 10.67 | 11.13 | 11.13 | 11.13 | 11.13 |
| 300 | 1.45 | 2.38 | 2.49 | 3.59 | 5.06 | 6.40 | 7.37 | 8.56 | 9.64 | 10.66 | 11.12 | 11.12 | 11.12 | 11.12 |
| 400 | 1.44 | 2.38 | 2.48 | 3.56 | 5.02 | 6.38 | 7.27 | 8.46 | 9.53 | 10.59 | 11.10 | 11.10 | 11.10 | 11.10 |
| 500 | 1.42 | 2.38 | 2.48 | 3.53 | 4.99 | 6.37 | 7.19 | 8.34 | 9.43 | 10.49 | 11.08 | 11.08 | 11.08 | 11.08 |
| 1,000 | 1.33 | 2.32 | 2.43 | 3.43 | 4.88 | 6.26 | 6.91 | 7.93 | 8.98 | 10.07 | 10.82 | 10.82 | 10.82 | 10.82 |
| 2,000 | 1.25 | 2.23 | 2.34 | 3.21 | 4.69 | 6.06 | 6.64 | 7.59 | 8.57 | 9.65 | 10.48 | 10.49 | 10.49 | 10.49 |
| 3,500 | 1.20 | 2.15 | 2.26 | 3.03 | 4.48 | 5.86 | 6.42 | 7.31 | 8.19 | 9.34 | 10.16 | 10.17 | 10.17 | 10.17 |
| 5,000 | 1.16 | 2.09 | 2.20 | 2.95 | 4.33 | 5.69 | 6.24 | 7.11 | 7.93 | 9.15 | 9.93 | 9.96 | 9.96 | 9.96 |
| 7,500 | 1.10 | 1.99 | 2.12 | 2.82 | 4.11 | 5.40 | 5.95 | 6.80 | 7.61 | 8.92 | 9.68 | 9.72 | 9.72 | 9.72 |
| 10,000 | 1.04 | 1.90 | 2.04 | 2.69 | 3.91 | 5.16 | 5.70 | 6.53 | 7.34 | 8.77 | 9.50 | 9.55 | 9.55 | 9.55 |
| 15,000 | 0.95 | 1.75 | 1.91 | 2.47 | 3.62 | 4.77 | 5.29 | 6.11 | 6.97 | 8.51 | 9.25 | 9.30 | 9.30 | 9.30 |
| 20,000 | 0.88 | 1.63 | 1.80 | 2.31 | 3.41 | 4.48 | 5.00 | 5.78 | 6.74 | 8.28 | 9.01 | 9.05 | 9.05 | 9.05 |
| 35,000 | 0.73 | 1.38 | 1.57 | 2.00 | 2.98 | 3.91 | 4.37 | 5.07 | 6.19 | 7.77 | 8.44 | 8.48 | 8.48 | 8.48 |
| 50,000 | 0.64 | 1.21 | 1.40 | 1.80 | 2.69 | 3.53 | 3.93 | 4.65 | 5.79 | 7.29 | 8.00 | 8.05 | 8.05 | 8.05 |
| 75,000 | 0.53 | 1.00 | 1.20 | 1.56 | 2.36 | 3.11 | 3.45 | 4.17 | 5.32 | 6.65 | 7.39 | 7.44 | 7.44 | 7.44 |
| 100,000 | 0.45 | 0.85 | 1.05 | 1.39 | 2.10 | 2.78 | 3.15 | 3.82 | 4.93 | 6.18 | 6.89 | 6.94 | 6.94 | 6.94 |
| 738,776 | 0.08 | 0.16 | 0.21 | 0.33 | 0.51 | 0.69 | 0.82 | 1.23 | 1.58 | 2.28 | 2.84 | 2.87 | 2.87 | 2.87 |




SPAS 1698 Storm Center Mass Curve: Zone 1
March 22 (0600 UTC) - March 28 (0500 UTC), 1913
Lat: 40.3625 Lon: -83.7125
Incremental
Accumulated
11.44"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour




**Total Storm (144-hours) Precipitation (inches)**
**March 22-27, 1913**
**SPAS 1698 - Bellefontaine, OH**

**Gauges**

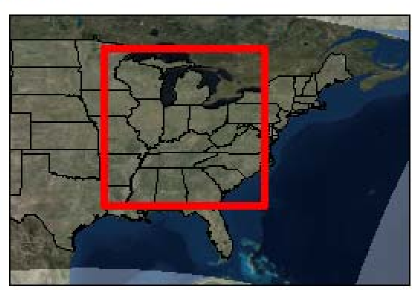
- Daily
- Hourly
- Hourly Pseudo
- Supplemental

Miles: 0, 75, 150, 300

Kilometers: 0, 155, 310, 620

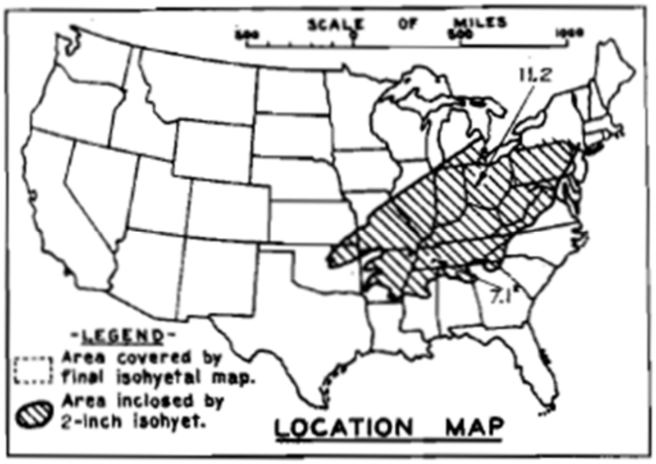
**Precipitation (inches)**

| | | | |
|---|---|---|---|
| 0.00 - 0.50 | 2.51 - 3.00 | 5.51 - 6.00 | 8.51 - 9.00 |
| 0.51 - 1.00 | 3.01 - 3.50 | 6.01 - 6.50 | 9.01 - 9.50 |
| 1.01 - 1.50 | 3.51 - 4.00 | 6.51 - 7.00 | 9.51 - 10.00 |
| 1.51 - 2.00 | 4.01 - 4.50 | 7.01 - 7.50 | 10.01 - 10.50 |
| 2.01 - 2.50 | 4.51 - 5.00 | 7.51 - 8.00 | 10.51 - 11.00 |
| | 5.01 - 5.50 | 8.01 - 8.50 | 11.01 - 11.50 |



WAR DEPARTMENT — CORPS OF ENGINEERS, U. S. ARMY

# STORM STUDIES - PERTINENT DATA SHEET




Storm of March 23 - 27, 1913
Assignment O R 1 - 15
Location Arkansas - New York
Study Prepared by:
Ohio River Division
Cincinnati District Office

Part I Reviewed by H. M. Sec. of Weather Bureau, 7/18/41
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 5/15/45
Remarks: Centers at; Bellefontaine, Ohio and Savannah, Tenn.

## DATA AND COMPUTATIONS COMPILED

### PART I

Preliminary isohyetal map, in sheet, scale

| Precipitation data and mass curves: | (Number of Sheets) |
|---|---|
| Form 5001-C (Hourly precip. data) | 18 |
| Form 5001-B (24-hour " " ) | 63 |
| Form 5001-D ( " " " " ) | 1 |
| Miscl. precip. records, meteorological data, etc. | - |
| Form 5002 (Mass rainfall curves) | 62 |

### PART II

Final isohyetal maps, in 1 sheet, scale 1 : 1,000,000

| Data and computation sheets: | |
|---|---|
| Form S-10 (Data from mass rainfall curves) | 13 |
| Form S-11 (Depth-area data from isohyetal map) | 5 |
| Form S-12 (Maximum depth-duration data) | 50 |
| Maximum duration-depth-area curves | 5 |
| Data relating to periods of maximum rainfall | 10 |

### MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

| Area in Sq. Mi. | Duration of Rainfall in Hours | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 12 | 18 | 24 | 30 | 36 | 48 | 60 | 72 | 96 | 120 |
| 10 | 3.4 | 6.0 | 6.6 | 7.3 | 8.2 | 8.5 | 9.5 | 10.4 | 10.4 | 11.2 | 11.2 |
| 100 | 3.3 | 5.6 | 6.5 | 7.1 | 7.9 | 8.2 | 9.3 | 10.2 | 10.2 | 11.1 | 11.1 |
| 200 | 3.3 | 5.4 | 6.4 | 7.0 | 7.8 | 8.1 | 9.2 | 10.0 | 10.1 | 11.1 | 11.1 |
| 500 | 3.2 | 5.1 | 6.2 | 6.8 | 7.5 | 7.8 | 9.0 | 9.7 | 9.9 | 10.9 | 10.9 |
| 1,000 | 3.1 | 4.9 | 6.0 | 6.6 | 7.3 | 7.6 | 8.7 | 9.5 | 9.7 | 10.7 | 10.8 |
| 2,000 | 2.9 | 4.6 | 5.7 | 6.3 | 7.0 | 7.4 | 8.4 | 9.1 | 9.4 | 10.5 | 10.6 |
| 5,000 | 2.6 | 4.1 | 5.2 | 5.8 | 6.5 | 6.9 | 7.9 | 8.6 | 9.0 | 10.1 | 10.2 |
| 10,000 | 2.3 | 3.8 | 4.8 | 5.4 | 6.1 | 6.5 | 7.5 | 8.2 | 8.6 | 9.6 | 9.7 |
| 20,000 | 2.0 | 3.4 | 4.3 | 4.9 | 5.5 | 5.9 | 6.9 | 7.6 | 8.1 | 9.1 | 9.2 |
| 50,000 | 1.6 | 2.7 | 3.5 | 4.1 | 4.5 | 4.9 | 5.8 | 6.5 | 7.1 | 8.1 | 8.2 |
| 100,000 | 1.1 | 2.0 | 2.7 | 3.2 | 3.6 | 4.0 | 4.8 | 5.4 | 6.0 | 6.9 | 7.0 |
| 160,000 | 0.7 | 1.4 | 2.0 | 2.5 | 2.9 | 3.3 | 4.0 | 4.5 | 5.1 | 6.0 | 6.1 |

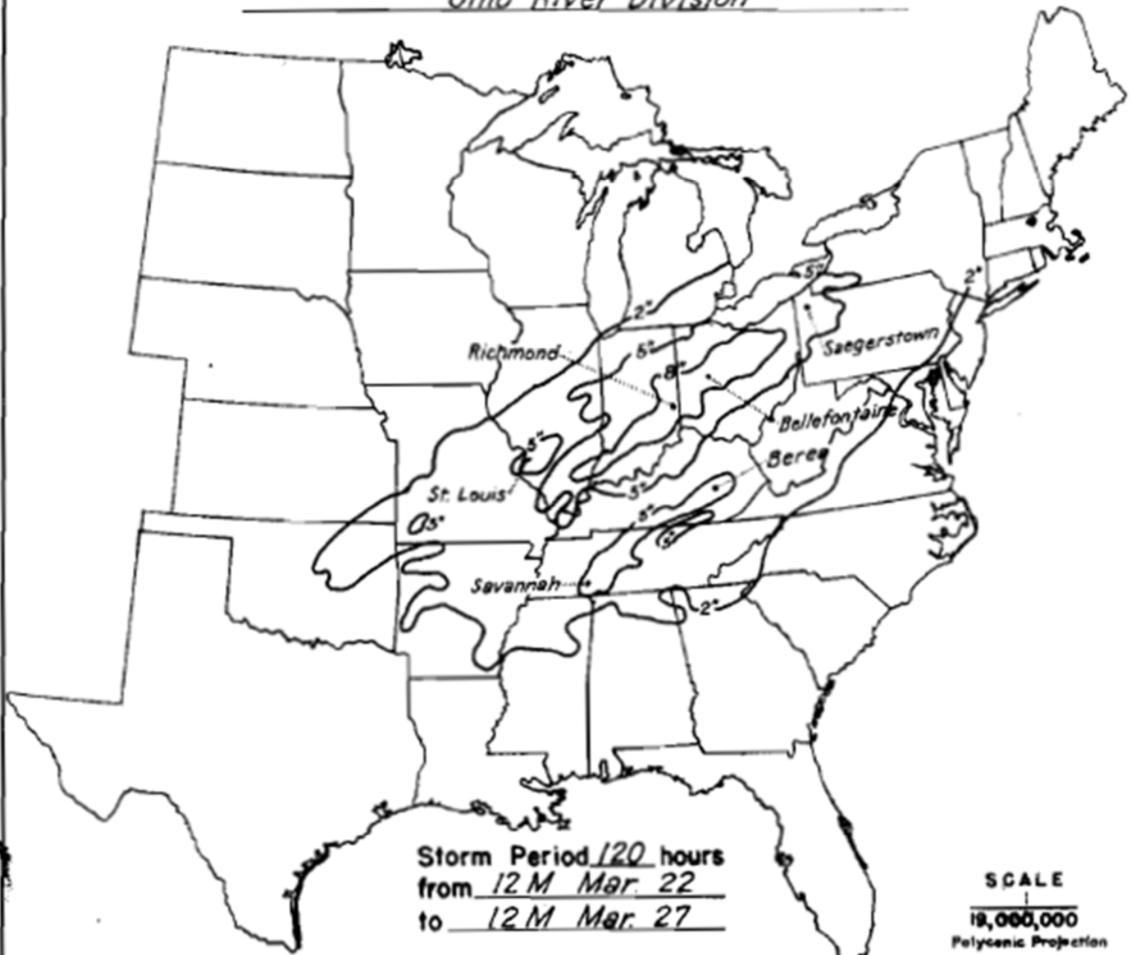
Form S-2

WAR DEPARTMENT CORPS OF ENGINEERS, U. S. ARMY

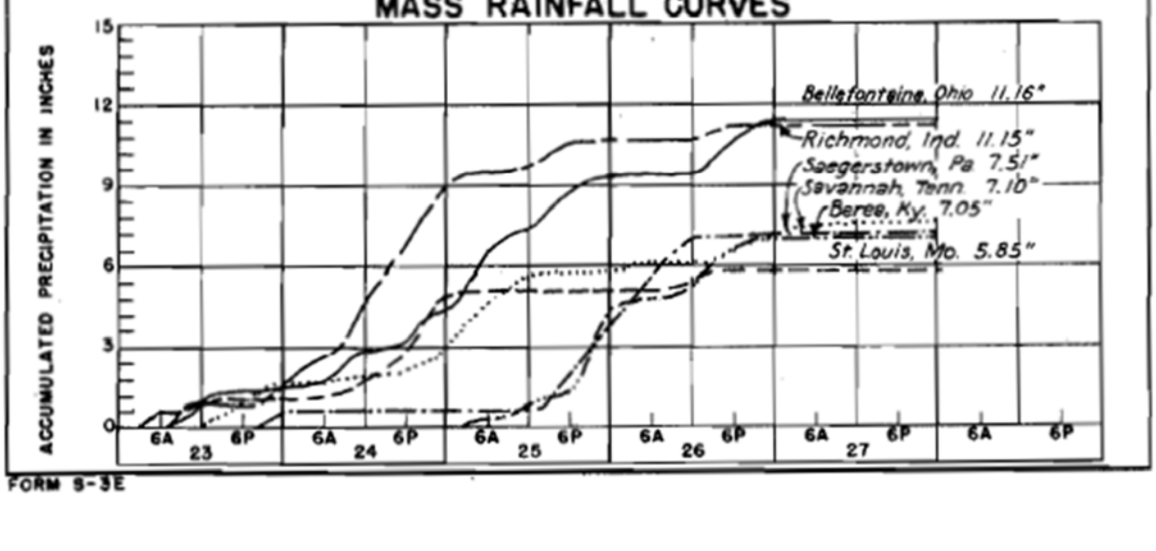
# STORM STUDIES – ISOHYETAL MAP

Storm of *March 23-27, 1913* Assignment *OR 1-15*

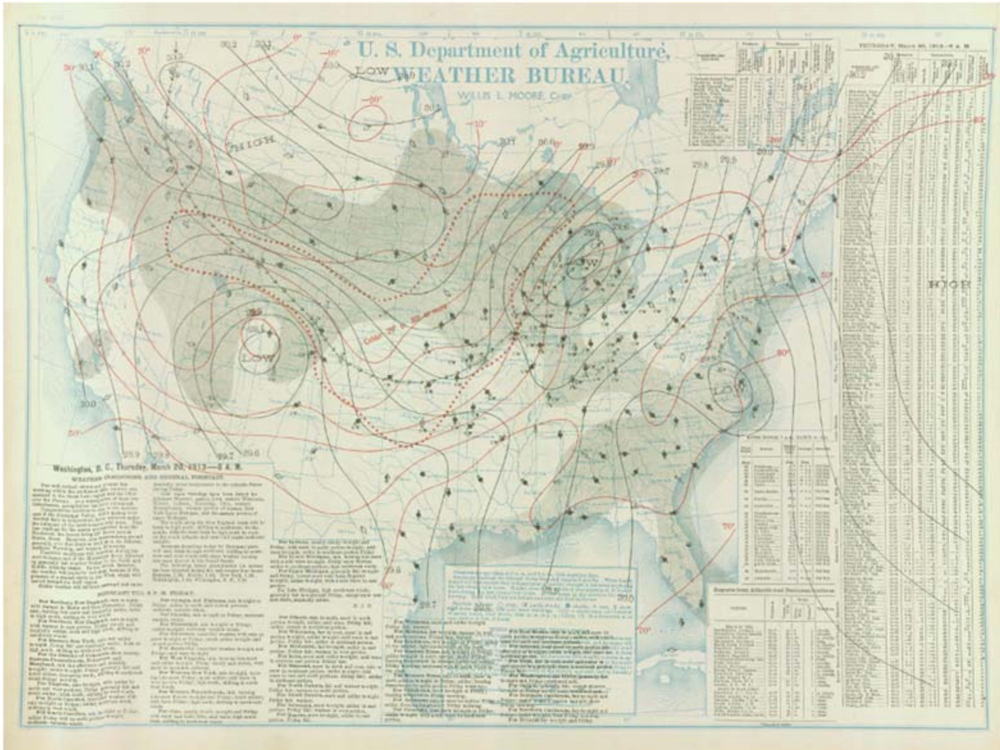
Study Prepared by: *Cincinnati, Ohio, District*
*Ohio River Division*

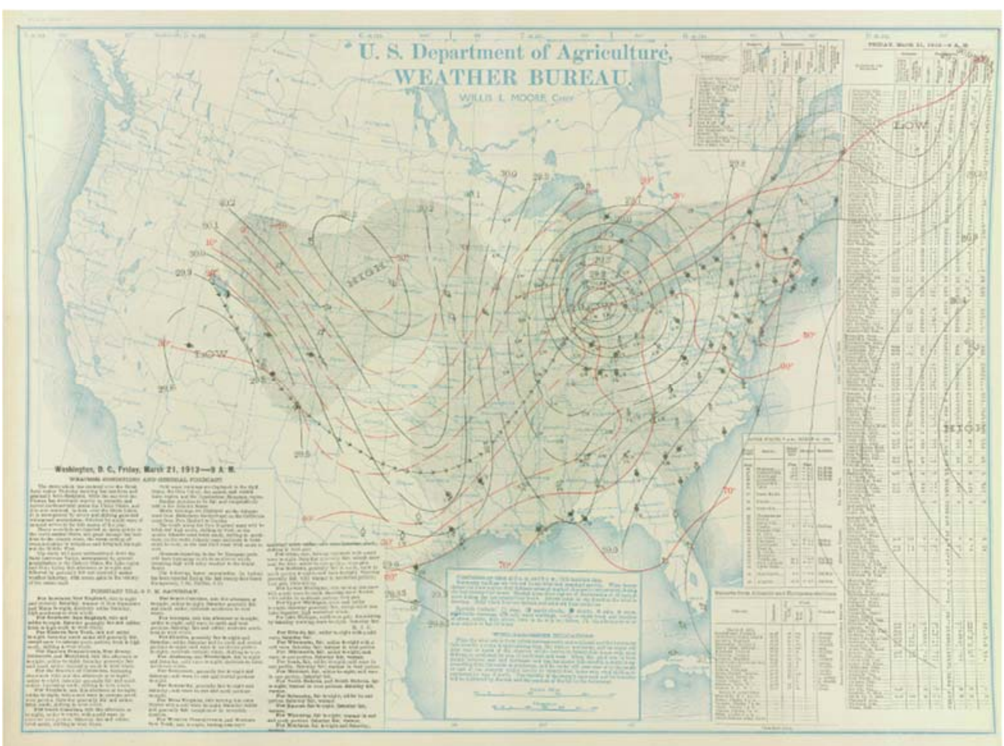


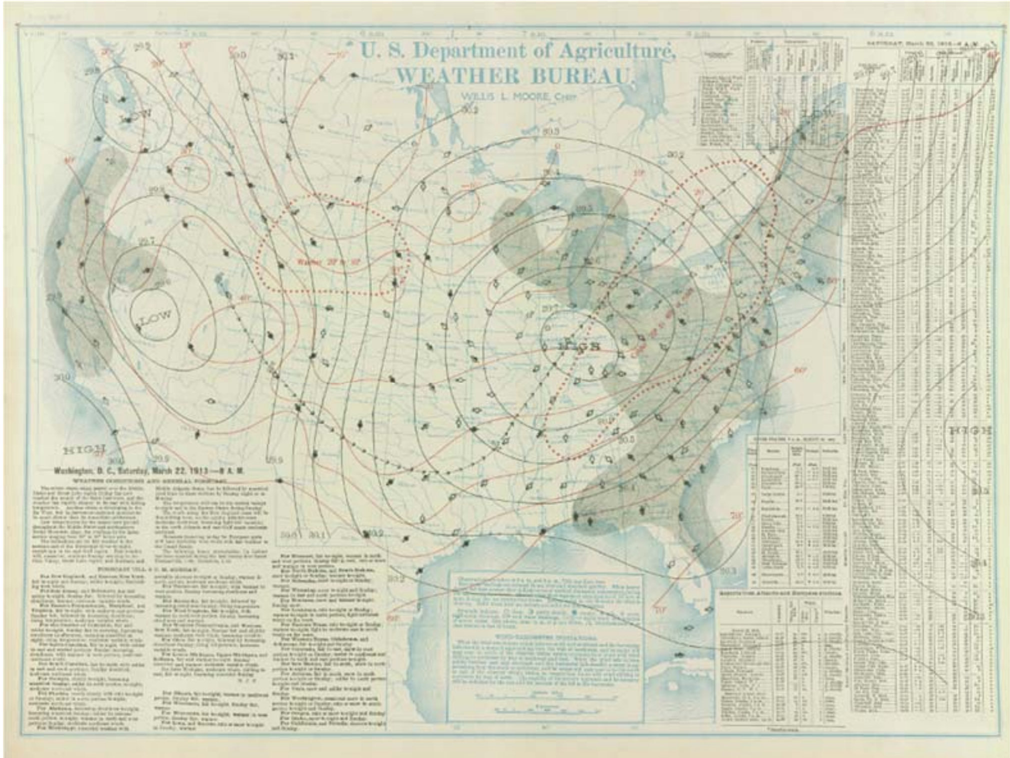

## MASS RAINFALL CURVES

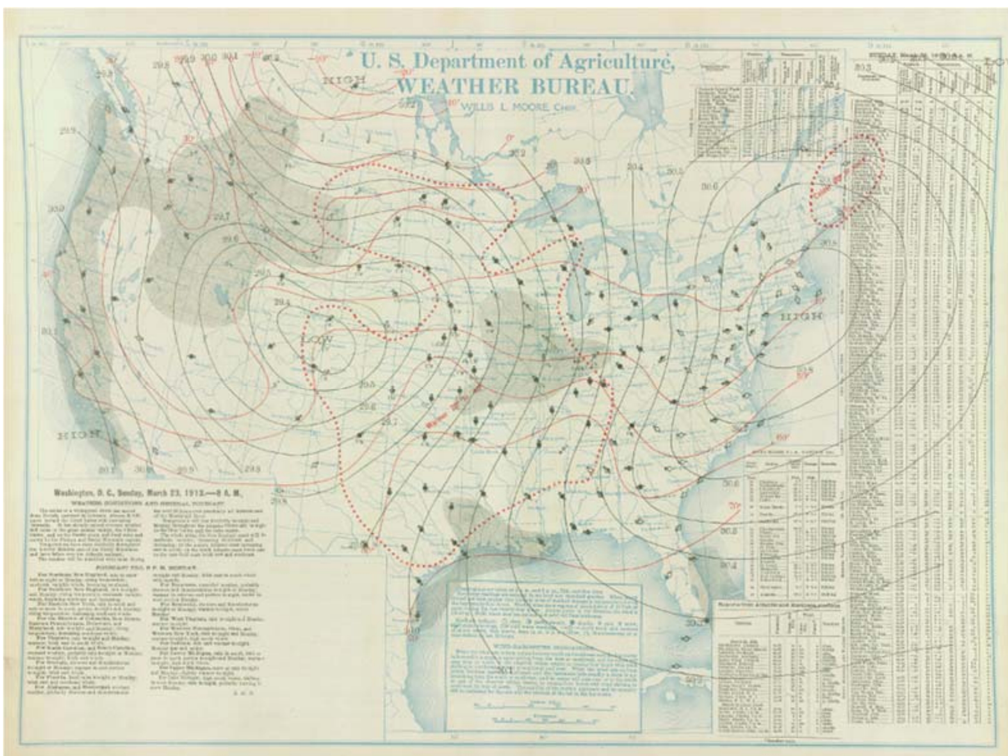


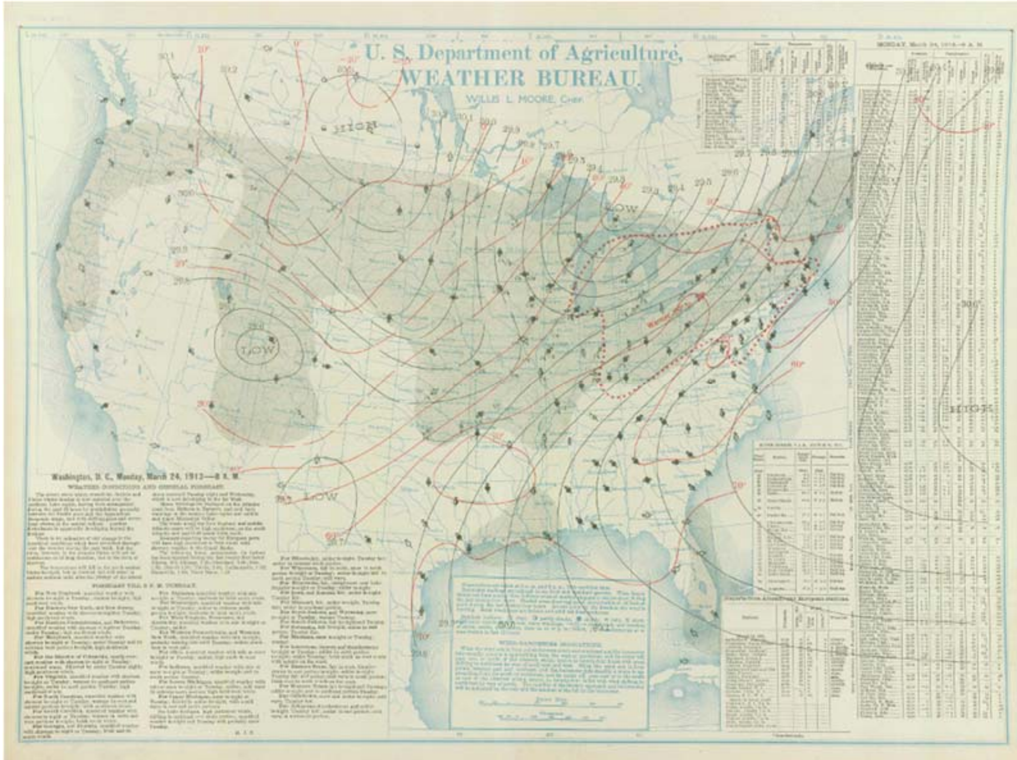

FORM 9-3E

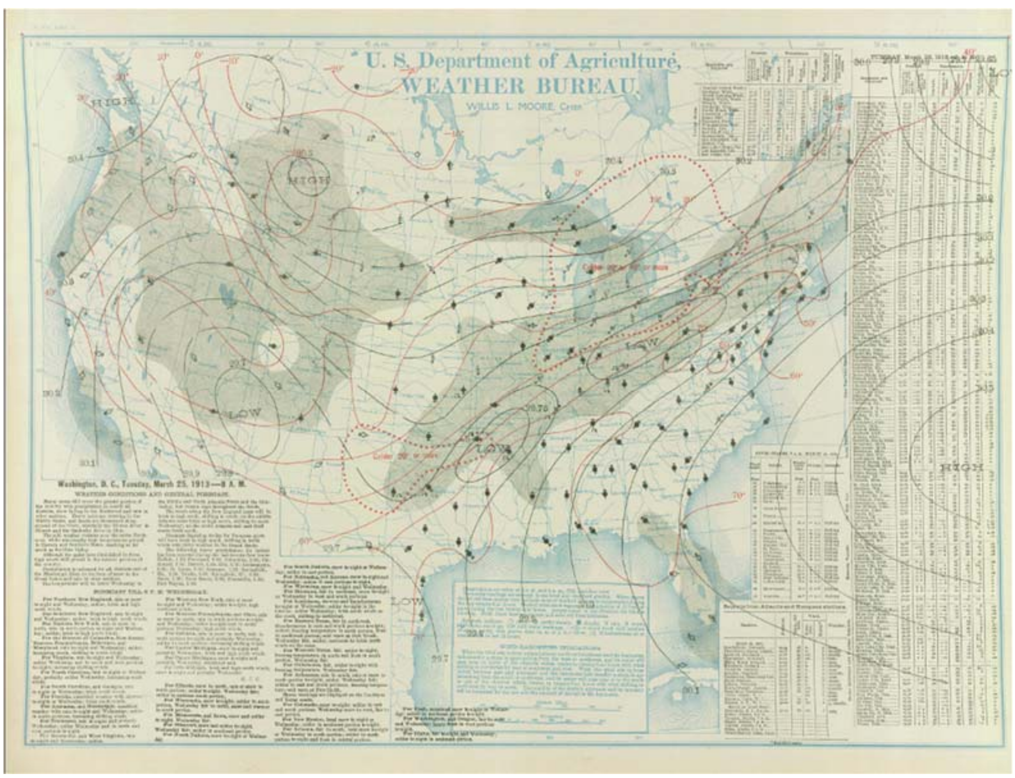

U. S. Department of Agriculture,
WEATHER BUREAU.
WILLIS L. MOORE Chief
HIGH
LOW
Washington, D. C., Thursday, March 20, 1913—8 A. M.

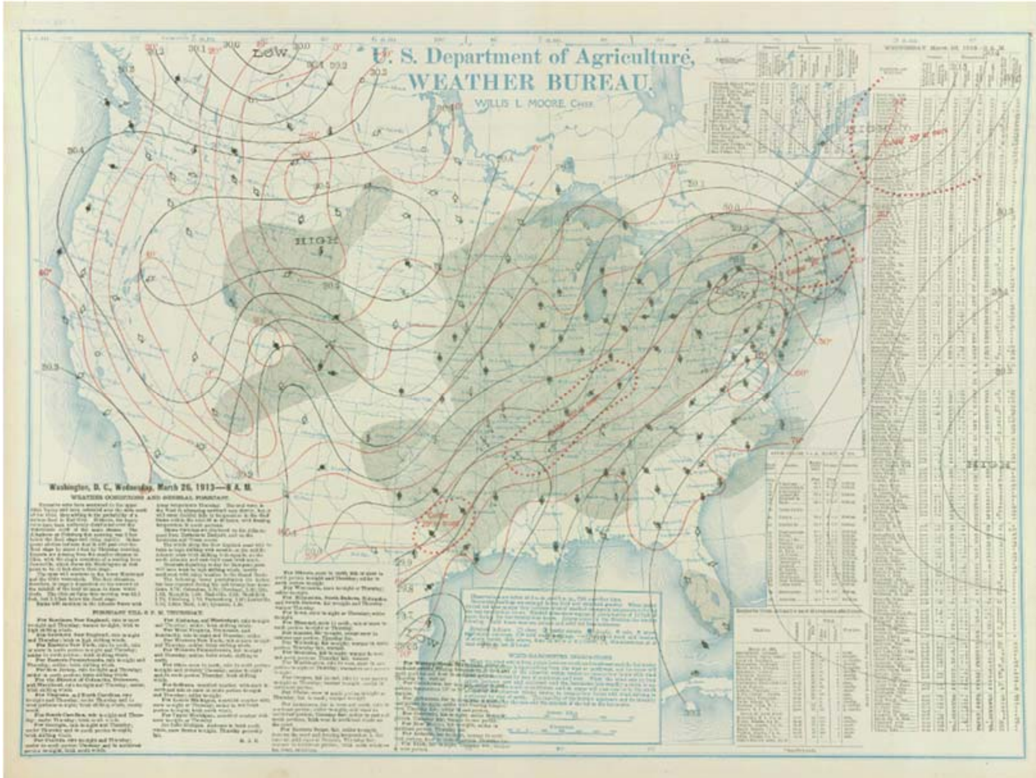

U. S. Department of Agriculture,
WEATHER BUREAU.
WILLIS L. MOORE Chief
HIGH
LOW
Washington, D. C., Friday, March 21, 1913—8 A. M.

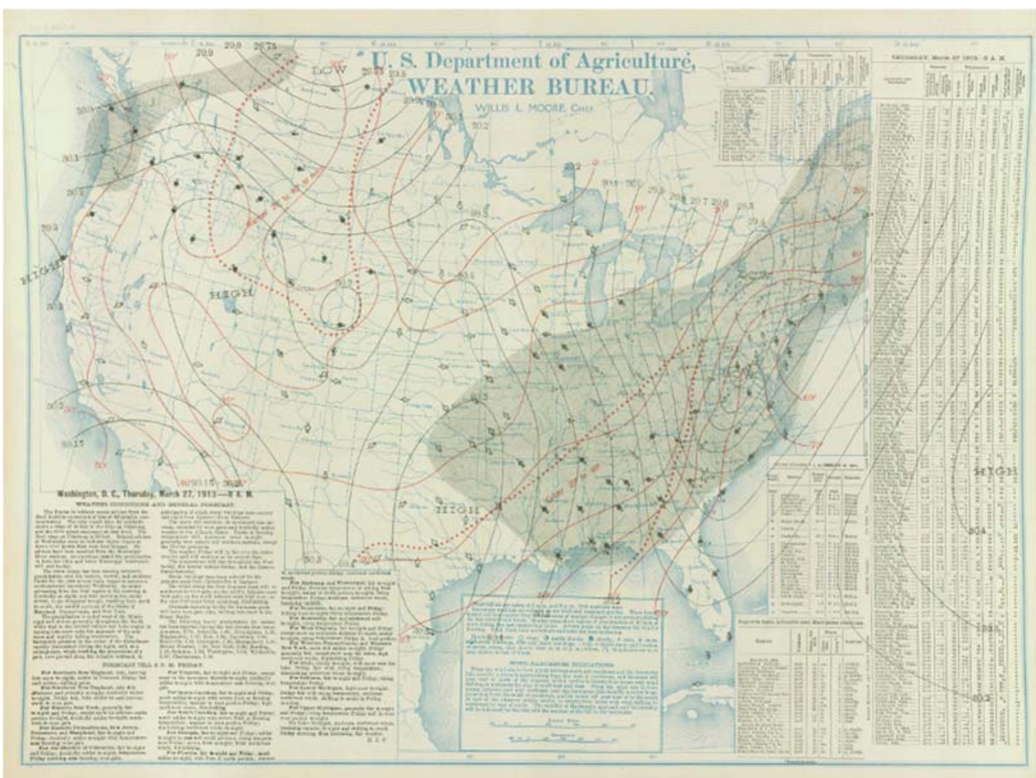

U. S. Department of Agriculture,
WEATHER BUREAU,
WILLIS L. MOORE, Chief
LOW
HIGH
HIGH
HIGH
Washington, D. C., Saturday, March 22, 1913—8 A. M.


U. S. Department of Agriculture,
WEATHER BUREAU,
WILLIS L. MOORE, Chief
HIGH
LOW
HIGH
HIGH
Washington, D. C., Sunday, March 23, 1913—8 A. M.


U. S. Department of Agriculture,
WEATHER BUREAU.
WILLIS L. MOORE, Chief
HIGH
LOW
Washington, D. C., Monday, March 24, 1913—8 A. M.

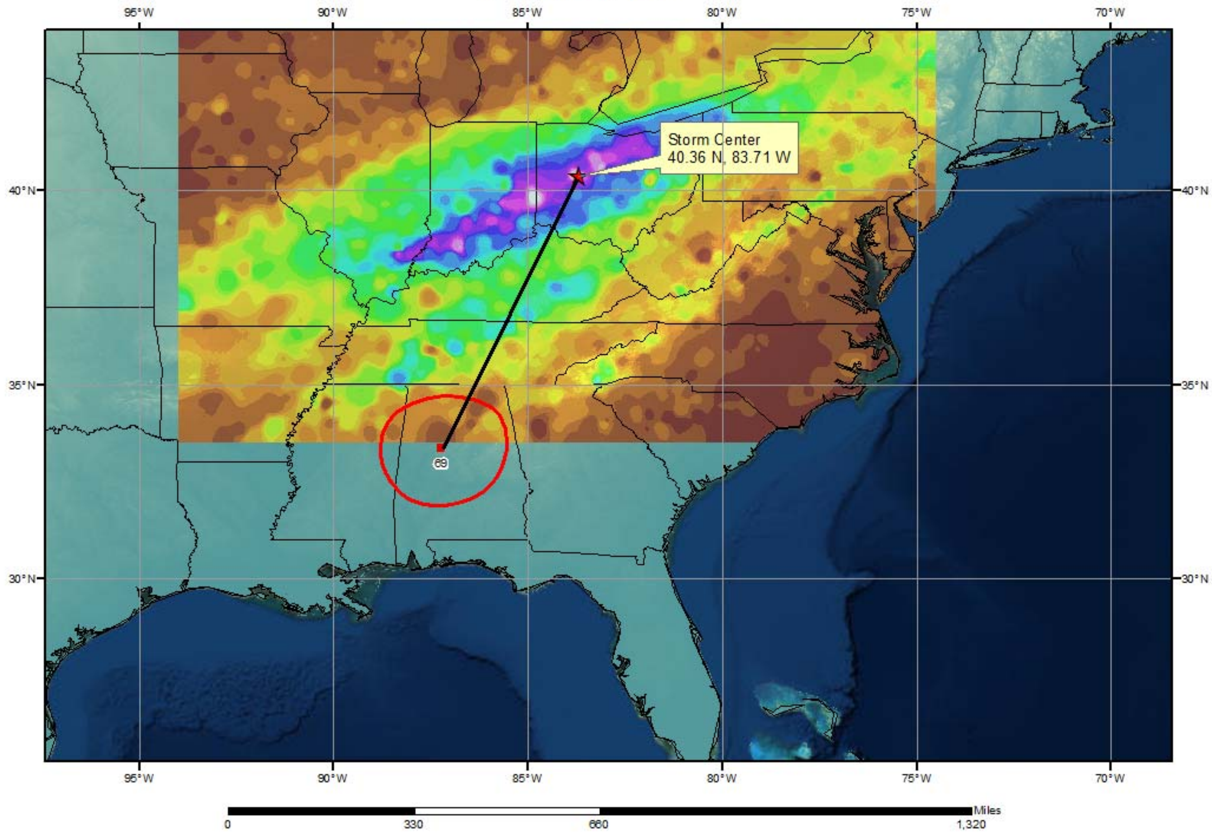

U. S. Department of Agriculture,
WEATHER BUREAU.
WILLIS L. MOORE, Chief
HIGH
LOW
Washington, D. C., Tuesday, March 25, 1913—8 A. M.


U. S. Department of Agriculture,
WEATHER BUREAU.
WILLIS L. MOORE, Chief
LOW
HIGH
Washington, D. C., Wednesday, March 26, 1913—8 A. M.


U. S. Department of Agriculture,
WEATHER BUREAU.
WILLIS L. MOORE, Chief
LOW
HIGH
Washington, D. C., Thursday, March 27, 1913—8 A. M.

**SPAS 1698 Bellefontaine, OH (OR 1-15) Storm Analysis**

March 22-27, 1913



# Storm Precipitation Analysis System (SPAS) For Storm #1311_1 SPAS Analysis

**General Storm Location**: Ohio River Basin

**Storm Dates**: January 17-25, 1937

**Event**: Frontal activity accompanied by almost continuous rain

**DAD Zone 1**

**Latitude**: 36.4375

**Longitude**: -87.9125

**Max. Grid rainfall amount**: 19.86”

**Max. Observed rainfall amount**: 19.75” (DOVER 1 NW, TN)

**Number of Stations**: 995

**SPAS Version**: 9.5

**Base Map Used:** Digitized TVA Isohyetal Map (storm total Jan 16-25)

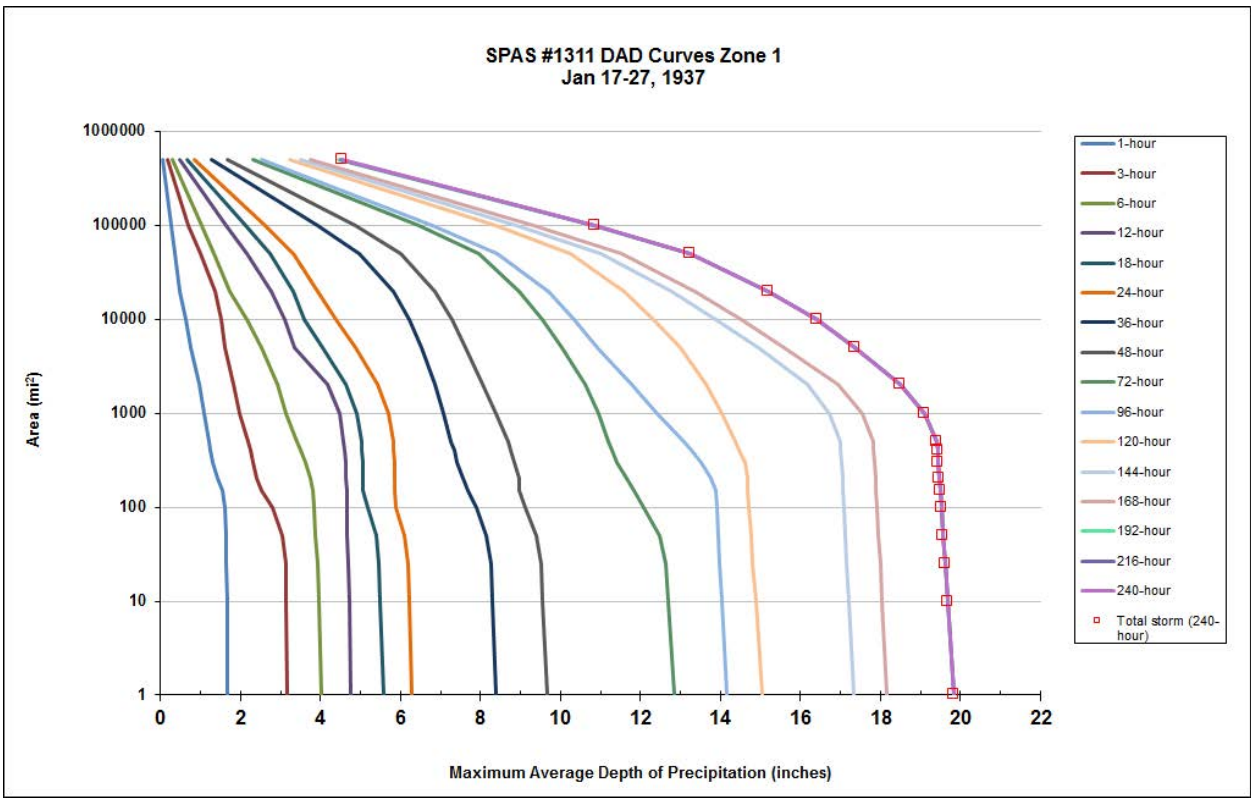
**Spatial resolution:** 30 seconds

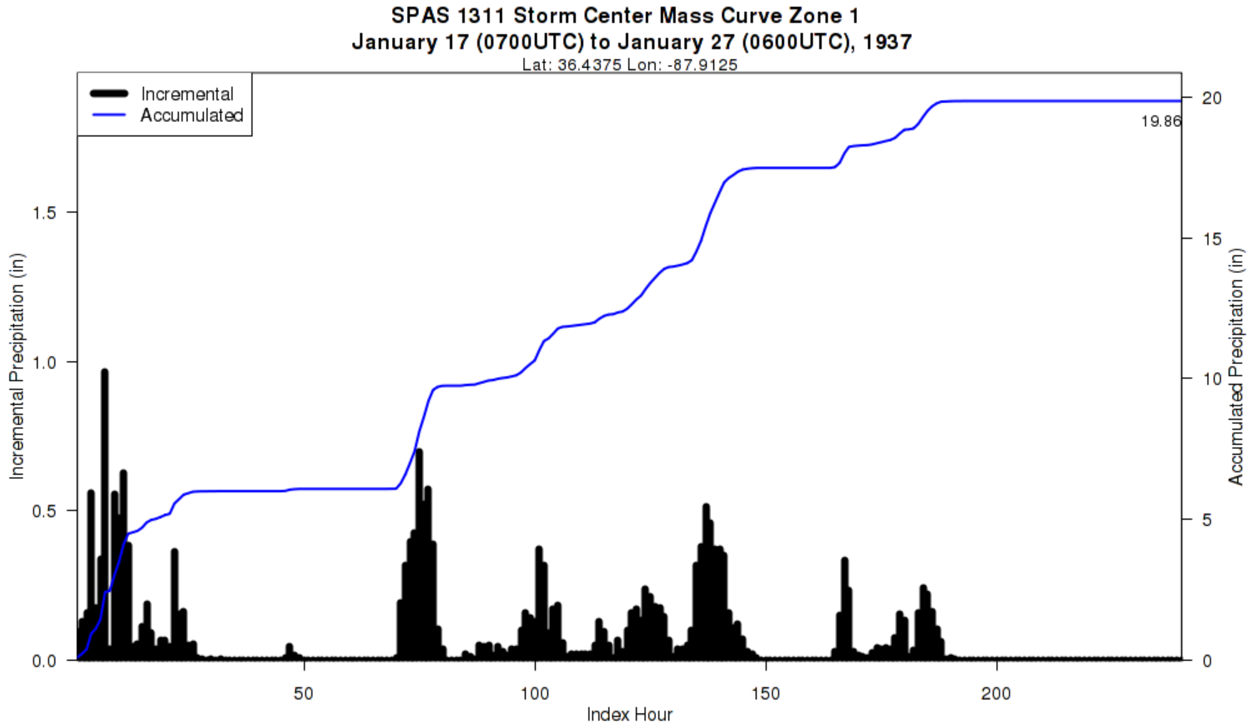
**Radar Included:** No

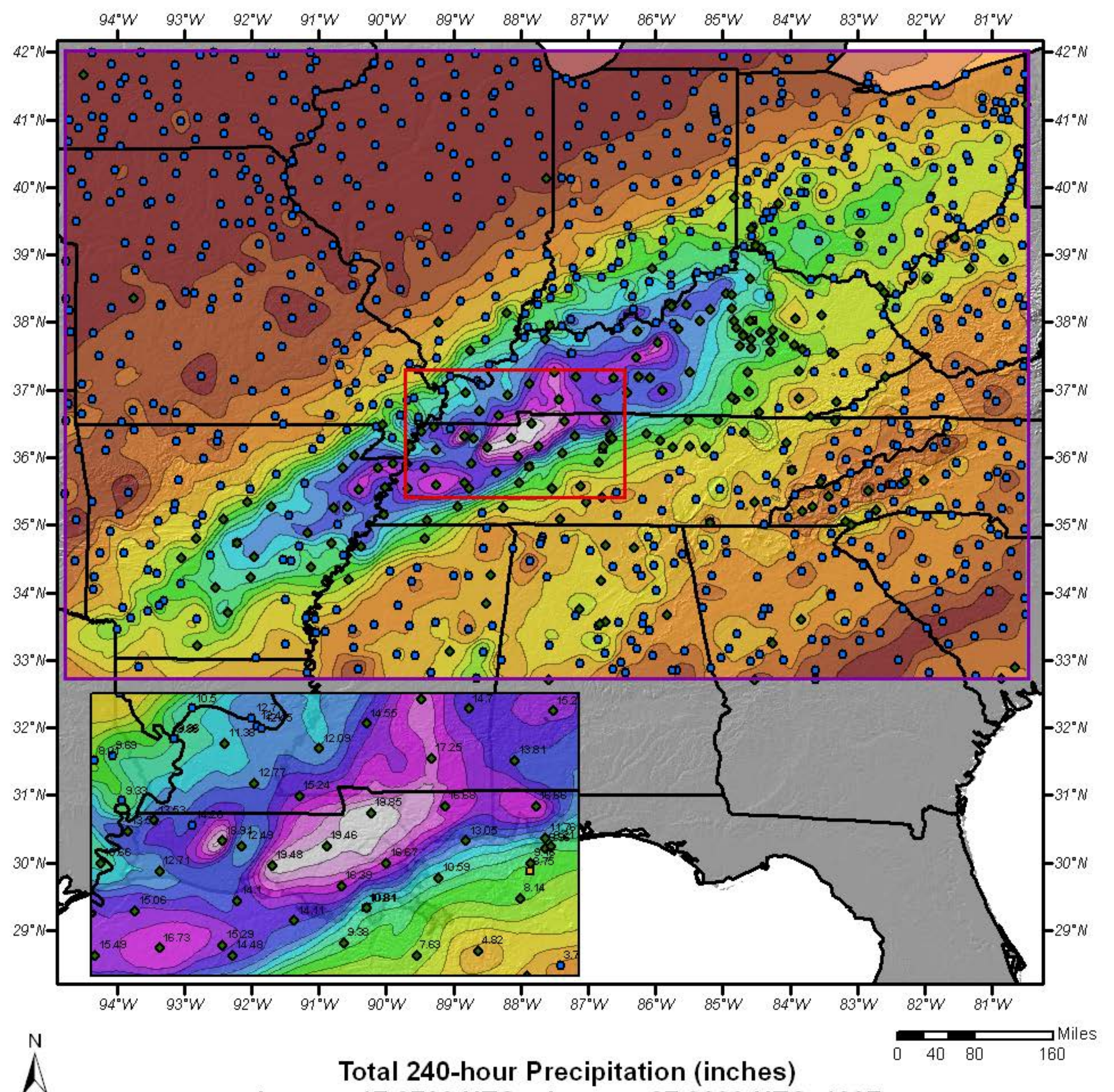
**Depth-Area-Duration (DAD) analysis**: Yes

**Reliability of Results**: Although only 13 hourly stations were available, they resided at locations in/near the storm center, therefore increasing confidence amongst the heaviest precipitation. Given this was a synoptic storm with large areas of nearly continuous precipitation (rainfall), it’s believed the temporal distribution of precipitation is reliable. A surprisingly high number (979) of daily and hourly stations, coupled with a total storm map prepared by TVA, provides a high degree of confidence in the spatial patterns and magnitude of precipitation.

| Storm 1311 - Jan. 17 (0700 UTC) - Jan. 27 (0600 UTC), 1937<br>MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Duration (hours) | | | | | | | | | | | | | | | |
| Area ($mi^2$) | 1 | 3 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | 96 | 120 | 144 | 168 | 192 | 216 | 240 | Total |
| **0.4** | 1.68 | 3.19 | 4.03 | 4.78 | 5.60 | 6.32 | 8.43 | 9.71 | 12.91 | 14.22 | 15.11 | 17.39 | 18.21 | 19.86 | 19.86 | 19.86 | 19.86 |
| **1** | 1.67 | 3.18 | 4.01 | 4.76 | 5.58 | 6.29 | 8.39 | 9.66 | 12.84 | 14.17 | 15.04 | 17.34 | 18.16 | 19.84 | 19.84 | 19.84 | 19.84 |
| **10** | 1.66 | 3.15 | 3.96 | 4.71 | 5.49 | 6.21 | 8.29 | 9.55 | 12.68 | 14.03 | 14.88 | 17.21 | 18.04 | 19.68 | 19.68 | 19.68 | 19.68 |
| **25** | 1.65 | 3.13 | 3.94 | 4.68 | 5.46 | 6.18 | 8.25 | 9.51 | 12.62 | 13.98 | 14.81 | 17.16 | 17.99 | 19.62 | 19.62 | 19.62 | 19.62 |
| **50** | 1.64 | 3.04 | 3.86 | 4.67 | 5.38 | 6.09 | 8.15 | 9.38 | 12.47 | 13.94 | 14.77 | 17.13 | 17.95 | 19.57 | 19.57 | 19.57 | 19.57 |
| **100** | 1.61 | 2.80 | 3.84 | 4.65 | 5.17 | 5.87 | 7.89 | 9.12 | 12.08 | 13.90 | 14.72 | 17.09 | 17.91 | 19.52 | 19.52 | 19.52 | 19.52 |
| **150** | 1.54 | 2.53 | 3.80 | 4.65 | 5.06 | 5.85 | 7.68 | 8.98 | 11.83 | 13.88 | 14.69 | 17.07 | 17.89 | 19.50 | 19.50 | 19.50 | 19.50 |
| **200** | 1.44 | 2.40 | 3.74 | 4.64 | 5.06 | 5.85 | 7.55 | 8.96 | 11.65 | 13.77 | 14.67 | 17.05 | 17.87 | 19.48 | 19.48 | 19.48 | 19.48 |
| **300** | 1.30 | 2.32 | 3.61 | 4.63 | 5.05 | 5.84 | 7.42 | 8.84 | 11.42 | 13.53 | 14.60 | 17.03 | 17.85 | 19.45 | 19.45 | 19.45 | 19.45 |
| **400** | 1.24 | 2.25 | 3.50 | 4.61 | 5.04 | 5.83 | 7.34 | 8.75 | 11.30 | 13.28 | 14.47 | 17.01 | 17.83 | 19.43 | 19.43 | 19.43 | 19.43 |
| **500** | 1.20 | 2.18 | 3.41 | 4.58 | 5.02 | 5.83 | 7.27 | 8.69 | 11.21 | 13.09 | 14.37 | 17.00 | 17.82 | 19.41 | 19.41 | 19.41 | 19.41 |
| **1,000** | 1.08 | 1.98 | 3.14 | 4.47 | 4.91 | 5.70 | 7.07 | 8.40 | 10.94 | 12.41 | 14.03 | 16.72 | 17.55 | 19.11 | 19.11 | 19.11 | 19.11 |
| **2,000** | 0.96 | 1.81 | 2.91 | 4.17 | 4.62 | 5.42 | 6.86 | 8.06 | 10.63 | 11.77 | 13.64 | 16.16 | 16.95 | 18.49 | 18.49 | 18.49 | 18.49 |
| **5,000** | 0.76 | 1.62 | 2.53 | 3.36 | 4.04 | 4.89 | 6.53 | 7.63 | 10.05 | 10.92 | 12.99 | 14.95 | 15.59 | 17.36 | 17.36 | 17.36 | 17.36 |
| **10,000** | 0.63 | 1.51 | 2.15 | 3.10 | 3.60 | 4.40 | 6.22 | 7.29 | 9.55 | 10.33 | 12.31 | 13.89 | 14.52 | 16.41 | 16.41 | 16.41 | 16.41 |
| **20,000** | 0.48 | 1.35 | 1.73 | 2.78 | 3.32 | 3.92 | 5.82 | 6.86 | 8.98 | 9.71 | 11.59 | 12.78 | 13.35 | 15.20 | 15.20 | 15.20 | 15.20 |
| **50,000** | 0.36 | 1.01 | 1.33 | 2.17 | 2.74 | 3.33 | 4.96 | 6.01 | 7.97 | 8.42 | 10.25 | 11.02 | 11.54 | 13.23 | 13.24 | 13.24 | 13.24 |
| **100,000** | 0.25 | 0.70 | 1.02 | 1.63 | 2.13 | 2.61 | 3.93 | 4.87 | 6.45 | 6.79 | 8.38 | 8.91 | 9.34 | 10.83 | 10.85 | 10.85 | 10.85 |
| **504,363** | 0.06 | 0.18 | 0.29 | 0.49 | 0.66 | 0.86 | 1.26 | 1.67 | 2.30 | 2.53 | 3.23 | 3.51 | 3.74 | 4.45 | 4.52 | 4.55 | 4.55 |

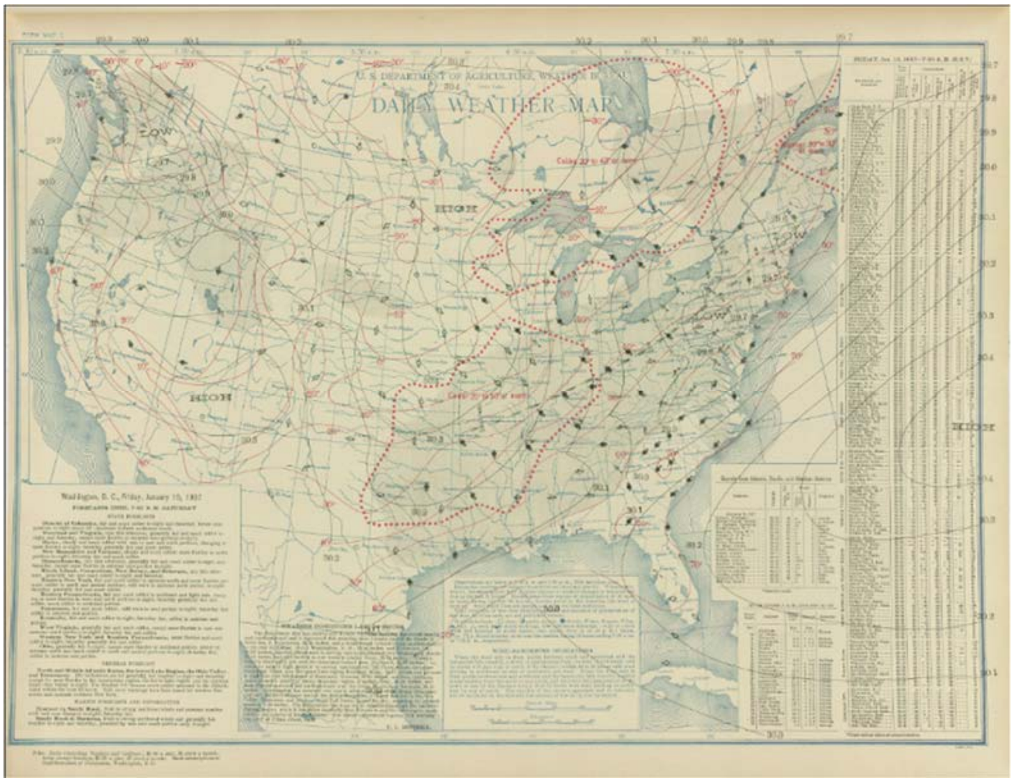


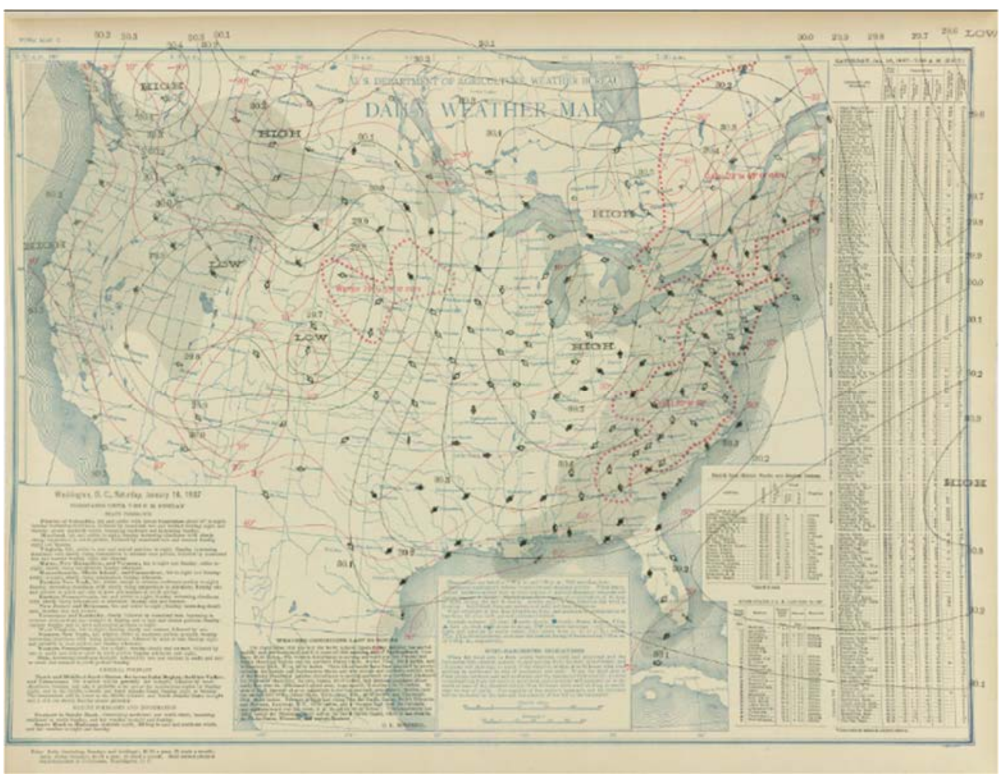

SPAS 1311 Storm Center Mass Curve Zone 1
January 17 (0700UTC) to January 27 (0600UTC), 1937
Lat: 36.4375 Lon: -87.9125
Incremental
Accumulated
19.86
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
0
5
10
15
20
50
100
150
200

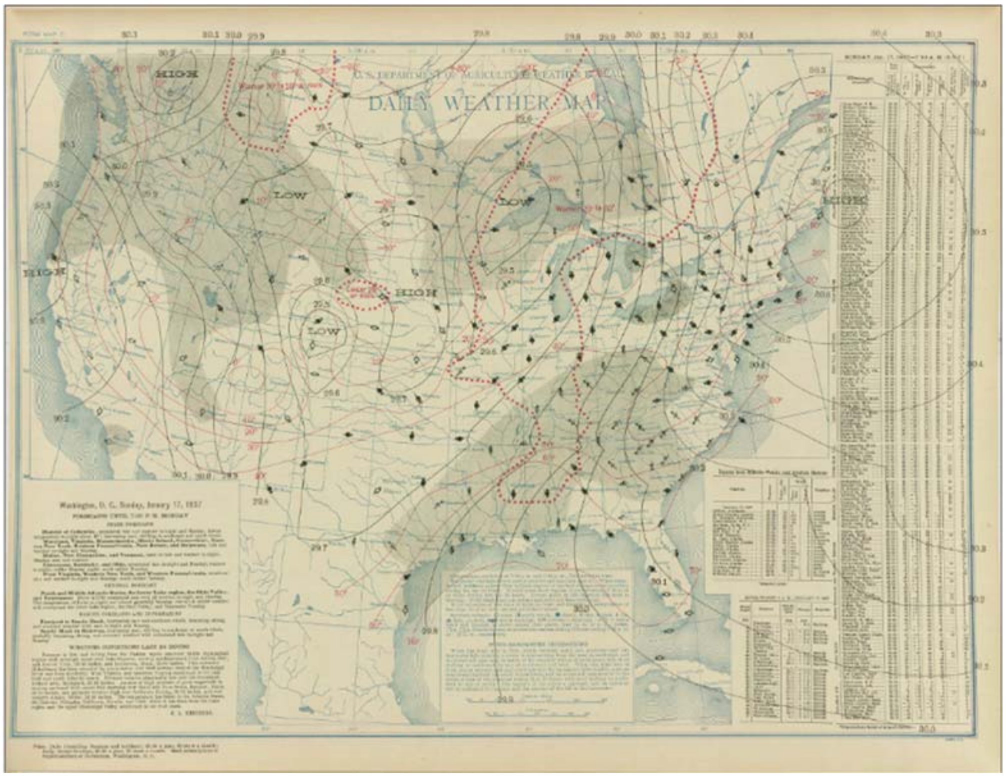



Total 240-hour Precipitation (inches)
January 17 0700 UTC - January 27 0600 UTC, 1937
SPAS #1311


01/24/2014


DAILY WEATHER MAP
HIGH
LOW
HIGH
LOW
HIGH


DAILY WEATHER MAP
HIGH
HIGH
LOW
LOW
HIGH
HIGH
HIGH
LOW


DAILY WEATHER MAP
HIGH
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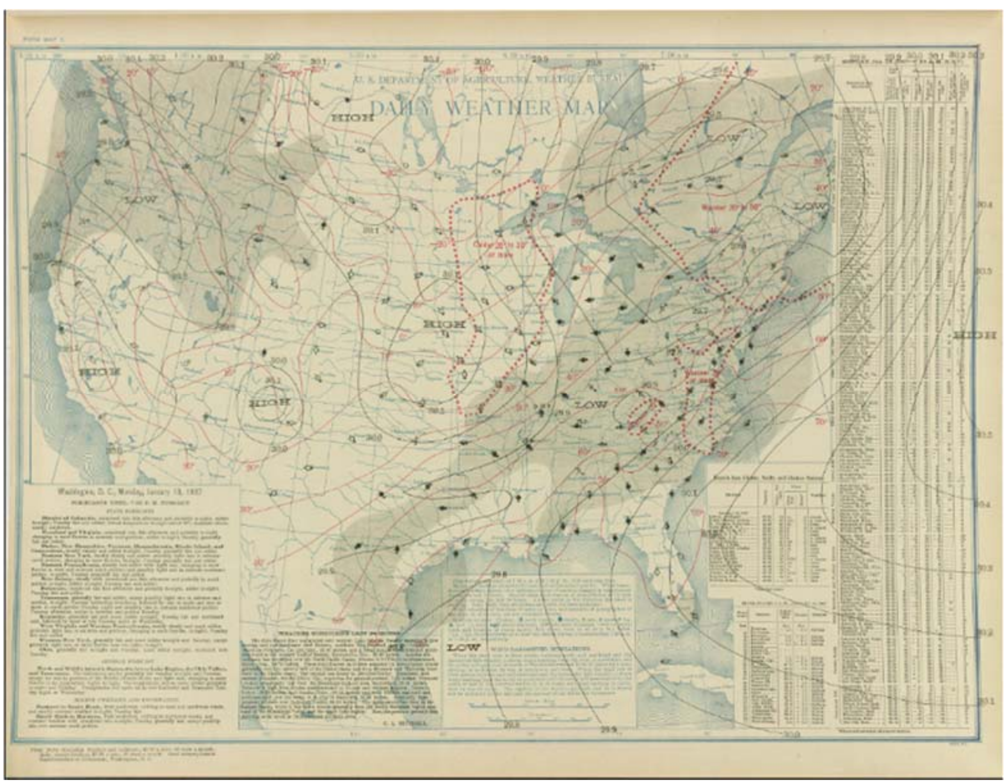
U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
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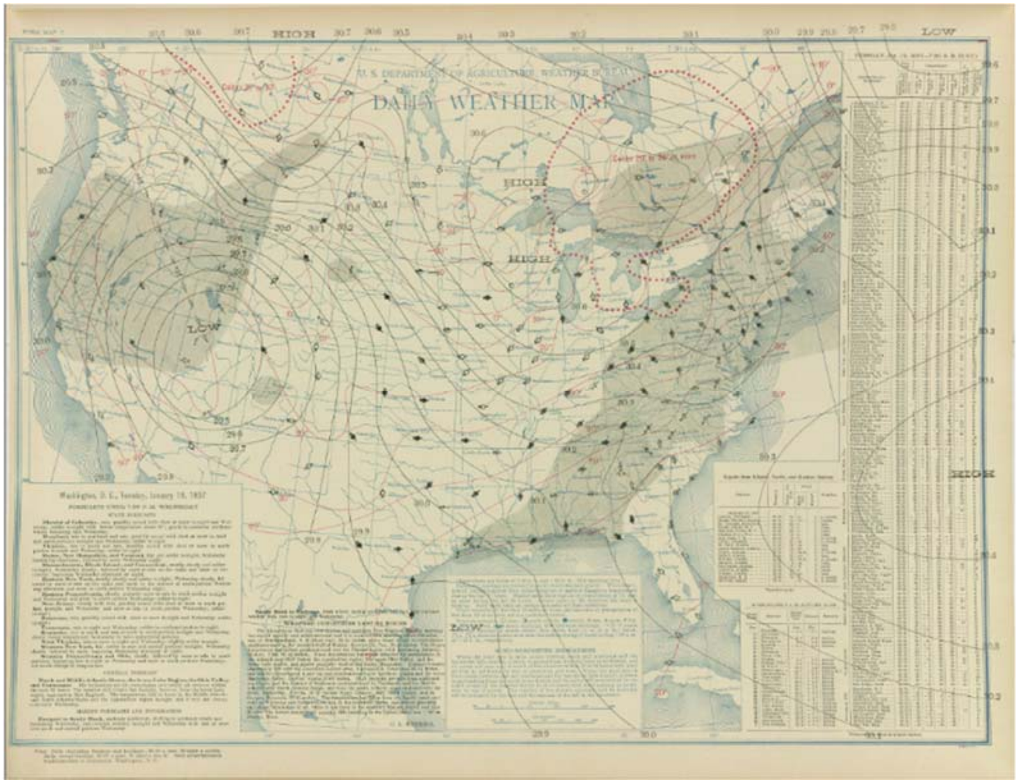
LOW
HIGH
LOW


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
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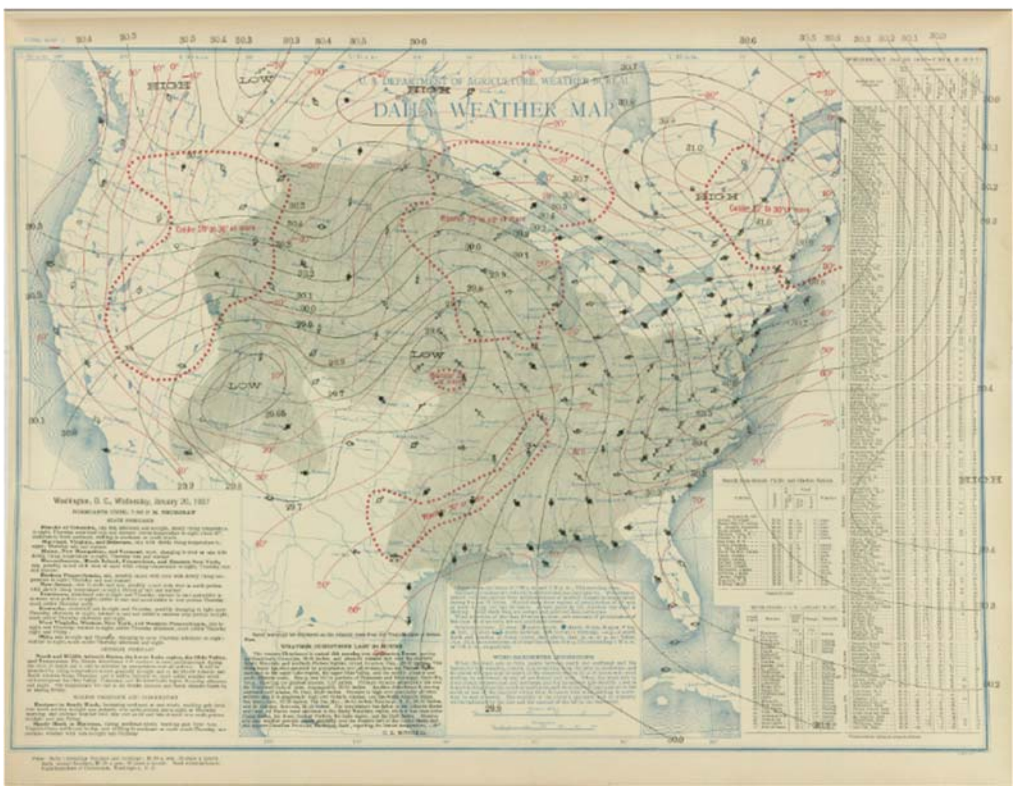
U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
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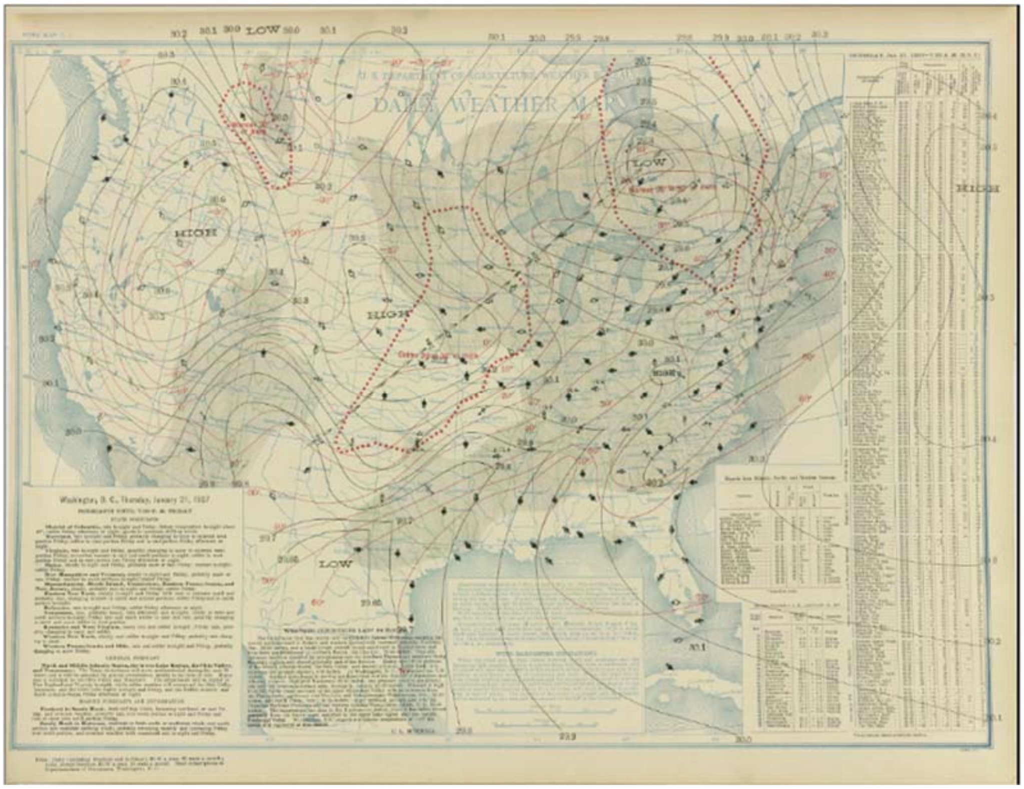
DAILY WEATHER MAP
LOW
HIGH
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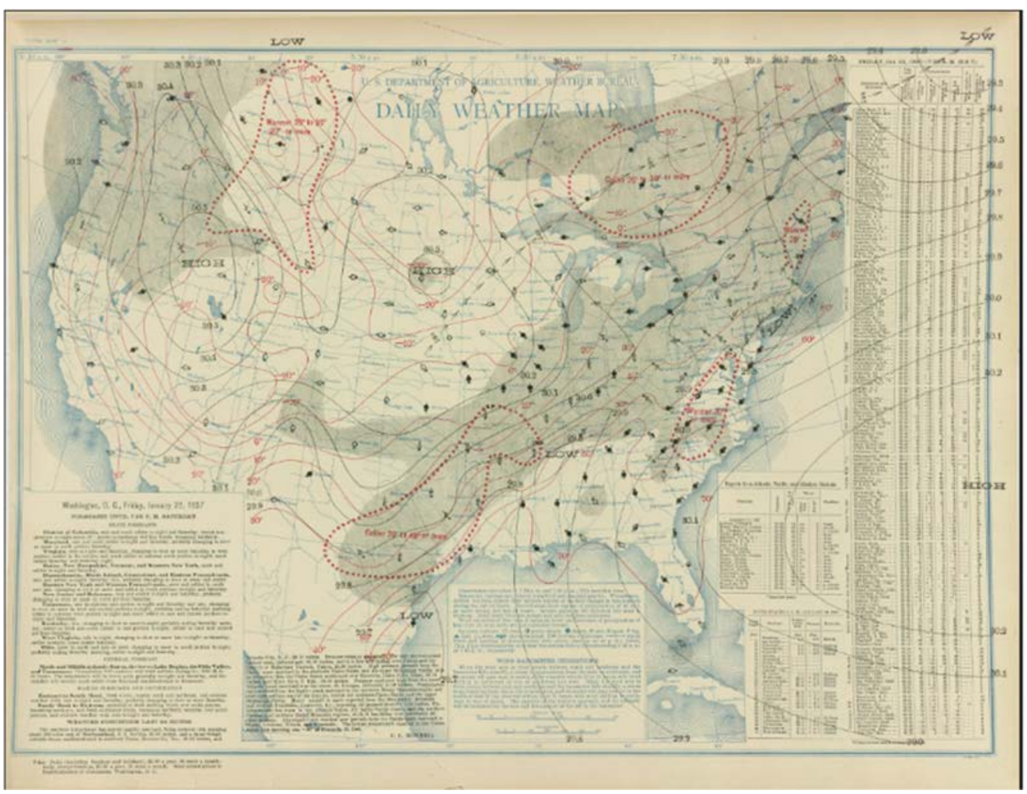
HIGH


DAILY WEATHER MAP
LOW
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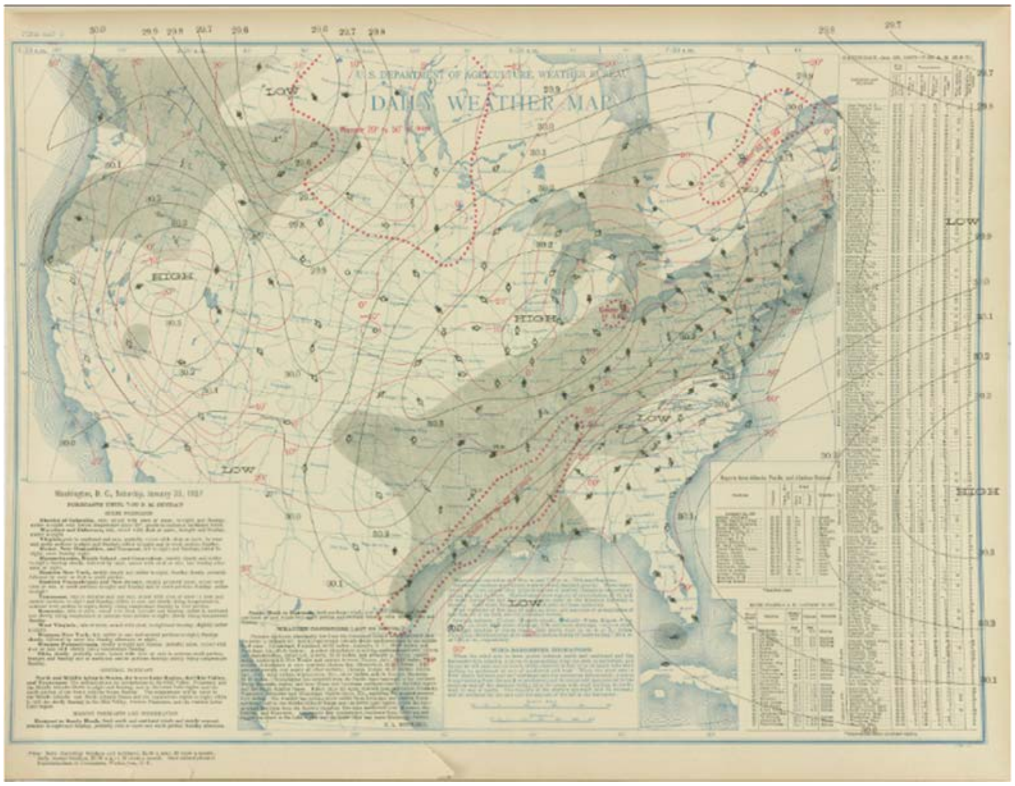
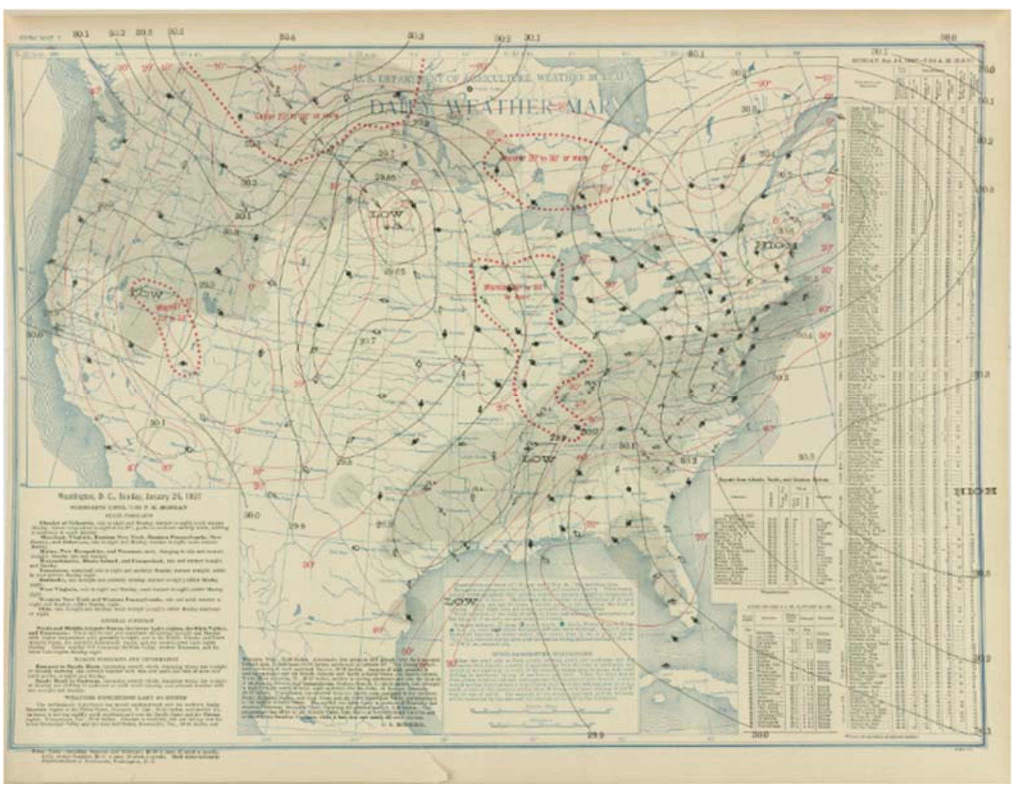
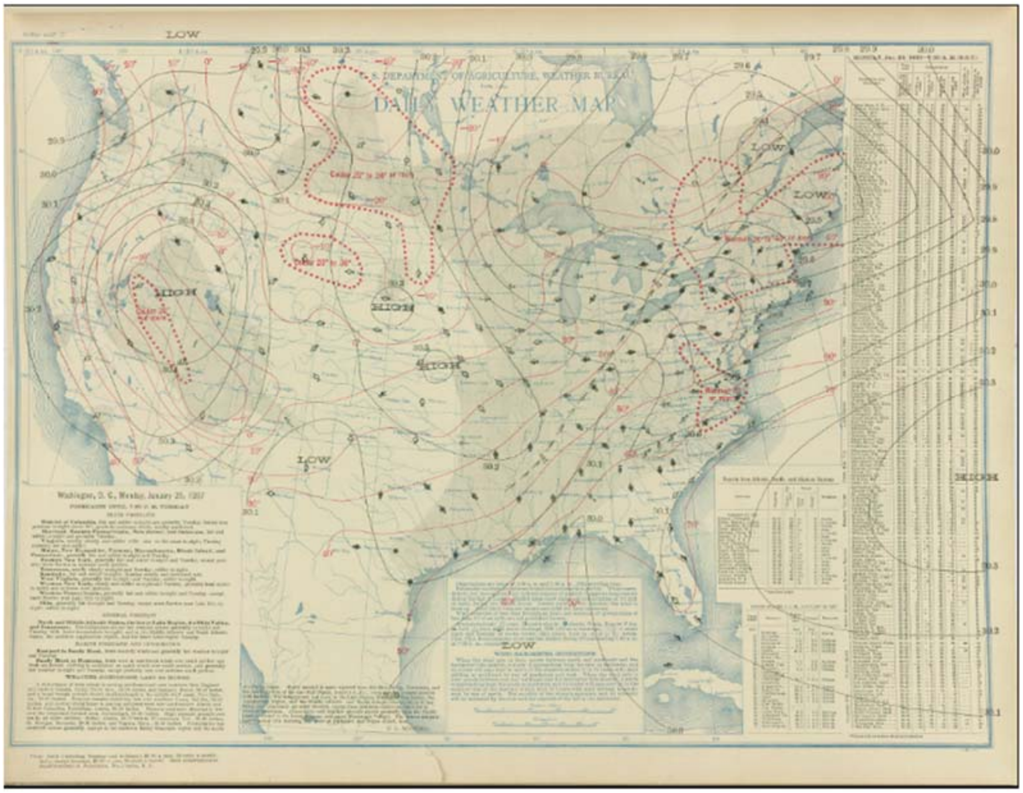
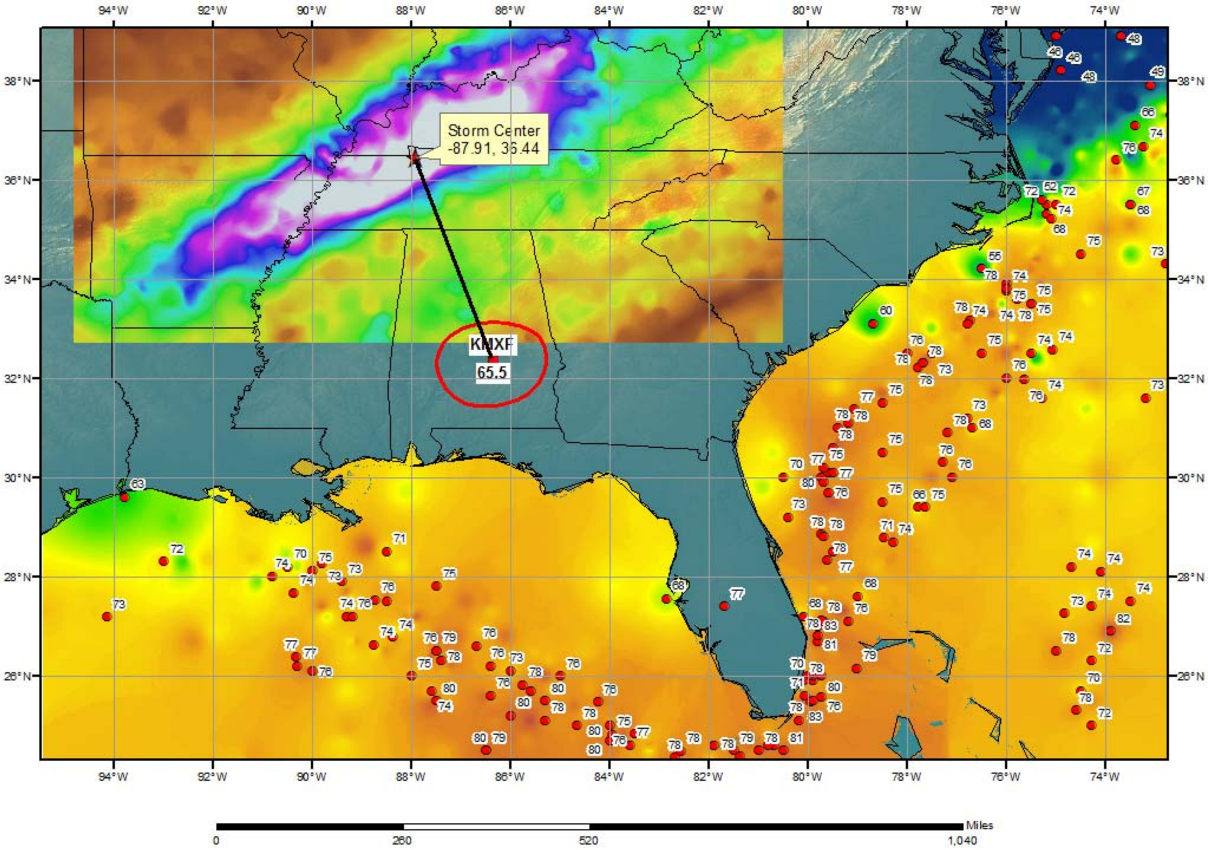
HIGH


DAILY WEATHER MAP
LOW
HIGH
LOW


DAILY WEATHER MAP
LOW
LOW
HIGH
LOW


LOW
HIGH
HIGH
HIGH
LOW
LOW
LOW
LOW
HIGH

**SPAS 1311 Dover, TN Storm Analysis**
January 15 - 16, 1937



# Storm Precipitation Analysis System (SPAS) For Storm #1433_1 SPAS Analysis

**General Storm Location**: Collinsville, Illinois (40.0, -91.5, 36.9, -87.3)

**Storm Dates**: August 13 – August 16, 1946

**Event**: Extreme Precipitation Event

**DAD Zone 1**

**Latitude**: 38.6708

**Longitude**: -90.0042

**Max. Grid rainfall amount**: 19.07”

**Max. Observed rainfall amount**: 19.07” (Collinsville, IL)

**Number of Stations**: 166

**SPAS Version**: 10.0

**Base Map Used:** Derived basemap based off of SPAS analysis

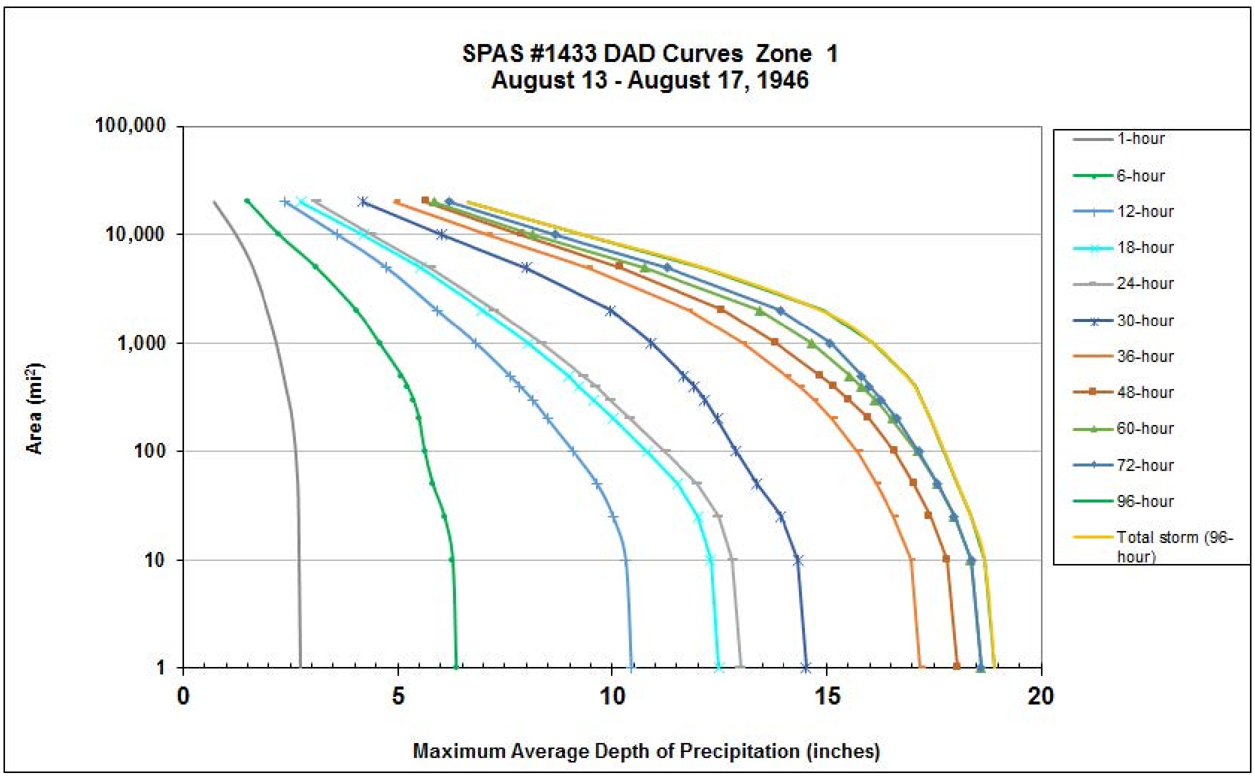
**Spatial resolution:** 0.2596

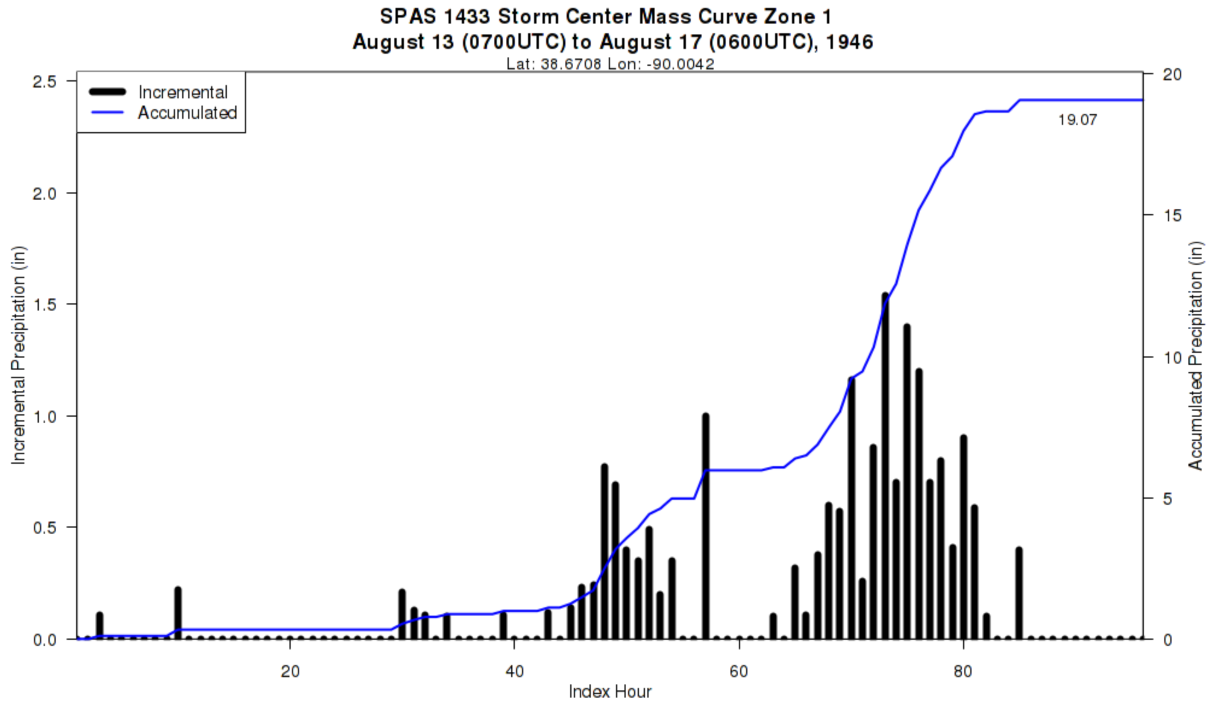
**Radar Included:** No

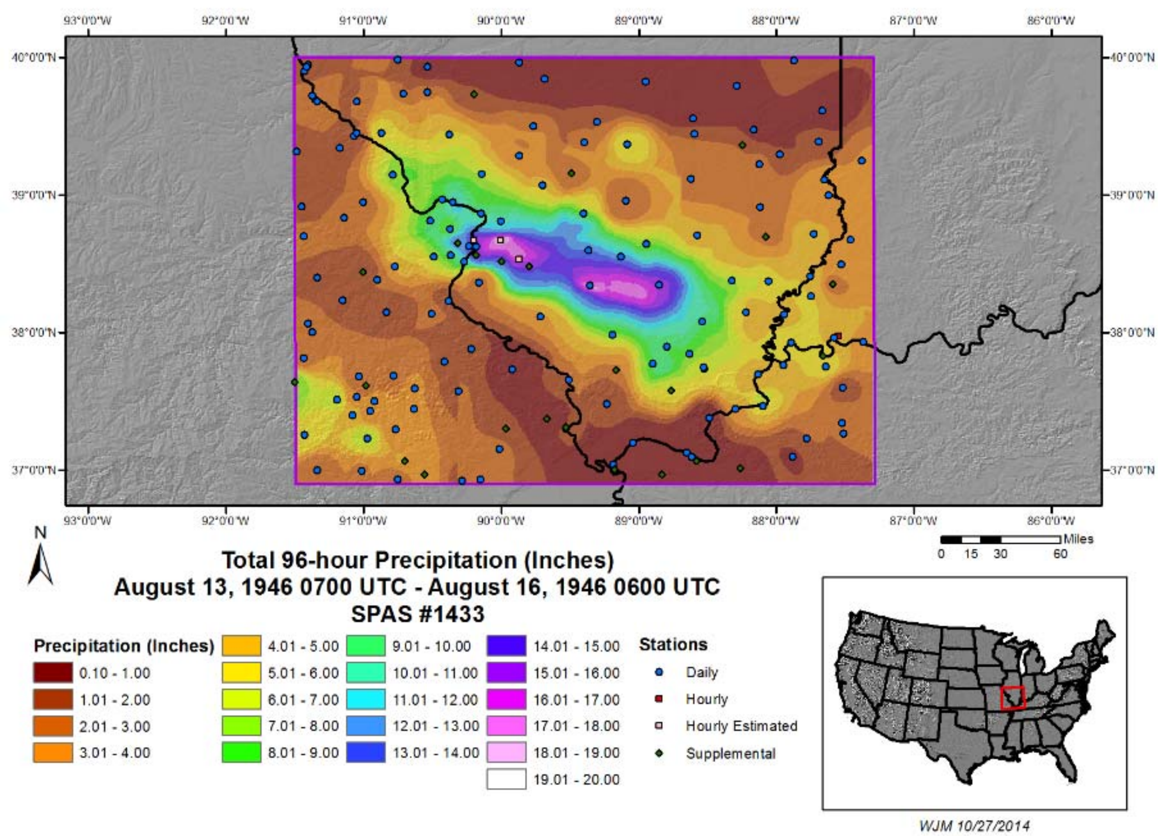
**Depth-Area-Duration (DAD) analysis**: Yes

**Reliability of Results**: In addition to the NCDC stations, twenty-four supplemental stations were added to ensure data consistency. Due to the amount and integrity of the U.S. Army Corps of Engineers (USACE), three hourly stations were added based on the mass rainfall curves. Three hourly stations were also added from local climatology from NCDC. With the density of stations available and the consistency of the resulting SPAS analysis to the U.S. Army Corps of Engineers report, this analysis is deemed quite reliable.

| Storm 1433 - August 13 (0700 UTC) - August 17 (0600 UTC), 1946 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | |
| Area (mi²) | Duration (hours) | | | | | | | | | | | |
| | 1 | 6 | 12 | 18 | 24 | 30 | 36 | 48 | 60 | 72 | 96 | Total |
| 0.4 | 2.72 | 6.39 | 10.49 | 12.56 | 13.07 | 14.60 | 17.28 | 18.15 | 18.69 | 18.70 | 19.02 | 19.02 |
| 1 | 2.72 | 6.36 | 10.44 | 12.49 | 12.99 | 14.53 | 17.18 | 18.05 | 18.60 | 18.60 | 18.92 | 18.92 |
| 10 | 2.69 | 6.28 | 10.31 | 12.30 | 12.81 | 14.33 | 16.96 | 17.82 | 18.36 | 18.37 | 18.67 | 18.67 |
| 25 | 2.68 | 6.09 | 10.02 | 12.00 | 12.47 | 13.94 | 16.56 | 17.42 | 17.97 | 17.97 | 18.36 | 18.36 |
| 50 | 2.66 | 5.82 | 9.65 | 11.54 | 11.99 | 13.38 | 16.16 | 17.04 | 17.58 | 17.59 | 18.05 | 18.05 |
| 100 | 2.61 | 5.63 | 9.09 | 10.81 | 11.23 | 12.89 | 15.72 | 16.59 | 17.12 | 17.16 | 17.75 | 17.75 |
| 200 | 2.53 | 5.50 | 8.49 | 10.04 | 10.42 | 12.46 | 15.14 | 15.98 | 16.53 | 16.64 | 17.42 | 17.42 |
| 300 | 2.45 | 5.37 | 8.14 | 9.56 | 9.95 | 12.16 | 14.70 | 15.52 | 16.13 | 16.26 | 17.21 | 17.21 |
| 400 | 2.38 | 5.23 | 7.85 | 9.22 | 9.61 | 11.91 | 14.36 | 15.16 | 15.80 | 15.99 | 17.06 | 17.06 |
| 500 | 2.33 | 5.10 | 7.61 | 8.97 | 9.33 | 11.67 | 14.05 | 14.86 | 15.54 | 15.81 | 16.86 | 16.86 |
| 1,000 | 2.16 | 4.58 | 6.82 | 8.03 | 8.34 | 10.91 | 13.02 | 13.82 | 14.65 | 15.08 | 16.08 | 16.08 |
| 2,000 | 1.95 | 4.04 | 5.92 | 6.97 | 7.25 | 9.96 | 11.78 | 12.57 | 13.42 | 13.91 | 14.90 | 14.90 |
| 5,000 | 1.61 | 3.10 | 4.73 | 5.55 | 5.77 | 8.00 | 9.44 | 10.21 | 10.76 | 11.28 | 12.14 | 12.14 |
| 10,000 | 1.22 | 2.24 | 3.58 | 4.21 | 4.39 | 6.04 | 7.12 | 7.90 | 8.15 | 8.68 | 9.35 | 9.35 |
| 20,000 | 0.71 | 1.51 | 2.37 | 2.75 | 3.09 | 4.18 | 4.94 | 5.66 | 5.84 | 6.21 | 6.64 | 6.64 |

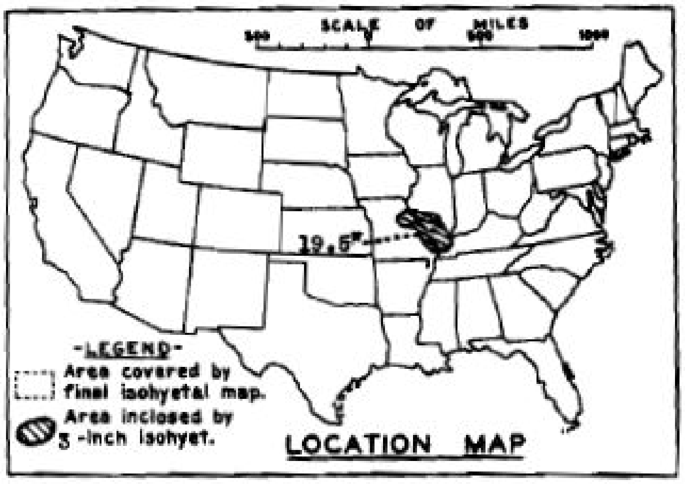



SPAS 1433 Storm Center Mass Curve Zone 1
August 13 (0700UTC) to August 17 (0600UTC), 1946
Lat: 38.6708 Lon: -90.0042
Incremental
Accumulated
19.07
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
20
40
60
80
0
5
10
15
20


Total 96-hour Precipitation (Inches)
August 13, 1946 0700 UTC - August 16, 1946 0600 UTC
SPAS #1433
Precipitation (Inches)
0.10 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
14.01 - 15.00
15.01 - 16.00
16.01 - 17.00
17.01 - 18.00
18.01 - 19.00
19.01 - 20.00
Stations
Daily
Hourly
Hourly Estimated
Supplemental
Miles
0 15 30 60
N
WJM 10/27/2014

DEPARTMENT OF THE ARMY | CORPS OF ENGINEERS

# STORM STUDIES – PERTINENT DATA SHEET




Storm of 12-16 August 1946
Assignment MR 7-2B
Location Mo., Ill., Ind. & Ky.
Study Prepared by: Upper Mississippi Valley Division St. Louis District

Part I Reviewed by H. M. Sec. of Weather Bureau, 3/8/49
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 3/20/50
Remarks: Center near Collinsville, Ill.
Dewpt. 74° Ref. Pt. 225 S
Grid F-12

## DATA AND COMPUTATIONS COMPILED

### PART I

Preliminary isohyetal map, in 1 sheet, scale 1: 1,000,000

Precipitation data and mass curves: (Number of Sheets)

| | |
|---|---|
| Form 5001-C (Hourly precip. data) | 58 |
| Form 5001-B (24-hour " " ) | — |
| Form 5001-D ( " " " " ) | 16 |
| Miscl. precip. records, meteorological data, etc. | 15 |
| Form 5002 (Mass rainfall curves) | 44 |

### PART II

Final isohyetal maps, in 1 sheet, scale 1: 1,000,000

Data and computation sheets:

| | |
|---|---|
| Form S-10 (Data from mass rainfall curves) | 5 |
| Form S-11 (Depth-area data from isohyetal map) | 3 |
| Form S-12 (Maximum depth-duration data) | 7 |
| Maximum duration-depth-area curves | 1 |
| Data relating to periods of maximum rainfall | 2 |

### MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

| Area in Sq. Mi. | Duration of Rainfall in Hours | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 12 | 18 | 24 | 30 | 36 | 48 | 60 | 72 | 96 | 114 |
| Max. Sta. | 6.4 | 10.2 | 12.6 | 12.7 | 14.1 | 18.0 | 18.1 | 18.6 | 18.7 | 19.4 | 19.5 |
| 10 | 6.0 | 9.8 | 12.1 | 12.1 | 13.7 | 17.5 | 17.6 | 18.3 | 18.3 | 18.9 | 19.0 |
| 100 | 5.6 | 8.8 | 10.9 | 11.1 | 13.2 | 16.6 | 16.7 | 17.5 | 17.6 | 18.0 | 18.1 |
| 200 | 5.4 | 8.3 | 10.5 | 10.6 | 13.0 | 16.2 | 16.3 | 17.2 | 17.3 | 17.7 | 17.8 |
| 500 | 5.2 | 7.7 | 9.7 | 9.9 | 12.8 | 15.5 | 15.6 | 16.7 | 16.9 | 17.1 | 17.2 |
| 1,000 | 4.9 | 7.0 | 8.9 | 9.0 | 12.6 | 14.7 | 14.8 | 15.9 | 16.0 | 16.3 | 16.4 |
| 2,000 | 4.3 | 6.1 | 7.6 | 7.8 | 11.2 | 13.3 | 13.4 | 14.3 | 14.3 | 14.6 | 14.7 |
| 5,000 | 3.3 | 4.8 | 5.9 | 6.0 | 8.6 | 10.4 | 10.6 | 11.3 | 11.4 | 11.6 | 11.8 |
| 10,000 | 2.4 | 3.7 | 4.5 | 4.6 | 6.6 | 8.0 | 8.2 | 8.7 | 8.8 | 9.0 | 9.1 |
| 20,000 | 1.5 | 2.5 | 3.1 | 3.2 | 4.5 | 5.6 | 5.8 | 6.0 | 6.1 | 6.3 | 6.5 |
| 20,400 | 1.5 | 2.5 | 3.1 | 3.2 | 4.5 | 5.5 | 5.7 | 6.0 | 6.1 | 6.3 | 6.4 |

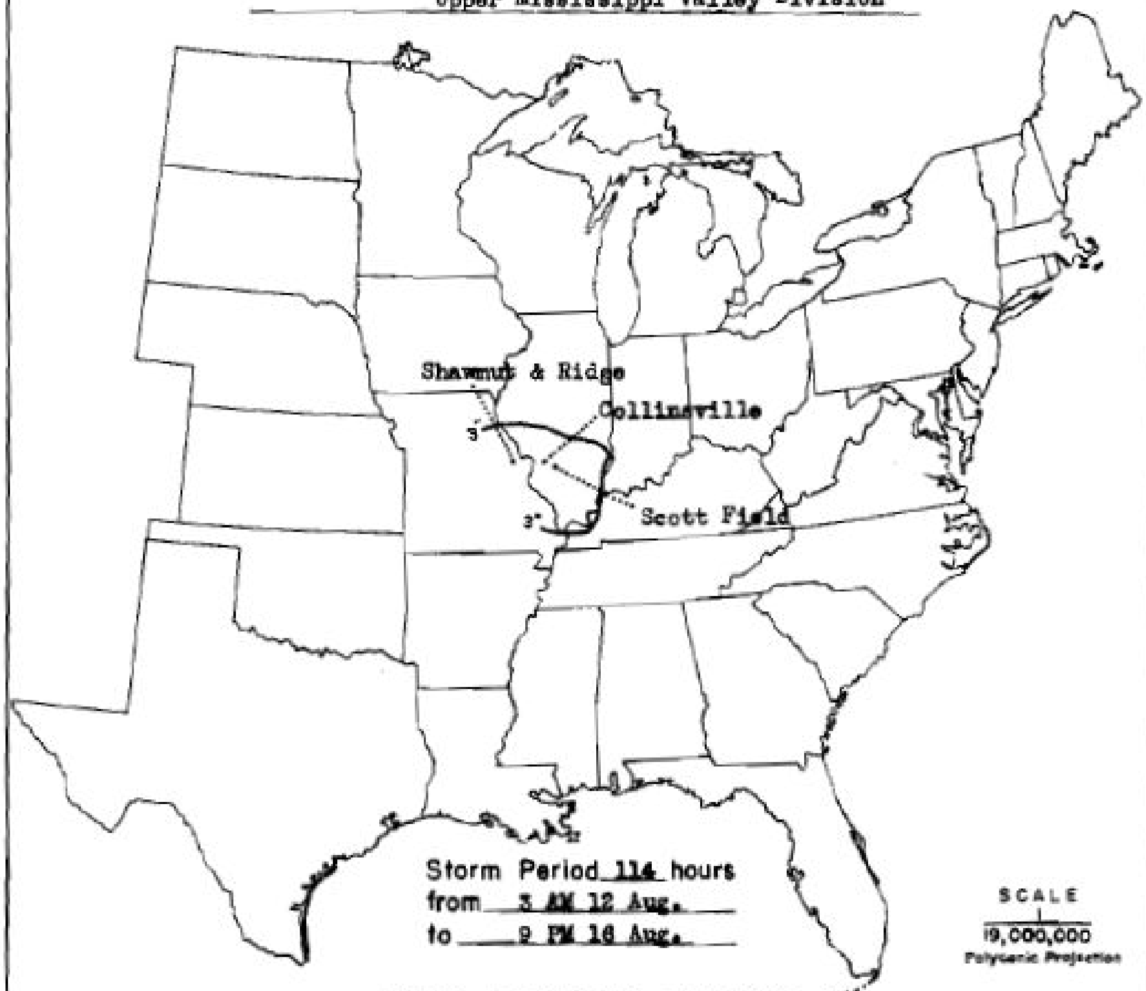
Form S-2

DEPARTMENT OF THE ARMY — CORPS OF ENGINEERS

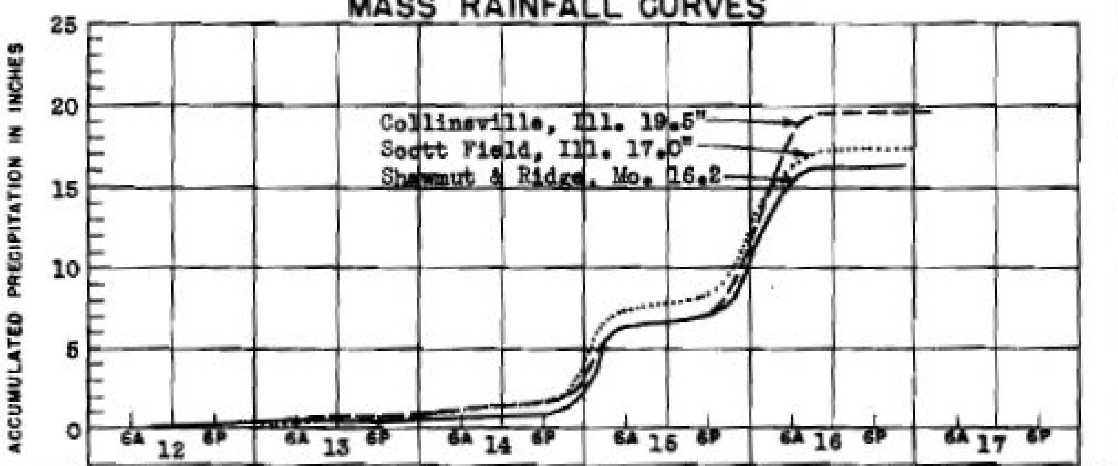
# STORM STUDIES - ISOHYETAL MAP

Storm of 12-16 August 1946 Assignment MR 7-2B

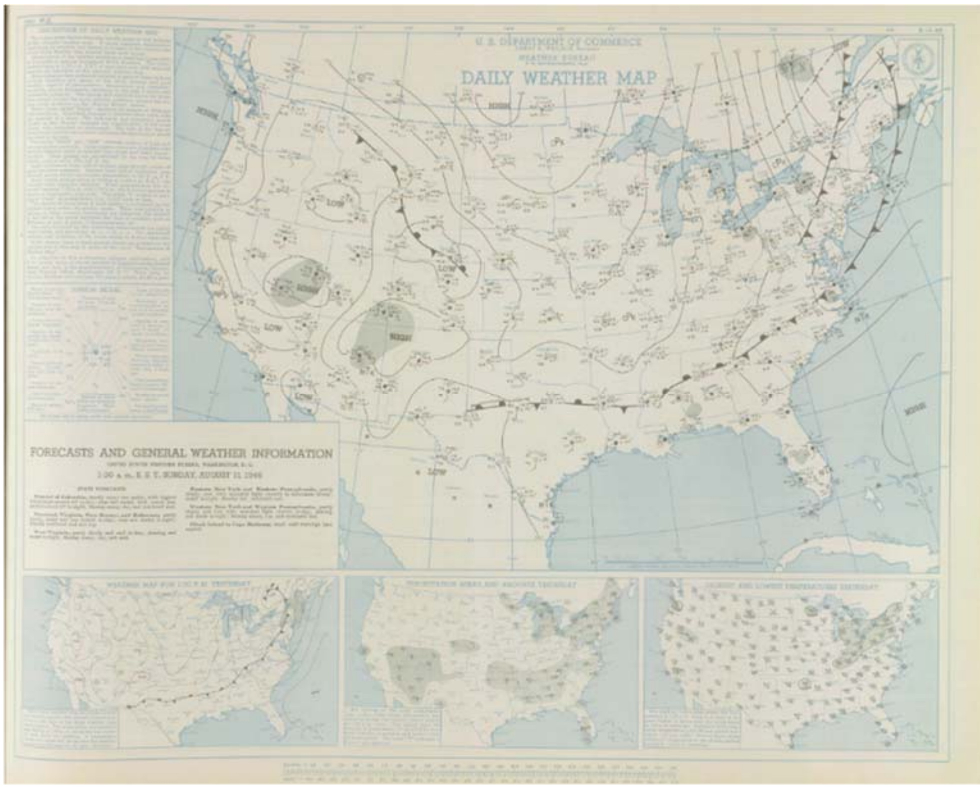
Study Prepared by: St. Louis, Mo. District
Upper Mississippi Valley Division

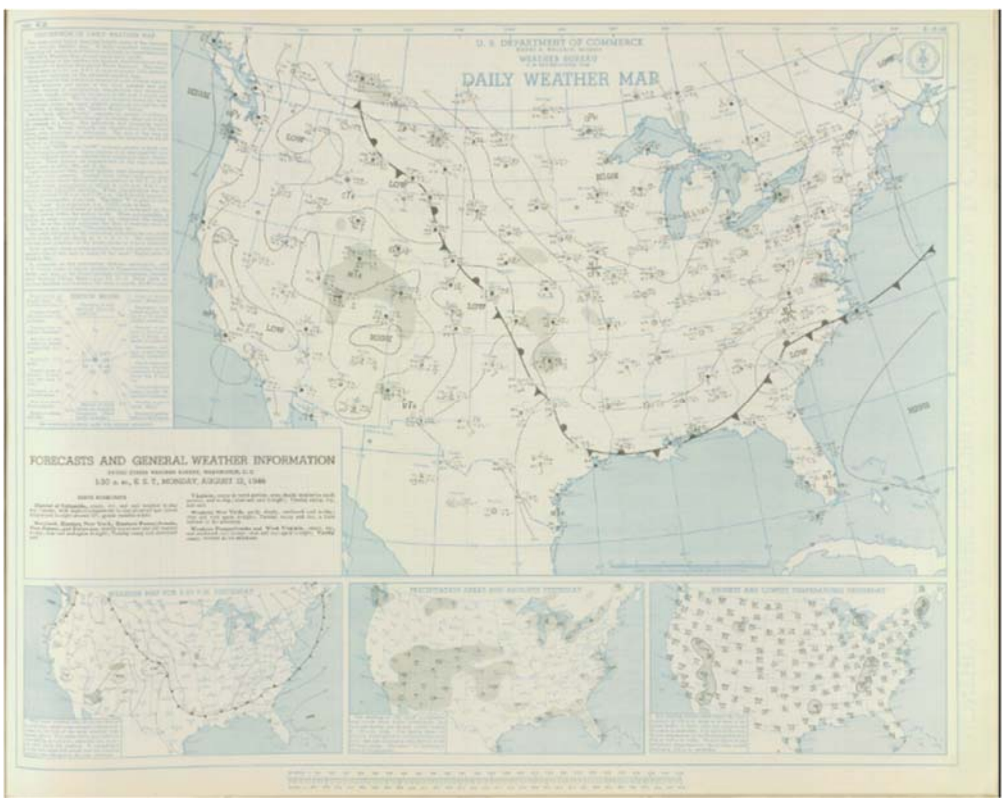


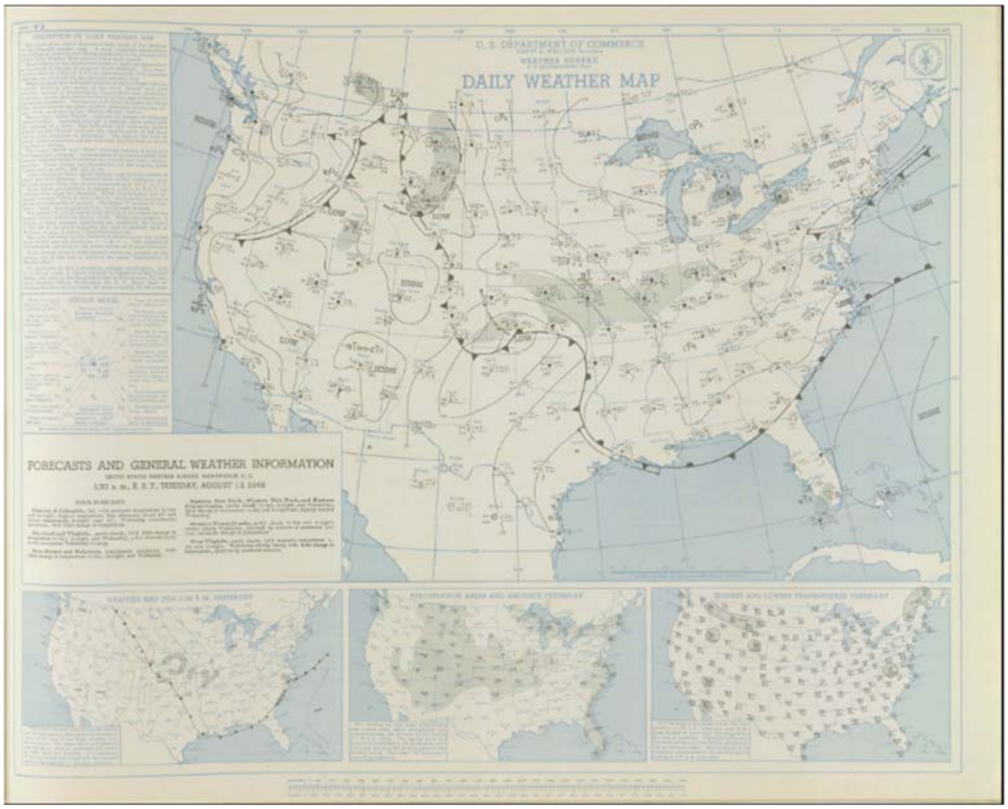

## MASS RAINFALL CURVES

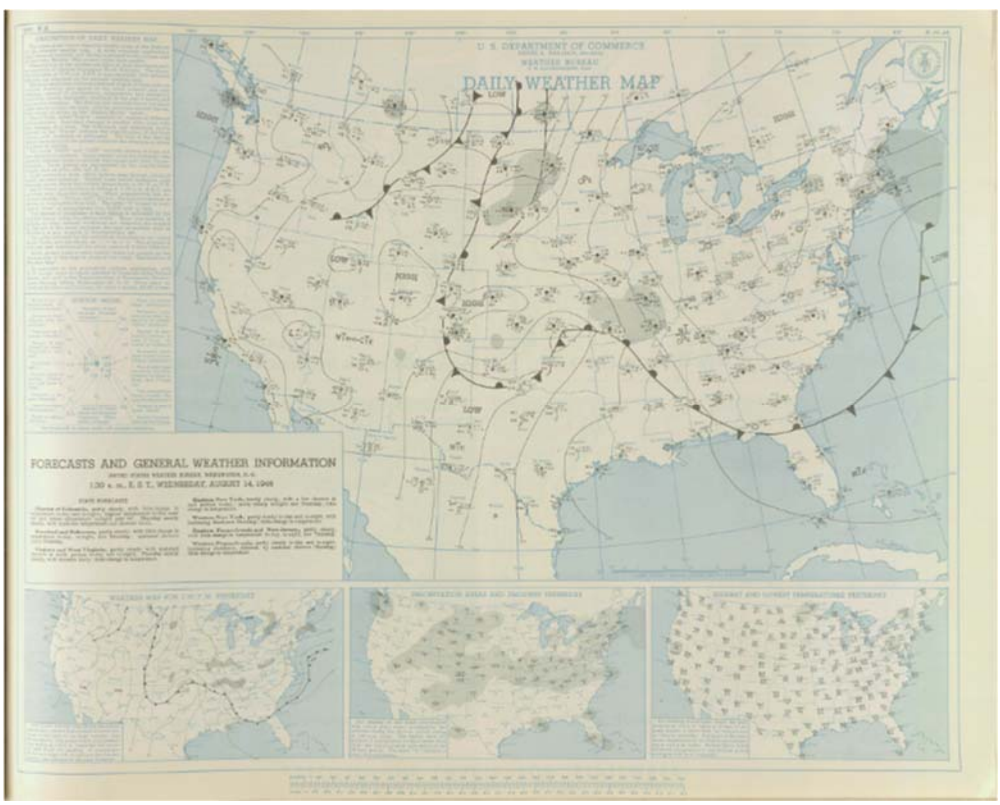


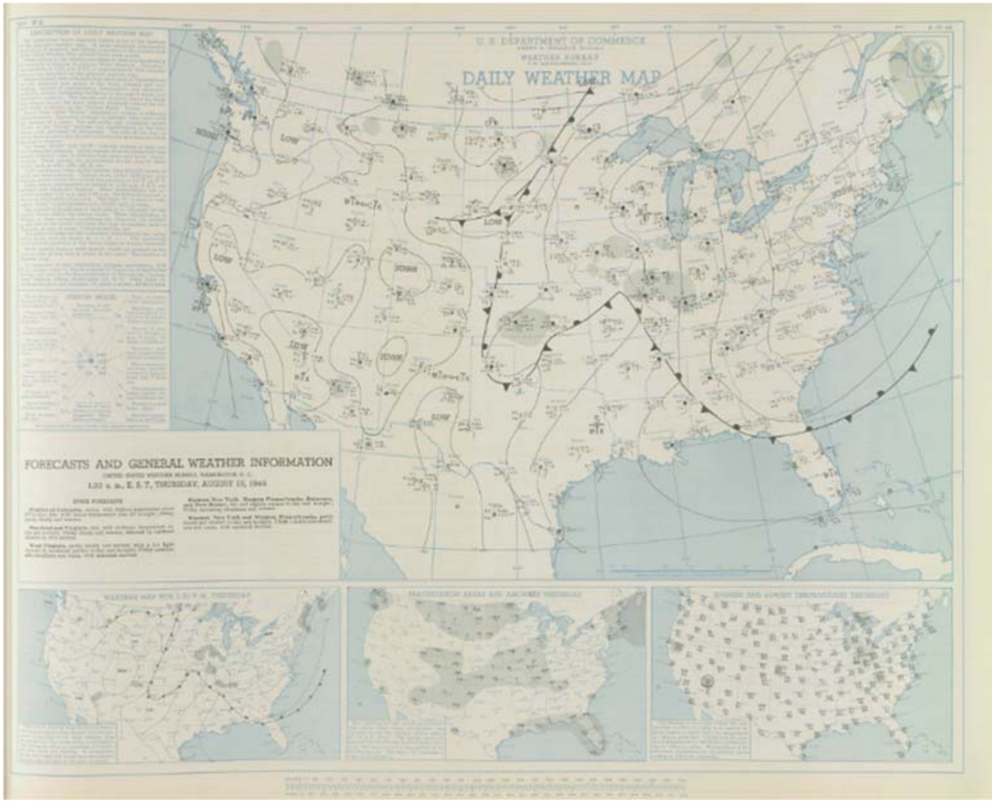

FORM 5-3E

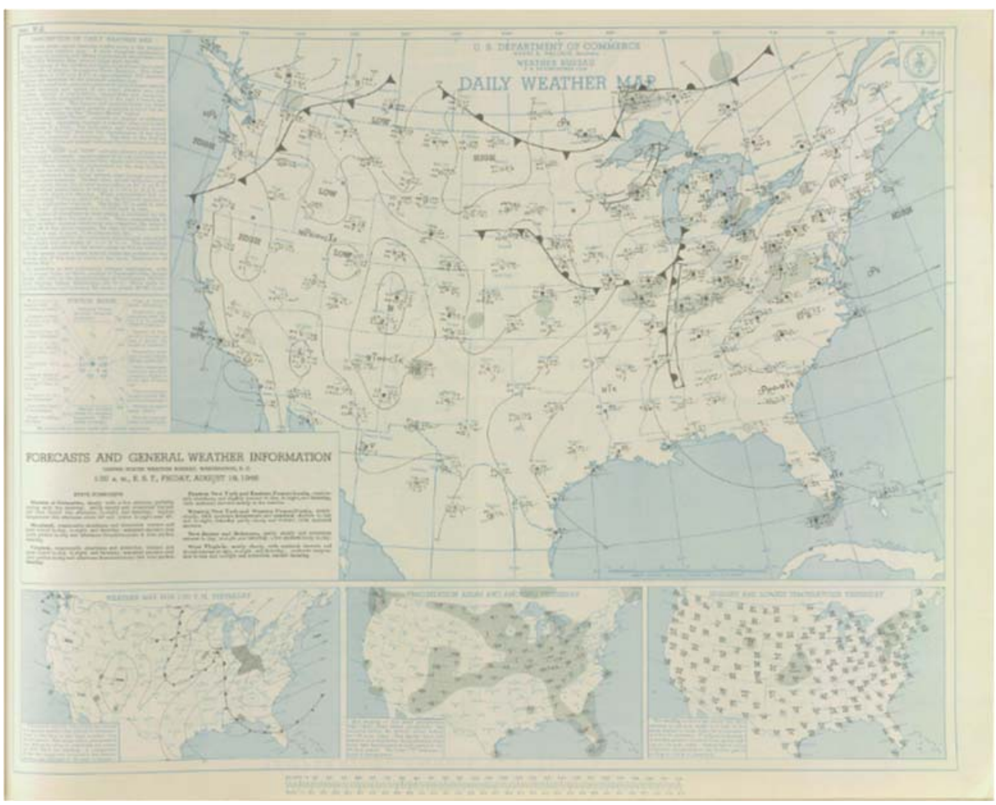

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION
LOW
HIGH


U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION
LOW
HIGH

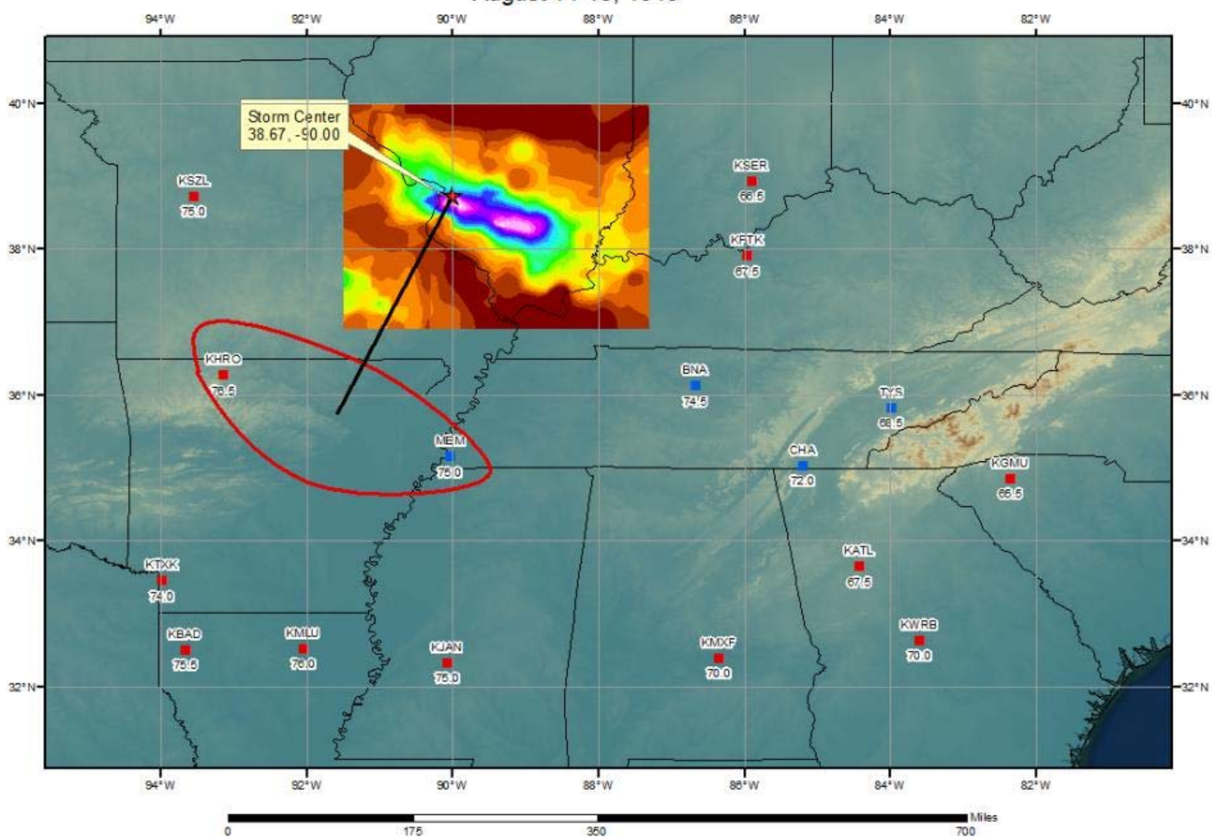

U. S. DEPARTMENT OF COMMERCE
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION
1:30 a. m., E. S. T., TUESDAY, AUGUST 13, 1946


U. S. DEPARTMENT OF COMMERCE
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION
1:30 a. m., E. S. T., WEDNESDAY, AUGUST 14, 1946


U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION

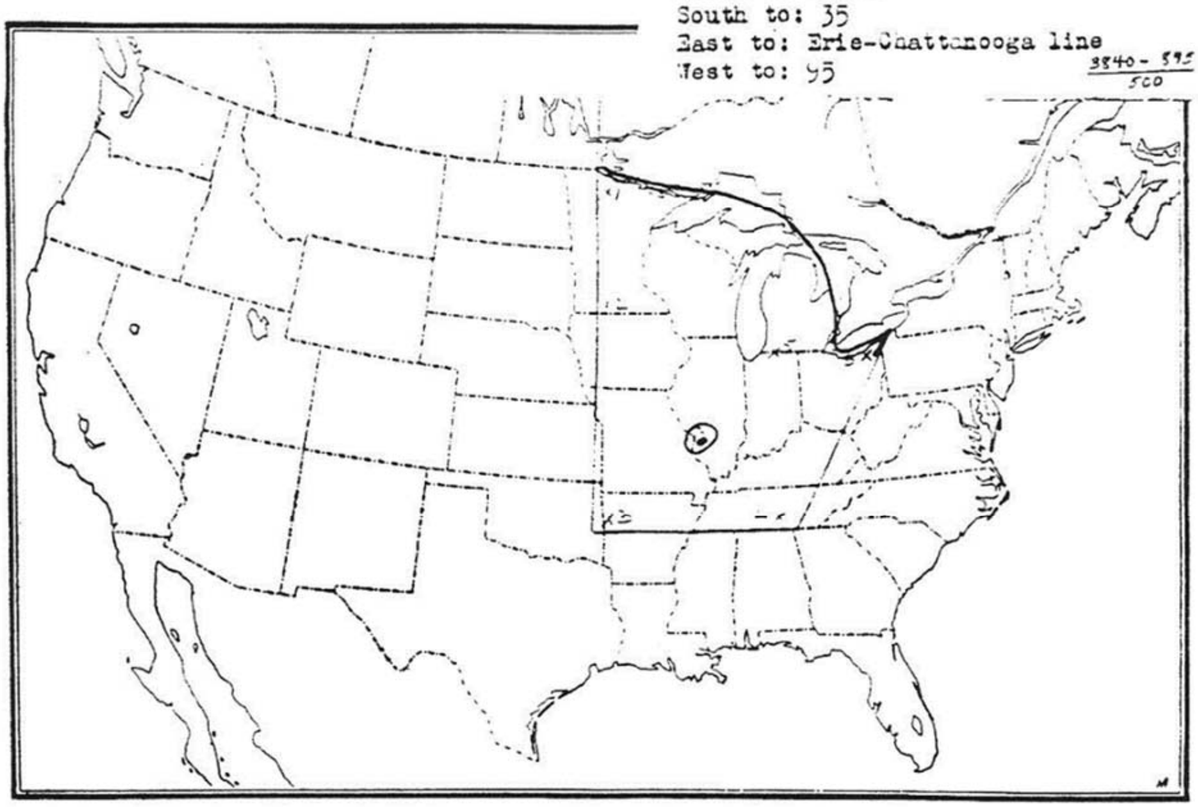

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION

**SPAS 1433 Collinsville, IL Storm Analysis**
August 14-15, 1946



MR 7-2B..Aug. 12-16,1946..Collinsvil[illegible]
12-hr. rTd 74..225 S..to 78, 21%
North to border
South to: 35
East to: Erie-Chattanooga line
West to: 95

3840 - 595 / 500



# Storm Precipitation Analysis System (SPAS) For Storm #1583_1 SPAS Analysis

**General Storm Location**: Kansas, Oklahoma, Nebraska, Colorado, Iowa, Missouri, Arkansas

**Storm Dates**: July 9-13, 1951

**Event**: Hurricane Georges

**DAD Zone 1**

**Latitude**: 38.65

**Longitude**: -96.62

**Max. Grid Rainfall Amount**: 18.56”

**Max. Observed Rainfall Amount**: 18.50

**Number of Stations**: 985

**SPAS Version**: 10.0

**Base Map Used:** conus_prism_ppt_in_1971_2000_07

**Spatial resolution:** 00:00:30 (0.3 sq. miles)

**Radar Included:** No

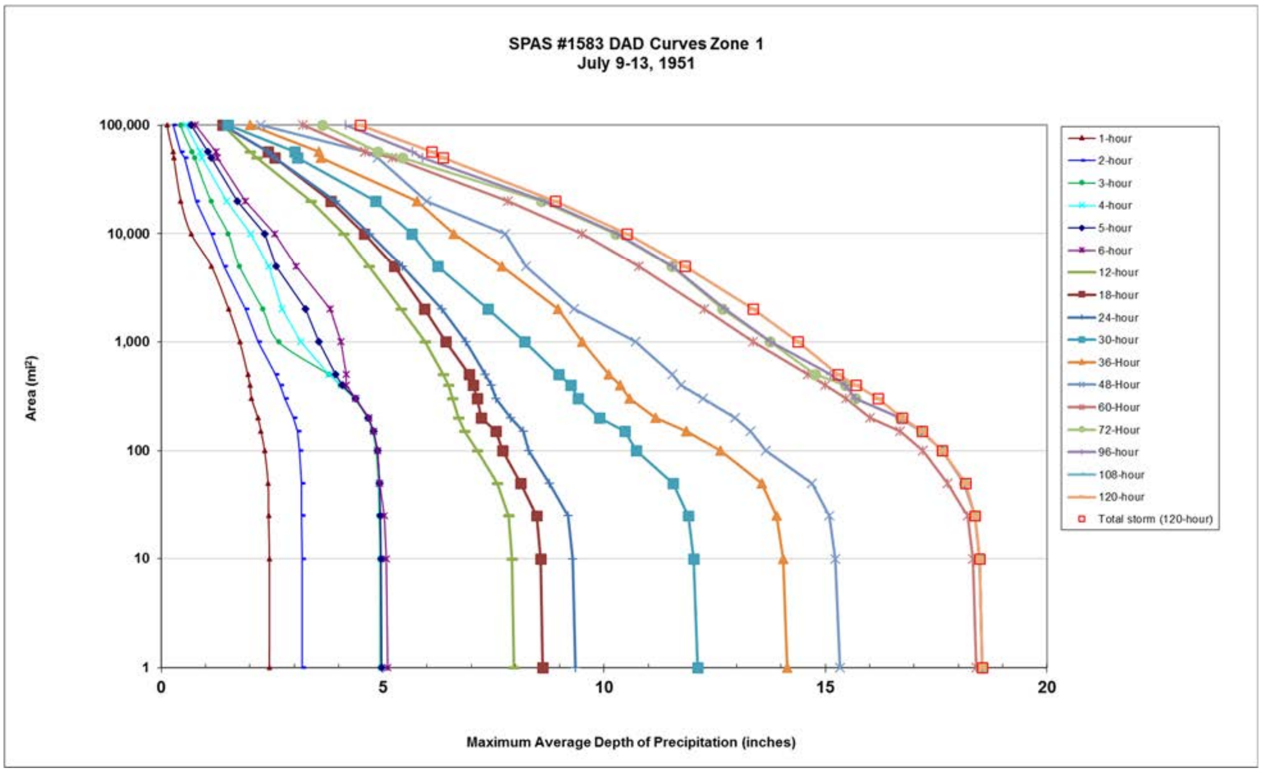
**Depth-Area-Duration (DAD) analysis:** Yes

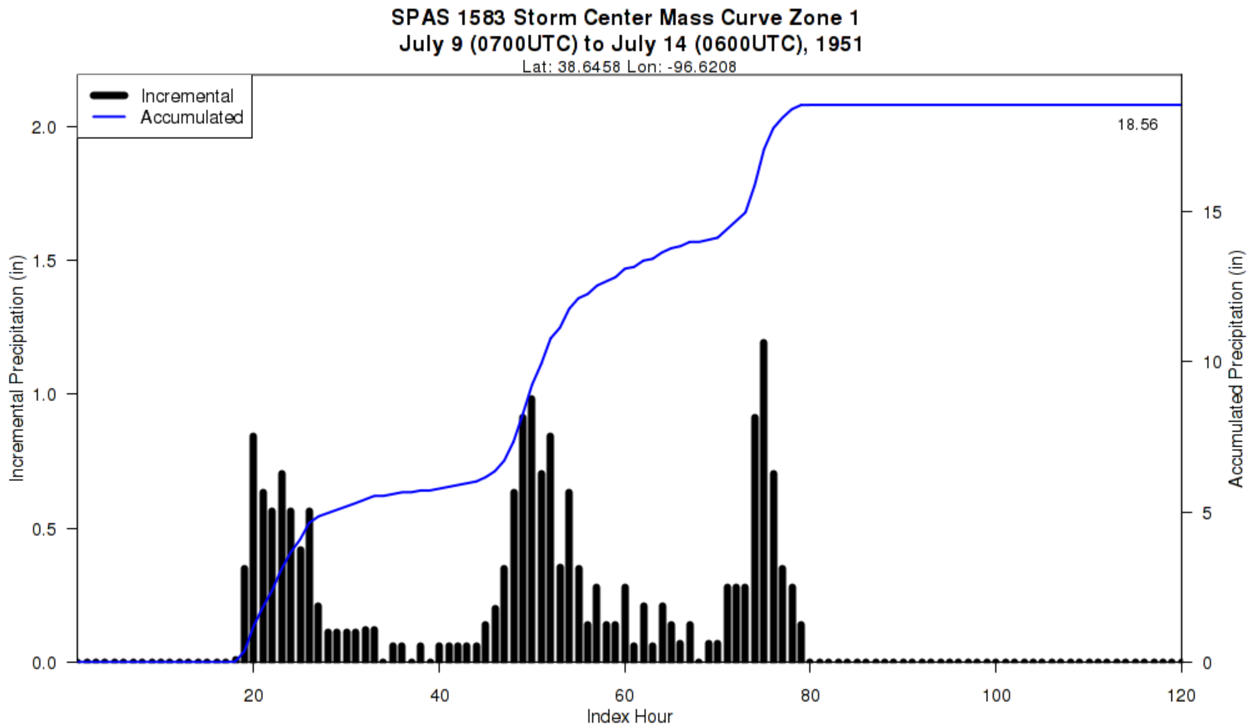
**Reliability of results:** This analysis was based on hourly data (H), hourly pseudo data (HP), daily data (D) and supplemental data (S). We have a high degree of confidence in the station based storm total results. The spatial pattern is dependent on basemap, and the timing is based on hourly and hourly pseudo stations.

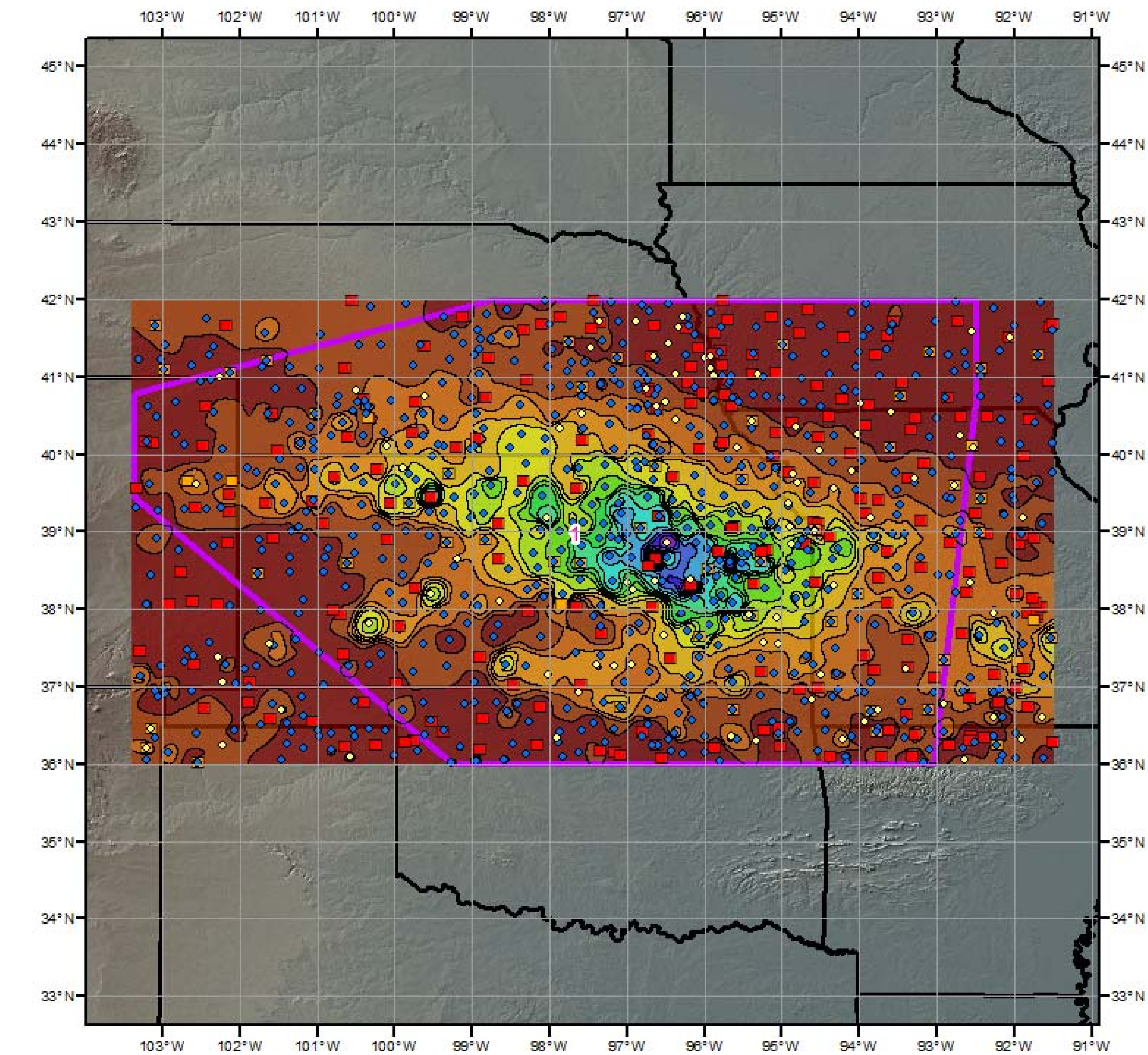
**Storm 1583 Zone 1 - Jul. 9 (0700 UTC) - Jul. 14 (0600 UTC), 1951**

**MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)**

| | Duration (hours) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **areasqmi** | 1-hr | 2-hr | 3-hr | 4-hr | 5-hr | 6-hr | 12-hr | 18-hr | 24-hr | 30-hr | 36-hr | 48-hr | 60-hr | 72-hr | 96-hr | 108-hr | 120-hr | Total |
| **0.3** | 2.44 | 3.18 | 4.95 | 4.97 | 4.97 | 5.11 | 7.97 | 8.62 | 9.35 | 12.11 | 14.14 | 15.33 | 18.41 | 18.56 | 18.56 | 18.56 | 18.56 | 18.56 |
| **1** | 2.44 | 3.18 | 4.94 | 4.97 | 4.97 | 5.11 | 7.97 | 8.62 | 9.35 | 12.11 | 14.14 | 15.33 | 18.40 | 18.55 | 18.55 | 18.55 | 18.55 | 18.55 |
| **10** | 2.44 | 3.18 | 4.94 | 4.96 | 4.96 | 5.08 | 7.92 | 8.57 | 9.29 | 12.03 | 14.05 | 15.23 | 18.33 | 18.48 | 18.48 | 18.48 | 18.48 | 18.48 |
| **25** | 2.42 | 3.17 | 4.92 | 4.95 | 4.95 | 5.03 | 7.84 | 8.48 | 9.19 | 11.91 | 13.90 | 15.08 | 18.21 | 18.37 | 18.37 | 18.37 | 18.37 | 18.37 |
| **50** | 2.41 | 3.16 | 4.90 | 4.92 | 4.93 | 4.93 | 7.59 | 8.11 | 8.77 | 11.56 | 13.57 | 14.70 | 17.76 | 18.14 | 18.14 | 18.16 | 18.16 | 18.16 |
| **100** | 2.33 | 3.12 | 4.85 | 4.88 | 4.88 | 4.89 | 7.14 | 7.71 | 8.30 | 10.73 | 12.62 | 13.65 | 17.20 | 17.63 | 17.63 | 17.64 | 17.64 | 17.64 |
| **150** | 2.25 | 3.07 | 4.77 | 4.79 | 4.79 | 4.80 | 6.84 | 7.55 | 8.17 | 10.47 | 11.85 | 13.31 | 16.68 | 17.17 | 17.17 | 17.18 | 17.18 | 17.18 |
| **200** | 2.18 | 2.99 | 4.65 | 4.67 | 4.67 | 4.69 | 6.71 | 7.23 | 7.89 | 9.90 | 11.17 | 12.96 | 16.00 | 16.68 | 16.68 | 16.73 | 16.73 | 16.73 |
| **300** | 2.04 | 2.78 | 4.36 | 4.38 | 4.38 | 4.38 | 6.58 | 7.14 | 7.55 | 9.41 | 10.57 | 12.23 | 15.47 | 15.67 | 15.67 | 16.19 | 16.19 | 16.19 |
| **400** | 2.00 | 2.68 | 4.04 | 4.07 | 4.08 | 4.17 | 6.48 | 7.04 | 7.45 | 9.25 | 10.36 | 11.74 | 15.00 | 15.45 | 15.45 | 15.69 | 15.69 | 15.69 |
| **500** | 1.95 | 2.58 | 3.79 | 3.79 | 3.93 | 4.17 | 6.37 | 6.95 | 7.31 | 8.98 | 10.11 | 11.54 | 14.60 | 14.77 | 15.12 | 15.29 | 15.29 | 15.29 |
| **1,000** | 1.77 | 2.19 | 2.65 | 3.15 | 3.55 | 4.05 | 5.95 | 6.43 | 6.87 | 8.21 | 9.51 | 10.71 | 13.37 | 13.75 | 13.76 | 14.38 | 14.38 | 14.38 |
| **2,000** | 1.52 | 1.90 | 2.29 | 2.72 | 3.25 | 3.81 | 5.42 | 5.94 | 6.34 | 7.37 | 8.96 | 9.32 | 12.26 | 12.67 | 12.73 | 13.36 | 13.36 | 13.36 |
| **5,000** | 1.13 | 1.42 | 1.76 | 2.43 | 2.59 | 3.04 | 4.69 | 5.26 | 5.45 | 6.24 | 7.69 | 8.24 | 10.79 | 11.53 | 11.54 | 11.83 | 11.83 | 11.83 |
| **10,000** | 0.67 | 1.12 | 1.51 | 2.02 | 2.33 | 2.56 | 4.11 | 4.58 | 4.71 | 5.66 | 6.61 | 7.77 | 9.51 | 10.25 | 10.31 | 10.51 | 10.51 | 10.51 |
| **20,000** | 0.44 | 0.78 | 1.12 | 1.48 | 1.72 | 1.90 | 3.37 | 3.83 | 3.93 | 4.84 | 5.78 | 5.99 | 7.83 | 8.58 | 8.66 | 8.89 | 8.90 | 8.90 |
| **50,000** | 0.28 | 0.52 | 0.75 | 0.92 | 1.12 | 1.26 | 2.15 | 2.56 | 2.56 | 3.08 | 3.60 | 4.89 | 5.21 | 5.44 | 5.89 | 6.37 | 6.37 | 6.37 |
| **57,000** | 0.26 | 0.43 | 0.69 | 0.87 | 1.05 | 1.23 | 2.01 | 2.41 | 2.41 | 3.01 | 3.56 | 4.60 | 4.60 | 4.89 | 5.67 | 6.11 | 6.11 | 6.11 |
| **100,000** | 0.13 | 0.26 | 0.43 | 0.56 | 0.68 | 0.77 | 1.38 | 1.38 | 1.38 | 1.51 | 2.00 | 2.25 | 3.20 | 3.63 | 4.16 | 4.48 | 4.49 | 4.49 |
| **200,206** | 0.09 | 0.16 | 0.23 | 0.30 | 0.38 | 0.44 | 0.79 | 0.99 | 1.06 | 1.29 | 1.53 | 1.79 | 2.20 | 2.38 | 2.66 | 2.67 | 2.68 | 2.68 |




SPAS 1583 Storm Center Mass Curve Zone 1
July 9 (0700UTC) to July 14 (0600UTC), 1951
Lat: 38.6458 Lon: -96.6208
Incremental
Accumulated
18.56
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
0
5
10
15
20
40
60
80
100
120



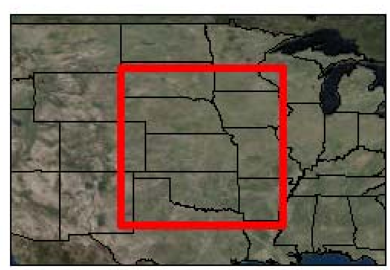

**Total Storm (120-hours) Precipitation (inches)**
**July 9-13, 1951**
**SPAS 1583 Council Grove, KS (MR 10-2)**

**Gauges**
- Daily
- Hourly
- Hourly Pseudo
- Supplemental

Miles: 0, 55, 110, 220
Kilometers: 0, 112.5, 225, 450

**Precipitation (inches)**

| | | | |
|---|---|---|---|
| 0.01 - 1.00 | 5.01 - 6.00 | 10.01 - 11.00 | 15.01 - 16.00 |
| 1.01 - 2.00 | 6.01 - 7.00 | 11.01 - 12.00 | 16.01 - 17.00 |
| 2.01 - 3.00 | 7.01 - 8.00 | 12.01 - 13.00 | 17.01 - 18.00 |
| 3.01 - 4.00 | 8.01 - 9.00 | 13.01 - 14.00 | 18.01 - 19.00 |
| 4.01 - 5.00 | 9.01 - 10.00 | 14.01 - 15.00 | |



3/9/2016

DEPARTMENT OF THE ARMY | CORPS OF ENGINEERS

# STORM STUDIES - PERTINENT DATA SHEET


Storm of 9-13 July 1951
Assignment MR 10-2
Location Kans., Nebr., Mo.
Study Prepared by:
Missouri River Division
Kansas City District Office

Part I Reviewed by H. M. Sec. of Weather Bureau, 10/29/51
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 12/10/52
Remarks: Center near Council Grove , Kans.
Dewpt. 73°F-Ref.Pt. 205 SSW
Grid F-16

## DATA AND COMPUTATIONS COMPILED

### PART I

Preliminary isohyetal map, in 1 sheet , scale 1: 1,000,000

Precipitation data and mass curves: (Number of Sheets)

- Form 5001-C (Hourly precip. data) ---- 78
- Form 5001-B (24-hour " " ) ---- –
- Form 5001-D ( " " " " ) ---- 2
- Miscl. precip. records, meteorological data, etc. ---- 151
- Form 5002 (Mass rainfall curves) ---- 61

### PART II

Final isohyetal maps, in 1 sheet , scale 1: 1,000,000

Data and computation sheets:

- Form S-10 (Data from mass rainfall curves) ---- 7
- Form S-11 (Depth-area data from isohyetal map) ---- 2
- Form S-12 (Maximum depth-duration data) ---- 11
- Maximum duration-depth-area curves ---- 1
- Data relating to periods of maximum rainfall ---- 6

### MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

| Area in Sq. Mi. | Duration of Rainfall in Hours | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 12 | 18 | 24 | 30 | 36 | 48 | 60 | 72 | 96 | 108 |
| Max. Station | 5.8 | 7.5 | 8.2 | 9.3 | 13.1 | 13.5 | 14.4 | 17.9 | 18.5 | 18.5 | 18.5 |
| 10 | 5.3 | 7.0 | 7.9 | 8.6 | 11.8 | 13.1 | 14.3 | 17.2 | 18.2 | 18.2 | 18.2 |
| 100 | 4.7 | 6.4 | 7.4 | 7.9 | 10.6 | 12.4 | 13.8 | 16.3 | 17.5 | 17.5 | 17.5 |
| 200 | 4.6 | 6.2 | 7.2 | 7.5 | 10.2 | 12.0 | 13.3 | 15.9 | 17.0 | 17.0 | 17.0 |
| 500 | 4.3 | 5.8 | 6.7 | 7.0 | 9.5 | 11.3 | 12.4 | 15.0 | 16.2 | 16.2 | 16.2 |
| 1,000 | 4.0 | 5.5 | 6.3 | 6.6 | 9.0 | 10.5 | 11.5 | 14.2 | 15.5 | 15.5 | 15.5 |
| 2,000 | 3.8 | 5.1 | 5.9 | 6.2 | 8.3 | 9.6 | 10.5 | 13.1 | 14.6 | 14.6 | 14.6 |
| 5,000 | 3.4 | 4.5 | 5.1 | 5.4 | 7.2 | 8.4 | 9.3 | 11.7 | 13.0 | 13.1 | 13.1 |
| 10,000 | 2.9 | 3.9 | 4.4 | 4.8 | 6.2 | 7.3 | 8.2 | 10.4 | 11.4 | 11.5 | 11.5 |
| 20,000 | 2.4 | 3.2 | 3.7 | 4.1 | 5.1 | 6.1 | 6.9 | 8.6 | 9.4 | 9.6 | 9.6 |
| 50,000 | 1.3 | 2.0 | 2.5 | 2.8 | 3.4 | 4.0 | 4.7 | 5.8 | 6.3 | 6.5 | 6.5 |
| 57,000 | 1.1 | 1.7 | 2.3 | 2.5 | 3.0 | 3.8 | 4.4 | 5.4 | 5.9 | 6.0 | 6.0 |

Form S-2

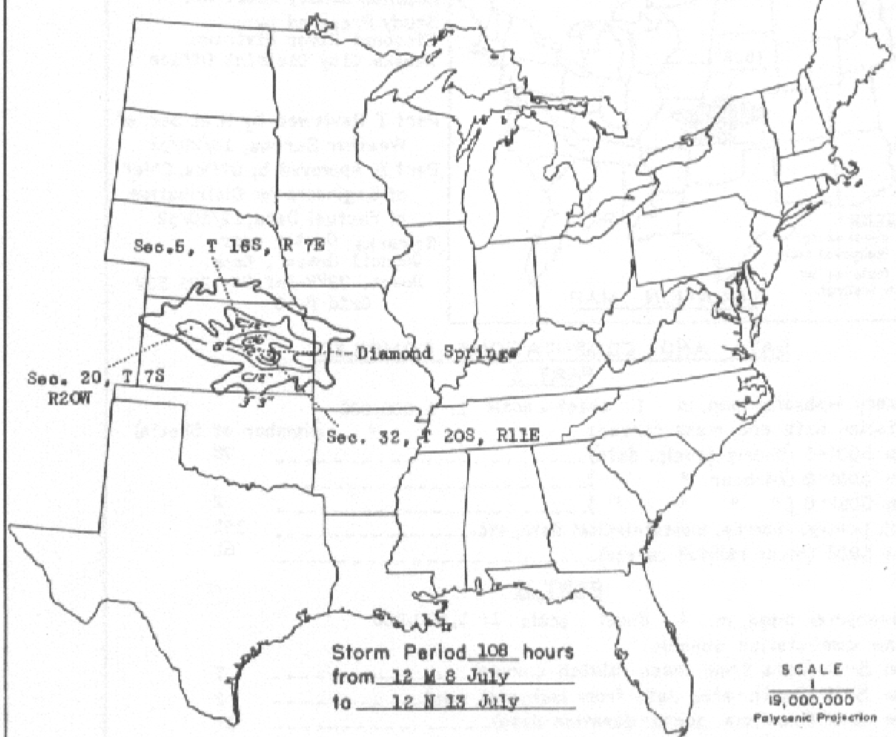
DEPARTMENT OF THE ARMY | CORPS OF ENGINEERS

# STORM STUDIES – ISOHYETAL MAP

Storm of 9-13 July 1951 Assignment MR 10-2

Study Prepared by: Kansas City, Mo. District

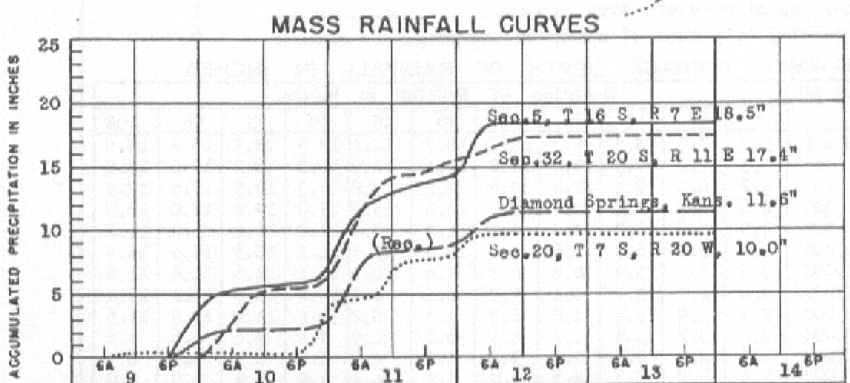
Missouri River Division



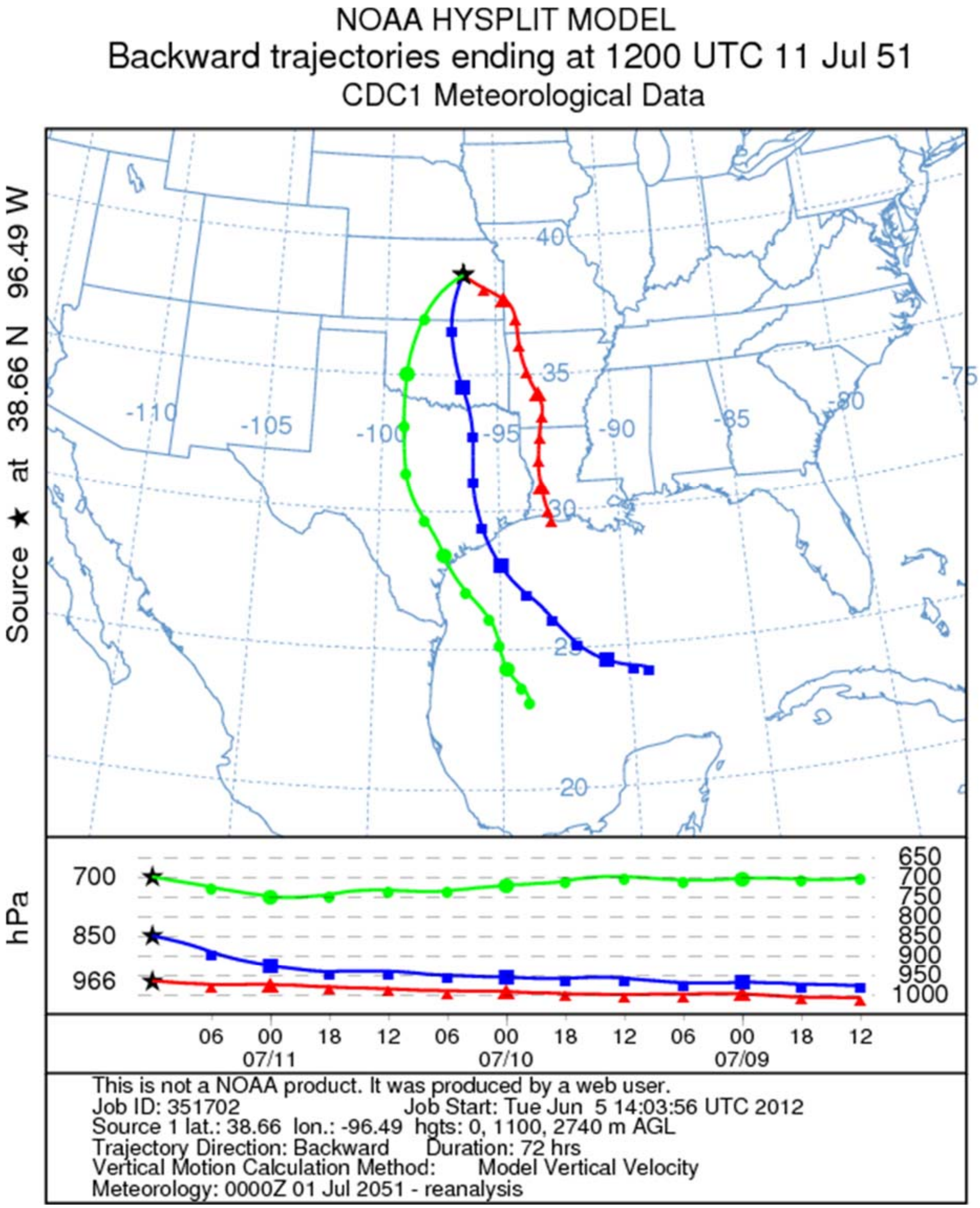

Storm Period 108 hours
from 12 M 8 July
to 12 N 13 July

SCALE 1/19,000,000
Polyconic Projection

## MASS RAINFALL CURVES

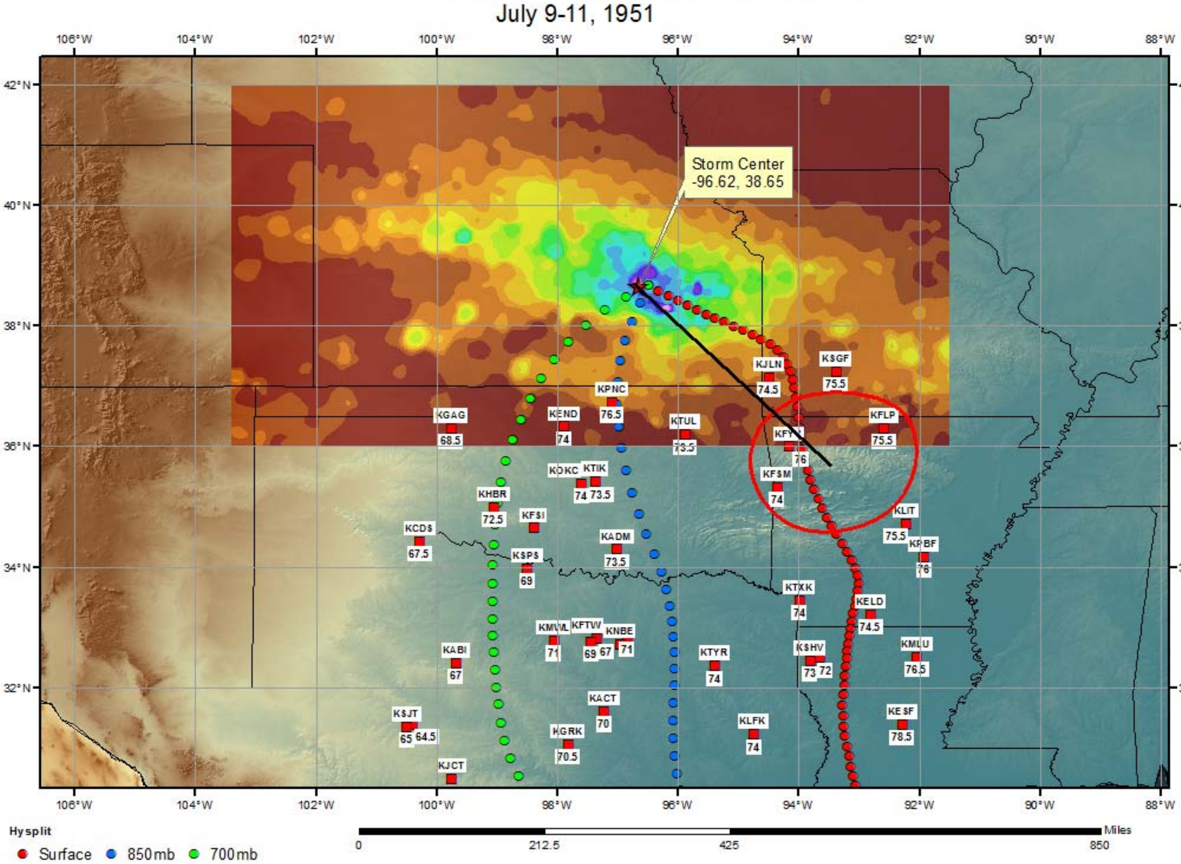



FORM 5-3E


NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 11 Jul 51
CDC1 Meteorological Data
Source ★ at 38.66 N 96.49 W
40
35
30
25
20
-110
-105
-100
-95
-90
-85
-80
-75
hPa
700
850
966
650
700
750
800
850
900
950
1000
06
00
18
12
06
00
18
12
06
00
18
12
07/11
07/10
07/09
This is not a NOAA product. It was produced by a web user.
Job ID: 351702 Job Start: Tue Jun 5 14:03:56 UTC 2012
Source 1 lat.: 38.66 lon.: -96.49 hgts: 0, 1100, 2740 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Jul 2051 - reanalysis

**SPAS 1583 Council Grove (MR 10-2) Storm Analysis**

July 9-11, 1951



# Storm Precipitation Analysis System (SPAS) For Storm #1527_1 SPAS Analysis

**General Storm Location**: Ida Grove, IA

**Storm Dates**: August 28-31, 1962

**Event**: Synoptic

**DAD Zone 1**

**Latitude**: 42.3625

**Longitude**: -95.4958

**Max. Grid/Radar Rainfall Amount**: 12.67”

**Max. Observed Rainfall Amount**: 12.05”

**Number of Stations**: 462

**SPAS Version**: 10.0

**Base Map Used:** Blend_sm – EPRI storm 19 isoheytal pattern (20%) and us_ppt_1962_08_in_sum (80%)

**Spatial resolution:** 30 seconds

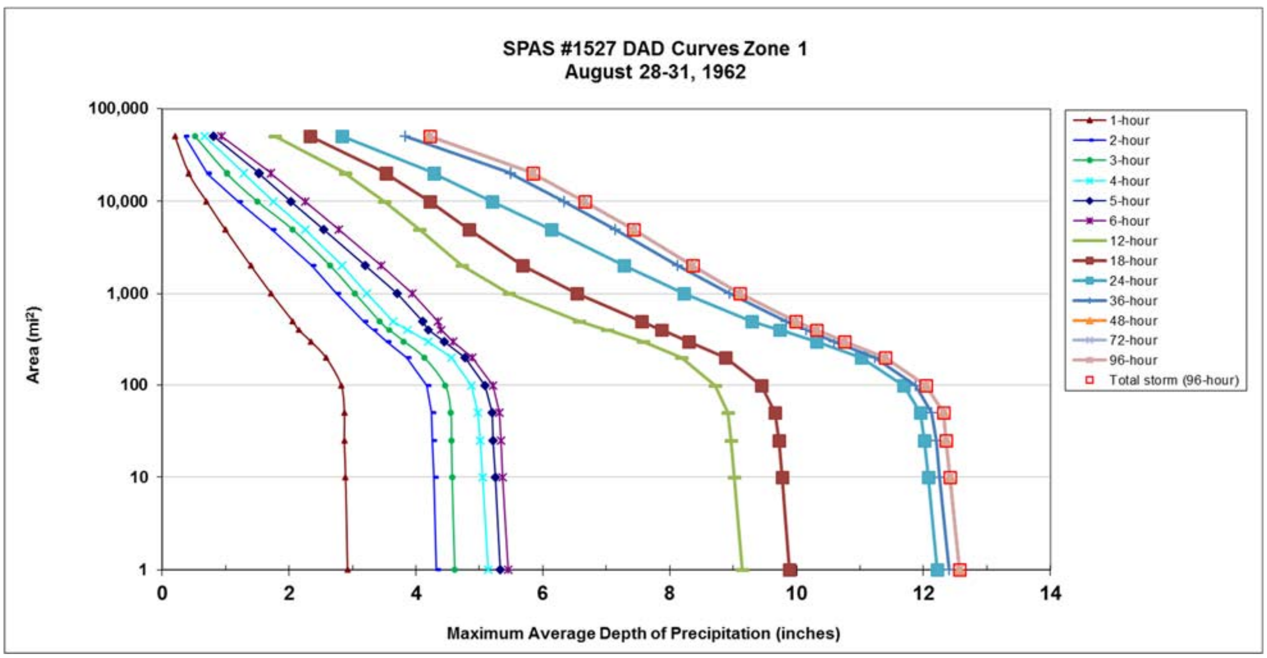
**Radar Included:** No

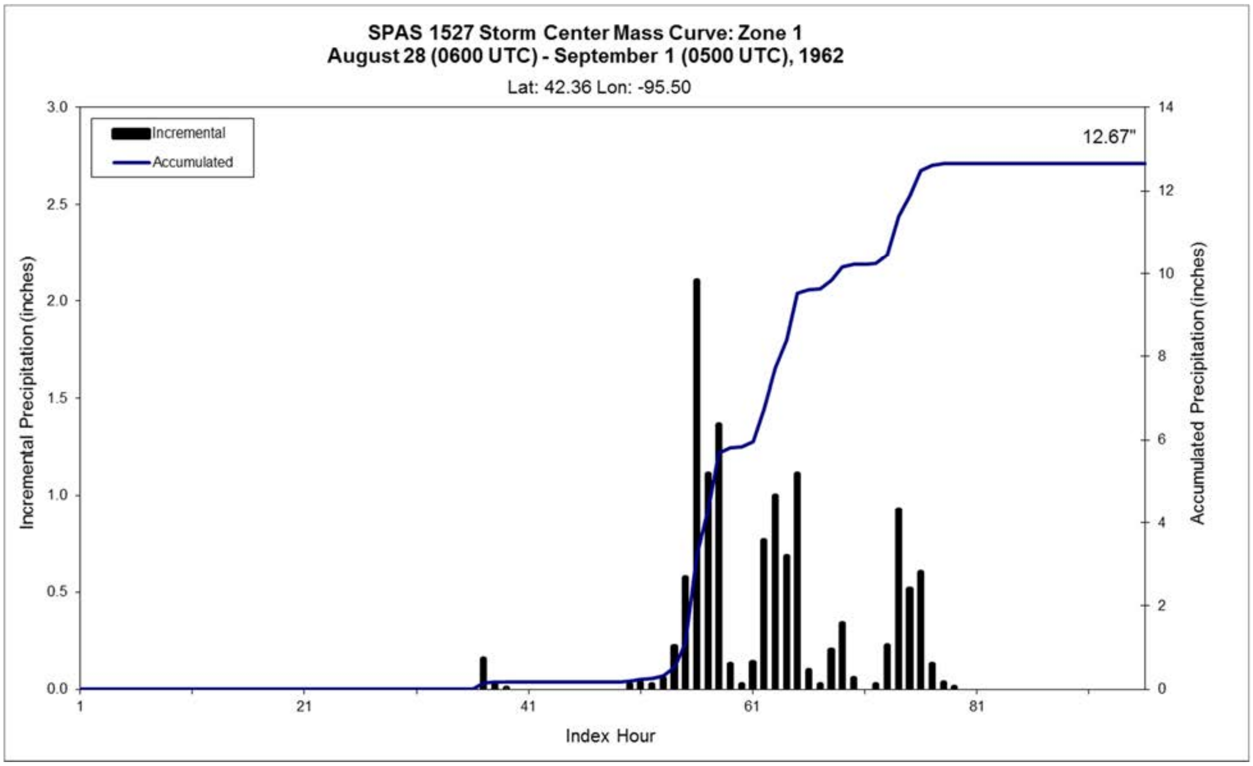
**Depth-Area-Duration (DAD) analysis**: Yes

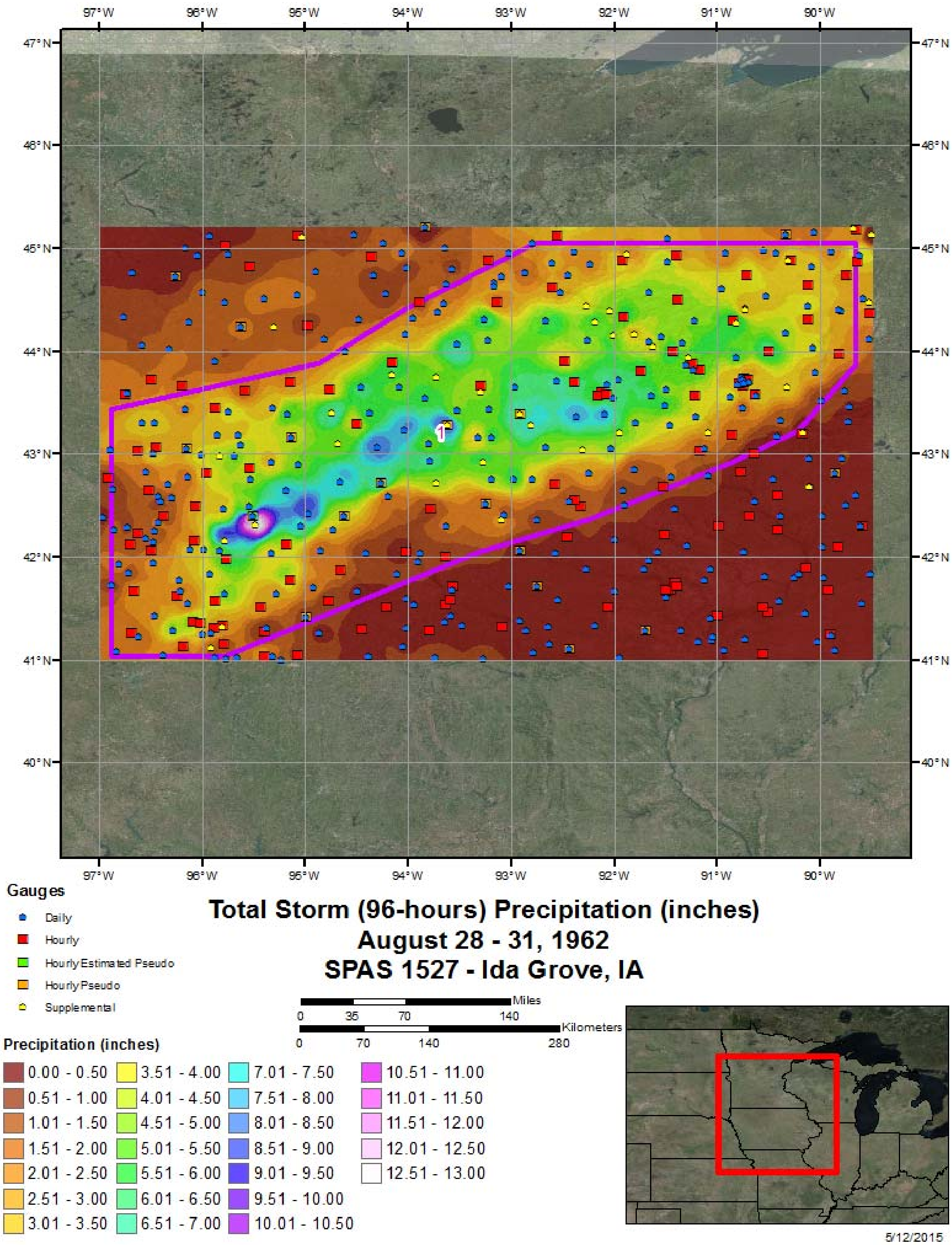
**Reliability of Results:**

This storm was originally analyzed as part of the Electric Power Research Institute (EPRI) Probable Maximum Precipitation Study (EPRI Storm 19). This analysis was based on an abundance of hourly data, daily data and supplemental station data. We have a good degree of confidence for the station based storm total results. The spatial pattern is dependent on the basemap, a blend between the EPRI storm isohyetal pattern and the PRISM August 1962 precipitation climatology (us_ppt_1962_08). There is a high degree of confidence with the timing based on the several hourly and hourly pseudo stations. Some daily stations were moved to supplemental due to timing issues. Additional details can be found in the “read_me_1527.txt” file. The Ida Grove 5 NW hourly station had missing data from August 30, 1900 CST to August 31, 0700 CST, so an estimated pseudo (HEP) station was created. The values not missing in the original station are comparable (although a little lower in magnitude) to the new HEP station.

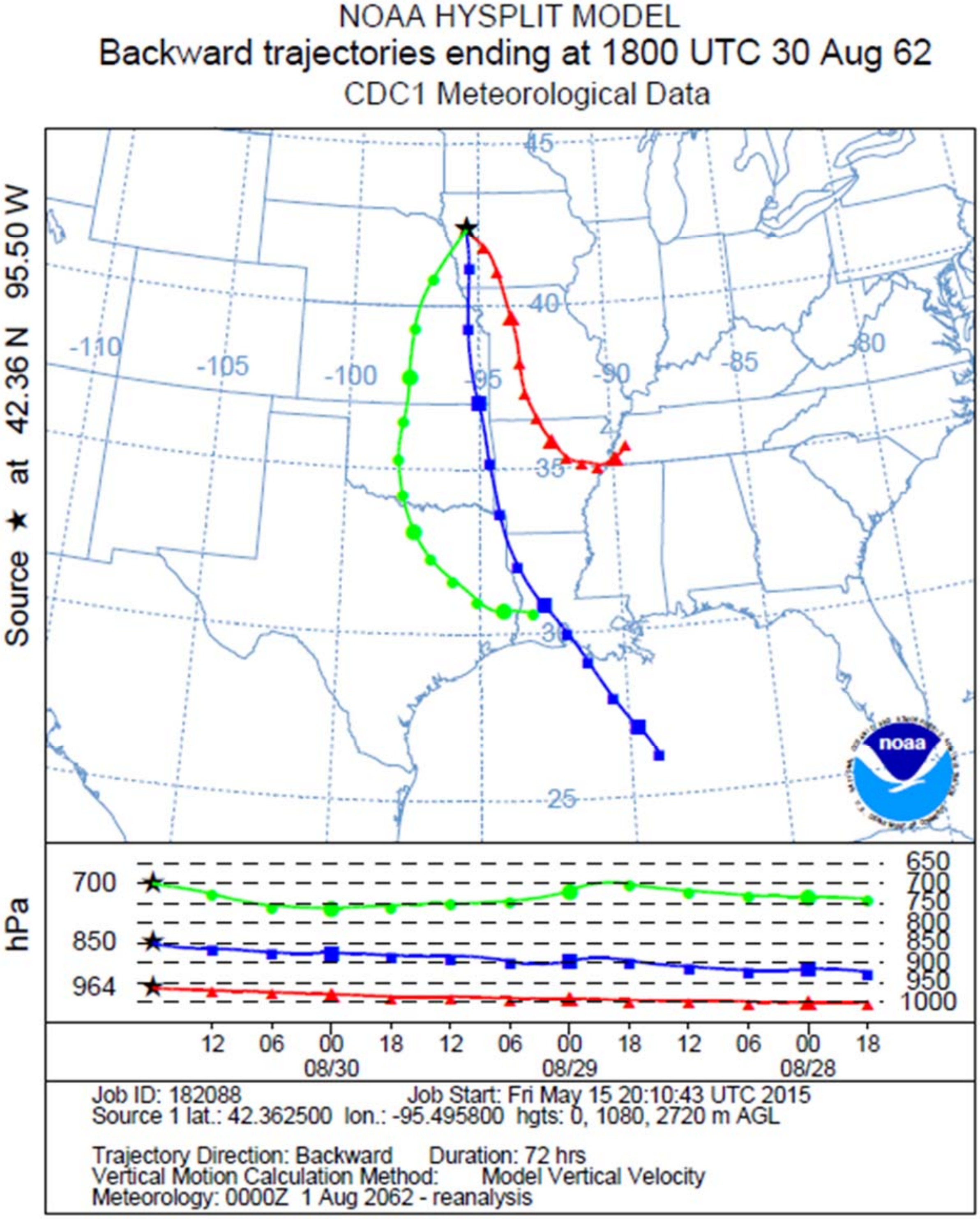
| Storm 1527 Zone 1 - Aug. 28 (0600 UTC) - Sep. 1 (0500 UTC), 1962 | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | | | |
| | Duration (hours) | | | | | | | | | | | | | |
| **areasqmi** | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | 96 | Total |
| **0.4** | 2.93 | 4.33 | 4.62 | 5.15 | 5.36 | 5.48 | 9.18 | 9.94 | 12.28 | 12.46 | 12.63 | 12.63 | 12.63 | 12.63 |
| **1** | 2.92 | 4.32 | 4.61 | 5.14 | 5.33 | 5.45 | 9.14 | 9.89 | 12.22 | 12.40 | 12.57 | 12.57 | 12.57 | 12.57 |
| **10** | 2.89 | 4.28 | 4.57 | 5.05 | 5.25 | 5.37 | 9.02 | 9.77 | 12.07 | 12.25 | 12.41 | 12.41 | 12.41 | 12.41 |
| **25** | 2.87 | 4.26 | 4.56 | 5.01 | 5.22 | 5.34 | 8.97 | 9.72 | 12.01 | 12.20 | 12.35 | 12.35 | 12.35 | 12.35 |
| **50** | 2.87 | 4.25 | 4.55 | 4.98 | 5.20 | 5.32 | 8.92 | 9.66 | 11.95 | 12.13 | 12.31 | 12.31 | 12.31 | 12.31 |
| **100** | 2.82 | 4.17 | 4.46 | 4.87 | 5.09 | 5.21 | 8.71 | 9.44 | 11.69 | 11.87 | 12.04 | 12.04 | 12.04 | 12.04 |
| **200** | 2.58 | 3.86 | 4.13 | 4.56 | 4.77 | 4.89 | 8.18 | 8.88 | 11.02 | 11.23 | 11.40 | 11.40 | 11.40 | 11.40 |
| **300** | 2.34 | 3.54 | 3.81 | 4.20 | 4.44 | 4.58 | 7.58 | 8.30 | 10.31 | 10.59 | 10.76 | 10.76 | 10.76 | 10.76 |
| **400** | 2.15 | 3.33 | 3.58 | 3.87 | 4.19 | 4.40 | 7.01 | 7.87 | 9.73 | 10.15 | 10.31 | 10.31 | 10.31 | 10.31 |
| **500** | 2.06 | 3.18 | 3.43 | 3.64 | 4.10 | 4.34 | 6.57 | 7.55 | 9.29 | 9.84 | 9.98 | 9.99 | 9.99 | 9.99 |
| **1,000** | 1.72 | 2.75 | 3.04 | 3.23 | 3.70 | 3.94 | 5.46 | 6.53 | 8.22 | 8.94 | 9.11 | 9.11 | 9.11 | 9.11 |
| **2,000** | 1.40 | 2.35 | 2.65 | 2.83 | 3.20 | 3.45 | 4.72 | 5.68 | 7.28 | 8.12 | 8.35 | 8.35 | 8.36 | 8.36 |
| **5,000** | 0.99 | 1.73 | 2.05 | 2.25 | 2.55 | 2.78 | 4.06 | 4.84 | 6.13 | 7.14 | 7.43 | 7.43 | 7.43 | 7.43 |
| **10,000** | 0.70 | 1.20 | 1.50 | 1.75 | 2.03 | 2.25 | 3.50 | 4.22 | 5.20 | 6.34 | 6.65 | 6.65 | 6.66 | 6.66 |
| **20,000** | 0.42 | 0.71 | 1.02 | 1.28 | 1.52 | 1.72 | 2.88 | 3.53 | 4.28 | 5.49 | 5.85 | 5.85 | 5.85 | 5.85 |
| **50,000** | 0.20 | 0.36 | 0.52 | 0.67 | 0.81 | 0.93 | 1.78 | 2.33 | 2.84 | 3.83 | 4.21 | 4.21 | 4.22 | 4.22 |

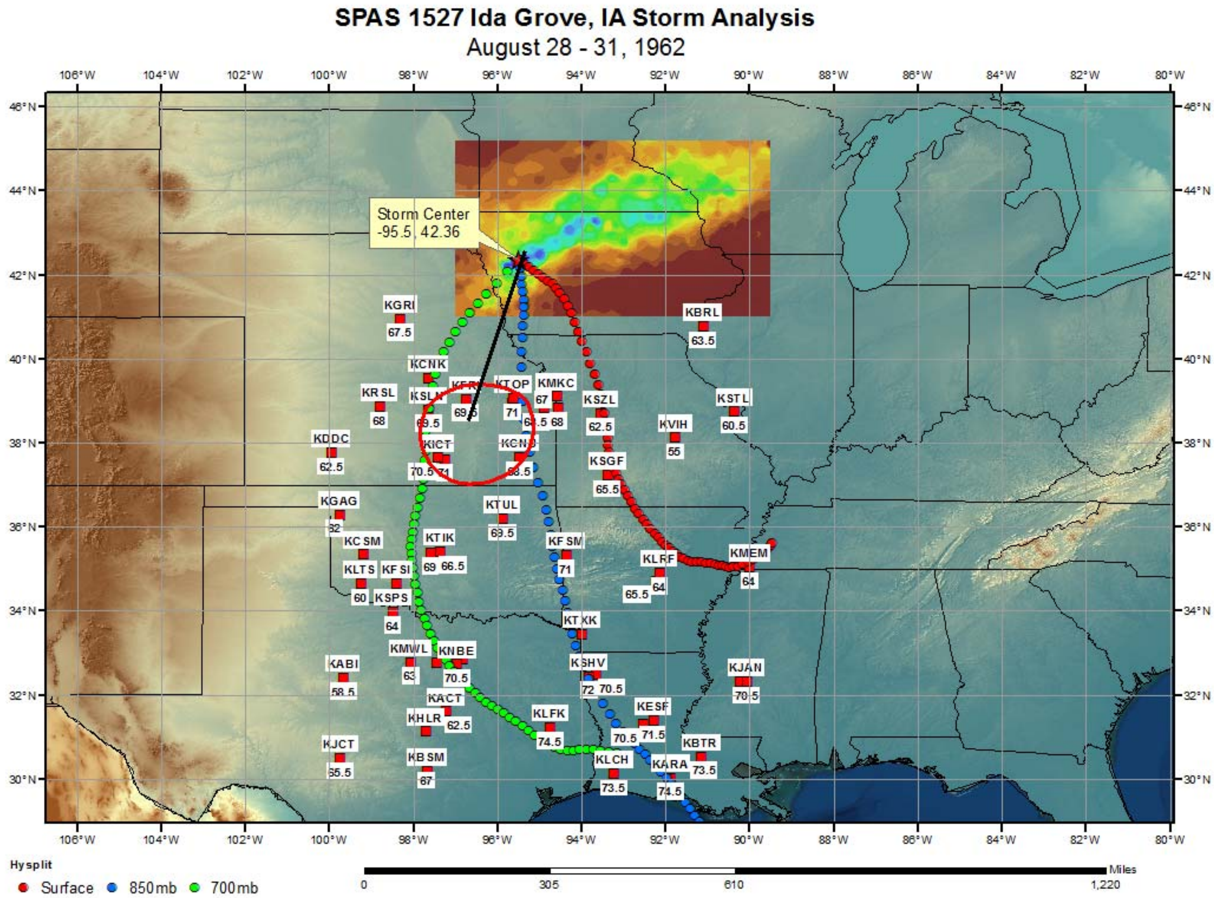



SPAS 1527 Storm Center Mass Curve: Zone 1
August 28 (0600 UTC) - September 1 (0500 UTC), 1962
Lat: 42.36 Lon: -95.50
Incremental
Accumulated
12.67"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
3.0
2.5
2.0
1.5
1.0
0.5
0.0
14
12
10
8
6
4
2
0
1
21
41
61
81




**Total Storm (96-hours) Precipitation (inches)**
**August 28 - 31, 1962**
**SPAS 1527 - Ida Grove, IA**


NOAA HYSPLIT MODEL
Backward trajectories ending at 1800 UTC 30 Aug 62
CDC1 Meteorological Data
Source ★ at 42.36 N 95.50 W
45
40
35
30
25
-110
-105
-100
-95
-90
-85
-80
noaa
hPa
700
850
964
650
700
750
800
850
900
950
1000
12 06 00 18 12 06 00 18 12 06 00 18
08/30
08/29
08/28
Job ID: 182088
Job Start: Fri May 15 20:10:43 UTC 2015
Source 1 lat.: 42.362500 lon.: -95.495800 hgts: 0, 1080, 2720 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Aug 2062 - reanalysis



SPAS 1527 Ida Grove, IA Storm Analysis
August 28 - 31, 1962
Storm Center
-95.5, 42.36
Hysplit
Surface
850mb
700mb
Miles
0
305
610
1,220

# Storm Precipitation Analysis System (SPAS) For Storm #1630_1 SPAS Analysis

**General Storm Location**: Toronto, Ontario

**Storm Dates**: October 13-17, 1954

**Event**: Hurricane Hazel

**DAD Zone 1**

**Latitude**: 43.8375

**Longitude**: -79.9792

**Max. Grid Rainfall Amount**: 11.23"

**Max. Observed Rainfall Amount**: 11.23"

**Number of Stations**: 162

**SPAS Version**: 10.0

**Basemap:** Canadian Storm Study (ONT 10-54) Isohyetal Pattern

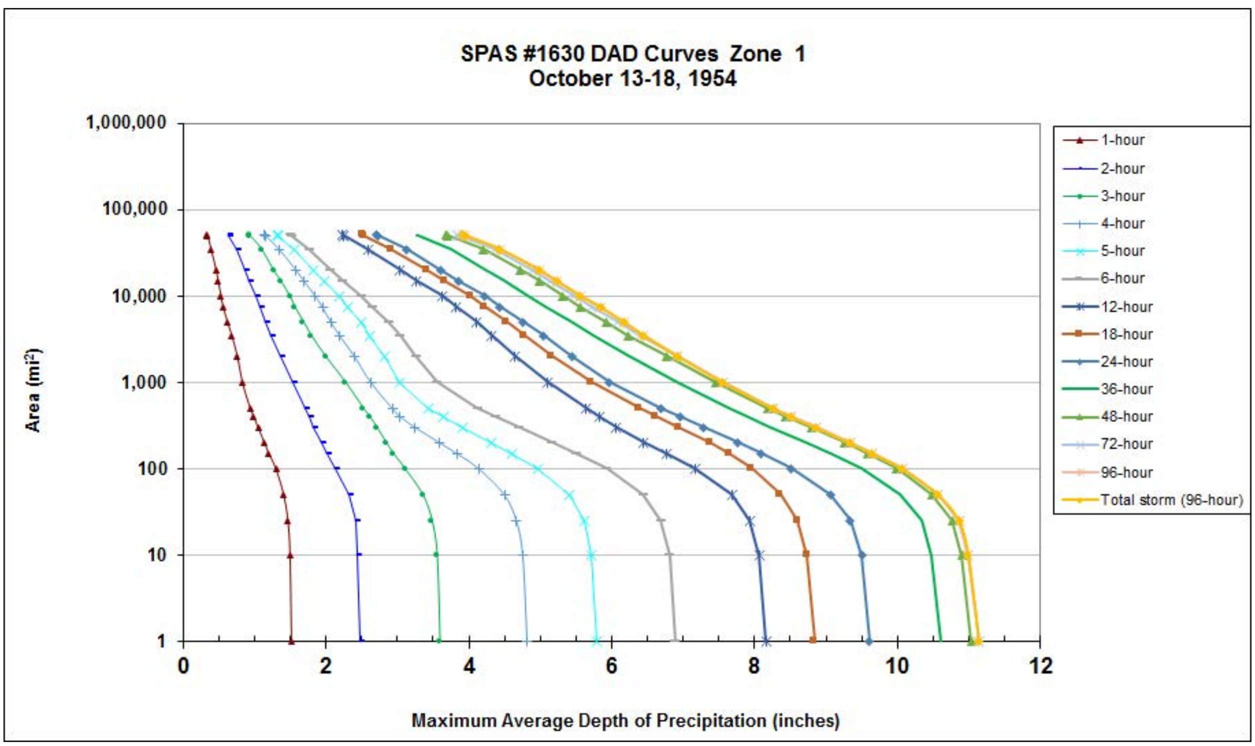
**Spatial resolution:** 0.3

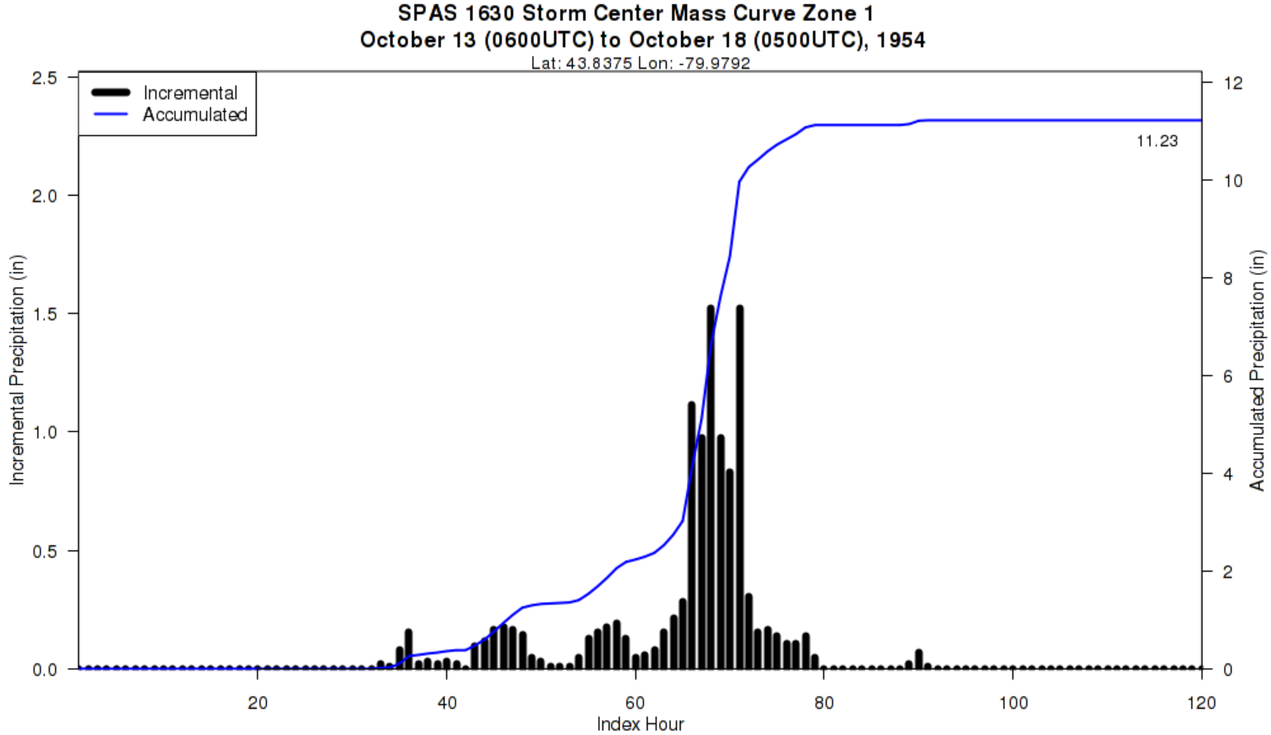
**Radar Included:** No

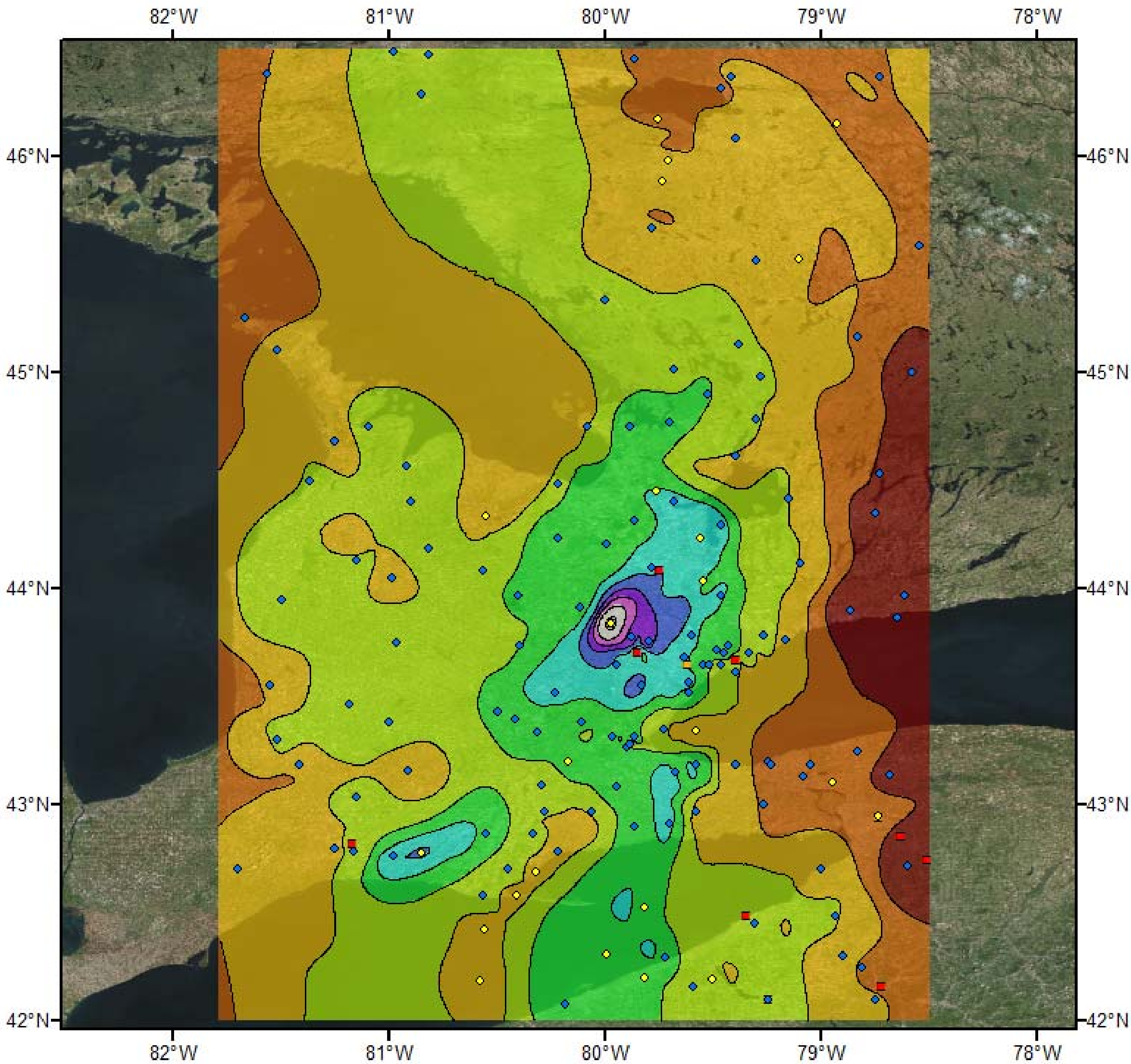
**Depth-Area-Duration (DAD) analysis**: Yes

**Reliability of results:** This analysis was based on 162 hourly stations, daily stations, supplemental station data, the Canadian Storm Study Report ONT 10-54, and article from Anderson and Bruce 1957. We have a good degree of confidence for the station based storm total results. The spatial pattern is dependent heavily on the basemap. Timing is based on the hourly stations at the storm center. One daily station was moved to a supplemental station due to timing issues and to ensure data consistency.

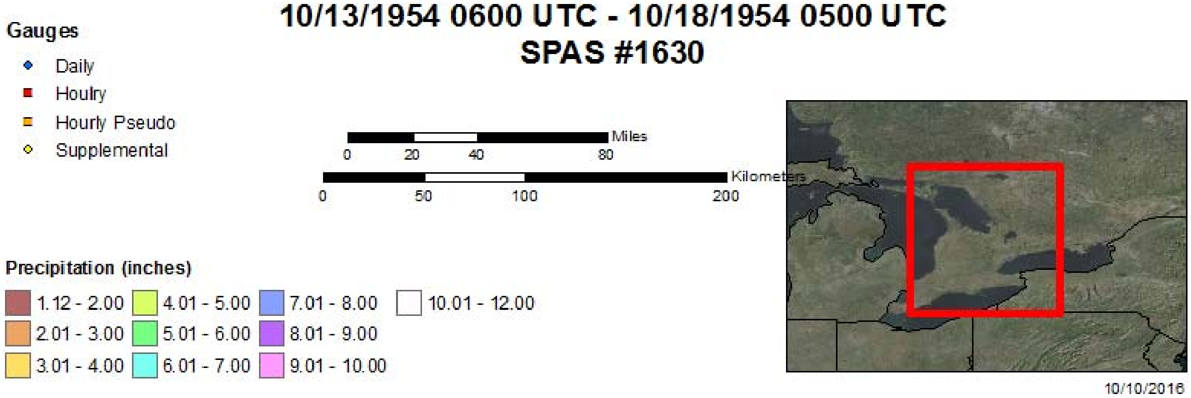
| Storm 1630 - October 13 (0600 UTC) - October 18 (0500 UTC), 1954 | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | | | |
| Area ($mi^2$) | Duration (hours) | | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | 96 | Total |
| 0.4 | 1.52 | 2.50 | 3.60 | 4.84 | 5.81 | 6.92 | 8.20 | 8.88 | 9.65 | 10.67 | 11.10 | 11.20 | 11.20 | 11.20 |
| 1 | 1.52 | 2.48 | 3.59 | 4.82 | 5.79 | 6.89 | 8.16 | 8.84 | 9.61 | 10.61 | 11.04 | 11.14 | 11.14 | 11.14 |
| 10 | 1.50 | 2.43 | 3.55 | 4.76 | 5.72 | 6.81 | 8.07 | 8.74 | 9.50 | 10.47 | 10.90 | 10.99 | 10.99 | 10.99 |
| 25 | 1.47 | 2.41 | 3.48 | 4.67 | 5.62 | 6.69 | 7.93 | 8.60 | 9.34 | 10.34 | 10.77 | 10.86 | 10.86 | 10.86 |
| 50 | 1.41 | 2.32 | 3.35 | 4.50 | 5.41 | 6.44 | 7.68 | 8.36 | 9.06 | 10.04 | 10.48 | 10.57 | 10.57 | 10.57 |
| 100 | 1.30 | 2.14 | 3.10 | 4.14 | 4.97 | 5.93 | 7.17 | 7.96 | 8.52 | 9.50 | 9.99 | 10.06 | 10.07 | 10.07 |
| 150 | 1.20 | 2.02 | 2.94 | 3.83 | 4.61 | 5.50 | 6.76 | 7.64 | 8.09 | 9.06 | 9.58 | 9.65 | 9.65 | 9.65 |
| 200 | 1.14 | 1.94 | 2.84 | 3.59 | 4.32 | 5.16 | 6.45 | 7.38 | 7.77 | 8.71 | 9.26 | 9.33 | 9.33 | 9.33 |
| 300 | 1.05 | 1.83 | 2.71 | 3.25 | 3.92 | 4.70 | 6.06 | 6.94 | 7.29 | 8.22 | 8.79 | 8.86 | 8.86 | 8.86 |
| 400 | 0.99 | 1.76 | 2.61 | 3.04 | 3.64 | 4.37 | 5.82 | 6.62 | 6.95 | 7.89 | 8.43 | 8.50 | 8.51 | 8.51 |
| 500 | 0.94 | 1.71 | 2.52 | 2.93 | 3.44 | 4.12 | 5.64 | 6.39 | 6.69 | 7.64 | 8.18 | 8.25 | 8.26 | 8.26 |
| 1,000 | 0.83 | 1.53 | 2.27 | 2.63 | 3.03 | 3.55 | 5.11 | 5.72 | 5.97 | 6.92 | 7.45 | 7.56 | 7.56 | 7.56 |
| 2,000 | 0.76 | 1.36 | 1.99 | 2.40 | 2.83 | 3.26 | 4.65 | 5.16 | 5.44 | 6.24 | 6.77 | 6.91 | 6.93 | 6.93 |
| 3,500 | 0.68 | 1.23 | 1.79 | 2.19 | 2.62 | 3.04 | 4.32 | 4.78 | 5.05 | 5.74 | 6.23 | 6.39 | 6.45 | 6.45 |
| 5,000 | 0.62 | 1.16 | 1.68 | 2.07 | 2.50 | 2.87 | 4.11 | 4.53 | 4.76 | 5.43 | 5.92 | 6.08 | 6.17 | 6.17 |
| 7,500 | 0.56 | 1.08 | 1.56 | 1.95 | 2.31 | 2.64 | 3.82 | 4.22 | 4.44 | 5.07 | 5.56 | 5.72 | 5.84 | 5.84 |
| 10,000 | 0.53 | 1.02 | 1.49 | 1.85 | 2.19 | 2.49 | 3.63 | 4.02 | 4.22 | 4.83 | 5.32 | 5.47 | 5.57 | 5.57 |
| 15,000 | 0.49 | 0.93 | 1.36 | 1.69 | 1.98 | 2.23 | 3.27 | 3.66 | 3.85 | 4.50 | 4.99 | 5.13 | 5.23 | 5.23 |
| 20,000 | 0.46 | 0.87 | 1.26 | 1.58 | 1.83 | 2.06 | 3.04 | 3.41 | 3.60 | 4.23 | 4.72 | 4.89 | 4.99 | 4.99 |
| 35,000 | 0.39 | 0.75 | 1.09 | 1.34 | 1.55 | 1.76 | 2.59 | 2.91 | 3.13 | 3.76 | 4.21 | 4.36 | 4.44 | 4.44 |
| 50,000 | 0.34 | 0.64 | 0.93 | 1.15 | 1.33 | 1.51 | 2.25 | 2.53 | 2.73 | 3.30 | 3.71 | 3.86 | 3.96 | 3.96 |
| 50,743 | 0.33 | 0.64 | 0.92 | 1.14 | 1.32 | 1.49 | 2.23 | 2.51 | 2.71 | 3.27 | 3.68 | 3.83 | 3.92 | 3.92 |

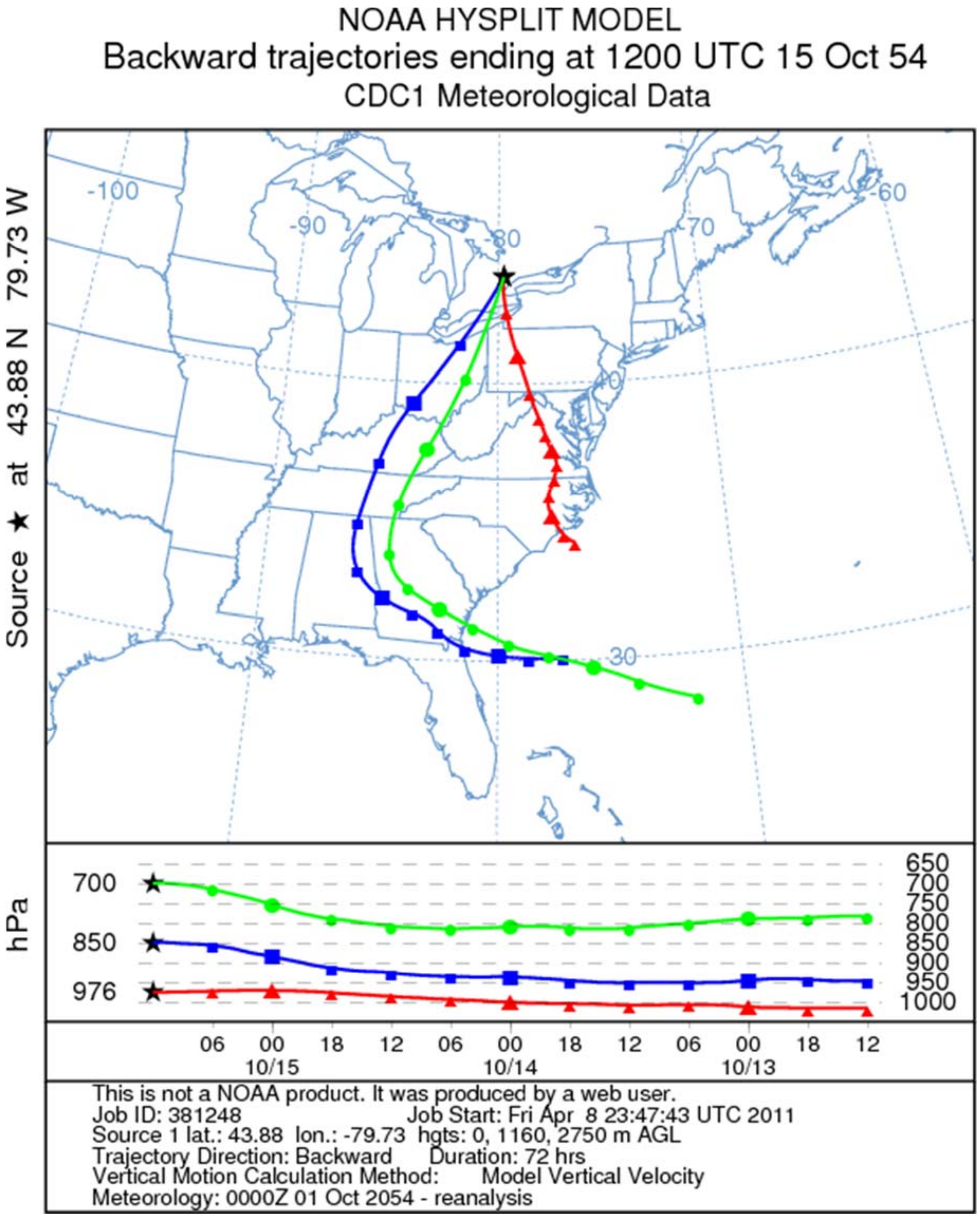


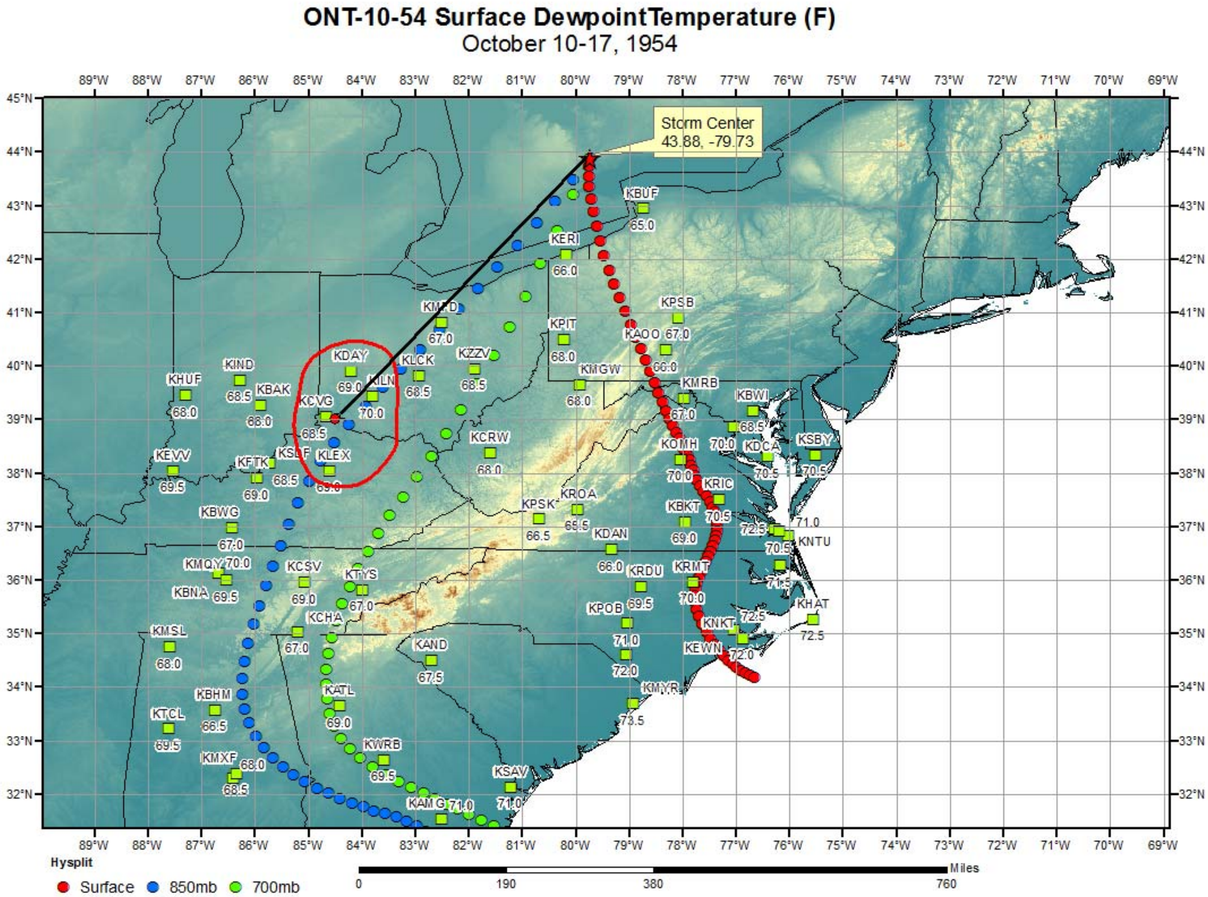

SPAS 1630 Storm Center Mass Curve Zone 1
October 13 (0600UTC) to October 18 (0500UTC), 1954
Lat: 43.8375 Lon: -79.9792
Incremental
Accumulated
11.23
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
0
2
4
6
8
10
12
20
40
60
80
100
120




**Total Storm (120-hr) Precipitation (inches)**
**10/13/1954 0600 UTC - 10/18/1954 0500 UTC**
**SPAS #1630**




NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 15 Oct 54
CDC1 Meteorological Data
Source ★ at 43.88 N 79.73 W
-100
-90
80
70
-60
40
30
hPa
700
850
976
650
700
750
800
850
900
950
1000
06 00 18 12 06 00 18 12 06 00 18 12
10/15
10/14
10/13
This is not a NOAA product. It was produced by a web user.
Job ID: 381248 Job Start: Fri Apr 8 23:47:43 UTC 2011
Source 1 lat.: 43.88 lon.: -79.73 hgts: 0, 1160, 2750 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Oct 2054 - reanalysis


ONT-10-54 Surface Dewpoint Temperature (F)
October 10-17, 1954
Storm Center
43.88, -79.73
Hysplit
Surface
850mb
700mb
Miles
0
190
380
760

# Storm Precipitation Analysis System (SPAS) For Storm #1278_1 SPAS Analysis

**General Storm Location**: Kentucky, Ohio River Valley

**Storm Dates**: March 7-11, 1964

**Event**: Synoptic

**DAD Zone 1**

**Latitude**: 37.35

**Longitude**: -87.50

**Max. Grid Rainfall Amount**: 11.67"

**Max. Observed Rainfall Amount**: 11.63"

**Number of Stations**: 1291 (819 Daily, 252 Hourly, 109 Hourly Pseudo, and 111 Supplemental)

**SPAS Version**: 9.5

**Basemap:** PRISM 30-yr Mean (1971-2000) March Precipitation

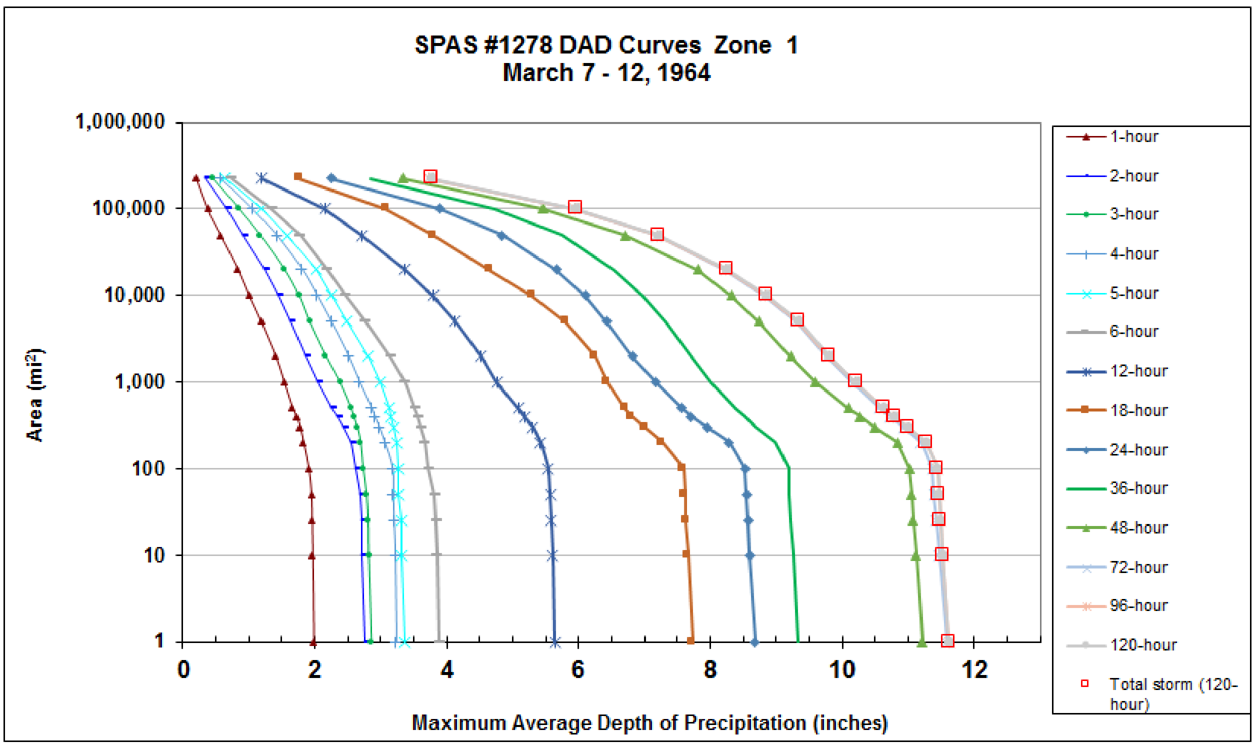
**Spatial resolution:** 00:00:30 (~ 0.30 $mi^2$)

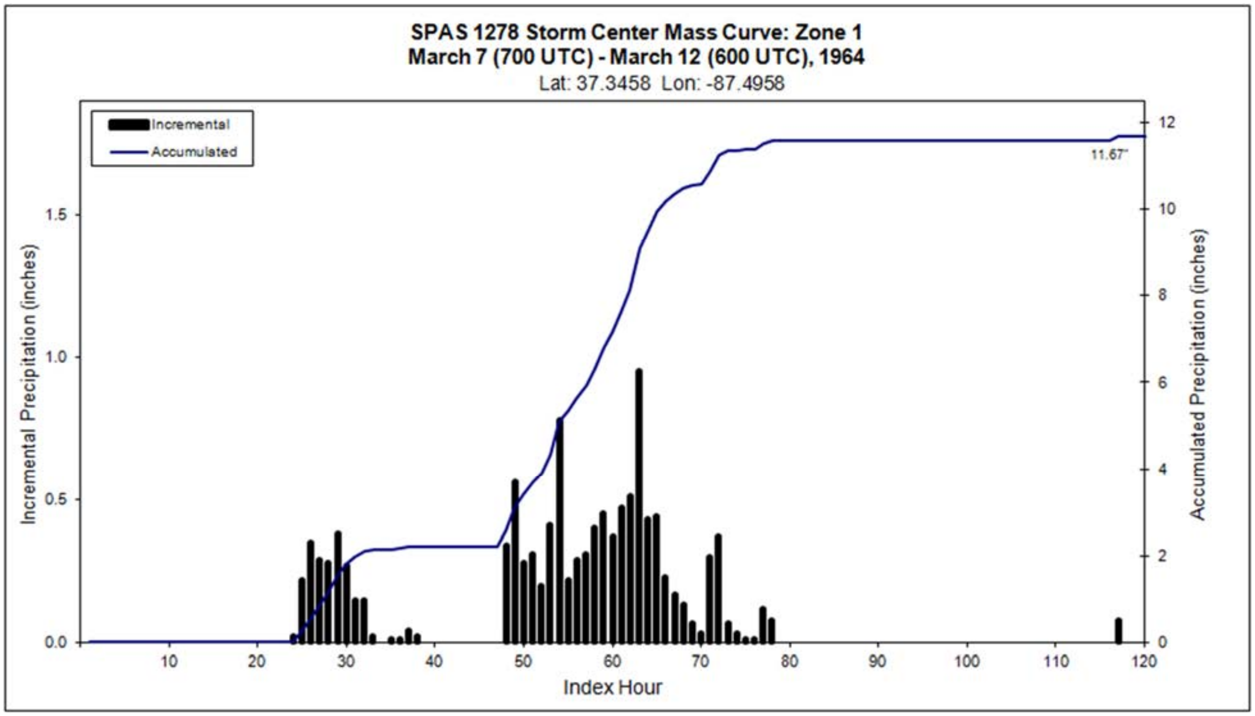
**Radar Included:** No

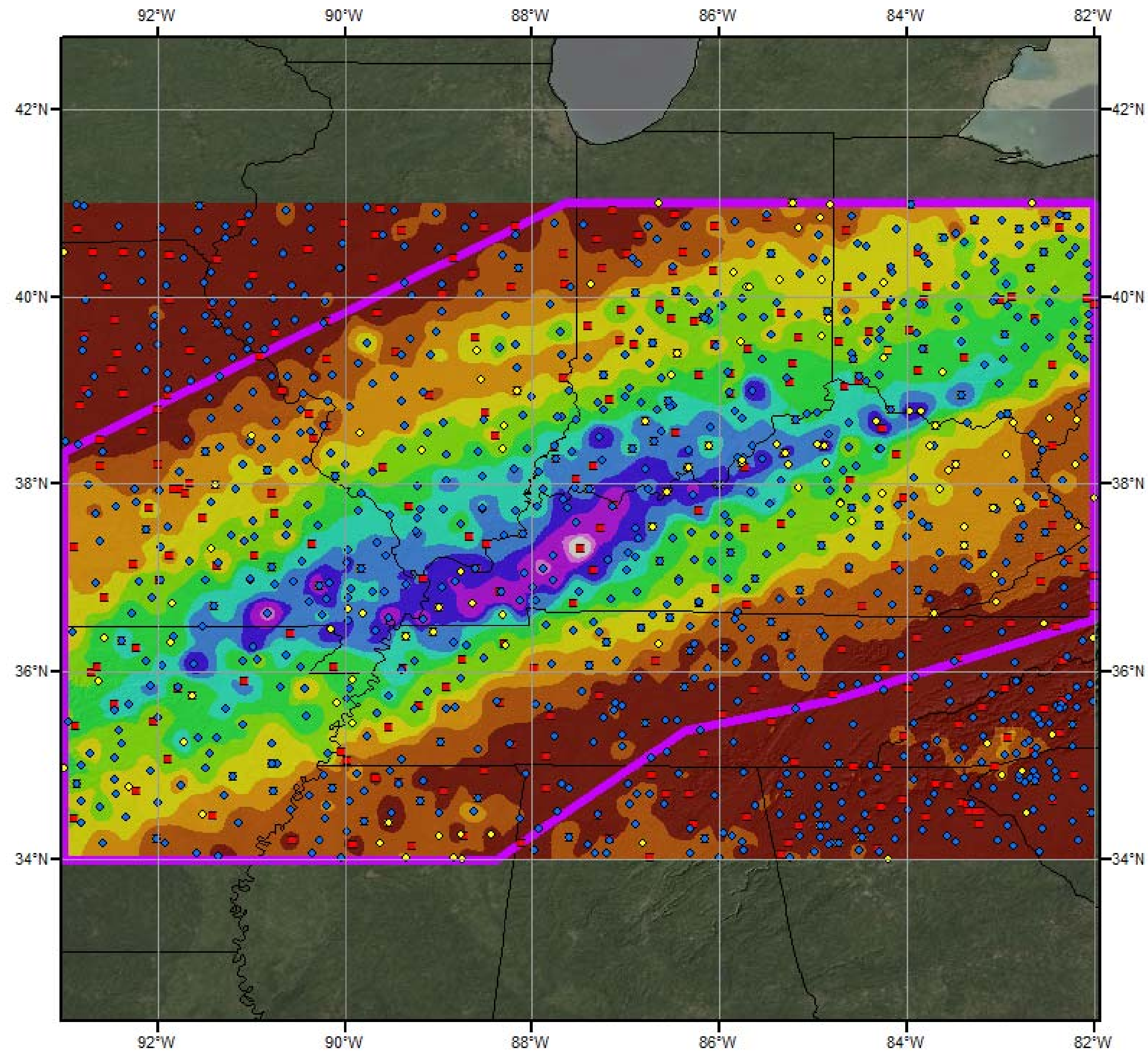
**Depth-Area-Duration (DAD) analysis**: Yes

**Reliability of results:** This analysis was based on hourly data, daily data, and supplemental station data. We have a high degree of confidence in the station based storm total results, the spatial pattern is dependent on basemap, and the timing is based on hourly and hourly pseudo stations. Results are similar to the analysis performed in the EPRI report for storm number 32.

| Storm 1278 - March 7 (0700 UTC) - March 12 (0600 UTC), 1964 | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | | | | |
| Area ($mi^2$) | Duration (hours) | | | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | 96 | 120 | Total |
| 0.4 | 1.99 | 2.77 | 2.88 | 3.23 | 3.37 | 3.90 | 5.64 | 7.74 | 8.69 | 9.36 | 11.25 | 11.59 | 11.65 | 11.65 | 11.65 |
| 1 | 1.98 | 2.76 | 2.86 | 3.23 | 3.36 | 3.89 | 5.64 | 7.73 | 8.67 | 9.33 | 11.22 | 11.58 | 11.62 | 11.62 | 11.62 |
| 10 | 1.96 | 2.72 | 2.82 | 3.21 | 3.32 | 3.85 | 5.60 | 7.66 | 8.59 | 9.25 | 11.12 | 11.47 | 11.53 | 11.53 | 11.53 |
| 25 | 1.95 | 2.71 | 2.81 | 3.19 | 3.31 | 3.84 | 5.58 | 7.63 | 8.57 | 9.22 | 11.08 | 11.42 | 11.49 | 11.49 | 11.49 |
| 50 | 1.94 | 2.70 | 2.79 | 3.18 | 3.27 | 3.82 | 5.57 | 7.61 | 8.55 | 9.20 | 11.05 | 11.39 | 11.47 | 11.47 | 11.47 |
| 100 | 1.90 | 2.63 | 2.74 | 3.17 | 3.26 | 3.72 | 5.54 | 7.59 | 8.52 | 9.18 | 11.02 | 11.36 | 11.44 | 11.44 | 11.44 |
| 200 | 1.82 | 2.54 | 2.70 | 3.05 | 3.25 | 3.66 | 5.42 | 7.27 | 8.28 | 8.97 | 10.83 | 11.19 | 11.27 | 11.27 | 11.27 |
| 300 | 1.77 | 2.44 | 2.65 | 2.97 | 3.20 | 3.61 | 5.31 | 7.00 | 7.95 | 8.68 | 10.49 | 10.93 | 11.00 | 11.00 | 11.00 |
| 400 | 1.72 | 2.34 | 2.59 | 2.90 | 3.16 | 3.56 | 5.18 | 6.81 | 7.71 | 8.51 | 10.27 | 10.73 | 10.78 | 10.79 | 10.79 |
| 500 | 1.66 | 2.26 | 2.55 | 2.85 | 3.12 | 3.52 | 5.09 | 6.70 | 7.57 | 8.39 | 10.10 | 10.57 | 10.62 | 10.63 | 10.63 |
| 1,000 | 1.53 | 2.04 | 2.38 | 2.67 | 2.99 | 3.37 | 4.76 | 6.44 | 7.17 | 8.01 | 9.60 | 10.16 | 10.20 | 10.21 | 10.21 |
| 2,000 | 1.40 | 1.86 | 2.17 | 2.50 | 2.80 | 3.15 | 4.52 | 6.25 | 6.82 | 7.70 | 9.22 | 9.77 | 9.80 | 9.81 | 9.81 |
| 5,000 | 1.18 | 1.62 | 1.92 | 2.24 | 2.48 | 2.77 | 4.13 | 5.80 | 6.42 | 7.32 | 8.73 | 9.30 | 9.33 | 9.34 | 9.34 |
| 10,000 | 1.00 | 1.44 | 1.76 | 2.03 | 2.26 | 2.47 | 3.79 | 5.29 | 6.10 | 6.98 | 8.32 | 8.83 | 8.84 | 8.86 | 8.86 |
| 20,000 | 0.83 | 1.23 | 1.54 | 1.80 | 2.01 | 2.19 | 3.37 | 4.65 | 5.66 | 6.53 | 7.81 | 8.22 | 8.24 | 8.26 | 8.26 |
| 50,000 | 0.57 | 0.92 | 1.17 | 1.41 | 1.59 | 1.77 | 2.71 | 3.79 | 4.84 | 5.74 | 6.70 | 7.18 | 7.19 | 7.21 | 7.21 |
| 100,000 | 0.37 | 0.65 | 0.85 | 1.04 | 1.19 | 1.34 | 2.15 | 3.08 | 3.90 | 4.74 | 5.47 | 5.93 | 5.94 | 5.96 | 5.96 |
| 227,344 | 0.20 | 0.34 | 0.45 | 0.56 | 0.64 | 0.73 | 1.20 | 1.76 | 2.24 | 2.85 | 3.34 | 3.72 | 3.72 | 3.77 | 3.77 |




SPAS 1278 Storm Center Mass Curve: Zone 1
March 7 (700 UTC) - March 12 (600 UTC), 1964
Lat: 37.3458 Lon: -87.4958
Incremental
Accumulated
11.67"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour




**Total Storm (120-hr) Precipitation (inches)**
**March 7-11, 1964**
**SPAS 1278**

**Gauges**

- Daily
- Hourly
- Hourly Pseudo
- Supplemental

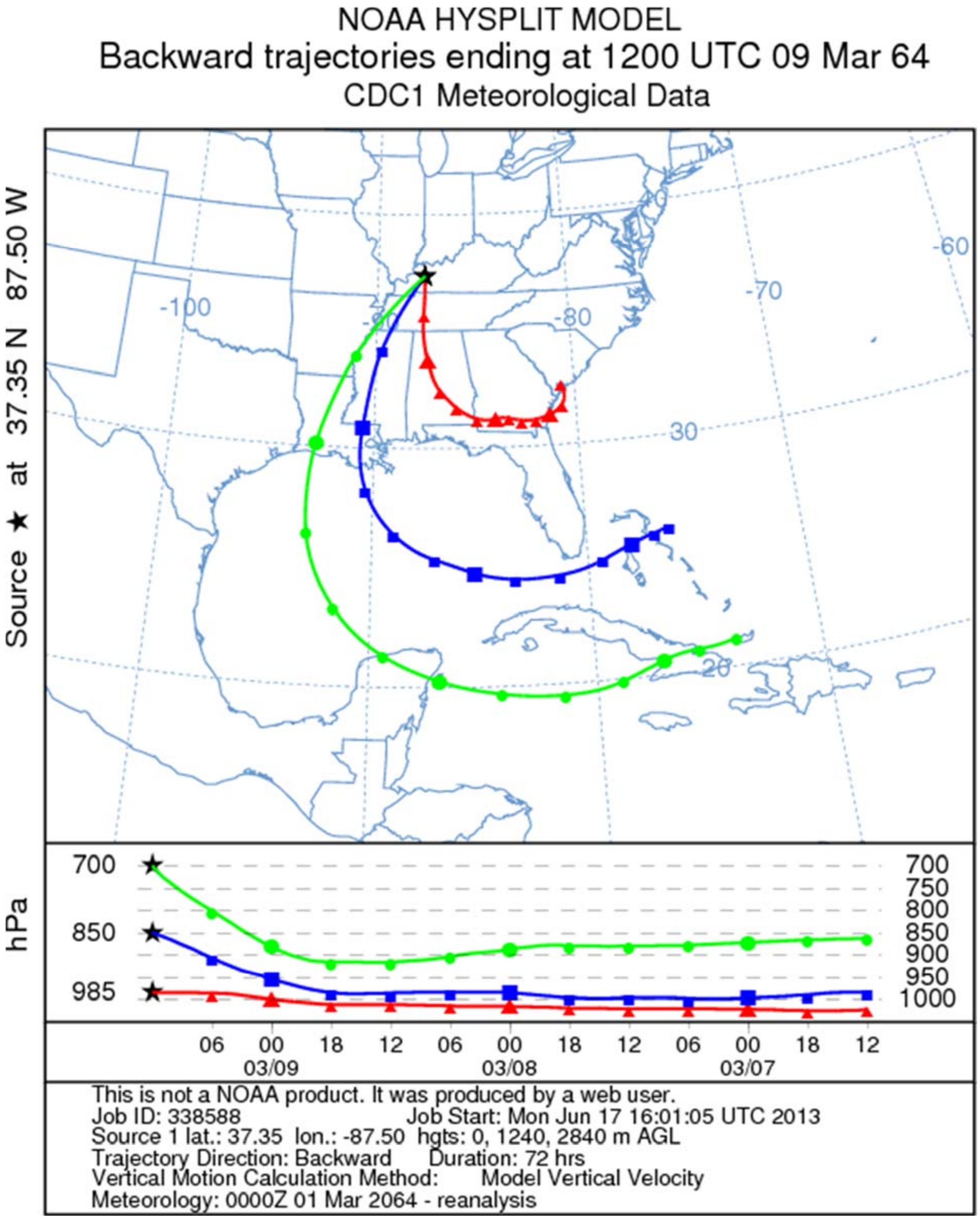
Miles: 0, 62.5, 125, 250

Kilometers: 0, 125, 250, 500

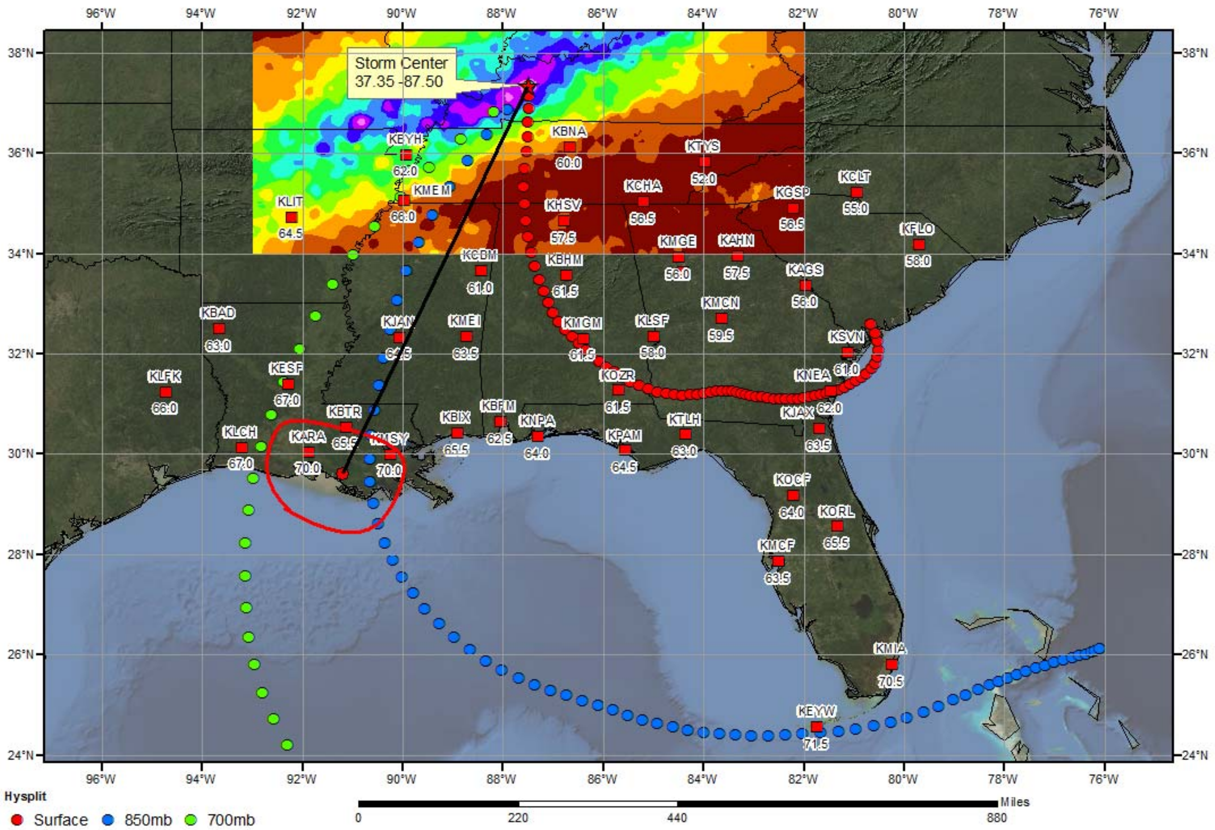
**Precipitation (inches)**

0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00

6/17/2013


NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 09 Mar 64
CDC1 Meteorological Data
Source ★ at 37.35 N 87.50 W
-100
-80
-70
-60
30
20
hPa
700
850
985
700
750
800
850
900
950
1000
06 00 18 12 06 00 18 12 06 00 18 12
03/09
03/08
03/07
This is not a NOAA product. It was produced by a web user.
Job ID: 338588 Job Start: Mon Jun 17 16:01:05 UTC 2013
Source 1 lat.: 37.35 lon.: -87.50 hgts: 0, 1240, 2840 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Mar 2064 - reanalysis

**SPAS 1278 Storm Analysis**
March 5-9, 1964



# Storm Precipitation Analysis System (SPAS) For Storm #1738_1 SPAS Analysis

**General Storm Location**: Harlan, IA

**Storm Dates**: September 9-14, 1972

**Event**: Synoptic/Warm Front

**DAD Zone 1**

**Latitude**: 41.7208

**Longitude**: -95.2125

**Max. Grid Rainfall Amount**: 15.81”

**Max. Observed Rainfall Amount**: 15.25”

**Number of Stations**: 1081

**SPAS Version**: 10.0

**Base Map Used:** Blend of PRISM climatology from Sept 1972 and CONUS 30-yr climatology

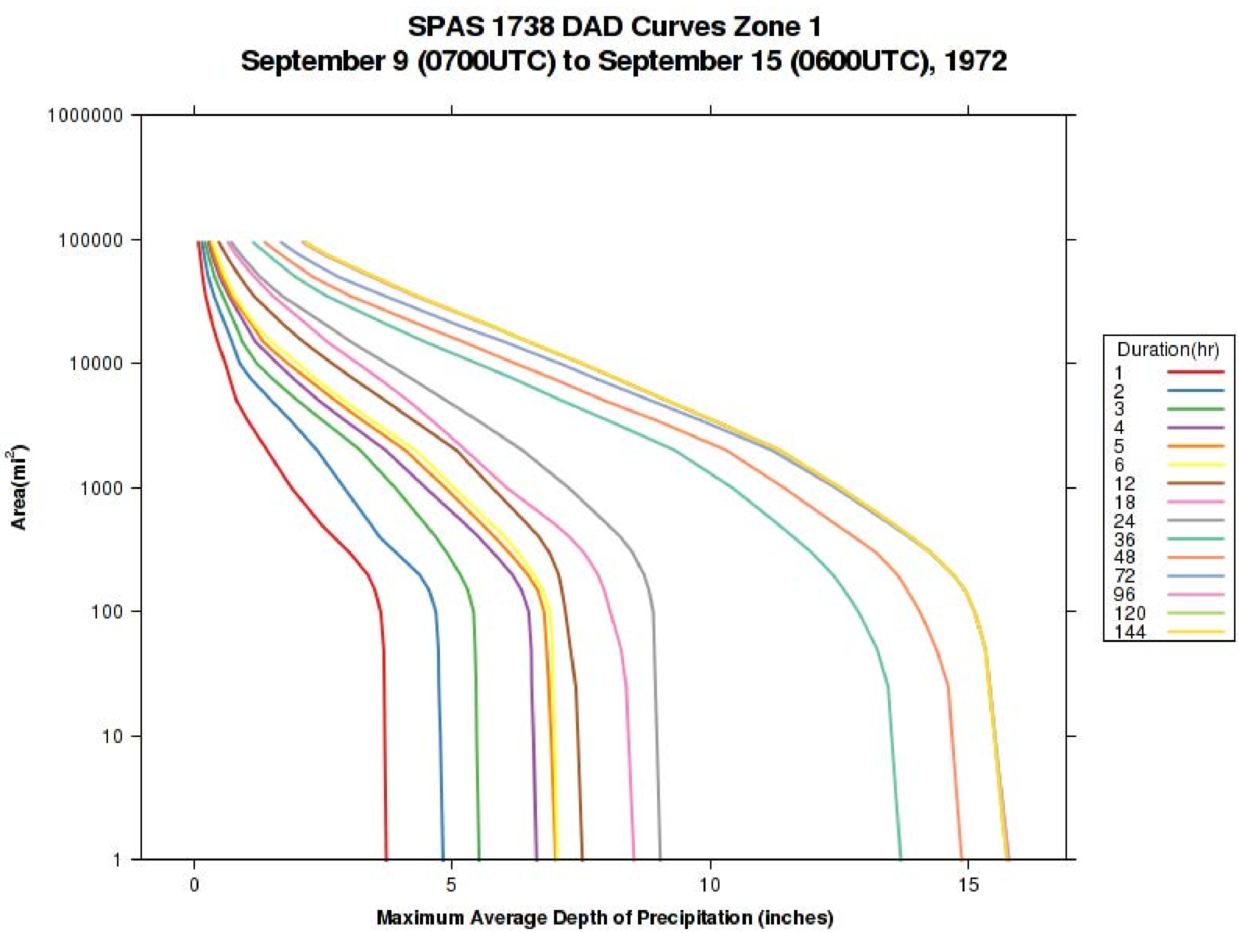
**Spatial resolution:** 0.2479

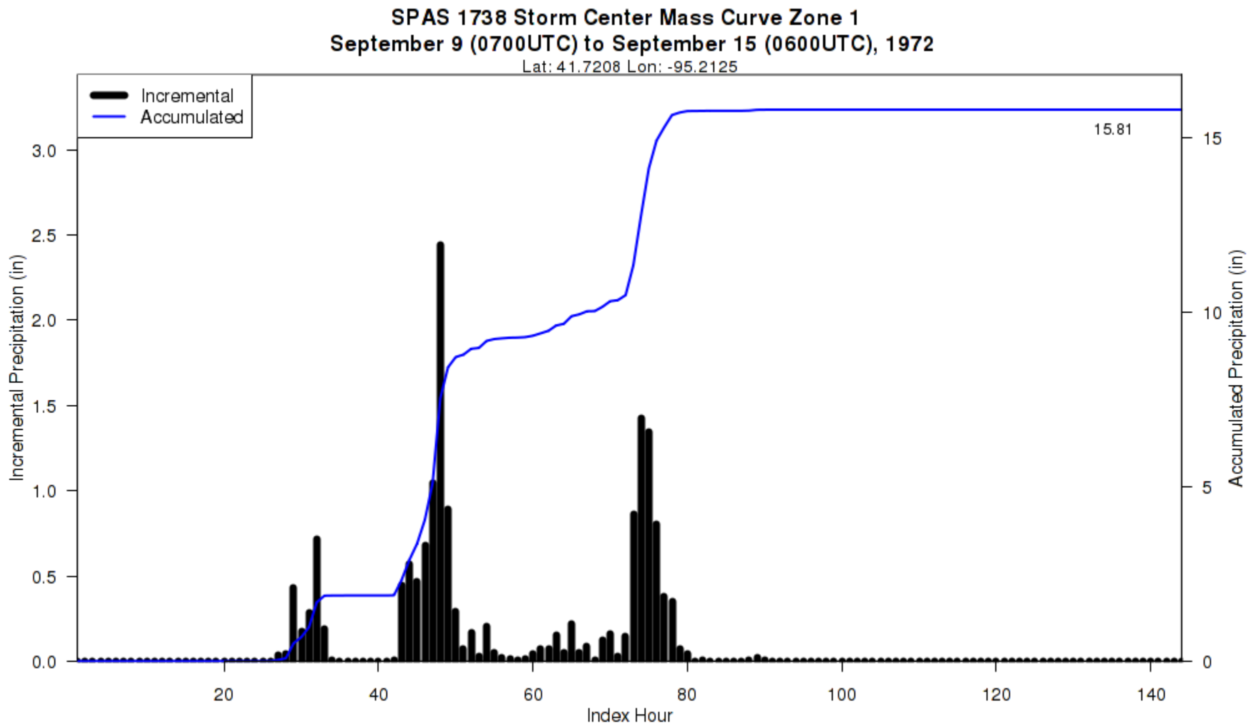
**Radar Included:** No

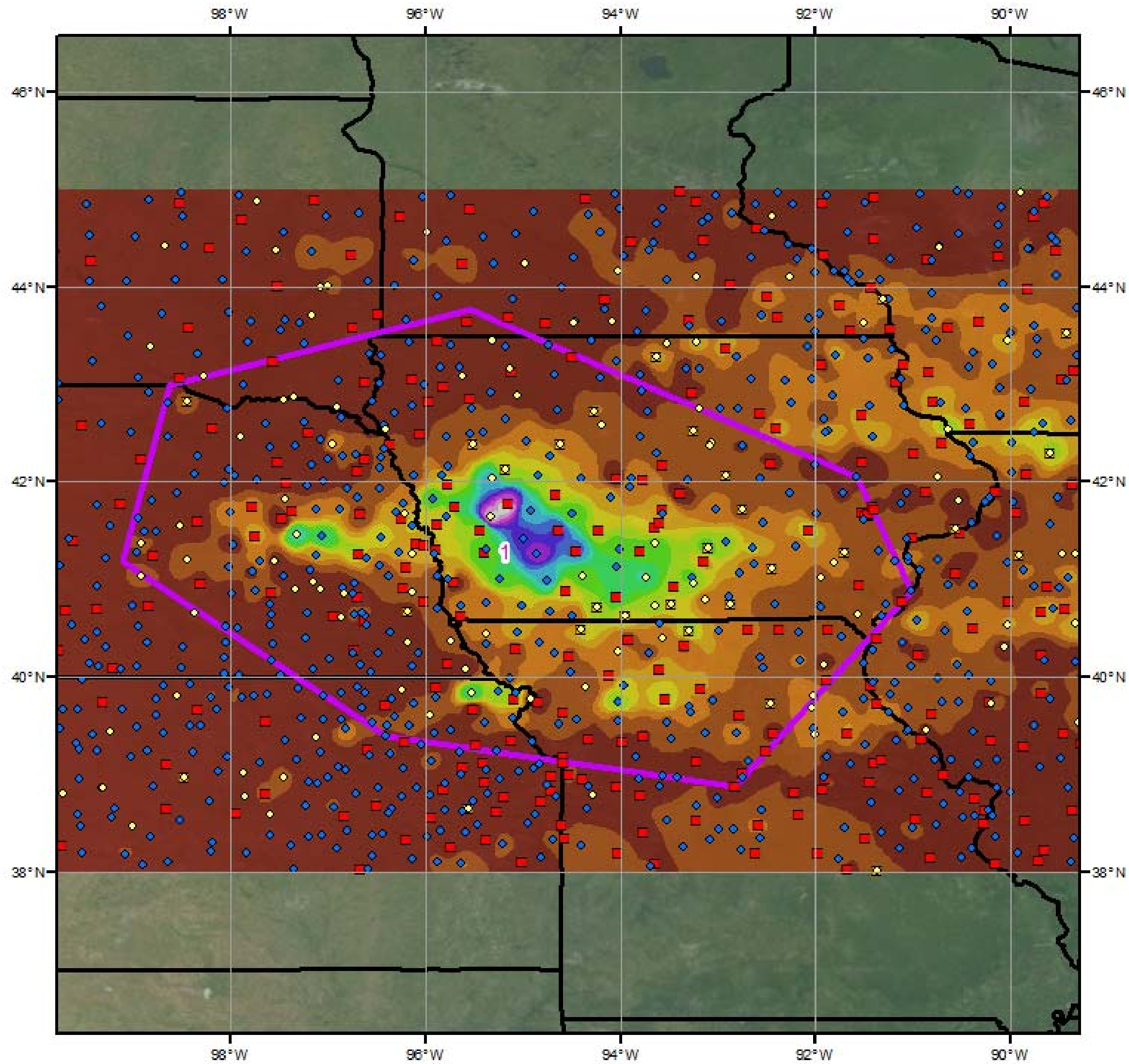
**Depth-Area-Duration (DAD) analysis**: Yes

**Degree of confidence in results:** This analysis was based on 1081 hourly stations, daily data, and supplemental station data. We have a good degree of confidence for the station based storm total results. The spatial pattern is fully dependent on the blended basemap. Timing is based on the hourly and hourly pseudo stations. Several daily stations were moved to supplemental due to timing issues and to ensure data consistency.

| SPAS 1738 - September 9 (0700 UTC) - September 15 (0600 UTC), 1972 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | |
| Area ($mi^2$) | Duration (hours) | | | | | | | | | |
| | 1 | 6 | 12 | 24 | 48 | 72 | 96 | 120 | 144 | Total |
| 0.4 | 3.72 | 7.05 | 7.55 | 9.06 | 14.94 | 15.81 | 15.81 | 15.81 | 15.81 | 15.81 |
| 1 | 3.72 | 7.03 | 7.52 | 9.03 | 14.87 | 15.78 | 15.78 | 15.74 | 15.74 | 15.74 |
| 10 | 3.69 | 6.98 | 7.43 | 8.96 | 14.68 | 15.51 | 15.51 | 15.50 | 15.50 | 15.50 |
| 25 | 3.68 | 6.95 | 7.39 | 8.93 | 14.61 | 15.41 | 15.41 | 15.40 | 15.40 | 15.40 |
| 50 | 3.67 | 6.94 | 7.29 | 8.91 | 14.38 | 15.33 | 15.33 | 15.33 | 15.33 | 15.33 |
| 100 | 3.61 | 6.89 | 7.19 | 8.89 | 14.06 | 15.12 | 15.12 | 15.12 | 15.12 | 15.12 |
| 200 | 3.36 | 6.57 | 7.06 | 8.71 | 13.62 | 14.70 | 14.70 | 14.70 | 14.70 | 14.70 |
| 300 | 3.01 | 6.27 | 6.88 | 8.49 | 13.21 | 14.26 | 14.27 | 14.27 | 14.27 | 14.27 |
| 400 | 2.70 | 6.02 | 6.68 | 8.26 | 12.79 | 13.85 | 13.89 | 13.89 | 13.89 | 13.89 |
| 500 | 2.47 | 5.78 | 6.47 | 8.02 | 12.45 | 13.51 | 13.56 | 13.57 | 13.57 | 13.57 |
| 1,000 | 1.88 | 5.03 | 5.77 | 7.25 | 11.42 | 12.42 | 12.50 | 12.51 | 12.51 | 12.51 |
| 2,000 | 1.41 | 4.29 | 5.08 | 6.36 | 10.31 | 11.19 | 11.33 | 11.35 | 11.35 | 11.35 |
| 5,000 | 0.82 | 2.91 | 3.71 | 4.89 | 7.96 | 8.86 | 9.16 | 9.18 | 9.18 | 9.18 |
| 10,000 | 0.60 | 2.01 | 2.67 | 3.73 | 6.22 | 7.08 | 7.50 | 7.51 | 7.52 | 7.52 |
| 20,000 | 0.36 | 1.19 | 1.76 | 2.59 | 4.44 | 5.16 | 5.75 | 5.77 | 5.78 | 5.78 |
| 50,000 | 0.16 | 0.60 | 0.88 | 1.27 | 2.29 | 2.78 | 3.43 | 3.48 | 3.49 | 3.49 |
| 94,561 | 0.08 | 0.35 | 0.48 | 0.72 | 1.36 | 1.68 | 2.10 | 2.15 | 2.15 | 2.15 |




SPAS 1738 Storm Center Mass Curve Zone 1
September 9 (0700UTC) to September 15 (0600UTC), 1972
Lat: 41.7208 Lon: -95.2125
Incremental
Accumulated
15.81
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
5
10
15
20
40
60
80
100
120
140




**Total Storm (144-hours) Precipitation (inches)**
**September 9-14, 1972**
**SPAS 1738 - Harlan, IA**

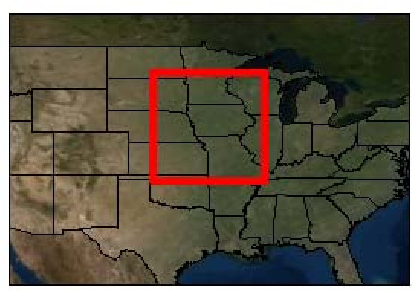
Gauges
- Daily
- Hourly
- Hourly Pseudo
- Supplemental

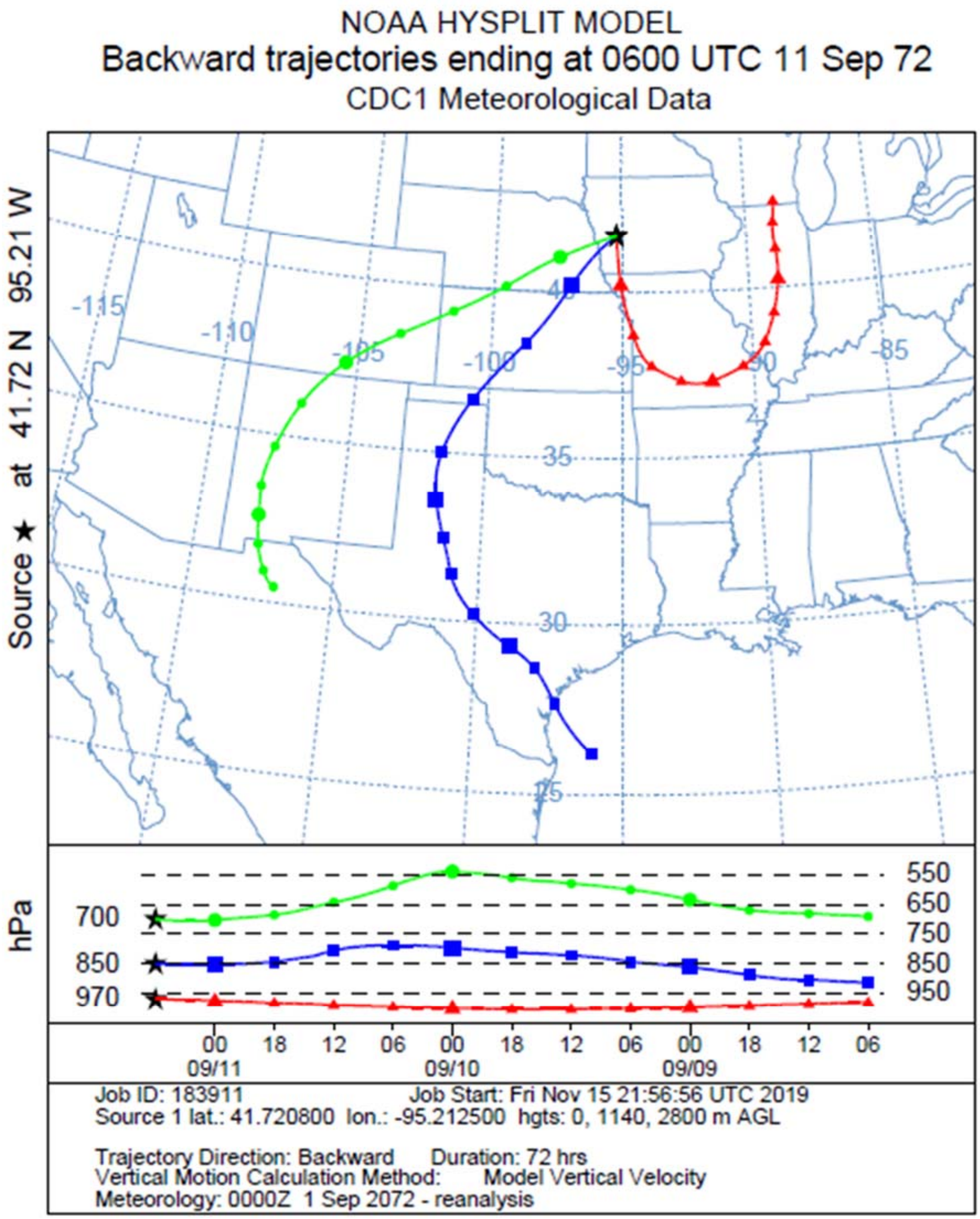
Miles: 0, 45, 90, 180

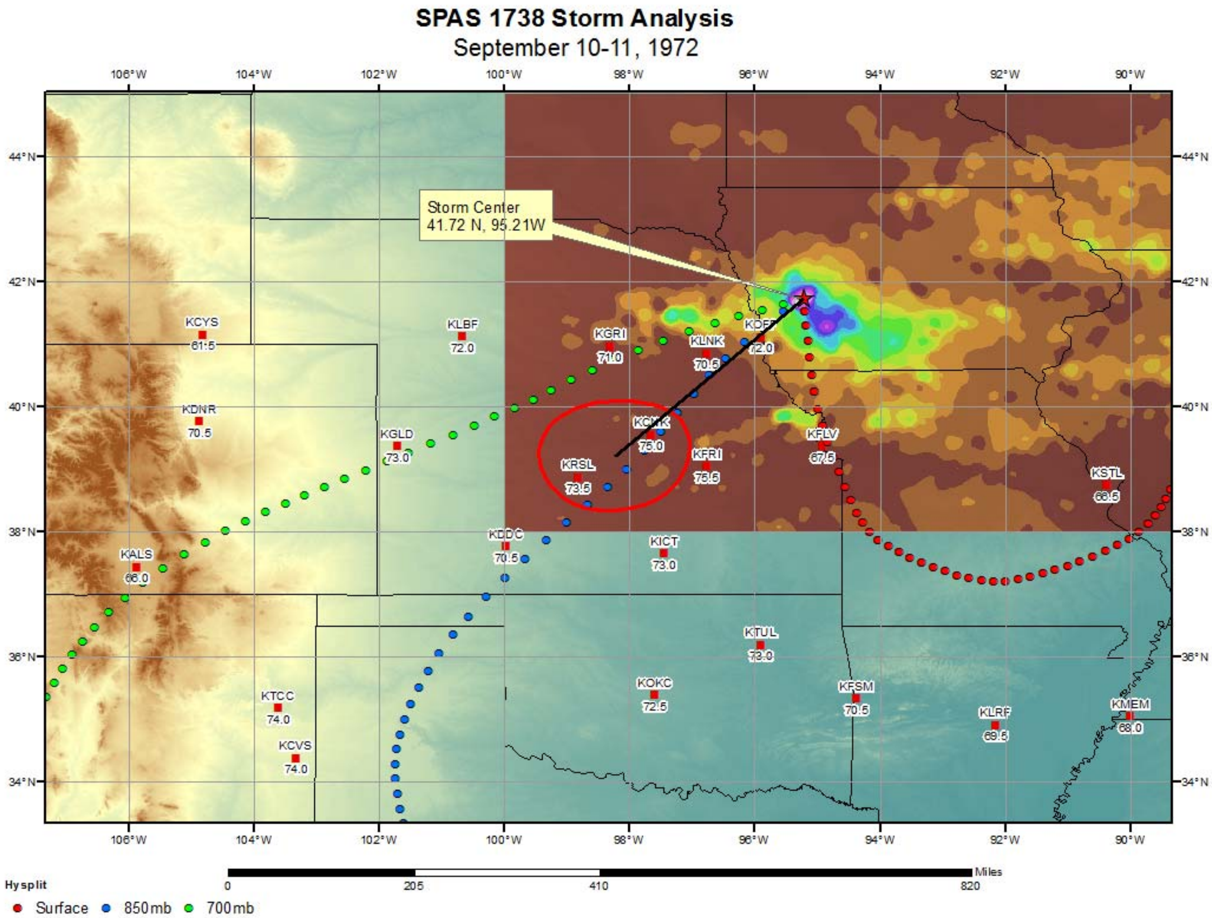
Kilometers: 0, 90, 180, 360

**Precipitation (inches)**

| | | |
|---|---|---|
| 0.00 - 1.00 | 5.01 - 6.00 | 11.01 - 12.00 |
| 1.01 - 2.00 | 6.01 - 7.00 | 12.01 - 13.00 |
| 2.01 - 3.00 | 7.01 - 8.00 | 13.01 - 14.00 |
| 3.01 - 4.00 | 8.01 - 9.00 | 14.01 - 15.00 |
| 4.01 - 5.00 | 9.01 - 10.00 | 15.01 - 16.00 |
| | 10.01 - 11.00 | |




NOAA HYSPLIT MODEL
Backward trajectories ending at 0600 UTC 11 Sep 72
CDC1 Meteorological Data
Source ★ at 41.72 N 95.21 W
-115
-110
-105
-100
-95
-90
-85
40
35
30
25
hPa
700
850
970
550
650
750
850
950
00 18 12 06 00 18 12 06 00 18 12 06
09/11
09/10
09/09
Job ID: 183911
Job Start: Fri Nov 15 21:56:56 UTC 2019
Source 1 lat.: 41.720800 lon.: -95.212500 hgts: 0, 1140, 2800 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Sep 2072 - reanalysis


SPAS 1738 Storm Analysis
September 10-11, 1972
Storm Center
41.72 N, 95.21W
KCYS
61.5
KLBF
72.0
KGRI
71.0
KLNK
70.5
KOFF
72.0
KDNR
70.5
KGLD
73.0
KCNK
76.0
KRSL
73.5
KFRI
76.5
KFLV
67.5
KSTL
66.5
KALS
66.0
KDDC
70.5
KICT
73.0
KTUL
73.0
KTCC
74.0
KOKC
72.5
KFSM
70.5
KLRF
69.5
KMEM
68.0
KCVS
74.0
Hysplit
Surface
850mb
700mb
Miles
0
205
410
820

# Storm Precipitation Analysis System (SPAS) For Storm #1206_1 SPAS Analysis

**General Storm Location**: Central Michigan -- “Big Rapids ‘86” storm

**Storm Dates**: September 9-12, 1986

**Event**: Synoptic/Warm Front

**DAD Zone 1**

**Latitude**: 43.6125

**Longitude**: -85.3125

**Max. Grid Rainfall Amount**: 13.18 inches

**Max. Observed Rainfall Amount**: 13.13” at Big Rapids, MI

**Number of Stations**: 114 (66 Daily, 15 Hourly, 1 Hourly Estimated, 1 Hourly Estimated Pseudo, 4 Hourly Pseudo, 20 Supplemental, and 7 Supplemental Estimated)

**SPAS Version**: 8.5

**Base Map Used:** Mean (1971-2000) PRISM September Precipitation

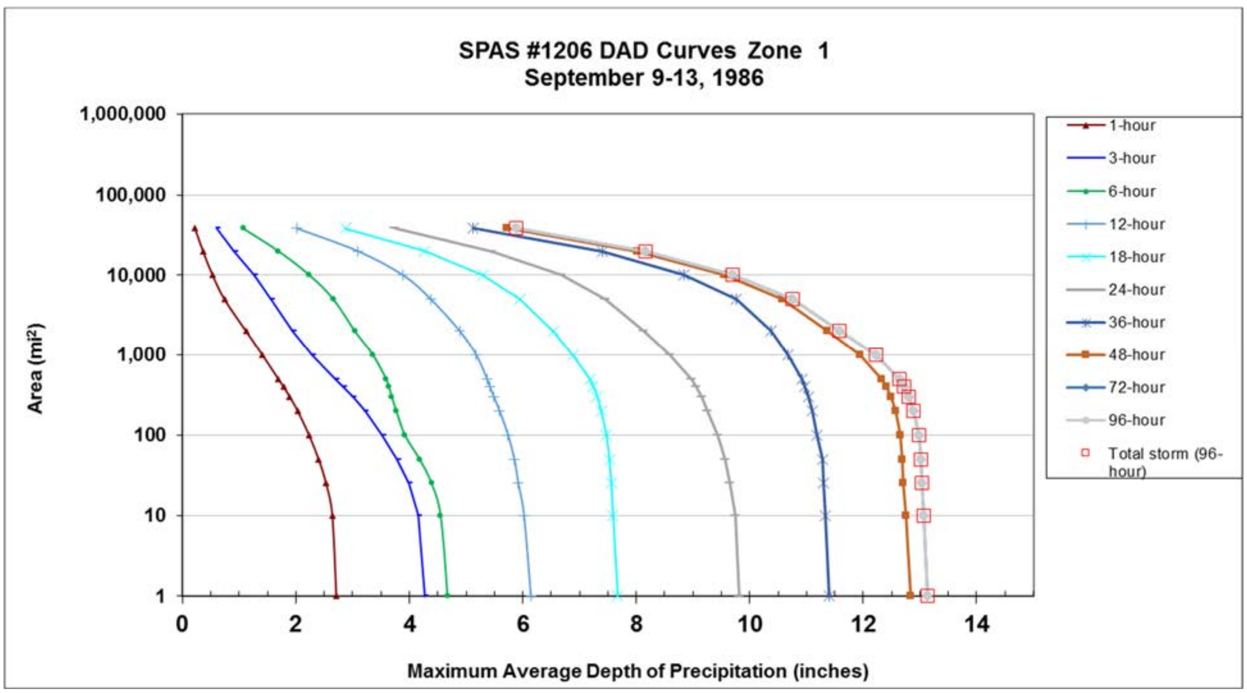
**Spatial resolution:** 30 seconds

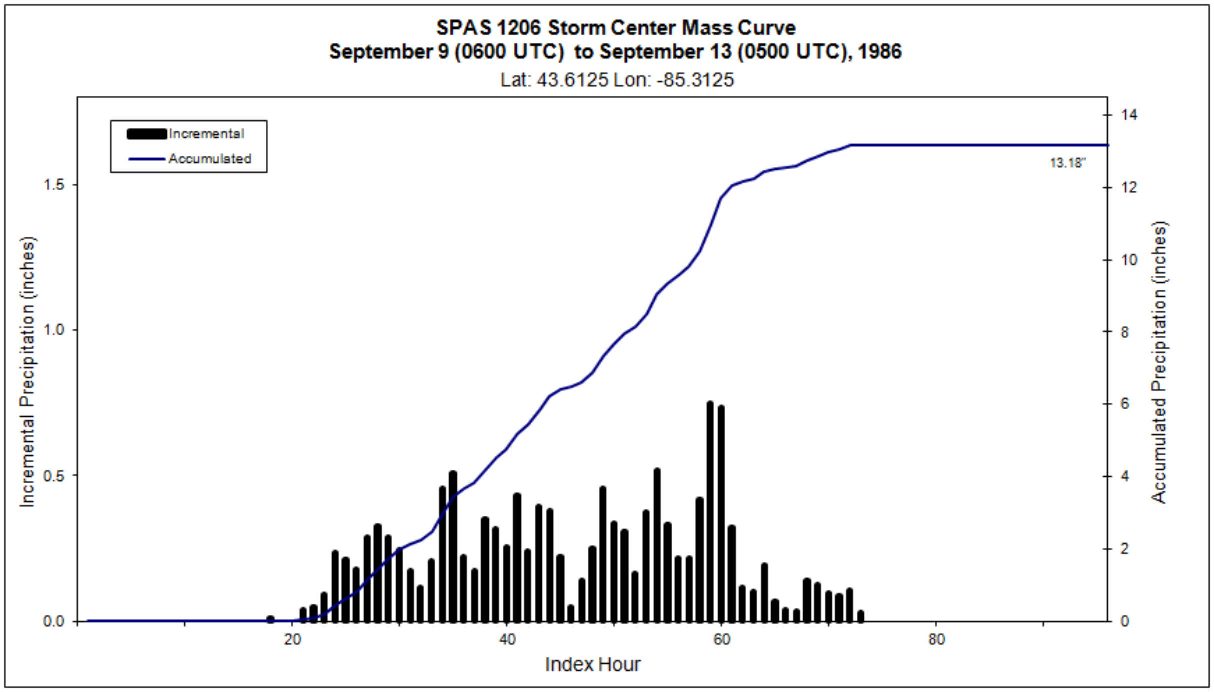
**Radar Included:** No

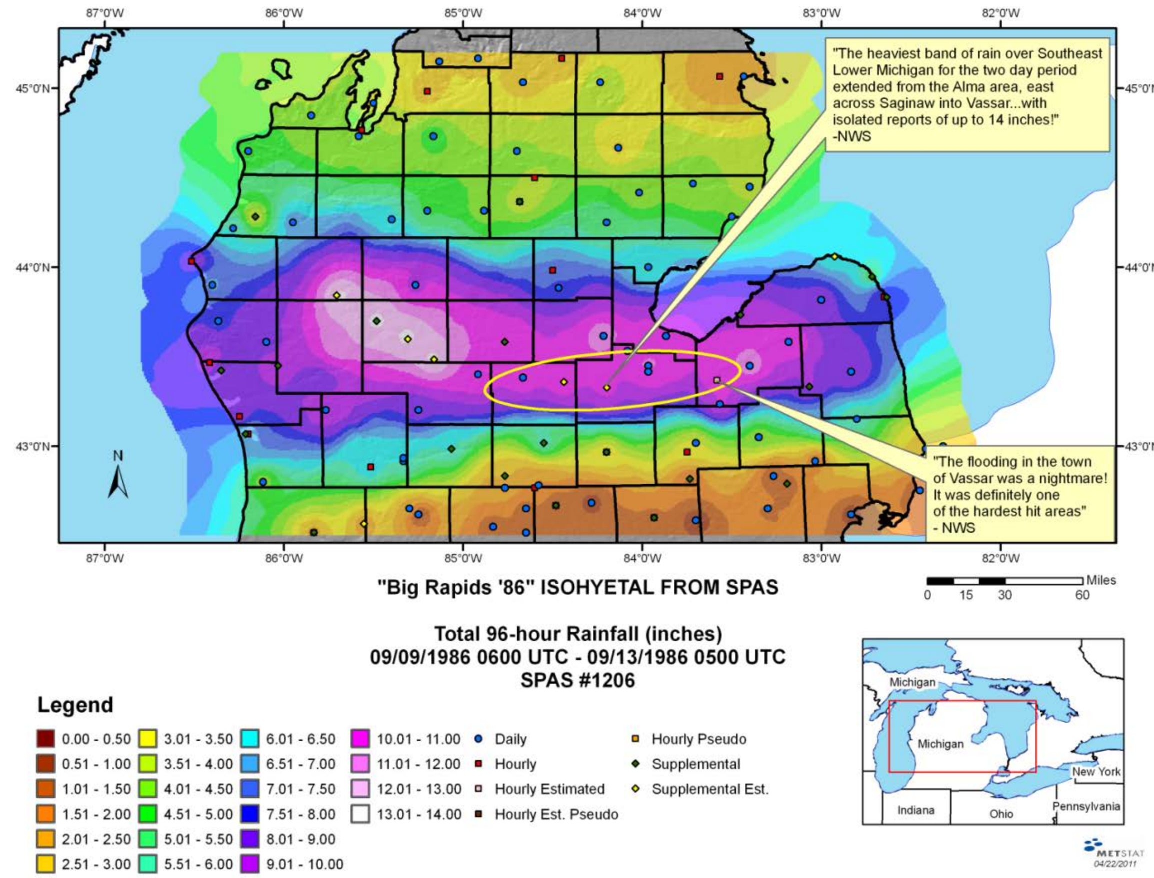
**Depth-Area-Duration (DAD) analysis**: Yes

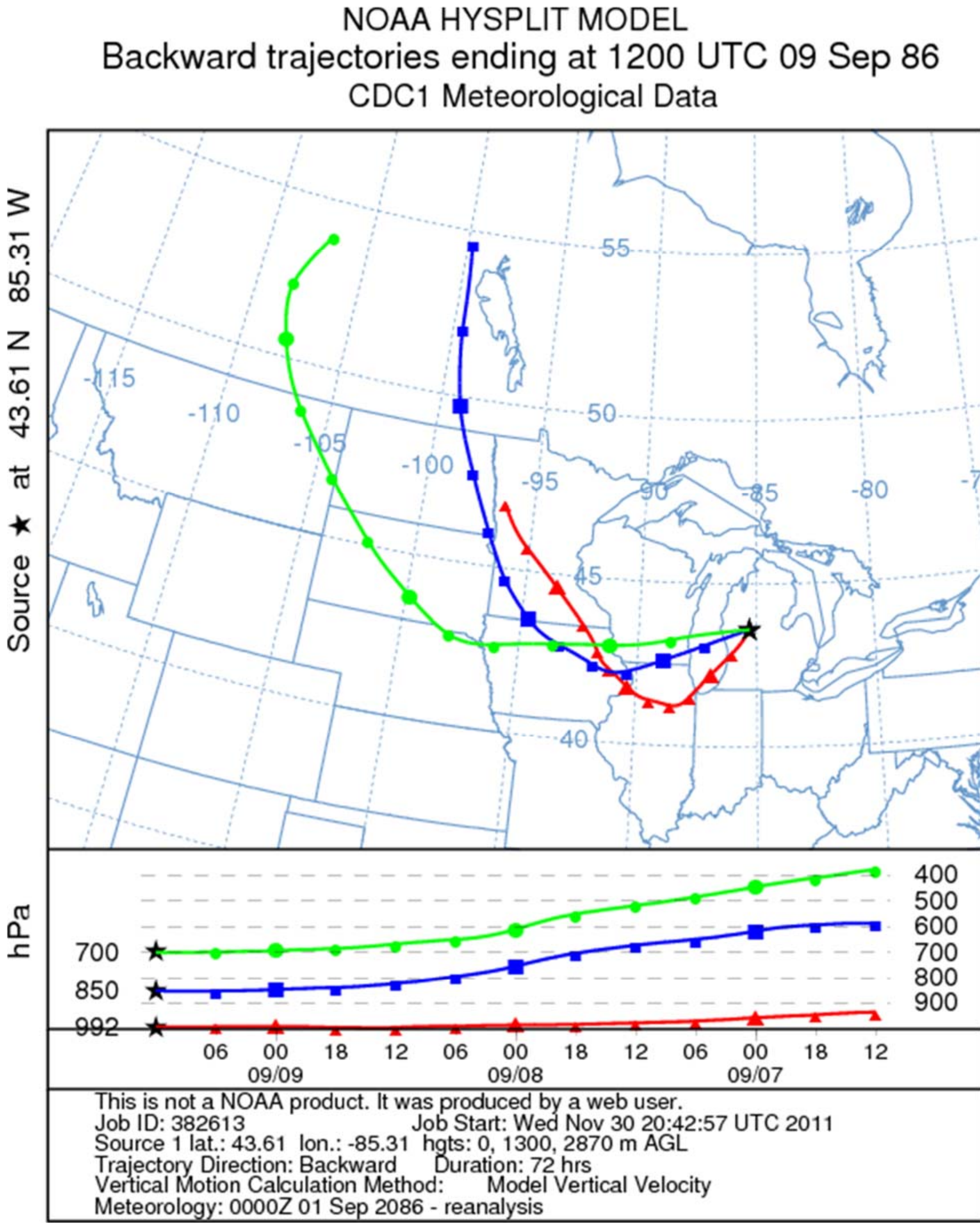
**Degree of confidence in results:** This storm occurred during a period of limited data, so our confidence in these results is slightly less than normal due to limited rainfall reports and limited hourly data throughout the storm center. Several supplemental estimated stations were added based on inferences from old isohyetal maps (NWS and EPRI) and discussions/summaries of the storm. I feel good about our analysis given the great cooperation we had from the Detroit NWS and the information they provided. Further confidence was instilled into the results when we found the DAD results compared rather favorably to those computed in the EPRI study.

| Storm 1206 - September 9 (0600 UTC) - September 13 (0500 UTC), 1986 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | |
| Area ($mi^2$) | Duration (hours) | | | | | | | | | | |
| | 1 | 3 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | 96 | Total |
| 0.4 | 2.72 | 4.28 | 4.68 | 6.17 | 7.68 | 9.84 | 11.42 | 12.86 | 13.17 | 13.17 | 13.17 |
| 1 | 2.71 | 4.27 | 4.67 | 6.14 | 7.67 | 9.81 | 11.40 | 12.83 | 13.13 | 13.13 | 13.13 |
| 10 | 2.64 | 4.15 | 4.55 | 6.02 | 7.59 | 9.74 | 11.33 | 12.75 | 13.06 | 13.06 | 13.06 |
| 25 | 2.53 | 3.99 | 4.39 | 5.92 | 7.56 | 9.65 | 11.30 | 12.71 | 13.03 | 13.03 | 13.03 |
| 50 | 2.40 | 3.78 | 4.18 | 5.85 | 7.53 | 9.57 | 11.28 | 12.69 | 13.01 | 13.01 | 13.01 |
| 100 | 2.23 | 3.52 | 3.92 | 5.74 | 7.47 | 9.43 | 11.19 | 12.66 | 12.98 | 12.98 | 12.98 |
| 200 | 2.03 | 3.21 | 3.77 | 5.59 | 7.38 | 9.26 | 11.10 | 12.57 | 12.89 | 12.89 | 12.89 |
| 300 | 1.89 | 3.00 | 3.69 | 5.49 | 7.31 | 9.16 | 11.03 | 12.49 | 12.81 | 12.81 | 12.81 |
| 400 | 1.78 | 2.83 | 3.64 | 5.42 | 7.24 | 9.06 | 10.97 | 12.40 | 12.72 | 12.72 | 12.72 |
| 500 | 1.69 | 2.69 | 3.59 | 5.37 | 7.18 | 8.97 | 10.92 | 12.33 | 12.64 | 12.64 | 12.64 |
| 1,000 | 1.41 | 2.29 | 3.36 | 5.18 | 6.89 | 8.59 | 10.68 | 11.94 | 12.22 | 12.22 | 12.22 |
| 2,000 | 1.12 | 1.94 | 3.04 | 4.89 | 6.54 | 8.13 | 10.37 | 11.36 | 11.58 | 11.58 | 11.58 |
| 5,000 | 0.74 | 1.56 | 2.66 | 4.38 | 5.95 | 7.45 | 9.76 | 10.57 | 10.75 | 10.75 | 10.75 |
| 10,000 | 0.53 | 1.26 | 2.24 | 3.89 | 5.30 | 6.68 | 8.84 | 9.55 | 9.70 | 9.70 | 9.70 |
| 20,000 | 0.36 | 0.91 | 1.69 | 3.09 | 4.27 | 5.45 | 7.40 | 8.01 | 8.16 | 8.16 | 8.16 |
| 38,327 | 0.22 | 0.60 | 1.07 | 2.02 | 2.87 | 3.73 | 5.13 | 5.72 | 5.88 | 5.88 | 5.88 |

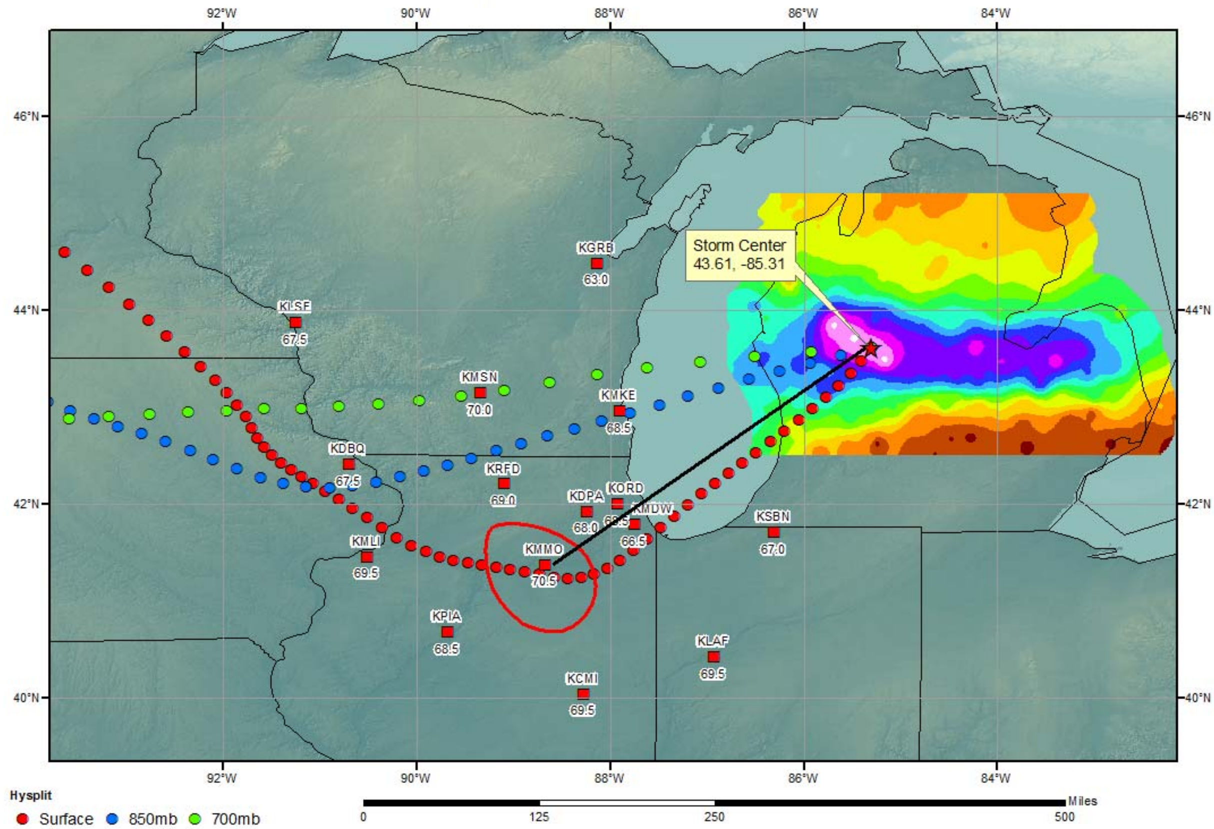



SPAS 1206 Storm Center Mass Curve
September 9 (0600 UTC) to September 13 (0500 UTC), 1986
Lat: 43.6125 Lon: -85.3125
Incremental
Accumulated
13.18"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
0
2
4
6
8
10
12
14
20
40
60
80


87°0'W
86°0'W
85°0'W
84°0'W
83°0'W
82°0'W
45°0'N
44°0'N
43°0'N
N
"The heaviest band of rain over Southeast Lower Michigan for the two day period extended from the Alma area, east across Saginaw into Vassar...with isolated reports of up to 14 inches!" -NWS
"The flooding in the town of Vassar was a nightmare! It was definitely one of the hardest hit areas" - NWS
"Big Rapids '86" ISOHYETAL FROM SPAS
Miles
0 15 30 60
Total 96-hour Rainfall (inches)
09/09/1986 0600 UTC - 09/13/1986 0500 UTC
SPAS #1206
Legend
0.00 - 0.50
0.51 - 1.00
1.01 - 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.00
3.01 - 3.50
3.51 - 4.00
4.01 - 4.50
4.51 - 5.00
5.01 - 5.50
5.51 - 6.00
6.01 - 6.50
6.51 - 7.00
7.01 - 7.50
7.51 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
Daily
Hourly
Hourly Estimated
Hourly Est. Pseudo
Hourly Pseudo
Supplemental
Supplemental Est.
Michigan
Michigan
New York
Indiana
Ohio
Pennsylvania
METSTAT
04/22/2011


NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 09 Sep 86
CDC1 Meteorological Data
Source ★ at 43.61 N 85.31 W
55
50
45
40
-115
-110
-105
-100
-95
-90
-85
-80
-75
hPa
700
850
992
400
500
600
700
800
900
06 00 18 12 06 00 18 12 06 00 18 12
09/09
09/08
09/07
This is not a NOAA product. It was produced by a web user.
Job ID: 382613 Job Start: Wed Nov 30 20:42:57 UTC 2011
Source 1 lat.: 43.61 lon.: -85.31 hgts: 0, 1300, 2870 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Sep 2086 - reanalysis

**SPAS 1206 Big Rapids, MI Storm Analysis**
September 9-13 1986



# Storm Precipitation Analysis System (SPAS) For Storm #1277_1 SPAS Analysis

**General Storm Location**: Kentucky, Ohio River Valley

**Storm Dates**: February 12-16, 1989

**Event**: Synoptic

**DAD Zone 1**

**Latitude**: 36.9958

**Longitude**: -88.2625

**Max. Grid Rainfall Amount**: 13.20"

**Max. Observed Rainfall Amount**: 13.16"

**Number of Stations**: 1177 (795 Daily, 256 Hourly, 78 Hourly Pseudo, and 48 Supplemental)

**SPAS Version**: 9.5

**Basemap:** PRISM 30-yr Mean (1981-2000) February Precipitation

**Spatial resolution:** 00:00:30 (~ 0.30 $mi^2$)

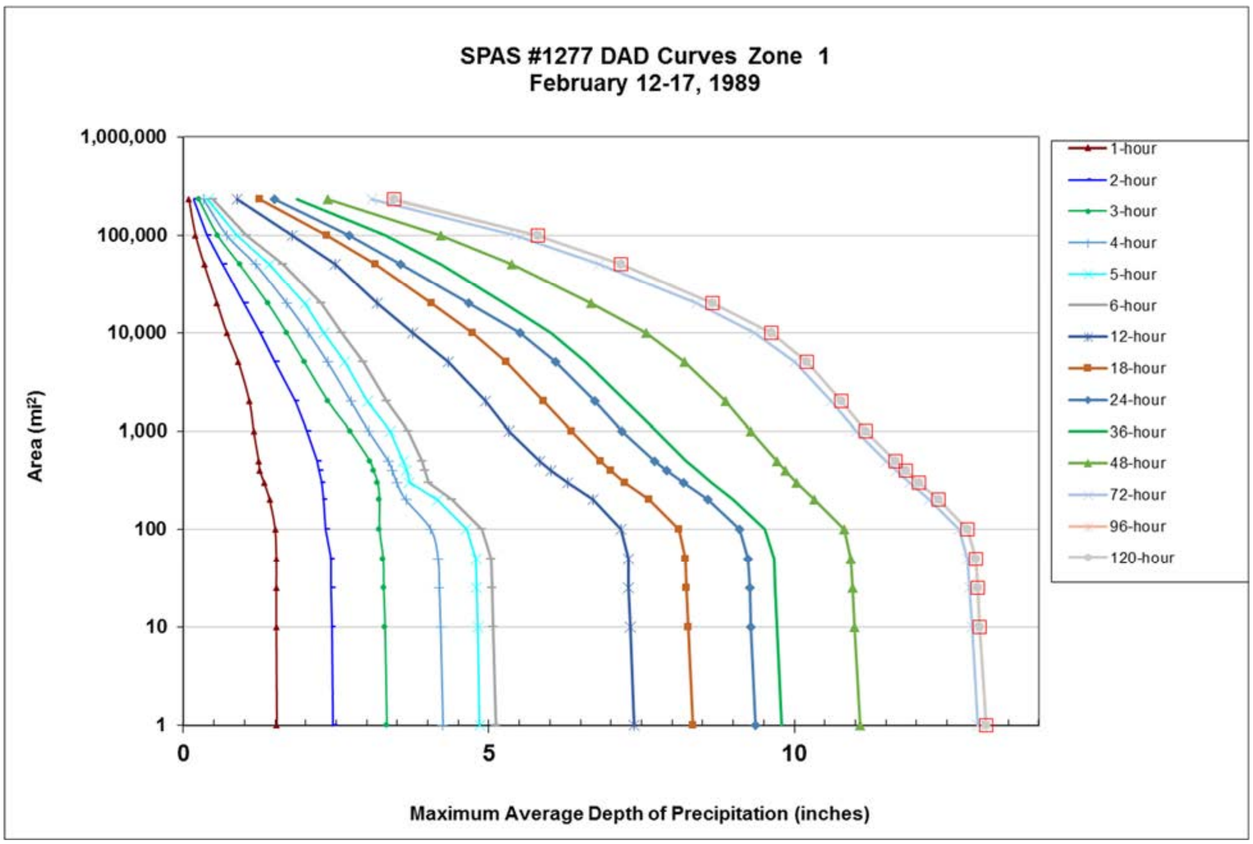
**Radar Included:** No

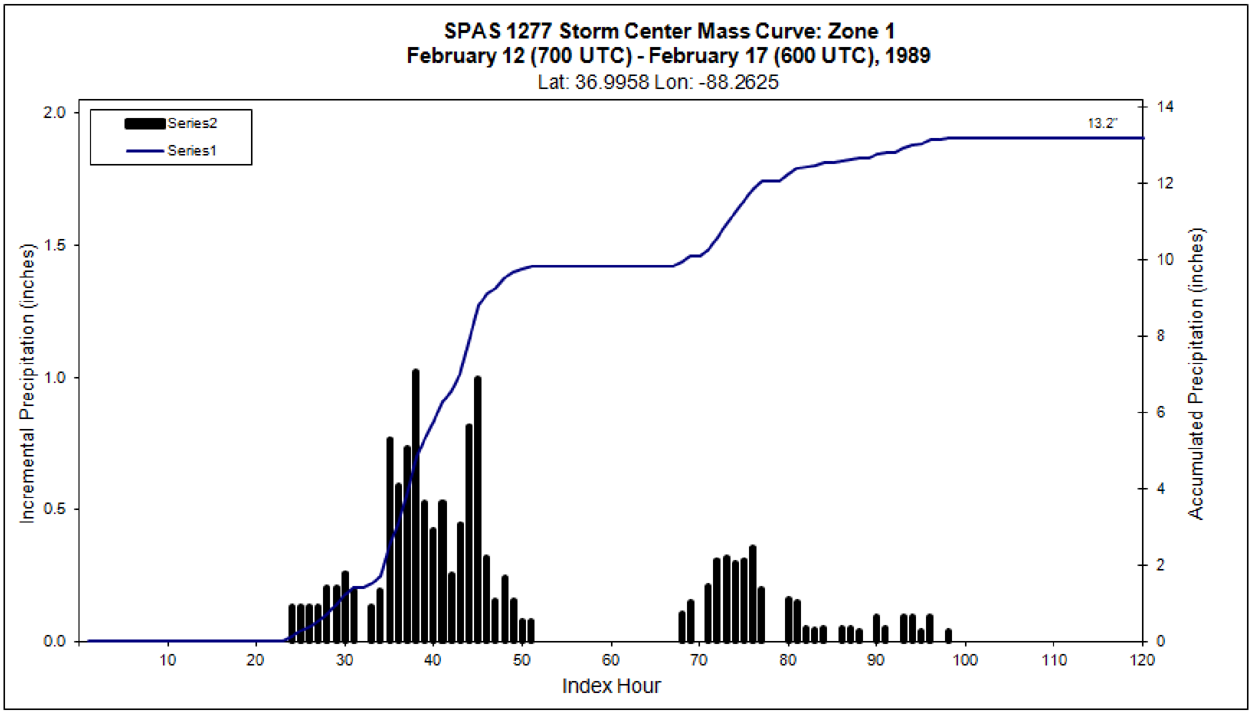
**Depth-Area-Duration (DAD) analysis**: Yes

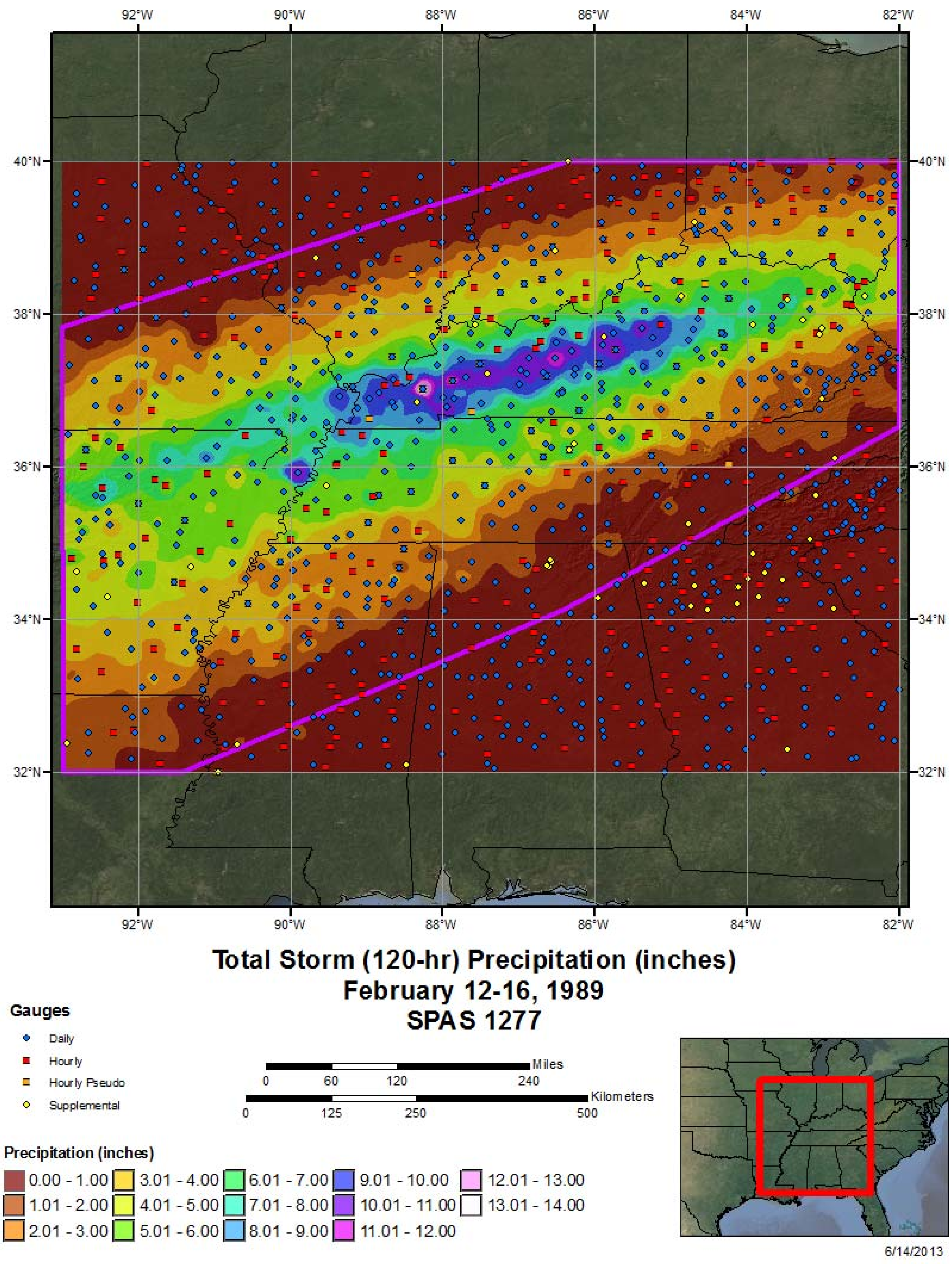
**Reliability of results:** This analysis was based on hourly data, daily data, and supplemental station data. We have a high degree of confidence in the station based storm total results, the spatial pattern is dependent on basemap, and the timing is based on hourly and hourly pseudo stations.

**Storm 1277 - February 12 (0700 UTC) - February 17 (0600 UTC), 1989**
**MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)**

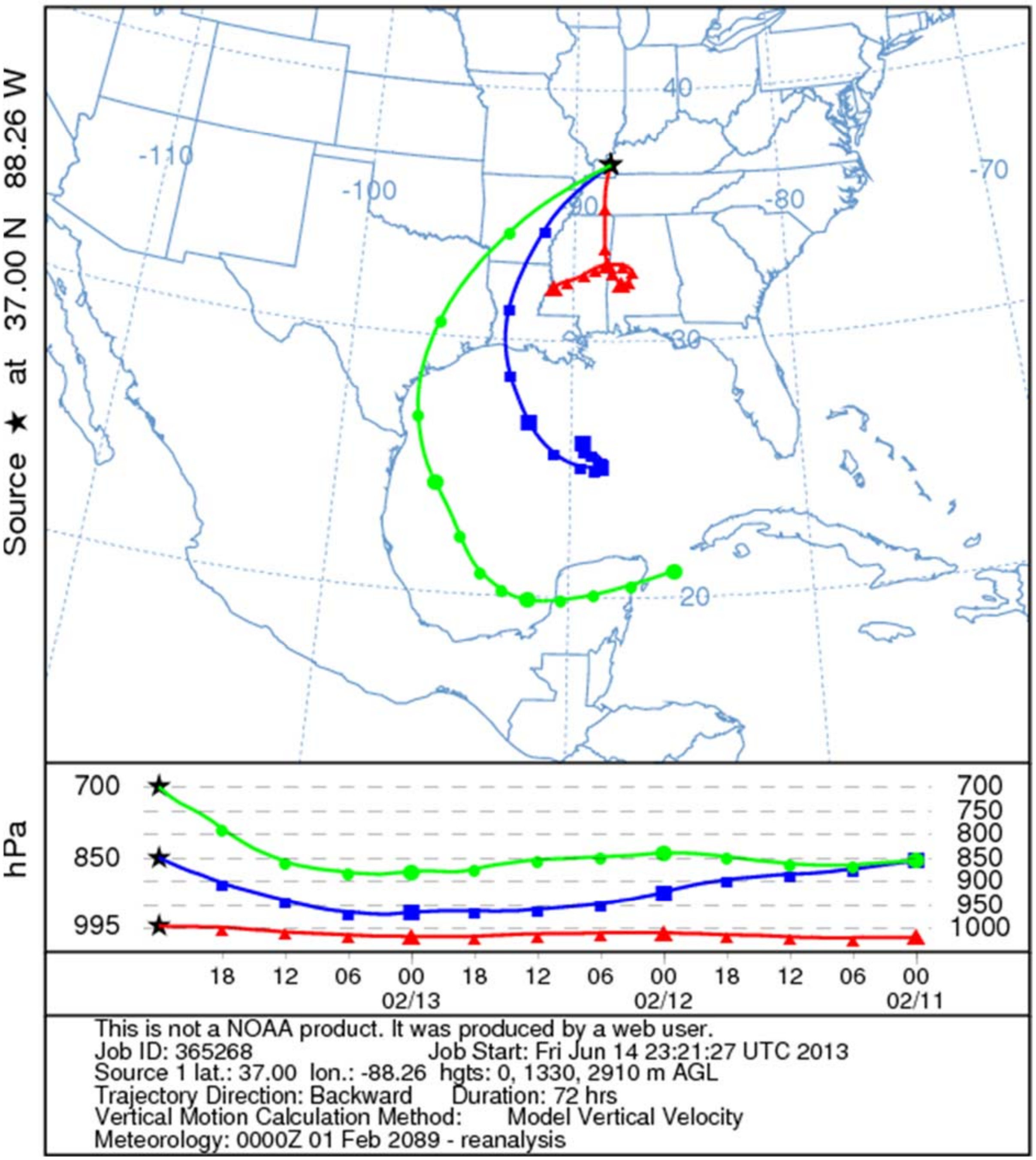
| Area ($mi^2$) | Duration (hours) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | 96 | 120 | Total |
| 0.4 | 1.54 | 2.45 | 3.33 | 4.26 | 4.87 | 5.13 | 7.39 | 8.37 | 9.40 | 9.82 | 11.12 | 13.05 | 13.19 | 13.19 | 13.19 |
| 1 | 1.53 | 2.45 | 3.33 | 4.25 | 4.85 | 5.12 | 7.37 | 8.34 | 9.37 | 9.79 | 11.08 | 13.01 | 13.14 | 13.14 | 13.14 |
| 10 | 1.52 | 2.43 | 3.30 | 4.21 | 4.82 | 5.07 | 7.32 | 8.27 | 9.29 | 9.72 | 10.99 | 12.91 | 13.04 | 13.04 | 13.04 |
| 25 | 1.52 | 2.42 | 3.28 | 4.19 | 4.80 | 5.05 | 7.29 | 8.24 | 9.27 | 9.69 | 10.95 | 12.87 | 13.00 | 13.00 | 13.00 |
| 50 | 1.52 | 2.41 | 3.27 | 4.17 | 4.79 | 5.04 | 7.28 | 8.22 | 9.24 | 9.67 | 10.92 | 12.84 | 12.97 | 12.97 | 12.97 |
| 100 | 1.50 | 2.33 | 3.21 | 4.05 | 4.63 | 4.89 | 7.16 | 8.11 | 9.10 | 9.51 | 10.81 | 12.70 | 12.83 | 12.83 | 12.83 |
| 200 | 1.41 | 2.29 | 3.21 | 3.64 | 4.16 | 4.40 | 6.71 | 7.62 | 8.58 | 9.00 | 10.33 | 12.21 | 12.36 | 12.36 | 12.36 |
| 300 | 1.32 | 2.26 | 3.18 | 3.49 | 3.70 | 4.02 | 6.29 | 7.23 | 8.18 | 8.65 | 10.03 | 11.89 | 12.04 | 12.04 | 12.04 |
| 400 | 1.25 | 2.22 | 3.11 | 3.42 | 3.65 | 3.96 | 6.02 | 6.99 | 7.91 | 8.41 | 9.85 | 11.68 | 11.82 | 11.82 | 11.82 |
| 500 | 1.23 | 2.19 | 3.05 | 3.35 | 3.60 | 3.90 | 5.83 | 6.82 | 7.72 | 8.23 | 9.71 | 11.51 | 11.66 | 11.66 | 11.66 |
| 1,000 | 1.15 | 2.02 | 2.73 | 3.03 | 3.38 | 3.68 | 5.33 | 6.35 | 7.18 | 7.74 | 9.29 | 11.02 | 11.17 | 11.17 | 11.17 |
| 2,000 | 1.08 | 1.83 | 2.37 | 2.74 | 3.02 | 3.32 | 4.95 | 5.90 | 6.73 | 7.24 | 8.88 | 10.61 | 10.77 | 10.77 | 10.77 |
| 5,000 | 0.90 | 1.50 | 1.98 | 2.36 | 2.64 | 2.94 | 4.34 | 5.28 | 6.09 | 6.58 | 8.21 | 10.01 | 10.20 | 10.20 | 10.20 |
| 10,000 | 0.71 | 1.25 | 1.69 | 2.04 | 2.30 | 2.59 | 3.75 | 4.74 | 5.51 | 6.02 | 7.57 | 9.35 | 9.62 | 9.62 | 9.62 |
| 20,000 | 0.55 | 1.00 | 1.38 | 1.69 | 1.99 | 2.26 | 3.17 | 4.06 | 4.67 | 5.26 | 6.68 | 8.40 | 8.66 | 8.66 | 8.66 |
| 50,000 | 0.34 | 0.65 | 0.92 | 1.18 | 1.41 | 1.63 | 2.49 | 3.14 | 3.56 | 4.21 | 5.37 | 6.81 | 7.16 | 7.17 | 7.17 |
| 100,000 | 0.20 | 0.39 | 0.56 | 0.71 | 0.88 | 1.03 | 1.78 | 2.35 | 2.72 | 3.31 | 4.21 | 5.44 | 5.78 | 5.80 | 5.80 |
| 233,469 | 0.09 | 0.17 | 0.25 | 0.33 | 0.40 | 0.48 | 0.88 | 1.24 | 1.49 | 1.86 | 2.36 | 3.08 | 3.39 | 3.45 | 3.45 |

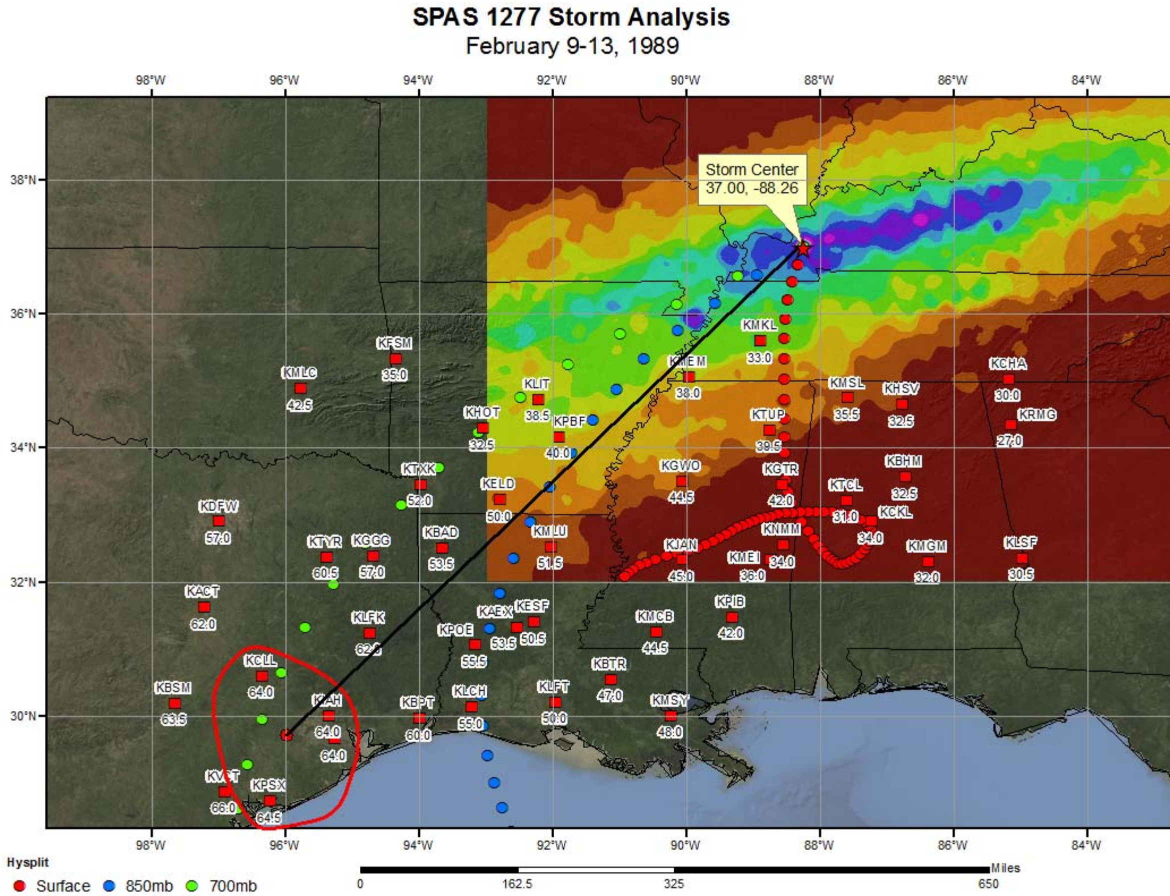



SPAS 1277 Storm Center Mass Curve: Zone 1
February 12 (700 UTC) - February 17 (600 UTC), 1989
Lat: 36.9958 Lon: -88.2625
Series2
Series1
13.2"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
2.0
0
2
4
6
8
10
12
14
10
20
30
40
50
60
70
80
90
100
110
120


92°W
90°W
88°W
86°W
84°W
82°W
40°N
38°N
36°N
34°N
32°N
Total Storm (120-hr) Precipitation (inches)
February 12-16, 1989
SPAS 1277
Gauges
Daily
Hourly
Hourly Pseudo
Supplemental
Miles
0
60
120
240
Kilometers
0
125
250
500
Precipitation (inches)
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
6/14/2013

NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 14 Feb 89
CDC1 Meteorological Data




SPAS 1277 Storm Analysis
February 9-13, 1989
Storm Center
37.00, -88.26
Hysplit
Surface
850mb
700mb
Miles
0
162.5
325
650

# Storm Precipitation Analysis System (SPAS) For Storm #1735_1 SPAS Analysis

**General Storm Location**: Coldwater, MI

**Storm Dates**: May 29 – June 3, 1989

**Event**: Synoptic/Warm Front

**DAD Zone 1**

**Latitude**: 41.9625

**Longitude**: - 85.0042

**Max. Grid Rainfall Amount**: 9.20”

**Max. Observed Rainfall Amount**: 9.10”

**Number of Stations**: 935

**SPAS Version**: 10.0

**Base Map Used:** PRISM climatology from May 1989

**Spatial resolution:** 0.2420

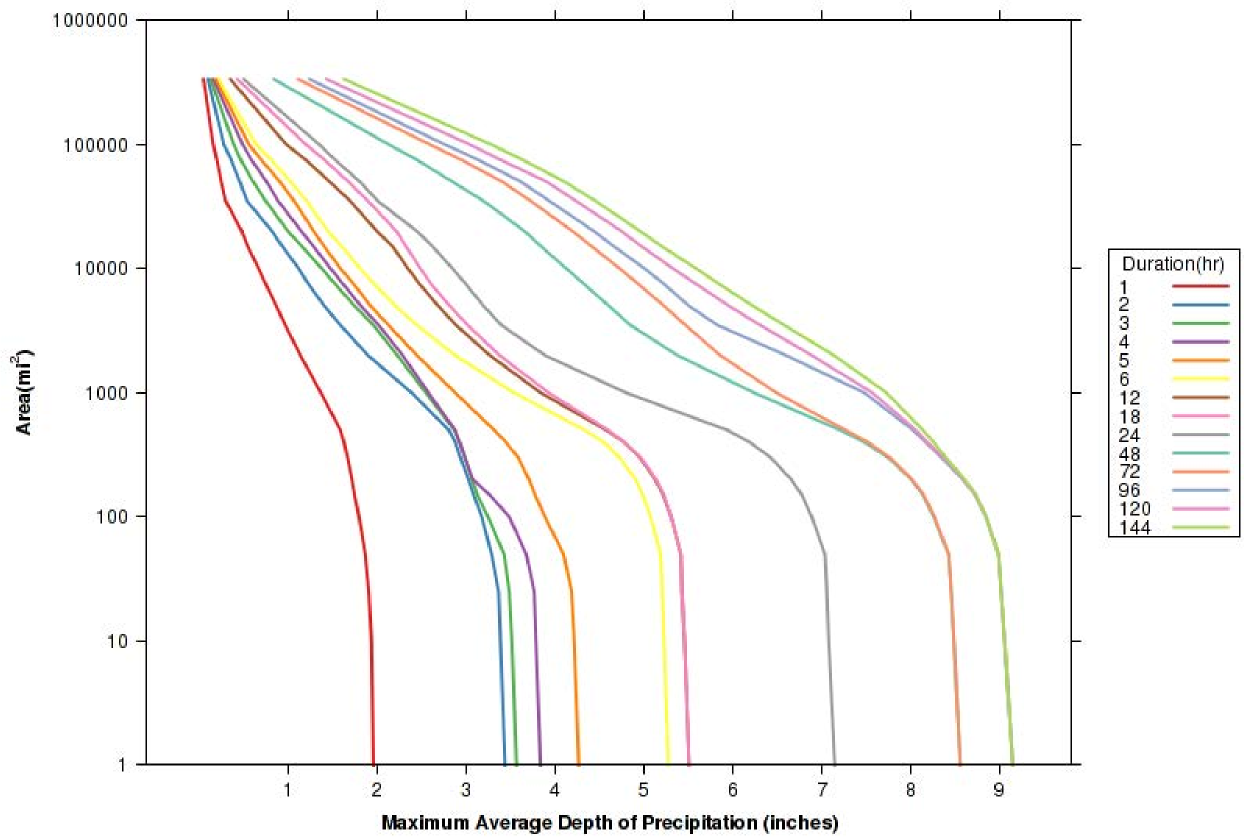
**Radar Included:** No

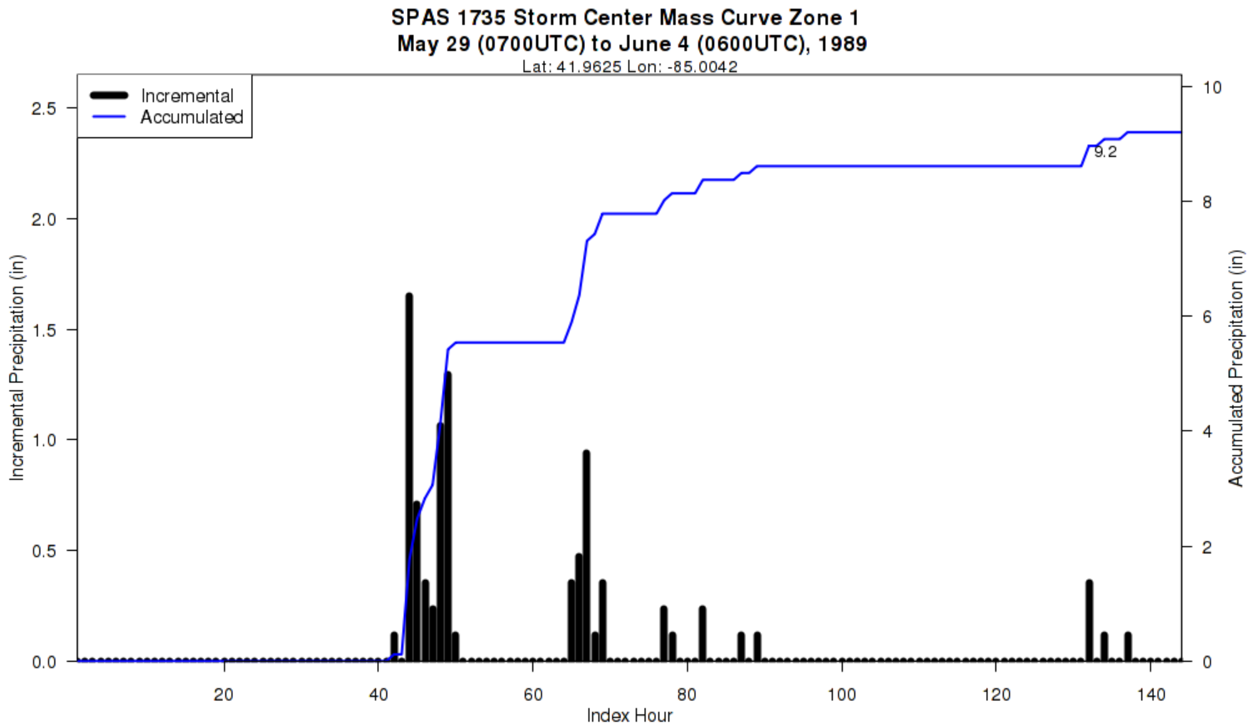
**Depth-Area-Duration (DAD) analysis**: Yes

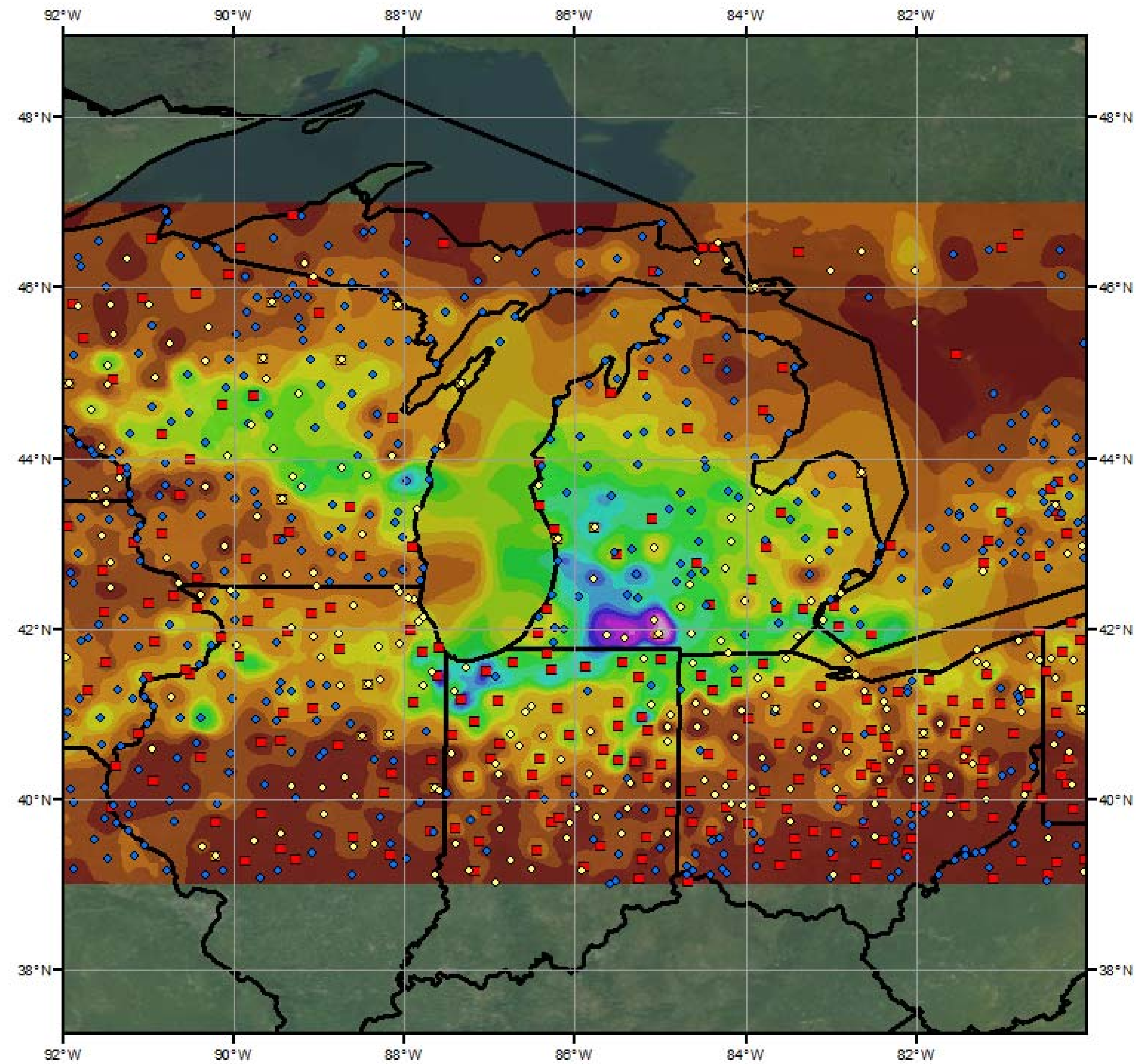
**Degree of confidence in results:** This analysis was based on 935 hourly stations, daily data, and supplemental station data. We have a good degree of confidence for the station based storm total results. The spatial pattern is fully dependent on the PRISM basemap. Timing is based on the hourly and hourly pseudo stations. Several daily stations were moved to supplemental due to timing issues and to ensure data consistency.

| SPAS 1735 - May 29 (0700 UTC) - June 4 (0600 UTC), 1989 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | |
| Area ($mi^2$) | Duration (hours) | | | | | | | | | |
| | 1 | 6 | 12 | 24 | 48 | 72 | 96 | 120 | 144 | Total |
| 0.4 | 1.96 | 5.30 | 5.53 | 7.18 | 8.59 | 8.59 | 9.18 | 9.18 | 9.18 | 9.18 |
| 1 | 1.96 | 5.28 | 5.51 | 7.15 | 8.56 | 8.56 | 9.15 | 9.15 | 9.15 | 9.15 |
| 10 | 1.94 | 5.23 | 5.46 | 7.08 | 8.49 | 8.49 | 9.06 | 9.06 | 9.06 | 9.06 |
| 25 | 1.91 | 5.21 | 5.43 | 7.06 | 8.46 | 8.46 | 9.02 | 9.02 | 9.02 | 9.02 |
| 50 | 1.87 | 5.19 | 5.42 | 7.04 | 8.43 | 8.43 | 8.99 | 8.99 | 8.99 | 8.99 |
| 100 | 1.80 | 5.08 | 5.31 | 6.89 | 8.26 | 8.27 | 8.85 | 8.85 | 8.85 | 8.85 |
| 200 | 1.72 | 4.91 | 5.13 | 6.66 | 8.01 | 8.02 | 8.59 | 8.60 | 8.61 | 8.61 |
| 300 | 1.67 | 4.73 | 4.96 | 6.43 | 7.75 | 7.77 | 8.35 | 8.37 | 8.40 | 8.40 |
| 400 | 1.63 | 4.55 | 4.78 | 6.19 | 7.48 | 7.52 | 8.17 | 8.19 | 8.26 | 8.26 |
| 500 | 1.59 | 4.34 | 4.58 | 5.94 | 7.21 | 7.27 | 8.03 | 8.06 | 8.14 | 8.14 |
| 1,000 | 1.37 | 3.54 | 3.84 | 4.80 | 6.24 | 6.49 | 7.48 | 7.57 | 7.73 | 7.73 |
| 2,000 | 1.14 | 2.88 | 3.27 | 3.89 | 5.38 | 5.86 | 6.60 | 6.89 | 7.14 | 7.14 |
| 5,000 | 0.87 | 2.21 | 2.69 | 3.20 | 4.61 | 5.23 | 5.51 | 5.96 | 6.23 | 6.23 |
| 10,000 | 0.67 | 1.81 | 2.35 | 2.85 | 4.13 | 4.73 | 5.01 | 5.33 | 5.59 | 5.59 |
| 20,000 | 0.48 | 1.45 | 2.00 | 2.45 | 3.66 | 4.20 | 4.44 | 4.75 | 4.96 | 4.96 |
| 50,000 | 0.25 | 1.03 | 1.47 | 1.81 | 2.85 | 3.41 | 3.62 | 3.91 | 4.11 | 4.11 |
| 100,000 | 0.16 | 0.64 | 0.98 | 1.35 | 2.13 | 2.59 | 2.76 | 3.04 | 3.28 | 3.28 |
| 335,486 | 0.05 | 0.22 | 0.35 | 0.50 | 0.84 | 1.11 | 1.24 | 1.43 | 1.63 | 1.63 |

**SPAS 1735 DAD Curves Zone 1**
**May 29 (0700UTC) to June 4 (0600UTC), 1989**




SPAS 1735 Storm Center Mass Curve Zone 1
May 29 (0700UTC) to June 4 (0600UTC), 1989
Lat: 41.9625 Lon: -85.0042
Incremental
Accumulated
9.2
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
0
2
4
6
8
10
20
40
60
80
100
120
140




**Total Storm (144-hours) Precipitation (inches)**
**May 29 - June 3, 1989**
**SPAS 1735 - Coldwater, MI**

**Gauges**

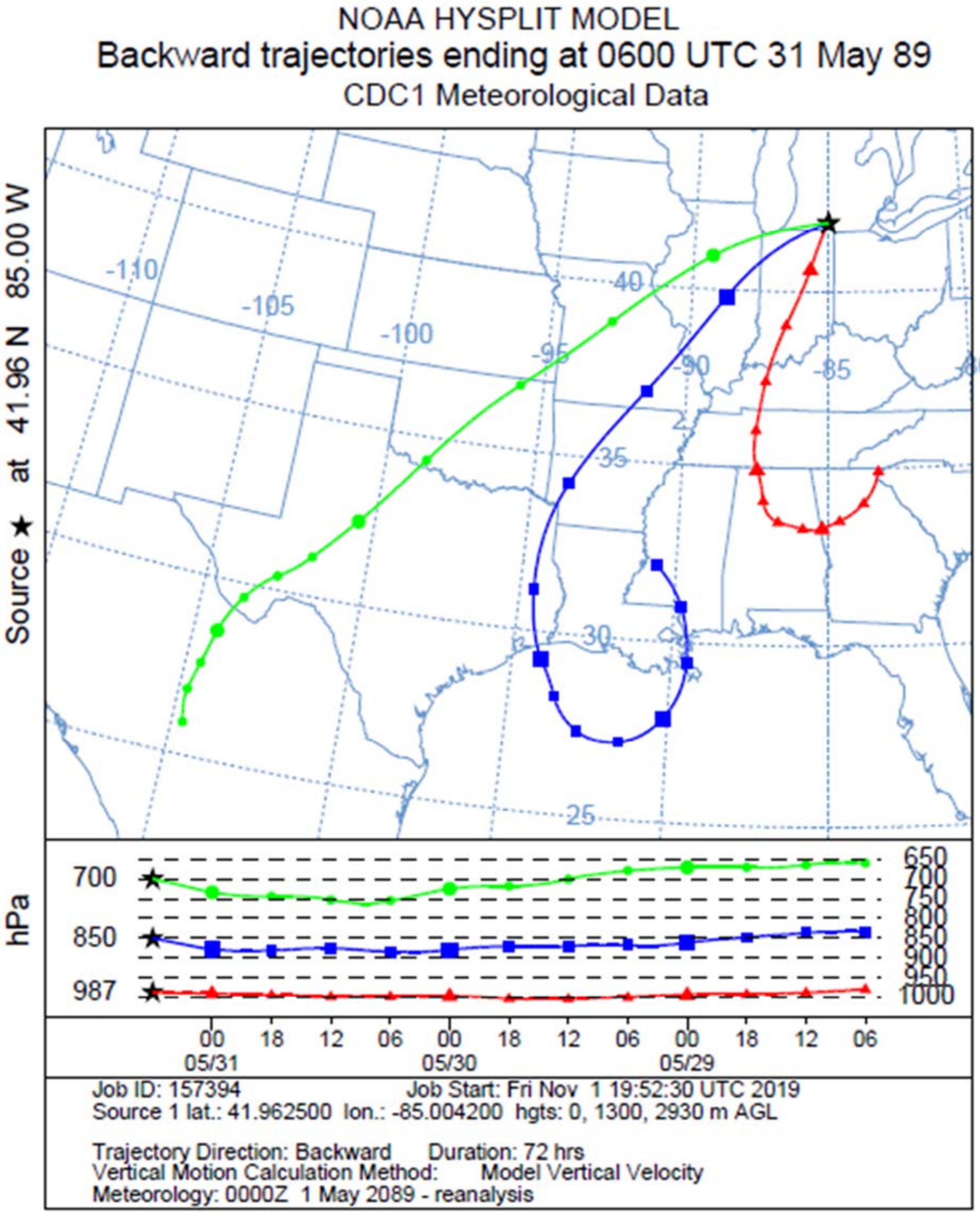
- Daily
- Hourly
- Hourly Pseudo
- Supplemental

Miles: 0, 50, 100, 200

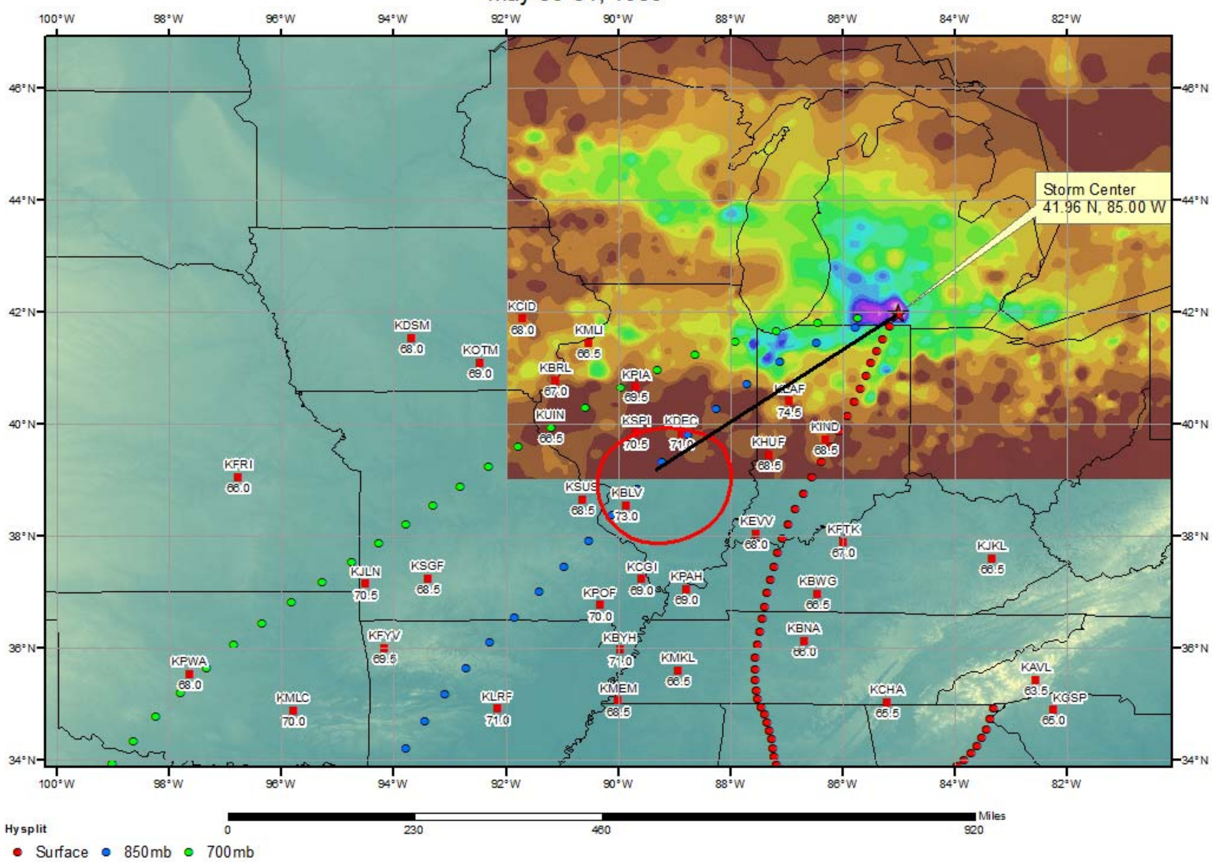
Kilometers: 0, 105, 210, 420

**Precipitation (inches)**

| | | | |
|---|---|---|---|
| 0.00 - 0.50 | 2.01 - 2.50 | 4.51 - 5.00 | 7.01 - 7.50 |
| 0.51 - 1.00 | 2.51 - 3.00 | 5.01 - 5.50 | 7.51 - 8.00 |
| 1.01 - 1.50 | 3.01 - 3.50 | 5.51 - 6.00 | 8.01 - 8.50 |
| 1.51 - 2.00 | 3.51 - 4.00 | 6.01 - 6.50 | 8.51 - 9.00 |
| | 4.01 - 4.50 | 6.51 - 7.00 | 9.01 - 9.50 |


NOAA HYSPLIT MODEL
Backward trajectories ending at 0600 UTC 31 May 89
CDC1 Meteorological Data
Source ★ at 41.96 N 85.00 W
-110
-105
-100
-95
-90
-85
-80
40
35
30
25
hPa
700
850
987
650
700
750
800
850
900
950
1000
00 18 12 06 00 18 12 06 00 18 12 06
05/31
05/30
05/29
Job ID: 157394 Job Start: Fri Nov 1 19:52:30 UTC 2019
Source 1 lat.: 41.962500 lon.: -85.004200 hgts: 0, 1300, 2930 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 May 2089 - reanalysis

## SPAS 1735 Storm Analysis
May 30-31, 1989



# Storm Precipitation Analysis System (SPAS) For Storm #1244_1 SPAS Analysis

**General Storm Location**: Mainly Kentucky and Tennessee.

**Storm Dates**: February 28 - March 4, 1997

**Event**: General storm

**DAD Zone 1**

**Latitude**: 38.1000

**Longitude**: -85.6700

**Max. Grid Rainfall Amount**: 13.51

**Max. Observed Rainfall Amount**: 13.04

**Number of Stations**: 872 (435 Daily, 118 Hourly, 0 Hourly Estimated, 48 Hourly Pseudo, 252 Supplemental, and 19 Supplemental Estimated)

**SPAS Version**: 9.5

**Basemap:** PRISM Mean (1971-2000) March precipitation and SPAS ippt precipitation

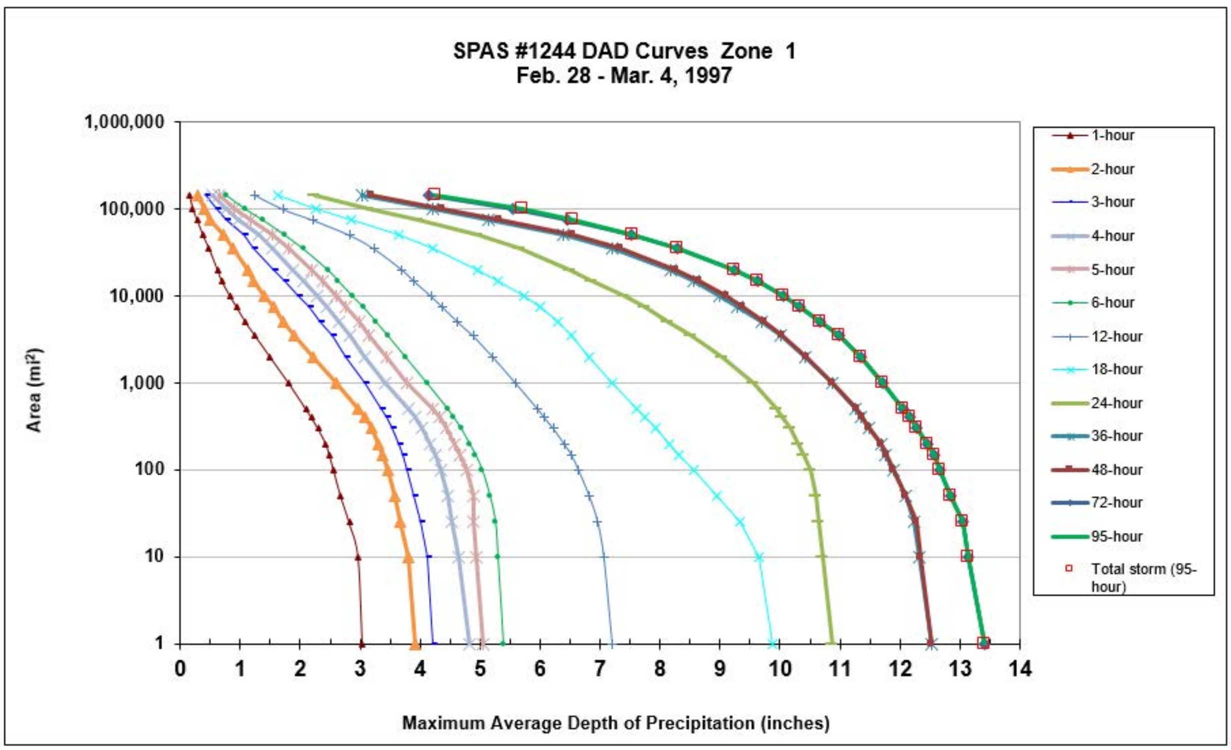
**Spatial resolution:** 36 seconds (~ 0.40 $mi^2$)

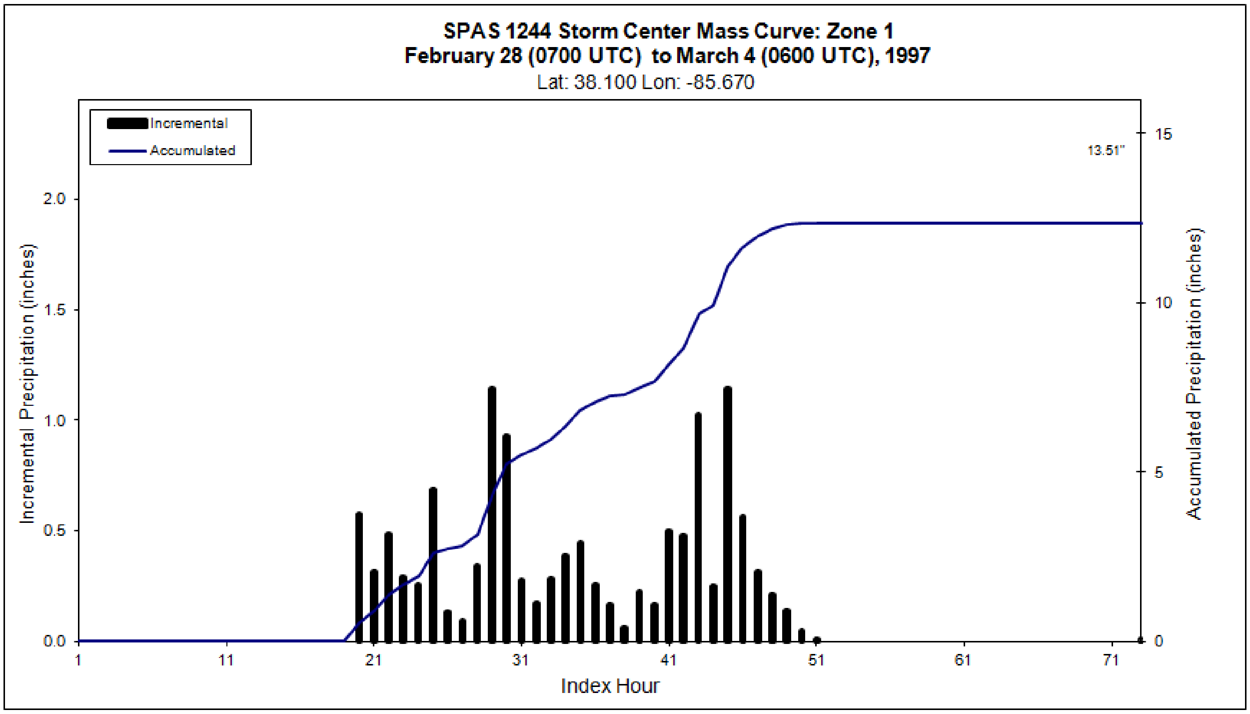
**Radar Included:** Yes

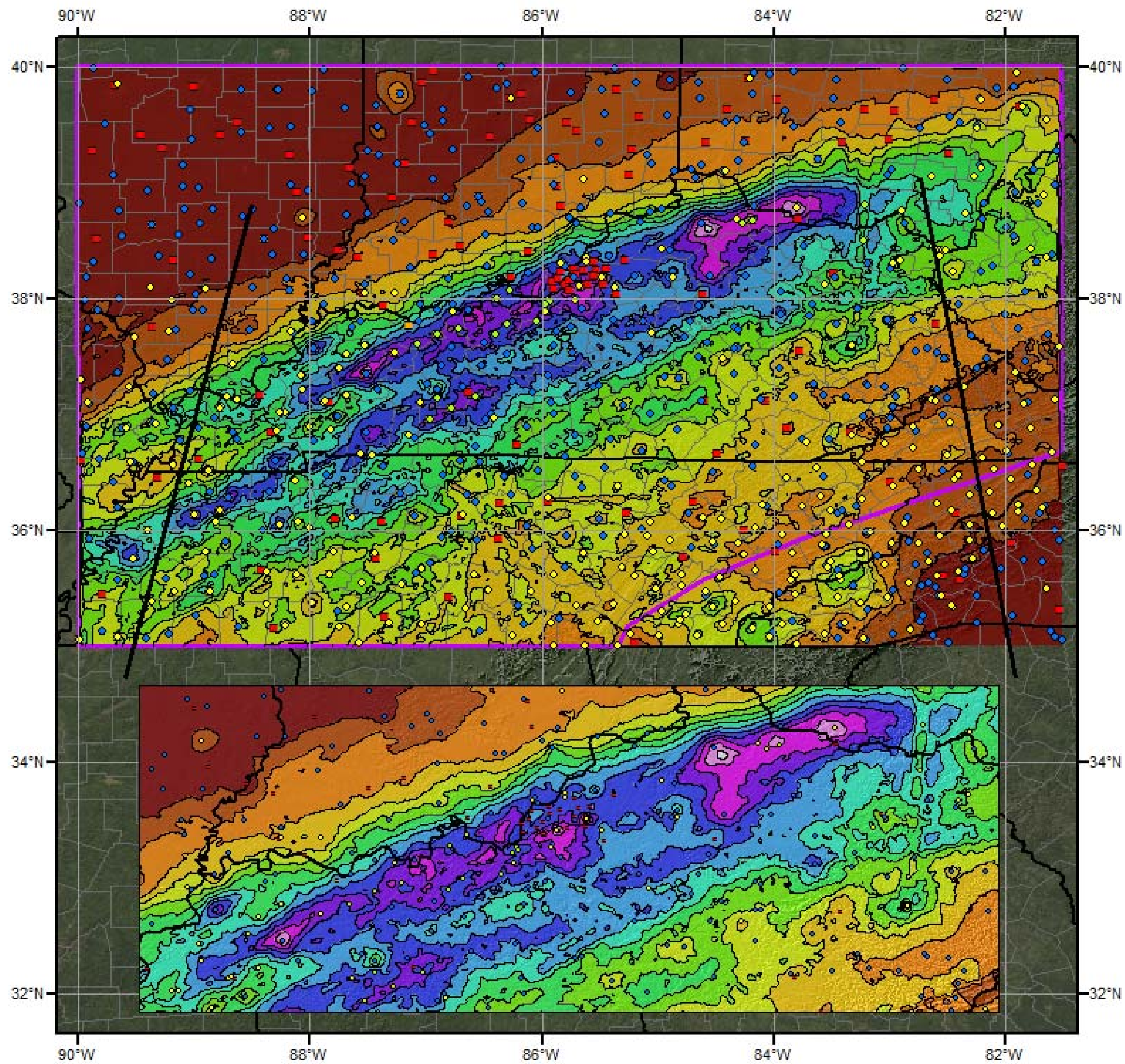
**Depth-Area-Duration (DAD) analysis**: Yes

**Reliability of results:** This analysis was based on WDT NEXRAD data (unblocked) and extensive gauge data, we have a very high degree of confidence in the results. There were a few areas of radar beam blockage in the domain, these areas were adjusted using a beam blockage mask. The radar blocked areas did not affect the SPAS analysis. The Southeastern region was not included in the DAD, these regions did not have radar coverage and the results are not completely accurate so they were not included in the analysis.

| Storm 1244 - February 28 (0700 UTC) - March 4 (0500 UTC), 1997<br>MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Duration (hours) | | | | | | | | | | | | | |
| Area (mi$^2$) | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | 95 | Total |
| 0.4 | 3.06 | 3.95 | 4.27 | 4.88 | 5.11 | 5.42 | 7.25 | 9.96 | 10.94 | 12.60 | 12.61 | 13.51 | 13.51 | 13.51 |
| 1 | 3.04 | 3.92 | 4.22 | 4.83 | 5.06 | 5.38 | 7.20 | 9.88 | 10.87 | 12.52 | 12.53 | 13.40 | 13.40 | 13.40 |
| 10 | 2.97 | 3.80 | 4.11 | 4.64 | 4.94 | 5.29 | 7.06 | 9.66 | 10.72 | 12.32 | 12.35 | 13.15 | 13.15 | 13.15 |
| 25 | 2.82 | 3.67 | 4.01 | 4.52 | 4.90 | 5.25 | 6.96 | 9.33 | 10.65 | 12.24 | 12.28 | 13.04 | 13.04 | 13.04 |
| 50 | 2.68 | 3.58 | 3.90 | 4.45 | 4.88 | 5.16 | 6.82 | 8.95 | 10.61 | 12.10 | 12.10 | 12.85 | 12.85 | 12.85 |
| 100 | 2.56 | 3.46 | 3.79 | 4.34 | 4.77 | 5.03 | 6.64 | 8.56 | 10.52 | 11.89 | 11.89 | 12.67 | 12.67 | 12.67 |
| 150 | 2.49 | 3.37 | 3.71 | 4.25 | 4.66 | 4.92 | 6.52 | 8.32 | 10.39 | 11.76 | 11.78 | 12.57 | 12.57 | 12.57 |
| 200 | 2.43 | 3.30 | 3.64 | 4.17 | 4.58 | 4.82 | 6.40 | 8.16 | 10.30 | 11.68 | 11.68 | 12.45 | 12.45 | 12.45 |
| 300 | 2.30 | 3.18 | 3.53 | 4.04 | 4.44 | 4.68 | 6.22 | 7.92 | 10.17 | 11.49 | 11.49 | 12.28 | 12.28 | 12.28 |
| 400 | 2.19 | 3.07 | 3.44 | 3.92 | 4.32 | 4.56 | 6.07 | 7.75 | 10.04 | 11.36 | 11.37 | 12.16 | 12.16 | 12.16 |
| 500 | 2.10 | 2.96 | 3.36 | 3.81 | 4.21 | 4.46 | 5.96 | 7.62 | 9.94 | 11.26 | 11.27 | 12.06 | 12.06 | 12.06 |
| 1,000 | 1.81 | 2.61 | 3.08 | 3.41 | 3.79 | 4.11 | 5.59 | 7.20 | 9.55 | 10.88 | 10.88 | 11.72 | 11.72 | 11.72 |
| 2,000 | 1.50 | 2.21 | 2.77 | 3.08 | 3.44 | 3.75 | 5.21 | 6.81 | 9.03 | 10.43 | 10.45 | 11.35 | 11.35 | 11.35 |
| 3,500 | 1.25 | 1.89 | 2.53 | 2.82 | 3.15 | 3.46 | 4.88 | 6.52 | 8.51 | 10.01 | 10.03 | 10.98 | 10.98 | 10.98 |
| 5,000 | 1.09 | 1.72 | 2.34 | 2.65 | 2.98 | 3.27 | 4.63 | 6.30 | 8.14 | 9.70 | 9.74 | 10.68 | 10.68 | 10.68 |
| 7,500 | 0.94 | 1.55 | 2.14 | 2.44 | 2.75 | 3.05 | 4.37 | 6.00 | 7.74 | 9.29 | 9.37 | 10.33 | 10.33 | 10.33 |
| 10,000 | 0.83 | 1.41 | 1.97 | 2.29 | 2.60 | 2.87 | 4.18 | 5.73 | 7.40 | 9.00 | 9.10 | 10.05 | 10.06 | 10.06 |
| 15,000 | 0.69 | 1.23 | 1.73 | 2.05 | 2.37 | 2.63 | 3.89 | 5.30 | 6.87 | 8.57 | 8.66 | 9.62 | 9.62 | 9.62 |
| 20,000 | 0.62 | 1.12 | 1.55 | 1.87 | 2.20 | 2.46 | 3.70 | 4.96 | 6.50 | 8.17 | 8.26 | 9.24 | 9.24 | 9.24 |
| 35,000 | 0.48 | 0.87 | 1.23 | 1.53 | 1.81 | 2.05 | 3.23 | 4.22 | 5.66 | 7.21 | 7.34 | 8.30 | 8.30 | 8.30 |
| 50,000 | 0.38 | 0.72 | 1.05 | 1.30 | 1.54 | 1.75 | 2.83 | 3.64 | 4.96 | 6.38 | 6.54 | 7.53 | 7.55 | 7.55 |
| 75,000 | 0.28 | 0.50 | 0.77 | 0.98 | 1.18 | 1.38 | 2.21 | 2.85 | 3.96 | 5.14 | 5.32 | 6.45 | 6.54 | 6.54 |
| 100,000 | 0.21 | 0.40 | 0.61 | 0.77 | 0.91 | 1.09 | 1.71 | 2.27 | 3.15 | 4.21 | 4.37 | 5.55 | 5.71 | 5.71 |
| 146,019 | 0.15 | 0.28 | 0.42 | 0.53 | 0.65 | 0.76 | 1.24 | 1.62 | 2.25 | 3.04 | 3.18 | 4.15 | 4.26 | 4.26 |



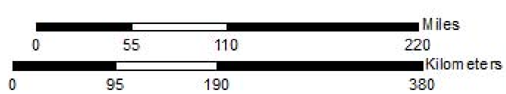

SPAS 1244 Storm Center Mass Curve: Zone 1
February 28 (0700 UTC) to March 4 (0600 UTC), 1997
Lat: 38.100 Lon: -85.670
Incremental
Accumulated
13.51"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
2.0
0
5
10
15
1
11
21
31
41
51
61
71




**Total Precipitation (95-hrs)**
**SPAS-NEXRAD: 1244 Louisville, KY**
**2/28/1997 0700 UTC- 3/4/1997 0500 UTC**

**Gauges**

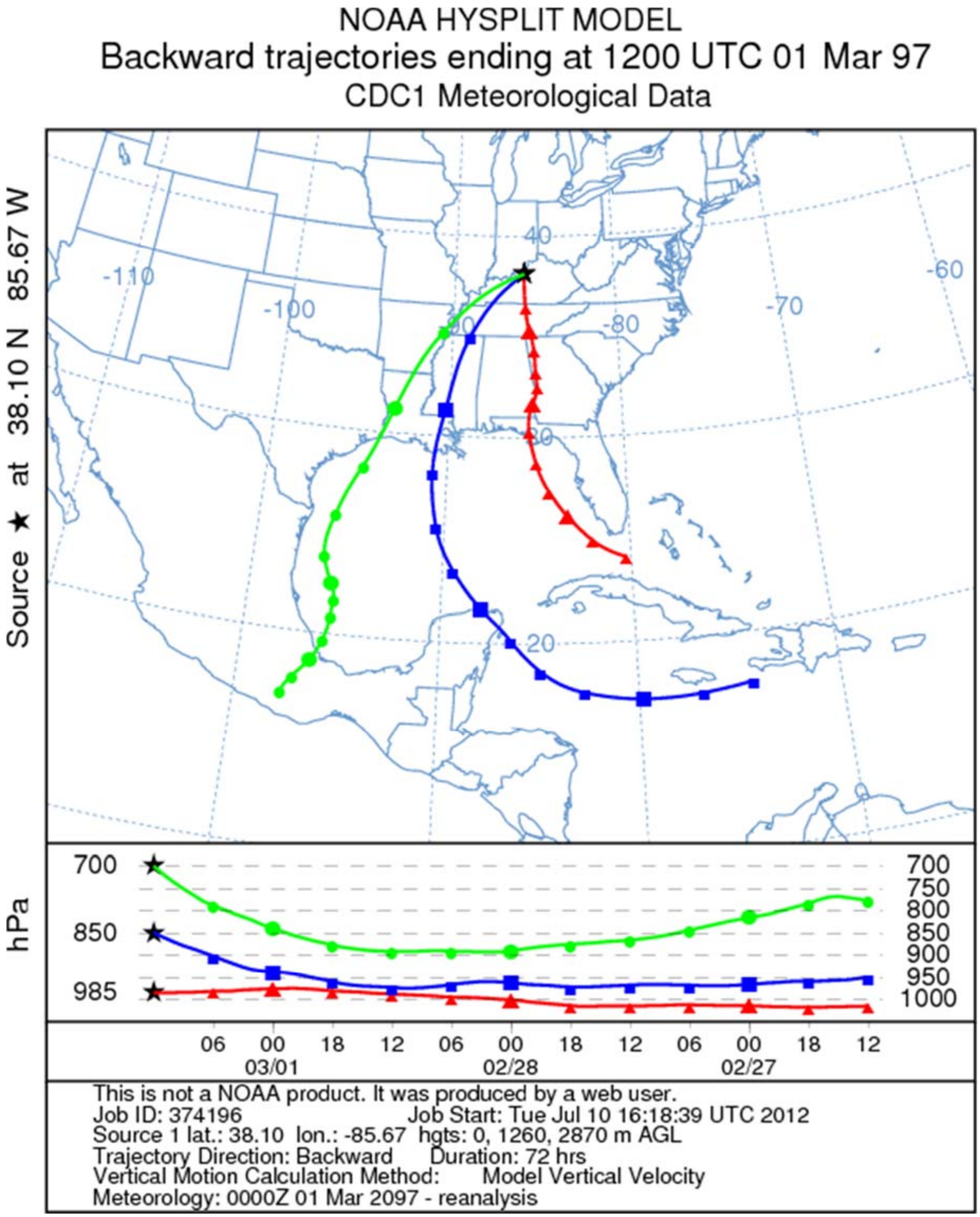
- Daily
- Hourly
- Hourly Pseudo
- Supplemental
- Supplemental Estimated




**Precipitation (inches)**

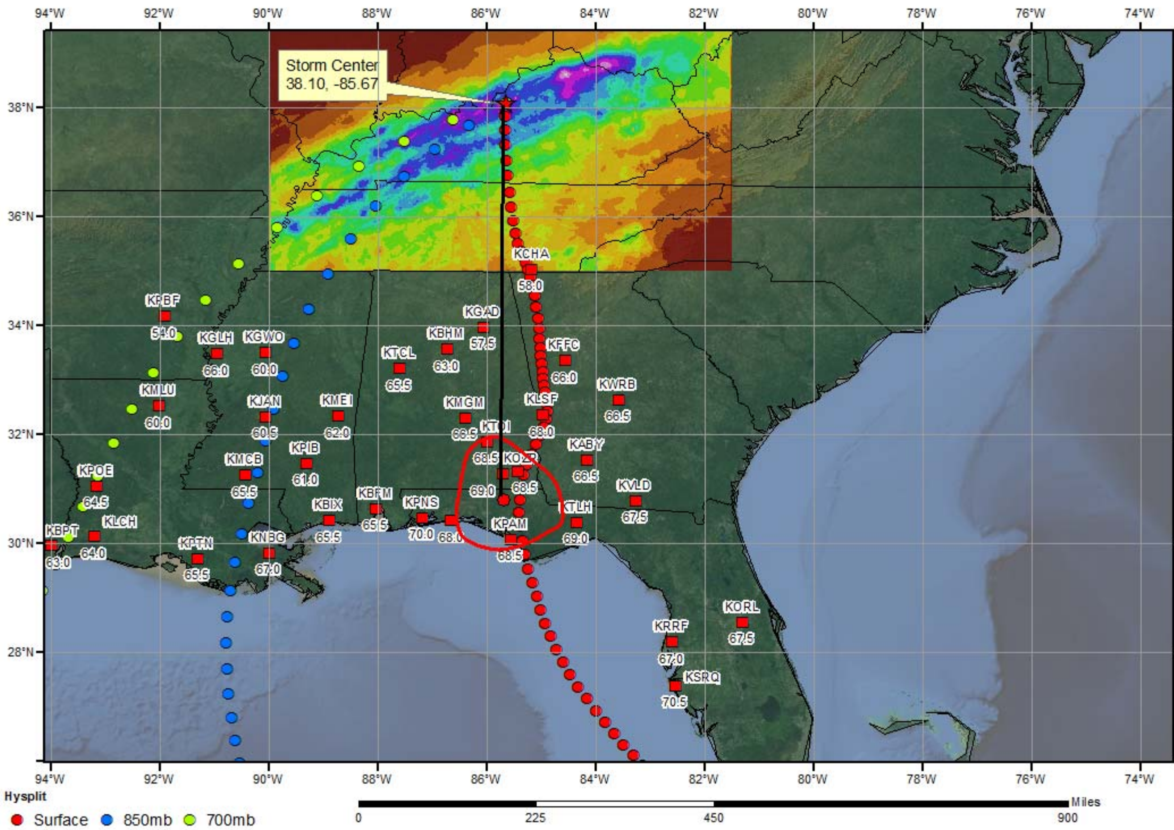
| | | | |
|---|---|---|---|
| 0.00 - 1.00 | 4.01 - 5.00 | 8.01 - 9.00 | 12.01 - 13.00 |
| 1.01 - 2.00 | 5.01 - 6.00 | 9.01 - 10.00 | 13.01 - 14.00 |
| 2.01 - 3.00 | 6.01 - 7.00 | 10.01 - 11.00 | |
| 3.01 - 4.00 | 7.01 - 8.00 | 11.01 - 12.00 | |

7/10/2012



NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 01 Mar 97
CDC1 Meteorological Data
Source ★ at 38.10 N 85.67 W
-110
-100
-90
-80
-70
-60
40
30
20
hPa
700
850
985
700
750
800
850
900
950
1000
06
00
18
12
06
00
18
12
06
00
18
12
03/01
02/28
02/27
This is not a NOAA product. It was produced by a web user.
Job ID: 374196 Job Start: Tue Jul 10 16:18:39 UTC 2012
Source 1 lat.: 38.10 lon.: -85.67 hgts: 0, 1260, 2870 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Mar 2097 - reanalysis

**SPAS 1244 Louisville, KY Storm Analysis**
Feb. 26-28 1997



# Storm Precipitation Analysis System (SPAS) For Storm #1297_1 SPAS-NEXRAD Analysis

**General Storm Location**: Roseau, Minnesota

**Storm Dates**: June 9-11, 2002

**Event**: MCC

**DAD Zone 1**

**Latitude**: 48.875

**Longitude**: -95.085

**Max. Grid Rainfall Amount**: 14.62"

**Max. Observed Rainfall Amount**: 14.55"

**Number of Stations**: 726 (2007 Daily, 50 Hourly, 32 Hourly Pseudo, and 437 Supplemental)

**SPAS Version**: 9.5

**Basemap:** PRISM 30-yr Mean (1981-2010) June Precipitation and Total Radar Reflectivity

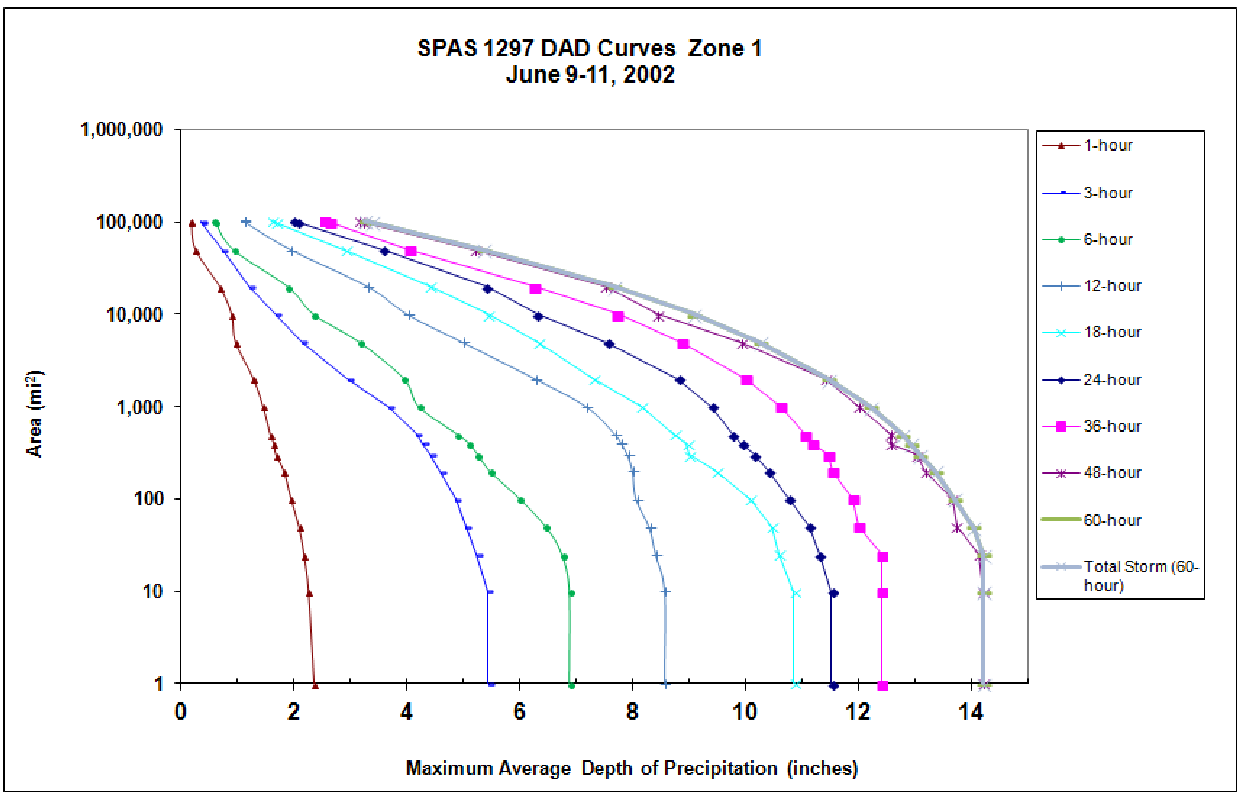
**Spatial resolution:** 0.01 (~ 0.30 mi$^2$)

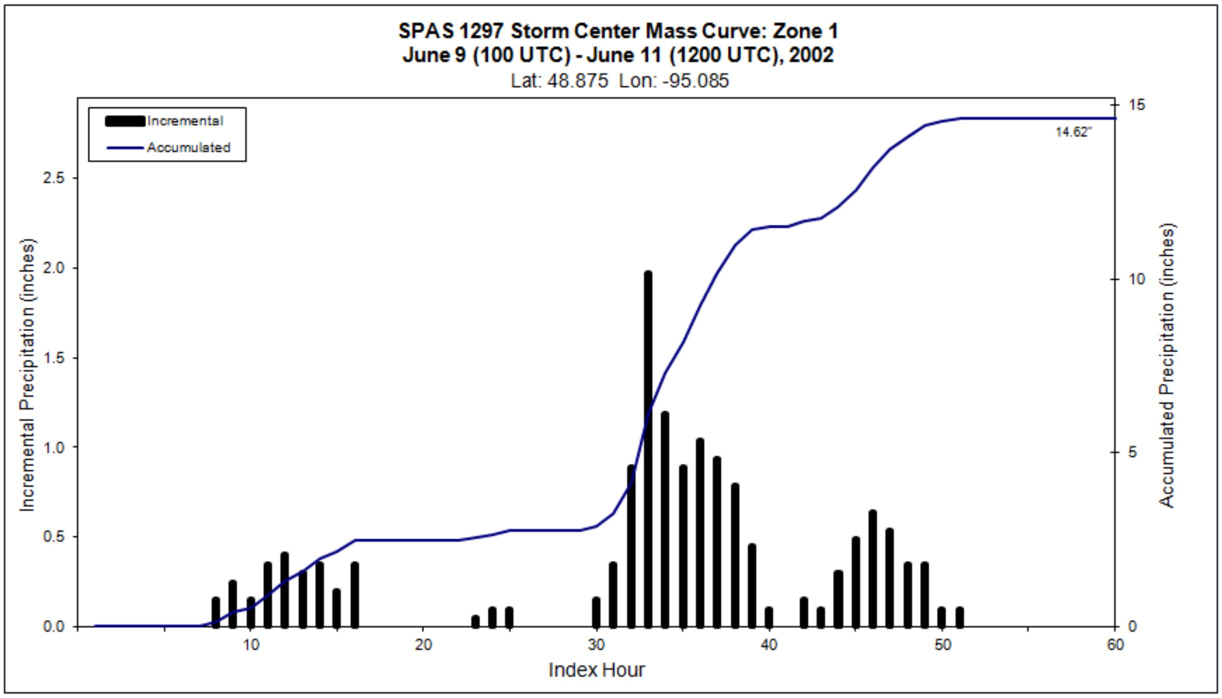
**Radar Included:** Yes

**Depth-Area-Duration (DAD) analysis**: Yes

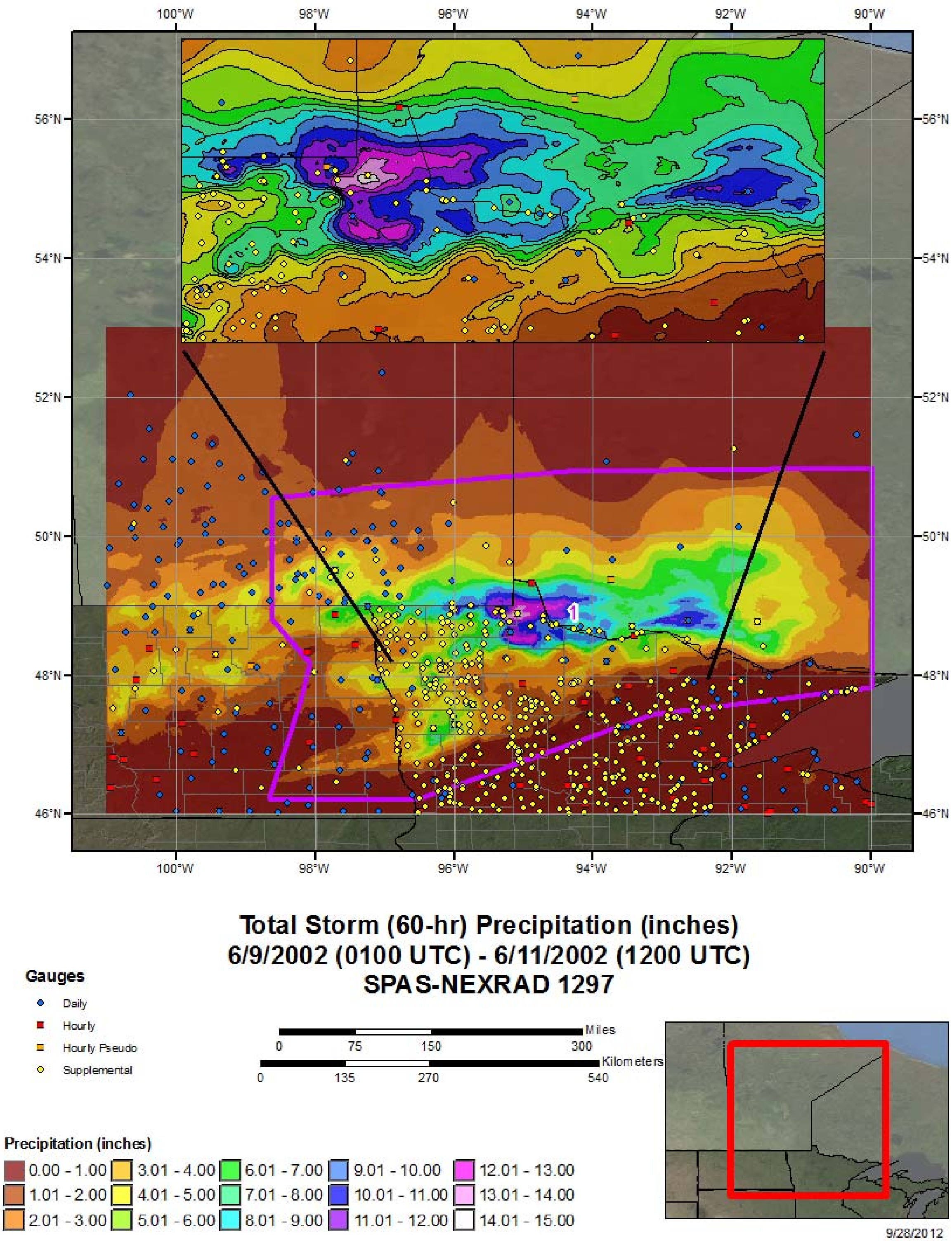
**Reliability of results:** This analysis was based on hourly data, daily data, supplemental station data and NEXRAD Radar. We have a high degree of confidence in the radar/station based storm total results, the spatial pattern is dependent on the radar data and basemap, and the timing is based on hourly and hourly pseudo stations.

| Storm 1297 - June 9 (100 UTC) - June 11 (1200 UTC), 2002 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | |
| | Duration (hours) | | | | | | | | | |
| Area (mi$^2$) | 1 | 3 | 6 | 12 | 18 | 24 | 36 | 48 | 60 | Total |
| **0.3** | 2.42 | 5.6 | 7.11 | 8.81 | 11.18 | 11.88 | 12.83 | 14.62 | 14.62 | 14.62 |
| **1** | 2.37 | 5.45 | 6.89 | 8.57 | 10.86 | 11.52 | 12.41 | 14.22 | 14.22 | 14.22 |
| **10** | 2.27 | 5.43 | 6.89 | 8.57 | 10.86 | 11.52 | 12.41 | 14.22 | 14.22 | 14.22 |
| **25** | 2.19 | 5.24 | 6.76 | 8.41 | 10.6 | 11.3 | 12.41 | 14.14 | 14.21 | 14.21 |
| **50** | 2.1 | 5.05 | 6.47 | 8.29 | 10.46 | 11.13 | 12.01 | 13.74 | 14.03 | 14.03 |
| **100** | 1.96 | 4.87 | 6.01 | 8.06 | 10.08 | 10.76 | 11.91 | 13.66 | 13.69 | 13.69 |
| **200** | 1.83 | 4.6 | 5.48 | 8 | 9.48 | 10.41 | 11.54 | 13.18 | 13.37 | 13.37 |
| **300** | 1.69 | 4.42 | 5.27 | 7.91 | 8.99 | 10.15 | 11.46 | 13.04 | 13.08 | 13.08 |
| **400** | 1.65 | 4.29 | 5.11 | 7.8 | 8.96 | 9.93 | 11.19 | 12.58 | 12.92 | 12.92 |
| **500** | 1.59 | 4.17 | 4.91 | 7.69 | 8.73 | 9.76 | 11.05 | 12.57 | 12.77 | 12.77 |
| **1,000** | 1.46 | 3.68 | 4.22 | 7.18 | 8.15 | 9.4 | 10.62 | 12.01 | 12.2 | 12.20 |
| **2,000** | 1.29 | 2.96 | 3.96 | 6.27 | 7.3 | 8.8 | 10 | 11.42 | 11.47 | 11.47 |
| **5,000** | 0.97 | 2.15 | 3.17 | 4.98 | 6.34 | 7.55 | 8.88 | 9.92 | 10.26 | 10.26 |
| **10,000** | 0.9 | 1.67 | 2.36 | 4.01 | 5.44 | 6.3 | 7.74 | 8.45 | 9.09 | 9.09 |
| **20,000** | 0.69 | 1.21 | 1.9 | 3.31 | 4.4 | 5.4 | 6.27 | 7.51 | 7.66 | 7.66 |
| **50,000** | 0.26 | 0.74 | 0.94 | 1.95 | 2.91 | 3.58 | 4.06 | 5.21 | 5.36 | 5.36 |
| **100,000** | 0.18 | 0.37 | 0.61 | 1.13 | 1.68 | 2.07 | 2.65 | 3.24 | 3.39 | 3.39 |
| **103,535** | 0.18 | 0.37 | 0.59 | 1.12 | 1.62 | 2 | 2.56 | 3.17 | 3.27 | 3.27 |



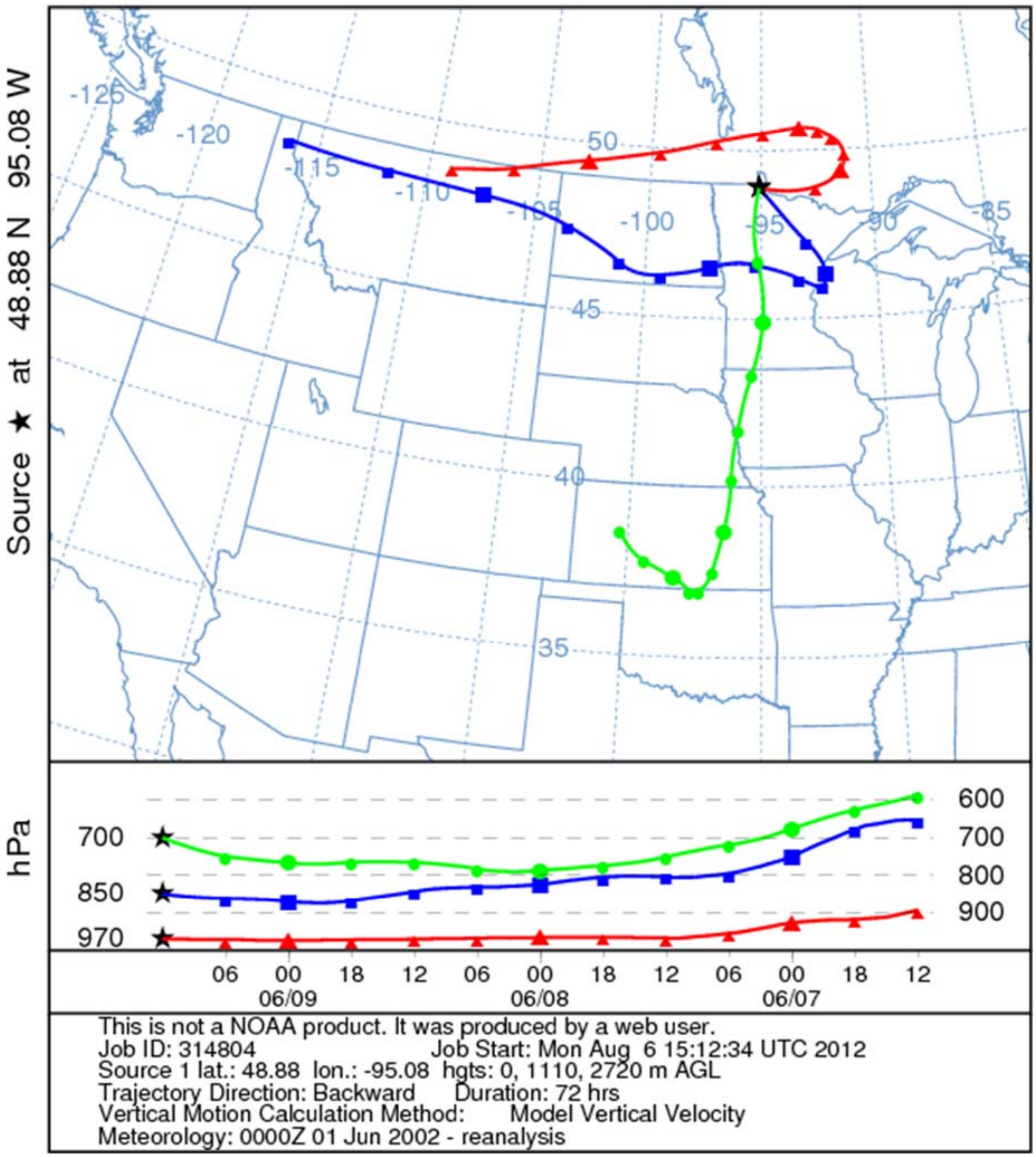


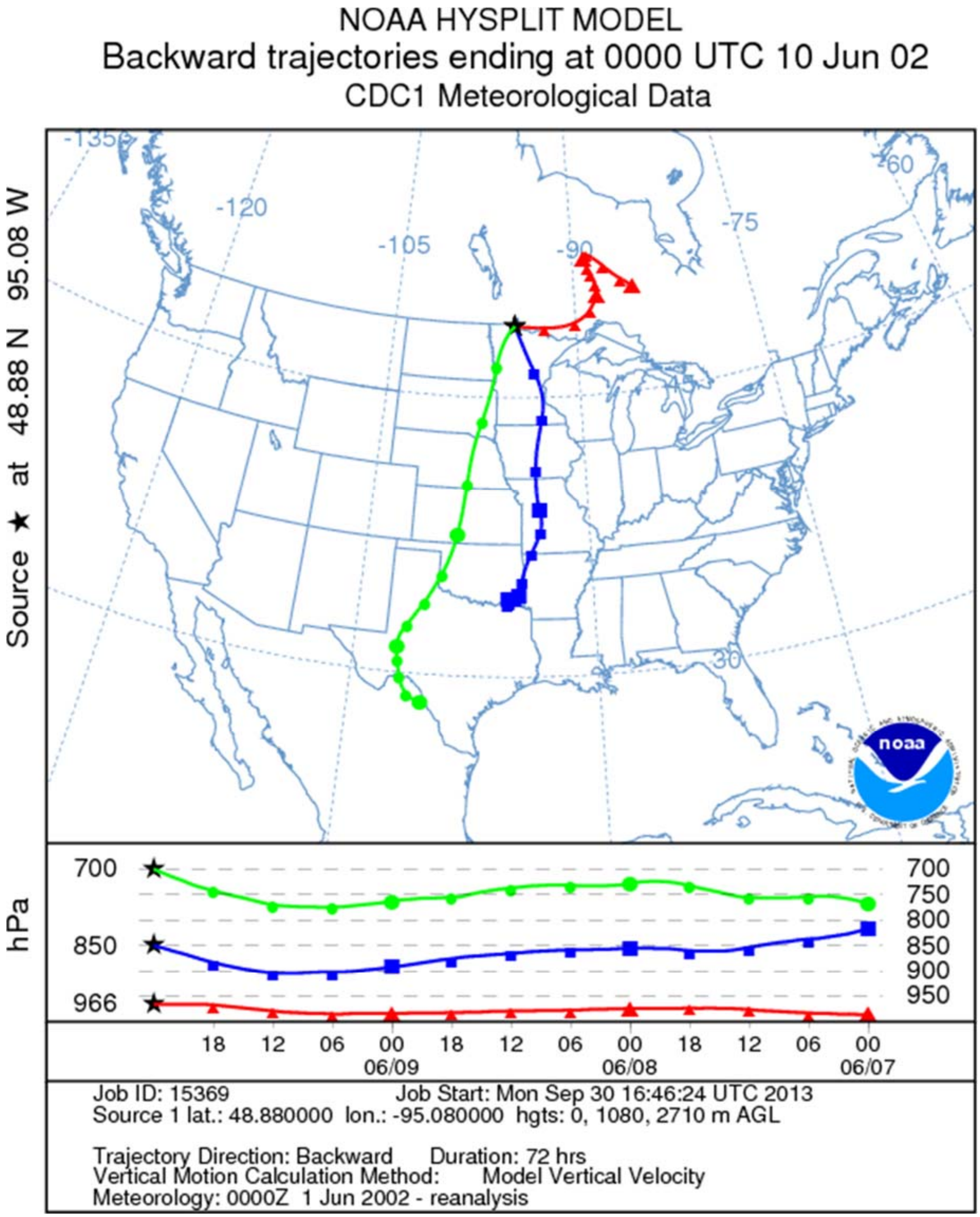
SPAS 1297 Storm Center Mass Curve: Zone 1
June 9 (100 UTC) - June 11 (1200 UTC), 2002
Lat: 48.875 Lon: -95.085
Incremental
Accumulated
14.62"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
0
5
10
15
10
20
30
40
50
60



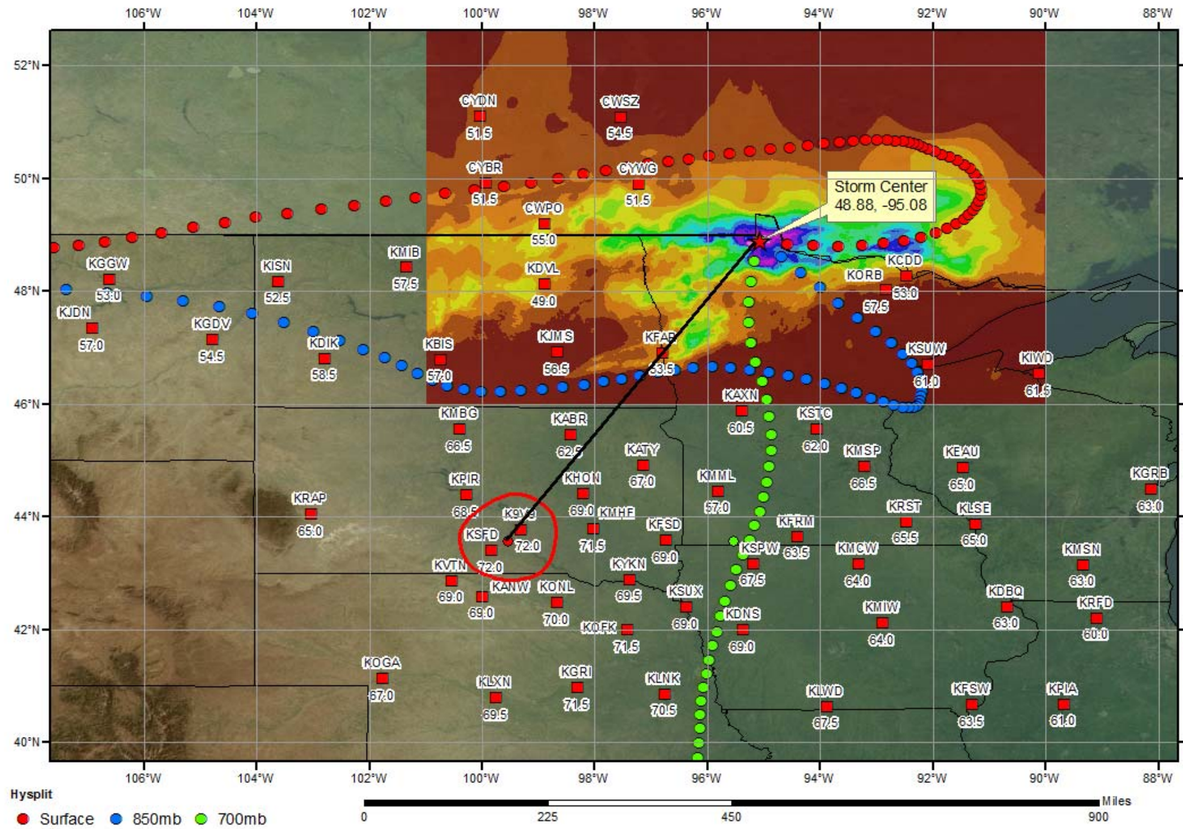
100°W
98°W
96°W
94°W
92°W
90°W
56°N
54°N
52°N
50°N
48°N
46°N
1
Total Storm (60-hr) Precipitation (inches)
6/9/2002 (0100 UTC) - 6/11/2002 (1200 UTC)
SPAS-NEXRAD 1297
Gauges
Daily
Hourly
Hourly Pseudo
Supplemental
Miles
0 75 150 300
Kilometers
0 135 270 540
Precipitation (inches)
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
14.01 - 15.00
9/28/2012

NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 09 Jun 02
CDC1 Meteorological Data




NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 10 Jun 02
CDC1 Meteorological Data
Source ★ at 48.88 N 95.08 W
-135
-120
-105
-90
-75
-60
30
noaa
hPa
700
850
966
700
750
800
850
900
950
18 12 06 00 18 12 06 00 18 12 06 00
06/09
06/08
06/07
Job ID: 15369 Job Start: Mon Sep 30 16:46:24 UTC 2013
Source 1 lat.: 48.880000 lon.: -95.080000 hgts: 0, 1080, 2710 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jun 2002 - reanalysis

**SPAS 1297 Roseau, MN Storm Analysis**
June 6-9, 2002



# Storm Precipitation Analysis System (SPAS) For Storm #1275_1 SPAS-NEXRAD Analysis

**General Storm Location**: Pennsylvania, West Virginia, Virginia, Ohio, New York, Kentucky

**Storm Dates**: September 17-19, 2004

**Event**: Hurricane Ivan

**DAD Zone 1**

**Latitude**: 40.645

**Longitude**: -80.385

**Max. Grid Rainfall Amount**: 8.79"

**Max. Observed Rainfall Amount**: 8.79"

**Number of Stations**: 955 (550 Daily, 183 Hourly, 62 Hourly Pseudo, and 160 Supplemental)

**SPAS Version**: 9.5

**Basemap:** PRISM 30-yr Mean (1981-2010) September Precipitation

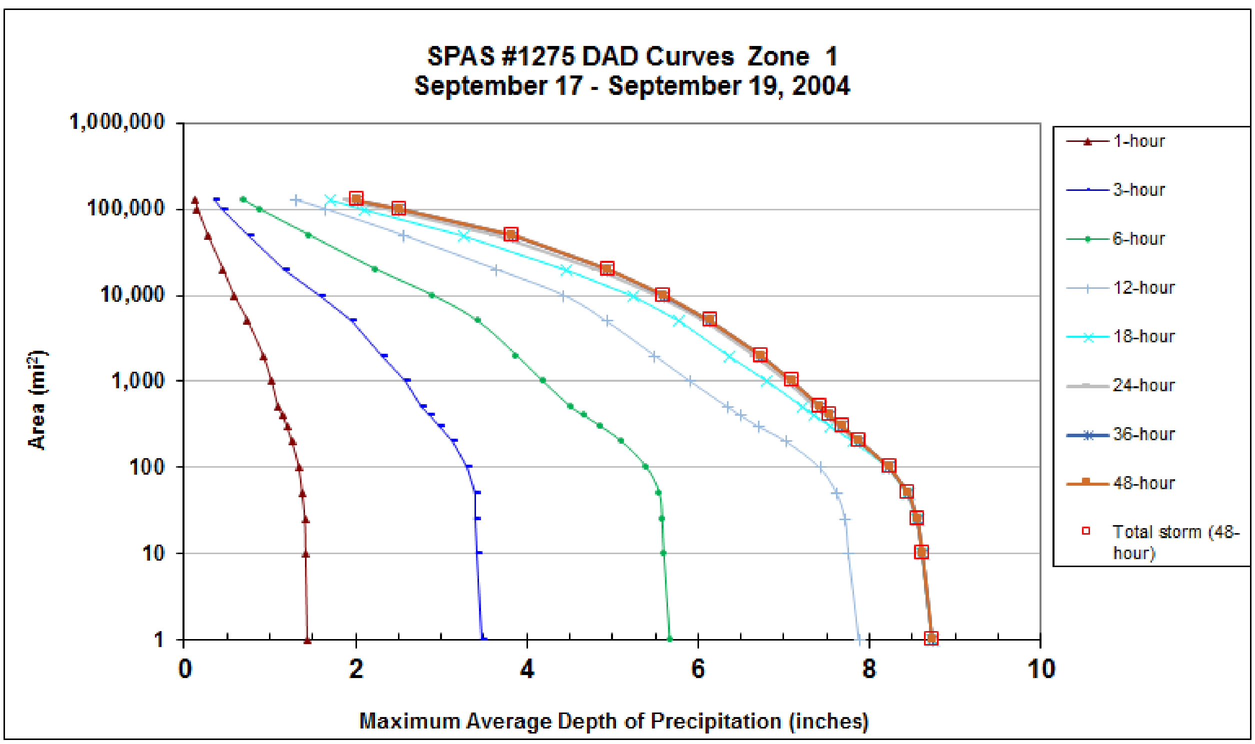
**Spatial resolution:** 0.01 (~ 0.40 $mi^2$)

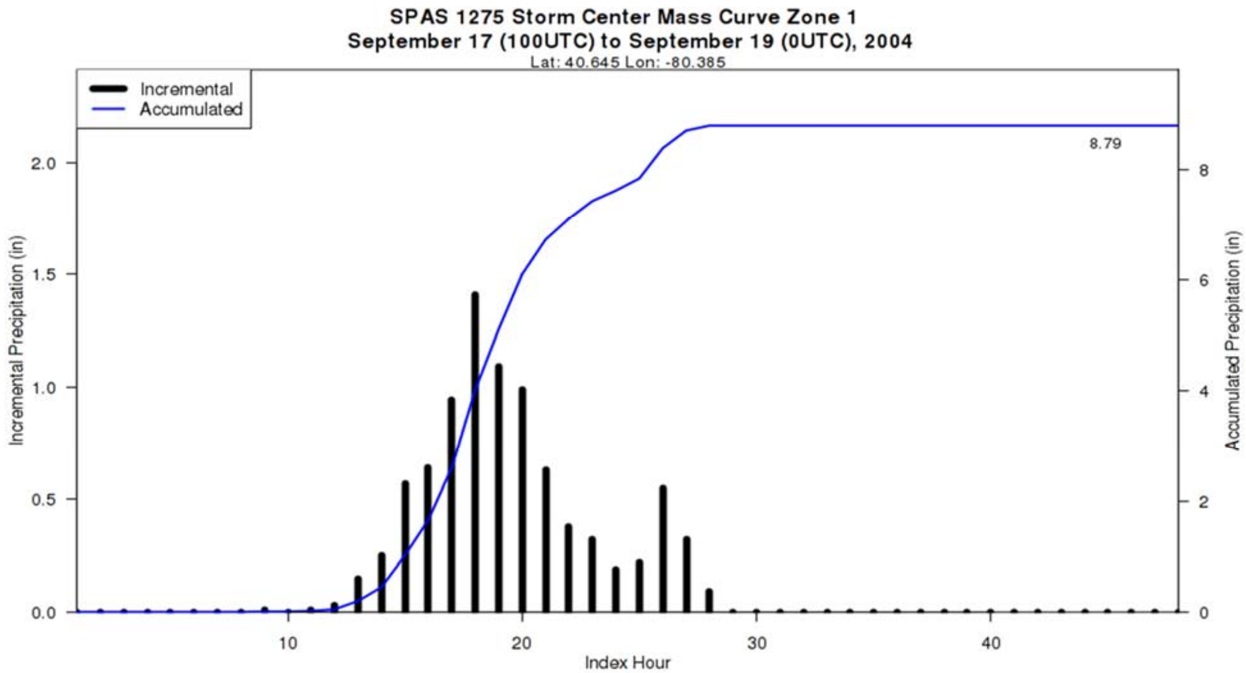
**Radar Included:** Yes

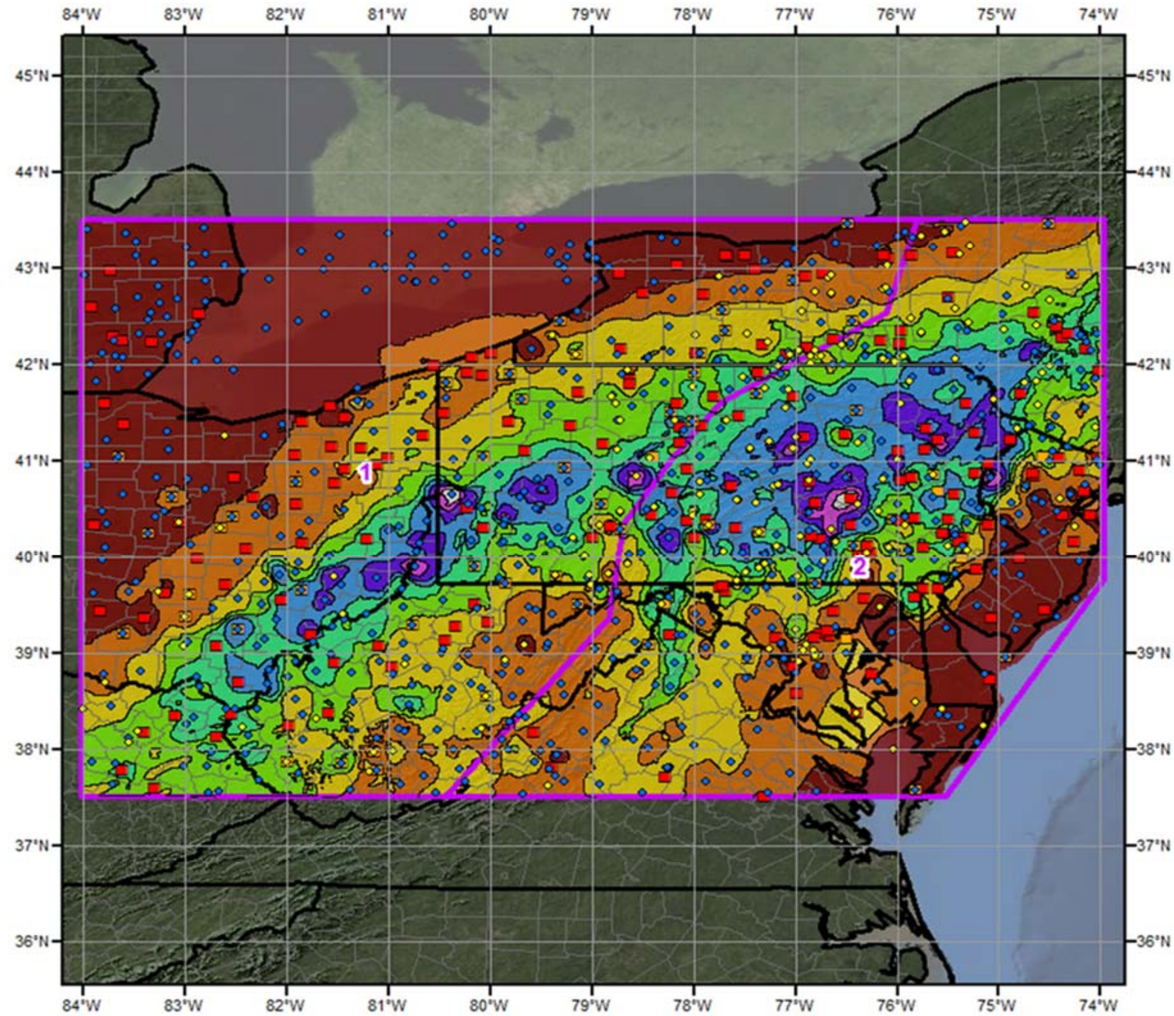
**Depth-Area-Duration (DAD) analysis**: Yes

**Reliability of results:** This analysis was based on hourly data, daily data, supplemental station data and NEXRAD Radar. We have a high degree of confidence in the radar/station based storm total results, the spatial pattern is dependent on the radar data and basemap, and the timing is based on hourly and hourly pseudo stations.

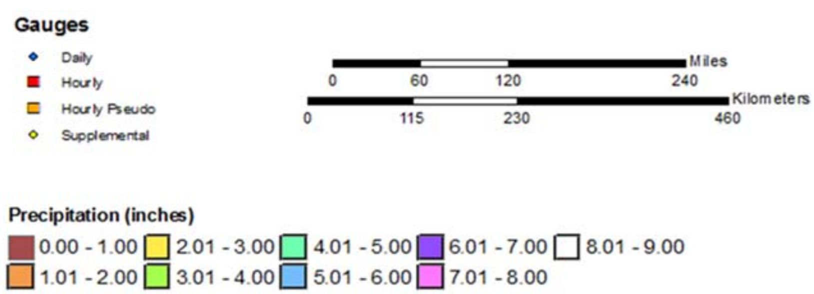
| Storm 1275 - September 17 (0100 UTC) - September 19 (0000 UTC), 2004 MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Area ($mi^2$) | Duration (hours) | | | | | | | | |
| | 1 | 3 | 6 | 12 | 18 | 24 | 36 | 48 | Total |
| 0.4 | 1.44 | 3.49 | 5.70 | 7.93 | 8.77 | 8.78 | 8.78 | 8.78 | 8.78 |
| 1 | 1.44 | 3.47 | 5.67 | 7.88 | 8.73 | 8.74 | 8.74 | 8.74 | 8.74 |
| 10 | 1.42 | 3.42 | 5.60 | 7.76 | 8.60 | 8.61 | 8.62 | 8.62 | 8.62 |
| 25 | 1.41 | 3.40 | 5.58 | 7.72 | 8.56 | 8.57 | 8.57 | 8.57 | 8.57 |
| 50 | 1.38 | 3.39 | 5.55 | 7.62 | 8.44 | 8.45 | 8.46 | 8.46 | 8.46 |
| 100 | 1.34 | 3.31 | 5.40 | 7.42 | 8.21 | 8.23 | 8.23 | 8.24 | 8.24 |
| 200 | 1.26 | 3.13 | 5.11 | 7.03 | 7.81 | 7.87 | 7.89 | 7.89 | 7.89 |
| 300 | 1.20 | 2.98 | 4.86 | 6.70 | 7.54 | 7.65 | 7.68 | 7.69 | 7.69 |
| 400 | 1.15 | 2.87 | 4.67 | 6.50 | 7.36 | 7.50 | 7.54 | 7.54 | 7.54 |
| 500 | 1.10 | 2.77 | 4.52 | 6.35 | 7.22 | 7.38 | 7.43 | 7.43 | 7.43 |
| 1,000 | 1.02 | 2.57 | 4.19 | 5.91 | 6.80 | 7.04 | 7.10 | 7.10 | 7.10 |
| 2,000 | 0.92 | 2.32 | 3.88 | 5.49 | 6.37 | 6.66 | 6.74 | 6.74 | 6.74 |
| 5,000 | 0.74 | 1.95 | 3.43 | 4.93 | 5.78 | 6.08 | 6.14 | 6.15 | 6.15 |
| 10,000 | 0.58 | 1.58 | 2.90 | 4.43 | 5.24 | 5.51 | 5.60 | 5.61 | 5.61 |
| 20,000 | 0.45 | 1.18 | 2.24 | 3.64 | 4.46 | 4.82 | 4.94 | 4.95 | 4.95 |
| 50,000 | 0.27 | 0.75 | 1.46 | 2.55 | 3.26 | 3.63 | 3.83 | 3.84 | 3.84 |
| 100,000 | 0.15 | 0.44 | 0.88 | 1.65 | 2.10 | 2.36 | 2.51 | 2.52 | 2.52 |
| 125,829 | 0.12 | 0.36 | 0.70 | 1.31 | 1.70 | 1.91 | 2.03 | 2.03 | 2.03 |



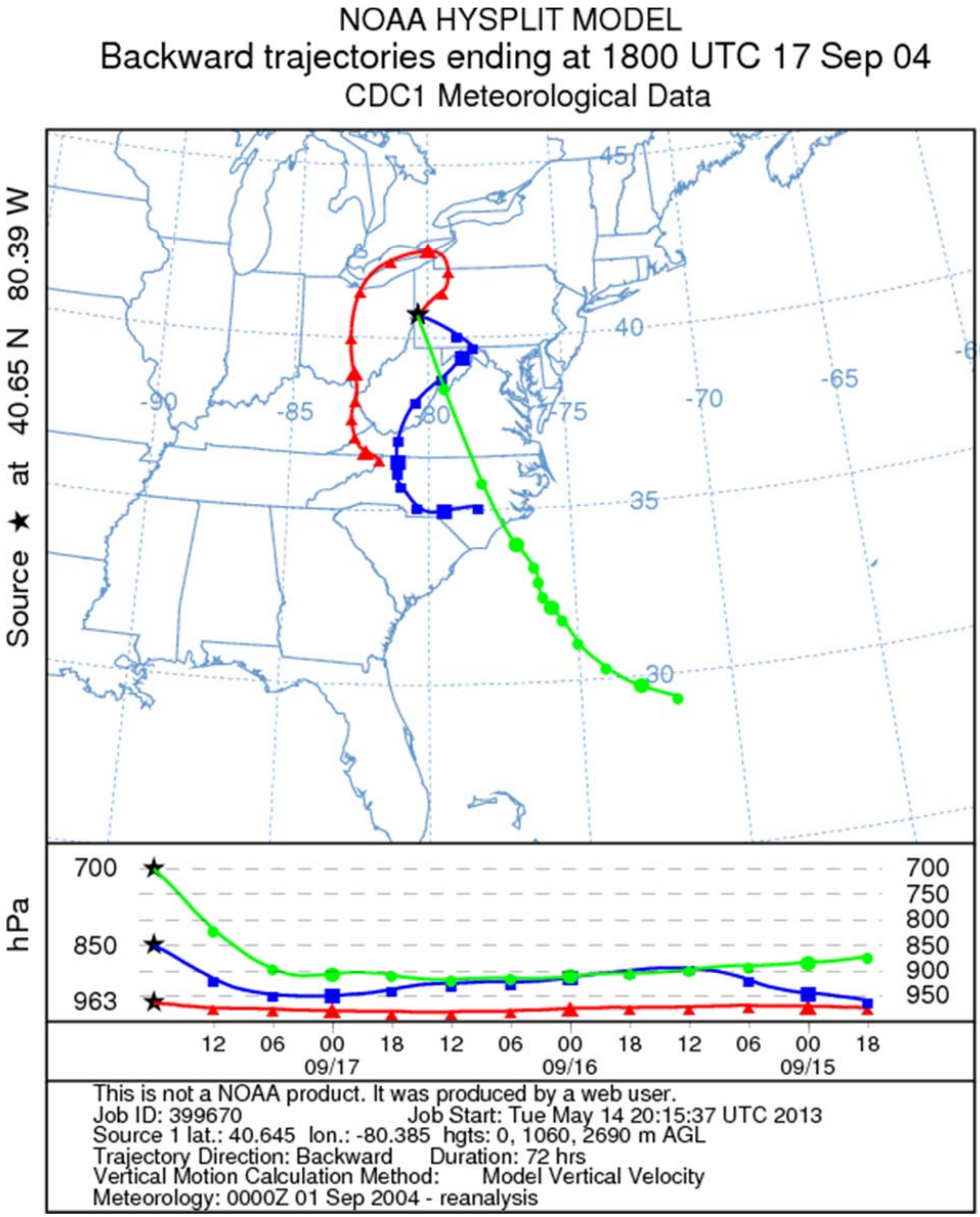

SPAS 1275 Storm Center Mass Curve Zone 1
September 17 (100UTC) to September 19 (0UTC), 2004
Lat: 40.645 Lon: -80.385
Incremental
Accumulated
8.79
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
0
2
4
6
8
10
20
30
40

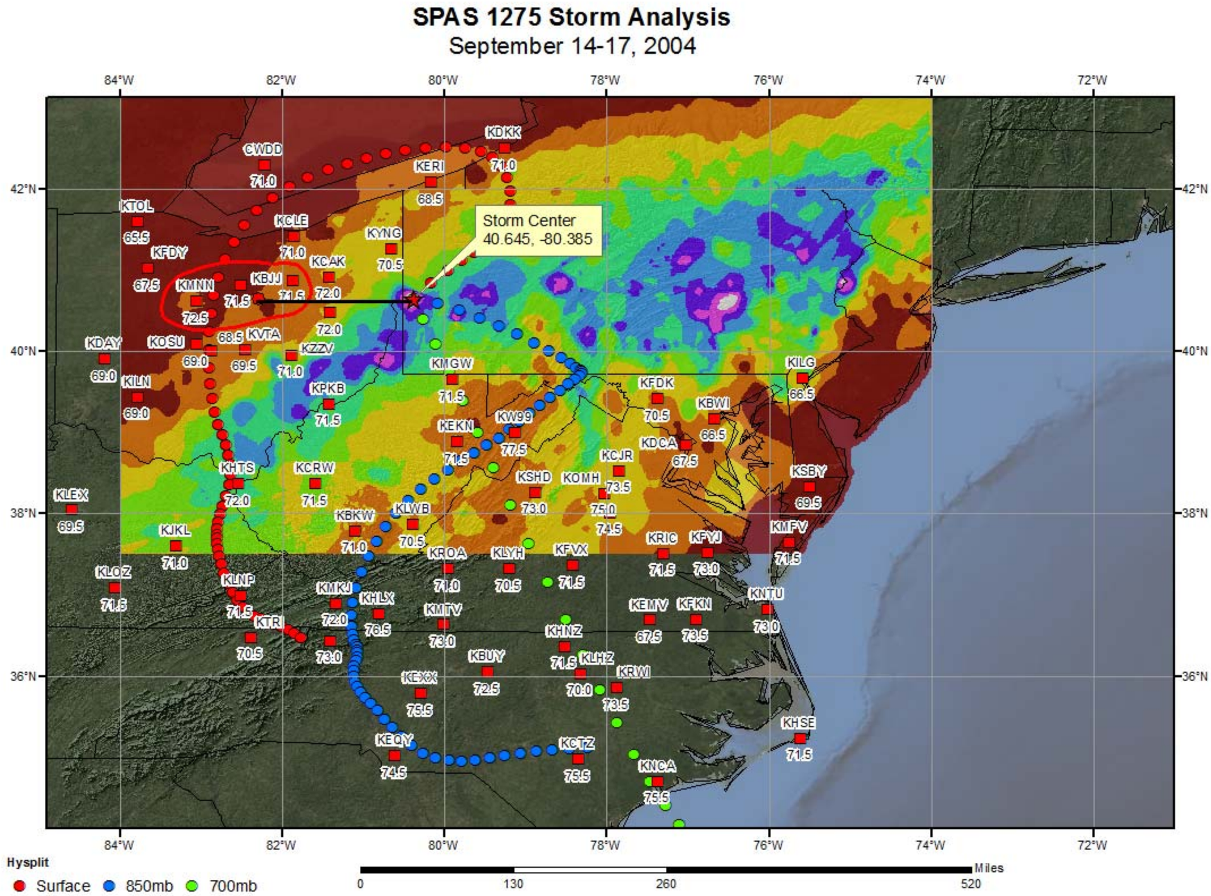



**Total Storm (48-hr) Precipitation (inches)**
**September 17 (0100 UTC) - 19 (0000 UTC), 2004**
**SPAS-NEXRAD 1276**




5/14/2013


NOAA HYSPLIT MODEL
Backward trajectories ending at 1800 UTC 17 Sep 04
CDC1 Meteorological Data
Source ★ at 40.65 N 80.39 W
45
40
35
30
-90
-85
-80
-75
-70
-65
-60
hPa
700
850
963
700
750
800
850
900
950
12 06 00 18 12 06 00 18 12 06 00 18
09/17
09/16
09/15
This is not a NOAA product. It was produced by a web user.
Job ID: 399670 Job Start: Tue May 14 20:15:37 UTC 2013
Source 1 lat.: 40.645 lon.: -80.385 hgts: 0, 1060, 2690 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Sep 2004 - reanalysis


SPAS 1275 Storm Analysis
September 14-17, 2004
Storm Center
40.645, -80.385
Hysplit
Surface
850mb
700mb
Miles
0
130
260
520

# Storm Precipitation Analysis System (SPAS) For Storm #1048_1 SPAS-NEXRAD Analysis

**General Storm Location**: Hokah, MN

**Storm Dates**: 8/18/2007 0600Z – 8/21/2007 1000Z

**Event**: Cloudburst Thunderstorm

**DAD Zone 1**

**Latitude**: 43.81251

**Longitude**: -91.3625

**Max. Grid/Radar Rainfall Amount**: 18.26" (Grid/Pixel Point)

**Max. Observed Rainfall Amount**: 18.32" (grid cell 18.26" at HIDEN519) ***elevated 18.32" to 18.93" (0.026" for 24-hr period), this was done to achieve the state record 24-hr rainfall (17.21"). Smoothing of the data reduced the observed max below 17.00"***

**Number of Stations**: 886 (99-hourly, 1 hourly pseudo, 574-daily, 212-daily supplemental) gauging stations within the defined search domain.

**SPAS Version**: 5.0

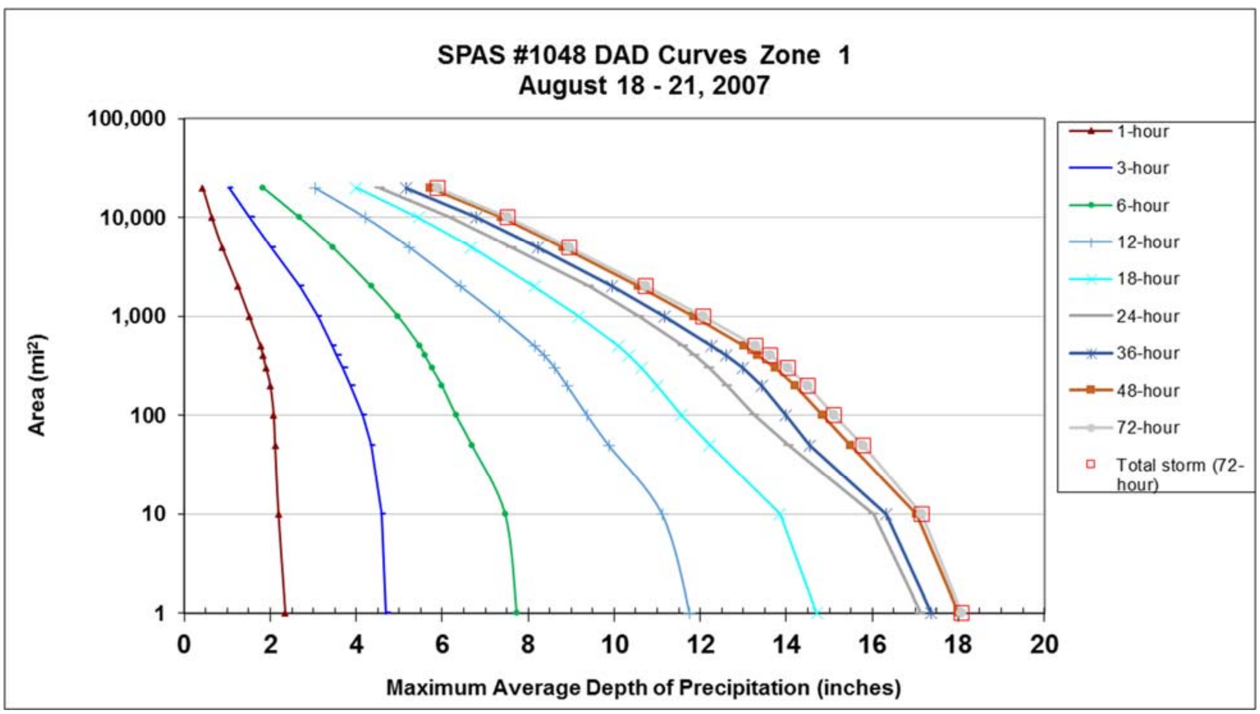
**Base Map Used:** No

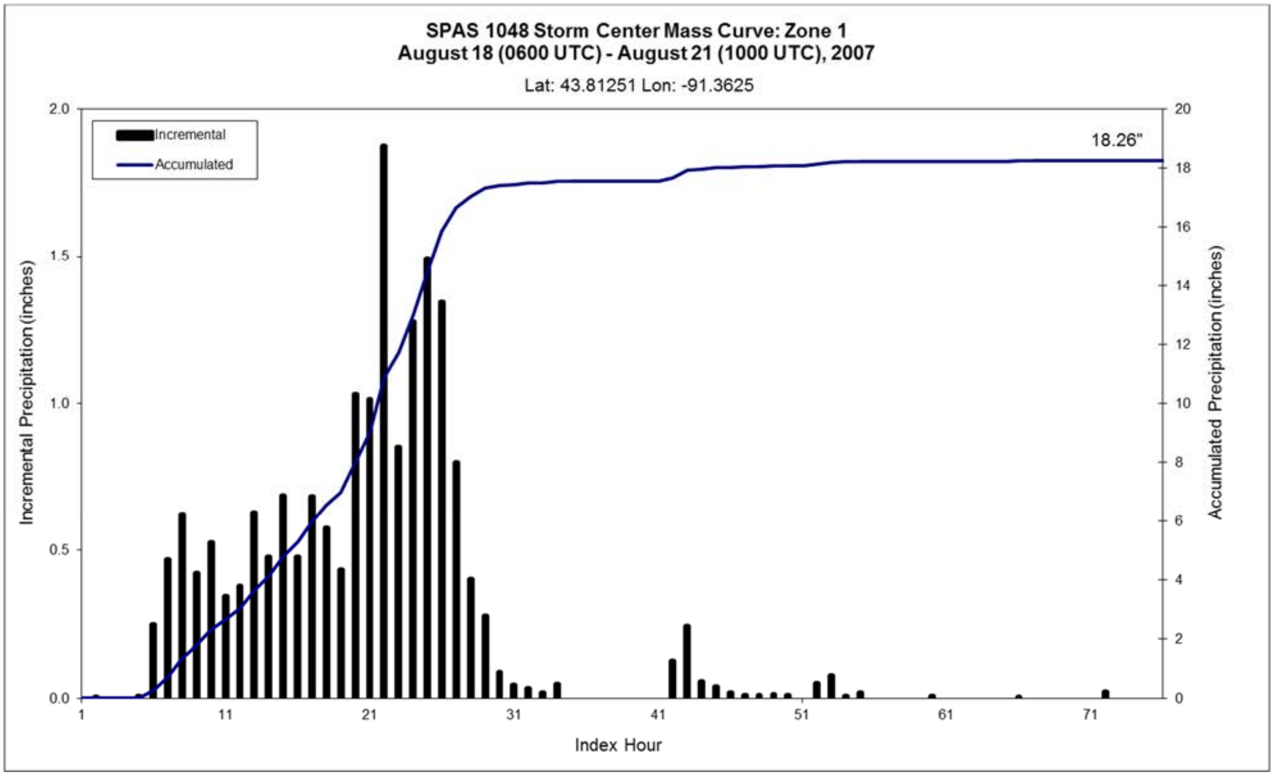
**Spatial resolution:** 0.24 $mi^2$

**Radar Included:** Yes, Weather Decision Technologies (WDT) Level-II radar reflectivity data based on Minneapolis/St. Paul, MN (KMPX), La Crosse, WI (KARX), Des Moines, IA (KDMX), and Milwaukee, WI (KMKX) NEXRAD.

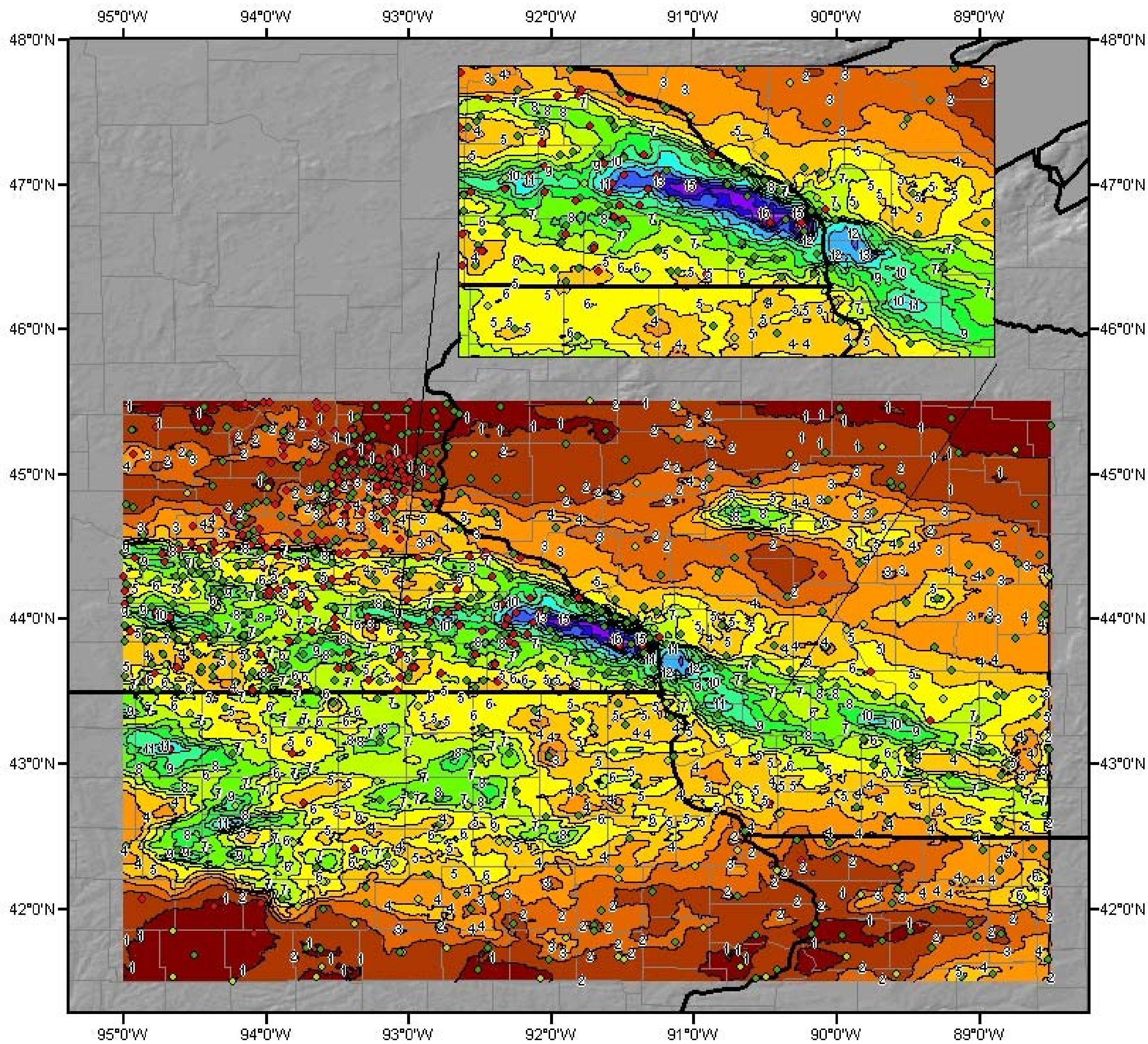
**Depth-Area-Duration (DAD) analysis**: Yes: 1, 3, 6, 12, 18, 24, 36, 48, 72, & 76 hours

| Storm 1048 - August 18 (0600 UTC) - August 21 (1000 UTC), 2007 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | |
| Area ($mi^2$) | Duration (hours) | | | | | | | | | |
| | 1 | 3 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | Total |
| 0.4 | 2.42 | 4.74 | 7.81 | 11.84 | 14.82 | 17.24 | 17.48 | 18.13 | 18.19 | 18.19 |
| 1 | 2.35 | 4.69 | 7.73 | 11.75 | 14.71 | 17.12 | 17.36 | 18.01 | 18.08 | 18.08 |
| 10 | 2.19 | 4.58 | 7.46 | 11.11 | 13.85 | 16.04 | 16.33 | 17.03 | 17.14 | 17.14 |
| 50 | 2.11 | 4.34 | 6.69 | 9.87 | 12.22 | 14.07 | 14.56 | 15.49 | 15.78 | 15.78 |
| 100 | 2.08 | 4.14 | 6.32 | 9.37 | 11.57 | 13.27 | 13.99 | 14.83 | 15.12 | 15.12 |
| 200 | 2.00 | 3.87 | 5.99 | 8.90 | 10.99 | 12.62 | 13.43 | 14.22 | 14.50 | 14.50 |
| 300 | 1.90 | 3.69 | 5.76 | 8.62 | 10.64 | 12.21 | 13.00 | 13.74 | 14.03 | 14.03 |
| 400 | 1.83 | 3.55 | 5.60 | 8.38 | 10.35 | 11.88 | 12.61 | 13.34 | 13.63 | 13.63 |
| 500 | 1.77 | 3.44 | 5.48 | 8.15 | 10.11 | 11.61 | 12.27 | 13.01 | 13.28 | 13.28 |
| 1000 | 1.51 | 3.10 | 4.97 | 7.32 | 9.17 | 10.59 | 11.17 | 11.84 | 12.06 | 12.06 |
| 2,000 | 1.25 | 2.69 | 4.35 | 6.43 | 8.15 | 9.41 | 9.96 | 10.57 | 10.74 | 10.74 |
| 5,000 | 0.88 | 2.02 | 3.45 | 5.23 | 6.67 | 7.63 | 8.23 | 8.80 | 8.95 | 8.95 |
| 10,000 | 0.64 | 1.53 | 2.68 | 4.21 | 5.45 | 6.18 | 6.78 | 7.37 | 7.53 | 7.53 |
| 20,000 | 0.43 | 1.03 | 1.84 | 3.04 | 4.00 | 4.55 | 5.15 | 5.71 | 5.88 | 5.88 |

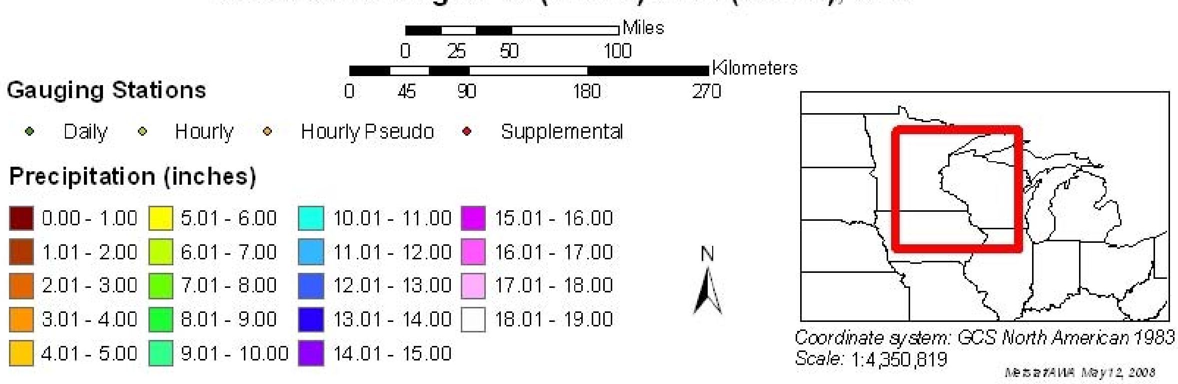


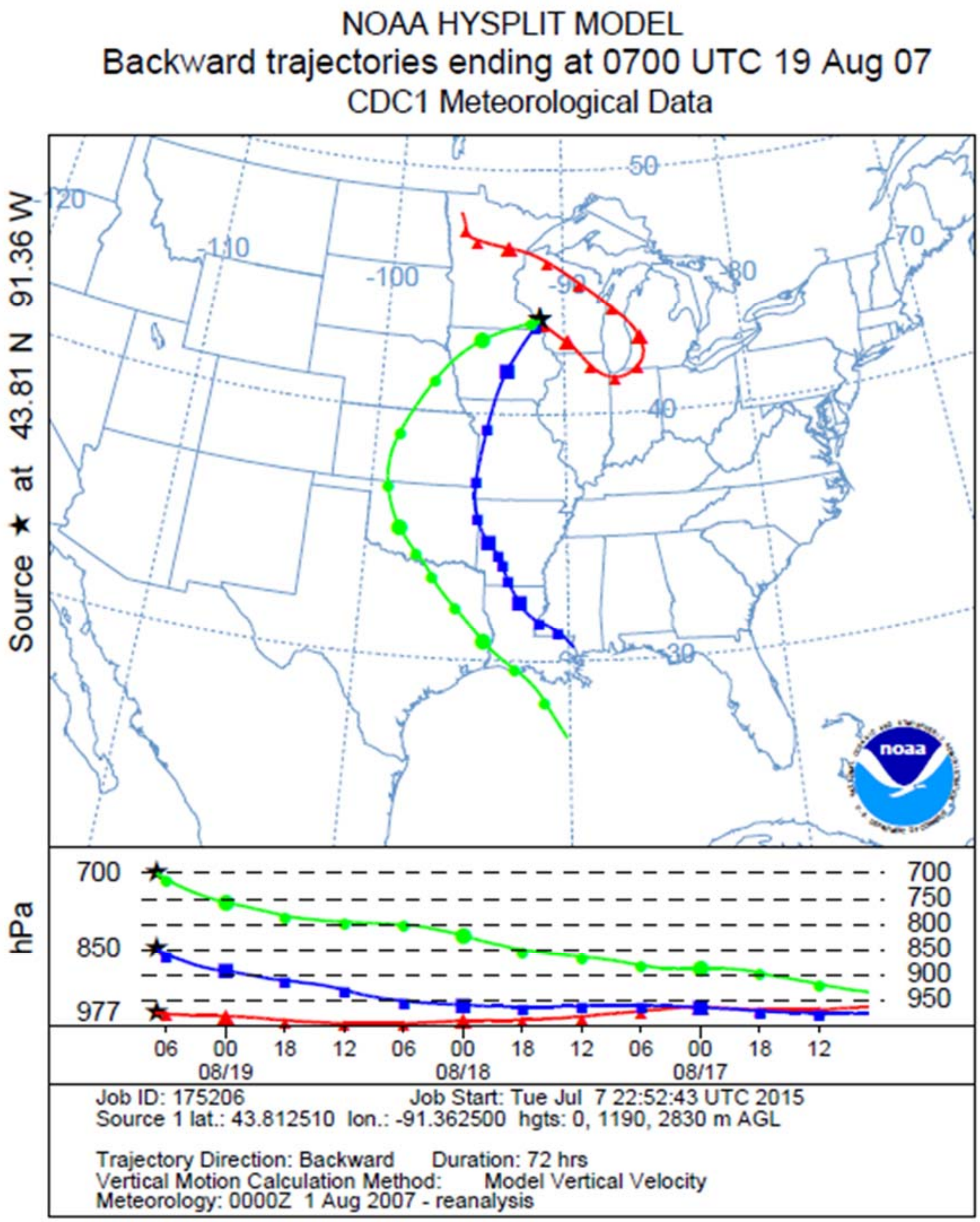


SPAS 1048 Storm Center Mass Curve: Zone 1
August 18 (0600 UTC) - August 21 (1000 UTC), 2007
Lat: 43.81251 Lon: -91.3625
Incremental
Accumulated
18.26"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour

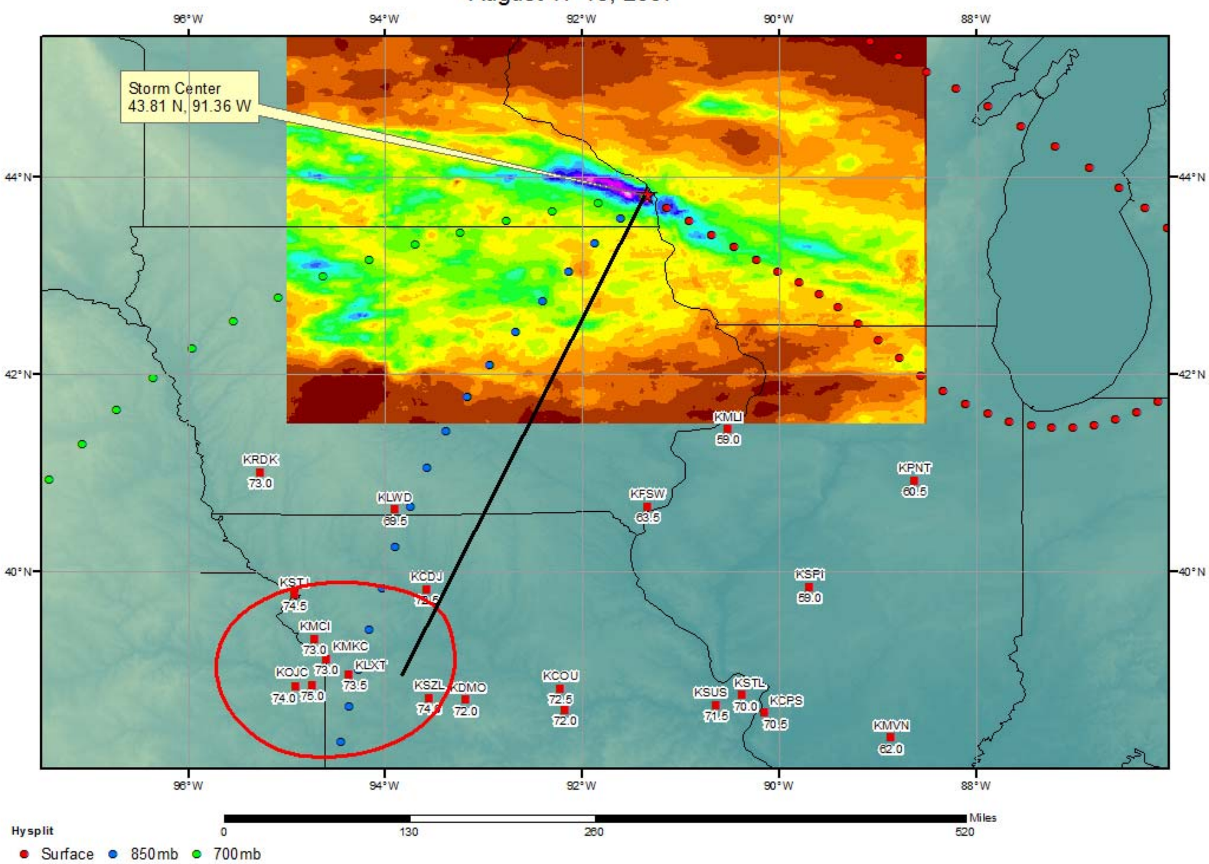



**Total Rainfall (76-hours)**
**Hokah, MN 2007 Storm**
**Storm #1048 August 18 (0600 Z) to 21 (1000 Z), 2007**




NOAA HYSPLIT MODEL
Backward trajectories ending at 0700 UTC 19 Aug 07
CDC1 Meteorological Data
Source ★ at 43.81 N 91.36 W
hPa
700
850
977
700
750
800
850
900
950
06 00 18 12 06 00 18 12 06 00 18 12
08/19
08/18
08/17
Job ID: 175206
Job Start: Tue Jul 7 22:52:43 UTC 2015
Source 1 lat.: 43.812510 lon.: -91.362500 hgts: 0, 1190, 2830 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Aug 2007 - reanalysis

**SPAS 1048 Hokah, MN Storm Analysis**
August 17-18, 2007



# Storm Precipitation Analysis System (SPAS) For Storm #1208_1 SPAS-NEXRAD Analysis

**General Storm Location**: Western and Central Tennessee, Southwestern Kentucky and adjacent portions of nearby states

**Storm Dates**: April 30 – May 3, 2010

**Event**: Synoptic

**DAD Zone 1**

> **Latitude**: 36.06
>
> **Longitude**: -86.91
>
> **Max. Grid Rainfall Amount**: 19.71”
>
> **Max. Observed Rainfall Amount**: 19.70” at WARNER PARK, TN, followed by 19.51” at USGS SR840 Rain gauge No. 4 near Bending Chestnut, TN followed by 19.41” at CoCoRaHS Camden 4.5 NW, TN.

**Number of Stations**: 753 (120 Daily, 52 Hourly, 46 Hourly Pseudo, 1 Hourly Estimated Pseudo, 5 Hourly Estimated, 521 Supplemental, and 8 Supplemental Estimated)

**SPAS Version**: 8.5

**Base Map Used:** Mean (1971-2000) PRISM May Precipitation

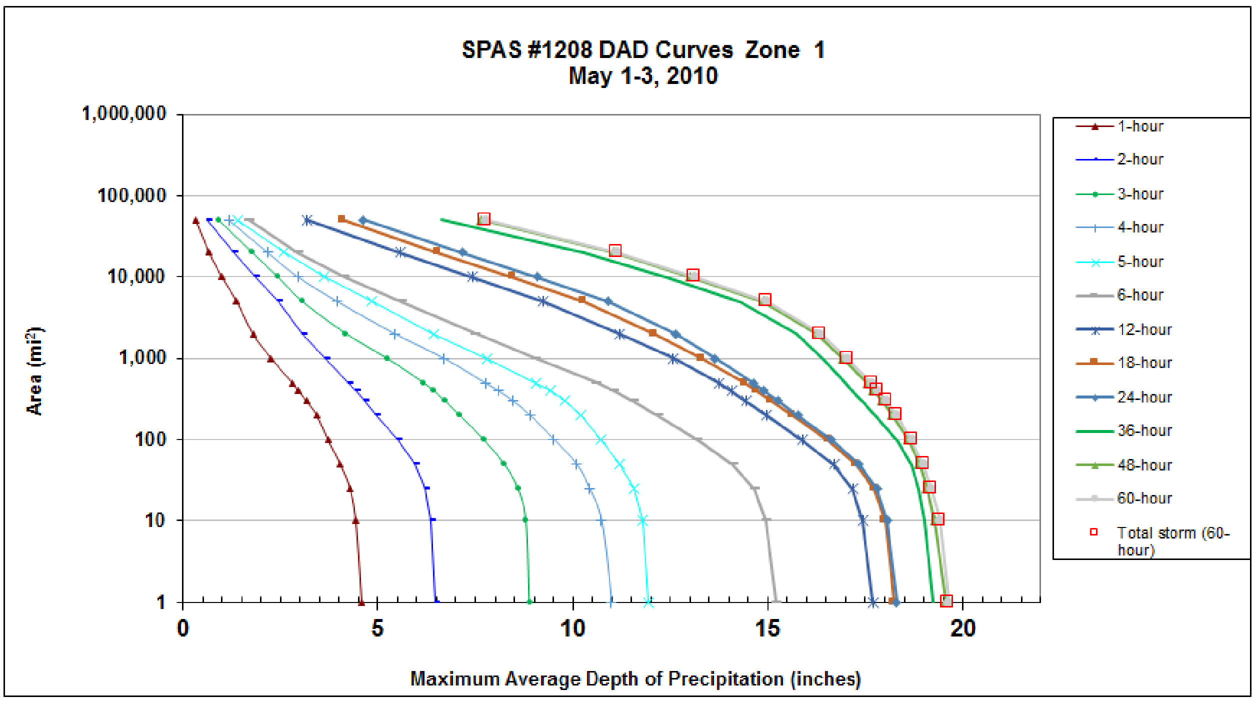
**Spatial resolution:** 36 seconds (0.39 sq-mi)

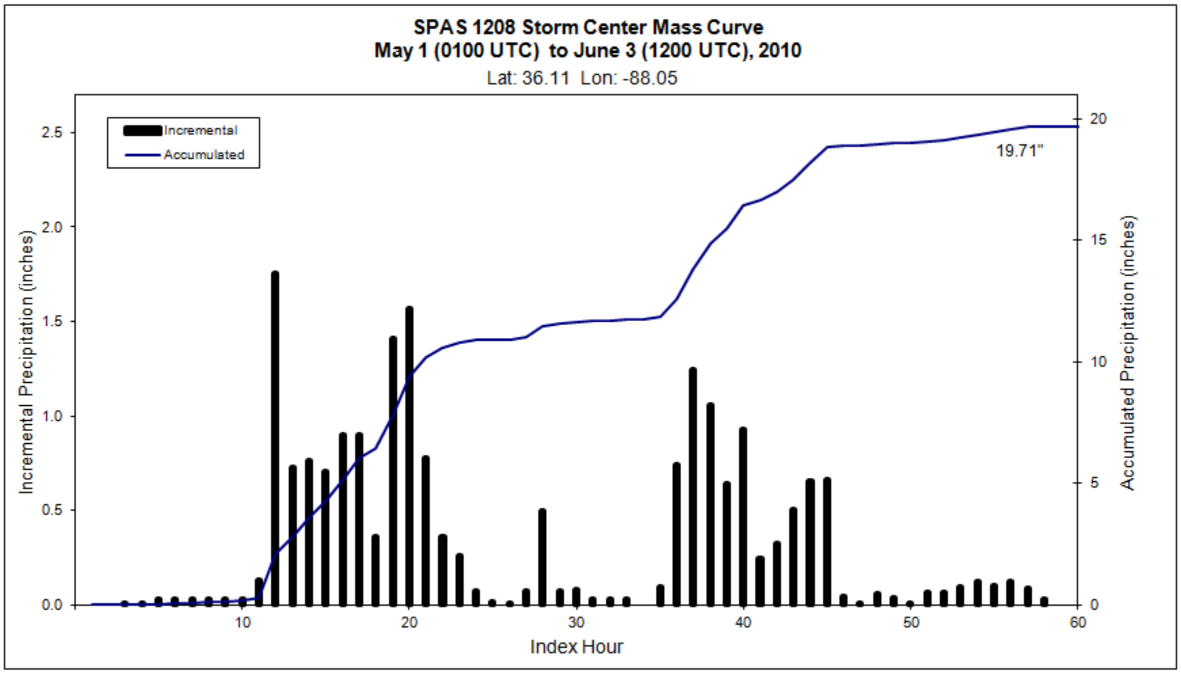
**Radar Included:** Yes

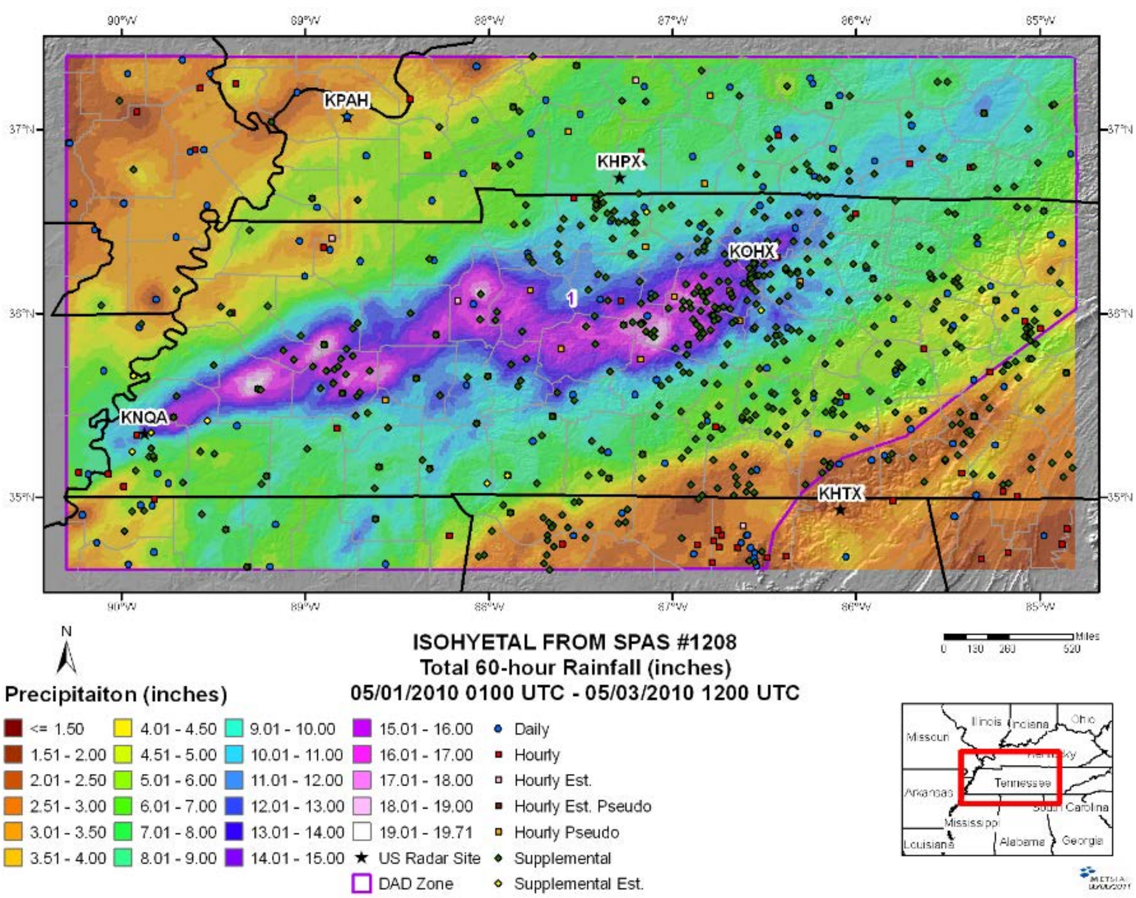
**Depth-Area-Duration (DAD) analysis**: Yes

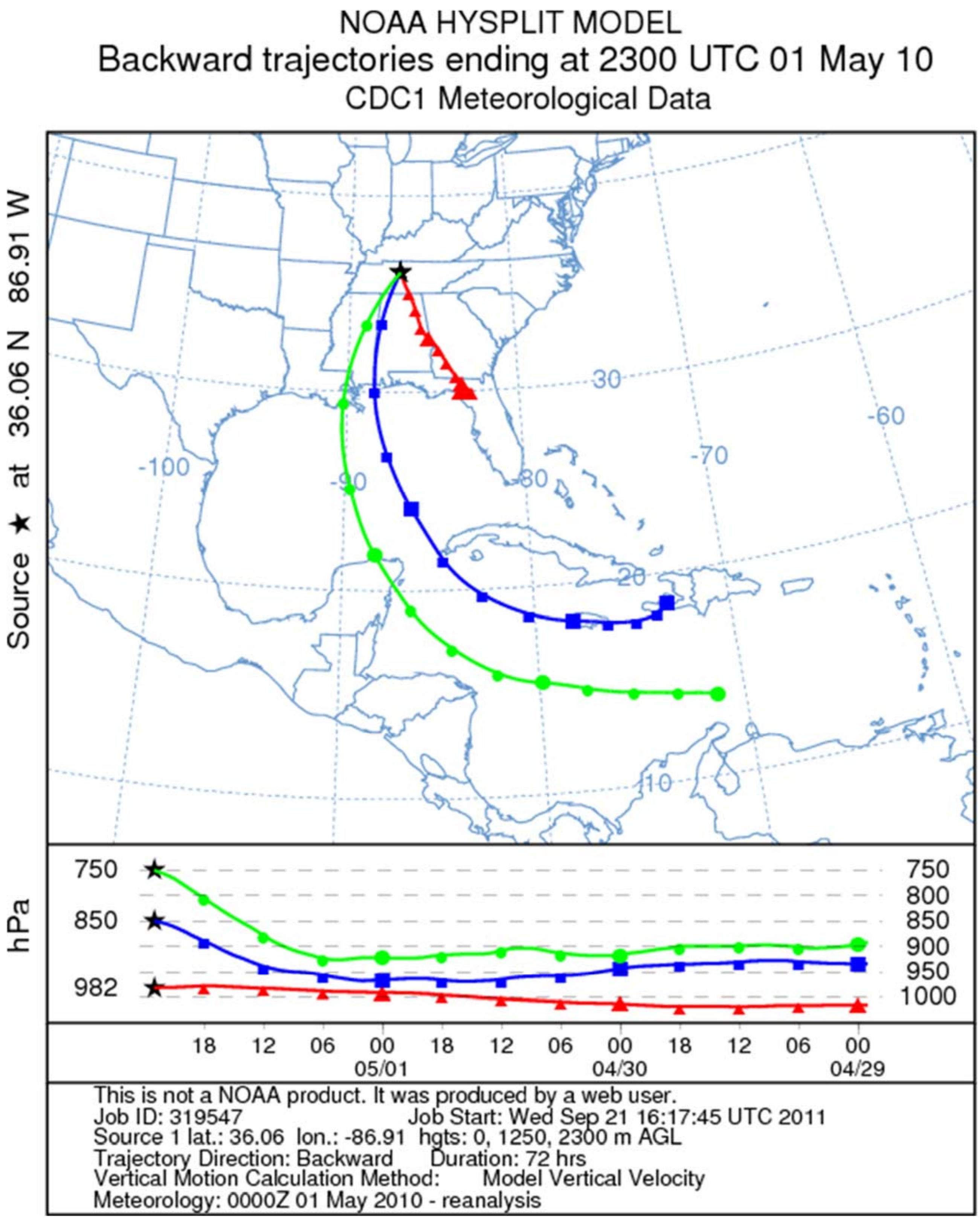
**Degree of confidence in results:** This was a difficult storm to analyze due to the extreme intensities, strong spatial rainfall gradients, large amount of data, relatively low radar reflectivity values across western Tennessee where among the heaviest rains fell. However, given this analysis was based on NEXRAD data and a plethora of gauge data, our confidence in the results is high.

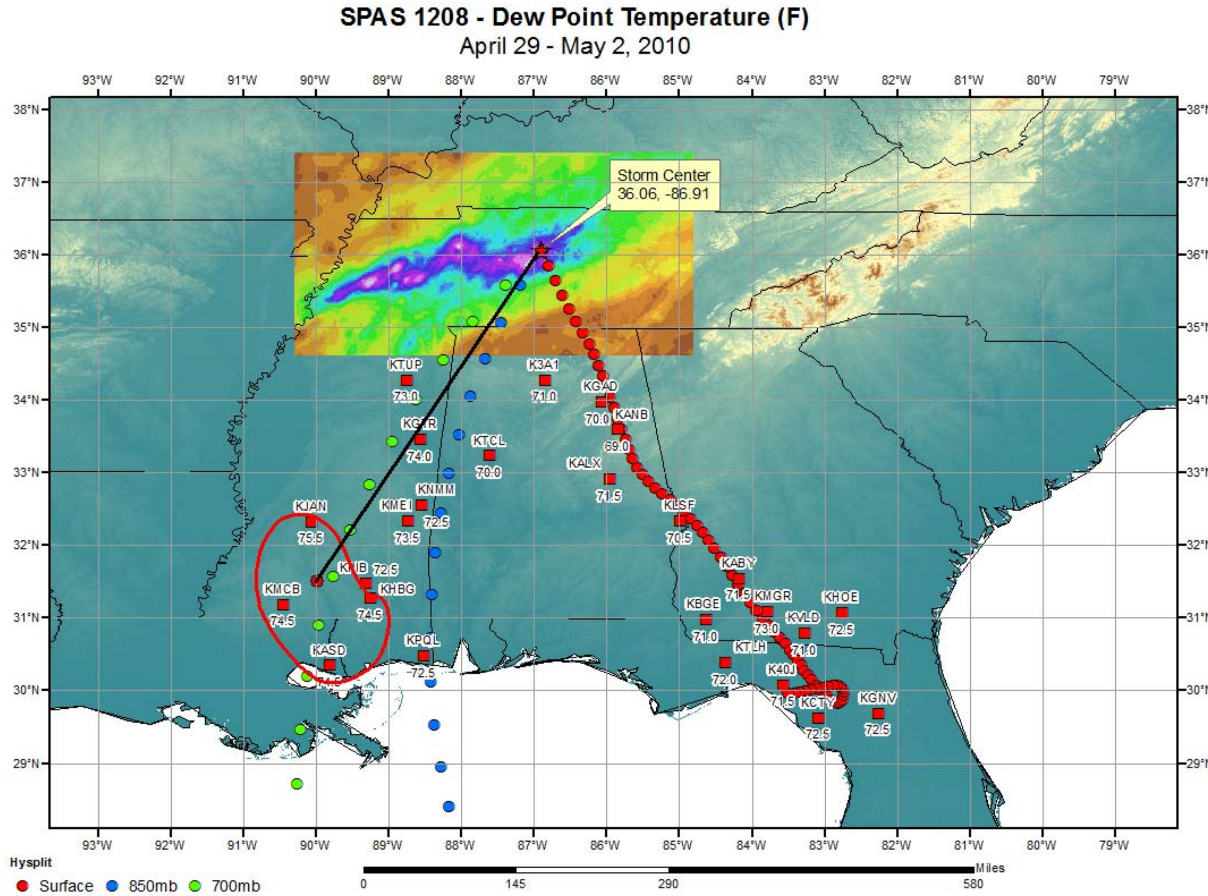
| Storm 1208 - May 1 (0100 UTC) - May 3 (1200 UTC), 2010 MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area (mi$^2$) | Duration (hours) | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 36 | 48 | 60 | Total |
| **0.4** | 4.63 | 6.50 | 8.92 | 11.04 | 12.01 | 15.31 | 17.77 | 18.33 | 18.39 | 19.35 | 19.66 | 19.70 | 19.70 |
| **1** | 4.59 | 6.48 | 8.89 | 10.99 | 11.95 | 15.22 | 17.69 | 18.24 | 18.30 | 19.24 | 19.57 | 19.63 | 19.63 |
| **10** | 4.44 | 6.36 | 8.81 | 10.73 | 11.77 | 14.96 | 17.44 | 18.01 | 18.06 | 19.03 | 19.28 | 19.41 | 19.41 |
| **25** | 4.29 | 6.20 | 8.60 | 10.42 | 11.56 | 14.66 | 17.18 | 17.74 | 17.81 | 18.87 | 19.08 | 19.19 | 19.19 |
| **50** | 4.04 | 5.93 | 8.25 | 10.09 | 11.21 | 14.11 | 16.69 | 17.27 | 17.34 | 18.67 | 18.89 | 18.98 | 18.98 |
| **100** | 3.72 | 5.50 | 7.72 | 9.51 | 10.73 | 13.20 | 15.89 | 16.55 | 16.64 | 18.30 | 18.60 | 18.69 | 18.69 |
| **200** | 3.43 | 4.96 | 7.10 | 8.89 | 10.19 | 12.18 | 14.98 | 15.64 | 15.78 | 17.77 | 18.19 | 18.30 | 18.30 |
| **300** | 3.16 | 4.65 | 6.72 | 8.45 | 9.80 | 11.55 | 14.45 | 15.09 | 15.27 | 17.43 | 17.93 | 18.04 | 18.04 |
| **400** | 2.96 | 4.42 | 6.44 | 8.08 | 9.42 | 11.06 | 14.07 | 14.71 | 14.91 | 17.18 | 17.72 | 17.83 | 17.83 |
| **500** | 2.80 | 4.25 | 6.18 | 7.74 | 9.07 | 10.62 | 13.73 | 14.40 | 14.63 | 16.99 | 17.54 | 17.66 | 17.66 |
| **1,000** | 2.26 | 3.65 | 5.24 | 6.69 | 7.80 | 9.04 | 12.57 | 13.29 | 13.64 | 16.38 | 16.92 | 17.03 | 17.03 |
| **2,000** | 1.79 | 3.06 | 4.19 | 5.43 | 6.44 | 7.50 | 11.19 | 12.07 | 12.63 | 15.72 | 16.25 | 16.35 | 16.35 |
| **5,000** | 1.37 | 2.44 | 3.06 | 3.95 | 4.85 | 5.60 | 9.25 | 10.29 | 10.91 | 14.28 | 14.89 | 14.98 | 14.98 |
| **10,000** | 0.99 | 1.84 | 2.43 | 2.94 | 3.62 | 4.14 | 7.41 | 8.46 | 9.08 | 12.39 | 13.02 | 13.12 | 13.12 |
| **20,000** | 0.66 | 1.27 | 1.77 | 2.16 | 2.60 | 2.94 | 5.56 | 6.53 | 7.16 | 10.28 | 11.05 | 11.14 | 11.14 |
| **50,000** | 0.32 | 0.62 | 0.91 | 1.17 | 1.41 | 1.68 | 3.17 | 4.08 | 4.63 | 6.64 | 7.63 | 7.75 | 7.75 |




SPAS 1208 Storm Center Mass Curve
May 1 (0100 UTC) to June 3 (1200 UTC), 2010
Lat: 36.11 Lon: -88.05
Incremental
Accumulated
19.71"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
0
5
10
15
20
10
20
30
40
50
60


90°W
89°W
88°W
87°W
86°W
85°W
37°N
36°N
35°N
KPAH
KHPX
KOHX
KNQA
KHTX
1
N
ISOHYETAL FROM SPAS #1208
Total 60-hour Rainfall (inches)
05/01/2010 0100 UTC - 05/03/2010 1200 UTC
Miles
Precipitaiton (inches)
<= 1.50
1.51 - 2.00
2.01 - 2.50
2.51 - 3.00
3.01 - 3.50
3.51 - 4.00
4.01 - 4.50
4.51 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
14.01 - 15.00
15.01 - 16.00
16.01 - 17.00
17.01 - 18.00
18.01 - 19.00
19.01 - 19.71
US Radar Site
DAD Zone
Daily
Hourly
Hourly Est.
Hourly Est. Pseudo
Hourly Pseudo
Supplemental
Supplemental Est.
Tennessee


NOAA HYSPLIT MODEL
Backward trajectories ending at 2300 UTC 01 May 10
CDC1 Meteorological Data
Source ★ at 36.06 N 86.91 W
30
-60
-70
-100
-90
-80
20
10
hPa
750
850
982
750
800
850
900
950
1000
18
12
06
00
05/01
18
12
06
00
04/30
18
12
06
00
04/29
This is not a NOAA product. It was produced by a web user.
Job ID: 319547
Job Start: Wed Sep 21 16:17:45 UTC 2011
Source 1 lat.: 36.06 lon.: -86.91 hgts: 0, 1250, 2300 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 May 2010 - reanalysis


SPAS 1208 - Dew Point Temperature (F)
April 29 - May 2, 2010
Storm Center
36.06, -86.91
KTUP 73.0
K3A1 71.0
KGAD 70.0
KANB 69.0
KGTR 74.0
KTCL 70.0
KALX 71.5
KNMM 72.5
KMEI 73.5
KJAN 75.5
KLSF 70.5
KHIB 72.5
KHBG 74.5
KMCB 74.5
KABY 71.5
KMGR 73.0
KHOE 72.5
KBGE 71.0
KVLD 71.0
KTLH 72.0
KASD
KPQL 72.5
K40J 71.5
KCTY 72.5
KGNV 72.5
Hysplit
Surface 850mb 700mb
Miles
0 145 290 580

# Hybrid Storms

# Storm Precipitation Analysis System (SPAS) For Storm #1699_1 SPAS Analysis

**General Storm Location**: Hayward, WI

**Storm Dates**: August 27-31, 1941

**Event**: Synoptic

**DAD Zone 1**

**Latitude**: 45.9958

**Longitude**: -91.0958

**Max. Grid Rainfall Amount**: 15.35”

**Max. Observed Rainfall Amount**: 15.31”

**Number of Stations**: 362

**SPAS Version**: 10.0

**Basemap:** 1699_isohyetal_sm

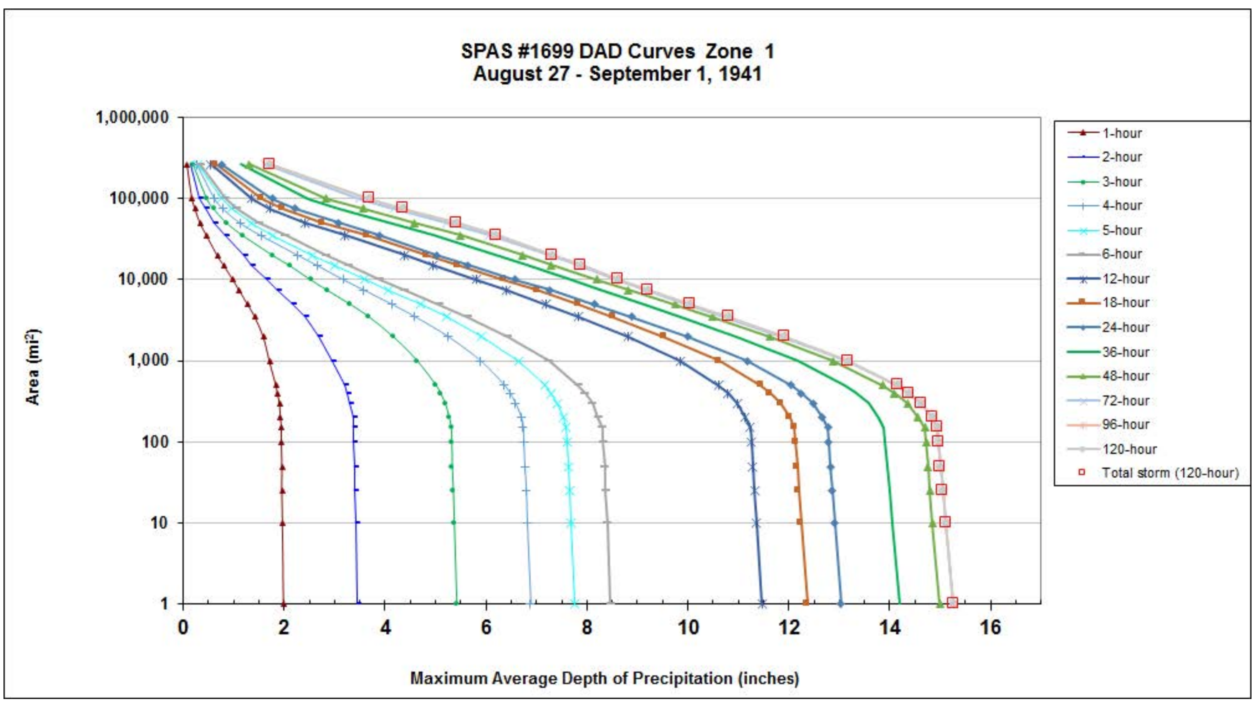
**Spatial resolution:** 0.2304

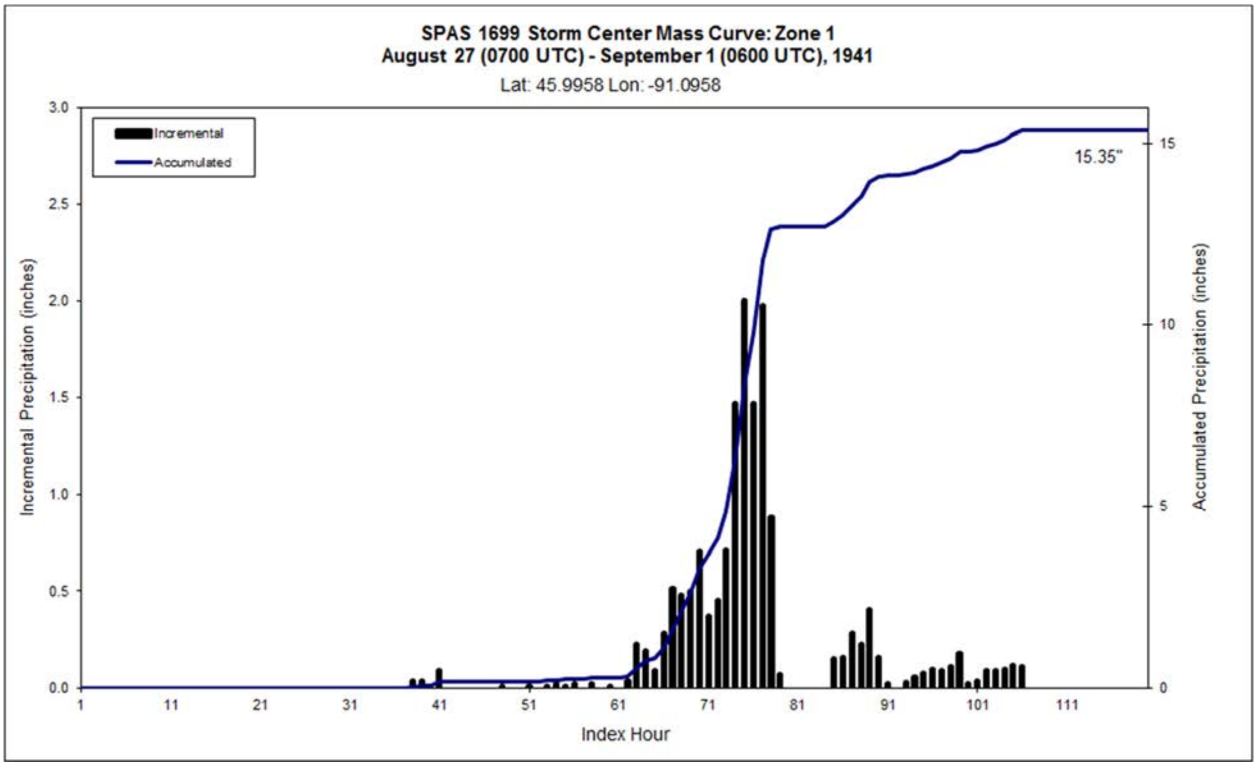
**Radar Included:** No

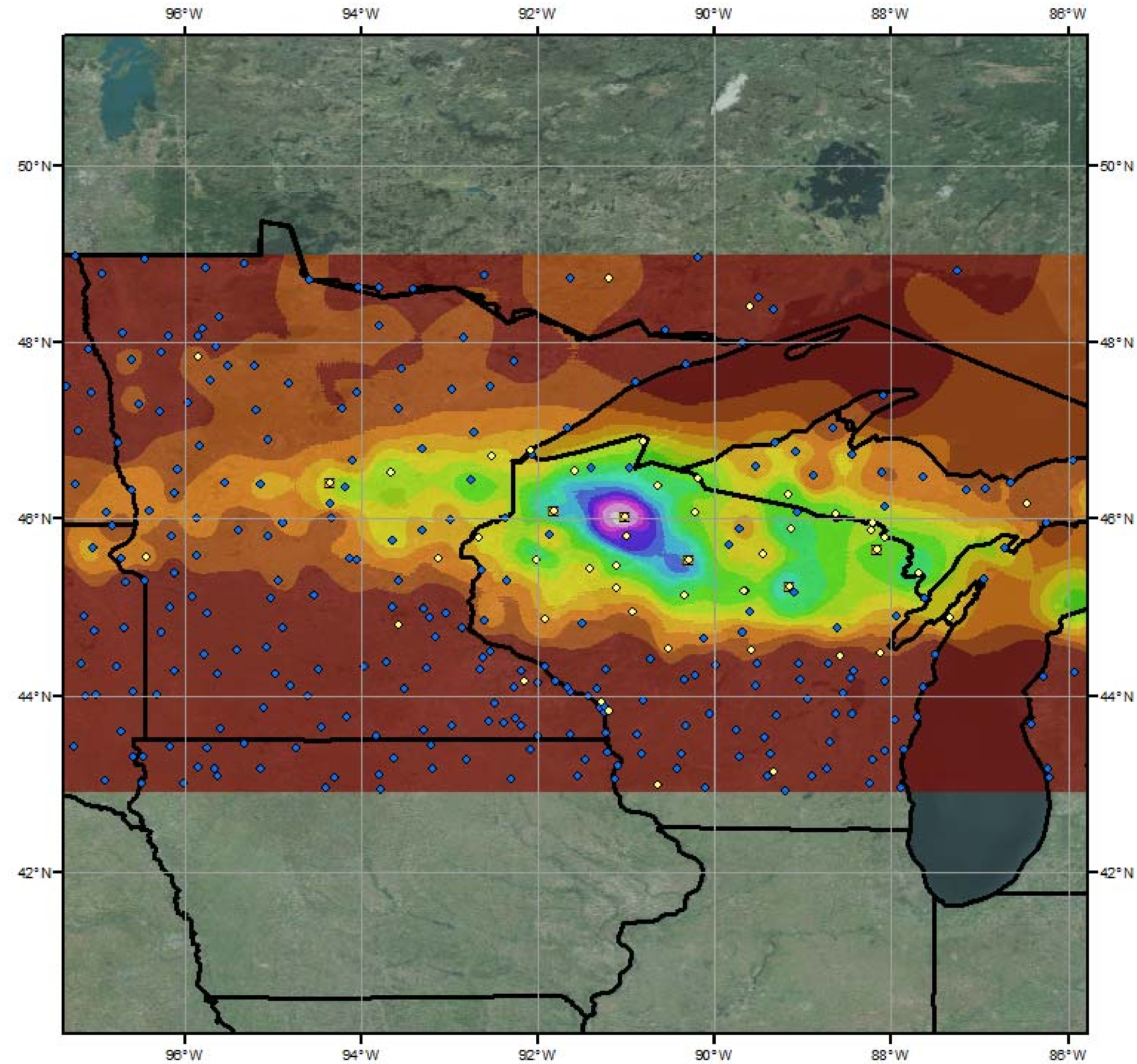
**Depth-Area-Duration (DAD) analysis**: Yes

**Reliability of results:** This analysis was based on 362 hourly pseudo stations, daily data and supplemental station data. We have a good degree of confidence for the station based storm total results. The spatial pattern is dependent on the USACE isohyetal basemap. Timing is based on the hourly pseudo stations. Several daily stations were moved to supplemental due to timing issues and to ensure data consistency.

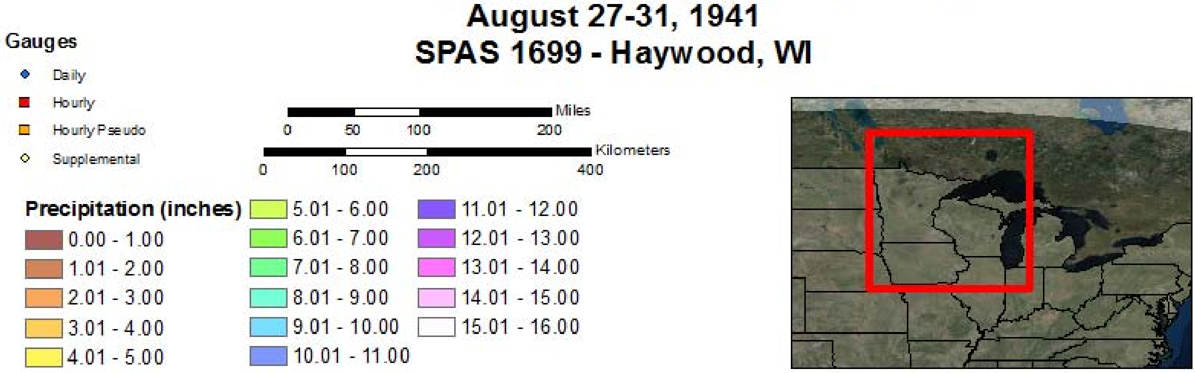
| Storm 1699 - August 27 (0700 UTC) - September 1 (0600 UTC), 1941 | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | | | | |
| Area ($mi^2$) | Duration (hours) | | | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | 96 | 120 | Total |
| 0.4 | 2.00 | 3.47 | 5.44 | 6.91 | 7.79 | 8.50 | 11.51 | 12.41 | 13.08 | 14.24 | 15.05 | 15.32 | 15.32 | 15.32 | 15.32 |
| 1 | 1.99 | 3.45 | 5.42 | 6.88 | 7.76 | 8.47 | 11.47 | 12.37 | 13.03 | 14.19 | 14.99 | 15.26 | 15.26 | 15.26 | 15.26 |
| 10 | 1.97 | 3.42 | 5.37 | 6.81 | 7.68 | 8.40 | 11.36 | 12.25 | 12.91 | 14.05 | 14.85 | 15.11 | 15.11 | 15.11 | 15.11 |
| 25 | 1.96 | 3.40 | 5.35 | 6.79 | 7.65 | 8.37 | 11.32 | 12.20 | 12.86 | 13.99 | 14.80 | 15.06 | 15.06 | 15.06 | 15.06 |
| 50 | 1.96 | 3.39 | 5.33 | 6.76 | 7.63 | 8.35 | 11.29 | 12.17 | 12.83 | 13.95 | 14.76 | 15.01 | 15.01 | 15.01 | 15.01 |
| 100 | 1.95 | 3.38 | 5.32 | 6.74 | 7.61 | 8.32 | 11.26 | 12.13 | 12.79 | 13.91 | 14.72 | 14.97 | 14.97 | 14.97 | 14.97 |
| 150 | 1.95 | 3.38 | 5.31 | 6.73 | 7.59 | 8.30 | 11.24 | 12.11 | 12.77 | 13.89 | 14.70 | 14.94 | 14.94 | 14.94 | 14.94 |
| 200 | 1.93 | 3.36 | 5.27 | 6.69 | 7.54 | 8.22 | 11.14 | 12.02 | 12.66 | 13.79 | 14.56 | 14.83 | 14.84 | 14.84 | 14.84 |
| 300 | 1.91 | 3.30 | 5.19 | 6.58 | 7.42 | 8.11 | 10.98 | 11.84 | 12.48 | 13.58 | 14.35 | 14.61 | 14.62 | 14.62 | 14.62 |
| 400 | 1.87 | 3.25 | 5.10 | 6.47 | 7.29 | 7.96 | 10.79 | 11.63 | 12.25 | 13.34 | 14.09 | 14.36 | 14.38 | 14.38 | 14.38 |
| 500 | 1.84 | 3.19 | 5.01 | 6.36 | 7.17 | 7.82 | 10.61 | 11.44 | 12.05 | 13.12 | 13.86 | 14.14 | 14.16 | 14.16 | 14.16 |
| 1,000 | 1.71 | 2.95 | 4.64 | 5.89 | 6.64 | 7.24 | 9.84 | 10.62 | 11.18 | 12.17 | 12.87 | 13.14 | 13.17 | 13.17 | 13.17 |
| 2,000 | 1.59 | 2.69 | 4.16 | 5.24 | 5.92 | 6.43 | 8.82 | 9.53 | 10.00 | 10.96 | 11.63 | 11.87 | 11.92 | 11.92 | 11.92 |
| 3,500 | 1.42 | 2.40 | 3.68 | 4.59 | 5.21 | 5.63 | 7.84 | 8.52 | 8.88 | 9.87 | 10.49 | 10.73 | 10.80 | 10.80 | 10.80 |
| 5,000 | 1.28 | 2.16 | 3.31 | 4.13 | 4.69 | 5.07 | 7.19 | 7.84 | 8.14 | 9.14 | 9.75 | 9.99 | 10.05 | 10.05 | 10.05 |
| 7,500 | 1.11 | 1.86 | 2.85 | 3.57 | 4.05 | 4.38 | 6.40 | 7.01 | 7.27 | 8.27 | 8.82 | 9.14 | 9.20 | 9.20 | 9.20 |
| 10,000 | 0.99 | 1.65 | 2.53 | 3.17 | 3.59 | 3.89 | 5.81 | 6.35 | 6.57 | 7.70 | 8.20 | 8.58 | 8.63 | 8.63 | 8.63 |
| 15,000 | 0.81 | 1.36 | 2.11 | 2.65 | 3.00 | 3.27 | 4.94 | 5.43 | 5.65 | 6.81 | 7.30 | 7.82 | 7.89 | 7.89 | 7.89 |
| 20,000 | 0.68 | 1.20 | 1.78 | 2.27 | 2.55 | 2.82 | 4.39 | 4.82 | 5.02 | 6.19 | 6.73 | 7.24 | 7.31 | 7.31 | 7.31 |
| 35,000 | 0.47 | 0.84 | 1.19 | 1.54 | 1.78 | 2.02 | 3.21 | 3.64 | 3.88 | 4.96 | 5.50 | 6.06 | 6.21 | 6.21 | 6.21 |
| 50,000 | 0.34 | 0.61 | 0.87 | 1.12 | 1.34 | 1.49 | 2.40 | 2.75 | 3.08 | 4.08 | 4.57 | 5.21 | 5.41 | 5.41 | 5.41 |
| 75,000 | 0.24 | 0.43 | 0.61 | 0.78 | 0.97 | 1.06 | 1.72 | 1.97 | 2.22 | 3.08 | 3.57 | 4.18 | 4.35 | 4.35 | 4.35 |
| 100,000 | 0.18 | 0.33 | 0.47 | 0.61 | 0.77 | 0.84 | 1.36 | 1.56 | 1.76 | 2.48 | 2.84 | 3.49 | 3.69 | 3.69 | 3.69 |
| 263,732 | 0.08 | 0.14 | 0.20 | 0.26 | 0.30 | 0.34 | 0.55 | 0.64 | 0.76 | 1.14 | 1.31 | 1.62 | 1.71 | 1.71 | 1.71 |




SPAS 1699 Storm Center Mass Curve: Zone 1
August 27 (0700 UTC) - September 1 (0600 UTC), 1941
Lat: 45.9958 Lon: -91.0958
Incremental
Accumulated
15.35"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour




**Total Storm (120-hours) Precipitation (inches)**
**August 27-31, 1941**
**SPAS 1699 - Haywood, WI**



WAR DEPARTMENT | CORPS OF ENGINEERS, U. S. ARMY

# STORM STUDIES – PERTINENT DATA SHEET

LOCATION MAP

Storm of August 28 – 31, 1941
Assignment U M V 1 – 22
Location Northern Wisconsin and Minn.
Study Prepared by:
Upper Mississippi Valley Division
St. Paul District Office
Part I Reviewed by H. M. Sec. of Weather Bureau, 3/24/42
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 4/11/45
Remarks: Center at:
Haywood and Moose Lake, Wisc.

## DATA AND COMPUTATIONS COMPILED

### PART I

Preliminary isohyetal map, in 4 sheet, scale 1 : 1,000,000

Precipitation data and mass curves: (Number of Sheets)

- Form 5001-C (Hourly precip. data) ---------- 33
- Form 5001-B (24-hour " " ) ---------- -
- Form 5001-D (" " " " ) ---------- 14
- Miscl. precip. records, meteorological data, etc. ---------- 3
- Form 5002 (Mass rainfall curves) ---------- 42

### PART II

Final isohyetal maps, in 1 sheet, scale 1,000,000

Data and computation sheets:

- Form S-10 (Data from mass rainfall curves) ---------- 6
- Form S-11 (Depth-area data from isohyetal map) ---------- 2
- Form S-12 (Maximum depth-duration data) ---------- 8
- Maximum duration-depth-area curves ---------- 1
- Data relating to periods of maximum rainfall ---------- 2

## MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

| Area in Sq. Mi. | Duration of Rainfall in Hours | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 12 | 18 | 24 | 30 | 36 | 48 | 60 | 72 | 78 |
| 10 | 8.5 | 11.5 | 12.4 | 12.4 | 13.3 | 13.8 | 14.4 | 15.0 | 15.0 | 15.0 |
| 100 | 8.1 | 11.0 | 11.8 | 11.8 | 12.7 | 13.3 | 13.8 | 14.3 | 14.5 | 14.5 |
| 200 | 7.8 | 10.6 | 11.3 | 11.3 | 12.3 | 13.0 | 13.4 | 13.9 | 14.1 | 14.1 |
| 500 | 6.8 | 9.5 | 10.2 | 10.3 | 11.2 | 12.0 | 12.5 | 12.9 | 13.1 | 13.1 |
| 1,000 | 5.6 | 8.2 | 9.0 | 9.1 | 10.0 | 10.9 | 11.5 | 11.9 | 12.0 | 12.0 |
| 2,000 | 4.3 | 6.9 | 7.7 | 7.9 | 8.8 | 9.7 | 10.4 | 10.8 | 10.9 | 10.9 |
| 5,000 | 3.0 | 5.2 | 5.9 | 6.3 | 7.2 | 8.1 | 8.9 | 9.3 | 9.5 | 9.5 |
| 10,000 | 2.1 | 3.8 | 4.6 | 5.1 | 5.9 | 6.8 | 7.8 | 8.2 | 8.4 | 8.4 |
| 20,000 | 1.5 | 2.7 | 3.4 | 3.8 | 4.7 | 5.5 | 6.5 | 7.1 | 7.3 | 7.3 |
| 50,000 | 0.9 | 1.6 | 2.1 | 2.5 | 3.1 | 3.6 | 4.5 | 5.1 | 5.2 | 5.2 |
| 60,000 | 0.8 | 1.4 | 1.9 | 2.2 | 2.8 | 3.3 | 4.1 | 4.5 | 4.7 | 4.7 |

Form S-2

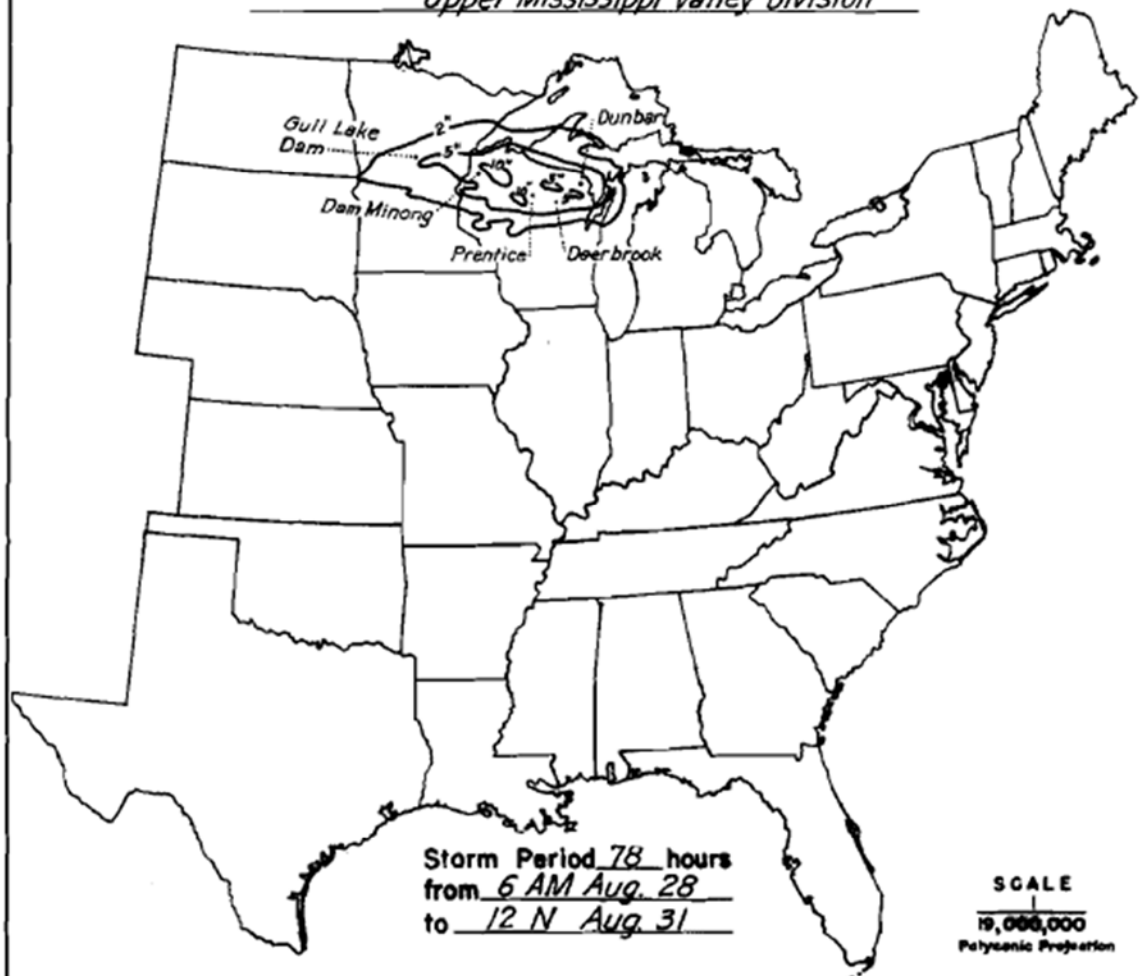
WAR DEPARTMENT CORPS OF ENGINEERS, U. S. ARMY

# STORM STUDIES – ISOHYETAL MAP

Storm of *August 28-31, 1941* Assignment *UMV 1-22*

Study Prepared by: *St. Paul, Minn. District*

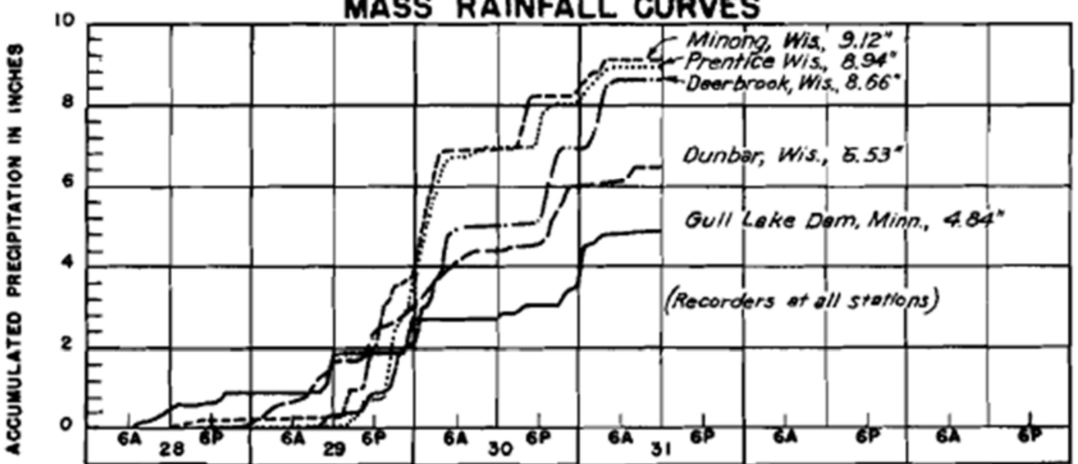
*Upper Mississippi Valley Division*



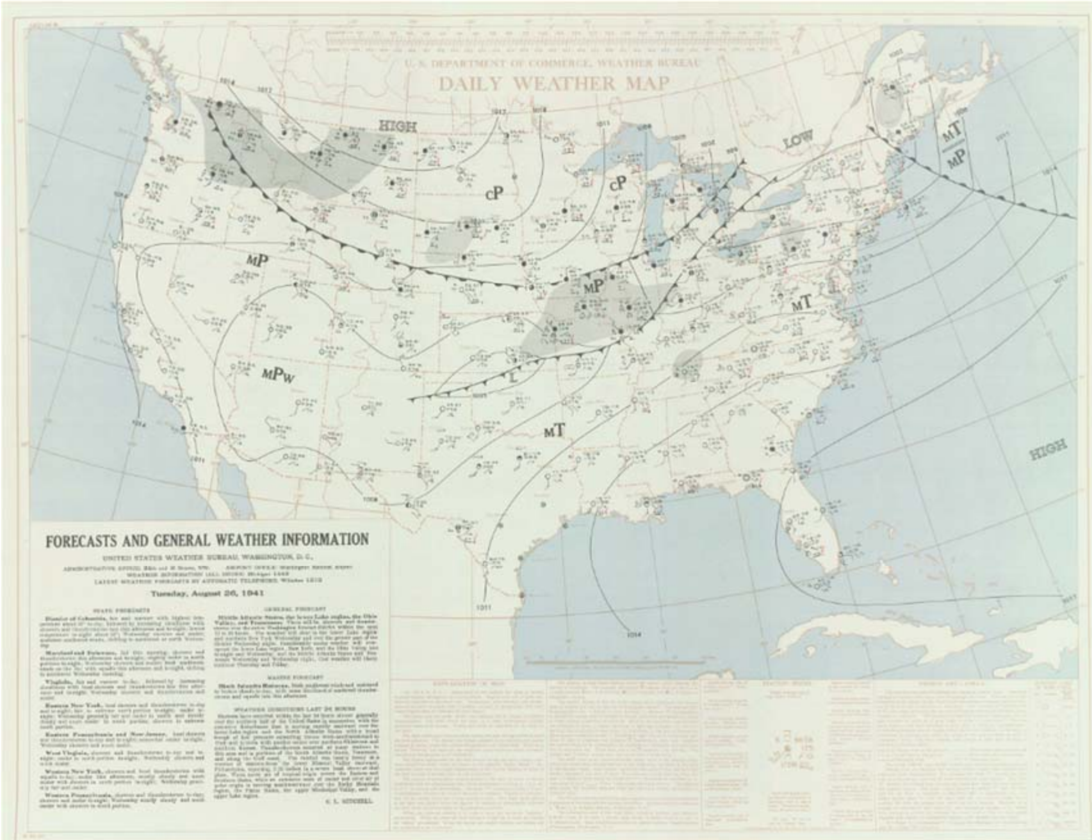

Storm Period *78* hours
from *6 AM Aug. 28*
to *12 N Aug. 31*

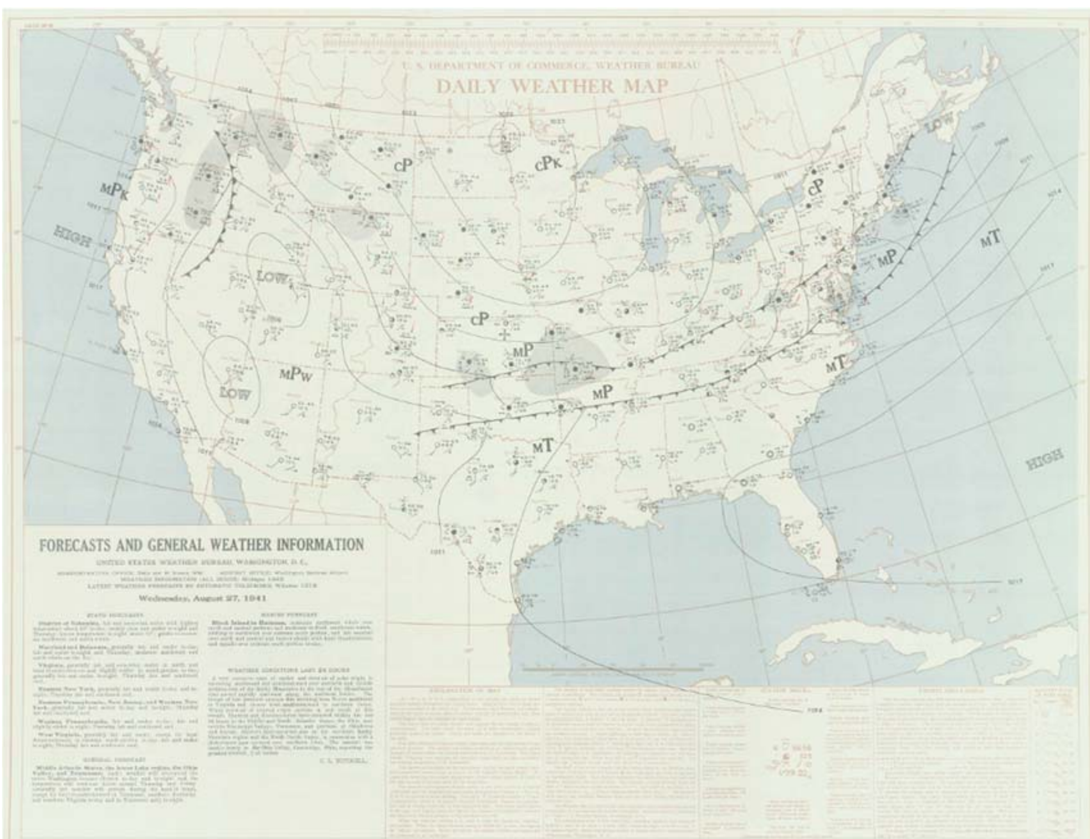
SCALE 1/19,000,000
Polyconic Projection

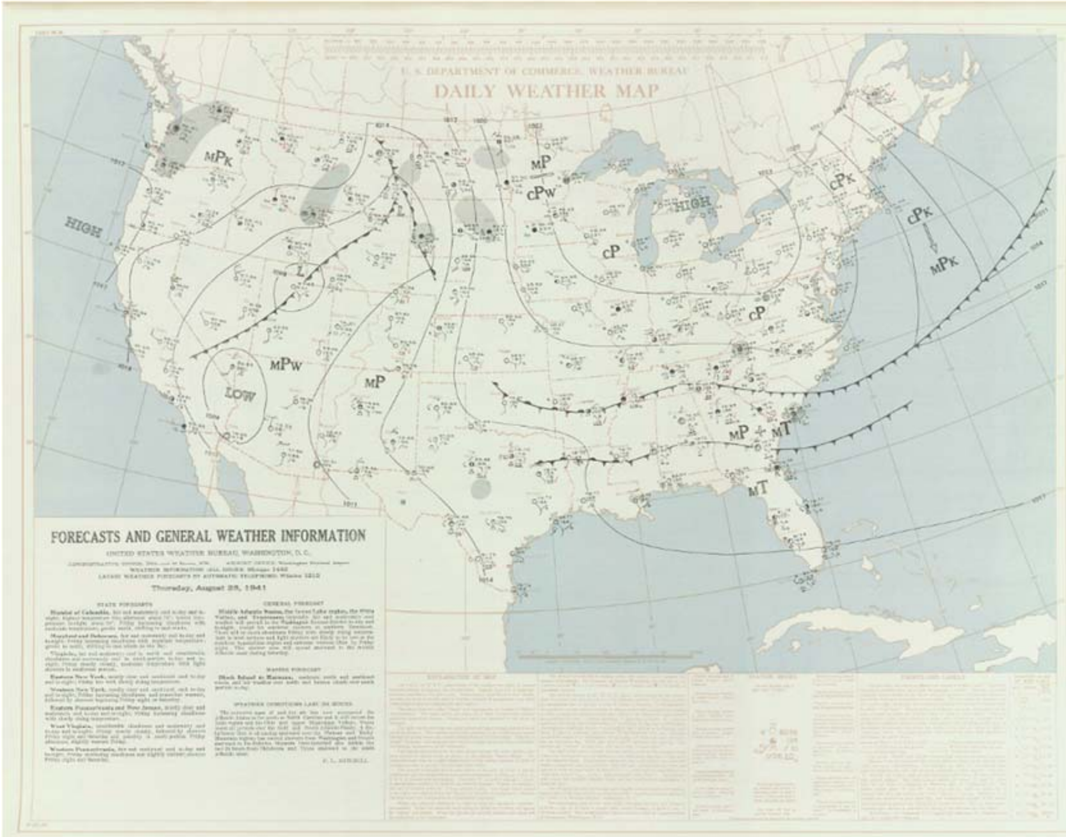
## MASS RAINFALL CURVES

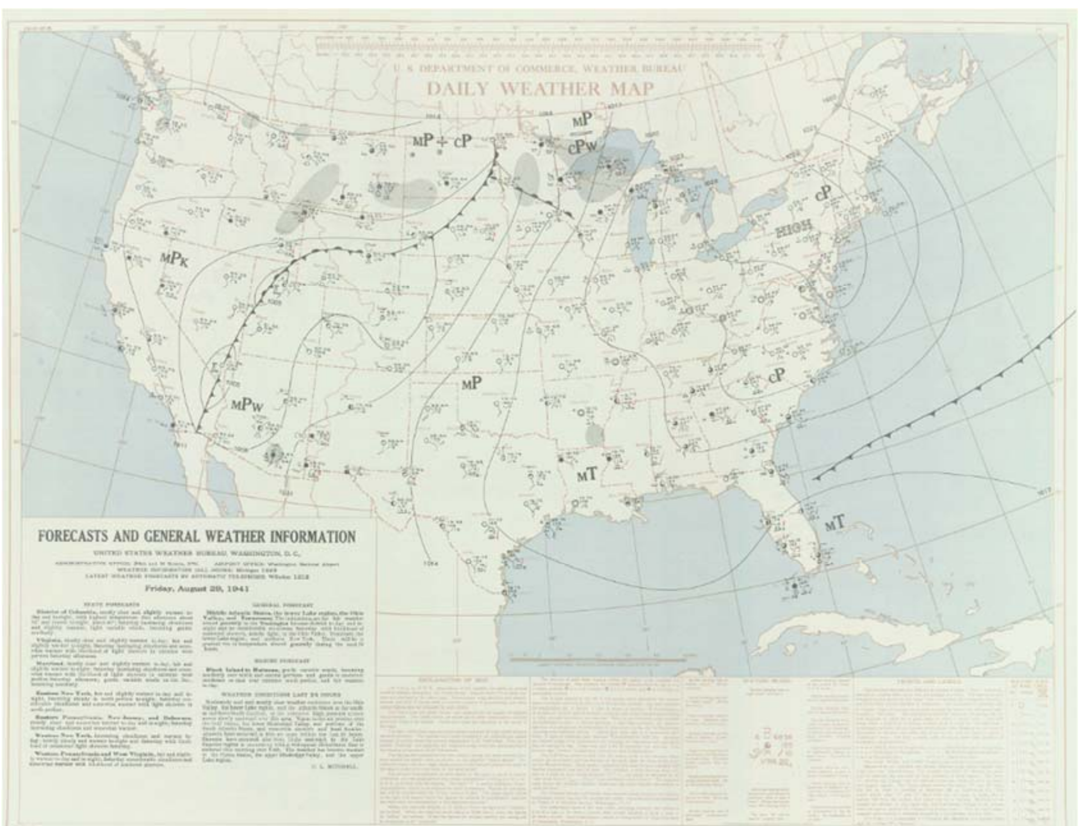


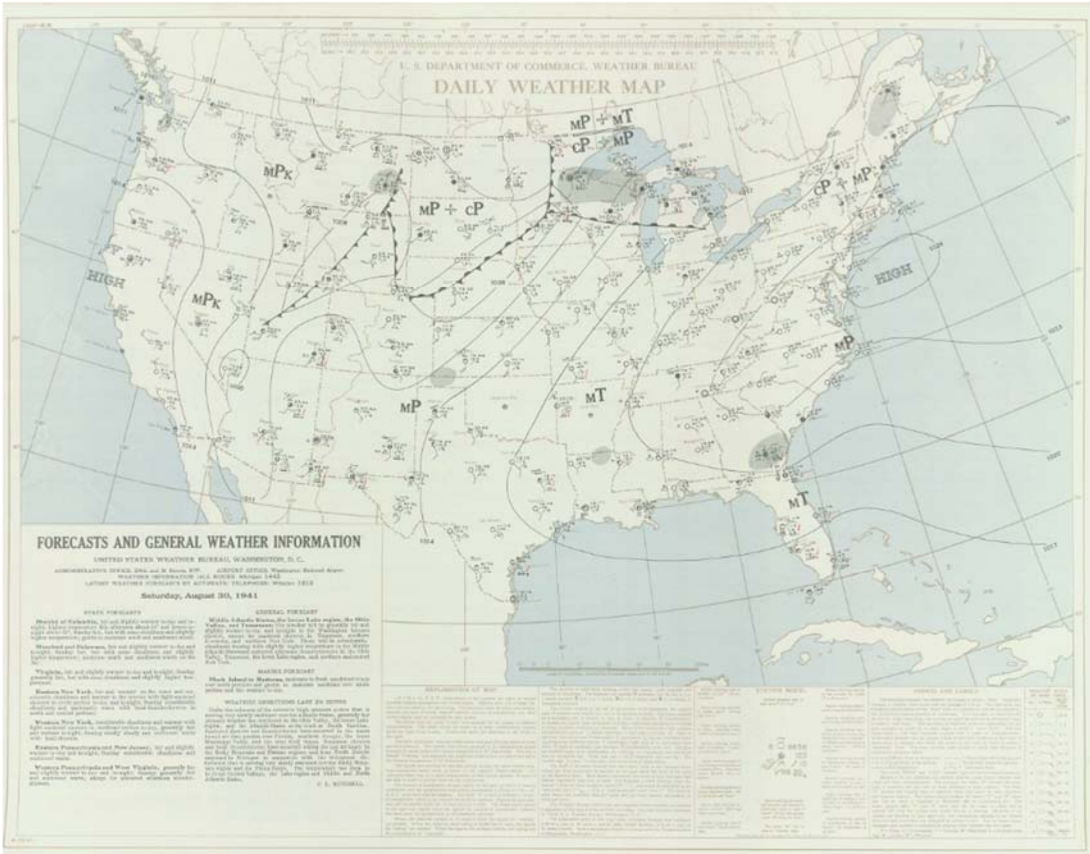

FORM S-3E


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
cP
cP
mP
mP
mT
mP
mPw
mT
mT
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D.C.
Tuesday, August 26, 1941

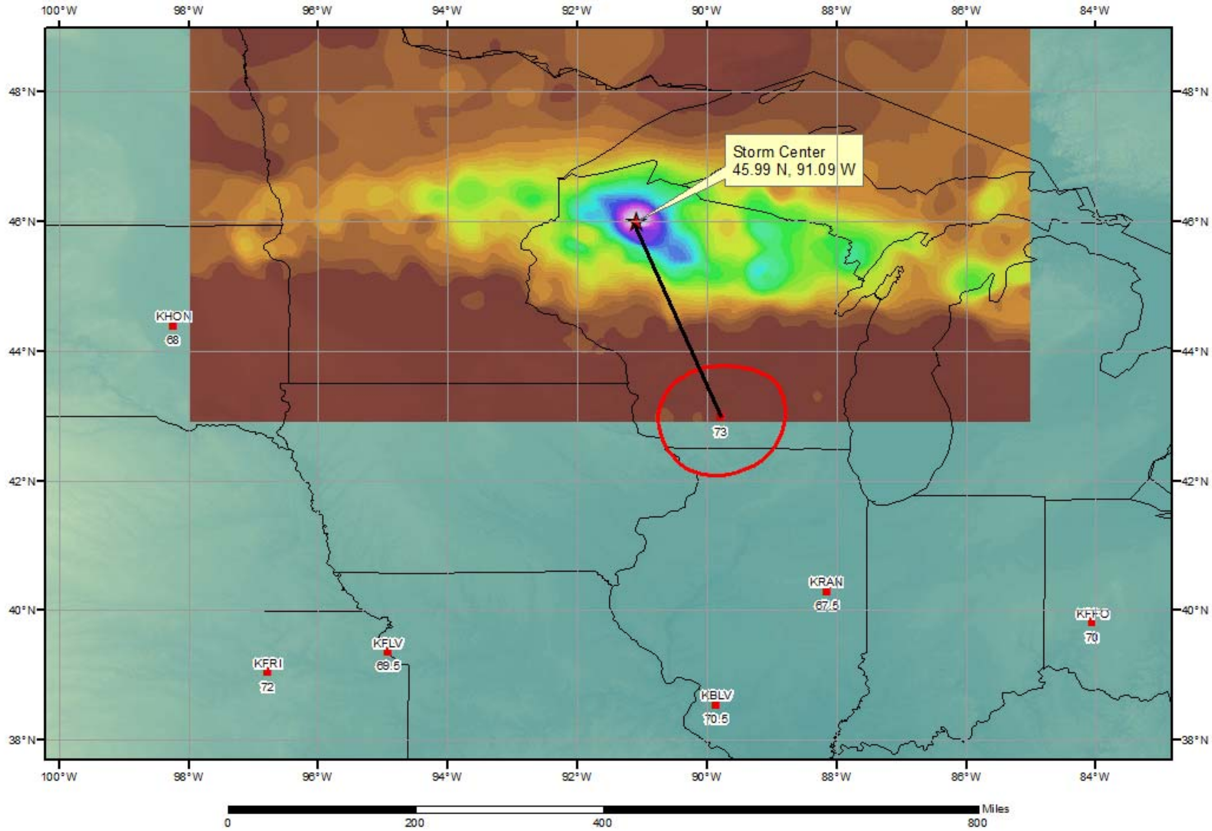

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
LOW
cP
cPk
cP
mPk
HIGH
LOW
LOW
mPw
cP
mP
mP
mP
mT
mT
mT
HIGH
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D.C.
Wednesday, August 27, 1941


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
MPK
cPW
MP
HIGH
cP
cPK
MPK
LOW
MPW
MP
cP
MP + MT
MT
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
Thursday, August 28, 1941


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
MP + cP
MP
cPW
cP
HIGH
MPK
MPW
MP
cP
MT
MT
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
Friday, August 29, 1941


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION
Saturday, August 30, 1941
HIGH
HIGH
mP + mT
cP + mP
mP + cP
cP + mP
mT
mP
mT

## SPAS 1699 Hayward, WI (UMV 1-22) Storm Analysis
August 27-31, 1941



# Storm Precipitation Analysis System (SPAS) For Storm #1183_1 SPAS Analysis

**General Storm Location**: Edgerton, Missouri

**Storm Dates**: July 18-20, 1965

**Event**: Synoptic

**DAD Zone 1**

**Latitude**: 40.4125

**Longitude**: -95.5125

**Max. Grid Rainfall Amount**: 20.76”

**Max. Observed Rainfall Amount**: 20.10” at ATCHISON 65N 41W SCT34

**Number of Stations**: **387** (90 Daily, 41 Hourly, 4 Hourly Estimated, 2 Hourly Estimated Pseudo, 13 Hourly Pseudo, and 237 Supplemental)

**SPAS Version**: 8.5

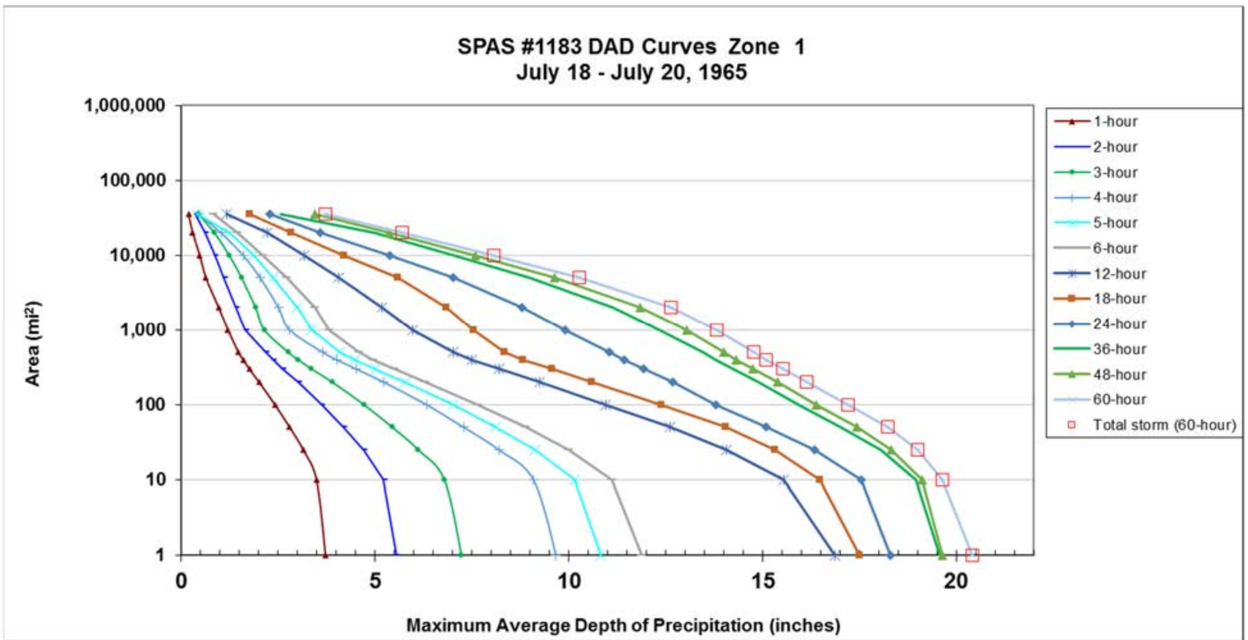
**Base Map Used:** Yes, conus_prism_ppt_in_1971_2000_07

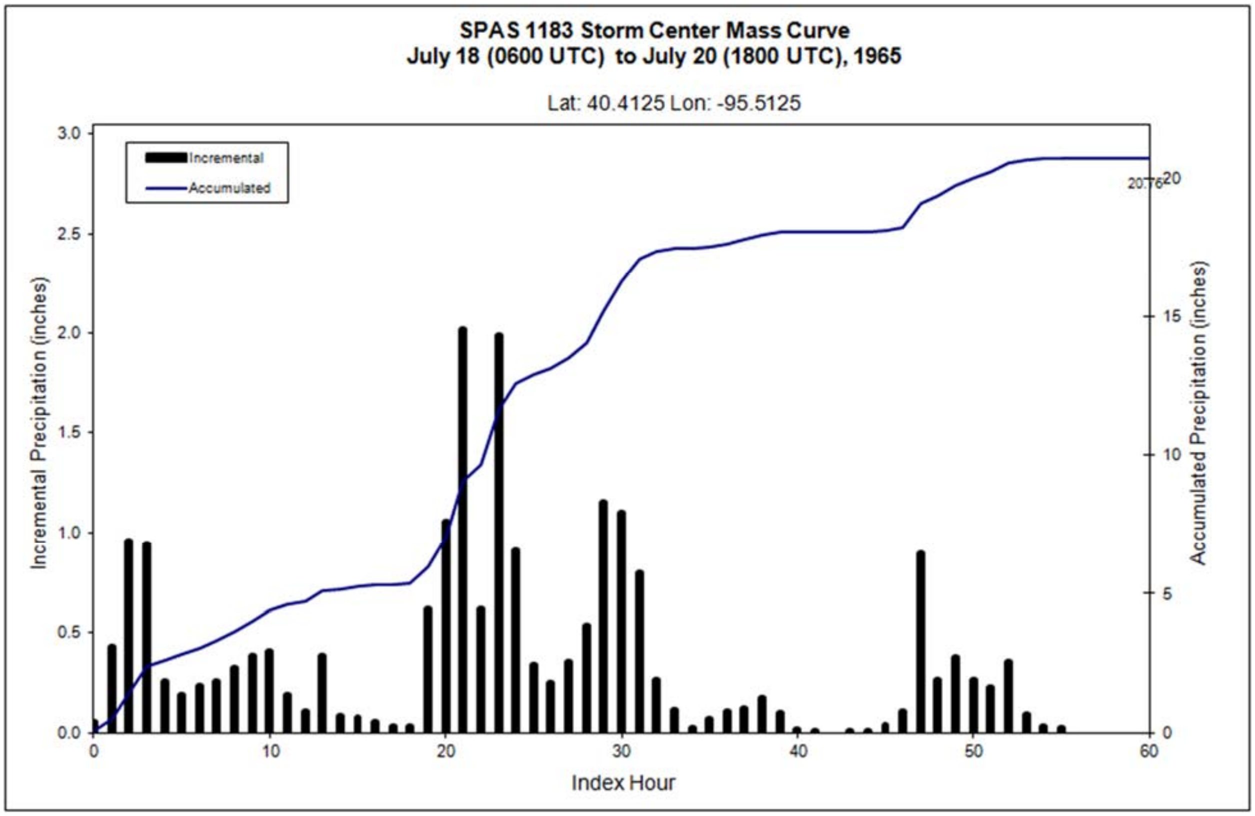
**Spatial resolution:** 00:00:30 (0.3 sq. miles)

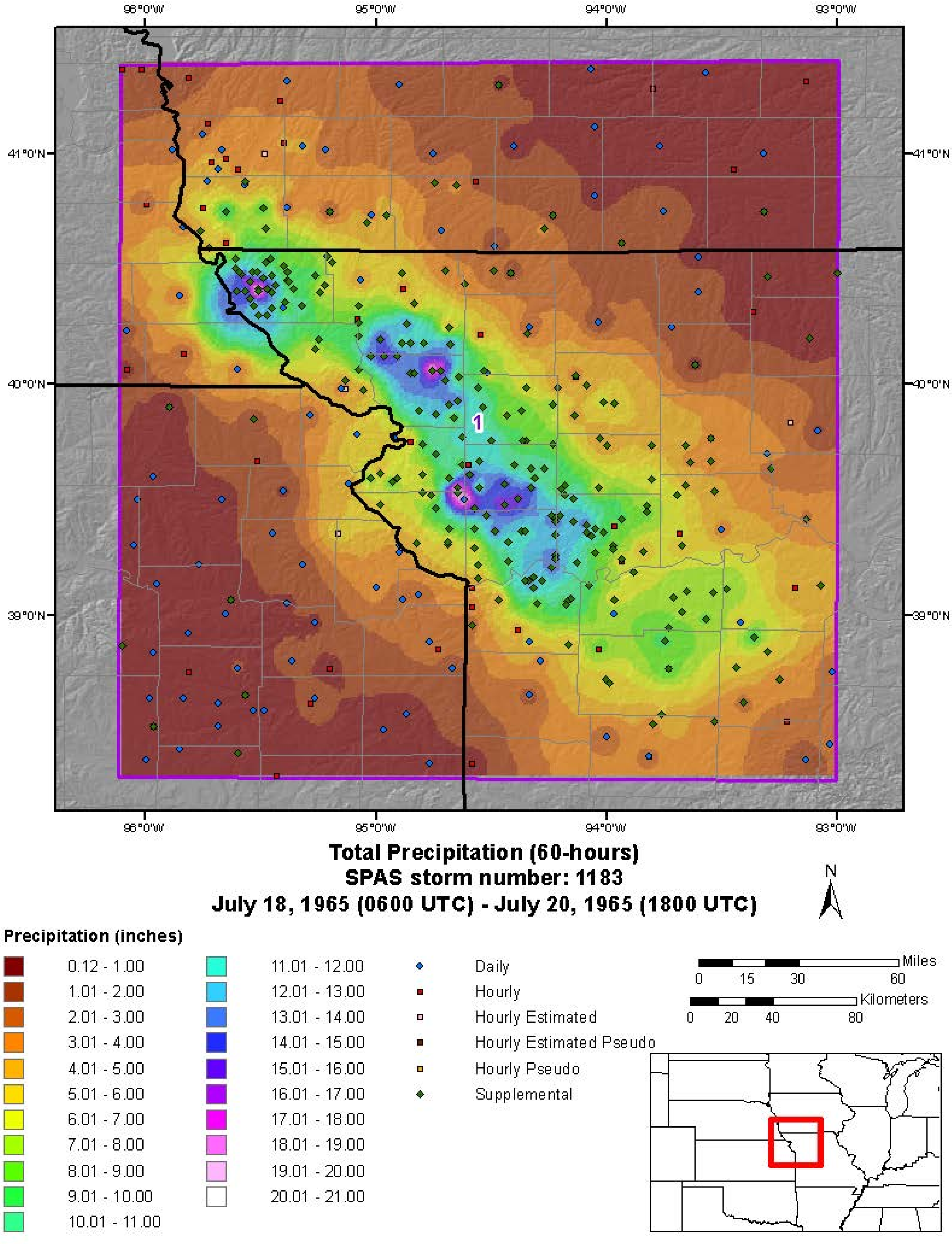
**Radar Included:** No

**Depth-Area-Duration (DAD) analysis**: Yes

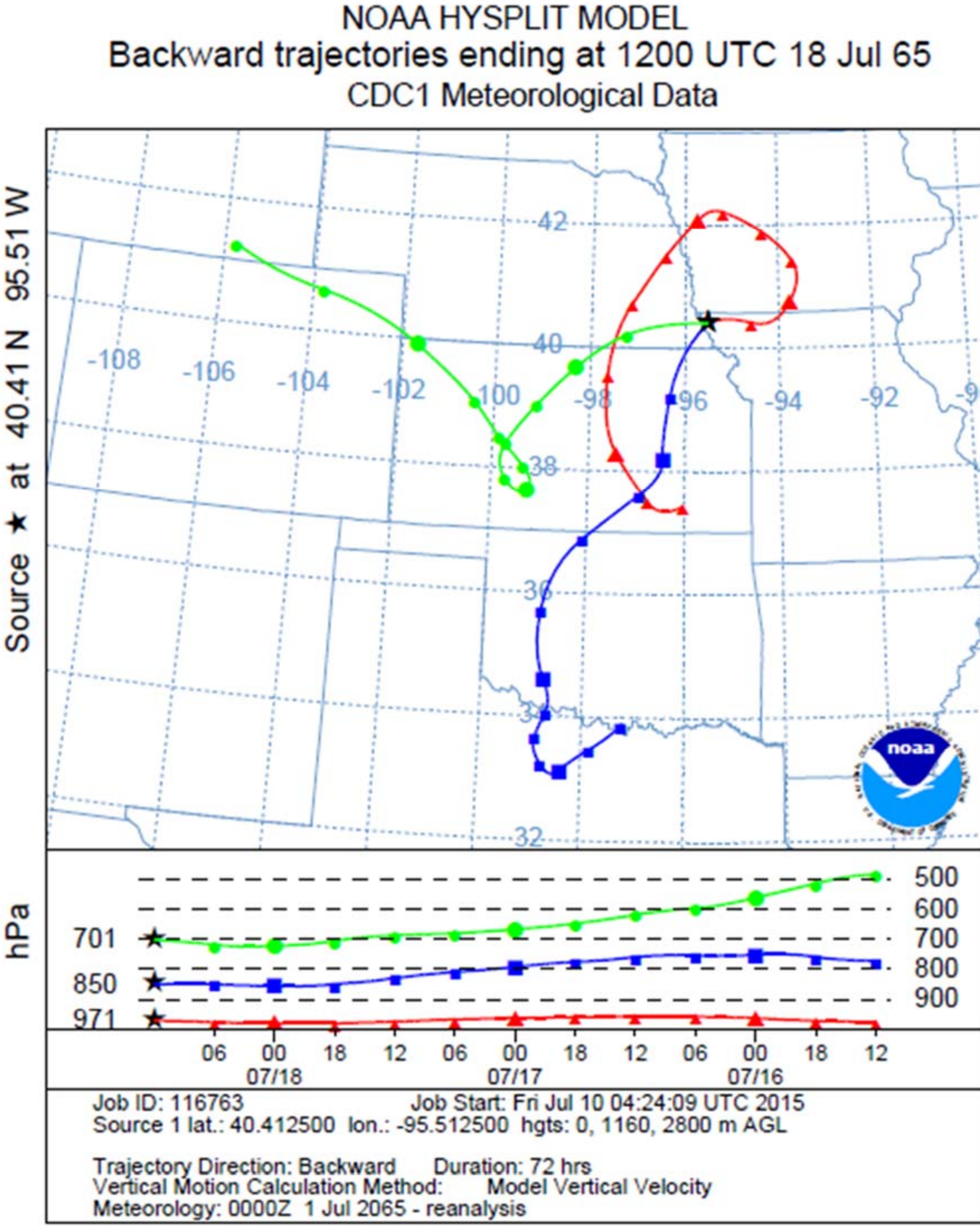
| Storm 1183 - July 18 (0600 UTC) - July 20 (1800 UTC), 1965 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | | |
| Area ($mi^2$) | Duration (hours) | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 36 | 48 | 60 | Total |
| 0.4 | 3.75 | 5.61 | 7.30 | 9.78 | 10.92 | 12.00 | 17.04 | 17.70 | 18.50 | 19.74 | 19.79 | 20.64 | 20.64 |
| 1 | 3.72 | 5.55 | 7.23 | 9.67 | 10.82 | 11.88 | 16.86 | 17.51 | 18.30 | 19.58 | 19.64 | 20.41 | 20.41 |
| 10 | 3.49 | 5.22 | 6.79 | 9.09 | 10.15 | 11.11 | 15.55 | 16.48 | 17.56 | 18.95 | 19.11 | 19.63 | 19.63 |
| 25 | 3.15 | 4.71 | 6.12 | 8.20 | 9.14 | 10.00 | 14.06 | 15.33 | 16.35 | 18.05 | 18.33 | 19.01 | 19.01 |
| 50 | 2.80 | 4.18 | 5.45 | 7.29 | 8.12 | 8.88 | 12.61 | 14.04 | 15.09 | 17.00 | 17.44 | 18.24 | 18.24 |
| 100 | 2.42 | 3.62 | 4.72 | 6.33 | 7.02 | 7.65 | 10.96 | 12.38 | 13.79 | 15.93 | 16.40 | 17.21 | 17.21 |
| 200 | 2.01 | 3.02 | 3.90 | 5.23 | 5.79 | 6.30 | 9.25 | 10.59 | 12.69 | 14.90 | 15.38 | 16.13 | 16.13 |
| 300 | 1.76 | 2.62 | 3.37 | 4.52 | 5.01 | 5.49 | 8.21 | 9.56 | 11.94 | 14.24 | 14.75 | 15.52 | 15.52 |
| 400 | 1.60 | 2.36 | 3.02 | 4.01 | 4.47 | 4.95 | 7.51 | 8.81 | 11.43 | 13.79 | 14.33 | 15.10 | 15.10 |
| 500 | 1.48 | 2.18 | 2.77 | 3.66 | 4.09 | 4.58 | 7.03 | 8.34 | 11.05 | 13.45 | 14.00 | 14.78 | 14.78 |
| 1,000 | 1.21 | 1.65 | 2.15 | 2.80 | 3.37 | 3.82 | 5.97 | 7.55 | 9.92 | 12.35 | 13.05 | 13.83 | 13.83 |
| 2,000 | 0.97 | 1.41 | 1.92 | 2.51 | 3.00 | 3.46 | 5.17 | 6.84 | 8.80 | 11.13 | 11.85 | 12.63 | 12.63 |
| 5,000 | 0.64 | 1.10 | 1.56 | 2.04 | 2.38 | 2.73 | 4.06 | 5.59 | 7.02 | 8.97 | 9.64 | 10.28 | 10.28 |
| 10,000 | 0.48 | 0.86 | 1.24 | 1.60 | 1.86 | 2.10 | 3.18 | 4.21 | 5.38 | 7.05 | 7.59 | 8.07 | 8.07 |
| 20,000 | 0.30 | 0.61 | 0.86 | 1.03 | 1.25 | 1.45 | 2.23 | 2.84 | 3.58 | 4.98 | 5.36 | 5.71 | 5.71 |
| 35,221 | 0.19 | 0.37 | 0.45 | 0.46 | 0.43 | 0.83 | 1.17 | 1.78 | 2.29 | 2.57 | 3.46 | 3.72 | 3.72 |



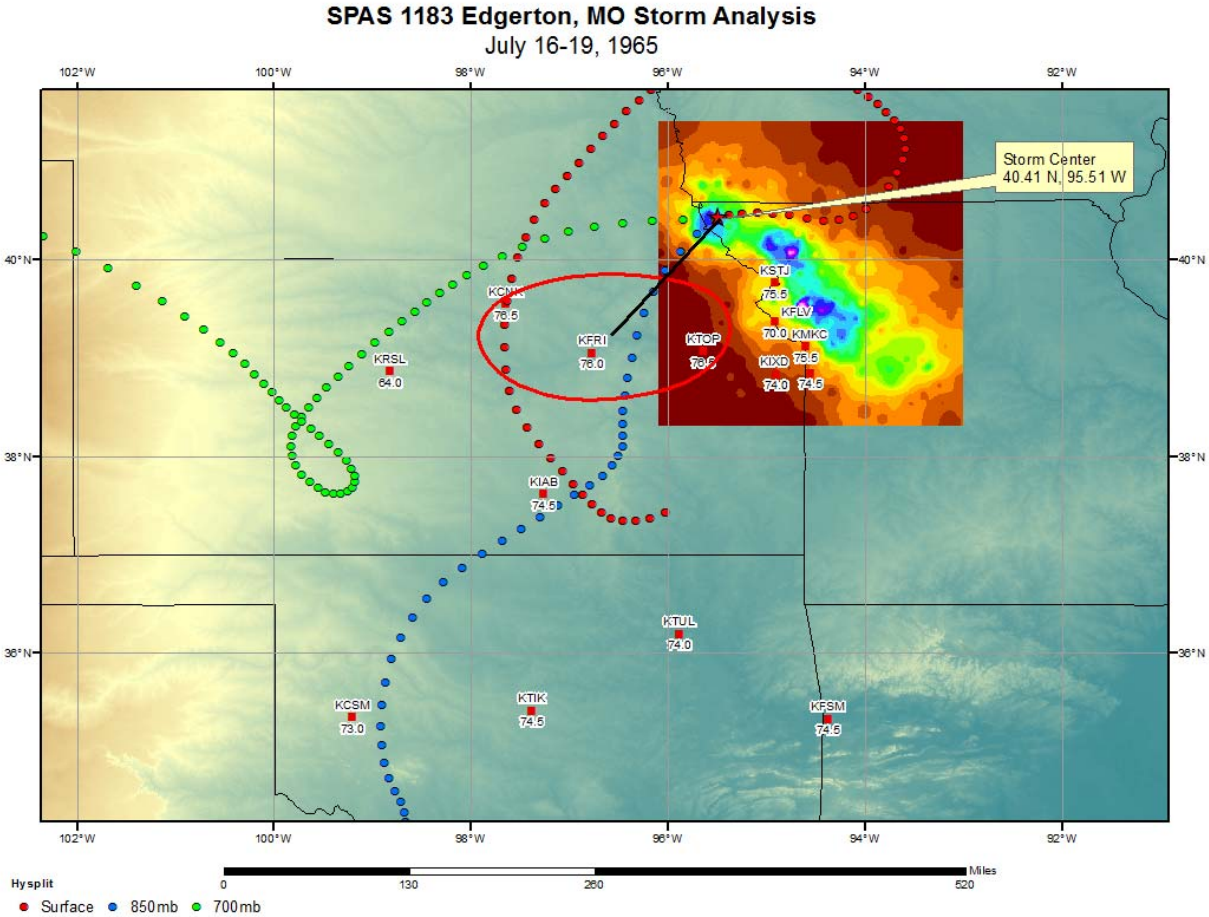

SPAS 1183 Storm Center Mass Curve
July 18 (0600 UTC) to July 20 (1800 UTC), 1965
Lat: 40.4125 Lon: -95.5125
Incremental
Accumulated
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
20.76
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
5
10
15
20
0
10
20
30
40
50
60




**Total Precipitation (60-hours)**
**SPAS storm number: 1183**
**July 18, 1965 (0600 UTC) - July 20, 1965 (1800 UTC)**



NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 18 Jul 65
CDC1 Meteorological Data
Source ★ at 40.41 N 95.51 W
-108
-106
-104
-102
-100
-98
-96
-94
-92
-90
42
40
38
36
34
32
hPa
701
850
971
500
600
700
800
900
06
00
18
12
06
00
18
12
06
00
18
12
07/18
07/17
07/16
Job ID: 116763 Job Start: Fri Jul 10 04:24:09 UTC 2015
Source 1 lat.: 40.412500 lon.: -95.512500 hgts: 0, 1160, 2800 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jul 2065 - reanalysis


SPAS 1183 Edgerton, MO Storm Analysis
July 16-19, 1965
Storm Center
40.41 N, 95.51 W
KCNK
76.5
KRSL
64.0
KFRI
76.0
KTOP
KSTJ
75.5
KFLV
70.0
KMKC
75.5
KIXD
74.0
74.5
KIAB
74.5
KTUL
74.0
KCSM
73.0
KTIK
74.5
KFSM
74.5
102°W
100°W
98°W
96°W
94°W
92°W
40°N
38°N
36°N
Miles
0
130
260
520
Hysplit
Surface
850mb
700mb

# Storm Precipitation Analysis System (SPAS) For Storm #1725_1 SPAS Analysis

**General Storm Location**: Leonard, ND

**Storm Dates**: June 27-30, 1975

**Event**: Local

**DAD Zone 1**

**Latitude**: 46.5958

**Longitude**: -97.3375

**Max. Grid Rainfall Amount**: 20.66”

**Max. Observed Rainfall Amount:** 20.00”

**Number of Stations**: 83

**SPAS Version**: 10.0

**Base Map Used:** USGS Report Isohyetal Image

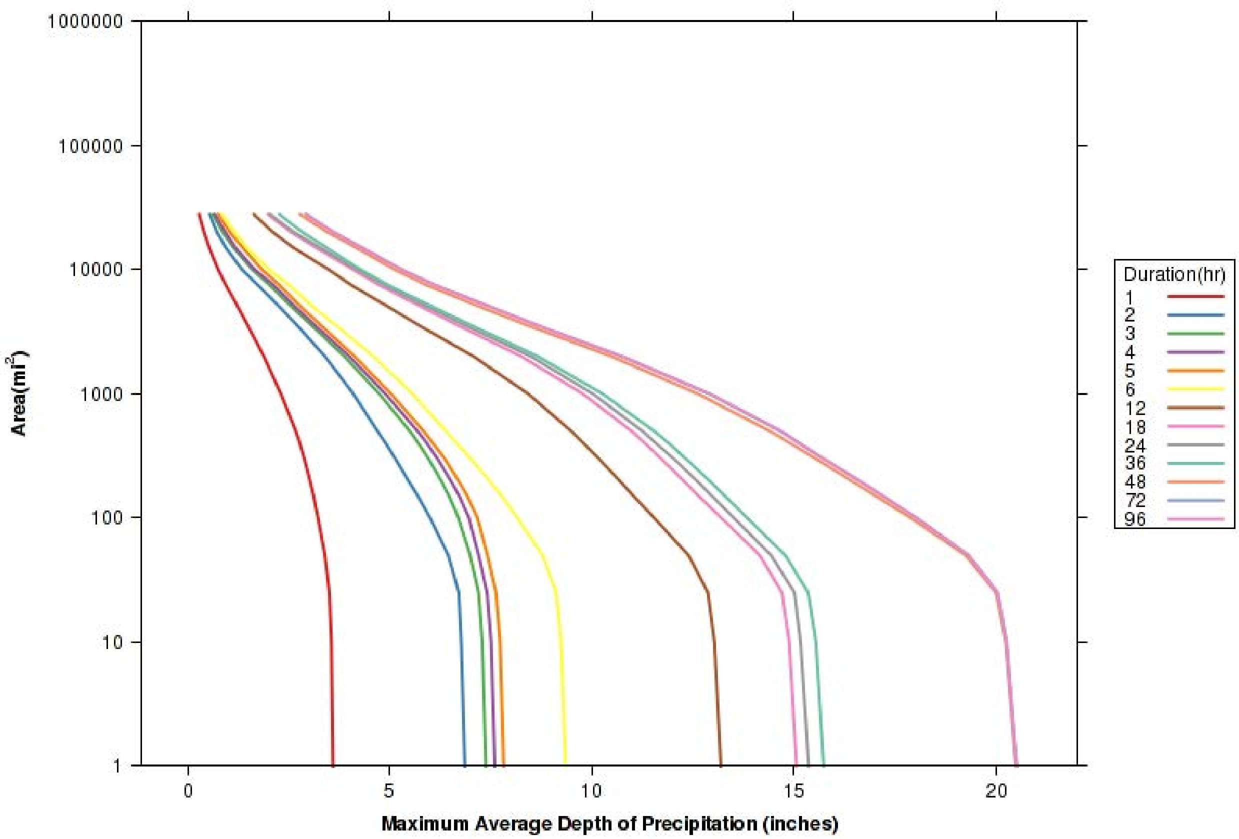
**Radar Included:** No

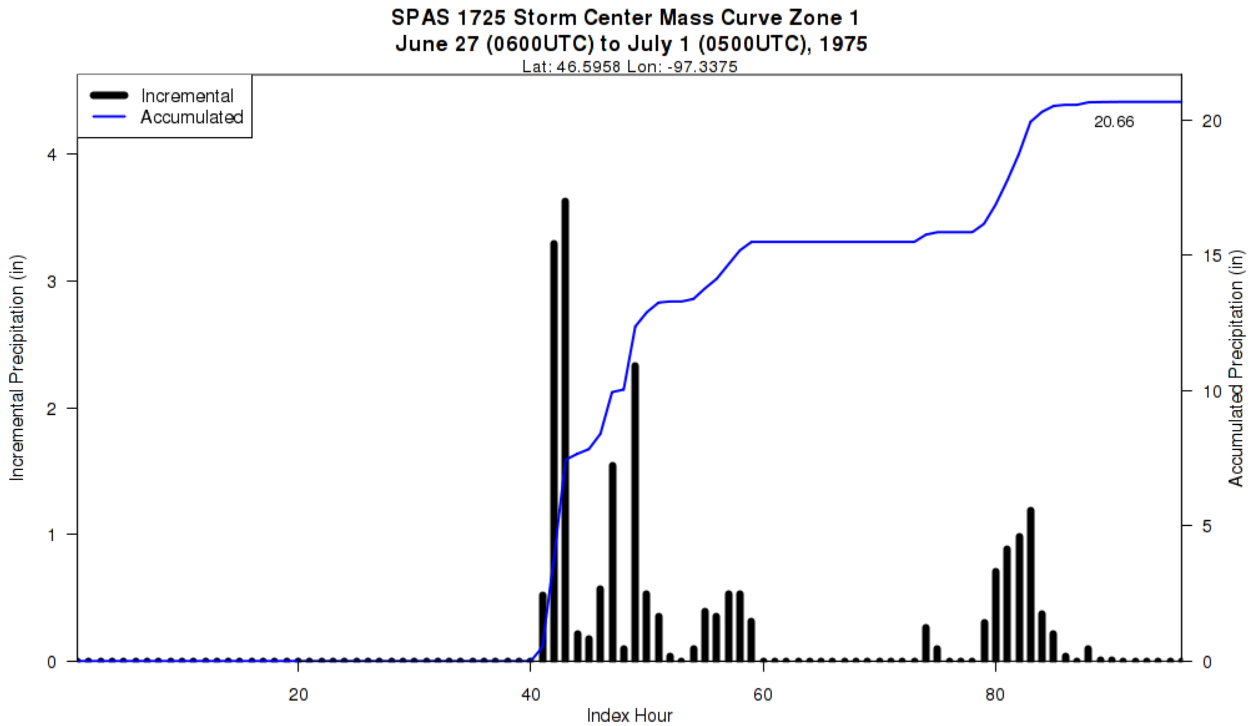
**Depth-Area-Duration (DAD) analysis**: Yes

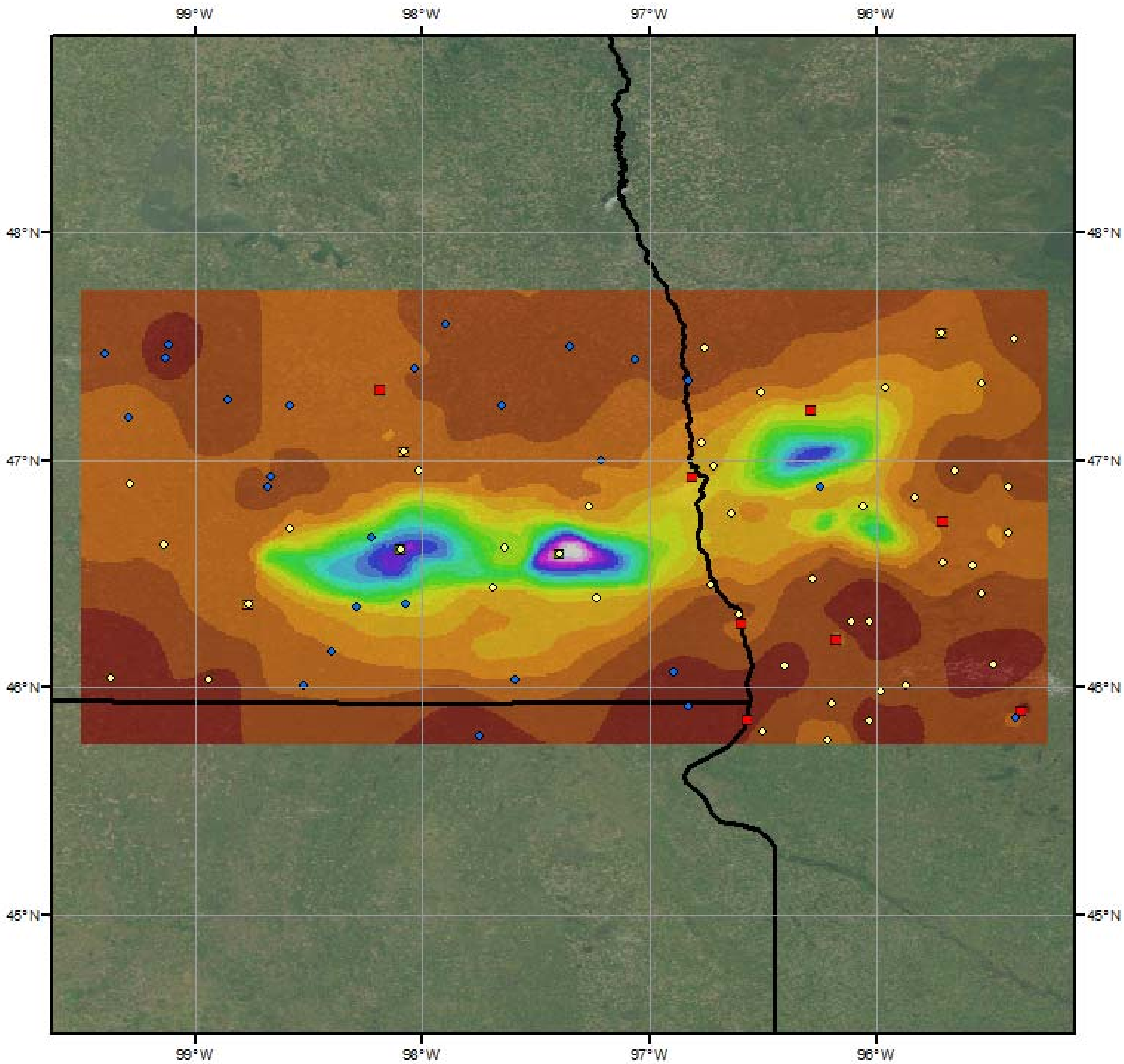
**Reliability of Results**: This analysis was based on 83 hourly stations, daily data, and supplemental station data. We have a good degree of confidence for the station based storm total results. The spatial pattern is fully dependent on the basemap created from the USGS Isohyetal image. Timing is based on the 13 hourly stations (see Miscellaneous notes below). Several daily stations were moved to supplemental due to timing issues and to ensure data consistency.

| Storm 1725 - June 27 (0600 UTC) - July 1 (0500 UTC), 1975 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | |
| Area ($mi^2$) | Duration (hours) | | | | | | | | | |
| | 1 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | 96 | Total |
| 0.4 | 3.62 | 9.39 | 13.25 | 15.13 | 15.44 | 15.80 | 20.58 | 20.60 | 20.60 | 20.60 |
| 1 | 3.60 | 9.35 | 13.19 | 15.06 | 15.36 | 15.73 | 20.48 | 20.50 | 20.50 | 20.50 |
| 10 | 3.56 | 9.24 | 13.03 | 14.88 | 15.16 | 15.54 | 20.23 | 20.25 | 20.25 | 20.25 |
| 25 | 3.51 | 9.12 | 12.87 | 14.70 | 15.01 | 15.35 | 19.99 | 20.03 | 20.03 | 20.03 |
| 50 | 3.40 | 8.78 | 12.39 | 14.15 | 14.43 | 14.78 | 19.24 | 19.31 | 19.31 | 19.31 |
| 100 | 3.23 | 8.16 | 11.54 | 13.20 | 13.51 | 13.84 | 17.88 | 18.02 | 18.02 | 18.02 |
| 200 | 3.03 | 7.46 | 10.68 | 12.26 | 12.59 | 12.90 | 16.41 | 16.60 | 16.60 | 16.60 |
| 300 | 2.89 | 7.00 | 10.17 | 11.71 | 12.02 | 12.32 | 15.53 | 15.72 | 15.72 | 15.72 |
| 400 | 2.78 | 6.65 | 9.79 | 11.31 | 11.58 | 11.90 | 14.90 | 15.12 | 15.12 | 15.12 |
| 500 | 2.68 | 6.39 | 9.49 | 10.98 | 11.25 | 11.54 | 14.40 | 14.67 | 14.67 | 14.67 |
| 1,000 | 2.31 | 5.56 | 8.42 | 9.77 | 10.02 | 10.26 | 12.61 | 12.90 | 12.90 | 12.90 |
| 2,000 | 1.89 | 4.60 | 7.07 | 8.25 | 8.49 | 8.66 | 10.48 | 10.73 | 10.73 | 10.73 |
| 5,000 | 1.25 | 3.11 | 4.97 | 5.79 | 5.94 | 6.07 | 7.24 | 7.49 | 7.49 | 7.49 |
| 10,000 | 0.76 | 2.01 | 3.49 | 4.09 | 4.19 | 4.28 | 5.12 | 5.29 | 5.29 | 5.29 |
| 20,000 | 0.41 | 1.17 | 2.11 | 2.56 | 2.63 | 2.84 | 3.46 | 3.61 | 3.61 | 3.61 |

SPAS 1725 DAD Curves Zone 1
June 27 (0600UTC) to July 1 (0500UTC), 1975




SPAS 1725 Storm Center Mass Curve Zone 1
June 27 (0600UTC) to July 1 (0500UTC), 1975
Lat: 46.5958 Lon: -97.3375
Incremental
Accumulated
20.66
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
1
2
3
4
0
5
10
15
20
20
40
60
80



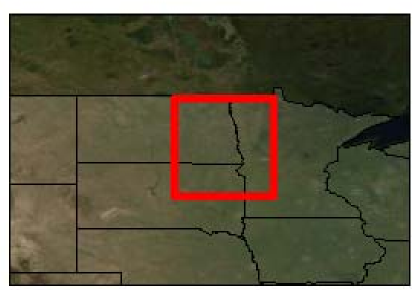

**Total Storm (96-hours) Precipitation (inches)**
**June 27-30, 1975**
**SPAS 1725 - Leonard, ND**

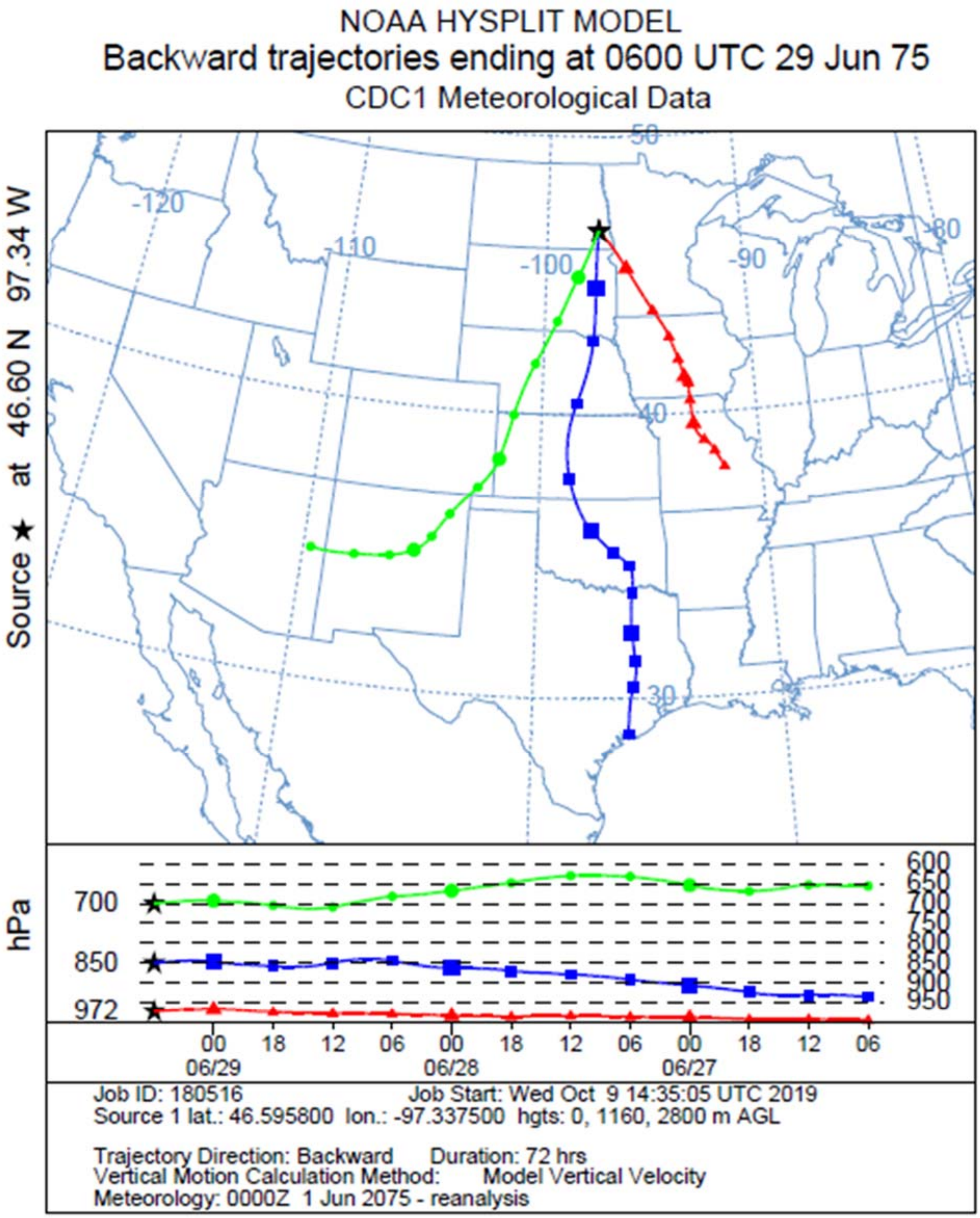
**Gauges**
- Daily
- Hourly
- HEP
- Hourly Pseudo
- Supplemental
- SE

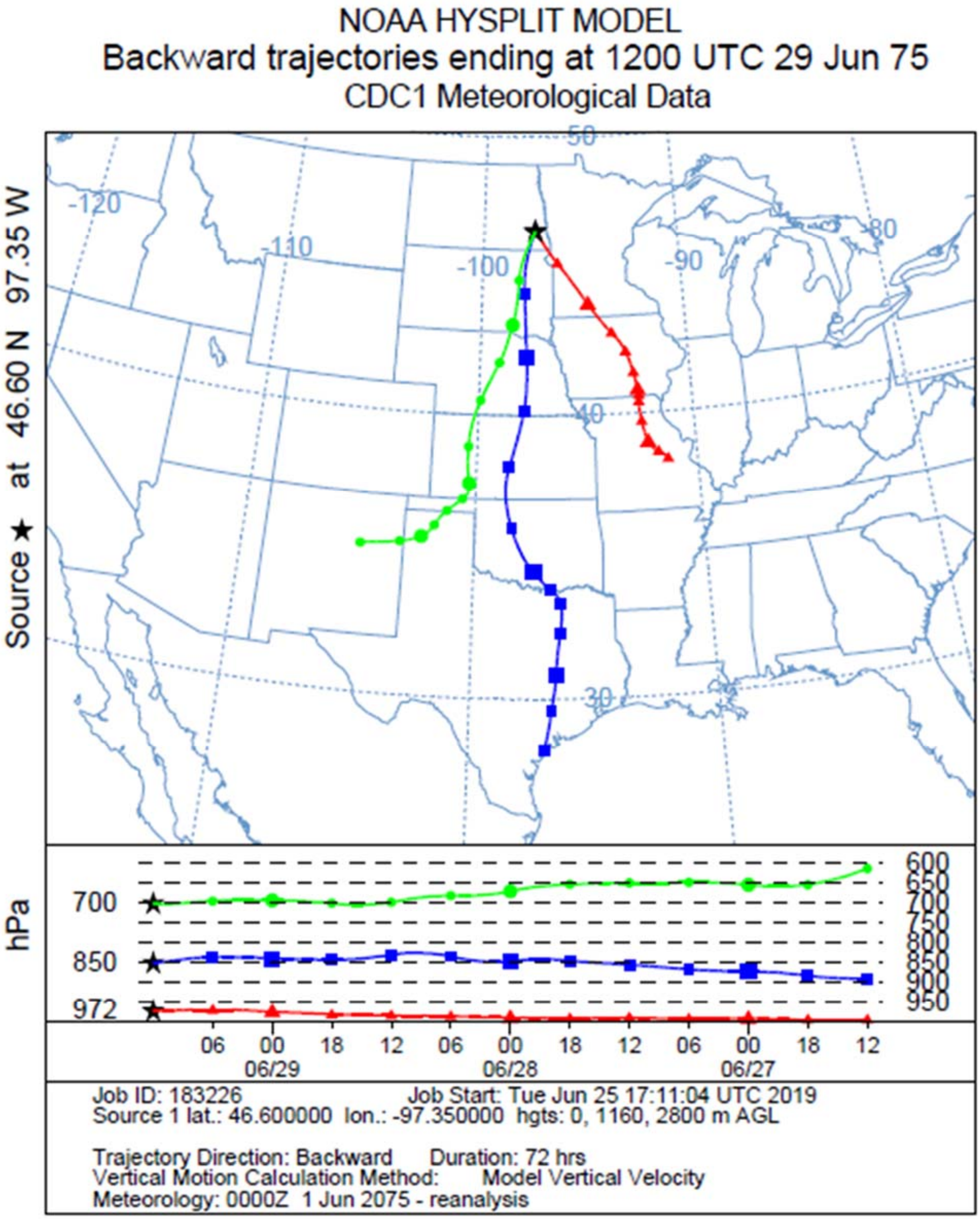
Miles: 0, 20, 40, 80
Kilometers: 0, 40, 80, 160

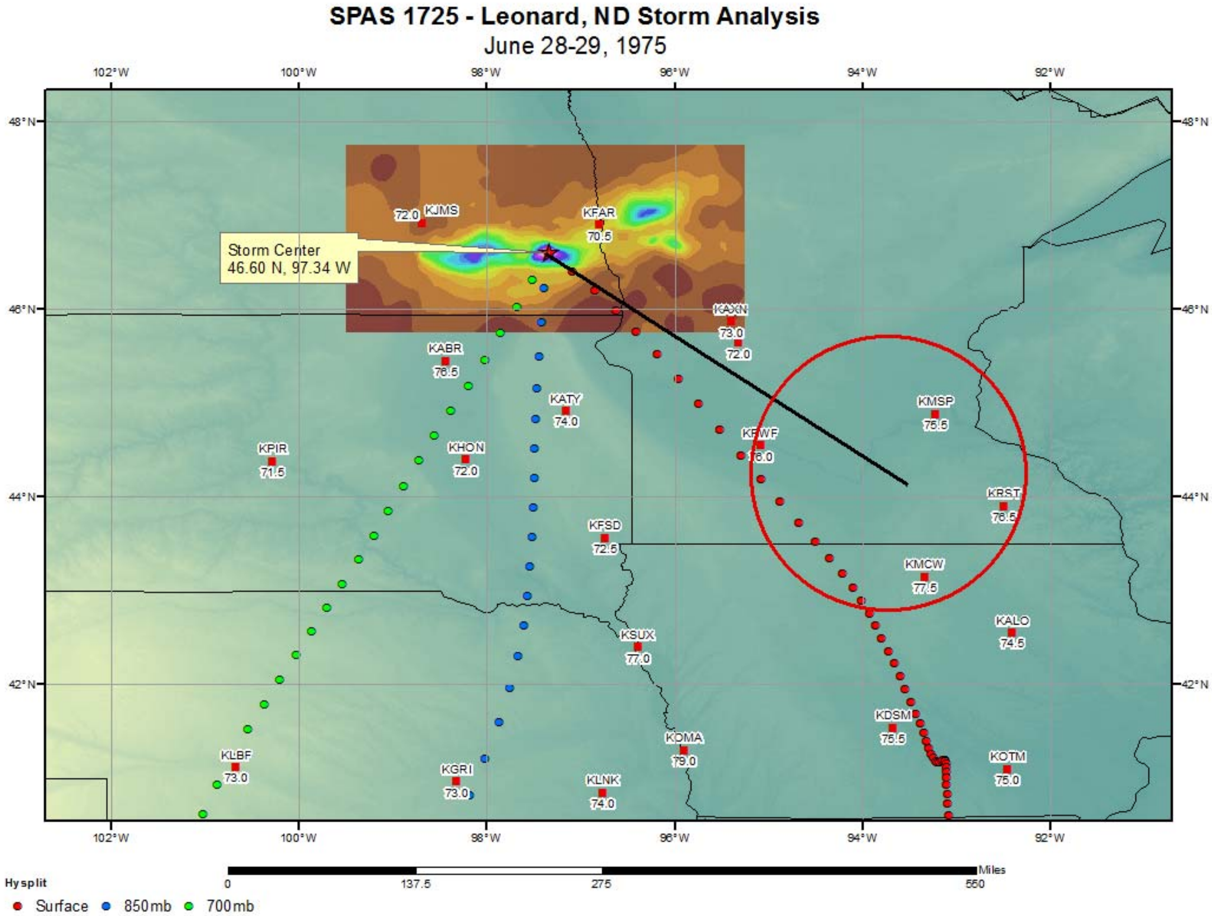
**Precipitation (inches)**

| | | | |
|---|---|---|---|
| 0.00 - 1.00 | 5.01 - 6.00 | 11.01 - 12.00 | 17.01 - 18.00 |
| 1.01 - 2.00 | 6.01 - 7.00 | 12.01 - 13.00 | 18.01 - 19.00 |
| 2.01 - 3.00 | 7.01 - 8.00 | 13.01 - 14.00 | 19.01 - 20.00 |
| 3.01 - 4.00 | 8.01 - 9.00 | 14.01 - 15.00 | 20.01 - 21.00 |
| 4.01 - 5.00 | 9.01 - 10.00 | 15.01 - 16.00 | |
| | 10.01 - 11.00 | 16.01 - 17.00 | |




NOAA HYSPLIT MODEL
Backward trajectories ending at 0600 UTC 29 Jun 75
CDC1 Meteorological Data
Source ★ at 46.60 N 97.34 W
50
-120
-110
-100
-90
-80
40
30
hPa
700
850
972
600
650
700
750
800
850
900
950
00 18 12 06 00 18 12 06 00 18 12 06
06/29
06/28
06/27
Job ID: 180516
Job Start: Wed Oct 9 14:35:05 UTC 2019
Source 1 lat.: 46.595800 lon.: -97.337500 hgts: 0, 1160, 2800 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method:
Model Vertical Velocity
Meteorology: 0000Z 1 Jun 2075 - reanalysis


NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 29 Jun 75
CDC1 Meteorological Data
Source ★ at 46.60 N 97.35 W
-120
-110
-100
-90
-80
50
40
30
hPa
700
850
972
600
650
700
750
800
850
900
950
06 00 18 12 06 00 18 12 06 00 18 12
06/29
06/28
06/27
Job ID: 183226
Job Start: Tue Jun 25 17:11:04 UTC 2019
Source 1 lat.: 46.600000 lon.: -97.350000 hgts: 0, 1160, 2800 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jun 2075 - reanalysis


SPAS 1725 - Leonard, ND Storm Analysis
June 28-29, 1975
Storm Center
46.60 N, 97.34 W
KJMS
72.0
KFAR
70.5
KAXN
73.0
72.0
KABR
76.5
KATY
74.0
KPIR
71.5
KHON
72.0
KMSP
75.5
KRWF
76.0
KRST
76.5
KFSD
72.5
KMCW
77.5
KSUX
77.0
KALO
74.5
KDSM
75.5
KOMA
79.0
KLBF
73.0
KGRI
73.0
KLNK
74.0
KOTM
75.0
102°W
100°W
98°W
96°W
94°W
92°W
48°N
46°N
44°N
42°N
Miles
0
137.5
275
550
Hysplit
Surface
850mb
700mb

# Storm Precipitation Analysis System (SPAS) For Storm #1286_1 SPAS Analysis

**General Storm Location**: Northern Illinois (Aurora College, IL)

**Storm Dates**: July 17, 1996 0100 UTC – July 19, 1996 0000 UTC (48 hours)

**Event**: Mesoscale convective complex (MCC)

**DAD Zone 1**

**Latitude**: 41.4575

**Longitude**: -88.0699

**Max. Grid Rainfall Amount**: 18.13”

**Number of Stations**: 173

- 86 daily
- 28 hourly
- 32 hourly pseudo
- 26 supplemental
- 1 supplemental estimated

**SPAS Version**: 10.0

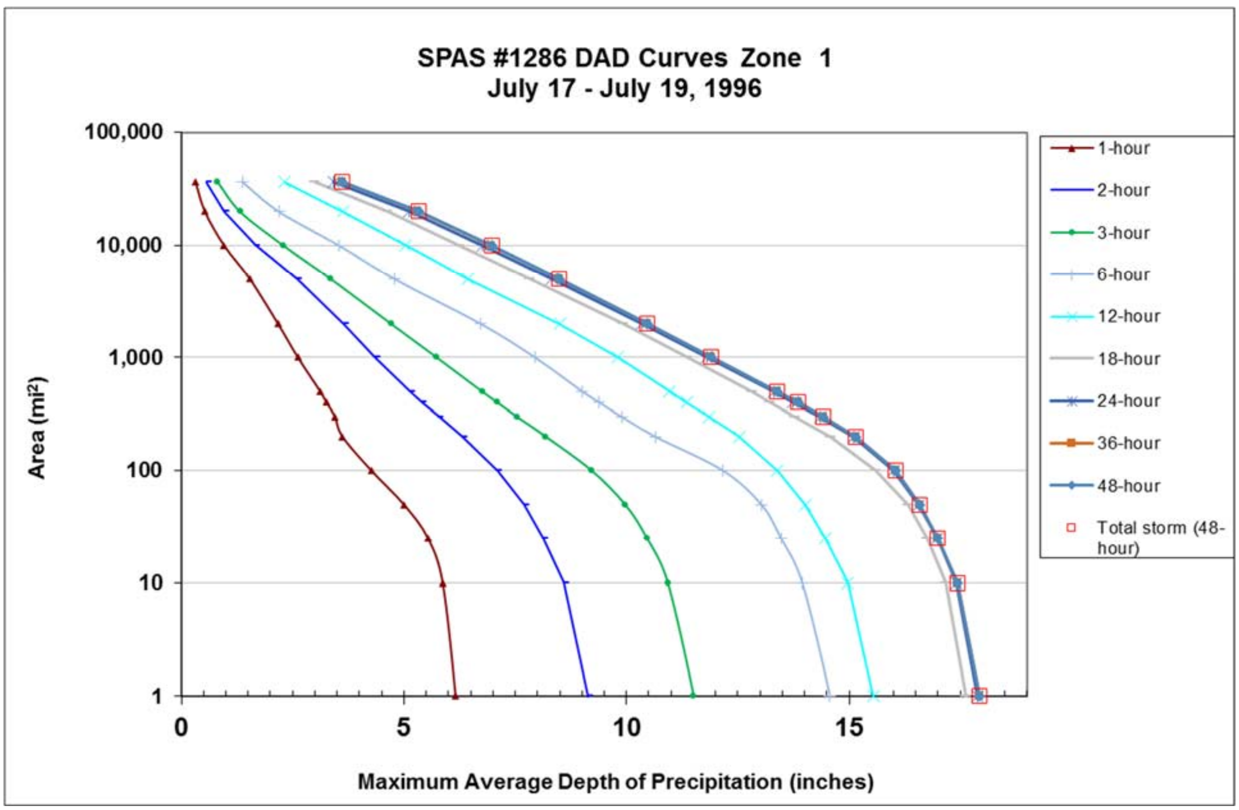
**Base Map Used:** 1981-2010 Mean July Precipitation (PRISM)

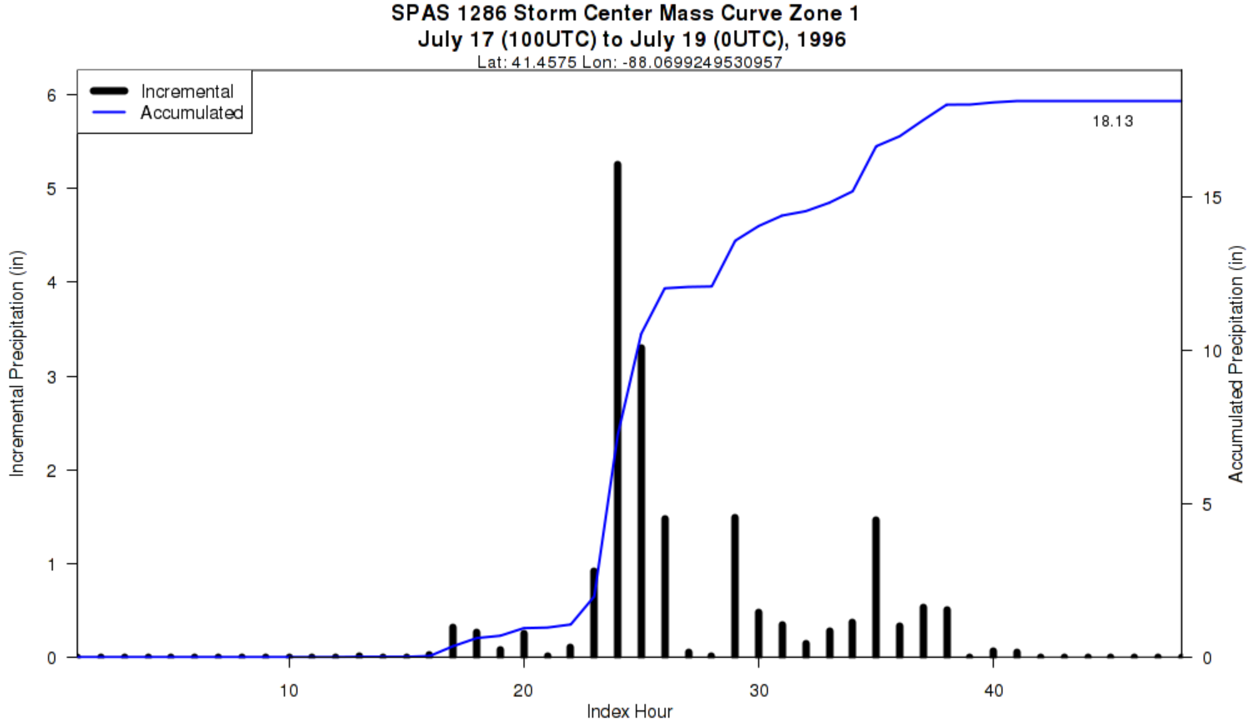
**Radar Included:** Yes (KMKX, KLOT and KIND)

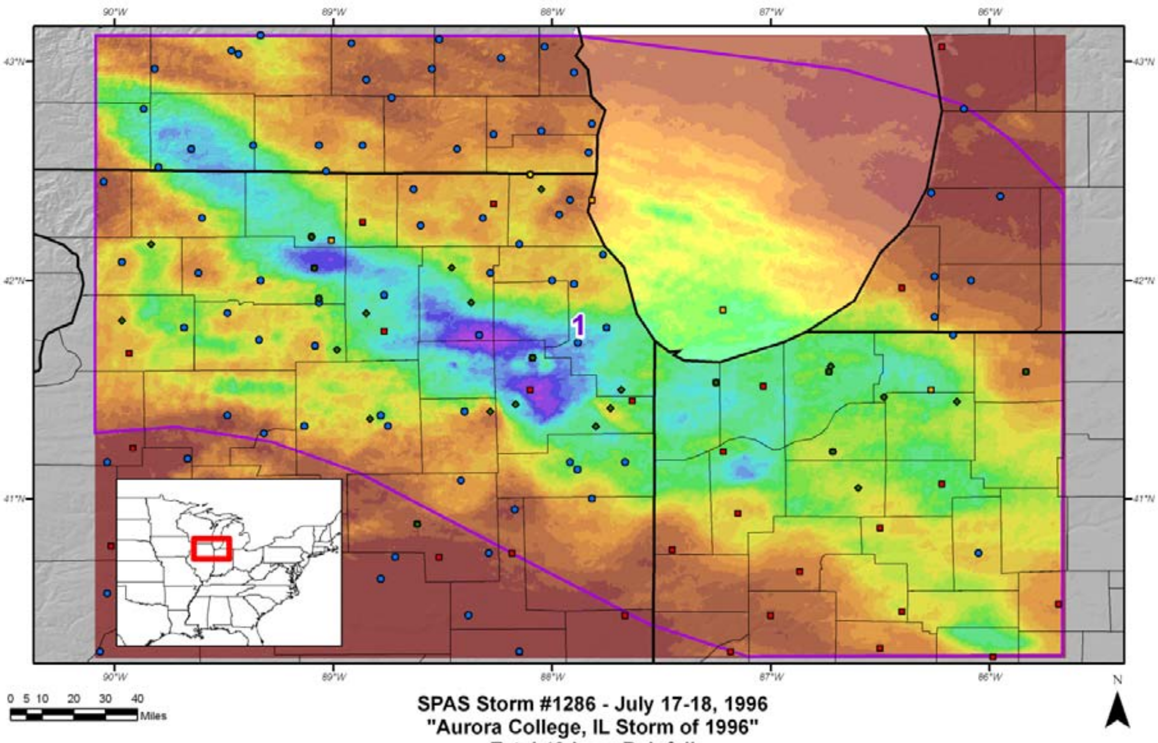
**Depth-Area-Duration (DAD) analysis**: Yes, 1, 2, 3, 4, 5, 6, 12, 18, 24, 36 and 48 hours

**Reliability of Results**: With the exception of the Southwestern corner of the analysis domain, we generally have a high degree of confidence in the results. Although there was a good deal of measured daily rainfall amounts in/around the storm center, a lack of hourly data forced us to develop and include several hourly-pseudo stations based on radar data and a default Z-R relationship.

| Storm 1286 - July 17 (0100 UTC) - July 19 (0000 UTC), 1996 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | |
| Area ($mi^2$) | Duration (hours) | | | | | | | | | |
| | 1 | 2 | 3 | 6 | 12 | 18 | 24 | 36 | 48 | Total |
| **0.4** | 6.22 | 9.20 | 11.64 | 14.70 | 15.68 | 17.75 | 18.00 | 18.06 | 18.06 | 18.06 |
| **1** | 6.16 | 9.14 | 11.51 | 14.57 | 15.55 | 17.62 | 17.89 | 17.92 | 17.92 | 17.92 |
| **10** | 5.87 | 8.60 | 10.93 | 13.95 | 14.97 | 17.18 | 17.42 | 17.43 | 17.43 | 17.43 |
| **25** | 5.54 | 8.13 | 10.46 | 13.47 | 14.46 | 16.75 | 16.98 | 17.00 | 17.00 | 17.00 |
| **50** | 5.00 | 7.70 | 9.97 | 13.03 | 14.02 | 16.32 | 16.57 | 16.59 | 16.59 | 16.59 |
| **100** | 4.27 | 7.11 | 9.22 | 12.17 | 13.39 | 15.60 | 16.01 | 16.04 | 16.04 | 16.04 |
| **200** | 3.62 | 6.32 | 8.19 | 10.65 | 12.53 | 14.59 | 15.11 | 15.16 | 15.16 | 15.16 |
| **300** | 3.45 | 5.79 | 7.54 | 9.89 | 11.85 | 13.79 | 14.35 | 14.42 | 14.42 | 14.42 |
| **400** | 3.26 | 5.41 | 7.10 | 9.39 | 11.36 | 13.23 | 13.75 | 13.86 | 13.86 | 13.86 |
| **500** | 3.12 | 5.14 | 6.76 | 9.01 | 10.97 | 12.81 | 13.31 | 13.39 | 13.39 | 13.39 |
| **1,000** | 2.62 | 4.36 | 5.74 | 7.95 | 9.81 | 11.37 | 11.82 | 11.90 | 11.90 | 11.90 |
| **2,000** | 2.17 | 3.65 | 4.71 | 6.72 | 8.50 | 9.93 | 10.36 | 10.46 | 10.46 | 10.46 |
| **5,000** | 1.54 | 2.61 | 3.36 | 4.79 | 6.45 | 7.82 | 8.33 | 8.49 | 8.49 | 8.49 |
| **10,000** | 0.96 | 1.66 | 2.29 | 3.54 | 5.03 | 6.25 | 6.77 | 6.96 | 6.97 | 6.97 |
| **20,000** | 0.53 | 0.97 | 1.32 | 2.19 | 3.63 | 4.63 | 5.11 | 5.32 | 5.33 | 5.33 |
| **36,456** | 0.32 | 0.57 | 0.82 | 1.38 | 2.33 | 3.00 | 3.43 | 3.61 | 3.62 | 3.62 |



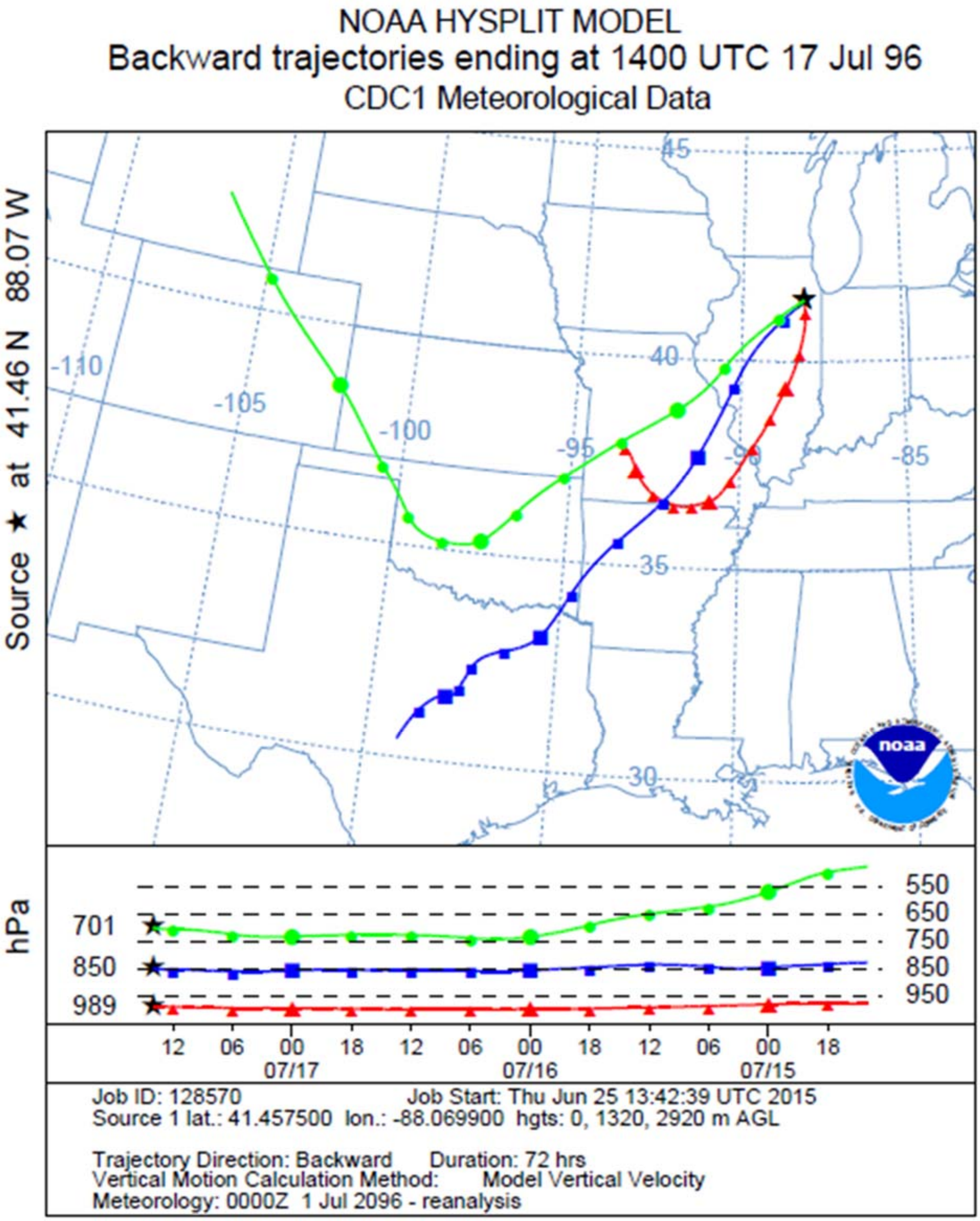

SPAS 1286 Storm Center Mass Curve Zone 1
July 17 (100UTC) to July 19 (0UTC), 1996
Lat: 41.4575 Lon: -88.0699249530957
Incremental
Accumulated
18.13
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
1
2
3
4
5
6
0
5
10
15
10
20
30
40




**SPAS Storm #1286 - July 17-18, 1996**
**"Aurora College, IL Storm of 1996"**
**Total 48-hour Rainfall**
**July 17, 1996 0100 UTC – July 19, 1996 0000 UTC (48 hours)**

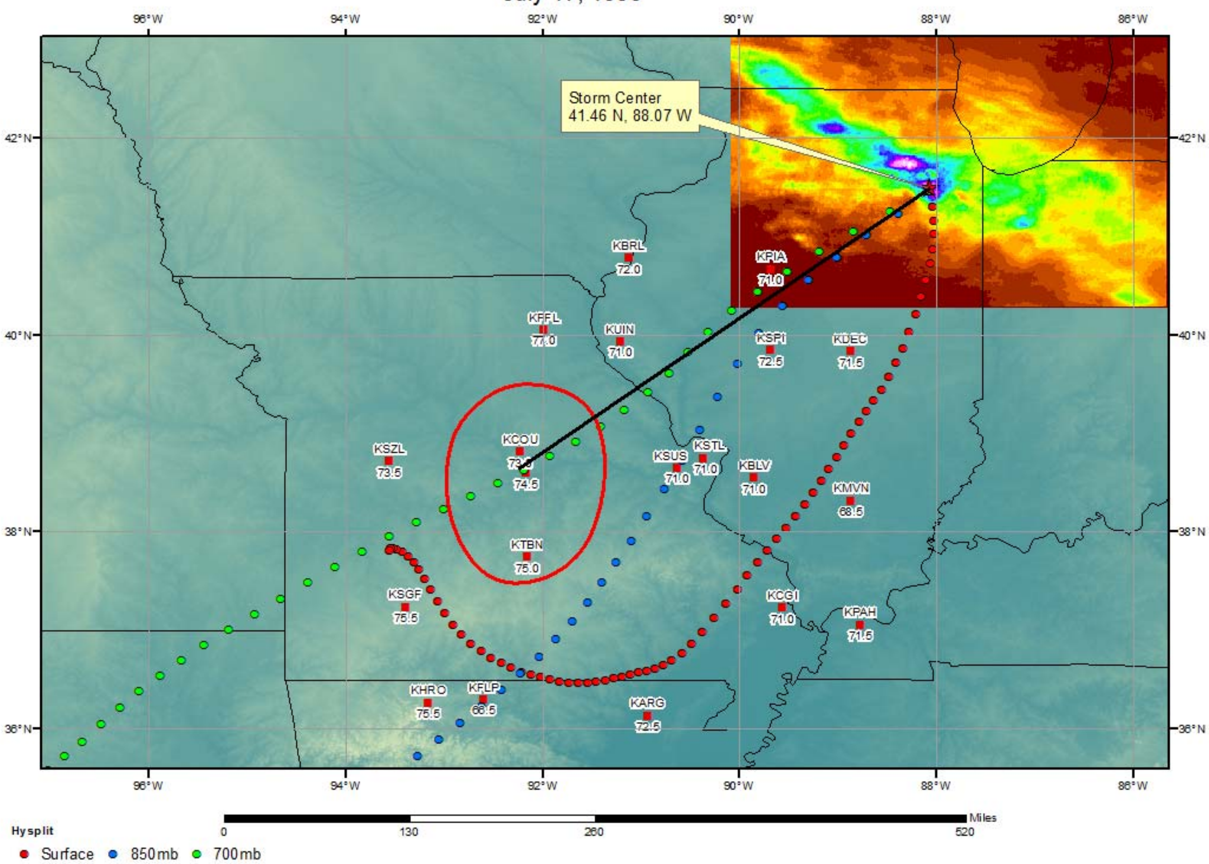
0.00 - 0.50, 0.51 - 1.00, 1.01 - 1.50, 1.51 - 2.00, 2.01 - 2.50, 2.51 - 3.00, 3.01 - 3.50, 3.51 - 4.00, 4.01 - 4.50, 4.51 - 5.00, 5.01 - 5.50, 5.51 - 6.00, 6.01 - 7.00, 7.01 - 8.00, 8.01 - 9.00, 9.01 - 10.00, 10.01 - 11.00, 11.01 - 12.00, 12.01 - 14.00, 14.01 - 16.00, 16.01 - 18.00, 18.01 - 20.00, 20.01 - 22.00, 22.01 - 24.00, 24.01 - 26.00, 26.01 - 28.00, dadzones_1286, Hourly, Hourly Pseudo, Daily, Supplemental, Supplemental Est.

MetStat 05/30/2012


NOAA HYSPLIT MODEL
Backward trajectories ending at 1400 UTC 17 Jul 96
CDC1 Meteorological Data
Source ★ at 41.46 N 88.07 W
45
40
35
30
-110
-105
-100
-95
-90
-85
hPa
701
850
989
550
650
750
850
950
12 06 00 18 12 06 00 18 12 06 00 18
07/17
07/16
07/15
noaa
Job ID: 128570 Job Start: Thu Jun 25 13:42:39 UTC 2015
Source 1 lat.: 41.457500 lon.: -88.069900 hgts: 0, 1320, 2920 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jul 2096 - reanalysis

**SPAS 1286 Aurora College, IL Storm Analysis**

July 17, 1996



# Storm Precipitation Analysis System (SPAS) For Storm #1228_1 SPAS-NEXRAD Analysis

**General Storm Location**: Eastern Kansas, Northeastern Oklahoma and western Missouri

**Storm Dates**: June 26 – July 1, 2007

**Event**: Mesoscale Convective System (MCS)

**DAD Zone 1 (entire domain)**

**Latitude**: 37.63

**Longitude**: -96.05

**Max. Grid Rainfall Amount**: 25.50”

**Max. Observed Rainfall Amount**: 21.40” (FALL RIVER, KS)

**Number of Stations**: 509 (175 Daily, 68 Hourly, 0 Hourly Estimated, 1 Hourly Estimated Pseudo, 60 Hourly Pseudo, 205 Supplemental, and 0 Supplemental Estimated)

**SPAS Version**: 9.0

**Basemap:** PRISM Mean (1971-2000) June precipitation

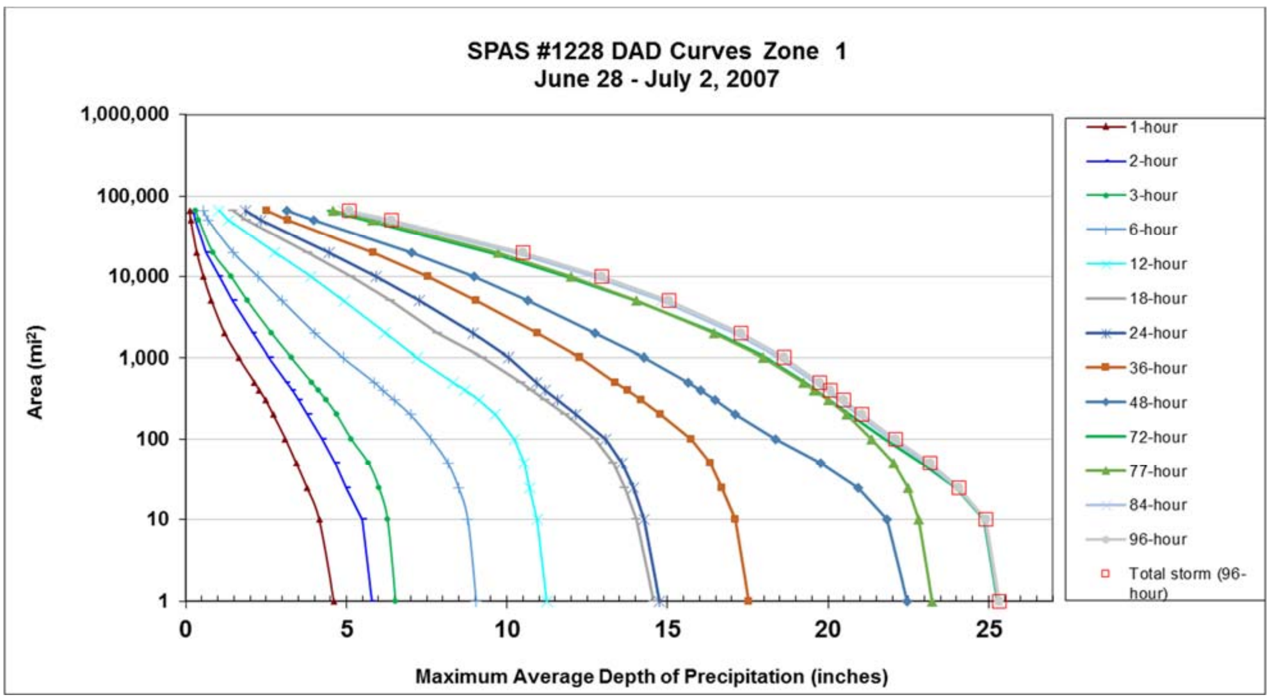
**Spatial resolution:** 36 seconds (~0.38 $mi^2$)

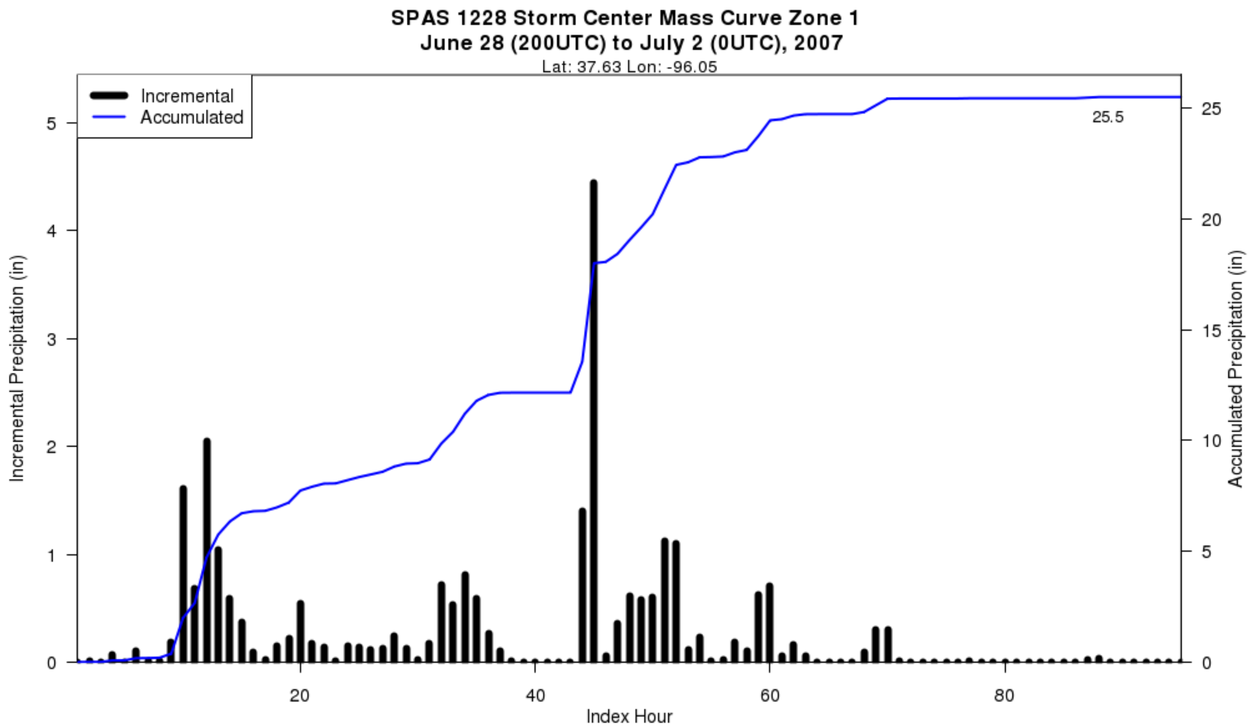
**Radar Included:** Yes (no outages)

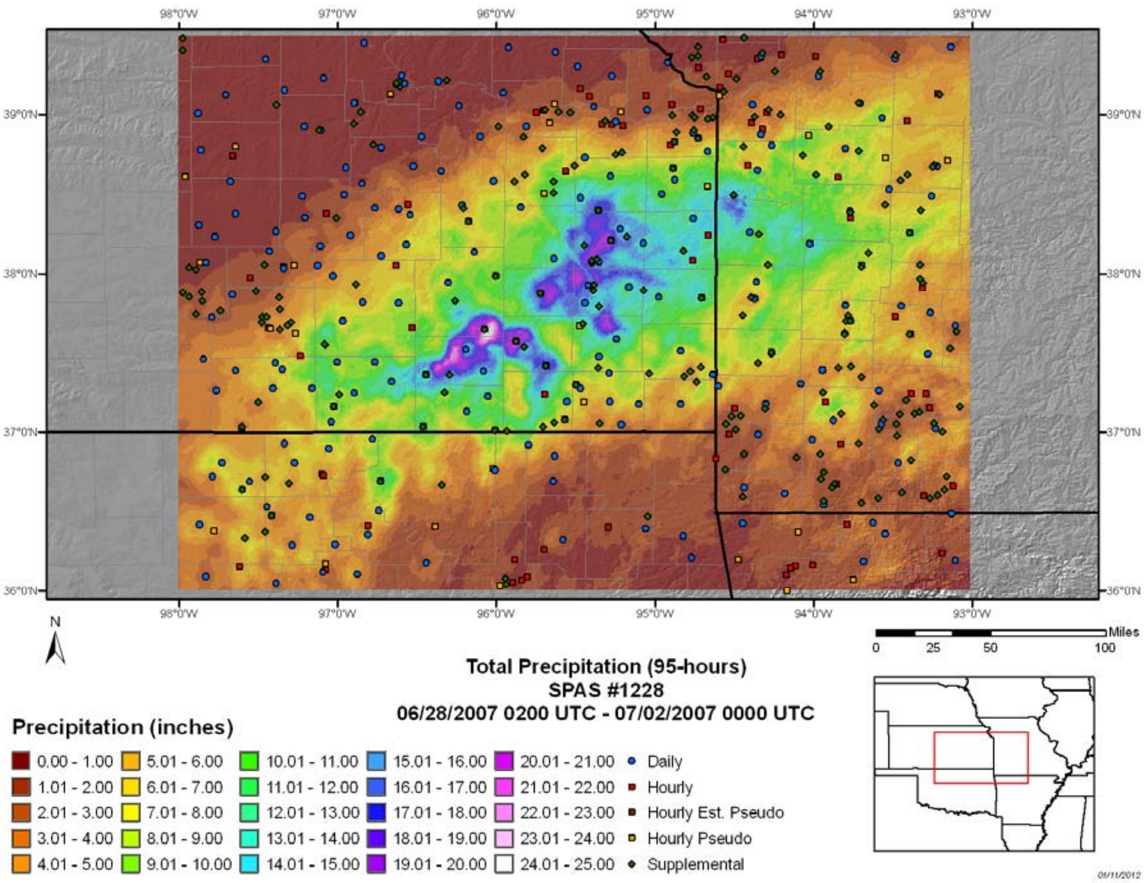
**Depth-Area-Duration (DAD) analysis**: Yes

**Reliability of results:** Given the unblocked, clean and QC’ed radar data coupled with relatively extensive gauge data, we have a very high degree of confidence in the results.  No supplemental estimated stations were warranted in this analysis.

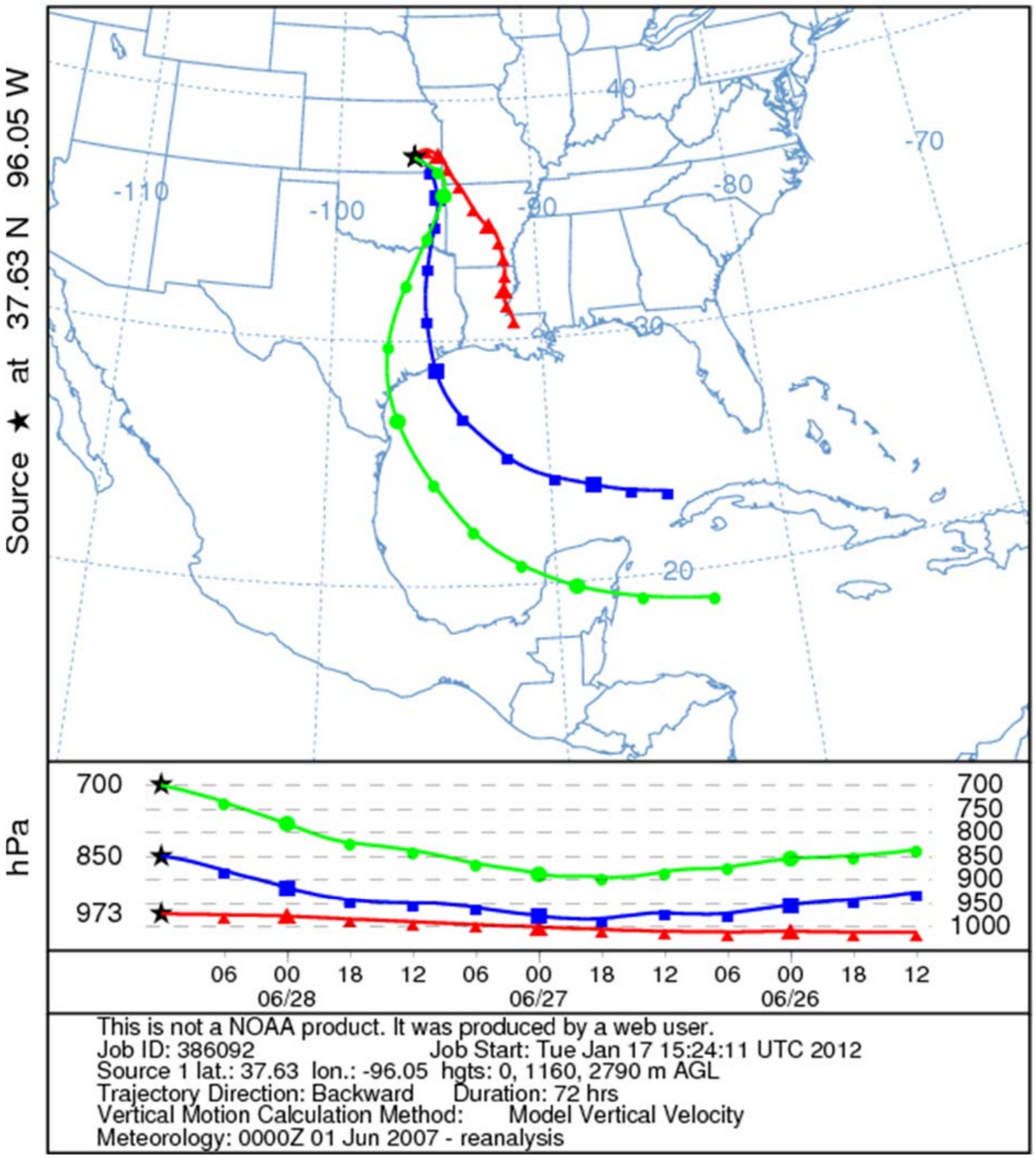
| Storm 1228 - June 28 (0200 UTC) - July 2 (0000 UTC), 2007 MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area ($mi^2$) | Duration (hours) | | | | | | | | | | | | | |
| | 1 | 2 | 3 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | 77 | 84 | 96 | Total |
| 0.4 | 4.68 | 5.84 | 6.60 | 9.12 | 11.37 | 14.71 | 14.90 | 17.71 | 22.65 | 25.42 | 23.42 | 25.45 | 25.49 | 25.49 |
| 1 | 4.60 | 5.78 | 6.53 | 9.04 | 11.25 | 14.57 | 14.75 | 17.54 | 22.47 | 25.26 | 23.25 | 25.29 | 25.32 | 25.32 |
| 10 | 4.15 | 5.50 | 6.28 | 8.78 | 10.95 | 14.04 | 14.27 | 17.11 | 21.82 | 24.85 | 22.83 | 24.87 | 24.91 | 24.91 |
| 25 | 3.77 | 4.99 | 6.01 | 8.49 | 10.71 | 13.68 | 13.93 | 16.69 | 20.93 | 23.99 | 22.50 | 24.02 | 24.08 | 24.08 |
| 50 | 3.44 | 4.66 | 5.69 | 8.16 | 10.54 | 13.31 | 13.59 | 16.33 | 19.77 | 22.91 | 22.03 | 23.05 | 23.17 | 23.17 |
| 100 | 3.10 | 4.24 | 5.15 | 7.64 | 10.23 | 12.75 | 13.06 | 15.74 | 18.37 | 21.76 | 21.37 | 21.95 | 22.10 | 22.10 |
| 200 | 2.72 | 3.80 | 4.70 | 6.99 | 9.65 | 11.82 | 12.15 | 14.78 | 17.12 | 20.66 | 20.57 | 20.91 | 21.07 | 21.07 |
| 300 | 2.49 | 3.52 | 4.38 | 6.50 | 9.14 | 11.19 | 11.58 | 14.17 | 16.48 | 20.05 | 20.02 | 20.33 | 20.48 | 20.48 |
| 400 | 2.29 | 3.30 | 4.12 | 6.13 | 8.68 | 10.77 | 11.19 | 13.75 | 16.04 | 19.63 | 19.57 | 19.92 | 20.07 | 20.07 |
| 500 | 2.14 | 3.13 | 3.92 | 5.87 | 8.32 | 10.44 | 10.91 | 13.38 | 15.64 | 19.29 | 19.23 | 19.60 | 19.75 | 19.75 |
| 1,000 | 1.65 | 2.60 | 3.29 | 4.90 | 7.21 | 9.25 | 10.04 | 12.26 | 14.27 | 18.06 | 17.99 | 18.47 | 18.64 | 18.64 |
| 2,000 | 1.21 | 2.08 | 2.67 | 4.02 | 6.20 | 7.85 | 8.94 | 10.95 | 12.76 | 16.53 | 16.46 | 17.08 | 17.30 | 17.30 |
| 5,000 | 0.80 | 1.46 | 1.92 | 3.00 | 4.94 | 6.38 | 7.26 | 9.04 | 10.64 | 14.00 | 14.03 | 14.81 | 15.06 | 15.06 |
| 10,000 | 0.55 | 1.03 | 1.41 | 2.24 | 3.89 | 5.16 | 5.93 | 7.53 | 8.97 | 11.85 | 11.99 | 12.68 | 12.94 | 12.94 |
| 20,000 | 0.34 | 0.63 | 0.84 | 1.47 | 2.77 | 3.80 | 4.46 | 5.83 | 7.04 | 9.49 | 9.72 | 10.24 | 10.50 | 10.50 |
| 50,000 | 0.15 | 0.29 | 0.41 | 0.70 | 1.32 | 1.90 | 2.33 | 3.18 | 3.98 | 5.59 | 5.80 | 6.17 | 6.40 | 6.40 |
| 65,762 | 0.12 | 0.23 | 0.31 | 0.55 | 1.03 | 1.48 | 1.87 | 2.51 | 3.15 | 4.44 | 4.59 | 4.91 | 5.10 | 5.10 |

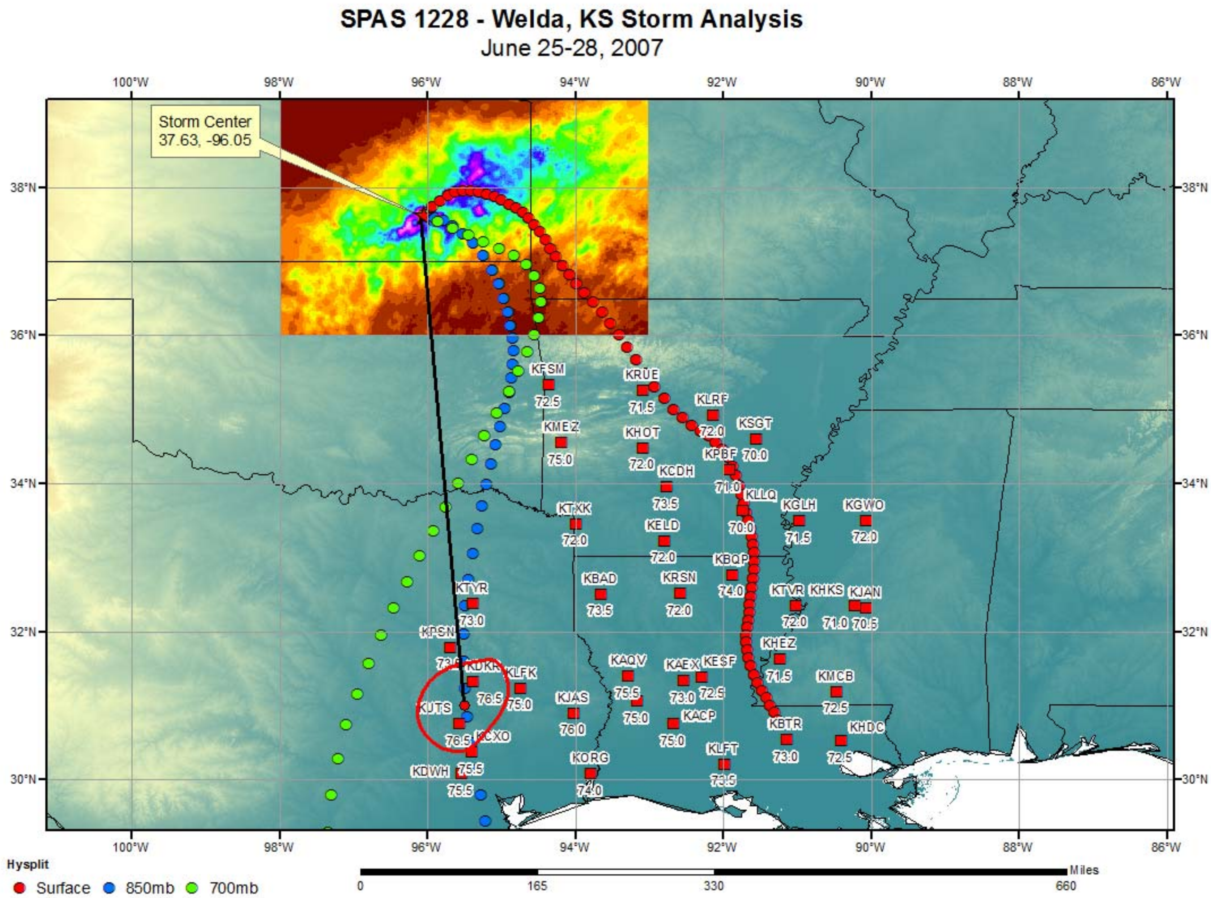



SPAS 1228 Storm Center Mass Curve Zone 1
June 28 (200UTC) to July 2 (0UTC), 2007
Lat: 37.63 Lon: -96.05
Incremental
Accumulated
25.5
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour


98°0'W
97°0'W
96°0'W
95°0'W
94°0'W
93°0'W
39°0'N
38°0'N
37°0'N
36°0'N
N
Miles
0 25 50 100
Total Precipitation (95-hours)
SPAS #1228
06/28/2007 0200 UTC - 07/02/2007 0000 UTC
Precipitation (inches)
0.00 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
14.01 - 15.00
15.01 - 16.00
16.01 - 17.00
17.01 - 18.00
18.01 - 19.00
19.01 - 20.00
20.01 - 21.00
21.01 - 22.00
22.01 - 23.00
23.01 - 24.00
24.01 - 25.00
Daily
Hourly
Hourly Est. Pseudo
Hourly Pseudo
Supplemental
01/11/2012

NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 28 Jun 07
CDC1 Meteorological Data




SPAS 1228 - Welda, KS Storm Analysis
June 25-28, 2007
Storm Center
37.63, -96.05
Hysplit
Surface 850mb 700mb
Miles
0 165 330 660

# Storm Precipitation Analysis System (SPAS) For Storm #1296_1 SPAS-NEXRAD Analysis

**General Storm Location**: Duluth, Minnesota

**Storm Dates**: June 19-21, 2012

**Event**: MCC, Flash Flood Event

**DAD Zone 1**

**Latitude**: 47.015

**Longitude**: -91.665

**Max. Grid Rainfall Amount**: 10.73"

**Max. Observed Rainfall Amount**: 10.71"

**Number of Stations**: 405 (83 Daily, 102 Hourly, 31 Hourly Pseudo, and 189 Supplemental)

**SPAS Version**: 9.5

**Basemap:** PRISM June 2012 Precipitation

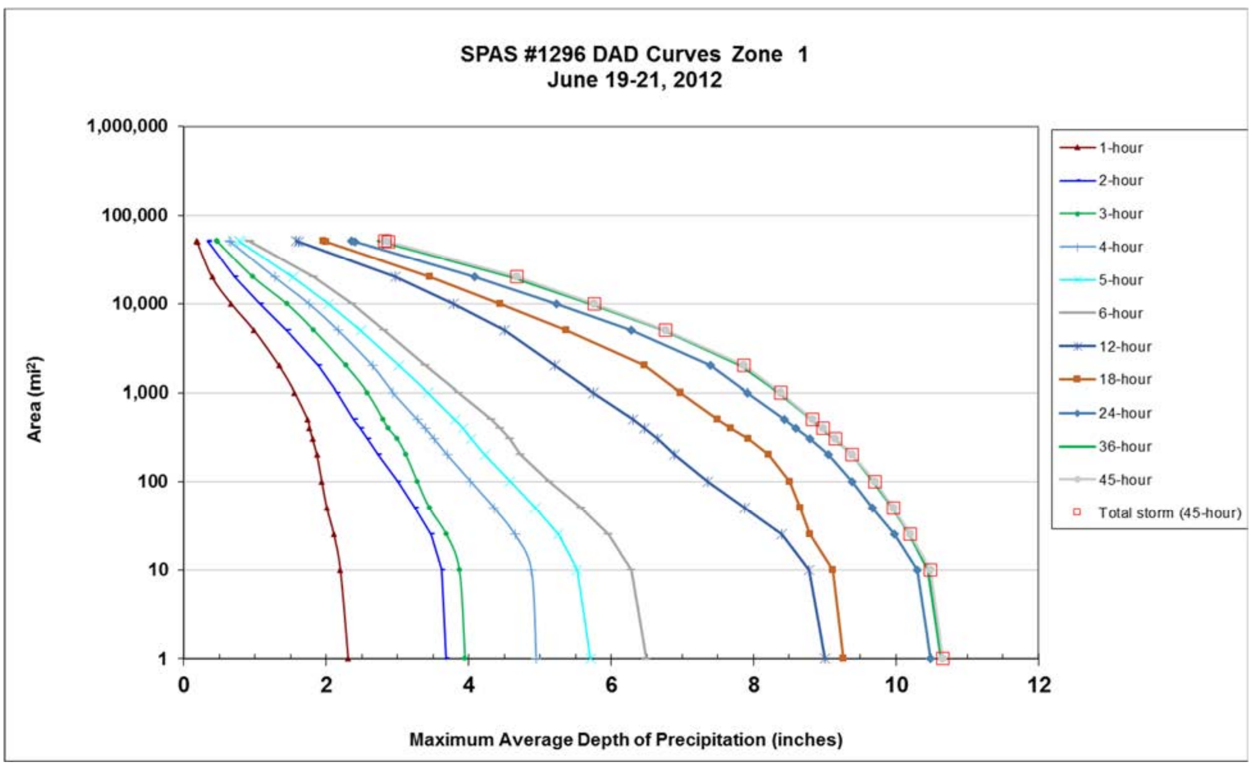
**Spatial resolution:** 0.01 (~ 0.40 $mi^2$)

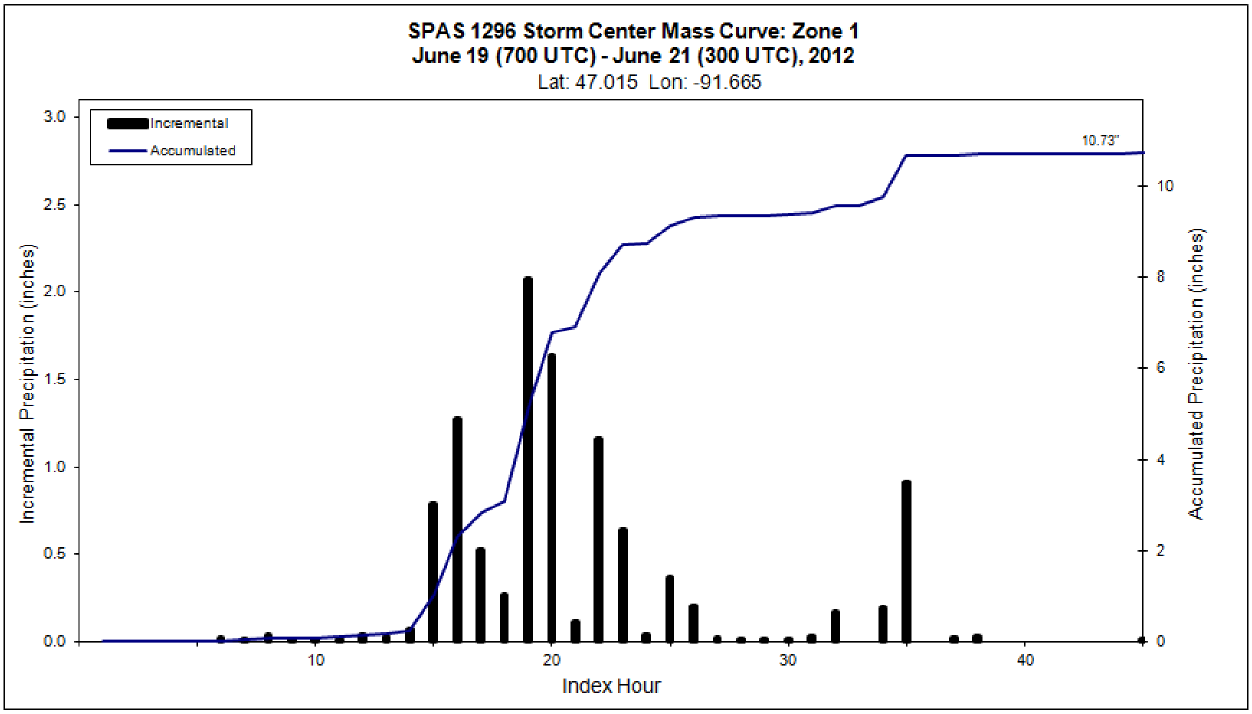
**Radar Included:** Yes

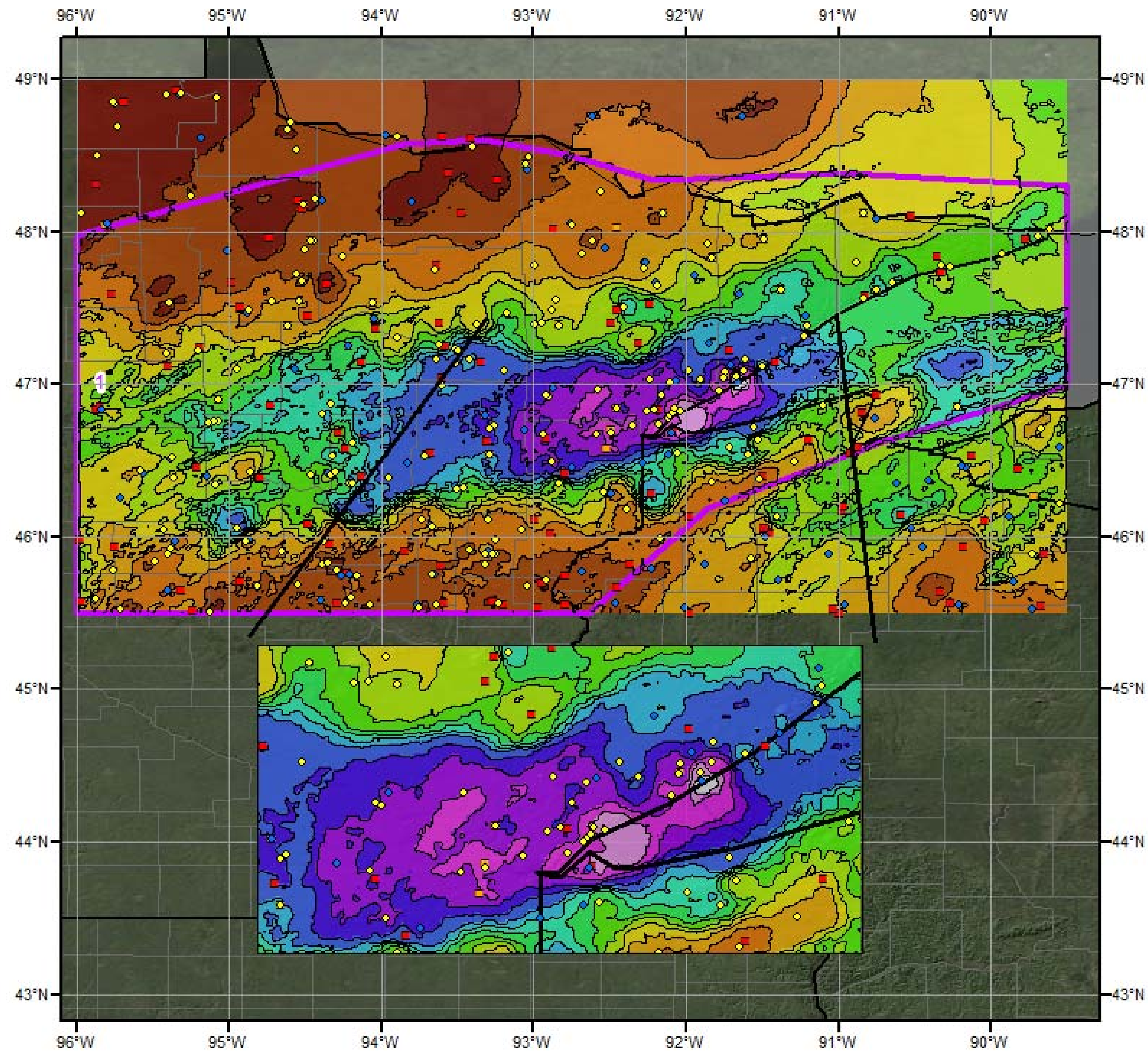
**Depth-Area-Duration (DAD) analysis**: Yes

**Reliability of results:** This analysis was based on hourly data, daily data, supplemental station data and NEXRAD Radar. We have a high degree of confidence in the radar/station based storm total results, the spatial pattern is dependent on the radar data and basemap, and the timing is based on hourly and hourly pseudo stations.

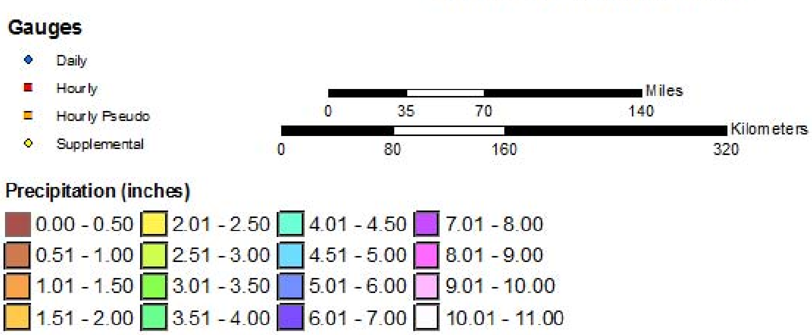
| Storm 1296 - June 19 (0700 UTC) - June 21 (0300 UTC), 2012 MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area ($mi^2$) | Duration (hours) | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 36 | 45 | Total |
| 0.4 | 2.34 | 3.71 | 3.97 | 4.98 | 5.76 | 6.55 | 9.07 | 9.32 | 10.55 | 10.70 | 10.72 | 10.72 |
| 1 | 2.31 | 3.68 | 3.95 | 4.95 | 5.71 | 6.49 | 9.00 | 9.26 | 10.48 | 10.63 | 10.65 | 10.65 |
| 10 | 2.20 | 3.62 | 3.87 | 4.88 | 5.52 | 6.28 | 8.78 | 9.11 | 10.30 | 10.44 | 10.48 | 10.48 |
| 25 | 2.11 | 3.47 | 3.69 | 4.65 | 5.26 | 5.96 | 8.39 | 8.79 | 9.97 | 10.19 | 10.20 | 10.20 |
| 50 | 2.01 | 3.25 | 3.45 | 4.36 | 4.94 | 5.58 | 7.88 | 8.65 | 9.67 | 9.95 | 9.96 | 9.96 |
| 100 | 1.94 | 3.00 | 3.28 | 4.03 | 4.58 | 5.13 | 7.36 | 8.51 | 9.38 | 9.68 | 9.70 | 9.70 |
| 200 | 1.87 | 2.73 | 3.12 | 3.70 | 4.23 | 4.73 | 6.89 | 8.21 | 9.05 | 9.38 | 9.38 | 9.38 |
| 300 | 1.81 | 2.58 | 3.00 | 3.52 | 4.04 | 4.58 | 6.65 | 7.92 | 8.79 | 9.14 | 9.15 | 9.15 |
| 400 | 1.77 | 2.48 | 2.87 | 3.39 | 3.92 | 4.44 | 6.47 | 7.68 | 8.59 | 8.95 | 8.97 | 8.97 |
| 500 | 1.74 | 2.39 | 2.80 | 3.28 | 3.81 | 4.32 | 6.31 | 7.50 | 8.43 | 8.81 | 8.83 | 8.83 |
| 1,000 | 1.56 | 2.15 | 2.58 | 2.94 | 3.43 | 3.86 | 5.75 | 6.98 | 7.91 | 8.36 | 8.38 | 8.38 |
| 2,000 | 1.34 | 1.89 | 2.28 | 2.65 | 3.03 | 3.40 | 5.21 | 6.47 | 7.39 | 7.82 | 7.87 | 7.87 |
| 5,000 | 0.99 | 1.45 | 1.83 | 2.17 | 2.49 | 2.82 | 4.50 | 5.37 | 6.28 | 6.74 | 6.76 | 6.76 |
| 10,000 | 0.67 | 1.07 | 1.45 | 1.76 | 2.03 | 2.37 | 3.79 | 4.44 | 5.24 | 5.71 | 5.77 | 5.77 |
| 20,000 | 0.40 | 0.72 | 0.98 | 1.28 | 1.54 | 1.83 | 2.98 | 3.46 | 4.08 | 4.59 | 4.68 | 4.68 |
| 50,000 | 0.19 | 0.35 | 0.48 | 0.66 | 0.80 | 0.94 | 1.62 | 2.00 | 2.41 | 2.79 | 2.88 | 2.88 |
| 51,309 | 0.18 | 0.34 | 0.47 | 0.64 | 0.78 | 0.92 | 1.58 | 1.96 | 2.36 | 2.73 | 2.83 | 2.83 |



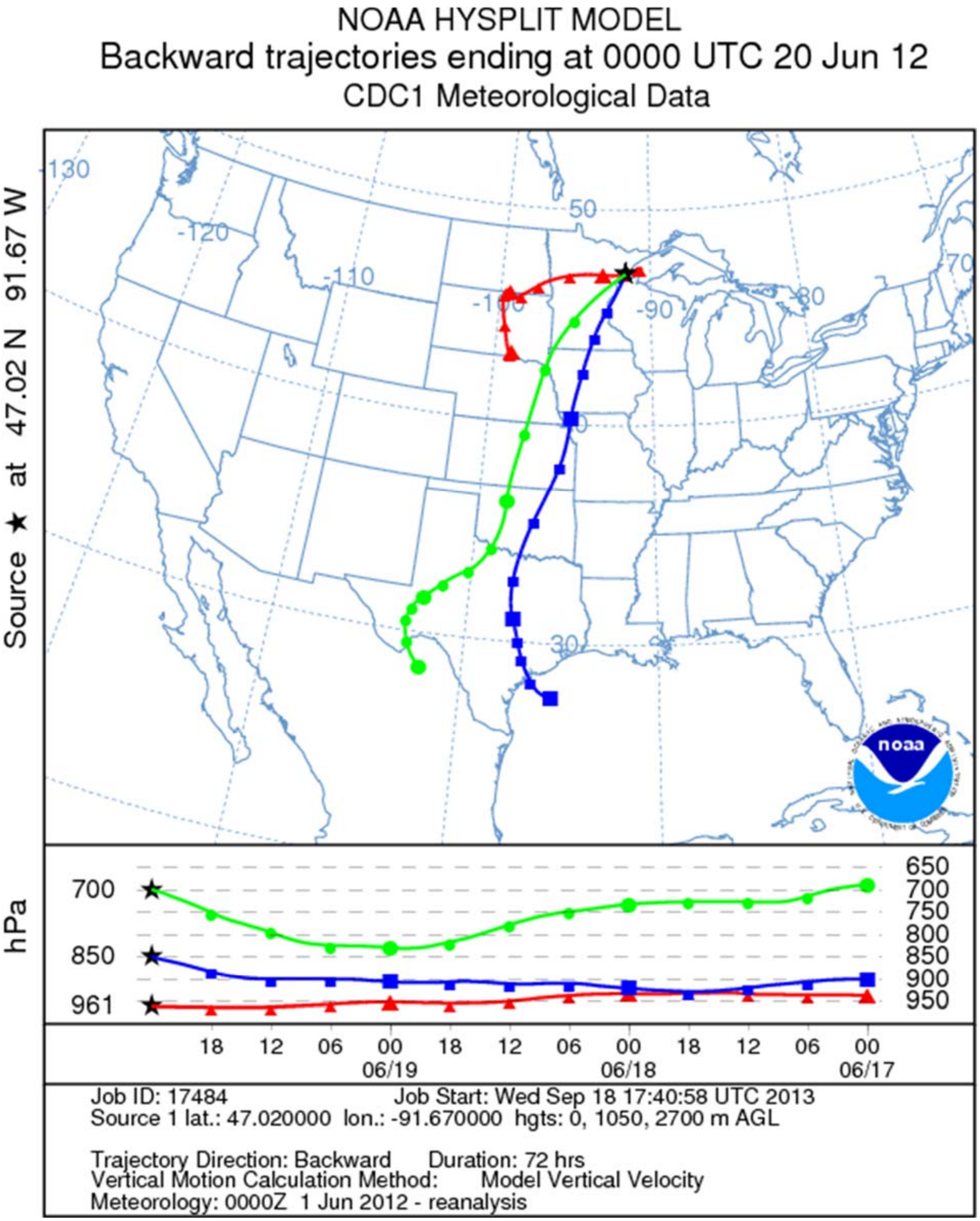

SPAS 1296 Storm Center Mass Curve: Zone 1
June 19 (700 UTC) - June 21 (300 UTC), 2012
Lat: 47.015 Lon: -91.665
Incremental
Accumulated
10.73"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
2
4
6
8
10
10
20
30
40

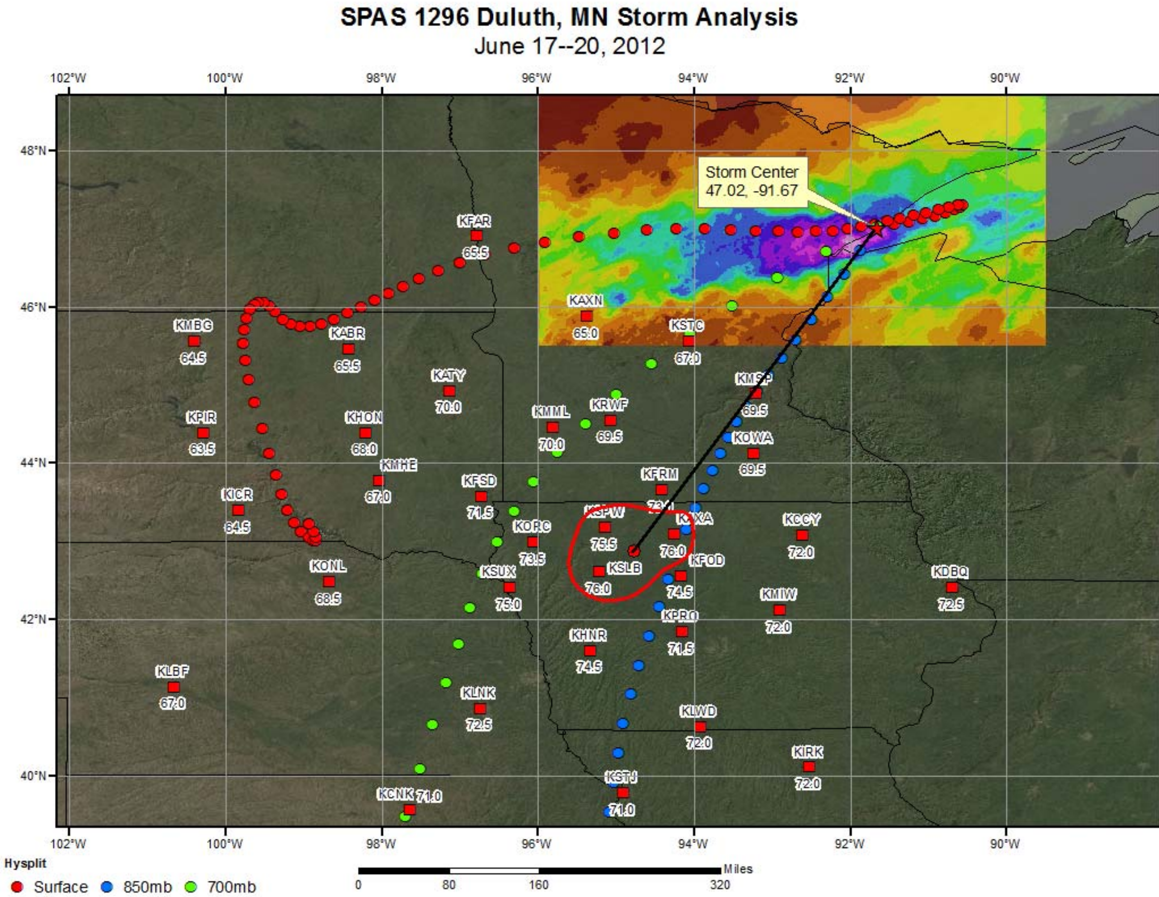



**Total Storm (45-hr) Precipitation (inches)**
**June 19 (0700 UTC) - 21 (0300), 2012**
**SPAS-NEXRAD 1296**




9/18/2013


NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 20 Jun 12
CDC1 Meteorological Data
Source ★ at 47.02 N 91.67 W
130
120
110
100
90
80
70
50
30
noaa
hPa
700
850
961
650
700
750
800
850
900
950
18 12 06 00 18 12 06 00 18 12 06 00
06/19
06/18
06/17
Job ID: 17484
Job Start: Wed Sep 18 17:40:58 UTC 2013
Source 1 lat.: 47.020000 lon.: -91.670000 hgts: 0, 1050, 2700 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jun 2012 - reanalysis


SPAS 1296 Duluth, MN Storm Analysis
June 17--20, 2012
Storm Center
47.02, -91.67
Hysplit
Surface
850mb
700mb
Miles
0
80
160
320

# Local Storms

# Storm Precipitation Analysis System (SPAS) For Storm #1426_1 SPAS Analysis

**General Storm Location**: Cooper, MI

**Storm Dates**: September 1 – September 2, 1914

**Event**: Extreme Precipitation Event

**DAD Zone 1**

**Latitude**: 42.3708

**Longitude**: -85.5875

**Max. Grid Rainfall Amount**: 13.39”

**Max. Observed Rainfall Amount**: 12.80”

**Number of Stations**: 30

**SPAS Version**: 10.0

**Base Map Used:** Continental United States 2 year 6 hour (conus_0002yr06h)

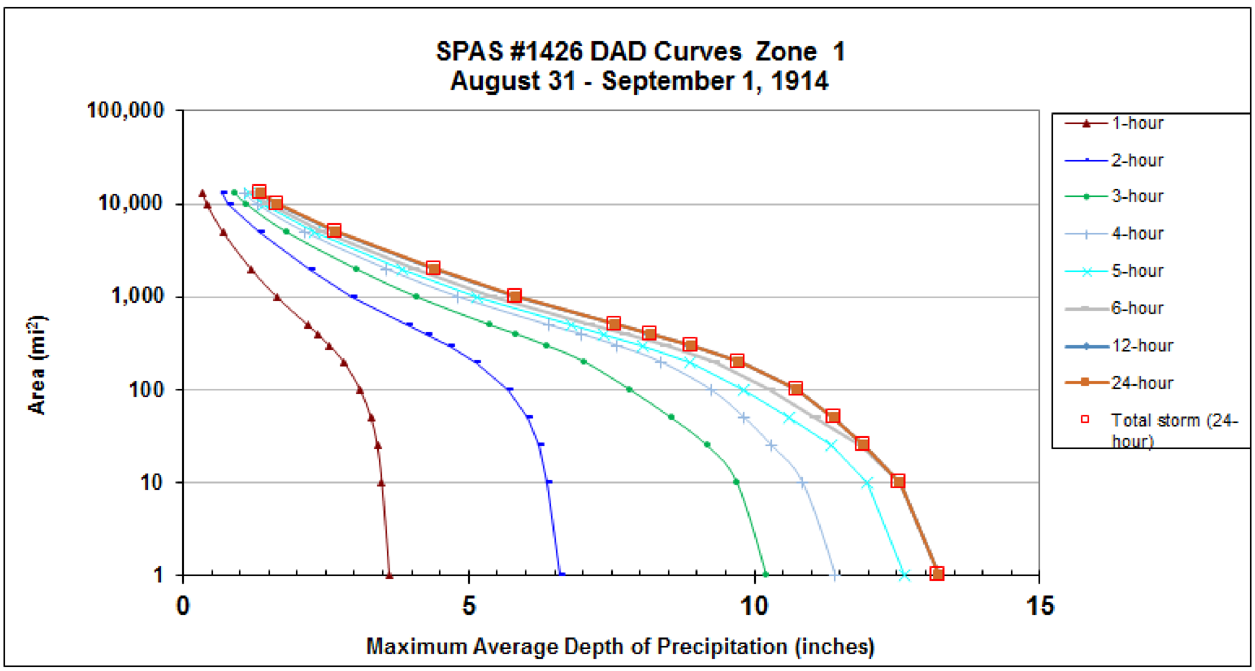
**Spatial resolution:** 0.2451

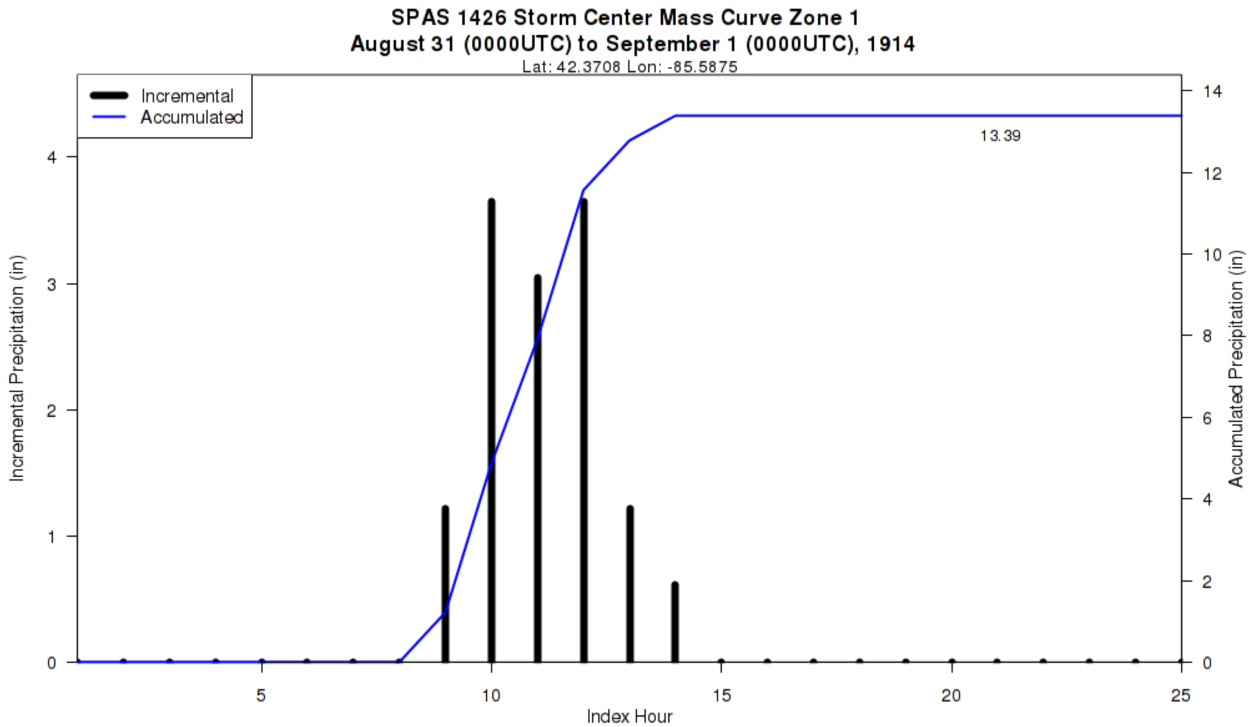
**Radar Included:** No

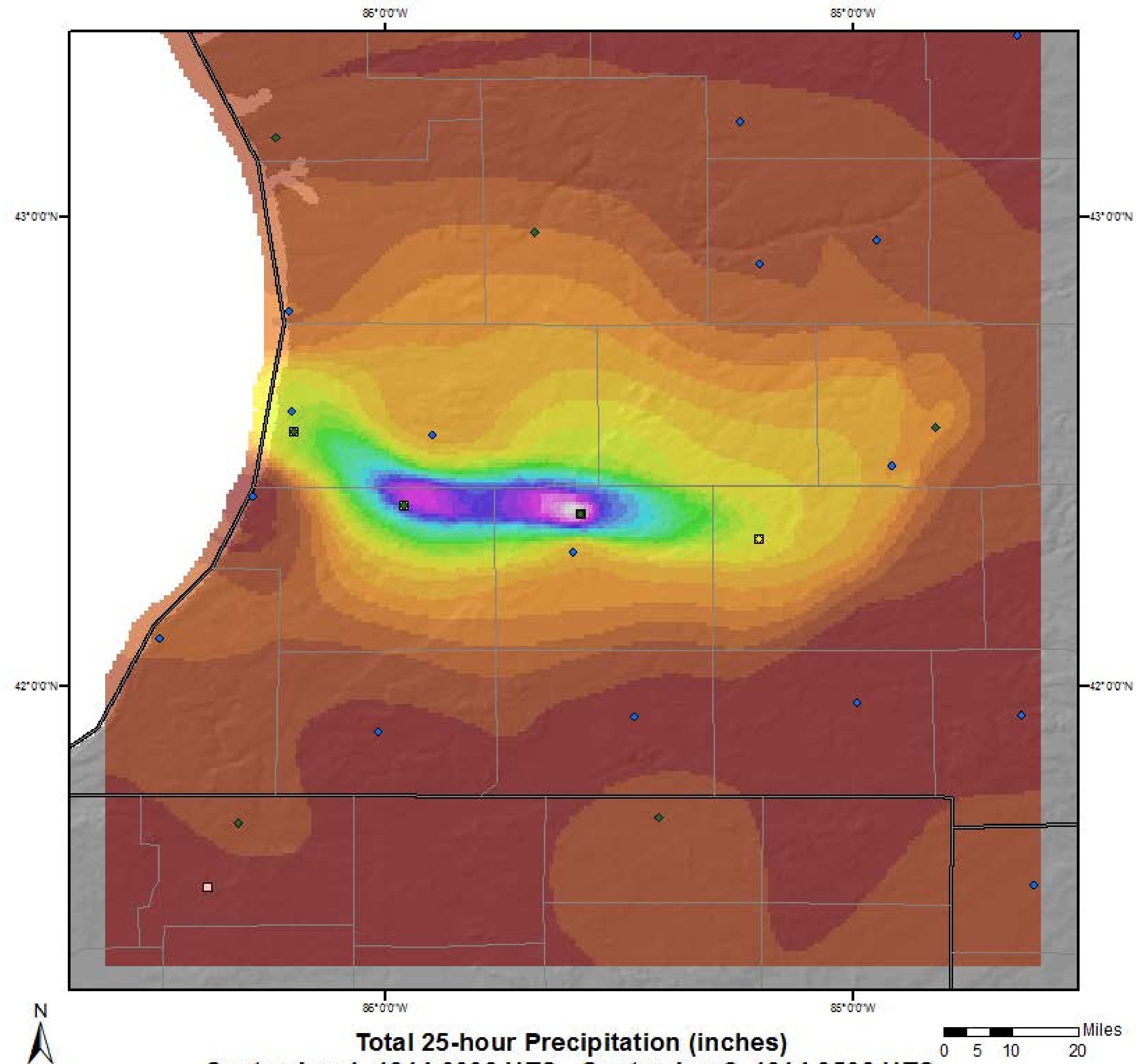
**Depth-Area-Duration (DAD) analysis**: Yes

**Reliability of results:** In addition to the NCDC stations, three hourly stations were digitized from the U.S. Army Corp of Engineers (USACE) Storm Study Pertinent Data Sheet (included below). These stations only provided precipitation timing for the time period beginning on August 31, 1914 at 6pm EST and ending at 6pm the following day. Due to the lack of hourly information, a 25-hour Core Precipitation Period (CPP) was established for this time period. While precipitation did fall outside of the CPP, results are unreliable due to the lack of data. The resulting DAD values are slightly less than those determined by the initial USACE report. Major adjustments were completed in order to simulate USACE results, however the original analysis likely over generalized the storm area and this analysis likely provides a more accurate depiction of the event.

| Storm 1426 - August 31 (0000 UTC) - September 1 (0000 UTC), 1914 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | |
| Area ($mi^2$) | Duration (hours) | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 24 | Total |
| 0.4 | 3.64 | 6.66 | 10.30 | 11.51 | 12.73 | 13.33 | 13.33 | 13.33 | 13.33 |
| 1 | 3.61 | 6.61 | 10.21 | 11.41 | 12.62 | 13.23 | 13.23 | 13.23 | 13.23 |
| 10 | 3.48 | 6.38 | 9.70 | 10.84 | 11.98 | 12.55 | 12.55 | 12.55 | 12.55 |
| 25 | 3.40 | 6.23 | 9.18 | 10.30 | 11.34 | 11.88 | 11.93 | 11.93 | 11.93 |
| 50 | 3.29 | 6.02 | 8.55 | 9.82 | 10.61 | 11.07 | 11.40 | 11.40 | 11.40 |
| 100 | 3.10 | 5.68 | 7.83 | 9.24 | 9.82 | 10.26 | 10.74 | 10.75 | 10.75 |
| 200 | 2.81 | 5.13 | 7.03 | 8.36 | 8.87 | 9.29 | 9.74 | 9.74 | 9.74 |
| 300 | 2.56 | 4.67 | 6.37 | 7.60 | 8.06 | 8.45 | 8.88 | 8.89 | 8.89 |
| 400 | 2.35 | 4.27 | 5.82 | 6.96 | 7.37 | 7.74 | 8.17 | 8.18 | 8.18 |
| 500 | 2.18 | 3.93 | 5.37 | 6.39 | 6.79 | 7.11 | 7.58 | 7.58 | 7.58 |
| 1,000 | 1.64 | 2.97 | 4.09 | 4.82 | 5.16 | 5.40 | 5.83 | 5.84 | 5.84 |
| 2,000 | 1.19 | 2.23 | 3.03 | 3.56 | 3.83 | 4.04 | 4.40 | 4.41 | 4.41 |
| 5,000 | 0.70 | 1.33 | 1.81 | 2.13 | 2.30 | 2.43 | 2.67 | 2.68 | 2.68 |
| 10,000 | 0.42 | 0.81 | 1.11 | 1.30 | 1.41 | 1.49 | 1.64 | 1.65 | 1.65 |
| 12,928 | 0.35 | 0.68 | 0.92 | 1.09 | 1.18 | 1.24 | 1.37 | 1.37 | 1.37 |




SPAS 1426 Storm Center Mass Curve Zone 1
August 31 (0000UTC) to September 1 (0000UTC), 1914
Lat: 42.3708 Lon: -85.5875
Incremental
Accumulated
13.39
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour

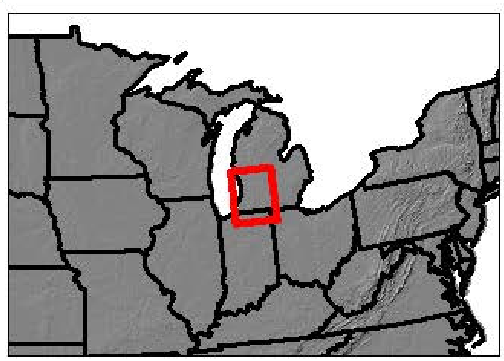



**Total 25-hour Precipitation (inches)**
**September 1, 1914 0000 UTC - September 2, 1914 0500 UTC**
**SPAS #1426**

**Stations**
- D
- HE
- HEP
- S
- SE

**Precipitaiton (inches)**

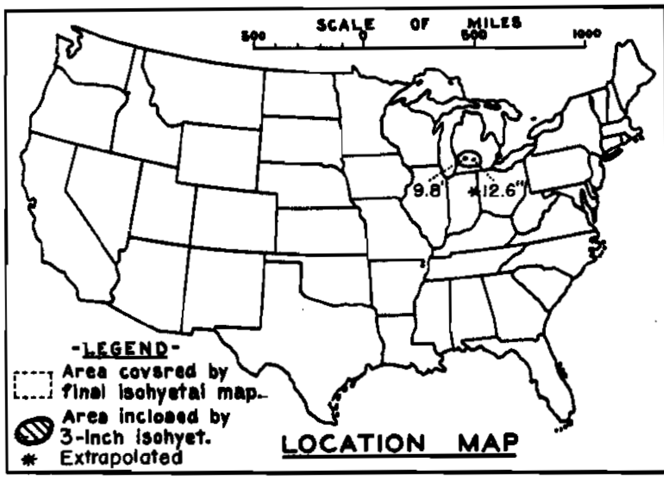
| | | |
|---|---|---|
| 0.00 - 0.50 | 4.51 - 5.00 | 9.01 - 9.50 |
| 0.51 - 1.00 | 5.01 - 5.50 | 9.51 - 10.00 |
| 1.01 - 1.50 | 5.51 - 6.00 | 10.01 - 10.50 |
| 1.51 - 2.00 | 6.01 - 6.50 | 10.51 - 11.00 |
| 2.01 - 2.50 | 6.51 - 7.00 | 11.01 - 11.50 |
| 2.51 - 3.00 | 7.01 - 7.50 | 11.51 - 12.00 |
| 3.01 - 3.50 | 7.51 - 8.00 | 12.01 - 12.50 |
| 3.51 - 4.00 | 8.01 - 8.50 | 12.51 - 13.00 |
| 4.01 - 4.50 | 8.51 - 9.00 | 13.01 - 13.50 |



*ADH 10/09/2014*

WAR DEPARTMENT　　　　　　　　　　　　　　　　CORPS OF ENGINEERS, U. S. ARMY

# STORM STUDIES - PERTINENT DATA SHEET




Storm of 31 Aug.-1 Sept. 1914
Assignment GL 2-16
Location Michigan
Study Prepared by:
Great Lakes Division
Milwaukee District Office and
Hydrometeorological Section of
U. S. Weather Bureau.
Part I Reviewed by H. M. Sec. of Weather Bureau, 10/26/39
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 10/26/46
Remarks: Centers near Cooper and Bloomingdale, Mich.

## DATA AND COMPUTATIONS COMPILED

### PART I

Preliminary isohyetal map, in 1 sheet, scale 1 : 2,500,000

Precipitation data and mass curves: (Number of Sheets)

| | |
|---|---|
| Form 5001-C (Hourly precip. data) | 8 |
| Form 5001-B (24-hour " " ) | 5 |
| Form 5001-D ( " " " " ) | - |
| Miscl. precip. records, meteorological data, etc. | 6 |
| Form 5002 (Mass rainfall curves) | 4 |

### PART II

Final isohyetal maps, in 1 sheet, scale 1 : 1,000,000

Data and computation sheets:

| | |
|---|---|
| Form S-10 (Data from mass rainfall curves) | 2 |
| Form S-11 (Depth-area data from isohyetal map) | - |
| Form S-12 (Maximum depth-duration data) | - |
| Maximum duration-depth-area curves | 1 |
| Data relating to periods of maximum rainfall | - |

### MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

| Area in Sq. Mi. | Duration of Rainfall in Hours | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | | | | | | | | | | |
| 10 | 12.6 | | | | | | | | | | |
| 50 | 12.0 | | | | | | | | | | |
| 100 | 11.3 | | | | | | | | | | |
| 200 | 10.0 | | | | | | | | | | |
| 500 | 7.6 | | | | | | | | | | |
| 800 | 6.3 | | | | | | | | | | |
| 1,000 | 5.7 | | | | | | | | | | |
| 1,200 | 5.2 | | | | | | | | | | |

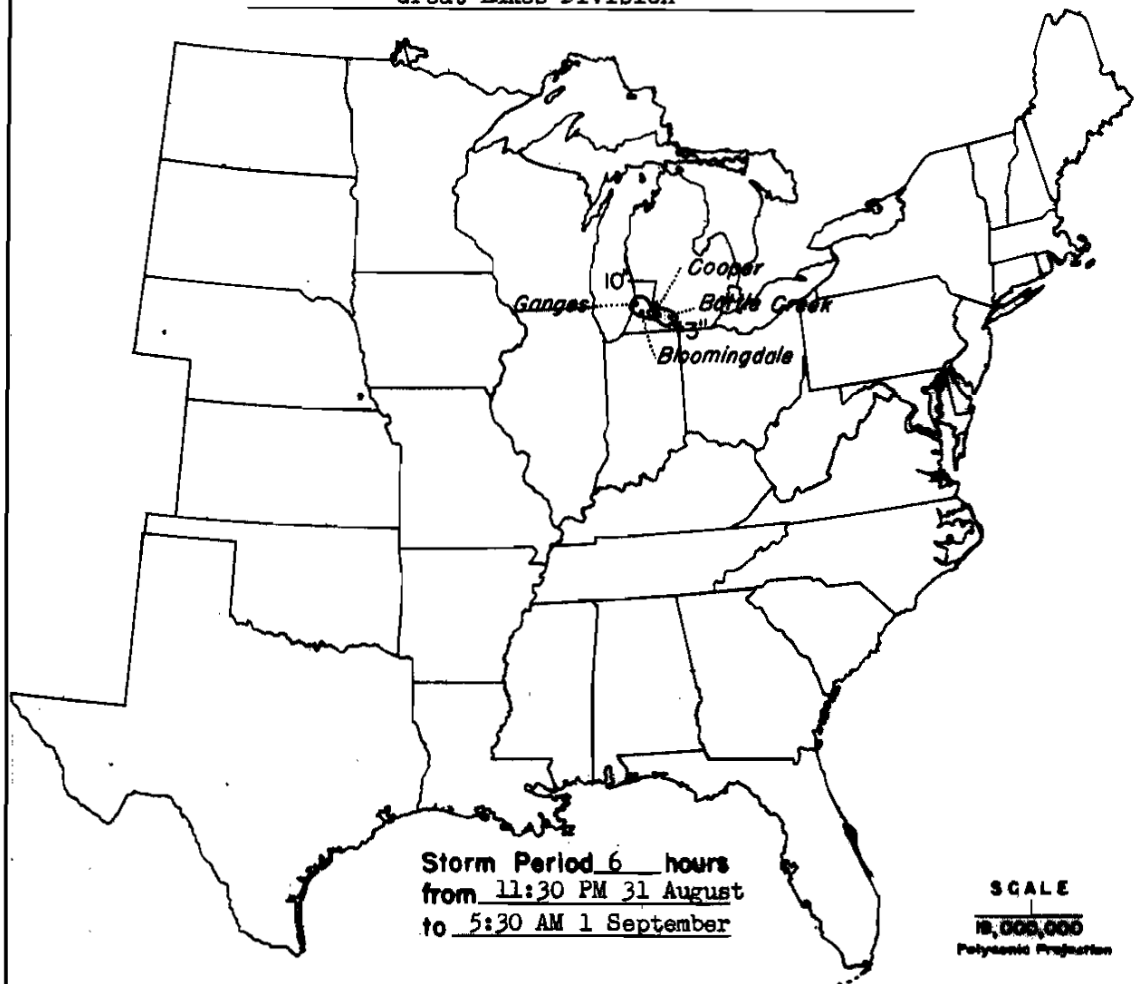
Form S-2

WAR DEPARTMENT — CORPS OF ENGINEERS, U. S. ARMY

# STORM STUDIES - ISOHYETAL MAP

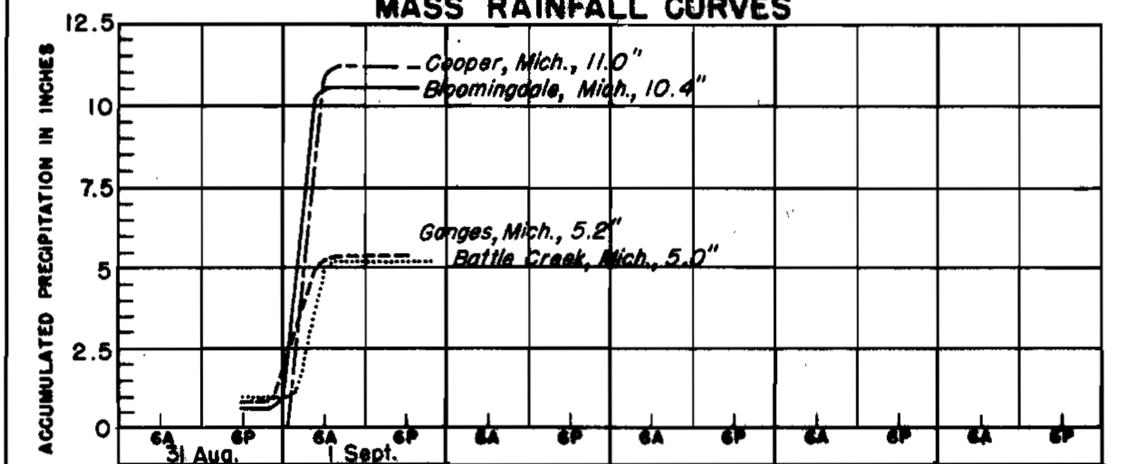
Storm of Aug. 31-Sept. 1, 1914 Assignment GL 2-16

Study Prepared by: Milwaukee, Wisc. District
Great Lakes Division

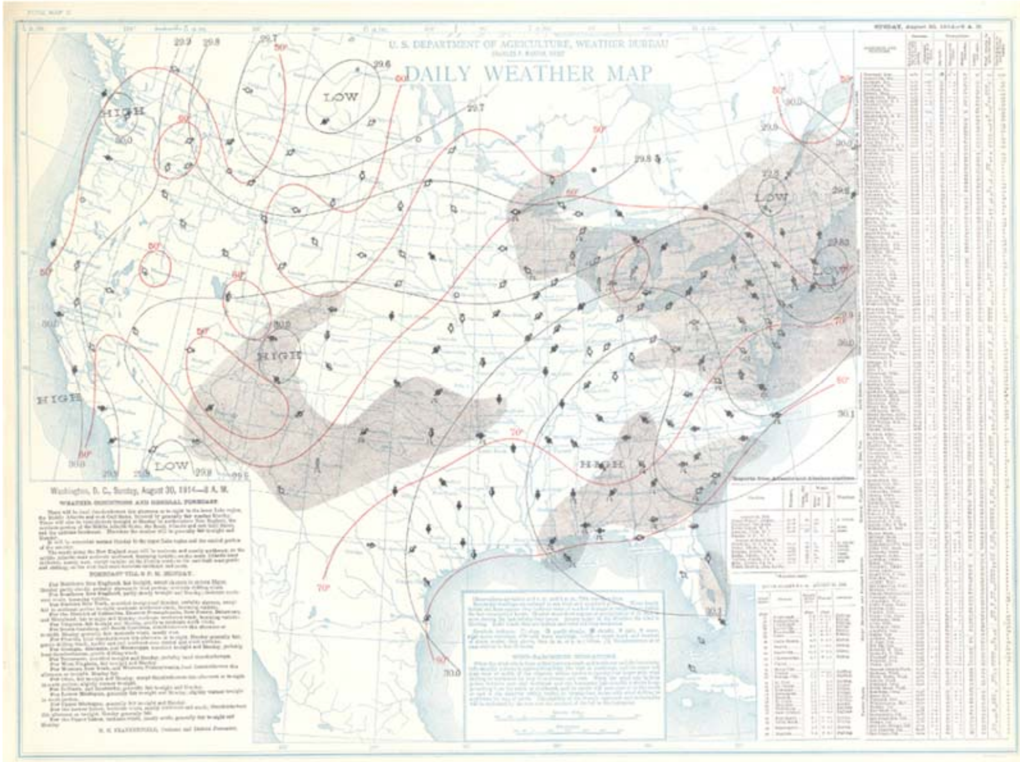


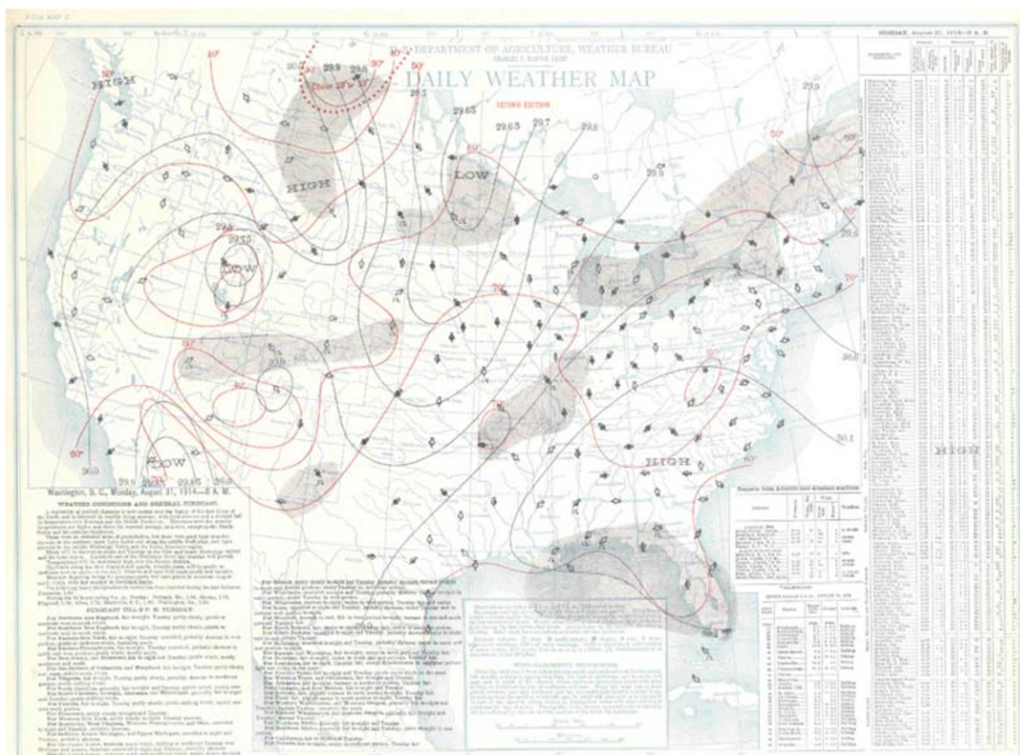

Storm Period 6 hours
from 11:30 PM 31 August
to 5:30 AM 1 September

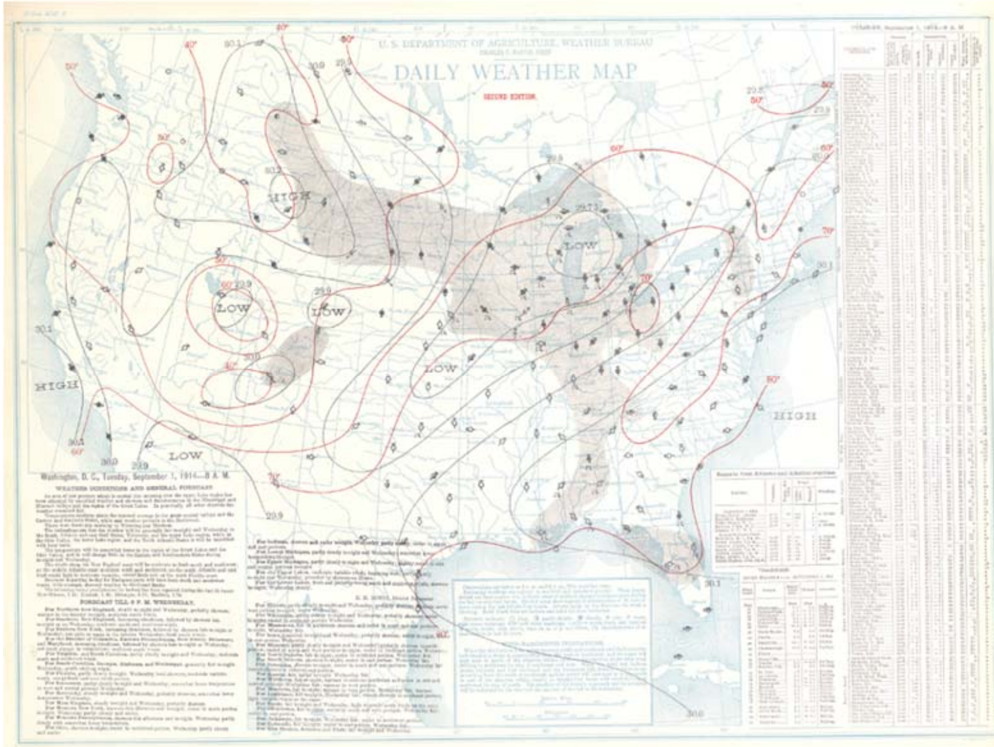
## MASS RAINFALL CURVES

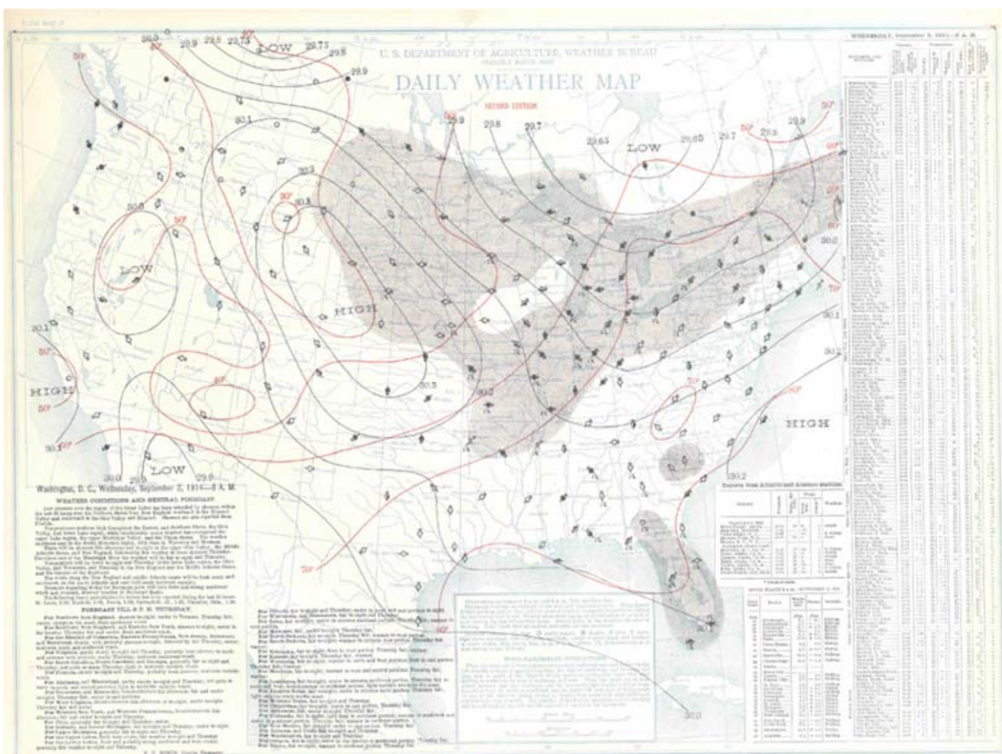



FORM S-3E


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Sunday, August 30, 1914—8 A. M.

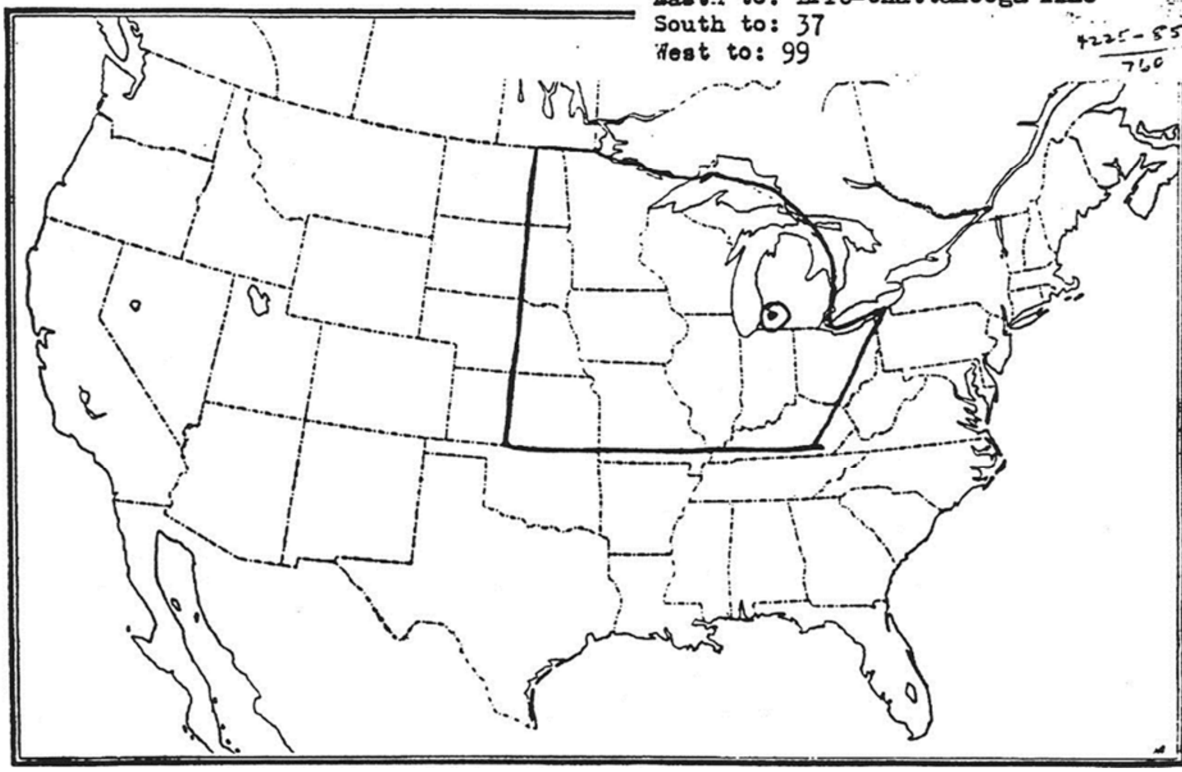

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Monday, August 31, 1914—8 A. M.


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
SECOND EDITION
HIGH
LOW
Washington, D. C., Tuesday, September 1, 1914—8 A. M.


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
SECOND EDITION
HIGH
LOW
Washington, D. C., Wednesday, September 2, 1914—8 A. M.

GL 2-16..Aug.31-Sept.1, 1914..Cooper,
12-hr. rTd 68..250 SW..~~to~~ 77.55%
North to: border
Eastn to: Erie-Chattanooga line
South to: 37
West to: 99

4225-853
760



# Storm Precipitation Analysis System (SPAS) For Storm #1427_1 SPAS Analysis

**General Storm Location**: Boyden, IA

**Storm Dates**: September 17 – September 18, 1926

**Event**: Extreme Precipitation Event

**DAD Zone 1**

**Latitude**: 43.1958

**Longitude**: -95.9958

**Max. Grid Rainfall Amount**: 24.22”

**Max. Observed Rainfall Amount**: 24.01”

**Number of Stations**: 159

**SPAS Version**: 10.0

**Basemap:** Manually digitized contours

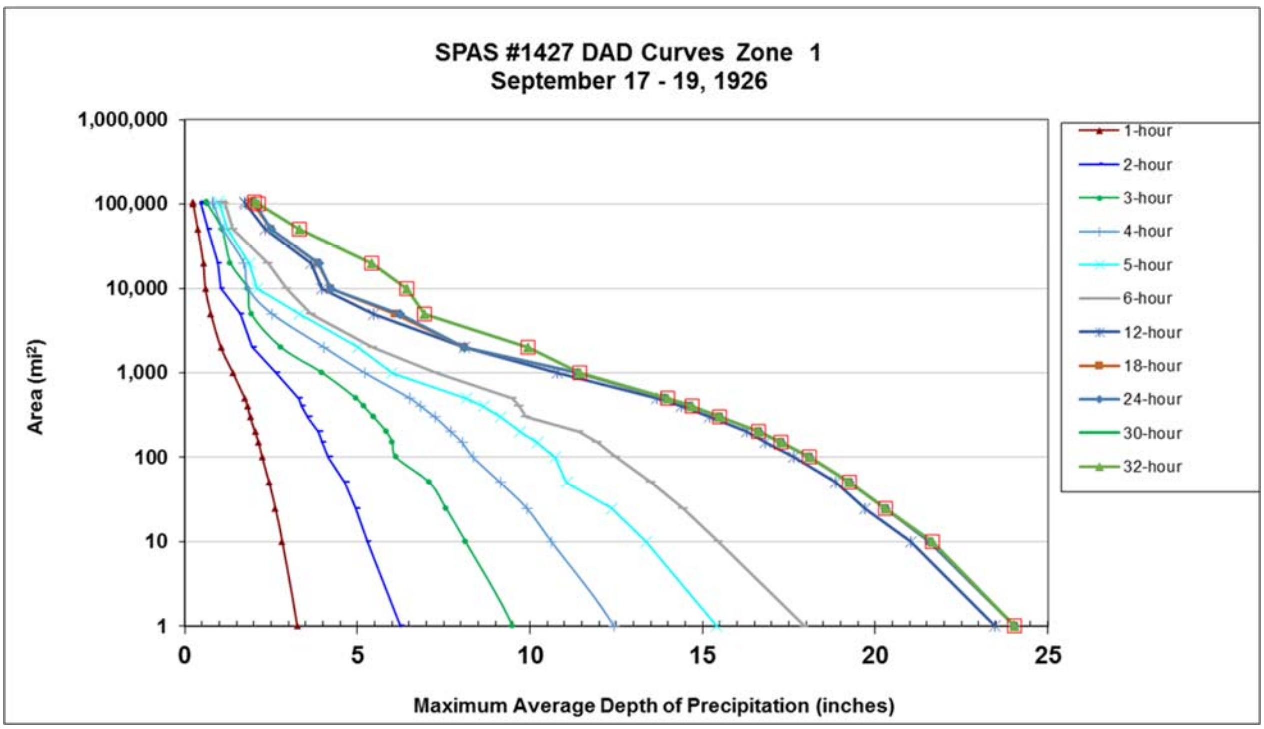
**Spatial resolution:** 0.242

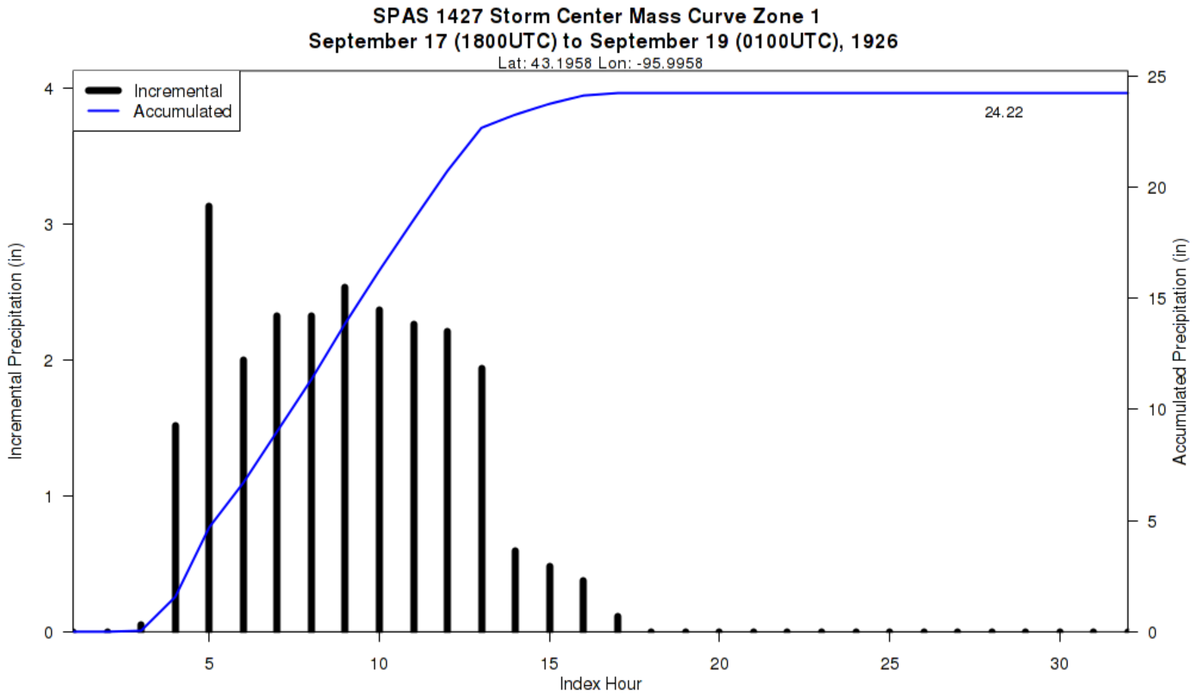
**Radar Included:** No

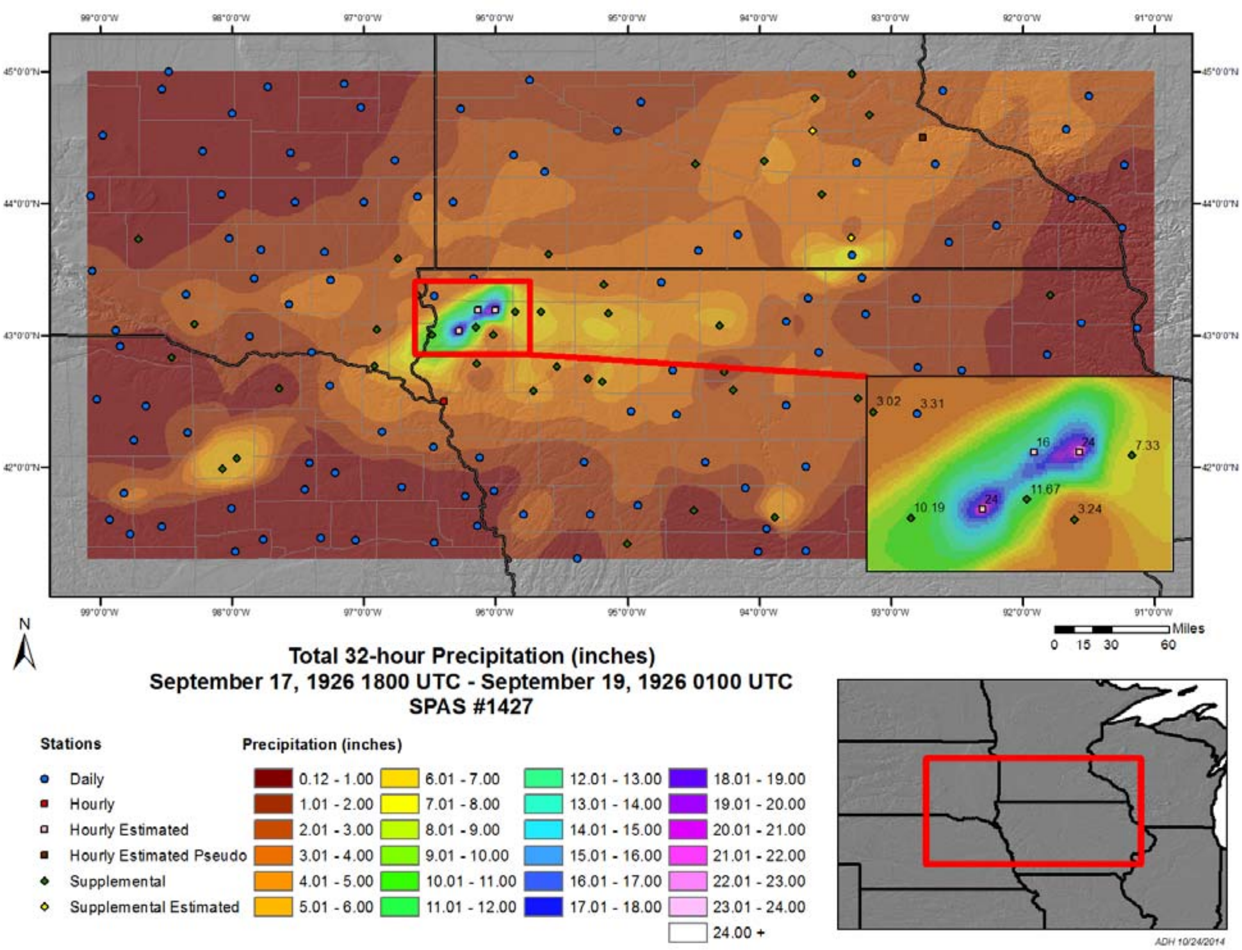
**Depth-Area-Duration (DAD) analysis**: Yes

**Reliability of results:** In addition to the NCDC stations, four hourly stations were digitized from the U.S. Army Corp of Engineers (USACE) Storm Study Pertinent Data Sheet (included below). These stations only provided precipitation timing for the time period beginning on September 17 around 12:00 CST to 18:00 CST on September 18. Data mining also produced an additional supplemental station at Foss Field/Sioux Falls Regional Airport, SD. Due to the lack of hourly information, a 32-hour Core Precipitation Period (CPP) was established for this time period. While precipitation did fall outside of the CPP, results are unreliable due to the lack of data. In addition to the three digitized hourly stations, an additional estimated hourly station with 2.40 inches of accumulated precipitation over the CPP was created in order to represent later timing as the frontal passage moved eastward. The resulting DAD values are about equal to those of the previous analysis. There are slight deviations, both high and low, which are likely due to the original analysis over generalizing the storm area. For this reason, the current analysis is considered more reliable and represents a more accurate depiction of the event.

| Storm 1427 - September 17 (1800 UTC) - September 19 (0100 UTC), 1926 MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area (mi²) | Duration (hours) | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 30 | 32 | Total |
| 0.4 | 3.37 | 6.39 | 9.68 | 12.72 | 15.78 | 18.37 | 23.60 | 24.14 | 24.14 | 24.14 | 24.14 | 24.14 |
| 1 | 3.29 | 6.23 | 9.45 | 12.42 | 15.41 | 17.93 | 23.46 | 24.01 | 24.01 | 24.01 | 24.01 | 24.01 |
| 10 | 2.83 | 5.35 | 8.15 | 10.67 | 13.25 | 15.45 | 20.98 | 21.48 | 21.48 | 21.48 | 21.48 | 21.48 |
| 25 | 2.62 | 4.97 | 7.57 | 9.91 | 12.33 | 14.38 | 19.73 | 20.17 | 20.17 | 20.17 | 20.17 | 20.17 |
| 50 | 2.44 | 4.62 | 7.06 | 9.20 | 11.48 | 13.41 | 18.79 | 19.18 | 19.19 | 19.19 | 19.19 | 19.19 |
| 100 | 2.24 | 4.25 | 6.47 | 8.46 | 10.60 | 12.43 | 17.62 | 18.04 | 18.04 | 18.04 | 18.04 | 18.04 |
| 200 | 2.03 | 3.88 | 5.89 | 7.71 | 9.66 | 11.32 | 16.17 | 16.51 | 16.51 | 16.51 | 16.51 | 16.51 |
| 300 | 1.90 | 3.63 | 5.45 | 7.17 | 8.98 | 10.52 | 15.10 | 15.41 | 15.42 | 15.42 | 15.42 | 15.42 |
| 400 | 1.81 | 3.45 | 5.16 | 6.82 | 8.51 | 9.94 | 14.21 | 14.50 | 14.51 | 14.51 | 14.51 | 14.51 |
| 500 | 1.73 | 3.32 | 4.96 | 6.55 | 8.16 | 9.50 | 13.49 | 13.77 | 13.78 | 13.78 | 13.78 | 13.78 |
| 1,000 | 1.40 | 2.67 | 4.00 | 5.28 | 6.57 | 7.68 | 11.07 | 11.33 | 11.35 | 11.35 | 11.35 | 11.35 |
| 2,000 | 1.03 | 1.98 | 2.93 | 3.86 | 4.83 | 5.73 | 8.55 | 8.94 | 9.03 | 9.03 | 9.03 | 9.03 |
| 5,000 | 0.79 | 1.50 | 2.18 | 2.73 | 3.32 | 3.89 | 6.20 | 6.60 | 6.69 | 6.69 | 6.69 | 6.69 |
| 10,000 | 0.65 | 1.26 | 1.80 | 2.24 | 2.66 | 3.09 | 4.90 | 5.34 | 5.43 | 5.43 | 5.43 | 5.43 |
| 20,000 | 0.53 | 1.02 | 1.44 | 1.82 | 2.15 | 2.49 | 3.87 | 4.33 | 4.40 | 4.40 | 4.40 | 4.40 |
| 50,000 | 0.38 | 0.72 | 1.05 | 1.31 | 1.53 | 1.73 | 2.66 | 2.99 | 3.08 | 3.08 | 3.08 | 3.08 |
| 100,000 | 0.24 | 0.47 | 0.66 | 0.83 | 1.01 | 1.16 | 1.79 | 2.02 | 2.06 | 2.06 | 2.06 | 2.06 |
| 104,550 | 0.23 | 0.45 | 0.64 | 0.81 | 0.96 | 1.12 | 1.74 | 1.97 | 2.01 | 2.01 | 2.01 | 2.01 |

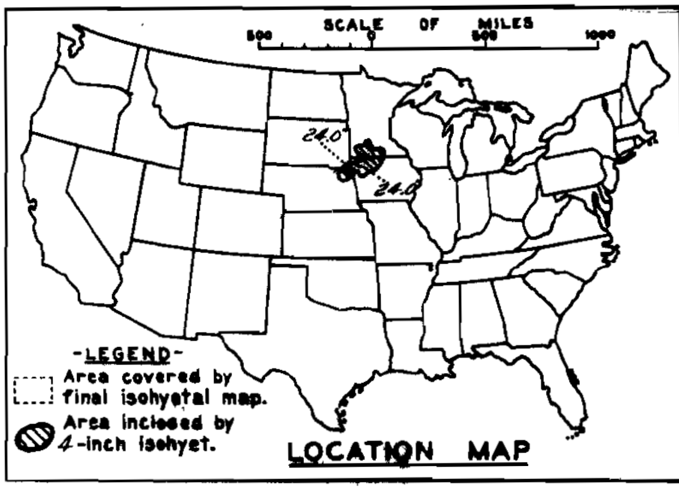



SPAS 1427 Storm Center Mass Curve Zone 1
September 17 (1800UTC) to September 19 (0100UTC), 1926
Lat: 43.1958 Lon: -95.9958
Incremental
Accumulated
24.22
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
1
2
3
4
5
10
15
20
25
30


3.02
3.31
16
24
7.33
10.19
24
11.67
3.24
N
0 15 30 60 Miles
Total 32-hour Precipitation (inches)
September 17, 1926 1800 UTC - September 19, 1926 0100 UTC
SPAS #1427
Stations
Daily
Hourly
Hourly Estimated
Hourly Estimated Pseudo
Supplemental
Supplemental Estimated
Precipitation (inches)
0.12 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
14.01 - 15.00
15.01 - 16.00
16.01 - 17.00
17.01 - 18.00
18.01 - 19.00
19.01 - 20.00
20.01 - 21.00
21.01 - 22.00
22.01 - 23.00
23.01 - 24.00
24.00 +
ADH 10/24/2014

DEPARTMENT OF THE ARMY — CORPS OF ENGINEERS

# STORM STUDIES - PERTINENT DATA SHEET



LOCATION MAP

Storm of 17-19 September 1926
Assignment MR 4-24
Location Ia, Minn, Nebr. S.D. & Wisc
Study Prepared by:
Missouri River Division
Omaha District Office

Part I Reviewed by H. M. Sec. of Weather Bureau, 8/5/47
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 12/23/47
Remarks: Centers near Boyden & Maurice, Ia.
Dewpt. 70° - Ref. Pt. 175 SSE Grid C-15

## DATA AND COMPUTATIONS COMPILED

### PART I

Preliminary isohyetal map, in 2 sheets, scale 1:500,000

Precipitation data and mass curves: (Number of Sheets)

- Form 5001-C (Hourly precip. data) ---------- 8
- Form 5001-B (24-hour " " ) ---------- -
- Form 5001-D ( " " " " ) ---------- 11
- Miscl. precip. records, meteorological data, etc. ---------- 29
- Form 5002 (Mass rainfall curves) ---------- 27

### PART II

Final isohyetal maps, in 1 sheet, scale 1:1,000,000

Data and computation sheets:

- Form S-10 (Data from mass rainfall curves) ---------- 3
- Form S-11 (Depth-area data from isohyetal map) ---------- 2
- Form S-12 (Maximum depth-duration data) ---------- 17
- Maximum duration-depth-area curves ---------- 1
- Data relating to periods of maximum rainfall ---------- 7

### MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

| Area in Sq. Mi. | Duration of Rainfall in Hours | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 12 | 18 | 24 | 30 | 36 | 48 | 54 | | | |
| Max. Station | 18.4 | 23.8 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | | | |
| 10 | 15.1 | 20.7 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | | | |
| 100 | 12.8 | 17.1 | 17.8 | 17.8 | 17.8 | 17.8 | 17.8 | 17.8 | | | |
| 200 | 11.7 | 15.8 | 16.6 | 16.6 | 16.6 | 16.6 | 16.6 | 16.6 | | | |
| 500 | 9.4 | 12.6 | 13.3 | 13.3 | 13.3 | 13.3 | 13.3 | 13.3 | | | |
| 1,000 | 7.5 | 10.1 | 10.4 | 10.6 | 10.6 | 10.6 | 10.6 | 10.6 | | | |
| 2,000 | 5.9 | 8.0 | 8.2 | 8.6 | 8.6 | 8.6 | 8.6 | 8.6 | | | |
| 5,000 | 4.1 | 6.3 | 6.4 | 6.6 | 6.6 | 6.6 | 6.6 | 6.6 | | | |
| 10,000 | 3.0 | 5.2 | 5.4 | 5.5 | 5.6 | 5.6 | 5.6 | 5.6 | | | |
| 20,000 | 2.1 | 4.1 | 4.3 | 4.4 | 4.6 | 4.8 | 4.9 | 4.9 | | | |
| 50,000 | 1.4 | 2.7 | 2.9 | 3.0 | 3.2 | 3.6 | 3.8 | 3.8 | | | |
| 63,000 | 1.2 | 2.4 | 2.6 | 2.7 | 2.9 | 3.3 | 3.5 | 3.5 | | | |

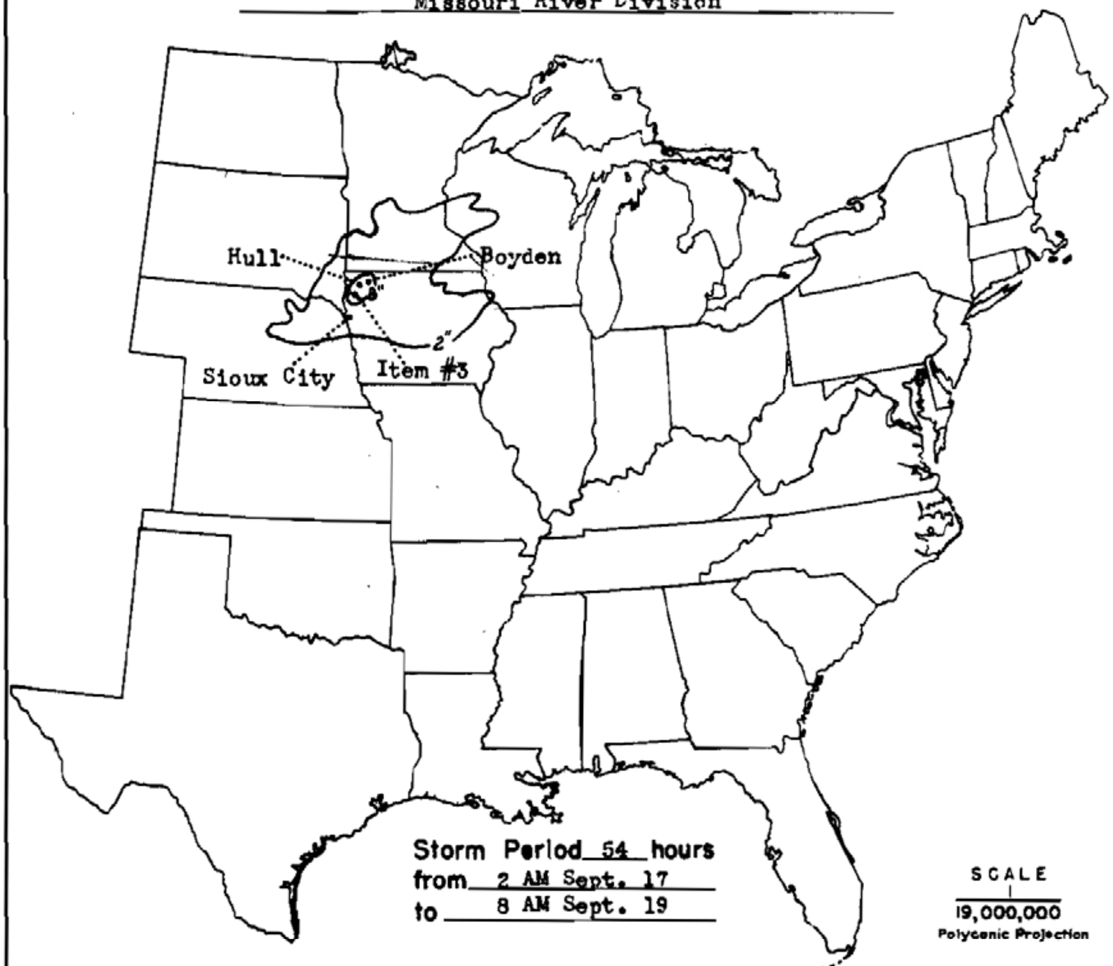
Form S-2

DEPARTMENT OF THE ARMY CORPS OF ENGINEERS

# STORM STUDIES – ISOHYETAL MAP

Storm of 17-19 September 1926 Assignment MR 4-24

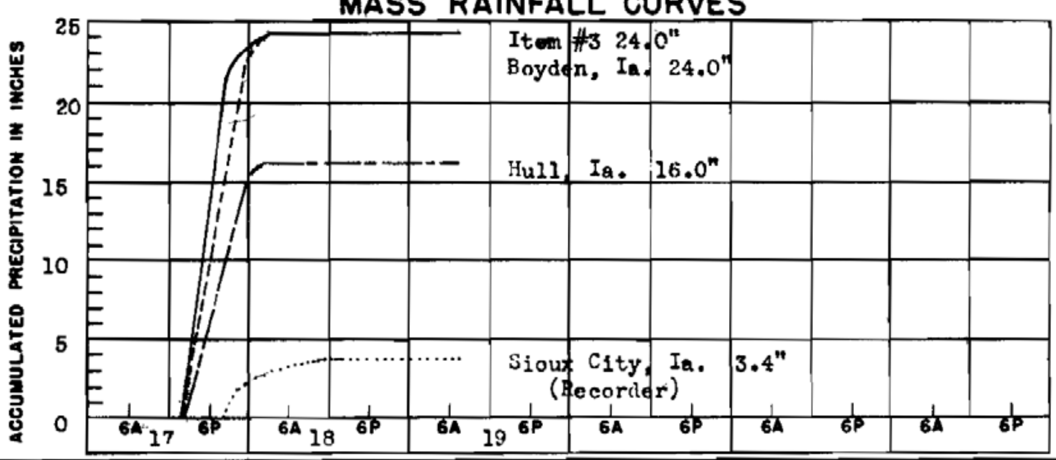
Study Prepared by: Omaha, Nebr. District
Missouri River Division



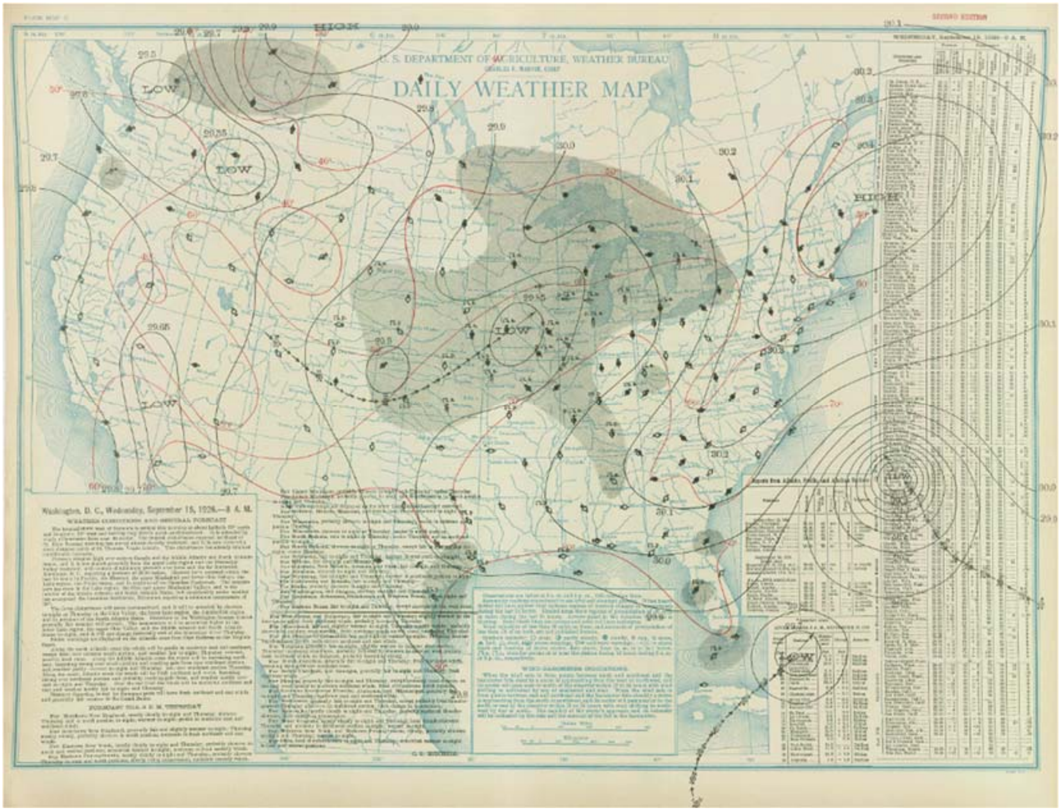

Storm Period 54 hours
from 2 AM Sept. 17
to 8 AM Sept. 19

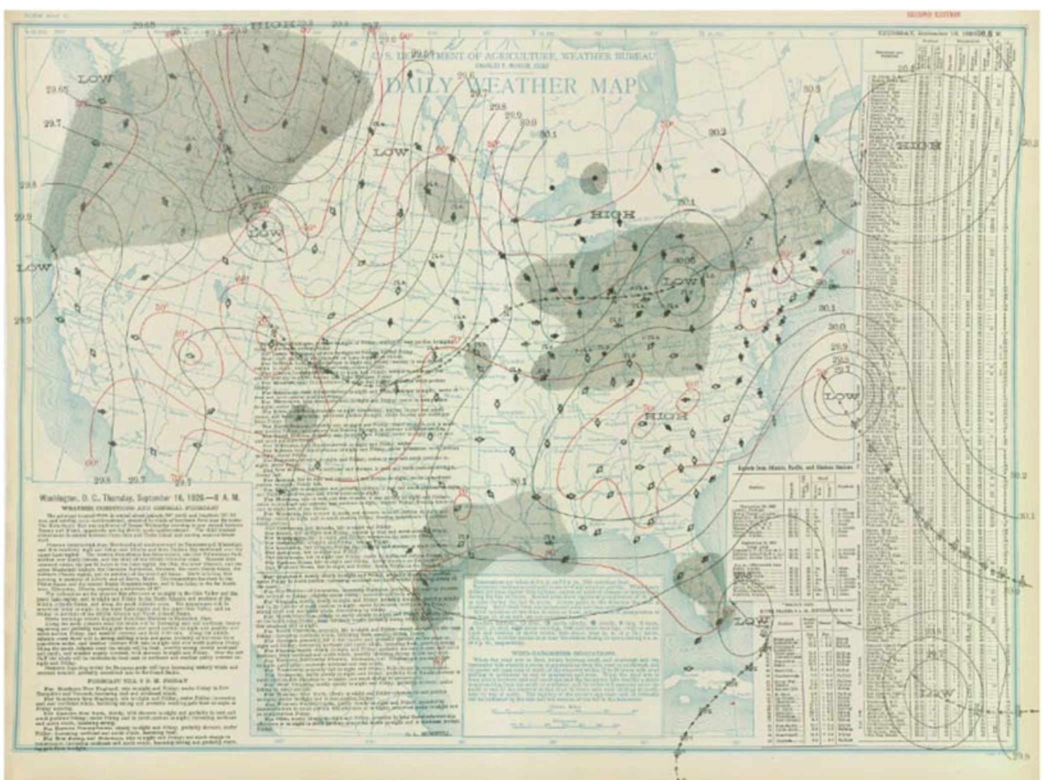
SCALE
1/19,000,000
Polyconic Projection

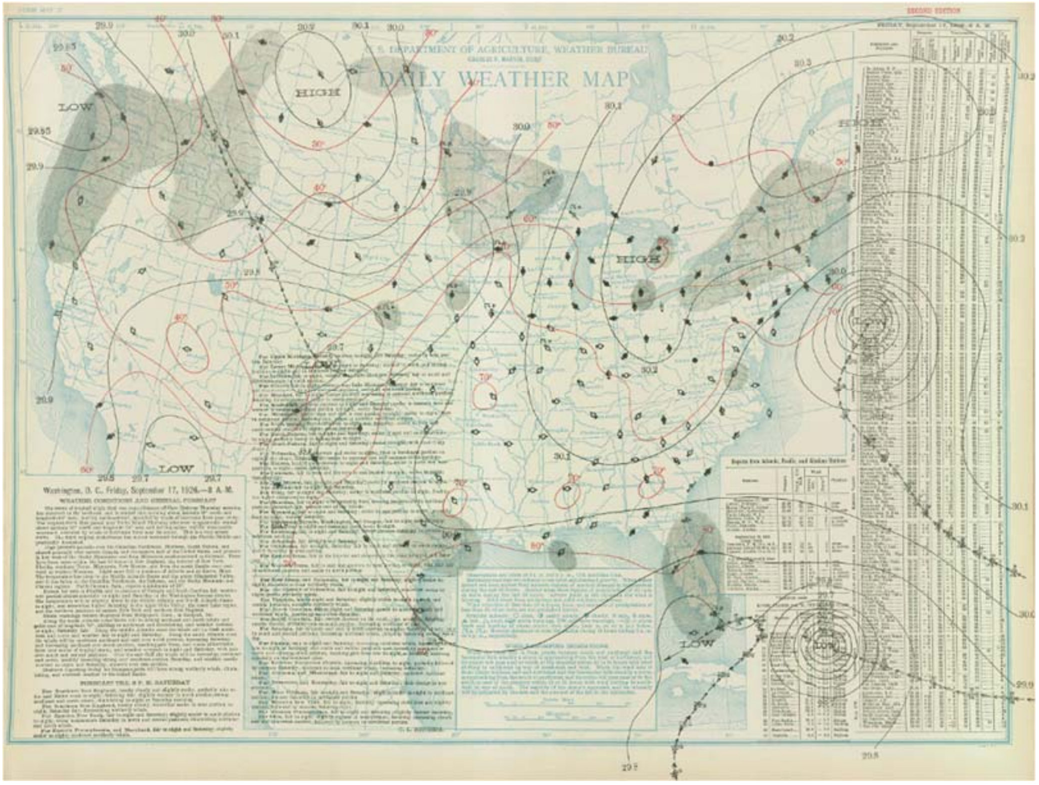
## MASS RAINFALL CURVES

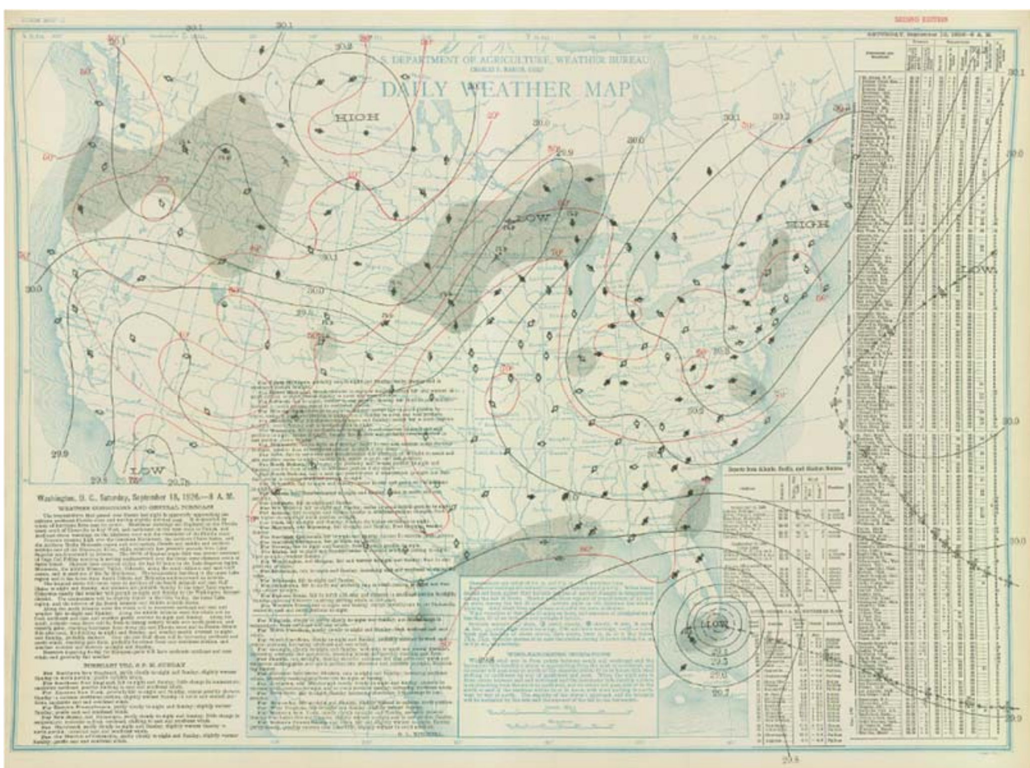


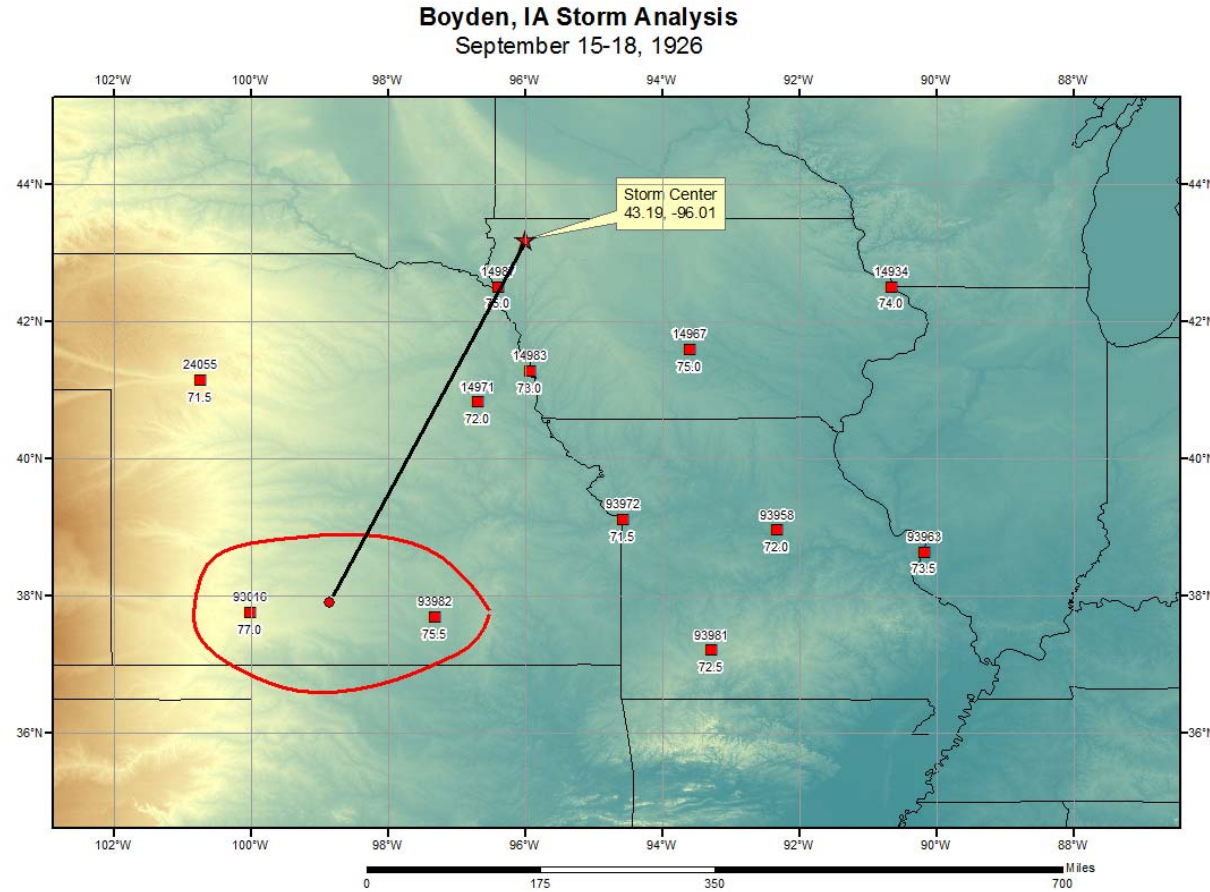

FORM S-3E

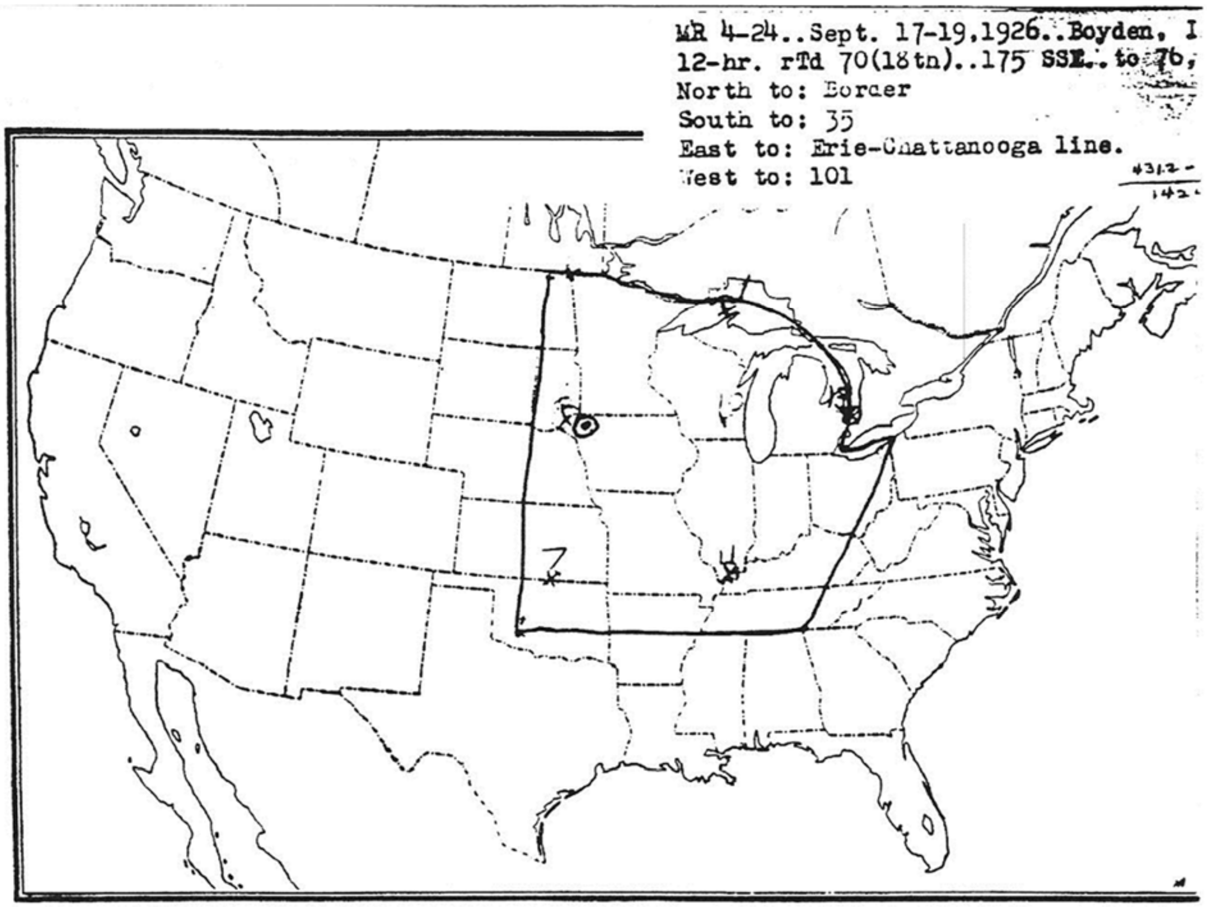

U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Wednesday, September 15, 1926—8 A. M.


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Thursday, September 16, 1926—8 A. M.


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Friday, September 17, 1926.—8 A. M.


U. S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
Washington, D. C., Saturday, September 18, 1926.—8 A. M.


Boyden, IA Storm Analysis
September 15-18, 1926
Storm Center
43.19, -96.01
14934
74.0
14967
75.0
14983
14971
72.0
24055
71.5
93972
71.5
93958
72.0
93963
73.5
93016
77.0
93982
75.5
93981
72.5
102°W
100°W
98°W
96°W
94°W
92°W
90°W
88°W
44°N
42°N
40°N
38°N
36°N
Miles
0
175
350
700


MR 4-24..Sept. 17-19,1926..Boyden, I
12-hr. rTd 70(18tn)..175 SSE..to 76,
North to: Border
South to: 35
East to: Erie-Chattanooga line.
West to: 101

# Storm Precipitation Analysis System (SPAS) For Storm #1736_1 SPAS Analysis

**General Storm Location**: Stanton, NE

**Storm Dates**: June 9-13, 1944

**Event**: General

**DAD Zone 1**

**Latitude**: 41.8208

**Longitude**: -97.0292

**Max. Grid/Radar Rainfall Amount**: 17.49"

**Max. Observed Rainfall Amount**: 17.40"

**Number of Stations**: 905

**Base Map Used:** Blend of Isohyetal Map and Conus PRISM Climatology

**Spatial resolution:** 0.2427

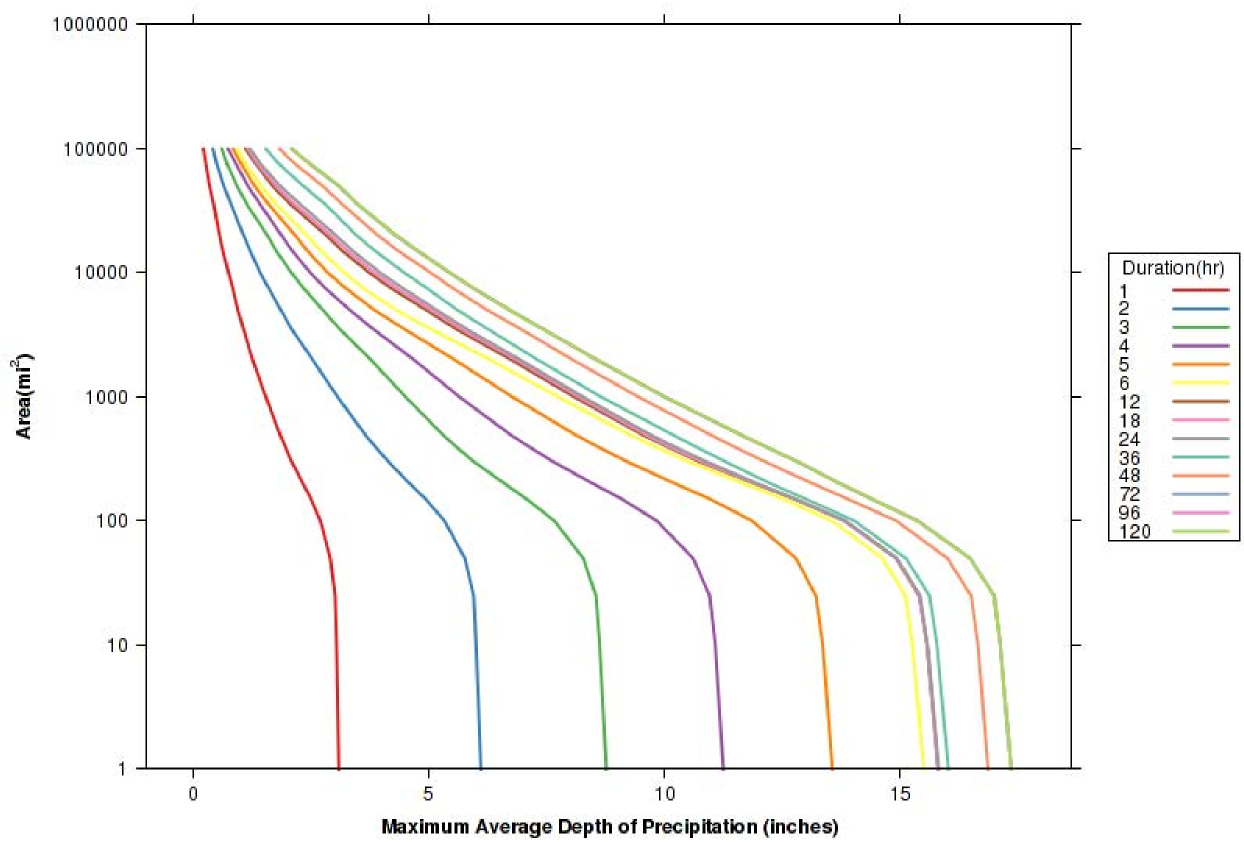
**Radar Included:** No

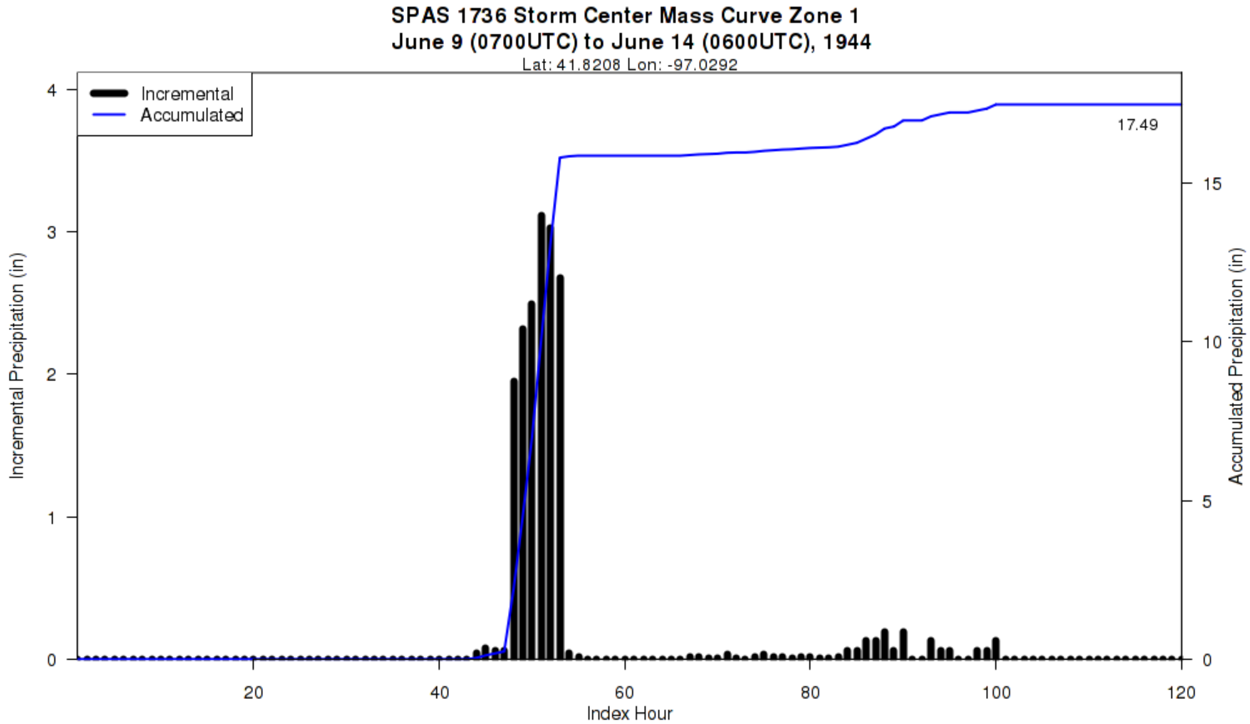
**Depth-Area-Duration (DAD) analysis**: Yes

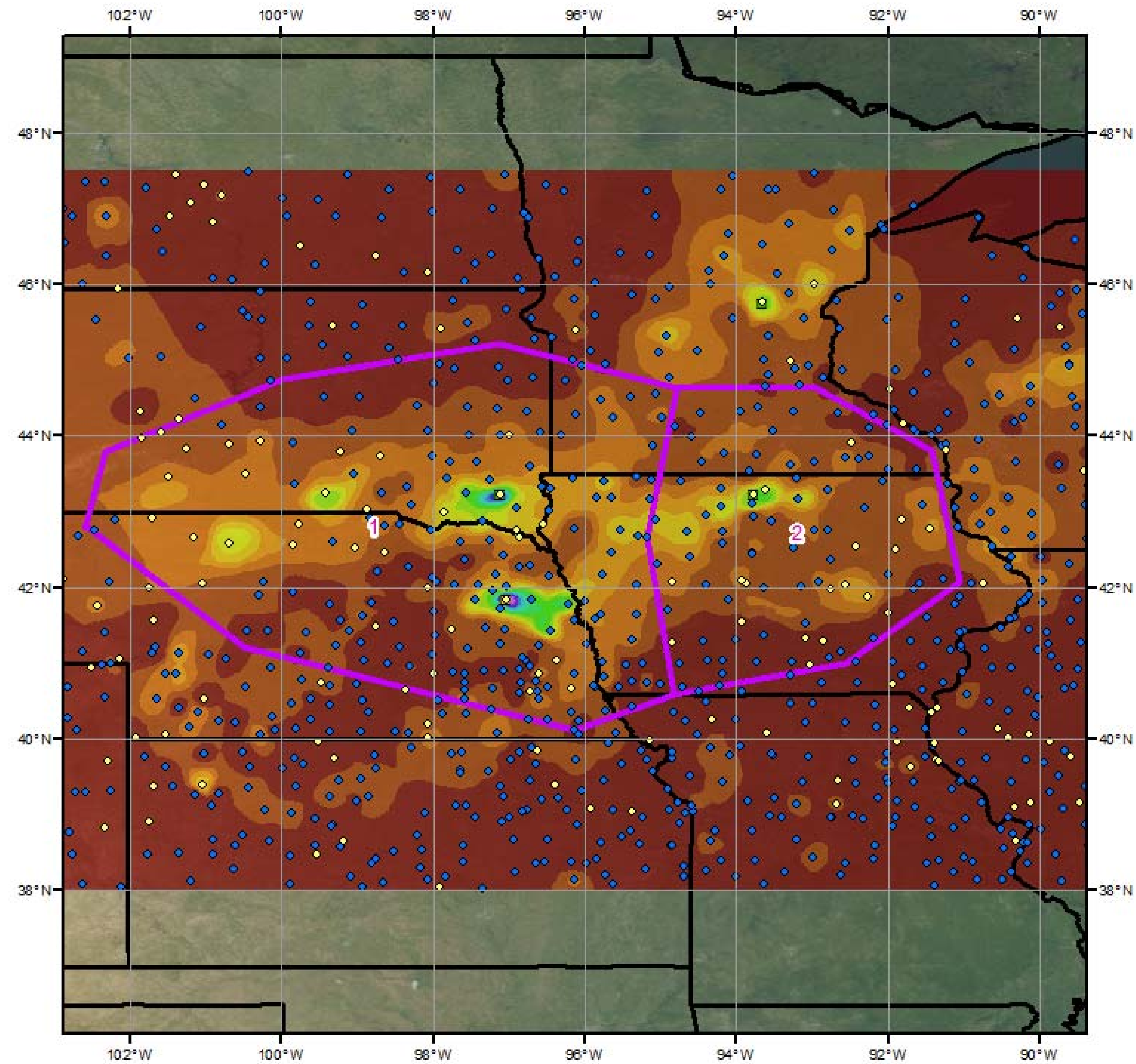
**Reliability of Results:** This analysis was based on 905 hourly pseudo stations, daily data, and supplemental station data. We have a good degree of confidence for the station based storm total results. The spatial pattern is fully dependent on the blended basemap. Timing is based on the hourly pseudo stations created from the mass curves in USACE storm study MR 6-15. Several daily stations were moved to supplemental due to timing issues and to ensure data consistency.

| SPAS 1736 - June 9 (0700 UTC) - June 14 (0600 UTC), 1944 MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Area (mi²) | Duration (hours) | | | | | | | | | | |
| | 1 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | 96 | 120 | Total |
| 0.4 | 3.11 | 15.57 | 15.87 | 15.87 | 15.89 | 16.10 | 16.95 | 17.44 | 17.44 | 17.44 | 17.44 |
| 1 | 3.10 | 15.50 | 15.80 | 15.80 | 15.82 | 16.02 | 16.86 | 17.35 | 17.35 | 17.35 | 17.35 |
| 10 | 3.05 | 15.26 | 15.57 | 15.57 | 15.58 | 15.78 | 16.65 | 17.12 | 17.12 | 17.12 | 17.12 |
| 25 | 3.02 | 15.11 | 15.40 | 15.40 | 15.42 | 15.62 | 16.50 | 16.99 | 16.99 | 16.99 | 16.99 |
| 50 | 2.92 | 14.62 | 14.91 | 14.91 | 14.93 | 15.12 | 16.00 | 16.48 | 16.48 | 16.48 | 16.48 |
| 100 | 2.71 | 13.56 | 13.82 | 13.82 | 13.84 | 14.03 | 14.92 | 15.37 | 15.37 | 15.37 | 15.37 |
| 200 | 2.34 | 11.68 | 11.91 | 11.93 | 11.97 | 12.25 | 13.14 | 13.72 | 13.72 | 13.72 | 13.72 |
| 300 | 2.10 | 10.52 | 10.74 | 10.79 | 10.89 | 11.29 | 12.13 | 12.82 | 12.82 | 12.82 | 12.82 |
| 400 | 1.96 | 9.78 | 10.03 | 10.08 | 10.19 | 10.64 | 11.45 | 12.12 | 12.12 | 12.12 | 12.12 |
| 500 | 1.85 | 9.24 | 9.51 | 9.58 | 9.68 | 10.15 | 10.95 | 11.59 | 11.59 | 11.59 | 11.59 |
| 1,000 | 1.55 | 7.74 | 8.08 | 8.18 | 8.27 | 8.65 | 9.44 | 10.00 | 10.00 | 10.00 | 10.00 |
| 2,000 | 1.27 | 6.29 | 6.74 | 6.85 | 6.93 | 7.30 | 8.04 | 8.55 | 8.55 | 8.55 | 8.55 |
| 5,000 | 0.96 | 4.31 | 4.95 | 5.06 | 5.17 | 5.61 | 6.24 | 6.72 | 6.72 | 6.72 | 6.72 |
| 10,000 | 0.76 | 3.21 | 3.74 | 3.85 | 3.97 | 4.48 | 5.04 | 5.44 | 5.45 | 5.45 | 5.45 |
| 20,000 | 0.57 | 2.42 | 2.83 | 2.92 | 3.03 | 3.47 | 3.92 | 4.29 | 4.31 | 4.31 | 4.31 |
| 50,000 | 0.36 | 1.44 | 1.69 | 1.76 | 1.85 | 2.34 | 2.75 | 3.09 | 3.10 | 3.10 | 3.10 |
| 99,026 | 0.23 | 0.95 | 1.12 | 1.17 | 1.22 | 1.55 | 1.84 | 2.10 | 2.10 | 2.10 | 2.10 |

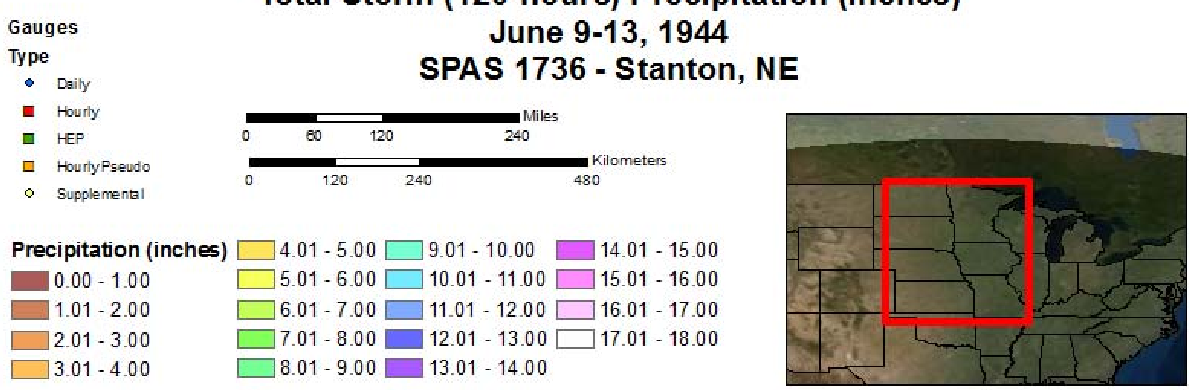
**SPAS 1736 DAD Curves Zone 1**
**June 9 (0700UTC) to June 14 (0600UTC), 1944**




SPAS 1736 Storm Center Mass Curve Zone 1
June 9 (0700UTC) to June 14 (0600UTC), 1944
Lat: 41.8208 Lon: -97.0292
Incremental
Accumulated
17.49
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
1
2
3
4
5
10
15
20
40
60
80
100
120




**Total Storm (120-hours) Precipitation (inches)**
**June 9-13, 1944**
**SPAS 1736 - Stanton, NE**



DEPARTMENT OF THE ARMY — CORPS OF ENGINEERS

# STORM STUDIES – PERTINENT DATA SHEET


LOCATION MAP

Storm of 10-13 June 1944
Assignment MR 6-15
Location Ia., Nebr., S. Dak.
Study Prepared by:
Missouri River Division
Omaha District Office

Part I Reviewed by H. M. Sec. of Weather Bureau, 8/7/46
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 2/10/48
Remarks: Center near Stanton, Nebr.
Dewpt. 70°- Ref. Pt. 125 SSE Grid D-16

## DATA AND COMPUTATIONS COMPILED

### PART I

Preliminary isohyetal map, in 2 sheets, scale 1:500,000
Precipitation data and mass curves: (Number of Sheets)

- Form 5001-C (Hourly precip. data) — 56
- Form 5001-B (24-hour " " ) — -
- Form 5001-D (" " " " ) — 19
- Miscl. precip. records, meteorological data, etc. — 11
- Form 5002 (Mass rainfall curves) — 34

### PART II

Final isohyetal maps, in 1 sheet, scale 500,000
Data and computation sheets:

- Form S-10 (Data from mass rainfall curves) — 3
- Form S-11 (Depth-area data from isohyetal map) — 2
- Form S-12 (Maximum depth-duration data) — 13
- Maximum duration-depth-area curves — 1
- Data relating to periods of maximum rainfall — 5

### MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

| Area in Sq. Mi. | Duration of Rainfall in Hours | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 12 | 18 | 24 | 30 | 36 | 48 | 60 | 72 | 78 |
| ~~Max.Sta.~~ | ~~15.5~~ | ~~15.8~~ | ~~15.8~~ | ~~15.8~~ | ~~15.8~~ | ~~15.8~~ | ~~16.8~~ | ~~17.3~~ | ~~17.3~~ | ~~17.3~~ |
| 10 | 13.4 | 15.3 | 15.3 | 15.3 | 15.3 | 15.3 | 16.2 | 16.4 | 16.7 | 16.7 |
| 100 | 11.7 | 13.6 | 13.6 | 13.6 | 13.6 | 13.7 | 14.8 | 14.9 | 15.1 | 15.1 |
| 200 | 11.1 | 12.9 | 12.9 | 12.9 | 12.9 | 13.1 | 14.1 | 14.3 | 14.4 | 14.4 |
| 500 | 9.8 | 11.3 | 11.5 | 11.5 | 11.5 | 11.6 | 12.5 | 12.7 | 12.8 | 12.8 |
| 1,000 | 7.8 | 9.0 | 9.3 | 9.3 | 9.3 | 9.4 | 10.1 | 10.4 | 10.4 | 10.4 |
| 2,000 | 5.9 | 6.9 | 7.1 | 7.1 | 7.2 | 7.3 | 7.8 | 8.1 | 8.1 | 8.1 |
| 5,000 | 3.4 | 4.0 | 4.2 | 4.6 | 4.7 | 4.9 | 5.3 | 5.5 | 5.7 | 5.8 |
| 10,000 | 2.2 | 2.5 | 2.7 | 3.5 | 3.9 | 4.1 | 4.5 | 4.7 | 4.9 | 5.0 |
| 16,000 | 1.8 | 2.0 | 2.2 | 2.9 | 3.5 | 3.7 | 4.1 | 4.3 | 4.5 | 4.6 |

Form S-2

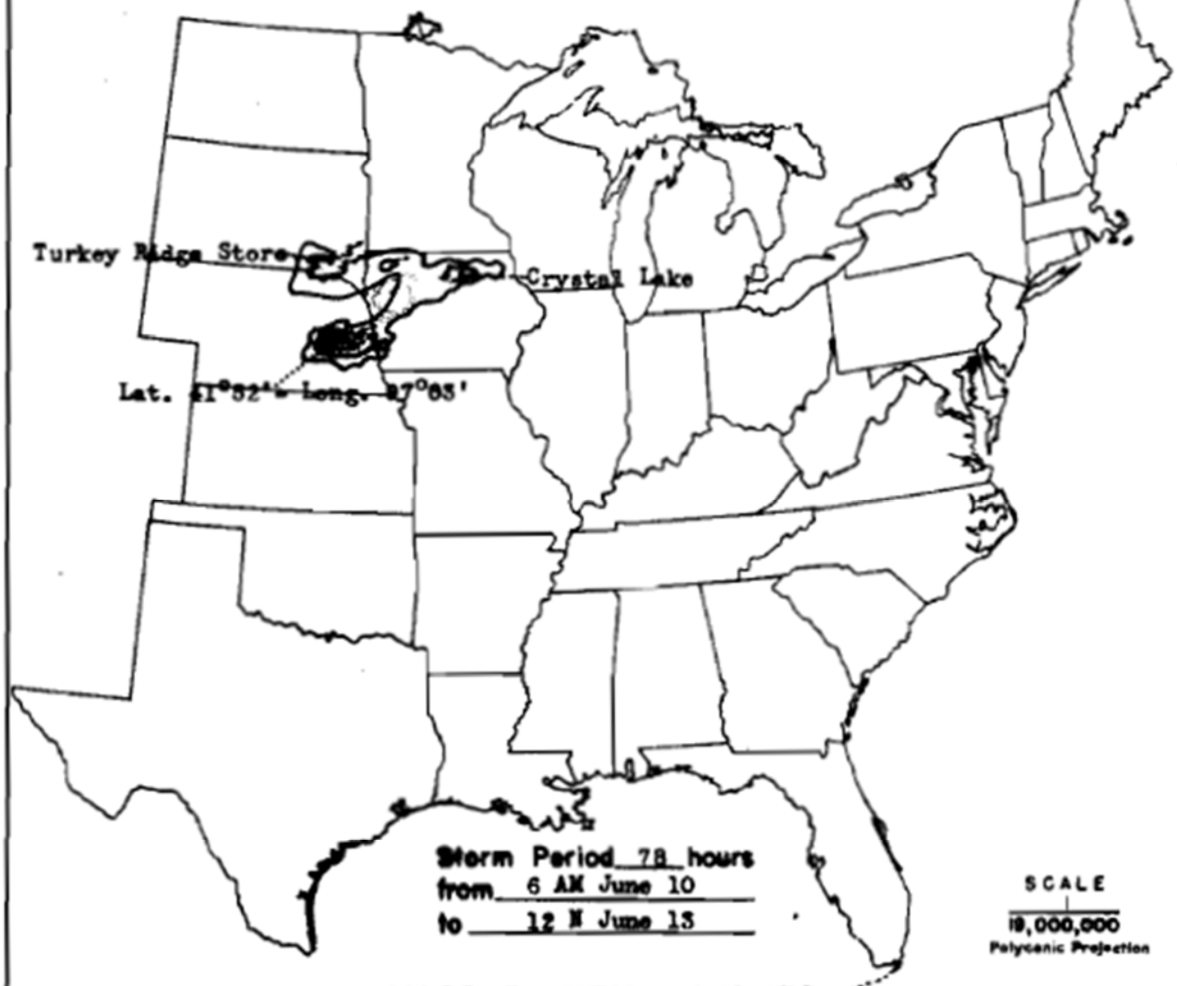
DEPARTMENT OF THE ARMY — CORPS OF ENGINEERS

# STORM STUDIES – ISOHYETAL MAP

Storm of 10-13 June 1944 Assignment MR 6-15

Study Prepared by: Omaha, Nebr. District

Missouri River Division




Storm Period 78 hours

from 6 AM June 10

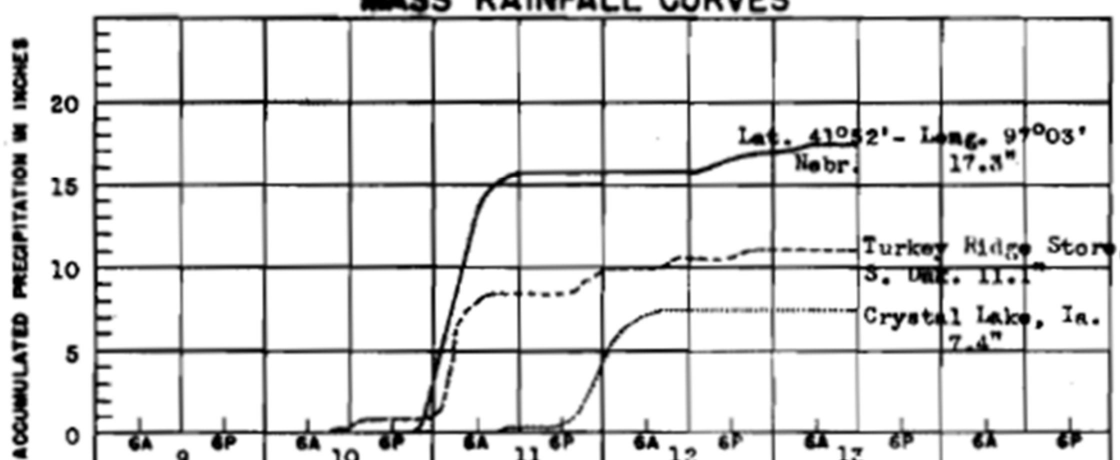
to 12 N June 13

SCALE

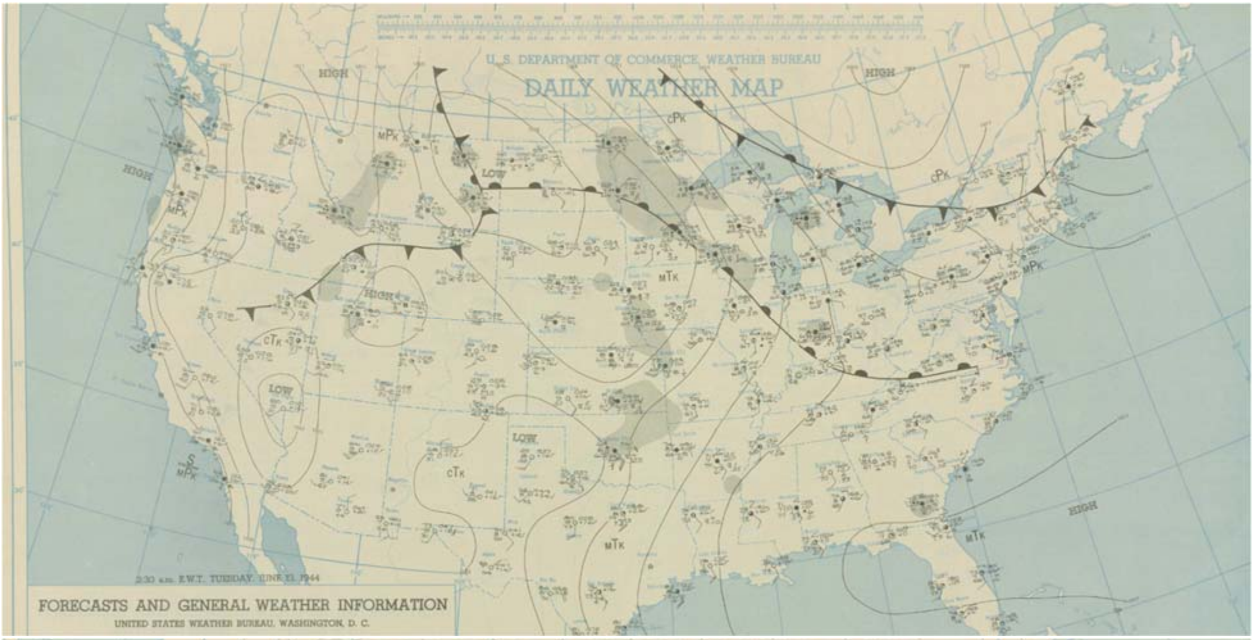
1
─────
19,000,000

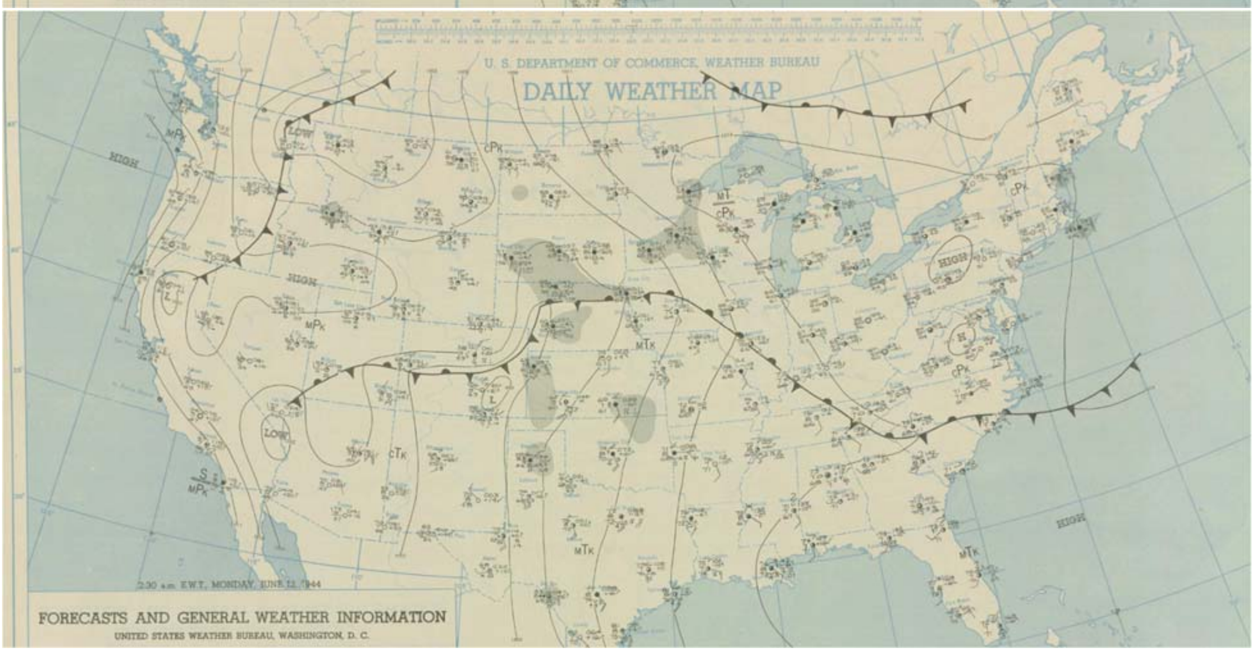
Polyconic Projection

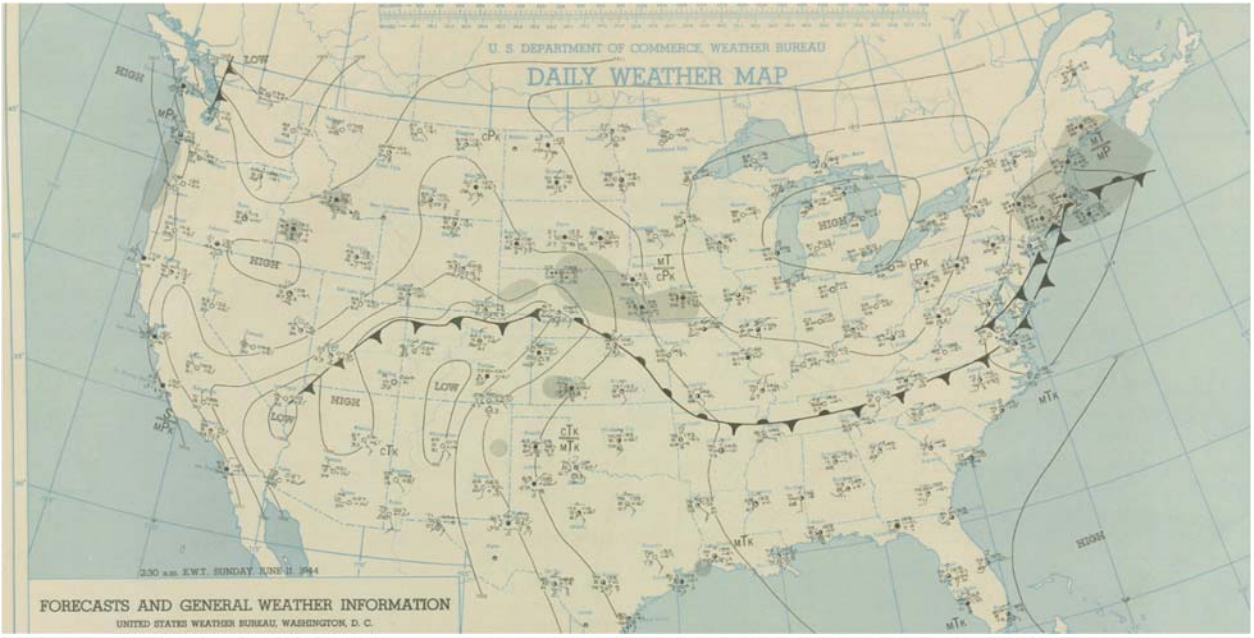
## MASS RAINFALL CURVES

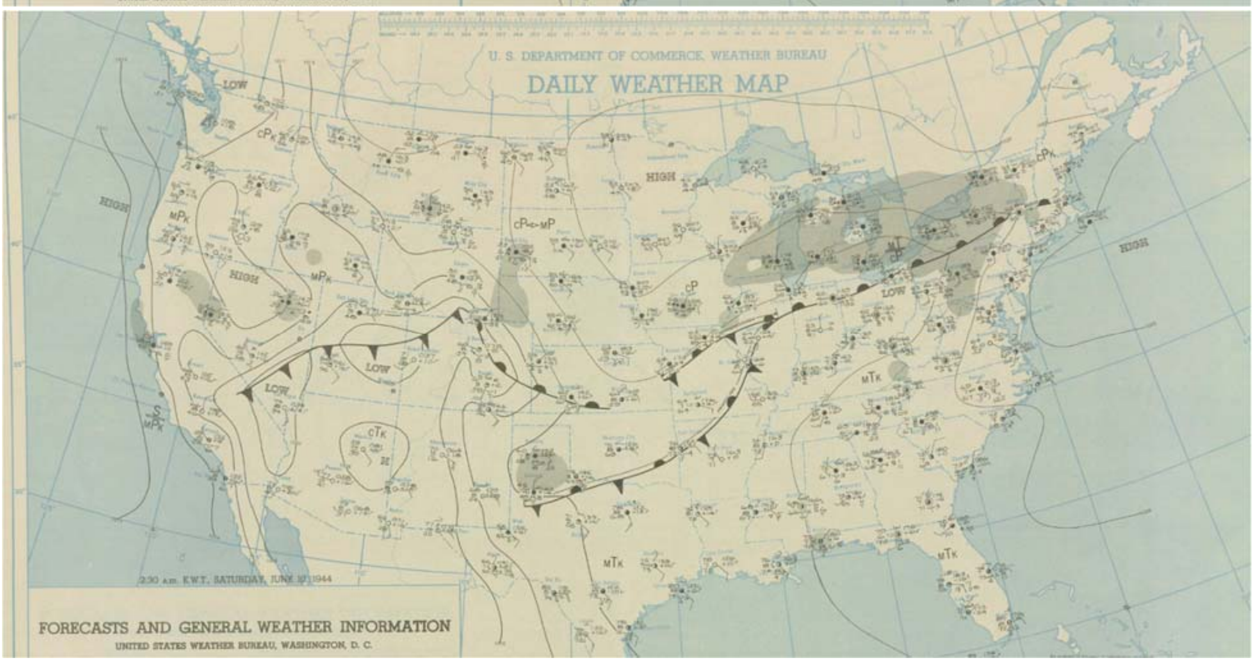


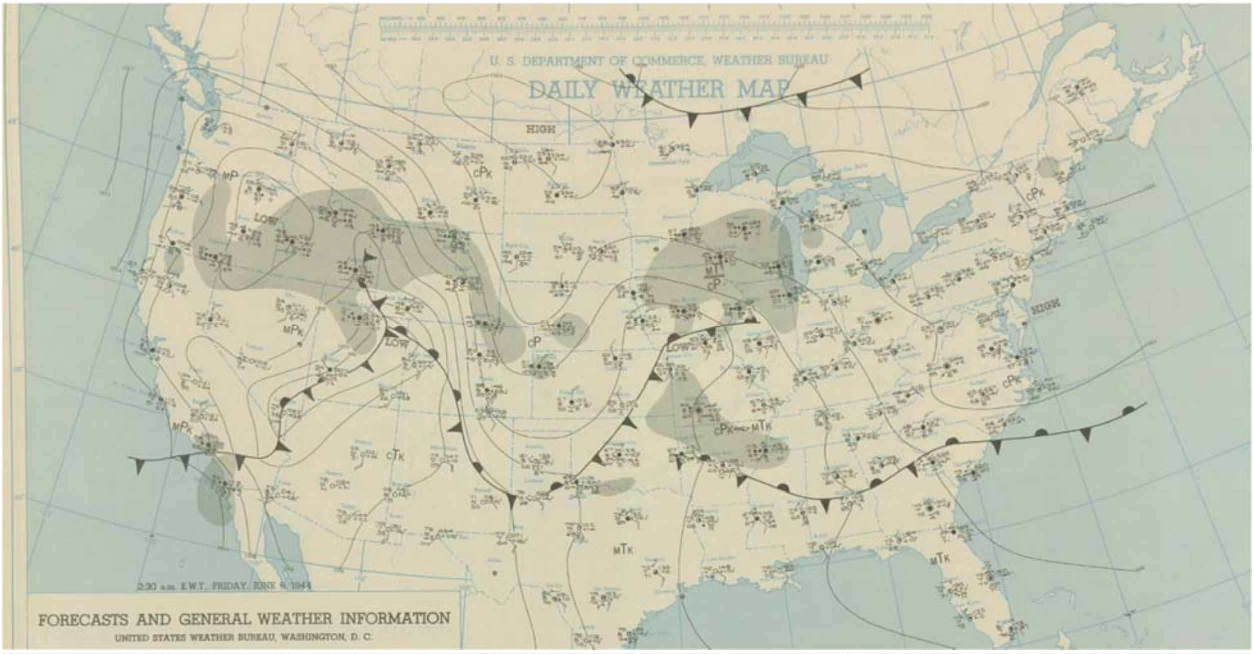

FORM 3-3E

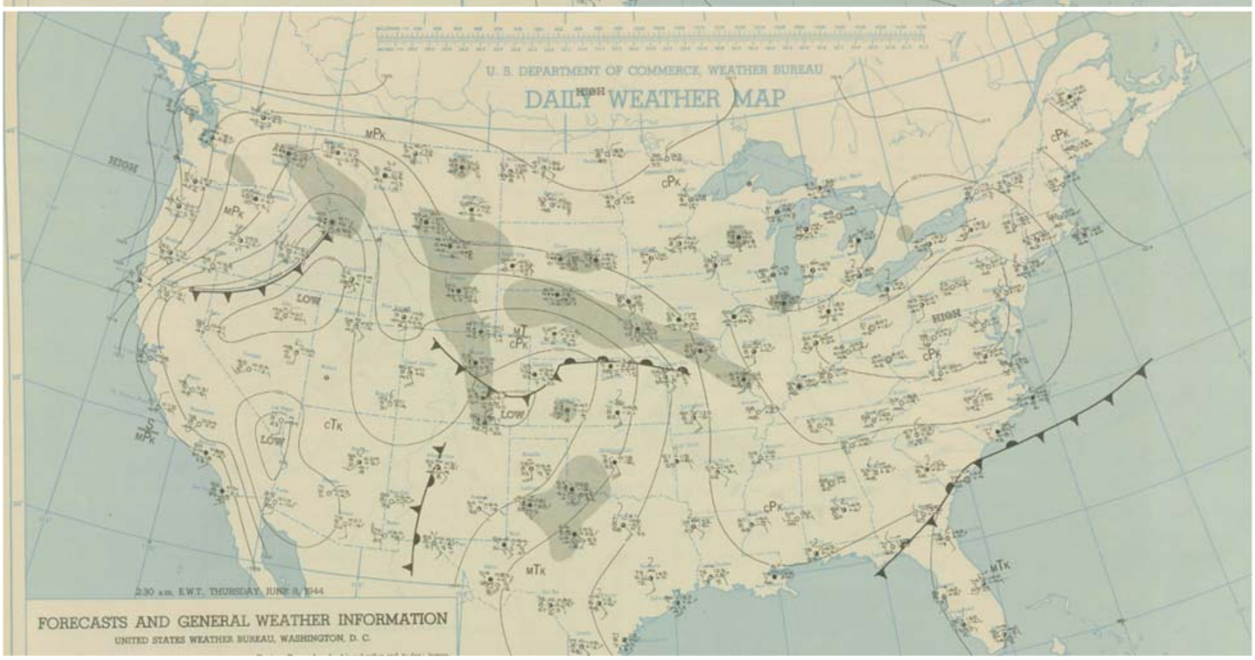

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
2:30 a.m. E.W.T., TUESDAY, JUNE 13, 1944
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.

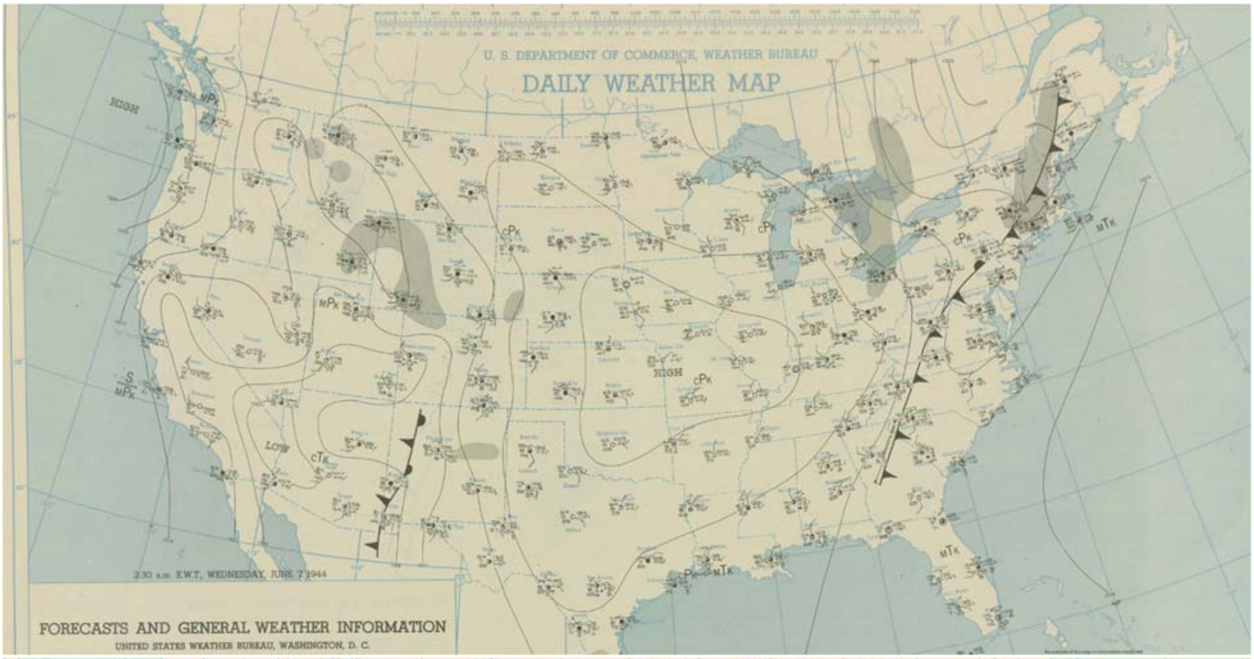

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
2:30 a.m. E.W.T., MONDAY, JUNE 12, 1944
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.

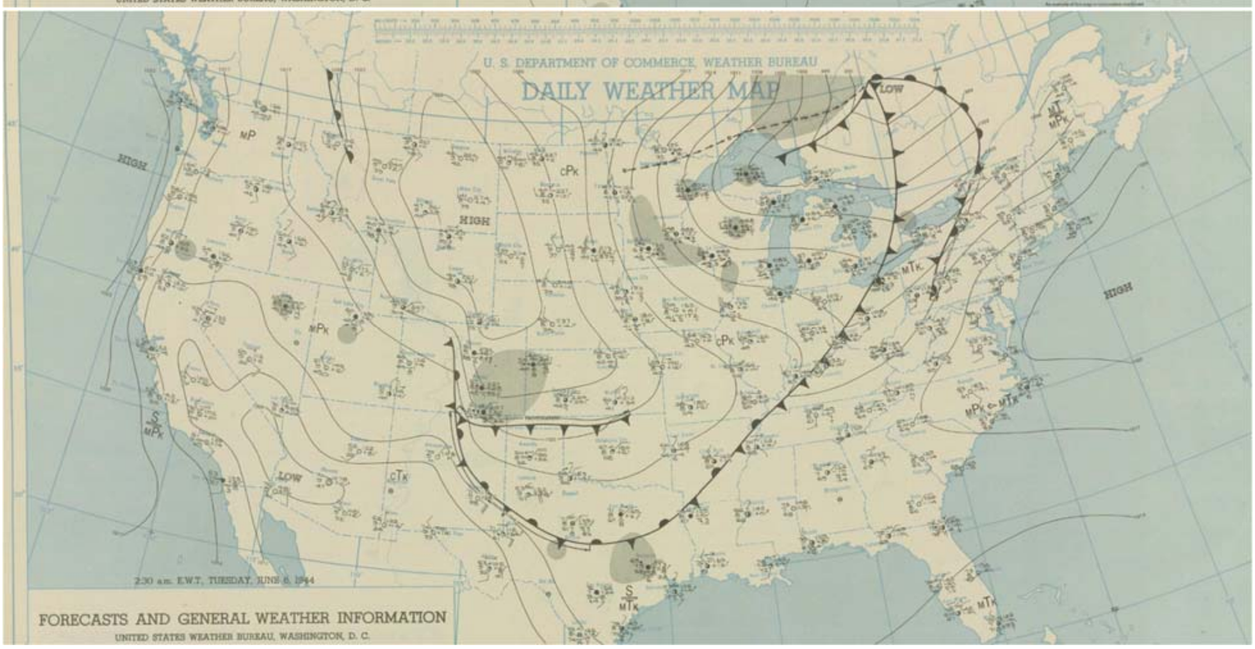

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
2:30 a.m. E.W.T. SUNDAY, JUNE 11, 1944
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.

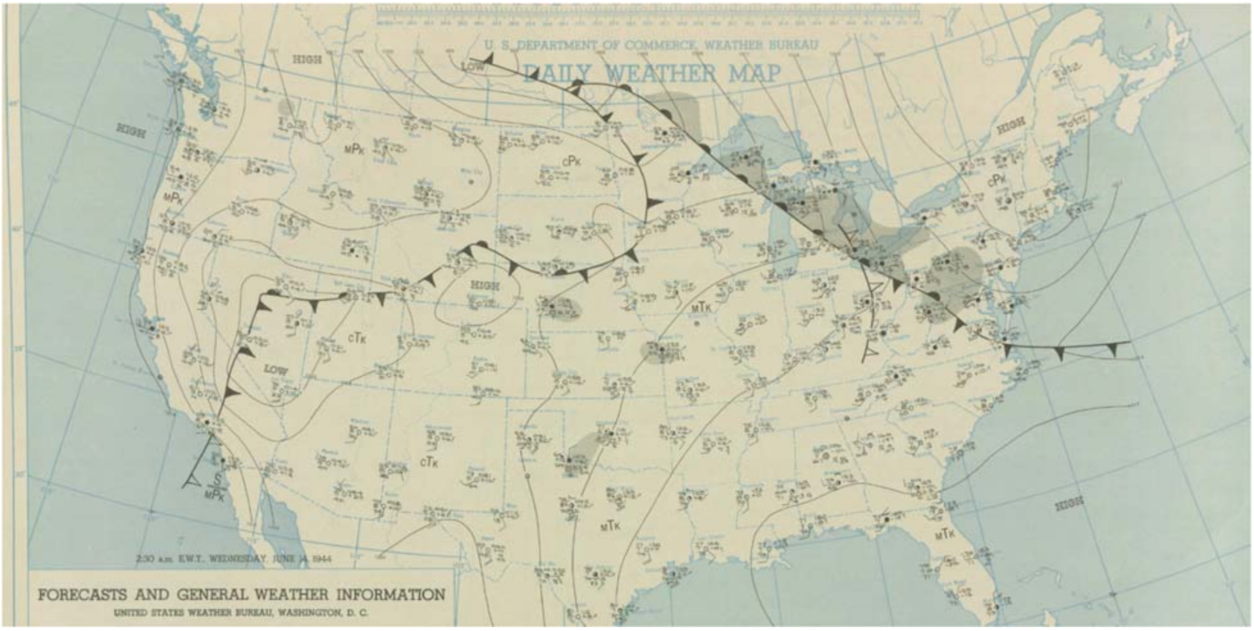

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
2:30 a.m. E.W.T. SATURDAY, JUNE 10, 1944
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.

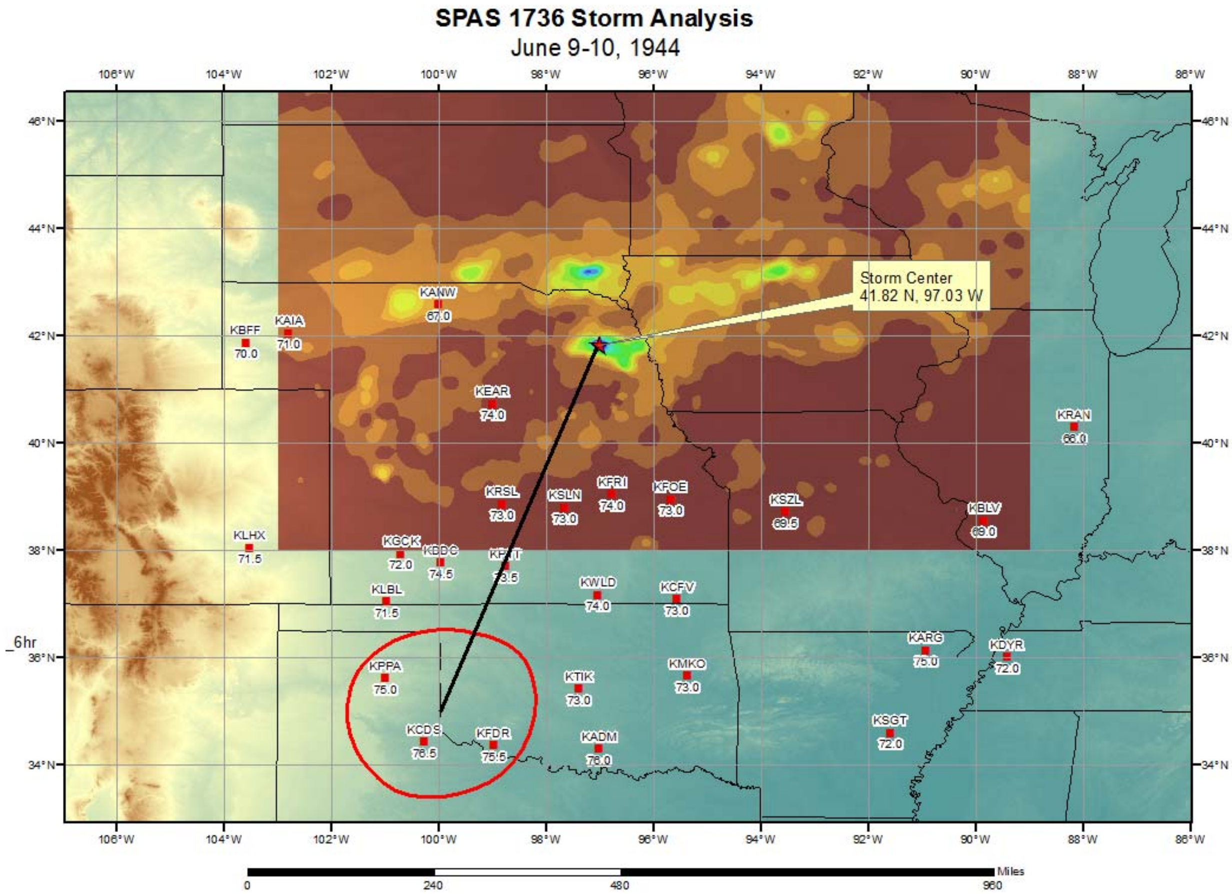

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
2:30 a.m. E.W.T., FRIDAY, JUNE 9, 1944
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
2:30 a.m. E.W.T., THURSDAY, JUNE 8, 1944
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
cPK
mPK
cTK
mTK
2:30 a.m. E.W.T., WEDNESDAY, JUNE 7, 1944
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
cPK
mP
mPK
cTK
mTK
2:30 a.m. E.W.T., TUESDAY, JUNE 6, 1944
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.


U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
2:30 a.m. E.W.T., WEDNESDAY, JUNE 14, 1944
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.


SPAS 1736 Storm Analysis
June 9-10, 1944
Storm Center
41.82 N, 97.03 W
KANW
67.0
KBFF
70.0
KAIA
71.0
KEAR
74.0
KRAN
66.0
KRSL
73.0
KSLN
73.0
KFRI
74.0
KFOE
73.0
KSZL
69.5
KBLV
69.0
KLHX
71.5
KGCK
72.0
KDDC
74.5
73.5
KLBL
71.5
KWLD
74.0
KCFV
73.0
_6hr
KARG
75.0
KDYR
72.0
KPPA
75.0
KTIK
73.0
KMKO
73.0
KCDS
76.5
KFDR
75.5
KADM
76.0
KSGT
72.0
Miles
0
240
480
960

# Storm Precipitation Analysis System (SPAS) For Storm #1434_1 SPAS Analysis

**General Storm Location**: Holt, Missouri

**Storm Dates**: June 18 – June 23, 1947

**Event**: CORPS of Engineers, US Army Assignment MR 8 – 20

**DAD Zone 1**

**Latitude**: 39.4542

**Longitude**: -94.3292

**Max. Grid Rainfall Amount**: 17.62”

**Max. Observed Rainfall Amount**: 17.62”

**Number of Stations**: 162

**SPAS Version**: 10.0

**Basemap:** Manually digitized contours using Army CORPS of Engineers isohyetal map.

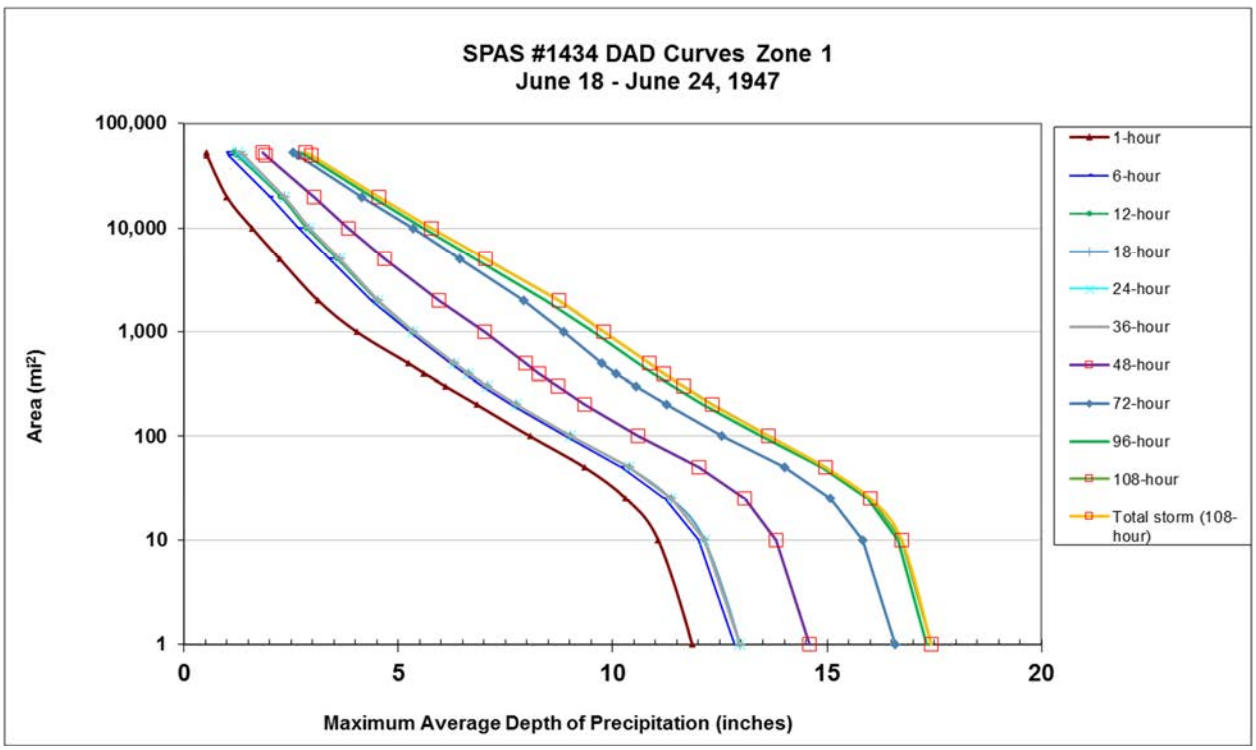
**Spatial resolution:** 0.2548

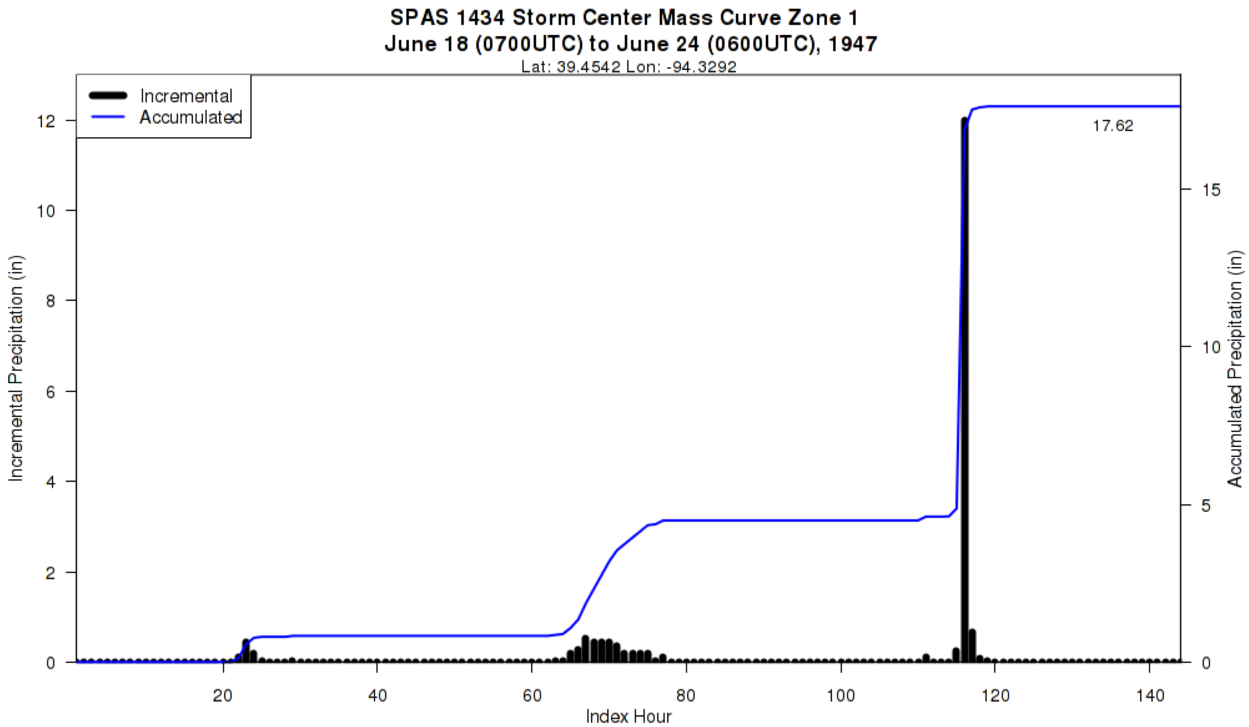
**Radar Included:** No

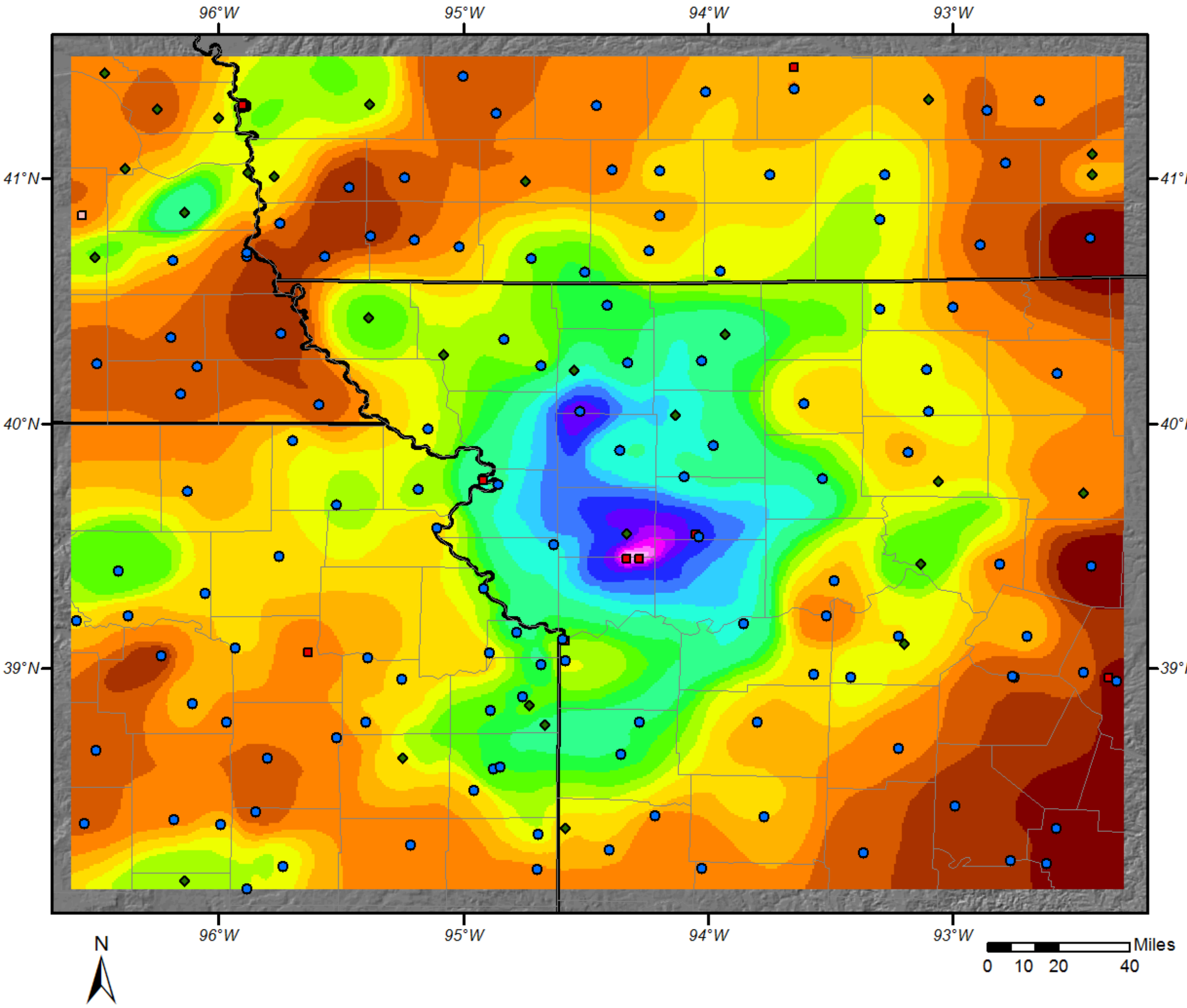
**Depth-Area-Duration (DAD) analysis**: Yes

**Reliability of results:** Ten of the eleven hourly stations used in this analysis were manually digitized from either the Army CORPS of Engineers’ pertinent data report or from local climatological data. The last hourly station was estimated from the spas precipitation grid due to daily and supplemental stations nearby needing more accurate timing. This provided very high accuracy of the hourly data, which is essential in the timing of the daily and supplemental stations. Of the 28 supplemental stations, 8 were formatted as daily stations. These stations were in the supplemental file due to there being more data on either end of the storm duration as defined for this analysis. For example, if the daily station took measurements in the morning, then there may have been more precipitation reported for the remainder of the storm that was actually part of the following day’s observation. Alternatively, if a station had an observation time in the evening then there could have been data not used from the day before that was valid for the period of the storm and could be added to the analysis. An additional 8 stations found in the CORPS report were added to the supplemental file as well. With all of the data being thoroughly inspected, the DAD and precipitation pattern following closely to the Army CORPS of Engineers report, and the precipitation totals for various periods throughout the storm being consistent with previous reports, this analysis is considered to be reliable.

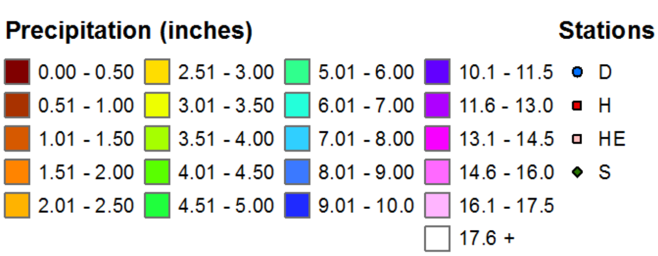
| Storm 1434 - June 18 (0700 UTC) - June 24 (0600 UTC), 1947 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | |
| Area ($mi^2$) | Duration (hours) | | | | | | | | | | |
| | 1 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | 96 | 108 | Total |
| 0.4 | 11.95 | 12.96 | 13.08 | 13.08 | 13.08 | 13.08 | 14.71 | 16.72 | 17.45 | 17.55 | 17.55 |
| 1 | 11.85 | 12.85 | 12.97 | 12.97 | 12.97 | 12.97 | 14.59 | 16.58 | 17.31 | 17.42 | 17.42 |
| 10 | 11.06 | 12.01 | 12.14 | 12.14 | 12.14 | 12.14 | 13.81 | 15.84 | 16.66 | 16.74 | 16.74 |
| 25 | 10.31 | 11.23 | 11.37 | 11.37 | 11.37 | 11.37 | 13.08 | 15.07 | 15.94 | 16.01 | 16.01 |
| 50 | 9.35 | 10.22 | 10.38 | 10.38 | 10.38 | 10.38 | 12.01 | 14.00 | 14.87 | 14.96 | 14.96 |
| 100 | 8.07 | 8.91 | 9.02 | 9.02 | 9.02 | 9.02 | 10.60 | 12.55 | 13.46 | 13.64 | 13.64 |
| 200 | 6.84 | 7.65 | 7.75 | 7.75 | 7.75 | 7.75 | 9.35 | 11.25 | 12.10 | 12.32 | 12.32 |
| 300 | 6.11 | 6.99 | 7.09 | 7.09 | 7.09 | 7.09 | 8.72 | 10.55 | 11.41 | 11.65 | 11.65 |
| 400 | 5.60 | 6.54 | 6.64 | 6.64 | 6.64 | 6.64 | 8.29 | 10.09 | 10.95 | 11.19 | 11.19 |
| 500 | 5.23 | 6.20 | 6.29 | 6.30 | 6.30 | 6.30 | 7.97 | 9.74 | 10.60 | 10.85 | 10.85 |
| 1,000 | 4.03 | 5.25 | 5.33 | 5.35 | 5.35 | 5.35 | 7.01 | 8.85 | 9.54 | 9.80 | 9.80 |
| 2,000 | 3.13 | 4.39 | 4.50 | 4.53 | 4.53 | 4.53 | 5.95 | 7.92 | 8.43 | 8.74 | 8.74 |
| 5,000 | 2.24 | 3.40 | 3.58 | 3.63 | 3.63 | 3.64 | 4.69 | 6.44 | 6.79 | 7.04 | 7.04 |
| 10,000 | 1.59 | 2.68 | 2.86 | 2.93 | 2.93 | 2.93 | 3.84 | 5.34 | 5.60 | 5.77 | 5.77 |
| 20,000 | 1.00 | 2.00 | 2.26 | 2.34 | 2.34 | 2.34 | 3.03 | 4.15 | 4.39 | 4.54 | 4.54 |
| 50,000 | 0.54 | 1.06 | 1.23 | 1.28 | 1.34 | 1.40 | 1.90 | 2.66 | 2.85 | 2.97 | 2.97 |
| 53,668 | 0.52 | 1.01 | 1.17 | 1.22 | 1.27 | 1.32 | 1.83 | 2.55 | 2.73 | 2.85 | 2.85 |

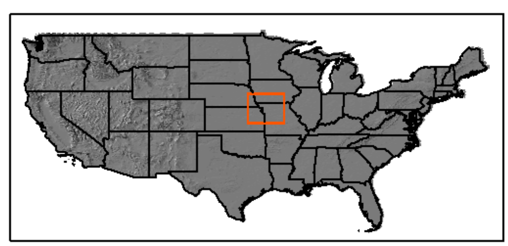



SPAS 1434 Storm Center Mass Curve Zone 1
June 18 (0700UTC) to June 24 (0600UTC), 1947
Lat: 39.4542 Lon: -94.3292
Incremental
Accumulated
17.62
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour




**Total 108-hour Precipitation (inches)**
**June 19, 1947 0000 UTC - June 23,1947 1200 UTC**
**SPAS #1434**

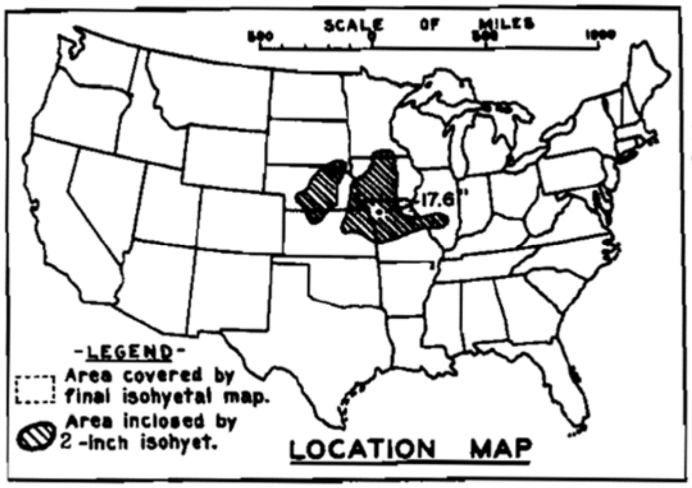


KLL 10/21/2014

DEPARTMENT OF THE ARMY | CORPS OF ENGINEERS

# STORM STUDIES - PERTINENT DATA SHEET




LOCATION MAP

**Storm of** 18-23 June 1947
**Assignment** MR 8-20
**Location** Ill, Ia, Kans, Minn. Mo, Nebr, & S.Dak.
**Study Prepared by:**
Missouri River Division
Omaha District Office

**Part I Reviewed by H. M. Sec. of Weather Bureau,** 12/17/52
**Part II Approved by Office, Chief of Engineers for Distribution of Factual Data,** 9/10/54
**Remarks:**

Center near Holt, Mo.
Dewpoint 75°, Ref. Pt. 140 S

## DATA AND COMPUTATIONS COMPILED

Grid E-14

### PART I

Preliminary isohyetal map, in sheet , scale
Precipitation data and mass curves: (Number of Sheets)
- Form 5001-C (Hourly precip. data)--
- Form 5001-B (24-hour " " )--------
- Form 5001-D ( " " " " )--------
- Miscl. precip. records, meteorological data, etc.
- Form 5002 (Mass rainfall curves)------------------------

NOTE: This study was computed by the Regional Method which does not employ the Part I and Part II phases in their entirety.

### PART II

Final isohyetal maps, in 1 sheet , scale 1:100,000
Data and computation sheets:
- Form S-10 (Data from mass rainfall curves)-------------- 9
- Form S-11 (Depth-area data from isohyetal map)----------- 4
- Form S-12 (Maximum depth-duration data)---------------- 7
- Maximum duration-depth-area curves------------------- 1
- Data relating to periods of maximum rainfall-------------

### MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

| Area in Sq. Mi. | Duration of Rainfall in Hours | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 12 | 18 | 24 | 36 | 48 | 72 | 96 | 120 | | |
| Max.Station | 12.0 | 12.0 | 12.0 | 12.0 | 12.0 | 14.4 | 16.6 | 16.6 | 17.6 | | |
| 10 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 12.6 | 15.8 | 15.8 | 16.9 | | |
| 100 | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 9.3 | 12.9 | 12.9 | 14.1 | | |
| 200 | 7.1 | 7.1 | 7.1 | 7.1 | 7.1 | 8.4 | 11.9 | 11.9 | 13.0 | | |
| 500 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 7.4 | 10.6 | 10.6 | 11.6 | | |
| 1000 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 6.6 | 9.6 | 9.6 | 10.5 | | |
| 2000 | 4.9 | 4.9 | 4.9 | 4.9 | 4.9 | 5.7 | 8.4 | 8.4 | 9.3 | | |
| 5000 | 3.5 | 3.7 | 3.7 | 3.7 | 3.7 | 4.6 | 6.7 | 6.7 | 7.3 | | |
| 10000 | 2.6 | 2.9 | 3.0 | 3.0 | 3.0 | 3.7 | 5.4 | 5.4 | 5.9 | | |
| 20000 | 1.8 | 2.1 | 2.2 | 2.2 | 2.2 | 3.1 | 4.4 | 4.6 | 4.9 | | |
| 50000 | 1.2 | 1.4 | 1.5 | 1.6 | 1.8 | 2.5 | 3.2 | 3.5 | 3.8 | | |
| 100000 | 0.8 | 1.0 | 1.2 | 1.4 | 1.6 | 2.1 | 2.7 | 2.9 | 3.0 | | |
| 200000 | 0.5 | 0.7 | 0.9 | 1.1 | 1.4 | 1.7 | 2.1 | 2.2 | 2.3 | | |
| 306000 | 0.3 | 0.5 | 0.6 | 0.7 | 0.9 | 1.2 | 1.5 | 1.6 | 1.8 | | |

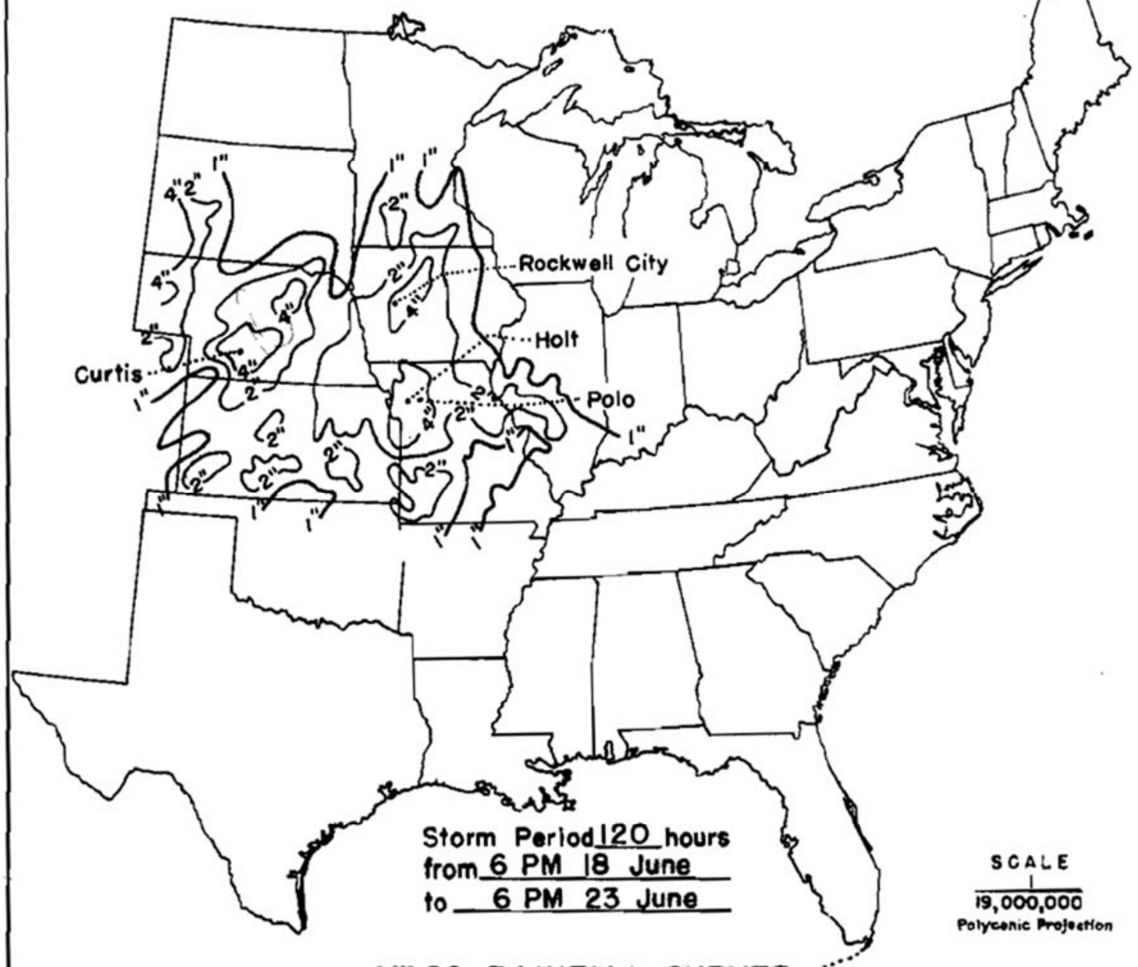
Form S-2

DEPARTMENT OF THE ARMY — CORPS OF ENGINEERS

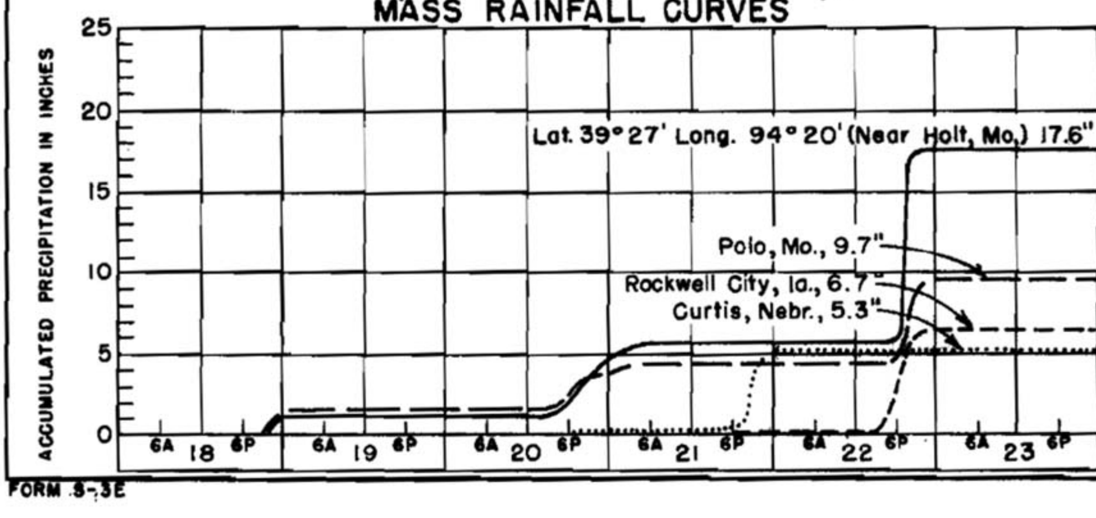
# STORM STUDIES - ISOHYETAL MAP

Storm of 18-23 June 1947 Assignment MR 8-20

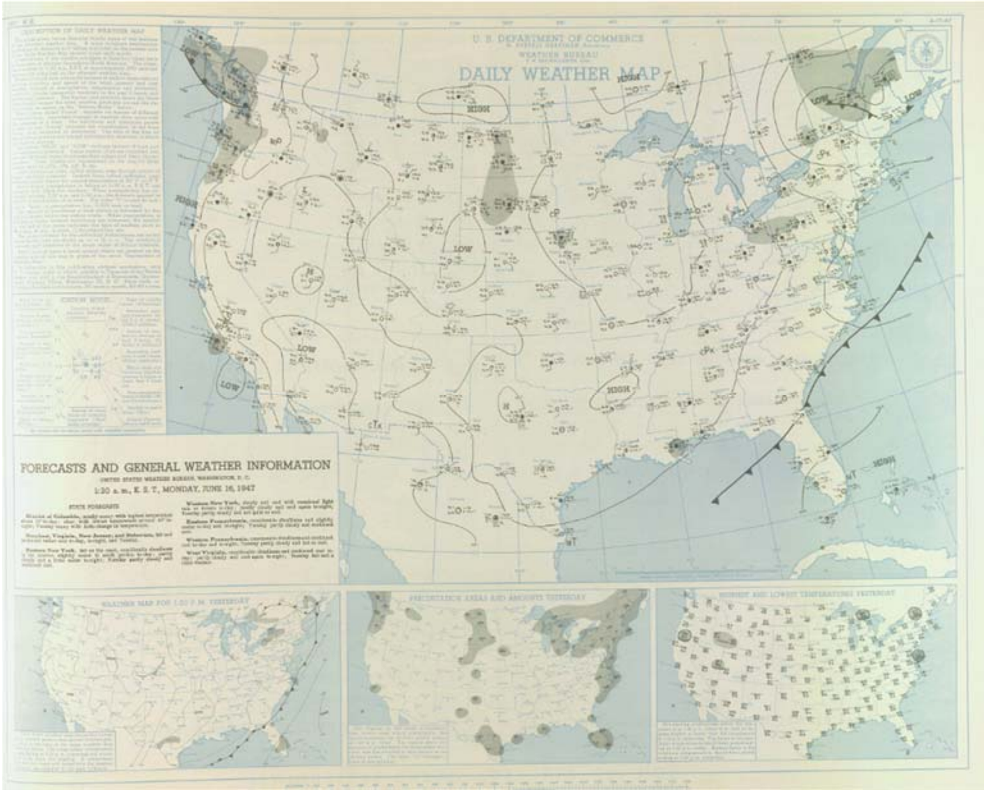
Study Prepared by: Omaha, Nebr., District
Missouri River Division

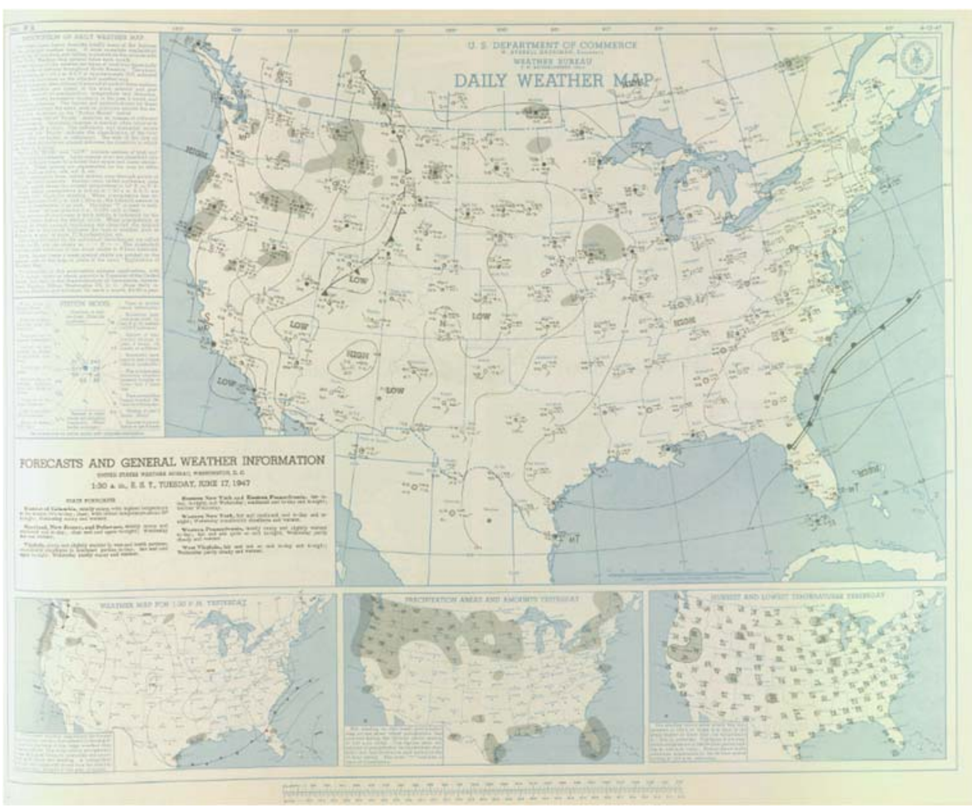


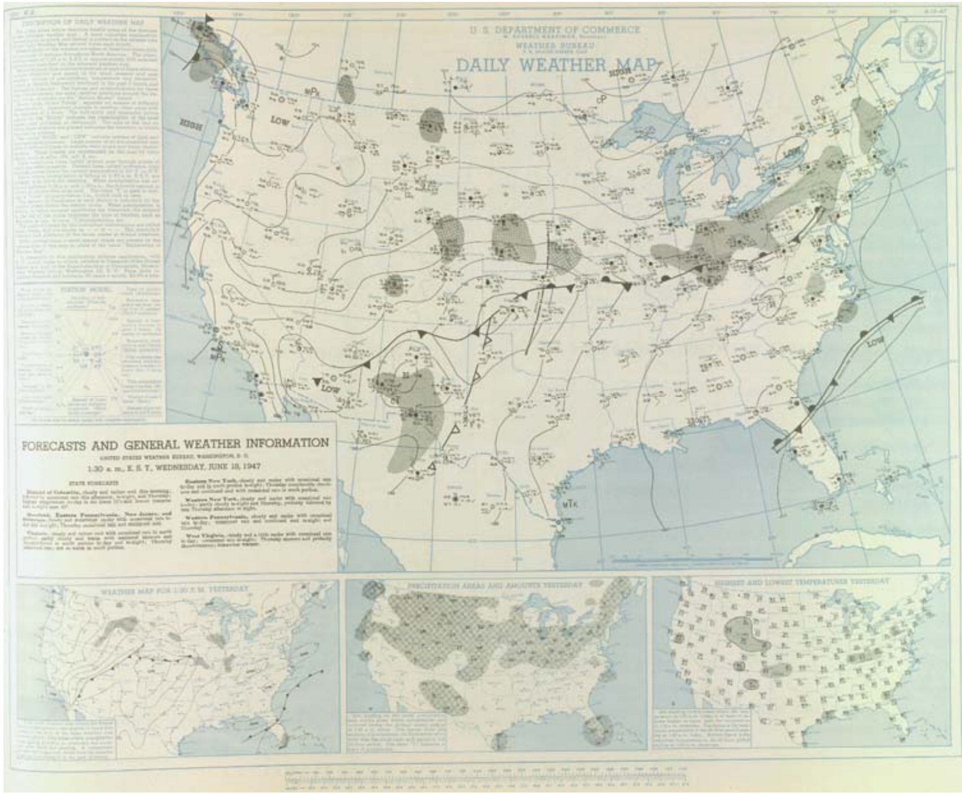

## MASS RAINFALL CURVES

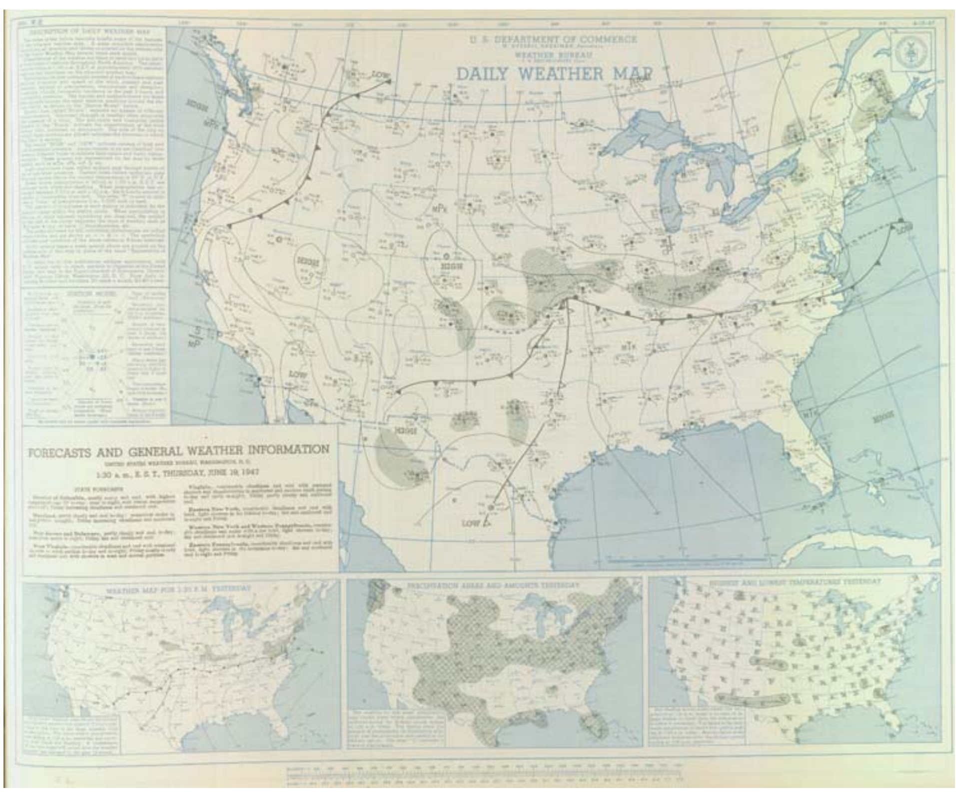


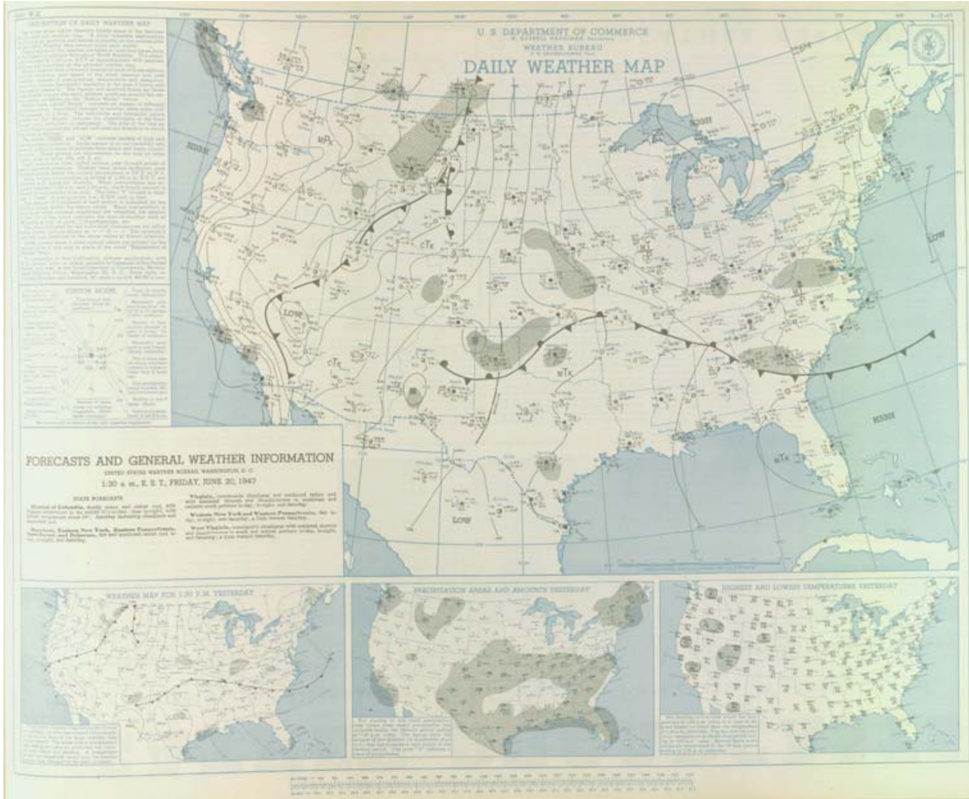

FORM S-3E

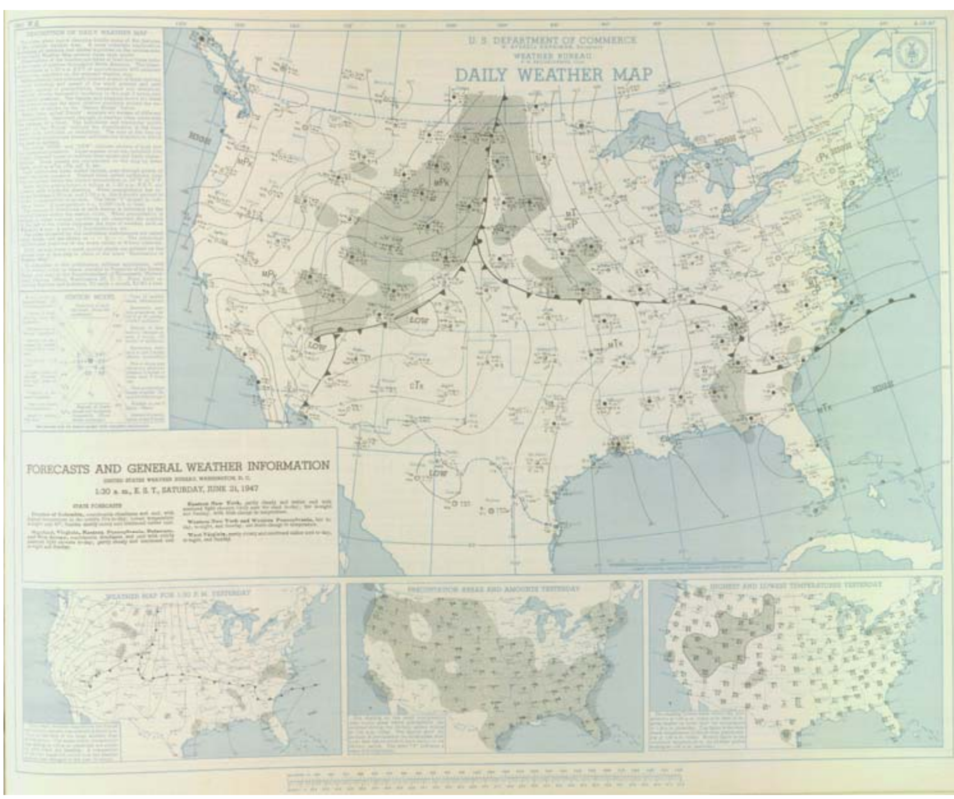

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION
1:30 a. m., E. S. T., MONDAY, JUNE 16, 1947
HIGH
LOW

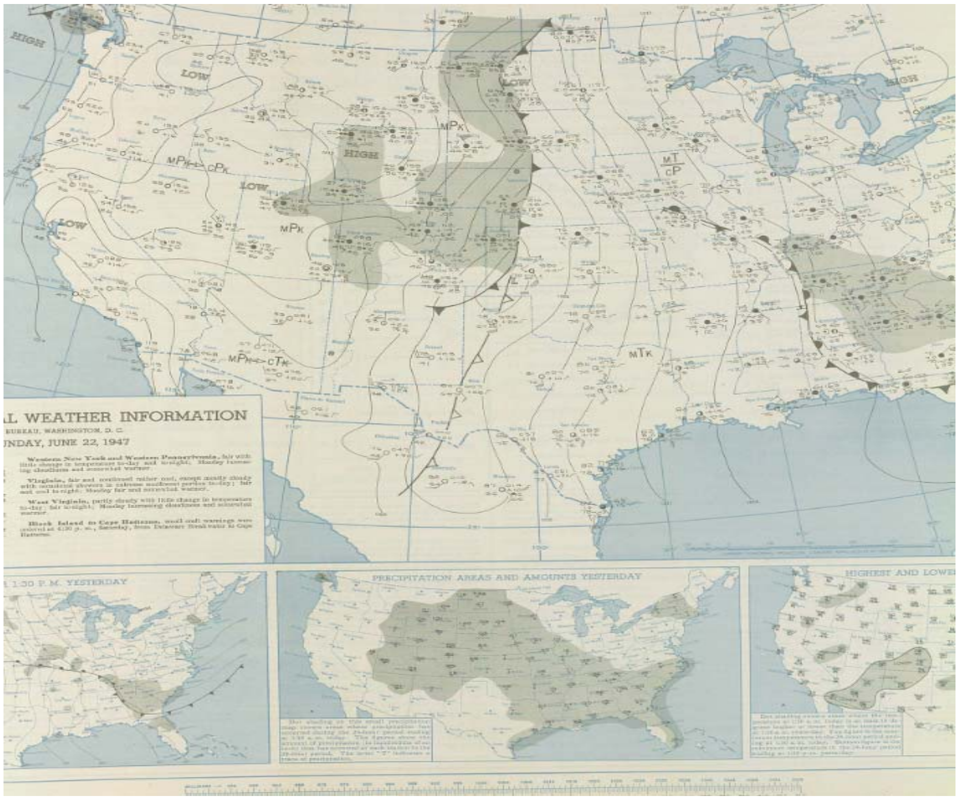

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION
1:30 a. m., E. S. T., TUESDAY, JUNE 17, 1947
HIGH
LOW

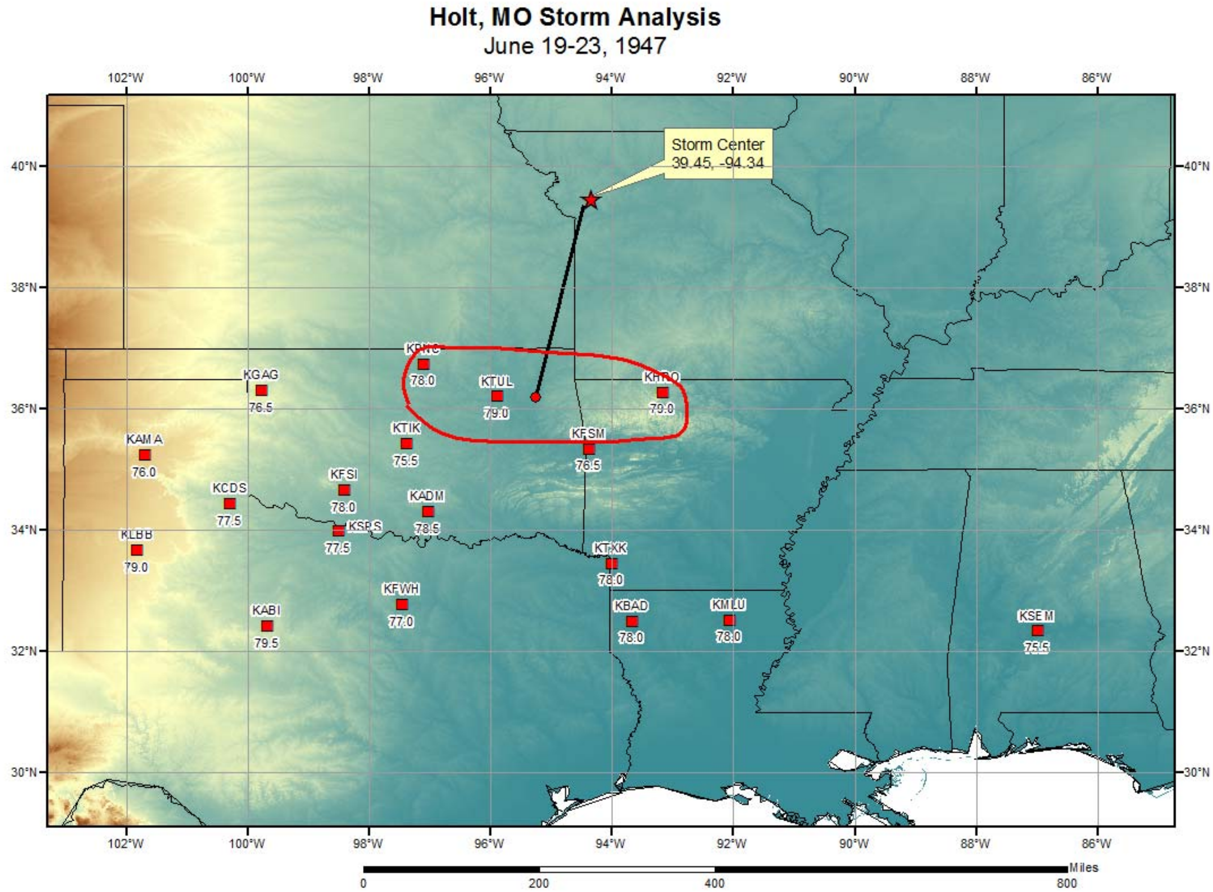

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION
1:30 a. m., E. S. T., WEDNESDAY, JUNE 18, 1947
WEATHER MAP FOR 1:30 P.M. YESTERDAY
PRECIPITATION AREAS AND AMOUNTS YESTERDAY
HIGHEST AND LOWEST TEMPERATURES YESTERDAY


U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
FORECASTS AND GENERAL WEATHER INFORMATION
1:30 a. m., E. S. T., THURSDAY, JUNE 19, 1947
WEATHER MAP FOR 1:30 P.M. YESTERDAY
PRECIPITATION AREAS AND AMOUNTS YESTERDAY
HIGHEST AND LOWEST TEMPERATURES YESTERDAY


U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
LOW
FORECASTS AND GENERAL WEATHER INFORMATION
1:30 a. m., E. S. T., FRIDAY, JUNE 20, 1947
WEATHER MAP FOR 1:30 P.M. YESTERDAY


U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
DAILY WEATHER MAP
LOW
FORECASTS AND GENERAL WEATHER INFORMATION
1:30 a. m., E. S. T., SATURDAY, JUNE 21, 1947
STATE FORECASTS


HIGH
LOW
HIGH
LOW
LOW
LOW
HIGH
mPk
mT
cP
mTk
L WEATHER INFORMATION
BUREAU, WASHINGTON, D. C.
UNDAY, JUNE 22, 1947
1:30 P.M. YESTERDAY
PRECIPITATION AREAS AND AMOUNTS YESTERDAY
HIGHEST AND LOWE


Holt, MO Storm Analysis
June 19-23, 1947
Storm Center
39.45, -94.34
KPNC
78.0
KGAG
76.5
KTUL
79.0
KHRO
79.0
KAMA
76.0
KTIK
75.5
KFSM
76.5
KFSI
78.0
KCDS
77.5
KADM
78.5
KSPS
77.5
KLBB
79.0
KTXK
78.0
KFWH
77.0
KBAD
78.0
KMLU
78.0
KABI
79.5
KSEM
75.5
Miles
0
200
400
800

# Storm Precipitation Analysis System (SPAS) For Storm #1734_1 SPAS Analysis

**General Storm Location**: Thief River, MN

**Storm Dates**: May 27-31, 1949

**Event**: Local

**DAD Zone 1**

> **Latitude**: 48.1625
>
> **Longitude**: -96.2625
>
> **Max. Grid/Radar Rainfall Amount**: 9.96"
>
> **Max. Observed Rainfall Amount**: 9.59"

**Number of Stations**: 271

**SPAS Version**: 10.0

**Base Map Used:** Blend of PRISM climatology and usda basemap

**Spatial resolution:** 0.2242

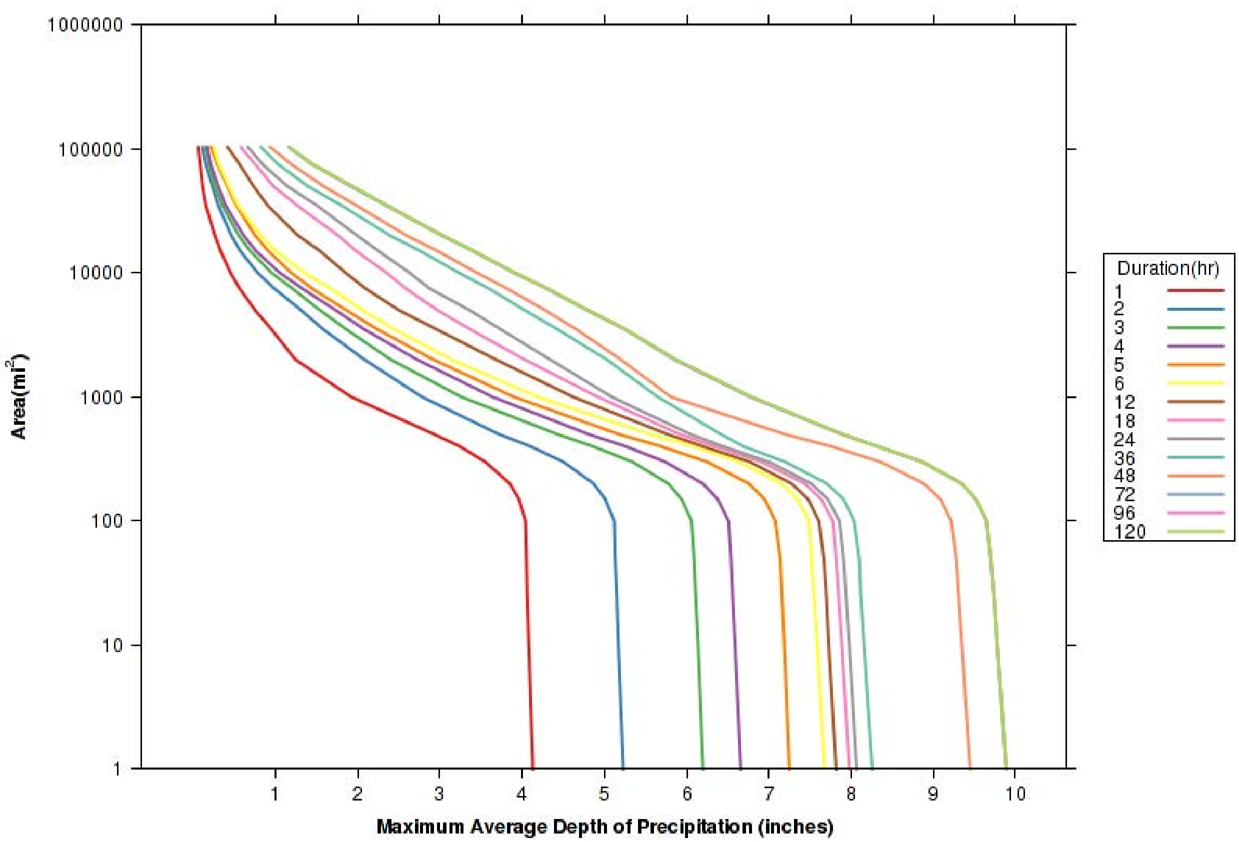
**Radar Included:** No

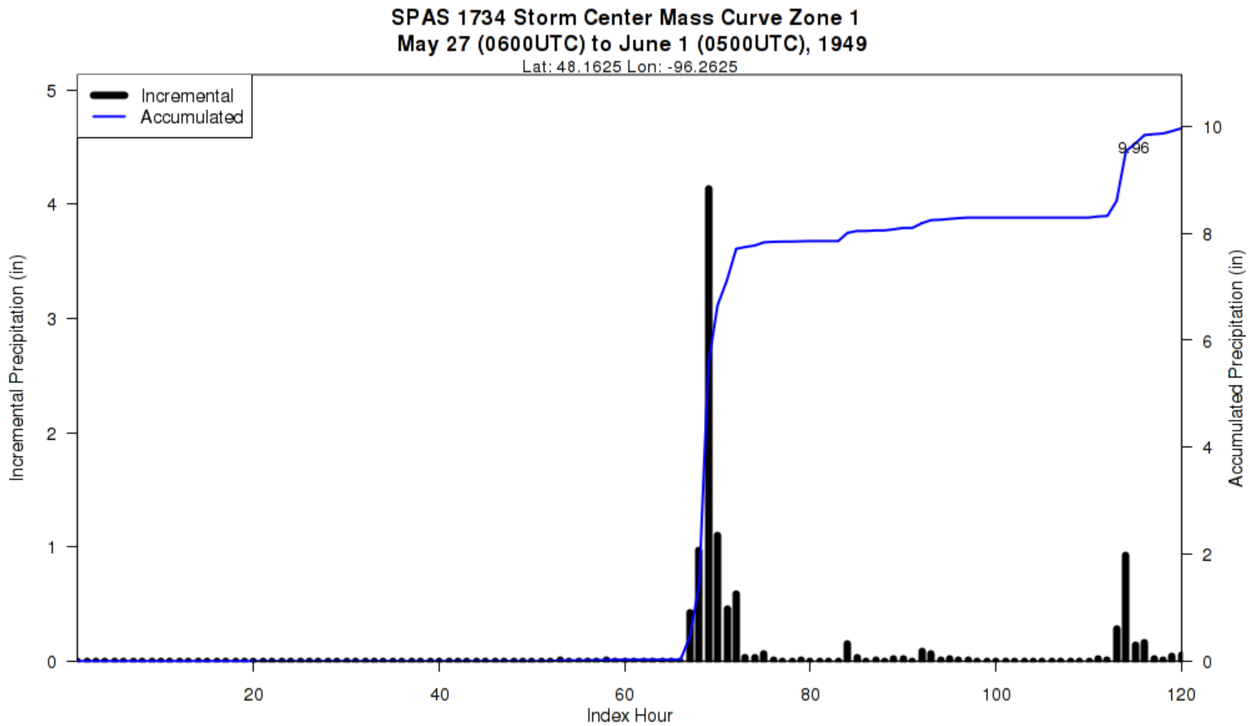
**Depth-Area-Duration (DAD) analysis**: Yes

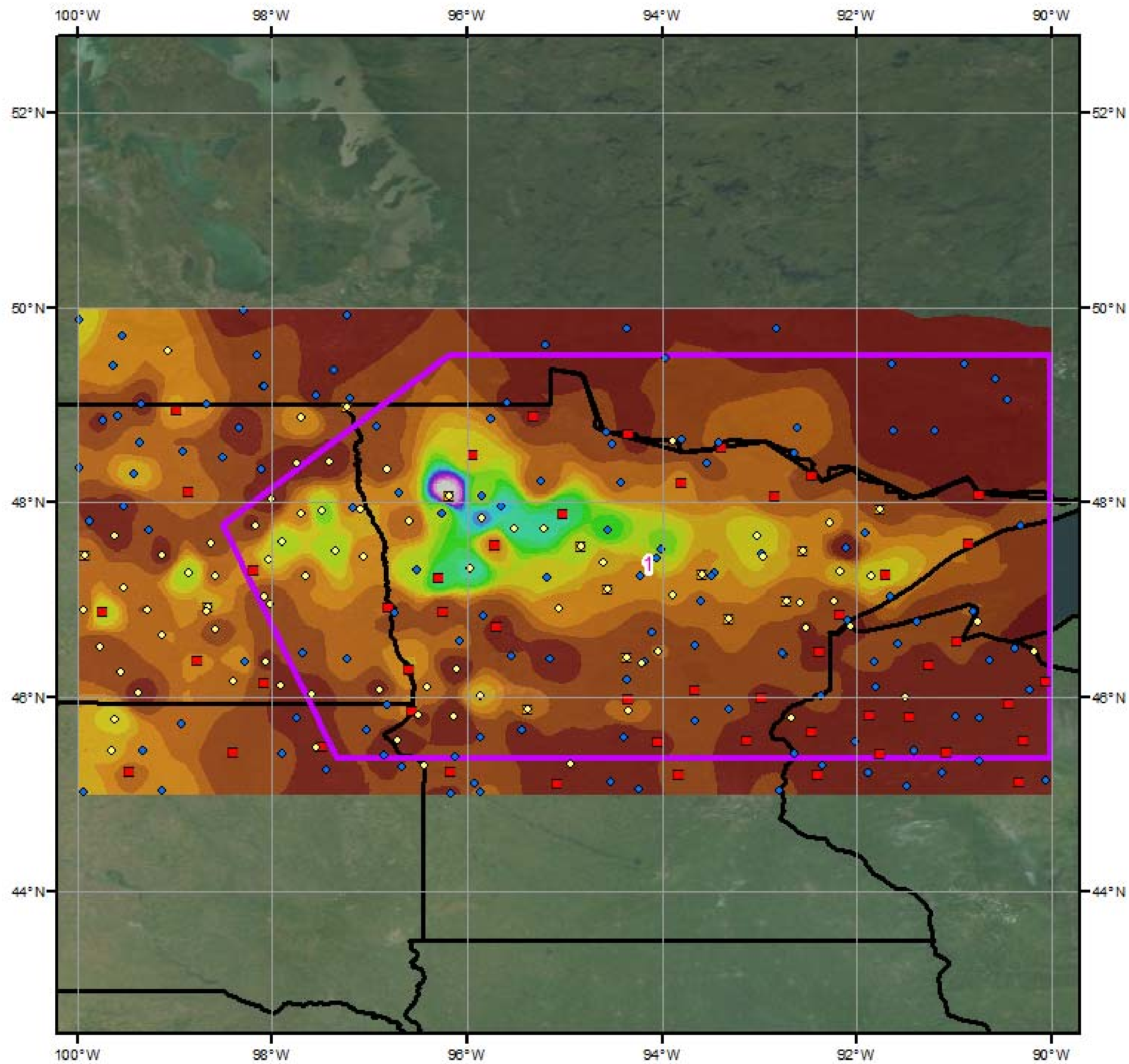
**Reliability of Results:** This analysis was based on 271 hourly stations, daily data, and supplemental station data. We have a good degree of confidence for the station based storm total results. The spatial pattern is fully dependent on the blended basemap. Timing is based on the hourly and hourly pseudo stations. Several daily stations were moved to supplemental due to timing issues and to ensure data consistency.

| Storm 1734 - May 27 (0600 UTC) - June 1 (0500 UTC), 1949 | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | | | | |
| Area ($mi^2$) | Duration (hours) | | | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | 96 | 120 | Total |
| 0.4 | 4.15 | 5.25 | 6.23 | 6.69 | 7.28 | 7.72 | 7.85 | 8.01 | 8.11 | 8.29 | 9.49 | 9.94 | 9.94 | 9.94 | 9.94 |
| 1 | 4.13 | 5.23 | 6.20 | 6.66 | 7.25 | 7.68 | 7.82 | 7.98 | 8.07 | 8.26 | 9.45 | 9.89 | 9.89 | 9.89 | 9.89 |
| 10 | 4.08 | 5.17 | 6.14 | 6.59 | 7.19 | 7.59 | 7.73 | 7.89 | 7.98 | 8.16 | 9.35 | 9.78 | 9.78 | 9.78 | 9.78 |
| 25 | 4.06 | 5.15 | 6.11 | 6.56 | 7.16 | 7.55 | 7.70 | 7.85 | 7.94 | 8.12 | 9.31 | 9.74 | 9.74 | 9.74 | 9.74 |
| 50 | 4.05 | 5.13 | 6.09 | 6.54 | 7.14 | 7.52 | 7.67 | 7.82 | 7.91 | 8.10 | 9.28 | 9.70 | 9.70 | 9.70 | 9.70 |
| 100 | 4.04 | 5.12 | 6.06 | 6.51 | 7.08 | 7.49 | 7.61 | 7.78 | 7.86 | 8.04 | 9.22 | 9.65 | 9.65 | 9.65 | 9.65 |
| 200 | 3.85 | 4.87 | 5.78 | 6.20 | 6.76 | 7.16 | 7.28 | 7.44 | 7.52 | 7.71 | 8.89 | 9.35 | 9.35 | 9.35 | 9.35 |
| 300 | 3.55 | 4.50 | 5.34 | 5.74 | 6.25 | 6.64 | 6.77 | 6.91 | 7.00 | 7.20 | 8.36 | 8.87 | 8.87 | 8.87 | 8.87 |
| 400 | 3.24 | 4.10 | 4.86 | 5.26 | 5.69 | 6.09 | 6.20 | 6.34 | 6.44 | 6.69 | 7.76 | 8.32 | 8.32 | 8.32 | 8.32 |
| 500 | 2.93 | 3.72 | 4.43 | 4.81 | 5.18 | 5.56 | 5.77 | 5.92 | 6.05 | 6.42 | 7.20 | 7.89 | 7.90 | 7.90 | 7.90 |
| 1,000 | 1.92 | 2.78 | 3.26 | 3.64 | 3.90 | 4.19 | 4.62 | 4.92 | 5.09 | 5.65 | 5.81 | 6.77 | 6.79 | 6.79 | 6.79 |
| 2,000 | 1.24 | 2.08 | 2.40 | 2.72 | 2.92 | 3.14 | 3.68 | 4.03 | 4.34 | 5.03 | 5.20 | 5.85 | 5.87 | 5.87 | 5.87 |
| 5,000 | 0.75 | 1.31 | 1.54 | 1.73 | 1.86 | 2.06 | 2.50 | 2.97 | 3.36 | 4.03 | 4.28 | 4.79 | 4.80 | 4.80 | 4.80 |
| 10,000 | 0.45 | 0.78 | 0.95 | 1.05 | 1.19 | 1.35 | 1.85 | 2.35 | 2.63 | 3.23 | 3.45 | 3.90 | 3.91 | 3.91 | 3.91 |
| 20,000 | 0.26 | 0.46 | 0.55 | 0.61 | 0.75 | 0.82 | 1.27 | 1.76 | 1.99 | 2.39 | 2.59 | 3.02 | 3.03 | 3.03 | 3.03 |
| 50,000 | 0.11 | 0.23 | 0.26 | 0.30 | 0.41 | 0.43 | 0.73 | 0.97 | 1.14 | 1.39 | 1.58 | 1.91 | 1.93 | 1.93 | 1.93 |
| 100,000 | 0.06 | 0.11 | 0.15 | 0.17 | 0.22 | 0.25 | 0.43 | 0.59 | 0.68 | 0.84 | 0.96 | 1.18 | 1.19 | 1.19 | 1.19 |

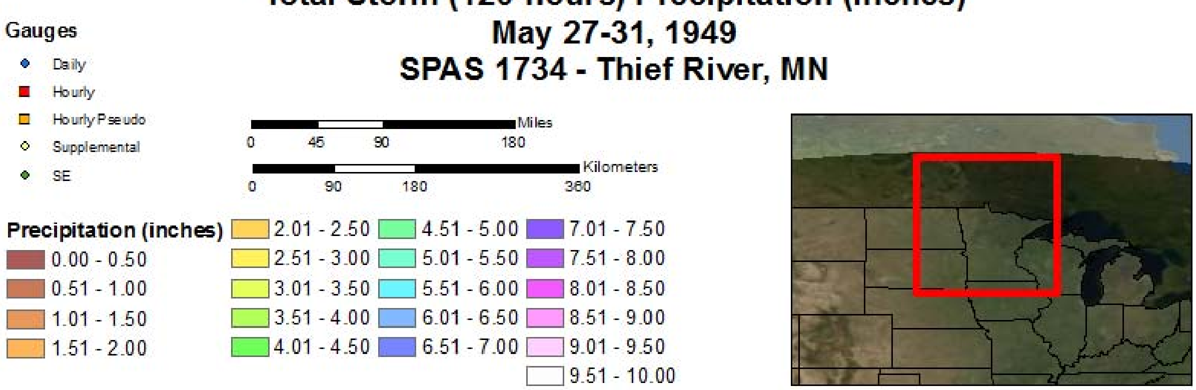
**SPAS 1734 DAD Curves Zone 1**
**May 27 (0600UTC) to June 1 (0500UTC), 1949**

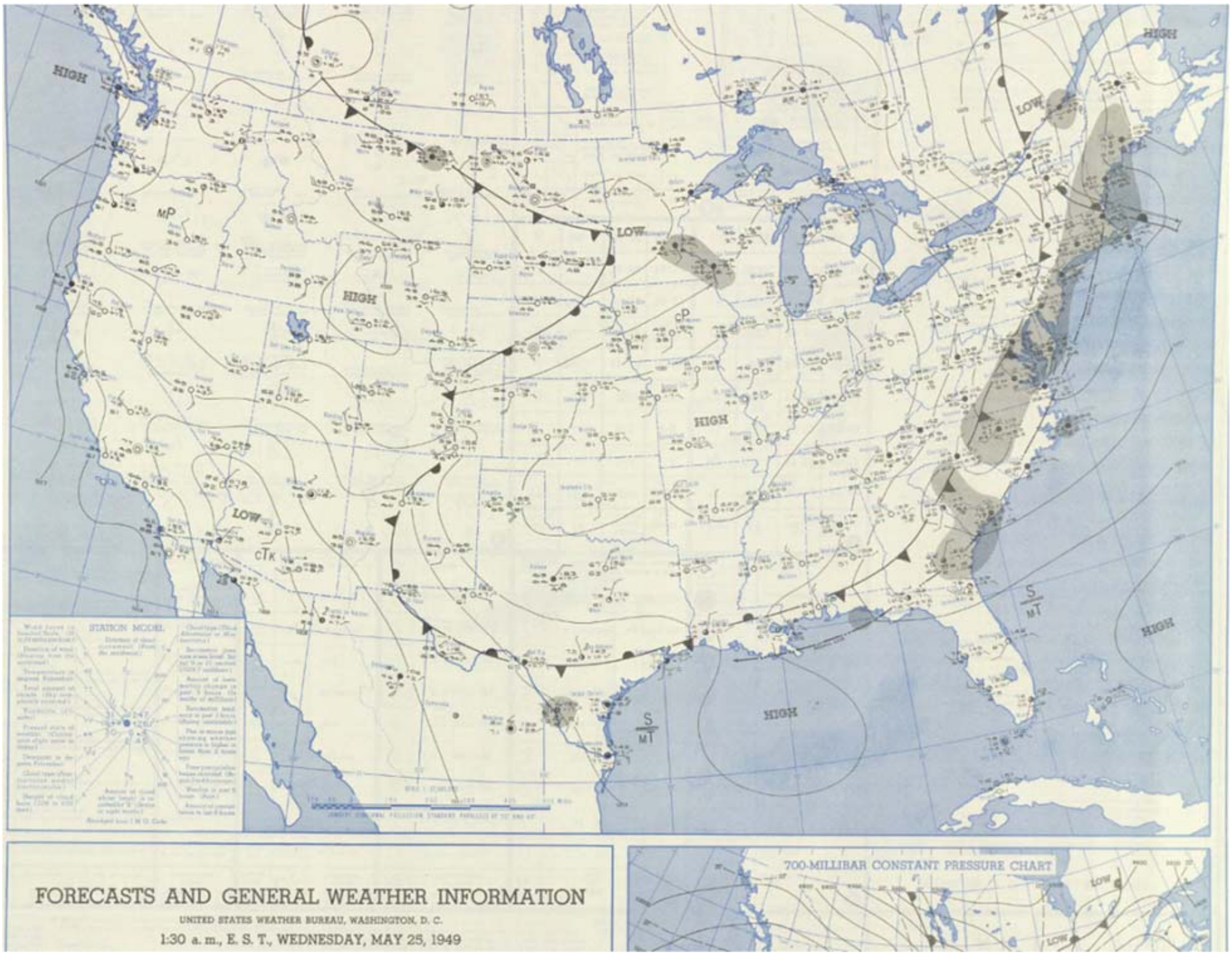


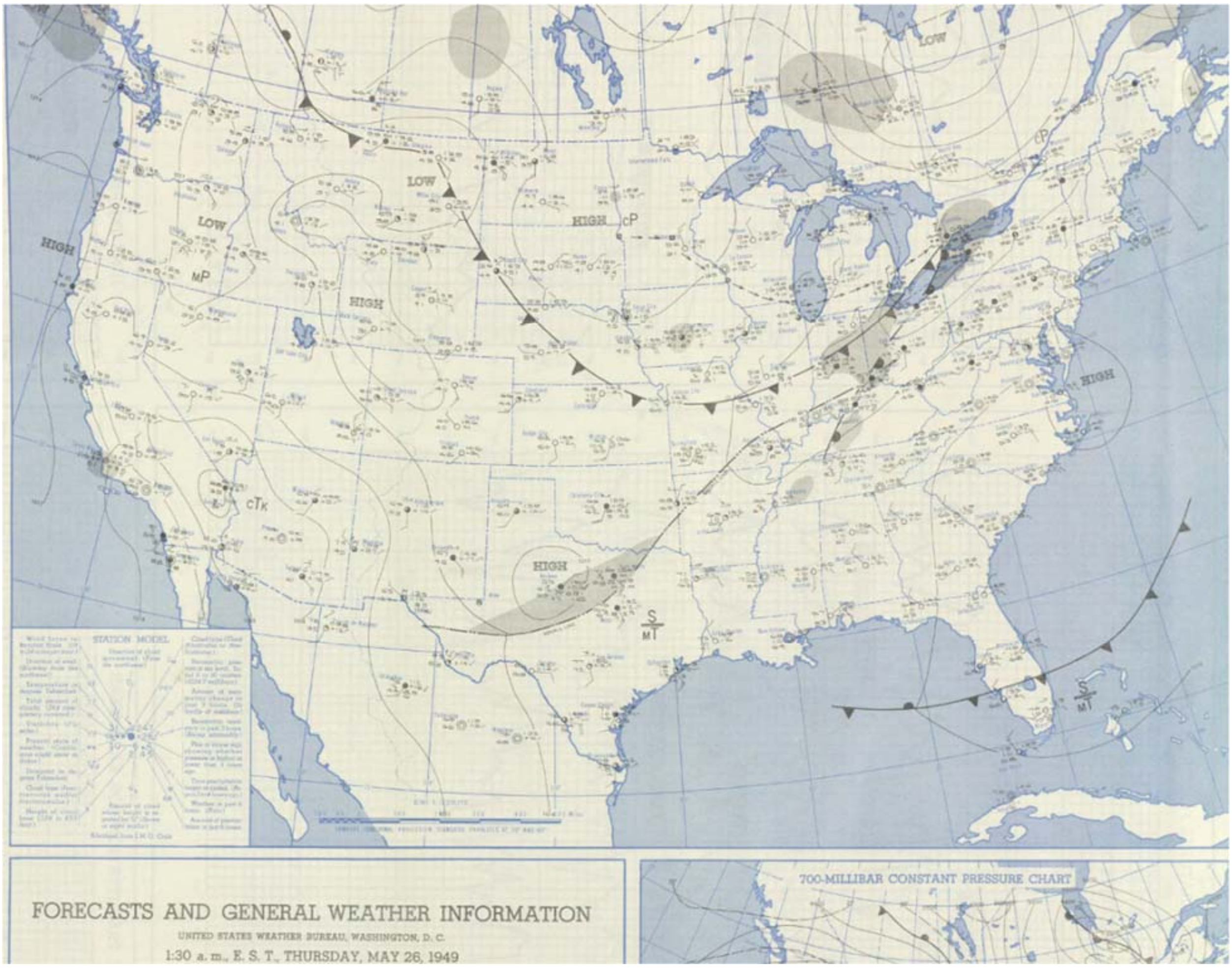

SPAS 1734 Storm Center Mass Curve Zone 1
May 27 (0600UTC) to June 1 (0500UTC), 1949
Lat: 48.1625 Lon: -96.2625
Incremental
Accumulated
9.96
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
1
2
3
4
5
0
2
4
6
8
10
20
40
60
80
100
120

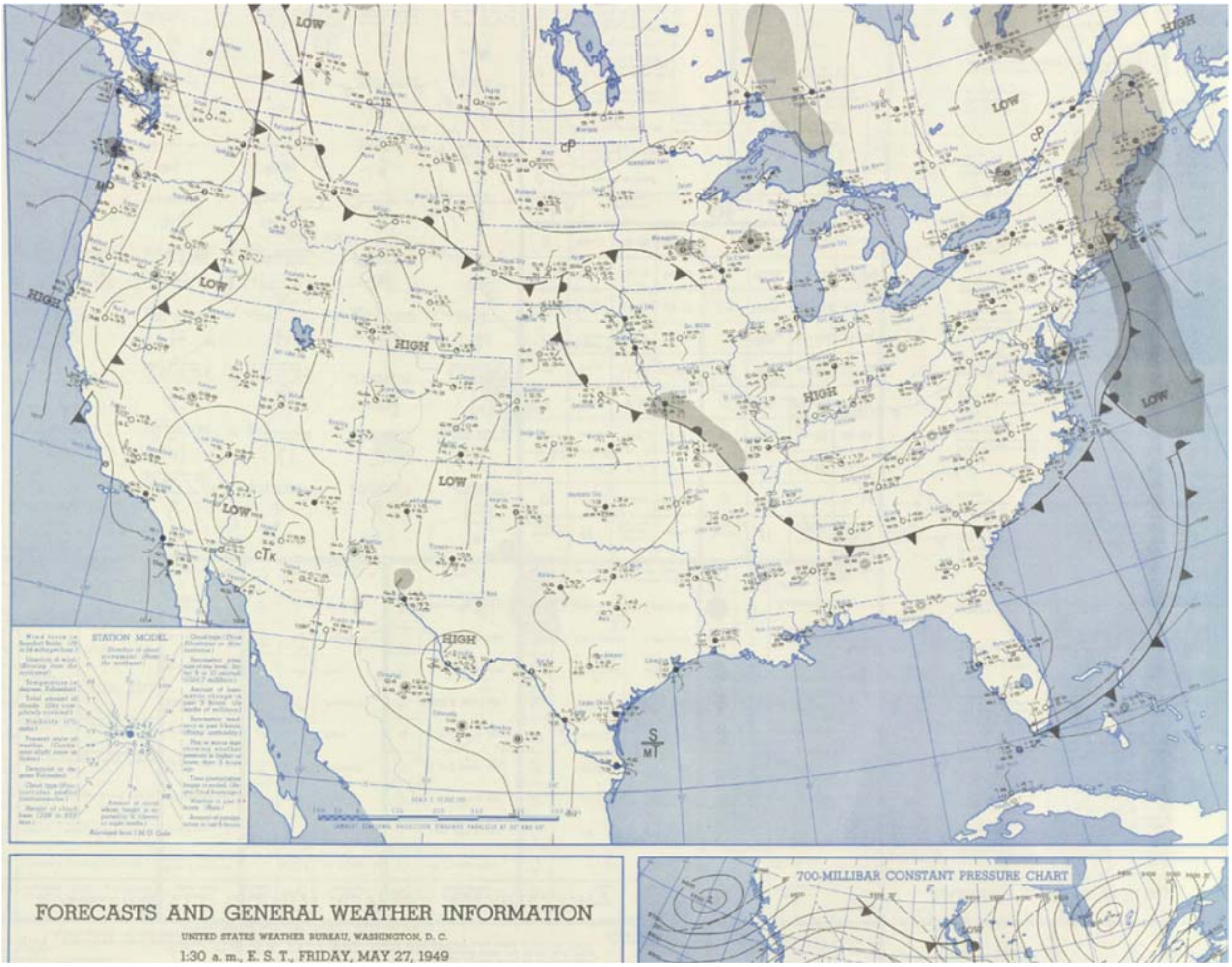


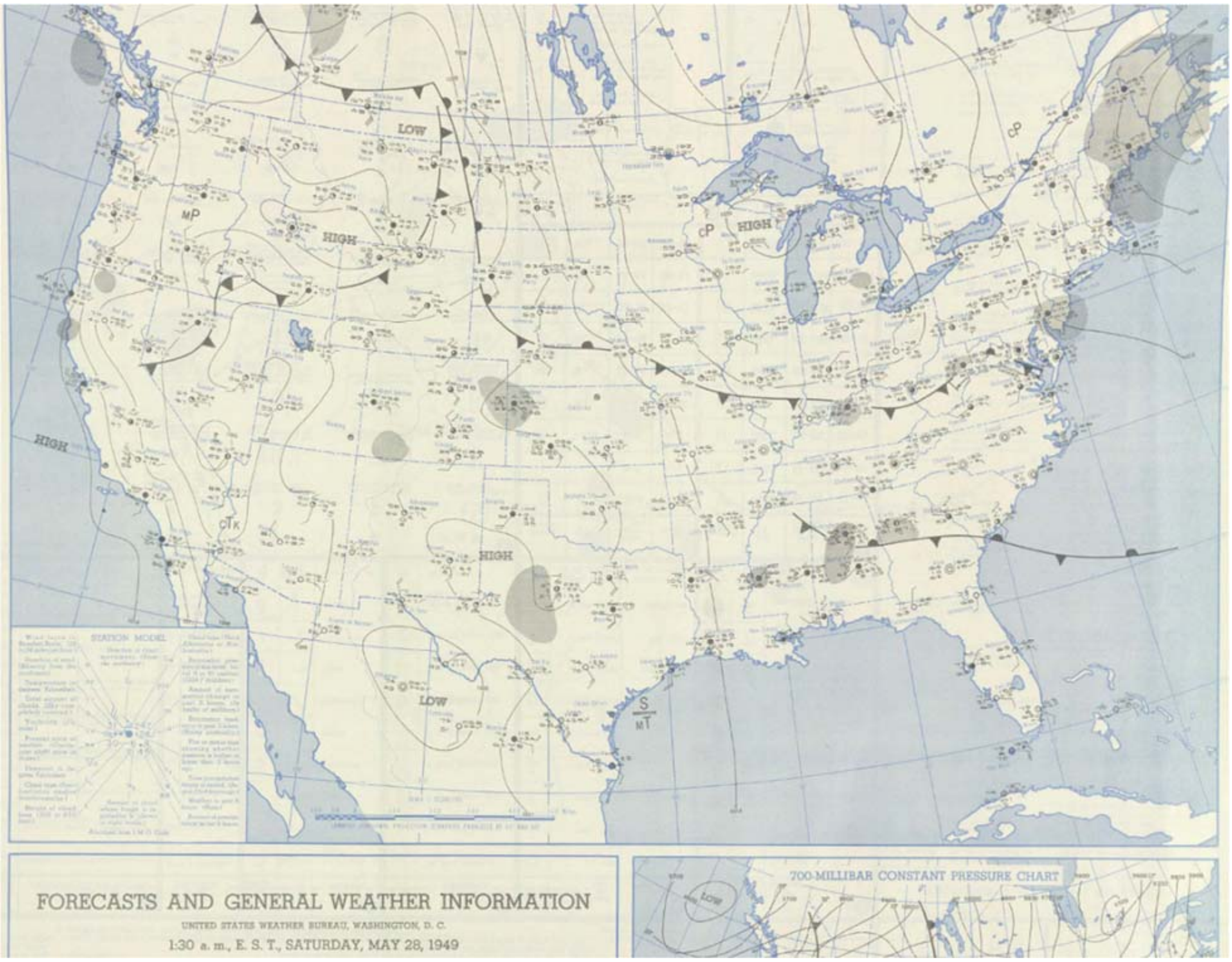

**Total Storm (120-hours) Precipitation (inches)**
**May 27-31, 1949**
**SPAS 1734 - Thief River, MN**

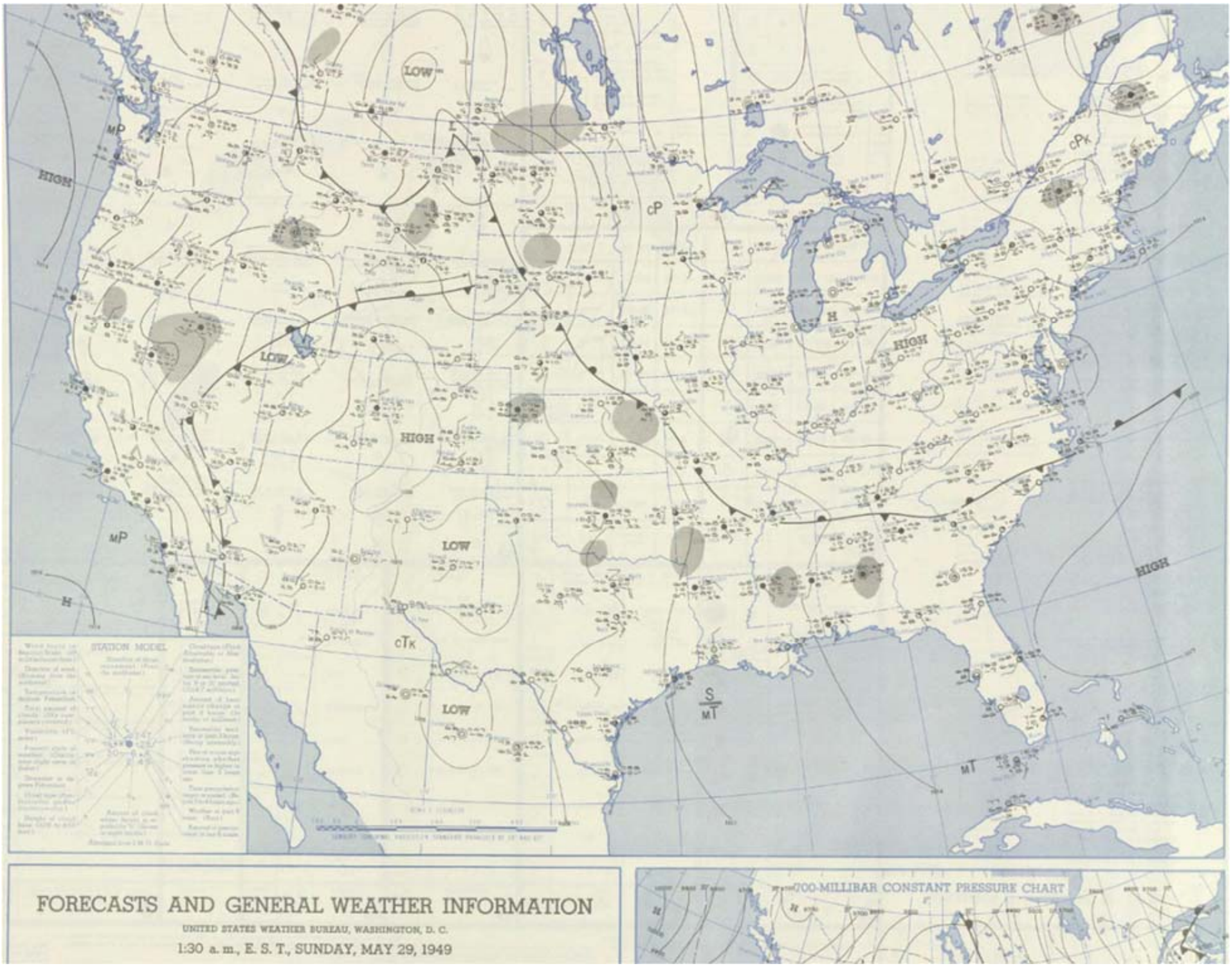


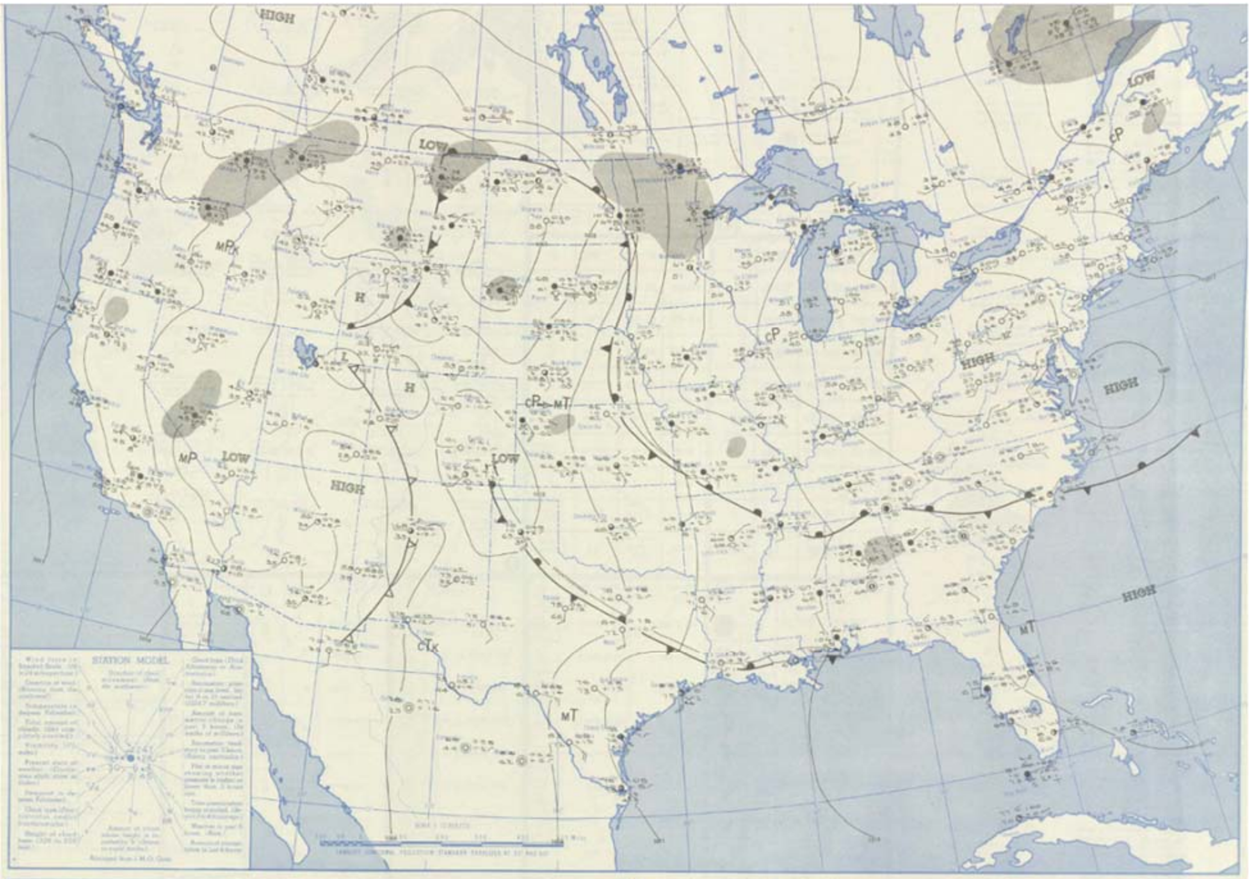

HIGH
LOW
mP
cP
cTk
S
mT
STATION MODEL
700-MILLIBAR CONSTANT PRESSURE CHART
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
1:30 a. m., E. S. T., WEDNESDAY, MAY 25, 1949


LOW
HIGH
cP
LOW
HIGH
LOW
mP
HIGH
cTk
HIGH
HIGH
S
mT
S
mT
STATION MODEL
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
1:30 a.m., E. S. T., THURSDAY, MAY 26, 1949
700-MILLIBAR CONSTANT PRESSURE CHART


LOW
HIGH
LOW
cP
LOW
HIGH
LOW
HIGH
HIGH
LOW
LOW
LOW
cTK
HIGH
STATION MODEL
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
1:30 a. m., E. S. T., FRIDAY, MAY 27, 1949
700-MILLIBAR CONSTANT PRESSURE CHART


LOW
HIGH
mP
cP
HIGH
HIGH
cP
cTK
HIGH
LOW
S
mT
STATION MODEL
700-MILLIBAR CONSTANT PRESSURE CHART
LOW
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
1:30 a. m., E. S. T., SATURDAY, MAY 28, 1949

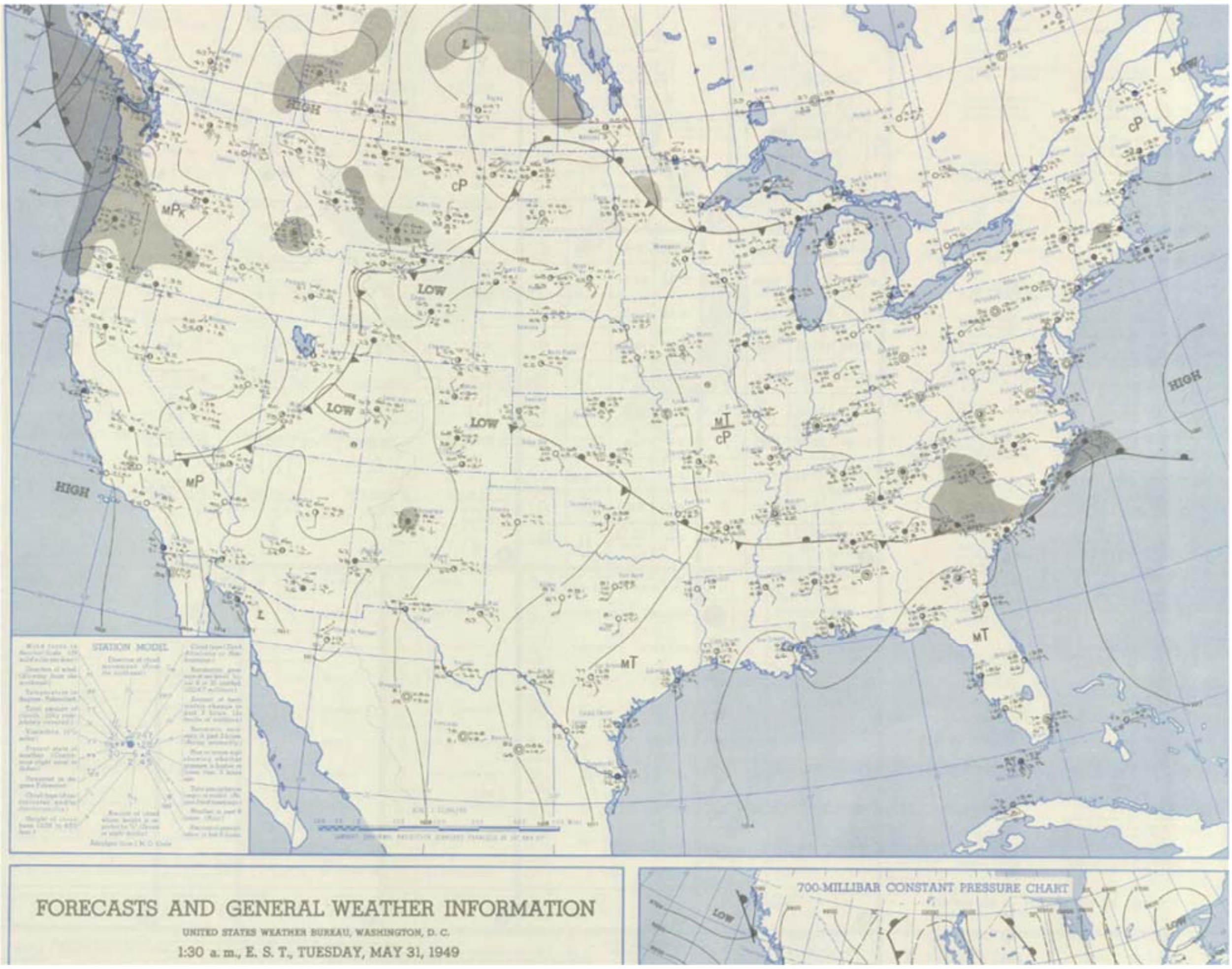

LOW
HIGH
mP
cP
cPK
H
LOW
HIGH
LOW
HIGH
mP
H
STATION MODEL
LOW
cTK
LOW
S
mT
HIGH
mT
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
1:30 a. m., E. S. T., SUNDAY, MAY 29, 1949
700-MILLIBAR CONSTANT PRESSURE CHART

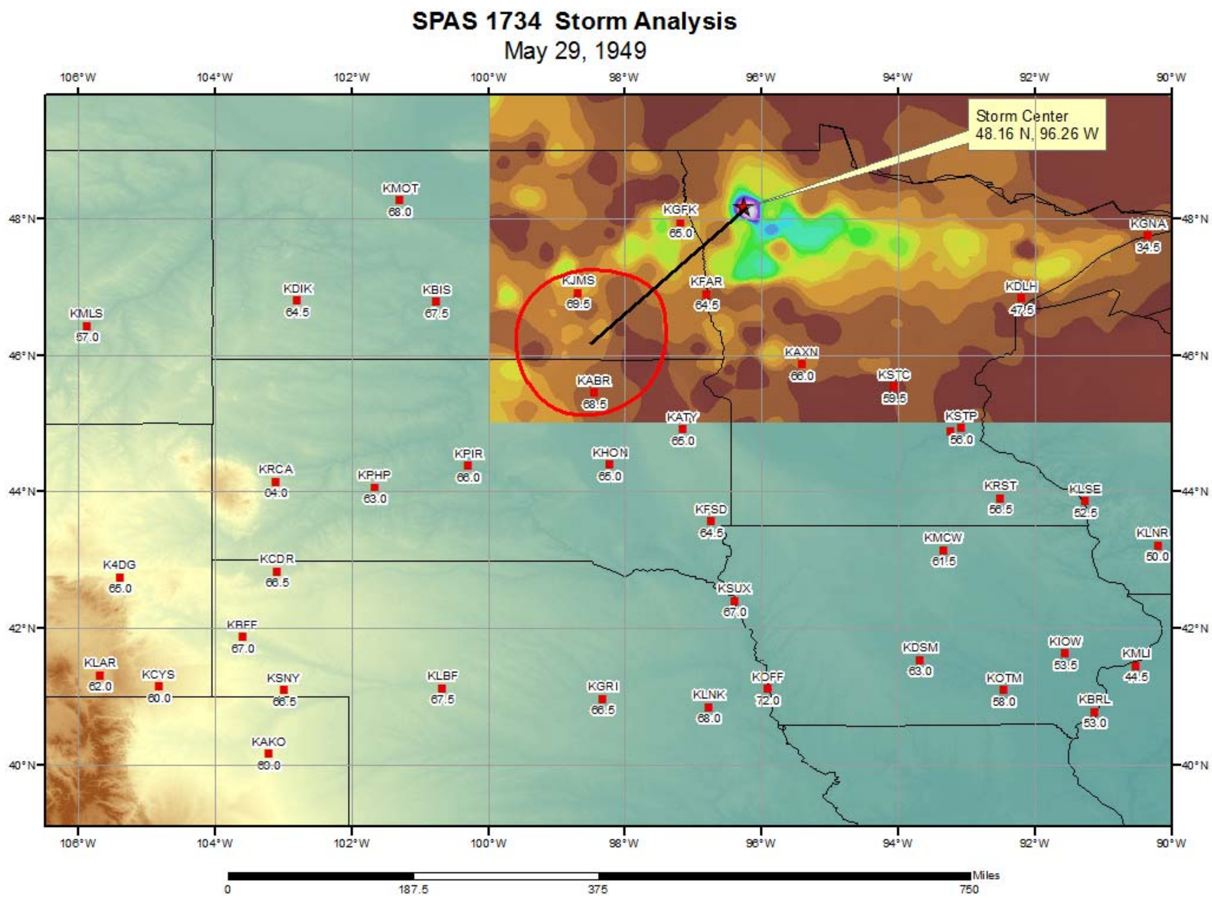



# FORECASTS AND GENERAL WEATHER INFORMATION

UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.

1:30 a. m., E. S. T., MONDAY, MAY 30, 1949


HIGH
LOW
cP
mPk
LOW
LOW
LOW
mT
cP
HIGH
HIGH
mP
L
mT
mT
LOW
cP
STATION MODEL
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
1:30 a. m., E. S. T., TUESDAY, MAY 31, 1949
700-MILLIBAR CONSTANT PRESSURE CHART
LOW
LOW


SPAS 1734 Storm Analysis
May 29, 1949
Storm Center
48.16 N, 96.26 W
KMOT
68.0
KGFK
65.0
KGNA
34.5
KJMS
69.5
KFAR
64.5
KDLH
47.5
KDIK
64.5
KBIS
67.5
KMLS
57.0
KAXN
66.0
KSTC
59.5
KABR
68.5
KATY
65.0
KSTP
58.0
KPIR
66.0
KHON
65.0
KRCA
64.0
KPHP
63.0
KRST
56.5
KLSE
52.5
KFSD
64.5
KLNR
50.0
KMCW
61.5
K4DG
65.0
KCDR
66.5
KSUX
67.0
KBFF
67.0
KIOW
53.5
KDSM
63.0
KMLI
44.5
KLAR
62.0
KCYS
60.0
KSNY
66.5
KLBF
67.5
KGRI
66.5
KLNK
68.0
KOFF
72.0
KOTM
58.0
KBRL
53.0
KAKO
60.0
106°W
104°W
102°W
100°W
98°W
96°W
94°W
92°W
90°W
48°N
46°N
44°N
42°N
40°N
Miles
0
187.5
375
750

# Storm Precipitation Analysis System (SPAS) For Storm #1030_1 SPAS Analysis

**General Storm Location**: Wahoo, NE

**Storm Dates**: June 22-24, 1963

**Event**: Thunderstorm, possibly associated with a mesoscale convective complex (MCC)

**DAD Zone 1**

**Latitude**: 41.2132

**Longitude**: -97.0710

**Rainfall Amount**: 15.98 inches

**Number of Stations**: 222

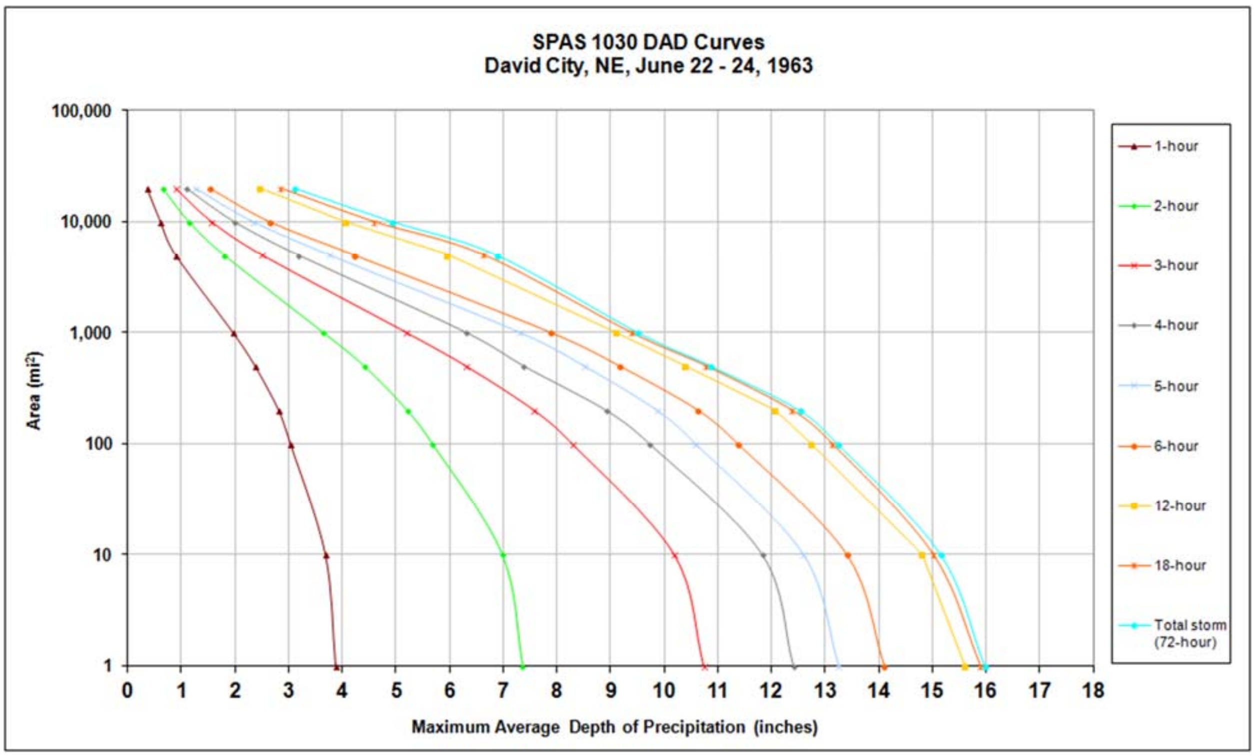
**SPAS Version**: 2.0

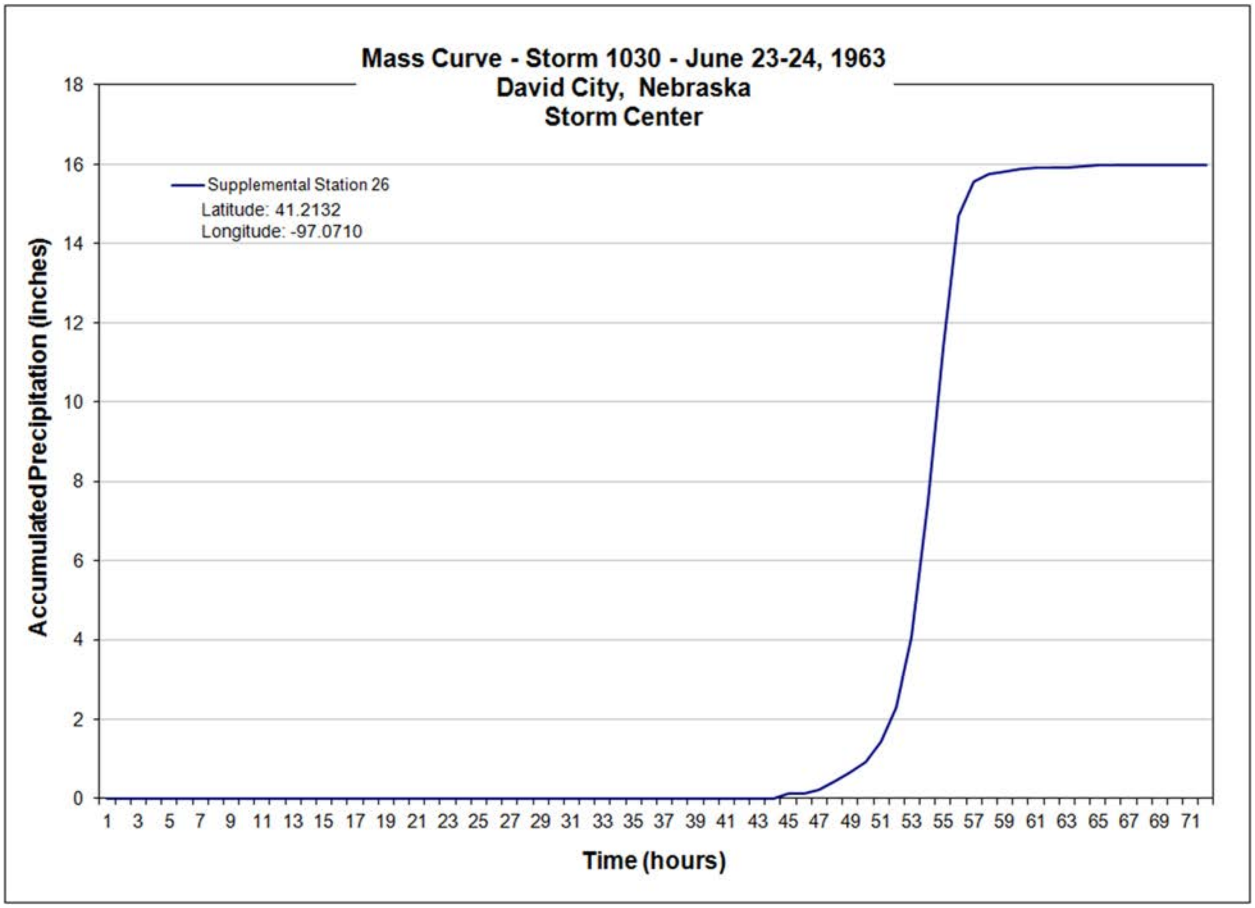
**Base Map Used:** No

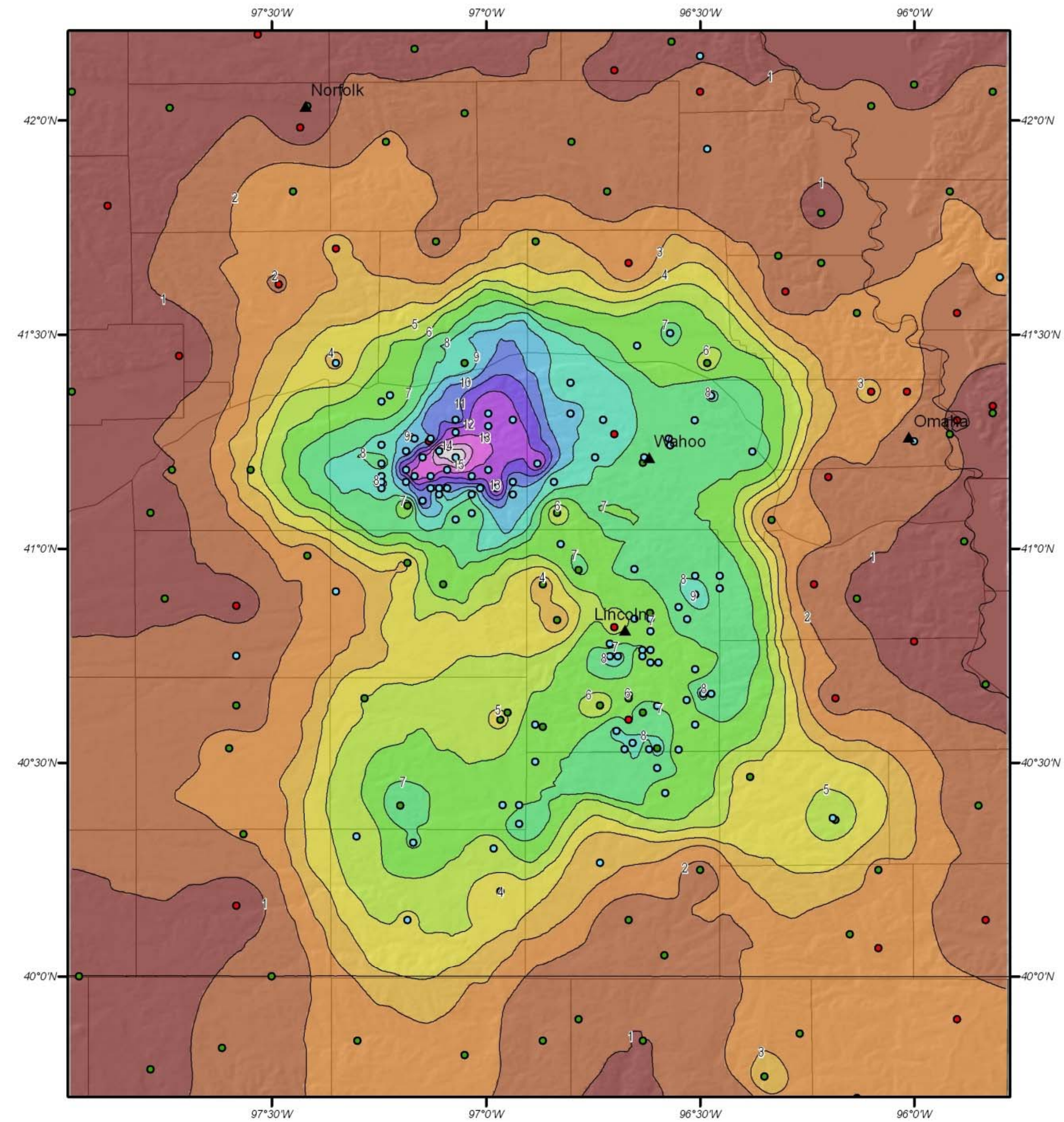
**Radar Included:** No

**Depth-Area-Duration (DAD) analysis**: Yes, 1, 2, 3, 4, 5, 6, 12, 18, 24, 36, 48, and 72 hours

| SPAS Storm 1030 - David City, NE, June 22 - 24, 1963<br>MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Duration (hours) | | | | | | | | | | | | |
| Area ($mi^2$) | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | total |
| **1** | 3.87 | 7.36 | 10.73 | 12.40 | 13.26 | 14.10 | 15.61 | 15.90 | 15.98 | 15.98 | 15.98 | 15.98 | 15.98 |
| **10** | 3.68 | 6.98 | 10.18 | 11.82 | 12.60 | 13.40 | 14.80 | 15.02 | 15.15 | 15.13 | 15.13 | 15.16 | 15.16 |
| **100** | 3.03 | 5.68 | 8.28 | 9.72 | 10.59 | 11.37 | 12.75 | 13.14 | 13.23 | 13.23 | 13.23 | 13.23 | 13.23 |
| **200** | 2.81 | 5.21 | 7.57 | 8.91 | 9.87 | 10.63 | 12.07 | 12.39 | 12.49 | 12.49 | 12.50 | 12.52 | 12.52 |
| **500** | 2.37 | 4.41 | 6.30 | 7.38 | 8.52 | 9.17 | 10.39 | 10.79 | 10.82 | 10.84 | 10.86 | 10.87 | 10.87 |
| **1,000** | 1.96 | 3.65 | 5.19 | 6.31 | 7.32 | 7.89 | 9.10 | 9.39 | 9.45 | 9.47 | 9.48 | 9.51 | 9.51 |
| **5,000** | 0.89 | 1.80 | 2.50 | 3.18 | 3.77 | 4.22 | 5.96 | 6.64 | 6.80 | 6.83 | 6.87 | 6.87 | 6.87 |
| **10,000** | 0.61 | 1.15 | 1.56 | 1.99 | 2.35 | 2.65 | 4.07 | 4.60 | 4.84 | 4.91 | 4.92 | 4.93 | 4.93 |
| **20,000** | 0.36 | 0.66 | 0.89 | 1.09 | 1.27 | 1.53 | 2.46 | 2.85 | 3.04 | 3.09 | 3.10 | 3.10 | 3.10 |




Mass Curve - Storm 1030 - June 23-24, 1963
David City, Nebraska
Storm Center
Supplemental Station 26
Latitude: 41.2132
Longitude: -97.0710
Accumulated Precipitation (inches)
Time (hours)
0
2
4
6
8
10
12
14
16
18
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71




## SPAS Storm #1030 - June 22 to 24, 1963
## Total Rainfall (72-hours) - Wahoo, Nebraska

**Precipitation (inches)**

0.05 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
14.01 - 15.00
15.01 - 16.00

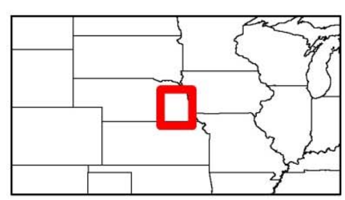
**Gauging Stations**

Daily
Hourly
Hourly Pseudo
Supplemental

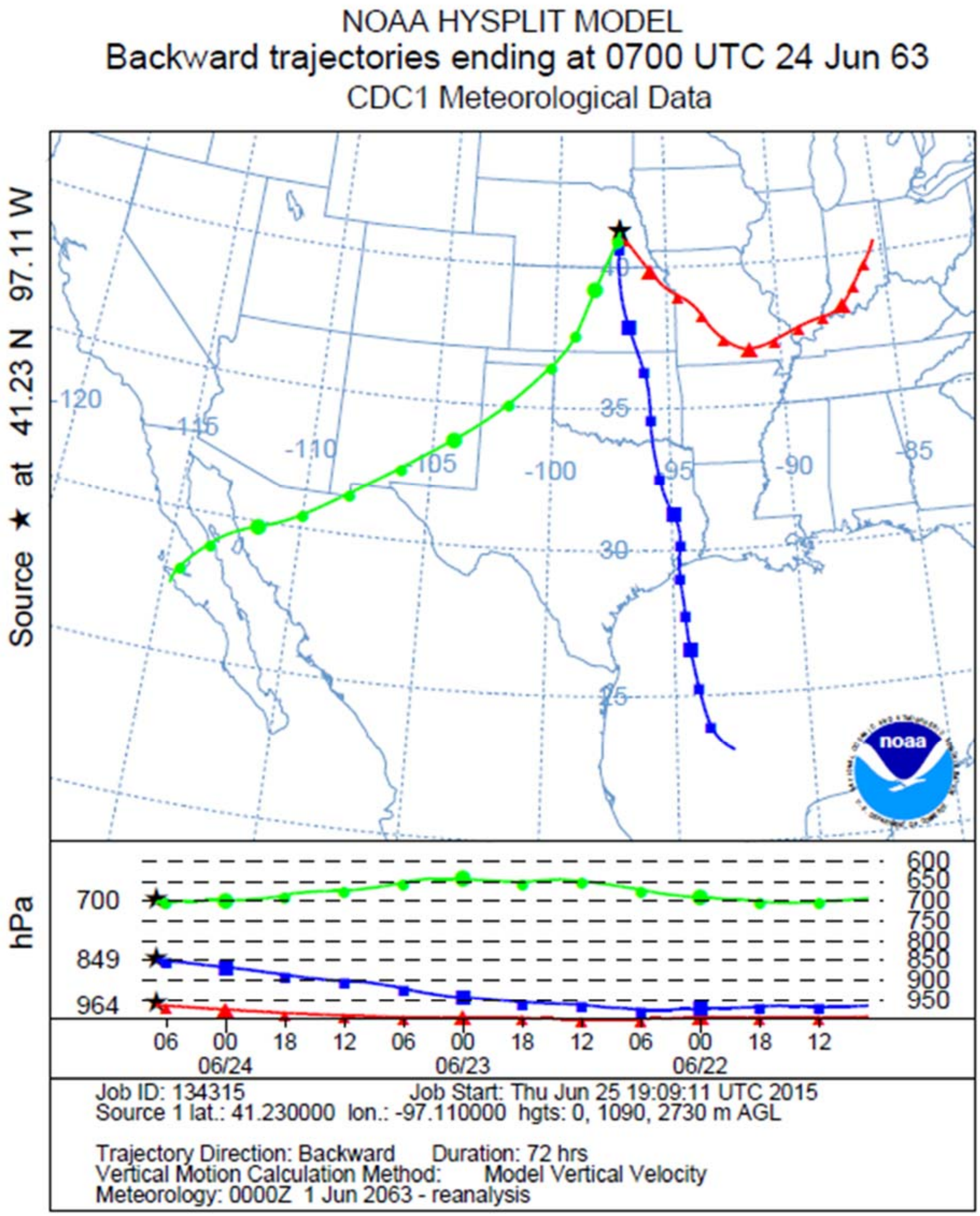
N

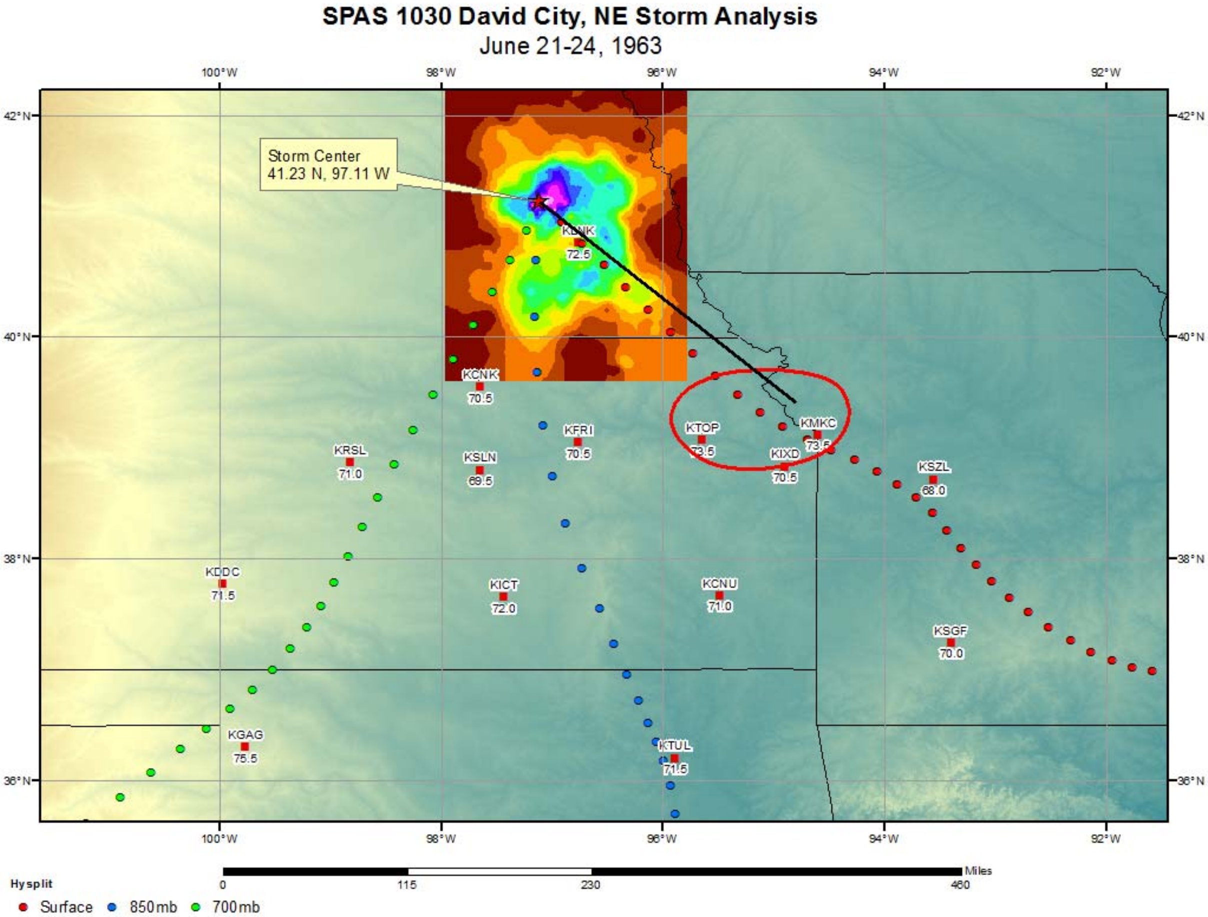
Miles: 0 5 10 20

Kilometers: 0 10 20 40 60

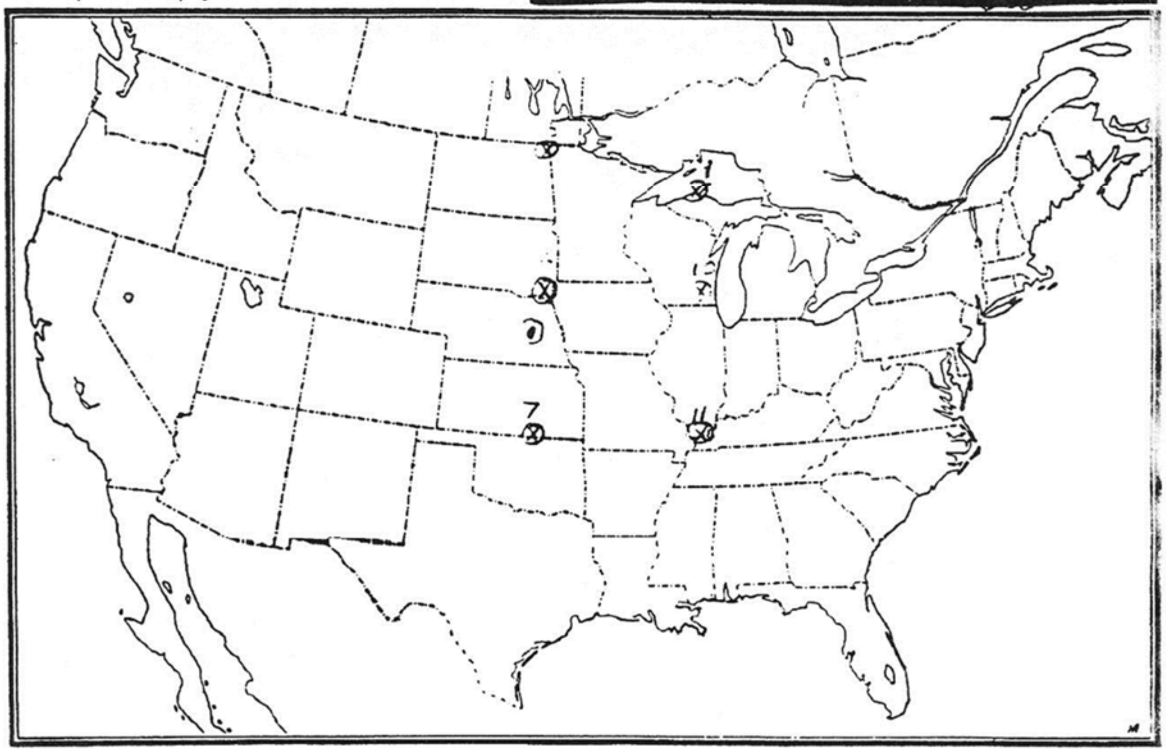


*Coordinate system: GCS North American 1983*
*Scale: 1:44,522,173* *Metstat/AWA March 1, 2007*


NOAA HYSPLIT MODEL
Backward trajectories ending at 0700 UTC 24 Jun 63
CDC1 Meteorological Data
Source ★ at 41.23 N 97.11 W
-120
-115
-110
-105
-100
-95
-90
-85
40
35
30
25
noaa
hPa
700
849
964
600
650
700
750
800
850
900
950
06 00 18 12 06 00 18 12 06 00 18 12
06/24
06/23
06/22
Job ID: 134315 Job Start: Thu Jun 25 19:09:11 UTC 2015
Source 1 lat.: 41.230000 lon.: -97.110000 hgts: 0, 1090, 2730 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jun 2063 - reanalysis


SPAS 1030 David City, NE Storm Analysis
June 21-24, 1963
Storm Center
41.23 N, 97.11 W
KLNK
72.5
KCNK
70.5
KFRI
70.5
KTOP
73.5
KMKC
73.5
KIXD
70.5
KRSL
71.0
KSLN
69.5
KSZL
68.0
KDDC
71.5
KICT
72.0
KCNU
71.0
KSGF
70.0
KGAG
75.5
KTUL
71.5
100°W
98°W
96°W
94°W
92°W
42°N
40°N
38°N
36°N
Hysplit
Surface
850mb
700mb
0
115
230
460
Miles

June 23-24, 1963 [redacted]
David City, Nebr. 41°14' 97°05'
FTd= 71°F, 790 SSW



# Storm Precipitation Analysis System (SPAS) For Storm #1226_1 SPAS Analysis

**General Storm Location**: College Hill, OH

**Storm Dates**: June 4 (0600) - June 5 (0600), 1963

**Event**: Convective

**DAD Zone 1**

**Latitude**: 40.0854

**Longitude**: -81.6479

**Max. Grid/Radar Rainfall Amount**: 19.39"

**Max. Observed Rainfall Amount**: 19.37"

**Number of Stations**: 132 (53 Daily, 15 Hourly, 6 Hourly Pseudo, 1 Hourly Estimated, 57 Supplemental)

**SPAS Version**: 9.0

**Base Map Used:** A basemap/grid was created based on USGS isohyetal.

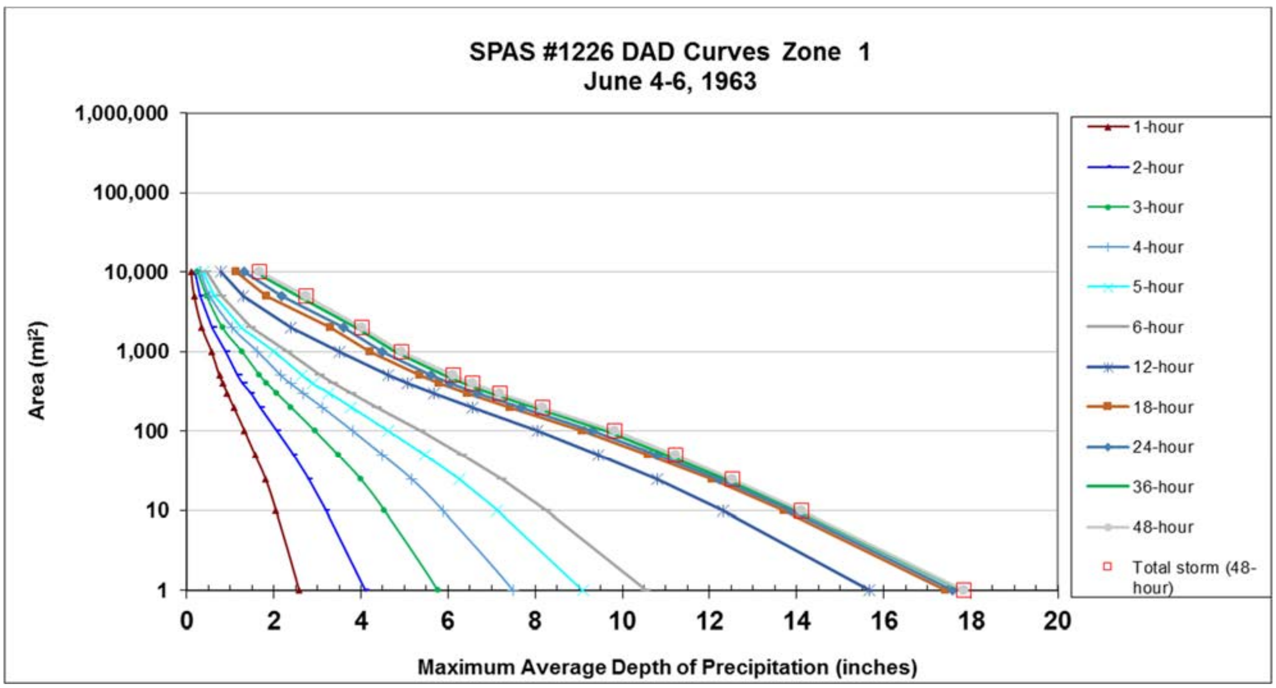
**Spatial resolution:** 15 seconds*

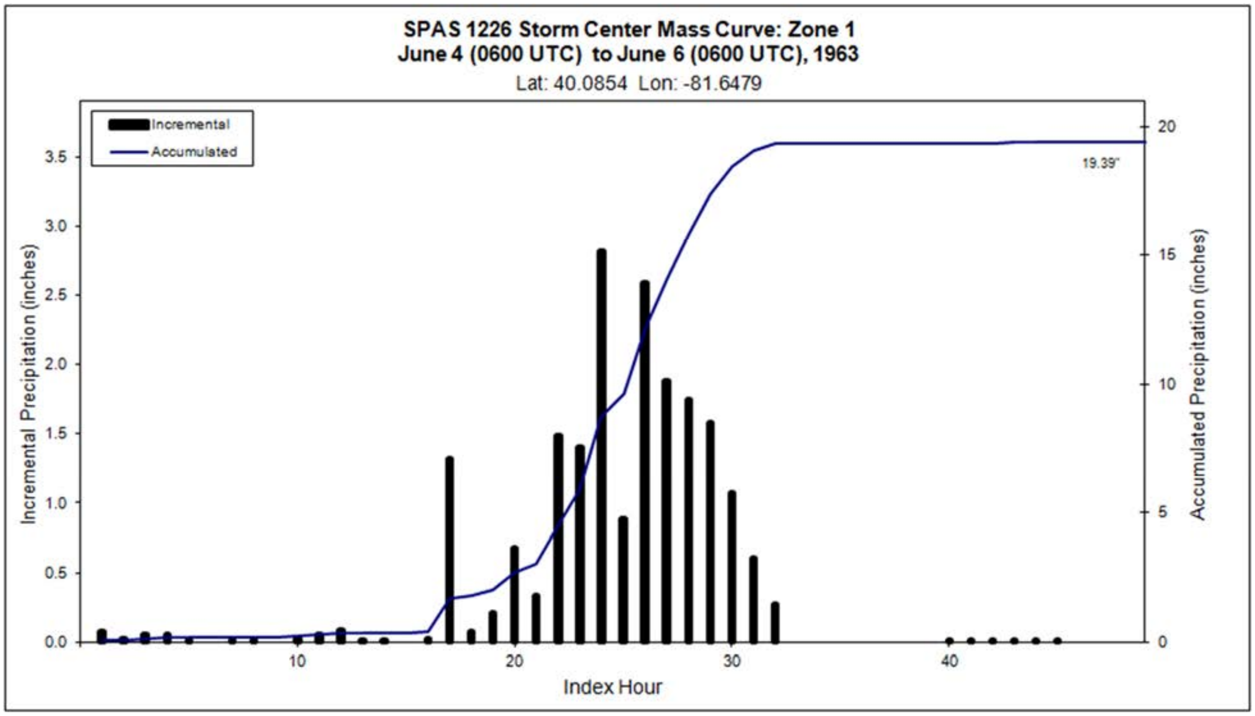
**Radar Included:** No

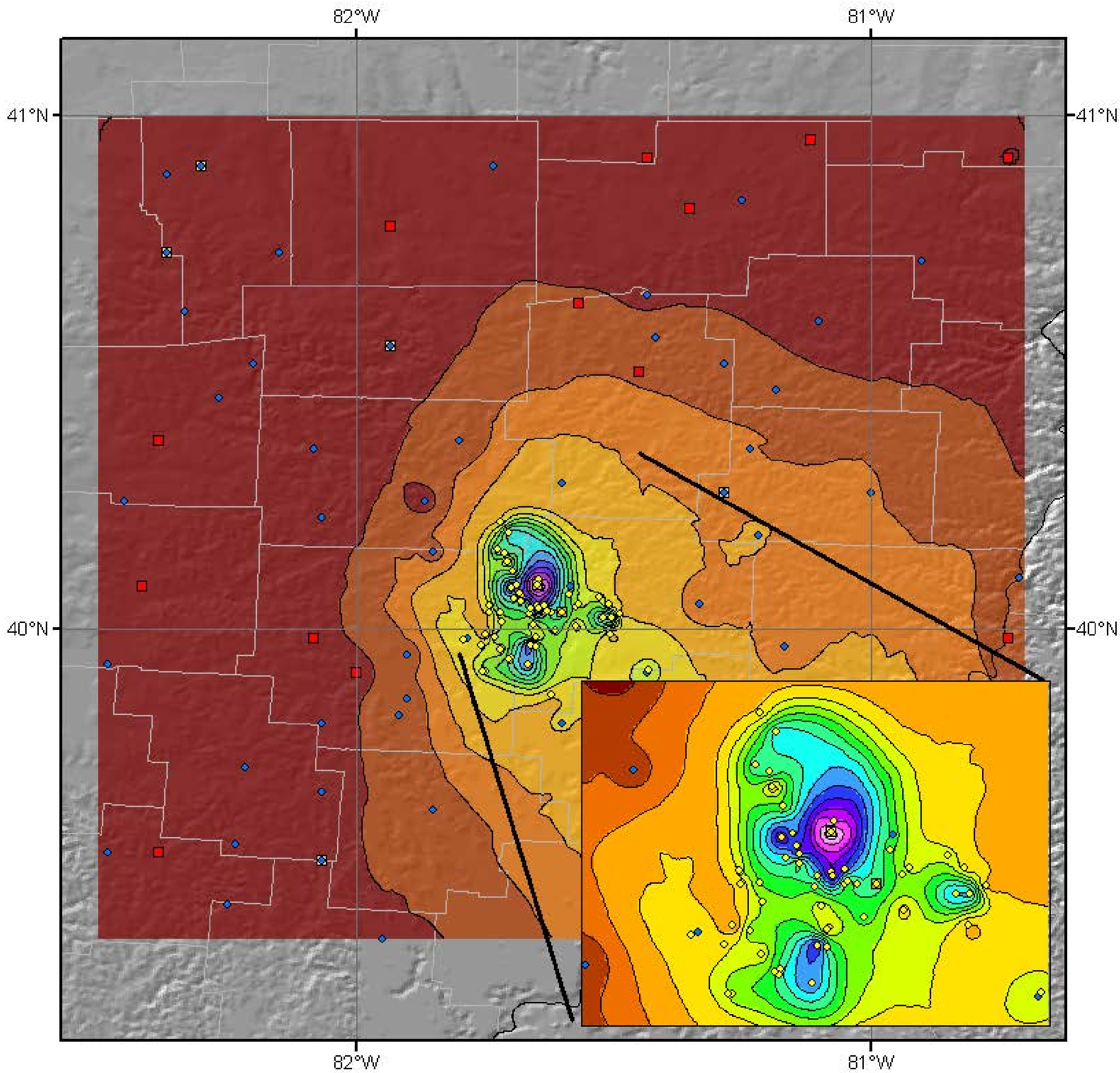
**Depth-Area-Duration (DAD) analysis**: Yes

*A higher spatial resolution (15-sec vs. 30-sec) was used in this analysis to better capture the spatial details.

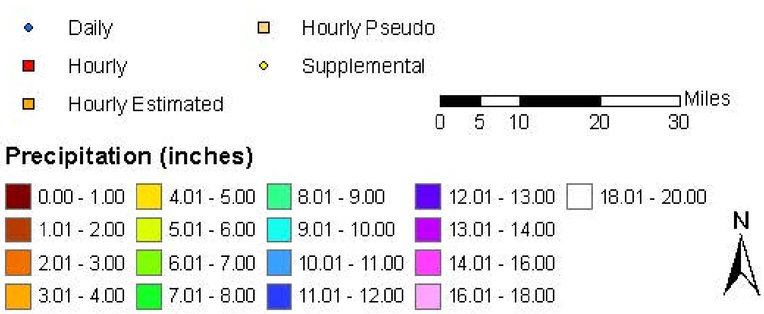
| Storm 1226 - June 4 (0600 UTC) - June 6 (0600 UTC), 1963 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | |
| Area ($mi^2$) | Duration (hours) | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 36 | 48 | Total |
| 0.4 | 2.71 | 4.30 | 6.02 | 7.86 | 9.51 | 11.06 | 16.37 | 18.20 | 18.38 | 18.58 | 18.63 | 18.63 |
| 1 | 2.58 | 4.10 | 5.76 | 7.49 | 9.10 | 10.54 | 15.67 | 17.43 | 17.59 | 17.79 | 17.83 | 17.83 |
| 10 | 2.05 | 3.19 | 4.54 | 5.88 | 7.13 | 8.26 | 12.32 | 13.72 | 13.87 | 14.04 | 14.12 | 14.12 |
| 25 | 1.81 | 2.79 | 3.99 | 5.16 | 6.25 | 7.24 | 10.81 | 12.06 | 12.22 | 12.39 | 12.53 | 12.53 |
| 50 | 1.57 | 2.44 | 3.48 | 4.50 | 5.46 | 6.33 | 9.46 | 10.59 | 10.80 | 11.02 | 11.22 | 11.22 |
| 100 | 1.33 | 2.07 | 2.95 | 3.82 | 4.64 | 5.38 | 8.05 | 9.07 | 9.31 | 9.62 | 9.83 | 9.83 |
| 200 | 1.08 | 1.69 | 2.40 | 3.11 | 3.77 | 4.38 | 6.56 | 7.43 | 7.69 | 7.99 | 8.18 | 8.18 |
| 300 | 0.93 | 1.46 | 2.07 | 2.68 | 3.26 | 3.79 | 5.68 | 6.44 | 6.68 | 6.99 | 7.20 | 7.20 |
| 400 | 0.83 | 1.29 | 1.84 | 2.38 | 2.90 | 3.37 | 5.07 | 5.80 | 6.04 | 6.36 | 6.57 | 6.57 |
| 500 | 0.75 | 1.18 | 1.68 | 2.17 | 2.65 | 3.07 | 4.63 | 5.36 | 5.61 | 5.92 | 6.13 | 6.13 |
| 1,000 | 0.57 | 0.89 | 1.27 | 1.63 | 2.00 | 2.32 | 3.51 | 4.20 | 4.49 | 4.78 | 4.94 | 4.94 |
| 2,000 | 0.35 | 0.59 | 0.82 | 1.05 | 1.26 | 1.49 | 2.39 | 3.29 | 3.60 | 3.88 | 4.02 | 4.02 |
| 5,000 | 0.17 | 0.30 | 0.46 | 0.53 | 0.64 | 0.80 | 1.30 | 1.83 | 2.18 | 2.55 | 2.73 | 2.73 |
| 10,000 | 0.10 | 0.18 | 0.25 | 0.32 | 0.38 | 0.45 | 0.78 | 1.13 | 1.31 | 1.56 | 1.66 | 1.66 |

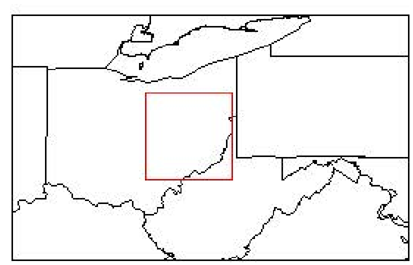



SPAS 1226 Storm Center Mass Curve: Zone 1
June 4 (0600 UTC) to June 6 (0600 UTC), 1963
Lat: 40.0854 Lon: -81.6479
Incremental
Accumulated
19.39"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
5
10
15
20
10
20
30
40

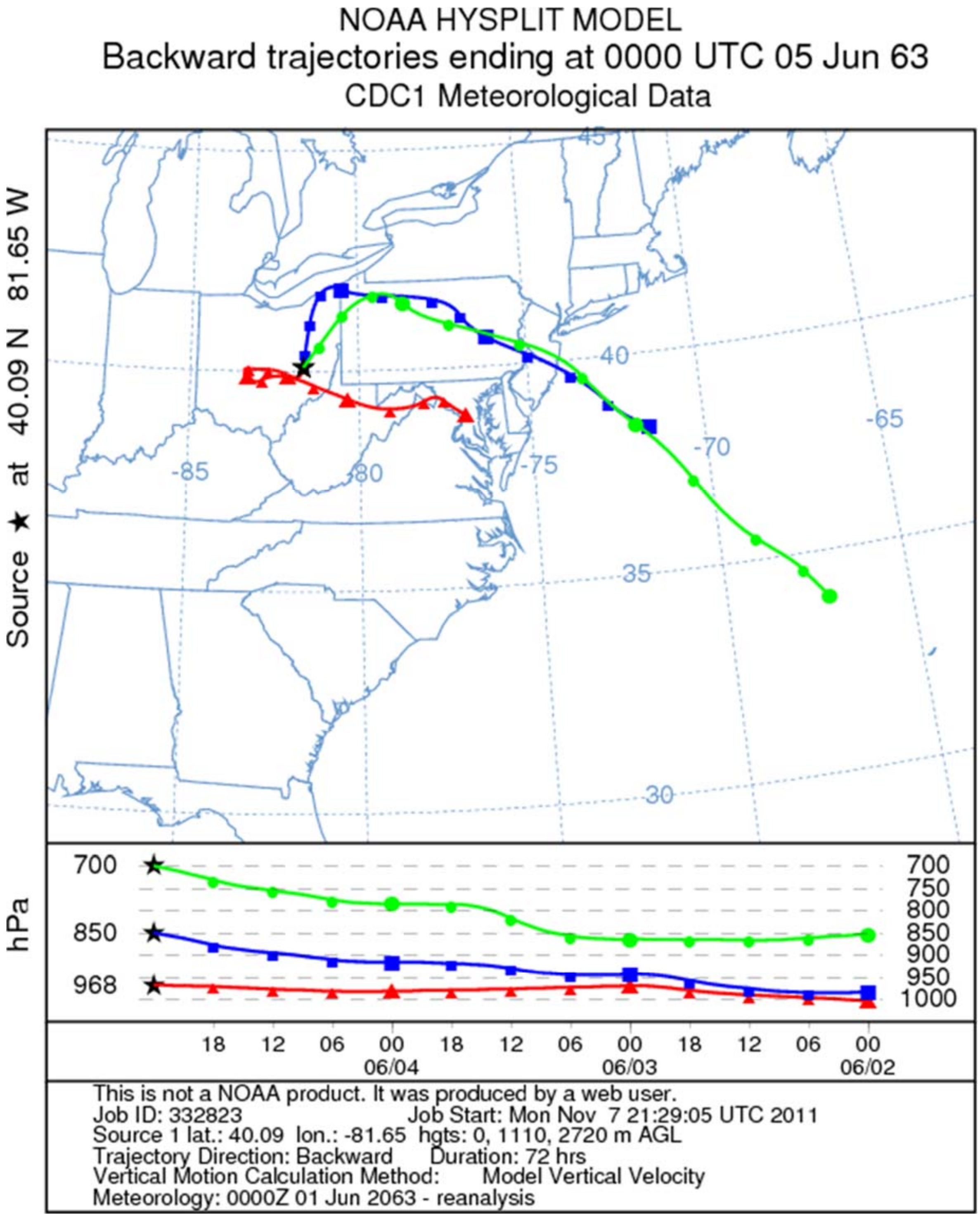



**Total Precipitation (48 hours)**
**SPAS #1226**
**6/04/1963 0600 UTC - 6/06/1963 0600 UTC**

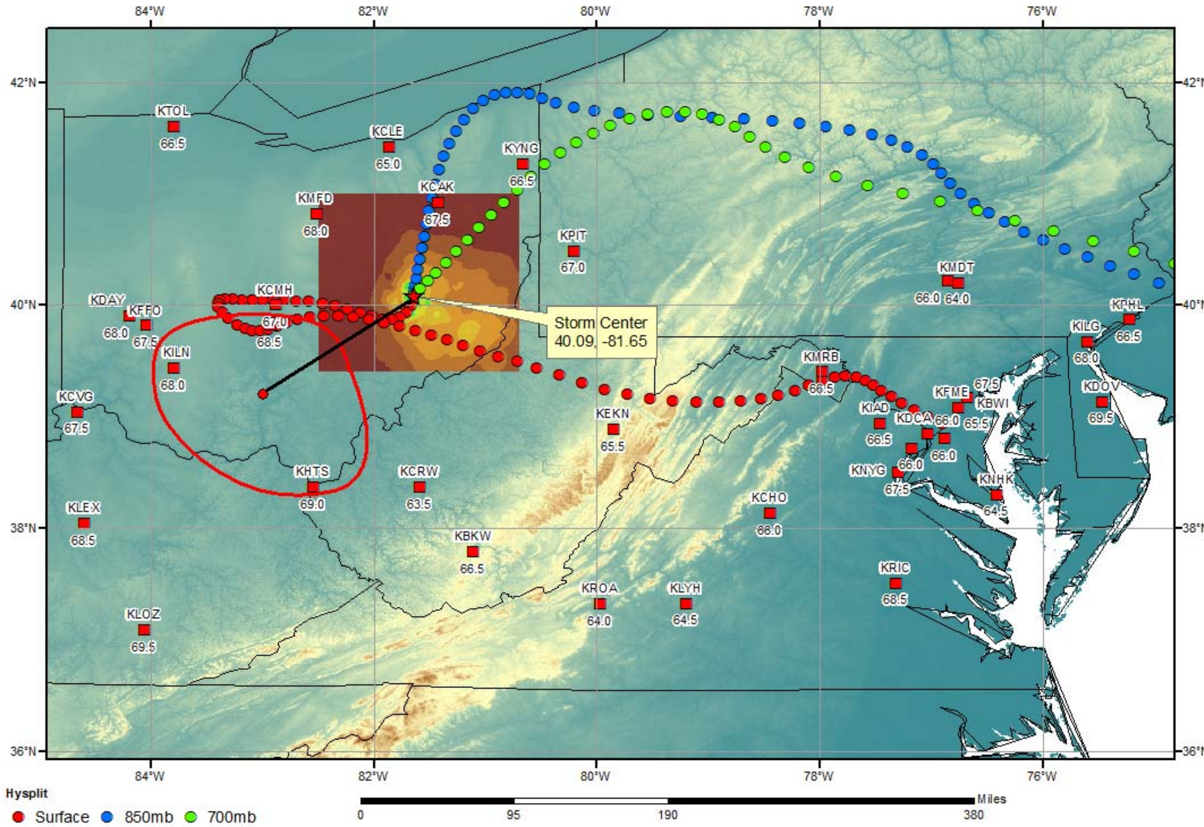


11/25/2011


NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 05 Jun 63
CDC1 Meteorological Data
Source ★ at 40.09 N 81.65 W
45
40
35
30
-85
-80
-75
-70
-65
hPa
700
850
968
700
750
800
850
900
950
1000
18 12 06 00 18 12 06 00 18 12 06 00
06/04
06/03
06/02
This is not a NOAA product. It was produced by a web user.
Job ID: 332823 Job Start: Mon Nov 7 21:29:05 UTC 2011
Source 1 lat.: 40.09 lon.: -81.65 hgts: 0, 1110, 2720 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Jun 2063 - reanalysis

**College Hill, OH Storm Analysis**
June 1-5, 1963



# Storm Precipitation Analysis System (SPAS) For Storm #1209_1 SPAS Analysis

**General Storm Location**: Wooster, Ohio – the "Independence Day storm"

**Storm Dates**: July 4-6, 1969 (July 4, 1969 0600 UTC – July 7, 1969 0500 UTC: 72 hours)

**Event**: Thunderstorm

**DAD Zone 1**

**Latitude**: 40.91458

**Longitude**: 81.9729

**Max. Grid Rainfall Amount**: 14.95”***

**Max. Observed Rainfall Amount**: 14.82” at Wooster 8 NNW***

**Number of Stations**: 509 (77 Daily, 46 Hourly, 2 Hourly Estimated, 3 Hourly Estimated Pseudo, 14 Hourly Pseudo, 360 Supplemental, and 7 Supplemental Estimated)

**SPAS Version**: 8.5

**Base Map Used:** Blended USGS, USACE, NWS and SPAS total storm isohyetal converted into a grid.

**Spatial resolution:** 15 seconds* (~ 0.25 $mi^2$)

**Radar Included:** No

**Depth-Area-Duration (DAD) analysis**: Yes**

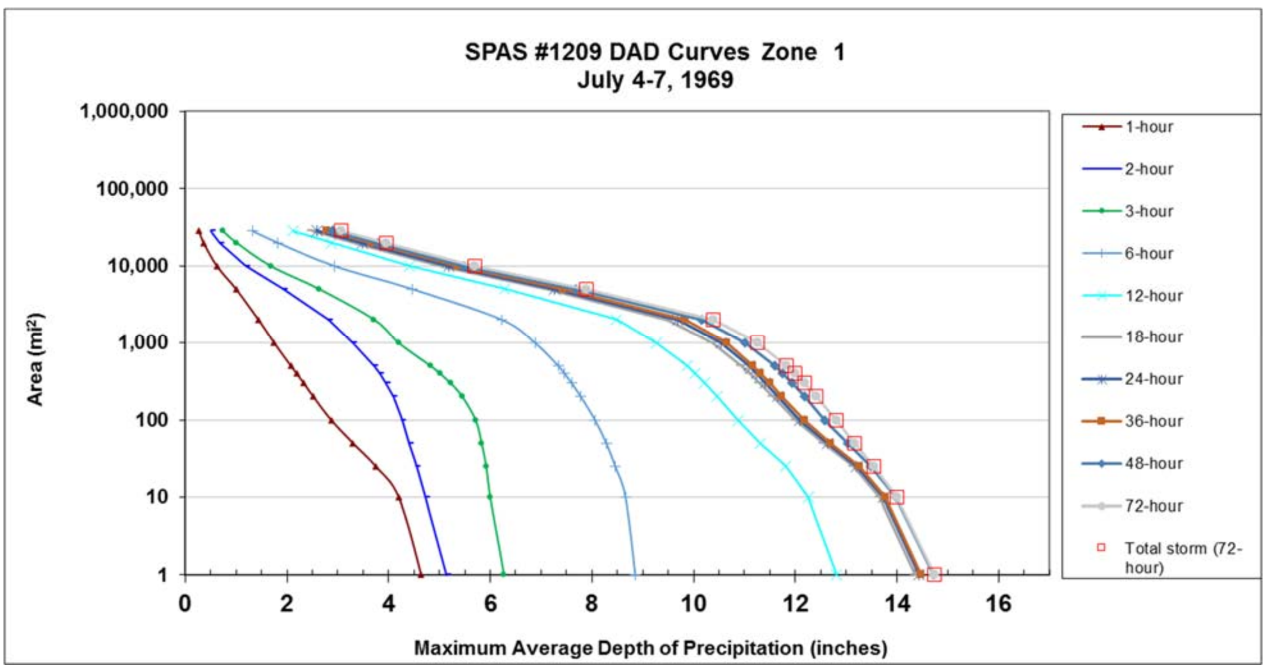
**Reliability of results:** Although this storm analysis obviously did not use radar data, the abundant gauge data and well positioned hourly rain gauges provided excellent spatial and temporal information and therefore a very high degree of confidence in the final results.

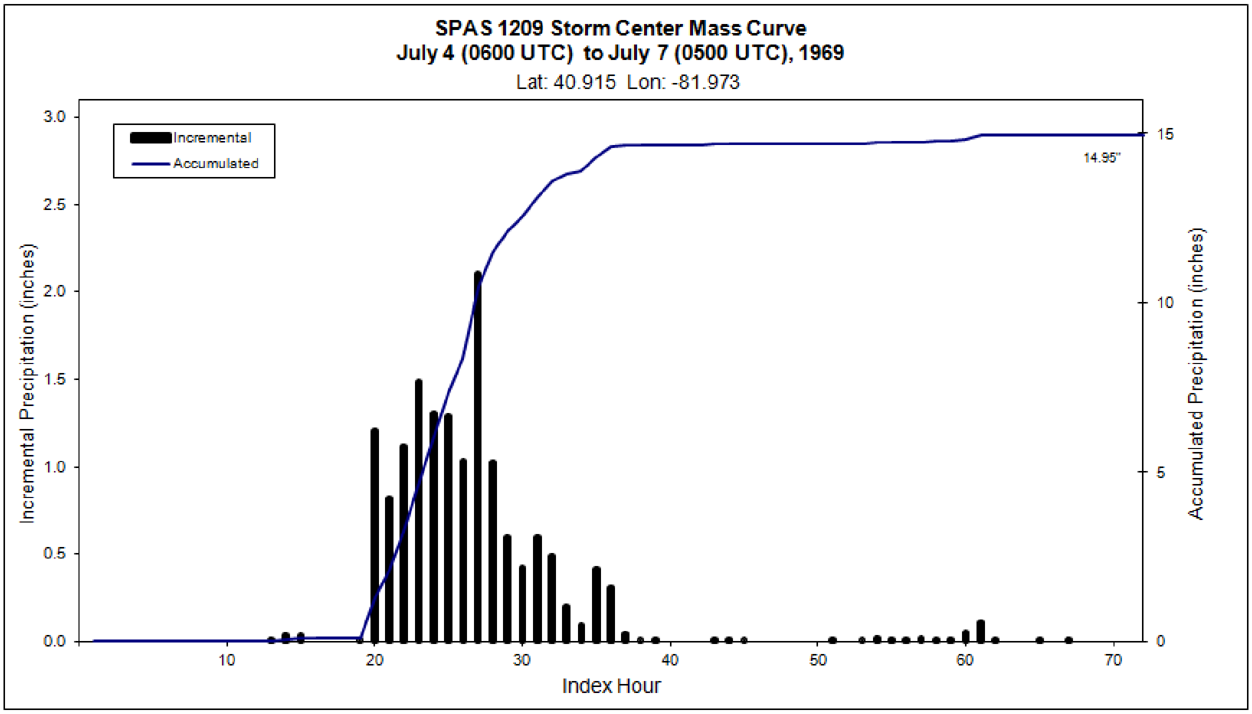
*A higher spatial resolution (15-sec vs. 30-sec) was used in this analysis to better capture the spatial details.

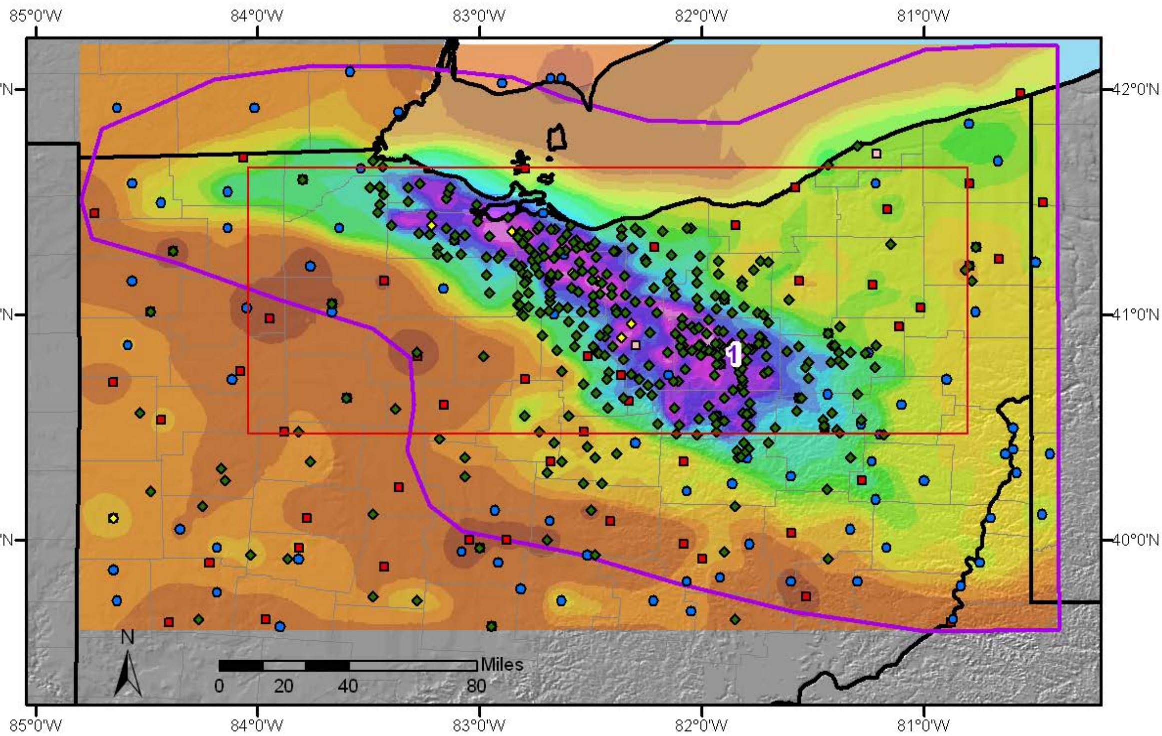
** The southwestern portion of the domain was NOT included in the DAD zone since a separate squall line passed through this area on July $6^{th}$, which is temporally very separate than the main event during the night of July $4^{th}$.

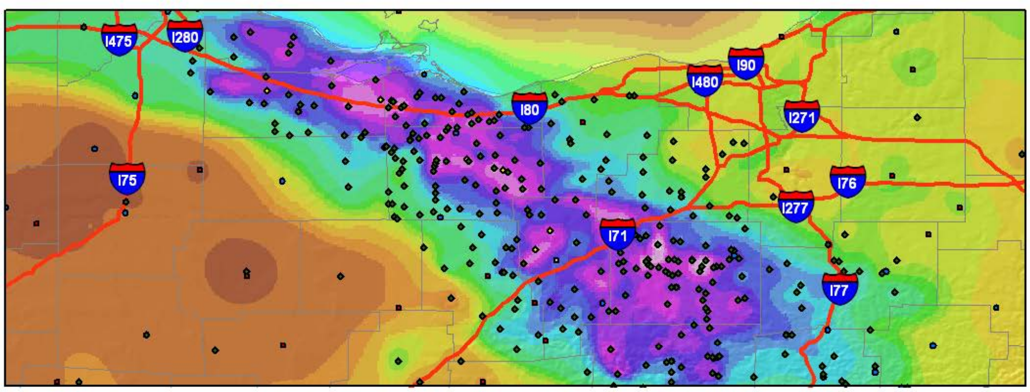
*** An unreliable and unofficial amount of 18” was reported (see below) near Wooster, but we choose not to use this amount because we couldn’t corroborate it with other sources. As it is, our storm center exceeds the highest official rainfall amount by 0.13”.

| Storm 1209 - July 4 (0600 UTC) - July 7 (0500 UTC), 1969 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | |
| Area ($mi^2$) | Duration (hours) | | | | | | | | | | |
| | 1 | 2 | 3 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | Total |
| 0.4 | 4.73 | 5.23 | 6.34 | 8.88 | 12.89 | 14.44 | 14.52 | 14.55 | 14.79 | 14.81 | 14.81 |
| 1 | 4.64 | 5.14 | 6.27 | 8.85 | 12.81 | 14.36 | 14.44 | 14.47 | 14.71 | 14.73 | 14.73 |
| 10 | 4.20 | 4.73 | 6.00 | 8.66 | 12.26 | 13.66 | 13.73 | 13.77 | 13.98 | 14.00 | 14.00 |
| 25 | 3.75 | 4.55 | 5.92 | 8.46 | 11.81 | 13.15 | 13.21 | 13.26 | 13.49 | 13.55 | 13.55 |
| 50 | 3.30 | 4.41 | 5.83 | 8.28 | 11.31 | 12.57 | 12.64 | 12.69 | 13.03 | 13.17 | 13.17 |
| 100 | 2.87 | 4.26 | 5.71 | 8.06 | 10.87 | 12.02 | 12.09 | 12.18 | 12.59 | 12.81 | 12.81 |
| 200 | 2.52 | 4.09 | 5.45 | 7.78 | 10.47 | 11.56 | 11.65 | 11.74 | 12.18 | 12.42 | 12.42 |
| 300 | 2.33 | 3.95 | 5.22 | 7.60 | 10.22 | 11.30 | 11.41 | 11.50 | 11.93 | 12.18 | 12.18 |
| 400 | 2.19 | 3.83 | 5.01 | 7.46 | 10.03 | 11.10 | 11.23 | 11.32 | 11.75 | 11.99 | 11.99 |
| 500 | 2.08 | 3.72 | 4.83 | 7.34 | 9.88 | 10.94 | 11.08 | 11.17 | 11.60 | 11.83 | 11.83 |
| 1,000 | 1.75 | 3.30 | 4.20 | 6.88 | 9.28 | 10.37 | 10.53 | 10.65 | 11.02 | 11.25 | 11.25 |
| 2,000 | 1.44 | 2.82 | 3.72 | 6.23 | 8.48 | 9.48 | 9.69 | 9.83 | 10.17 | 10.38 | 10.38 |
| 5,000 | 1.00 | 1.93 | 2.64 | 4.47 | 6.29 | 7.13 | 7.26 | 7.44 | 7.69 | 7.89 | 7.89 |
| 10,000 | 0.62 | 1.19 | 1.68 | 2.93 | 4.41 | 5.03 | 5.18 | 5.36 | 5.49 | 5.69 | 5.69 |
| 20,000 | 0.36 | 0.68 | 1.01 | 1.82 | 2.88 | 3.36 | 3.49 | 3.67 | 3.78 | 3.95 | 3.95 |
| 28,280 | 0.27 | 0.51 | 0.74 | 1.33 | 2.13 | 2.50 | 2.59 | 2.79 | 2.89 | 3.06 | 3.06 |




SPAS 1209 Storm Center Mass Curve
July 4 (0600 UTC) to July 7 (0500 UTC), 1969
Lat: 40.915 Lon: -81.973
Incremental
Accumulated
14.95"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour
3.0
2.5
2.0
1.5
1.0
0.5
0.0
15
10
5
0
10
20
30
40
50
60
70



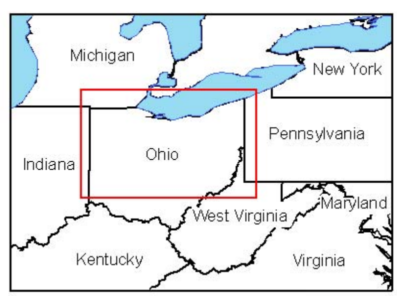




**Wooster, Ohio "Independence Day storm" - ISOHYETAL FROM SPAS**

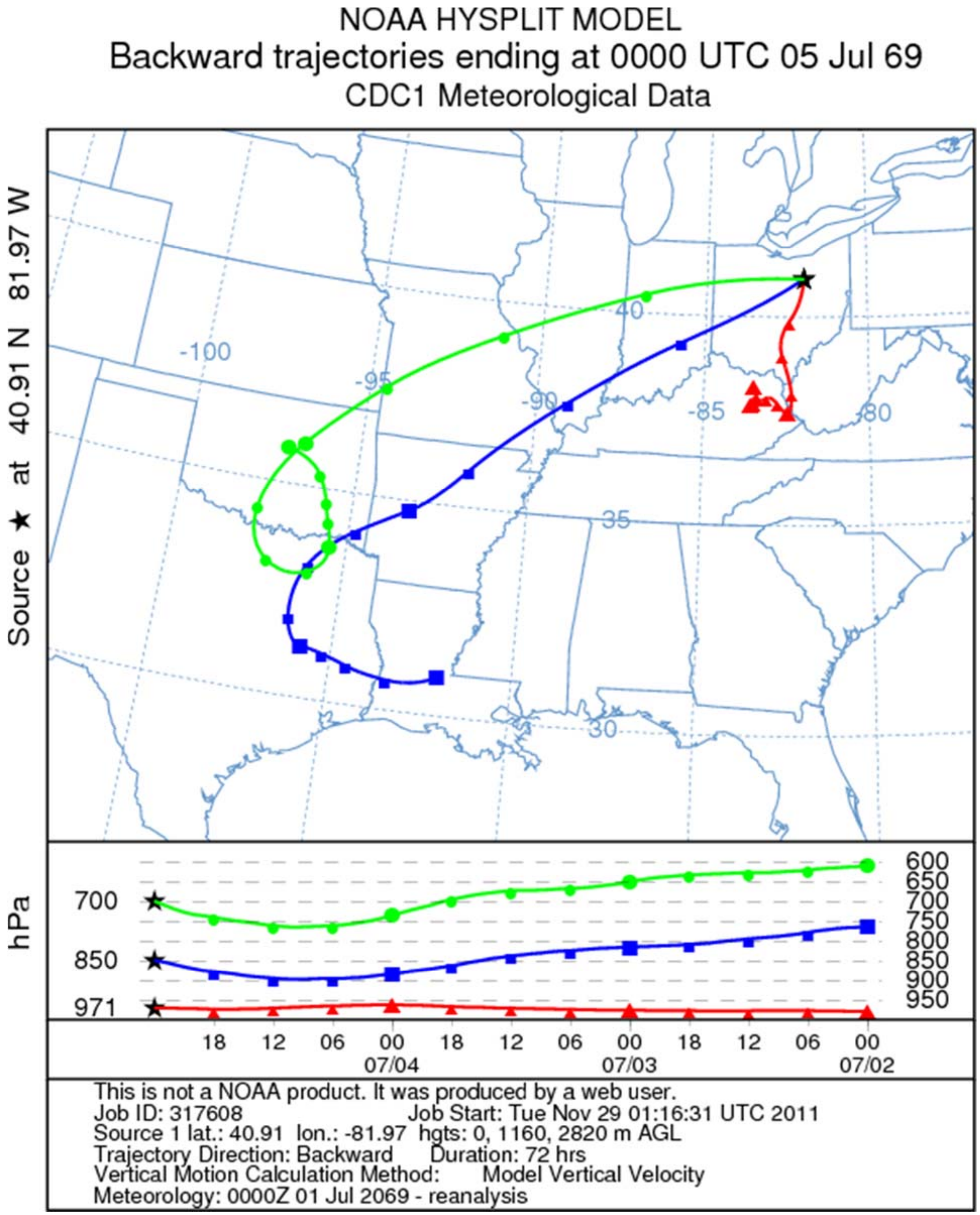
**Total 72-hour Rainfall (inches)**
**07/04/1969 0600 UTC - 07/07/1969 0500 UTC**
**SPAS #1209**

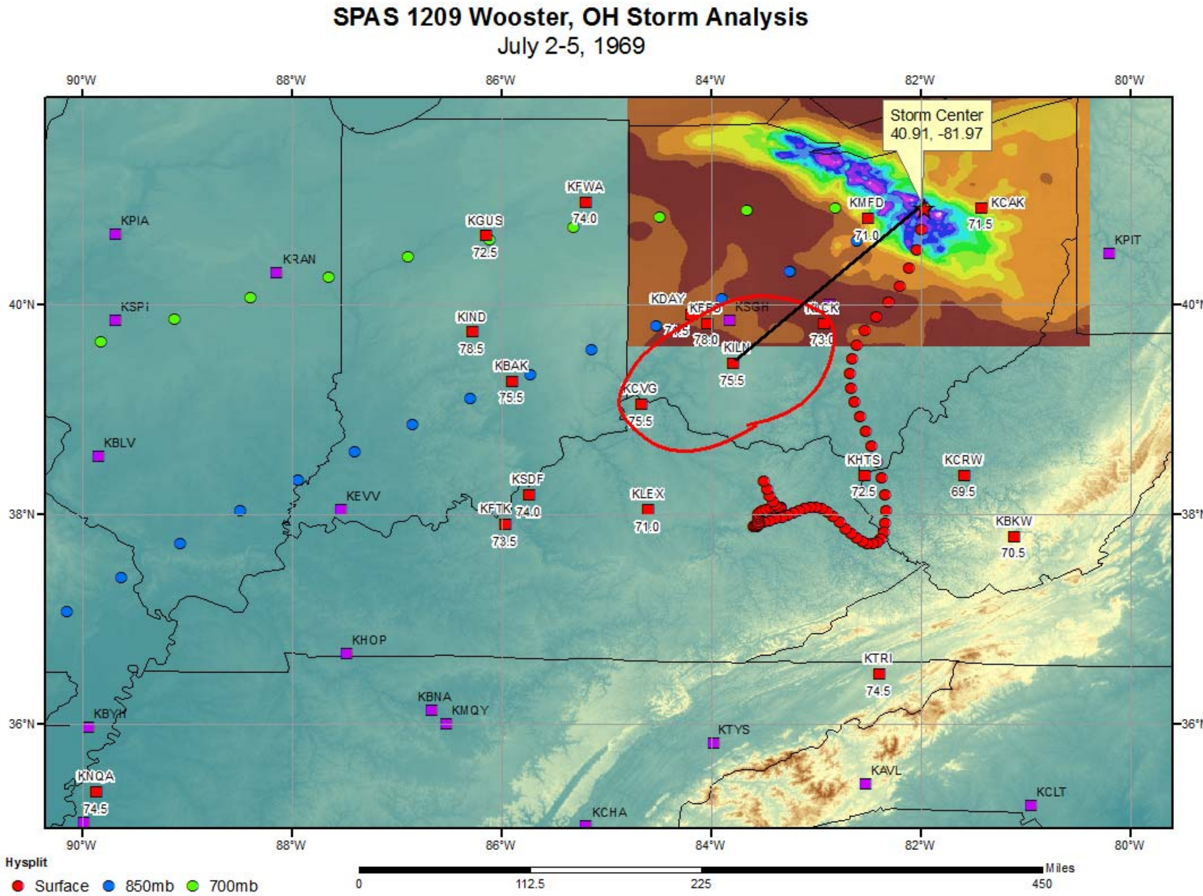
**Inches**

| | | | |
|---|---|---|---|
| 0.00 | 3.01 - 3.50 | 9.01 - 10.00 | Daily |
| 0.01 - 0.50 | 3.51 - 4.00 | 10.01 - 11.00 | Hourly |
| 0.51 - 1.00 | 4.01 - 5.00 | 11.01 - 12.00 | Hourly Est. |
| 1.01 - 1.50 | 5.01 - 6.00 | 12.01 - 13.00 | Hourly Est. Pseudo |
| 1.51 - 2.00 | 6.01 - 7.00 | 13.01 - 14.00 | Hourly Pseudo |
| 2.01 - 2.50 | 7.01 - 8.00 | >14.00 | Supplemental |
| 2.51 - 3.00 | 8.01 - 9.00 | DAD zone | Supplemental Est. |




06/15/2011 METSTAT


NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 05 Jul 69
CDC1 Meteorological Data
Source ★ at 40.91 N 81.97 W
-100
-95
-90
-85
-80
40
35
30
hPa
700
850
971
600
650
700
750
800
850
900
950
18 12 06 00 18 12 06 00 18 12 06 00
07/04
07/03
07/02
This is not a NOAA product. It was produced by a web user.
Job ID: 317608 Job Start: Tue Nov 29 01:16:31 UTC 2011
Source 1 lat.: 40.91 lon.: -81.97 hgts: 0, 1160, 2820 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 01 Jul 2069 - reanalysis


SPAS 1209 Wooster, OH Storm Analysis
July 2-5, 1969
Storm Center
40.91, -81.97
Hysplit
Surface
850mb
700mb
Miles
0
112.5
225
450

# Storm Precipitation Analysis System (SPAS) For Storm #1035_1 SPAS Analysis

**General Storm Location**: Forest City, MN

**Storm Dates**: June 19 – 22, 1983

**Event**: Convective Thunderstorm

**DAD Zone 1**

**Latitude**: 45.23941

**Longitude**: -94.54040

**Rainfall Amount**: 17.00” (Grid/Pixel Point =16.53”)

**Number of Stations**: 515 (h=8, hp=1, d=498 (434 Coop), s=8)

**SPAS Version**: 2.0

**Base Map Used:** No

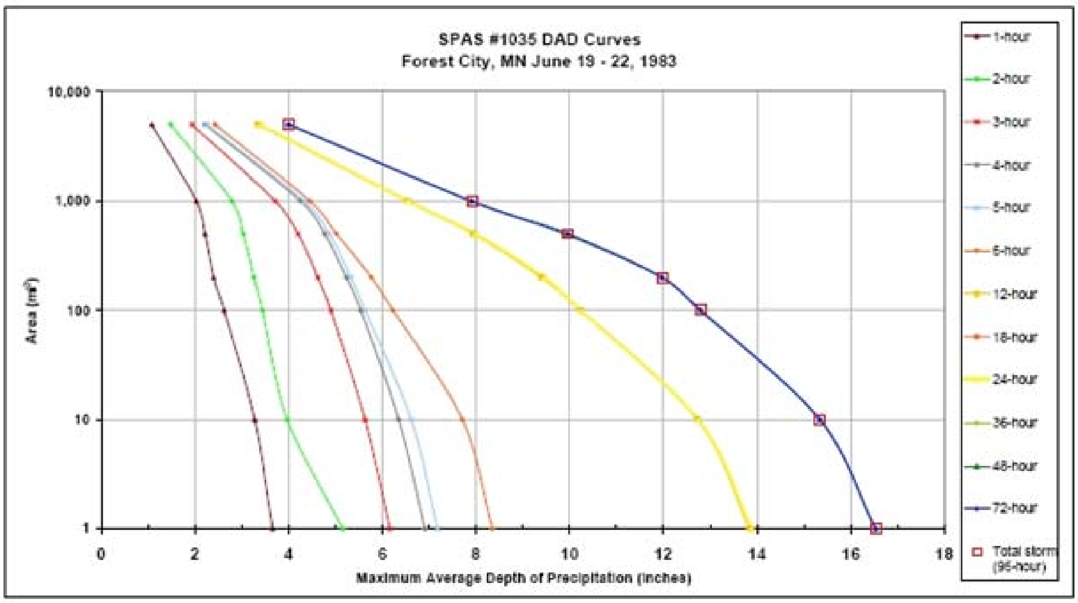
**Radar Included:** No

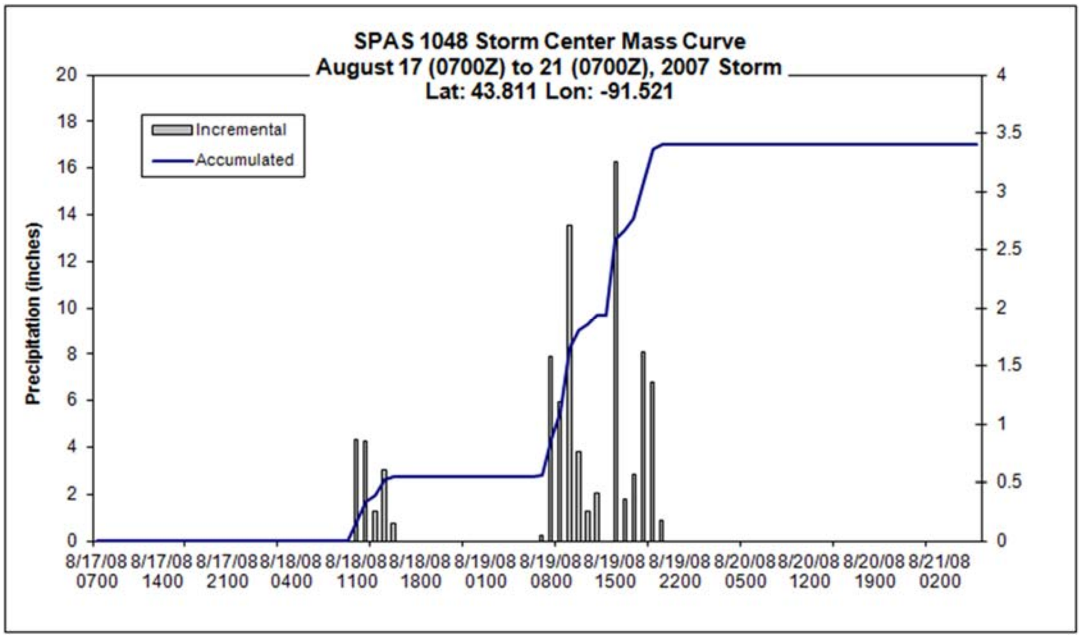
**Depth-Area-Duration (DAD) analysis**: Yes, 1, 2, 3, 4, 5, 6, 12, 18, 24, 36, 48, 72, and 96 hours.

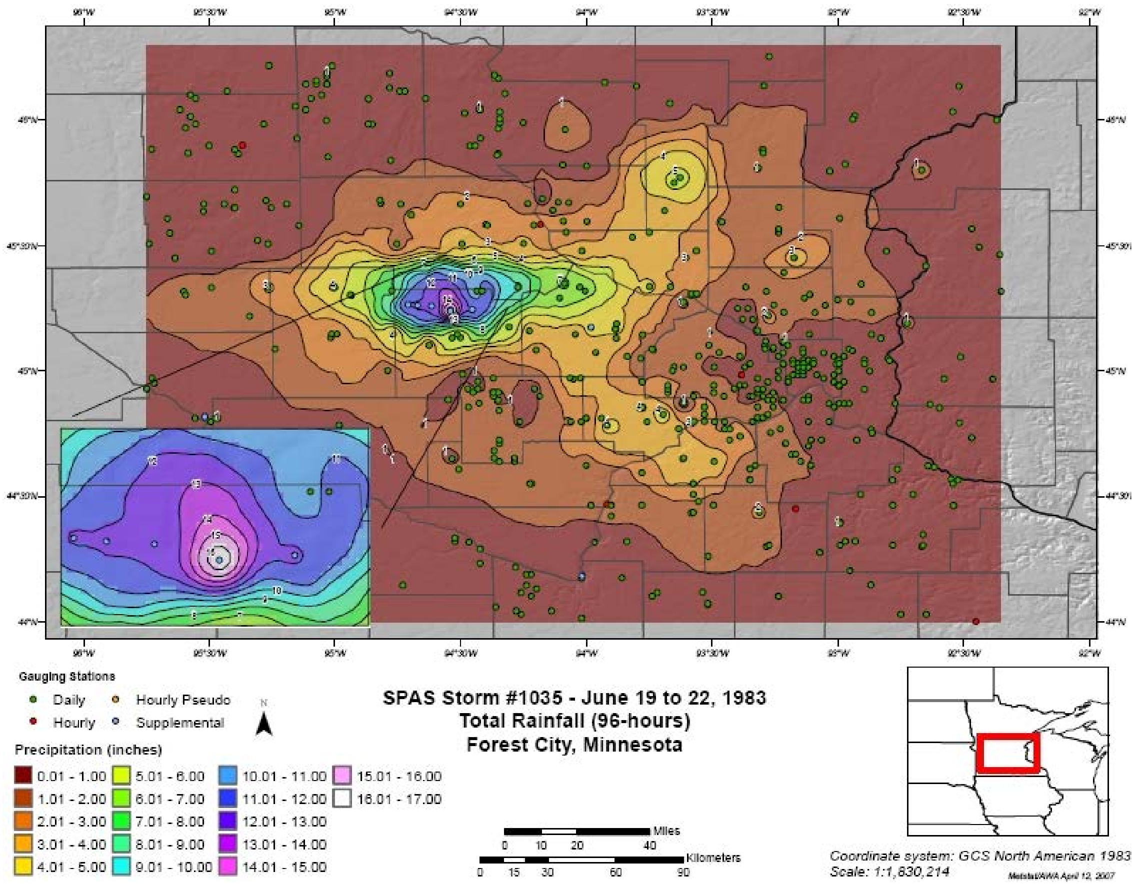
## Storm 1035 - Forest City, MN June 19 - 22, 1983

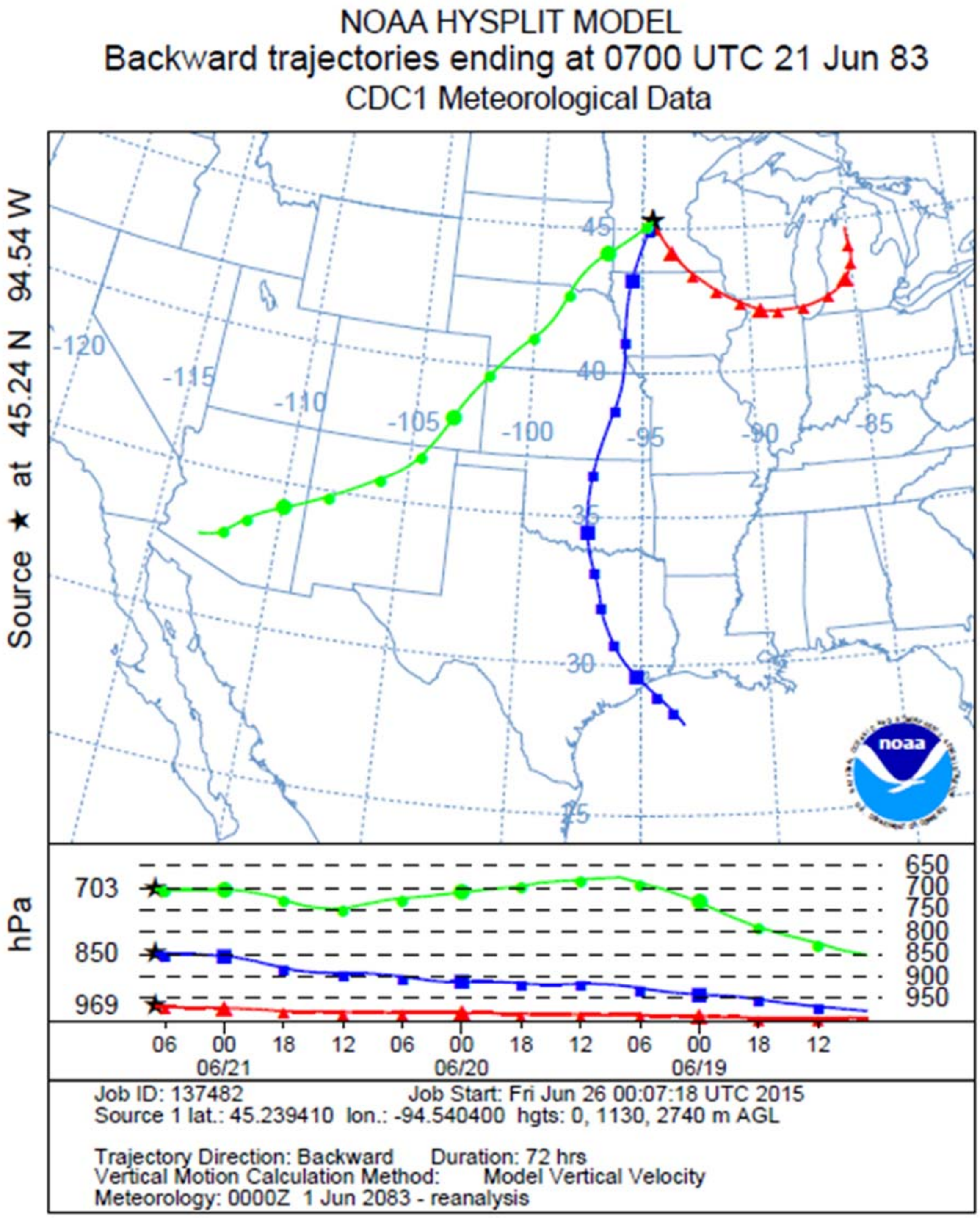
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

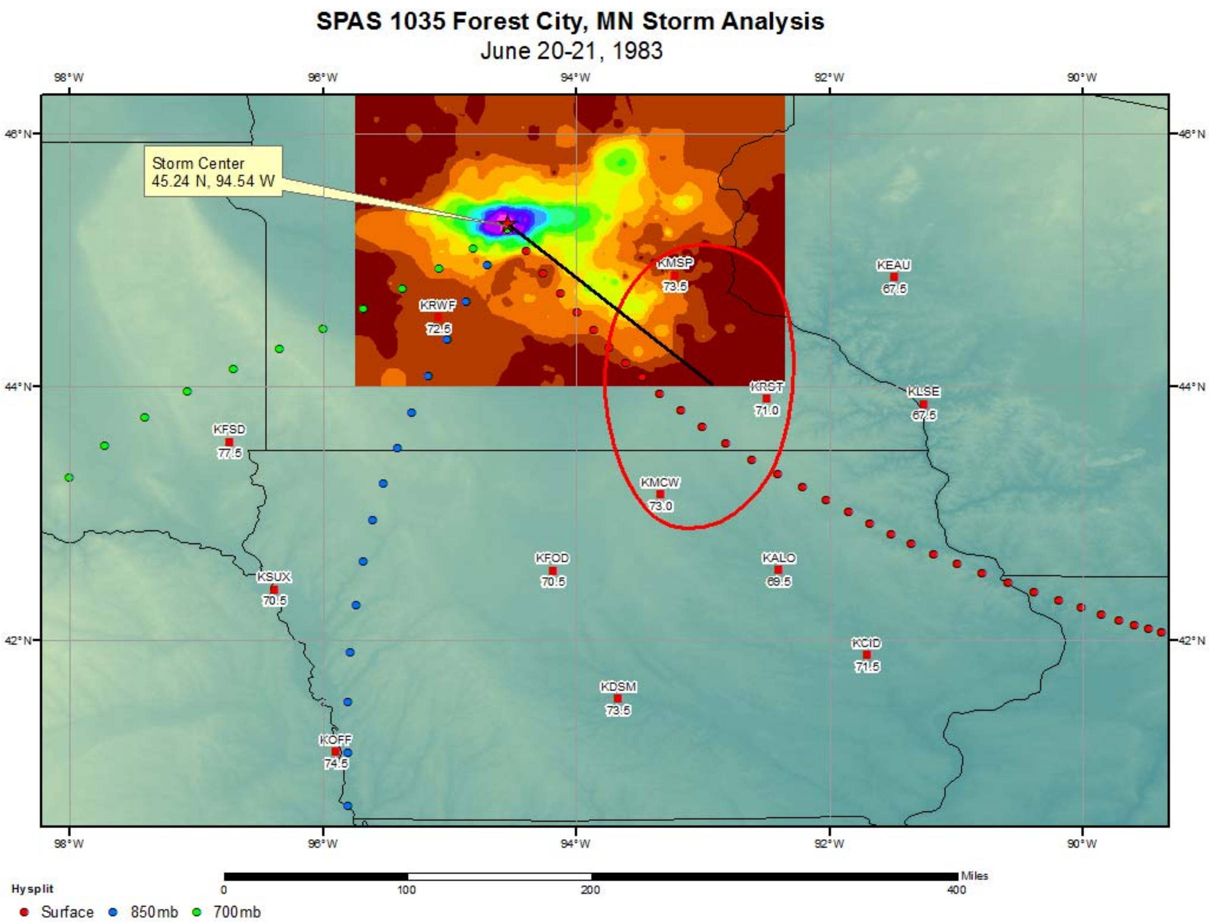
| Area ($mi^2$) | Duration (hours) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | 96 | total |
| 1 | 3.66 | 5.16 | 6.16 | 6.91 | 7.18 | 8.35 | 13.84 | 13.89 | 13.89 | 16.53 | 16.53 | 16.53 | 16.53 | 16.53 |
| 10 | 3.28 | 3.97 | 5.63 | 6.35 | 6.62 | 7.71 | 12.73 | 12.74 | 12.74 | 15.34 | 15.34 | 15.34 | 15.34 | 15.34 |
| 100 | 2.62 | 3.44 | 4.90 | 5.54 | 5.63 | 6.23 | 10.23 | 10.23 | 10.23 | 12.79 | 12.79 | 12.79 | 12.79 | 12.79 |
| 200 | 2.40 | 3.26 | 4.62 | 5.23 | 5.33 | 5.77 | 9.38 | 9.45 | 9.45 | 11.97 | 11.97 | 11.97 | 11.97 | 11.97 |
| 500 | 2.22 | 3.03 | 4.20 | 4.77 | 4.87 | 5.02 | 7.94 | 7.98 | 7.98 | 9.90 | 9.90 | 9.97 | 9.97 | 9.97 |
| 1,000 | 2.03 | 2.79 | 3.71 | 4.25 | 4.33 | 4.45 | 6.54 | 6.55 | 6.55 | 7.89 | 7.89 | 7.91 | 7.91 | 7.91 |
| 5,000 | 1.08 | 1.48 | 1.94 | 2.22 | 2.26 | 2.43 | 3.35 | 3.38 | 3.38 | 4.00 | 4.00 | 4.00 | 4.01 | 4.01 |




SPAS 1048 Storm Center Mass Curve
August 17 (0700Z) to 21 (0700Z), 2007 Storm
Lat: 43.811 Lon: -91.521
Incremental
Accumulated
Precipitation (inches)
20
18
16
14
12
10
8
6
4
2
0
4
3.5
3
2.5
2
1.5
1
0.5
0
8/17/08 0700
8/17/08 1400
8/17/08 2100
8/18/08 0400
8/18/08 1100
8/18/08 1800
8/19/08 0100
8/19/08 0800
8/19/08 1500
8/19/08 2200
8/20/08 0500
8/20/08 1200
8/20/08 1900
8/21/08 0200


SPAS Storm #1035 - June 19 to 22, 1983
Total Rainfall (96-hours)
Forest City, Minnesota
Gauging Stations
Daily
Hourly
Hourly Pseudo
Supplemental
Precipitation (inches)
0.01 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 6.00
6.01 - 7.00
7.01 - 8.00
8.01 - 9.00
9.01 - 10.00
10.01 - 11.00
11.01 - 12.00
12.01 - 13.00
13.01 - 14.00
14.01 - 15.00
15.01 - 16.00
16.01 - 17.00
Miles
Kilometers
Coordinate system: GCS North American 1983
Scale: 1:1,830,214


NOAA HYSPLIT MODEL
Backward trajectories ending at 0700 UTC 21 Jun 83
CDC1 Meteorological Data
Source ★ at 45.24 N 94.54 W
45
40
35
30
25
-120
-115
-110
-105
-100
-95
-90
-85
hPa
703
850
969
650
700
750
800
850
900
950
06
00
18
12
06
00
18
12
06
00
18
12
06/21
06/20
06/19
Job ID: 137482
Job Start: Fri Jun 26 00:07:18 UTC 2015
Source 1 lat.: 45.239410 lon.: -94.540400 hgts: 0, 1130, 2740 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jun 2083 - reanalysis


SPAS 1035 Forest City, MN Storm Analysis
June 20-21, 1983
Storm Center
45.24 N, 94.54 W
KMSP
73.5
KEAU
67.5
KRWF
72.5
KRST
71.0
KLSE
67.5
KFSD
77.5
KMCW
73.0
KFOD
70.5
KALO
69.5
KSUX
70.5
KCID
71.5
KDSM
73.5
KOFF
74.5
Hysplit
Surface
850mb
700mb
Miles

# Storm Precipitation Analysis System (SPAS) For Storm #1210_1 SPAS Analysis

**General Storm Location**: Twin Cities, MN

**Storm Dates**: 07/23/1987 0700 UTC - 07/24/1987 1800 UTC (CPP: 36-hours)

**Event**: Mesoscale Convective Complex

**DAD Zone 1**

**Latitude**: 44.8895

**Longitude**: -93.40208

**Max. Grid Rainfall Amount**: 11.55"

**Max. Observed Rainfall Amount**: 11.32"*** (EDEN PRAIRIE, MN)

**Number of Stations**: 293 (37 Daily, 8 Hourly, 3 Hourly Pseudo, 245 Supplemental)

**SPAS Version**: 8.5

**Base Map Used**: A basemap/grid was created with a blend of the Univ. of Minnesota/MN Climate Center isohyetal, the EPRI isohyetal, a composite of 5 geo-referenced WSR-57 radar images and the SPAS total storm (based on PRISM mean 1971-2000 July Precipitation as a basemap).

**Spatial resolution:** 15 seconds* (~ 0.25 $mi^2$)

**Radar Included:** No**

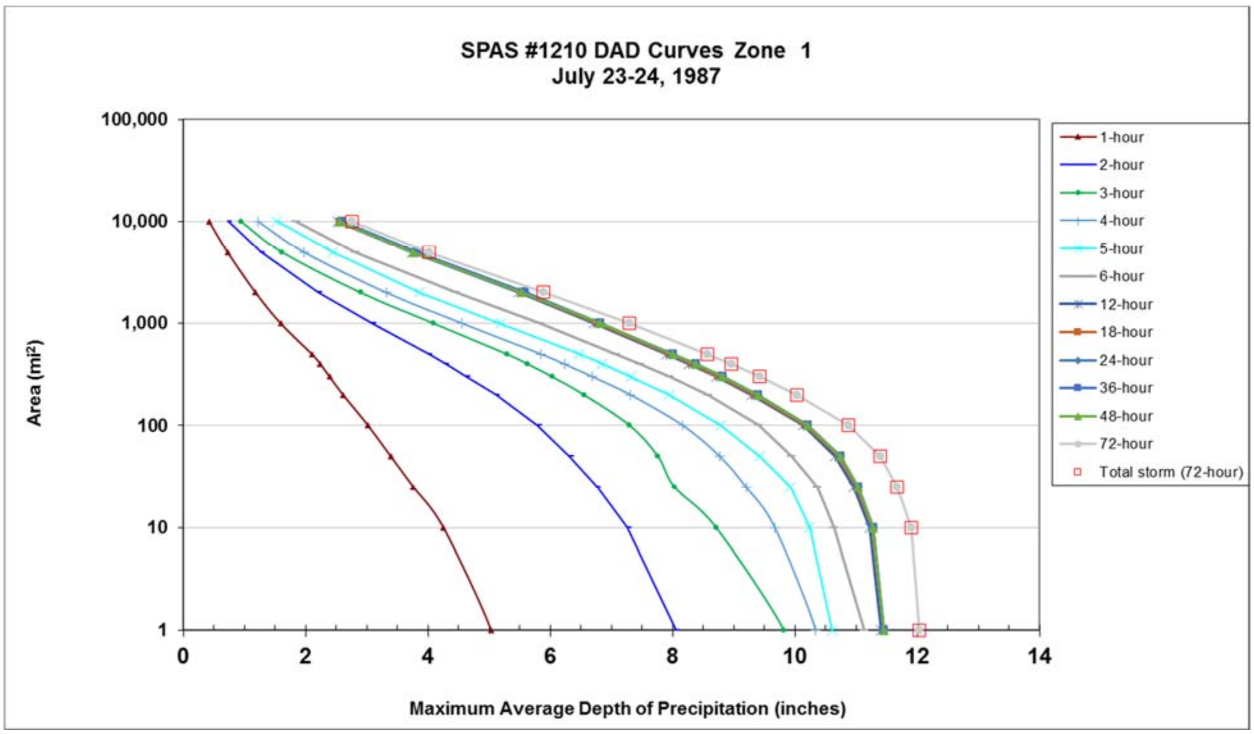
**Depth-Area-Duration (DAD) analysis**: Yes

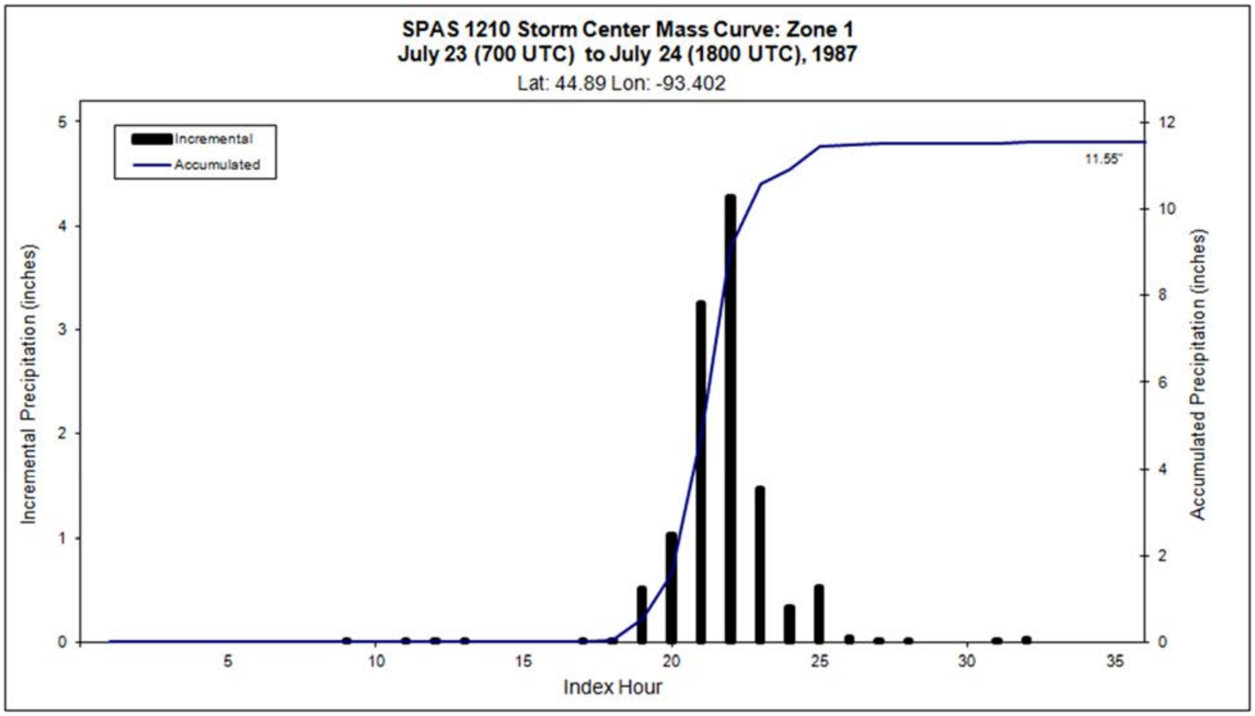
**Reliability of results:** Although this storm analysis did not use radar data, the abundant gauge data and well positioned hourly rain gauges provided excellent spatial and temporal information and therefore a very high degree of confidence in the final results.

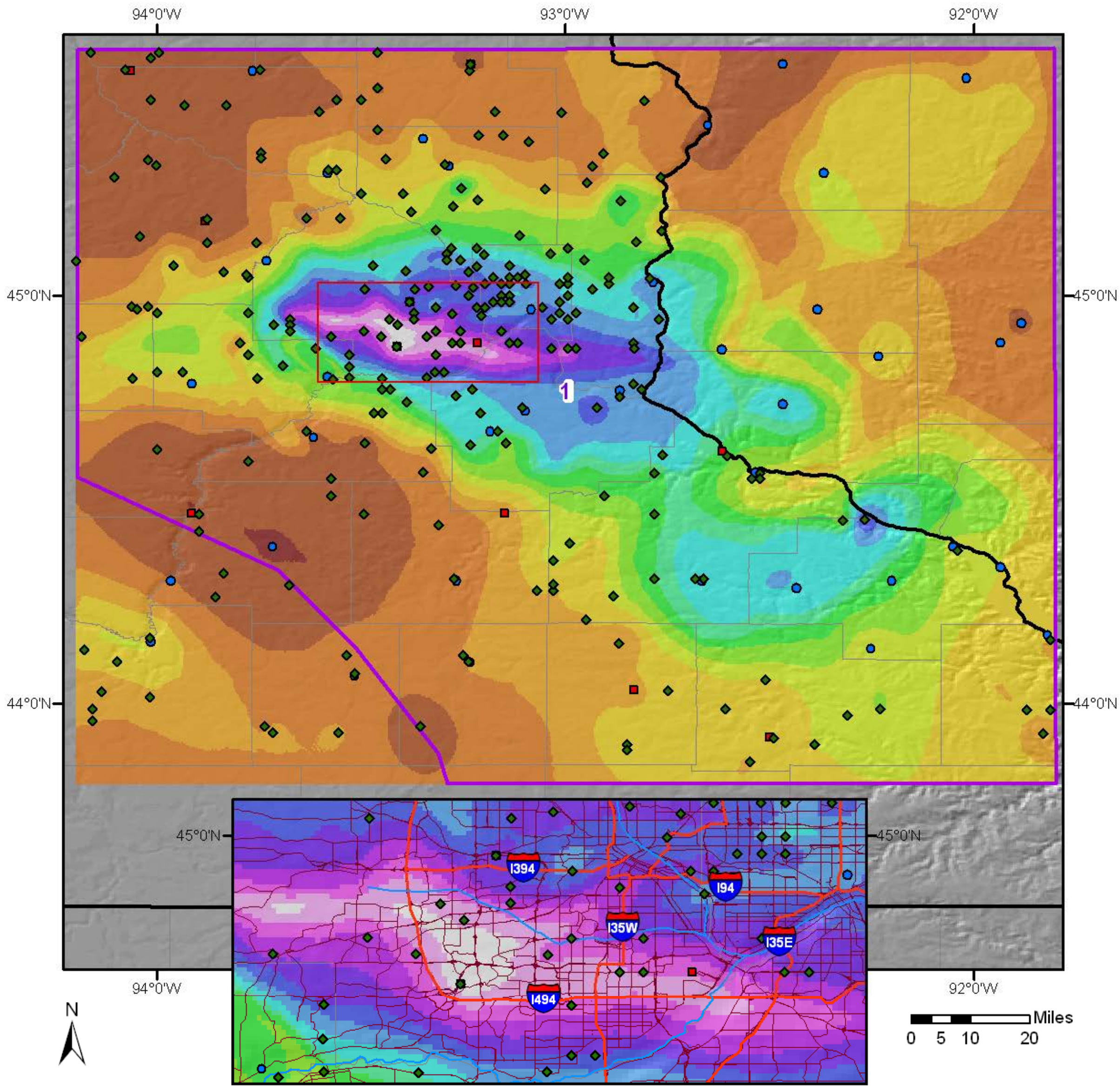
*A higher spatial resolution (15-sec vs. 30-sec) was used in this analysis to better capture the spatial details.
** Although no radar data was used, 5 WSR-57 geo-referenced images provided some useful information. See more details below.

*** Given this station was nudged in the analysis, the 11.32" value won't clearly show up in the av1201.txt file. Furthermore, the CPP was limited to a 36 hour window, whereas this station reported more precip at the very end of the 72-hour analyzed period.

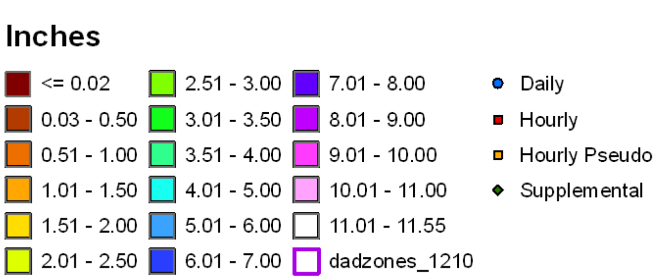
| Storm 1210 - July 23 (0700 UTC) - July 24 (1800 UTC), 1987 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | | |
| Area (mi$^2$) | Duration (hours) | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | Total |
| 0.4 | 5.10 | 8.12 | 9.91 | 10.38 | 10.67 | 11.17 | 11.45 | 11.48 | 11.49 | 11.49 | 11.49 | 12.06 | 12.06 |
| 1 | 5.03 | 8.06 | 9.82 | 10.34 | 10.61 | 11.13 | 11.41 | 11.46 | 11.46 | 11.46 | 11.46 | 12.03 | 12.03 |
| 10 | 4.25 | 7.26 | 8.71 | 9.67 | 10.24 | 10.64 | 11.22 | 11.27 | 11.28 | 11.28 | 11.28 | 11.90 | 11.90 |
| 25 | 3.76 | 6.76 | 8.03 | 9.20 | 9.92 | 10.36 | 10.96 | 11.01 | 11.04 | 11.04 | 11.04 | 11.67 | 11.67 |
| 50 | 3.39 | 6.32 | 7.76 | 8.77 | 9.43 | 9.95 | 10.66 | 10.71 | 10.75 | 10.75 | 10.75 | 11.39 | 11.39 |
| 100 | 3.02 | 5.80 | 7.30 | 8.17 | 8.79 | 9.41 | 10.13 | 10.16 | 10.21 | 10.21 | 10.21 | 10.87 | 10.87 |
| 200 | 2.61 | 5.11 | 6.55 | 7.31 | 7.94 | 8.58 | 9.30 | 9.34 | 9.40 | 9.40 | 9.40 | 10.04 | 10.04 |
| 300 | 2.39 | 4.63 | 6.03 | 6.69 | 7.32 | 7.95 | 8.71 | 8.75 | 8.81 | 8.81 | 8.81 | 9.42 | 9.42 |
| 400 | 2.24 | 4.28 | 5.63 | 6.23 | 6.85 | 7.47 | 8.27 | 8.31 | 8.38 | 8.38 | 8.38 | 8.96 | 8.96 |
| 500 | 2.10 | 4.01 | 5.29 | 5.85 | 6.47 | 7.08 | 7.90 | 7.95 | 8.01 | 8.01 | 8.01 | 8.57 | 8.57 |
| 1,000 | 1.59 | 3.09 | 4.09 | 4.56 | 5.19 | 5.83 | 6.71 | 6.76 | 6.82 | 6.82 | 6.81 | 7.29 | 7.29 |
| 2,000 | 1.18 | 2.21 | 2.90 | 3.32 | 3.86 | 4.45 | 5.48 | 5.53 | 5.58 | 5.58 | 5.52 | 5.89 | 5.89 |
| 5,000 | 0.72 | 1.27 | 1.61 | 1.97 | 2.44 | 2.82 | 3.74 | 3.78 | 3.83 | 3.83 | 3.76 | 4.02 | 4.02 |
| 10,000 | 0.42 | 0.73 | 0.94 | 1.22 | 1.53 | 1.84 | 2.53 | 2.56 | 2.60 | 2.60 | 2.56 | 2.75 | 2.75 |



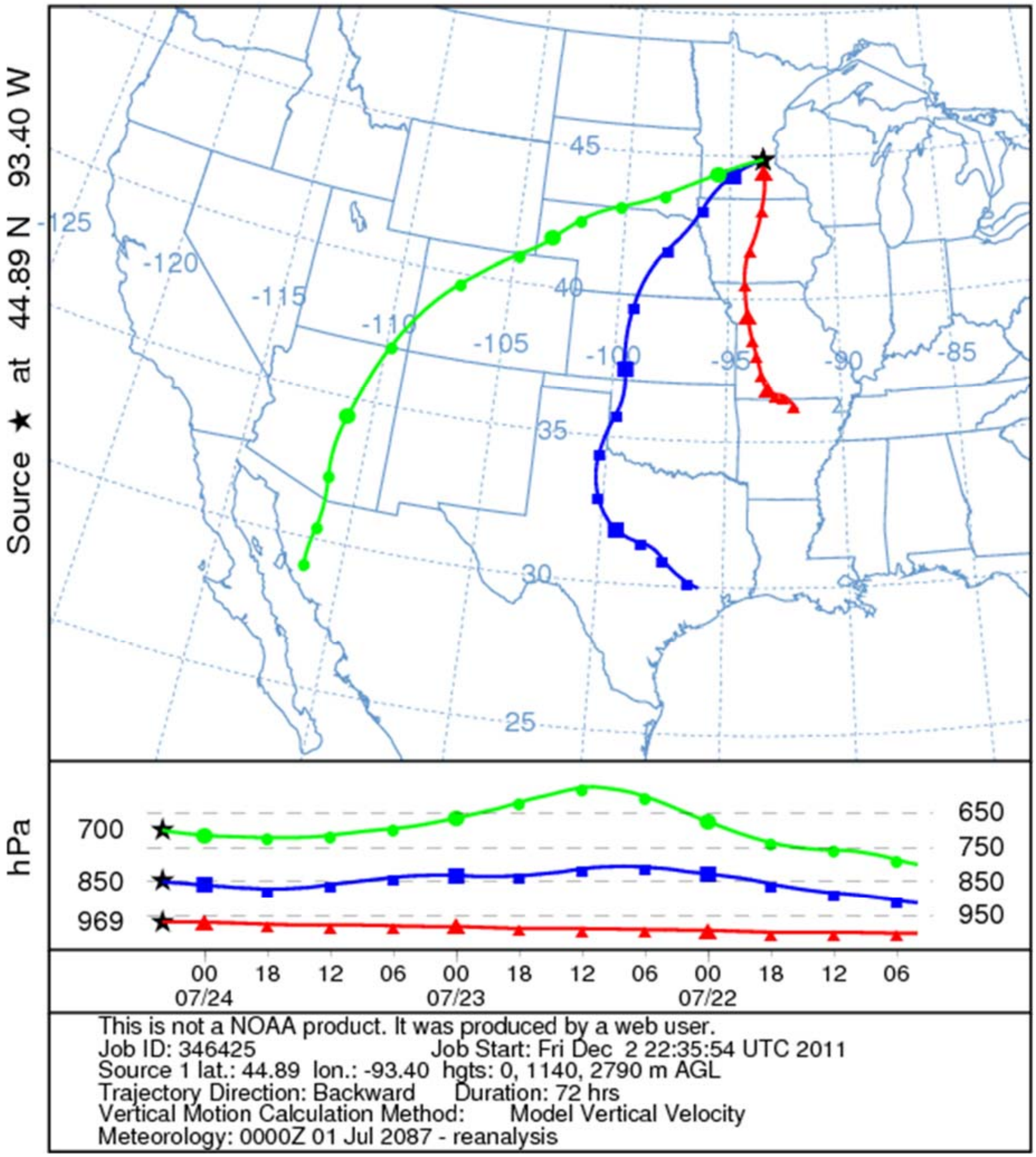

SPAS 1210 Storm Center Mass Curve: Zone 1
July 23 (700 UTC) to July 24 (1800 UTC), 1987
Lat: 44.89 Lon: -93.402
Incremental
Accumulated
11.55"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour

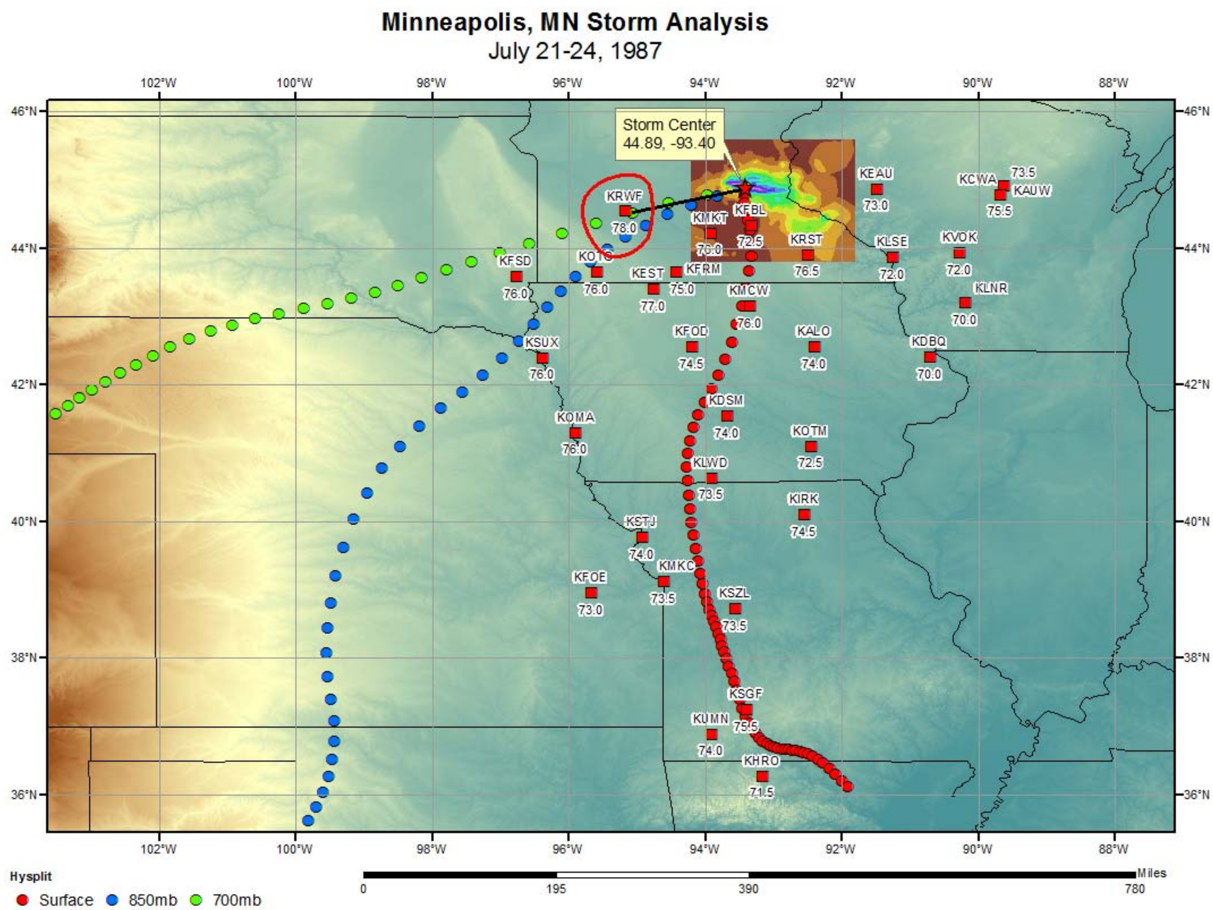



**ISOHYETAL FROM SPAS #1210 - "Twin Cities Super Storm"**
**Total 36-hour Rainfall (inches)**
**07/23/1987 0700 UTC - 07/24/1987 1800 UTC**




NOAA HYSPLIT MODEL
Backward trajectories ending at 0400 UTC 24 Jul 87
CDC1 Meteorological Data





Minneapolis, MN Storm Analysis
July 21-24, 1987
Storm Center
44.89, -93.40
KRWF
78.0
KMKT
76.0
KFBL
72.5
KEAU
73.0
KCWA
73.5
KAUW
75.5
KRST
76.5
KLSE
72.0
KVOK
72.0
KLNR
70.0
KFSD
76.0
KOTG
76.0
KEST
77.0
KFRM
75.0
KMCW
76.0
KFOD
74.5
KALO
74.0
KDBQ
70.0
KSUX
76.0
KDSM
74.0
KOMA
76.0
KOTM
72.5
KLWD
73.5
KIRK
74.5
KSTJ
74.0
KMKC
73.5
KFOE
73.0
KSZL
73.5
KSGF
75.5
KUMN
74.0
KHRO
71.5
Hysplit
Surface
850mb
700mb
Miles
0
195
390
780

# Storm Precipitation Analysis System (SPAS) For Storm #1673_1 SPAS Analysis

**General Storm Location**: Rapidan, VA - Marion County

**Storm Dates**: June 26 – 27, 1995

**Event**: Orographic

**DAD Zone 1**

**Latitude**: 38.415

**Longitude**: -78.335

**Max. Grid Rainfall Amount**: 28.39" in 41 hours

**Max. Observed Rainfall Amount**: 27.4" – Storm Center as indicated by Sterling WSR-88D in Smith et al., 1995 Catastrophic rainfall from an upslope thunderstorm in the central Appalachians: The Rapidan storm of June 27, 1995

**Number of Stations**: 295 (220 Daily, 48 Hourly, 18 Hourly Pseudo and 9 Supplemental)

**SPAS Version**: 10

**Basemap:** PRISM June 1981-2010; ippt_allsites_1406_sum_in (SPAS-NEXRAD hrly basemap)

**Spatial resolution:** 00:00:36

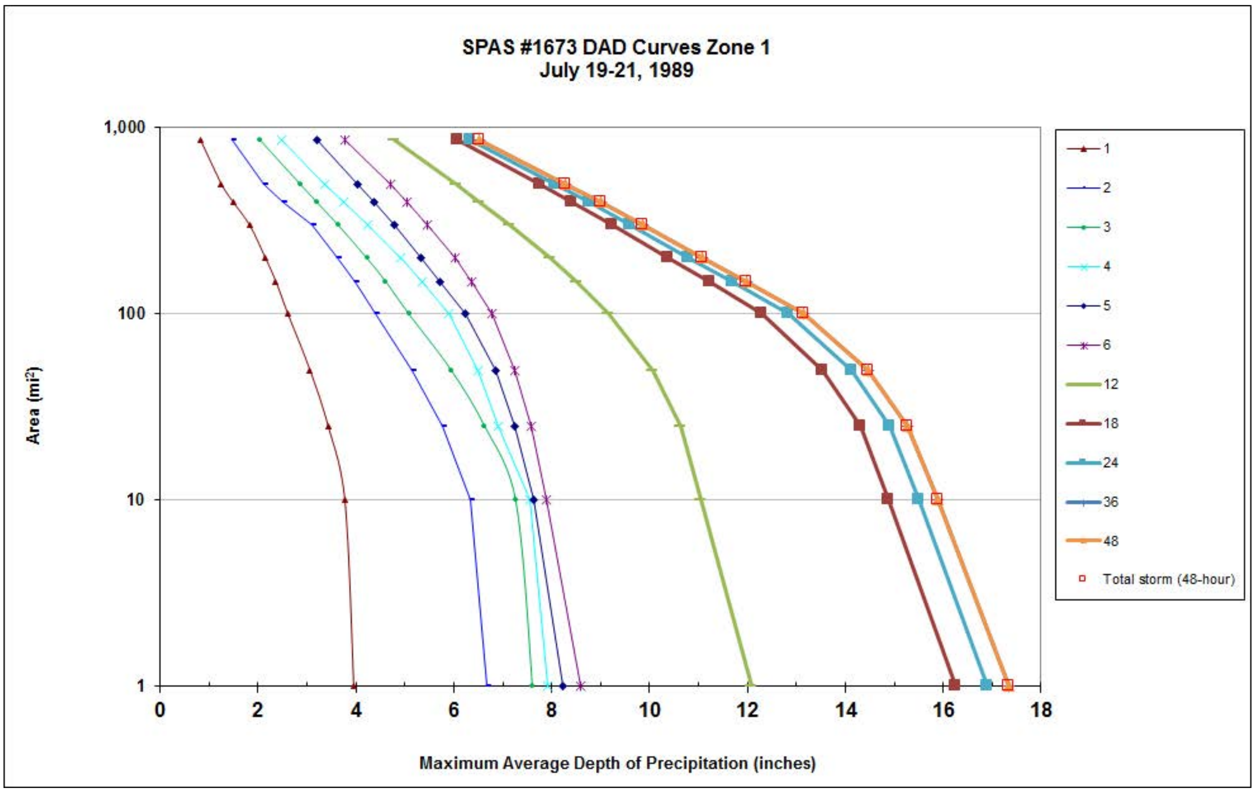
**Radar Included:** Yes

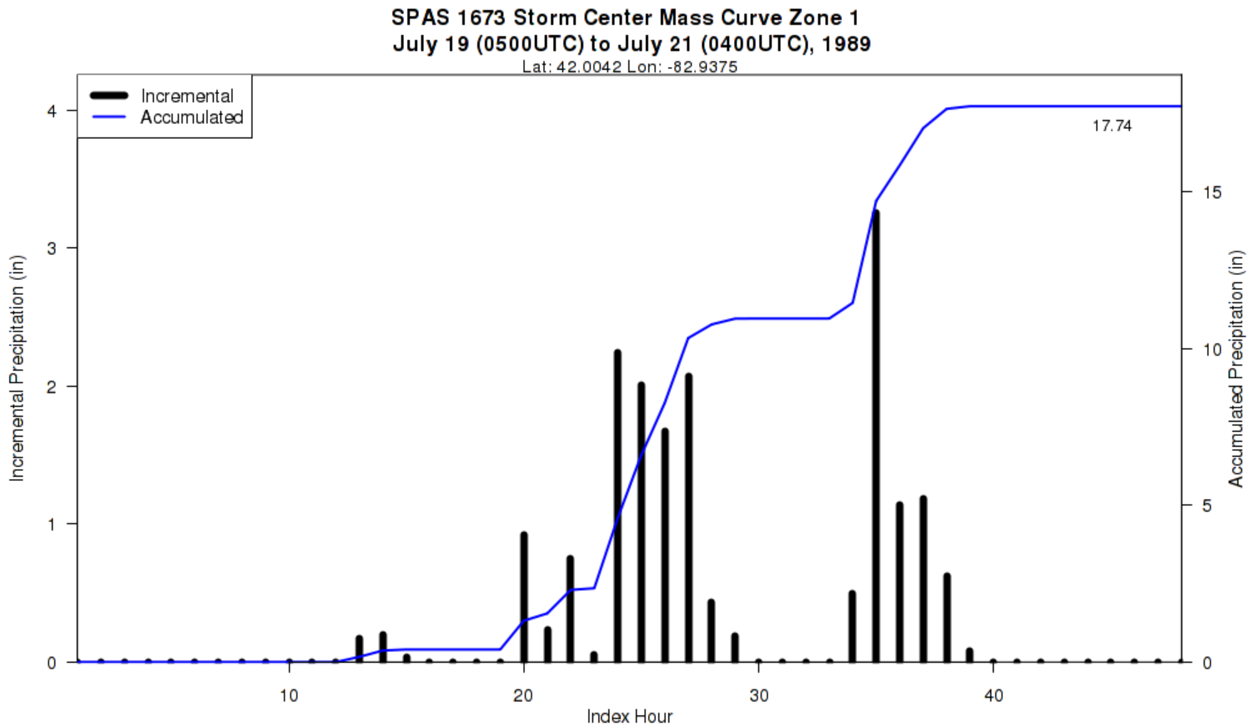
**Radar Beam-Blockage shapefile created:** Yes

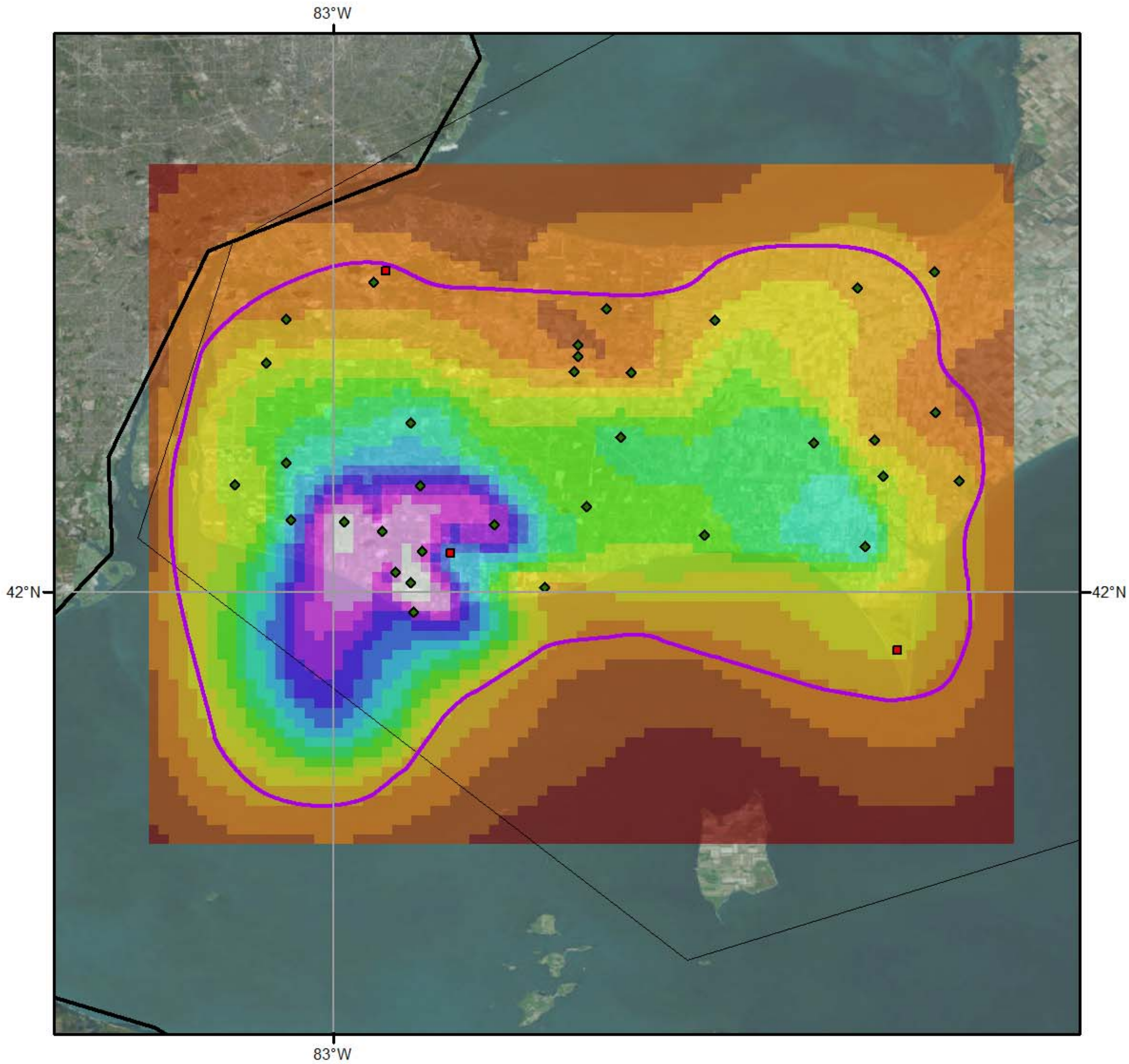
**Depth-Area-Duration (DAD) analysis**: Yes

**Reliability of results:** This analysis was based on hourly data, daily data and supplemental station data paired with SPAS-NEXRAD.  We have a high degree of confidence for the radar and station based storm total results. The spatial pattern dependent on the basemap and radar data with a high degree of confidence with the timing based on hourly and hourly pseudo stations.

| Storm 1673 Zone 1 - July 19 (0500 UTC) - July 21 (0400 UTC), 1989 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | |
| | Duration (hours) | | | | | | | | | | | |
| areasqmi | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 36 | 48 | Total |
| 0.4 | 3.98 | 6.71 | 7.65 | 7.97 | 8.35 | 8.72 | 12.26 | 16.50 | 17.21 | 17.60 | 17.60 | 17.60 |
| 1 | 3.95 | 6.67 | 7.60 | 7.92 | 8.23 | 8.59 | 12.08 | 16.25 | 16.89 | 17.33 | 17.33 | 17.33 |
| 10 | 3.77 | 6.35 | 7.26 | 7.56 | 7.63 | 7.88 | 11.05 | 14.87 | 15.51 | 15.88 | 15.88 | 15.88 |
| 25 | 3.43 | 5.77 | 6.63 | 6.92 | 7.24 | 7.57 | 10.63 | 14.30 | 14.91 | 15.27 | 15.27 | 15.27 |
| 50 | 3.06 | 5.15 | 5.95 | 6.50 | 6.86 | 7.25 | 10.06 | 13.53 | 14.13 | 14.47 | 14.47 | 14.47 |
| 100 | 2.61 | 4.40 | 5.09 | 5.90 | 6.23 | 6.77 | 9.16 | 12.30 | 12.83 | 13.15 | 13.15 | 13.15 |
| 150 | 2.36 | 3.97 | 4.61 | 5.36 | 5.72 | 6.37 | 8.50 | 11.22 | 11.70 | 11.99 | 11.99 | 11.99 |
| 200 | 2.15 | 3.63 | 4.23 | 4.91 | 5.34 | 6.02 | 7.98 | 10.38 | 10.80 | 11.07 | 11.07 | 11.07 |
| 300 | 1.83 | 3.09 | 3.65 | 4.24 | 4.79 | 5.45 | 7.14 | 9.24 | 9.60 | 9.85 | 9.85 | 9.85 |
| 400 | 1.49 | 2.52 | 3.21 | 3.75 | 4.36 | 5.05 | 6.51 | 8.42 | 8.76 | 9.00 | 9.00 | 9.00 |
| 500 | 1.25 | 2.12 | 2.87 | 3.36 | 4.04 | 4.71 | 6.06 | 7.75 | 8.06 | 8.28 | 8.28 | 8.28 |
| 864 | 0.82 | 1.48 | 2.05 | 2.47 | 3.21 | 3.78 | 4.79 | 6.09 | 6.35 | 6.53 | 6.53 | 6.53 |




SPAS 1673 Storm Center Mass Curve Zone 1
July 19 (0500UTC) to July 21 (0400UTC), 1989
Lat: 42.0042 Lon: -82.9375
Incremental
Accumulated
17.74
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
1
2
3
4
5
10
15
20
30
40




**Total Storm (48-hours) Precipitation (inches)**
**July 19 - 20, 1989**
**SPAS 1673 - Harrow, ON**

0 3.75 7.5 15 Miles
0 5 10 20 Kilometers

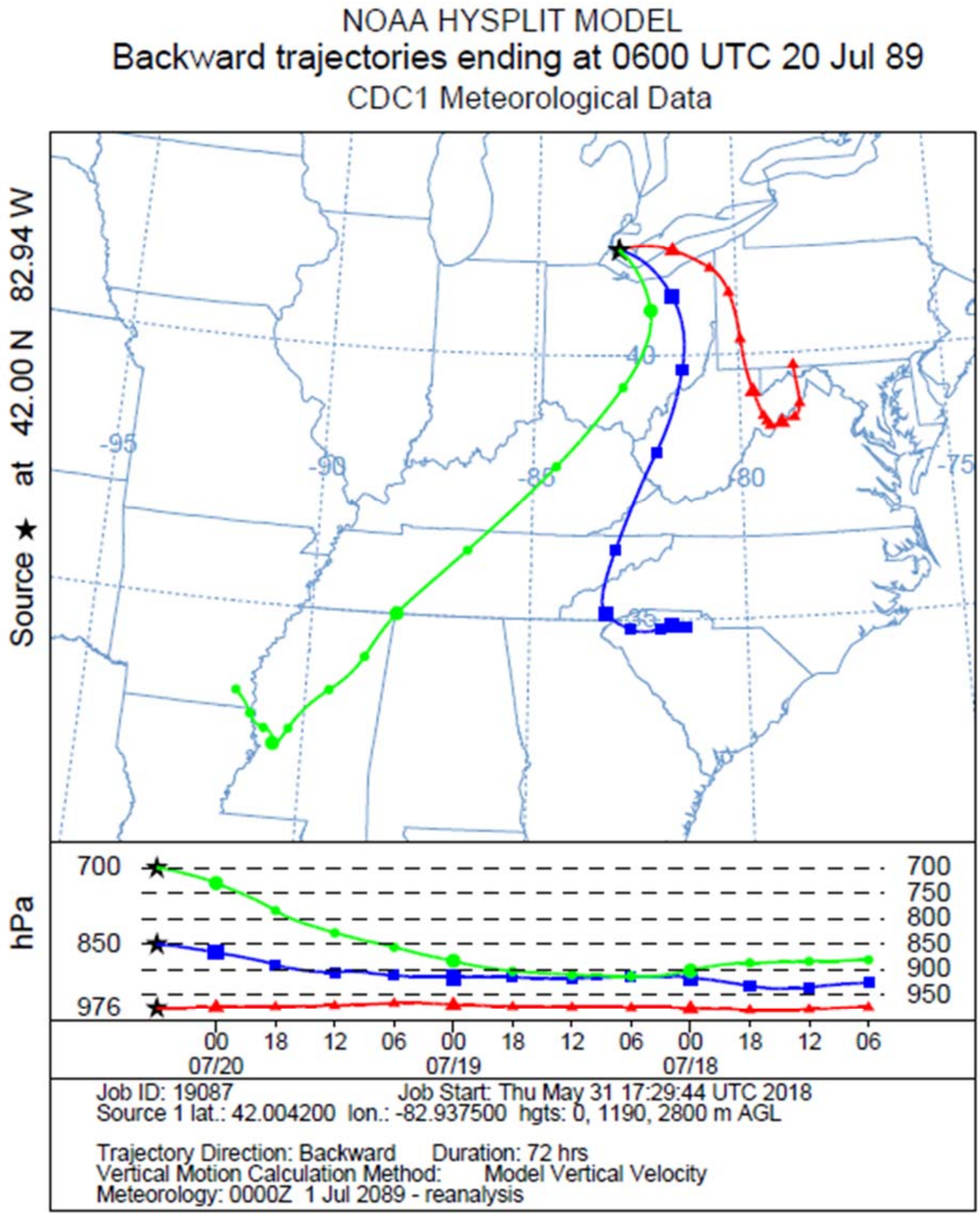
**Gauges**

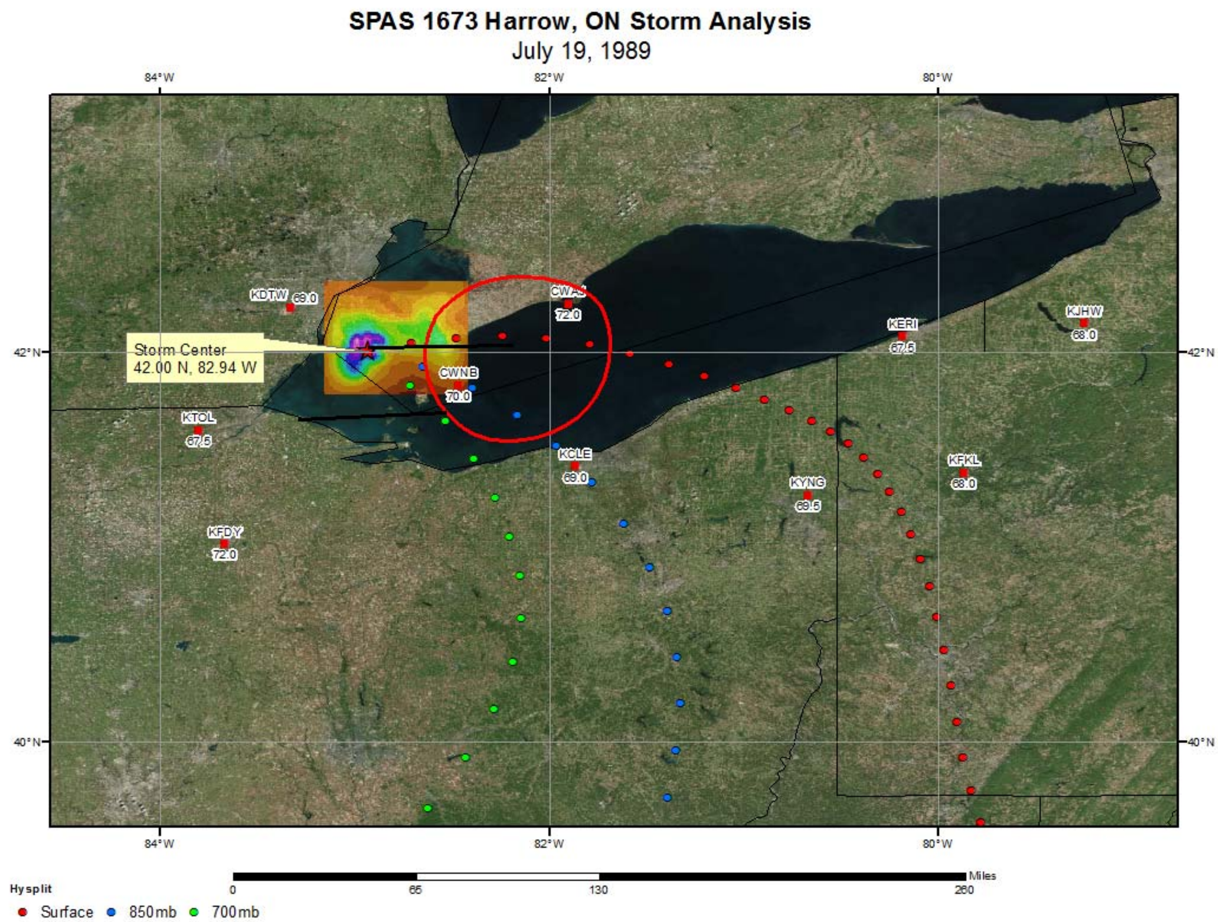
- H
- S

**Precipitation (Inches)**

- 0.82 - 2.07
- 2.08 - 2.87
- 2.88 - 3.60
- 3.61 - 4.46
- 4.47 - 5.32
- 5.33 - 6.25
- 6.26 - 7.18
- 7.19 - 8.11
- 8.12 - 9.11
- 9.12 - 10.23
- 10.24 - 11.36
- 11.37 - 12.36
- 12.37 - 13.35
- 13.36 - 14.41
- 14.42 - 15.61
- 15.62 - 17.76

3/4/2018


NOAA HYSPLIT MODEL
Backward trajectories ending at 0600 UTC 20 Jul 89
CDC1 Meteorological Data
Source ★ at 42.00 N 82.94 W
-95
-90
-85
-80
-75
40
35
hPa
700
850
976
700
750
800
850
900
950
00 18 12 06 00 18 12 06 00 18 12 06
07/20
07/19
07/18
Job ID: 19087 Job Start: Thu May 31 17:29:44 UTC 2018
Source 1 lat.: 42.004200 lon.: -82.937500 hgts: 0, 1190, 2800 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jul 2089 - reanalysis


SPAS 1673 Harrow, ON Storm Analysis
July 19, 1989
84°W
82°W
80°W
42°N
40°N
Storm Center
42.00 N, 82.94 W
KDTW 69.0
CWAJ 72.0
CWNB 70.0
KTOL 67.5
KCLE 69.0
KERI 67.5
KJHW 68.0
KYNG 69.5
KFKL 68.0
KFDY 72.0
Hysplit
Surface
850mb
700mb
0
65
130
260
Miles

# Storm Precipitation Analysis System (SPAS) For Storm #1726_1 SPAS-NEXRAD Analysis

**General Storm Location**: Upper Turtle River Watershed

**Storm Dates**: October 11-13, 2000

**Event**: Local

**DAD Zone 1**

**Latitude**: 47.9550

**Longitude**: -97.7550

**Max. Grid Rainfall Amount**: 20.00”

**Max. Observed Rainfall Amount**: 20.00”

**Number of Stations**: 254

**Basemap:** defaultP_285

**Spatial resolution:** 0.3189

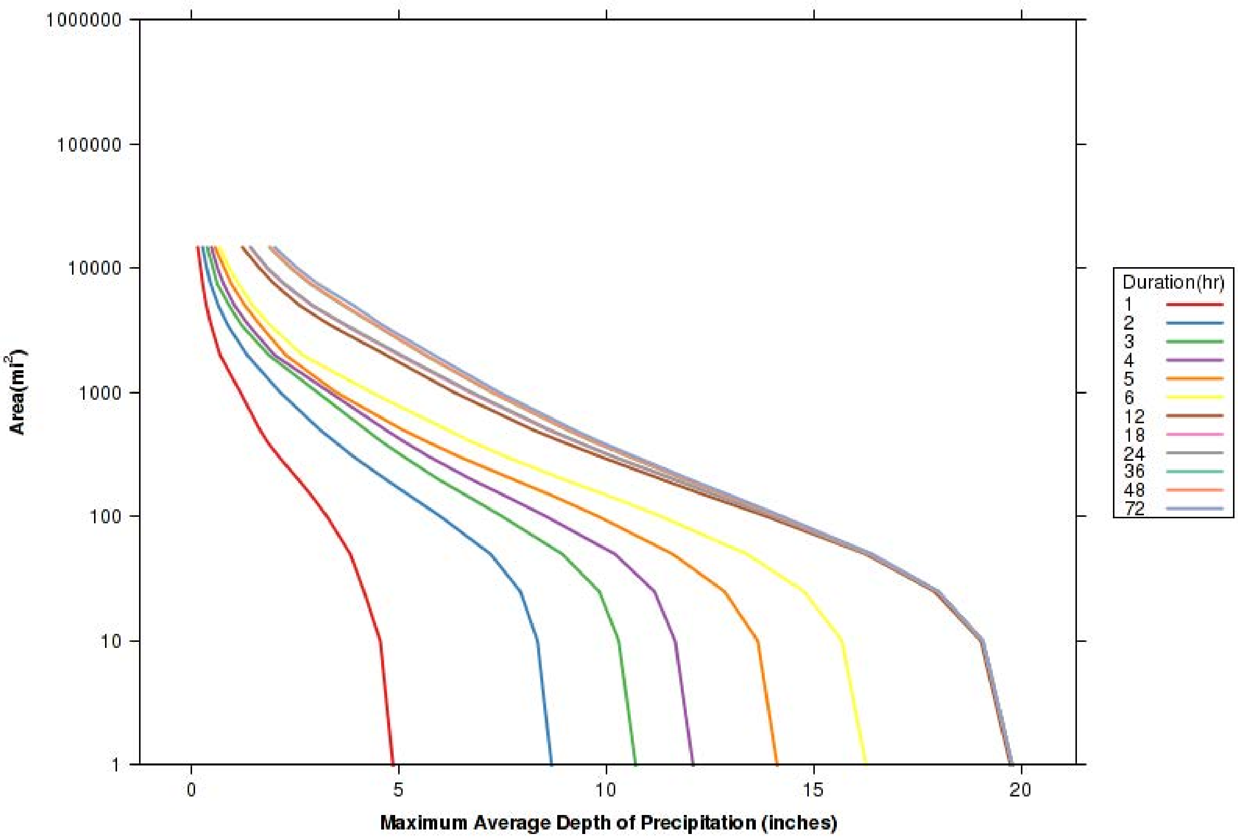
**Radar Included:** Yes

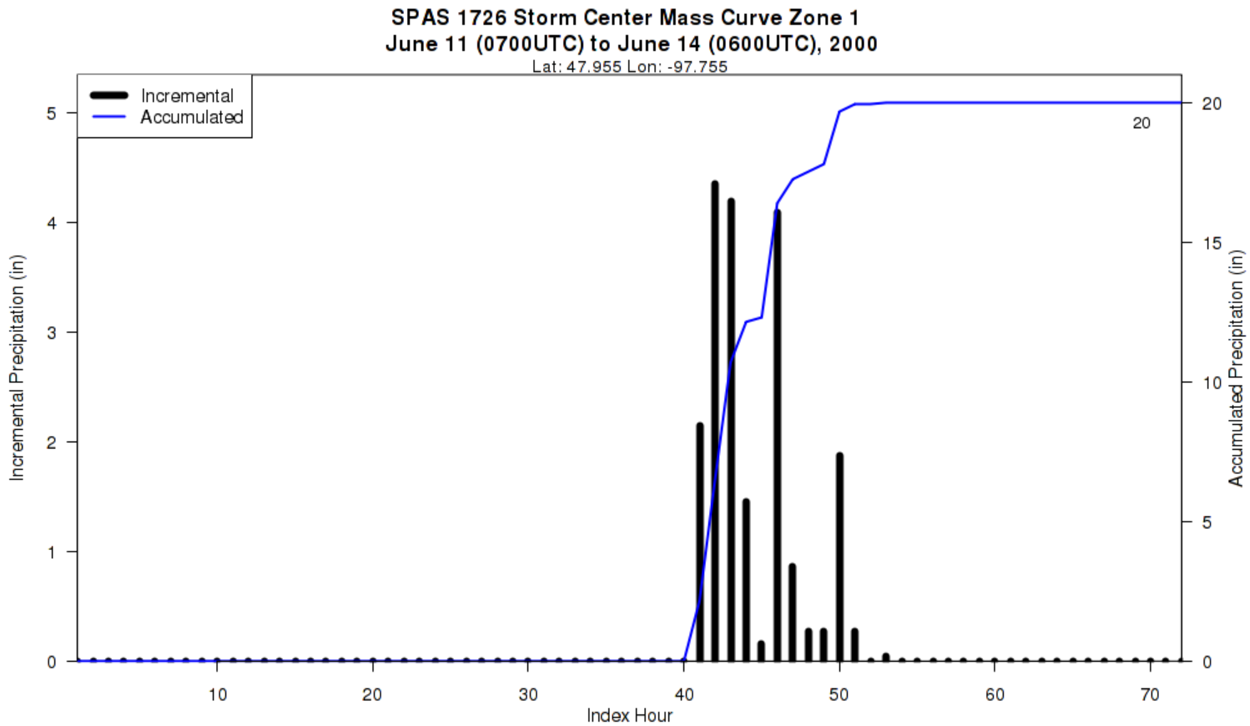
**Depth-Area-Duration (DAD) analysis**: Yes

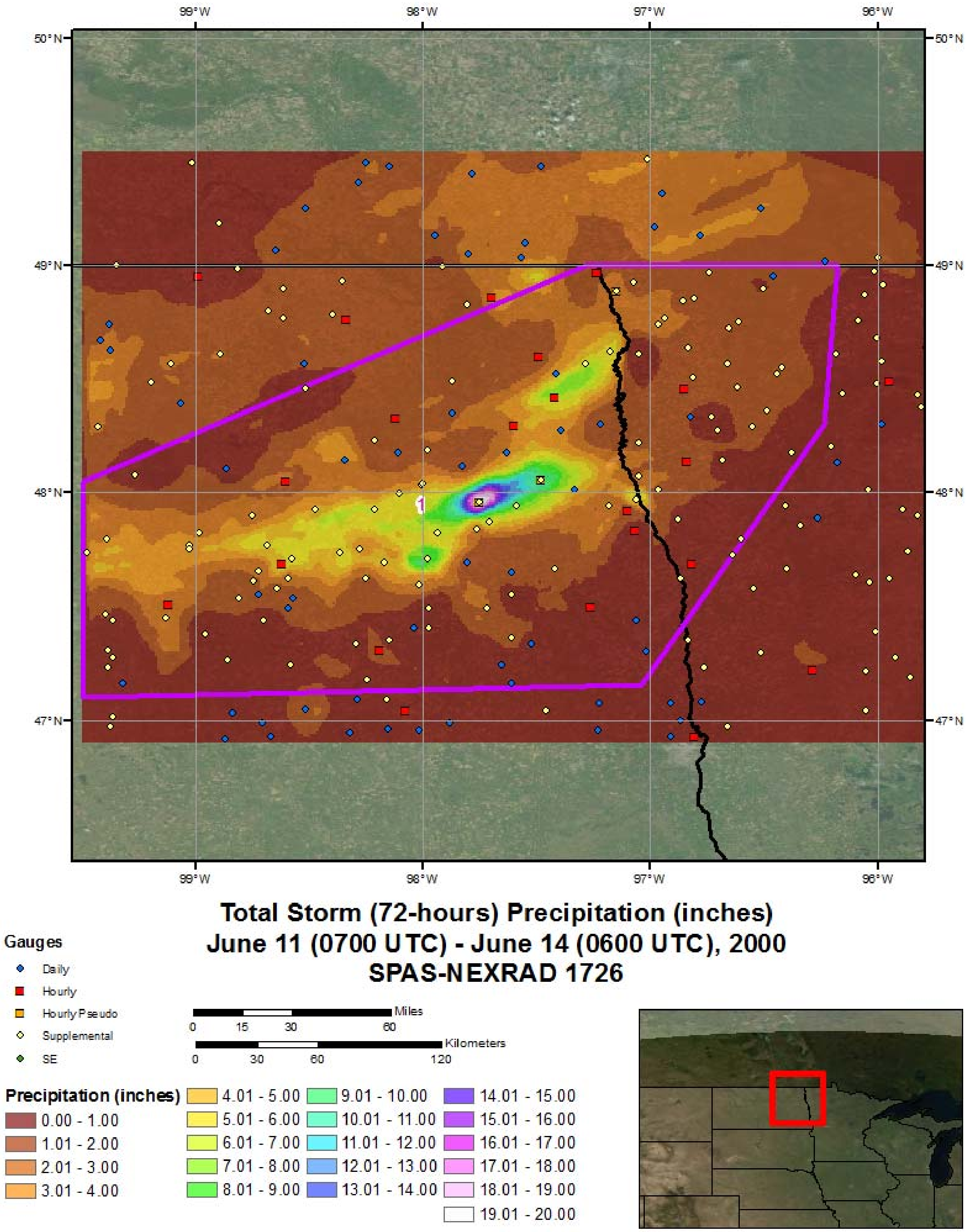
**Reliability of results:** This analysis was based on 254 hourly stations, daily data, supplemental station data and NEXRAD Radar. We have a good degree of confidence for the radar/station based storm total results. The spatial pattern is dependent on the radar data and basemap. Timing is based on the hourly and hourly pseudo stations. Several daily stations were moved to supplemental due to timing issues and to ensure data consistency.

| Storm 1726 - June 11 (0700 UTC) - June 14 (0600 UTC), 2000 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | | |
| Area (mi$^2$) | Duration (hours) | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | 36 | 48 | 72 | Total |
| 0.4 | 4.91 | 8.77 | 10.81 | 12.18 | 14.24 | 16.39 | 19.91 | 19.96 | 19.96 | 19.96 | 19.96 | 19.96 | 19.96 |
| 1 | 4.86 | 8.68 | 10.71 | 12.09 | 14.12 | 16.26 | 19.74 | 19.79 | 19.79 | 19.79 | 19.79 | 19.79 | 19.79 |
| 10 | 4.55 | 8.34 | 10.30 | 11.66 | 13.65 | 15.68 | 19.03 | 19.08 | 19.08 | 19.08 | 19.08 | 19.08 | 19.08 |
| 25 | 4.16 | 7.93 | 9.83 | 11.16 | 12.85 | 14.77 | 17.91 | 17.99 | 17.99 | 18.00 | 18.00 | 18.01 | 18.01 |
| 50 | 3.83 | 7.21 | 8.94 | 10.21 | 11.60 | 13.39 | 16.25 | 16.32 | 16.32 | 16.38 | 16.38 | 16.41 | 16.41 |
| 100 | 3.27 | 6.01 | 7.50 | 8.56 | 9.82 | 11.33 | 13.88 | 14.05 | 14.06 | 14.17 | 14.18 | 14.26 | 14.26 |
| 200 | 2.57 | 4.68 | 5.95 | 6.74 | 7.75 | 8.96 | 11.33 | 11.62 | 11.64 | 11.87 | 11.89 | 12.01 | 12.01 |
| 300 | 2.12 | 3.93 | 5.14 | 5.76 | 6.49 | 7.62 | 9.90 | 10.20 | 10.22 | 10.58 | 10.61 | 10.74 | 10.74 |
| 400 | 1.83 | 3.46 | 4.59 | 5.13 | 5.69 | 6.76 | 8.94 | 9.28 | 9.32 | 9.69 | 9.71 | 9.85 | 9.85 |
| 500 | 1.65 | 3.10 | 4.21 | 4.68 | 5.09 | 6.16 | 8.23 | 8.59 | 8.64 | 9.05 | 9.07 | 9.22 | 9.22 |
| 1,000 | 1.18 | 2.14 | 3.04 | 3.34 | 3.49 | 4.34 | 6.33 | 6.71 | 6.76 | 7.24 | 7.26 | 7.42 | 7.42 |
| 2,000 | 0.69 | 1.34 | 1.86 | 2.00 | 2.27 | 2.67 | 4.69 | 5.00 | 5.05 | 5.62 | 5.65 | 5.84 | 5.84 |
| 5,000 | 0.36 | 0.65 | 0.91 | 1.04 | 1.29 | 1.48 | 2.61 | 2.90 | 2.93 | 3.66 | 3.69 | 3.91 | 3.91 |
| 10,000 | 0.22 | 0.37 | 0.52 | 0.63 | 0.79 | 0.91 | 1.64 | 1.82 | 1.84 | 2.39 | 2.41 | 2.55 | 2.55 |

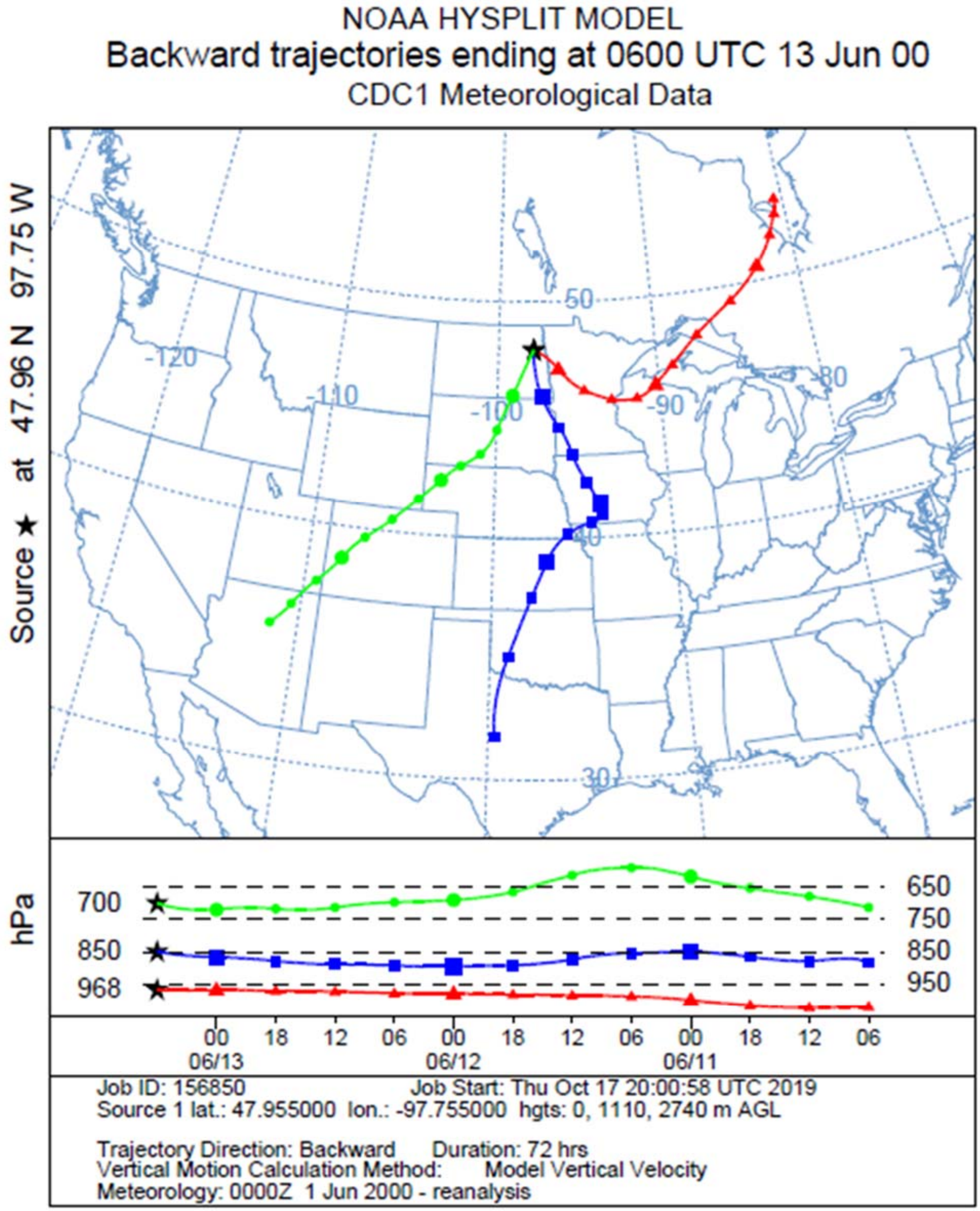
**SPAS 1726 DAD Curves Zone 1**
**June 11 (0700UTC) to June 14 (0600UTC), 2000**




SPAS 1726 Storm Center Mass Curve Zone 1
June 11 (0700UTC) to June 14 (0600UTC), 2000
Lat: 47.955 Lon: -97.755
Incremental
Accumulated
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
20

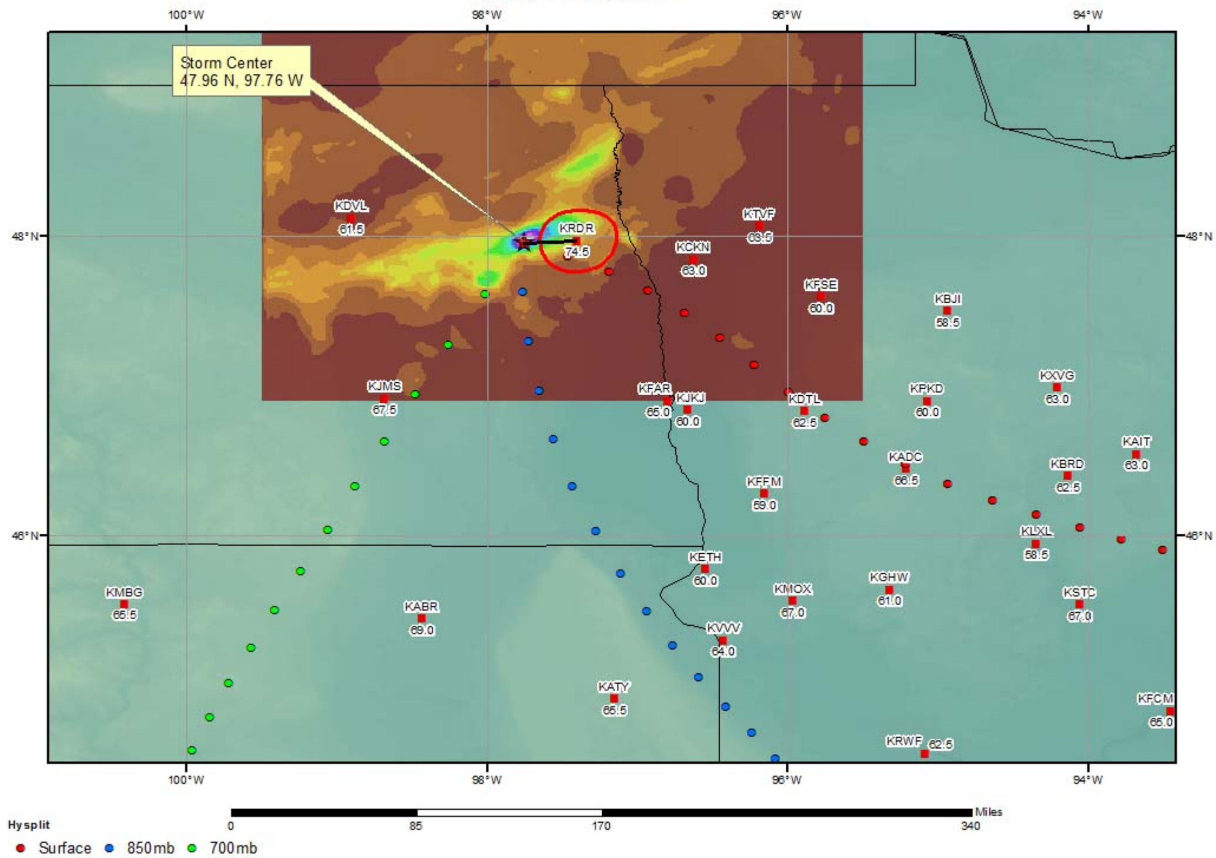



**Total Storm (72-hours) Precipitation (inches)**
**June 11 (0700 UTC) - June 14 (0600 UTC), 2000**
**SPAS-NEXRAD 1726**



NOAA HYSPLIT MODEL
Backward trajectories ending at 0600 UTC 13 Jun 00
CDC1 Meteorological Data
Source ★ at 47.96 N 97.75 W
50
-120
-110
-100
-90
-80
40
30
hPa
700
850
968
650
750
850
950
00
18
12
06
00
18
12
06
00
18
12
06
06/13
06/12
06/11
Job ID: 156850
Job Start: Thu Oct 17 20:00:58 UTC 2019
Source 1 lat.: 47.955000 lon.: -97.755000 hgts: 0, 1110, 2740 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jun 2000 - reanalysis

## SPAS 1726 Storm Analysis
June 12-13, 2000



# Storm Precipitation Analysis System (SPAS) For Storm #1220_1
# SPAS-NEXRAD Analysis

**General Storm Location**: Eastern Iowa, Southwestern Wisconsin and Northwestern Illinois

**Storm Dates**: July 27, 2011 2100 UTC - July 28, 2011 2000 UTC

**Event**: Mesoscale Convective System (MCS) along a stalled front

**DAD Zone 1**

**Latitude**: 42.44

**Longitude**: -90.75

**Max. Grid Rainfall Amount**: 15.14”

**Max. Observed Rainfall Amount**: 15.10” (2 miles SE of Julien, IA)

**Number of Stations**: 157 (25 Daily, 42 Hourly, 0 Hourly Estimated, 0 Hourly Estimated Pseudo, 14 Hourly Pseudo, 76 Supplemental, and 0 Supplemental Estimated)

**SPAS Version**: 9.0

**Basemap:** PRISM Mean (1971-2000) July precipitation

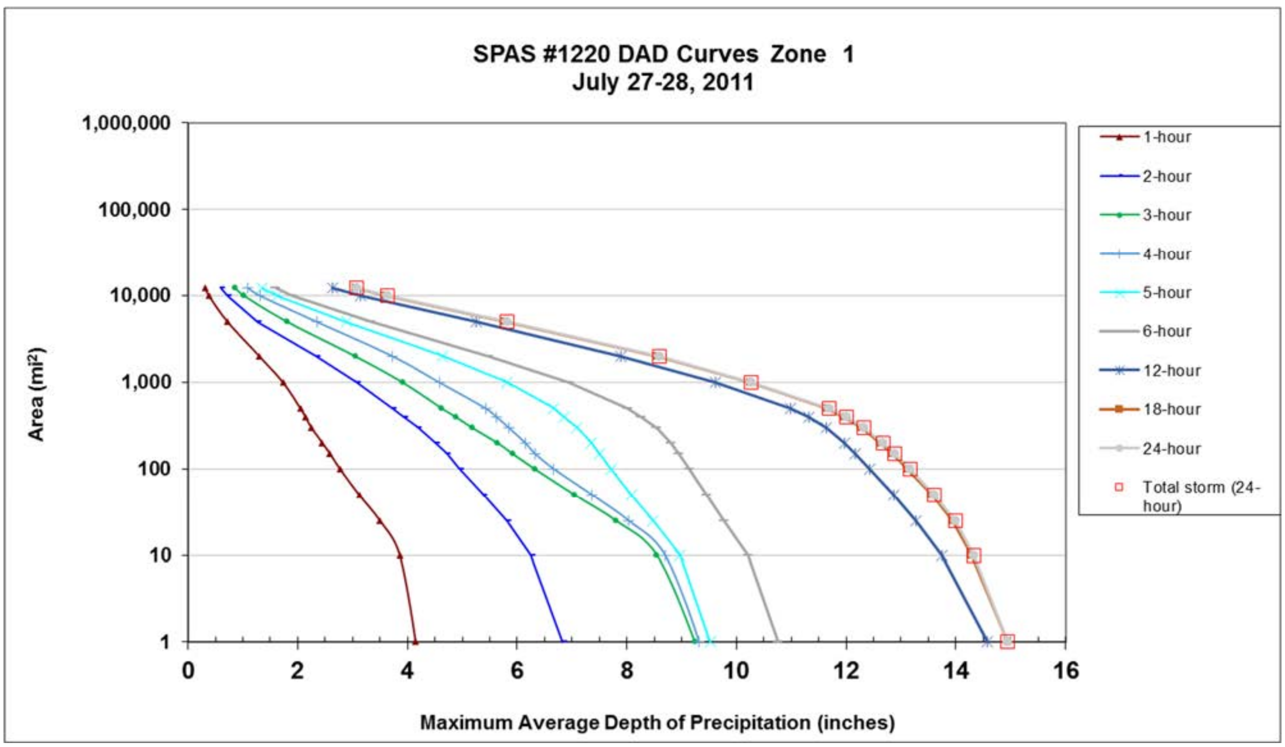
**Spatial resolution:** 36 seconds (~0.35 $mi^2$)

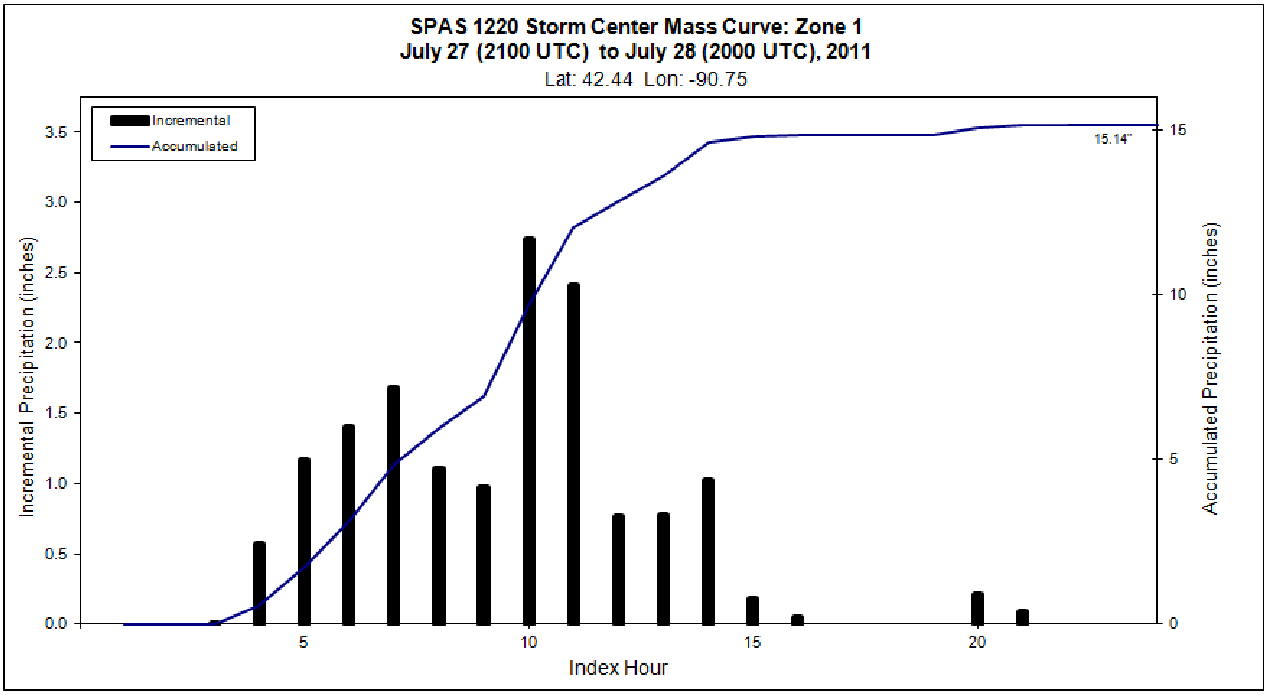
**Radar Included:** Yes

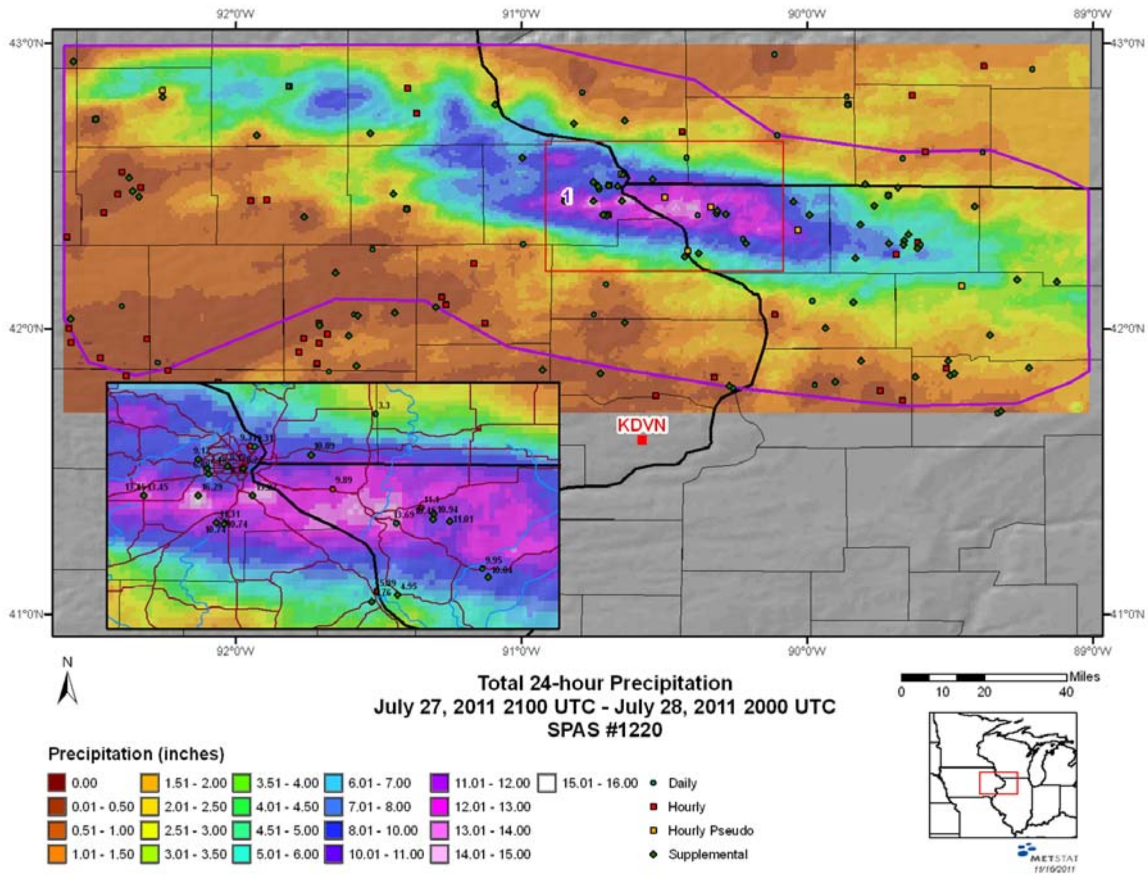
**Depth-Area-Duration (DAD) analysis**: Yes

**Reliability of results:** Given the unblocked, clean and QC’ed radar data coupled with relatively extensive gauge data, we have a very high degree of confidence in the results.  No supplemental estimated stations were warranted in this analysis.

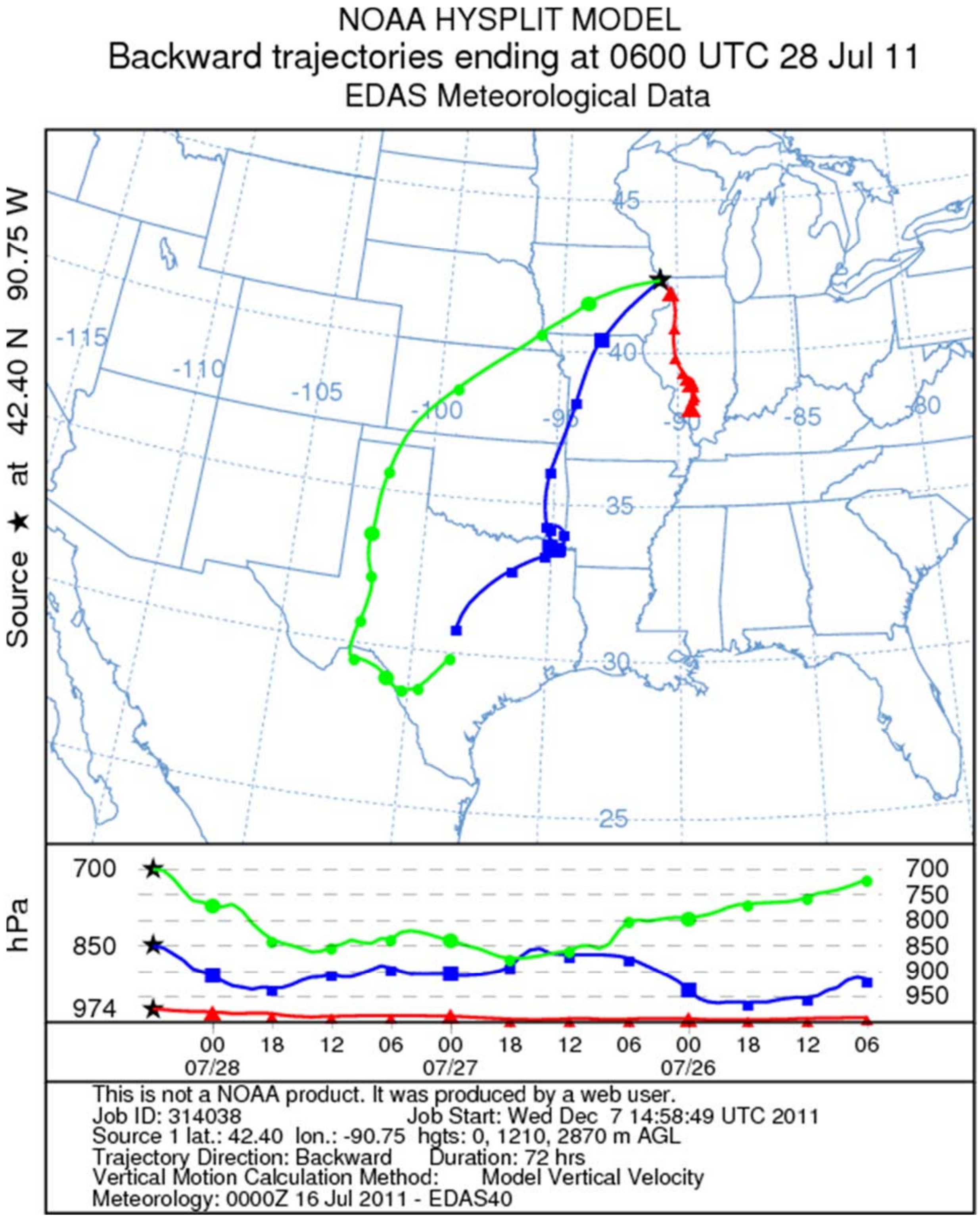
| Storm 1220 - July 27 (2100 UTC) - July 28 (2000 UTC), 2011 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | |
| Area ($mi^2$) | Duration (hours) | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | Total |
| 0.4 | 4.19 | 6.91 | 9.36 | 9.40 | 9.63 | 10.88 | 14.77 | 15.11 | 15.12 | 15.12 |
| 1 | 4.15 | 6.83 | 9.24 | 9.32 | 9.52 | 10.75 | 14.58 | 14.94 | 14.95 | 14.95 |
| 10 | 3.86 | 6.25 | 8.55 | 8.70 | 8.97 | 10.22 | 13.75 | 14.30 | 14.32 | 14.32 |
| 25 | 3.50 | 5.81 | 7.81 | 8.04 | 8.48 | 9.77 | 13.27 | 13.94 | 13.99 | 13.99 |
| 50 | 3.12 | 5.38 | 7.05 | 7.37 | 8.08 | 9.45 | 12.86 | 13.57 | 13.60 | 13.60 |
| 100 | 2.77 | 4.95 | 6.32 | 6.67 | 7.71 | 9.14 | 12.43 | 13.12 | 13.16 | 13.16 |
| 150 | 2.59 | 4.71 | 5.92 | 6.33 | 7.50 | 8.95 | 12.16 | 12.85 | 12.89 | 12.89 |
| 200 | 2.45 | 4.51 | 5.64 | 6.15 | 7.35 | 8.81 | 11.97 | 12.63 | 12.67 | 12.67 |
| 300 | 2.25 | 4.19 | 5.18 | 5.85 | 7.09 | 8.55 | 11.64 | 12.29 | 12.33 | 12.33 |
| 400 | 2.14 | 3.93 | 4.88 | 5.62 | 6.85 | 8.26 | 11.32 | 11.96 | 12.00 | 12.00 |
| 500 | 2.05 | 3.72 | 4.63 | 5.43 | 6.67 | 8.02 | 10.99 | 11.66 | 11.69 | 11.69 |
| 1,000 | 1.73 | 3.07 | 3.91 | 4.58 | 5.81 | 6.95 | 9.62 | 10.24 | 10.27 | 10.27 |
| 2,000 | 1.30 | 2.33 | 3.05 | 3.73 | 4.64 | 5.49 | 7.89 | 8.56 | 8.59 | 8.59 |
| 5,000 | 0.72 | 1.27 | 1.81 | 2.35 | 2.89 | 3.33 | 5.25 | 5.79 | 5.81 | 5.81 |
| 10,000 | 0.38 | 0.72 | 1.02 | 1.31 | 1.64 | 1.89 | 3.14 | 3.61 | 3.63 | 3.63 |
| 12,296 | 0.31 | 0.60 | 0.86 | 1.09 | 1.36 | 1.59 | 2.63 | 3.06 | 3.07 | 3.07 |

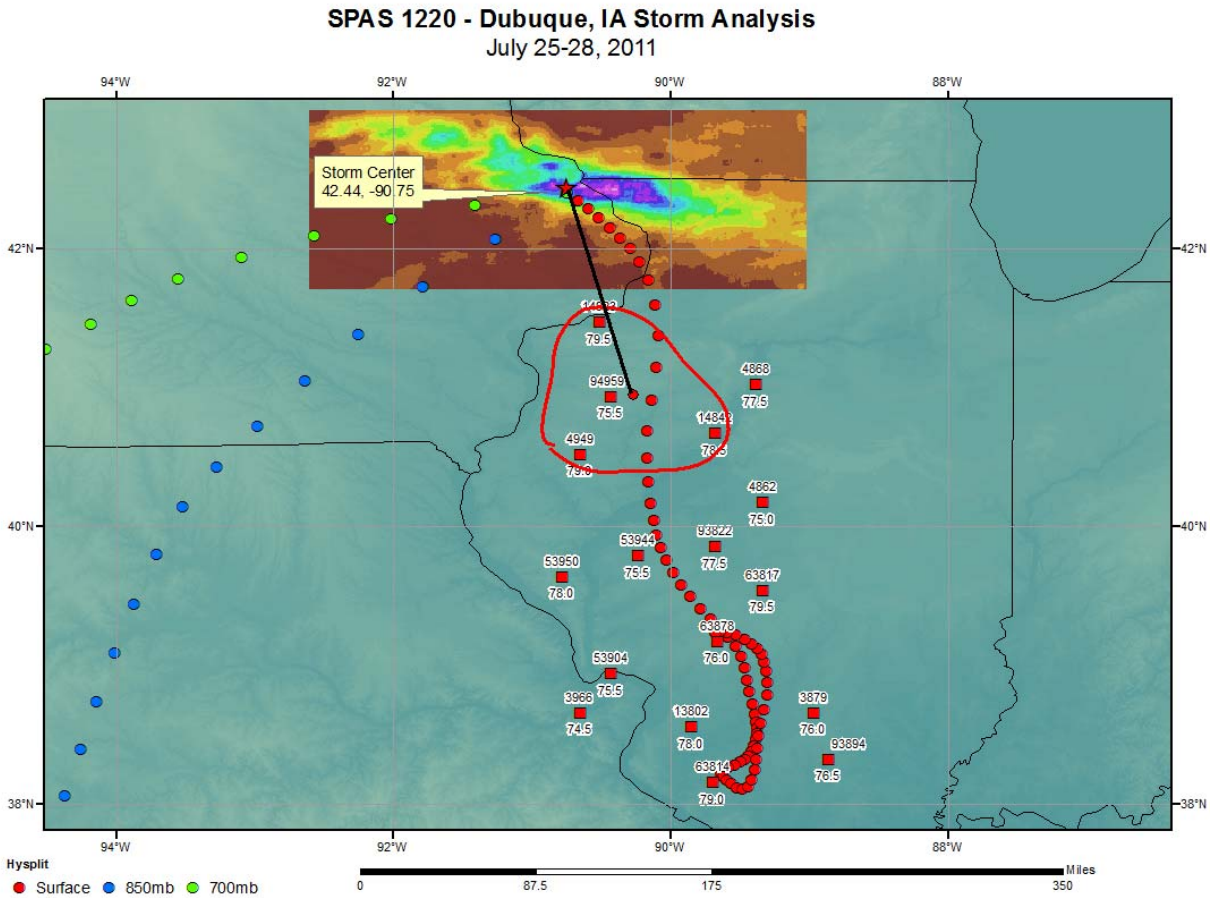



SPAS 1220 Storm Center Mass Curve: Zone 1
July 27 (2100 UTC) to July 28 (2000 UTC), 2011
Lat: 42.44 Lon: -90.75
Incremental
Accumulated
15.14"
Incremental Precipitation (inches)
Accumulated Precipitation (inches)
Index Hour




**Total 24-hour Precipitation**
**July 27, 2011 2100 UTC - July 28, 2011 2000 UTC**
**SPAS #1220**


NOAA HYSPLIT MODEL
Backward trajectories ending at 0600 UTC 28 Jul 11
EDAS Meteorological Data
Source ★ at 42.40 N 90.75 W
hPa
700
850
974
700
750
800
850
900
950
00 18 12 06 00 18 12 06 00 18 12 06
07/28
07/27
07/26
This is not a NOAA product. It was produced by a web user.
Job ID: 314038 Job Start: Wed Dec 7 14:58:49 UTC 2011
Source 1 lat.: 42.40 lon.: -90.75 hgts: 0, 1210, 2870 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 16 Jul 2011 - EDAS40


SPAS 1220 - Dubuque, IA Storm Analysis
July 25-28, 2011
Storm Center
42.44, -90.75
Hysplit
Surface
850mb
700mb
Miles
0
87.5
175
350

# Storm Precipitation Analysis System (SPAS) For Storm #1727_1 SPAS-NEXRAD Analysis

**General Storm Location**: Drummond, WI

**Storm Dates**: June 15-18, 2018

**Event**: Local

**DAD Zone 1**

**Latitude**: 46.3150

**Longitude**: -91.4150

**Max. Grid Rainfall Amount**: 17.33”

**Max. Observed Rainfall Amount**: 15.03”

**Number of Stations**: 433

**Basemap:** Default Radar Precipitation Total Strom (300R1.4)

**Spatial resolution:** 0.33

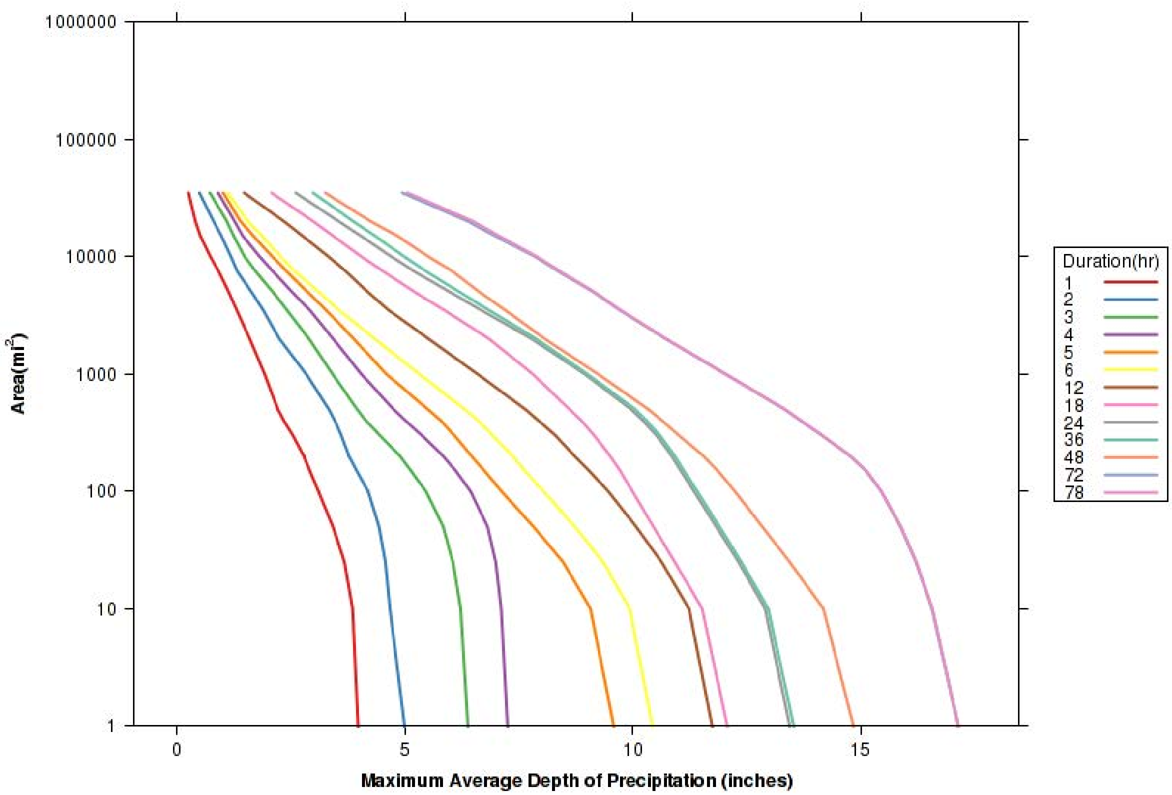
**Radar Included:** Yes

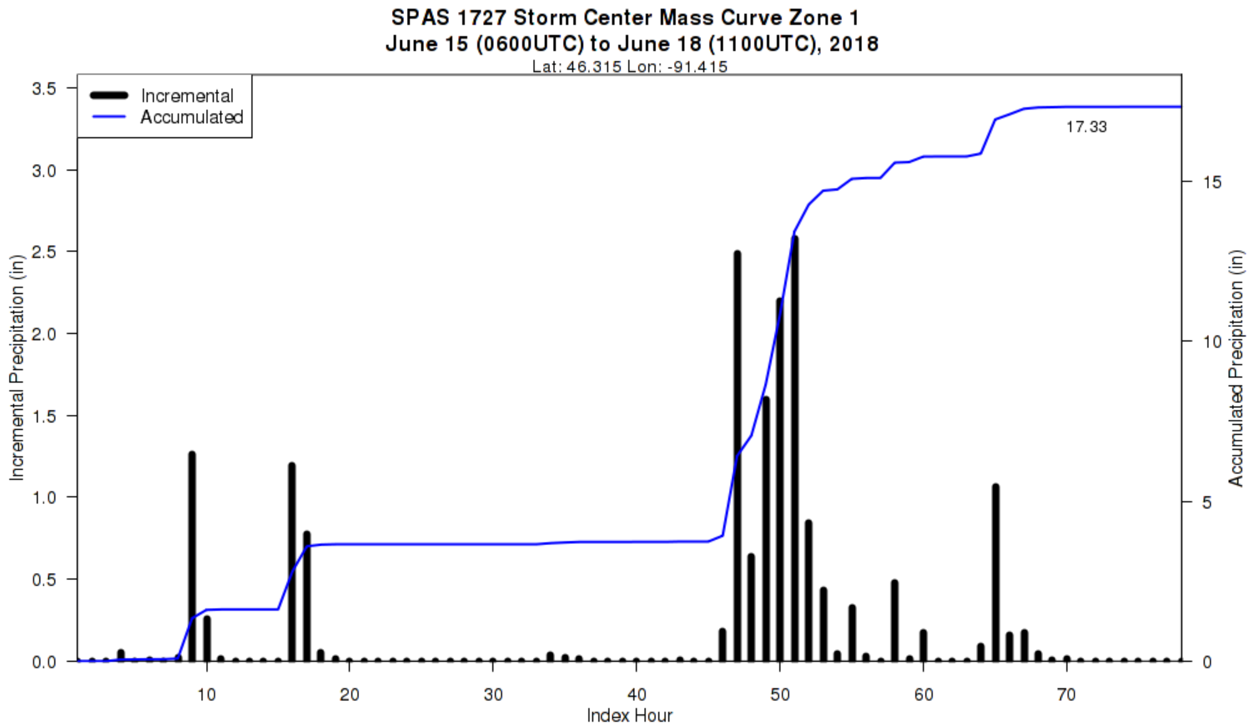
**Depth-Area-Duration (DAD) analysis**: Yes

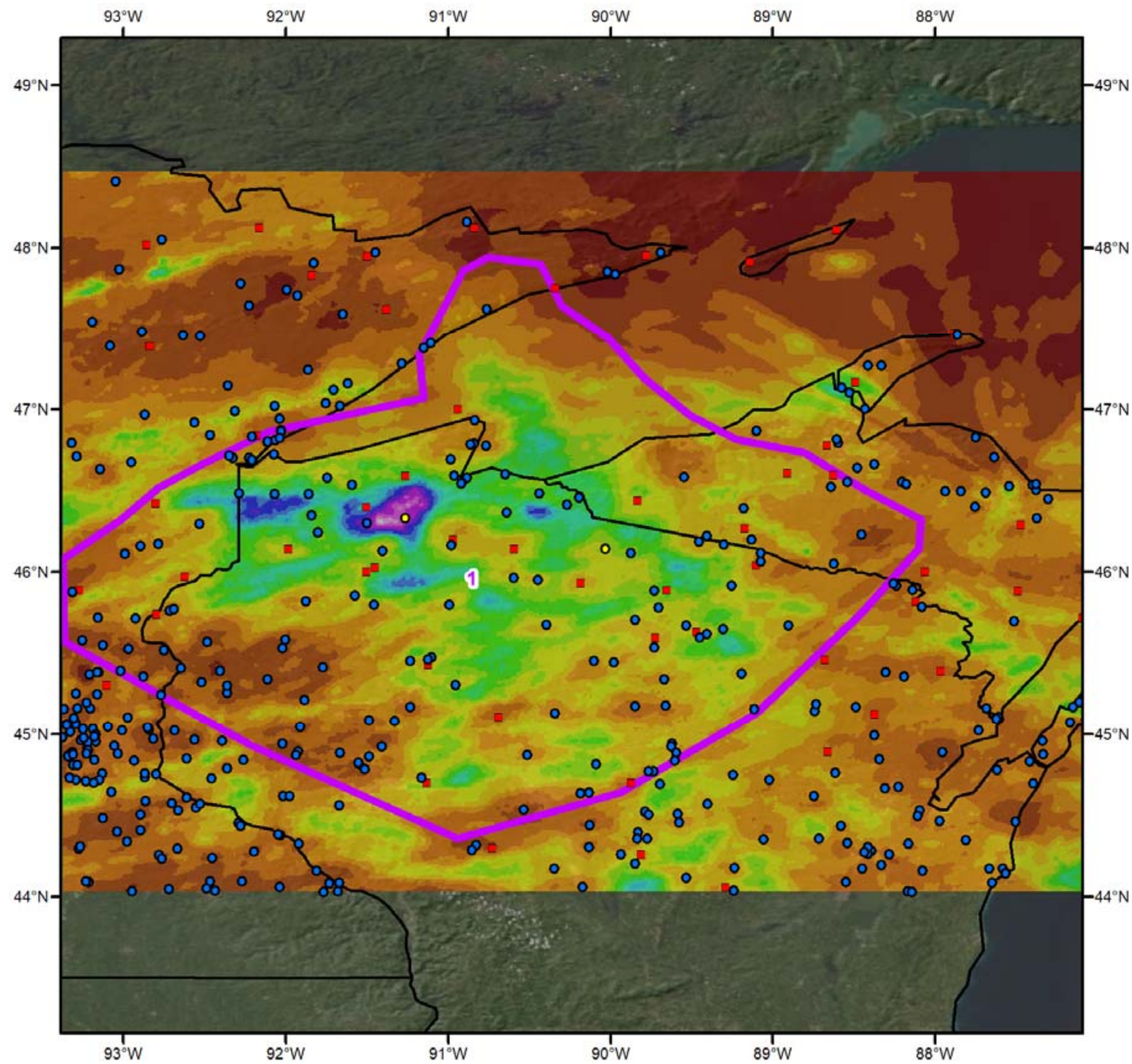
**Reliability of results:** This analysis was based on 433 hourly stations, daily data, supplemental station data and radar data. We have a good degree of confidence for the radar and station based storm total results. The spatial pattern is fully dependent on the radar data and basemap. Timing is based on hourly stations and sun-hourly data is based on 5-minute radar data. A couple daily stations were moved to supplemental due to timing issues and to ensure data consistency.

| SPAS 1727 - June 15 (0600 UTC) - June 18 (1100 UTC), 2018 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | | | | |
| Area ($mi^2$) | Duration (hours) | | | | | | | | | | | | |
| | 1hr | 2hr | 3hr | 4hr | 5hr | 6hr | 12hr | 18hr | 24hr | 36hr | 48hr | 72hr | Total (78hr) |
| 0.4 | 4.01 | 5.08 | 6.46 | 7.33 | 9.68 | 10.54 | 11.85 | 12.19 | 13.58 | 13.64 | 14.99 | 17.30 | 17.30 |
| 1 | 3.98 | 5.00 | 6.39 | 7.26 | 9.59 | 10.44 | 11.75 | 12.08 | 13.45 | 13.54 | 14.85 | 17.15 | 17.15 |
| 10 | 3.86 | 4.68 | 6.23 | 7.12 | 9.08 | 9.94 | 11.24 | 11.53 | 12.91 | 12.98 | 14.19 | 16.57 | 16.58 |
| 25 | 3.68 | 4.58 | 6.06 | 7.00 | 8.48 | 9.36 | 10.64 | 10.93 | 12.33 | 12.39 | 13.45 | 16.22 | 16.23 |
| 50 | 3.43 | 4.44 | 5.85 | 6.82 | 7.83 | 8.74 | 10.08 | 10.46 | 11.84 | 11.91 | 12.85 | 15.88 | 15.89 |
| 100 | 3.11 | 4.20 | 5.47 | 6.45 | 7.13 | 8.05 | 9.47 | 10.00 | 11.35 | 11.42 | 12.25 | 15.46 | 15.46 |
| 150 | 2.92 | 3.95 | 5.14 | 6.12 | 6.75 | 7.64 | 9.05 | 9.73 | 11.06 | 11.13 | 11.87 | 15.12 | 15.13 |
| 200 | 2.79 | 3.78 | 4.90 | 5.85 | 6.47 | 7.37 | 8.73 | 9.51 | 10.86 | 10.93 | 11.56 | 14.78 | 14.78 |
| 300 | 2.55 | 3.61 | 4.46 | 5.38 | 6.09 | 6.93 | 8.31 | 9.16 | 10.53 | 10.60 | 11.02 | 14.16 | 14.16 |
| 400 | 2.35 | 3.47 | 4.15 | 5.02 | 5.80 | 6.62 | 7.94 | 8.88 | 10.23 | 10.31 | 10.65 | 13.69 | 13.70 |
| 500 | 2.22 | 3.34 | 3.96 | 4.76 | 5.51 | 6.32 | 7.65 | 8.62 | 9.97 | 10.06 | 10.35 | 13.34 | 13.34 |
| 1,000 | 1.93 | 2.84 | 3.42 | 4.05 | 4.60 | 5.32 | 6.60 | 7.81 | 8.95 | 9.01 | 9.24 | 12.04 | 12.04 |
| 2,000 | 1.60 | 2.25 | 2.90 | 3.43 | 3.88 | 4.34 | 5.52 | 6.85 | 7.78 | 7.88 | 8.07 | 10.72 | 10.73 |
| 3,500 | 1.32 | 1.90 | 2.42 | 2.92 | 3.28 | 3.56 | 4.65 | 5.87 | 6.68 | 6.85 | 7.21 | 9.72 | 9.74 |
| 5,000 | 1.14 | 1.64 | 2.11 | 2.53 | 2.87 | 3.12 | 4.19 | 5.22 | 5.99 | 6.20 | 6.64 | 9.14 | 9.16 |
| 7,500 | 0.92 | 1.33 | 1.73 | 2.11 | 2.41 | 2.59 | 3.71 | 4.53 | 5.21 | 5.47 | 6.05 | 8.37 | 8.41 |
| 10,000 | 0.74 | 1.19 | 1.49 | 1.82 | 2.10 | 2.28 | 3.33 | 4.05 | 4.71 | 4.99 | 5.52 | 7.86 | 7.90 |
| 15,000 | 0.52 | 0.98 | 1.25 | 1.45 | 1.68 | 1.87 | 2.76 | 3.43 | 4.04 | 4.35 | 4.84 | 6.98 | 7.07 |
| 20,000 | 0.41 | 0.81 | 1.10 | 1.27 | 1.40 | 1.56 | 2.35 | 2.99 | 3.55 | 3.87 | 4.25 | 6.39 | 6.50 |
| 34,917 | 0.26 | 0.50 | 0.73 | 0.91 | 1.02 | 1.12 | 1.48 | 2.08 | 2.61 | 2.99 | 3.26 | 4.95 | 5.06 |

**SPAS 1727 DAD Curves Zone 1**
**June 15 (0600UTC) to June 18 (1100UTC), 2018**




SPAS 1727 Storm Center Mass Curve Zone 1
June 15 (0600UTC) to June 18 (1100UTC), 2018
Lat: 46.315 Lon: -91.415
Incremental
Accumulated
17.33
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
5
10
15
10
20
30
40
50
60
70




**Total Storm (78-hr) Precipitation (inches)**
**6/15/2018 0600 UTC - 6/18/2018 1100 UTC**
**SPAS-NEXRAD #1727**

**Gauges**

- Daily
- Hourly
- Supplemental

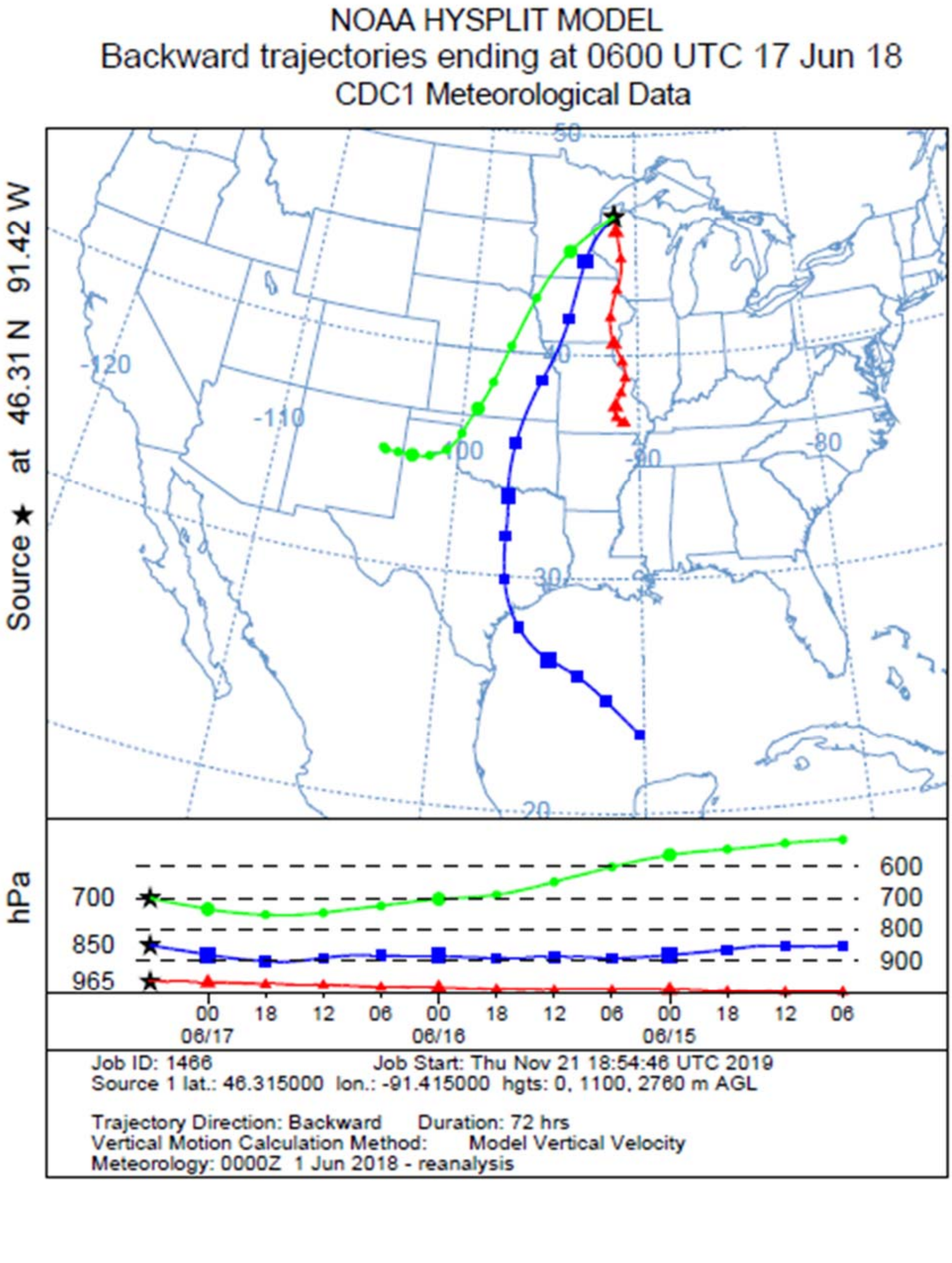
Miles: 0, 30, 60, 120

Kilometers: 0, 65, 130, 260

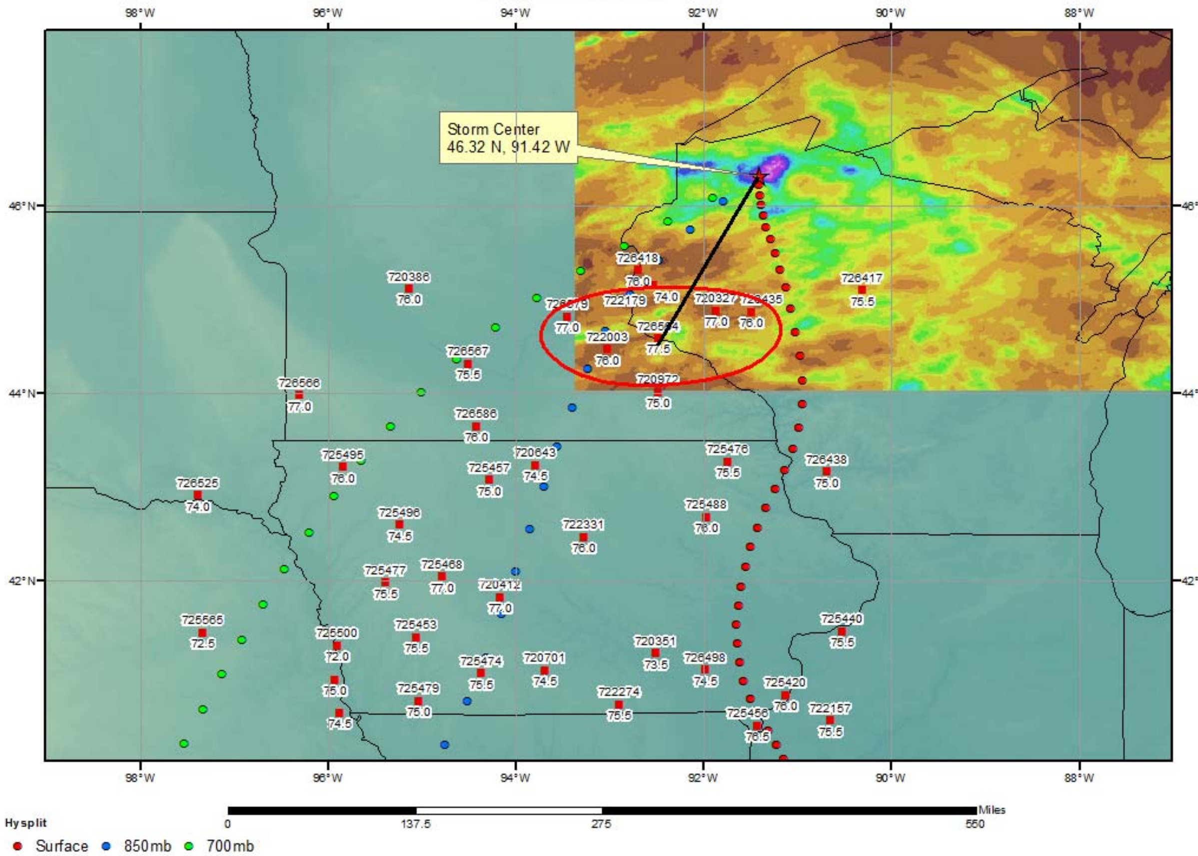
**Precipitation (inches)**

| | | | | |
|---|---|---|---|---|
| 0.08 - 1.00 | 4.01 - 5.00 | 8.01 - 9.00 | 12.01 - 13.00 | 16.01 - 17.00 |
| 1.01 - 2.00 | 5.01 - 6.00 | 9.01 - 10.00 | 13.01 - 14.00 | 17.01 - 18.00 |
| 2.01 - 3.00 | 6.01 - 7.00 | 10.01 - 11.00 | 14.01 - 15.00 | |
| 3.01 - 4.00 | 7.01 - 8.00 | 11.01 - 12.00 | 15.01 - 16.00 | |

11/21/2019


NOAA HYSPLIT MODEL
Backward trajectories ending at 0600 UTC 17 Jun 18
CDC1 Meteorological Data
Source ★ at 46.31 N 91.42 W
hPa
700
850
965
600
700
800
900
00 18 12 06 00 18 12 06 00 18 12 06
06/17
06/16
06/15
Job ID: 1466 Job Start: Thu Nov 21 18:54:46 UTC 2019
Source 1 lat.: 46.315000 lon.: -91.415000 hgts: 0, 1100, 2760 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jun 2018 - reanalysis

**SPAS 1727 Storm Analysis**
June 16-17, 2018



# Storm Precipitation Analysis System (SPAS) For Storm #1728_1 SPAS-NEXRAD Analysis

**General Storm Location**: Cross Plains, WI

**Storm Dates**: August 20-22, 2018

**Event**: Local

**DAD Zone 1**

**Latitude**: 43.1450

**Longitude**: -89.6150

**Max. Grid Rainfall Amount**: 16.24”

**Max. Observed Rainfall Amount**: 15.28”

**Number of Stations**: 656

**SPAS Version**: 10

**Basemap:** 80/20 split of radar and ippt

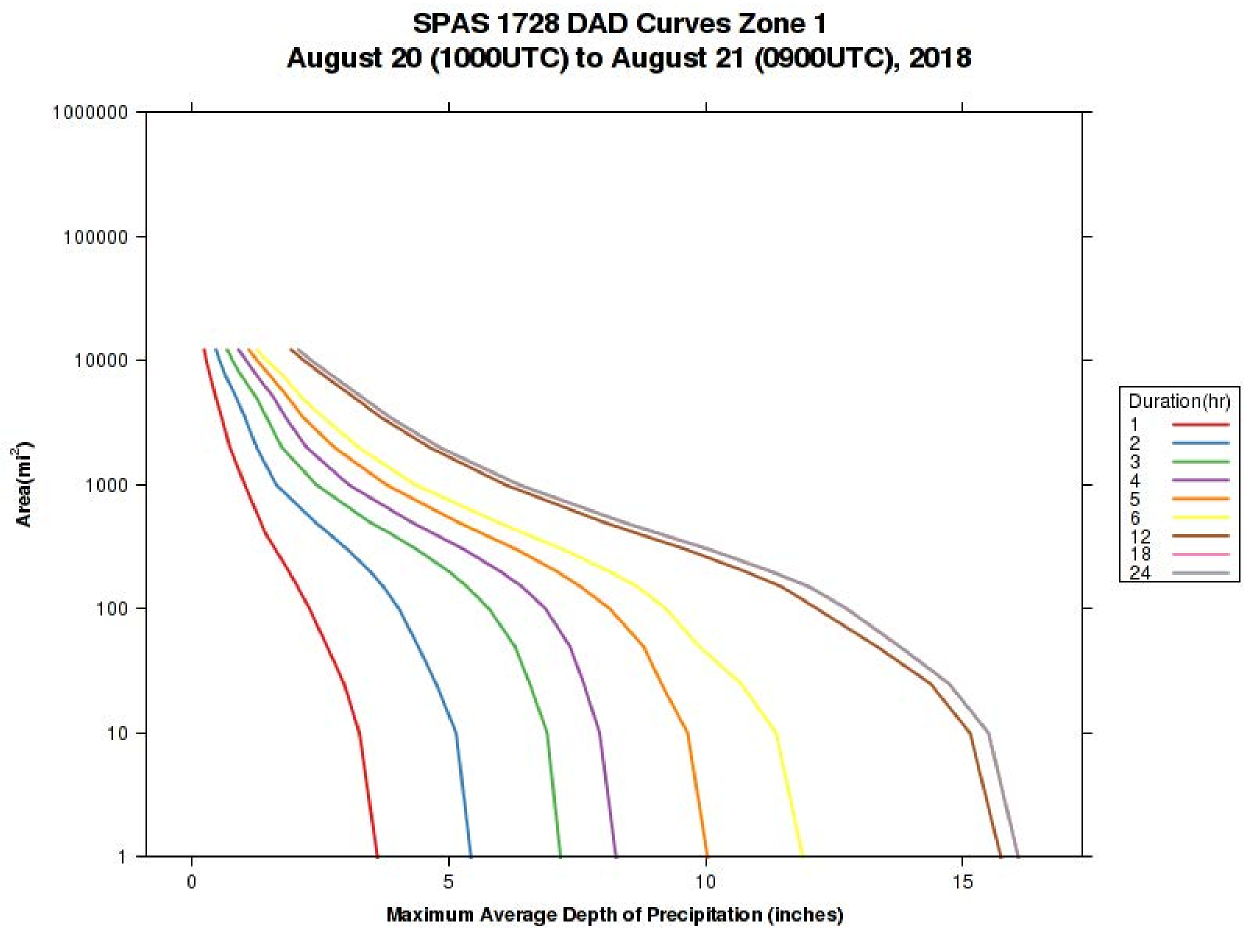
**Spatial resolution:** 0.3502

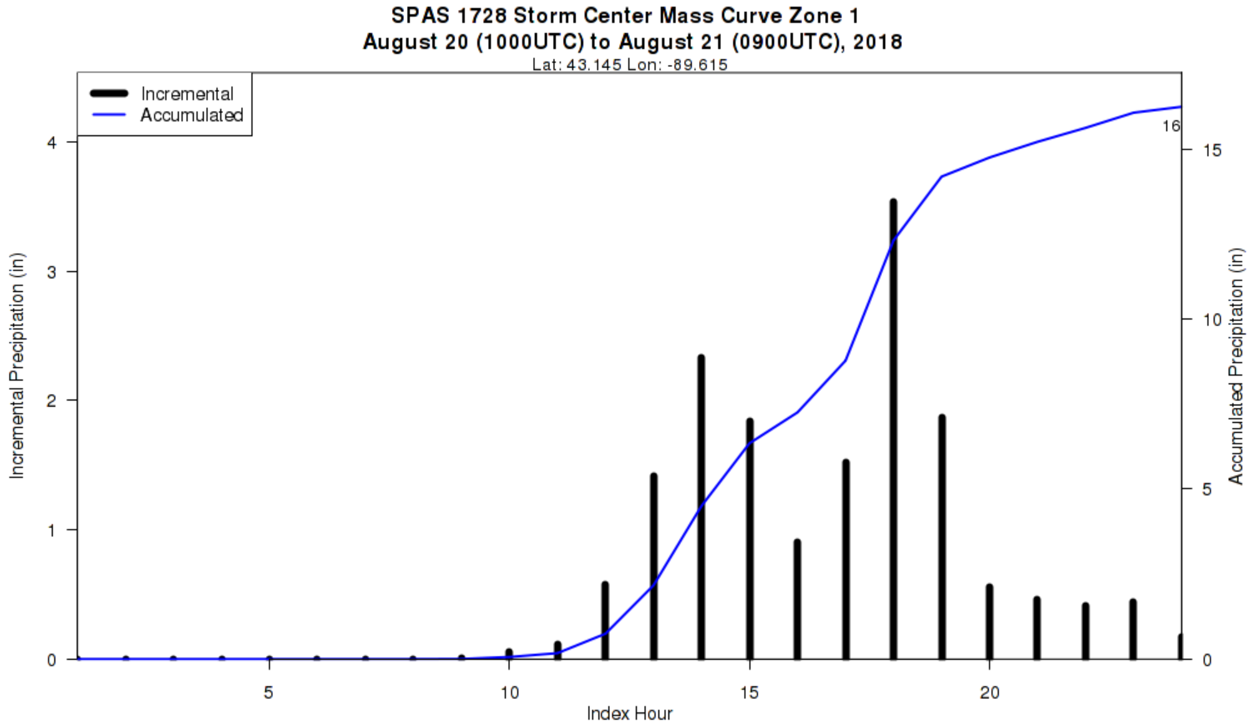
**Radar Included:** Yes

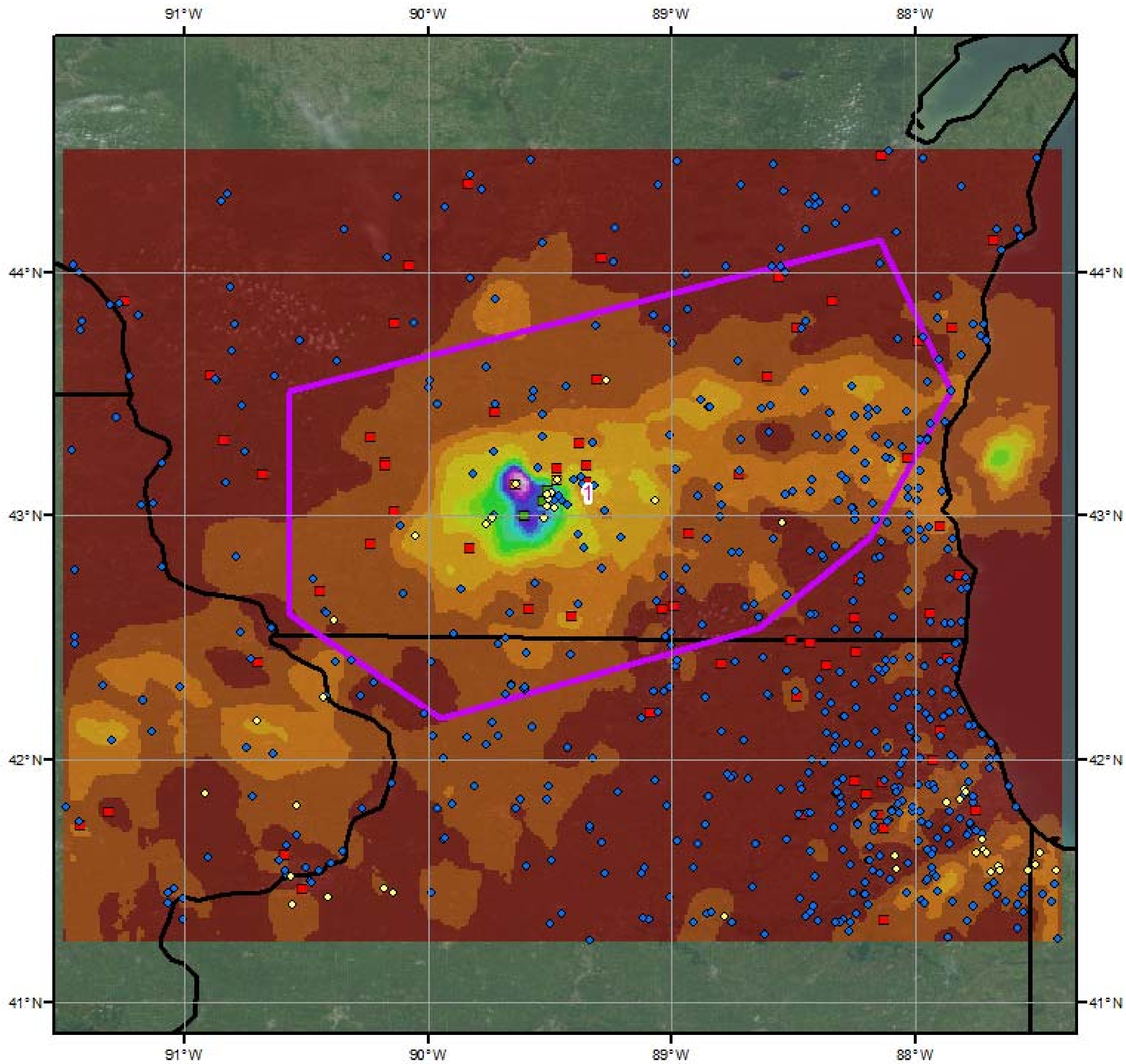
**Depth-Area-Duration (DAD) analysis**: Yes

**Reliability of results:** This analysis was based on 656 hourly stations, daily data, supplemental station data and NEXRAD Radar. We have a good degree of confidence for the radar/station based storm total results. The spatial pattern is dependent on the radar data and basemap. Timing is based on the hourly and hourly pseudo stations. Several daily stations were moved to supplemental due to timing issues and to ensure data consistency.

| SPAS 1728 - August 20 (1000 UTC) - August 21 (0900 UTC), 2018<br>MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Area (mi²) | Duration (hours) | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | Total |
| 0.4 | 3.65 | 5.50 | 7.24 | 8.33 | 10.13 | 12.00 | 15.87 | 16.22 | 16.22 | 16.22 |
| 1 | 3.62 | 5.44 | 7.18 | 8.26 | 10.04 | 11.89 | 15.74 | 16.08 | 16.08 | 16.08 |
| 10 | 3.27 | 5.15 | 6.92 | 7.94 | 9.65 | 11.37 | 15.14 | 15.50 | 15.50 | 15.50 |
| 25 | 2.97 | 4.76 | 6.58 | 7.63 | 9.14 | 10.69 | 14.37 | 14.73 | 14.73 | 14.73 |
| 50 | 2.64 | 4.41 | 6.29 | 7.36 | 8.79 | 9.87 | 13.32 | 13.76 | 13.77 | 13.76 |
| 100 | 2.30 | 4.04 | 5.79 | 6.89 | 8.14 | 9.23 | 12.17 | 12.74 | 12.75 | 12.74 |
| 200 | 1.90 | 3.48 | 5.01 | 6.01 | 7.11 | 8.13 | 10.77 | 11.27 | 11.28 | 11.27 |
| 300 | 1.64 | 3.04 | 4.39 | 5.31 | 6.33 | 7.24 | 9.63 | 10.08 | 10.08 | 10.08 |
| 400 | 1.45 | 2.69 | 3.89 | 4.73 | 5.68 | 6.51 | 8.71 | 9.12 | 9.13 | 9.12 |
| 500 | 1.35 | 2.41 | 3.47 | 4.28 | 5.18 | 5.95 | 8.01 | 8.39 | 8.39 | 8.39 |
| 1,000 | 1.04 | 1.65 | 2.43 | 3.06 | 3.79 | 4.35 | 6.10 | 6.36 | 6.37 | 6.36 |
| 2,000 | 0.75 | 1.27 | 1.76 | 2.24 | 2.78 | 3.25 | 4.63 | 4.82 | 4.83 | 4.82 |
| 5,000 | 0.48 | 0.88 | 1.27 | 1.61 | 1.89 | 2.15 | 3.18 | 3.34 | 3.34 | 3.34 |
| 10,000 | 0.29 | 0.55 | 0.80 | 1.07 | 1.28 | 1.47 | 2.19 | 2.33 | 2.34 | 2.33 |
| 12,235 | 0.25 | 0.48 | 0.70 | 0.92 | 1.12 | 1.28 | 1.94 | 2.08 | 2.08 | 2.08 |




SPAS 1728 Storm Center Mass Curve Zone 1
August 20 (1000UTC) to August 21 (0900UTC), 2018
Lat: 43.145 Lon: -89.615
Incremental
Accumulated
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
1
2
3
4
0
5
10
15
16
5
10
15
20



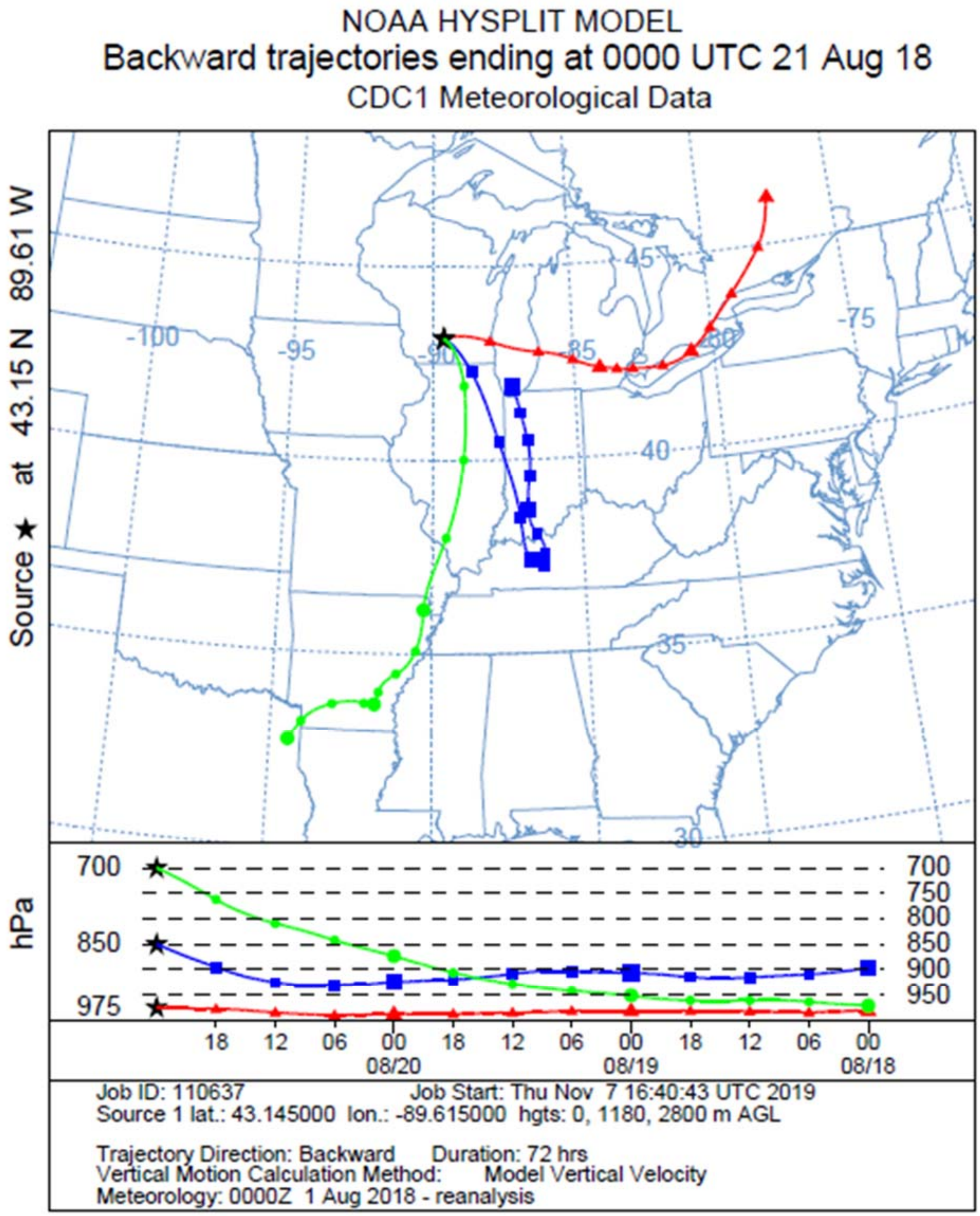

**Total Storm (24-hours) Precipitation (inches)**
**August 20 (1000 UTC) - August 21 (0900 UTC), 2018**
**SPAS NEXRAD 1728 - Cross Plains, WI**

Gauges
- Daily
- Hourly
- HEP
- Hourly Pseudo
- Supplemental
- SE

Miles: 0, 15, 30, 60

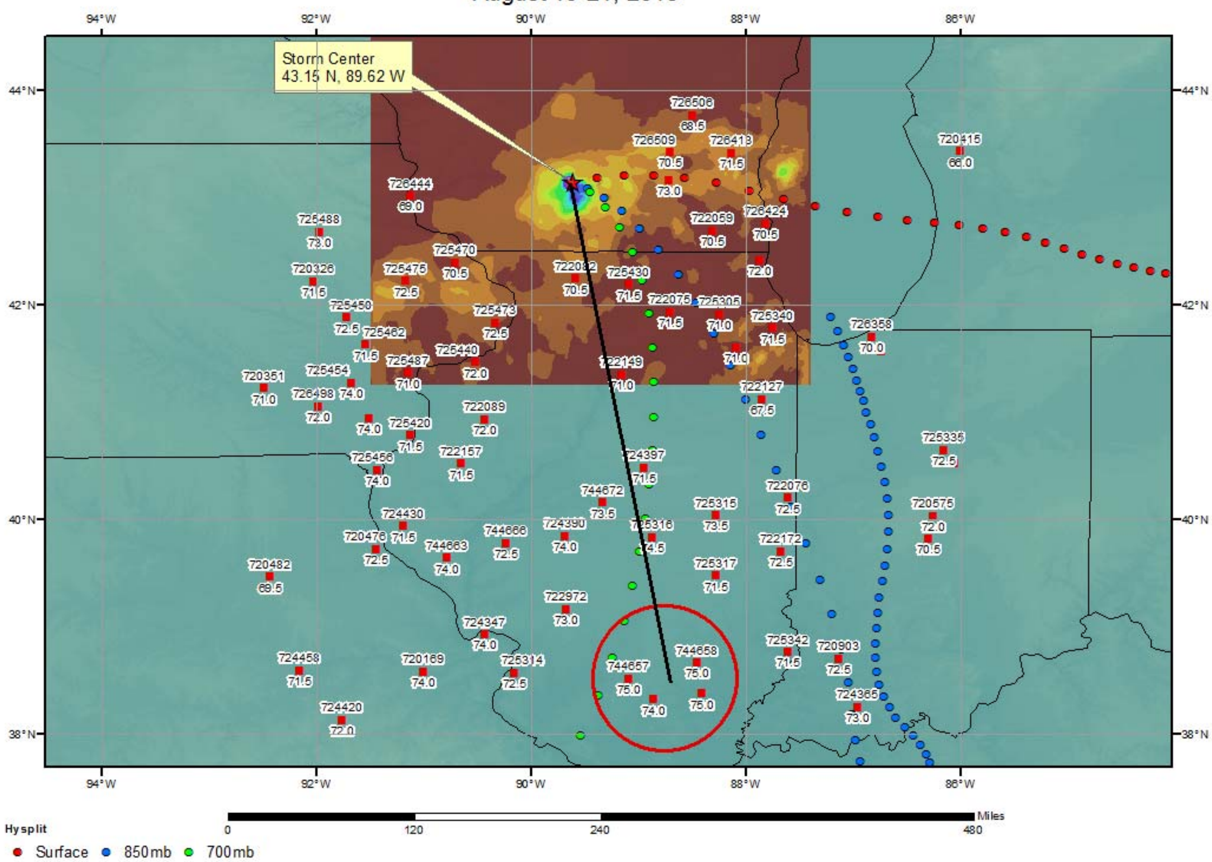
Kilometers: 0, 37.5, 75, 150

**Precipitation (inches)**
- 0.00 - 1.00
- 1.01 - 2.00
- 2.01 - 3.00
- 3.01 - 4.00
- 4.01 - 5.00
- 5.01 - 6.00
- 6.01 - 7.00
- 7.01 - 8.00
- 8.01 - 9.00
- 9.01 - 10.00
- 10.01 - 11.00
- 11.01 - 12.00
- 12.01 - 13.00
- 13.01 - 14.00
- 14.01 - 15.00
- 15.01 - 16.00
- 16.01 - 17.00


NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 21 Aug 18
CDC1 Meteorological Data
Source ★ at 43.15 N 89.61 W
-100
-95
-90
-85
-80
-75
45
40
35
30
hPa
700
850
975
700
750
800
850
900
950
18 12 06 00 18 12 06 00 18 12 06 00
08/20
08/19
08/18
Job ID: 110637 Job Start: Thu Nov 7 16:40:43 UTC 2019
Source 1 lat.: 43.145000 lon.: -89.615000 hgts: 0, 1180, 2800 m AGL
Trajectory Direction: Backward Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Aug 2018 - reanalysis

**SPAS 1728 Storm Analysis**

August 19-21, 2018



# Storm Precipitation Analysis System (SPAS) For Storm #1729_1 SPAS-NEXRAD Analysis

**General Storm Location**: Iron River, MI

**Storm Dates**: July 20-21, 2019

**Event**: Local

**DAD Zone 1**

**Latitude**: 44.0350

**Longitude**: -86.1850

**Max. Grid Rainfall Amount**: 15.77”

**Max. Observed Rainfall Amount**: 13.53”

**Number of Stations**: 707

**SPAS Version**: 10

**Basemap:** Default ZR Relationship 3001.4

**Spatial resolution:** 0.35

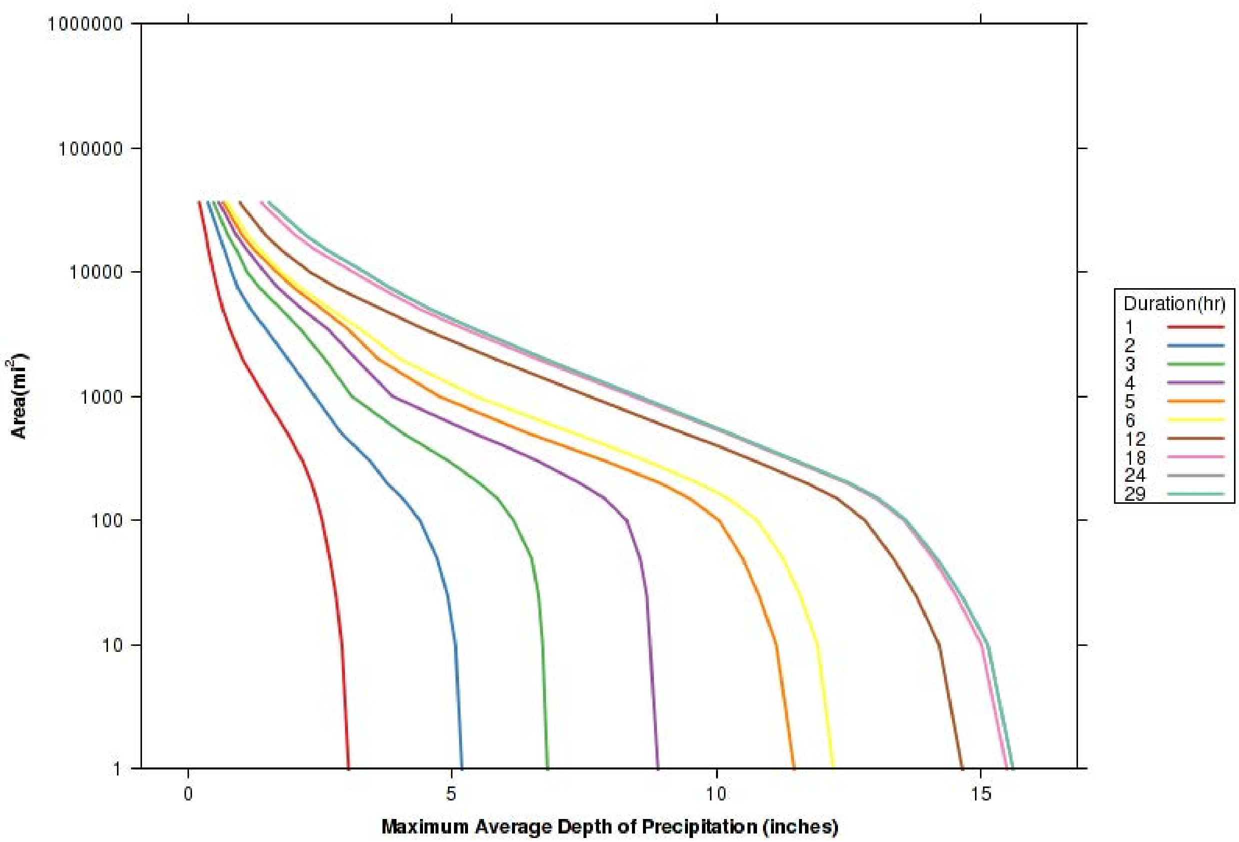
**Radar Included:** Yes

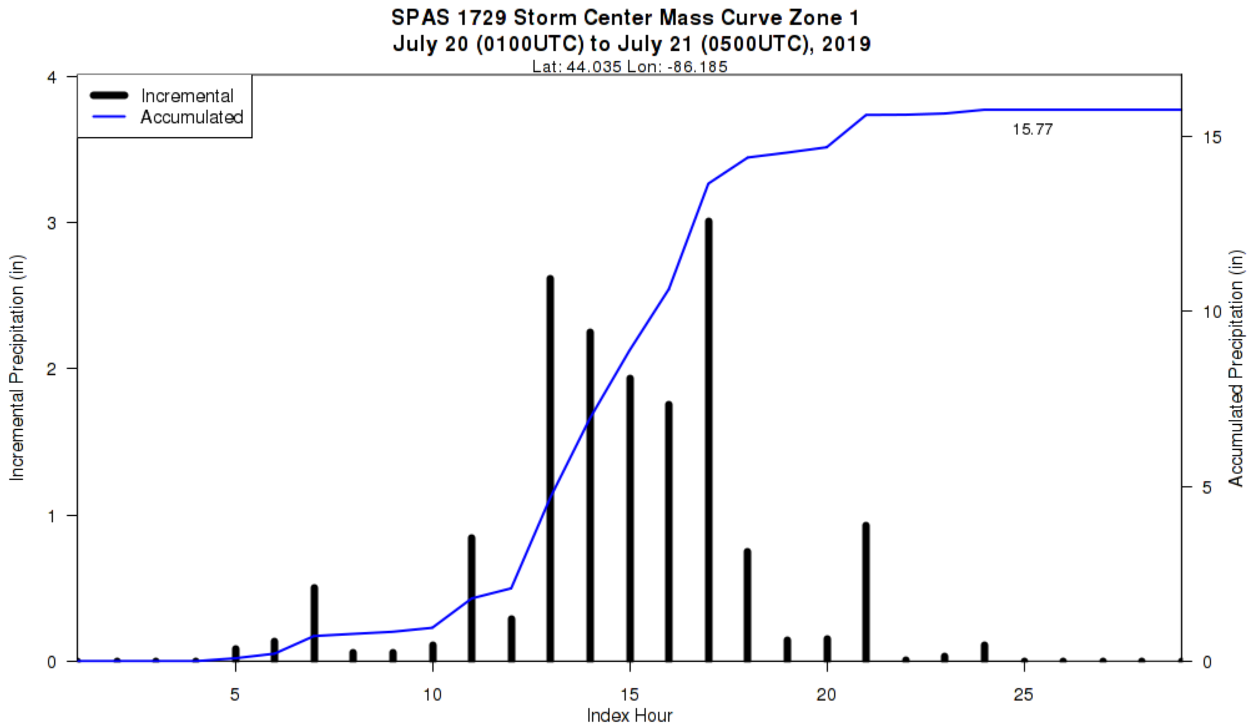
**Depth-Area-Duration (DAD) analysis**: Yes

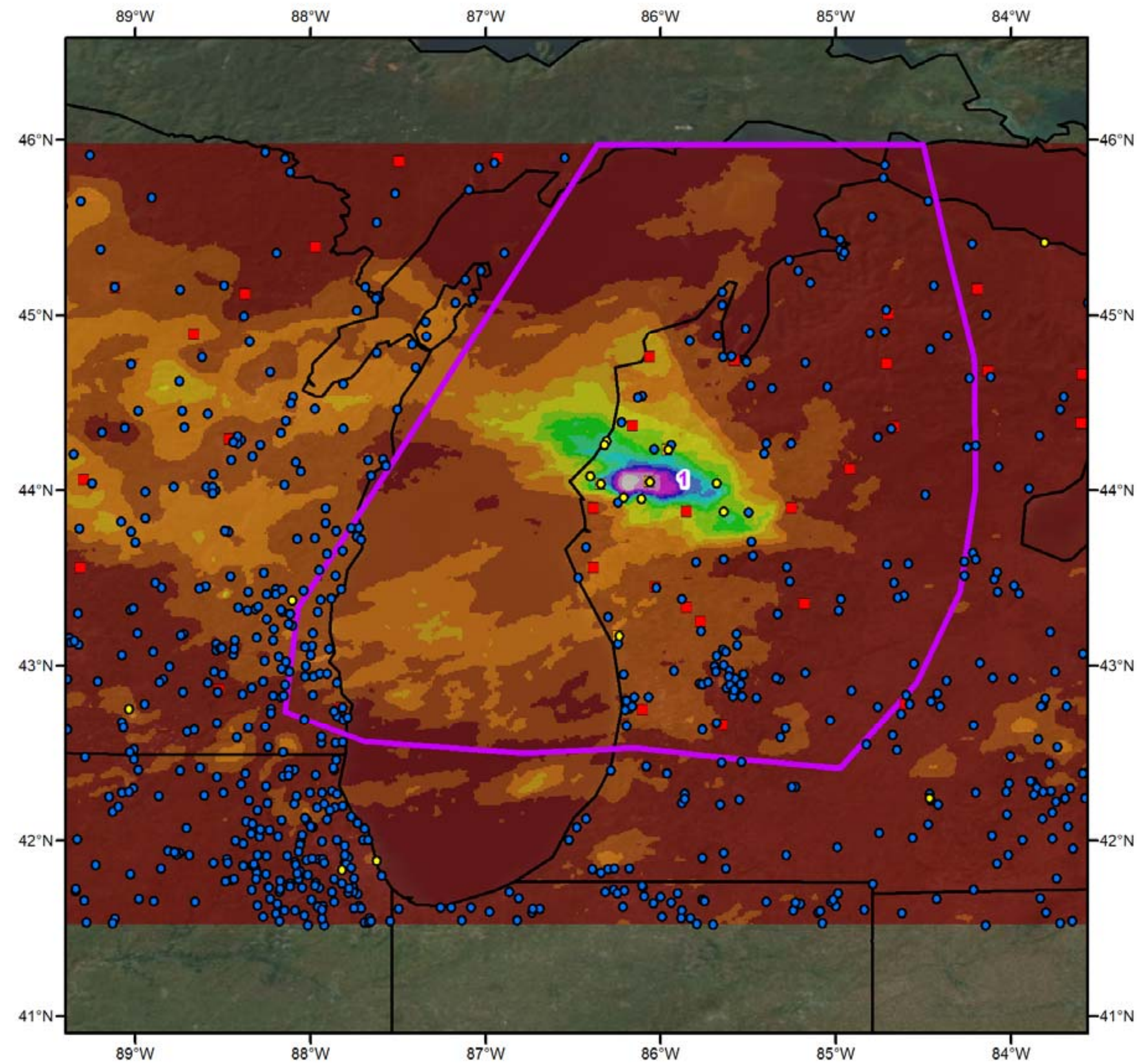
**Reliability of results:** This analysis was based on 707 hourly stations, daily data, supplemental station data and radar data. We have a good degree of confidence for the radar and station based storm total results. The spatial pattern is fully dependent on the radar data and basemap. Timing is based on hourly stations and sun-hourly data is based on 5-minute radar data. Several daily stations were moved to supplemental due to timing issues and to ensure data consistency.

| SPAS 1729 - July 20 (0100 UTC) - July 21 (0500 UTC), 2019 MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Area ($mi^2$) | Duration (hours) | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 12 | 18 | 24 | Total |
| 0.4 | 3.07 | 5.23 | 6.83 | 8.95 | 11.56 | 12.30 | 14.78 | 15.61 | 15.75 | 15.61 |
| 1 | 3.04 | 5.18 | 6.80 | 8.89 | 11.47 | 12.21 | 14.65 | 15.49 | 15.61 | 15.49 |
| 10 | 2.91 | 5.06 | 6.71 | 8.74 | 11.13 | 11.91 | 14.21 | 15.01 | 15.13 | 15.01 |
| 25 | 2.80 | 4.91 | 6.63 | 8.68 | 10.80 | 11.58 | 13.77 | 14.53 | 14.63 | 14.53 |
| 50 | 2.68 | 4.71 | 6.50 | 8.55 | 10.49 | 11.25 | 13.34 | 14.09 | 14.16 | 14.09 |
| 100 | 2.54 | 4.39 | 6.16 | 8.30 | 10.05 | 10.77 | 12.81 | 13.55 | 13.59 | 13.55 |
| 200 | 2.34 | 3.77 | 5.52 | 7.42 | 8.94 | 9.66 | 11.71 | 12.47 | 12.52 | 12.47 |
| 300 | 2.17 | 3.45 | 4.94 | 6.63 | 7.91 | 8.69 | 10.74 | 11.47 | 11.53 | 11.47 |
| 400 | 2.01 | 3.15 | 4.46 | 5.98 | 7.10 | 7.95 | 10.02 | 10.75 | 10.81 | 10.75 |
| 500 | 1.89 | 2.91 | 4.08 | 5.43 | 6.46 | 7.33 | 9.41 | 10.21 | 10.27 | 10.21 |
| 1,000 | 1.45 | 2.40 | 3.10 | 3.87 | 4.75 | 5.44 | 7.59 | 8.41 | 8.52 | 8.41 |
| 2,000 | 1.03 | 1.89 | 2.59 | 3.18 | 3.60 | 4.01 | 5.81 | 6.60 | 6.75 | 6.60 |
| 5,000 | 0.66 | 1.19 | 1.77 | 2.17 | 2.55 | 2.70 | 3.68 | 4.40 | 4.59 | 4.40 |
| 10,000 | 0.48 | 0.83 | 1.12 | 1.45 | 1.68 | 1.76 | 2.31 | 3.13 | 3.34 | 3.13 |
| 20,000 | 0.34 | 0.59 | 0.75 | 0.91 | 1.02 | 1.12 | 1.46 | 2.02 | 2.21 | 2.02 |
| 35,000 | 0.22 | 0.39 | 0.50 | 0.61 | 0.69 | 0.76 | 1.01 | 1.42 | 1.57 | 1.42 |
| 36,448 | 0.21 | 0.38 | 0.48 | 0.58 | 0.67 | 0.74 | 0.98 | 1.39 | 1.53 | 1.39 |

## SPAS 1729 DAD Curves Zone 1
## July 20 (0100UTC) to July 21 (0500UTC), 2019




SPAS 1729 Storm Center Mass Curve Zone 1
July 20 (0100UTC) to July 21 (0500UTC), 2019
Lat: 44.035 Lon: -86.185
Incremental
Accumulated
15.77
Incremental Precipitation (in)
Accumulated Precipitation (in)
Index Hour
0
1
2
3
4
5
10
15
20
25




**Total Storm (29-hr) Precipitation (inches)**
**07/20/2019 0100 UTC - 07/21/2019 0500 UTC**
**SPAS-NEXRAD #1729**

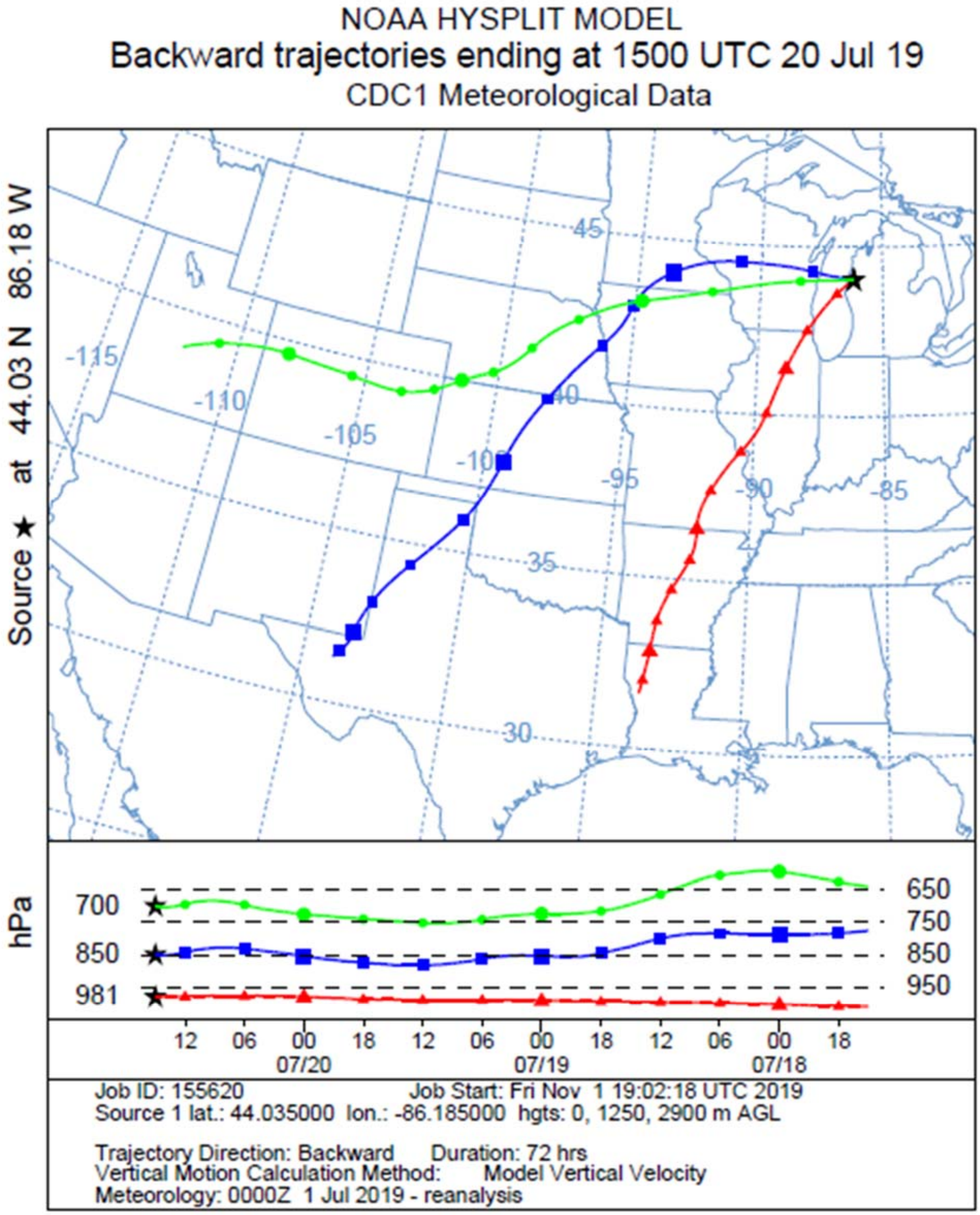
**Gauges**
- Daily
- Hourly
- Hourly Pseudo
- Supplemental

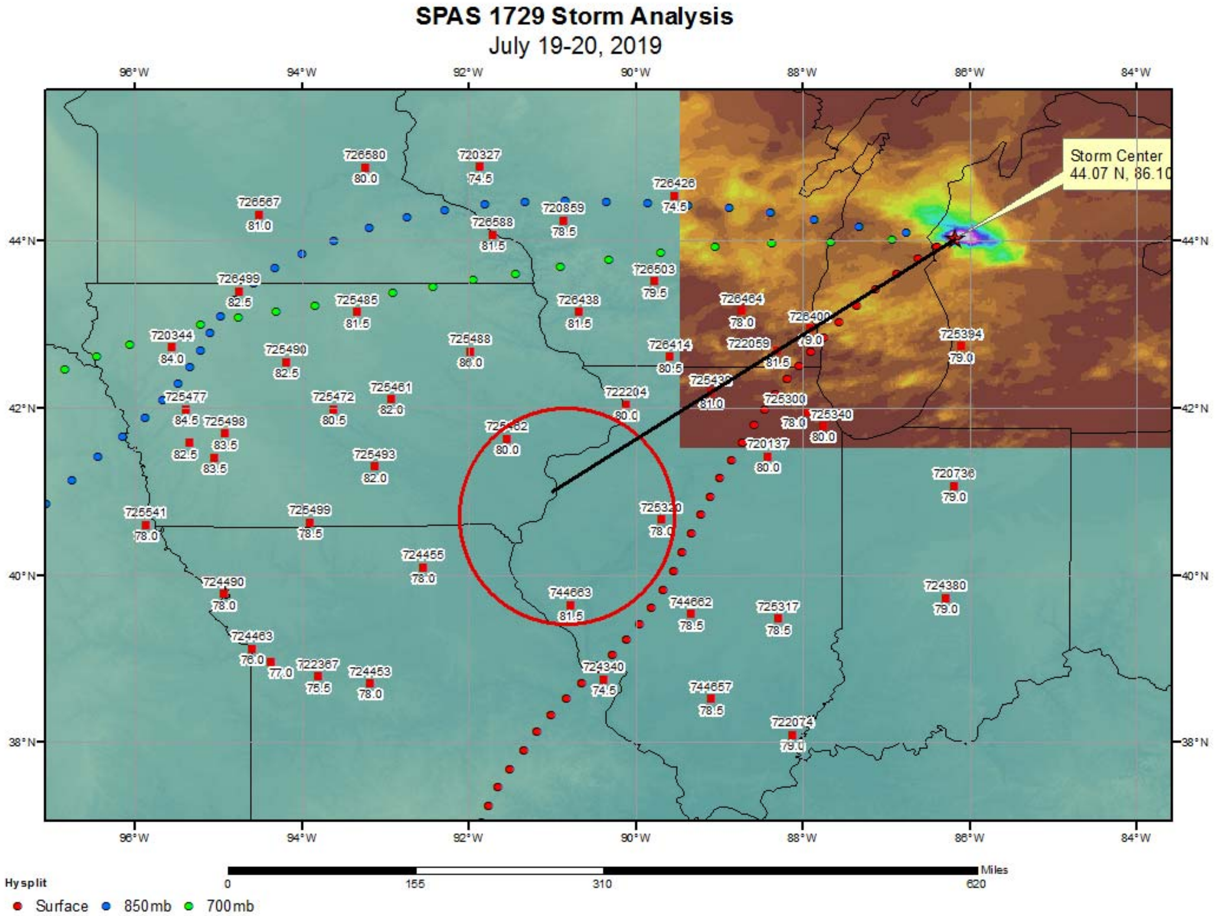
Miles: 0, 25, 50, 100
Kilometers: 0, 62.5, 125, 250

**Precipitation (inches)**

| | | | | |
|---|---|---|---|---|
| 0.00 - 1.00 | 3.01 - 4.00 | 6.01 - 7.00 | 9.01 - 10.00 | 12.01 - 13.00 |
| 1.01 - 2.00 | 4.01 - 5.00 | 7.01 - 8.00 | 10.01 - 11.00 | 13.01 - 14.00 |
| 2.01 - 3.00 | 5.01 - 6.00 | 8.01 - 9.00 | 11.01 - 12.00 | 14.01 - 15.00 |

10/31/2019


NOAA HYSPLIT MODEL
Backward trajectories ending at 1500 UTC 20 Jul 19
CDC1 Meteorological Data
Source ★ at 44.03 N 86.18 W
45
40
35
30
-115
-110
-105
-100
-95
-90
-85
hPa
700
850
981
650
750
850
950
12 06 00 18 12 06 00 18 12 06 00 18
07/20
07/19
07/18
Job ID: 155620
Job Start: Fri Nov 1 19:02:18 UTC 2019
Source 1 lat.: 44.035000 lon.: -86.185000 hgts: 0, 1250, 2900 m AGL
Trajectory Direction: Backward
Duration: 72 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 Jul 2019 - reanalysis


SPAS 1729 Storm Analysis
July 19-20, 2019
Storm Center
44.07 N, 86.10
96°W
94°W
92°W
90°W
88°W
86°W
84°W
44°N
42°N
40°N
38°N
Hysplit
Surface
850mb
700mb
Miles
0
155
310
620