Challenges in Determining the Probable Maximum Precipitation (PMP)

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Washington, DC
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Challenges in Determining the Probable Maximum Precipitation (PMP)

- Applied Weather Associates Overview
- Definition of PMP
- HMR methodology overview
  - Procedures used Current HMRs
  - HMR issues
    - Storm maximization
    - Storm transposition
- Technical challenges
  - Extreme storm rainfall analyses
  - Orographic evaluations
- Site-specific/Statewide/Regional PMP studies
- Updates to the HMRs

Applied Weather Associates, LLP

Established 1996
Ed Tomlinson, PhD
- **President and Chief Meteorologist**

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Seven meteorologists and a GIS specialist

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- **Senior Meteorologists**
  - **Bill Kappel – Vice President**
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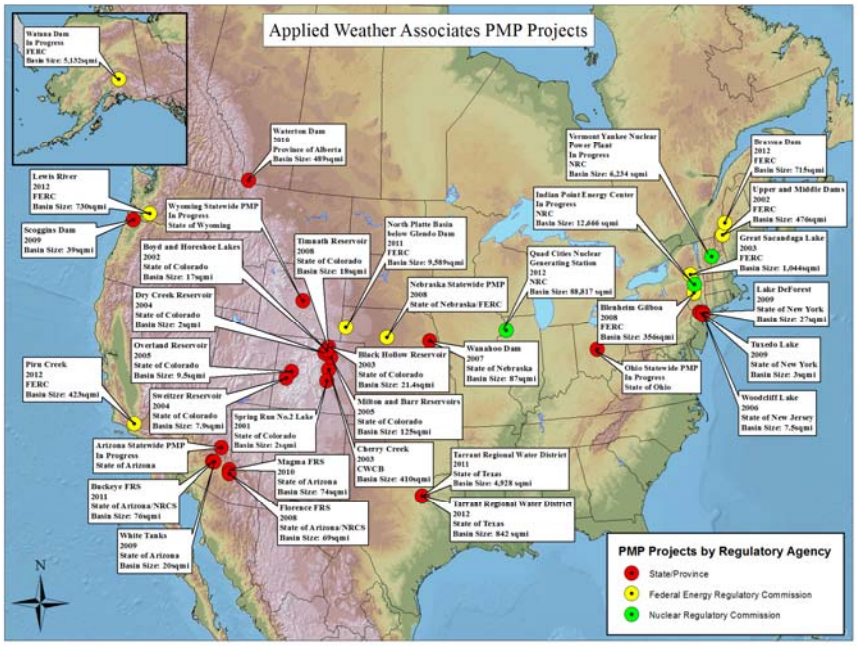
  - **Bob Wright**
- **Hydrometeorologist**
  - **Doug Hultstrand**
- **Staff Meteorologists**
  - **Patrice Sutter**
  - **Steve Lovisone**
- **GIS Specialist**
  - **Geoff Muhlestein**



Probable Maximum Precipitation

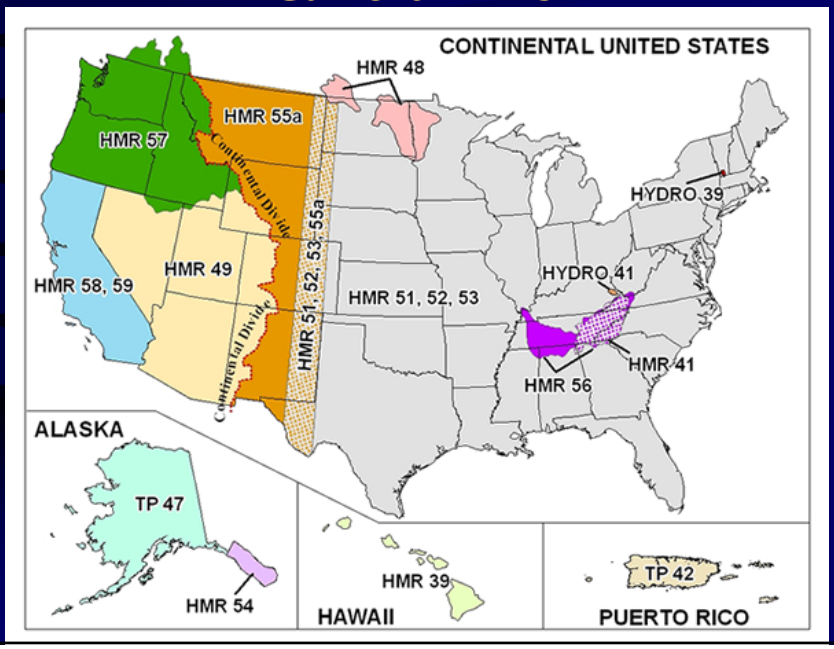
Definition:

The theoretically greatest depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographic location at a certain time of year (HMR 59, 1999)

Probable Maximum Precipitation

- **Definition**
  - i. Theoretical values
  - ii. Maximum depth of precipitation
  - iii. Physically possible
  - iv. Geographic region
  - v. Certain time of year

Current HMRs



Probable Maximum Precipitation

- **Evolution of PMP determination procedures**
- **Differences in procedures used in current HMRs**
  - **HMR 49**
  - **HMR 51**
  - **HMR 55A**
  - **HMR 57**
  - **HMR 59**

HMR 49

- **Oldest of the current HMRs**
- **Same methods used in HMR 33 and HMR 36**
  - **These have been replaced by HMR 57 and HMR 59**
- **Methods no longer used in any of the other HMR**
  - **Orographic methods not used in subsequent HMRs**
  - **No storm Depth-Area-Duration analyses**
    - **Ratios are used from point rainfall amounts to determine other rainfall for area sizes and durations amounts**
  - **Very little actual storm data analyzed**

HMR 51

- No orographic procedures used
  - stippled regions
- Maximum dew point climatology not representative of moisture feeding storms
- Implicit influence of storms throughout large areas of domain not appropriate
  - Smethport, PA
- Improper storm analyses
  - Smethport (1942), Yankeetown (1950), Alta Pass (1916)
- Storm database outdated
  - Most recent general storm:
    Hurricane Agnes 1972
  - Most recent Midwest thunderstorm complex:
    Ritter, Iowa 1953

Probable Maximum Precipitation

HMR 51

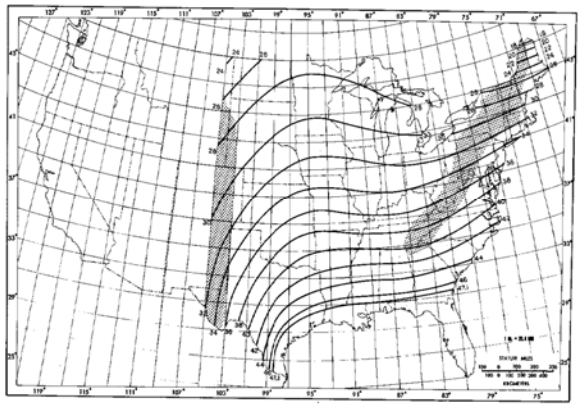


Figure 30.—All-season PMP (in.) for 24 hr 10 mi^2 (26 km^2).

HMR 55A

- Storm Separation Method (SSM) introduced
  - "Highly complex involving a number of subjective decisions"
  - Use of actual storm rainfall analysis data is not clear
- New concept of half precipitable water adjustment made in HMR 55
  - This new concept resulted in very large local storm PMP values at high elevations
  - HMR 55A was published resulting in considerable decreases in local storm PMP and general storm PMP at some locations

HMR 57

- No working papers are available
- Storm Separation Method used
  - Unclear how storm rainfall spatial and temporal data were used
- Use of controlling storms questionable
  - Gibson Dam, Seymour Falls
- Sea Surface Temperatures used to determine maximization and transposition factors
- Many storm maximization factors can not be replicated, numerous errors/inconsistencies

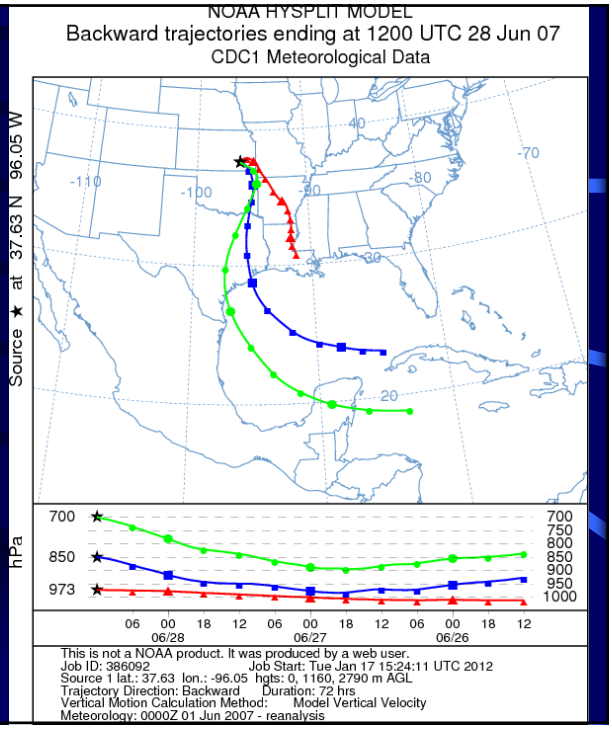
HMR 59

- No working papers are available
- Storm Separation Method used
- Use of storm rainfall data to derive PMP values is not presented
- Results cannot be reproduced
- Many errors/inconsistencies in storm maximization/transposition values found

Challenges in Determining the Probable Maximum Precipitation (PMP)

- HMR issues
  - Storm maximization
    - HYSPLIT use for storm moisture inflow vectors
    - Storm representative dew point temperature (T_d)
    - Dew point temperature vs Sea Surface Temperature (SST)
    - Average T_d vs persisting T_d
    - Variable durations (6-, 12-, and 24-hour) vs 12-hour
    - Storm elevation vs 1000mb (sea level)
    - Updated maximum T_d and SST climatologies
      - Maximum T_d
        - » Maximum observed
        - » Return frequency (e.g. 100-year)
      - Maximum SST (2 Sigma SST = Mean SST + 2 standard deviations)
    - Documentation

Use of the HYSPLIT air parcel trajectory model



Examples of Site-Specific PMP Study Findings

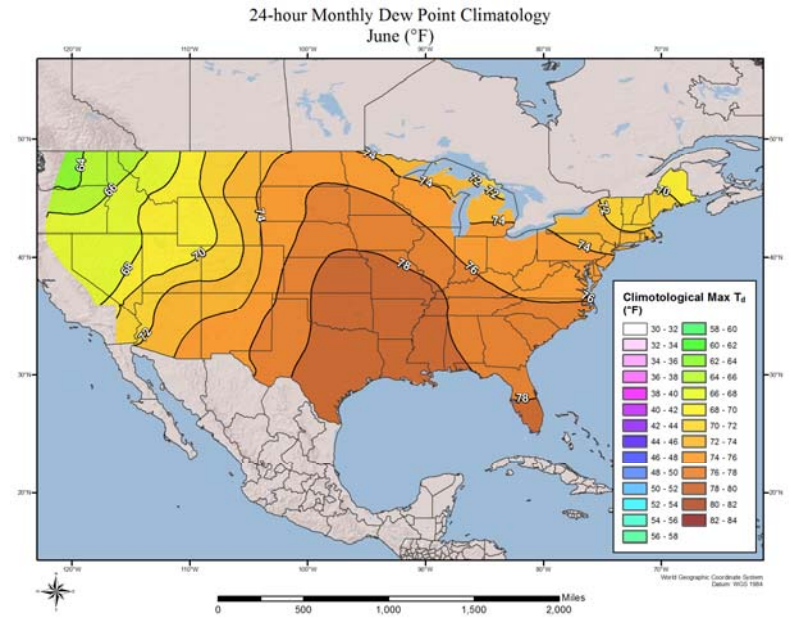
- **Storm Maximization, Dew point Analyses**
  - **12-hour vs 6-hour persisting dew points**
  - **12-hour persisting vs 6-hour average**
- **Observed dew point values**

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Td	68	67	69	69	72	75	75	74	75	73	70	69	68	65	66	65	65	65	67	66

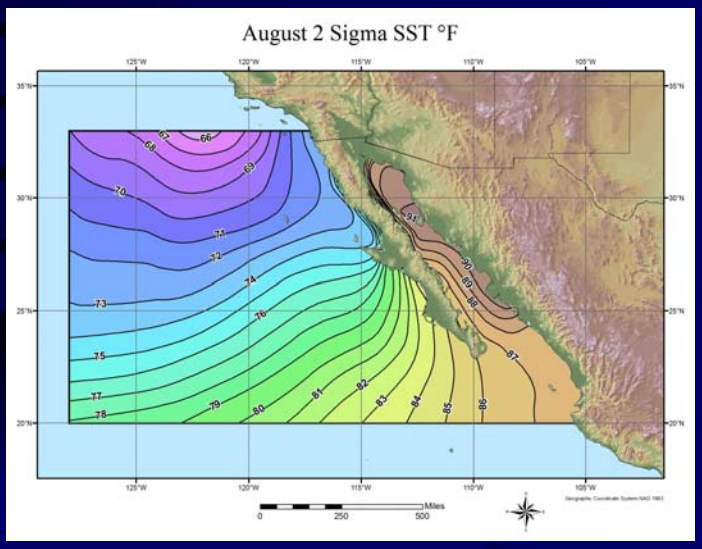
! Rainfall Event !

- **12-hour persisting: 65**
- **6-hour persisting: 72**
- **6-hour average: 74**

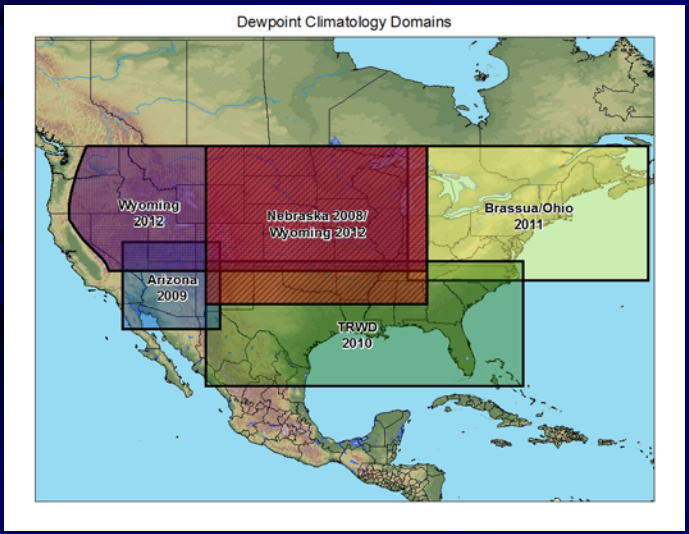
Updated Maximum Dew Point Climatology



Updated 2 Sigma SST Map



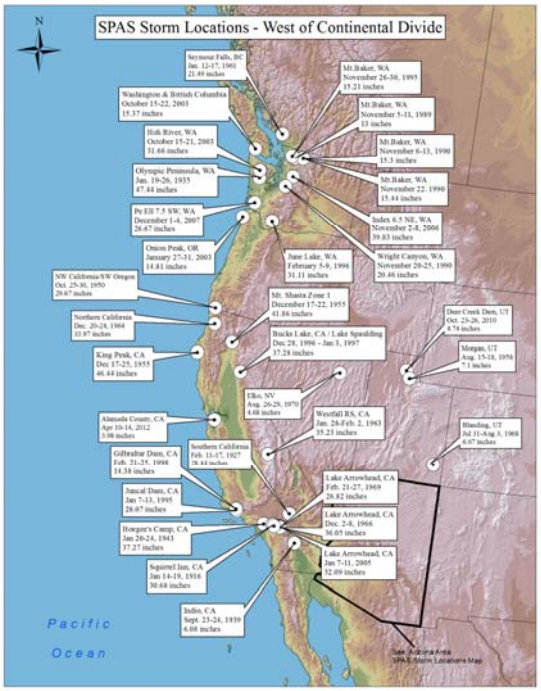
Updated Dew Point Climatologies



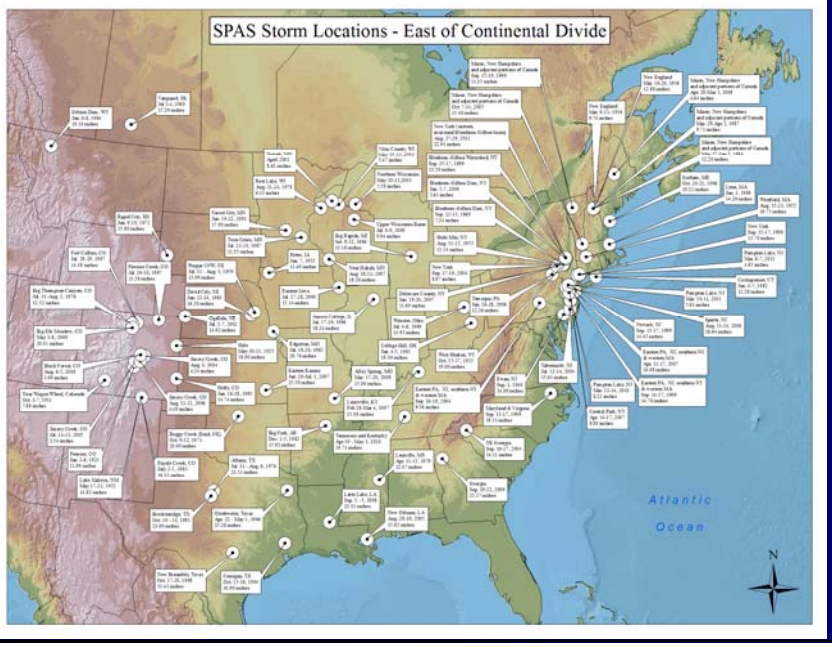
Storm Precipitation Analysis System (SPAS)

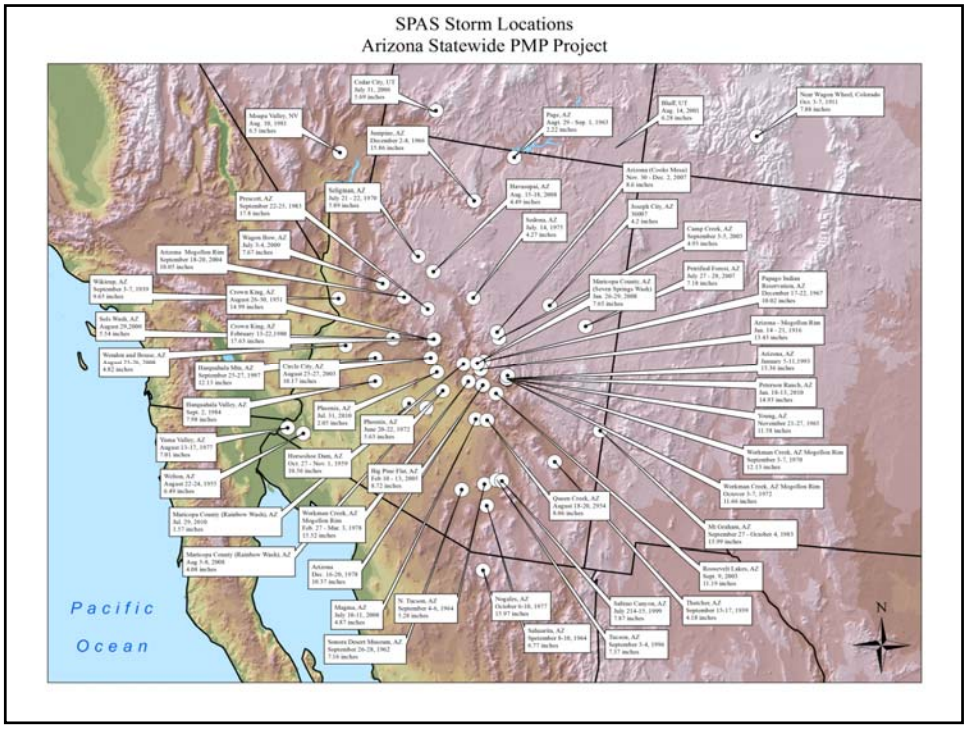
- A comprehensive, state-of-the-science precipitation analysis system
  - Produces high resolution, gridded precipitation fields
- Developed in 2002
  - Semi-automated GIS-based software program
- Spatial interpolation between rain gauges by radar data and "climatologically-aided" methodology
- Generates a plethora of output
  - High resolution hourly precipitation grids
  - Depth-Area-Duration (DAD) plots
- More than 200 storms have been analyzed

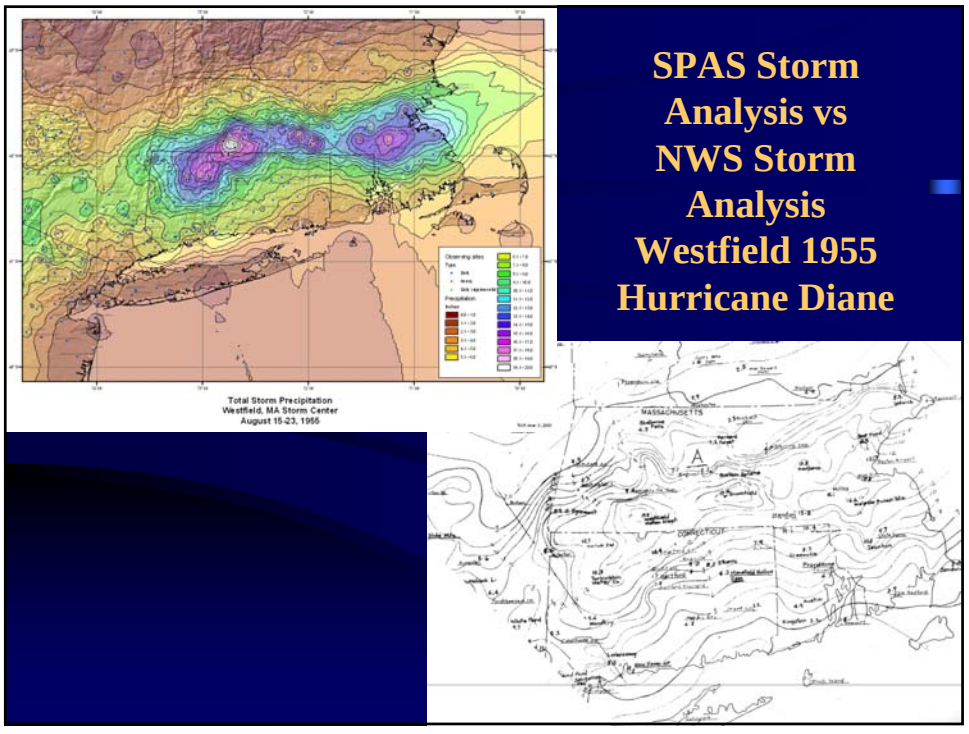
New Storms Analyzed for PMP Development



New Storms Analyzed for PMP Development




SPAS Storm Locations
Arizona Statewide PMP Project
Pacific
Ocean
N


Total Storm Precipitation
Westfield, MA Storm Center
August 15-23, 1955
SPAS Storm Analysis vs NWS Storm Analysis Westfield 1955 Hurricane Diane
MASSACHUSETTS
CONNECTICUT

Storm Precipitation Analysis System (SPAS)

- SPAS uses the same basic principles used by the USACE and National Weather Service/Bureau thereby achieving consistency among the storm analyses
- The DAD results compared favorably to previously analyzed storms, including:
  - Westfield, MA, storm of August 17-20, 1955
- Results
  - Improved spatial, timing, etc

Generally within +/- 5% !!

SPAS							
Sq-Miles	6-hour	12-hour	24-hour	36-hour	48-hour	60-hour	Total
10	7.96	11.48	16.40	19.10	19.11	19.47	19.70
100	7.22	10.72	15.20	17.77	17.76	18.23	18.47
200	6.99	10.27	14.28	16.91	16.84	17.39	17.54
1000	5.97	9.06	12.55	14.97	15.08	15.40	15.95
5000	4.14	6.45	9.25	11.70	12.02	12.35	13.05
10000	3.23	5.46	7.63	9.60	9.91	10.26	10.86
20000	2.24	4.03	5.91	7.66	7.97	8.22	8.77

Weather Bureau							
Sq-Miles	6-hour	12-hour	24-hour	36-hour	48-hour	60-hour	Total
10	7.80	11.10	16.40	18.90	19.40	19.40	19.40
100	7.60	10.50	14.60	18.10	18.80	19.00	19.00
200	7.40	10.20	14.20	17.60	18.20	18.40	18.40
1000	6.20	9.20	12.40	15.90	16.20	16.40	16.40
5000	4.00	6.30	9.50	12.10	12.60	13.00	13.00
10000	3.10	5.00	8.00	10.00	10.60	10.80	10.80
20000	2.10	3.60	6.30	7.90	8.30	8.50	8.50

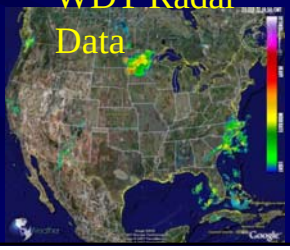
Percent Difference							
Sq-Miles	6-hour	12-hour	24-hour	36-hour	48-hour	60-hour	Total
10	2.1%	3.4%	0.0%	1.1%	-1.5%	0.4%	1.5%
100	-5.0%	2.1%	4.1%	-1.8%	-5.5%	-4.1%	-2.8%
200	-5.5%	0.7%	0.6%	-3.9%	-7.5%	-5.5%	-4.7%
1000	-3.7%	-1.5%	1.2%	-5.8%	-6.9%	-6.1%	-2.7%
5000	3.5%	2.4%	-2.6%	-3.3%	-4.6%	-5.0%	0.4%
10000	4.2%	9.2%	-4.6%	-4.0%	-6.5%	-5.0%	0.6%
20000	6.7%	11.9%	-6.2%	-3.0%	-4.0%	-3.3%	3.2%

NEXRAD Radar Reflectivity (Z)

- Advanced algorithms for mosaicing and QCing reflectivity (Z) data from multiple radar sites
  - ✓ Spatial: ~ 1km x ~1 km
  - ✓ Temporal: Every 5-minutes (10-mins Canada)

Raw Radar Data

WDT Radar Data



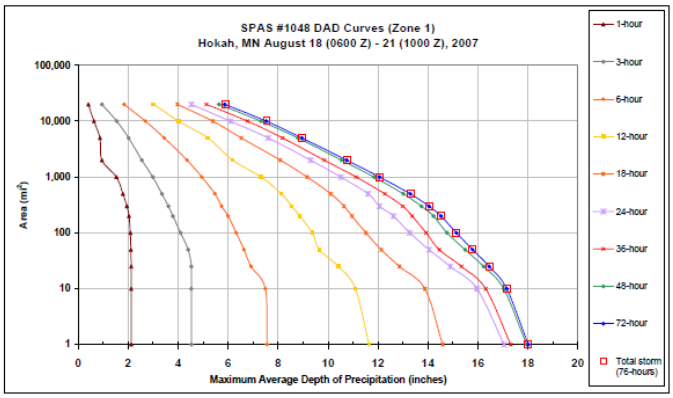
SPAS Output

- Storm-centered DAD table and plot

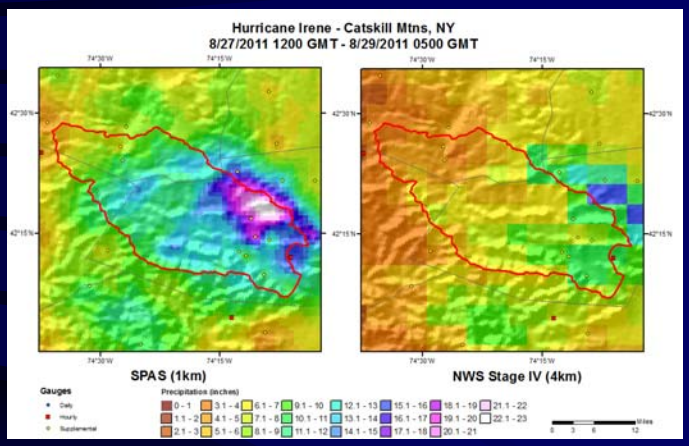
Storm 1048 - Hokah, MN August 18 - August 21, 2007

MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

Area (mi²)	Duration (hours)									
	1	3	6	12	18	24	36	48	72	Total
0.24	2.45	4.77	7.85	11.89	14.88	17.31	17.55	18.19	18.26	18.26
1	2.12	4.53	7.56	11.64	14.59	17.05	17.31	17.95	18.02	18.02
10	2.12	4.53	7.49	11.10	13.88	15.96	16.31	17.03	17.15	17.17
25	2.12	4.53	6.92	10.42	12.86	14.89	15.34	16.23	16.45	16.46
50	2.11	4.40	6.64	9.65	12.13	14.05	14.46	15.49	15.79	15.79
100	2.09	4.10	6.33	9.37	11.52	13.27	13.93	14.76	15.14	15.14
200	2.03	3.79	6.00	8.87	10.96	12.62	13.37	14.22	14.52	14.52
300	1.95	3.61	5.74	8.55	10.64	12.06	12.99	13.74	14.04	14.04
500	1.79	3.35	5.47	8.13	10.11	11.60	12.27	13.01	13.29	13.30
1,000	1.53	2.99	4.95	7.33	9.17	10.51	11.13	11.84	12.07	12.07
2,000	0.95	2.55	4.36	6.18	8.09	9.30	9.85	10.54	10.75	10.76
5,000	0.87	2.02	3.45	5.19	6.53	7.61	8.18	8.79	8.96	8.98
10,000	0.63	1.54	2.69	4.02	5.39	6.09	6.78	7.31	7.53	7.55
20,000	0.41	0.95	1.84	3.02	3.97	4.53	5.13	5.63	5.87	5.90



SPAS vs NWS MPE

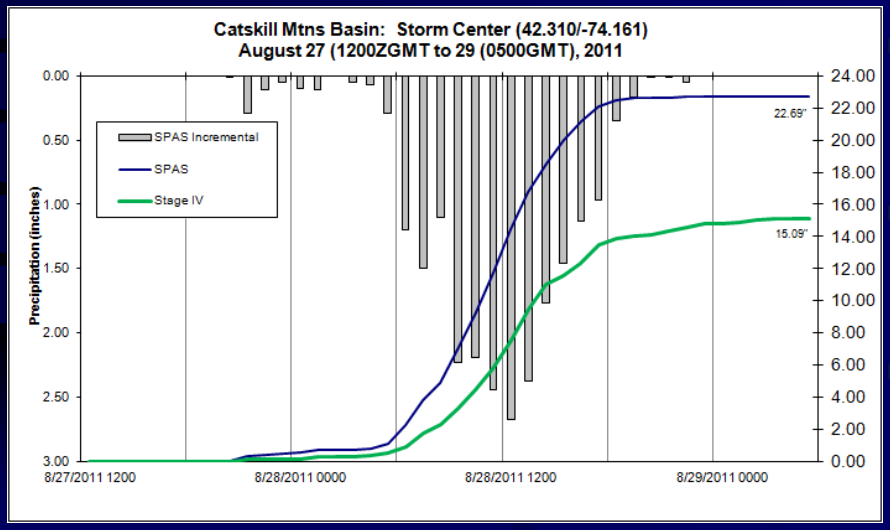


Basin Average Comparison

Precipiation (in)

	1hr Max.	1hr Min.	1hr Avg.	Total
SPAS	1.32	0.00	0.30	*12.39*
Stage IV	0.78	0.00	0.17	*7.25*
% Diff	*-41%*	-	*-41%*	*-41%*

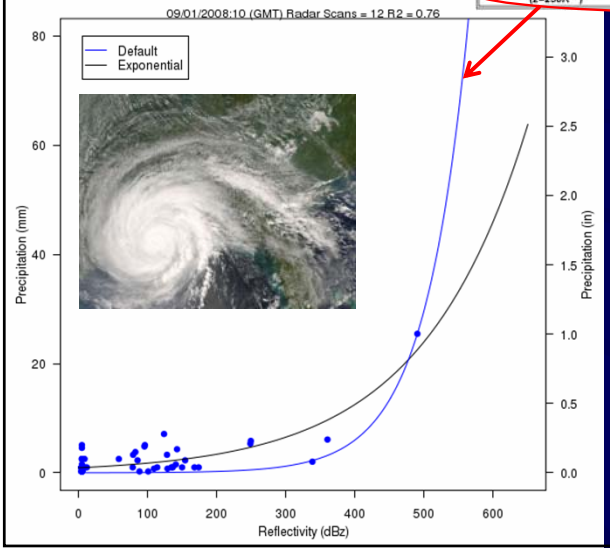
SPAS vs NWS MPE

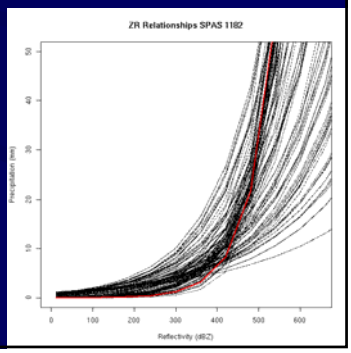


Dynamic ZR Relationship

Table 1. Z-R RECOMMENDATIONS

RELATIONSHIP	Optimum for:	Also recommended for:
Marshall-Palmer ($z=200R^{1.6}$)	General stratiform precipitation	
East-Cool Stratiform ($z=130R^{2.0}$)	Winter stratiform precipitation - east of continental divide	Orographic rain - East
West-Cool Stratiform ($z=75R^{2.0}$)	Winter stratiform precipitation - west of continental divide	Orographic rain - West
WSR-88D Convective ($z=300R^{1.4}$)	Summer deep convection	Other non-tropical convection
Rosenfeld Tropical ($z=250R^{1.2}$)	Tropical convective systems	



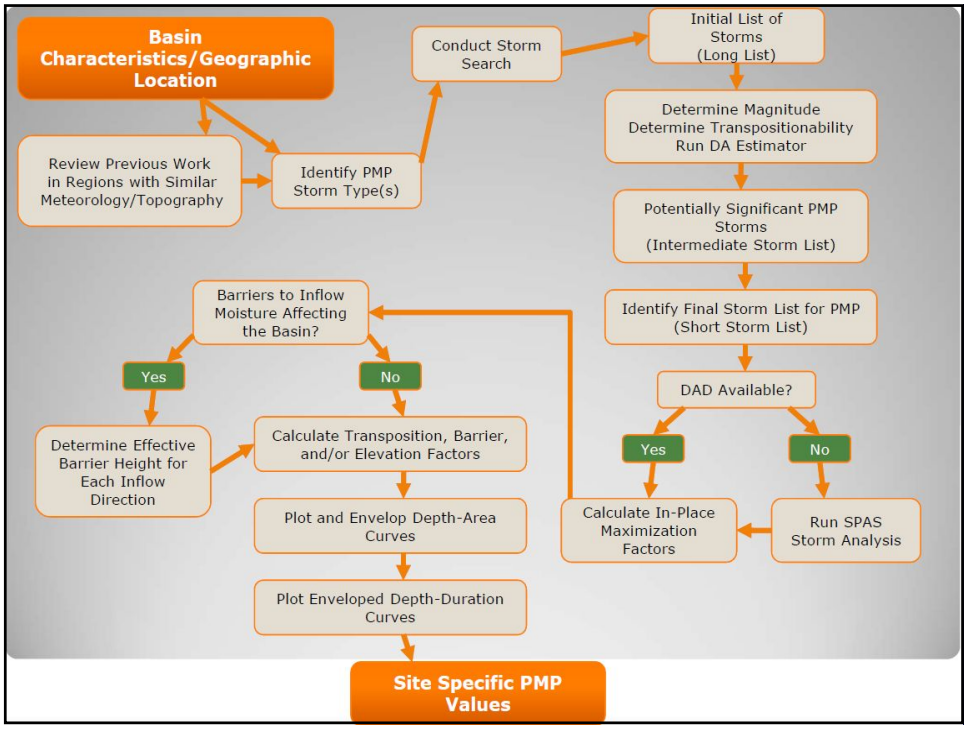


Key Tasks for Site-Specific PMP Studies

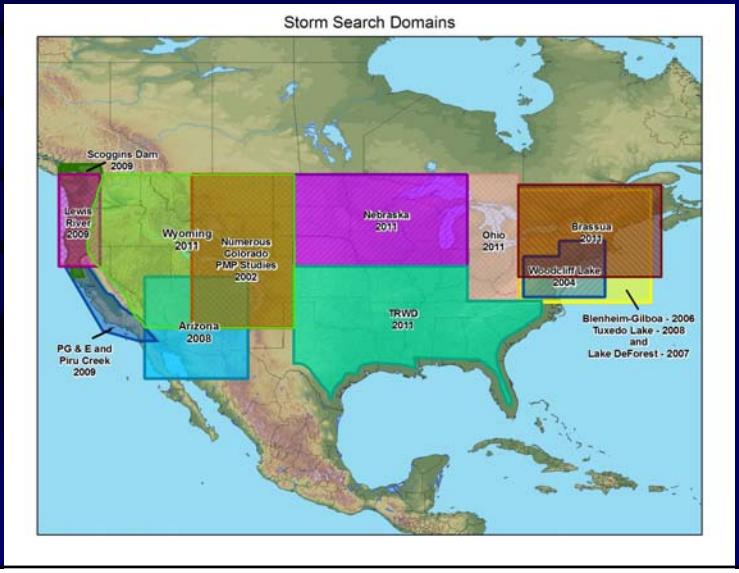
- **I**dentify extreme storm types
  - **E**valuate the use of HMR procedures for each storm type
- **I**dentify unique topography
  - **M**oisture depletion by upwind barriers
  - **P**recipitation enhancement/decrease
  - **E**ffects on storm center location
- **R**eview HMR procedures used for the basin location
  - **I**dentify inconsistent assumptions

Site-Specific/Regional/Statewide PMP Studies

- **Storm search**
- **Short list of significant storms**
- **Storm rainfall analyses**
  - **D-A-D (Depth-Area-Duration)**
  - **Rainfall timing (mass curves)**
- **Storm in-place maximization**
- **Storm transposition**
  - **Moisture transposition**
  - **Elevation moisture adjustment**
  - **Orographic transposition**
- **Depth-Area envelopment**
- **Depth-Duration envelopment**



Updated Storm Search Locations

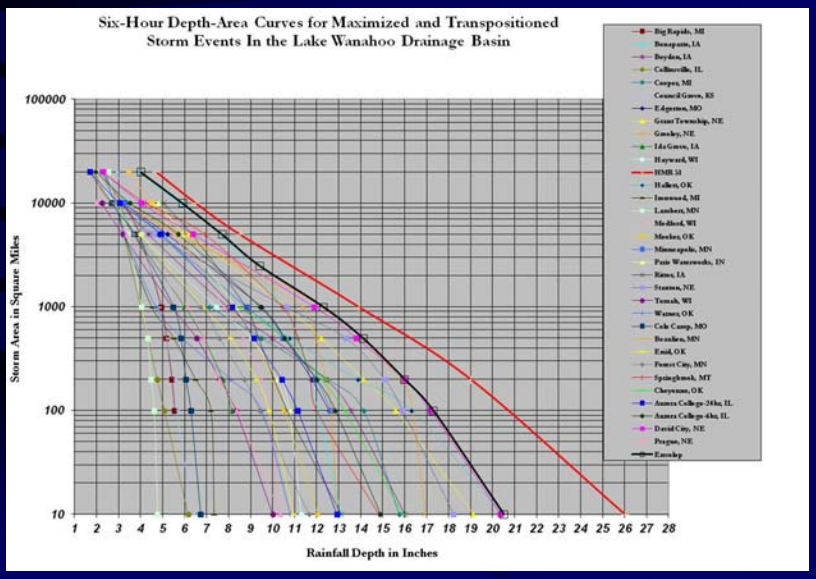


Method for Computing PMP Values

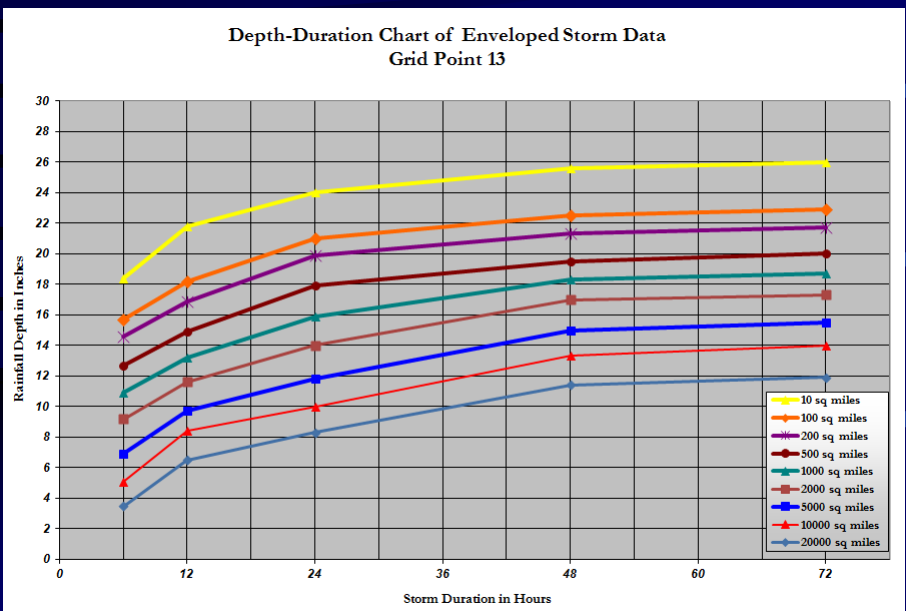
Enveloping

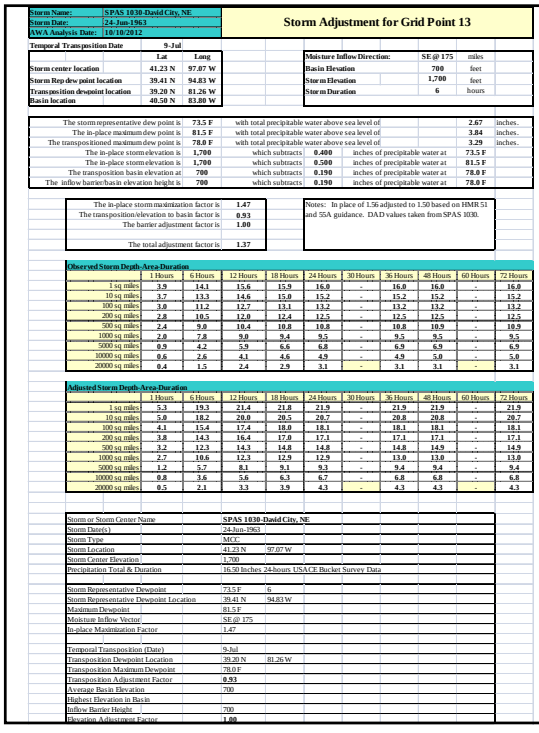
- For any location in a region
  - The maximized and transpositioned Depth-Area (D-A) rainfall is plotted for each storm for each duration
  - For each duration, an envelop curve is constructed that envelopes the rainfall values at each area size
- The D-A envelop curve procedure insures continuity in space
  - i.e. The rainfall at each area size has continuity with smaller and larger area sizes
- The same procedure is followed for the Depth-Duration (D-D) rainfall plots
- The D-D envelop curve procedure insures continuity in time
  - i.e. The rainfall at each duration has continuity with shorter and longer durations

Area Enveloping



Duration Enveloping





Storm Adjustment for Grid Point 13

Storm Name:	SPAS 1030-Dasid City, NE
Storm Date:	24-Jun-1963
AWA Analysis Date:	10/10/2012

Temporal Transposition Date: 9-Jul

	Lat	Long
Storm center location	41.23 N	97.07 W
Storm Rep dew point location	39.41 N	94.83 W
Transposition dewpoint location	39.20 N	81.26 W
Basin location	40.50 N	83.80 W

Moisture Inflow Direction:	SE @ 175	miles
Basin Elevation	700	feet
Storm Elevation	1,700	feet
Storm Duration	6	hours

The storm representative dew point is	73.5 F	with total precipitable water above sea level of		2.67	inches.
The in-place maximum dew point is	81.5 F	with total precipitable water above sea level of		3.84	inches.
The transpositioned maximum dew point is	78.0 F	with total precipitable water above sea level of		3.29	inches.
The in-place storm elevation is	1,700	which subtracts	0.400	inches of precipitable water at	73.5 F
The in-place storm elevation is	1,700	which subtracts	0.500	inches of precipitable water at	81.5 F
The transposition basin elevation at	700	which subtracts	0.190	inches of precipitable water at	78.0 F
The inflow barrier/basin elevation height is	700	which subtracts	0.190	inches of precipitable water at	78.0 F

The in-place storm maximization factor is	1.47
The transposition/elevation to basin factor is	0.93
The barrier adjustment factor is	1.00
The total adjustment factor is:	1.37

Notes: In place of 1.56 adjusted to 1.50 based on HMR 51 and 55A guidance. DAD values taken from SPAS 1030.

Observed Storm Depth-Area-Duration

	1 Hours	6 Hours	12 Hours	18 Hours	24 Hours	30 Hours	36 Hours	48 Hours	60 Hours	72 Hours
1 sq miles	3.9	14.1	15.6	15.9	16.0	-	16.0	16.0	-	16.0
10 sq miles	3.7	13.3	14.6	15.0	15.2	-	15.2	15.2	-	15.2
100 sq miles	3.0	11.2	12.7	13.1	13.2	-	13.2	13.2	-	13.2
200 sq miles	2.8	10.5	12.0	12.4	12.5	-	12.5	12.5	-	12.5
500 sq miles	2.4	9.0	10.4	10.8	10.8	-	10.8	10.9	-	10.9
1000 sq miles	2.0	7.8	9.0	9.4	9.5	-	9.5	9.5	-	9.5
5000 sq miles	0.9	4.2	5.9	6.6	6.8	-	6.9	6.9	-	6.9
10000 sq miles	0.6	2.6	4.1	4.6	4.9	-	4.9	5.0	-	5.0
20000 sq miles	0.4	1.5	2.4	2.9	3.1	-	3.1	3.1	-	3.1

Adjusted Storm Depth-Area-Duration

	1 Hours	6 Hours	12 Hours	18 Hours	24 Hours	30 Hours	36 Hours	48 Hours	60 Hours	72 Hours
1 sq miles	5.3	19.3	21.4	21.8	21.9	-	21.9	21.9	-	21.9
10 sq miles	5.0	18.2	20.0	20.5	20.7	-	20.8	20.8	-	20.7
100 sq miles	4.1	15.4	17.4	18.0	18.1	-	18.1	18.1	-	18.1
200 sq miles	3.8	14.3	16.4	17.0	17.1	-	17.1	17.1	-	17.1
500 sq miles	3.2	12.3	14.3	14.8	14.8	-	14.8	14.9	-	14.9
1000 sq miles	2.7	10.6	12.3	12.9	12.9	-	13.0	13.0	-	13.0
5000 sq miles	1.2	5.7	8.1	9.1	9.3	-	9.4	9.4	-	9.4
10000 sq miles	0.8	3.6	5.6	6.3	6.7	-	6.8	6.8	-	6.8
20000 sq miles	0.5	2.1	3.3	3.9	4.3	-	4.3	4.3	-	4.3

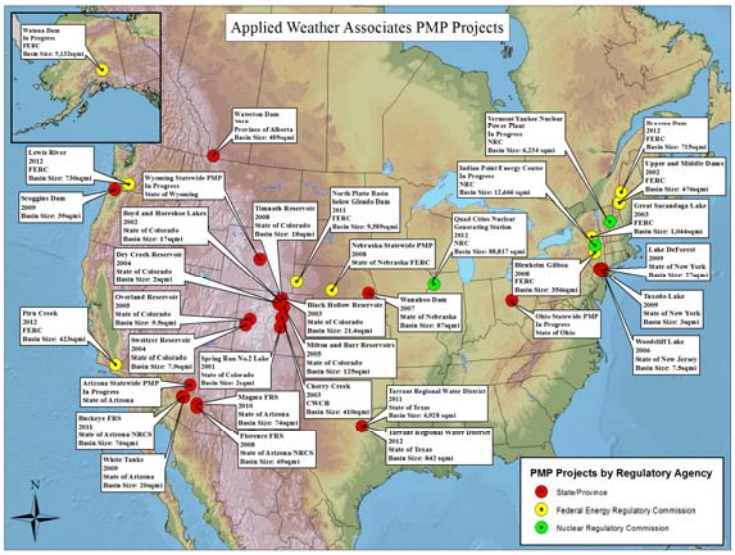
Storm or Storm Center Name	SPAS 1030-Dasid City, NE	
Storm Date(s)	24-Jun-1963	
Storm Type	MCC	
Storm Location	41.23 N	97.07 W
Storm Center Elevation	1,700	
Precipitation Total & Duration	16.50 Inches 24-hours USACE Bucket Survey Data	
Storm Representative Dewpoint	73.5 F	6
Storm Representative Dewpoint Location	39.41 N	94.83 W
Maximum Dewpoint	81.5 F	
Moisture Inflow Vector	SE @ 175	
In-place Maximization Factor	1.47	
Temporal Transposition (Date)	9-Jul	
Transposition Dewpoint Location	39.20 N	81.26 W
Transposition Maximum Dewpoint	78.0 F	
Transposition Adjustment Factor	0.93	
Average Basin Elevation	700	
Highest Elevation in Basin		
Inflow Barrier Height	700	
Elevation Adjustment Factor	1.00	

Storm Adjustment Spreadsheet

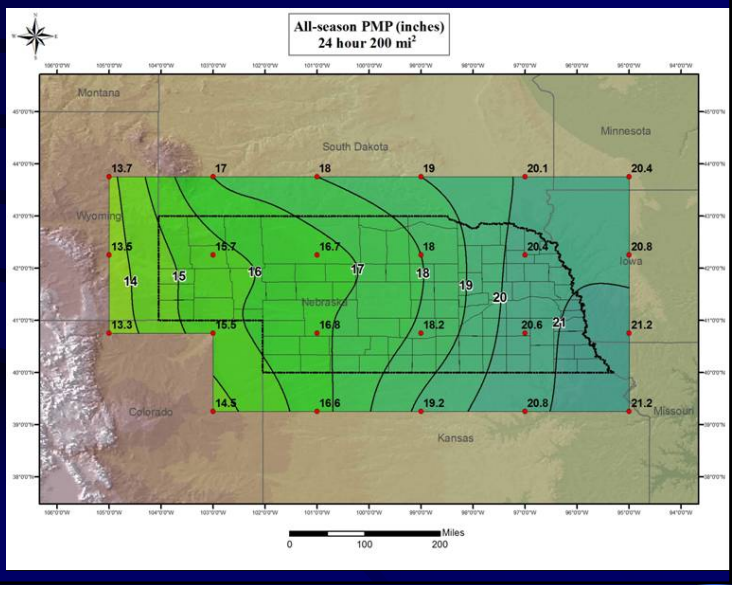
Probable Maximum Precipitation

- Types of PMP studies:
  - Generalized (Hydrometeorological Reports)
  - Regional (EPRI Michigan/Wisconsin 1993)
  - Statewide (Nebraska 2008, Arizona, Ohio, Wyoming)
  - Site-Specific

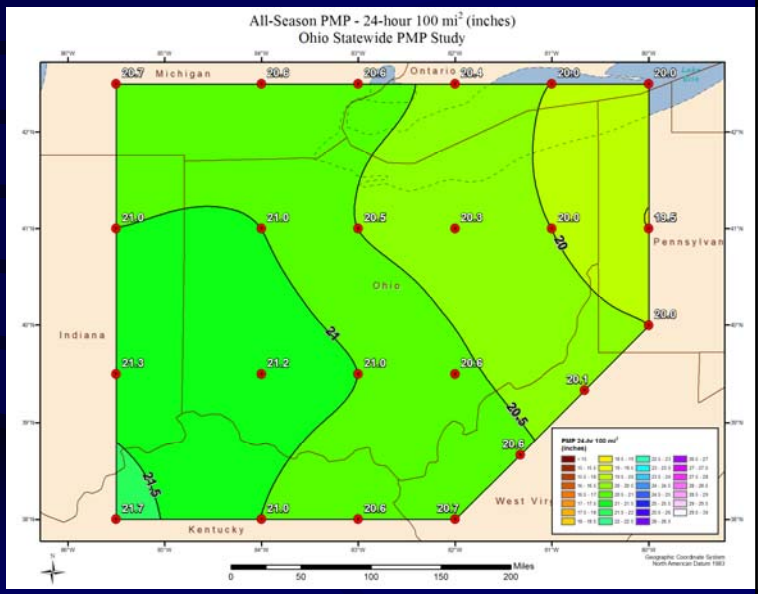
Completed and In-Progress PMP Studies



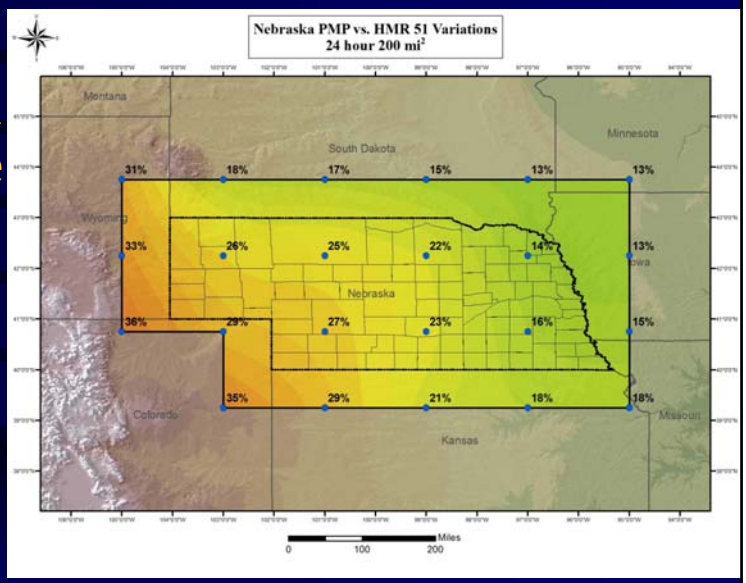
Nebraska Statewide PMP Study Results



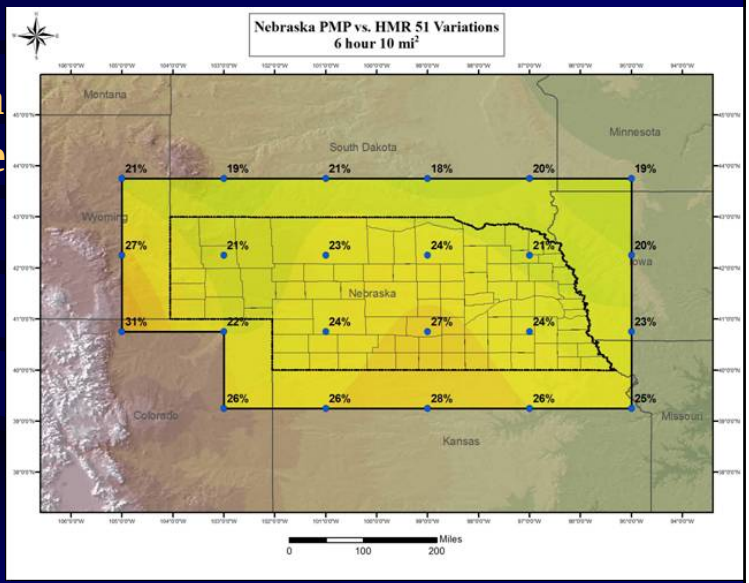
Ohio Statewide PMP Study Results



Nebraska Statewide PMP Study Results vs HMR 51



Nebraska Statewide PMP Study Results vs HMR 51



Results from Selected Site-Specific PMP Studies

- Wisconsin/Michigan
  - Accepted by FERC
- Great Miami River, Ohio
  - Accepted by Ohio State Engineer
- Catawba-Wateree Rivers, Carolinas
  - Not accepted by FERC
- Williams Fork River, Colorado
  - Accepted by FERC & Colorado State Engineer

Results from Selected Site-Specific PMP Studies

- Muddy Creek, Colorado
  - Accepted by Colorado State Engineer
- Elkhead Creek, Colorado
  - Accepted by Colorado State Engineer
- Broomfield Reservoir, Colorado
  - Accepted by Colorado State Engineer
- Chelan Reservoir, Washington
  - Study suspended
- Upper and Middle Dams, Maine
  - Accepted by the FERC
- Great Sacandaga Lake, New York
  - Accepted by the FERC

Results from Selected Site-Specific PMP Studies

- **Nebraska Statewide**
  - **Accepted by Nebraska Dam Safety office**
  - **Accepted by the FERC**
- **Blenheim-Gilboa Reservoir, New York**
  - **Accepted by the FERC**
- **Tuxedo Lake**
  - **Accepted by New York Dam Safety office**
- **Woodcliff Lake**
  - **Accepted by New Jersey Dam Safety office**
- **Brassua Dam drainage basin, Maine**
  - **FERC acceptance pending**
- **Lewis River drainage basin, Washington**
  - **FERC acceptance pending**

Applied Weather Associates Completed PMP Studies

- Site-specific PMP values are used instead of HMR values to compute the Probable Maximum Flood
- PMP studies have produced reductions in the PMP values from individual drainage basins and statewide regions
- AWA site-specific and statewide PMP studies have been accepted by appropriate regulators
  - Federal Energy Regulatory Commission (FERC)
  - State dam safety regulators

Updates to the HMRs

- Updates to the HMRs
  - Need consistent analysis procedures across the US
  - Need comprehensive documentation and working paper archives
  - Leverage off of site-specific/statewide/regional PMP studies
    - Can be developed by region
    - Much has been completed for the Midwest
      - » Storm search
      - » Storm rainfall analyses
      - » Maximum T_d and 2-sigma SST climatologies completed
      - » In-place storm maximization complete
  - Coordinated development
    - Federal agencies
      - » FERC
      - » USBR
      - » COE
      - » NRCS
      - » NRC
      - » NRCS
    - State dam safety offices
    - Others (e.g. TVA)
    - Review Committee review and endorsement

Applied Weather Associates

Challenges in Determining the Probable Maximum Precipitation (PMP)

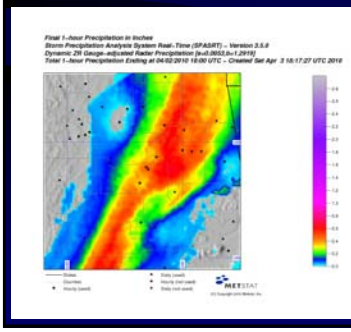
????? Questions ????

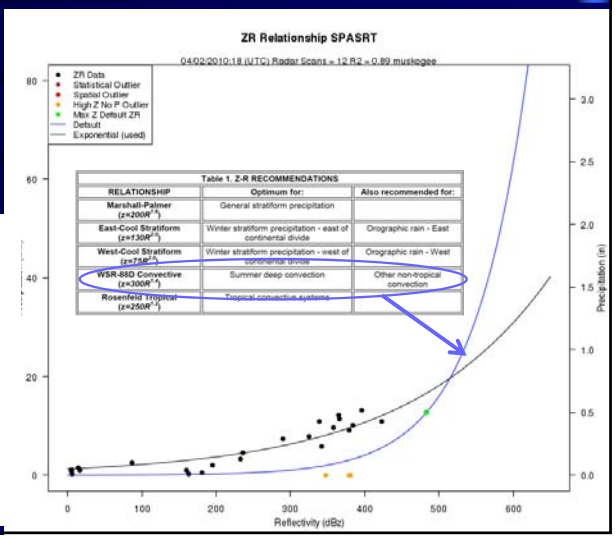
!!!!! Comments !!!!!

Applied Weather Associates

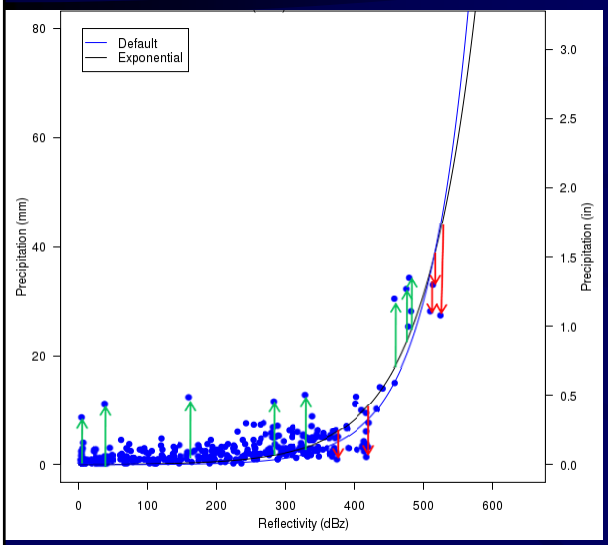
ZR Relationship

- Reflectivity-rainfall (ZR) relationships are computed using a weighted best-fit exponential function and thresholds in order to compute rainfall rates from radar reflectivity
- Instead of adopting a standard (e.g. 300^1.4) ZR relationship, SPASRT computes and applies a ZR relationship <u>each hour</u>





Gauge-Adjusted Algorithms (a.k.a. bias correction)



- The bias at each gauge is spatially interpolated to a grid and applied to the initial rainfall grid.
  - ✓ Ensures gauge and grid rainfall are equal when/where appropriate.
  - ✓ Allows for local variation in the bias field instead of applying a single bias adjustment.