Probable Maximum Precipitation and Site-Specific PMP-Where Are We Today

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EWRI Conference

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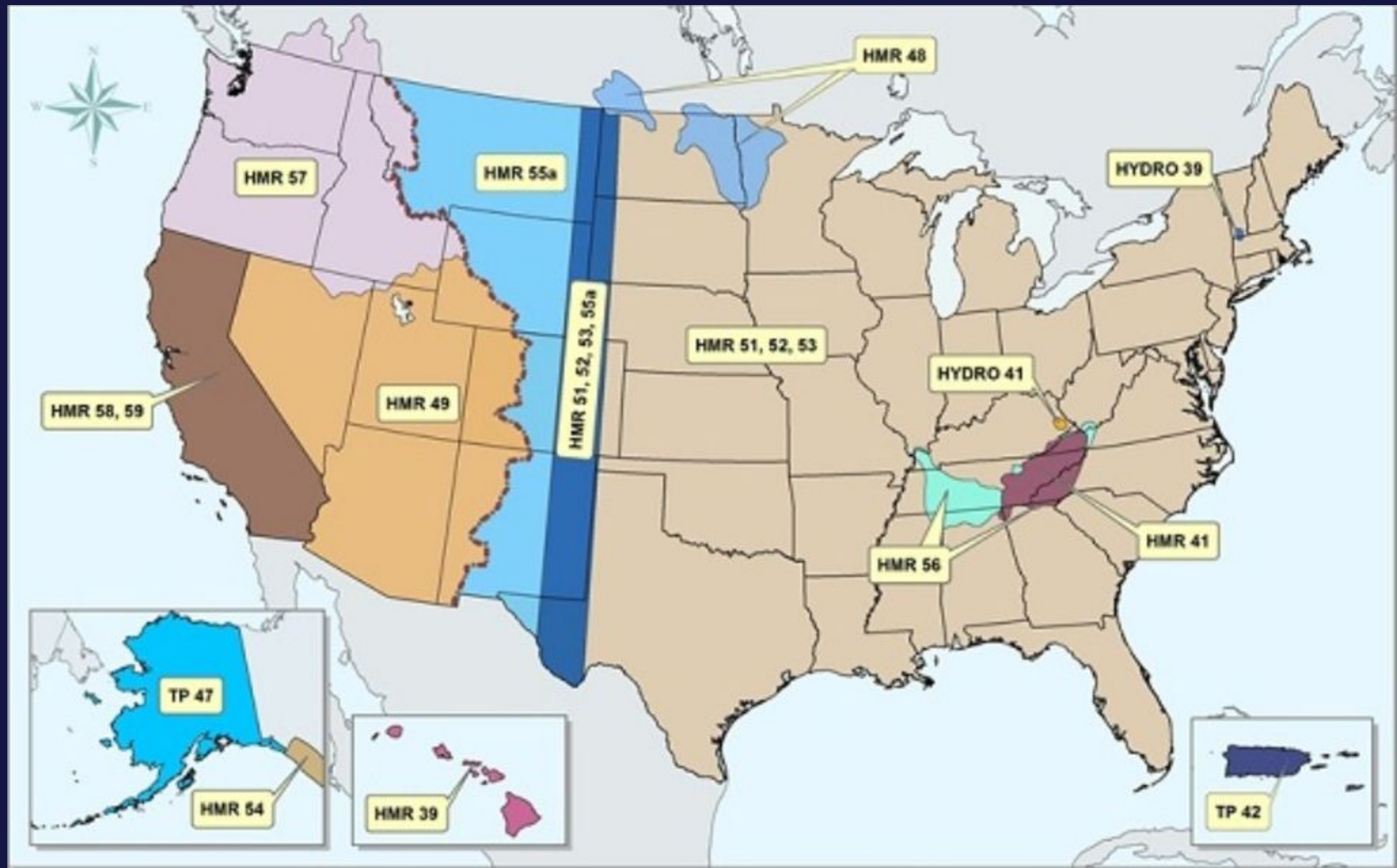
Probable Maximum Precipitation

- **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)
- Types of PMP studies:
  - Generalized (Hydrometeorological Reports)
    - Provides PMP values for a region
    - HMR 51 - East of the 105th Meridian from Canada to Mexico
  - Regional/Statewide
    - Provide PMP values over regions with varying topography
    - Individual basins are included in the regional/statewide results
  - Site-Specific
    - Provides PMP values for individual drainage basins
    - Considers unique meteorology and topography

PMP History

- Weather Bureau (now National Weather Service) published first HMR in 1940
  - HMR 1-Ompompanoosuc Basin, Vermont
- Latest HMR published in 1999
  - HMR 59-California
- All followed the storm-based approach
- Significant advancement applied throughout the years
- Storms continually analyzed and added
  - HMR 51-only through 1972
  - HMR 55A, HMR 57, HMR 59 added storms relevant to their regions
- All HMRs can be downloaded from NWS HDSC PMP website

Coverage of National Weather Service HMRs



How Is PMP Computed?

- Storm Based Approach-Deterministic
  - Maximize storms
  - Transposition storms
  - Combine into PMP design storm
    - By storm type
- Subjective decisions involved

PMP History

- HMRs have become out-of-date
  - Based on outdated methods and techniques
    - Better understanding of meteorology
  - Storm datasets not updated
    - More than 40 years missing from HMR 51
- Effect of topography not accurate
  - Subjective
  - Lack of empirical data-unknowns
- Many processes subjective and not reproducible
  - Several inconsistencies between each report
  - Not clear how storm data used to develop the PMP values
  - No or limited working papers/notes
  - Limited to no external/independent review

HMR 51-PMP Map

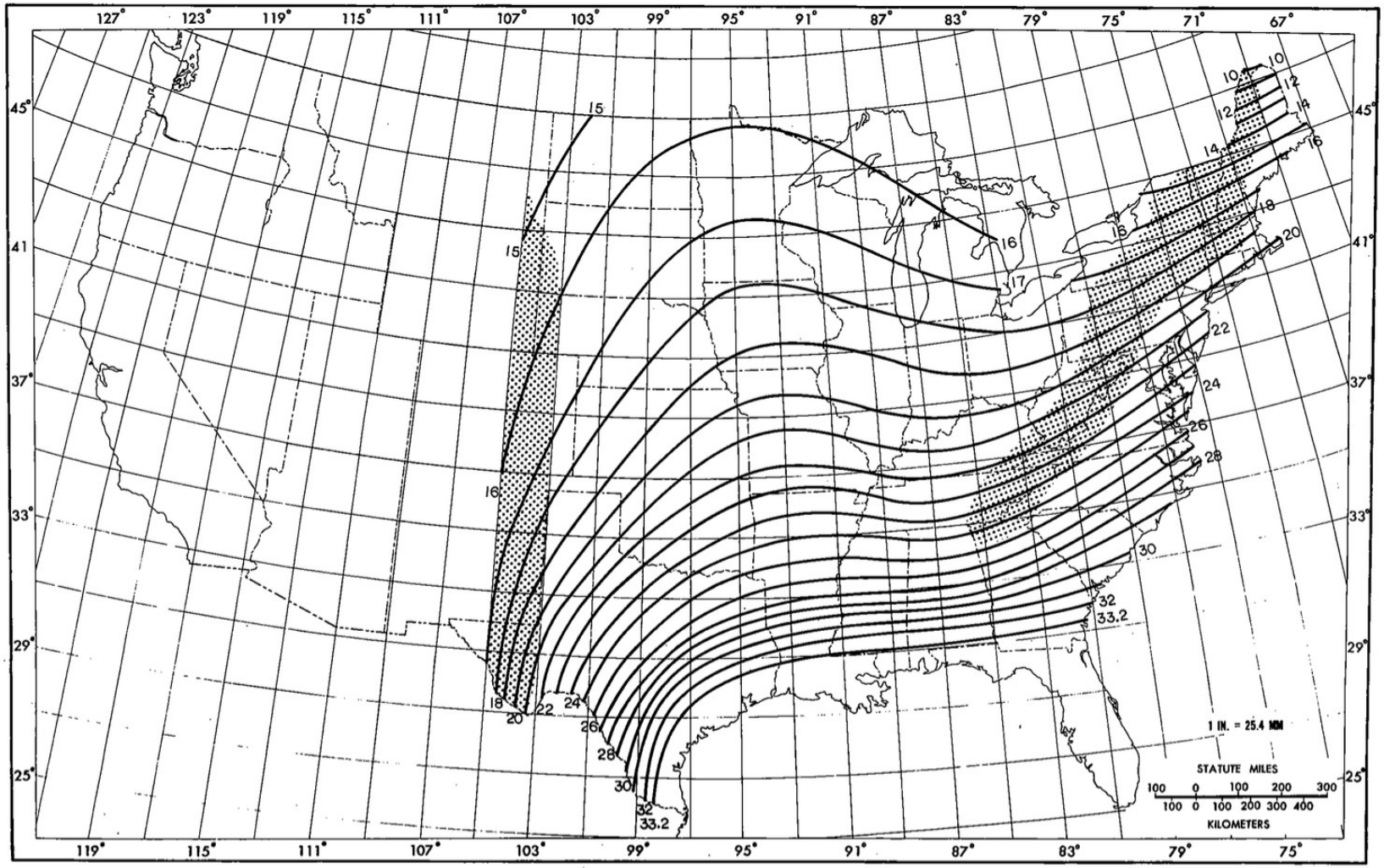


Figure 30.--All-season PMP (in.) for 24 hr 1,000 mi^2 (2,590 km^2).

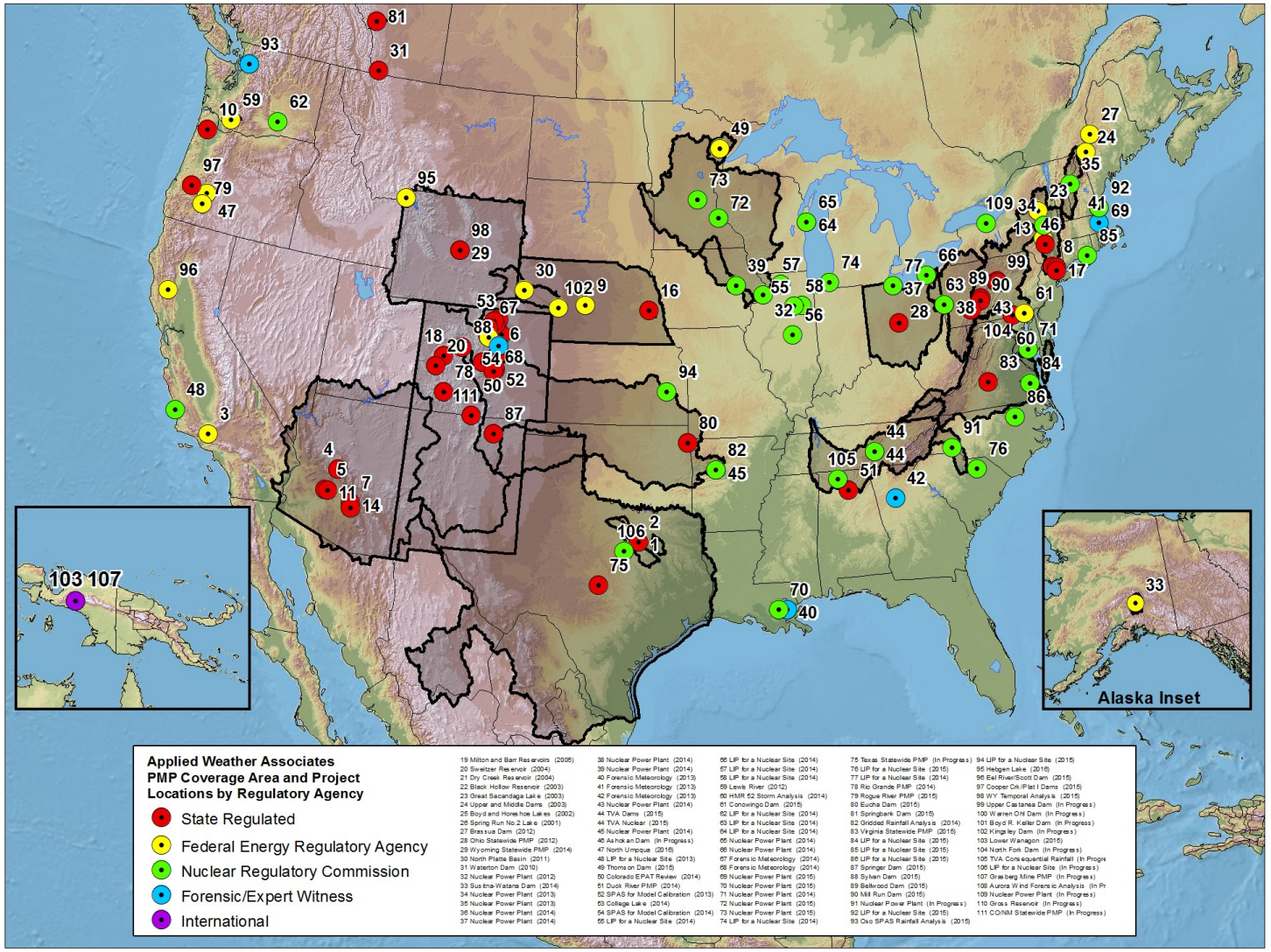
PMP Improvement Used Today

- NEXRAD weather radar
  - Very important for spatial distribution
  - Must be calibrated first
- GIS
- Computing power/speed
- Updated understanding of rainfall
- Updated understanding of topographic effects
- Updated climatologies for maximization

Current PMP Work

- Many PMP studies completed last 30 years
  - Private industry-numerous site-specific, statewide, regional studies
  - Need for updating PMP to better design/update spillways
  - Understand flood hydrology/PMF
  - State dam safety, FERC, NRC main users
  - Bureau of Reclamation, Corps of Engineers
  - NWS no longer involved

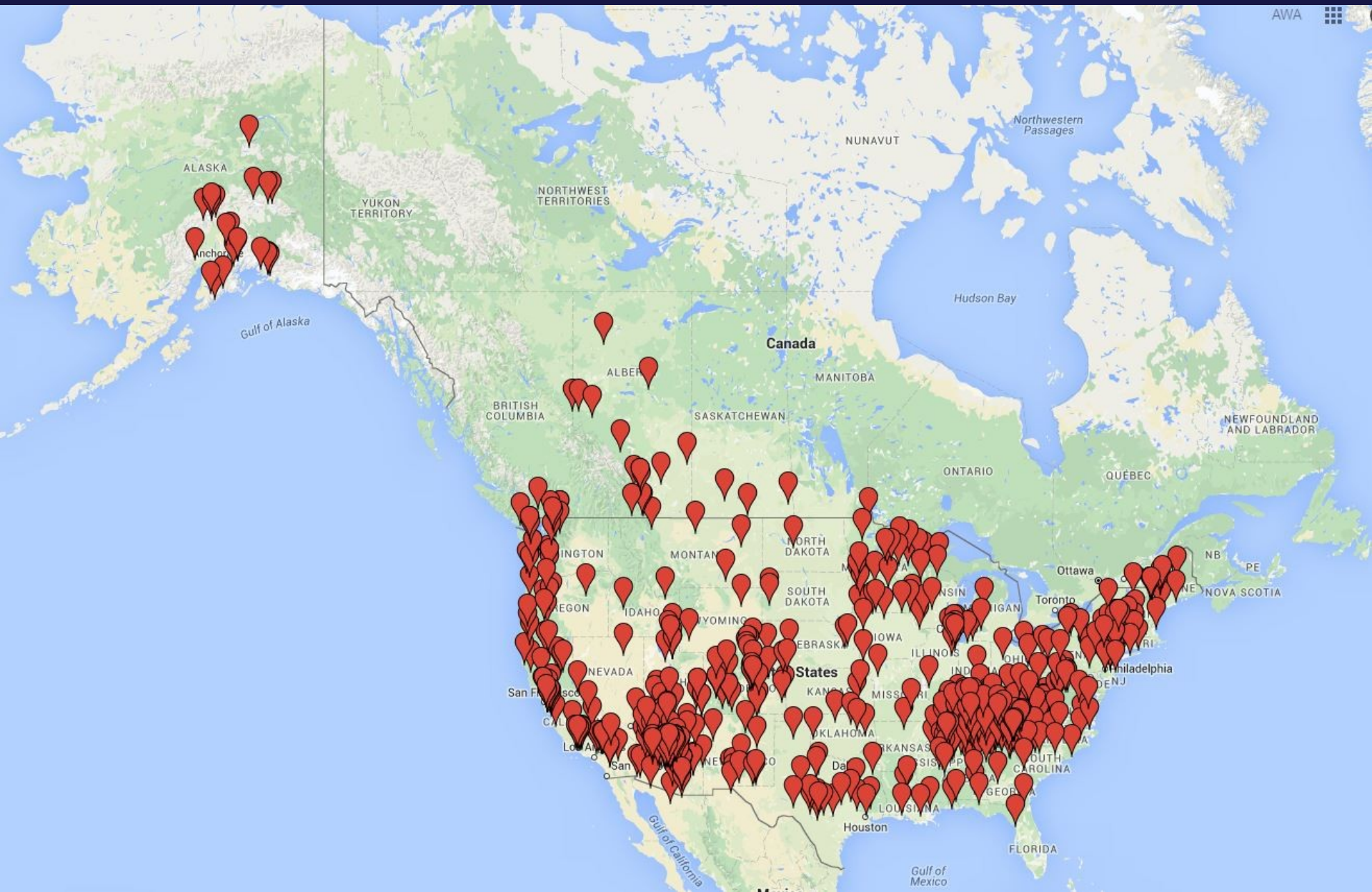
AWA Project Locations



Current PMP Work

- Storm database updated continuously
- Use of current meteorology
  - NEXRAD
  - GIS
  - Updated climatologies
  - Trajectory models
- Latest technology continue to be employed
- What about modeling?
- Still subjectivity/uncertainty

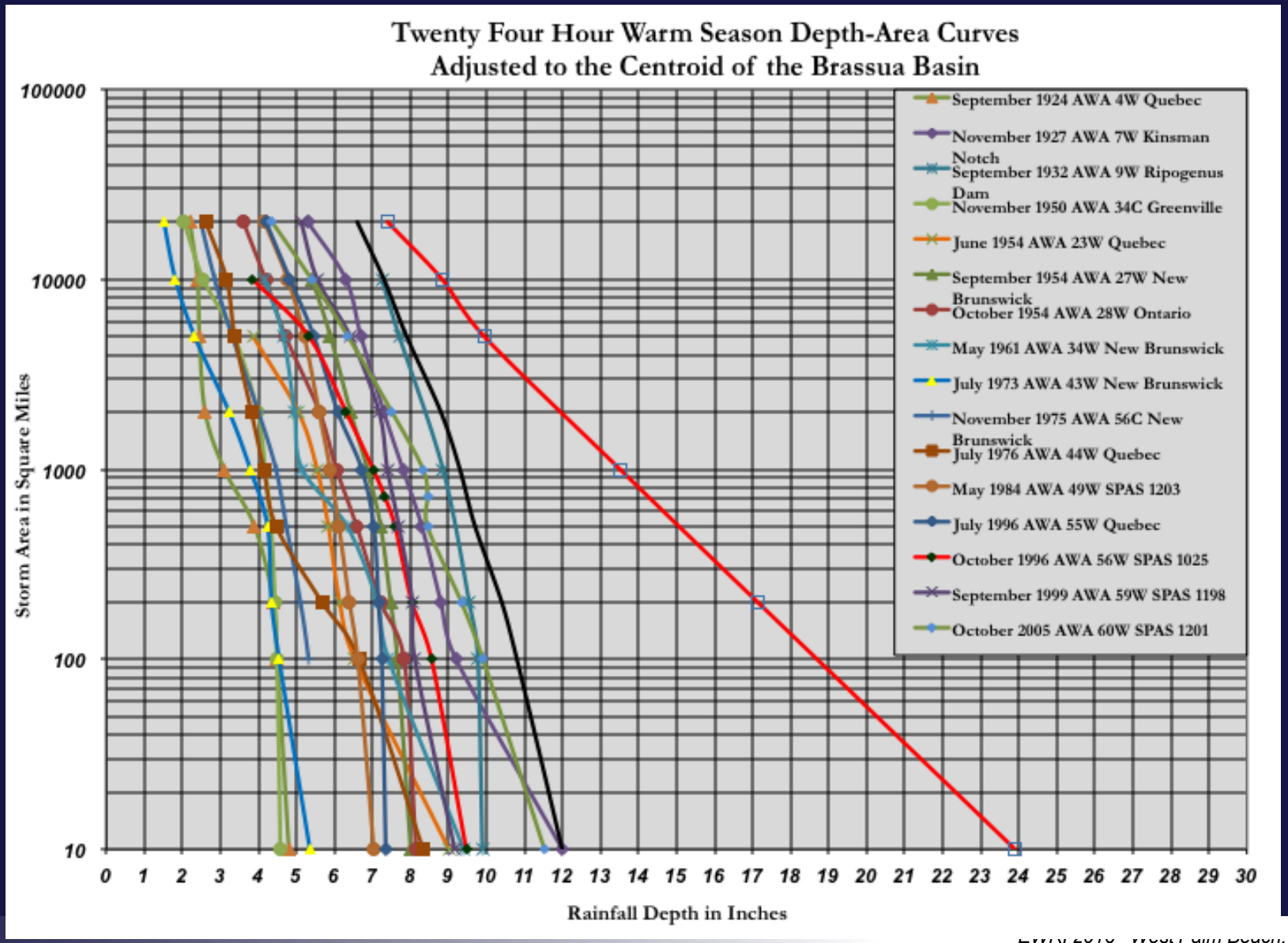
AWA SPAS Storm Locations



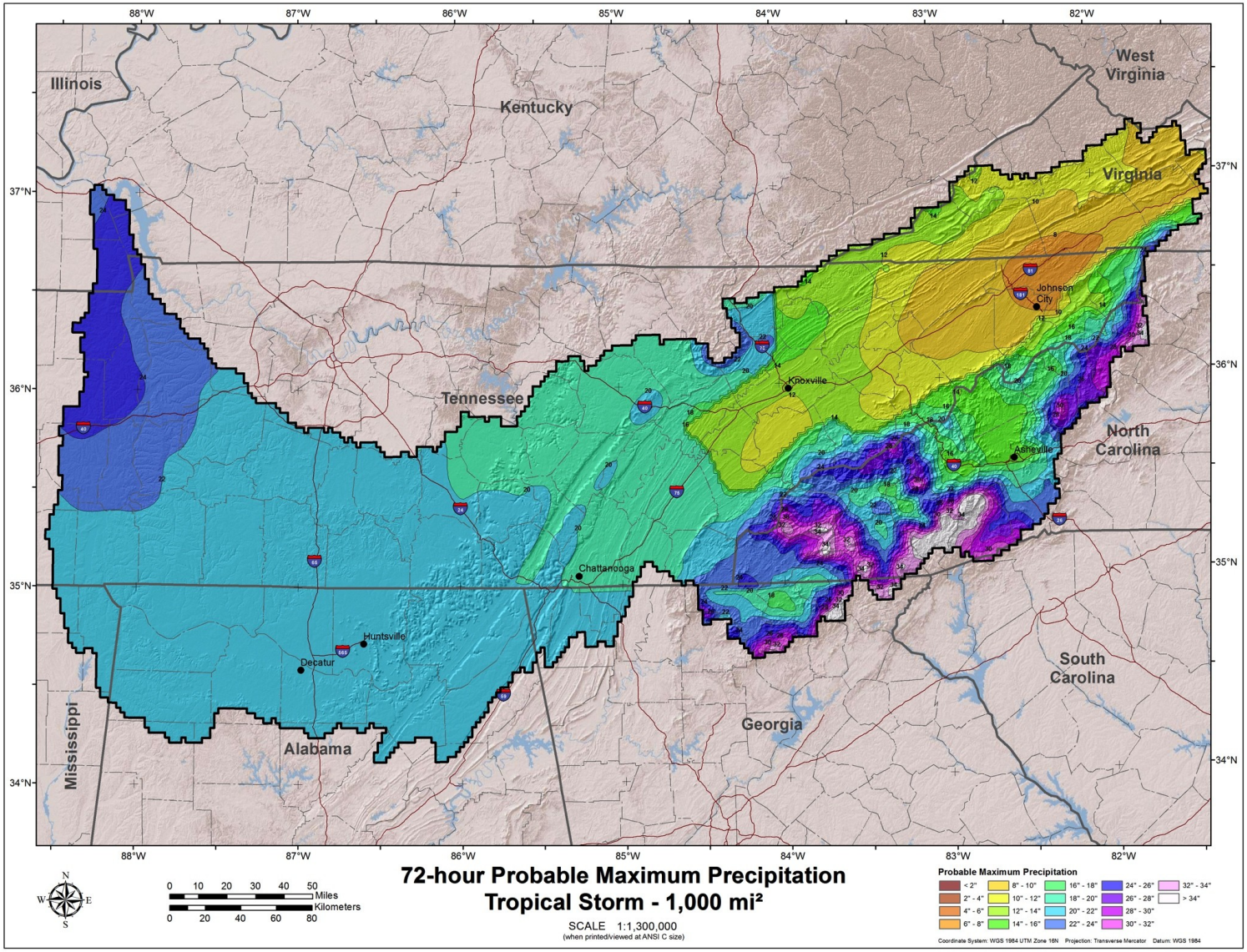
Current PMP Work

- Results are used in place of HMR values
- Coordination with dam safety/hydrologist/engineers
  - Understand how developed
  - Aware of sensitivity/uncertainty
  - Better information to make more informed decisions
- Objective not to reduce the values, but to make them as accurate as possible given current understanding of meteorology

HMR 51 Example PMP-Single Basin



HMR 51 Example PMP-Stippled Region

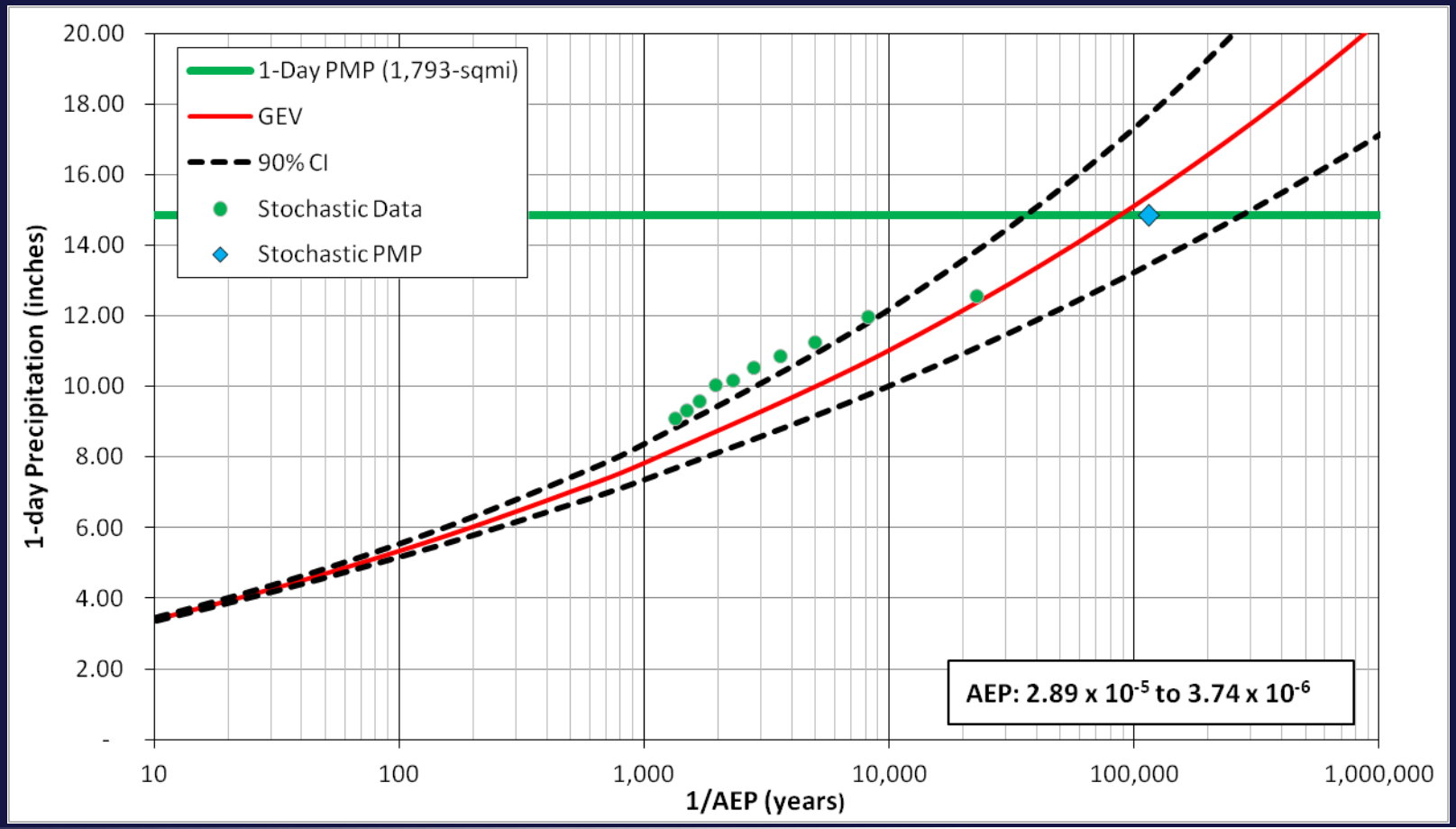


What About Probability of PMP?

- Deterministic, but probability can still be estimated
- Traditionally compared to Precip Frequency
  - 2 to 5 x greater than 24-hr, 100-year values
  - But only point estimates
- Recent work completed to derive recurrence interval of PMP
  - Follows methods developed by Corps and Bureau
  - Utilize Area of storm search domain, period of record, observed values compared to PMP

PMP Probability Example

- Regional L-moments Method
- Stochastic Storm Transposition (SST) Method



What About Uncertainty of PMP?

- Each parameter has various amounts of uncertainty
  - Storm selection
  - Storm maximization choice
  - Storm transposition
  - Storm analysis
  - Micovic et al. 2015-detailed examples and variance

QUESTIONS

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EXTRA SLIDES

SPAS Storm Analyses

- Catskill, NY 1819
  - 10+ inches in 1-hour
  - American Journal of Science
  - Enough data to analyze today-not used in HMRs
- Unofficial observations very important
  - Bucket surveys
  - Anecdotal

Catskill, NY-July 1819

ART. XII.—*An account of a remarkable storm which occurred at Catskill, July 26, 1819.*

[Read before the Catskill Lyceum.]

TO PROF. SILLIMAN,

Dear Sir—Agreeably to your request, I now transmit to you an account of the great storm, which occurred here on Monday afternoon the 26th July, 1819. At that time I was absent on a journey, in the state of Pennsylvania. Of course I am indebted to others for that class of facts which relate to the immediate phenomena of the storm. I reached home on the following Monday; and during that week spent much of the time in collecting facts relative to it; and have since from time to time, visited various places, where uncommon ravages were occasioned, and have spared no pains in obtaining all the information of an interesting nature which could be collected. Every fact communicated by others, or observed by myself, was immediately committed to writing. The manuscript has lain by me about fifteen months. I have more than once, visited several of the places, where peculiar ravages exist, and believe the account to be in no degree exaggerated.

I am respectfully, yours, &c.

BENJAMIN W. DWIGHT.

Catskill, February 5, 1821.

ACCOUNT OF A STORM, &c.

IN several places in the mountainous country of New-England, it has been supposed by many of the inhabitants, that *clouds have in various instances burst*, or suddenly discharged great quantities of water. As the phenomena indicated by this phraseology have, in almost all instances, in which they have occurred, in that section of the country, existed in thinly settled regions, or in the night, in consequence of which the accounts given of them are imperfect; I suppose that it may be gratifying to some of your readers, to see a detailed account of the storm, which occurred here.

This storm exhibited phenomena analagous to those, which have occurred from what is called the bursting of a cloud, and in some respects more remarkable than any, of which I have heard.

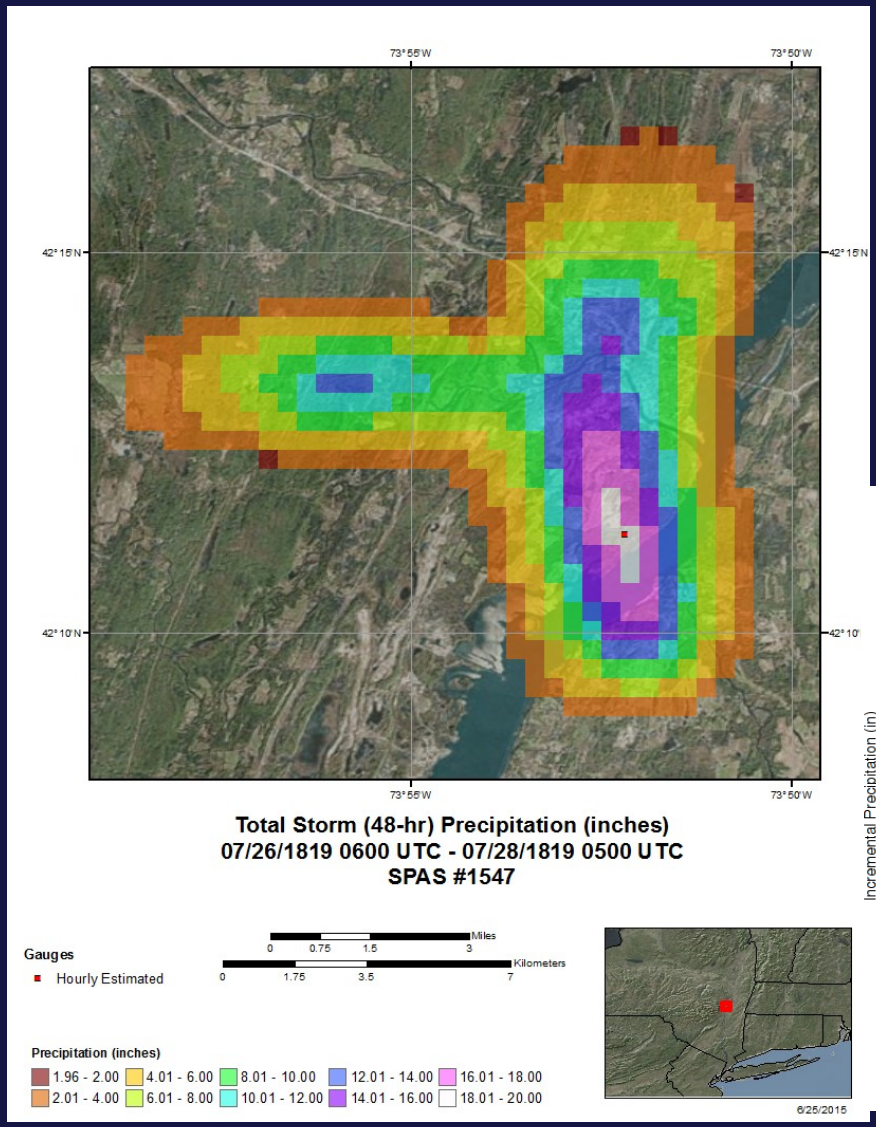
To render the description more intelligible, a few explanatory observations may be useful.

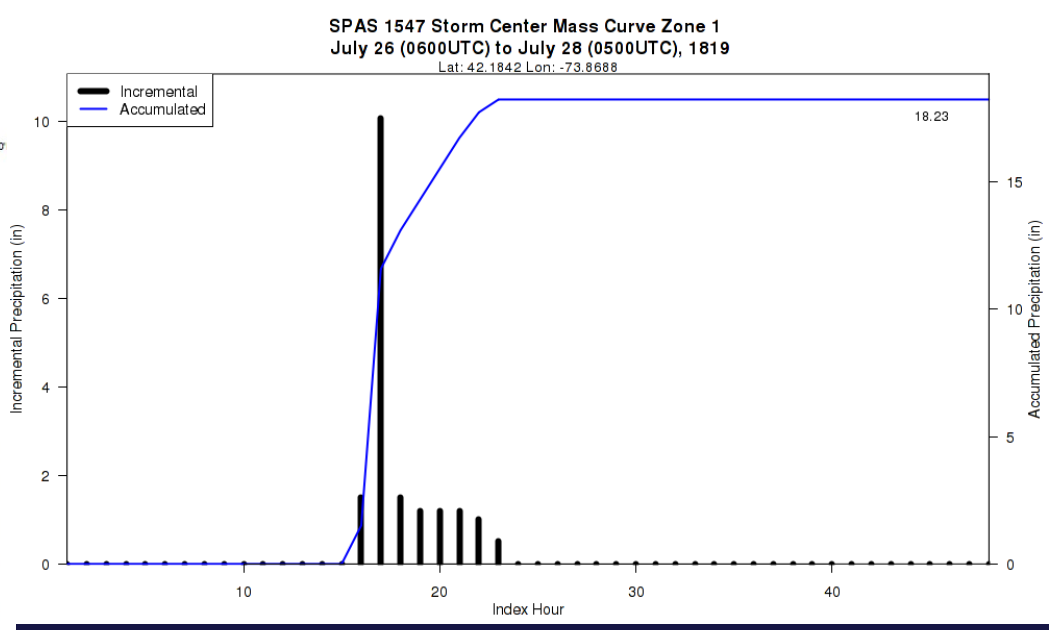
The *township* of Catskill is situated on the West side of the Hudson, and is bounded on the East by that river; on the North by the township of Athens; on the West by Cairo; and on the South by Saugerties. The *town* is estimated to be about one hundred and twenty miles north from the city of New-York. Three rivers, or creeks, as they are here customarily called, have their courses in part, through this township; the Kistatom, the Kaaterskill, and the Catskill. The Kiskatom rises, if I am correctly informed, between the Catskill mountains and the Round Top,* a mountain in Cairo; and runs about five miles in the township of Catskill, and empties into the Kaaterskill. The Kaaterskill is a fine mill stream, which rises in the Catskill mountains, and empties into the Catskill, about two miles from the mouth of the latter stream.

The Catskill, which I shall usually denominate the *Creek*, rises in Middleburgh, in Scoharie County, and empties after a course of about forty miles, into the Hudson. The Catskill mountains lie westward from the town, and are distant from it in their nearest part, about seven or eight miles. *The town* is situated along the creek, and commences at

* The highest peak of the Catskill mountains is also called Round Top.

Catskill, NY-July 1819





Smethport, PA-July 1942

- World record rainfall at 4.5 and 6 hours
- Hard to believe reports-but it rained a lot
- Lots of data for 1942

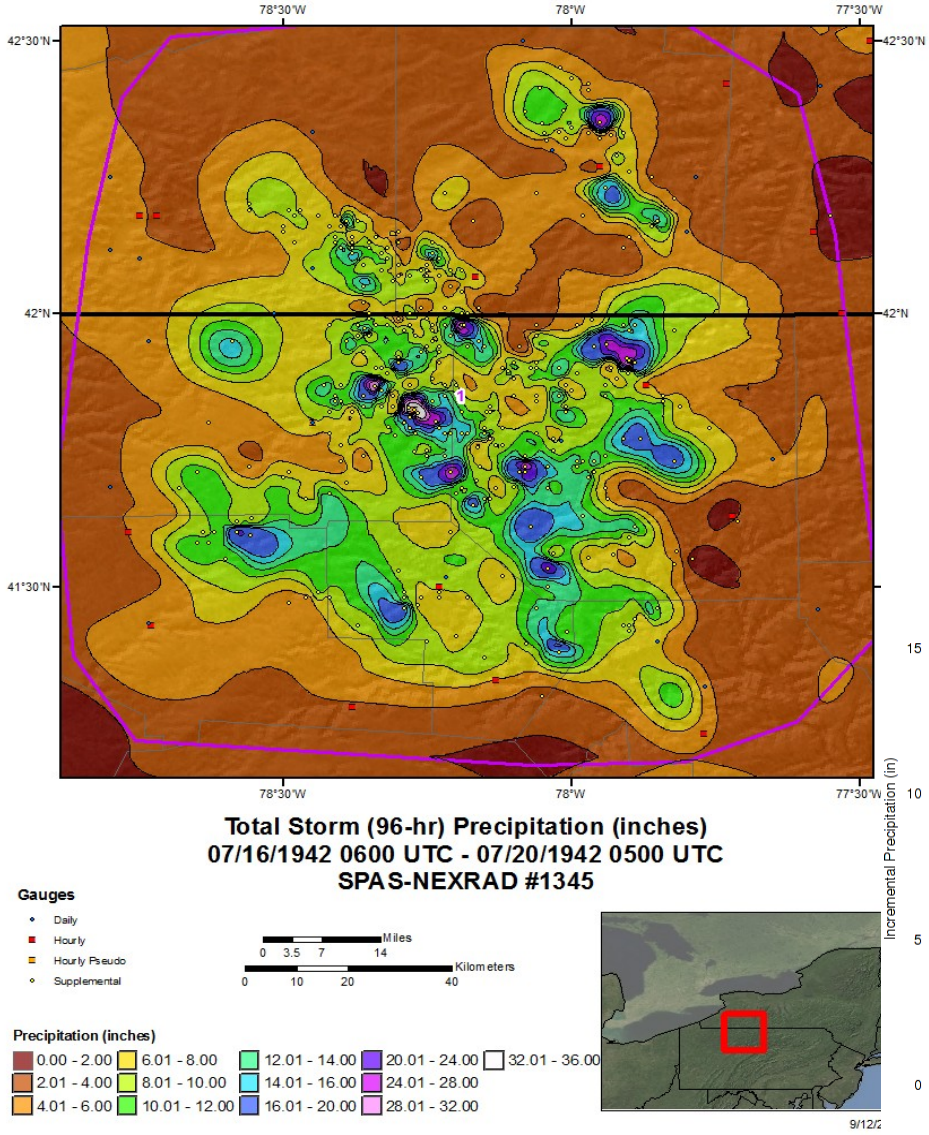
Smethport, PA-July 1942

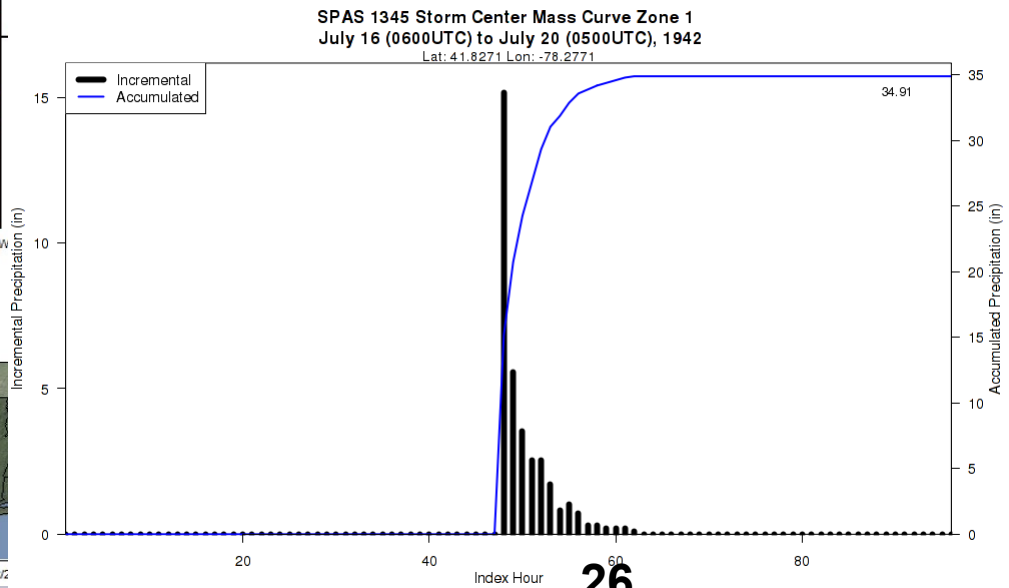
Rainfall observation site for the world

Record rainfall amount

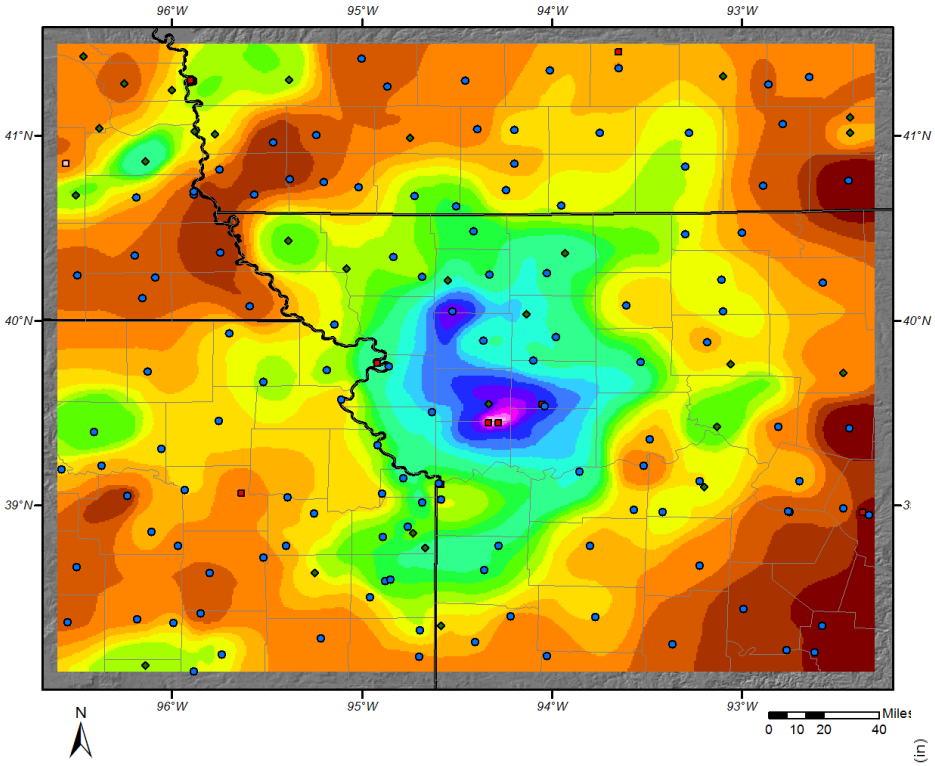
- 30.8 inches
- 4.5 hours
- 8” pickle jar with 3.5” opening!
- ~22” from roofline

Smethport, PA-July 1942





Holt, MO-June 1947



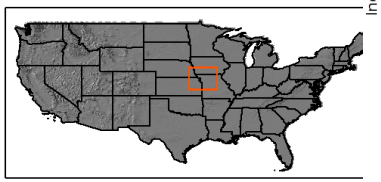
Total 108-hour Precipitation (inches)
June 19, 1947 0000 UTC - June 23,1947 1200 UTC
SPAS #1434

Precipitation (inches)

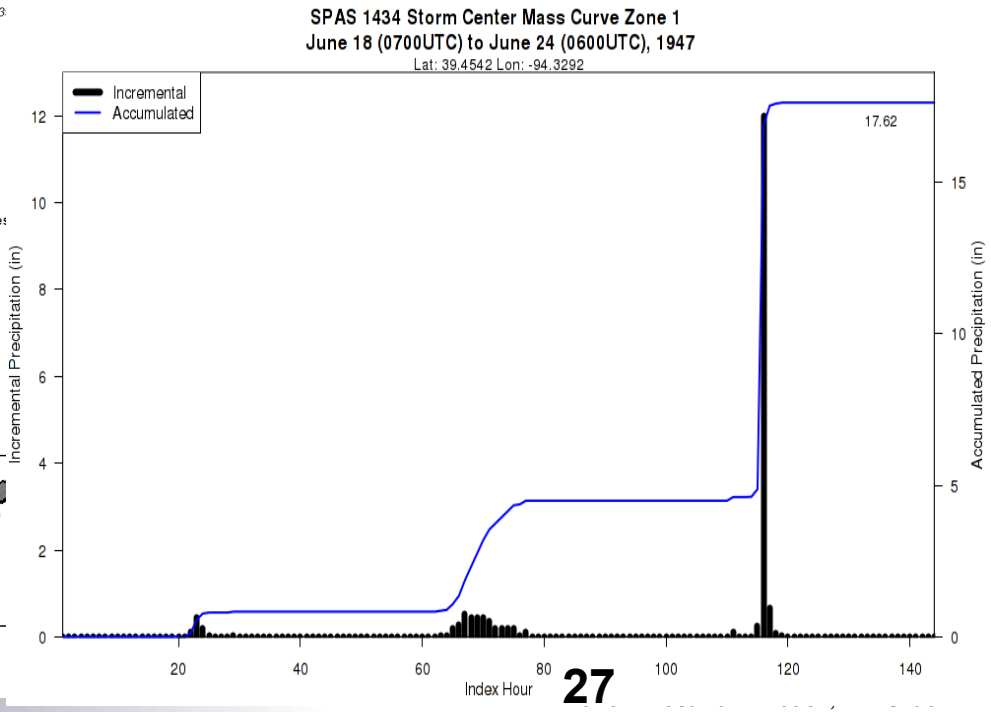
0.00 - 0.50	2.51 - 3.00	5.01 - 6.00	10.1 - 11.5
0.51 - 1.00	3.01 - 3.50	6.01 - 7.00	11.6 - 13.0
1.01 - 1.50	3.51 - 4.00	7.01 - 8.00	13.1 - 14.5
1.51 - 2.00	4.01 - 4.50	8.01 - 9.00	14.6 - 16.0
2.01 - 2.50	4.51 - 5.00	9.01 - 10.0	16.1 - 17.5
			17.6 +

Stations

D
H
HE
S



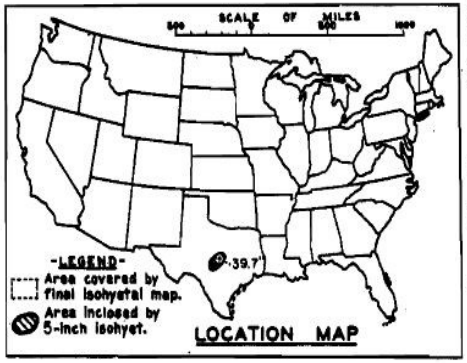
KLL 10/21/2014



Thrall, TX-September 1921

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

STORM STUDIES - PERTINENT DATA SHEET



Storm of 8-10 Sept. 1921
Assignment GM 4-12
Location Central Texas
Study Prepared by:
Southwestern Division
Galveston District Office
& Hydrometeorological Section
Part I Reviewed by H. M. Sec. of Weather Bureau, 8/20/45
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 11/7/46
Remarks: Center near Thrall (Taylor), Texas

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)	7
Form 5001-B (24-hour " ")	23
Form 5001-D (" " " ")	2
Misc. precip. records, meteorological data, etc.	30
Form 5002 (Mass rainfall curves)	35

PART II

Final isohyetal maps, in 1 sheet, scale 1:500,000

Data and computation sheets:

Form S-10 (Data from mass rainfall curves)	2
Form S-11 (Depth-area data from isohyetal map)	2
Form S-12 (Maximum depth-duration data)	38
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	30	36	48				
Max. Station	23.4	31.8	36.4	38.2	39.2	39.7	39.7				
10	22.4	29.8	35.0	36.5	37.2	37.6	37.6				
100	19.6	26.2	30.7	31.9	32.6	32.9	32.9				
200	17.9	24.3	28.7	29.7	30.4	30.7	30.8				
500	15.4	21.4	25.6	26.6	27.3	27.6	27.7				
1,000	13.4	18.8	22.9	24.0	24.6	24.9	25.1				
2,000	11.2	15.7	19.5	20.6	21.2	21.5	21.6				
5,000	8.1	11.1	14.1	15.0	15.9	16.2	16.3				
10,000	5.6	7.7	9.7	10.7	11.8	12.1	12.2				
12,500	4.7	6.7	8.4	9.4	10.3	10.7	10.9				

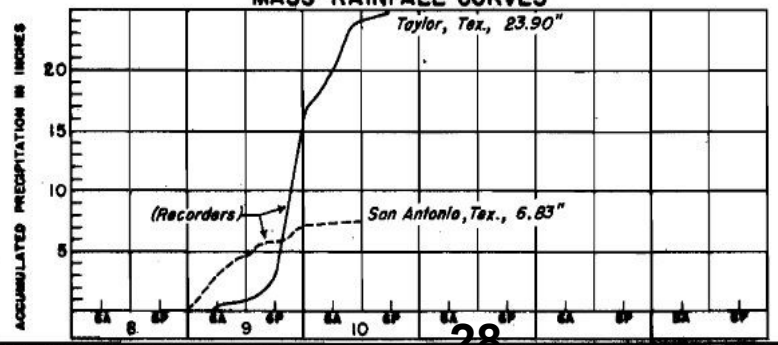
Form S-2

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

STORM STUDIES - ISOHYETAL MAP

Storm of September 8-10, 1921 — Assignment GM 4-12
Study Prepared by: Galveston, Tex. District
Southwestern Division & Hydrometeorological Section

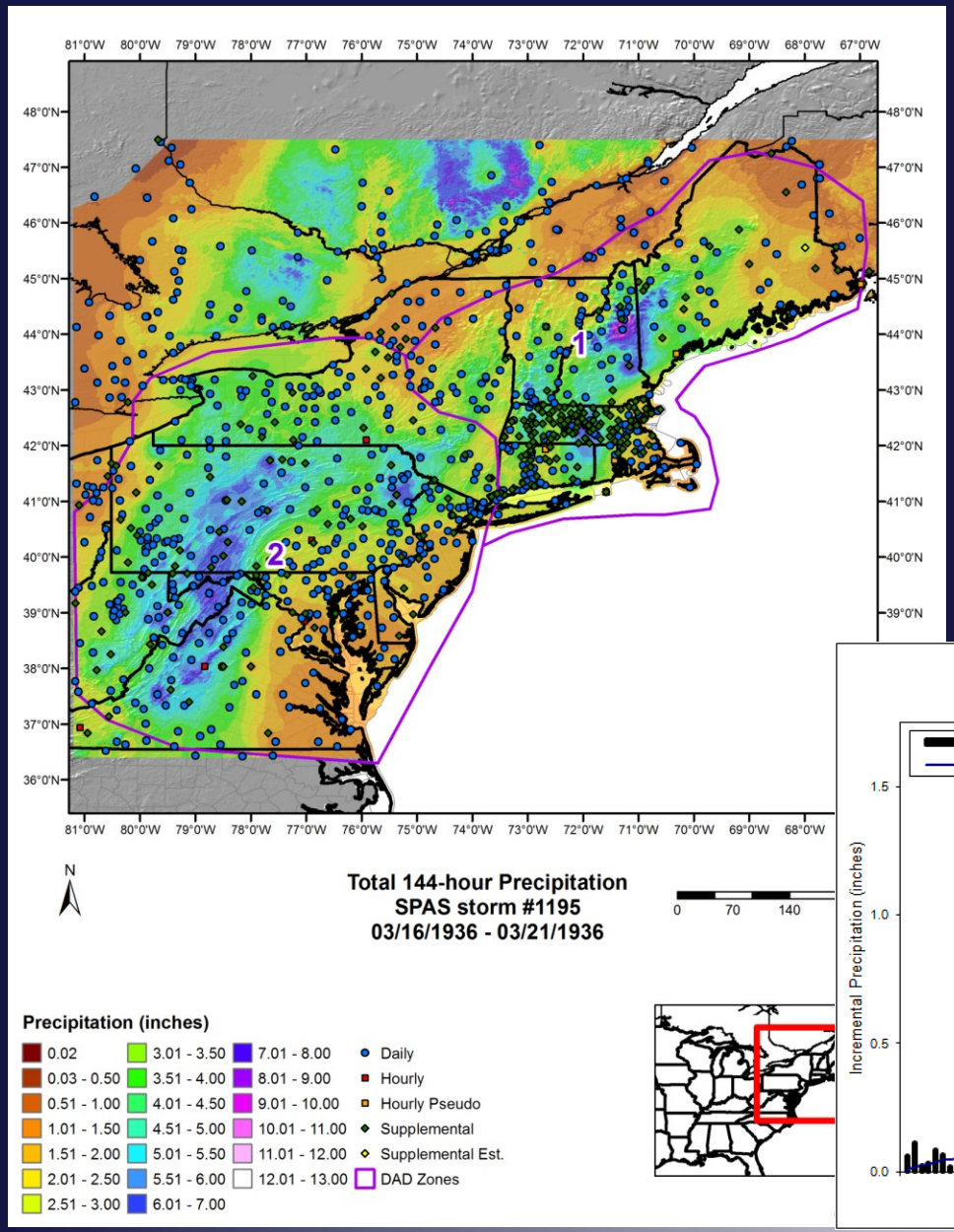
MASS RAINFALL CURVES

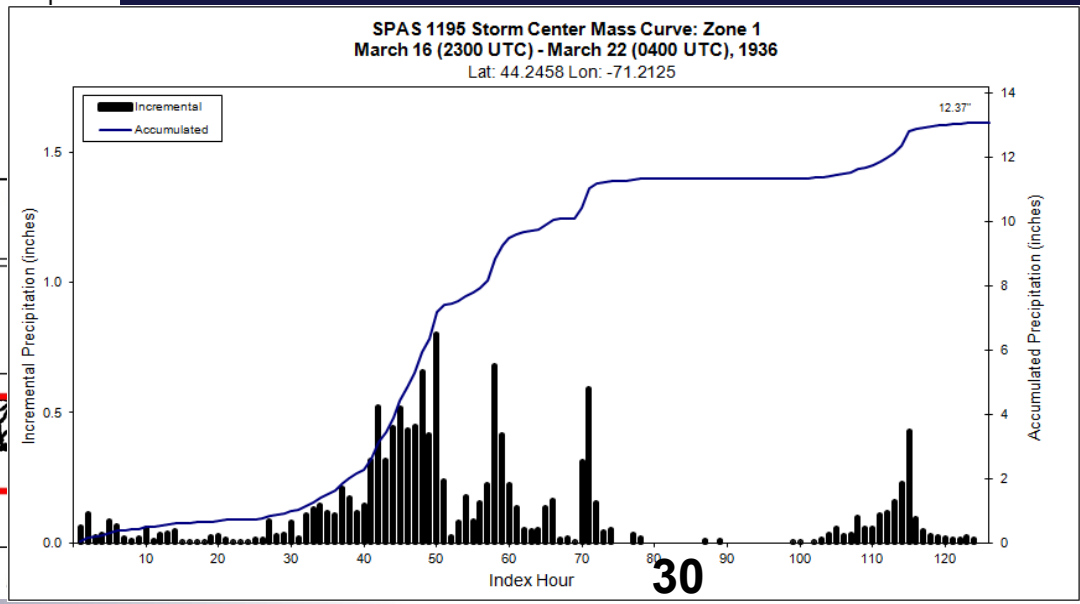


FORM S-12

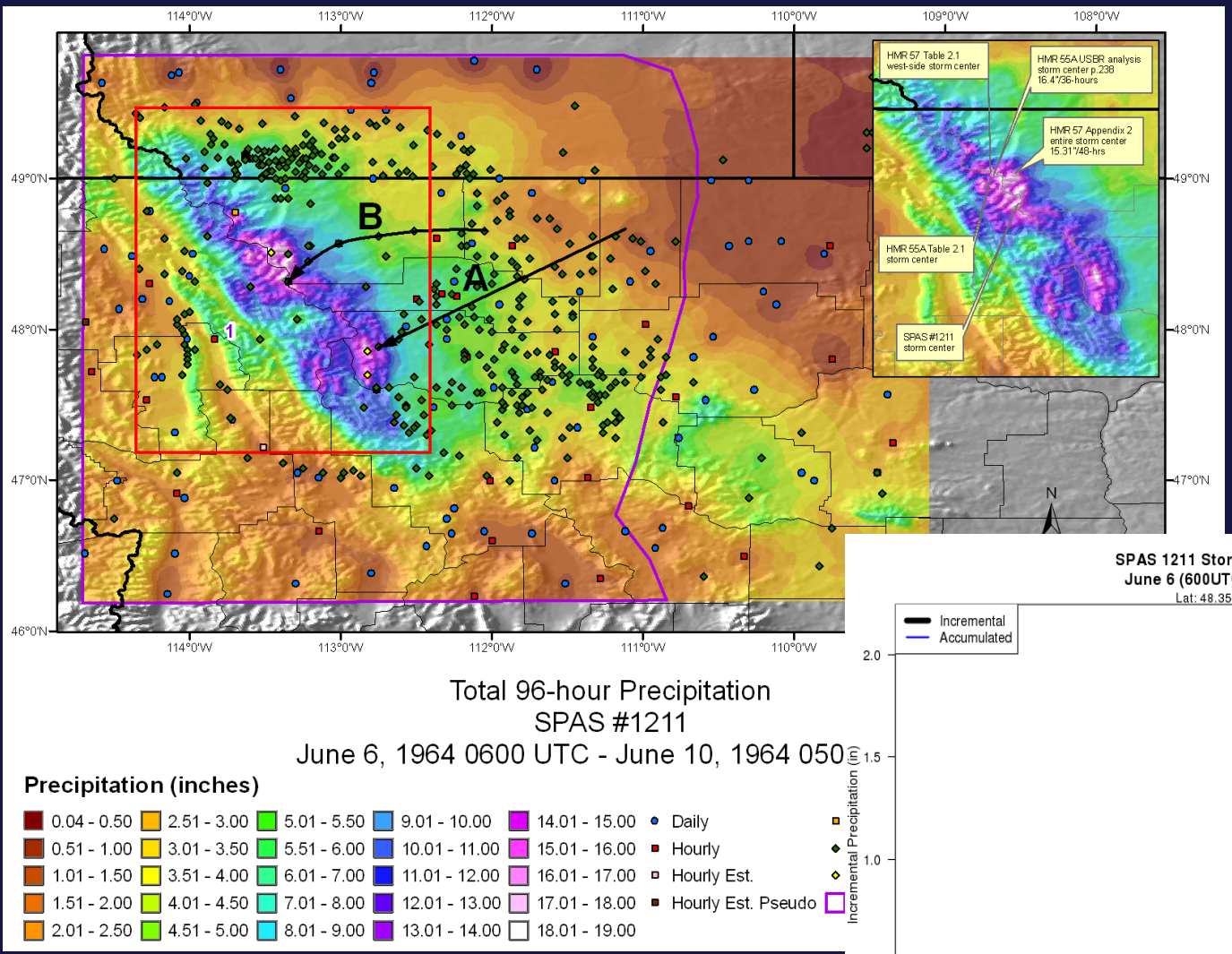
Thrall, TX-September 1921

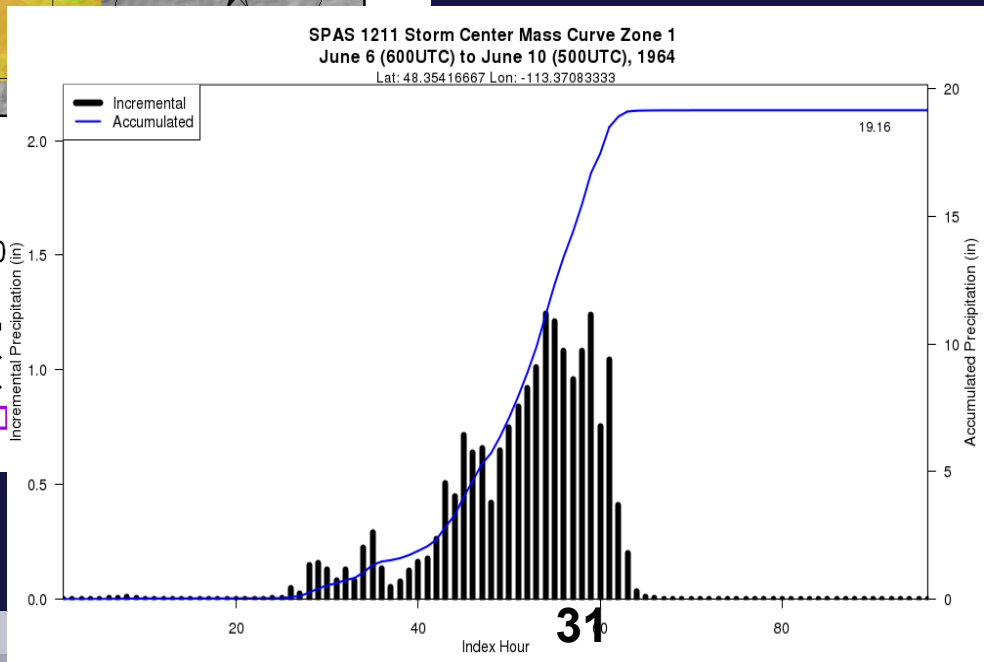
Great New England Flood-March 1936



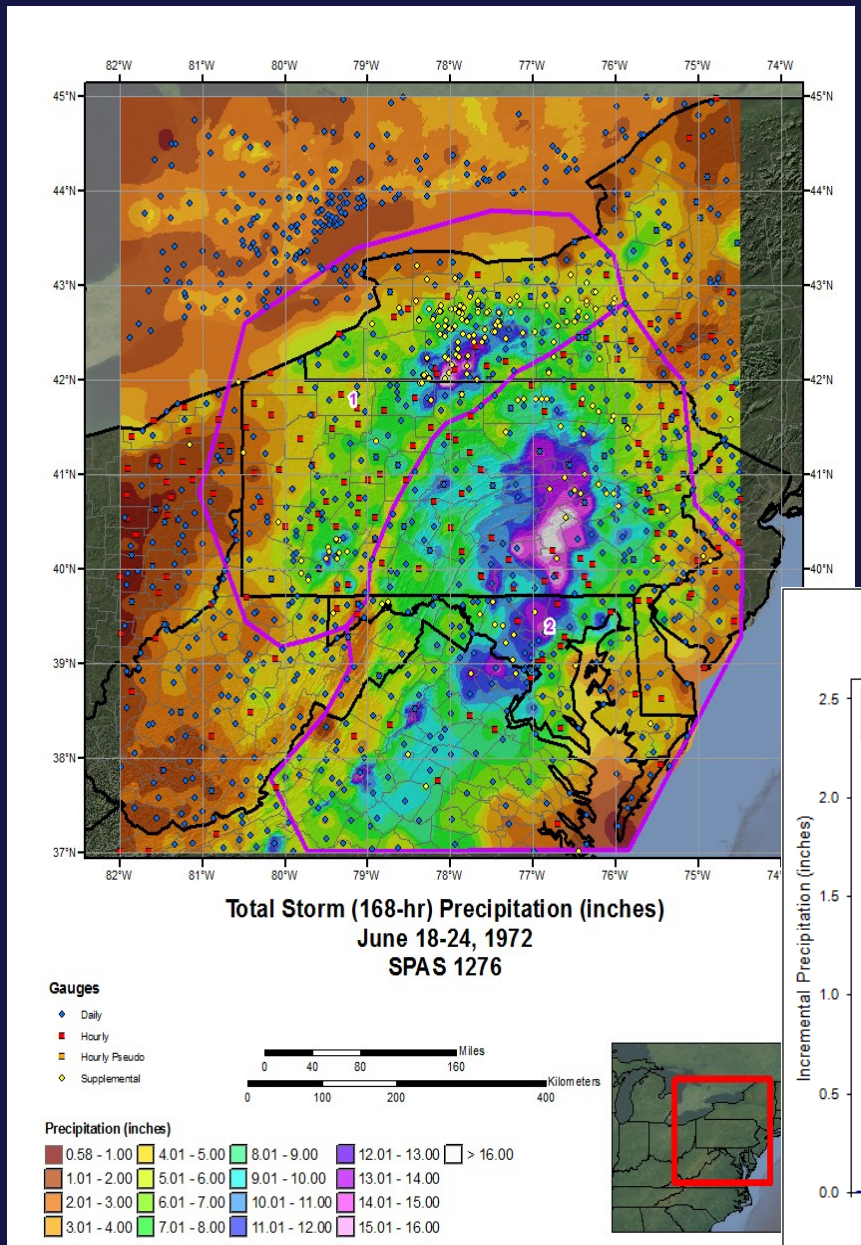


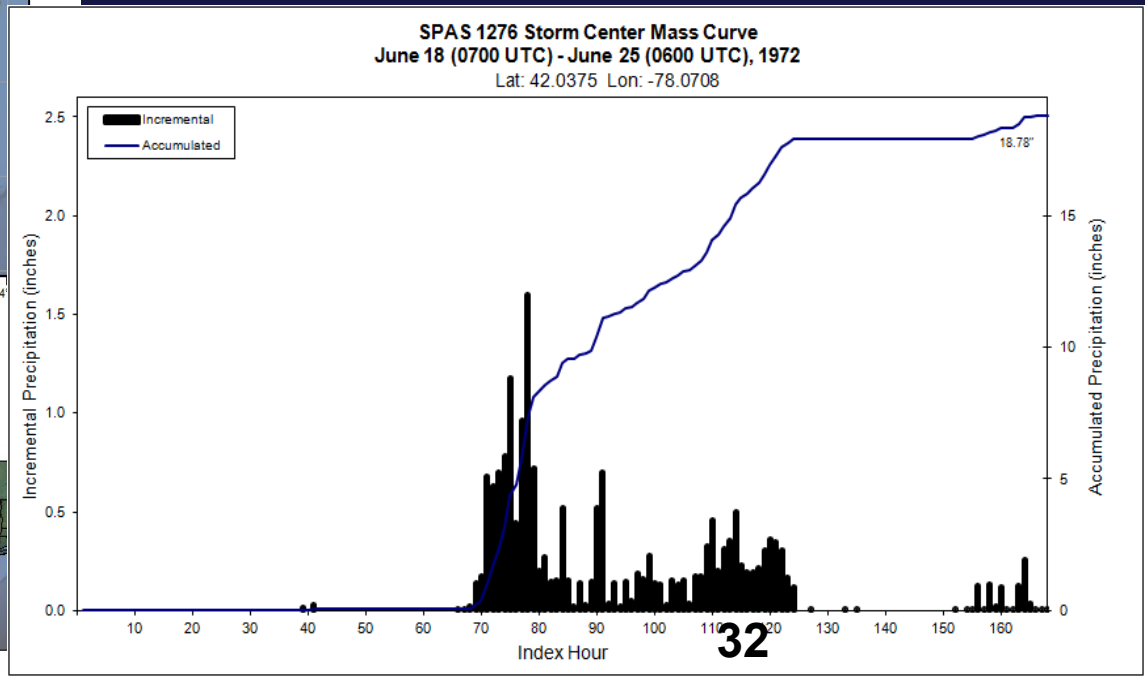
Gibson Dam, MT-June 1964



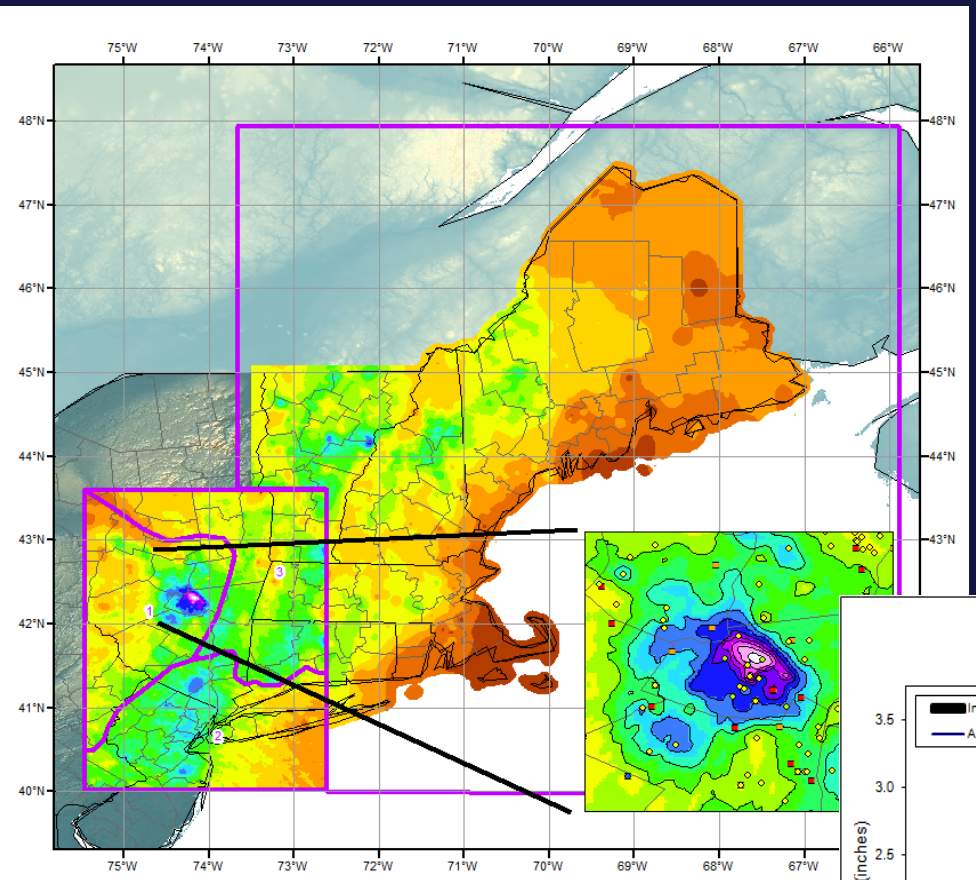


Hurricane Agnes-June 1972





Hurricane Irene-August 2011



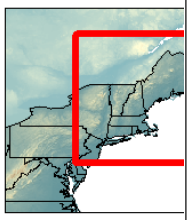
Total Storm Precipitation
Hurricane Irene August 27-29, 2011
SPAS 1224

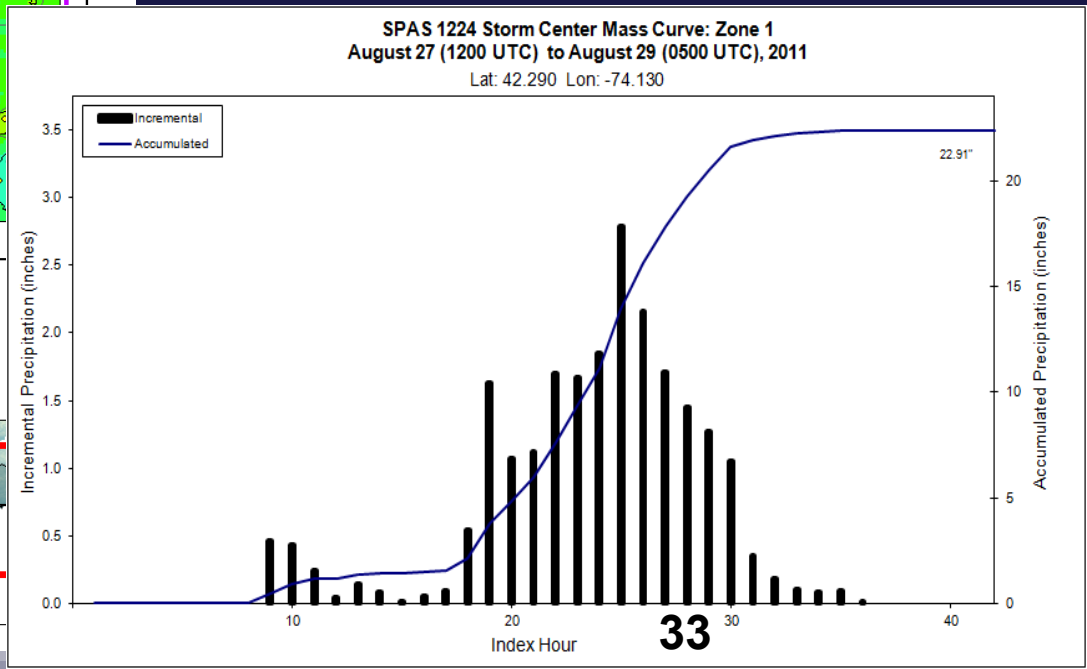
Gauges
- Daily
- Hourly
- Hourly Pseudo
- Supplemental
- Supplemental Estimated

Miles: 0 40 80 160
Kilometers: 0 80 160 320

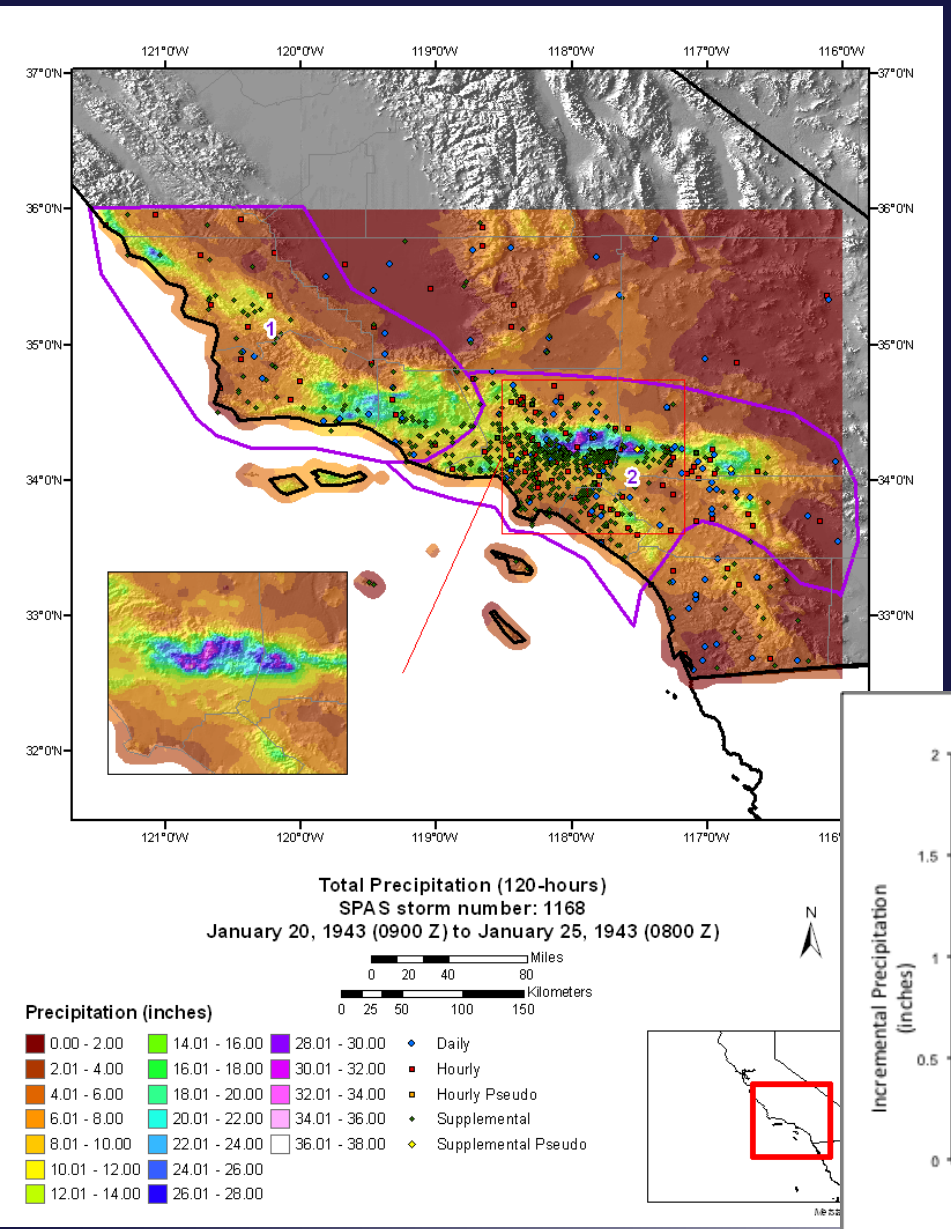
Precipitation (inches)

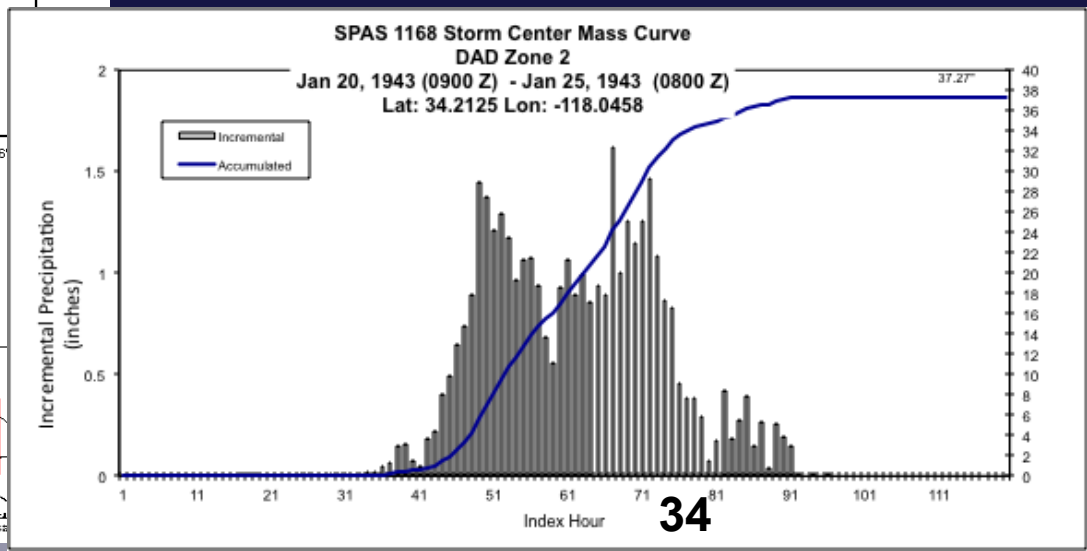
0.00 - 0.01	3.01 - 4.00	7.01 - 8.00	12.01 - 14.00	20.01 - 22.00
0.02 - 1.00	4.01 - 5.00	8.01 - 9.00	14.01 - 16.00	22.01 - 24.00
1.01 - 2.00	5.01 - 6.00	9.01 - 10.00	16.01 - 18.00	
2.01 - 3.00	6.01 - 7.00	10.01 - 12.00	18.01 - 20.00	



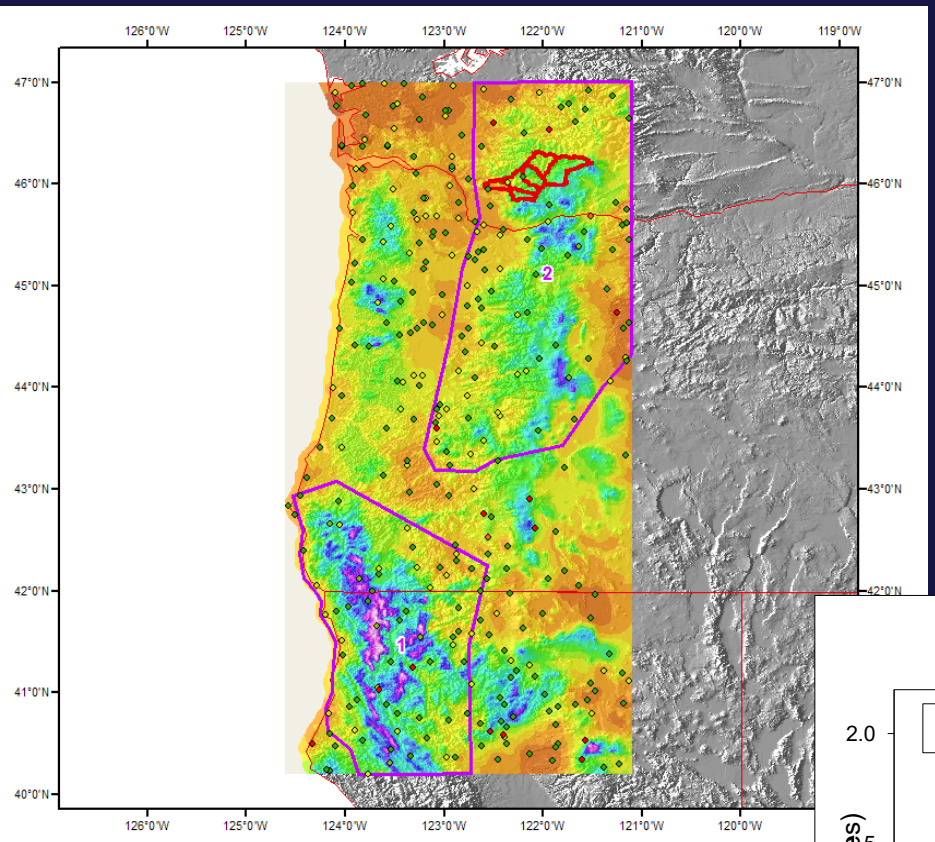


Hoegee's Camp, CA-January 1943





OR-CA-Dec 1964



Total 96-hour Precipitation
SPAS # 1190 (Elk Valley Dec 1964 Storm)
December 21, 1964 0200 UTC - December 25, 1964 0100 UTC

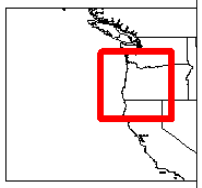
Miles: 0 40 80 160
Kilometers: 0 70 140 280

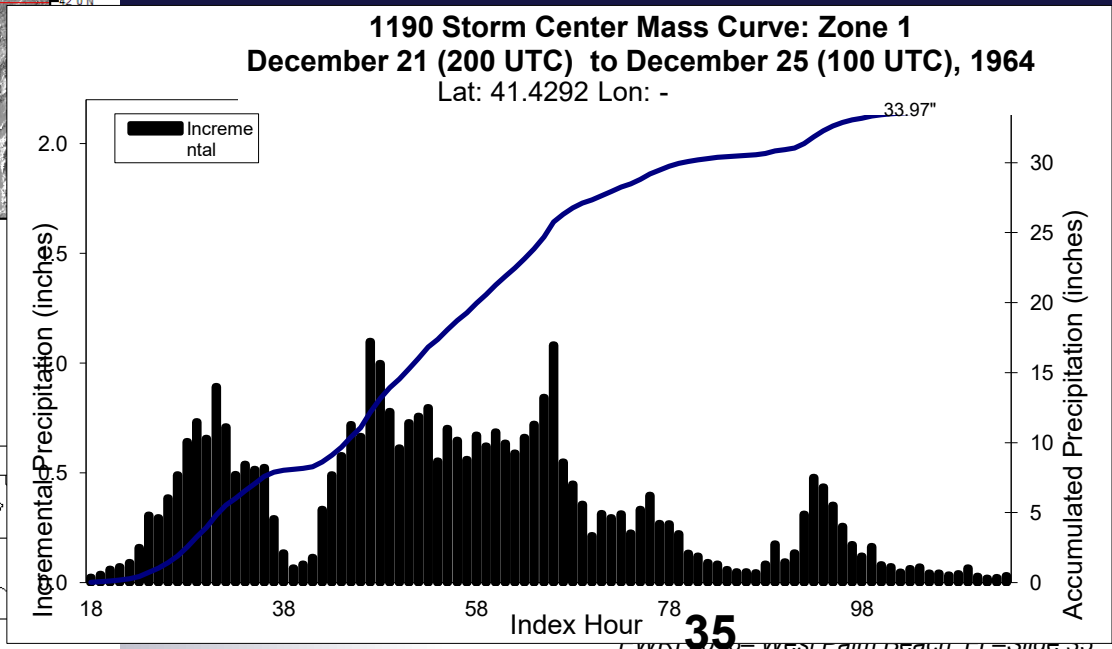
Precipitation (inches)

0.00 - 0.10	10.01 - 12.00	22.01 - 24.00
0.11 - 2.00	12.01 - 14.00	24.01 - 26.00
2.01 - 4.00	14.01 - 16.00	26.01 - 28.00
4.01 - 6.00	16.01 - 18.00	28.01 - 30.00
6.01 - 8.00	18.01 - 20.00	30.01 - 32.00
8.01 - 10.00	20.01 - 22.00	32.01 - 34.00

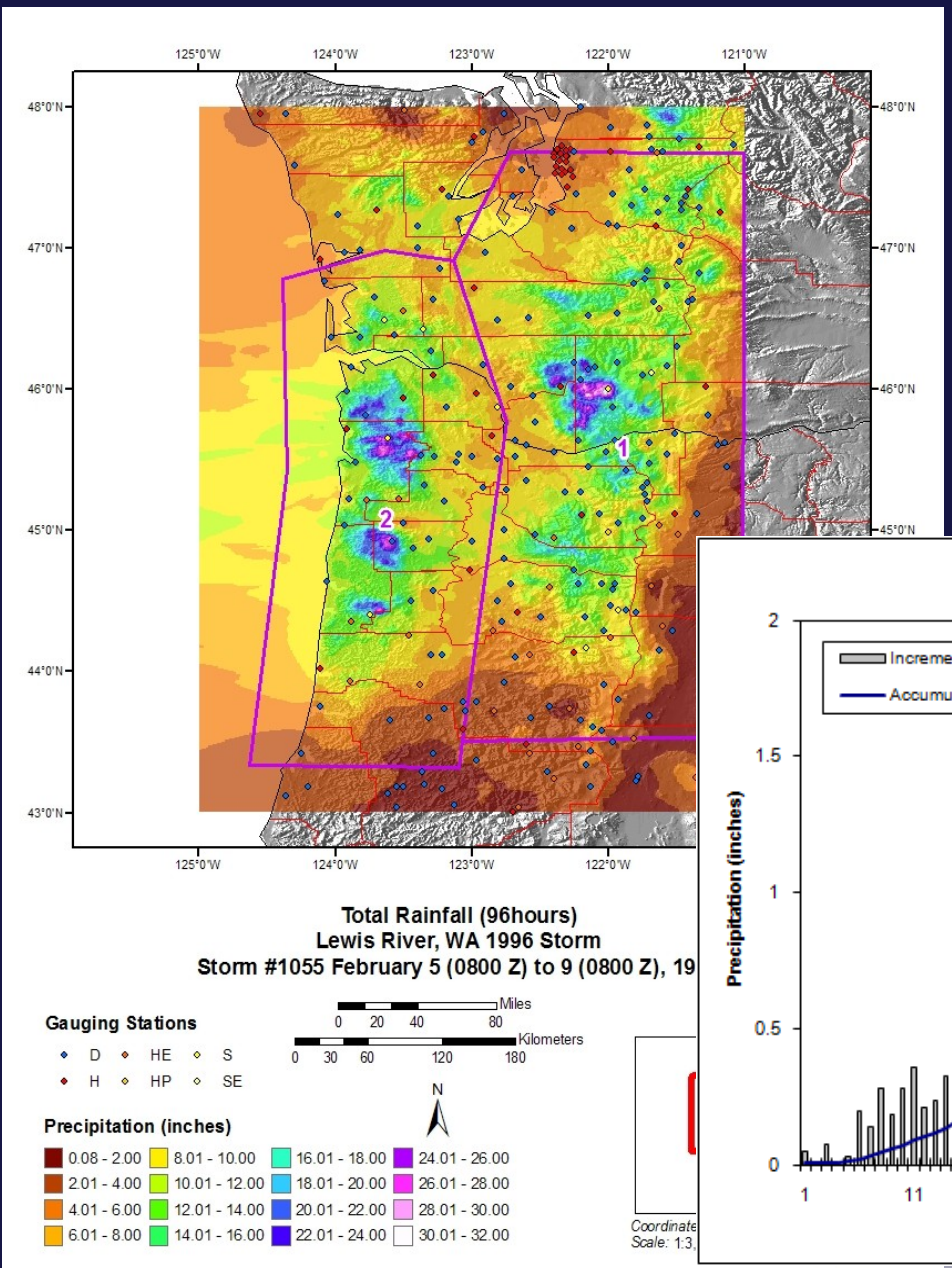
Gauging Stations

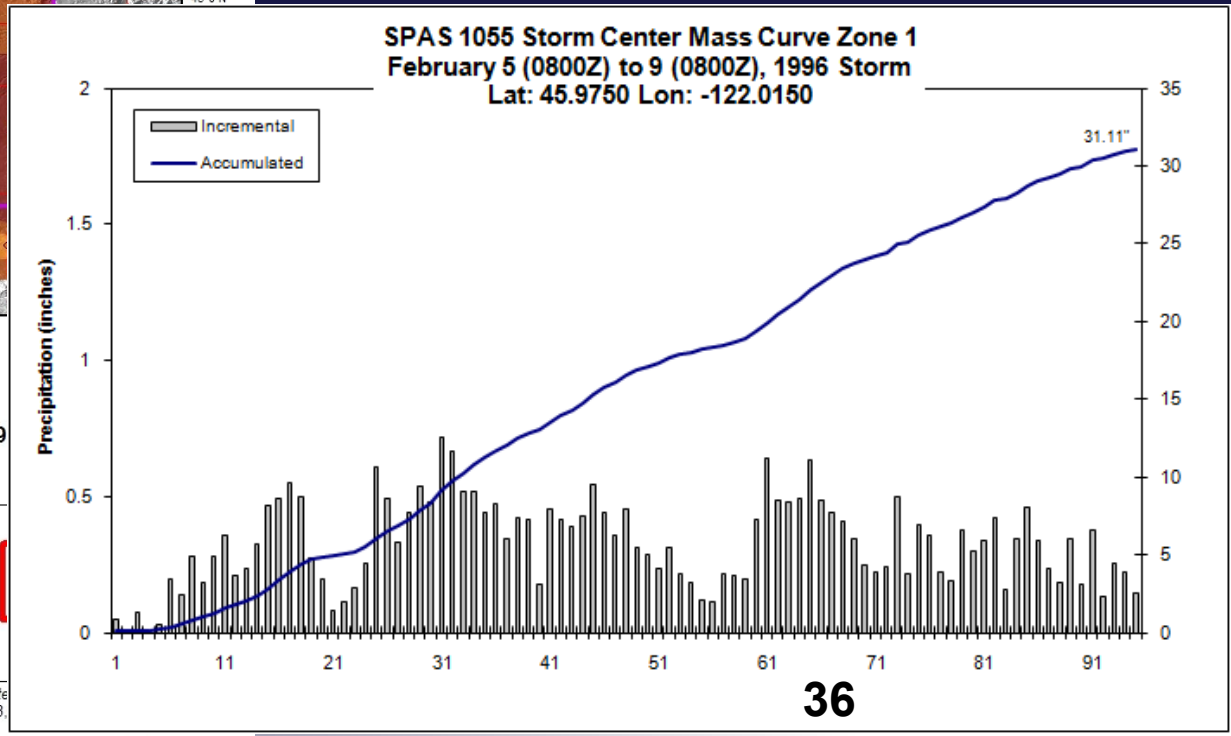
- Daily
- Hourly
- Hourly Estimated
- Hourly Pseudo
- Supplemental
- Supplemental Estimated



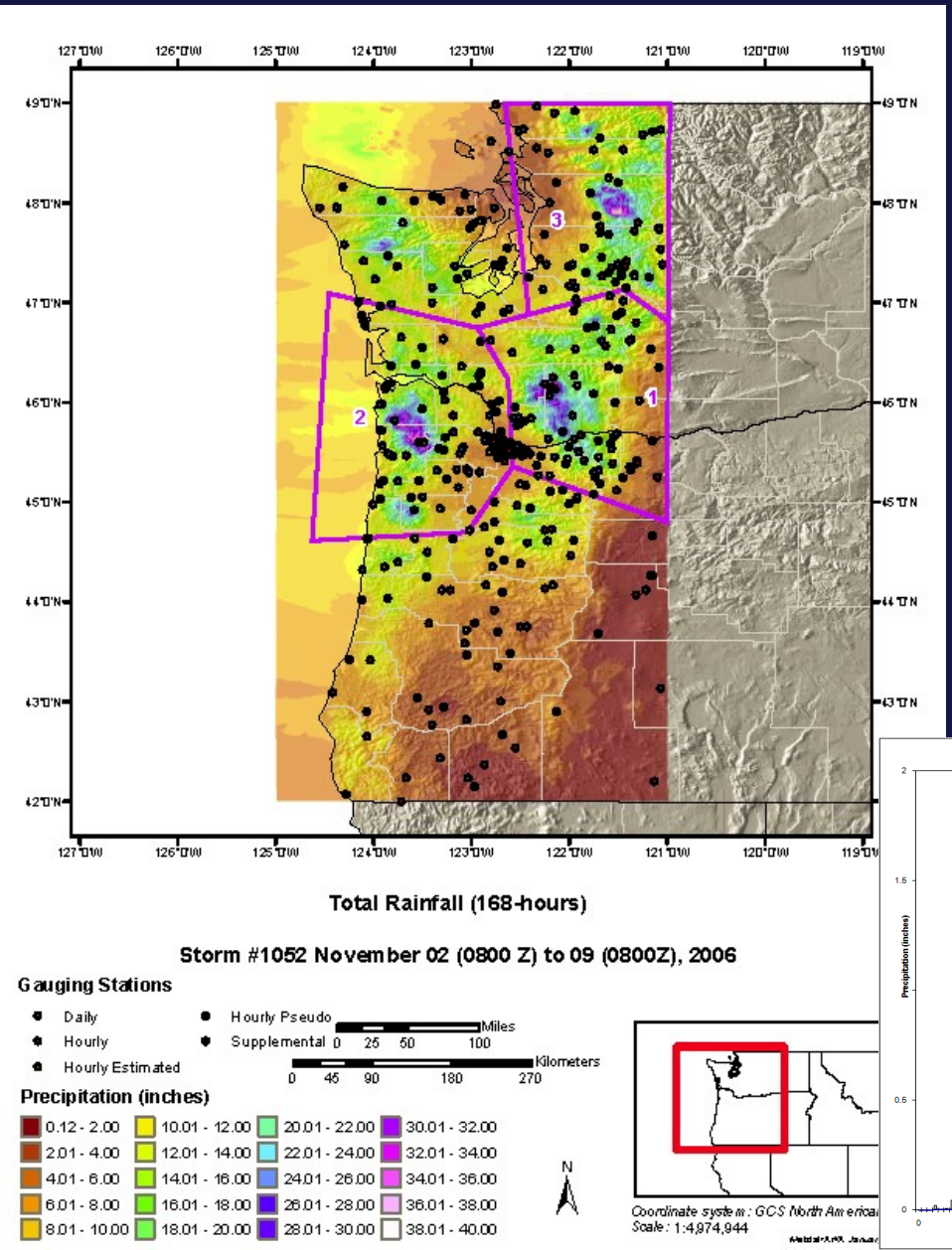


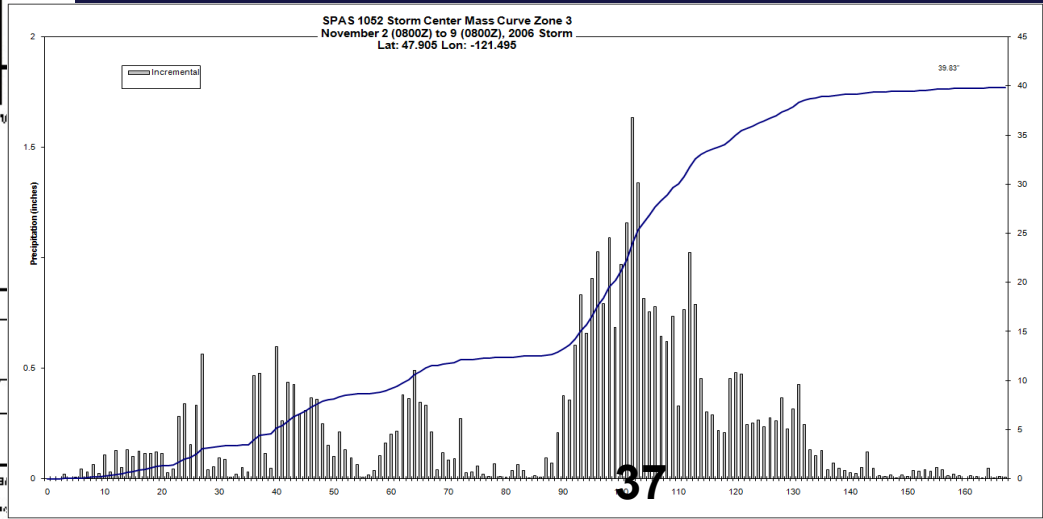
WA-OR-February 1996



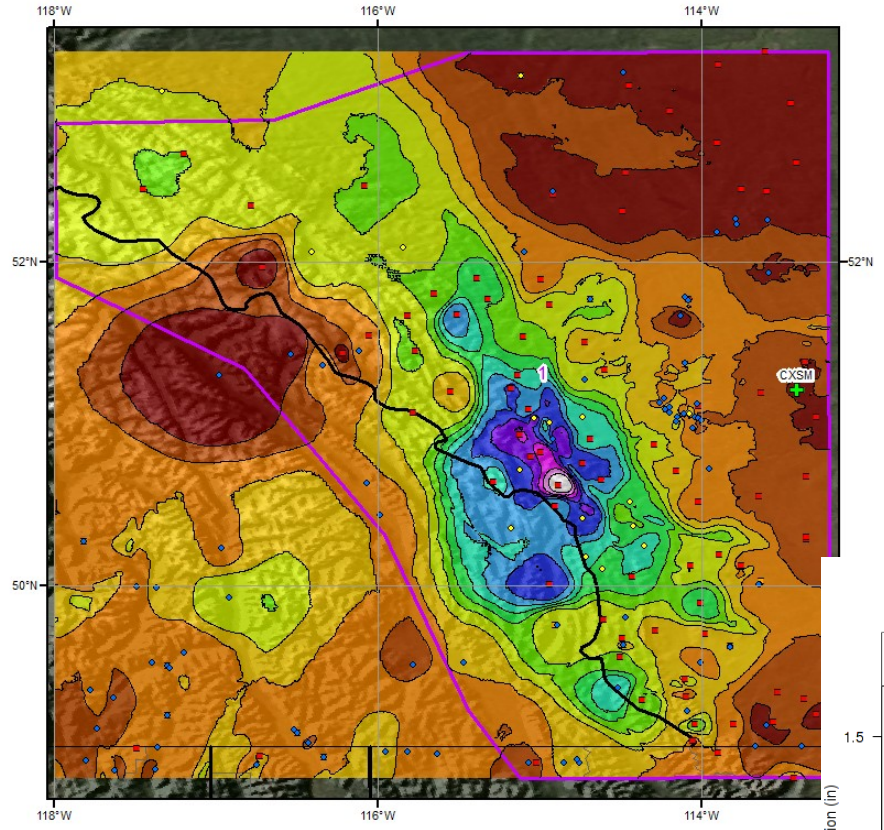


WA-OR-November 2006





Calgary-June 2013



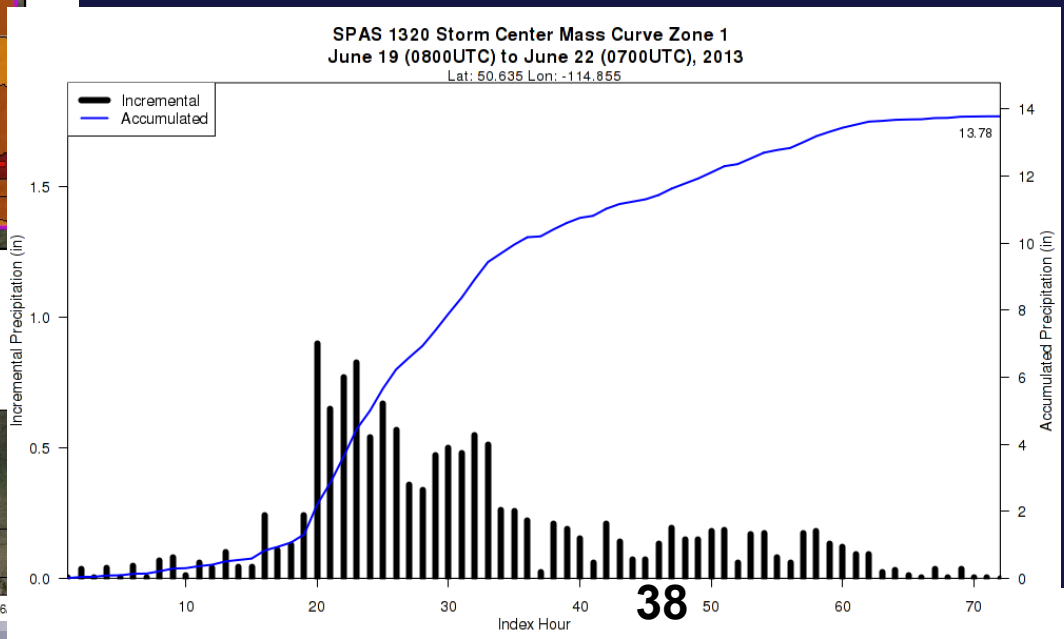
Total Storm (72-hr) Precipitation (inches)
6/19/2013 (0800 UTC) - 6/22/2013 (0700 UTC)
SPAS-NEXRAD 1320

Gauges
- Daily
- Hourly
- Hourly Pseudo
- Supplemental

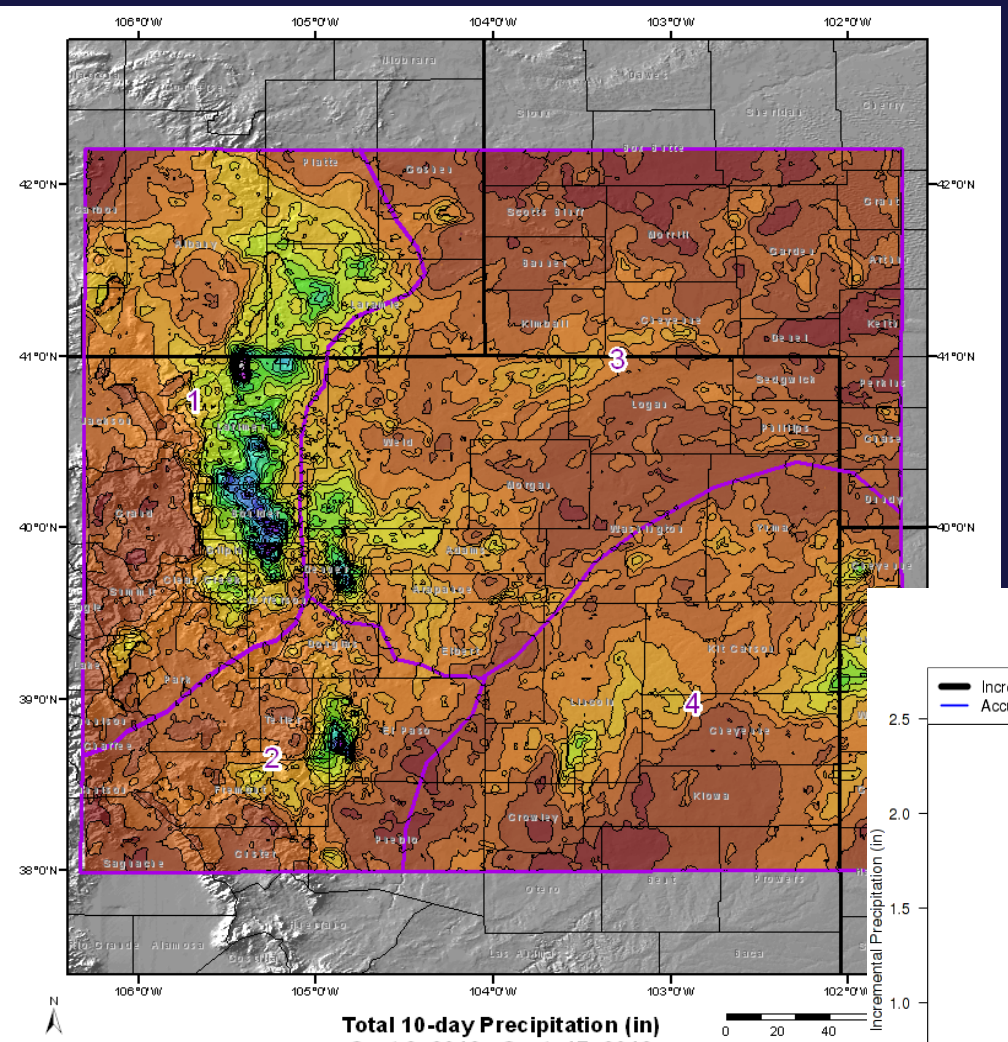
Miles: 0 35 70 140
Kilometers: 0 55 110 220

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	



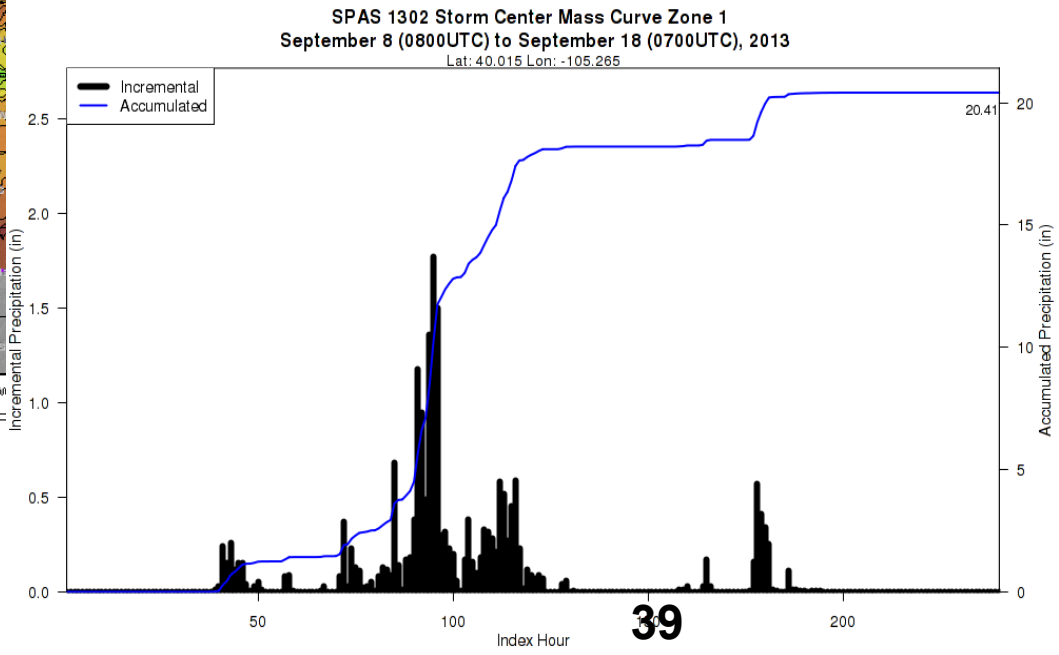
WY-CO-NM-September 2013



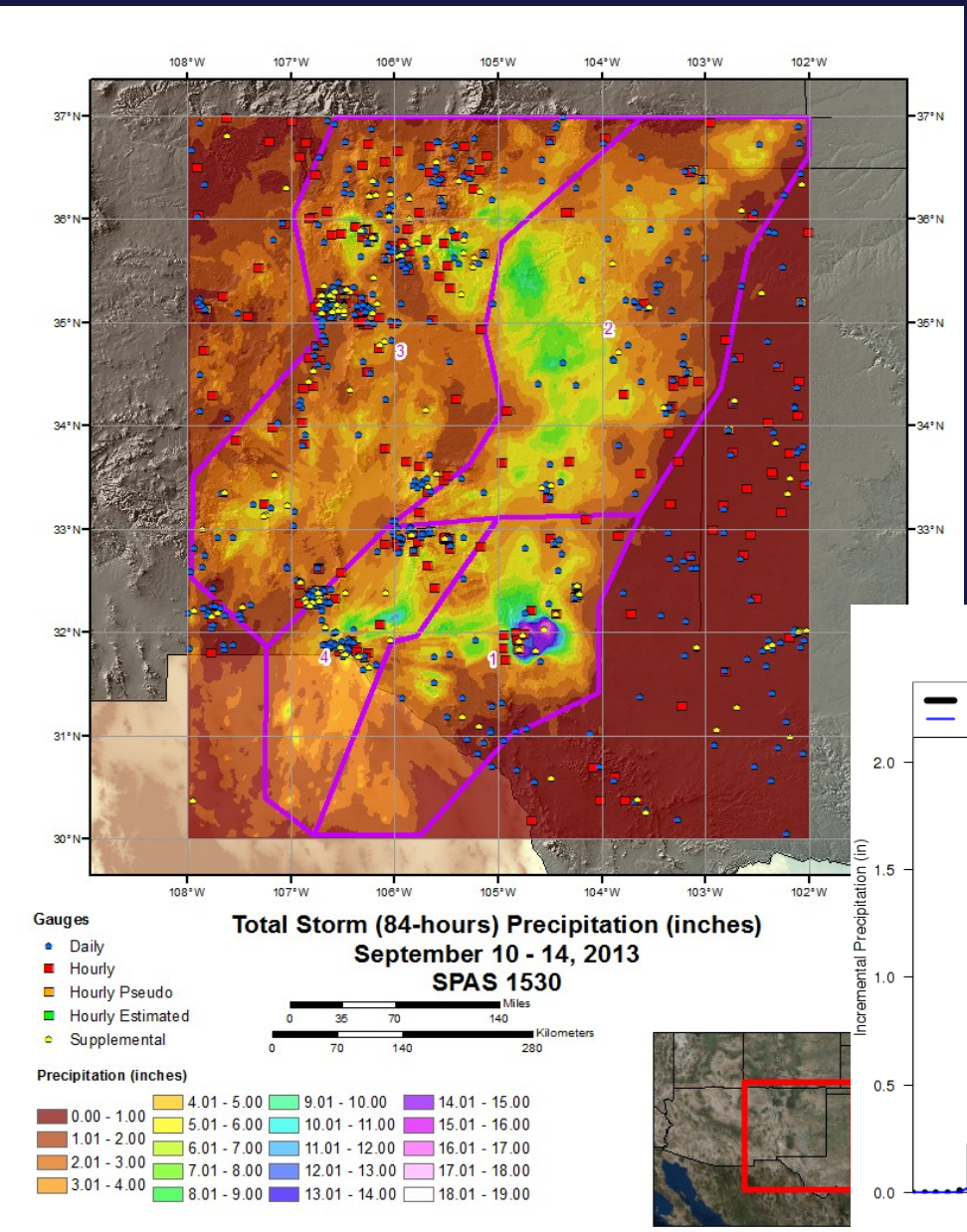
Total 10-day Precipitation (in)
Sept 8, 2013 - Sept. 17, 2013
SPAS #1302

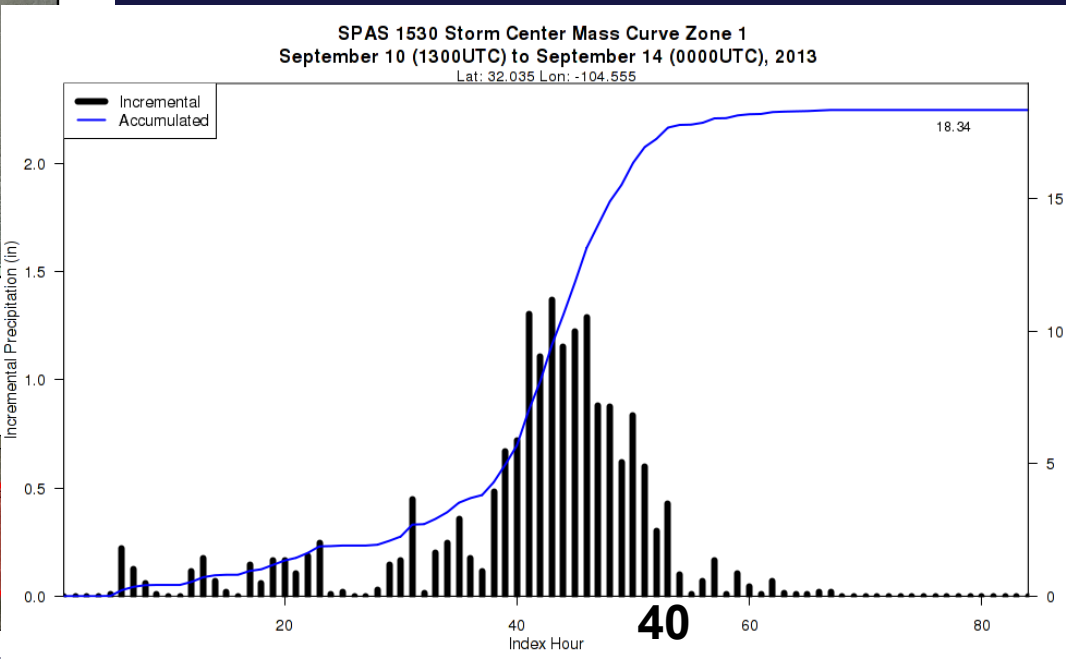
Precipitation (inches)

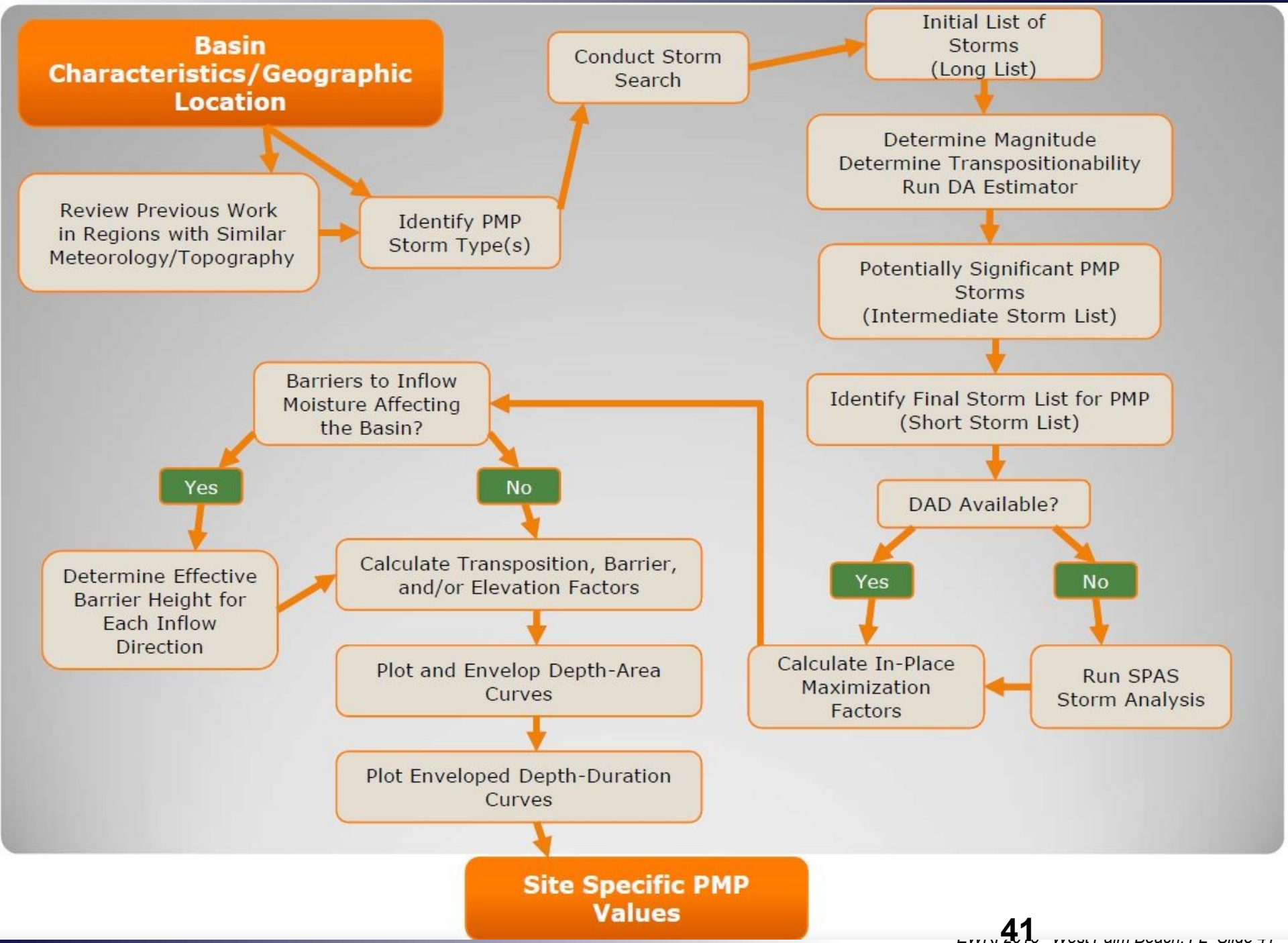
0.13 - 1.00	5.01 - 6.00	10.01 - 11.00	15.01 - 16.00	20.01 - 21.00
1.01 - 2.00	6.01 - 7.00	11.01 - 12.00	16.01 - 17.00	21.01 - 22.00
2.01 - 3.00	7.01 - 8.00	12.01 - 13.00	17.01 - 18.00	22.01 - 23.00
3.01 - 4.00	8.01 - 9.00	13.01 - 14.00	18.01 - 19.00	
4.01 - 5.00	9.01 - 10.00	14.01 - 15.00	19.01 - 20.00	



WY-CO-NM-September 2013






Basin Characteristics/Geographic Location
Review Previous Work in Regions with Similar Meteorology/Topography
Identify PMP Storm Type(s)
Conduct Storm Search
Initial List of Storms (Long List)
Determine Magnitude
Determine Transpositionability
Run DA Estimator
Potentially Significant PMP Storms (Intermediate Storm List)
Identify Final Storm List for PMP (Short Storm List)
DAD Available?
Yes
No
Run SPAS Storm Analysis
Calculate In-Place Maximization Factors
Barriers to Inflow Moisture Affecting the Basin?
Yes
No
Determine Effective Barrier Height for Each Inflow Direction
Calculate Transposition, Barrier, and/or Elevation Factors
Plot and Envelop Depth-Area Curves
Plot Enveloped Depth-Duration Curves
Site Specific PMP Values

PMP History

- HMRs completed using the best data/science at that time
- Reflective of the data/processes at the time of development
  - Limited meteorological understanding
  - Limited technology used
  - No satellite
  - No radar
  - No GIS

HMR 49-Local Storm PMP Map

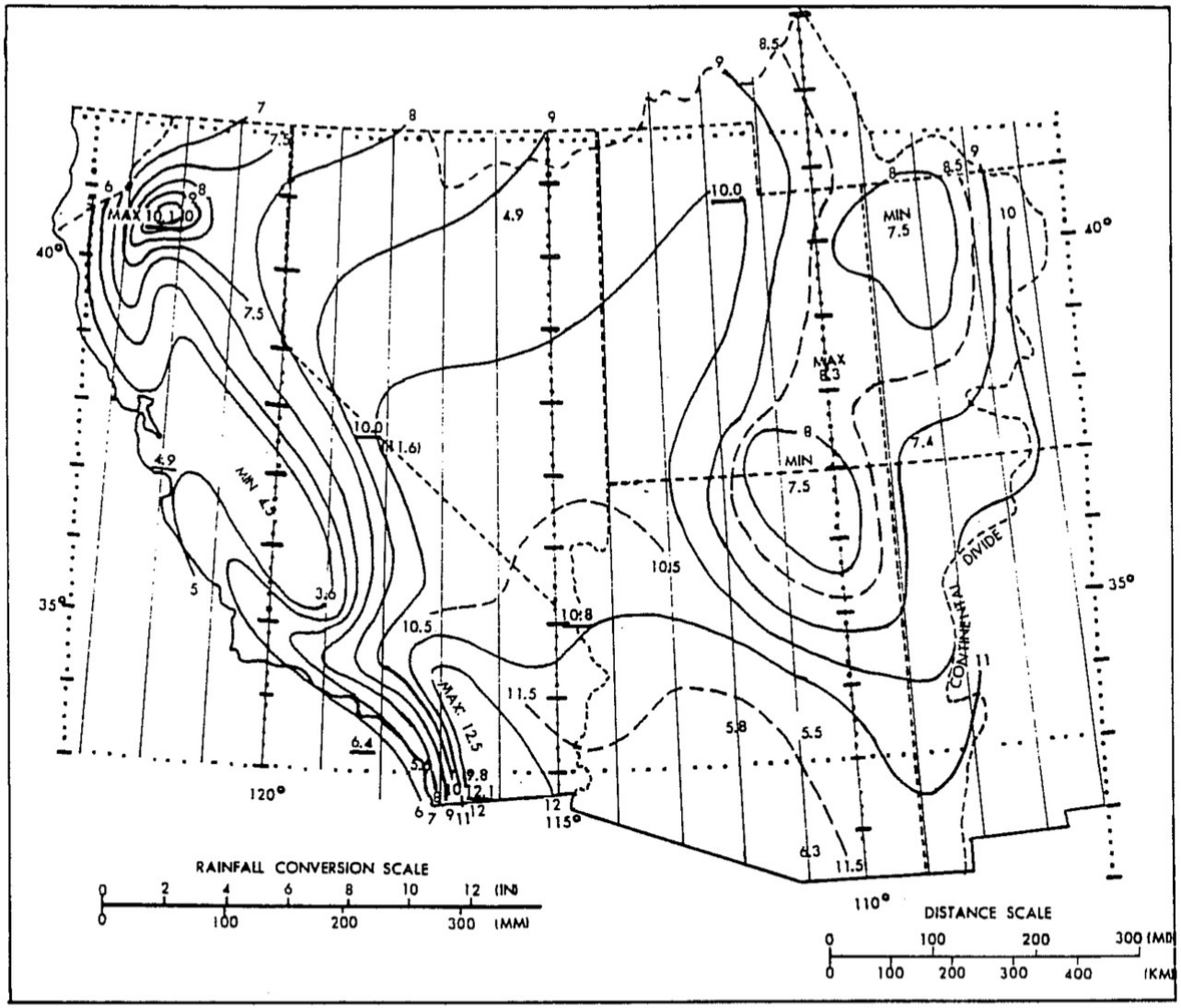


Figure 4.5--Local-storm PMP for 1 mi^2 (2.6 km^2) 1 hr. Directly applicable for locations between sea level and 5000 ft (1524 m). Elevation adjustment must be applied for locations above 5000 ft.

HMR 51-PMP Map

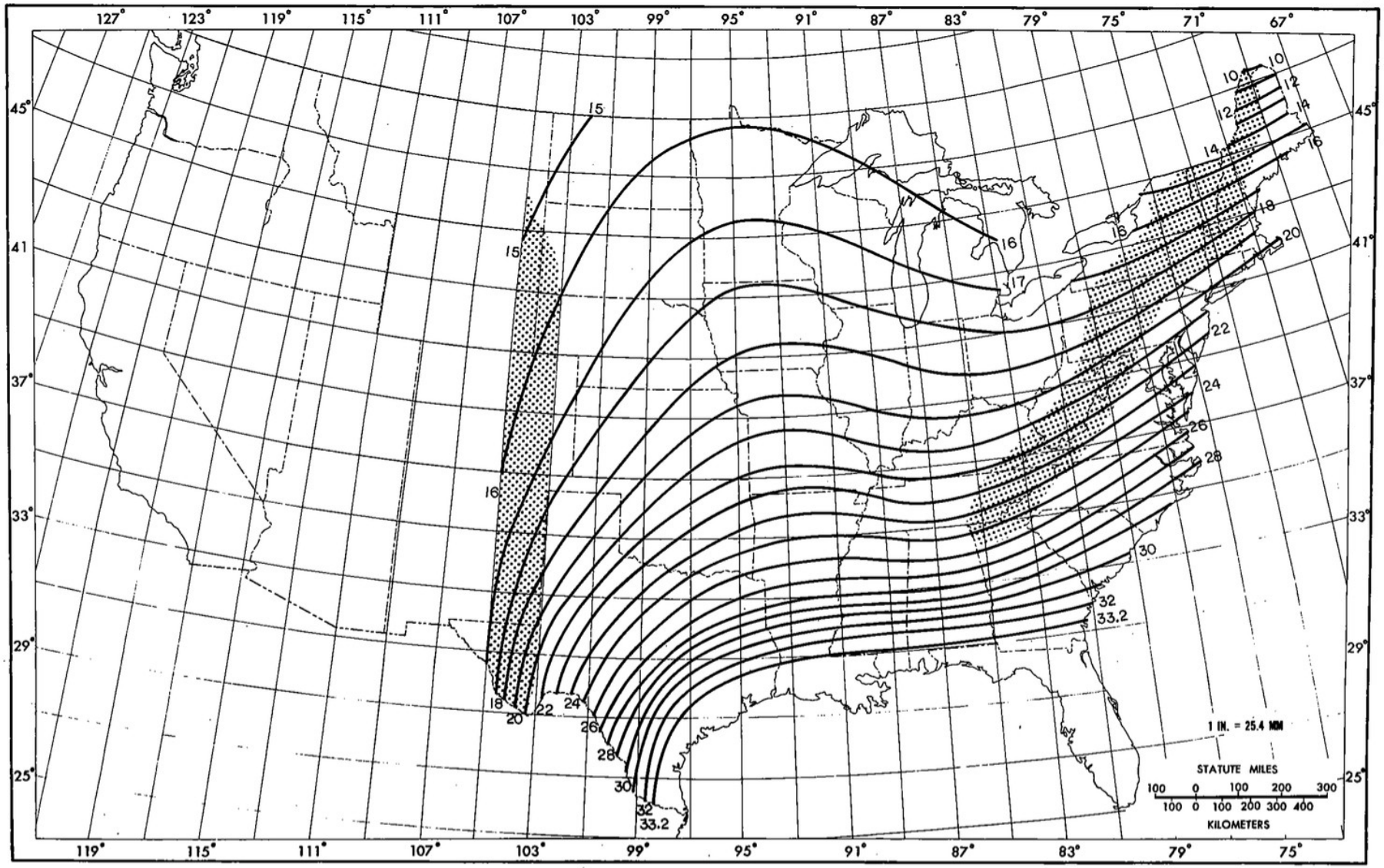
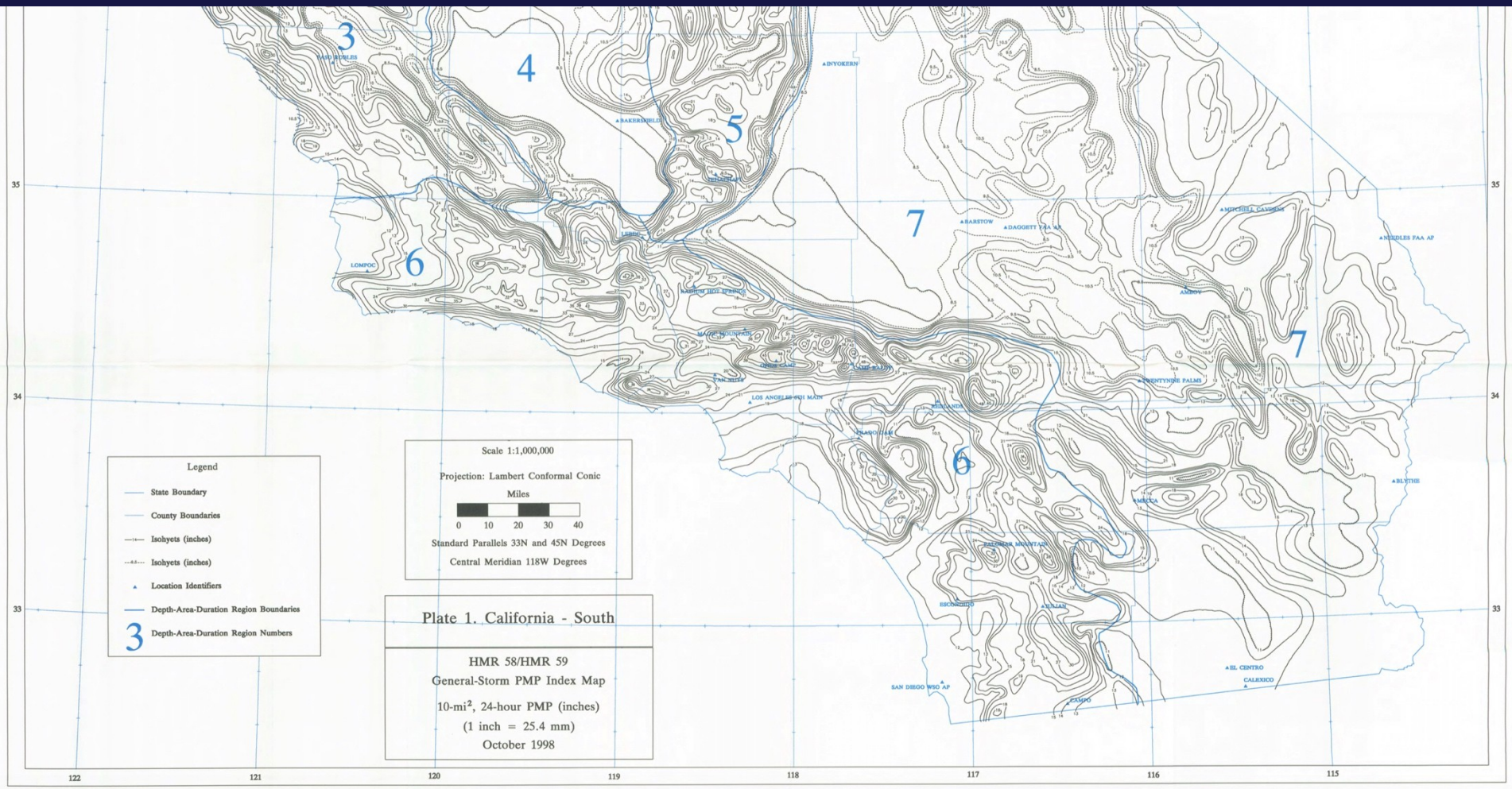


Figure 30.--All-season PMP (in.) for 24 hr 1,000 mi^2 (2,590 km^2).

HMR 59-General Storm PMP Map



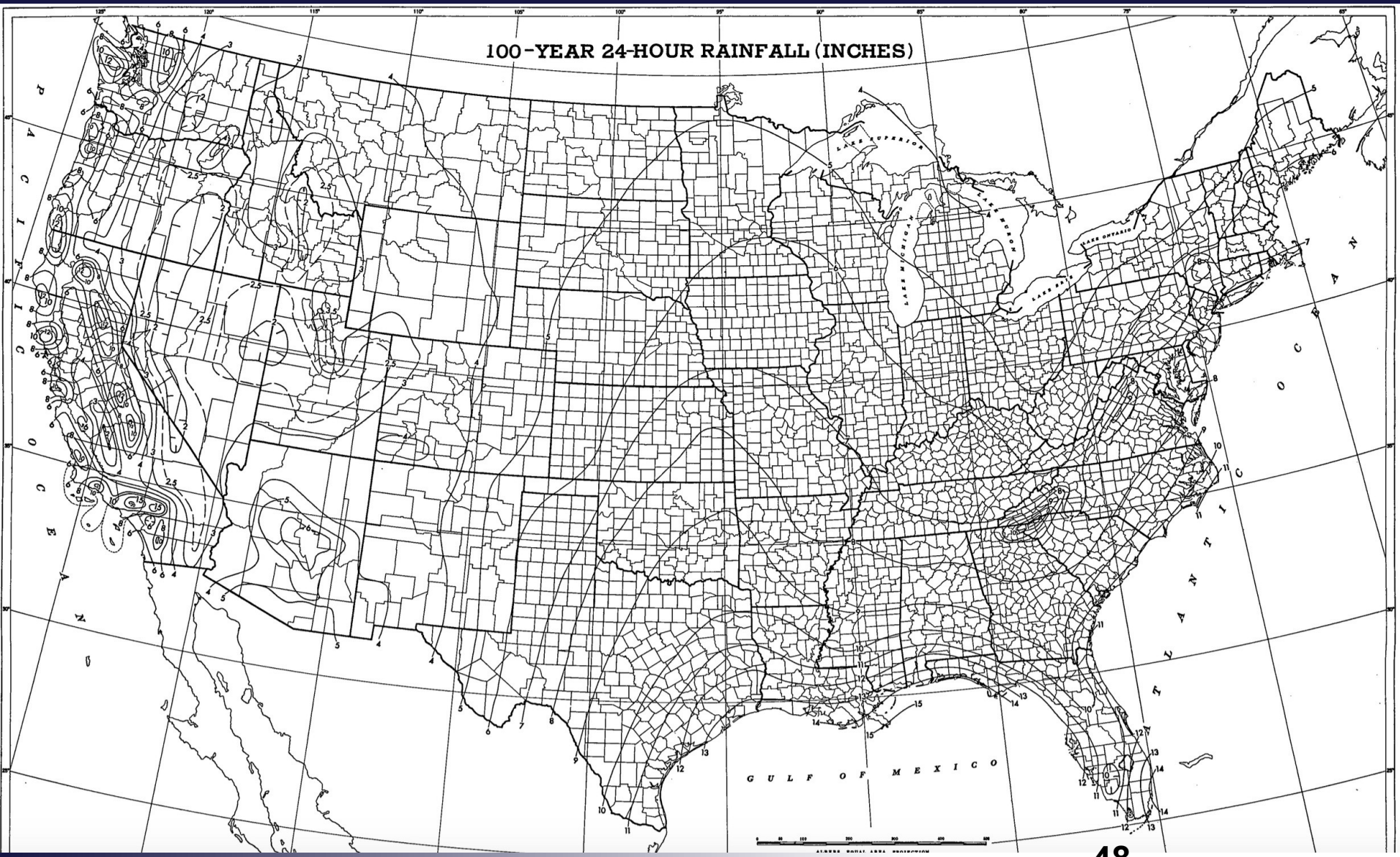
Rainfall Climate Atlases

- Technical Paper-40
  - Published in
  - Covers areas of eastern US
- NOAA Atlas 2
  - Covers western US
- NOAA Atlas 14
  - Supersedes all previous NWS documents

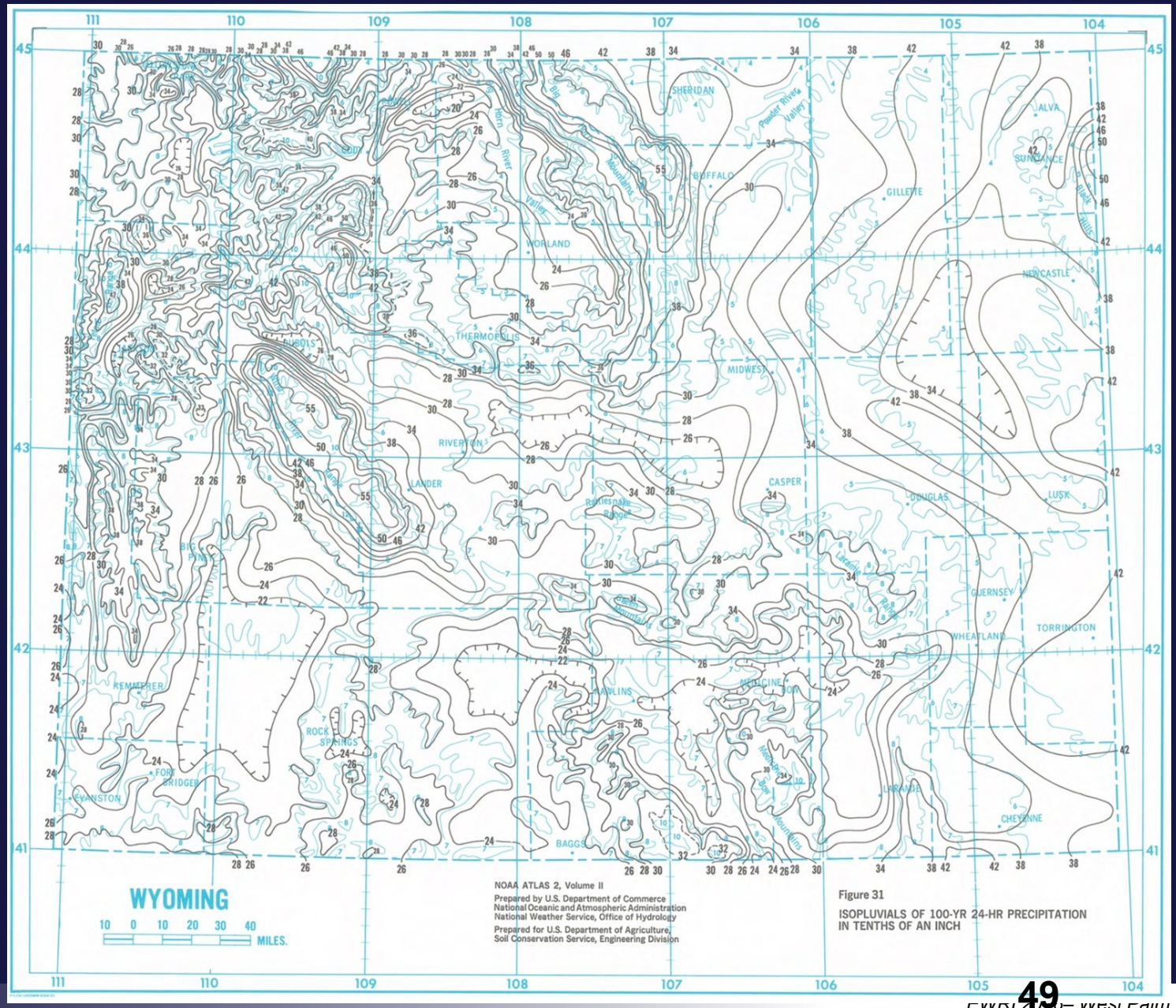
Rainfall Climate Atlases

- Several others
  - WA-OR, WDOT (Schaefer)
  - Regional precip climatology for Pacific Northwest
  - Montana
  - Southeast Regional Climate Center
  - Northeast Regional Climate Center
  - Asquith-Texas
  - Tennessee Valley Authority

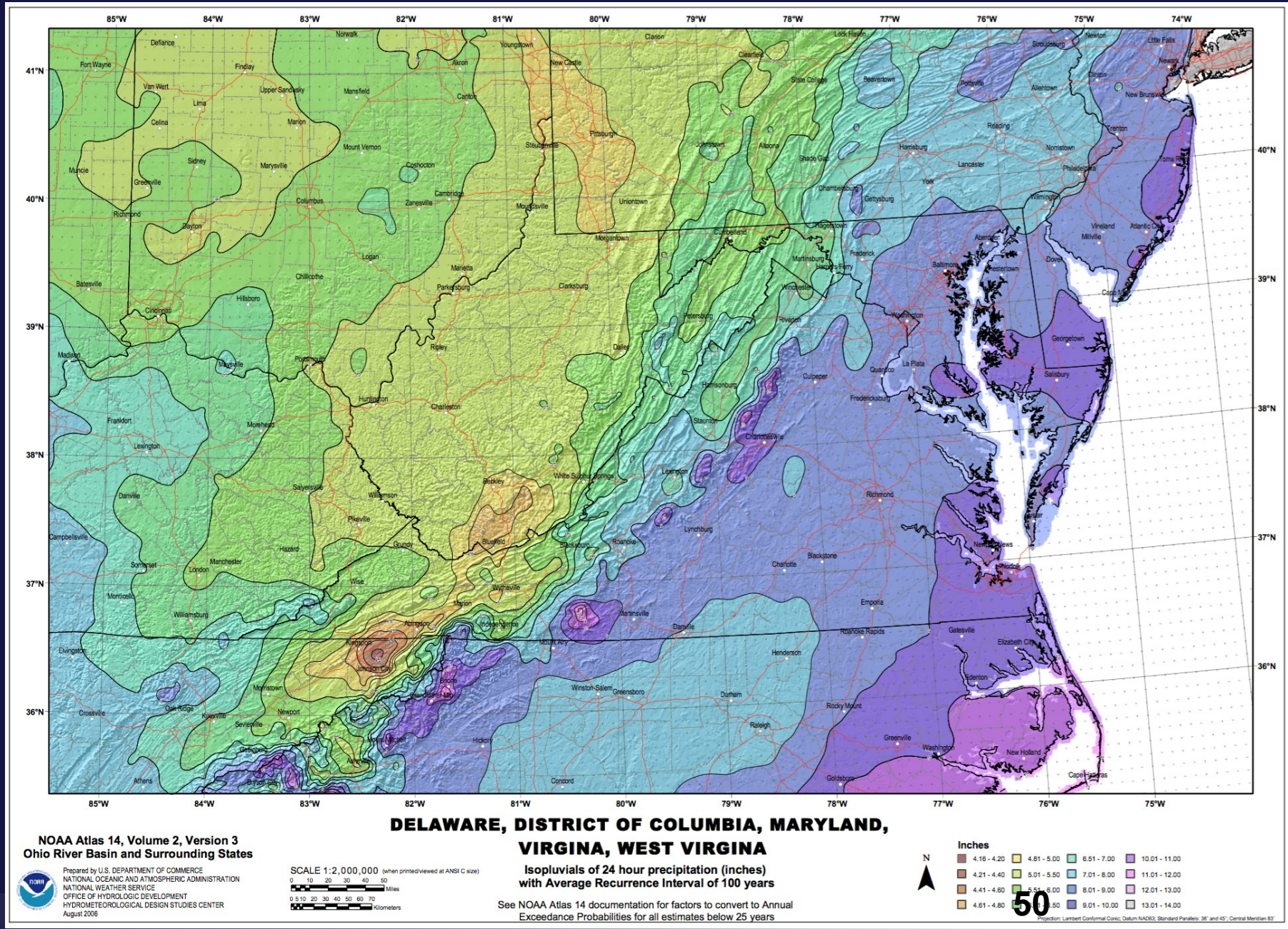
Technical Paper 40-100 year 24 hour



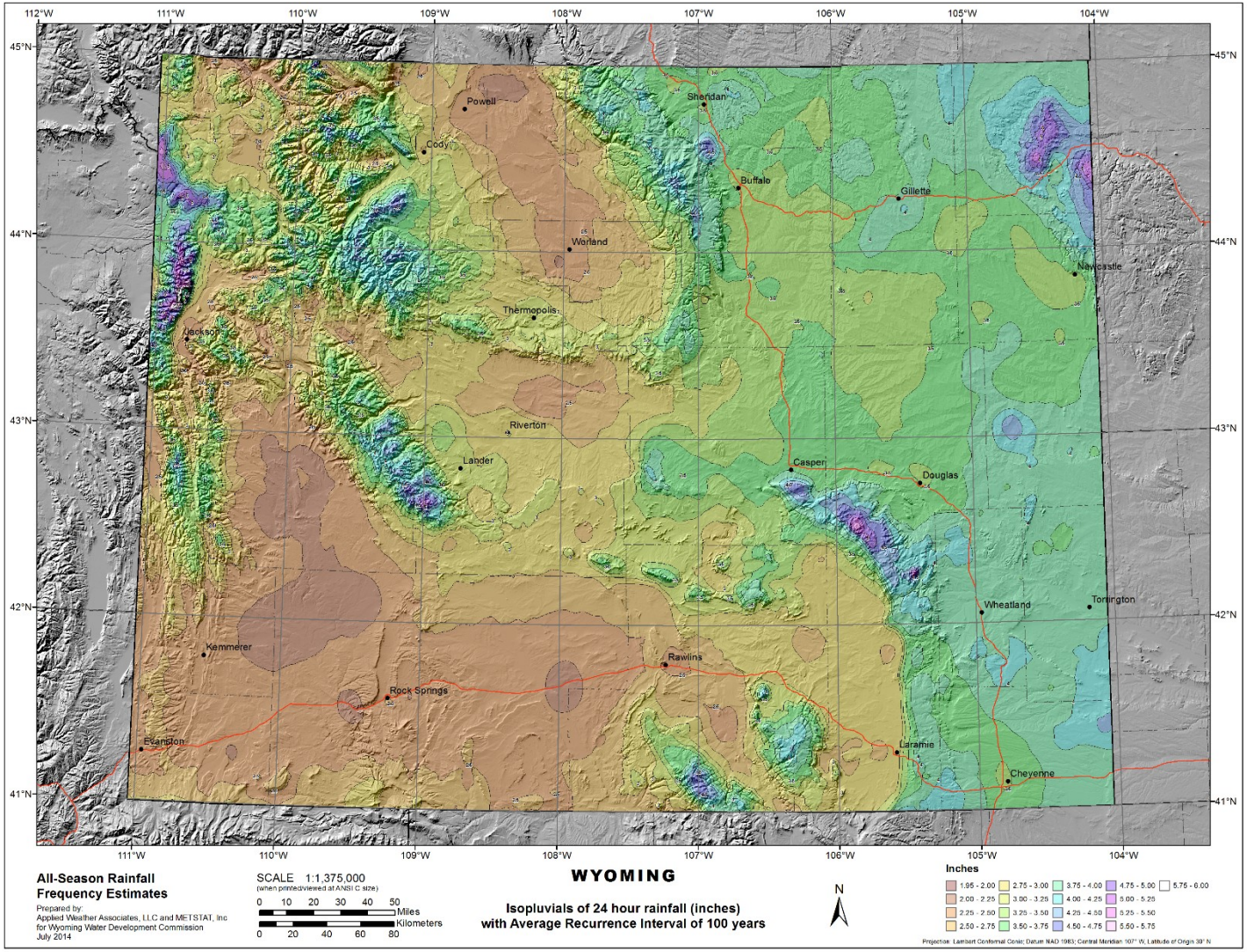
NOAA Atlas 2-100 year 24 hour



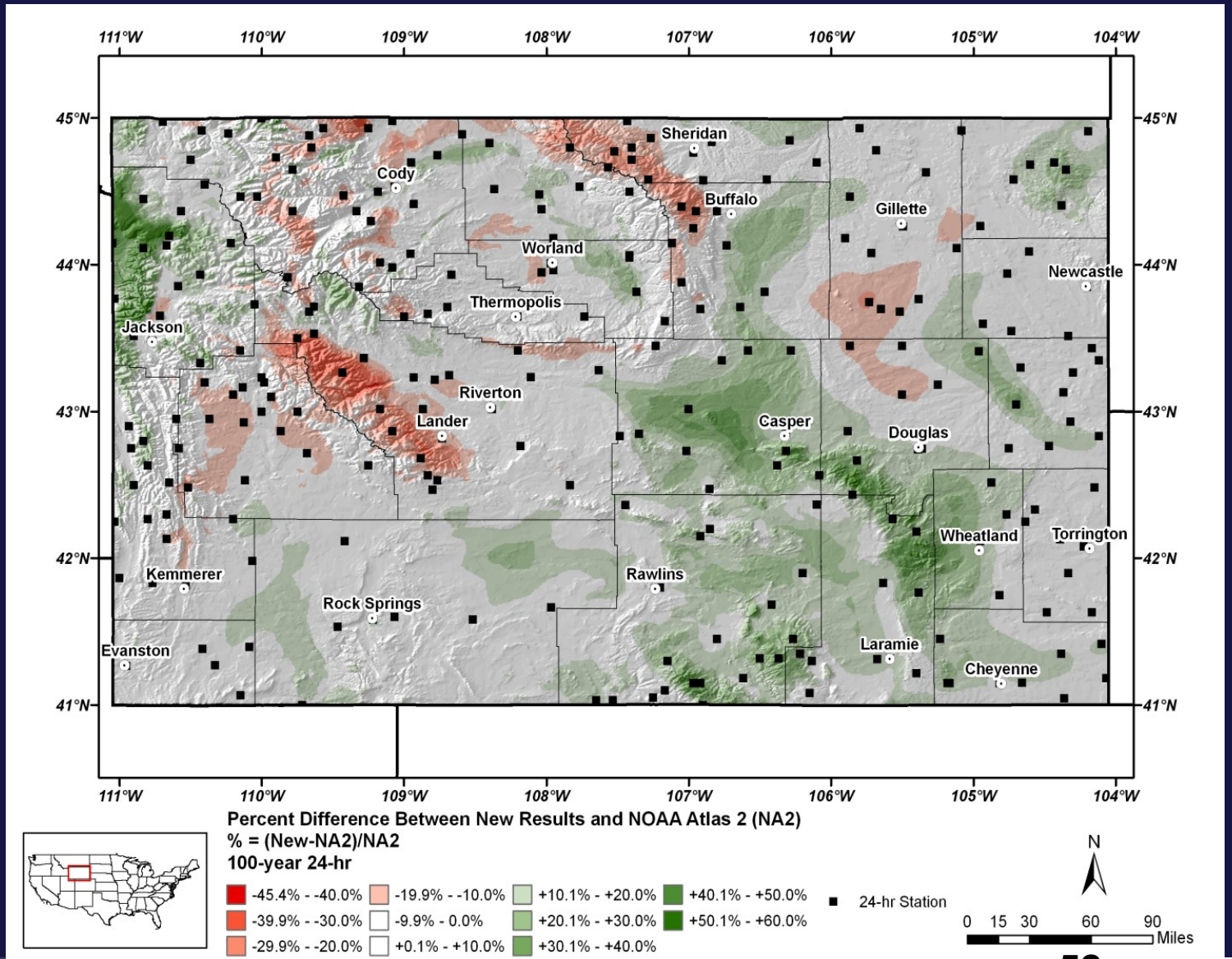
NOAA Atlas 14 Map-Volume 2



Precip Frequency Wyoming-100 year 24 hour



Updated Precip Frequency vs NOAA Atlas 2

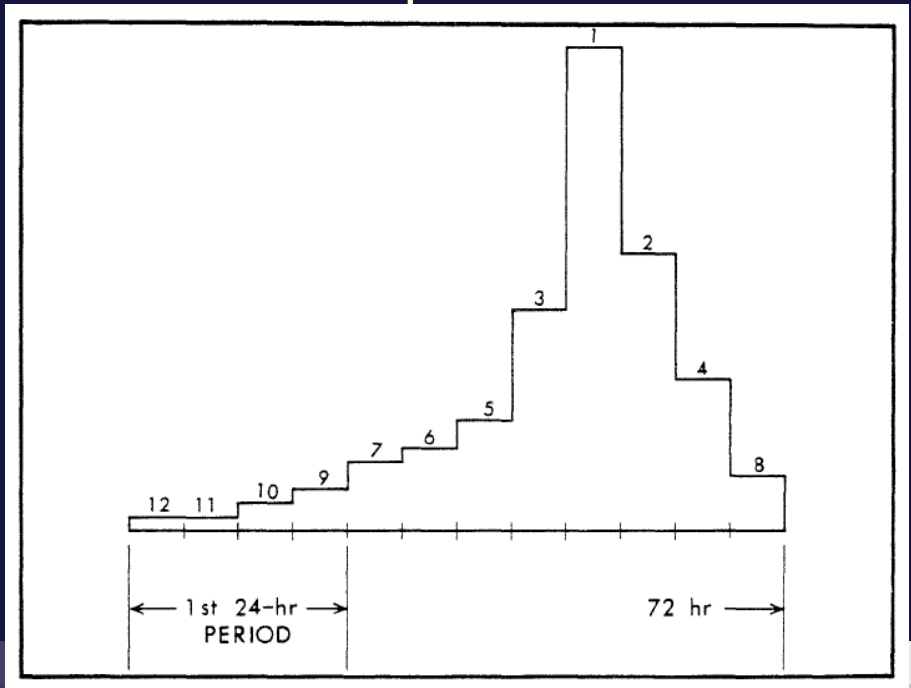


Temporal Distribution of PMP

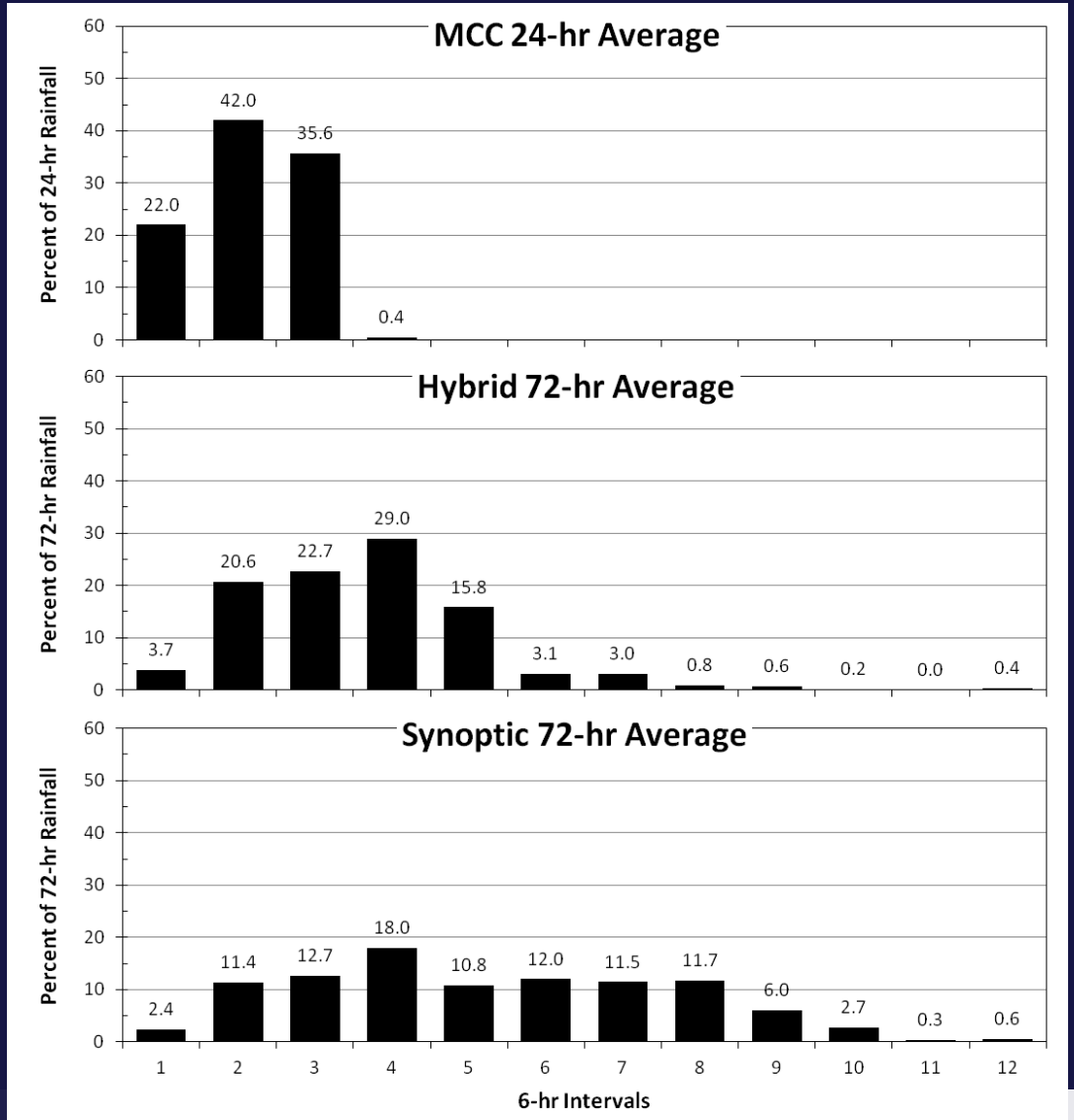
- Guidance in HMRs
  - Critical stacking
  - Storm based
- New developments for site-specific and storm based
- Hourly incremental
- Continues to progress

Temporal Distribution of PMP

- Example of one potential temporal timing sequence based on HMR 52
  - 6-hr increments be arranged with single peak
  - Decrease on either side of the greatest 6-hr increment.
  - Four greatest 6-hr increments at any position except within the first 24-hr period.

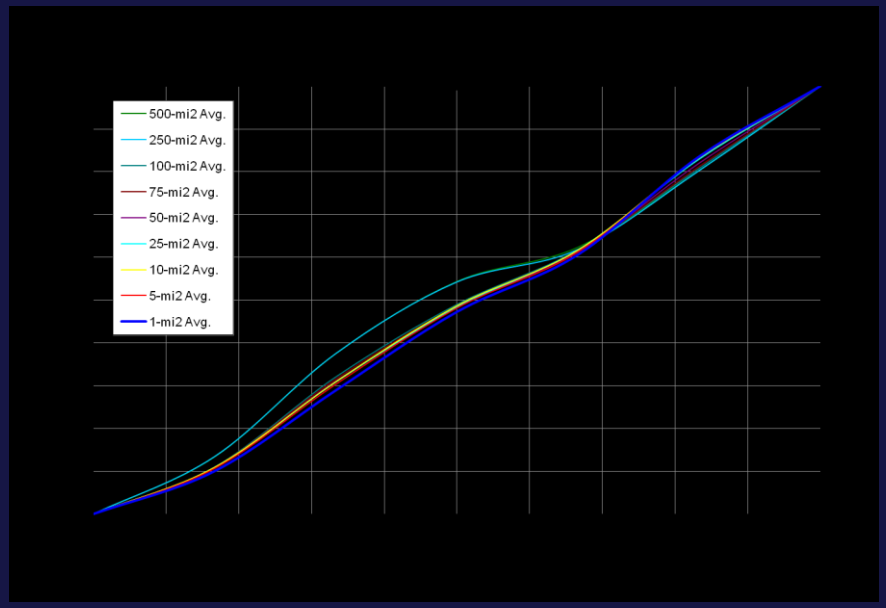


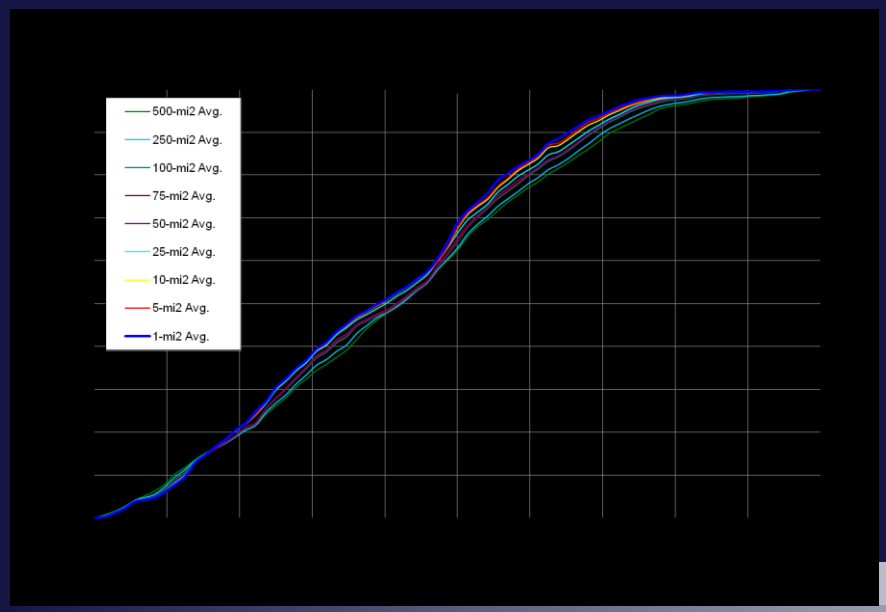
Temporal Distribution of PMP



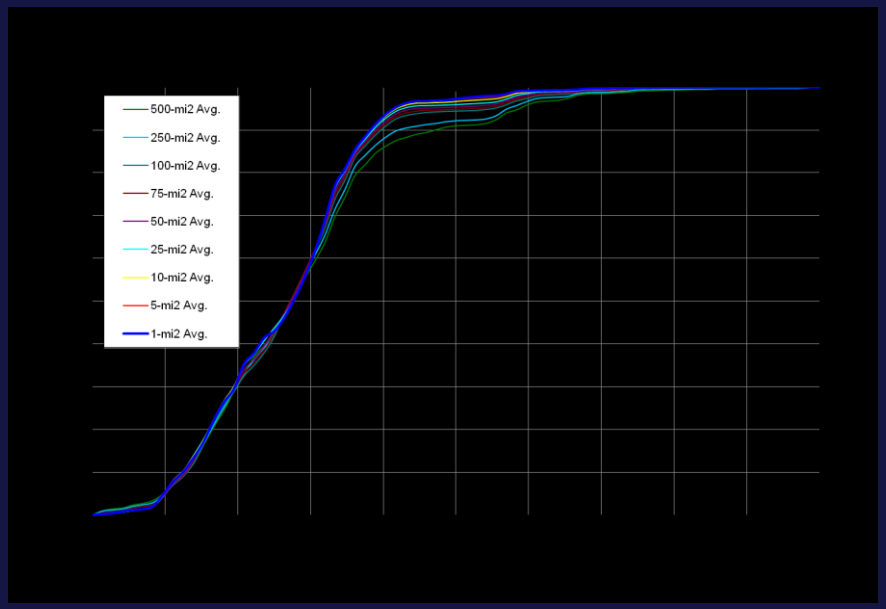
- Storm Based Timing
  - MCC
  - Hybrid
  - Synoptic
- Different than HMR recommendations

Temporal Distribution of PMP

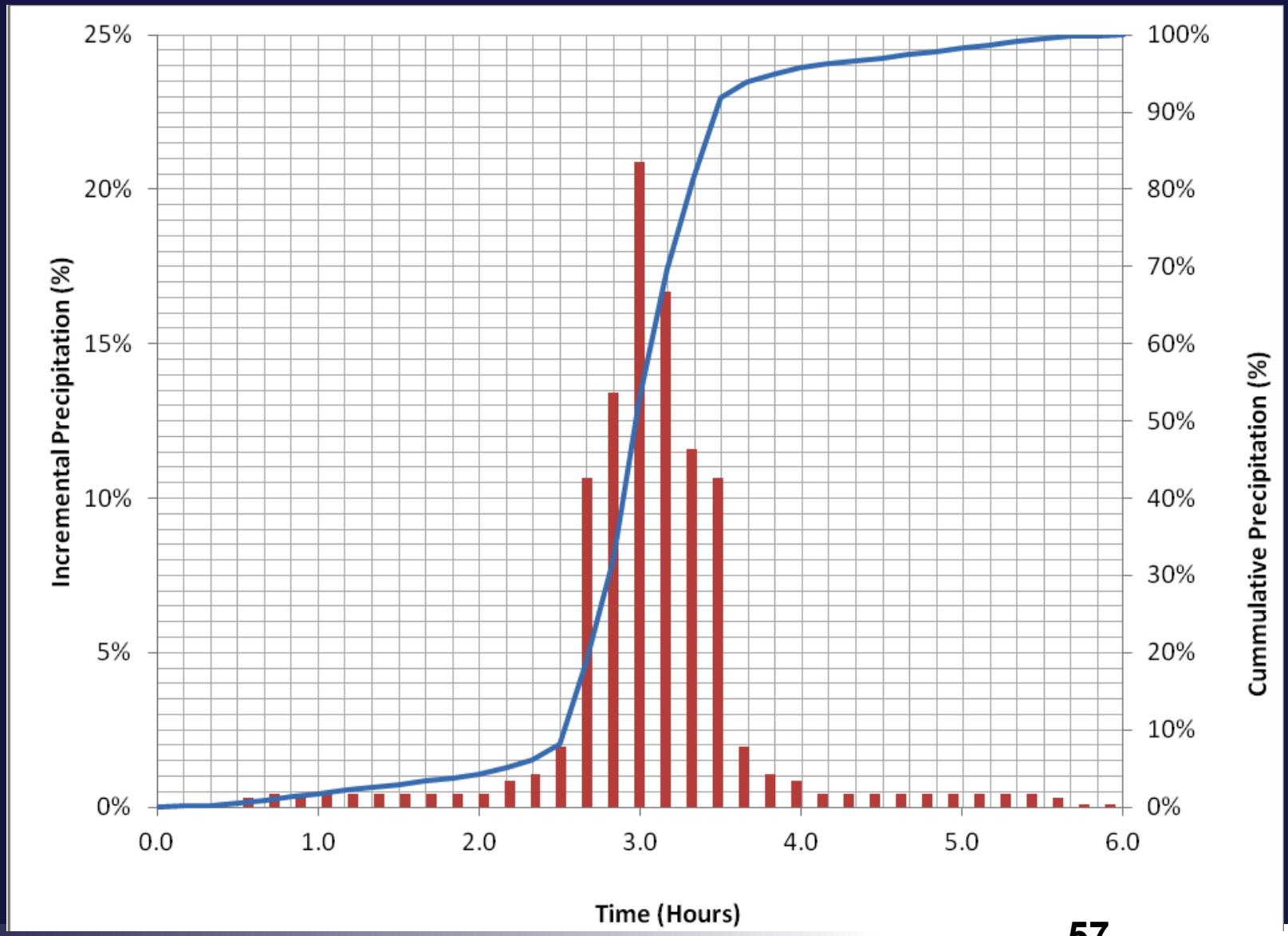




- Storm Based Timing
  - Areal Timing



Temporal Distribution of PMP-Arizona



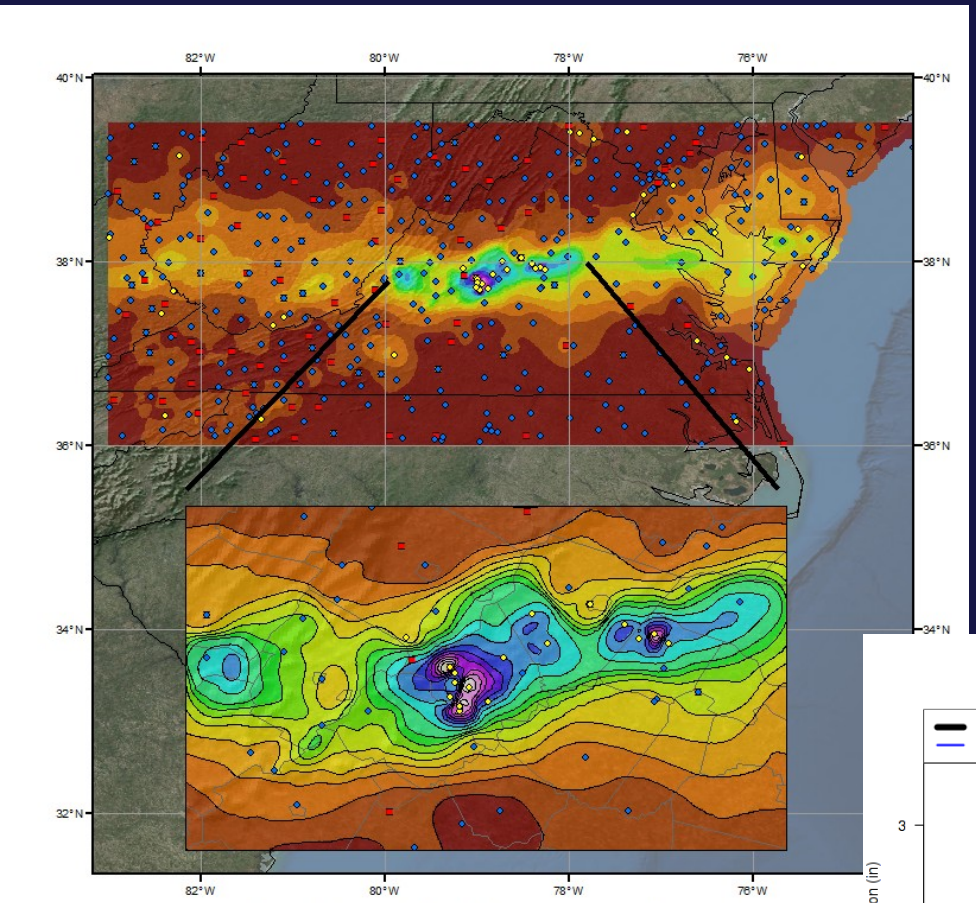
Smethport, PA-July 1942

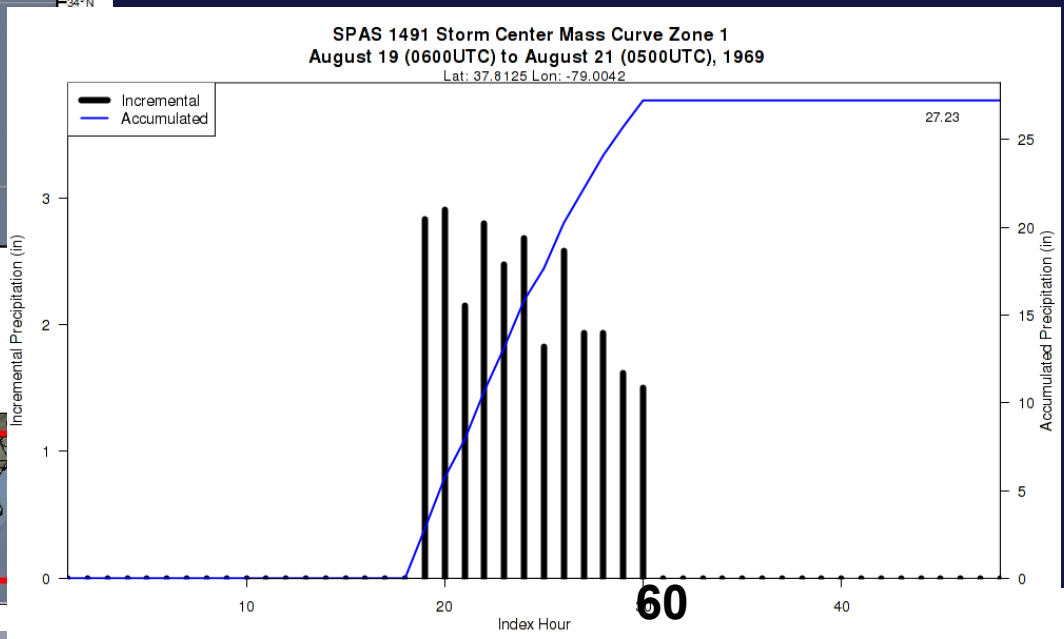
- Extreme rainfall cells occurred at different times
  - During the evening hours of July 17
  - During the early morning hours of July 18
- Spatial/temporal separation of these storm cells is very important for Depth-Area-Duration
- Individual cells contributed to the initiation of other cells, indicating separation in both time and space among the cells (Weather Bureau, date unknown)
  - Thirteen rainfall centers of 20 inches or more
- The Weather Bureau letter stated that any duration-depth computations for areas under 100 square miles should be classed as doubtful
- The 100 square mile area contained almost all of the rainfall centers with 20 inches or more that the USGS considered doubtful

Smethport, PA-July 1942

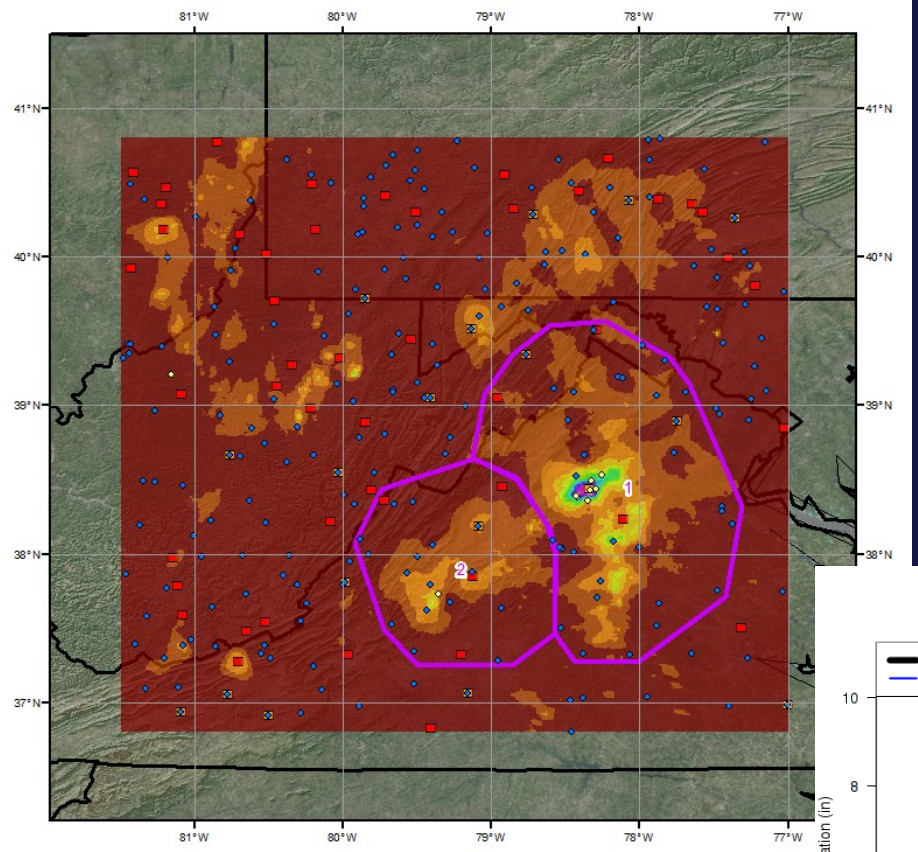
- The Smethport 1942 is the major storm in the historical record for the central Appalachian Mountains
- The Smethport storm produced its heaviest rainfall in multiple rainfall centers
  - Thirteen rainfall centers of 20 inches or more
- Rainfall values from the Smethport storm determine PMP values for the region
- If
  - Rainfall amounts from the Smethport storm determine PMP rainfall amounts
- Then
  - Following HMR 52 guidance, the spatial characteristics of the Smethport storm should be used to modify the design PMP storm pattern to have multiple centers (HMR 52, Section 5.1)

Hurricane Camille-Tyro, VA-August 1969





Madison County, VA-June 1995



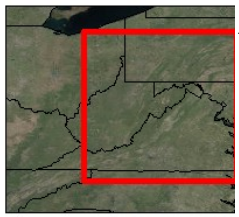
Total Storm (41-hours) Precipitation (inches)
June 26 - 27, 1995
SPAS 1406 - Rapidan, VA

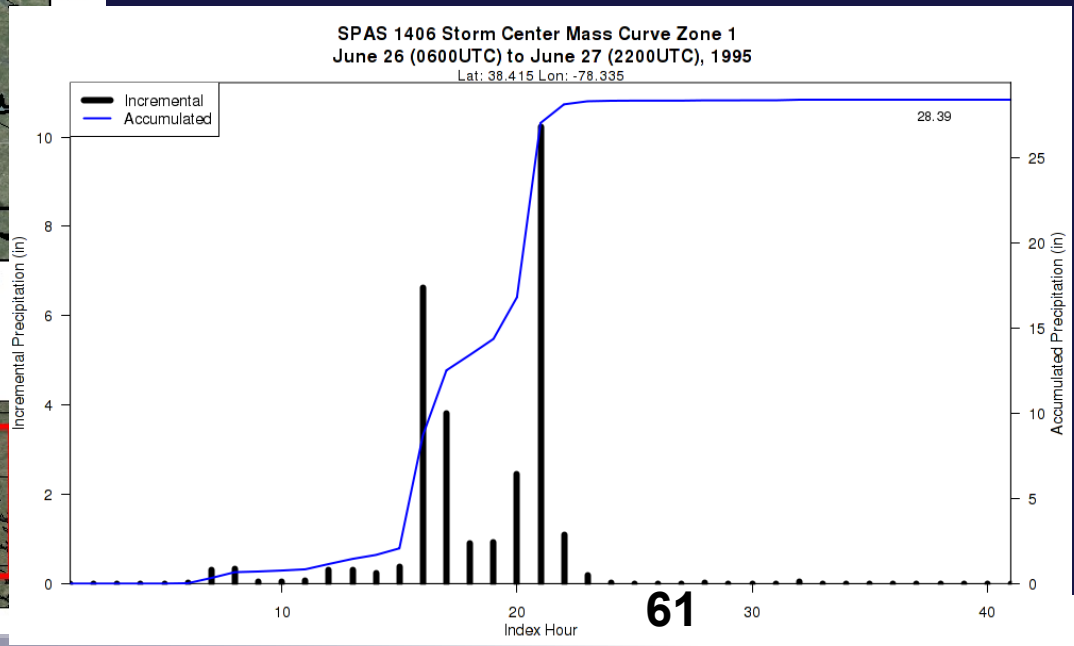
Gauges
- Daily
- Hourly
- Hourly Pseudo
- Supplemental

Miles: 0 20 40 80
Kilometers: 0 45 90 180

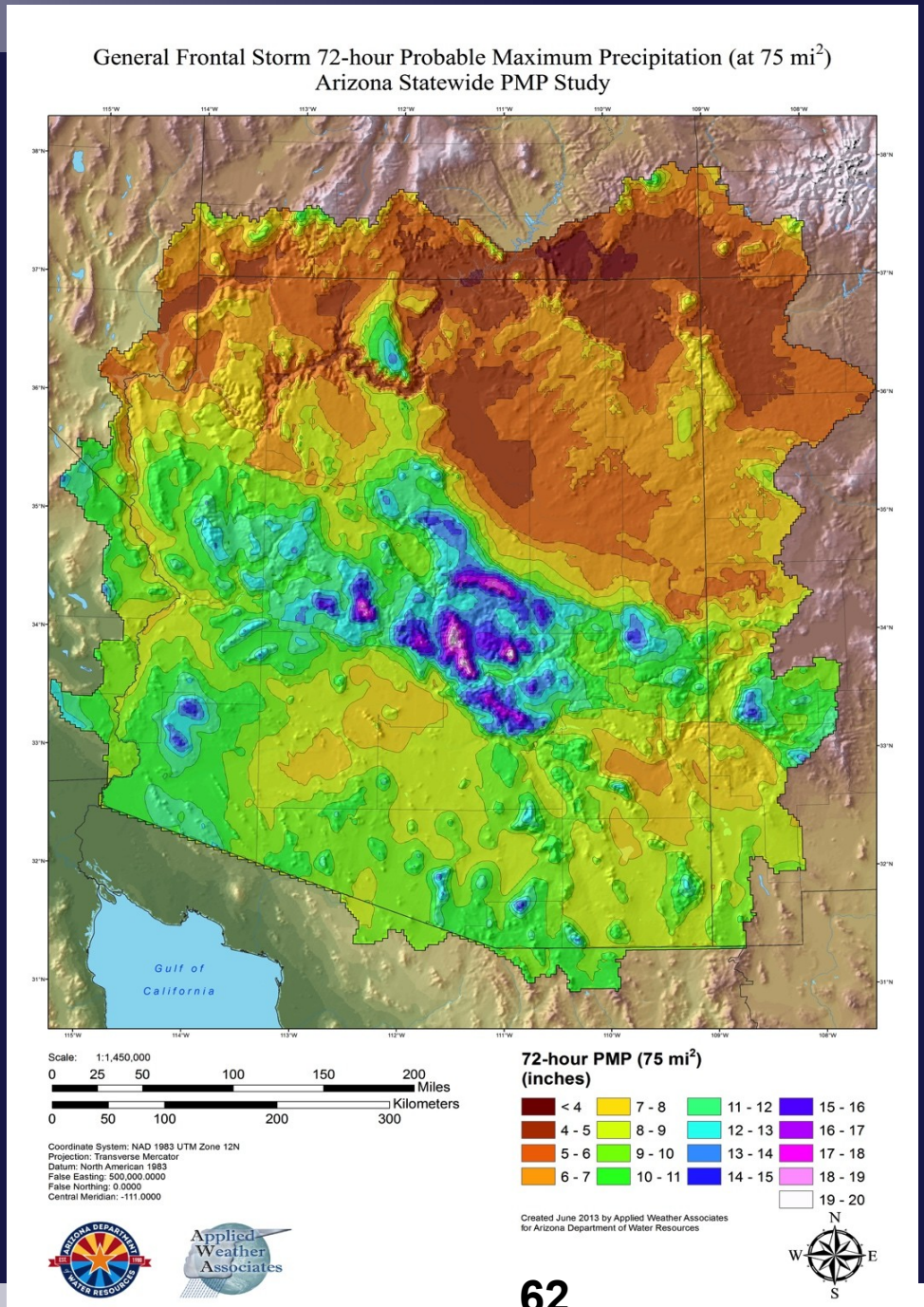
Precipitation (inches)

0.00 - 2.00	8.01 - 10.00	16.01 - 18.00	24.01 - 26.00
2.01 - 4.00	10.01 - 12.00	18.01 - 20.00	26.01 - 28.00
4.01 - 6.00	12.01 - 14.00	20.01 - 22.00	
6.01 - 8.00	14.01 - 16.00	22.01 - 24.00	

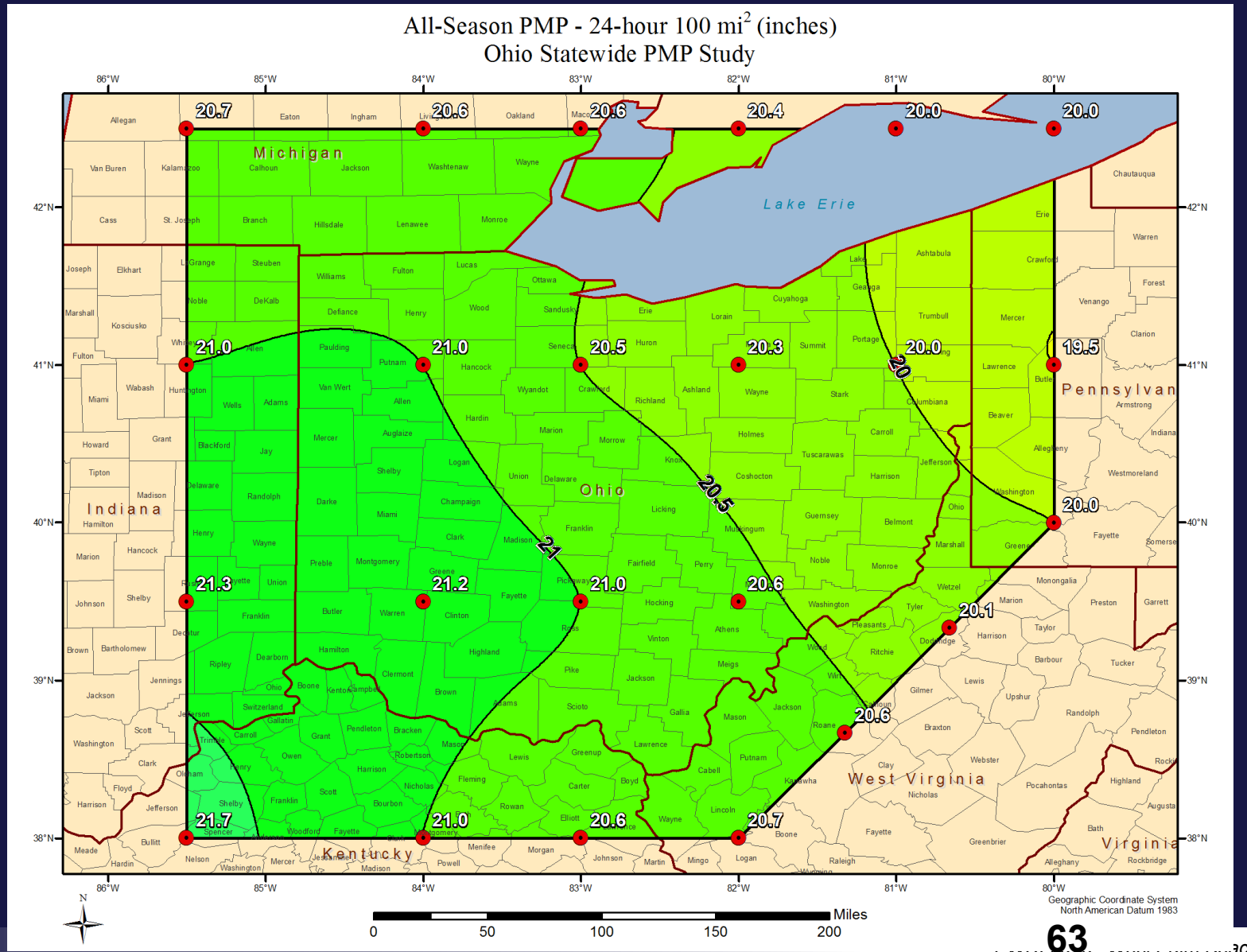




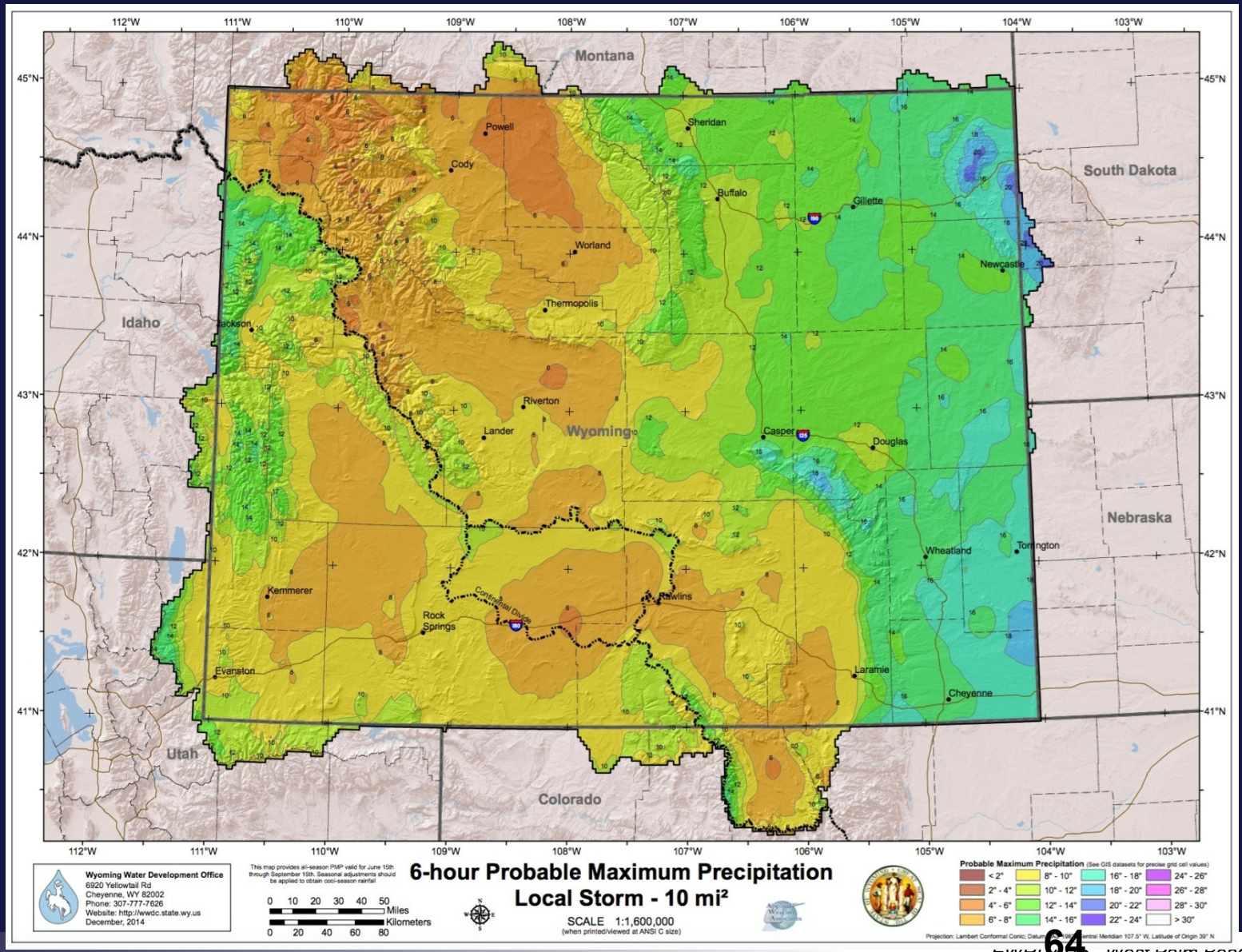
HMR 49 Example PMP-Arizona General Storm



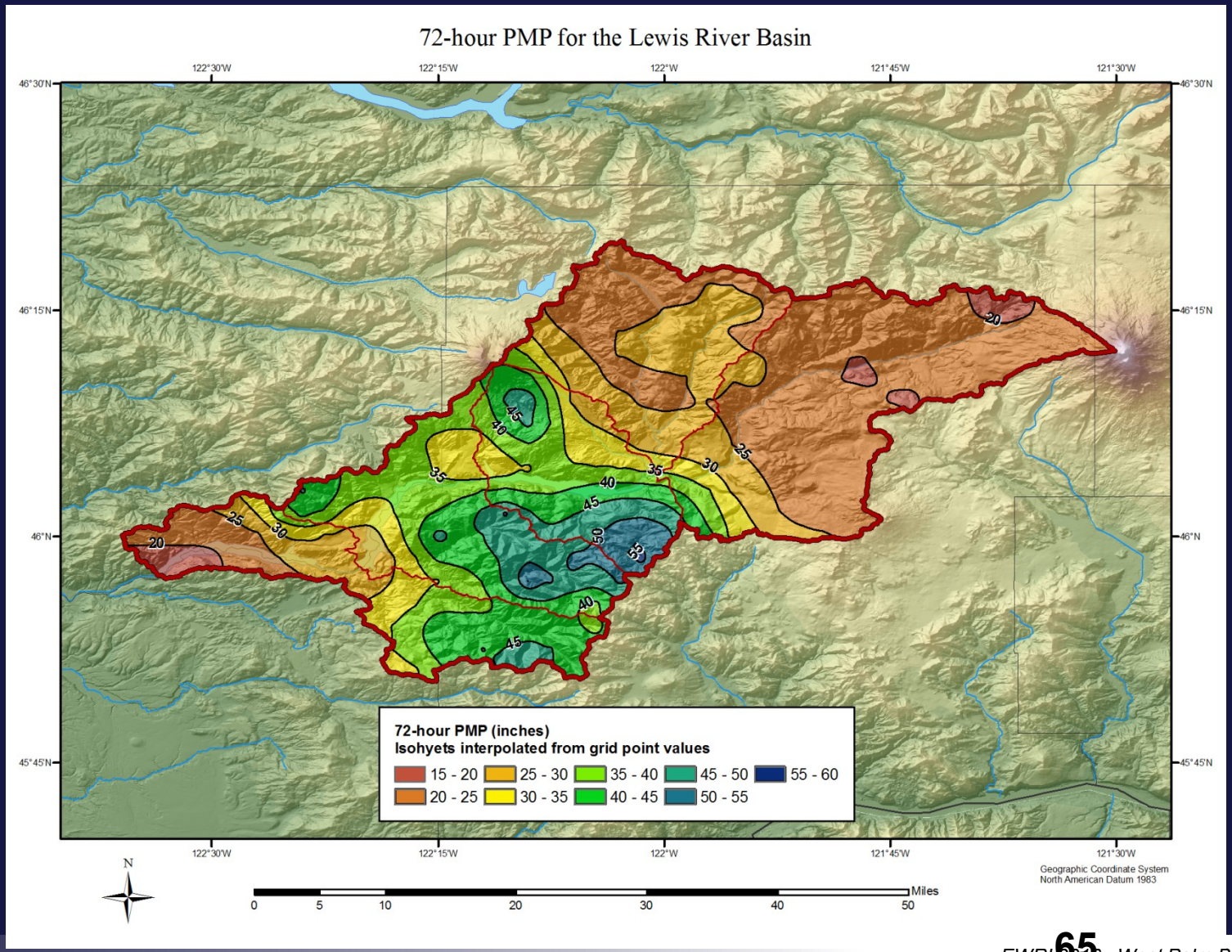
HMR 51 Example PMP-Ohio Statewide



HMR Example PMP-Wyoming Statewide



HMR 57 Example PMP-Site-Specific

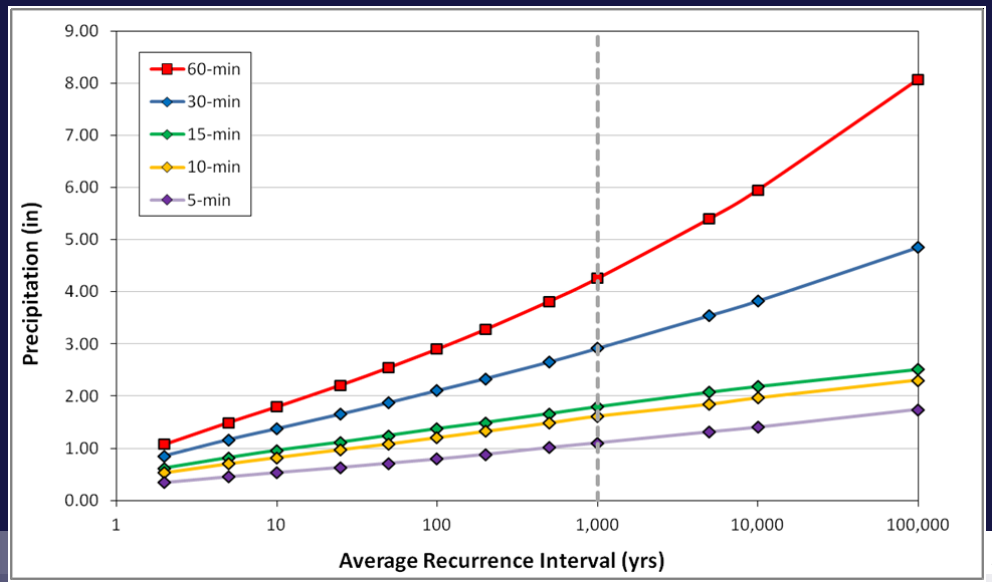


PMP Probability Example

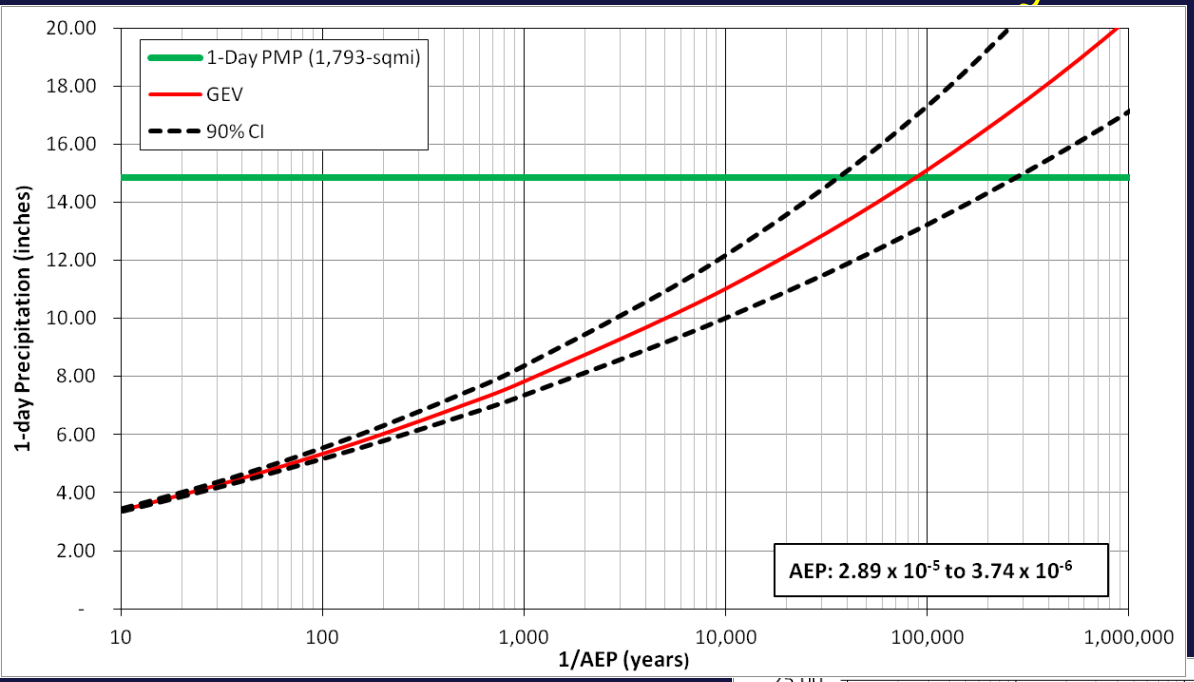
- NOAA Atlas 14 Statistical Extension
- Regional L-moments Method
- Stochastic Storm Transposition (SST) Method
- AEP of PMP ranges from 10^{-5} to 10^{-9} AEP
  - Varies by location, duration, and storm areal coverage

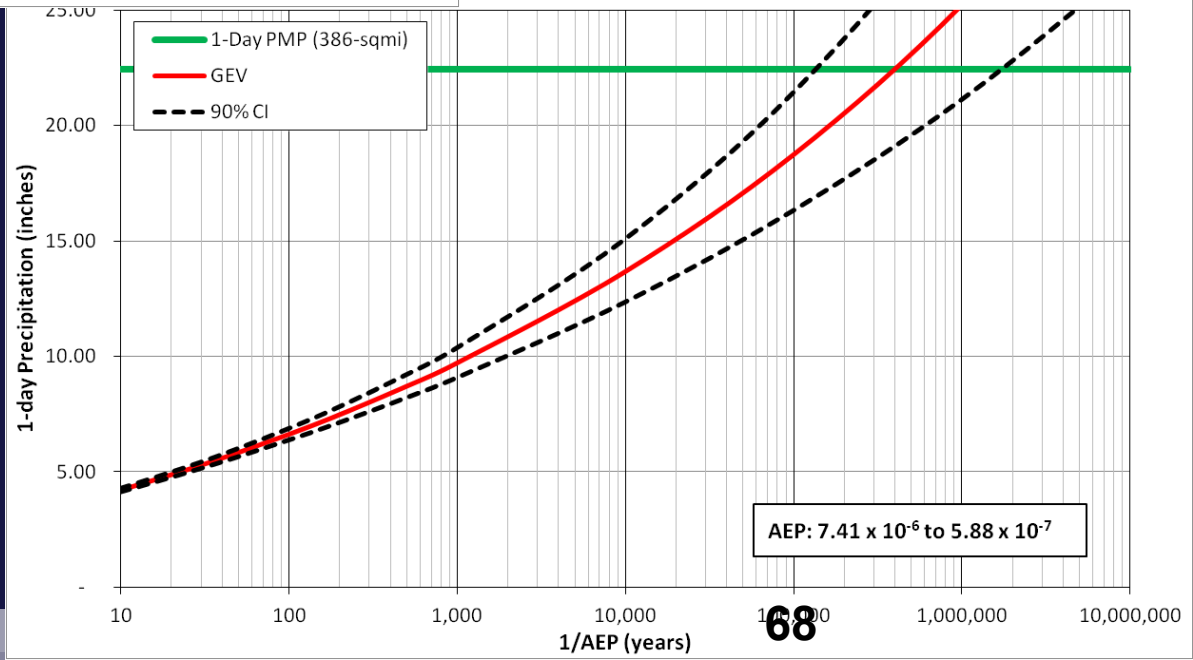
PMP Probability Example

- NOAA Atlas 14 Statistical Extension
  - Identify station representative of region
  - ARF – reduce point to area
  - Fit regression to NOAA Atlas 14 data
  - Simulate AMS data and distribution to statically extend NOAA Atlas 14 curves



PMP Probability Example





PMP Probability Example

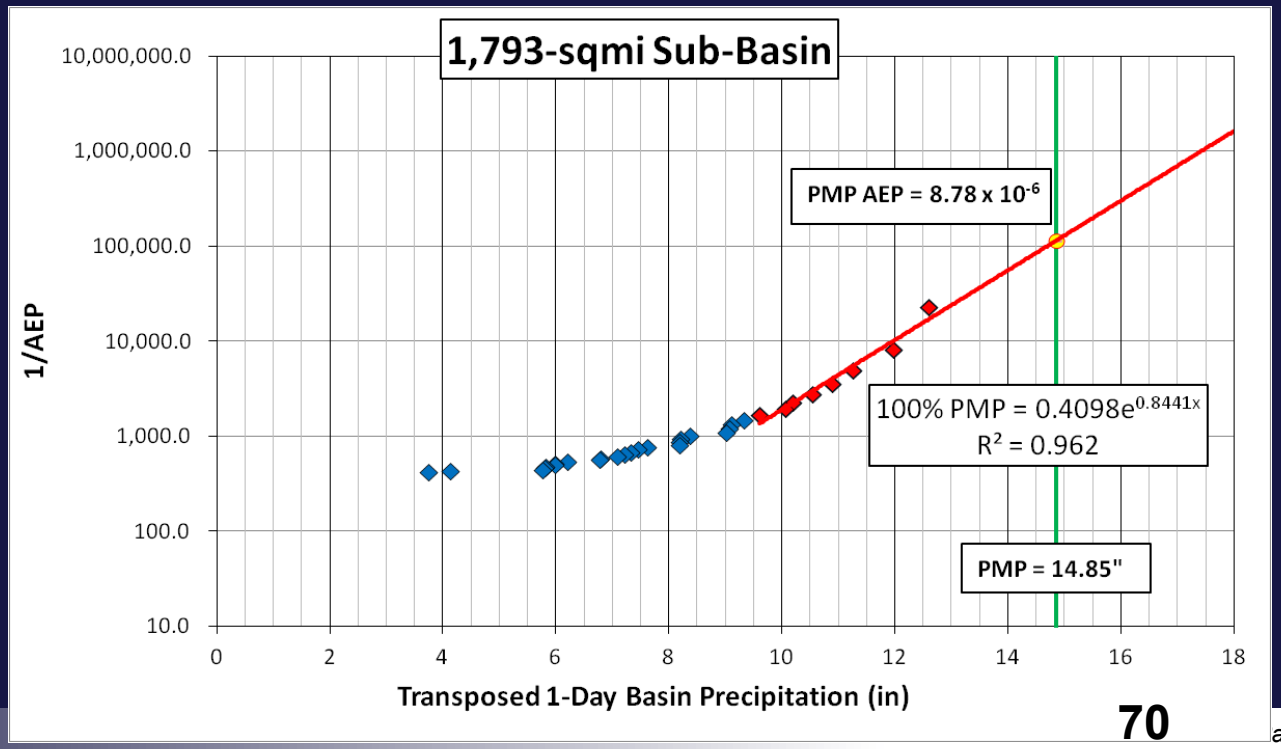
# Events	31
Trans Area (mi^2)	180,426.0
Basin Area (mi^2)	386.0
P2	0.0021
1day pmp	22.46
# Data years	126
P3	0.2460

		P1	P2 and P3				
1d			AEP				
Ppt	Rank	AEP	Adj Basin	1/AEP	EV Plot	Fx	%PMP
16.29	1	0.01806	0.0000095	105,170.6	8.56	0.9999905	0.725
16.18	2	0.05032	0.0000265	37,753.5	7.77	0.9999735	0.720
14.84	3	0.08258	0.0000435	23,006.1	7.38	0.9999565	0.661
13.89	4	0.11484	0.0000604	16,543.7	7.12	0.9999396	0.618
13.7	5	0.1471	0.0000774	12,915.7	6.93	0.9999226	0.610
13.31	6	0.1794	0.0000944	10,592.7	6.77	0.9999056	0.593
12.28	7	0.2116	0.0001114	8,978.0	6.65	0.9998886	0.547
11.74	8	0.2439	0.0001284	7,790.4	6.54	0.9998716	0.523
10.71	9	0.2761	0.0001453	6,880.3	6.44	0.9998547	0.477
10.69	10	0.3084	0.0001623	6,160.6	6.35	0.9998377	0.476
10.66	11	0.3406	0.0001793	5,577.2	6.27	0.9998207	0.475
10.23	12	0.3729	0.0001963	5,094.8	6.20	0.9998037	0.455
10.19	13	0.4052	0.0002133	4,689.1	6.14	0.9997867	0.454
10.11	14	0.4374	0.0002302	4,343.3	6.08	0.9997698	0.450
9.81	15	0.4697	0.0002472	4,045.0	6.02	0.9997528	0.437
9.48	16	0.5019	0.0002642	3,785.1	5.97	0.9997358	0.422
9.48	17	0.5342	0.0002812	3,556.5	5.92	0.9997188	0.422
9.03	18	0.5665	0.0002982	3,354.0	5.88	0.9997018	0.402
8.78	19	0.5987	0.0003151	3,173.3	5.83	0.9996849	0.391
8.77	20	0.6310	0.0003321	3,011.0	5.79	0.9996679	0.390
8.71	21	0.6632	0.0003491	2,864.6	5.76	0.9996509	0.388
8.3	22	0.6955	0.0003661	2,731.7	5.72	0.9996339	0.370
8.2	23	0.7277	0.0003831	2,610.6	5.68	0.9996169	0.365
8.18	24	0.7600	0.0004000	2,499.8	5.65	0.9996000	0.364
8.16	25	0.7923	0.0004170	2,398.0	5.62	0.9995830	0.363
7.77	26	0.8245	0.0004340	2,304.2	5.59	0.9995660	0.346
7.46	27	0.8568	0.0004510	2,217.5	5.56	0.9995490	0.332
6.64	28	0.8890	0.0004679	2,137.0	5.53	0.9995321	0.296
6.55	29	0.9213	0.0004849	2,062.2	5.50	0.9995151	0.292
5.86	30	0.9535	0.0005019	1,992.4	5.47	0.9994981	0.261
4.76	31	0.9858	0.0005189	1,927.2	5.45	0.9994811	0.212

- Probability of precipitation occurrence
- Probability of watershed size from storm transposition region
- Probability of PMP events from sample period of record
- Annual Exceedance Probability

PMP Probability Example

- Probability of precipitation occurrence
- Probability of watershed size from storm transposition region
- Probability of PMP events from sample period of record
- Annual Exceedance Probability

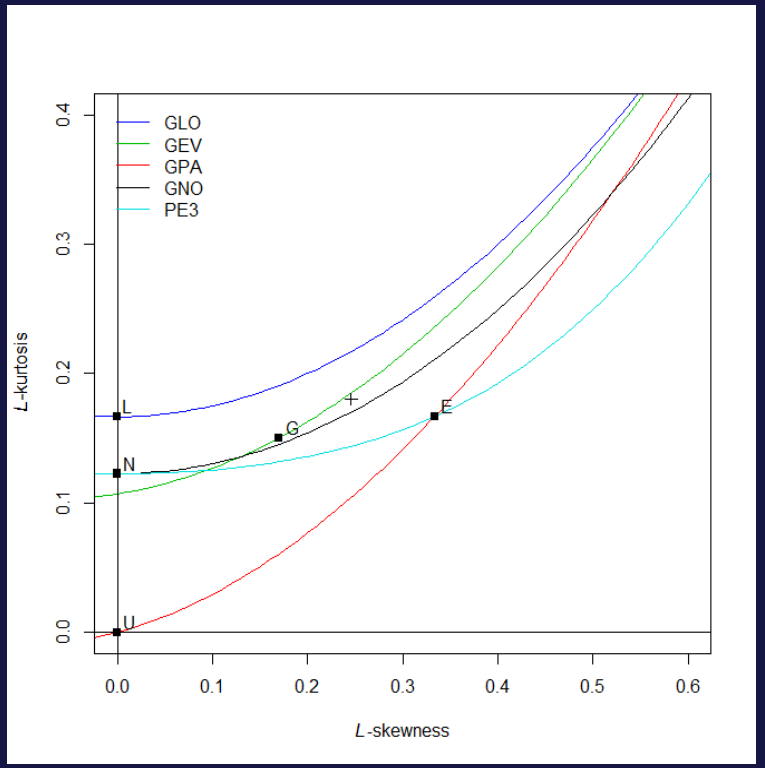


What About Climate Change?

- Climate has always been changing and always will
- Storms used reflect those changes last ~150 years
- PMP values represent the extreme upper limit
  - This is not affected by shorter term fluctuations
  - Captured under the umbrella of maximization/combination
  - Warmer atmosphere = more moisture, but not necessarily more heavy rain
  - Many unknowns, both positive and negative feedbacks
- Follow recommendations of HMRs/WMO-no adjustment for climate change

PMP Probability Example

- Regional L-moments
  - AMS
  - ARF
    - Point to area
  - Homogenous Regions
    - Trade space for time
  - Uncertainty Bounds
  - Regional Probability Distribution
    - Goodness-of-fit



PMP Probability Example

- Stochastic Storm Transposition (SST) Method
  - Transposition Storms to Basin
  - Probability of precipitation occurrence

$$p1 = \frac{r - 0.44}{N}$$

  - Probability of watershed size from storm transposition region

$$p2 = \frac{B_a}{S_a}$$

  - Probability of PMP events from sample period of record

$$p3 = \frac{N_s}{P_r}$$

  - Annual Exceedance Probability

$$AEP = p1 * p2 * p3$$

What About Uncertainty of PMP?

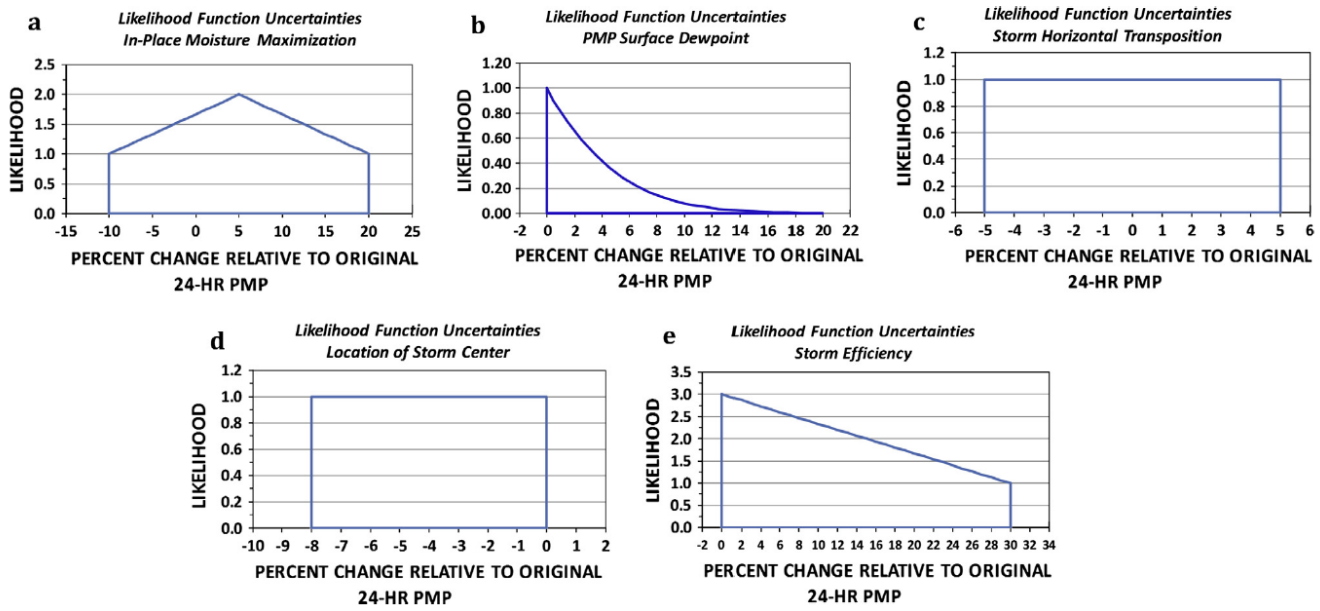


Fig. 6. Likelihood functions for the effect of uncertainties expressed relative to the original 24-h PMP estimate (a: in-place moisture maximization; b: dewpoint; c: storm horizontal transposition; d: storm center location; e: storm efficiency).

From Micovic et al. 2015

5. Proposed methodology for assessing PMP uncertainties

The methodology for assessing uncertainties in PMP estimates is as follows:

a. Identify sources of uncertainty (parameters) for a project-specific application.
b. Determine the range of plausible parameter values for each of the identified parameters used in computation of PMP.
c. Develop a probability distribution or otherwise characterize the likelihood of parameter values over the range of values for each parameter.
d. Use numerical integration methods to determine the distribution of possible PMP values and uncertainty bounds for the adopted PMP value.

Presentation Outline

- History of PMP Development and Background
- Current state of PMP
- How are storms analyzed and used for PMP
  - Extreme storms-talking about the “big ones”
- Probability of PMP and other events
- Uncertainty in the process
- Next steps/Dam safety uses

So What About Dam Safety and PMP?

- Need for reliable, updated values
- Need for consistency
- Many dams not previous high hazard reclassified
- Better numbers can lead to reclaimed opportunities/storage
- Most importantly-more confidence in regulatory process
  - Safety of lives
  - Safety of property

PMP-Lessons Learned

- Work with regulator, hydrologists, reviewers
- Be clear about unknowns/limitations
- Communicate how to apply results