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Virginia Department of Conservation & Recreation

Virginia Probable Maximum Precipitation (PMP) Study Overview

Virginia Soil and Water Conservation Board December 9, 2015

PMP Definition

(4VAC50-20-50.H) Probable maximum precipitation means the theoretically greatest depth of precipitation for a given duration that is meteorologically possible over a given size storm area at a particular geographical location at a particular time of year with no allowance made for future long term climatic trends.

PMP, PMF, SDF Relationship

- The Probable Maximum Flood (PMF) is calculated from the PMP and is the flood that might be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the region.
- Accordingly, from the PMP and subsequently the PMF, the Spillway Design Flood (SDF) is calculated and represents the largest flood that needs to be safely passed by the impounding structure.
- A sufficient spillway design is critical as a high percentage of dam failures are due to overtopping.

Legislation - 2014

- HB 1006 Delegate Kathy J. Byron (Chapter 475)
- SB 582 Senator Thomas A. Garrett, Jr. (Chapter 489)
- Directed DCR, on behalf of the VSWCB, to study and update by December 1, 2015, Virginia's Probable Maximum Precipitation (PMP) values.
- Stated that the results shall be considered by the VSWCB in its decision to authorize the use of the updated PMP values in Probable Maximum Flood calculations, thus replacing the current PMP values.
- Stated that such PMP revisions shall be adopted by the Board if it finds that the analysis is valid and reliable and will result in cost savings to owners for impounding structure spillway construction or rehabilitation efforts.

Applied Weather Associates

- Completed PMP Studies across country
  - Arizona
  - Ohio
  - Wyoming
  - Texas
  - Tennessee Valley Authority
  - Federal Energy Regulatory Commission
  - Nuclear Regulatory Commission

Technical Review Board and Meetings

Board:

Mathew Lyons – State Conservation Engineer – USDA NRCS

John Harrison – Schnabel Dam Engineering

Arthur Miller – AECOM

Stephen Rich – Southeast Weather Consulting

With Support from the Federal Energy Regulatory Commission: Kenneth Fearon, Elise Dombeck, and Kevin Griebenow

Meetings:

- July 8, 2014
- November 18, 2014
- April 7,8, 2015
- October 6, 7, 2015

Final Report: November 15, 2015

Goals of the PMP Study

- Consider More Storms
- Utilize New Technologies
- Correct Problems/Unknowns of Older studies
- Address Topographic Features
- Use Updated Climatologies
- Improve Data Resolution
- Ensure that the Results were Reproducible and Reliable
- Ensure a Higher Confidence in Results/Data
- Ensure an Extensive Review Process
- Create a Set of Virginia Specific PMP Values to Replace Older HMR Values

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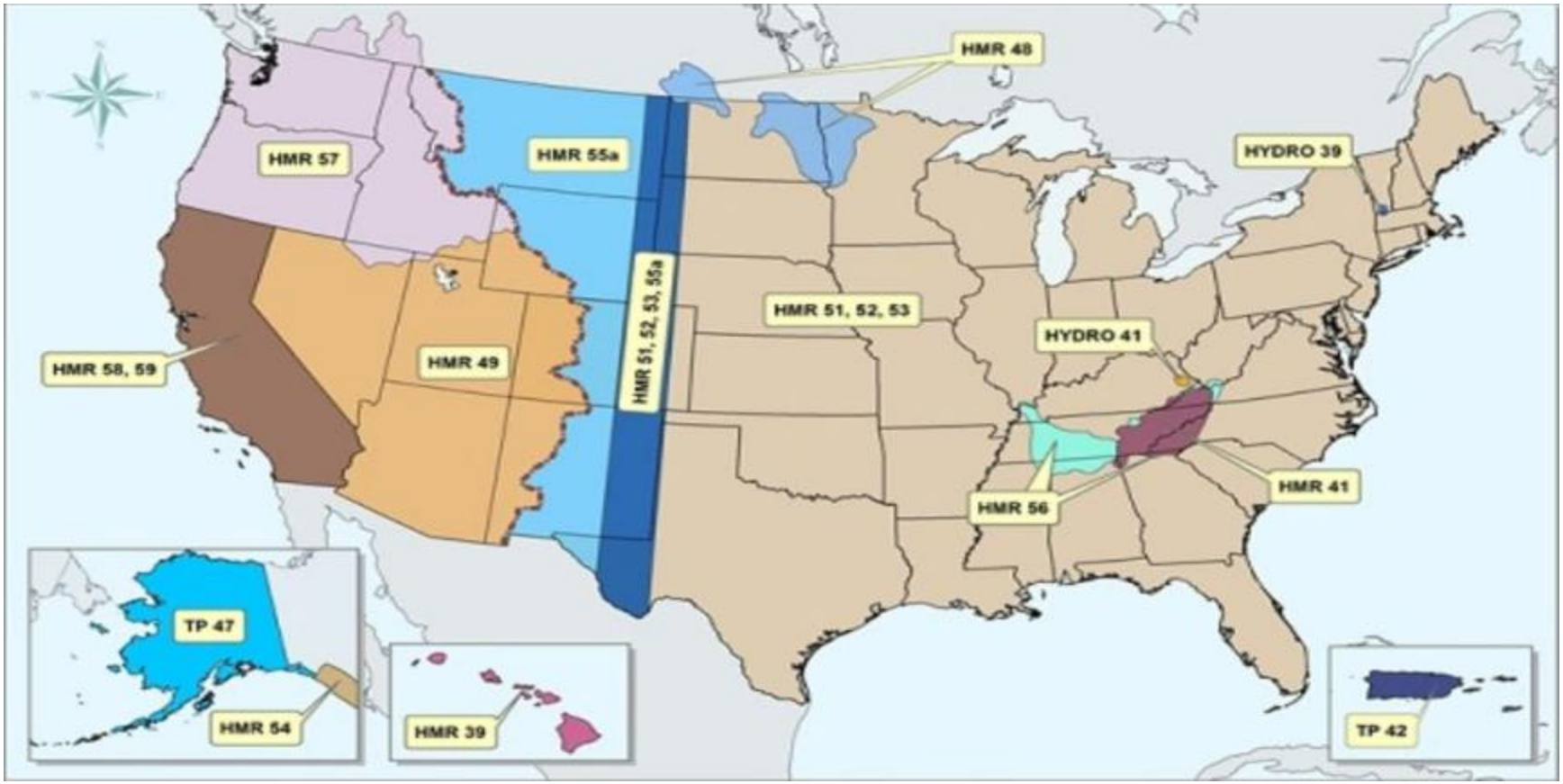
NOAA Hydrometeorological Reports (HMR) (National Weather Service/ USACE)



HMR 51 PMP-24hr 1000mi2

(23 grid points – hand drawn smooth lines)

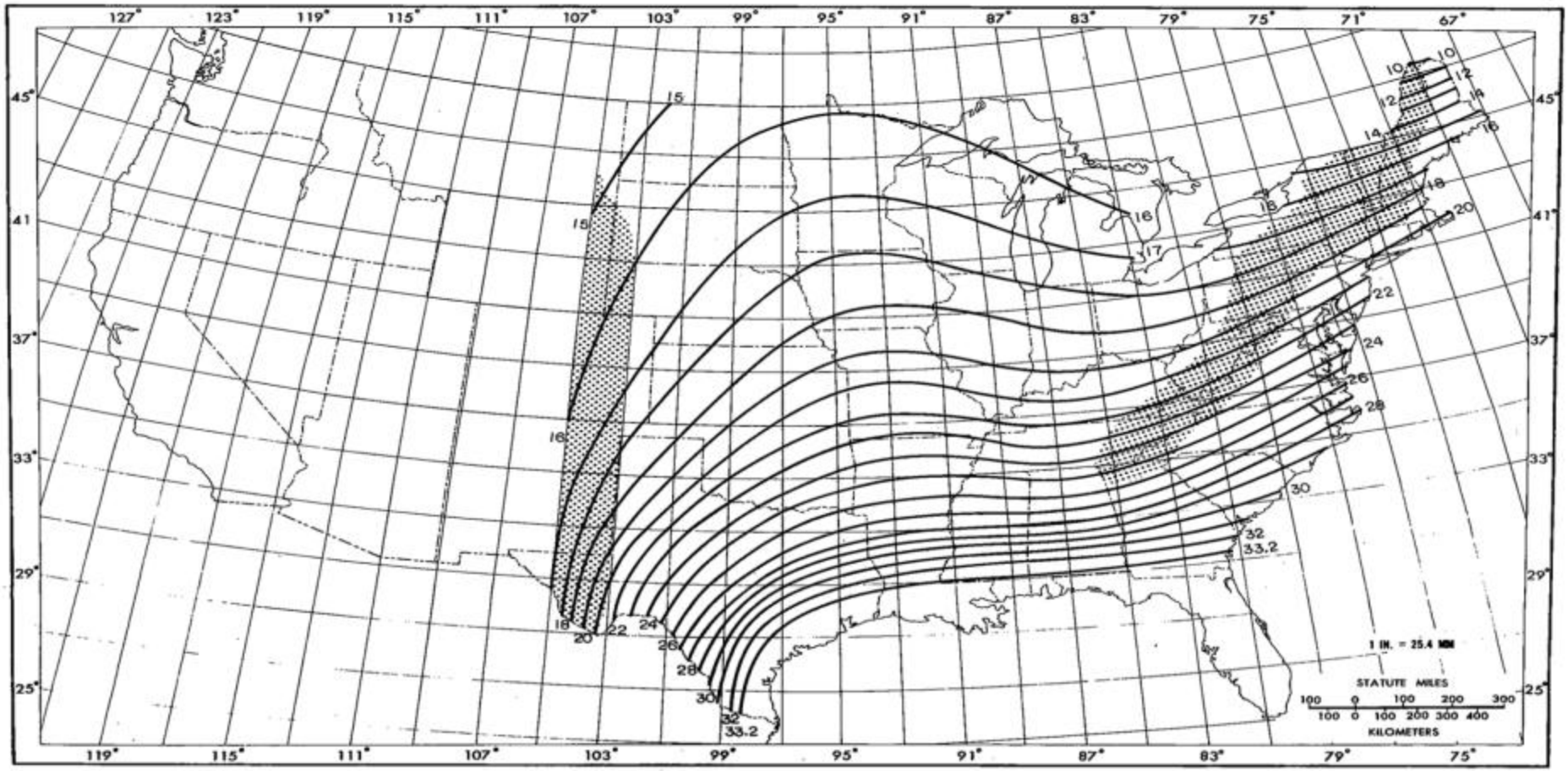
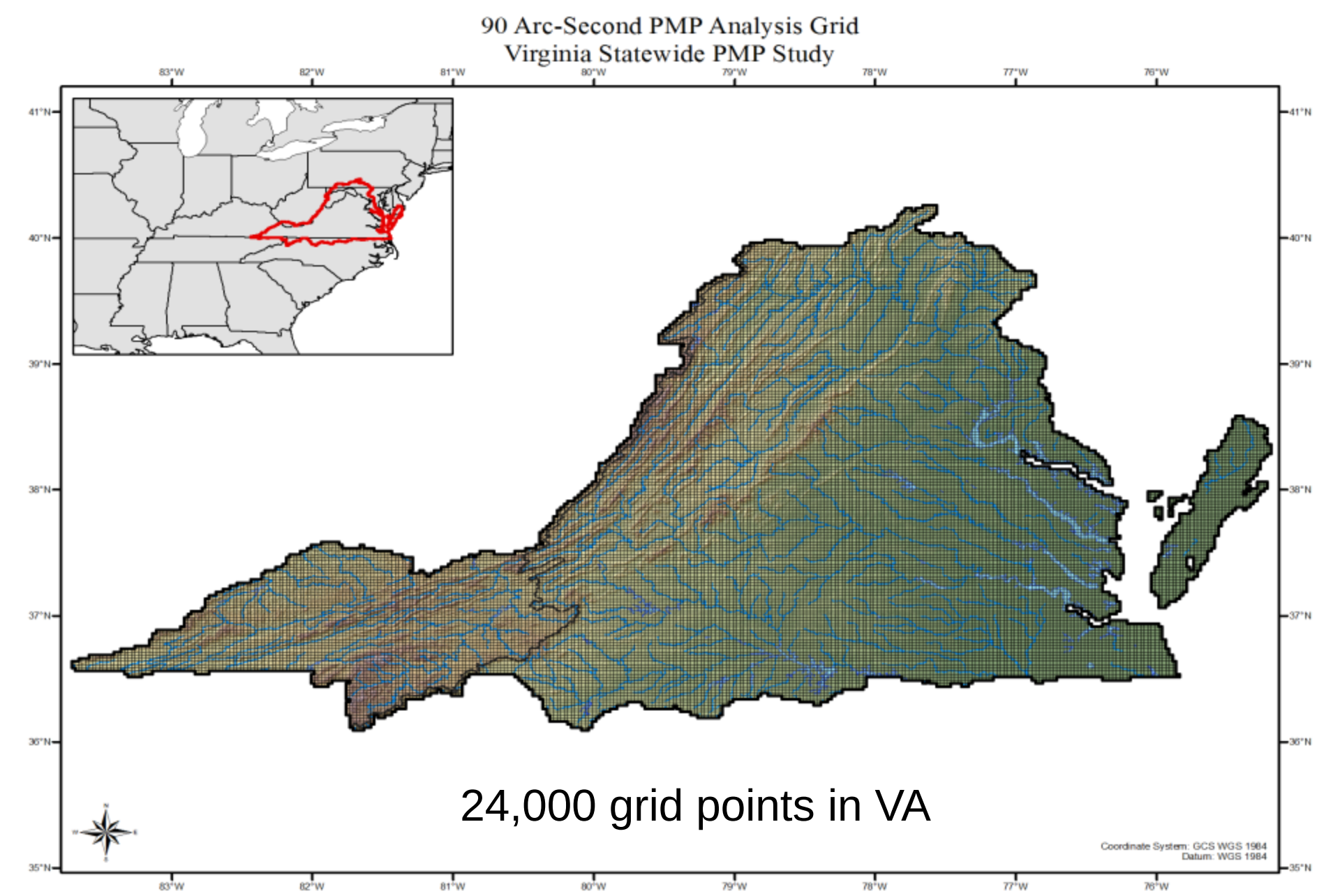


Figure 30.--All-season PMP (in.) for 24 hr 1,000 mi^2 (2,590 km^2).


90 Arc-Second PMP Analysis Grid
Virginia Statewide PMP Study
83°W
82°W
81°W
80°W
79°W
78°W
77°W
76°W
41°N
40°N
39°N
38°N
37°N
36°N
35°N
24,000 grid points in VA
Coordinate System: GCS WGS 1984
Datum: WGS 1984

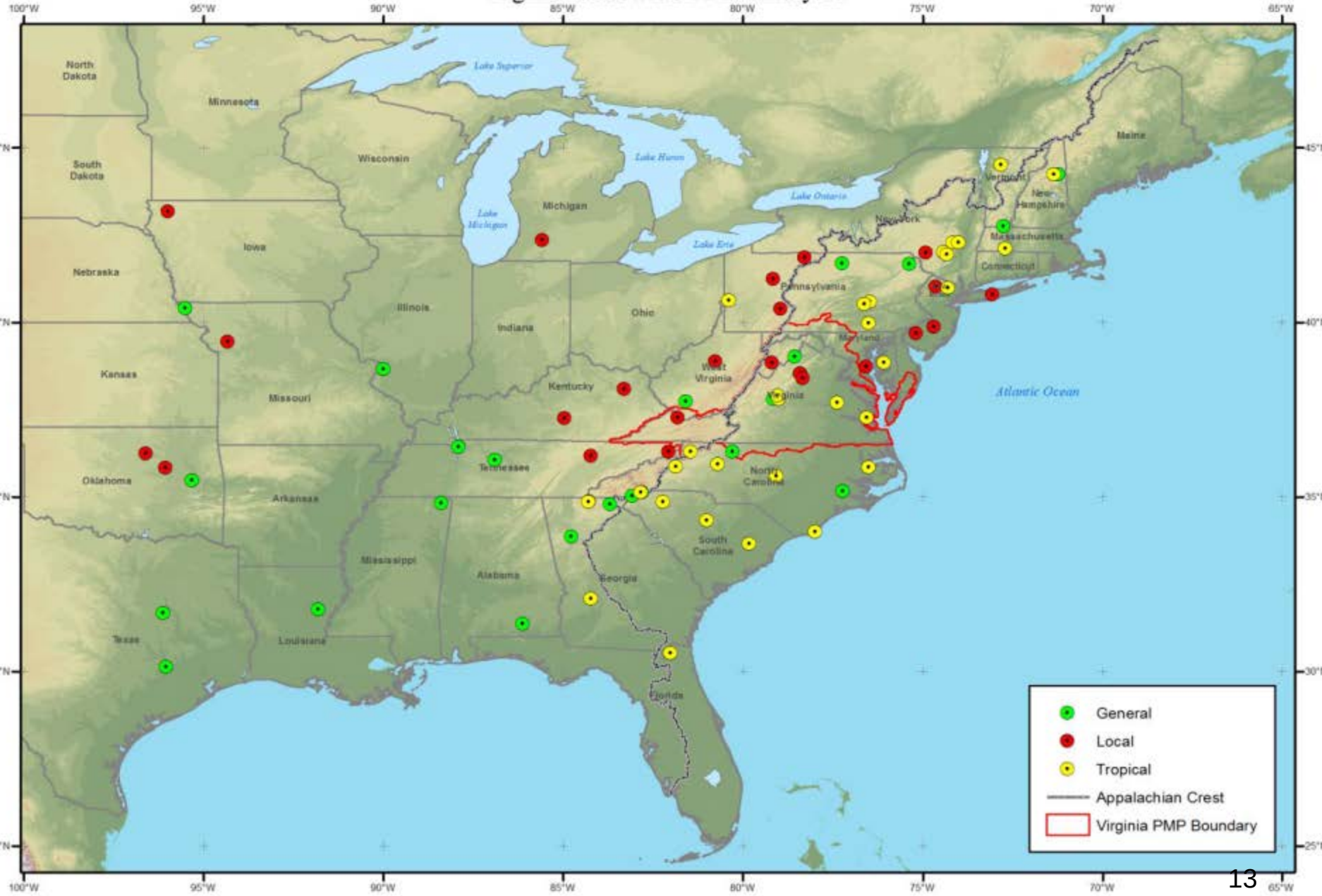
1. Review Previous Studies

- AWA PMP Studies
- Hydrometeorological Reports (HMRs)
  - HMR 40 – 1965
  - HMR 51 – 1978
  - HMR 52 – 1982
  - HMR 56 – 1986
- USACE/USGS Storm and Flood Analyses

2. Storm Search & List Development

- Identify Storms in Hydrometeorological Reports and Other PMP Studies
- Storm Search to Identify Significant and Transpositionable Storms in Region
- Identify Most Significant Flood Events
- Identify Extreme Storm Types (79 Analyzed)
  a. Local Storms (Thunderstorms) (23)
  b. General Storms (Frontal System) (25)
  c. Hurricanes and Tropical Storms (31)
- Storms occurred between 1889 and 2014

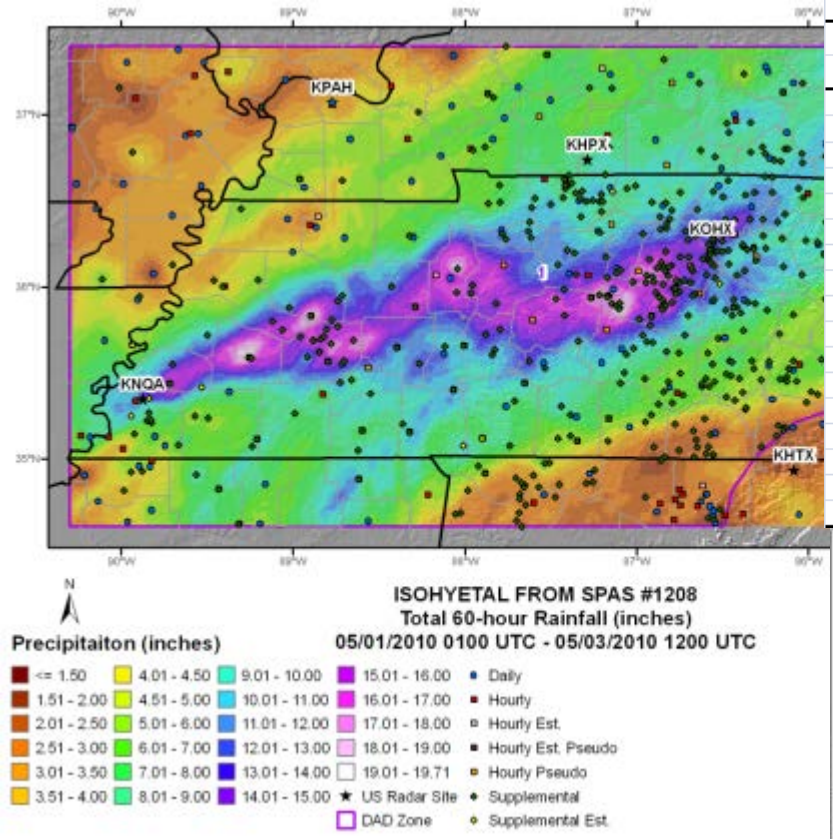
Locations of all Storm Events - Short List
Virginia Statewide PMP Analysis



3. Storm Analysis

- Analyze Extreme Storms with Storm Precipitation Analysis System (SPAS)
  - Hourly (5-minute rainfall) at 1/3rd square mile
  - Depth-Area-Duration Table
  - Mass Curves
  - Total Storm and Hourly Isohyetal Patterns
  - Dynamically adjusted radar and/or basemap for spatial interpolation
- Produces Gridded Rainfall Analysis
- Produces Required Data Sets

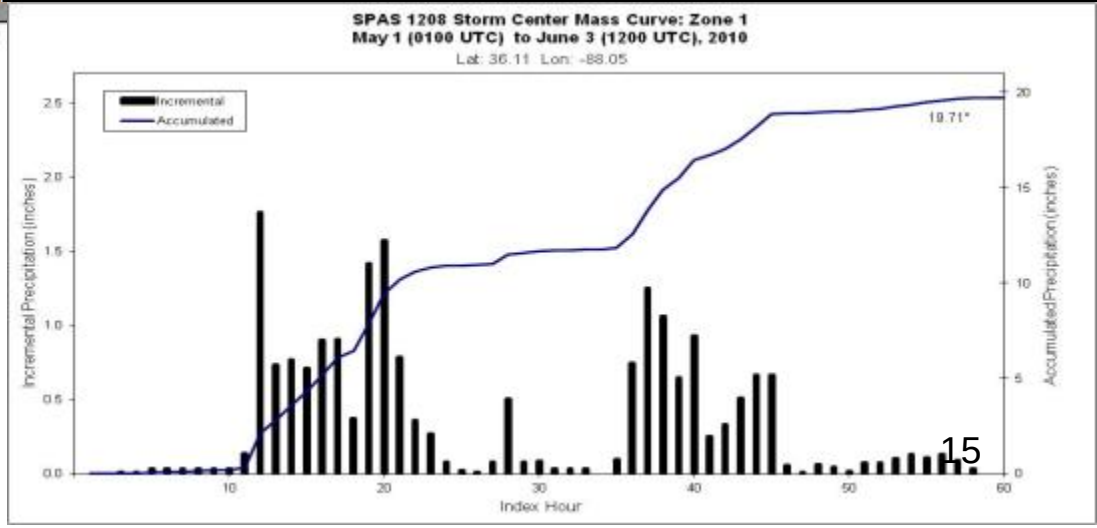
SPAS Storm Analysis Results



Storm 1208 - May 1 (0100 UTC) - May 3 (1200 UTC), 2010

MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

	Duration (hours)									
Area (mi^2)	1	3	6	12	18	24	36	48	60	Total
0	4.63	8.92	15.31	17.77	18.33	18.39	19.36	19.66	19.71	19.71
1	4.58	8.82	15.06	17.52	18.03	18.12	19.11	19.38	19.45	19.45
10	4.44	8.81	14.98	17.31	17.97	18.06	19.04	19.15	19.43	19.43
25	4.29	8.61	14.66	17.08	17.69	17.8	18.91	19.05	19.24	19.24
50	4.04	8.25	14.12	16.7	17.2	17.33	18.67	18.82	19.01	19.01
100	3.72	7.72	13.21	15.9	16.52	16.63	18.31	18.51	18.71	18.71
150	3.58	7.37	12.62	15.37	16.04	16.07	17.91	18.35	18.48	18.48
200	3.43	7.12	12.18	14.99	15.57	15.78	17.75	18.11	18.32	18.32
300	3.16	6.72	11.56	14.47	15.07	15.28	17.33	17.85	18.05	18.05
400	2.97	6.44	11.07	14.08	14.65	14.91	16.9	17.65	17.85	17.85
500	2.81	6.19	10.63	13.52	14.34	14.61	16.84	17.4	17.67	17.67
1,000	2.27	5.26	8.99	12.55	13.27	13.5	16.39	16.86	17.05	17.05
2,000	1.79	4.19	7.41	11.11	11.96	12.62	15.72	16.14	16.37	16.37
5,000	1.38	3	5.23	9.24	10.3	10.93	14.12	14.79	15	15.00
10,000	0.99	2.28	3.76	7.39	8.42	8.64	12.21	13	13.13	13.13
20,000	0.66	1.6	2.93	5.44	6.33	7.16	10.24	11.04	11.15	11.15
50,000	0.32	0.88	1.58	3.19	4.08	4.59	6.63	7.63	7.75	7.75

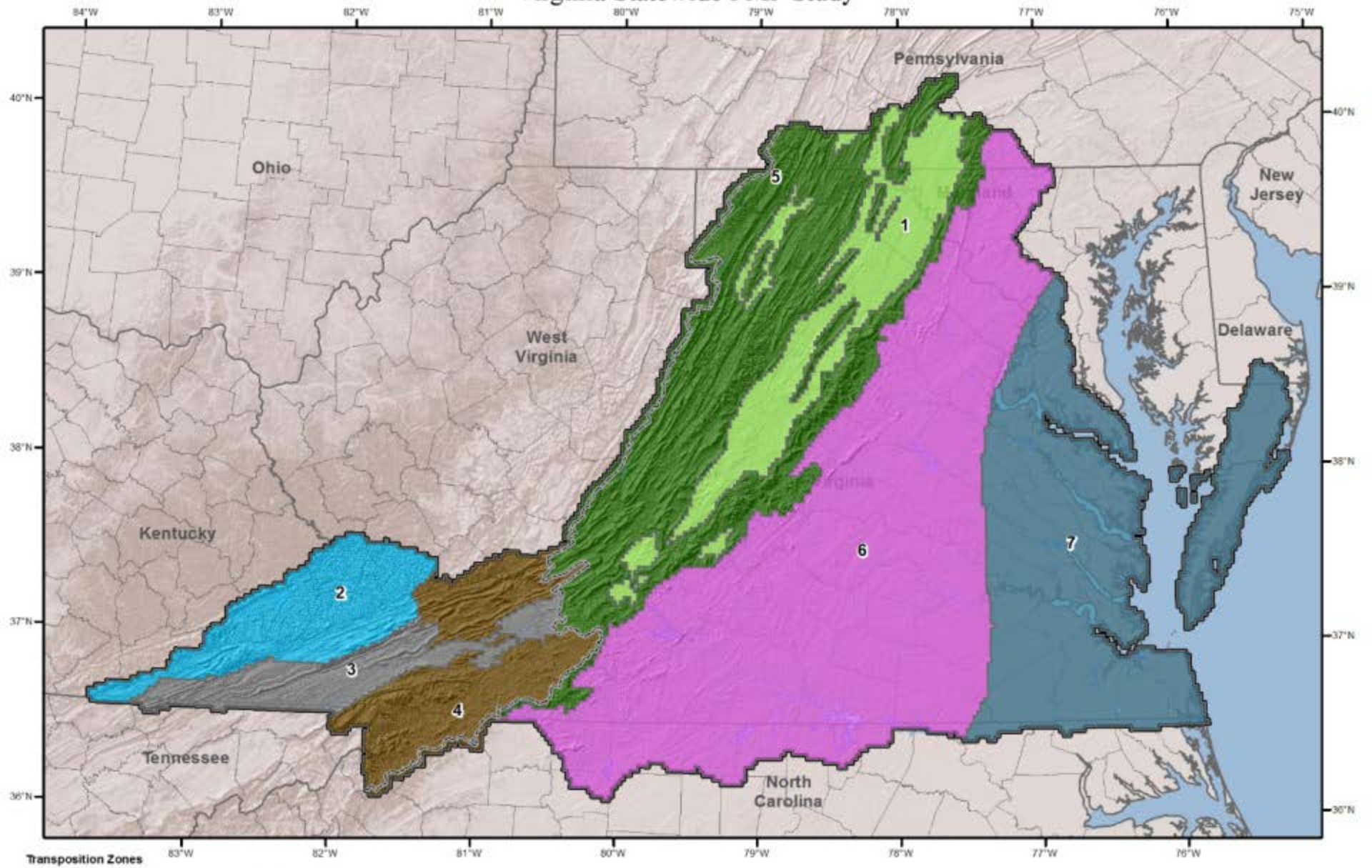


4. Storm Maximization, Transpositioning, Orographic Analysis

- Adjustment Factors Calculated For Each Storm:

1. Maximization Factor
2. Moisture Transposition Factor
3. Orographic Transposition Factor

Transposition Zones
Virginia Statewide PMP Study



Transposition Zones

- 1 - Interior Valley
- 2 - Cumberland Plateau
- 3 - Great Valley
- 4 - Blue Ridge West
- 5 - Blue Ridge East
- 6 - Piedmont
- 7 - Coastal Plain

0 25 50 100 Miles

Coordinate System: USA Contiguous Albers Equal Area Conic
Projection: Albers
Datum: North American 1983

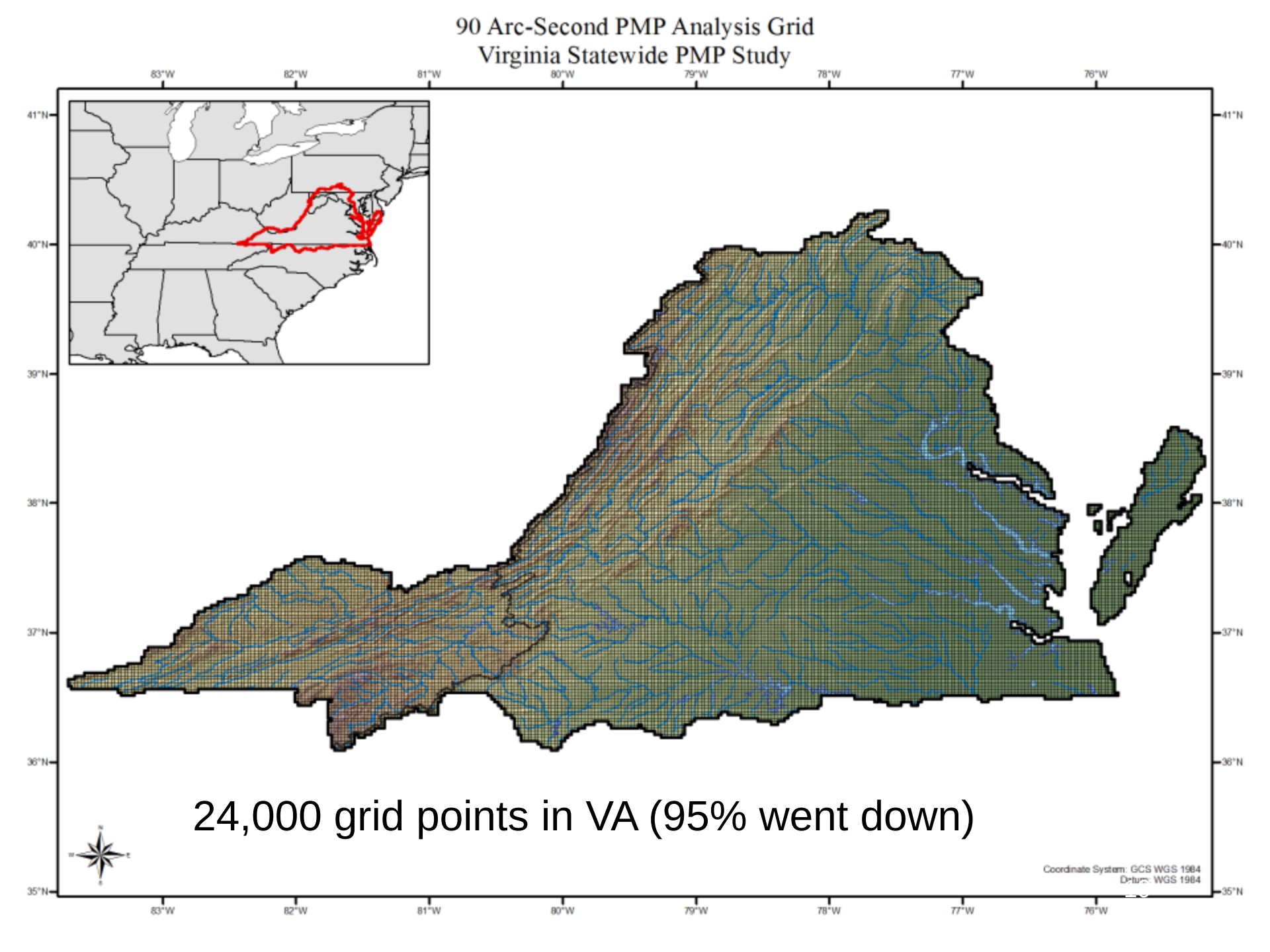
5. PMP Values Developed

Area: 2.5 square mile grid

Durations: 1 – 72 hours

PMP Evaluation Tool:

- PMP values in each 2.5 square mile grid
- Watershed overlay will give average PMP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38°N
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36°N
35°N
24,000 grid points in VA (95% went down)
Coordinate System: GCS WGS 1984
Datum: WGS 1984

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Local Storm PMP Comparison

Grayed out rows signify where the one of the other storm types is controlling

Local Storm 10 Sq Mi Average PMP									
Transposition Zone	HMR 51 6hr	PMP 6hr	Change 6hr	HMR 51 12hr	PMP 12hr	Change 12hr	HMR 51 24hr	PMP 24hr	Change 24hr
1 - Interior Valley	27.6	19.7	-28.7%	32.2	21.2	-34.3%	35.5	21.8	-38.5%
2 - Cumberland Plateau	28.7	19.2	-33.2%	33.8	21.5	-36.6%	36.9	21.7	-41.3%
3 - Great Valley	28.9	17.1	-40.7%	34.1	19.2	-43.9%	37.4	19.4	-48.3%
4 - Blue Ridge West	28.9	19.7	-31.8%	34.1	22.1	-35.5%	37.6	22.3	-40.8%
5 - Blue Ridge East	27.8	19.8	-28.8%	32.5	21.3	-34.5%	35.8	22.0	-38.6%
6 - Piedmont	28.5	26.1	-8.5%	33.7	29.0	-13.9%	37.7	29.1	-22.7%
7 - Coastal Plain	28.6	29.6	3.7%	33.8	33.1	-2.1%	38.5	33.1	-14.0%
Statewide Domain	**28.4**	**23.8**	**-16.2%**	**33.4**	**26.3**	**-21.4%**	**37.2**	**26.6**	**-28.9%**

Local Storm 200 Sq Mi Average PMP									
Transposition Zone	HMR 51 6hr	PMP 6hr	Change 6hr	HMR 51 12hr	PMP 12hr	Change 12hr	HMR 51 24hr	PMP 24hr	Change 24hr
1 - Interior Valley	19.2	11.5	-40.2%	22.9	12.5	-45.5%	26.5	14.3	-46.0%
2 - Cumberland Plateau	20.4	16.7	-18.1%	24.3	18.4	-24.6%	27.4	18.7	-31.7%
3 - Great Valley	20.5	14.9	-27.5%	24.6	16.4	-33.3%	27.8	16.7	-39.9%
4 - Blue Ridge West	20.5	17.1	-16.8%	24.5	18.8	-23.5%	28.1	19.2	-31.8%
5 - Blue Ridge East	19.4	11.6	-40.4%	23.1	12.8	-44.6%	26.7	15.5	-41.8%
6 - Piedmont	20.2	17.4	-14.1%	24.2	19.4	-19.7%	28.4	19.8	-30.4%
7 - Coastal Plain	20.4	21.2	3.6%	24.4	23.8	-2.5%	29.3	24.2	-17.7%
Statewide Domain	**20.1**	**16.3**	**-19.0%**	**24.0**	**18.2**	**-24.5%**	**28.0**	**19.1**	**-32.0%**

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Tropical Storm PMP Comparison

Grayed out rows signify where the one of the other storm types is controlling

Tropical Storm 10 Sq Mi Average PMP

Transposition Zone	HMR 51 6hr	PMP 6hr	Change 6hr	HMR 51 12hr	PMP 12hr	Change 12hr	HMR 51 24hr	PMP 24hr	Change 24hr	HMR 51 72hr	PMP 72hr	Change 72hr
1 - Interior Valley	27.6	13.3	-51.7%	32.2	21.0	-34.8%	35.5	21.0	-40.8%	40.8	21.4	-47.5%
2 - Cumberland Plateau	28.7	8.4	-70.7%	33.8	11.7	-65.6%	36.9	13.6	-63.2%	42.3	16.5	-61.1%
3 - Great Valley	28.9	7.5	-74.2%	34.1	10.3	-69.7%	37.4	11.9	-68.2%	43.0	14.4	-66.5%
4 - Blue Ridge West	28.9	9.8	-66.3%	34.1	14.1	-58.9%	37.6	20.4	-46.0%	43.3	21.9	-49.6%
5 - Blue Ridge East	27.8	14.4	-48.2%	32.5	22.7	-30.2%	35.8	22.7	-36.6%	41.1	23.5	-42.9%
6 - Piedmont	28.5	17.7	-37.7%	33.7	28.0	-16.8%	37.7	28.0	-25.6%	43.5	28.0	-35.3%
7 - Coastal Plain	28.6	20.7	-27.4%	33.8	32.7	-3.3%	38.5	32.7	-15.0%	44.5	32.7	-26.4%
Statewide Domain	**28.4**	**15.8**	**-44.3%**	**33.4**	**24.6**	**-26.2%**	**37.2**	**25.3**	**-32.3%**	**42.9**	**25.8**	**-39.9%**

Tropical Storm 200 Sq Mi Average PMP

Transposition Zone	HMR 51 6hr	PMP 6hr	Change 6hr	HMR 51 12hr	PMP 12hr	Change 12hr	HMR 51 24hr	PMP 24hr	Change 24hr	HMR 51 72hr	PMP 72hr	Change 72hr
1 - Interior Valley	19.2	8.7	-54.6%	22.9	14.8	-35.6%	26.5	16.7	-37.1%	31.5	19.3	-38.8%
2 - Cumberland Plateau	20.4	7.7	-62.0%	24.3	10.7	-56.2%	27.4	12.3	-54.9%	33.1	16.0	-51.7%
3 - Great Valley	20.5	6.9	-66.6%	24.6	9.4	-61.5%	27.8	10.8	-61.1%	33.6	14.0	-58.4%
4 - Blue Ridge West	20.5	9.0	-56.4%	24.5	12.9	-47.4%	28.1	19.2	-31.9%	33.8	21.0	-38.2%
5 - Blue Ridge East	19.4	9.4	-51.5%	23.1	15.9	-31.3%	26.7	20.0	-25.0%	31.7	22.1	-30.4%
6 - Piedmont	20.2	11.6	-42.4%	24.2	19.6	-18.6%	28.4	20.3	-28.5%	33.8	25.9	-23.3%
7 - Coastal Plain	20.4	13.6	-33.3%	24.4	22.9	-5.7%	29.3	22.9	-21.6%	34.7	29.1	-16.1%
Statewide Domain	**20.1**	**10.7**	**-46.5%**	**24.0**	**17.7**	**-25.9%**	**28.0**	**19.5**	**-30.3%**	**33.3**	**23.8**	**-28.7%**

Tropical Storm 1000 Sq Mi Average PMP

Transposition Zone	HMR 51 6hr	PMP 6hr	Change 6hr	HMR 51 12hr	PMP 12hr	Change 12hr	HMR 51 24hr	PMP 24hr	Change 24hr	HMR 51 72hr	PMP 72hr	Change 72hr
1 - Interior Valley	13.9	6.6	-52.7%	17.6	10.5	-40.5%	21.2	12.0	-43.5%	25.0	14.8	-41.1%
2 - Cumberland Plateau	15.0	6.2	-59.0%	18.9	8.8	-53.7%	22.2	10.8	-51.2%	26.5	14.3	-46.0%
3 - Great Valley	15.1	5.5	-63.9%	19.2	7.8	-59.6%	22.8	9.5	-58.1%	27.1	12.5	-53.8%
4 - Blue Ridge West	15.1	7.3	-51.5%	19.2	11.0	-43.1%	23.1	13.9	-40.1%	27.3	18.0	-34.4%
5 - Blue Ridge East	14.1	7.1	-49.5%	17.8	11.3	-36.6%	21.3	14.5	-32.2%	25.2	18.3	-27.8%
6 - Piedmont	14.7	9.0	-38.7%	18.9	14.2	-24.7%	23.4	17.5	-24.7%	27.5	23.1	-15.5%
7 - Coastal Plain	14.8	10.3	-30.2%	19.1	16.3	-14.4%	24.3	19.7	-18.6%	28.6	26.1	-8.6%
Statewide Domain	**14.6**	**8.3**	**-43.4%**	**18.6**	**12.9**	**-30.7%**	**22.9**	**15.9**	**-30.5%**	**27.0**	**20.8**	**-23.3%**

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General Storm PMP Comparison

Grayed out rows signify where the one of the other storm types is controlling

General Storm 10 Sq Mi Average PMP												
Transposition Zone	HMR 51 6hr	PMP 6hr	Change 6hr	HMR 51 12hr	PMP 12hr	Change 12hr	HMR 51 24hr	PMP 24hr	Change 24hr	HMR 51 72hr	PMP 72hr	Change 72hr
1 - Interior Valley	27.6	12.5	-54.6%	32.2	14.5	-55.0%	35.5	14.9	-58.0%	40.8	18.0	-56.0%
2 - Cumberland Plateau	28.7	12.6	-56.0%	33.8	15.9	-53.1%	36.9	17.9	-51.6%	42.3	20.7	-51.1%
3 - Great Valley	28.9	10.9	-62.3%	34.1	13.7	-59.9%	37.4	15.7	-58.1%	43.0	18.3	-57.5%
4 - Blue Ridge West	28.9	15.3	-47.1%	34.1	17.8	-47.9%	37.6	18.7	-50.4%	43.3	20.4	-53.1%
5 - Blue Ridge East	27.8	13.1	-52.8%	32.5	15.2	-53.3%	35.8	16.0	-55.4%	41.1	19.2	-53.3%
6 - Piedmont	28.5	15.7	-45.1%	33.7	18.2	-46.0%	37.7	19.7	-47.6%	43.5	23.8	-45.2%
7 - Coastal Plain	28.6	8.1	-71.8%	33.8	14.5	-57.2%	38.5	21.7	-43.7%	44.5	26.1	-41.3%
Statewide Domain	**28.4**	**13.0**	**-54.0%**	**33.4**	**16.2**	**-51.4%**	**37.2**	**18.6**	**-50.1%**	**42.9**	**22.2**	**-48.3%**

General Storm 200 Sq Mi Average PMP												
Transposition Zone	HMR 51 6hr	PMP 6hr	Change 6hr	HMR 51 12hr	PMP 12hr	Change 12hr	HMR 51 24hr	PMP 24hr	Change 24hr	HMR 51 72hr	PMP 72hr	Change 72hr
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2 - Cumberland Plateau	20.4	10.1	-50.4%	24.3	12.9	-47.1%	27.4	16.0	-41.5%	33.1	17.9	-46.0%
3 - Great Valley	20.5	8.7	-57.7%	24.6	10.7	-56.4%	27.8	13.7	-50.6%	33.6	16.1	-52.2%
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5 - Blue Ridge East	19.4	12.7	-34.5%	23.1	14.5	-37.4%	26.7	14.9	-44.0%	31.7	15.8	-50.2%
6 - Piedmont	20.2	15.2	-24.6%	24.2	17.3	-28.2%	28.4	17.9	-37.0%	33.8	19.3	-42.8%
7 - Coastal Plain	20.4	6.6	-67.6%	24.4	11.6	-52.4%	29.3	17.6	-39.9%	34.7	21.3	-38.7%
Statewide Domain	**20.1**	**12.1**	**-39.7%**	**24.0**	**14.7**	**-38.5%**	**28.0**	**16.6**	**-40.9%**	**33.3**	**18.4**	**-44.9%**

General Storm 1000 Sq Mi Average PMP												
Transposition Zone	HMR 51 6hr	PMP 6hr	Change 6hr	HMR 51 12hr	PMP 12hr	Change 12hr	HMR 51 24hr	PMP 24hr	Change 24hr	HMR 51 72hr	PMP 72hr	Change 72hr
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7 - Coastal Plain	14.8	5.7	-61.3%	19.1	10.4	-45.2%	24.3	15.7	-35.3%	28.6	18.3	-36.9%
Statewide Domain	**14.6**	**10.5**	**-28.0%**	**18.6**	**13.0**	**-30.0%**	**22.9**	**14.4**	**-36.9%**	**27.0**	**16.7**	**-38.2%**

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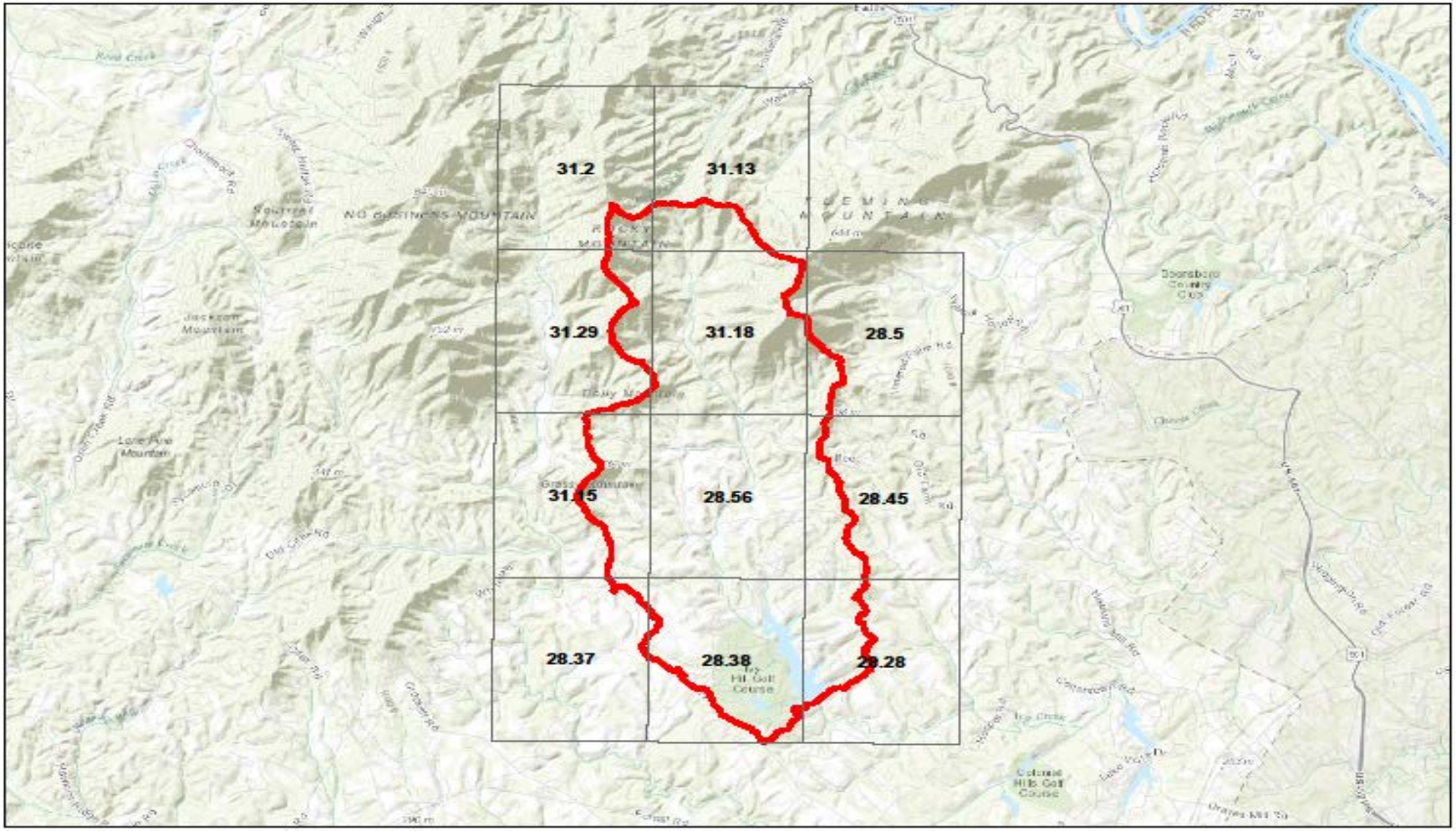
24-Hour Tropical Storm PMP
(9 Sq Mi)
Ivy Hill Dam - 01922



Coordinate System: USA Contiguous Albers Equal Area Conic
Projection: Albers
Datum: North American 1983

DCR
Virginia Department of Conservation & Recreation

341-square mile basin average PMP depths and controlling storms for the North Anna Dam basin

		6-hour PMP (in)	12-hour PMP (in)	24-hour PMP (in)	72-hour PMP (in)
General	PMP (in)	15.2	17.5	17.9	19.2
	Source Storm(s)	Wellsboro, PA 1889	Wellsboro, PA 1889	Wellsboro, PA 1889	Halifax, VT 2005 Wellsboro, PA 1889
Tropical	PMP (in)	11.5	18.7	19.6	26.4
	Source Storm(s)	Tyro, VA 1969	Tyro, VA 1969	Alta Pass, NC 1916 Glenville, GA 1929	Alta Pass, NC 1916 Glenville, GA 1929

		1-hour PMP (in)	6-hour PMP (in)	12-hour PMP (in)	24-hour PMP (in)
Local	PMP (in)	4.5	15.8	18.2	18.2
	Source Storm(s)	Rapidan, VA 1995 Ewan, NJ 1940	Rapidan, VA 1995 Jewell, MD 1897 Ewan, NJ 1940	Jewell, MD 1897 Ewan, NJ 1940 Little River, VA 1949	Jewell, MD 1897 Ewan, NJ 1940 Little River, VA 1949

Summary Procedure

- Updated the storm database
  - Produced Depth-Area-Duration (DAD) analyses for all major storm events
- Used updated dew point analyses to maximize storms
  - Storm representative & maximum dew points
- Used state-of-the-science procedures and tools
  - GIS & Orographic Transposition Factor
- Provided PMP values for all dams located within Virginia
  - All storm types, durations, and area sizes as required
- Utilized PMP Evaluation Tool to produce PMP on a gridded basis (~2.5 sq. mi. grid)

Summary

- Extensive storm record extending back to the early1800s. Hundreds of storms were considered. 79 Key Storms Analyzed for Virginia PMP Study.
- Anticipate the values will be good for 20-30 years (but can be updated as needed).
- 24,000 grid points in VA (95% went down) (HMR 51 – 23 grid points – hand drawn smooth lines).
- PMP values are highest near the coast and along the Blue Ridge. These regions have exhibited past extreme rainfall accumulations that are the result of both moisture availability and topographic enhancement.
- Commonwealth-wide it was found that on average, PMP values for local storms showed a 16% reduction at 6-hour 10-square miles and a 21% reduction at 12-hour 10-square miles. For the longer durations, larger area sizes, Commonwealth-wide reductions were 30% at 24-hour 200-square miles and 1000-square miles, and 25% at 72-hours 200-square miles and 1000-square miles.
- Cost Savings Estimate - ~$72 M (very conservative); only high and significant hazard; doesn't account for potential changes in hazard classification for some dams; a number could be eligible for the 2/3 rule (0.6 PMP).
- 45 District High Hazard Dams Identified for Rehabilitation Previously – Total estimated savings of ~$19 M; ~25% savings; 5 dams potentially will not require upgrades.
- We have pre-run the PMPs for 900 high and significant hazard impoundments.