Recent Extreme Storms and Their Relation to PMP

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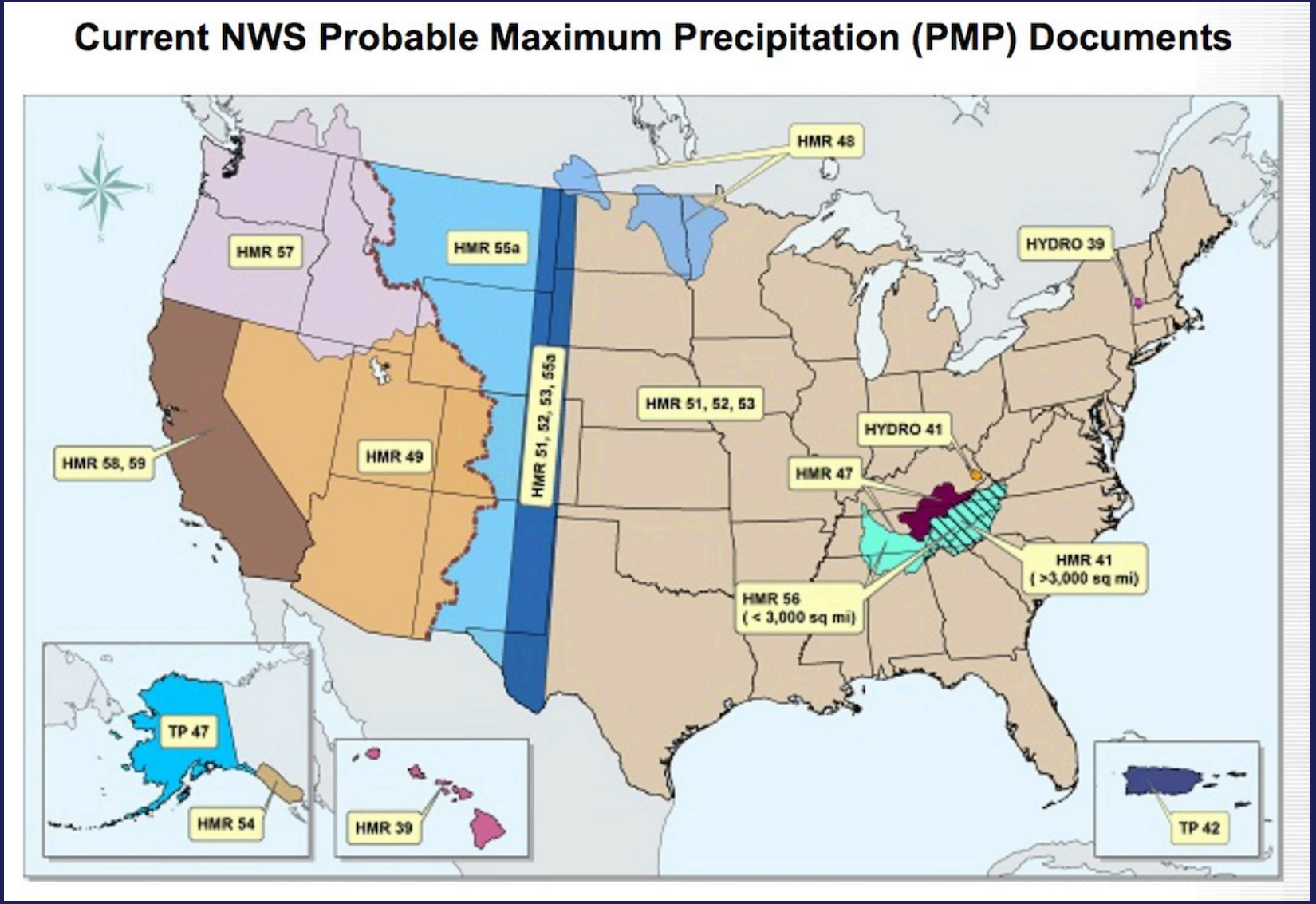
www.appliedweatherassociates.com

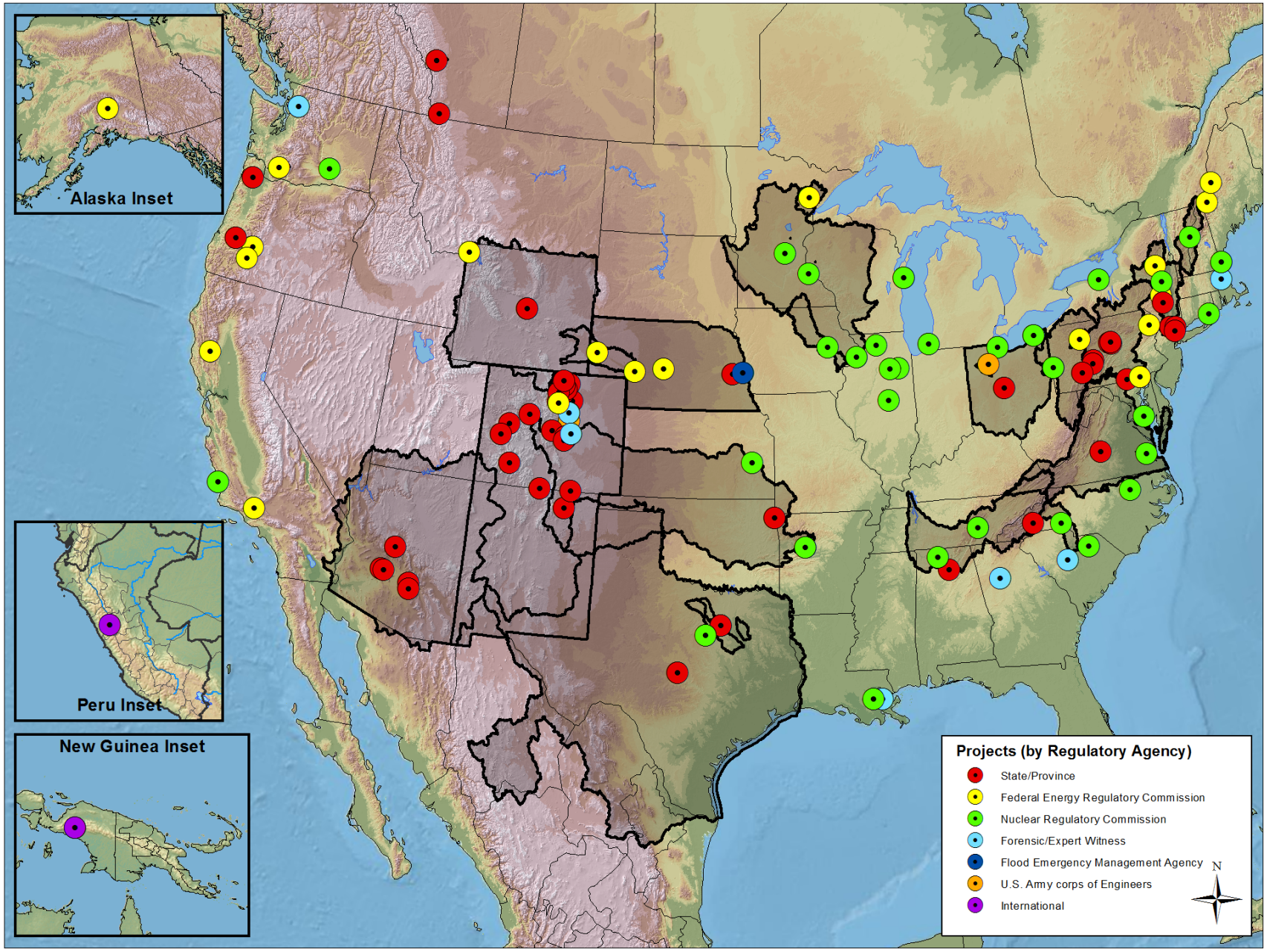
719-488-4311

Probable Maximum Precipitation

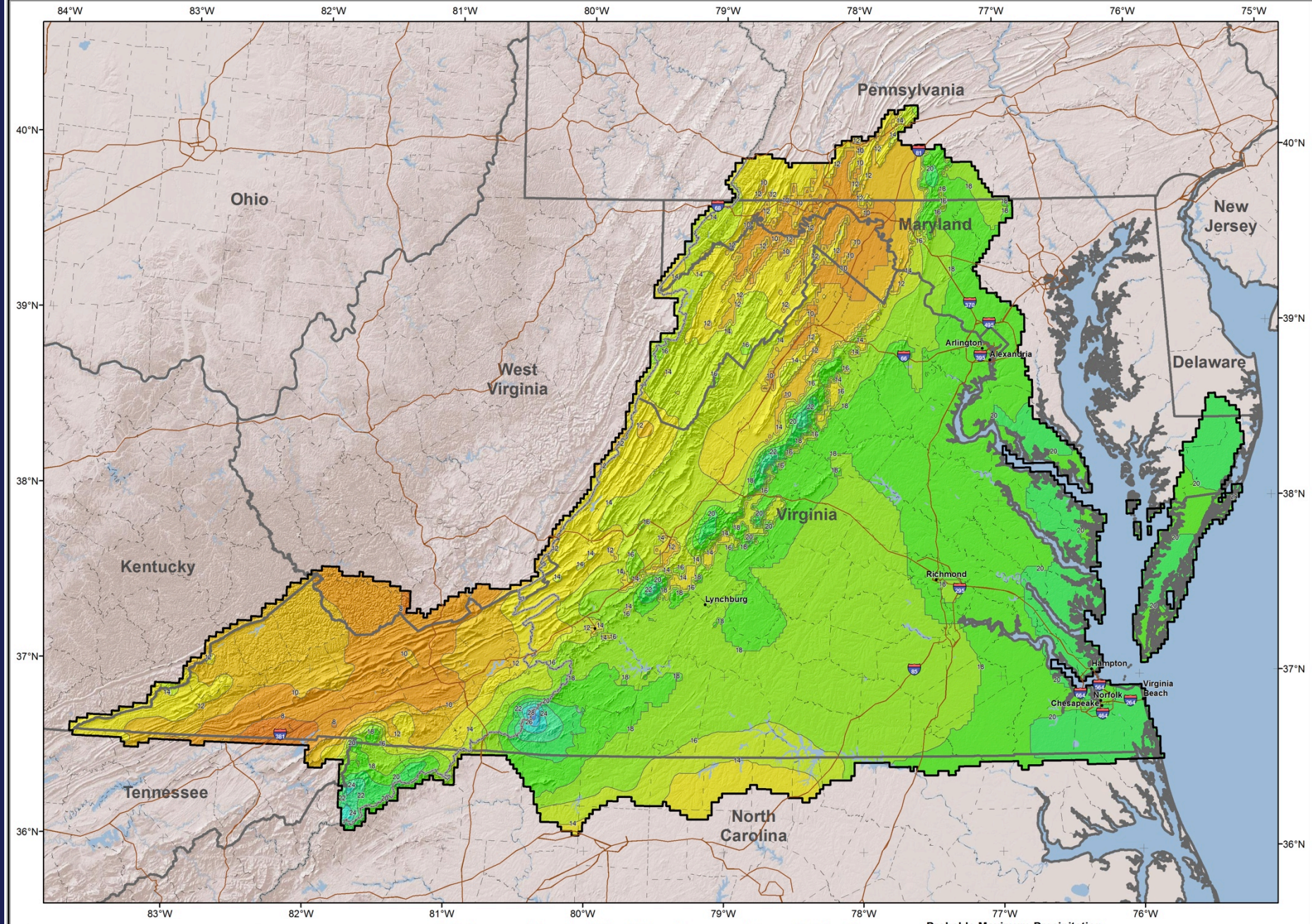
- **Definition:** The ***theoretically*** greatest depth of precipitation for a given duration that is ***physically possible*** over a given storm area at a particular ***geographic location*** at a certain time of year (HMR 59, 1999)
- Deterministic values
- Storm-based approach

NWS HMR Reports Coverage




Alaska Inset
Peru Inset
New Guinea Inset
Projects (by Regulatory Agency)
State/Province
Federal Energy Regulatory Commission
Nuclear Regulatory Commission
Forensic/Expert Witness
Flood Emergency Management Agency
U.S. Army corps of Engineers
International
N

Virginia PMP Comparisons



Virginia Department of Conservation and Recreation
600 East Main Street
Richmond, VA 23219-2094
Phone: 804-786-1712
Website: www.dcr.virginia.gov
November 1, 2015

DCR
Virginia Department of Conservation & Recreation

0 5 10 20 30 40 50 Miles
0 10 20 40 60 80 Kilometers

24-hour Probable Maximum Precipitation
Tropical Storm - 1,000 mi²

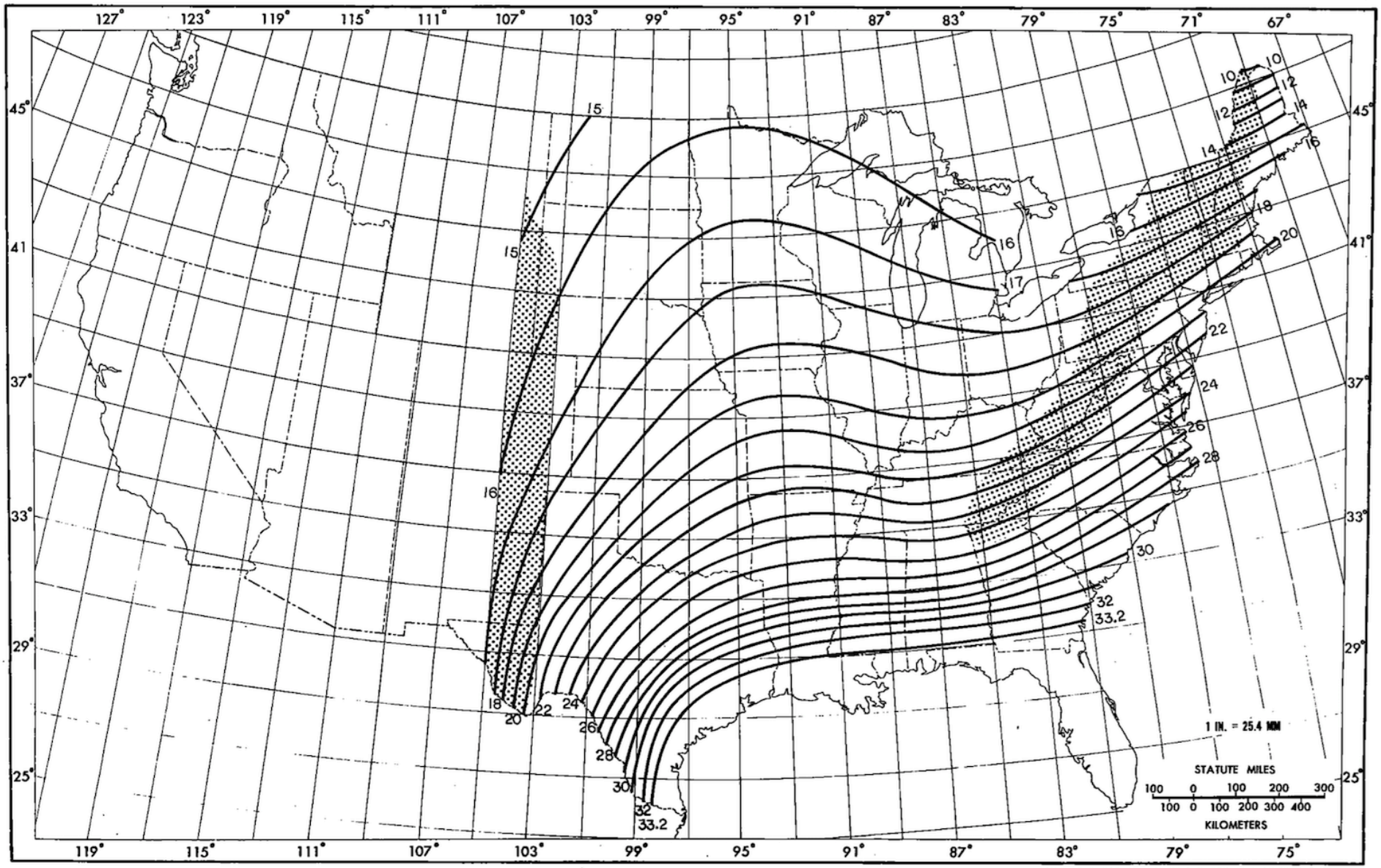
Scale 1:1,500,000

Applied Weather Associates

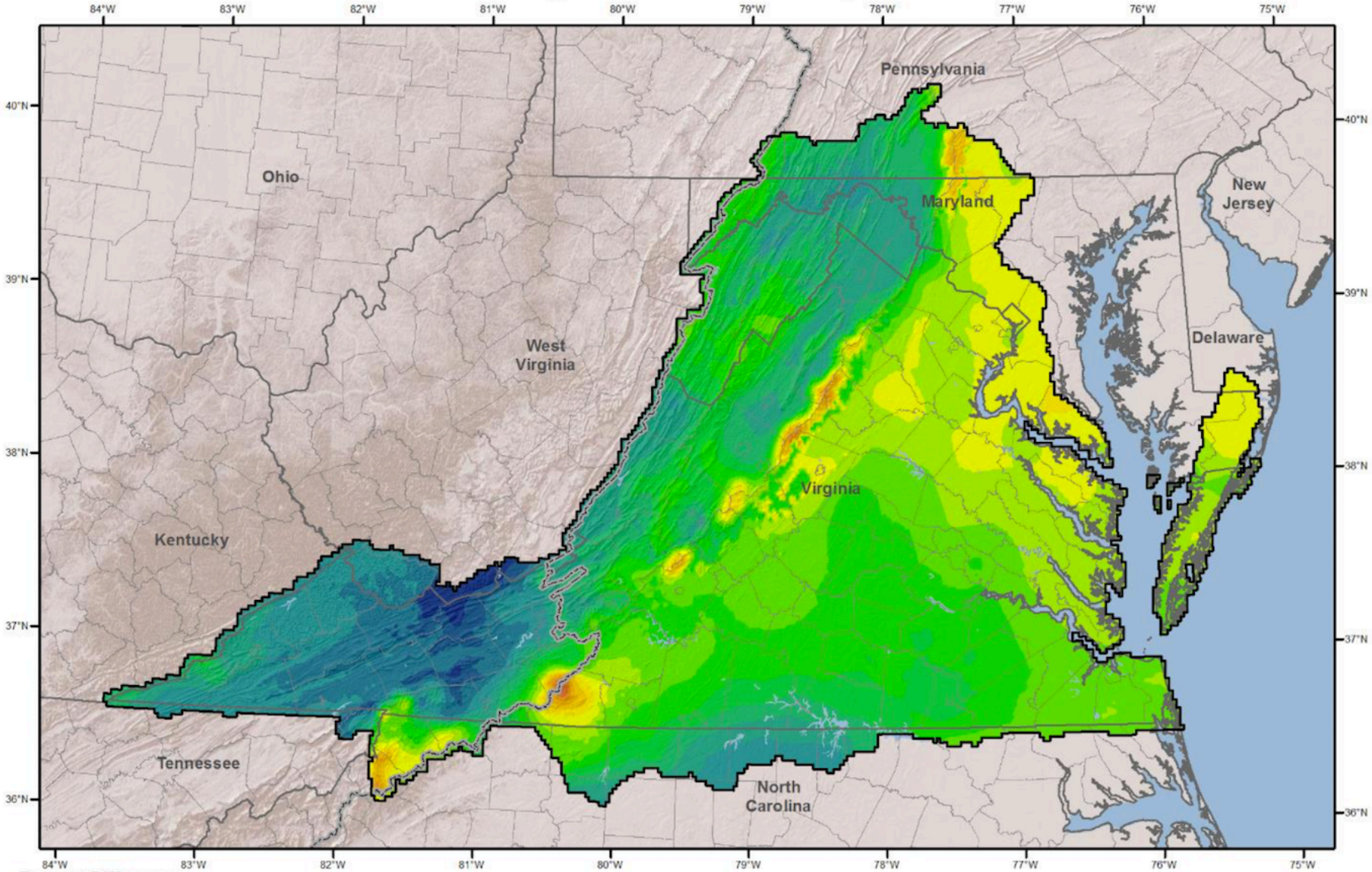
Probable Maximum Precipitation

< 2"	8" - 10"	16" - 18"	24" - 26"	32" - 34"	40" - 42"	
2" - 4"	10" - 12"	18" - 20"	26" - 28"	34" - 36"	42" - 44"	
4" - 6"	12" - 14"	20" - 22"	28" - 30"	36" - 38"	> 44"	
6" - 8"	14" - 16"	22" - 24"	30" - 32"	38" - 40"		

HMR 51 24-hour 1,000-square mile PMP

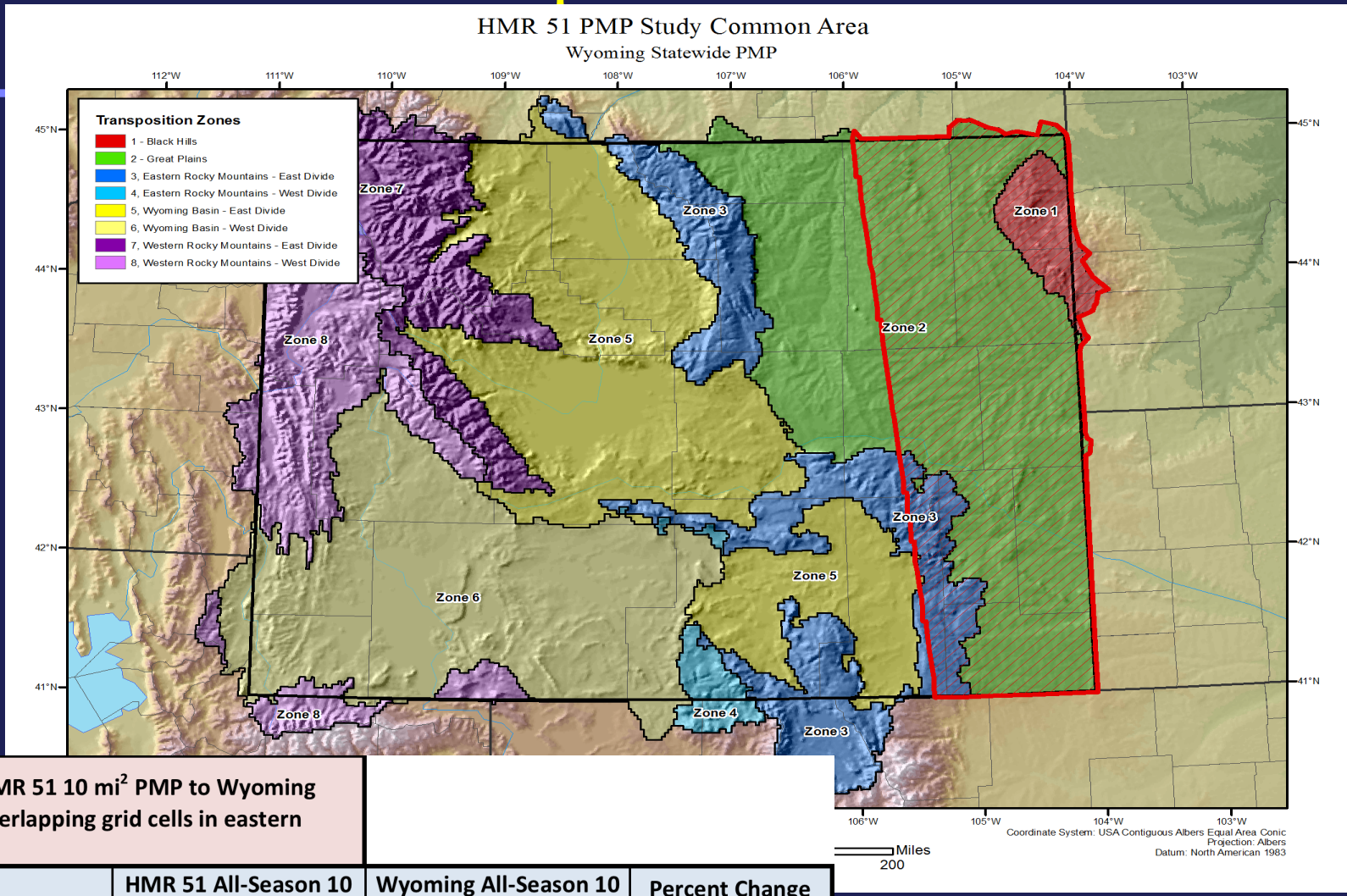


PMP Comparison to HMR 51 - Percent Difference 24-Hour 1000 mi²
Virginia Statewide PMP Study



Wyoming comparisons

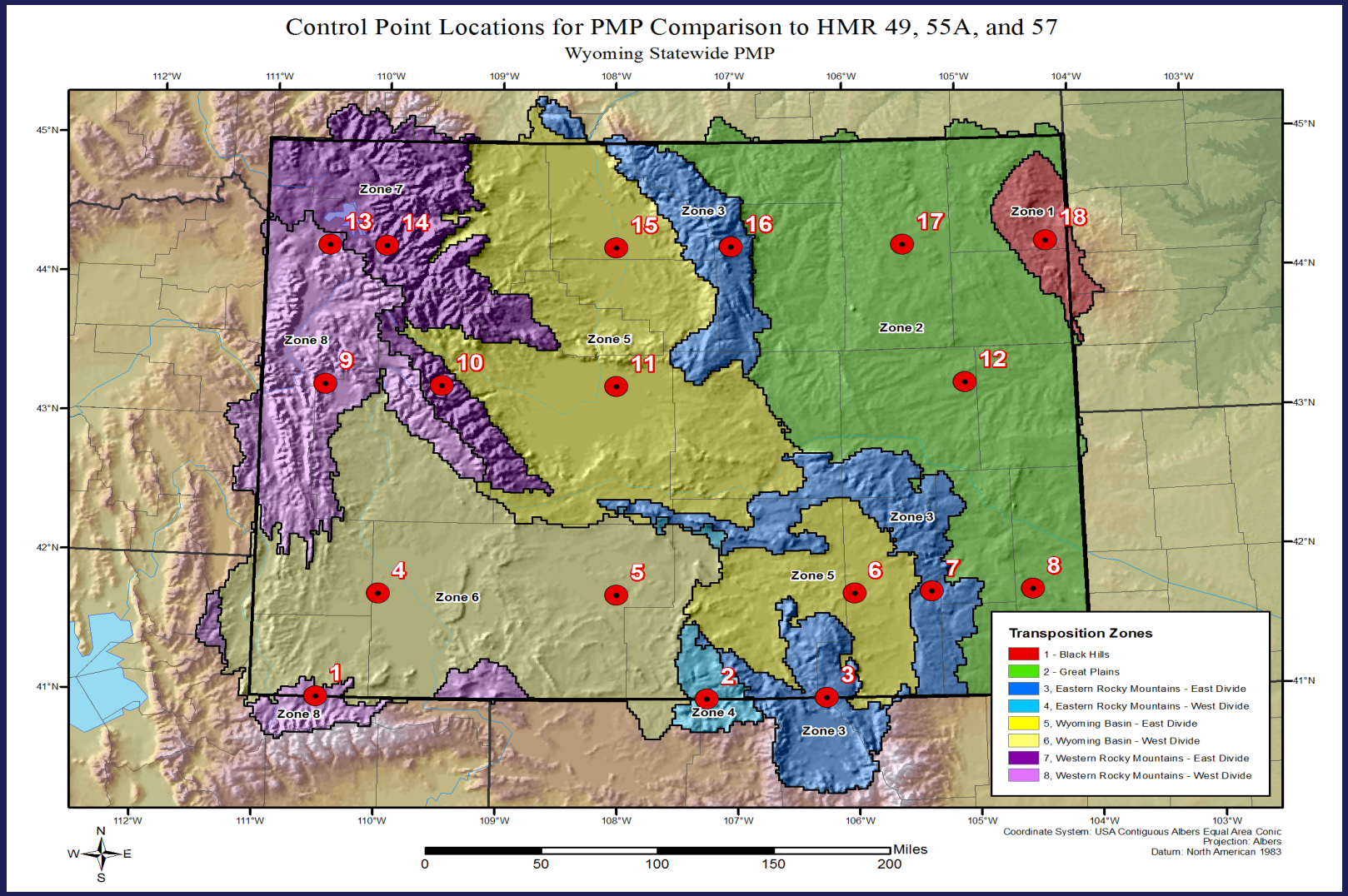
HMR 51 10-mi^2 Comparison to WY PMP



Comparison of Average HMR 51 10 mi^2 PMP to Wyoming General Storm PMP for overlapping grid cells in eastern region of study area:

Area (mi^2)	Duration (hours)	Trans Zone	HMR 51 All-Season 10 mi^2 PMP (in)	Wyoming All-Season 10 mi^2 PMP (in)*	Percent Change (HMR to AWA)
10	6	1, 2, 3	21.75	12.73	-41%
10	12	1, 2, 3	25.63	16.55	-35%
10	24	1, 2, 3	27.70	16.55	-40%
10	48	1, 2, 3	30.21	23.25	-23%
10	72	1, 2, 3	31.46	23.42	-26%

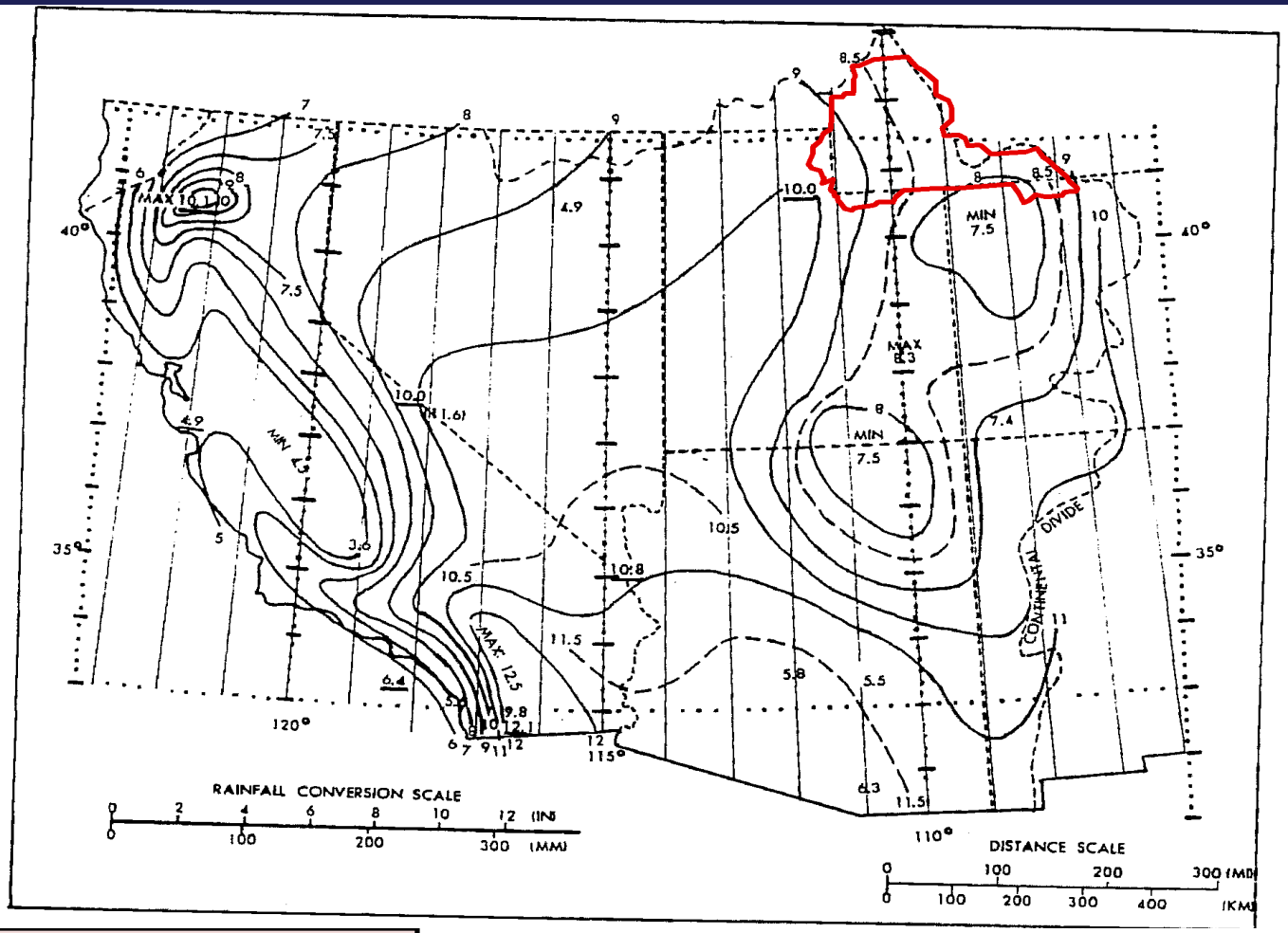
HMR 49, 55A, 57 24-hour 10-mi^2 PMP



HMR 49, 55A, 57 24-hour 10-mi^2 PMP

Comparison of HMR 49, 55A, and 57 general storm PMP to AWA Wyoming general storm PMP over various control points:
10mi^2 24-hour

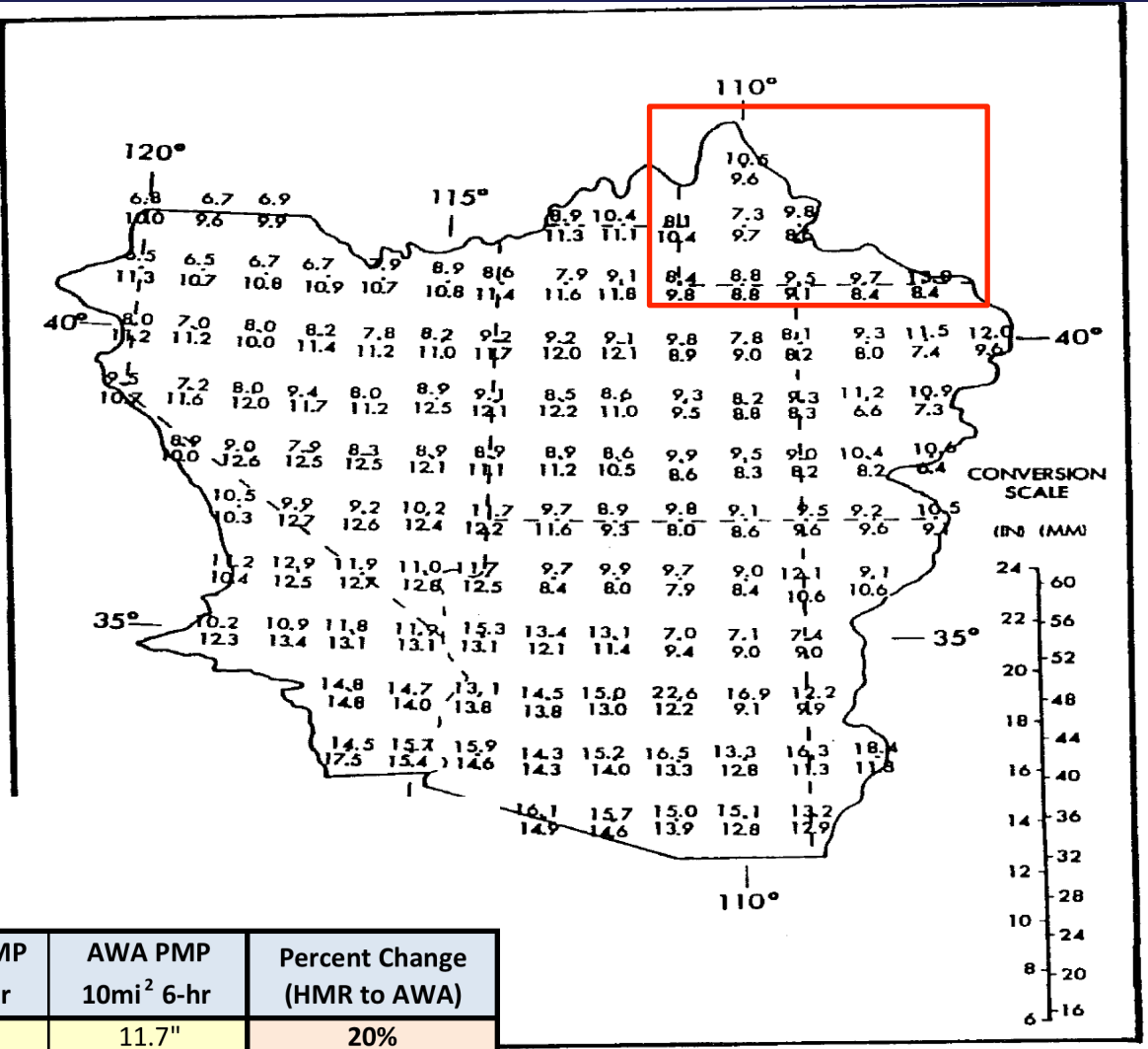
Control Point	Longitude	Latitude	Trans Zone	Elev_Ft	HMR Source	HMR General PMP 10mi^2 24-hr	AWA General PMP 10mi^2 24-hr	Percent Change (HMR to AWA)
1	-110.5°	41°	8	9,032	HMR 49	8.7"	11.7"	34%
2	-107.25°	41°	4	6,709	HMR 49	12.5"	14.7"	17%
3	-106.25°	41°	3	8,921	HMR 55a	19.5"	10.6"	-46%
4	-110°	41.75°	6	6,522	HMR 49	7.5"	11.3"	50%
5	-108°	41.75°	6	6,785	HMR 55a	16.5"	12.2"	-26%
6	-106°	41.75°	5	6,982	HMR 55a	21.0"	12.1"	-43%
7	-105.35°	41.75°	3	6,450	HMR 55a	27.5"	16.1"	-41%
8	-104.5°	41.75°	2	5,331	HMR 55a	30.0"	17.0"	-43%
9	-110.5°	43.25°	8	6,545	HMR 57	9.0"	11.4"	27%
10	-109.5°	43.25°	7	9,865	HMR 55a	26.5"	8.9"	-66%
11	-108°	43.25°	5	5,249	HMR 55a	19.5"	8.6"	-56%
12	-105°	43.25°	2	4,613	HMR 55a	29.0"	16.8"	-42%
13	-110.5°	44.25°	8	7,543	HMR 57	14.5"	15.2"	5%
14	-110°	44.25°	7	8,789	HMR 55a	21.8"	12.3"	-44%
15	-108°	44.25°	5	4,055	HMR 55a	16.9"	8.8"	-48%
16	-107°	44.25°	3	8,750	HMR 55a	26.2"	17.5"	-33%
17	-105.5°	44.25°	2	4,603	HMR 55a	28.1"	17.3"	-38%
18	-104.25°	44.25°	1	5,469	HMR 55a	29.0"	18.2"	-37%
				Average:		20.2"	13.4"	-24%



Gridded comparison of HMR 49 local storm PMP to AWA Wyoming local storm PMP:

$1mi^2$ 1-hour

Trans Zone	NAME	Statistic	Average Elevation (ft)	HMR 49 PMP $1mi^2$ 1-hr*	AWA PMP $1mi^2$ 1-hr	Percent Change (HMR to AWA)
4	Eastern Rocky Mountains - West Divide	Zone 3 Average	8,031	7.3"	8.2"	**12%**
6	Wyoming Basin - West Divide	Zone 6 Average	6,940	7.7"	6.4"	**-17%**
8	Western Rocky Mountains - West Divide	Zone 8 Average	8,711	7.1"	8.2"	**15%**
-	Southwest Wyoming	Full Domain Average	7,313	7.6"	6.8"	**-11%**



Comparison of HMR 49 local storm PMP to AWA Wyoming local storm PMP:

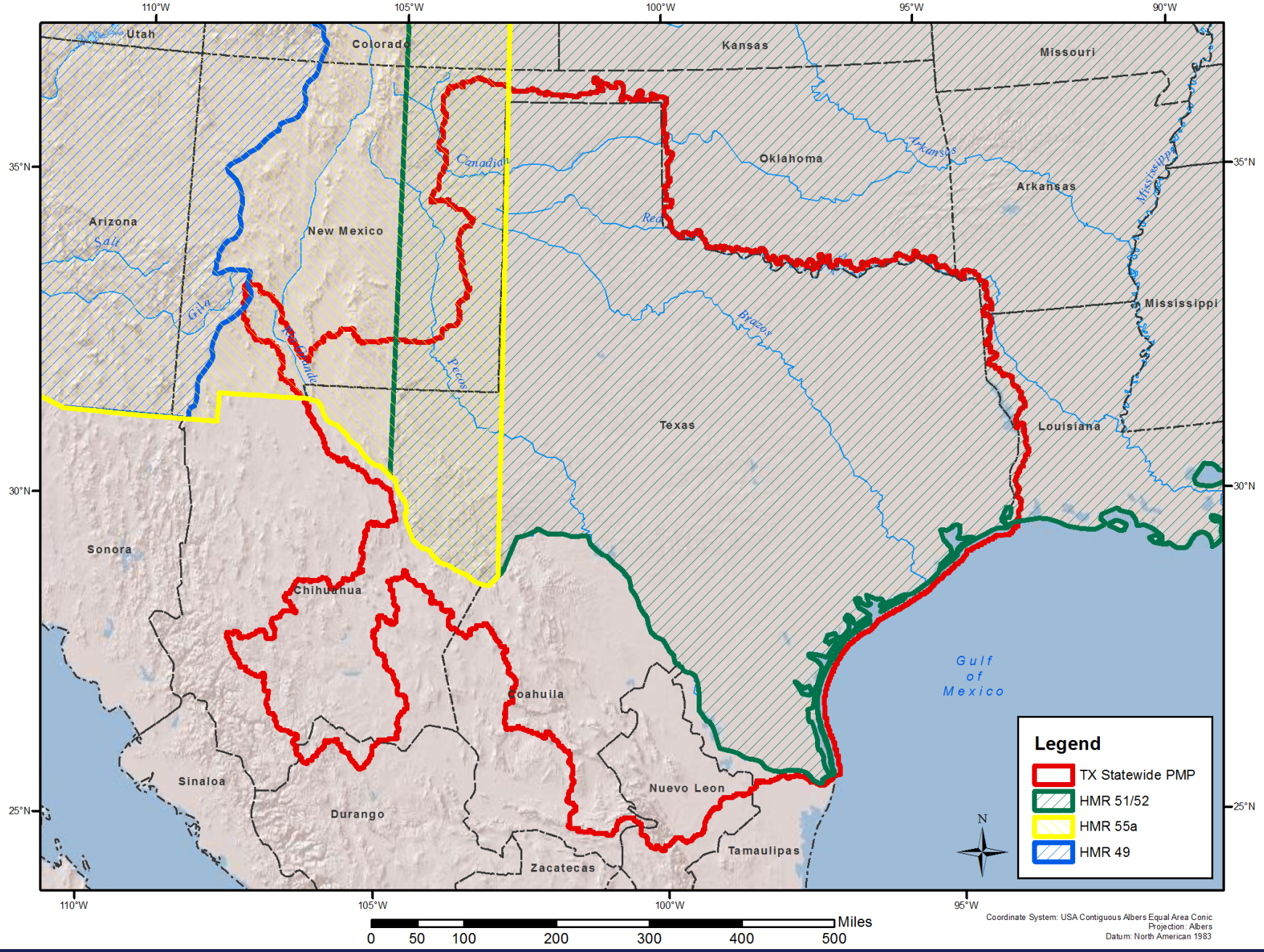
10mi^2 6-hour

Control Point	Longitude	Latitude	Trans Zone	HMR 49 PMP 10mi^2 6-hr	AWA PMP 10mi^2 6-hr	Percent Change (HMR to AWA)
1	-111°	41°	6	9.8"	11.7"	20%
2	-110°	41°	6	8.8"	10.2"	16%
3	-109°	41°	8	9.1"	10.0"	10%
4	-108°	41°	6	8.4"	8.5"	1%
5	-107°	41°	4	8.4"	10.3"	23%
6	-111°	42°	6	10.4"	8.9"	-14%
7	-110°	42°	6	9.7"	6.7"	-31%
8	-109°	42°	6	8.6"	9.5"	10%
9	-110°	43°	6	9.6"	8.0"	-17%
		Average:		9.2"	9.3"	2%

storm PMP for 10 mi^2 (26
es (upper number) and local-
i^2 (26 km^2) 6 hr in inches
1° grid points.

Texas comparisons

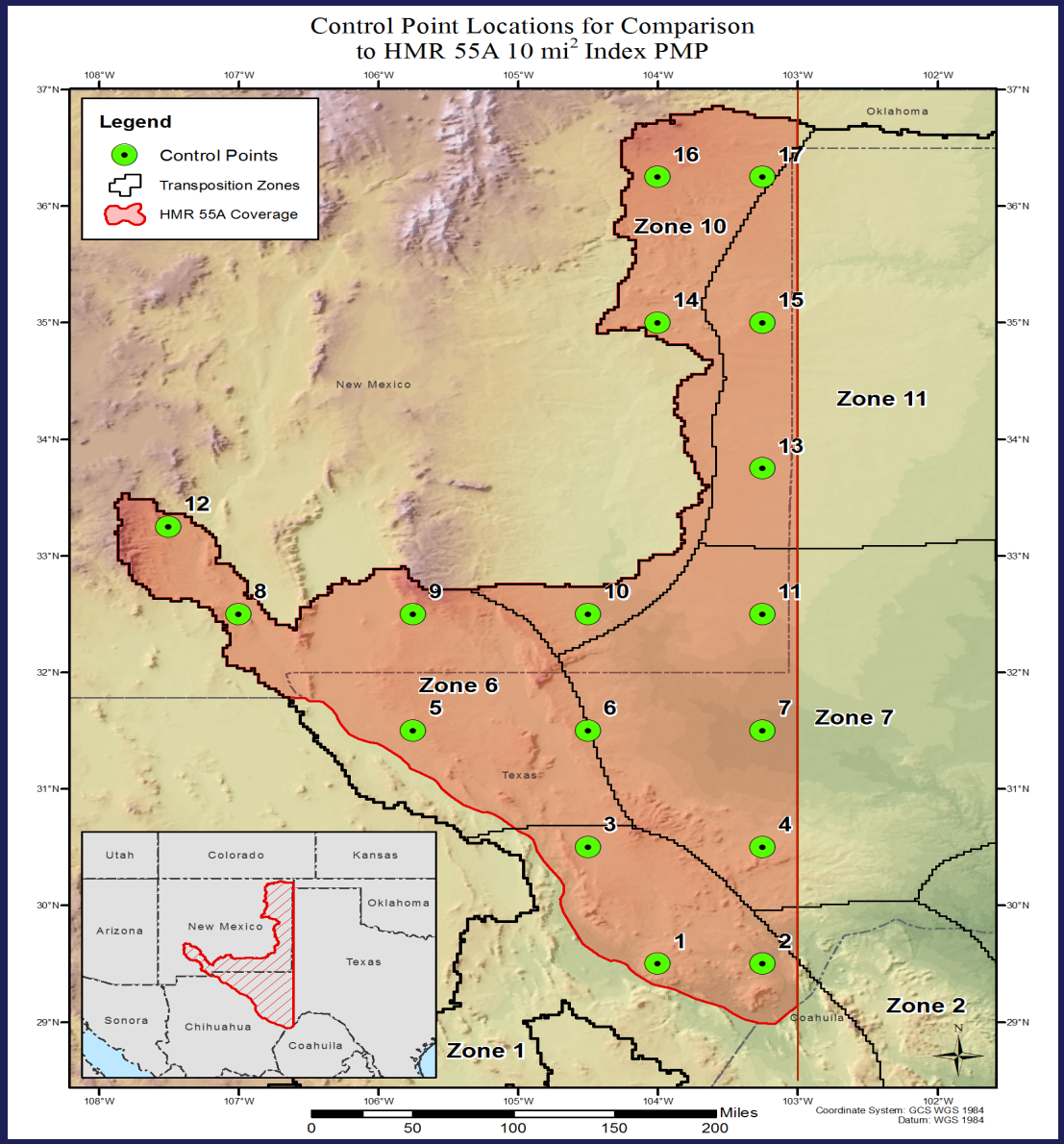
Analysis Domain of NWS Hydrometerological Studies
Texas PMP Study



HMR 51 PMP Compared to Texas PMP

Average PMP Percent Change from HMR 51 (by transposition zone)										
Duration	Area	Zone 3	Zone 4	Zone 5	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12
6-hour	10-sqmi	-18%	-10%	-11%	-31%	-16%	-15%	-28%	-28%	-20%
6-hour	200-sqmi	-14%	-8%	-3%	-30%	-15%	-11%	-31%	-27%	-19%
6-hour	1,000-sqmi	-13%	-7%	-11%	-35%	-20%	-12%	-37%	-33%	-23%
6-hour	5,000-sqmi	-10%	-5%	3%	-39%	-15%	-2%	-51%	-47%	-20%
6-hour	10,000-sqmi	-18%	-14%	-3%	-40%	-23%	-7%	-47%	-42%	-27%
6-hour	20,000-sqmi	-19%	-11%	-7%	-38%	-25%	-9%	-49%	-38%	-30%
12-hour	10-sqmi	-9%	-4%	-3%	-34%	-18%	-7%	-37%	-33%	-21%
12-hour	200-sqmi	-9%	-2%	-5%	-26%	-10%	-5%	-29%	-24%	-11%
12-hour	1,000-sqmi	-18%	-10%	-10%	-25%	-14%	-8%	-25%	-21%	-13%
12-hour	5,000-sqmi	-4%	0%	9%	-29%	-12%	9%	-41%	-34%	-16%
12-hour	10,000-sqmi	-4%	2%	11%	-35%	-10%	11%	-44%	-37%	-16%
12-hour	20,000-sqmi	-7%	0%	7%	-28%	-11%	5%	-43%	-33%	-15%
24-hour	10-sqmi	-9%	-3%	-4%	-33%	-15%	-4%	-33%	-27%	-15%
24-hour	200-sqmi	-10%	-2%	-8%	-18%	-2%	-4%	-15%	-10%	2%
24-hour	1,000-sqmi	-10%	-3%	-16%	-10%	4%	-7%	-3%	2%	13%
24-hour	5,000-sqmi	-13%	-3%	-2%	-17%	-7%	2%	-12%	-8%	-1%
24-hour	10,000-sqmi	-4%	8%	8%	-17%	2%	12%	-29%	-20%	3%
24-hour	20,000-sqmi	7%	18%	21%	-9%	11%	21%	-36%	-14%	12%
48-hour	10-sqmi	-8%	-5%	-9%	-23%	-5%	-8%	-22%	-16%	-3%
48-hour	200-sqmi	4%	10%	-4%	-5%	15%	6%	-3%	4%	19%
48-hour	1,000-sqmi	-1%	6%	-4%	-2%	13%	2%	1%	8%	21%
48-hour	5,000-sqmi	-12%	-5%	4%	-15%	-4%	4%	-10%	-7%	1%
48-hour	10,000-sqmi	-9%	1%	4%	-22%	-5%	7%	-21%	-19%	-6%
48-hour	20,000-sqmi	-2%	8%	12%	-16%	2%	14%	-30%	-18%	1%
72-hour	10-sqmi	-14%	-9%	-15%	-25%	-10%	-13%	-25%	-19%	-8%
72-hour	200-sqmi	-6%	0%	-9%	-10%	5%	-3%	-6%	-1%	12%
72-hour	1,000-sqmi	-10%	-4%	-1%	-10%	2%	0%	-4%	1%	11%
72-hour	10,000-sqmi	-20%	-8%	4%	-22%	-9%	3%	-18%	-14%	-6%
72-hour	10,000-sqmi	-23%	-11%	-1%	-27%	-11%	-1%	-29%	-25%	-9%
72-hour	20,000-sqmi	-20%	-10%	-4%	-25%	-13%	-4%	-34%	-23%	-12%

HMR 55A PMP Compared to Texas PMP



HMR 55A PMP Compared to Texas PMP

Percent Change from HMR 55A PMP							
Point	Latitude	Longitude	Zone	1-hour 1-mi^2	6-hour 10-mi^2	24-hour 10-mi^2	72-hour 10-mi^2
1	29.50°	-104.00°	1	-54.2%	-41.0%	-44.1%	-38.0%
2	29.50°	-103.25°	1	-53.0%	-38.6%	-40.1%	-33.8%
3	30.50°	-104.50°	1	-54.9%	-41.4%	-40.9%	-35.0%
4	30.50°	-103.25°	7	-51.2%	-31.1%	-33.1%	-26.3%
5	31.50°	-105.75°	6	-42.6%	-20.0%	-17.1%	-8.9%
6	31.50°	-104.50°	6	-53.3%	-38.9%	-36.9%	-30.3%
7	31.50°	-103.25°	7	-65.3%	-44.4%	-46.0%	-37.8%
8	32.50°	-107.00°	6	-38.9%	-25.0%	-28.2%	-22.1%
9	32.50°	-105.75°	6	-51.7%	-31.1%	-27.9%	-21.3%
10	32.50°	-104.50°	10	-53.9%	-38.6%	-34.6%	-27.4%
11	32.50°	-103.25°	7	-51.9%	-21.4%	-19.7%	-10.8%
12	33.25°	-107.50°	6	-38.2%	-25.7%	-29.8%	-24.3%
13	33.75°	-103.25°	11	-52.3%	-37.1%	-31.0%	-22.6%
14	35.00°	-104.00°	10	-52.8%	-27.5%	-35.1%	-26.7%
15	35.00°	-103.25°	11	-53.8%	-39.0%	-34.7%	-24.7%
16	36.25°	-104.00°	10	-45.1%	-33.9%	-38.7%	-31.2%
17	36.25°	-103.25°	10	-33.1%	-22.0%	-30.4%	-21.6%

AZ comparisons

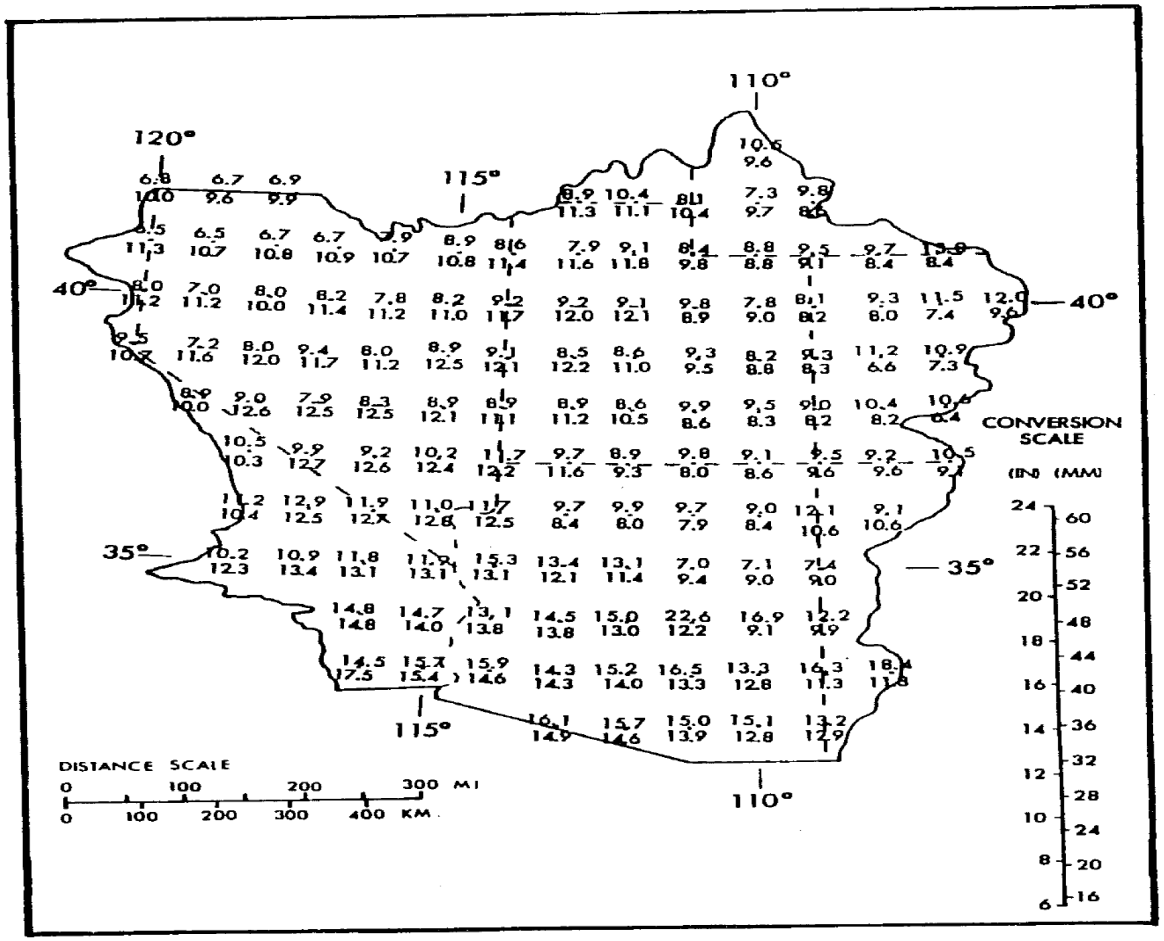
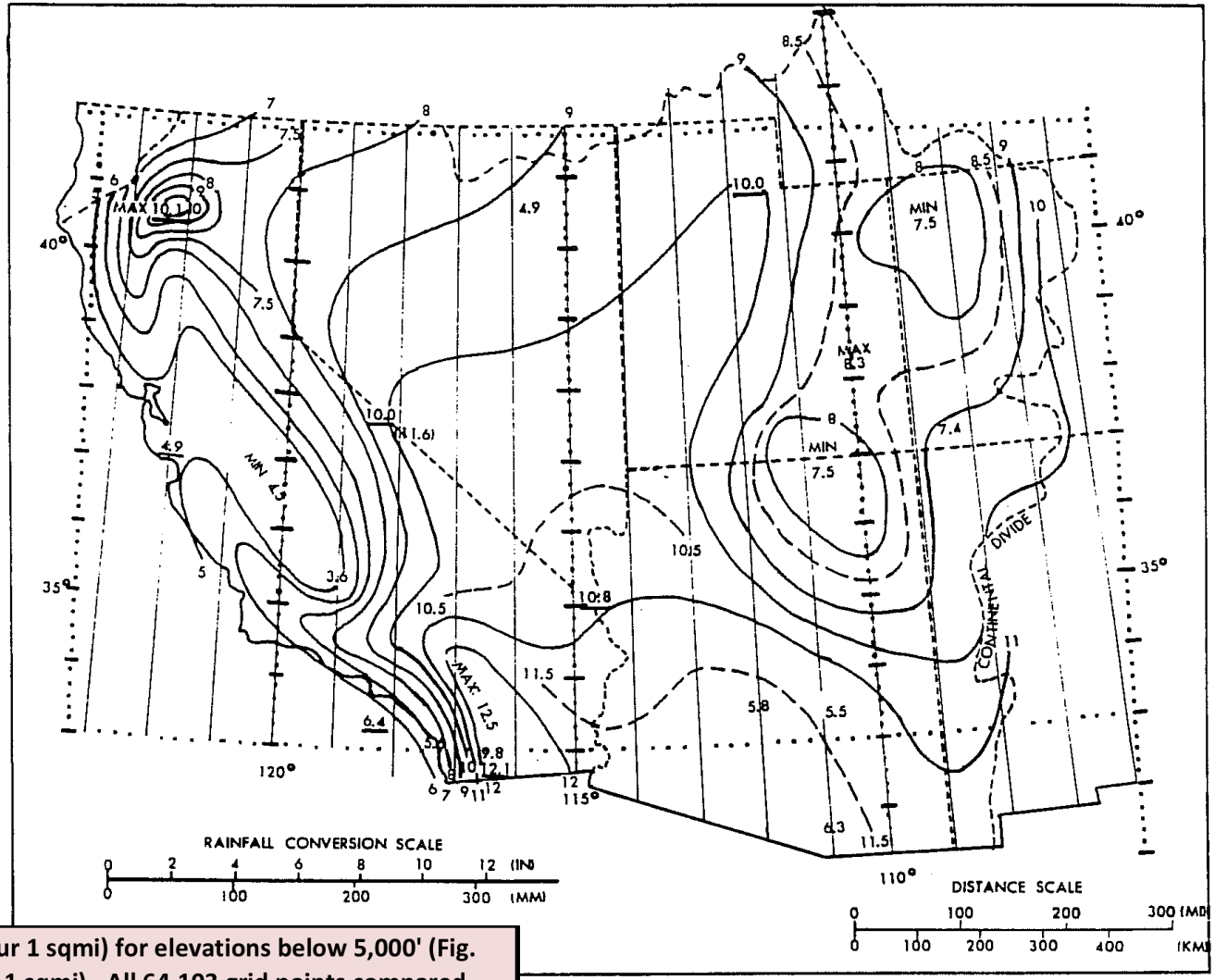


Figure 5.4.--General-storm PMP for 10 mi^2 (26 km^2) 24 hr in inches (upper number) and local-storm PMP for 10 mi^2 (26 km^2) 6 hr in inches (lower number) at 1° grid points.

Comparison: HMR 49 10 sqmi general storm 24-hour PMP and local storm 6-hour PMP (fig. 5.4, pg 136) vs. AZ PET 10 sqmi 24-hour (general & topical) PMP and 6-hour local storm PMP at 1° grid points.

10 sqmi General Storm (24-hour) Average % Change:	-56.5%
10 sqmi Tropical Storm (24-hour) Average % Change:	-25.9%
10 sqmi Local Storm (6-hour) Average % Change:	-10.0%



Comparison: HMR 49 local storm PMP (1-hour 1 sqmi) for elevations below 5,000' (Fig. 4.6, pg. 117) vs. PET local storm PMP (1-hour 1 sqmi). All 64,103 grid points compared (except for those above 5,000')

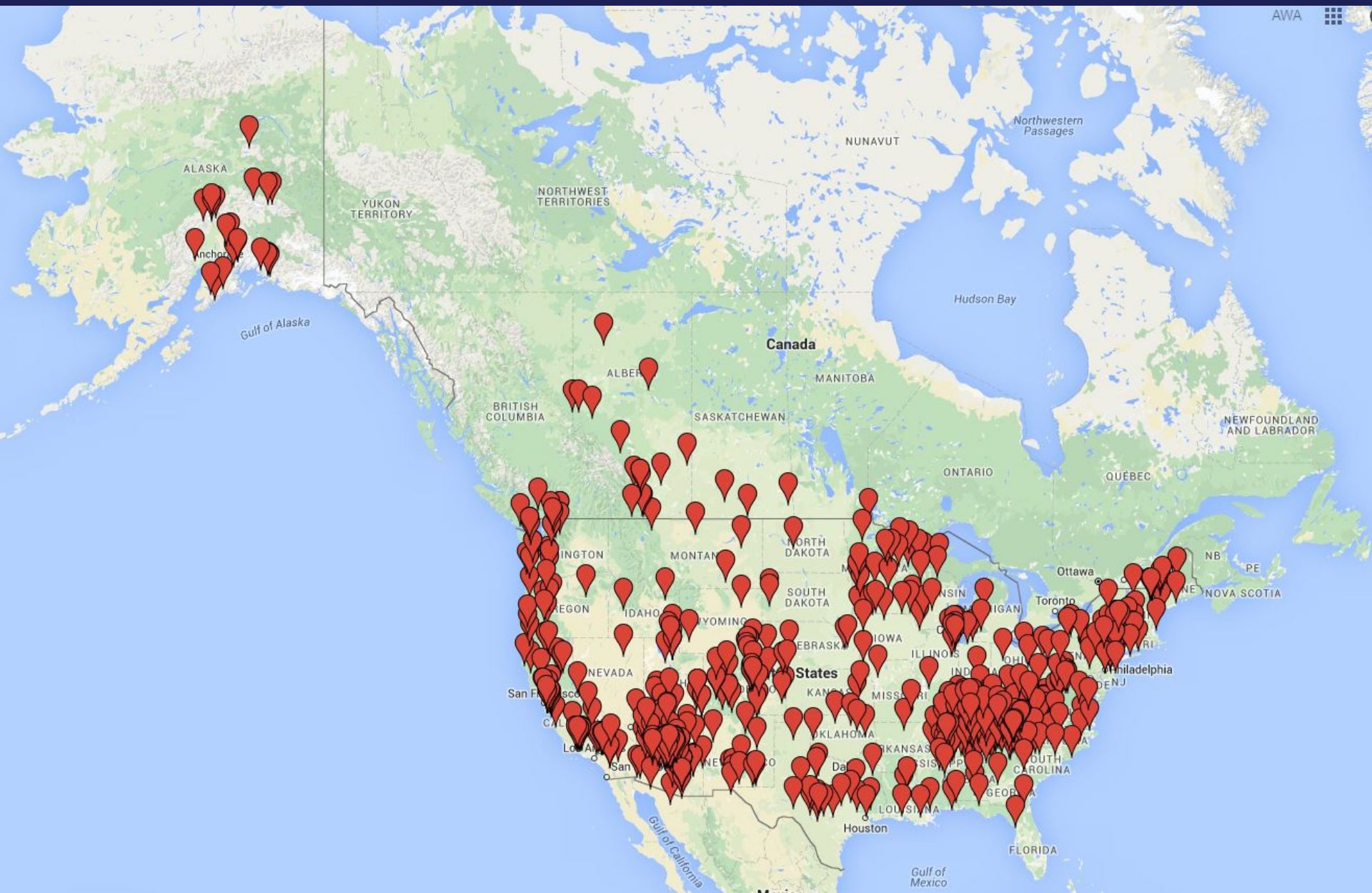
Total Average % Change:	**-0.10**
Zone 1 Average % Change:	**-0.42**
Zone 2 Average % Change:	**0.01**
Zone 3 Average % Change:	**0.04**
Zone 4 Average % Change:	**0.01**
Zone 5 Average % Change:	**-0.14**

for 1 mi^2 (2.6 km^2) 1 hr. Directly
etween sea level and 5000 ft (1524 m).
e applied for locations above 5000 ft.

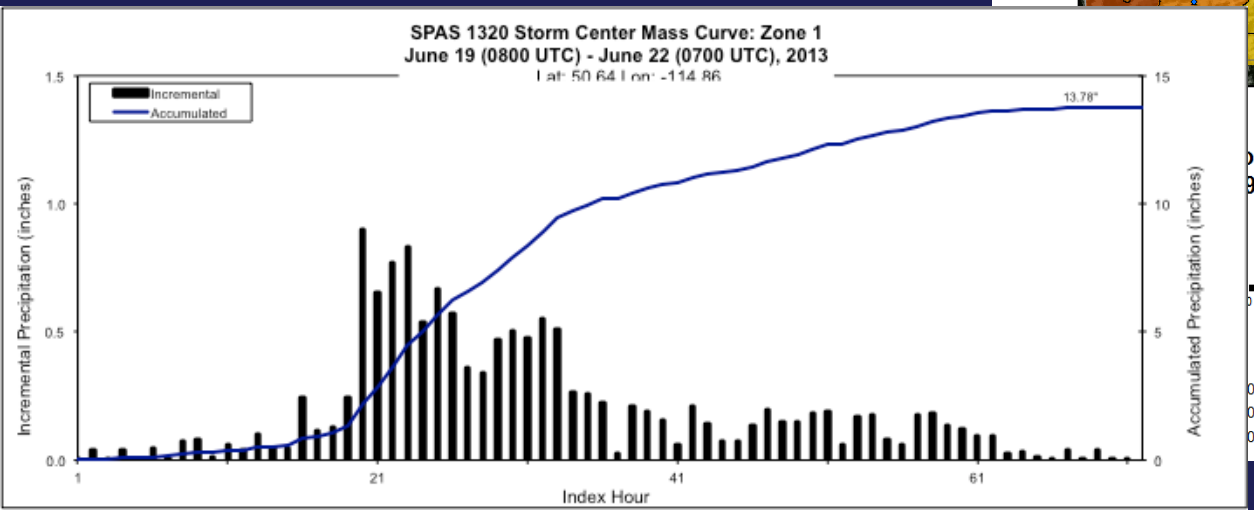
PMP Development Process

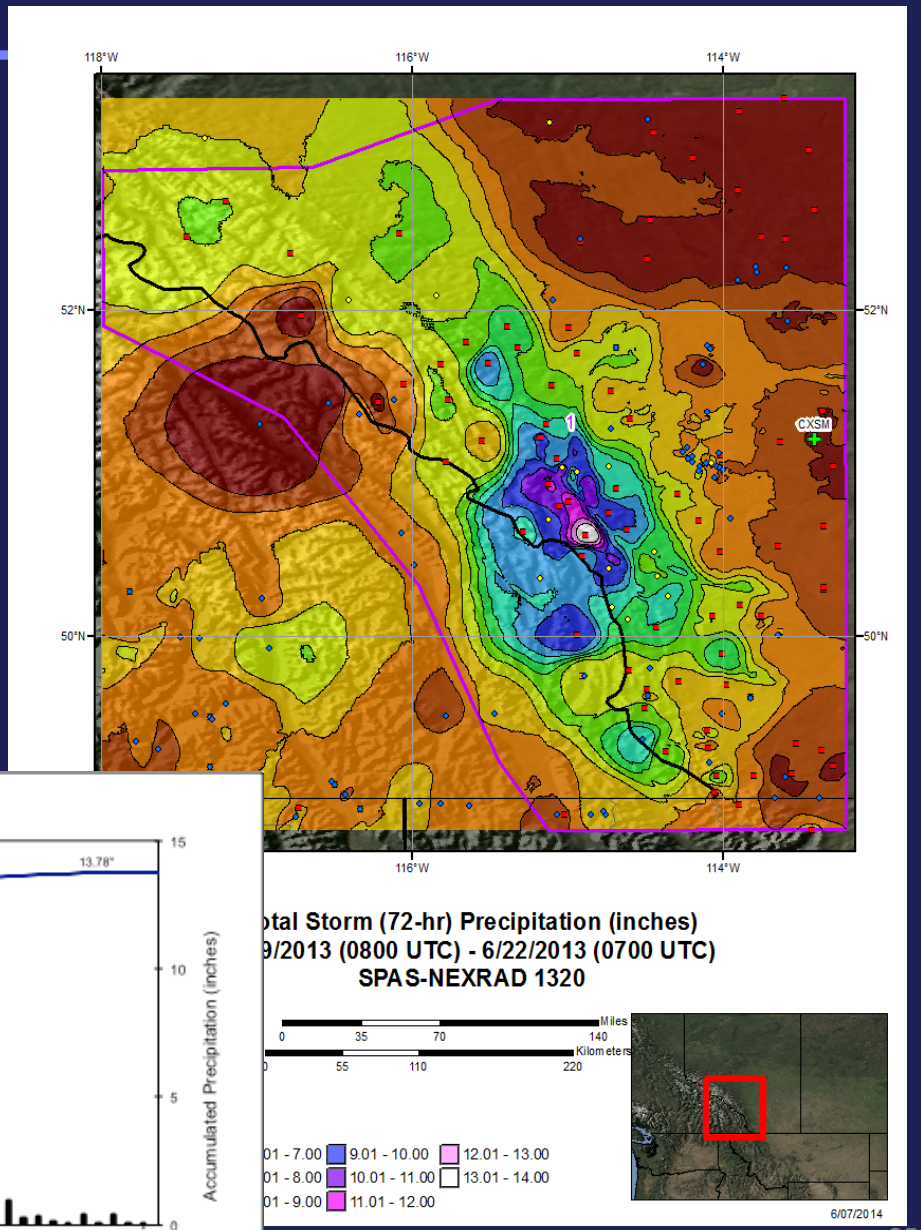
- **Storm-based approach**
- **Deterministic**
- **Can derive probabilistic estimation as well**

AWA SPAS Storm Locations



Calgary, Alberta June 2013

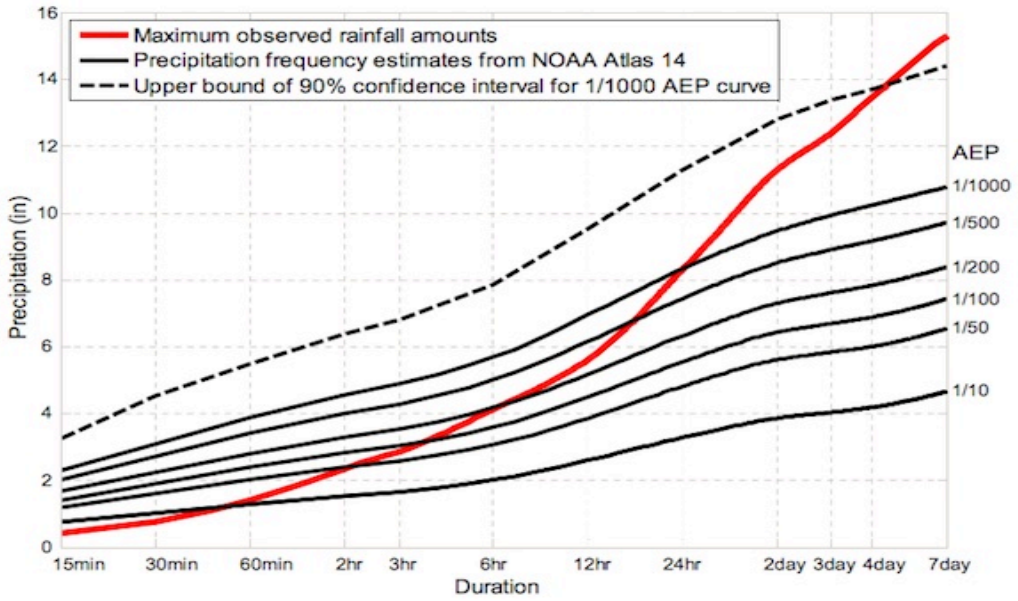


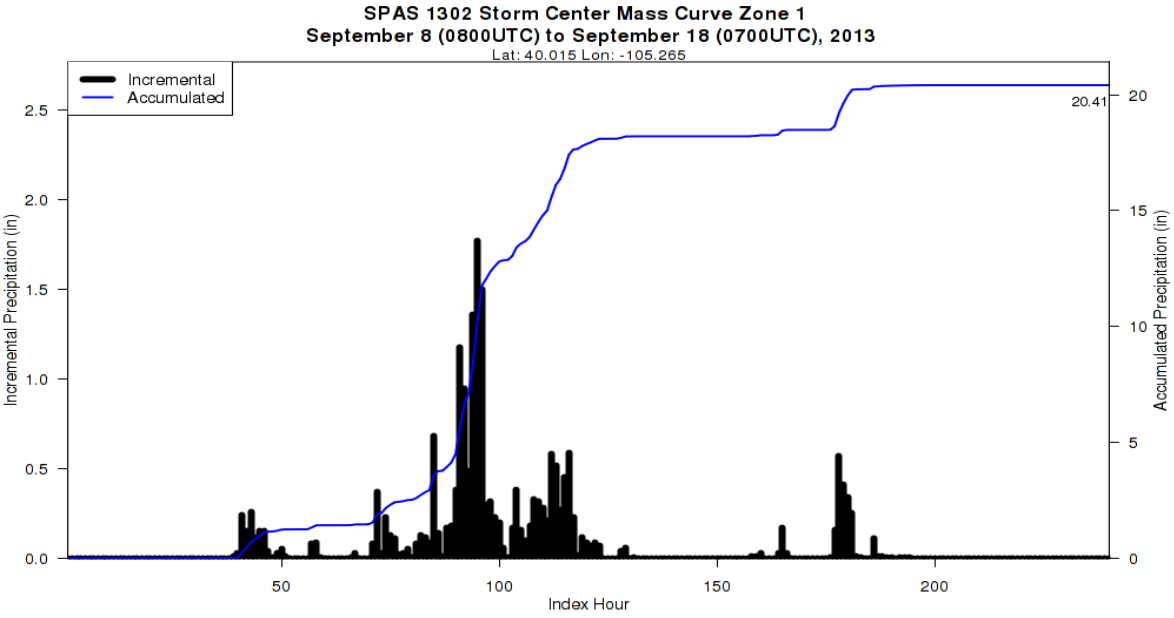


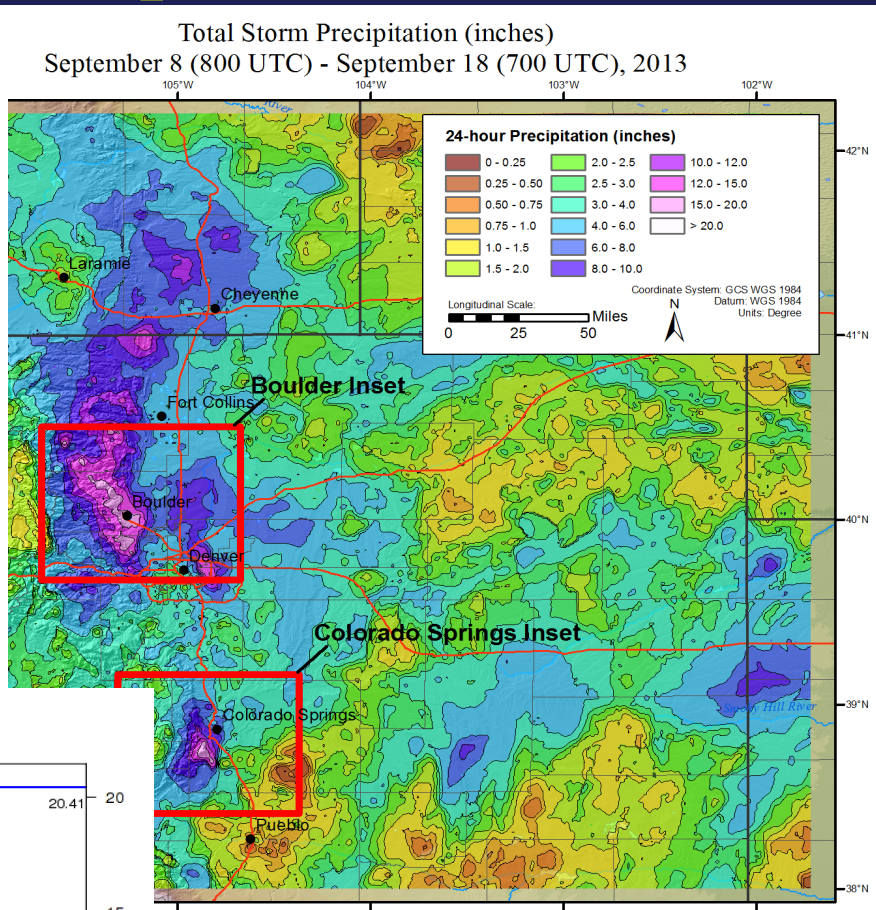
Calgary, Alberta June 2013

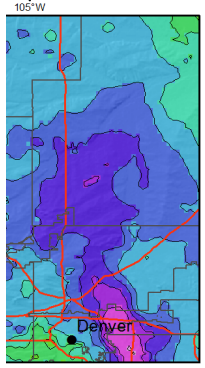
- Costliest natural disaster in Canadian history at the time
- But could have been worse
  - If the Gibson Dam storm had occurred in same place-flooding would have been more extreme
- Didn't control PMP for the Elbow River basin

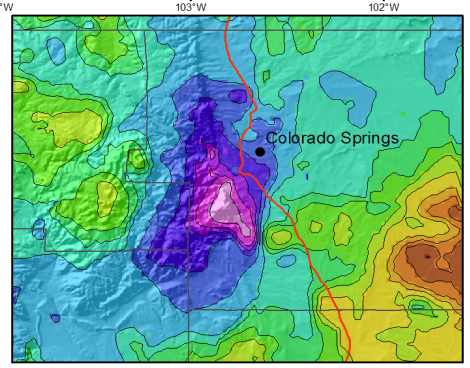
Colorado Front Range, September 2013











Colorado Springs Inset

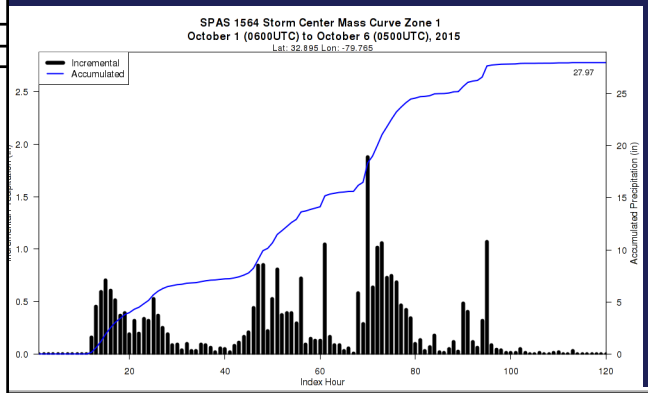
Colorado Front Range, September 2013

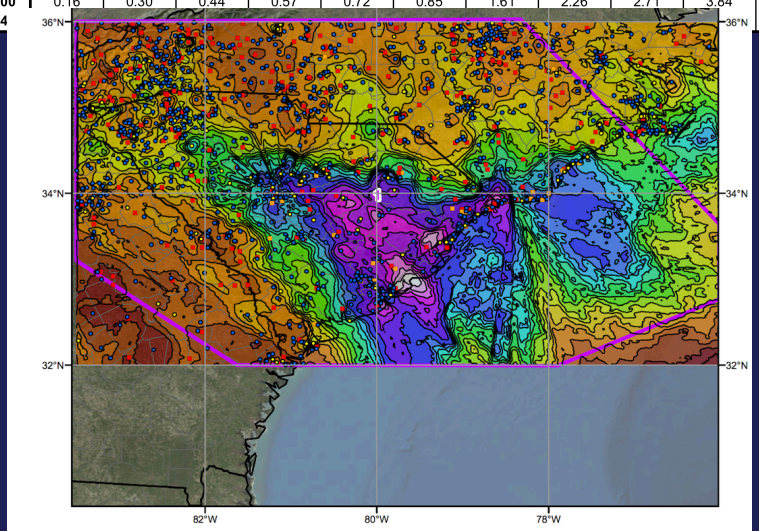
- Significant damage, live and property loss
- Widespread from southern WY, through CO and into southern NM/northwest TX
- Unusual evnet
  - Long duration
  - Nearly continuous rainfall by Colorado Front Range standards
  - Not intense convection
  - Do we need to re-define PMP/PMF for some basins for this storm type?
- Doesn’t control standard PMP for most basins

South Carolina, October 2015

Storm 1564 - October 1 (0600 UTC) - October 6 (0500 UTC), 2015
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	3.33	5.83	7.36	8.84	9.98	10.77	13.02	14.70	15.41	19.97	21.23	24.81	27.91	27.97	27.97
1	3.30	5.82	7.35	8.84	9.97	10.58	13.02	14.57	15.25	19.86	21.07	24.80	27.90	27.96	27.96
10	3.11	5.69	7.23	8.74	9.75	10.55	12.94	14.53	15.21	19.02	20.40	24.64	27.82	27.88	27.88
25	2.93	5.50	7.04	8.58	9.54	10.49	12.81	14.47	15.14	18.86	19.89	24.37	27.69	27.75	27.75
50	2.76	5.18	6.88	8.36	9.31	10.27	12.57	14.37	15.03	18.59	19.72	23.83	27.46	27.52	27.52
100	2.56	4.73	6.60	8.01	9.08	9.86	12.35	14.10	14.86	18.05	19.41	23.43	26.98	27.11	27.11
150	2.46	4.43	6.27	7.66	8.88	9.51	12.17	13.86	14.65	17.51	19.36	23.00	26.68	26.79	26.79
200	2.39	4.34	5.71	7.39	8.68	9.21	12.09	13.82	14.58	17.32	19.28	22.64	26.38	26.47	26.47
300	2.28	4.15	5.44	6.96	8.27	8.69	11.93	13.68	14.40	17.07	19.06	22.09	25.83	25.98	25.98
400	2.14	3.94	5.15	6.62	7.44	8.31	11.76	13.43	14.17	16.83	18.82	21.96	24.92	25.51	25.51
500	2.11	3.78	4.83	6.39	7.39	8.19	11.59	13.30	13.98	16.61	18.69	21.85	24.54	25.18	25.18
1,000	1.87	3.33	4.43	5.60	6.63	7.47	10.75	12.46	13.10	15.46	18.04	20.98	23.33	23.92	23.92
2,000	1.63	2.72	3.83	4.89	5.73	6.46	9.60	11.37	12.10	14.91	17.22	20.33	21.74	22.55	22.55
5,000	1.02	2.06	2.95	3.93	4.69	5.34	8.25	9.58	10.54	13.66	15.65	18.66	20.17	20.72	20.72
10,000	0.81	1.56	2.25	2.95	3.56	3.91	6.60	8.31	8.86	11.83	13.99	16.18	18.24	18.79	18.79
20,000	0.59	1.09	1.66	2.17	2.60	2.97	5.42	6.67	7.23	9.85	11.24	13.70	15.54	16.47	16.47
50,000	0.29	0.53	0.78	0.95	1.06	1.26	2.33	4.11	4.77	6.20	7.09	9.80	11.55	12.14	12.14
100,000	0.16	0.30	0.44	0.57	0.72	0.85	1.61	2.26	2.71	3.84	5.01	6.63	7.67	8.02	8.02
100,54											5.01	6.61	7.64	7.99	7.99





Total Storm (120-hours) Precipitation (inches)
10/1/2015 0600 UTC - 10/6/2015 0500
SPAS-NEXRAD #1564

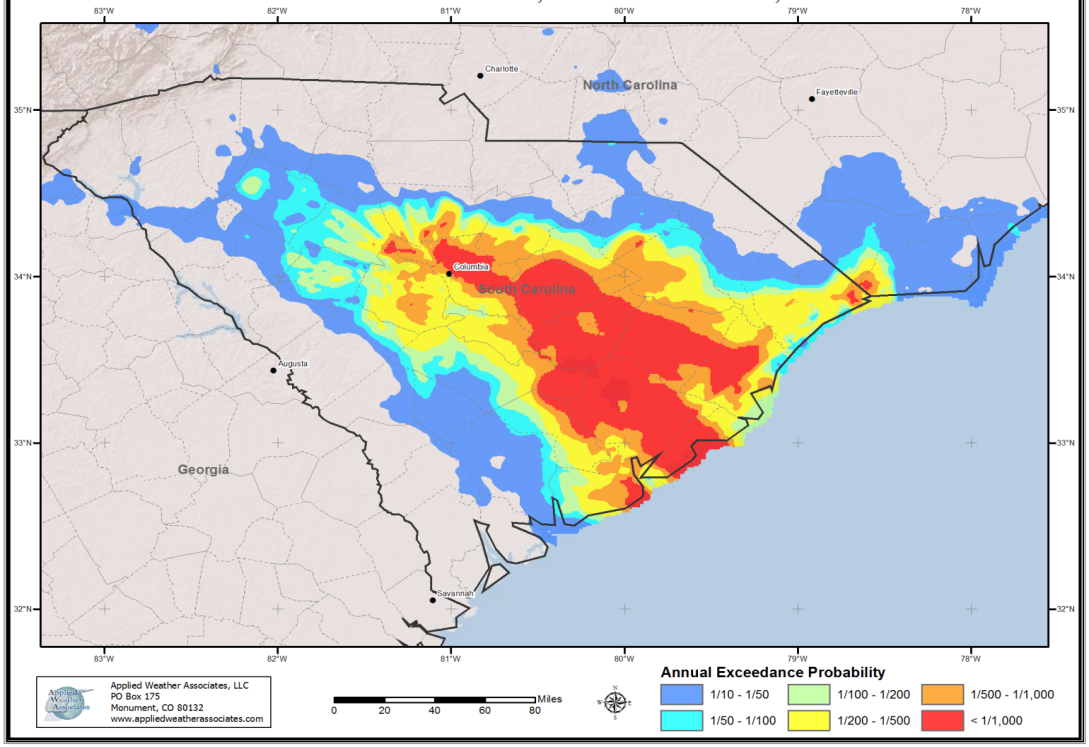
Gauges
- Daily
- Hourly
- Hourly Pseudo
- Supplemental

Miles: 0 40 80 160
Kilometers: 0 85 170 340

Precipitation (inches)

0.00 - 1.00	4.01 - 5.00	8.01 - 9.00	12.01 - 13.00	18.01 - 20.00
1.01 - 2.00	5.01 - 6.00	9.01 - 10.00	13.01 - 14.00	20.01 - 22.00
2.01 - 3.00	6.01 - 7.00	10.01 - 11.00	14.01 - 16.00	22.01 - 24.00
3.01 - 4.00	7.01 - 8.00	11.01 - 12.00	16.01 - 18.00	24.01 - 26.00
				26.01 - 28.00

ance Probabilities (AEPs) for 72-hour Maximum Rainfall
SPAS 1564 - October 1 - 6, 2015 - Mount Pleasant, SC



Applied Weather Associates, LLC
PO Box 175
Monument, CO 80132
www.appliedweatherassociates.com

Miles: 0 20 40 60 80

Annual Exceedance Probability

1/10 - 1/50	1/100 - 1/200	1/500 - 1/1,000
1/50 - 1/100	1/200 - 1/500	< 1/1,000

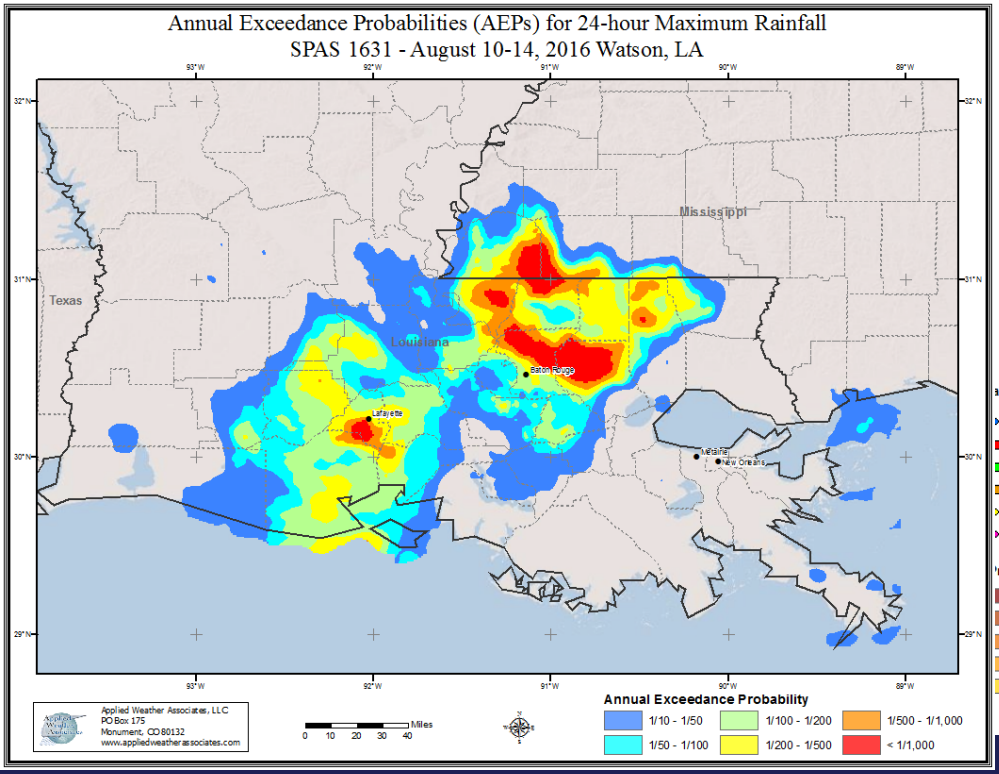
South Carolina, October 2015

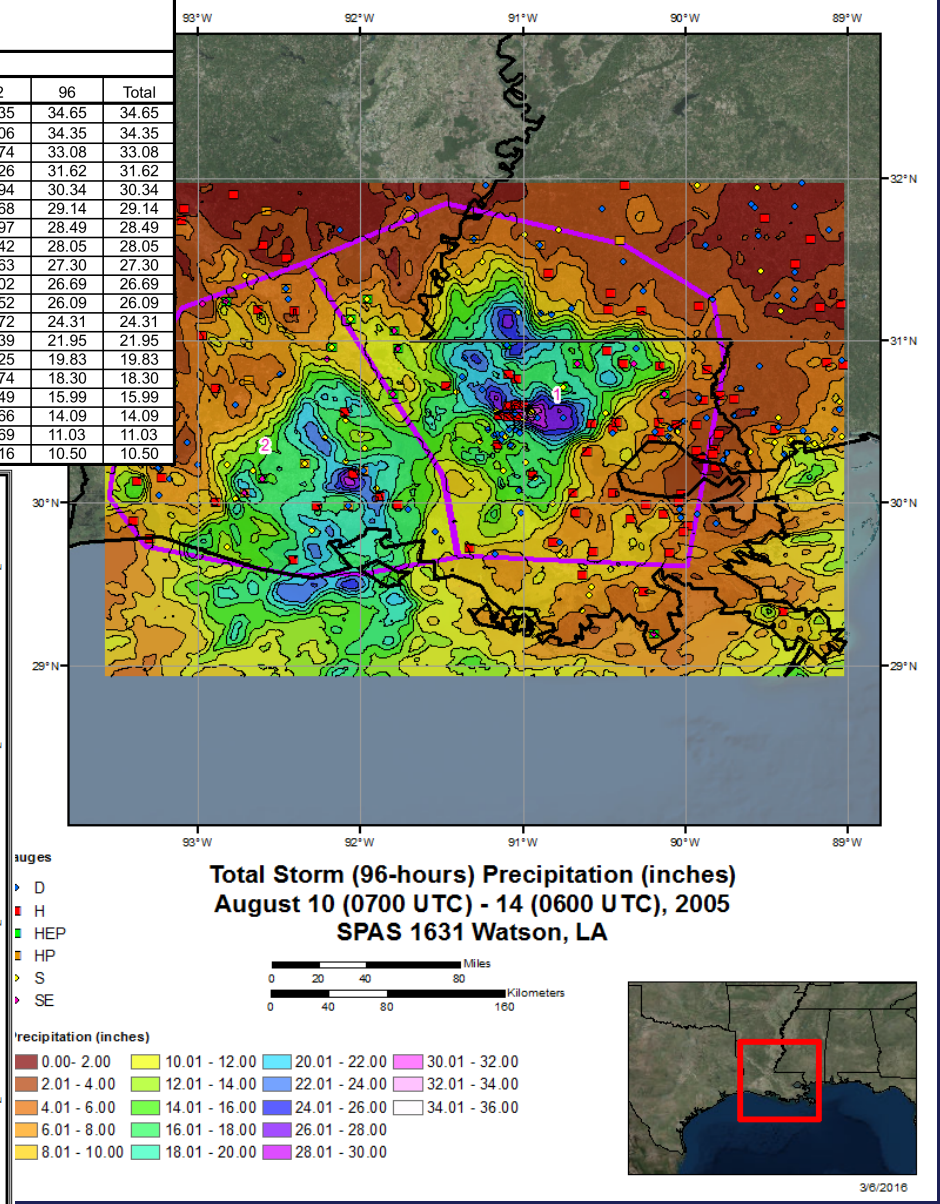
- Significant property damage, lives lost, hundreds of dam failures
- But not the first time in this area
  - August 1908, July 1916, August 1940
- This storm competes with some of those old ones at 1-2 days and larger area sizes (>500mi^2)

Baton Rouge, LA August 2016

Storm 1631 Zone 1 - Aug. 10 (0700 UTC) - Aug. 14 (0600 UTC), 2016
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	4.25	6.39	7.24	8.71	10.11	11.64	16.59	20.36	23.25	28.53	32.17	34.35	34.65	34.65
1	4.22	6.34	7.19	8.65	10.06	11.54	16.43	20.18	23.05	28.29	31.90	34.06	34.35	34.35
10	4.14	6.07	7.06	8.50	9.93	11.12	15.92	19.38	22.14	27.25	30.77	32.74	33.08	33.08
25	4.11	5.75	6.85	8.32	9.83	10.88	15.53	18.63	21.44	26.19	29.47	31.26	31.62	31.62
50	4.00	5.40	6.62	7.98	9.52	10.52	15.10	18.07	21.19	25.23	28.31	29.94	30.34	30.34
100	3.84	5.05	6.35	7.53	8.90	9.97	14.55	17.46	20.64	24.17	27.05	28.68	29.14	29.14
150	3.65	4.84	6.15	7.27	8.40	9.60	14.22	16.91	20.10	23.56	26.31	27.97	28.49	28.49
200	3.44	4.66	5.94	7.06	8.16	9.35	13.90	16.47	19.60	23.14	25.80	27.42	28.05	28.05
300	3.00	4.34	5.49	6.72	7.79	8.98	13.43	15.83	18.87	22.47	25.08	26.63	27.30	27.30
400	2.58	4.03	5.18	6.46	7.55	8.71	13.07	15.38	18.35	21.99	24.57	26.02	26.69	26.69
500	2.26	3.78	5.02	6.25	7.35	8.50	12.74	15.05	17.91	21.55	24.08	25.52	26.09	26.09
1,000	1.79	3.25	4.46	5.58	6.64	7.66	11.66	13.95	16.50	19.85	22.31	23.72	24.31	24.31
2,000	1.41	2.67	3.68	4.74	5.75	6.60	10.33	12.63	14.82	17.81	20.07	21.39	21.95	21.95
3,500	1.15	2.14	2.95	3.81	4.63	5.35	8.92	11.12	13.01	15.79	17.94	19.25	19.83	19.83
5,000	0.97	1.77	2.49	3.22	3.89	4.51	7.71	9.68	11.31	14.13	16.21	17.74	18.30	18.30
7,500	0.77	1.41	2.00	2.57	3.09	3.59	6.20	7.94	9.40	11.97	13.91	15.49	15.99	15.99
10,000	0.61	1.14	1.65	2.14	2.59	3.02	5.23	6.73	7.95	10.27	12.10	13.66	14.09	14.09
15,000	0.43	0.83	1.19	1.54	1.89	2.20	3.85	5.05	5.96	7.80	9.41	10.69	11.03	11.03
16,075	0.41	0.78	1.11	1.44	1.76	2.05	3.61	4.79	5.66	7.41	8.95	10.16	10.50	10.50





Recent Big Storms

- Lots of big recent storms, is something different?
- No, storms as big and bigger have happened before and will continue to happen
  - More media coverage
  - More people affected

Storms That Still Control PMP Today

- Hurricane Agnes, June 1972
- Tyro, VA (Camille) July 1969
- Gibson Dam, MT June 1964
- Hoegee's Camp, CA January 1943
- Smethport, PA July 1942
- Rosman, NC August 1940
- Cherry Creek/Hale, CO May 1935
- Quinault, WA January 1935
- Thrall, TX September 1921
- Alta Pass, NC July 1916
- Hearne, TX June 1899
- Catskill, NY July 1819

Extra Slides

What About Climate Change and PMP?

- Climate has always changed and always will
- Is something different now?
  - Pace of change not unusual
  - But, like most science, we don't know all the answers
- Climate models are projections
  - They do not produce data
  - Many unknowns/errors/etc
- Nothing wrong with preparing for "what if" scenarios
  - But don't pretend we know more than we do

What About Climate Change and PMP?

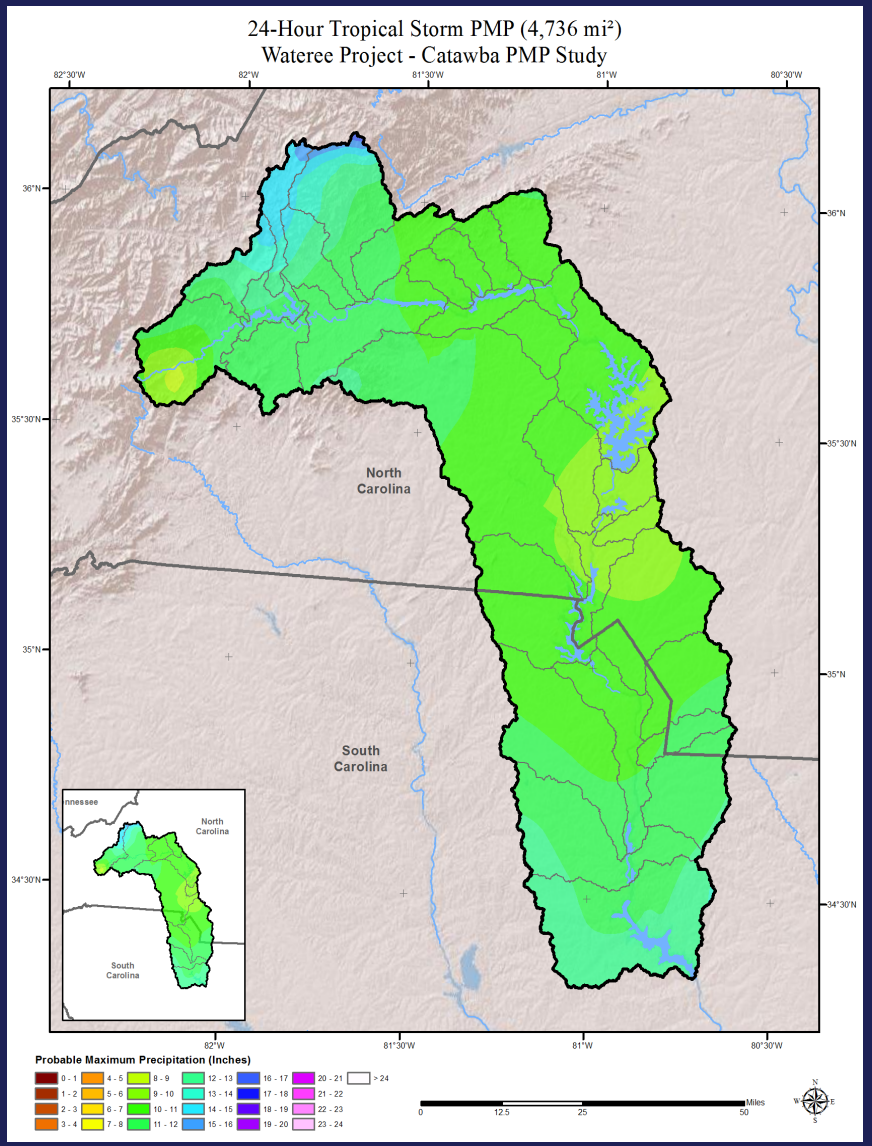
- What if it's getting warmer, doesn't that mean more moisture?
  - Yes, but that is not the only factor that causes rainfall-especially heavy rainfall
  - Many other feedback mechanisms and other factors
  - Some we understand, some we don't
  - For Example, less thermal contrast means weak storm dynamics, which can mean less intense rainfall
- PMP storm data and period of record already captures all these things and potential changes

What About Probability of PMP?

- Deterministic, but probability can still be estimated
- Very useful for RIDM and context
- 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 Methods

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



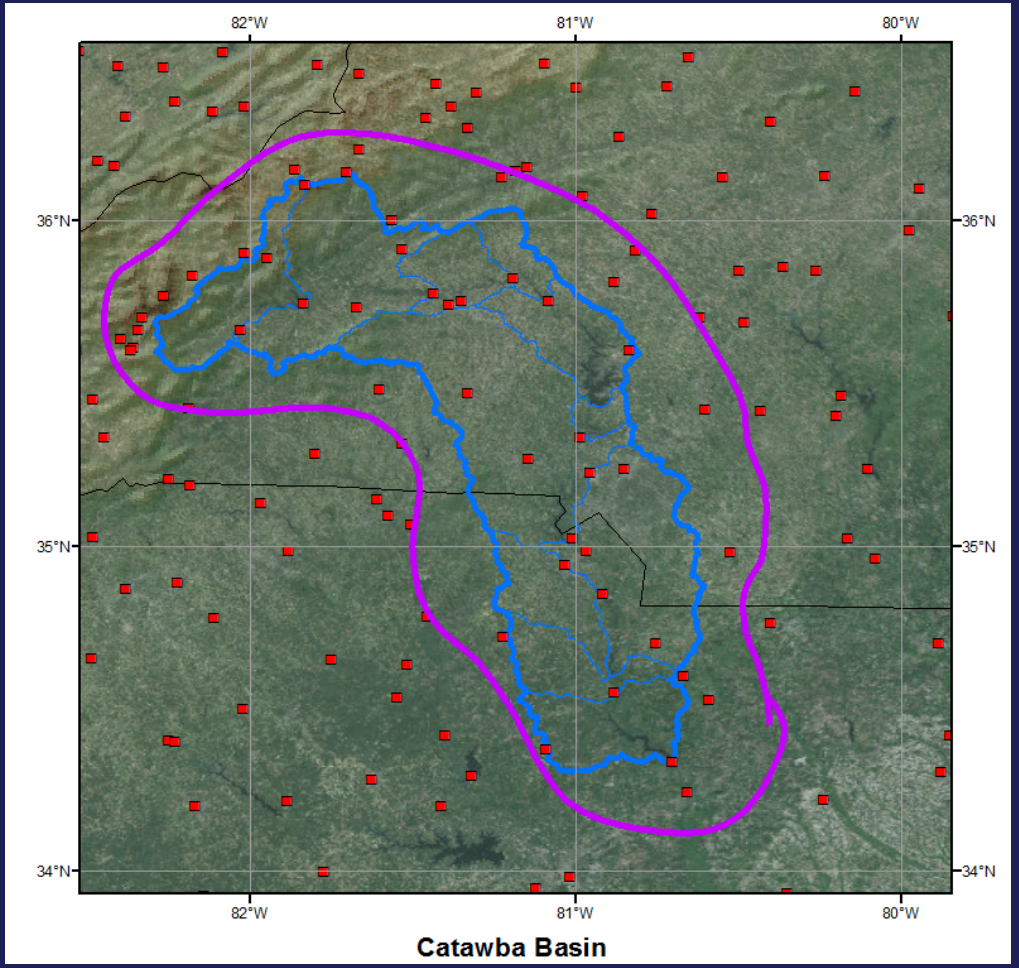
Regional L-moments

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

Regional L-moments

AMS and Homogeneous Regions

- Identify homogenous region
- 56 stations amounting to 4500+ years of station record
- Equivalent independence recorded length

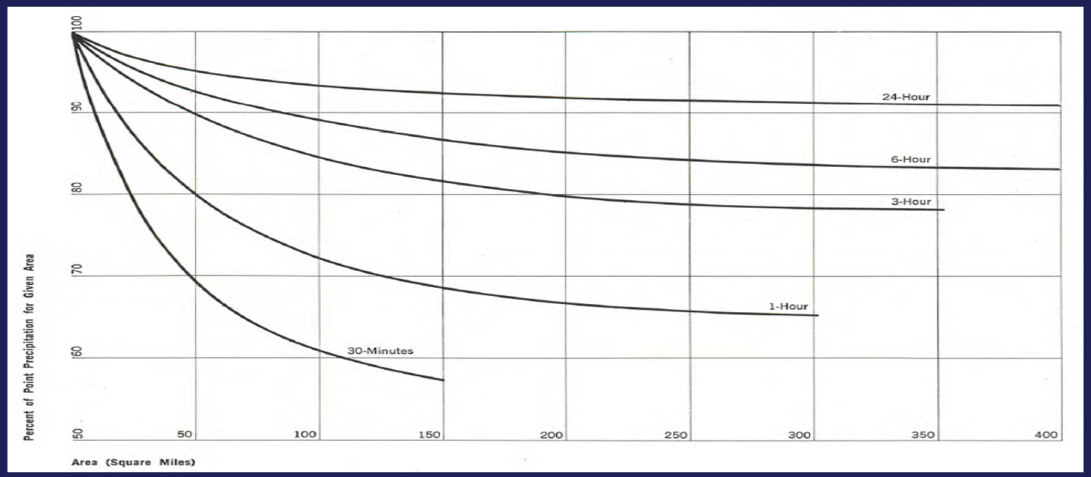


Regional L-moments
Areal Reduction Factor

- AWA calculated ARFs using a storm centered depth-area approach based on gridded hourly rainfall data from the Storm Precipitation Analysis System (SPAS)
  - Used SPAS hourly precipitation grids for calculation

	Bridgewater 386-mi^2	Cowans Ford 1793-mi^2	Catawba 4737-mi^2
Average	0.81	0.65	0.51
Maximum	0.96	0.90	0.78
Minimum	0.40	0.22	0.17
Controlling Storm*	0.88	0.71	0.72

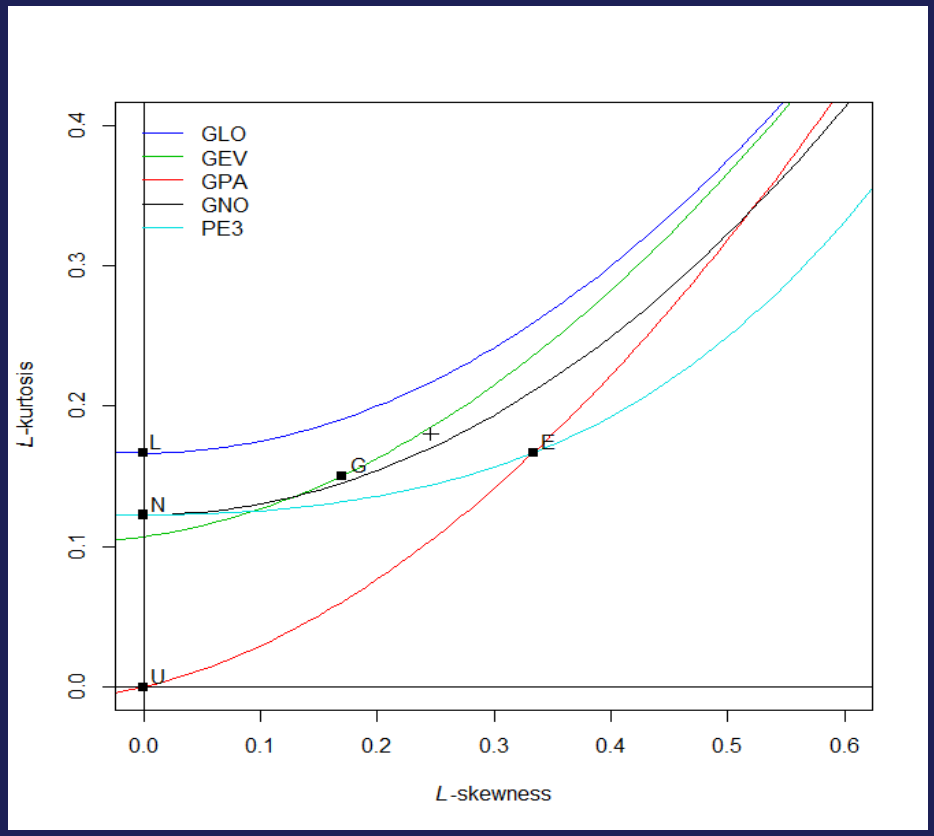
* Controlling storm ARF values used for conversion



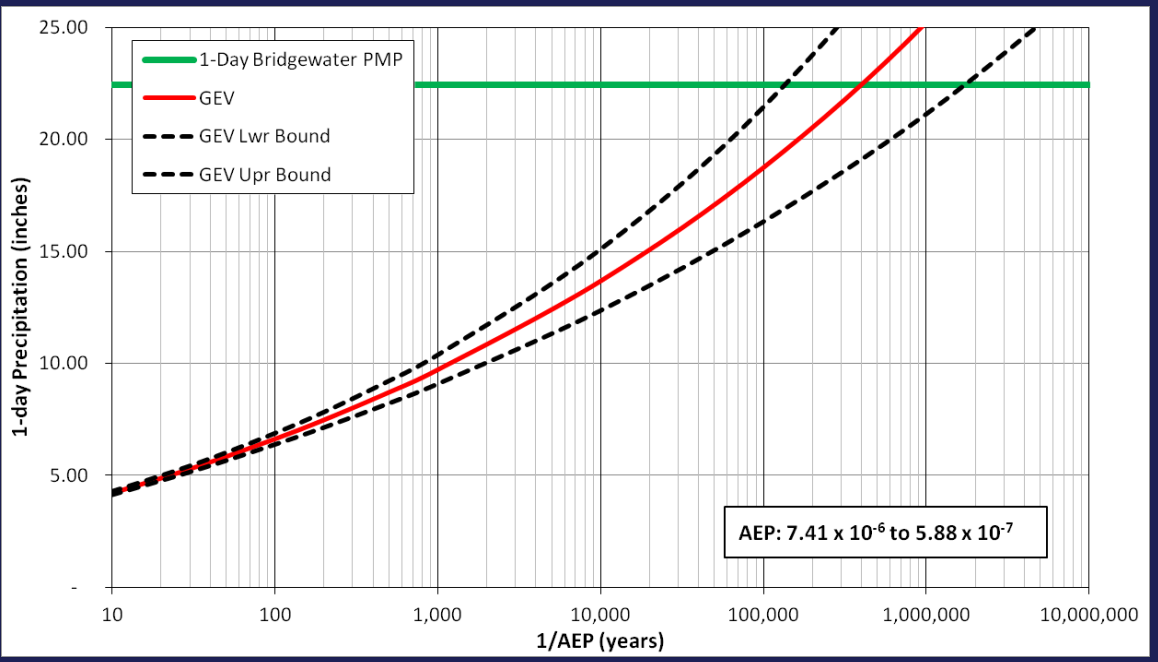
Regional L-moments

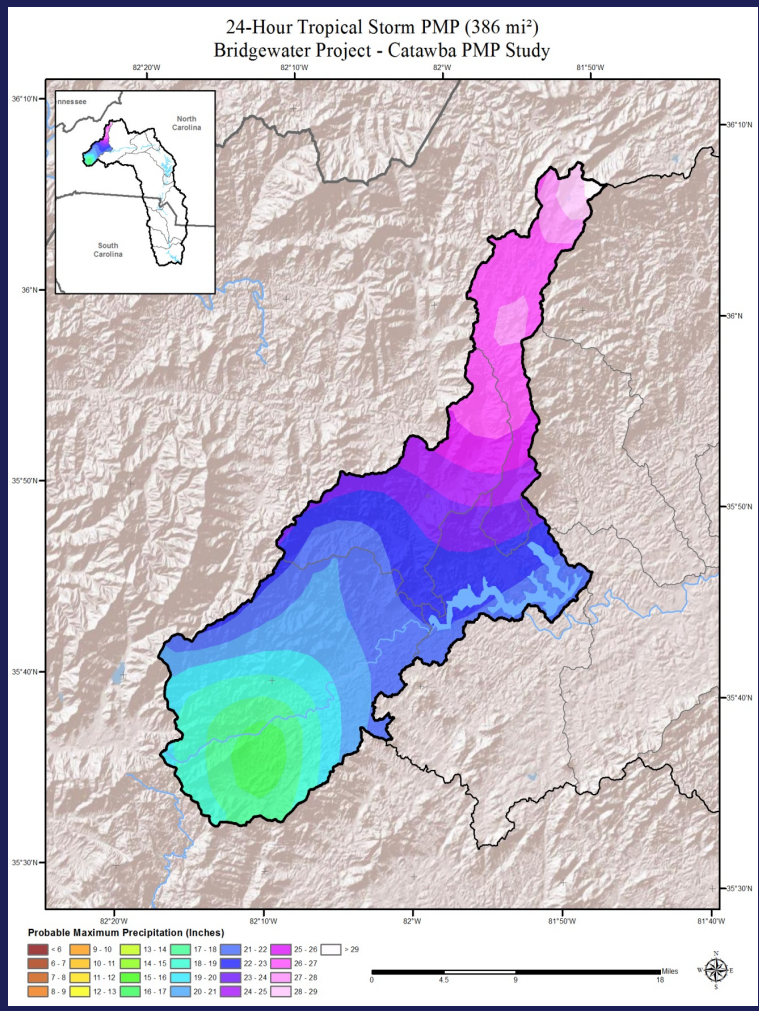
Goodness of fit - Uncertainty

- Identification of Regional Probability Distribution
- Goodness of fit measures (Hosking and Wallis, 1997)
- L-moment Ratio Diagram
- The regional weighted-average L-Skewness and L-Kurtosis pairing were found to be very near the GEV distribution
- Derivation of uncertainty bounds



Regional L-moments
Bridgewater AEP





- Bridgewater Basin (386-sqmi)
- PMP = 22.46”
- AEP = 7.41 x 10^{-6} to 5.88 x 10^{-7}

Stochastic Storm Transpositioning

- 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

$$AEP = p1 * p2 * p3$$

Stochastic Storm Transitioning

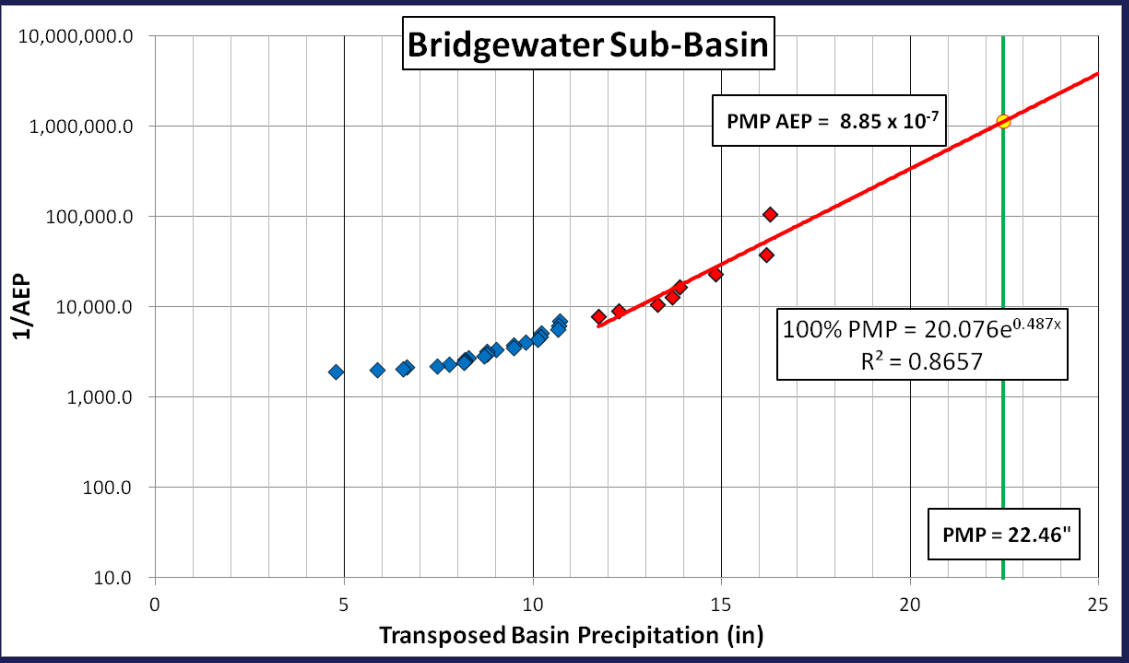
# Events	31
Trans Area (mi^2)	180,426.0
Basin Area (mi^2)	386.0
P2	0.0021
1day pmp	22.46
# Data years	126
P3	0.2460

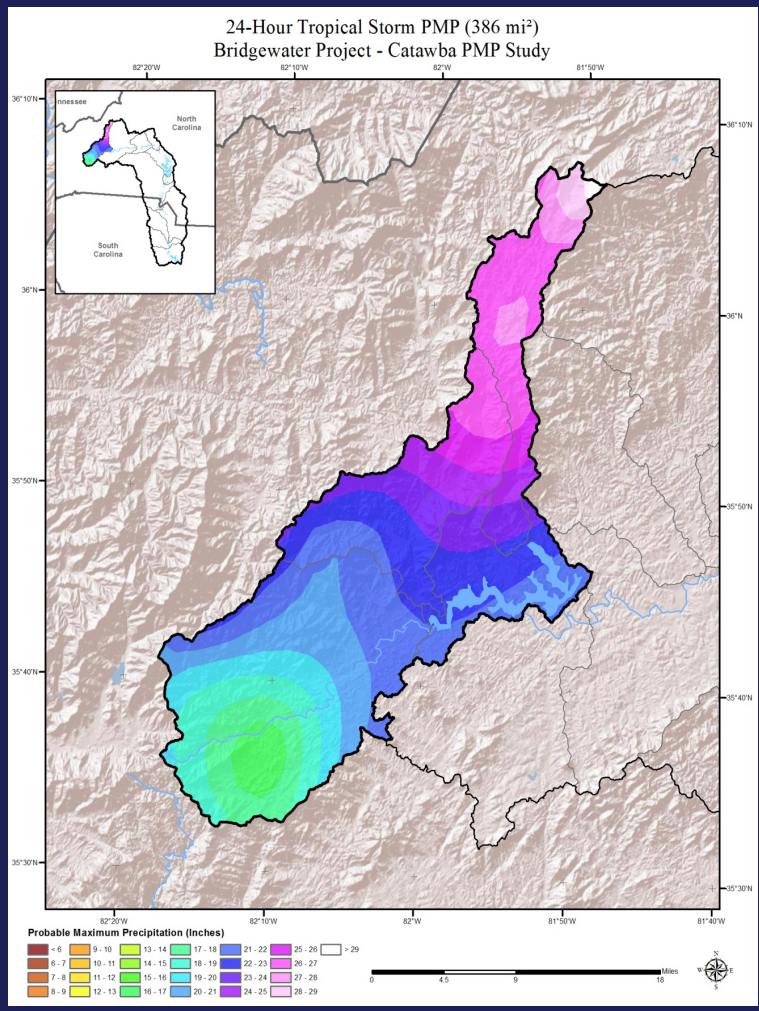
	P1	P2 and P3					
1d Ppt	Rank	AEP	AEP Adj Basin	1/AEP	EV Plot	Fx	%PMP
16.29	1	0.01806	0.0000095	105,170.6	8.56	0.9999905	0.725
16.18	2	0.05032	0.0000265	37,753.5	7.77	0.9999735	0.720
14.84	3	0.08258	0.0000435	23,006.1	7.38	0.9999565	0.661
13.89	4	0.11484	0.0000604	16,543.7	7.12	0.9999396	0.618
13.7	5	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

Stochastic Storm Transitioning

Bridgewater AEP

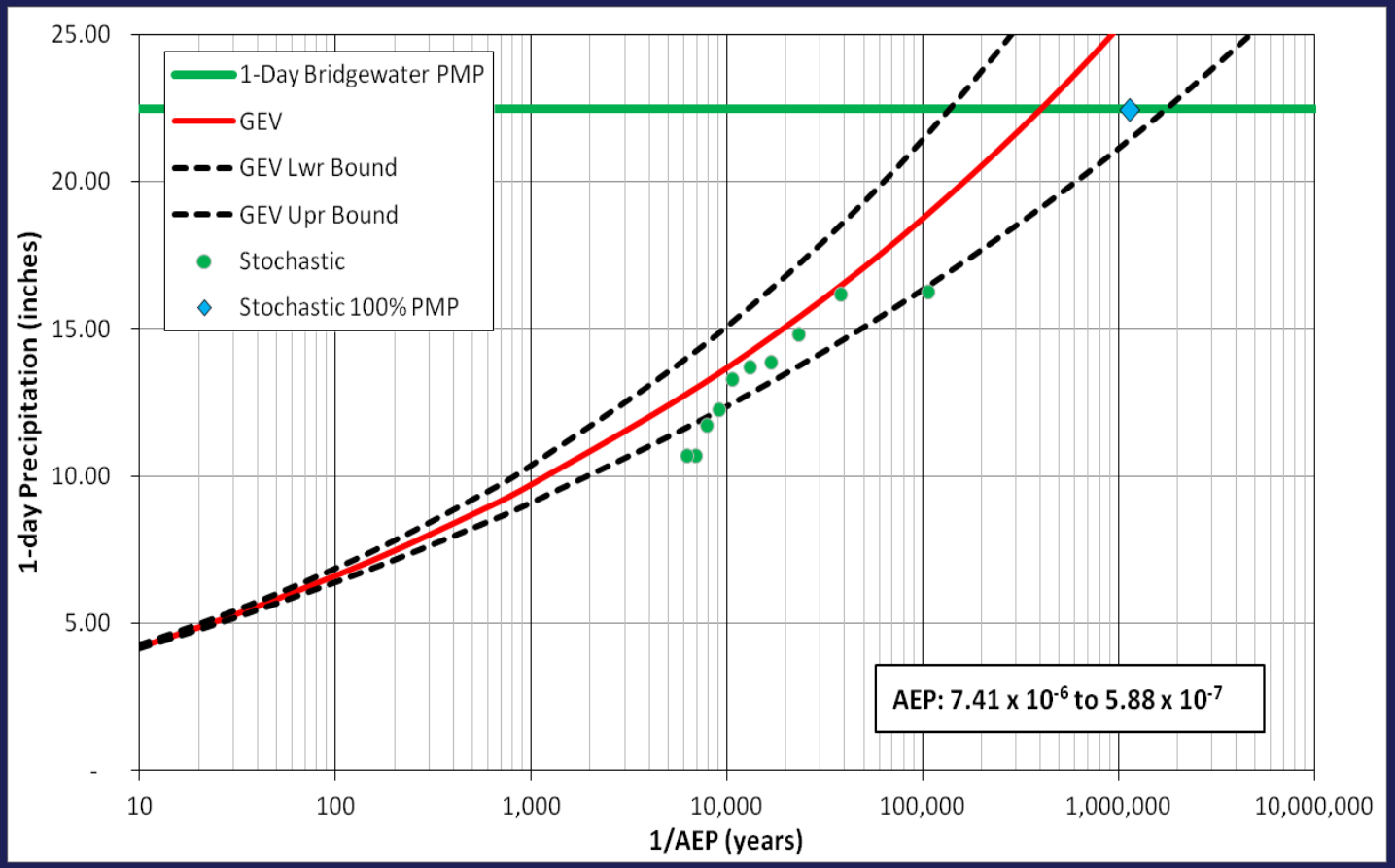




- Bridgewater Basin (386-sqmi)
- PMP = 22.46”
- AEP = 8.85×10^{-7} (1,129,793 yrs)

Summary of 1-Day Precipitation Frequency

- Bridgewater Basin (386-sqmi)
- AEP = 7.41 x 10^{-6} to 5.88 x 10^{-7}



Use of Paleoflood Data

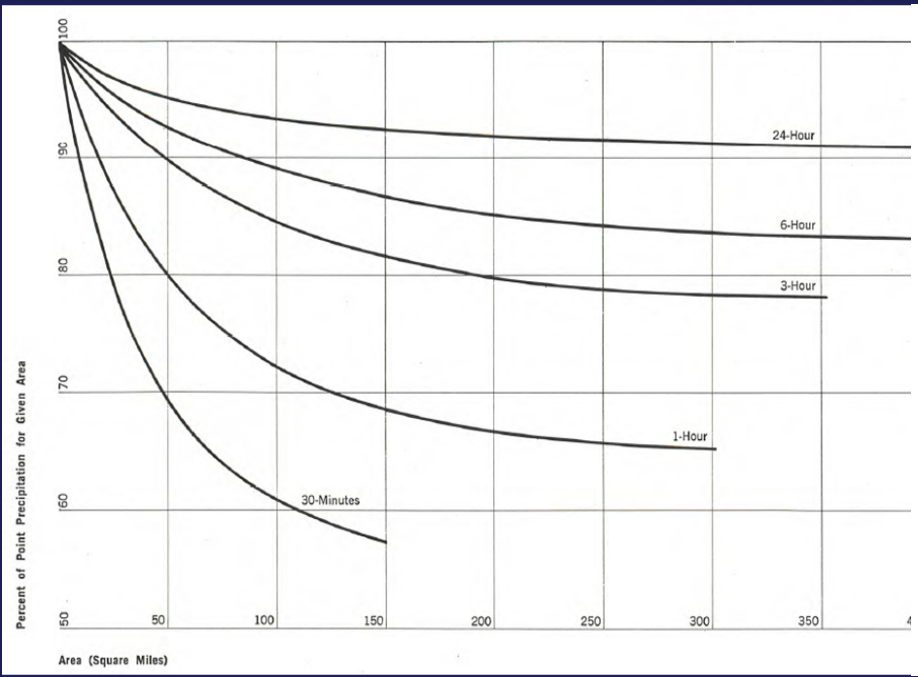
- Provide bounding conditions of PMP
  - Reasonableness check
  - Lots of uncertainty with paleoflood estimates
    - Must be understand and communicated
  - Paleofloods MUCH smaller than PMP
- Provide upper limits of largest floods for a basin
- Provide info for risk assessment, climate
- USBR uses risk-based approach and incorporates paleoflood data
- USACE uses both deterministic and risk-based data

Regional L-moments

Areal Reduction Factor

- NOAA defines an ARF as the ratio between area-averaged rainfall to the maximum depth at the storm center

- The most common sources for generalized ARFs and depth-area curves in the United States are from the NOAA Atlas 2 and the U.S. Weather Bureau's Technical Paper 29



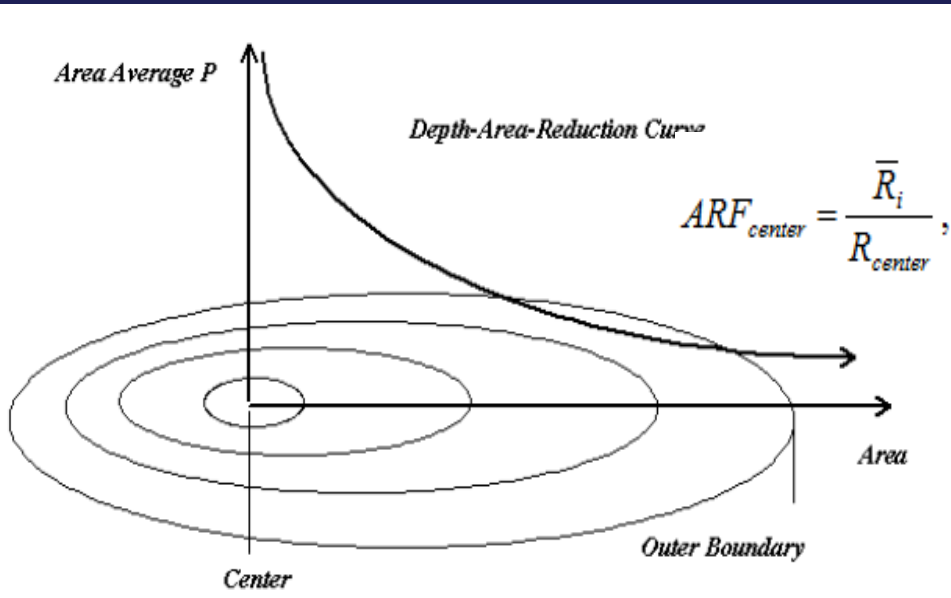
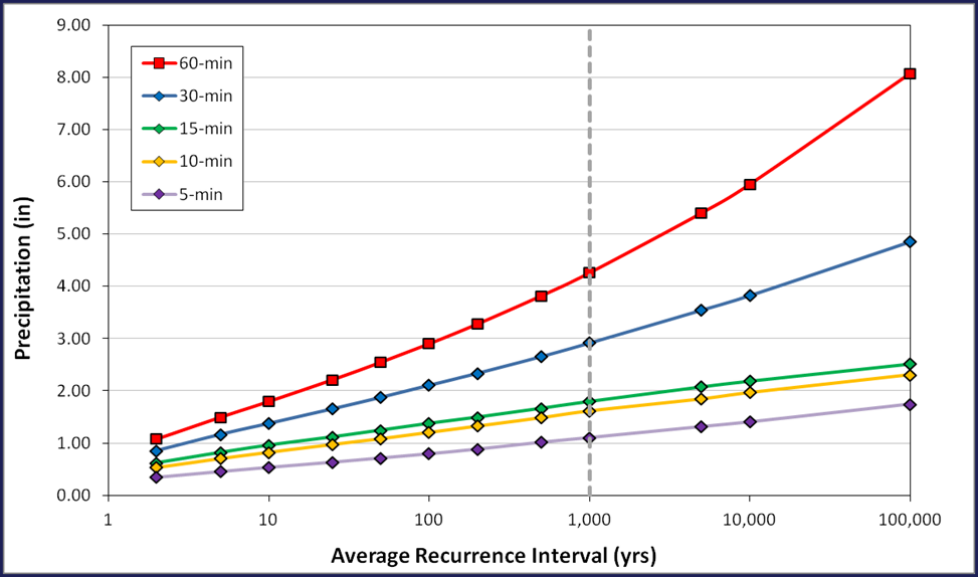


Figure 1 Illustration of Decay of Rainfall Depth from the Storm Center.

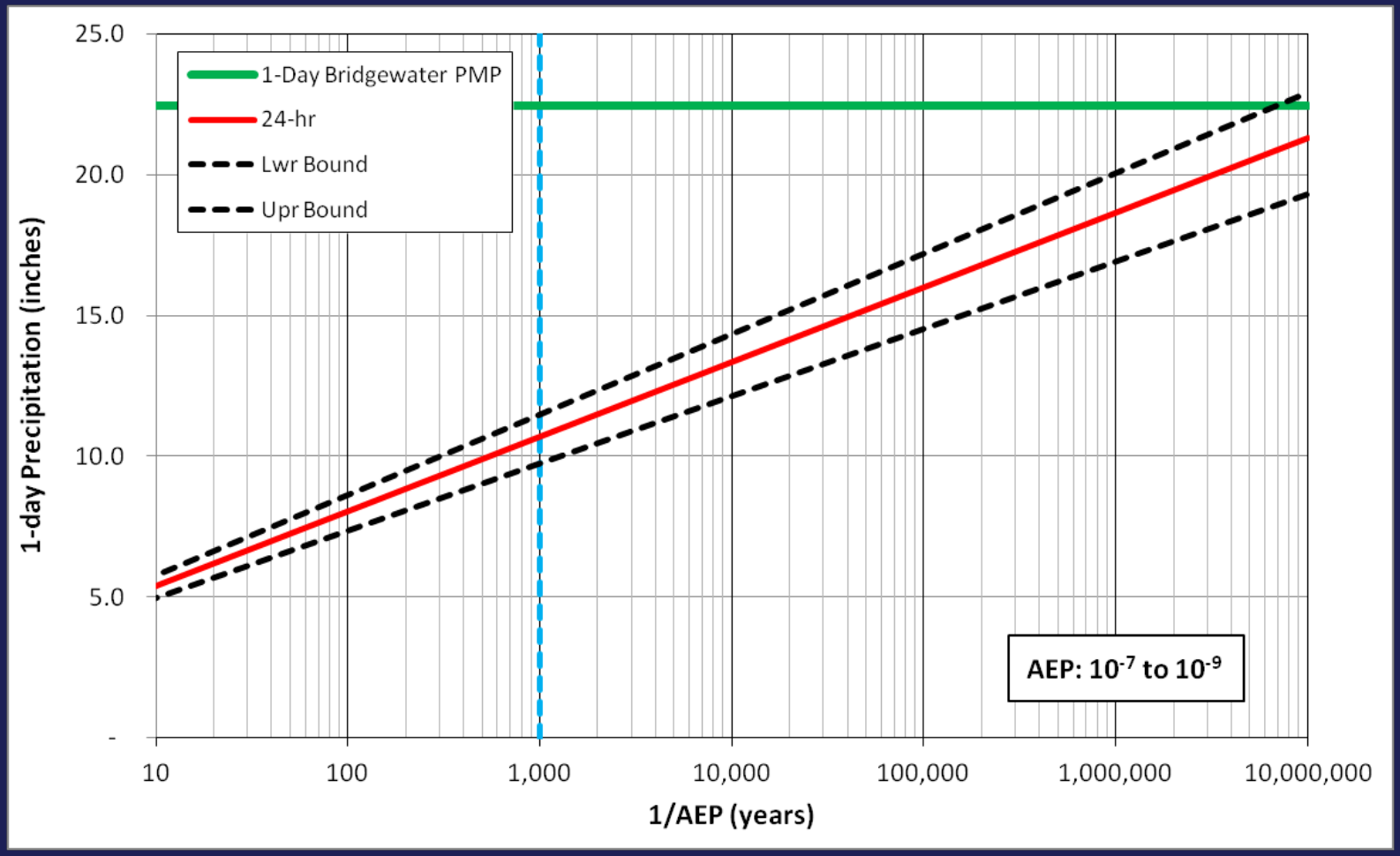
Statistical Extension

- 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 statistically extend NOAA Atlas 14 curves

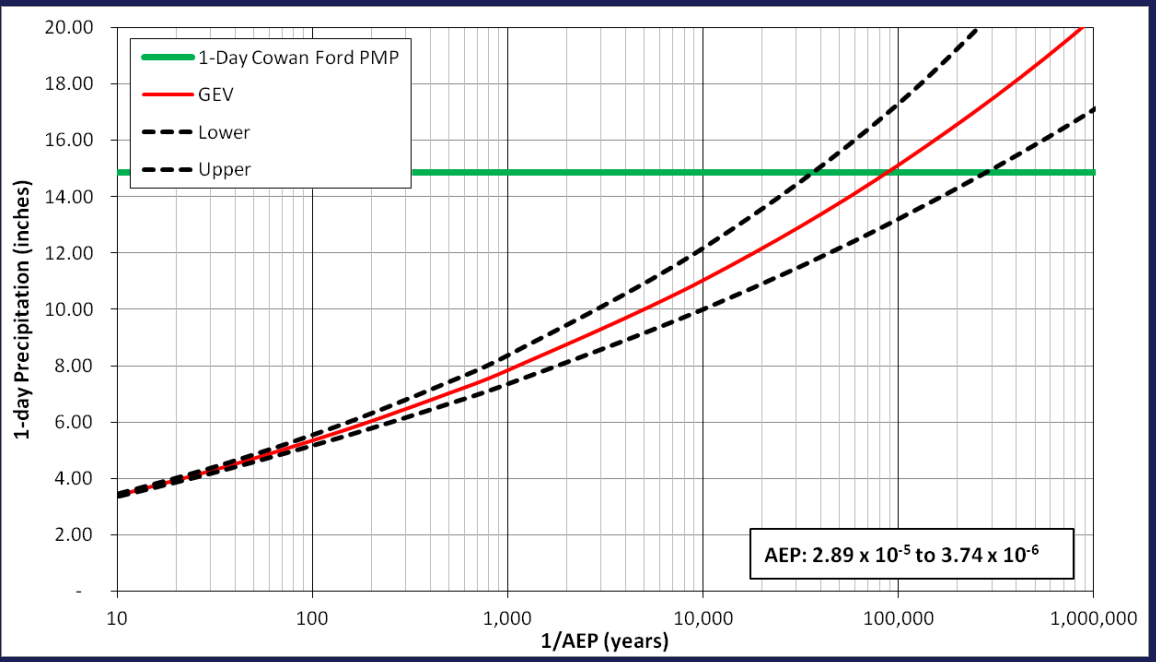


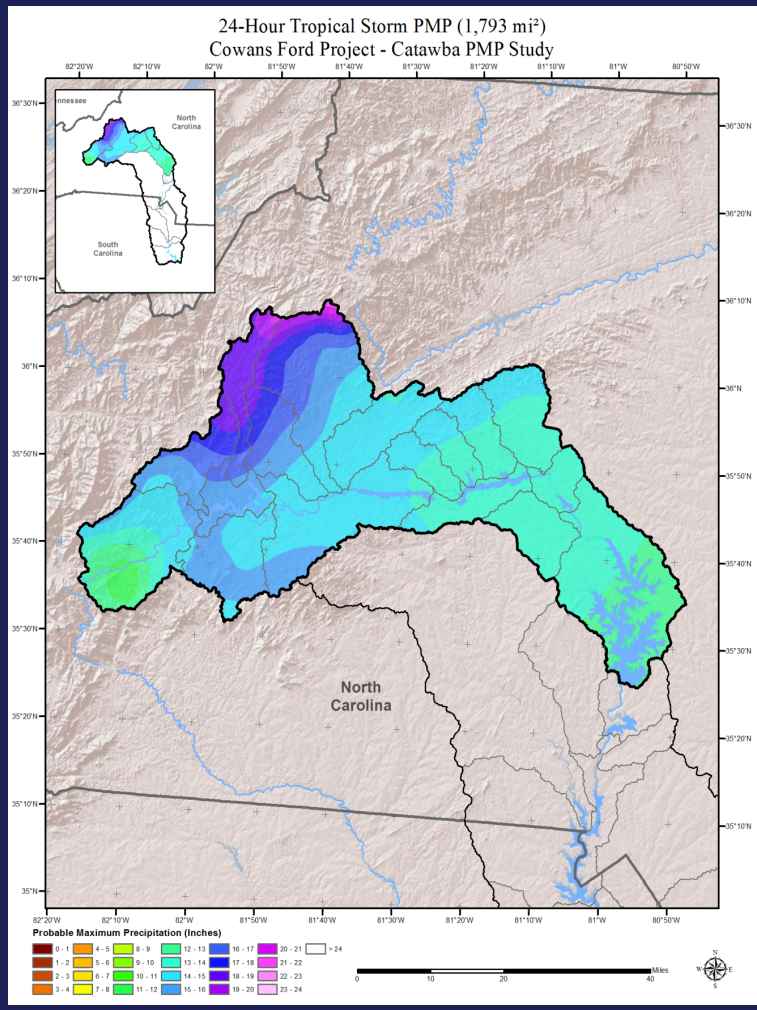
Statistical Extension

- NOAA Atlas 14 Statistical Extension



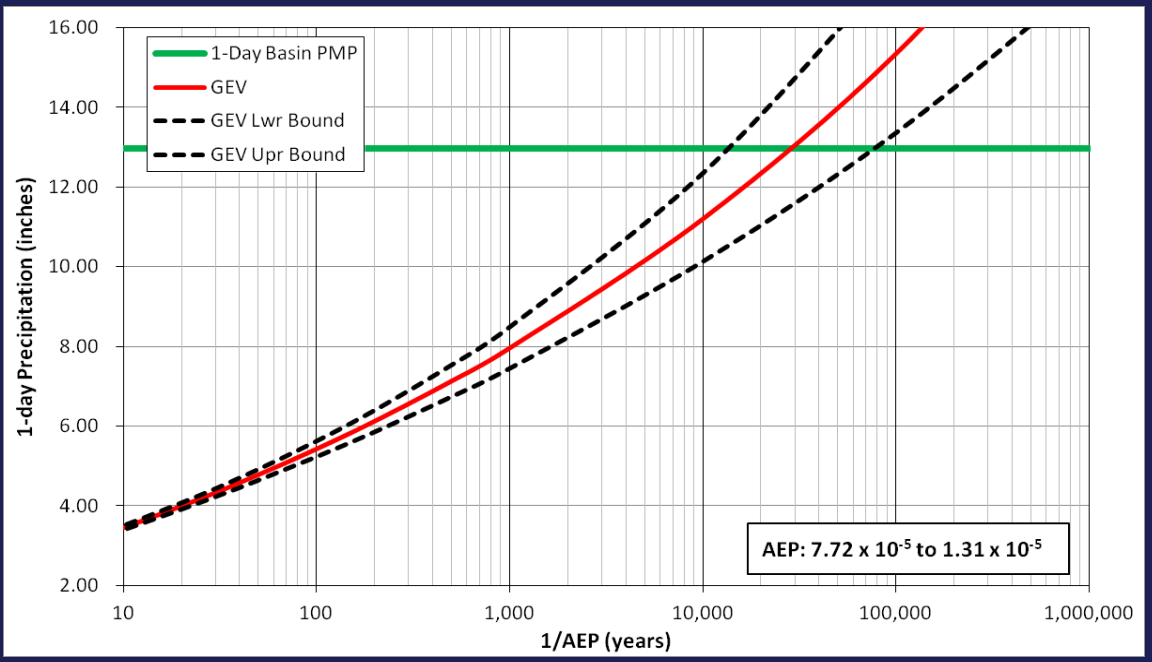
Regional L-moments
Cowan Ford AEP

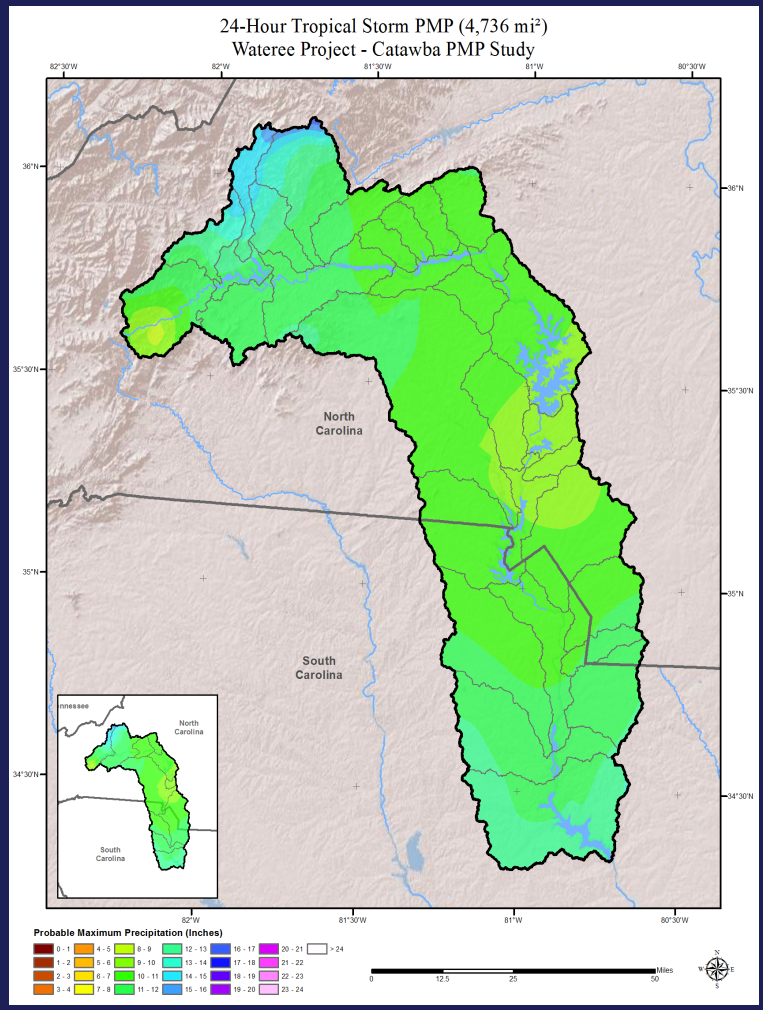




- Cowan Ford Basin (1793-sqmi)
- PMP = 14.85”
- AEP = 2.89×10^{-5} to 3.74×10^{-6}

Regional L-moments
Catawba AEP

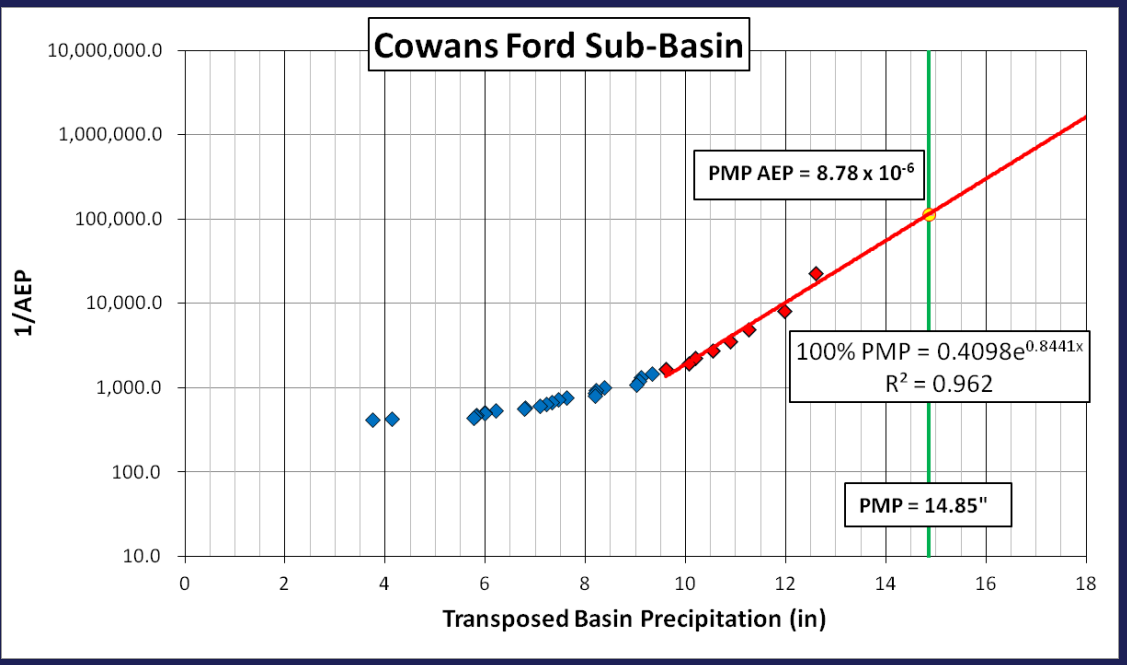


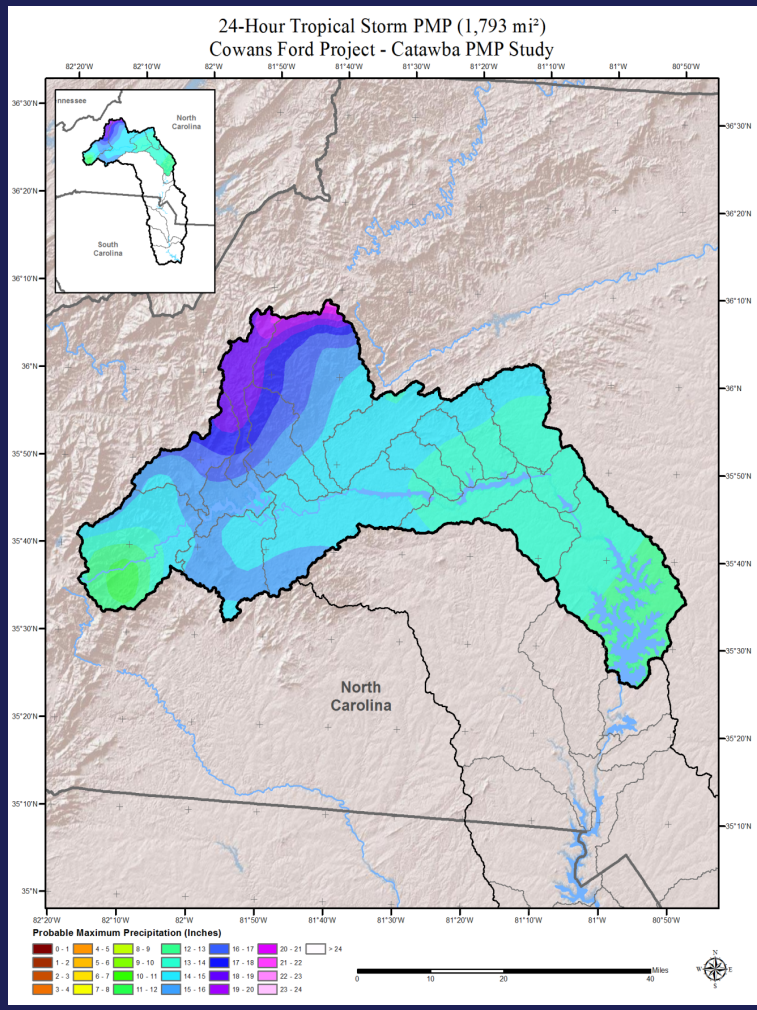


- Catawba Basin (4737-sqmi)
- PMP = 12.96”
- AEP = 7.72×10^{-5} to 1.31×10^{-5}

Stochastic Storm Transitioning

Cowan Ford AEP

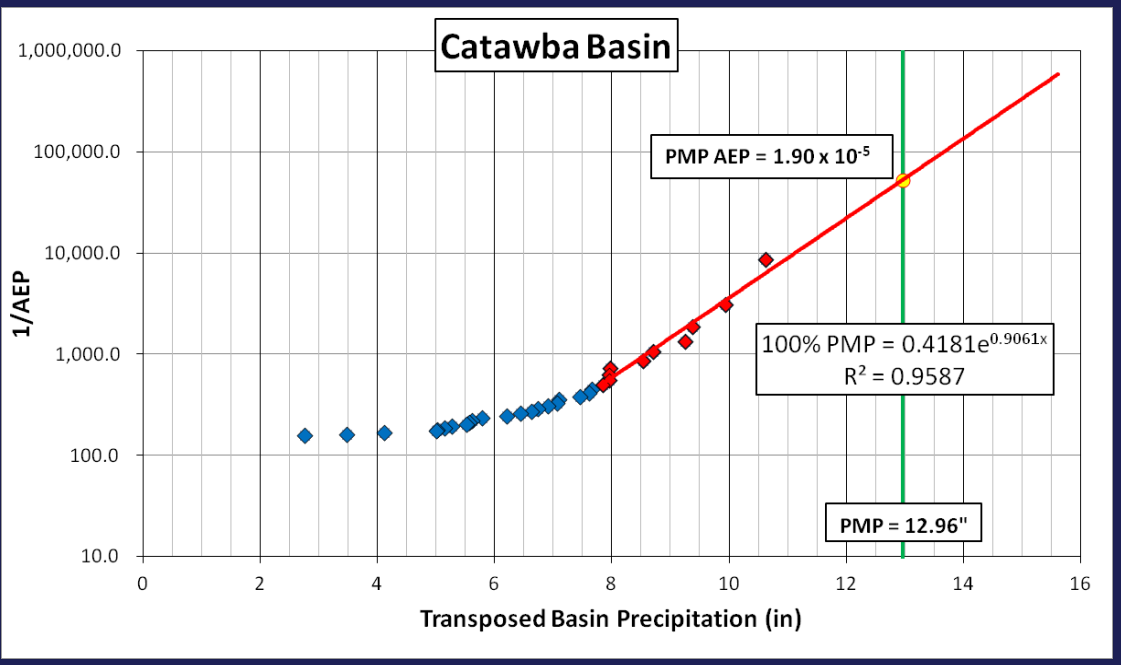


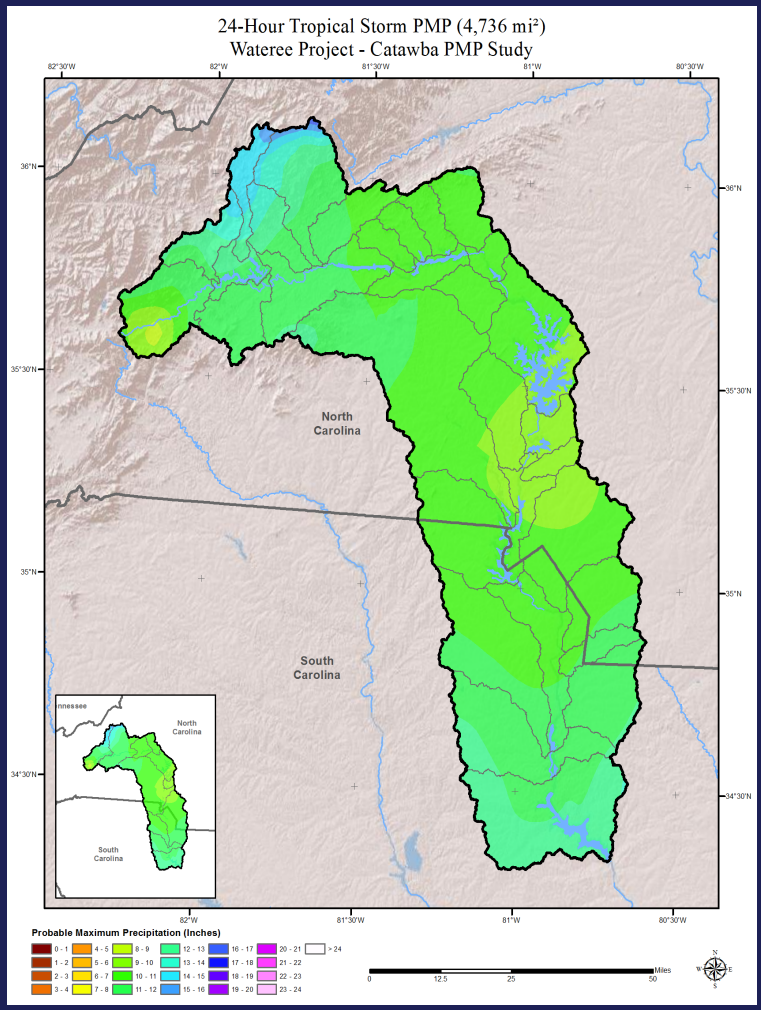


- Cowan Ford Basin (1793-sqmi)
- PMP = 14.85”
- AEP = 8.78×10^{-6} (113,868 yrs)

Stochastic Storm Transitioning

Catawba AEP

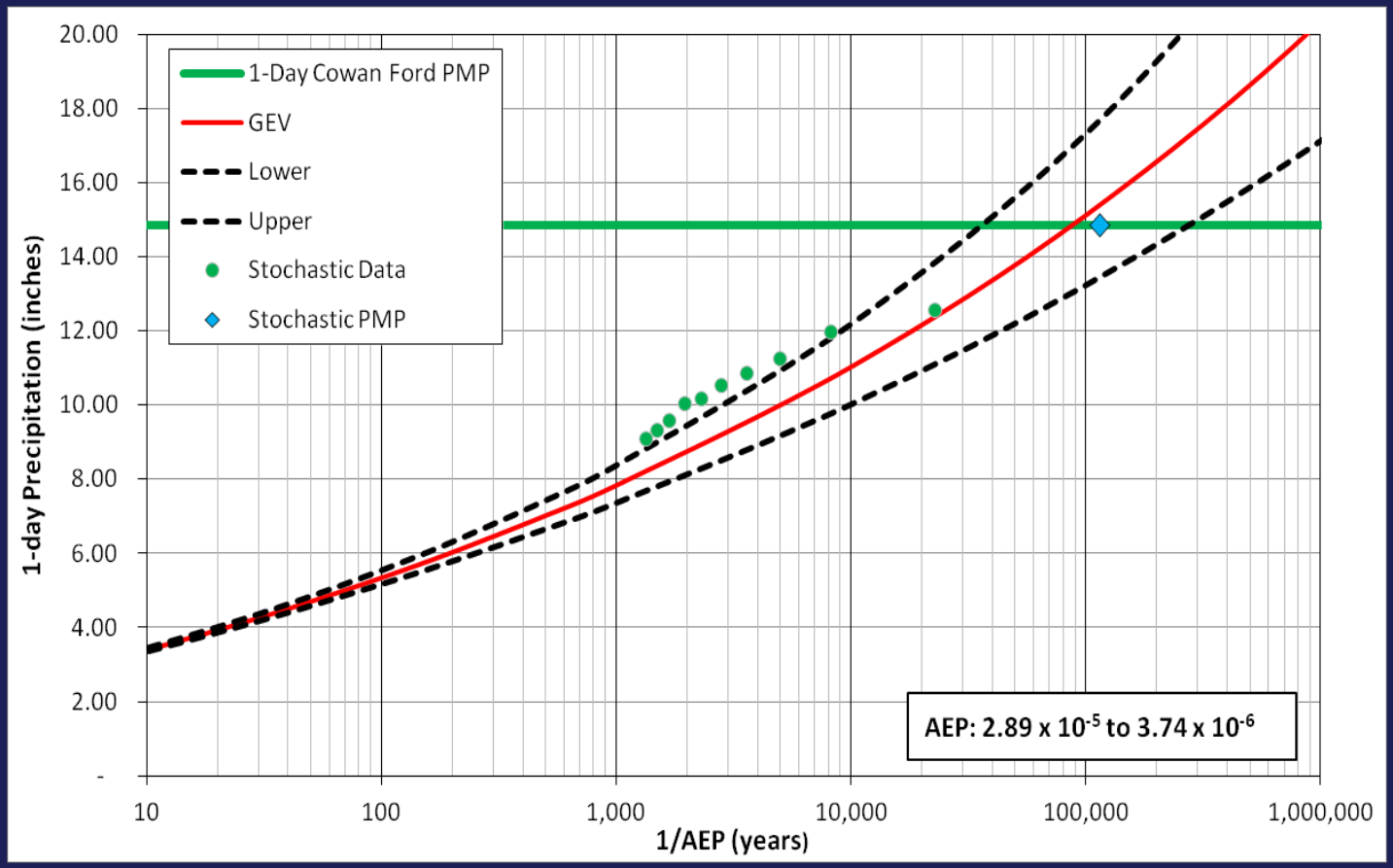




- Catawba Basin (4737-sqmi)
- PMP = 12.96”
- AEP = 1.90×10^{-5} (52,629 yrs)

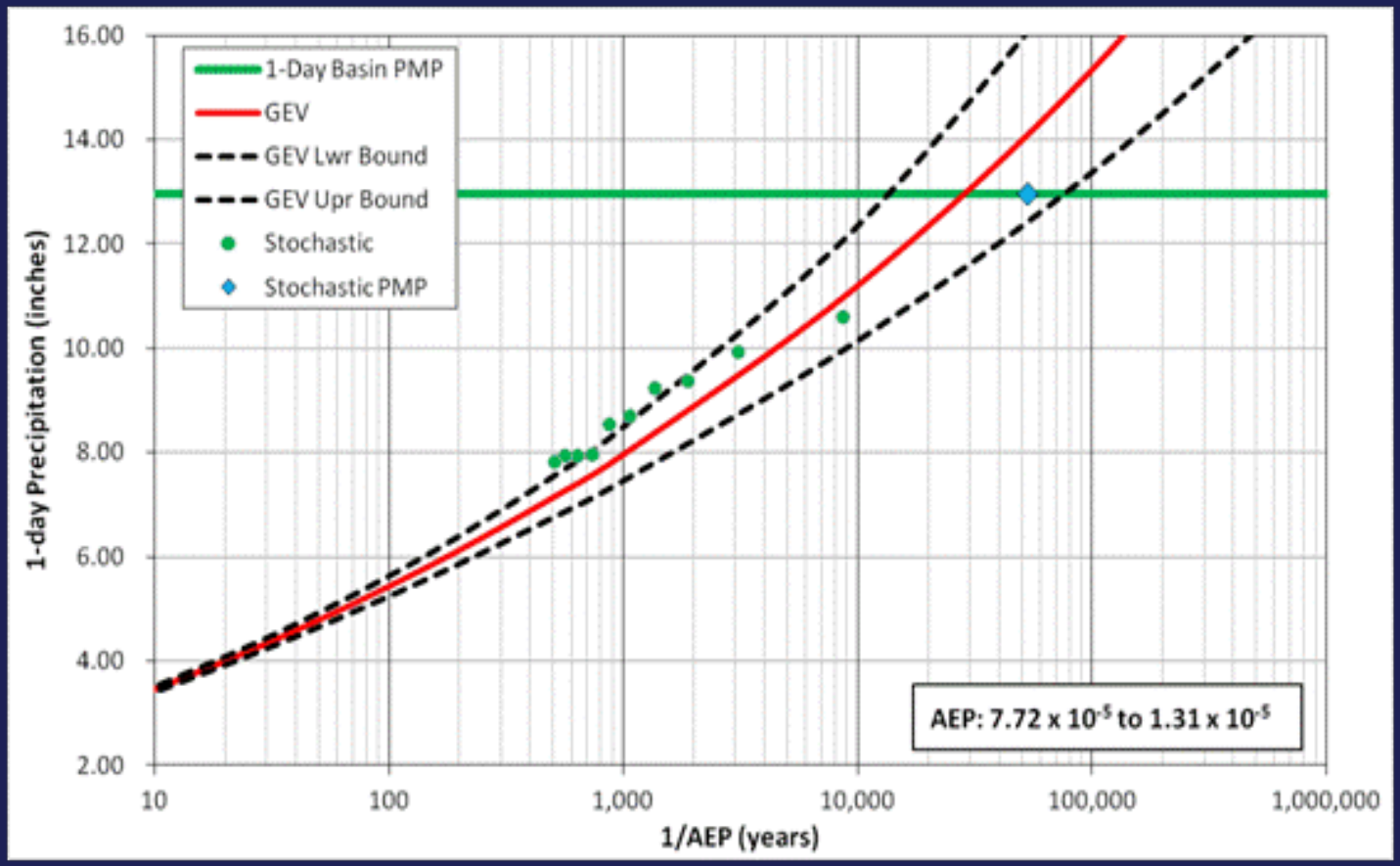
Summary of 1-Day Precipitation Frequency

- Cowan Ford Basin (1793-sqmi)
- AEP = 2.89 x 10^{-5} to 3.74 x 10^{-6}



Summary of 1-Day Precipitation Frequency

- Catawba Basin (4737-sqmi)
- AEP = 7.72×10^{-5} to 1.31×10^{-5}



Summary of PMP Probability Methods

- AEP of PMP ranges from 10^{-5} to 10^{-7} AEP
  - Varies by location, duration, and storm areal coverage
- Multiple methods provide confidence in AEP

Basin	Stochastic	AEP Upper	AEP Lower
Bridgewater	8.87×10^{-7}	7.41×10^{-6}	5.88×10^{-7}
Cowans Ford	8.78×10^{-6}	2.89×10^{-5}	3.74×10^{-6}
Catawba	1.90×10^{-5}	7.72×10^{-5}	1.31×10^{-5}