HYDROLOGY - 2

Precipitation

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Definition of Precipitation

Definition

- ***Precipitation*** consists of rain, snow, hail or sleet, all of which emerge by condensation of moisture in the atmosphere and subsequently descend to the ground

Due to specific climatic conditions of our state, from this point forward in this presentation, our focus will be on rainfall

"***On average the global precipitation increases in a warmer climate***"
Gerald Meehl

Significant Facts about Precipitation

- Precipitation is one important component or system of the Hydrologic Cycle (***HC***) because it returns the water back to the Earth
- Precipitation on Earth (global annual average)
  - ✓ **Land** = 119,000 Km^3 (approximately 9.2 times the water in the atmosphere, which is 12,900 Km^3 → ***31 inch/year*** (*800 mm/year*)
  - ✓ **Oceans** = 458,000 Km^3 (approximately 35.5 times) → ***50 inch/year*** (*1268 mm/year*)
- Much more activity over the oceans than over the land (3.85 larger: 458,000 Km^3/year and 119,000 Km^3/year, respectively)

The Precipitation Process

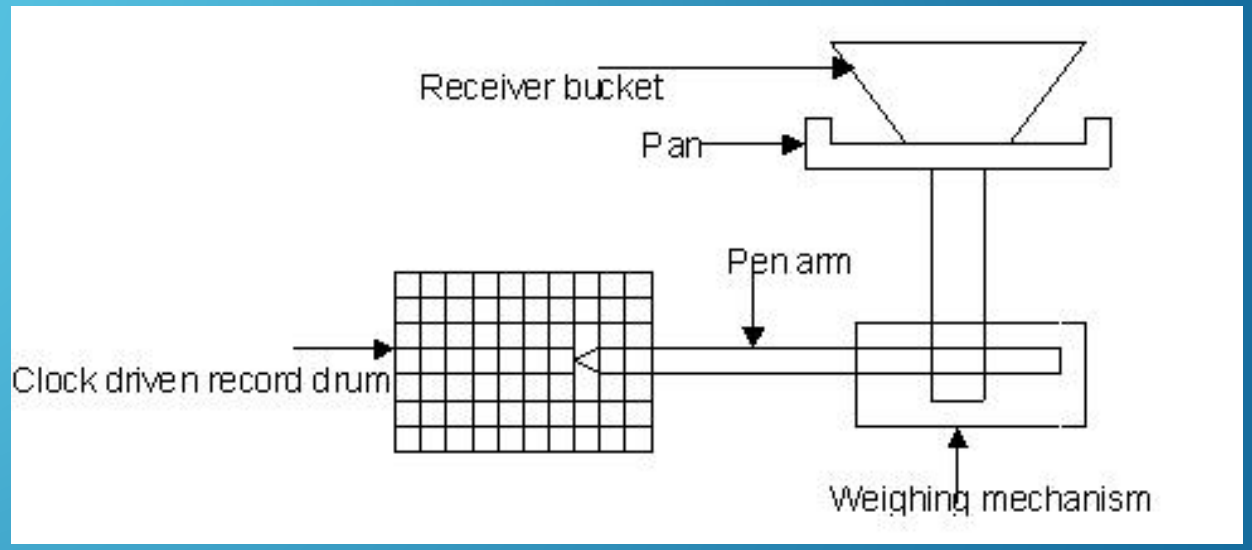
- The sun is the driving force behind the convection activity which is the most important one in the formation of rain
- The sun heats up the surface water (mostly in oceans and seas) and this in turn warms up the air in the atmosphere, then the water is converted into water vapor
- Warmed air rises up into the atmosphere and takes the water vapor with it. As they rise further away from the heat source (oceans, seas, etc.), the temperature of the water vapor continuously decreases

The Precipitation Process

- This activity reaches the point where eventually the water vapor condenses and forms the clouds which become visible
- Clouds move in the atmosphere depending on the wind activity. Water droplets within the clouds collide and join together by saturation activity until they cannot remain in equilibrium any longer and form rain drops, which fall back down to the surface of the Earth
- In conclusion, precipitation is generally more abundant close to the Equator, in coastal areas and in the mountains. It also depends on the temperature and atmospheric fronts.

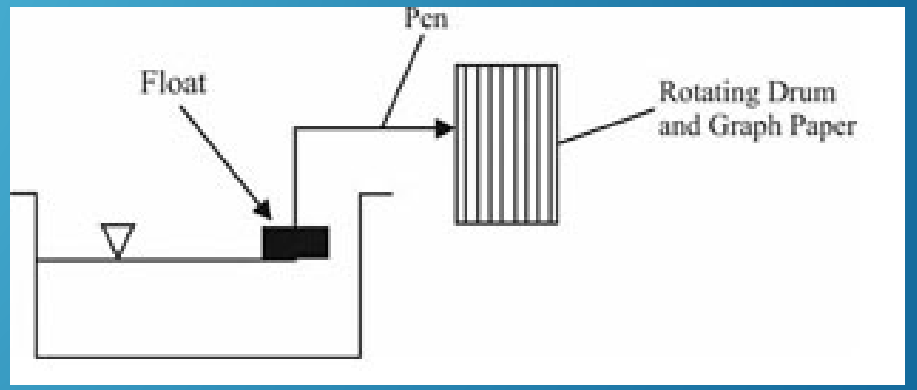
Precipitation Measurement

- Rain Gauges (a.k.a. pluviometers) are devices to gather and register precipitation data. They suffer from errors due to physical conditions (wind, temperature, etc.) of the environment where they are located
  - ✓ **Recording rain gauges** automatically record rainfall accumulation at temporal resolutions to 1 min or less and they are often equipped with telemetry systems to allow real-time transmission of the data. The three major types of these rain gauges are the ***weighing*** type, the ***float*** type, and the ***tipping-bucket*** type
  - ✓ **Non-recording rain gauges** are cylindrical containers with measuring stick or scale. These are primitive devices that require manual labor



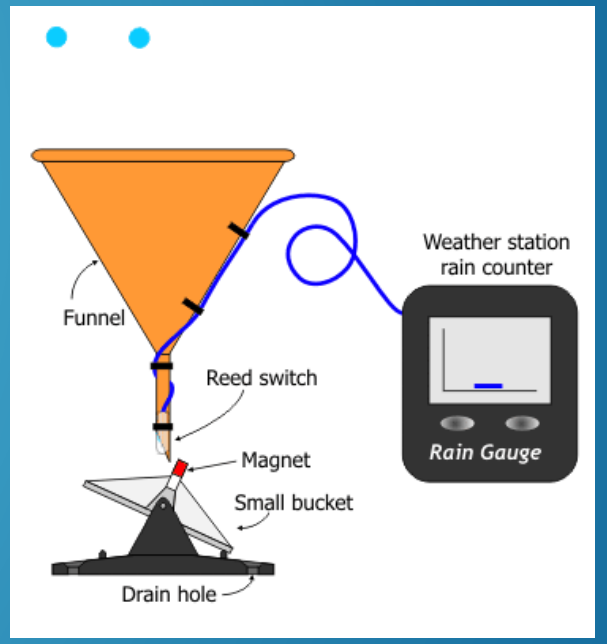
Weighing Rain Gauge and its basic mechanism

Precipitation Measurement



Float Rain Gauge and its basic mechanism

Precipitation Measurement



Tipping-bucket Rain Gauge and its basic mechanism

Precipitation Measurement

Precipitation Measurement

- Radars provide high resolution both spatial and temporal of rainfall (1Km^2 and 5 min, respectively). NEXRAD (Next-Generation Radar) is a network of 158 high Doppler Weather Radars operated by the National Weather Service (NOAA). The first unit, located in Oklahoma City, began operation in 1991. WSR-88D (Weather Surveillance Radar 88 Doppler) system was founded in 1988 in Norman, OK. It began the use of radars and their control and processing equipment to collect rainfall and atmospheric movement (wind) for weather forecasting.

Spatial Estimation of Rainfall

- It is often necessary in hydrology to calculate mean areal precipitation for a basin from rain gauge records
- Most of the methods that are used for these calculations can be expressed as linear combination of the records
- The ***Thiessen Polygon*** method is based on the assumption that for any point in the basin, its rainfall is equal to the rainfall recorded at the closest rain gauge. The mean areal precipitation for the basin can be estimated as a *weighted* mean or average based on the area of influence for each rain gauge.

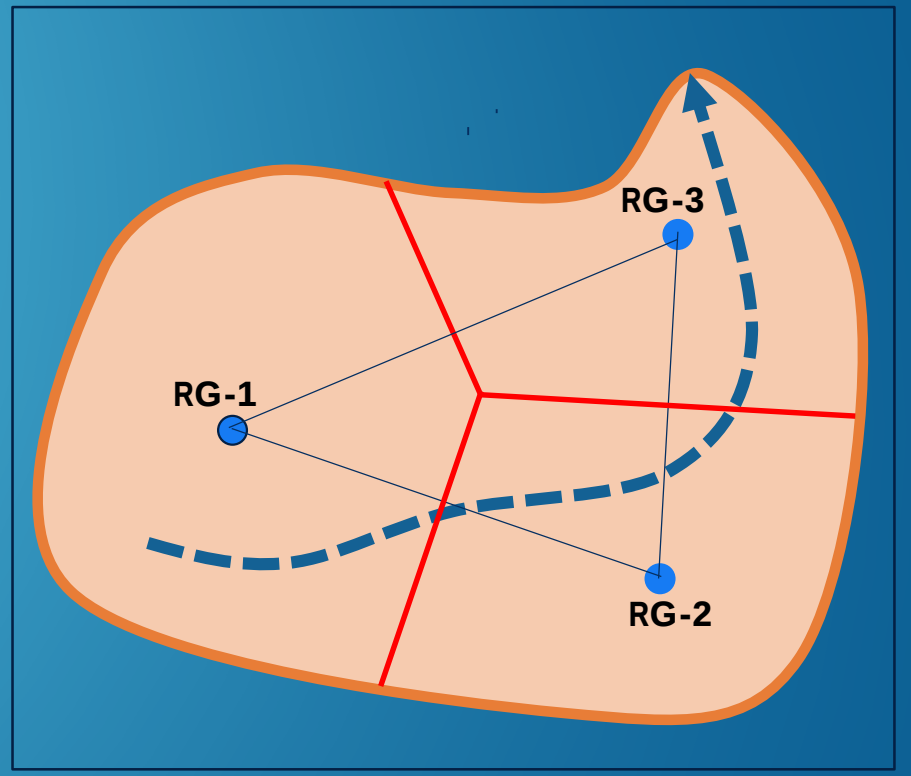
Spatial Estimation of Rainfall

- The stream shown has a basin with a surface area of 60 acres and three rain gauges
- Polygons are determined by joining every gauge with straight lines, then drawing the perpendicular bisector to each line
- The surface areas for each polygon are:

  $A_{(RG-1)}$ = 24.6 acres

  $A_{(RG-2)}$ = 19.2 acres

  $A_{(RG-3)}$ = 16.2 acres



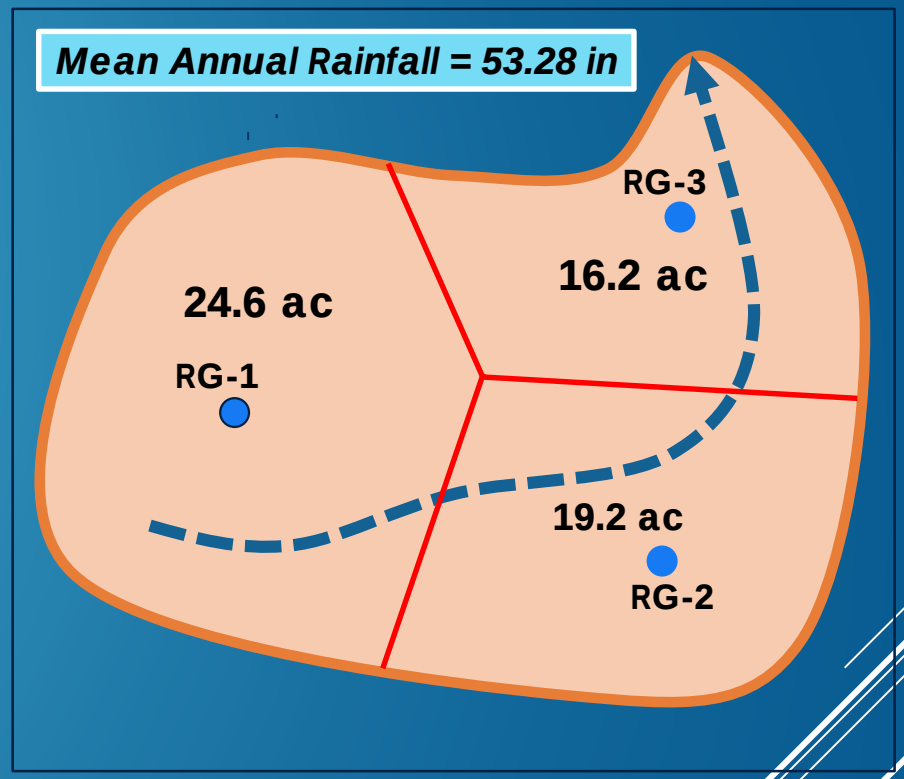
Spatial Estimation of Rainfall

- From 30-year record, the mean annual rainfall is given in the following table

Calculation of Mean Annual Rainfall for the Basin

	RG-1	RG-2	RG-3
P, mean annual rainfall (in)	56.8	50.6	51.1
A, Thiessen Polygon (acres)	24.6	19.2	16.2
a, area ratio of each polygon	0.41	0.32	0.27
P x a **(in)**	23.29	16.19	13.80

$$\overline{P} = \sum_{i=1}^{n} P_i \times a_i = P_1 \times a_1 + P_2 \times a_2 + \ldots P_n \times a_n = 23.29 + 16.19 + 13.80 = 53.28 in \ldots [2.1]$$



Estimation of Missing Data

- In hydrologic analysis, missing rainfall data occurs frequently and when required has to be estimated based on records from nearby stations
- Data of an 18-hour storm is missing for a station (RG-4) that is nearby the three previous stations (RG-1, RG-2 and RG-3). The mean annual rainfall for **RG-4** is **54.6 in**

Mean Annual and 18-hour Storm Rainfall for the four Stations

	RG-1	RG-2	RG-3	RG-4
P, mean annual rainfall (inch)	56.8	50.6	51.1	54.6
Ps, storm rainfall (inch)	3.6	3.0	4.1	*missing*

Estimation of Missing Data

- The rainfall for the18-hour storm at RG-4 can be estimated as follows,

$$Ps_{RG-4(mis)} = \frac{1}{3}\left(Ps_{RG-1}\frac{P_{RG-4}}{P_{RG-1}} + Ps_{RG-2}\frac{P_{RG-4}}{P_{RG-2}} + Ps_{RG-3}\frac{P_{RG-4}}{P_{RG-3}} \right) ...[2.2]$$

The ratios of the above equation are calculated by the mean annual rainfall of the station with the missing data (RG-4) divided by the mean annual data of the three used stations (RG-1, RG-2 and RG-3)

$$Ps_{RG-4(mis)} = \frac{1}{3}\left(3.6inch\frac{54.6}{56.8} + 3.0inch\frac{54.6}{50.6} + 4.1inch\frac{54.6}{51.1} \right) = 3.7inch$$

	RG-1	RG-2	RG-3	RG-4
P (inch)	56.8	50.6	51.1	54.6
Ps (inch)	3.6	3.0	4.1	*missing*

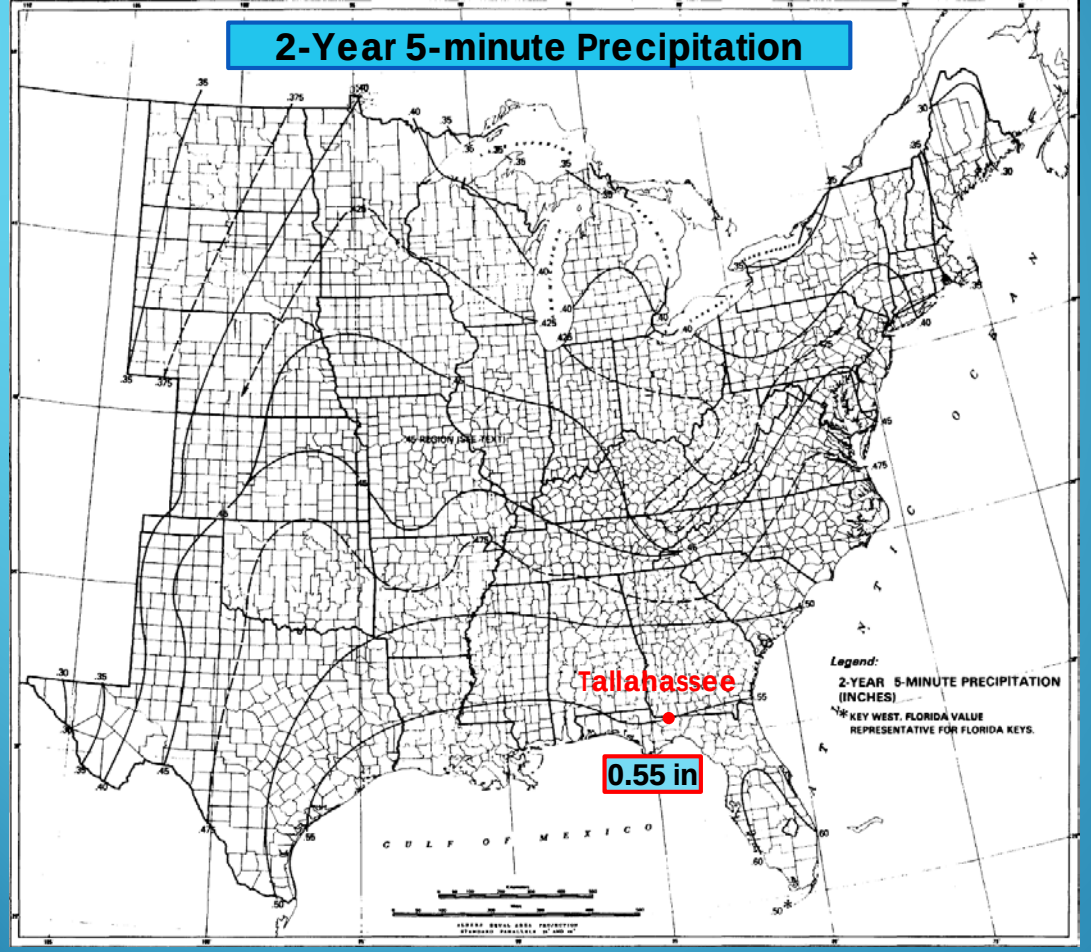
Precipitation Frequency Analysis

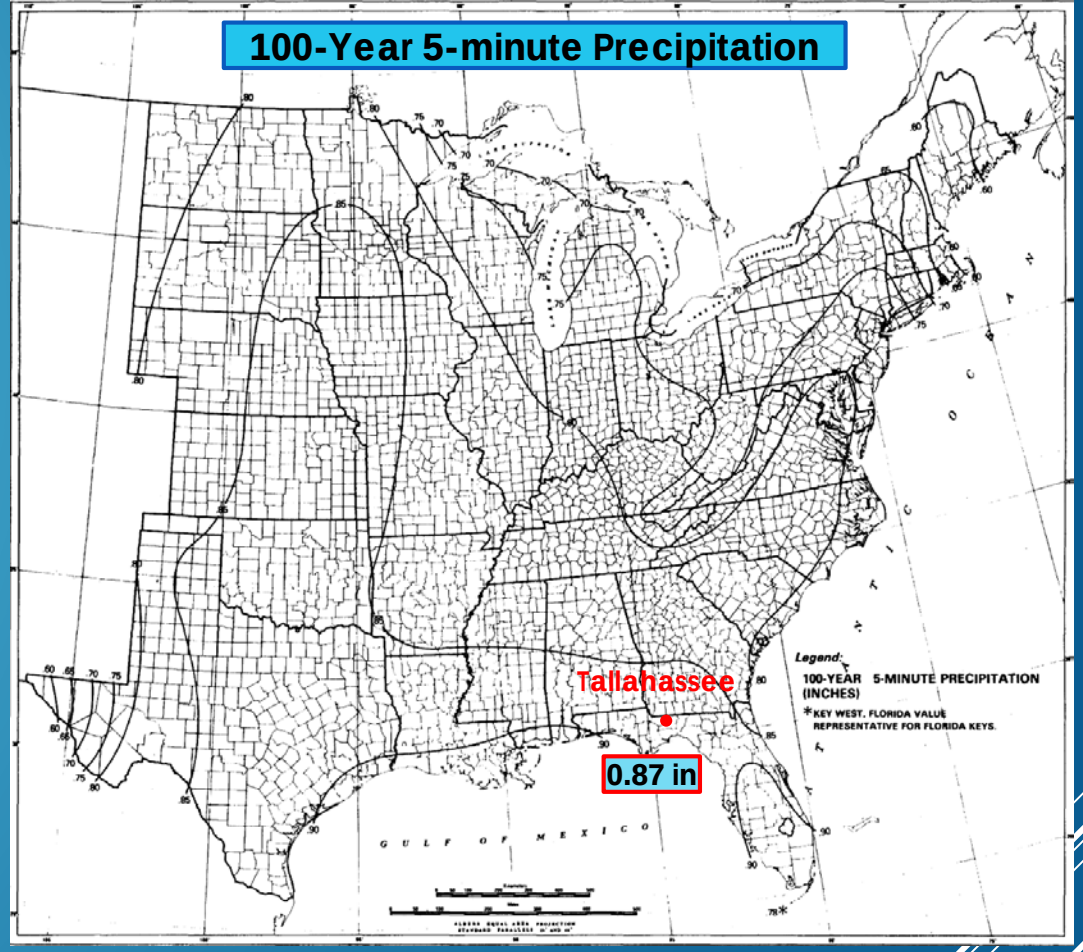
- Precipitation Frequency Analyses are widely used in design works that control and convey storm runoff. They are also used in non-structural problems involving natural hazards. Their purpose is to compute the amount of precipitation falling over a given area, in a specific duration with a given probability of occurrence in any given year
- The probability of occurrence of a storm is equal to the inverse of its return period,

$$p = \frac{1}{T} \ldots [2.3]$$

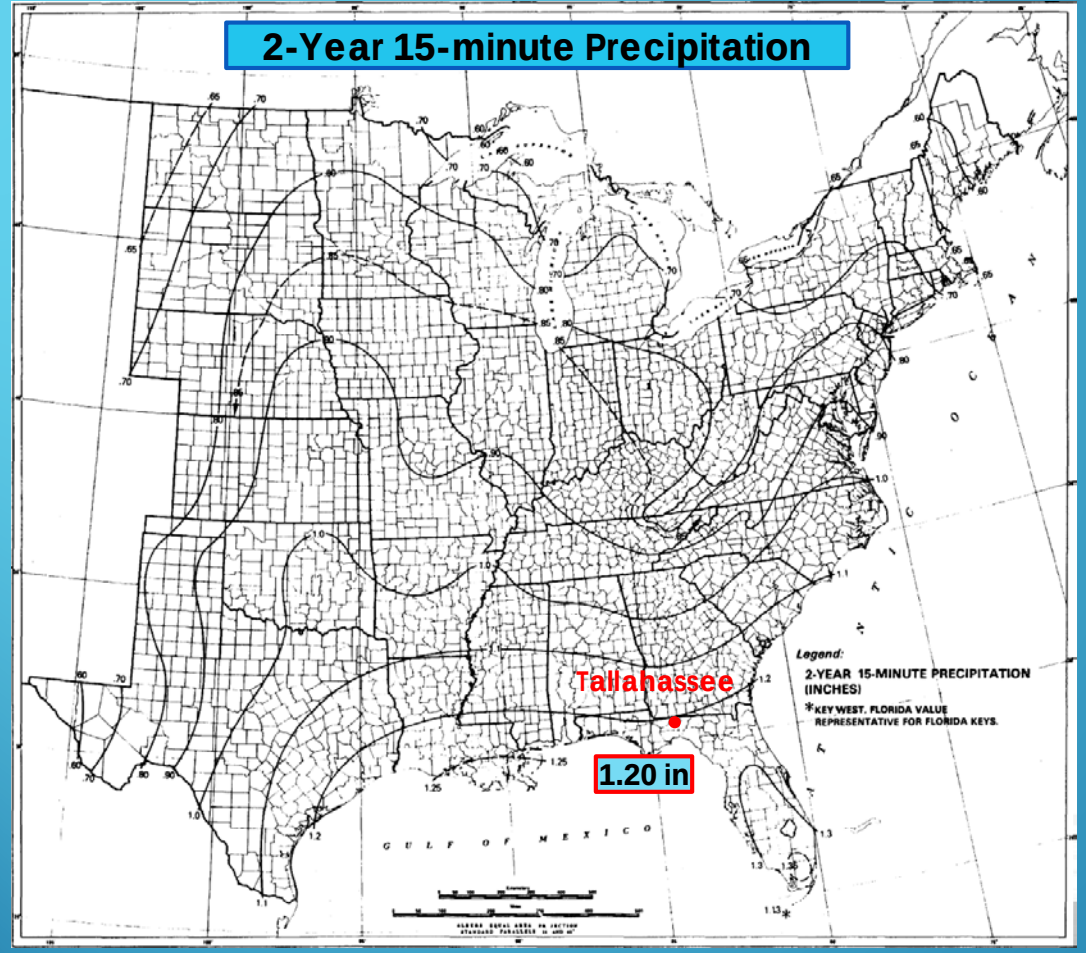
Precipitation Frequency Analysis

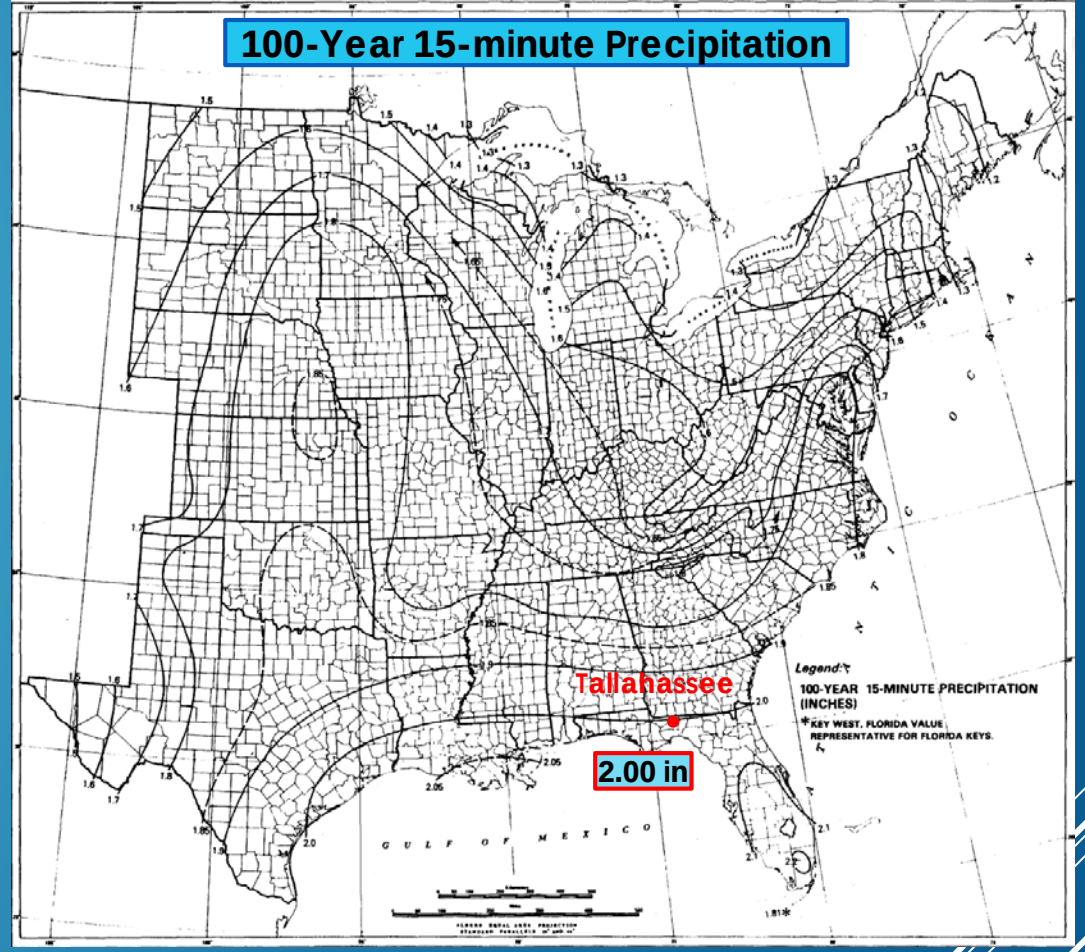
- If a storm has a return period, ***T*** of 5 years (i.e., it would occur statistically every 5 years), its occurrence probability, ***p*** will be 1/5 = 0.2 or 20%. If ***T*** is 100 years, ***p*** will be 1/100 = 0.01 or 1%
- NOAA released its Technical Memorandum ***NWS HYDRO-35*** in June 1977 entitled ***Five- to 60-minute Precipitation Frequency for the Eastern and Central United States***. The report provides isohyets (contour lines) for 5-, 15- and 60-minute durations with 2- and 100-year return periods. Additionally, it gives equations statistically developed to compute interpolated precipitation frequencies



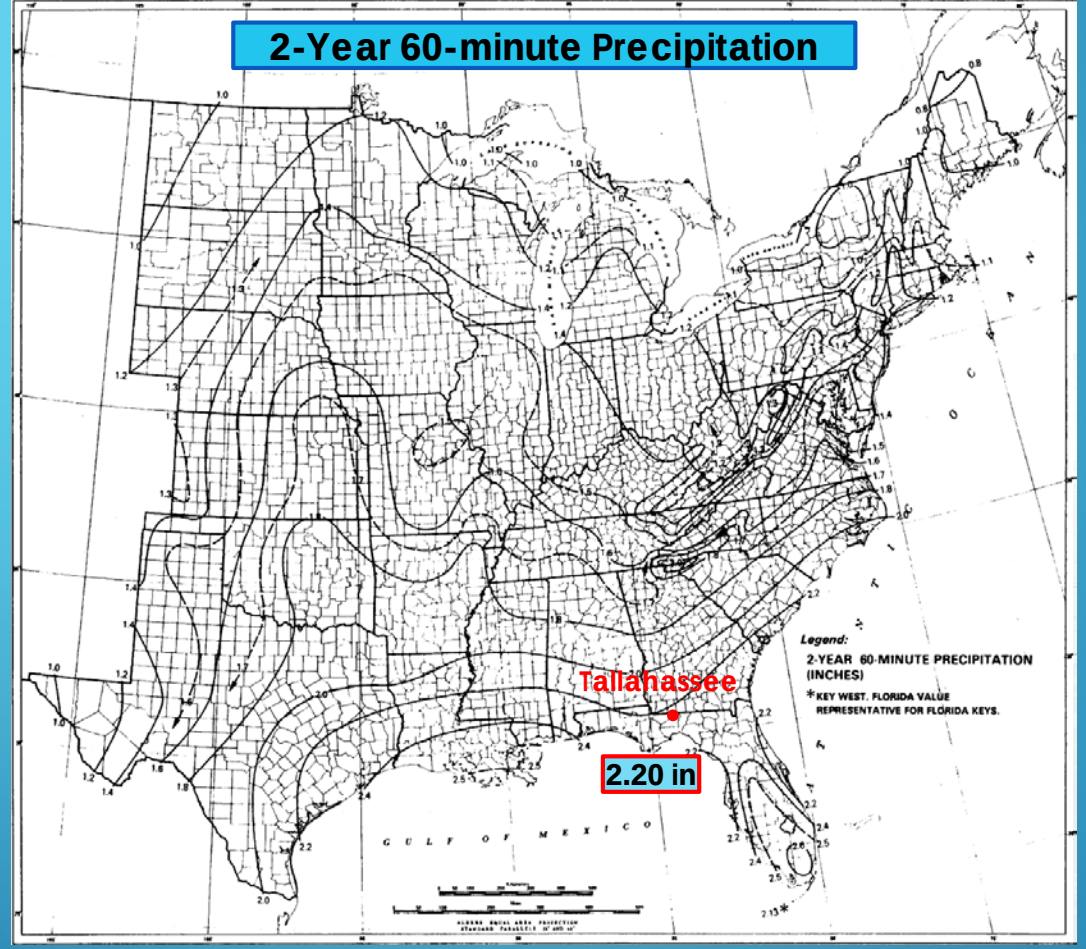


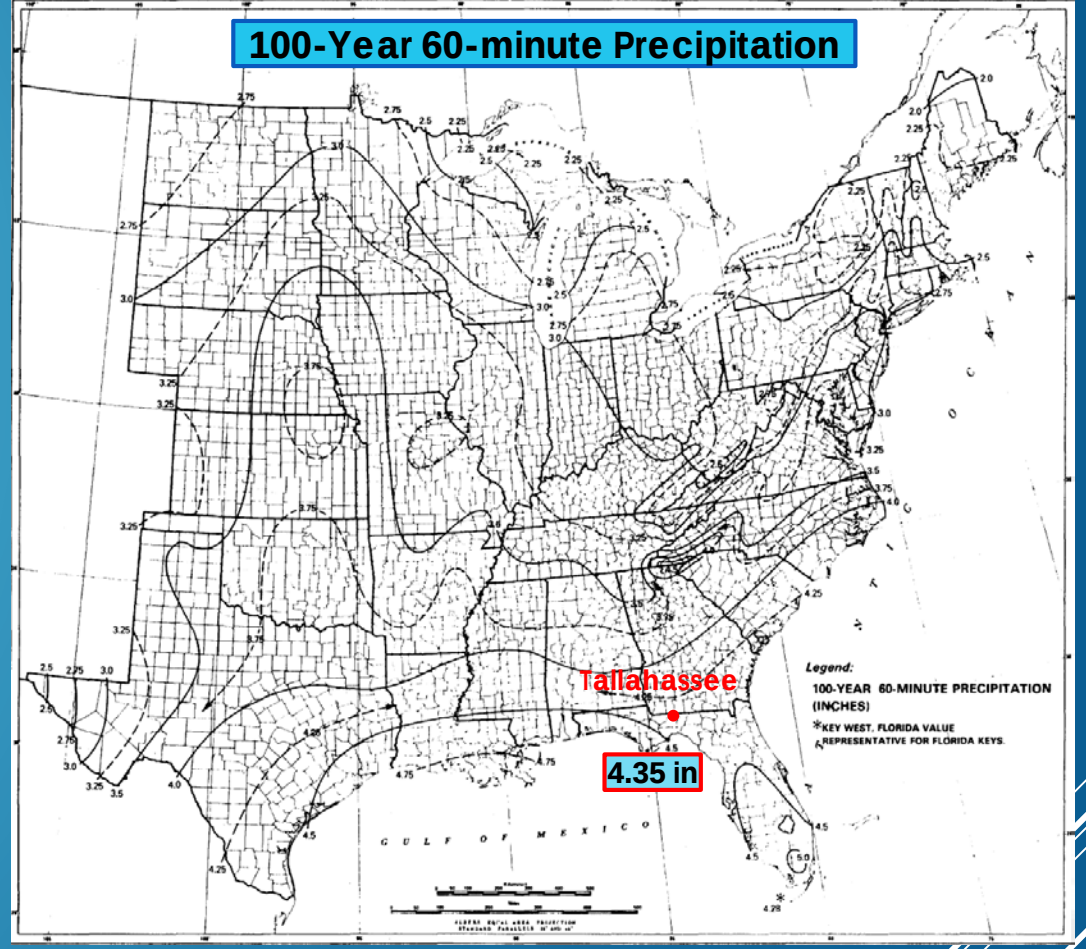
Precipitation Frequency Analysis





Precipitation Frequency Analysis





Precipitation Frequency Analysis

Precipitation Frequency Analysis

- Empirical equations for relating the isohyets for the six maps from the ***NWS HYDRO-35*** are as follows,
  - ✓ Precipitation values for ***10-*** and ***30-minute*** durations can be estimated from the *5-* and *15-minute* and from the *15-* and *60-minute* values, respectively for both ***2-*** and ***100-year*** return periods

$$P_{10\text{min}} = 0.41 \times P_{5\text{min}} + 0.59 \times P_{15\text{min}} \ldots [2.4]$$

$$P_{30\text{min}} = 0.51 \times P_{15\text{min}} + 0.49 \times P_{60\text{min}} \ldots [2.5]$$

  - ✓ Precipitation values for other return periods between ***2-*** and ***100-year*** can be computed by the following equation,

$$P_{T-yr} = a \times P_{2-yr} + b \times P_{100-yr} \ldots [2.6]$$

parameters *a* and *b* for several return periods are provided in the following table

TABLE 2.1 Frequency Parameters for Use with Eq. 2.6 (NWS HYDRO-35)

Return Period, T (years)	a	b
5	0.674	0.278
10	0.496	0.449
25	0.293	0.669
50	0.146	0.835

Precipitation Frequency Analysis

Precipitation Frequency Analysis

- Precipitation values from the six maps (2- and 100-year return periods and 5-, 15- and 60-min durations)
- Eqs. **2.4**, **2.5** and **2.6** and parameters a and b from Table **2.1** are used to compute the additional precipitation frequency values

Precipitation (inch) Frequency for Tallahassee (NWS HYDRO-35)

Duration \ Probability, p	0.50	0.20	0.10	0.04	0.02	0.01
	2-year	5-year	10-year	25-year	50-year	100-year
5-min	0.55	0.61	0.66	0.74	0.81	0.87
10-min	0.93	1.06	1.15	1.30	1.42	1.54
15-min	1.20	1.36	1.49	1.69	1.85	2.00
30-min	1.69	2.02	2.25	2.60	2.88	3.15
60-min	2.20	2.69	3.04	3.55	3.95	4.35

0.41x**0.87**+**0.59**x**2.0** [2.4]

0.51x**2.0**+**0.49**x**4.35** [2.5]

0.293x**1.69**+**0.669**x**3.15** [2.6]

Intensity Duration Frequency Curves

- Some design methods in hydrology need rainfall intensity which is defined as a rainfall depth per time (inch/hour) for a storm with a specific return period ***T***. Intensity Duration Frequency (***IDF***) curve calculations are carried out in the following table:

Estimated Values of Rainfall Intensity (inch/hour) for Tallahassee IDF

Probability, p / Duration	0.50	0.20	0.10	0.04	0.02	0.01
	2-year	5-year	10-year	25-year	50-year	100-year
5-min	6.60	7.32	7.92	8.88	9.72	10.44
10-min	5.58	6.36	6.90	7.80	8.52	9.24
15-min	4.80	5.44	5.96	6.76	7.40	8.00
30-min	3.38	4.04	4.50	5.20	5.76	6.30
60-min	2.20	2.69	3.04	3.55	3.95	4.35

0.87/(5/60)

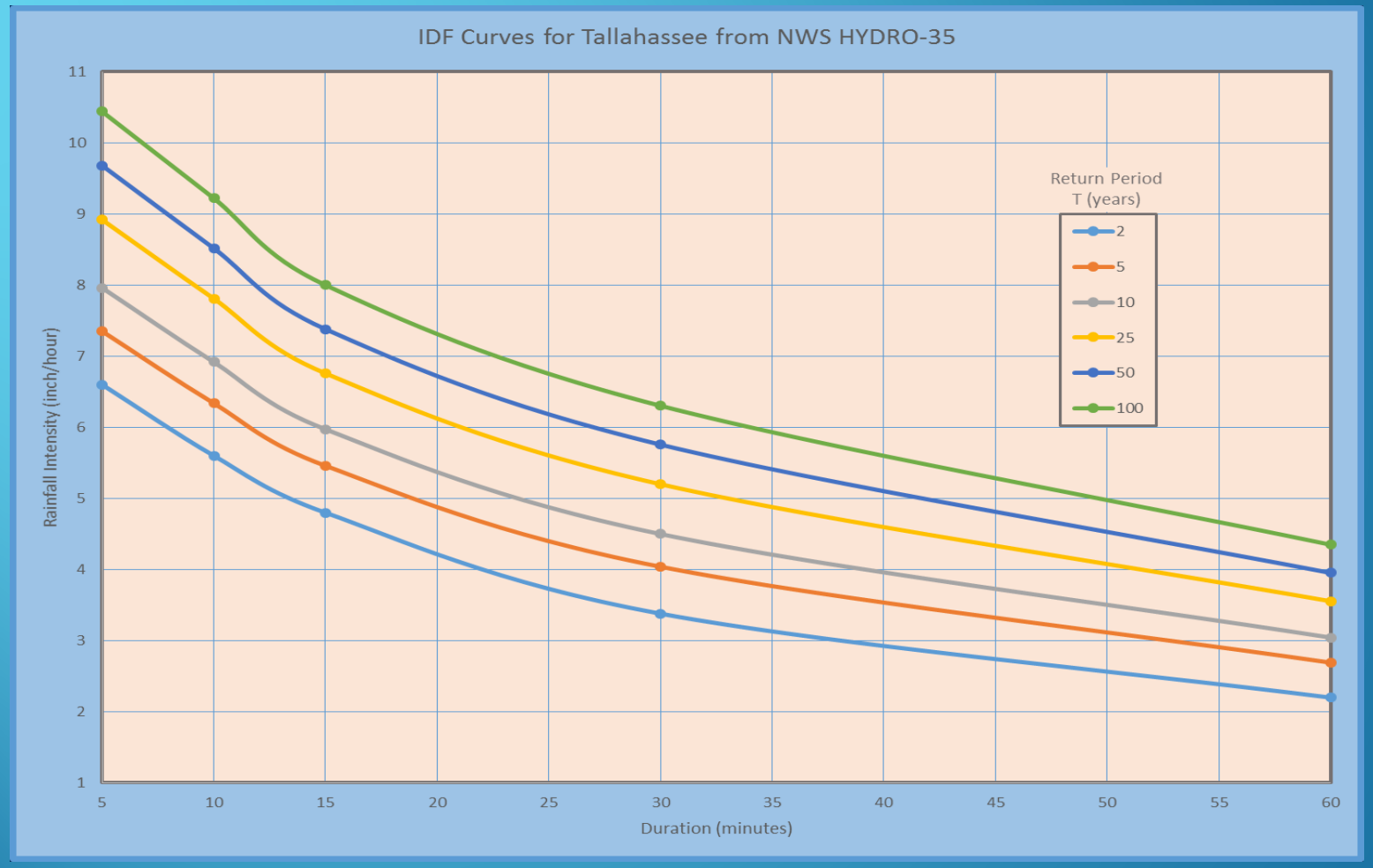
0.55/(5/60)

1.06/(10/60)

1.49/(15/60)

2.60/(30/60)

3.95/(60/60)



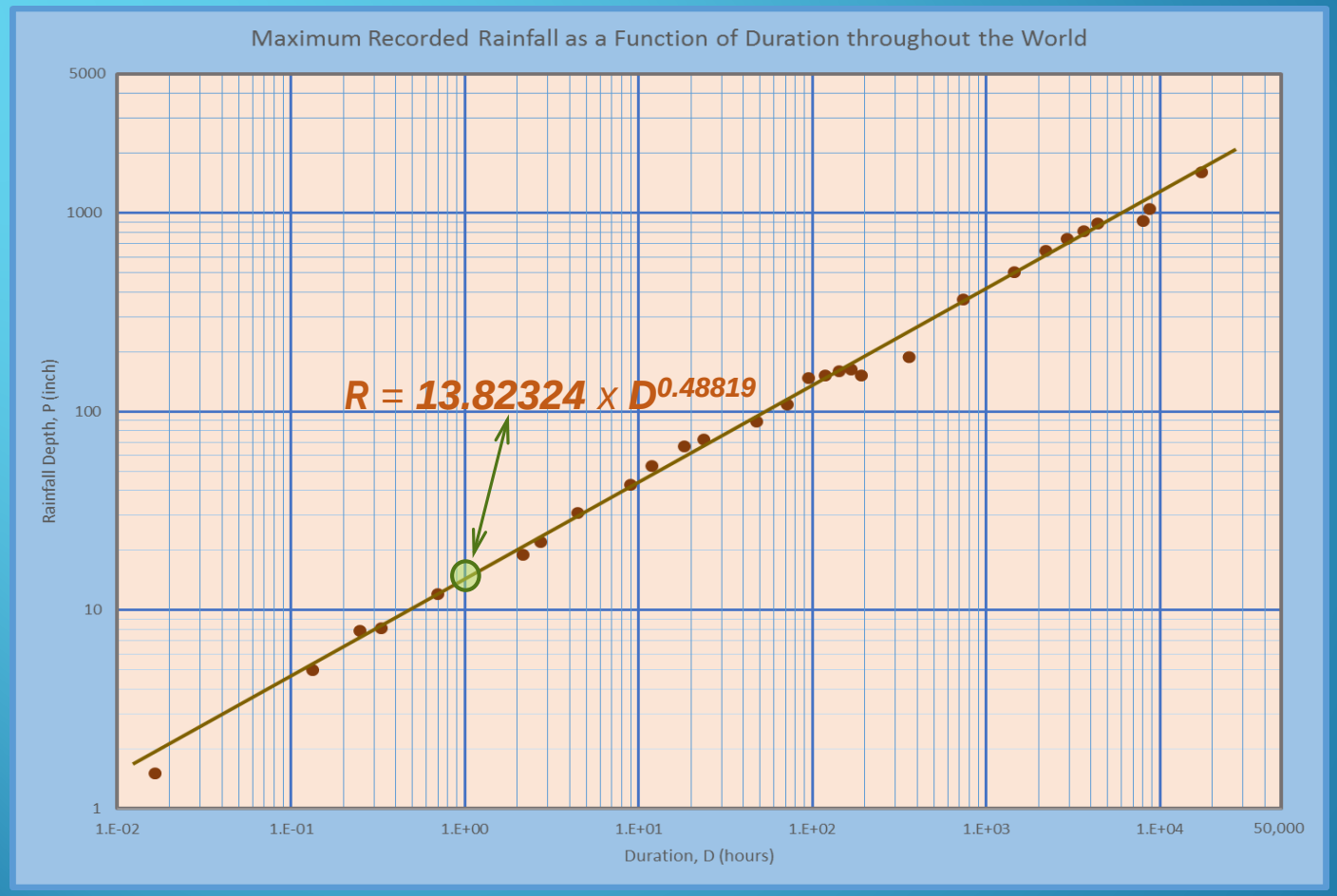
Intensity Duration Frequency Curves

Probable Maximum Precipitation

- Design of high-hazard structures such as spillways on large dams require precipitation values with very low risk of exceedance
- The values are achieved by the ***Probable Maximum Precipitation*** (***PMP***) which represents the upper limit of a realistic rainfall amount
- ***PMP*** is defined by the WMO as "theoretically the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location at a certain part of year"
- Analysis on 41 sites in eastern and central United States showed that observed extreme rainfall was, on average, 60% of ***PMP*** estimate at those sites

Duration	hours	P (inch)	P (mm)	I (inch/hr)	Station Location	Date
1 m	0.017	1.50	38	90.00	Barot, Guadeloupe	Nov 26, 1970
8 m	0.133	4.96	126	37.20	Fussen, Bavaria, Germany	May 25, 1920
15 m	0.25	7.80	198	31.20	Plumb Point, Jamaica	May 12, 1916
20 m	0.33	8.10	206	24.30	Curtea-de-Arges, Romania	Jul 7, 1947
42 m	0.7	12.00	305	17.14	Holt, MO, USA	Jun 22, 1948
2 h-10 m	2.17	19.00	483	8.77	Rockport, WV, USA	Jul 18, 1942
2 h-45 m	2.75	22.00	559	8.00	D'Hanis, TX, USA	May 31, 1935
4 h-30 m	4.50	30.80	782	6.84	Smerhport, PA, USA	Jul 18, 1942
9 h	9	42.79	1087	4.75	Belouve, La Réunion	Feb 28, 1964
12 h	12	52.76	1340	4.40	Belouve, La Réunion	Feb 28-29, 1964
18 h-30 m	18.5	66.49	1689	3.59	Belouve, La Réunion	Feb 28-29, 1964
24 h	24	71.85	1825	2.99	Foc Foc, La Réunion	Mar 15-16, 1953
2 d	48	88.94	2259	1.85	Hsin-Liao, Taiwan	Oct 17-18, 1967
3 d	72	108.62	2759	1.51	Cherrapunji, India	Sep 12-14, 1974
4 d	96	146.50	3721	1.53	Cherrapunji, India	Sep 12-15, 1974
5 d	120	151.73	3854	1.26	Cilaos, La Réunion	Mar 13-18, 1952
6 d	144	159.65	4055	1.11	Cilaos, La Réunion	Mar 13-19, 1952
7 d	168	161.81	4110	0.96	Cilaos, La Réunion	Mar 12-19, 1952
8 d	192	151.46	3847	0.79	Bellenden Ker, Australia	Jan 1-8, 1979
15 d	360	188.88	4798	0.52	Cherrapunji, India	Jun 24-Jul 8, 1931
31 d	744	366.14	9300	0.49	Cherrapunji, India	Jul 1861
2 m	1464	502.63	12767	0.34	Cherrapunji, India	Jun-Jul 1861
3 m	2208	644.44	16369	0.29	Cherrapunji, India	May-Jul 1861
4 m	2928	737.70	18738	0.25	Cherrapunji, India	Apr-Jul 1861
5 m	3672	803.62	20412	0.22	Cherrapunji, India	Apr-Aug 1861
6 m	4392	884.03	22454	0.20	Cherrapunji, India	Apr-Sep 1861
11 m	8016	905.12	22990	0.11	Cherrapunji, India	Jan-Nov 1861
1 y	8760	1041.78	26461	0.12	Cherrapunji, India	Aug 1860-Jul 1861
2 y	17520	1605.05	40768	0.09	Cherrapunji, India	1860-1861

World Record Rainfall



Regression Equation

$Y = m \times X + b$

m = slope (from log-log graph) = **0.48819**

b = y-intercept (from log-log graph corresponds to D =1 hour) = **1.14061**

Exponential Equation

$R\ (inch) = A \times D^{m}\ (hours)$

$A = 10^{b} = 10^{1.14061} = 13.82324\ inch$

r = correlation coefficient = **0.998**

$R = 13.82324 \times D^{0.48819}$

World Record Rainfall

Facts about Precipitation in Florida

- In spite of Florida's nickname "*The Sunshine State,*" our state has distinct dry and wet seasons which are characterized by very different weather conditions.
- Dry season extends through late fall, winter and early spring (November-April). Cold and dry fronts, originating in Canada, cross the state southeastward sweeping away hot and humid air. Any rain associated with the quick passage of these fronts does not dump significant rainfall. There are no tropical cyclones.

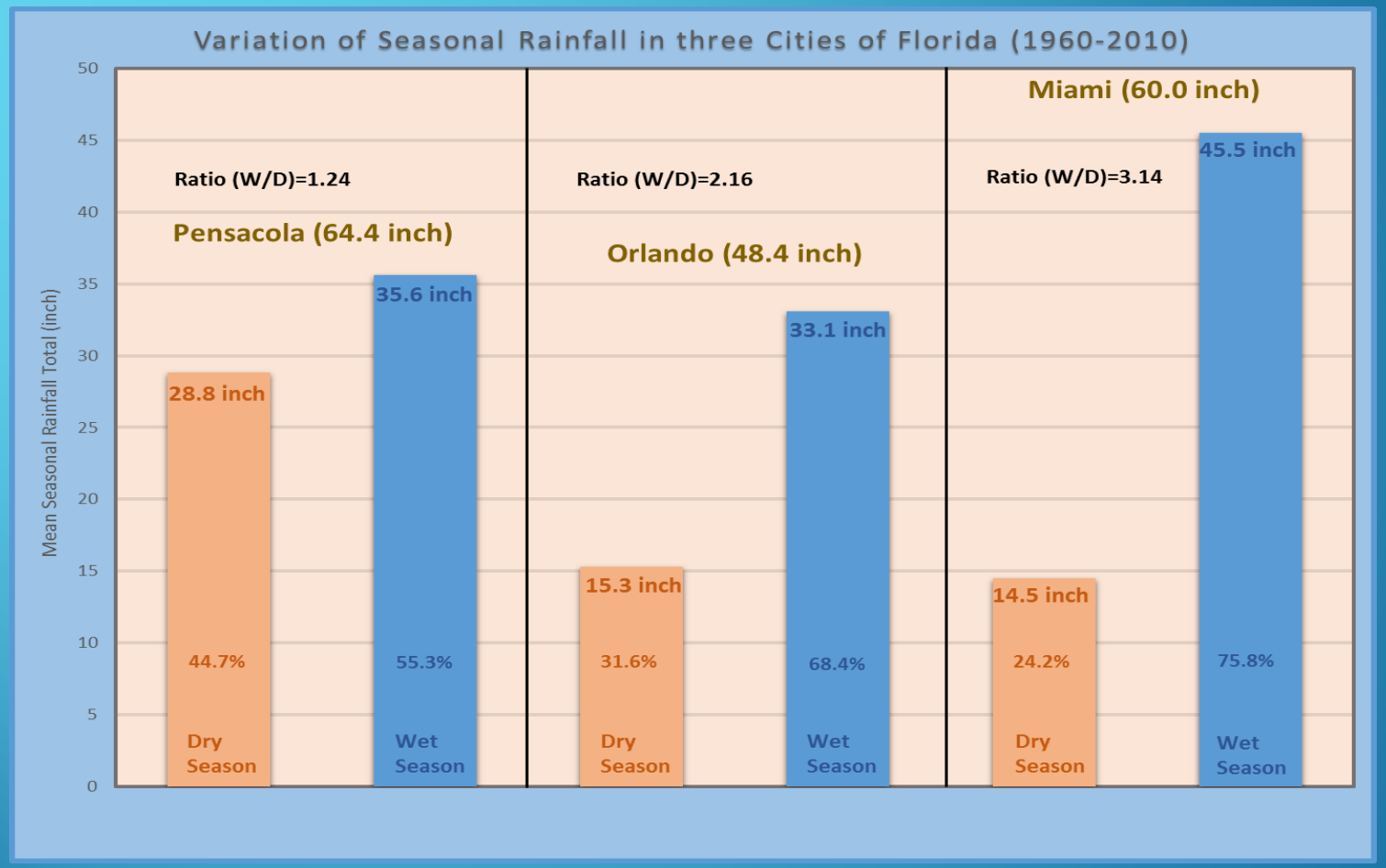
Facts about Precipitation in Florida

- The wet season starts in late spring and ends in early fall (May-October). By mid May cold fronts cannot penetrate into Florida allowing hot and humid atmospheric layers to build. As cooler air from the Gulf of Mexico and the Atlantic Ocean is pulled inland, sea-breeze fronts form and create thunderstorms of an almost daily occurrence. Their frequency and slow movement creates the significant difference in seasonal rainfall in Florida. Tropical cyclone activity is a threat that can contribute to extreme rainfall events in the wet season.
- To analyze this seasonal variation in Florida, the average monthly rain in three cities is shown in the following table.

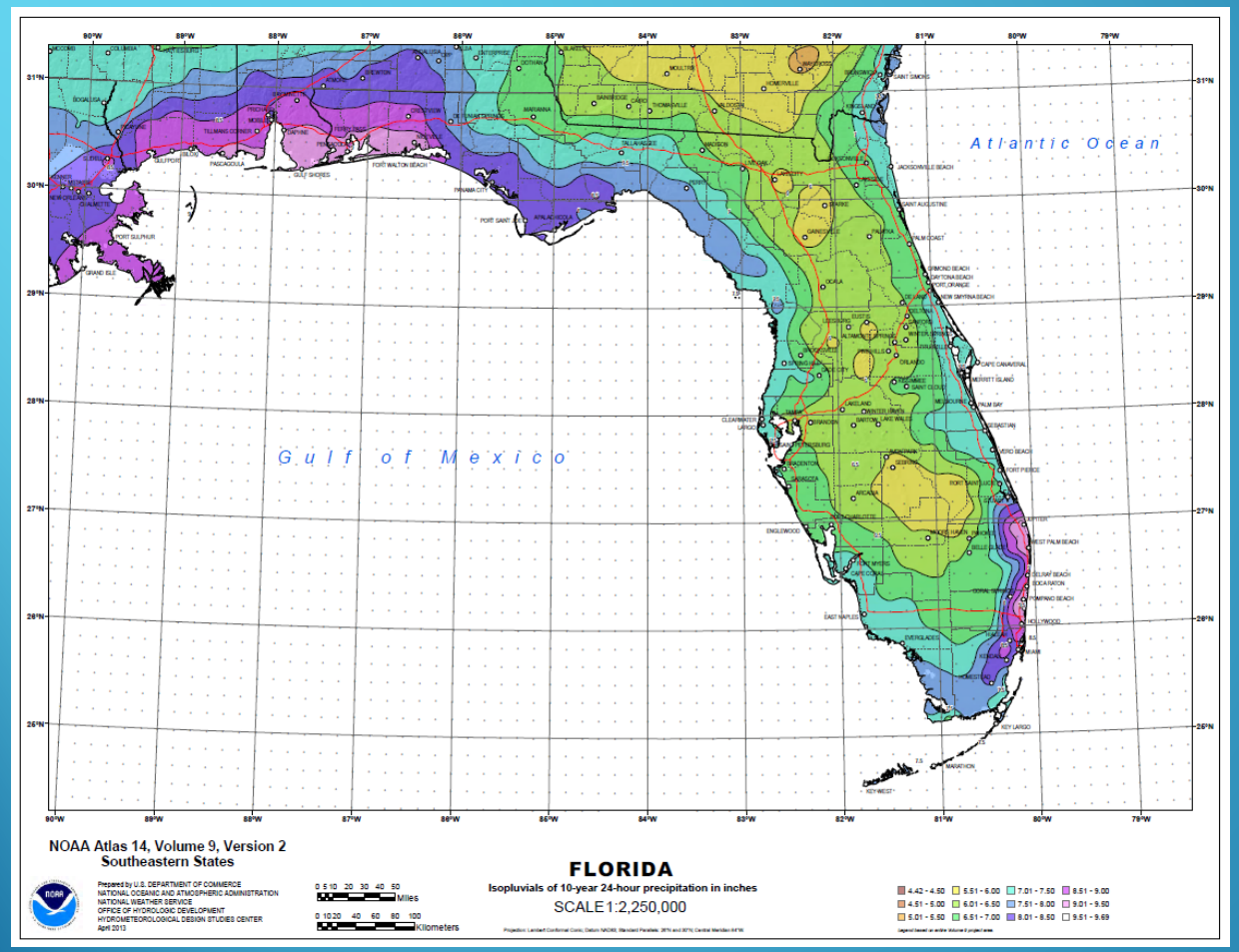
TABLE 2.2 Mean Monthly Rainfall and Mean Annual Rainfall Total from 51-year record (1960-2010)

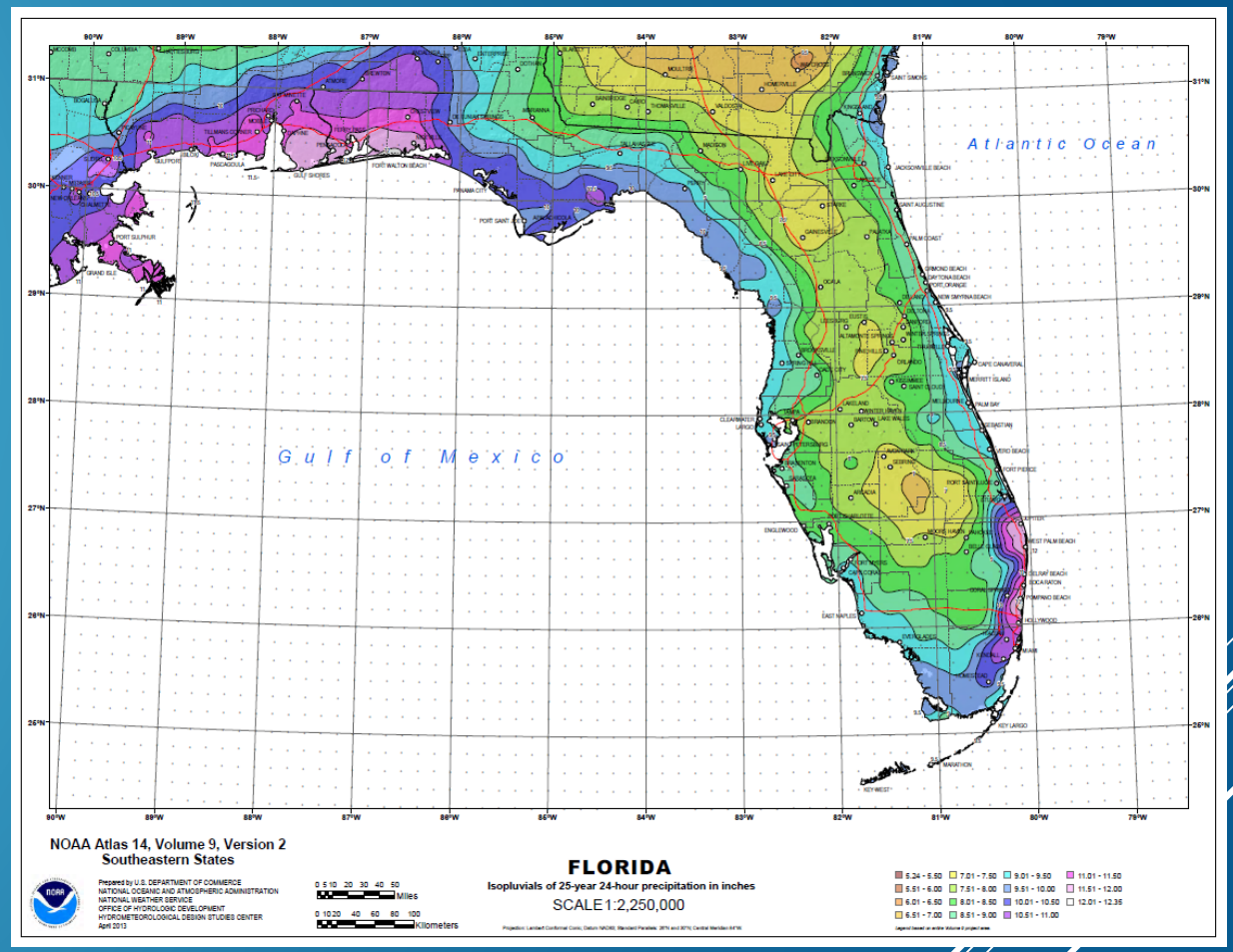
City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total (inch)
	Mean Monthly Rainfall (inch)												
Pensacola	5.3	4.7	6.4	3.9	4.4	6.4	8.0	6.9	5.8	4.1	4.5	4.0	64.4
Orlando	2.4	2.4	3.5	2.4	3.7	7.4	7.2	6.3	5.8	2.7	2.3	2.3	48.4
Miami	1.8	2.1	2.5	3.2	5.9	9.3	6.2	8.0	9.1	7.0	2.9	2.0	60.0

Facts about Precipitation in Florida

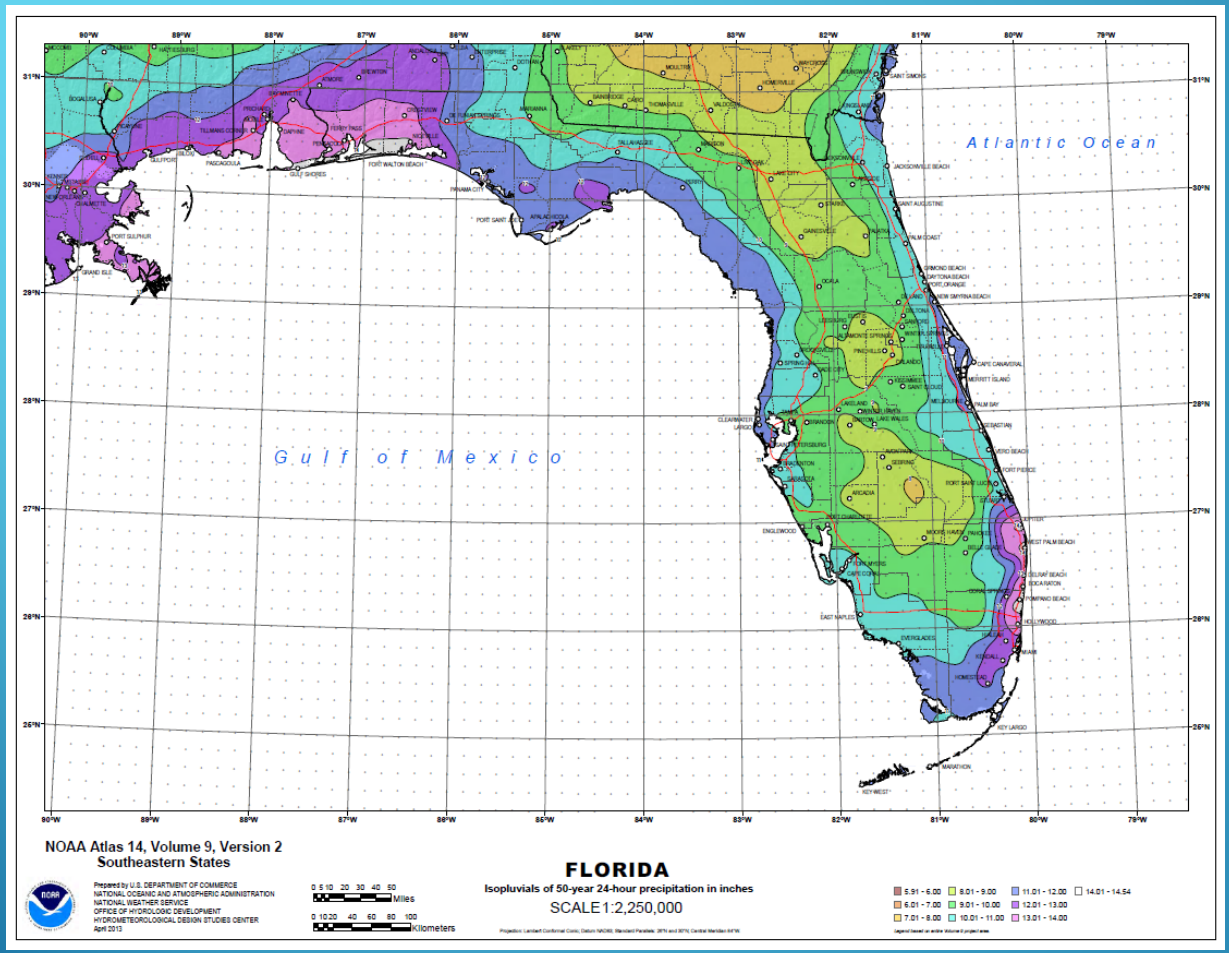


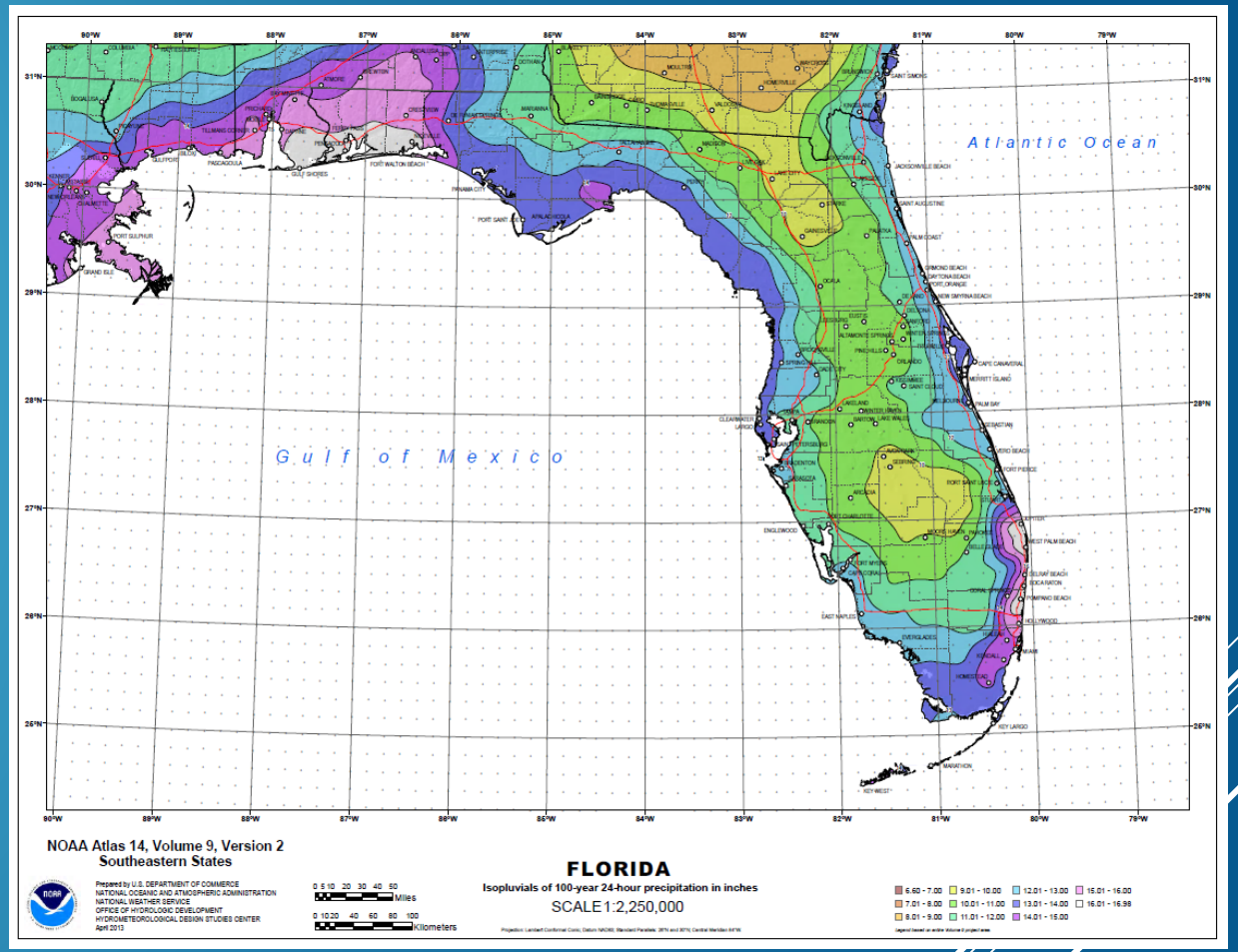
Seasonal Precipitation in Florida





Florida Isopluvials of One-Day Rainfall





Florida Isopluvials of One-Day Rainfall

Questions?

Thank you!