



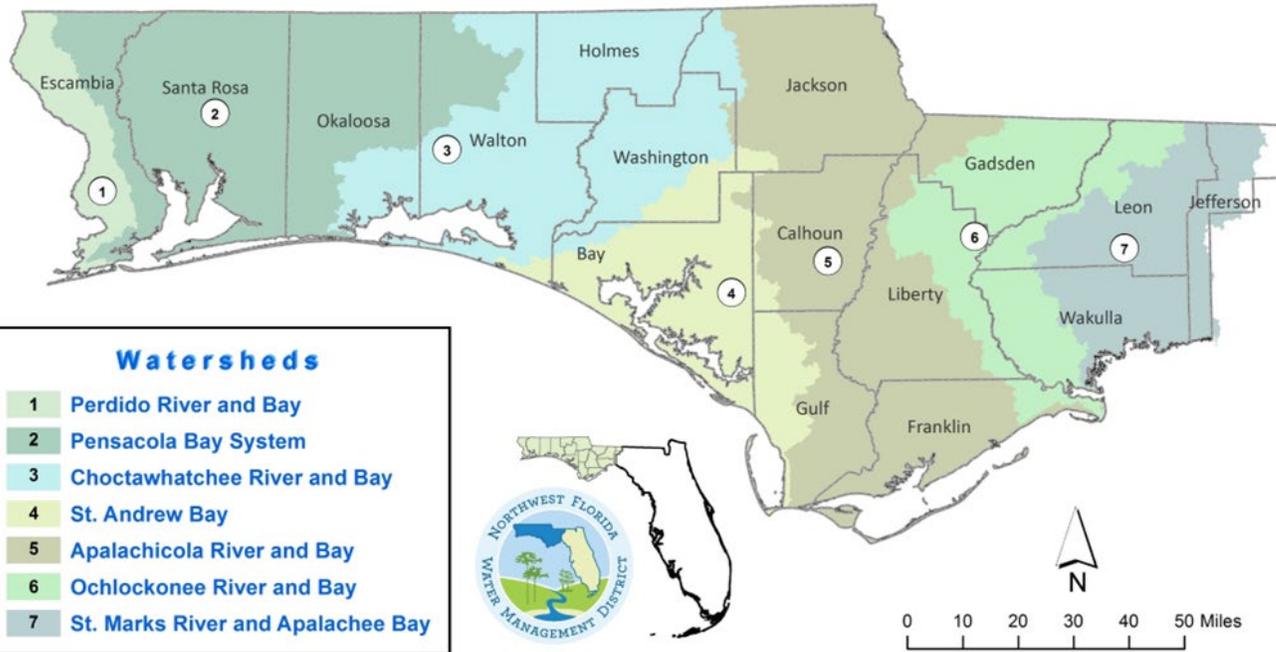
***Factors Driving Persistent
Compound Flooding in
Northwest Florida:
2018-2022***

*Kathleen Coates, P.E., Ph.D.
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Photo Credits: Flooding at Piney Lake, Washington County, Florida

Northwest Florida Water Management District



1.5 million residents across 16 counties



2020 water use of 342 million gallons per day



225,811 acres (349 square miles) of District land



Some of Florida's largest rivers and most diverse and productive estuaries



Rich in surface and groundwater resources

Areas of Responsibility



Water Supply

Ensure sufficient water for all existing and future reasonable-beneficial uses and natural systems.



Flood Protection and Floodplain Management

Maintain natural floodplain functions and minimize harm from flooding.



Water Quality

Protect and improve the quality of the District's water resources.



Natural Systems

Protect and enhance natural systems.



Factors Driving Compound Flooding



Compound Flooding:

Two or more physical processes combine to cause flooding impacts.

- Hurricane-related flooding, for example:
 - Storm surge
 - Rainfall
 - Tides
 - Onshore winds
- Drivers may be synchronous or asynchronous

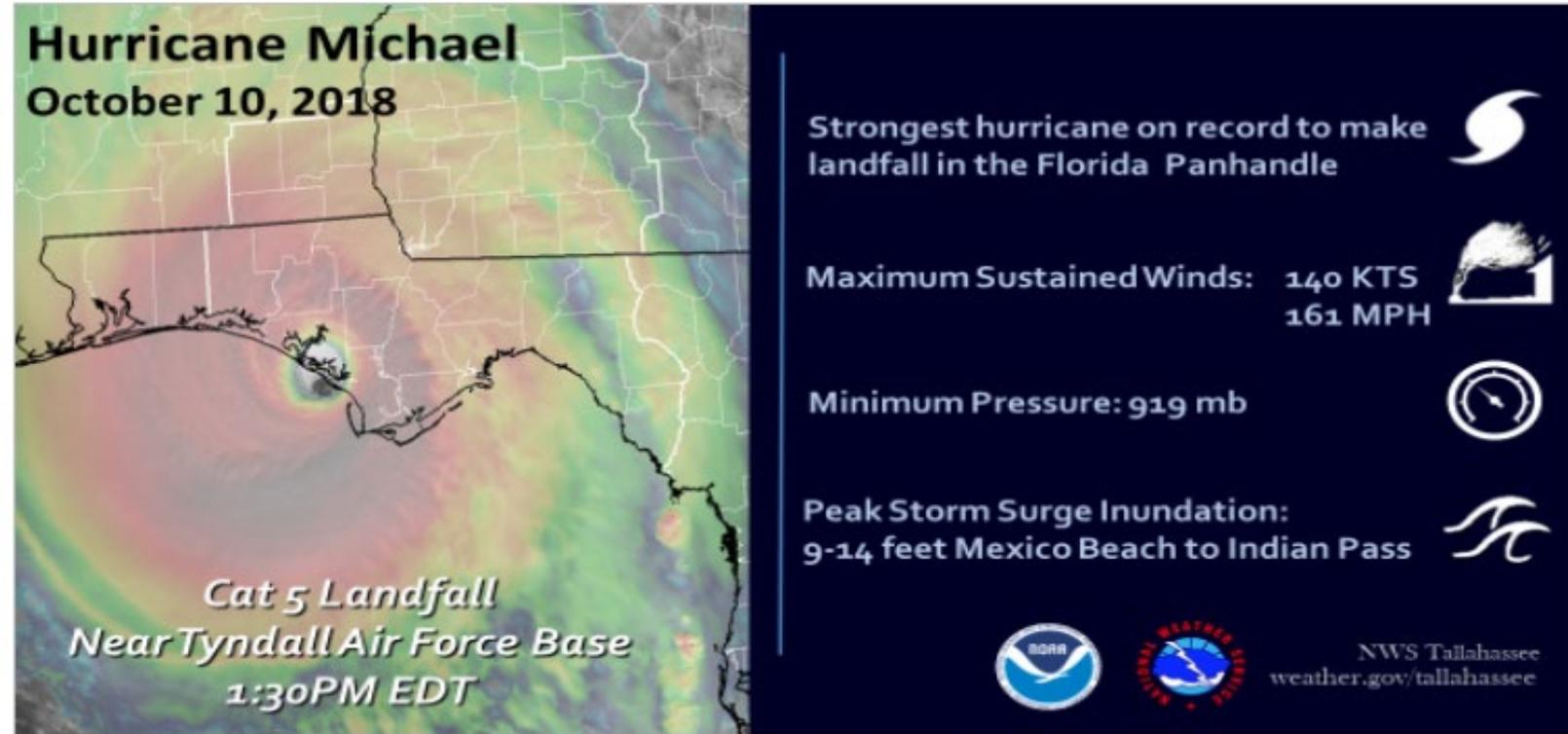


Factors Driving Compound Flooding



Background

- Hurricane Michael made landfall on October 10, 2018, at 1:30 p.m. EDT as a category 5 storm.
- Remained at category 3 strength as it moved into southwest Georgia at 6 p.m.
- Devastating impacts across a broad area of northwest Florida.
- Rainfall totals in Florida ranged from about 4 to 8 inches in most areas.



Statistics from Hurricane Michael

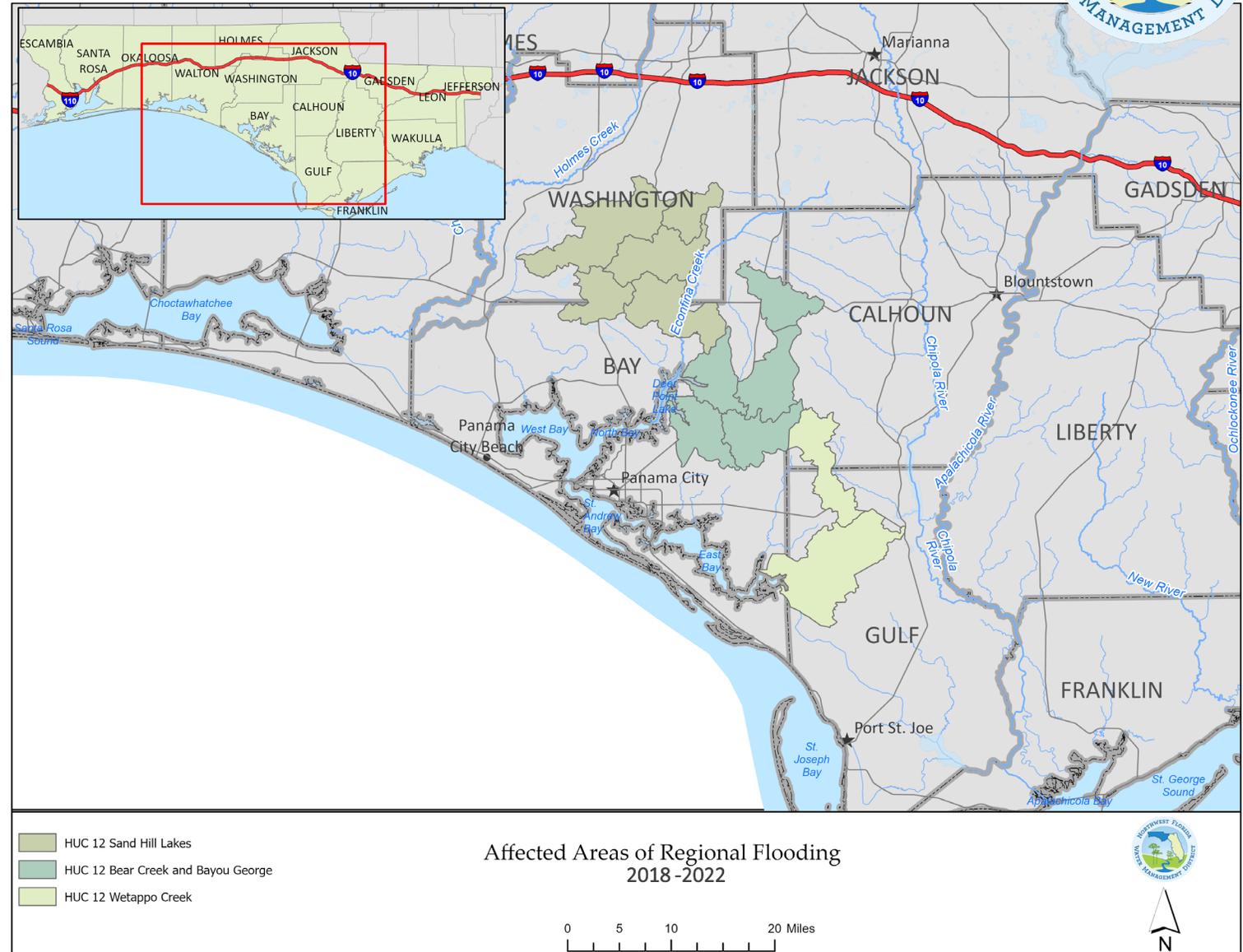
Source: NOAA

Factors Driving Compound Flooding



Background

- Significant flooding impacts within Bay, Washington, and Gulf counties
 - Bear Creek, Bayou George Creek, Wetappo Creek watersheds.
 - Sand Hill Lakes Region
 - Other areas
- Flooding impacts reported in the weeks *following* Hurricane Michael.
- Impacts persisted into 2022.
- An evaluation of causal factors was performed to inform future flood management efforts.



Factors Driving Compound Flooding



Data Evaluated

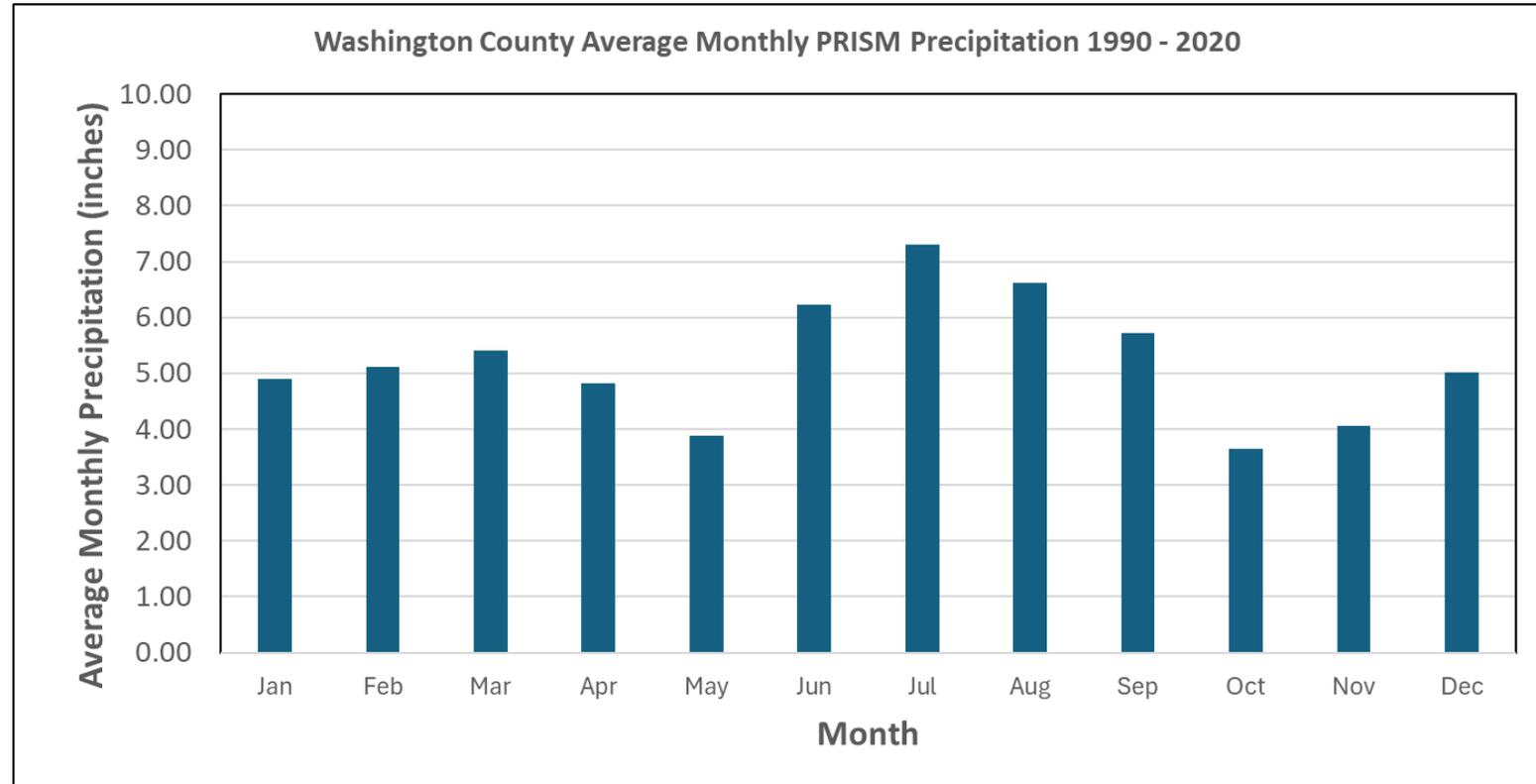
- **Rainfall**
 - PRISM Climate Group monthly data
 - District rainfall stations
- **Climate Cycles**
 - ENSO seasonal indices
 - Atlantic Multidecadal Oscillation index
- **Hurricane/Tropical Storm Events**
- **Landcover Data**
 - Landsat 8 Imagery
 - National Landcover Database
- **Evapotranspiration**
 - USGS Mean Monthly ET Estimates, Operational Simplified Surface Energy Balance (SSEBop) (Senay et al., 2013)
- **Aquifer Levels**
 - District monitoring stations
 - Domestic self-supply wells
- **Stream Stage and Discharge**
 - District and USGS monitoring stations

Factors Driving Compound Flooding



Rainfall

- Average annual rainfall, based on 1991-2020:
 - 62-64 inches
- Two wet seasons
 - Summer convective storms
 - Winter frontal systems
- Short and long-term cycles
 - El Niño/La Niña patterns
 - Atlantic Multidecadal Oscillation
 - No indication that these climate cycles were key drivers of observed flooding



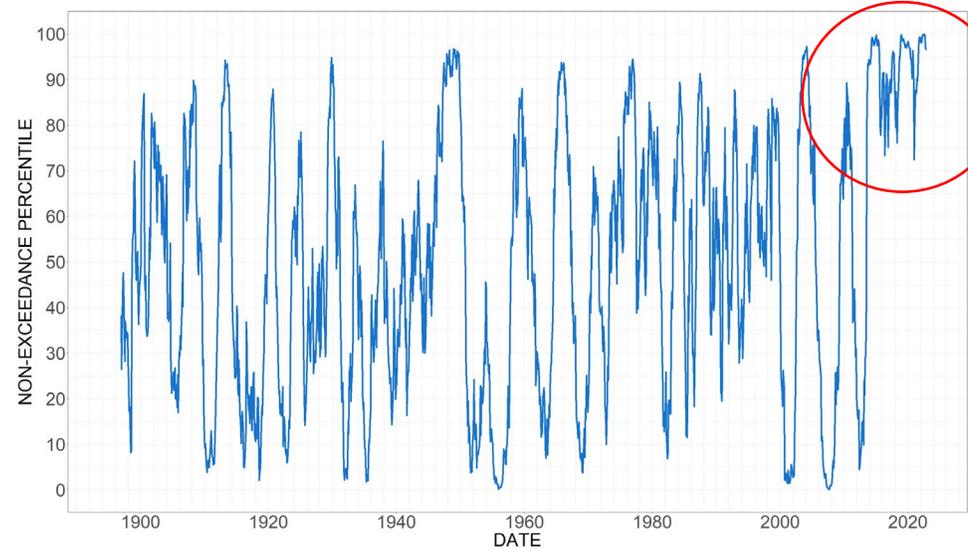
Factors Driving Compound Flooding



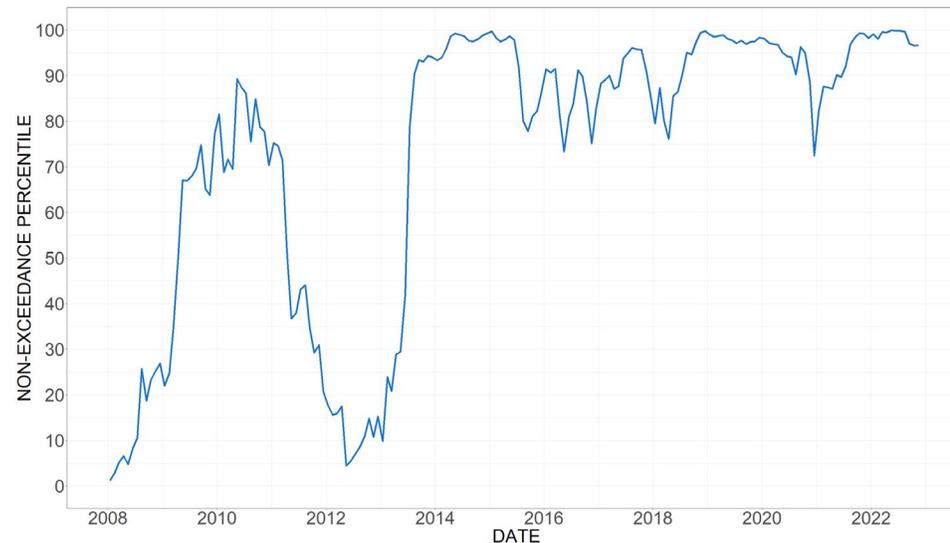
Rainfall

- Above average rainfall from 2014 through 2022
- High 24-month cumulative rainfall totals
- Washington County Example
 - 70th percentile exceeded in all months
 - 90th percentile exceeded most months
- 24-month cumulative rainfall for September 2018, *prior to* Hurricane Michael, was the 95th percentile.
- Continued through 2022.

Non-exceedance Percentiles for 24-month Antecedent Rainfall



Refer to graph below



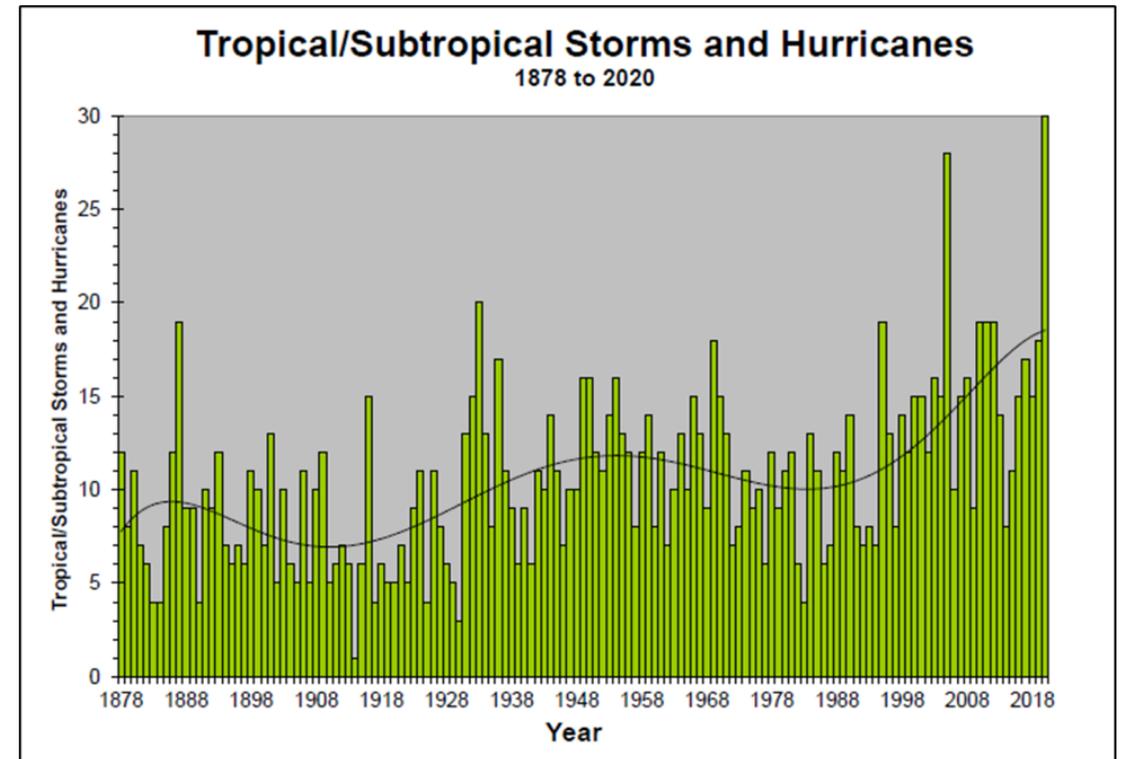
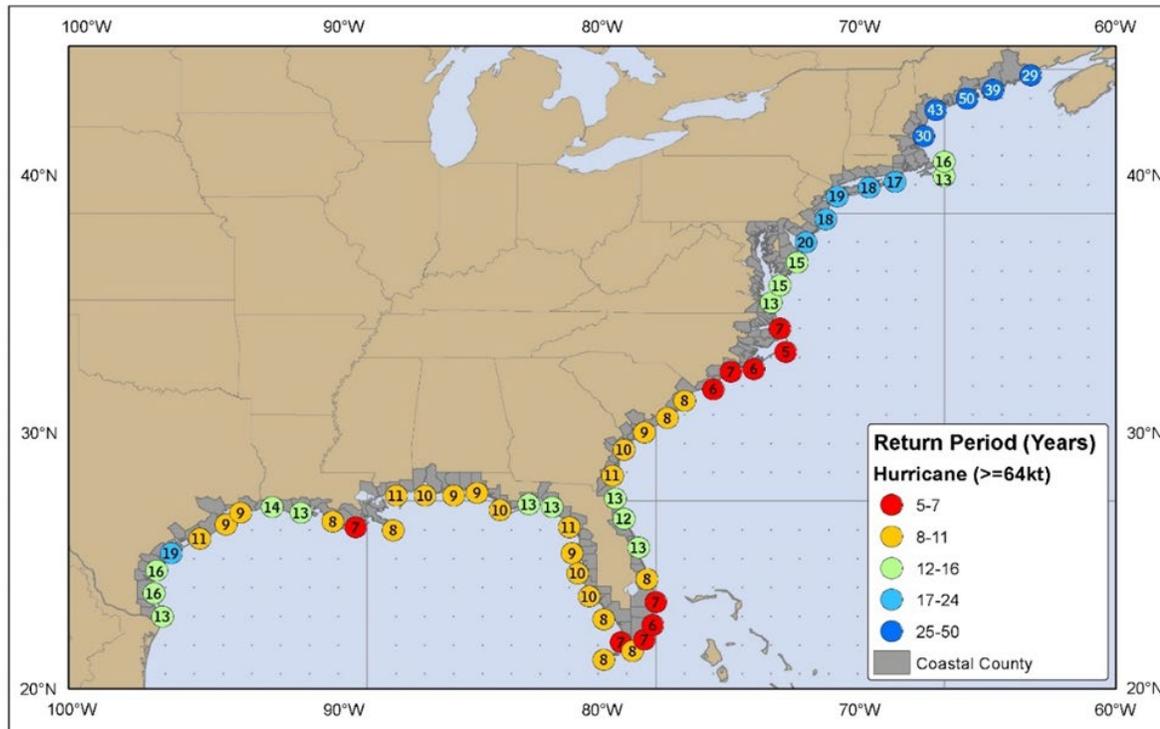
Factors Driving Compound Flooding



Tropical Storms and Hurricanes

Hurricanes expected to impact the Florida Panhandle approximately every 10 years.

Annual hurricane return intervals (NOAA 2022)



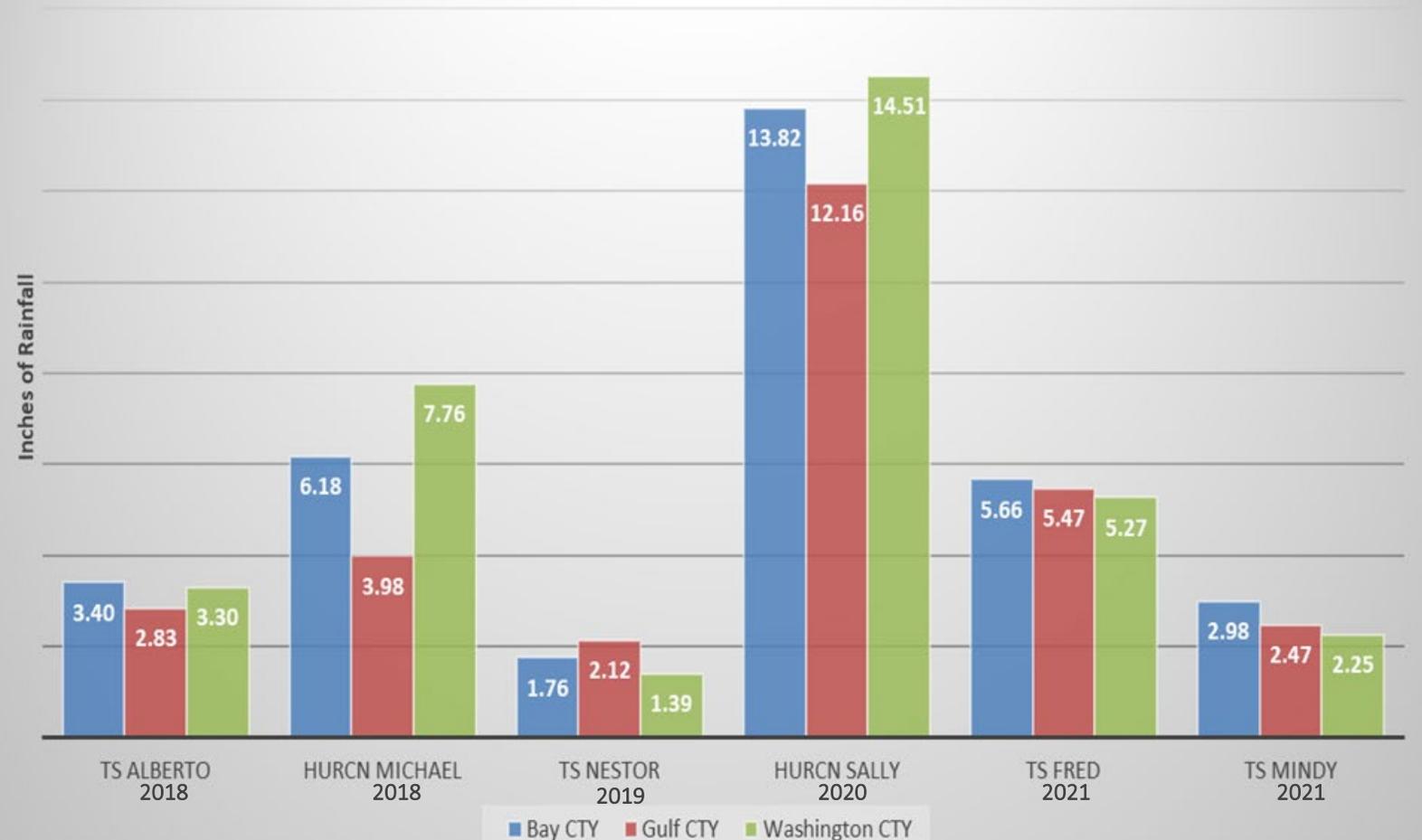
Factors Driving Compound Flooding



Rainfall Associated with Tropical Systems

- Six named storms impacted the region within five years
 - Two hurricanes
 - Four tropical storms
- Gulf County
 - 29.0 inches of rainfall
- Bay County
 - 33.8 inches of rainfall
- Washington County
 - 34.5 inches of rainfall

Precipitation During Named Storm Events 2018-2021

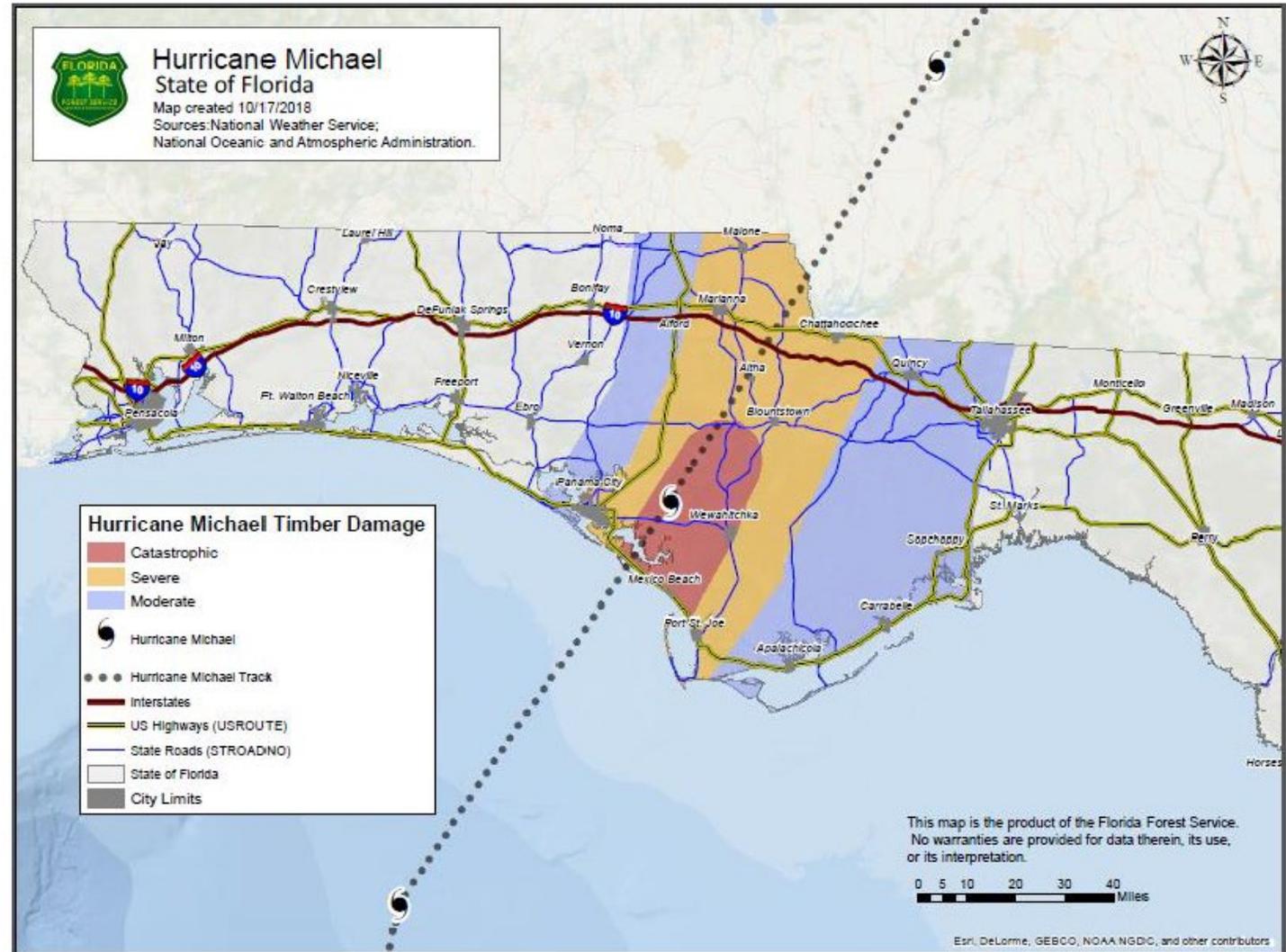


Factors Driving Compound Flooding



Hurricane Michael Caused Widespread Impacts to Forest Resources

- 2.8 million acres of timber damaged (DOF)
 - Catastrophic (95% loss)
 - Severe (75% loss)
 - Moderate (15% loss)
- Losses estimated at \$1.3 billion



Factors Driving Compound Flooding



Hurricane Michael Forest Losses

- Comparison of pre-/post hurricane conditions (National Landcover Database)
 - 79,981 acres of evergreen forest lost
 - 28,411 acres of woody wetlands lost
- Forested landcover losses offset by increases in herbaceous wetlands (+30,021 acres) and herbaceous and shrub/scrub uplands (+72,769 acres)

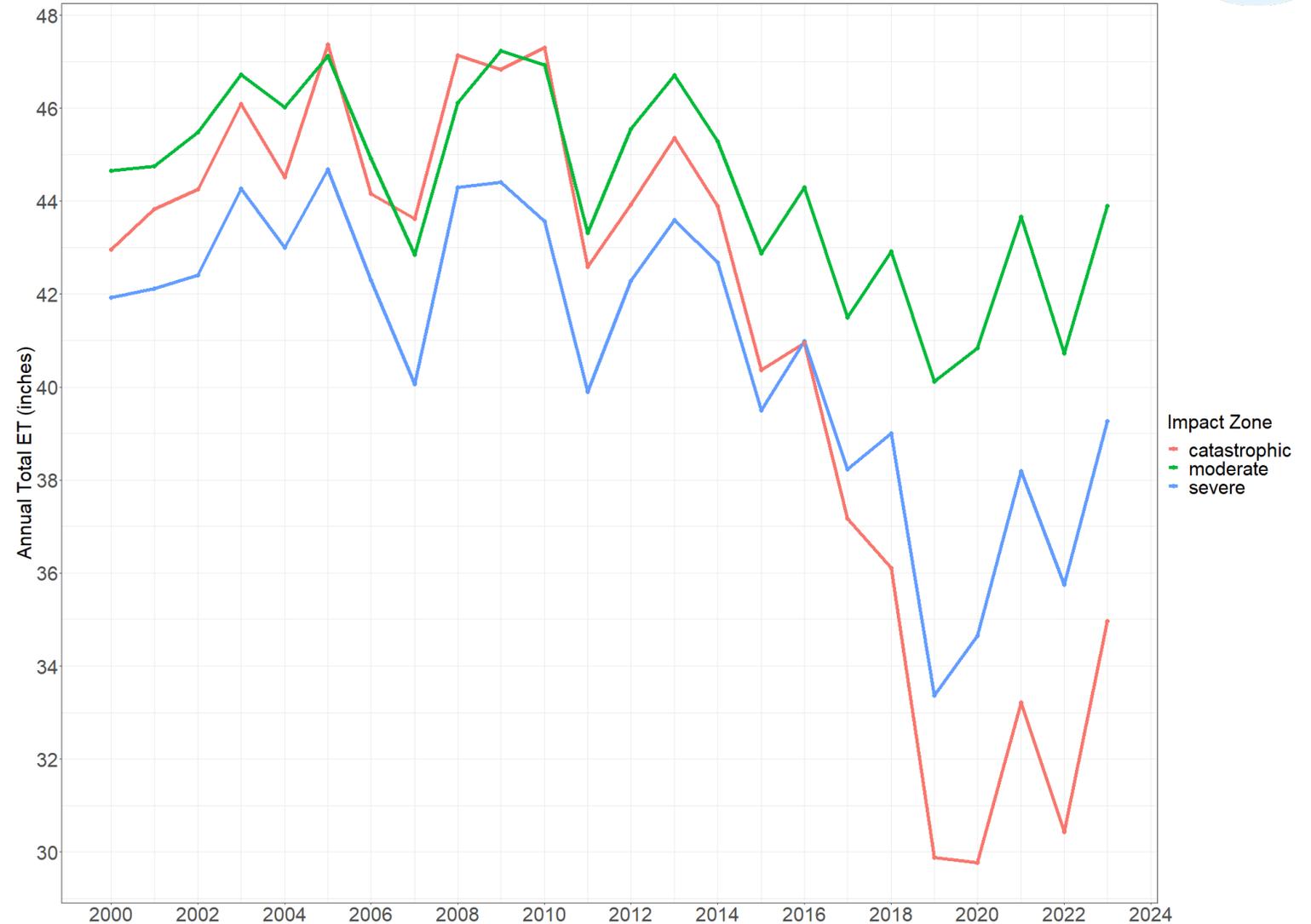


Factors Driving Compound Flooding



Declines in Evapotranspiration

- Average ET: 42 in/yr
- Widespread loss of forest land cover correlated with record low ET during 2019/2020
- 2019 reduction in ET:
 - Catastrophic zone: -9.6 in.
 - Severe impact zone: -4.8 in.
 - Moderate zone: -0.8 in.
- Some recovery in post-2020 ET rates
 - Vegetation regrowth
 - Climate factors

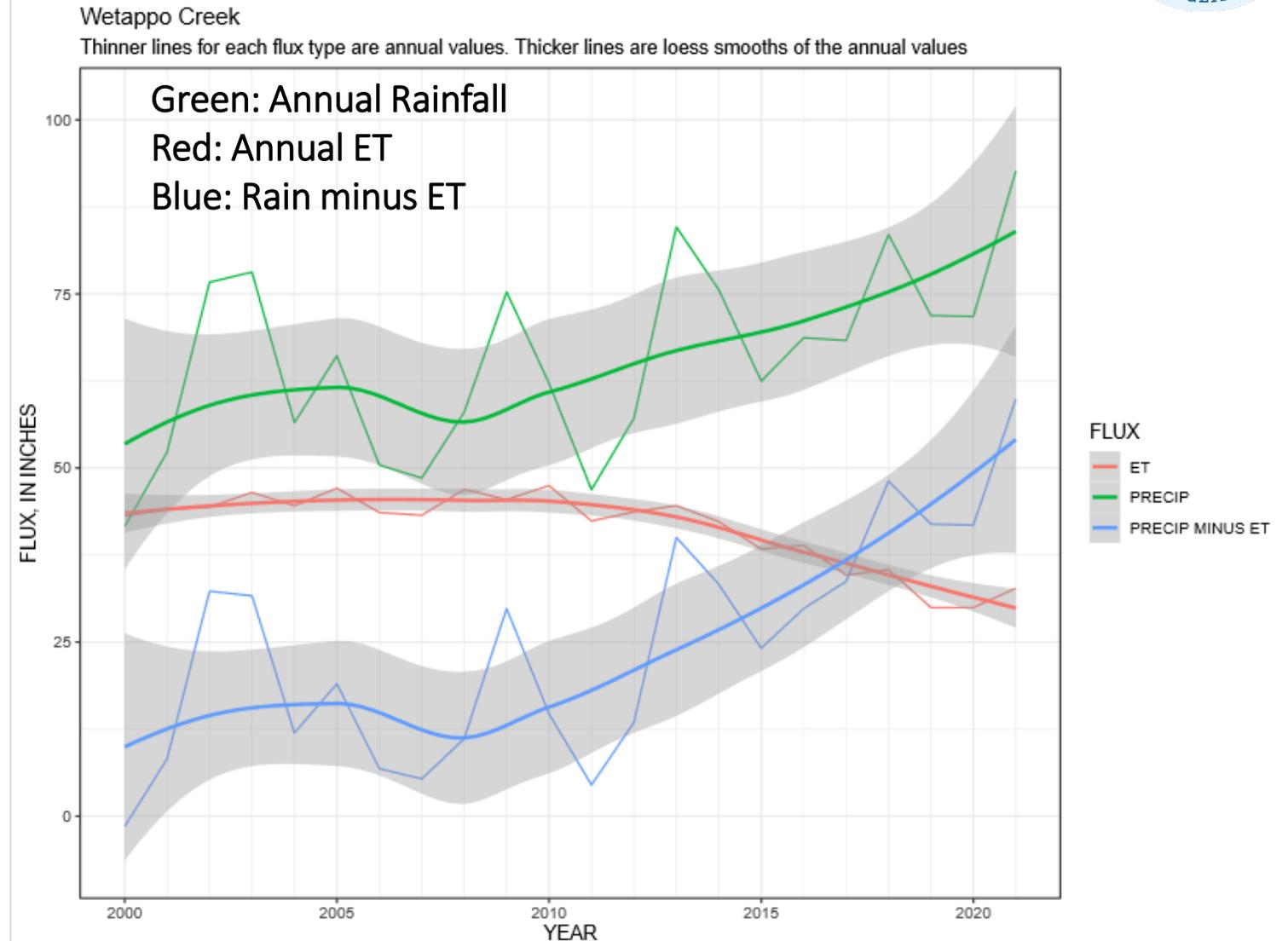


Factors Driving Compound Flooding



Rainfall vs. ET Rates

- Patterns similar across affected watersheds
- Cumulative excess rainfall somewhat larger than ET declines
- Data suggest possible multi-year trends in climate or landcover fluxes
 - Declining ET rates?
 - Increased precipitation?



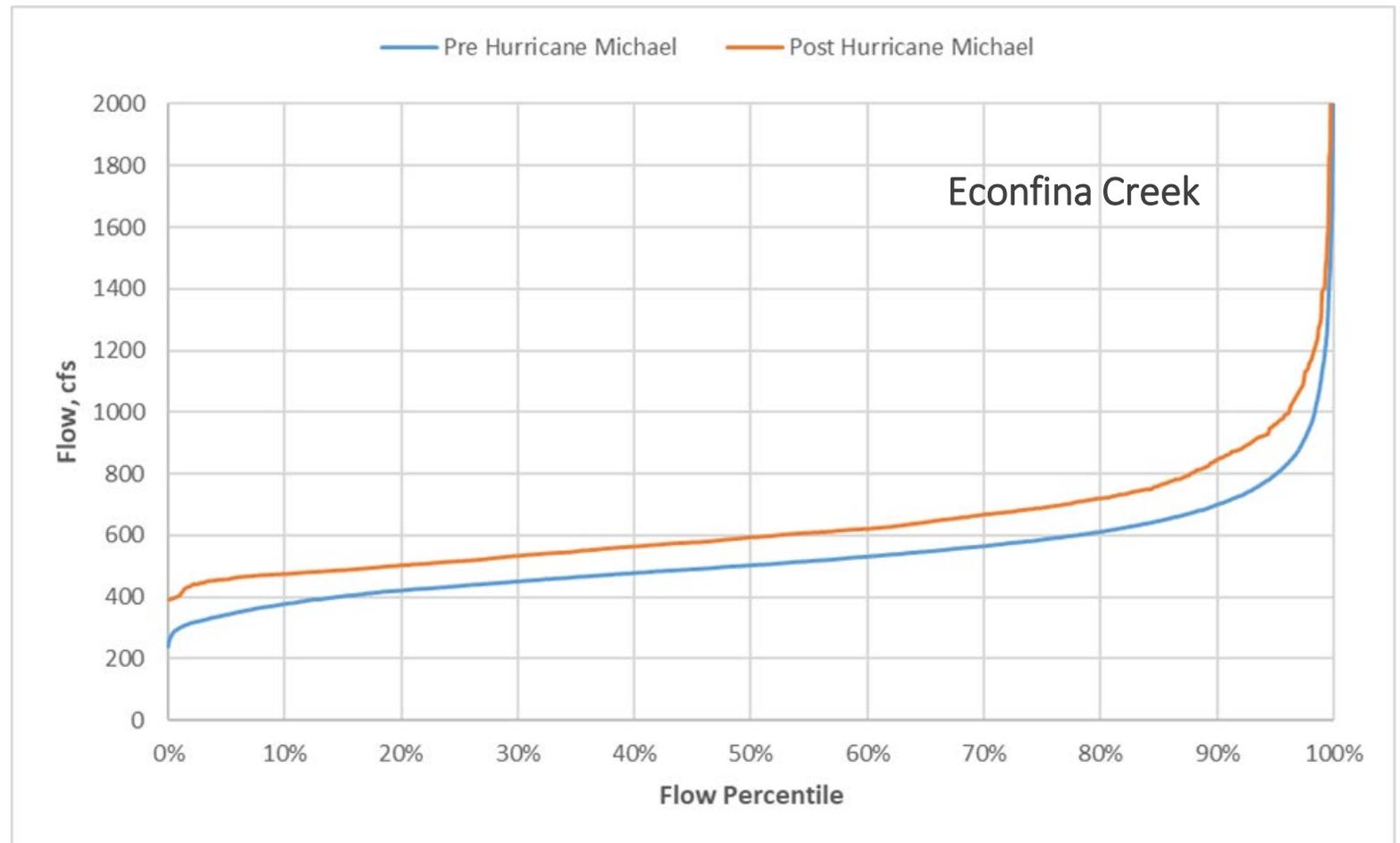
Factors Driving Compound Flooding



Extended period of high stream discharge

- Increases in discharge driven by:
 - Storm events
 - Above average rainfall
 - Above average baseflow

Stream and Riverine Flooding



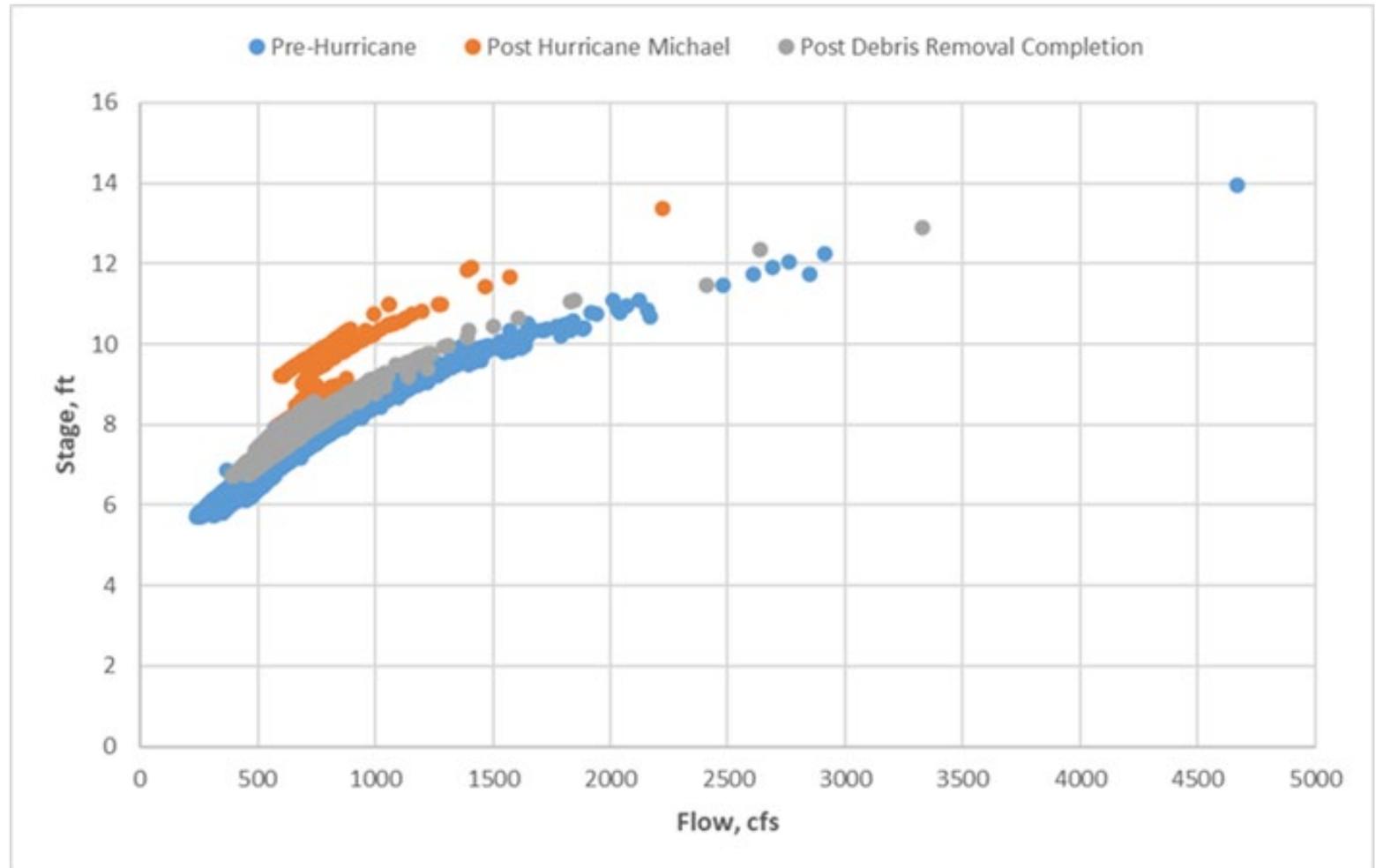
Factors Driving Compound Flooding



Hurricane Michael storm debris reduced the conveyance of many streams

- Higher stages for a given flow
- Contributed to flooding in low-lying areas proximal to streams
- Effects persisted through subsequent storm events, including Hurricane Sally
- After debris removal, stages trend toward pre-hurricane levels.

Stream and Riverine Flooding



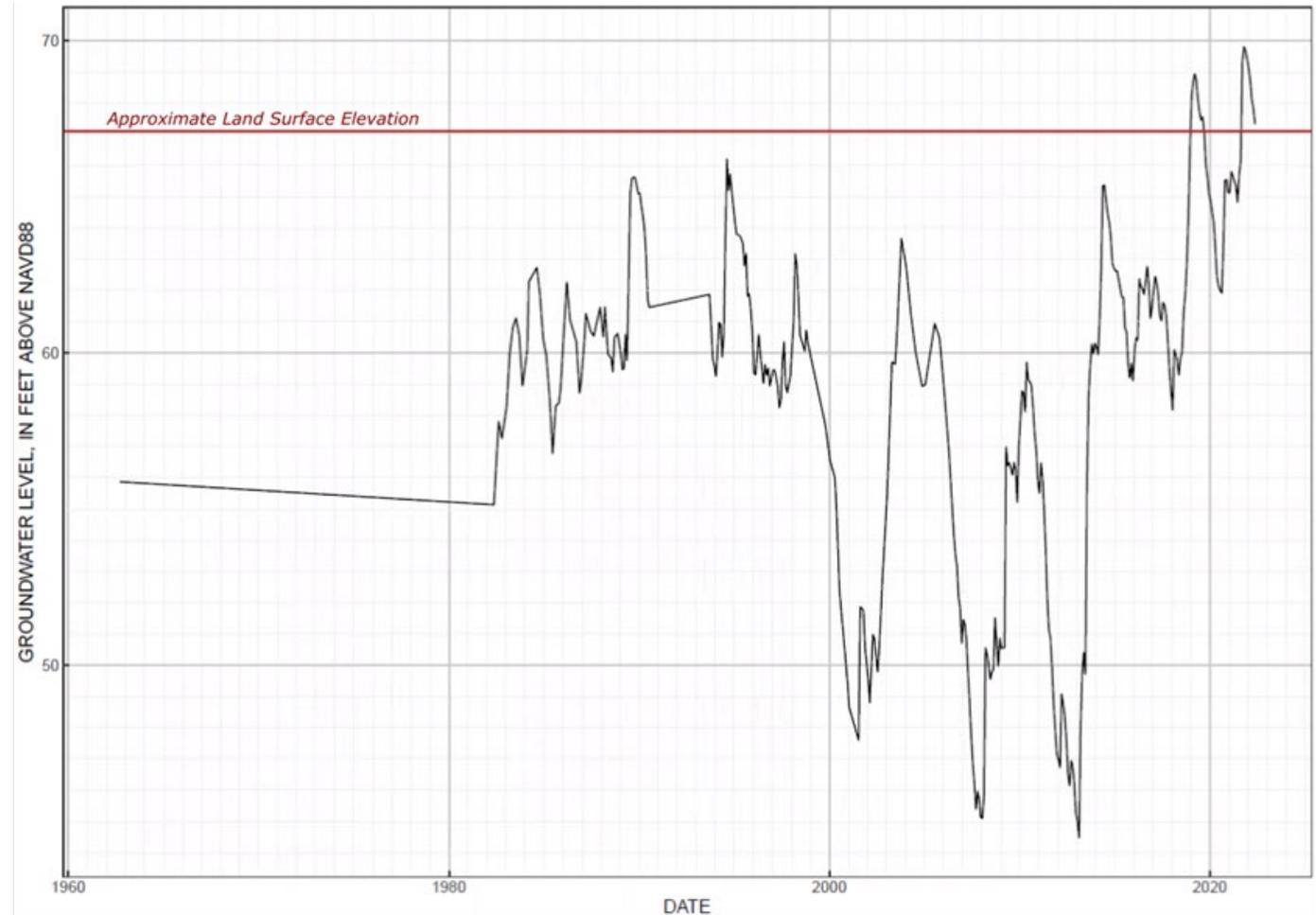
Factors Driving Compound Flooding



Aquifer levels

- Cumulative above-average rainfall and reduced ET resulted in very high aquifer levels during 2018 to 2022.
- Aquifer levels at or above land surface contributed to surface flooding in some areas.
- Head differences between surficial and Floridan aquifers decreased.
- Reduced head gradients affected lake-aquifer outflows and contributed to flooding in closed basins.

Floridan Aquifer Monitor Well



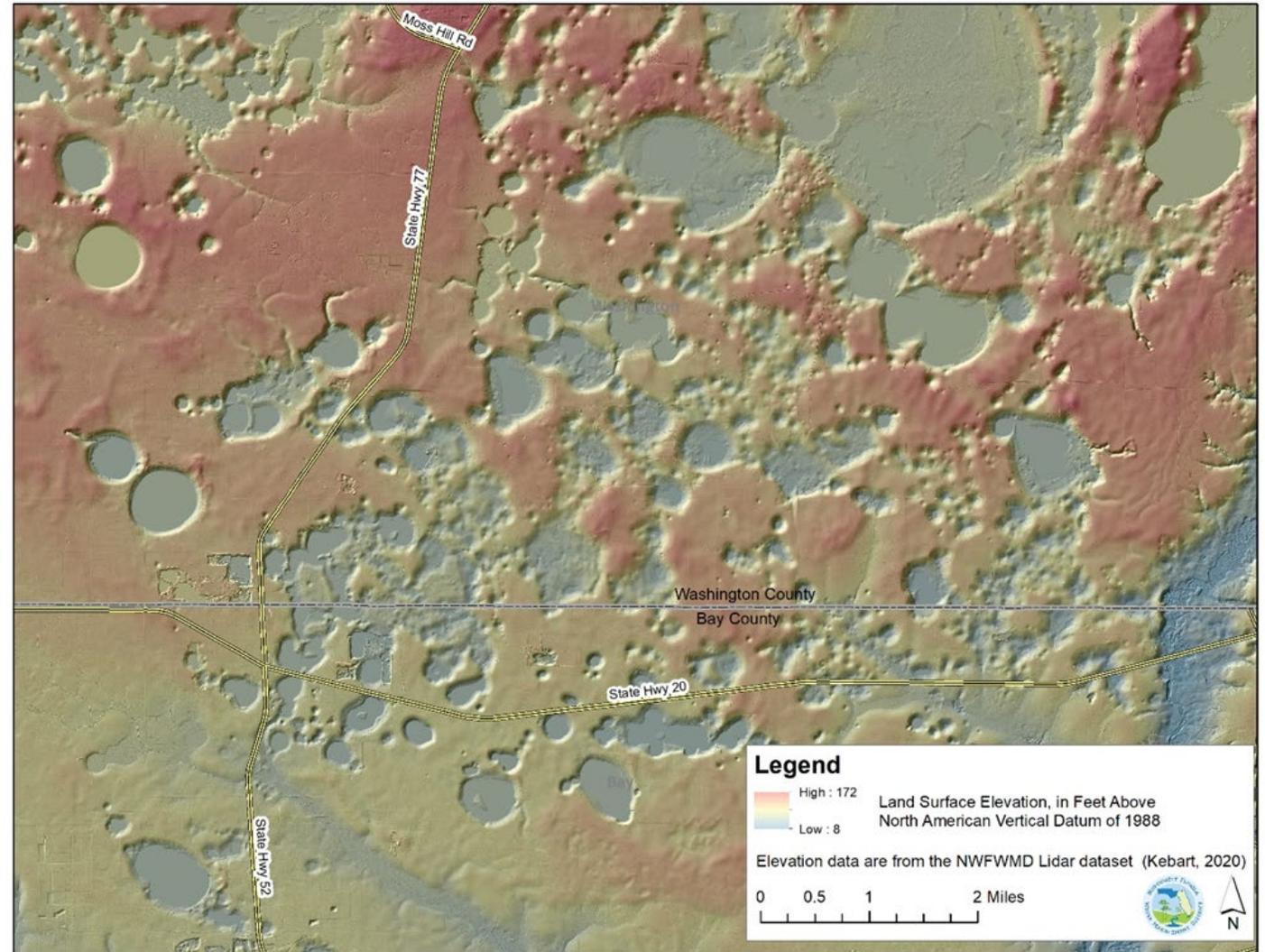
Factors Driving Compound Flooding



Hydrogeologic Setting

- In Washington County, many flooded residences were lakefront.
- Numerous sinkhole lakes and closed topographic depressions
- Internally drained basins
- Lake outflows are ET and subsurface leakage.
- Leakage occurred more slowly due to high aquifer levels.

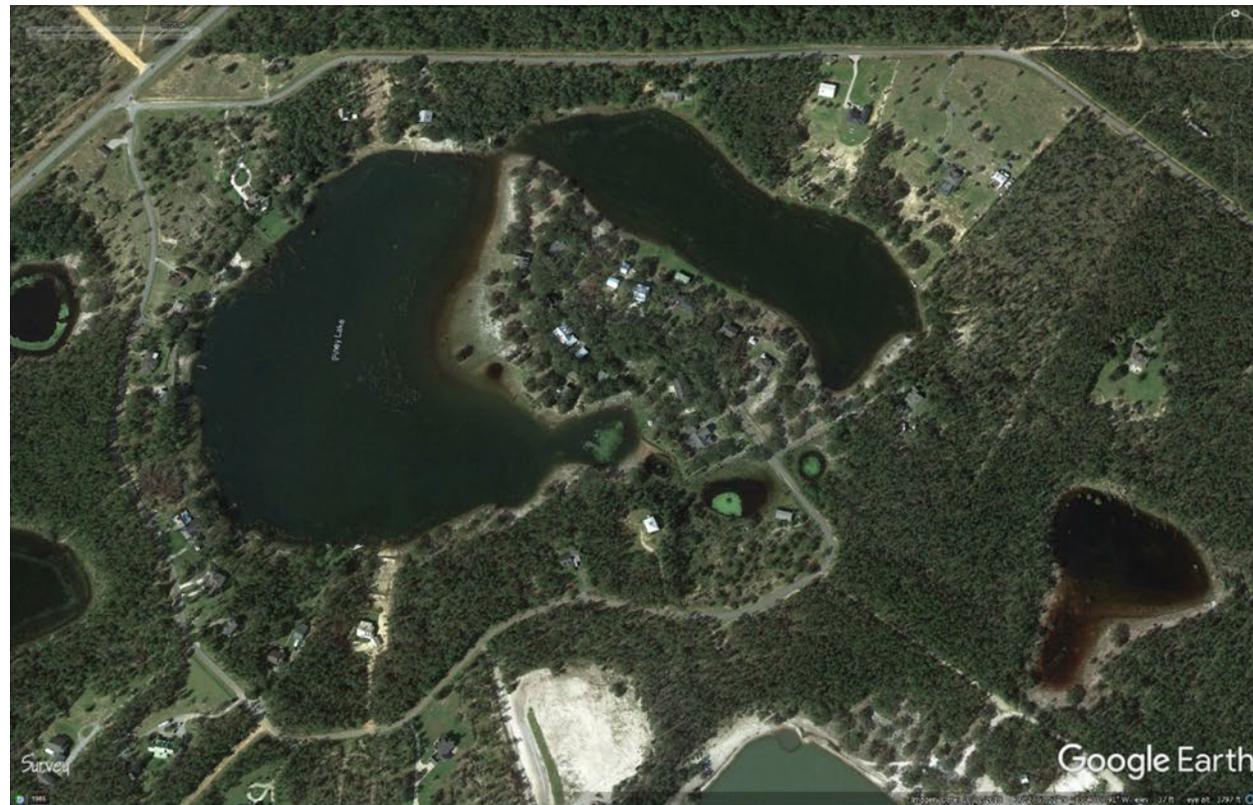
Sand Hill Lakes Region



Factors Driving Compound Flooding



Natural Lake Level Variability in Sand Hill Lakes Region



Lake Level Fluctuations (Wet Period)
October 11, 2018



Lake Level Fluctuations (Dry Period)
December 2012

Piney Lake is relatively shallow

Factors Driving Compound Flooding



Summary

- **Rainfall**

- Above average rainfall occurred during multiple years since 2013.
- Multiple years of above average rainfall were the primary driver of the flooding that occurred from 2018 through 2022 in Bay, Gulf, and Washington counties, resulting in an extended period of extreme hydrologic conditions.
- Six named storms during 2018-2022 significantly contributed to the cumulative rainfall.

- **Evapotranspiration**

- Large declines in ET associated with forest losses within Hurricane Michael impact zone.
- Magnitude of the cumulative excess rainfall occurring during multiple years was larger than the ET declines.

Factors Driving Compound Flooding



Summary, continued

- **Aquifer and Lake Levels**
 - High cumulative rainfall resulted in very high aquifer levels, which in turn, affected stream baseflows, lake outflows via leakage, and contributed to flooding.
 - Within the Sand Hill Lakes region, lake levels are highly variable. Flooded properties were often located on shallow lakes within closed basins.
- **Streamflow and Stage**
 - Increases in streamflow and stage were caused by above average rainfall, increased baseflow, and reduced conveyance in streams impacted by Hurricane Michael.
 - These effects persisted and were alleviated following stream debris removal activities.
- **Additional Factors Contributing to Short-term Flooding**
 - Storm surge, high tides, and wind-related flooding impacts also occurred during hurricanes and tropical storms.

Factors Driving Compound Flooding



Acknowledgements

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Questions ?

Thank you!

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