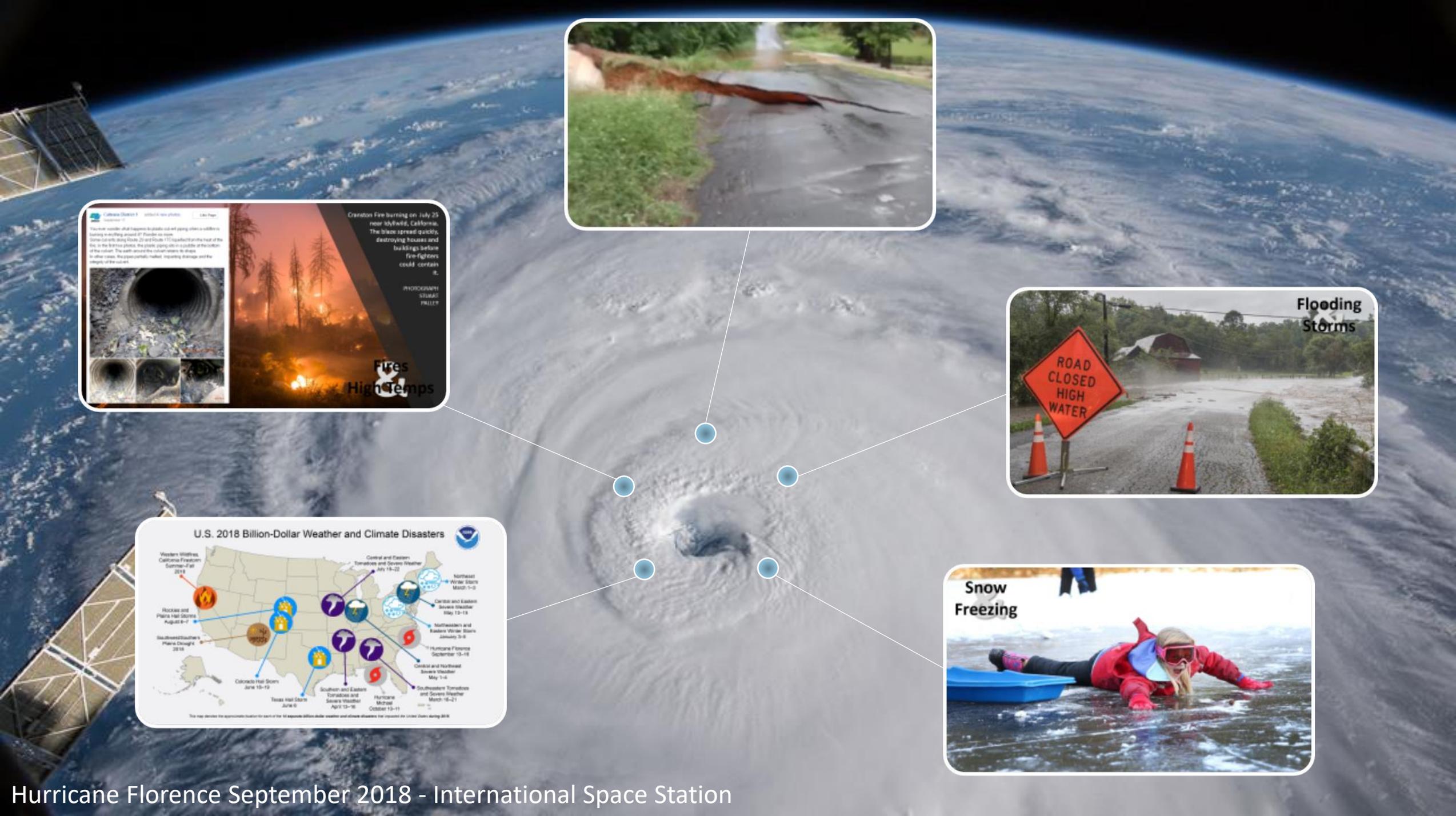


# Resilient Infrastructure



Trygve W. Hoff, PE  
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**Creason Fire burning on July 25 near Idyllwild, California.**  
The breeze spread quickly, destroying houses and buildings before fire-fighters could contain it.

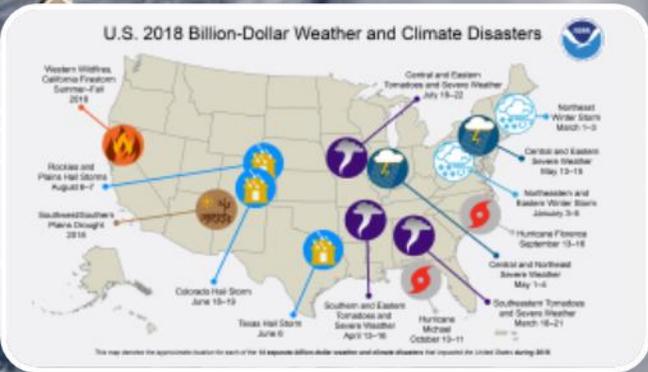
**PHOTOGRAPHY: STUART PRILETT**

**Fires**  
**High Temps**

Fire-fighters consider what happens to people and what happens when a wildfire is burning is a very different story. Fire-fighters are not just fighting the fire, they are also fighting the heat of the fire. In the future photos, the photos show the fire-fighters in the heat of the fire. In other cases, the photos show the fire-fighters in the heat of the fire.



**Flooding**  
**Storms**



**Snow**  
**Freezing**

Hurricane Florence September 2018 - International Space Station

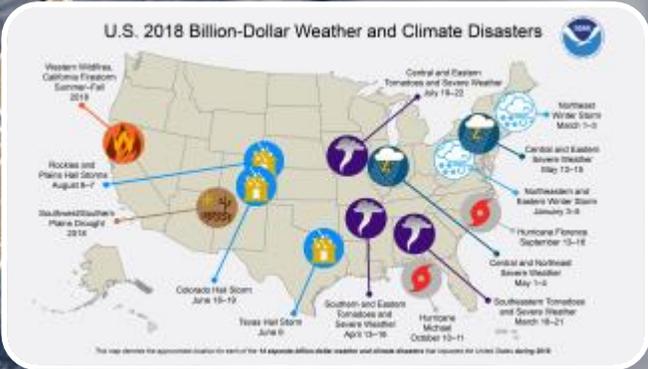


**Crateron Fire burning on July 25 near Skyview, California.**  
The blaze spread quickly, destroying houses and buildings before fire-fighters could contain it.

**PHOTOGRAPH BY STEVE GRANITZ**

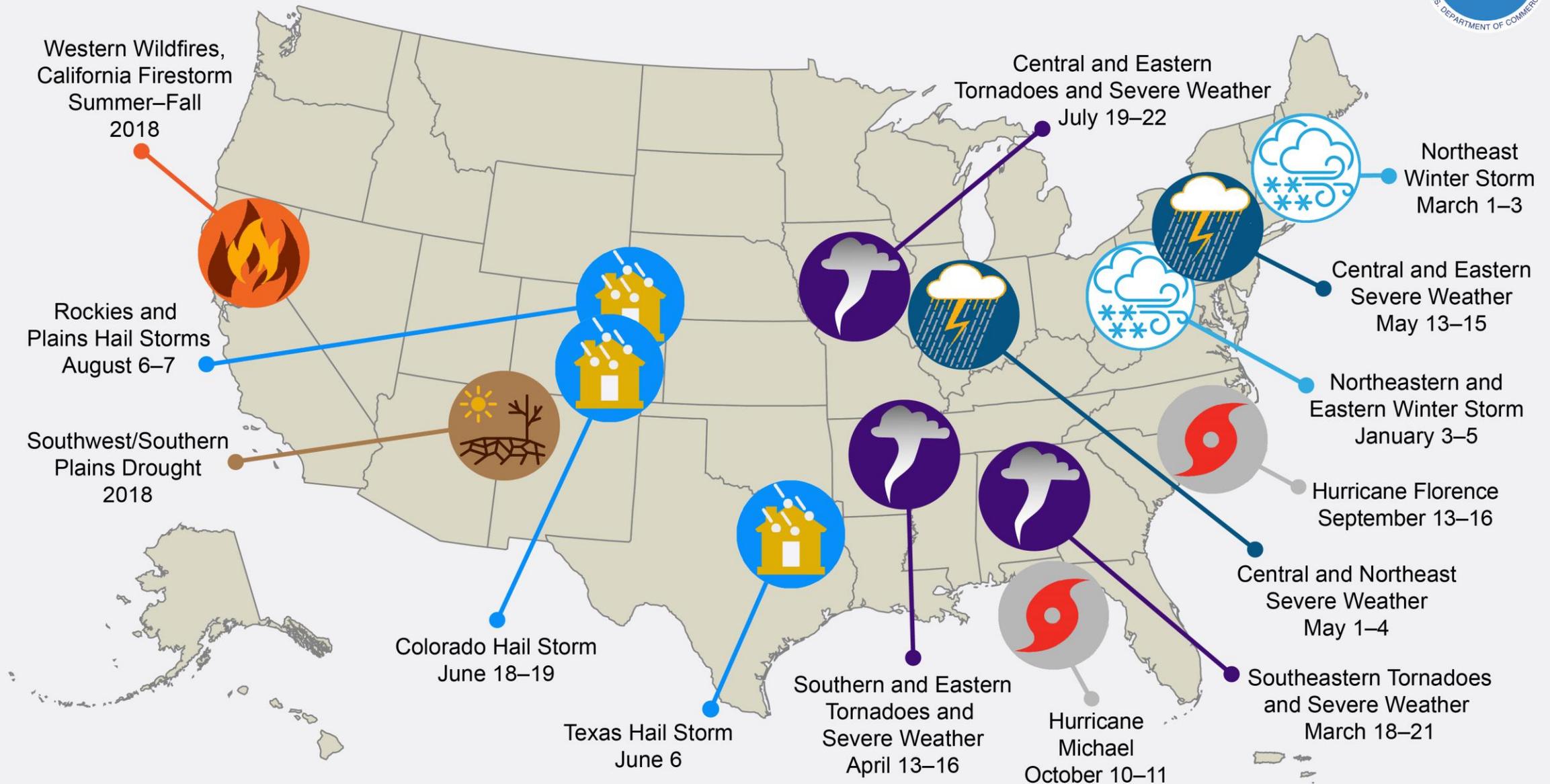
**Fires**  
**High Temps**

Firefighters worked all day long to contain a wildfire in a heavily wooded area of Skyview, California. The fire, which started on July 25, spread quickly, destroying houses and buildings before fire-fighters could contain it. The fire is now under control, but firefighters are still working to clear the area. The fire is now under control, but firefighters are still working to clear the area.



Hurricane Florence September 2018 - International Space Station

# U.S. 2018 Billion-Dollar Weather and Climate Disasters



*This map denotes the approximate location for each of the 14 separate billion-dollar weather and climate disasters that impacted the United States during 2018.*

# Flooding & Storms



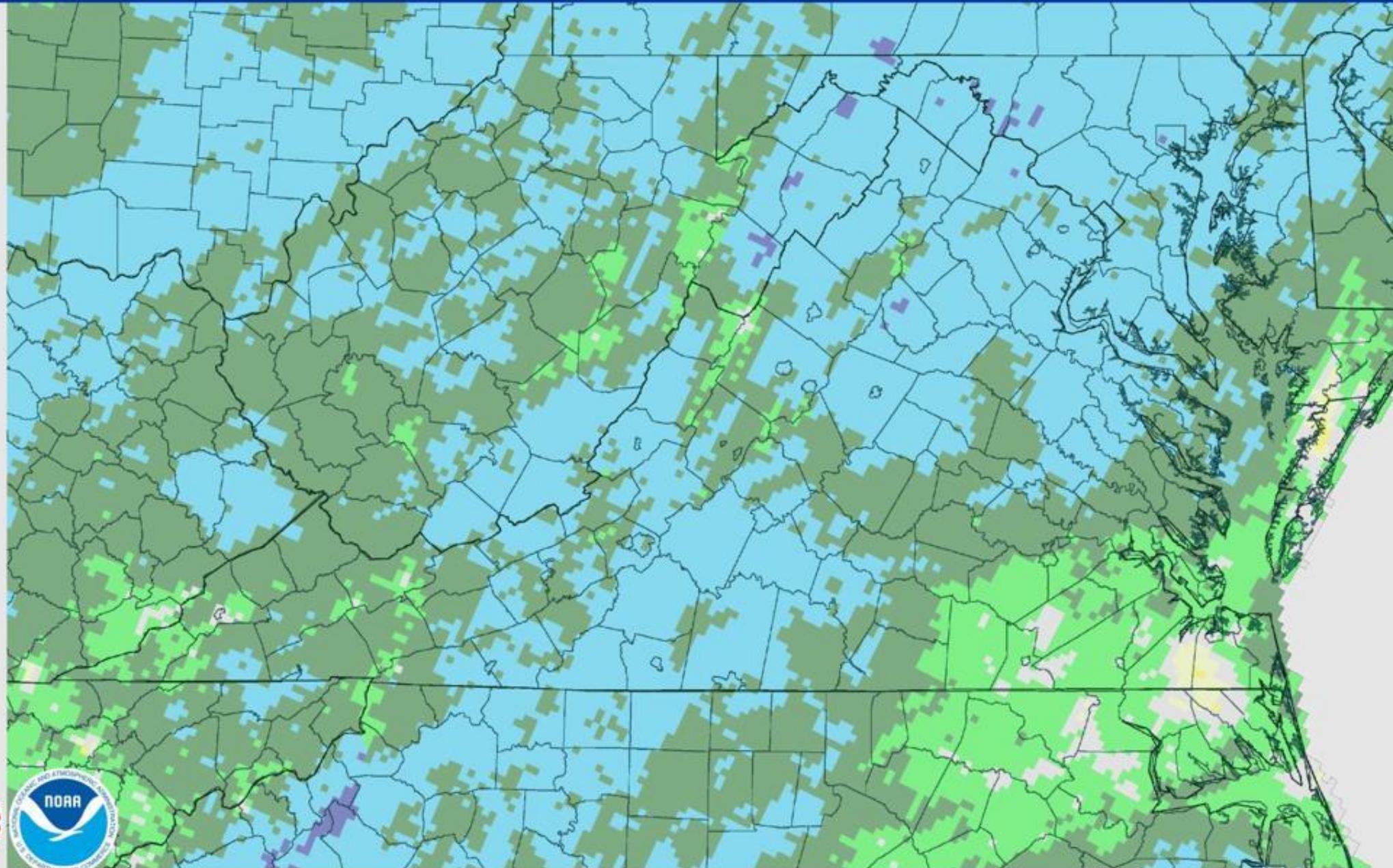


Vehicle stuck in floodwater near the intersection of Gayton Road and Cedarbluff Drive in Henrico on May 18, 2018.

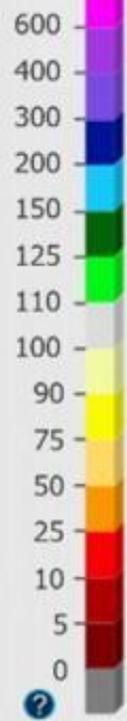
# December 30, 2018 Year to Date Percent Precipitation

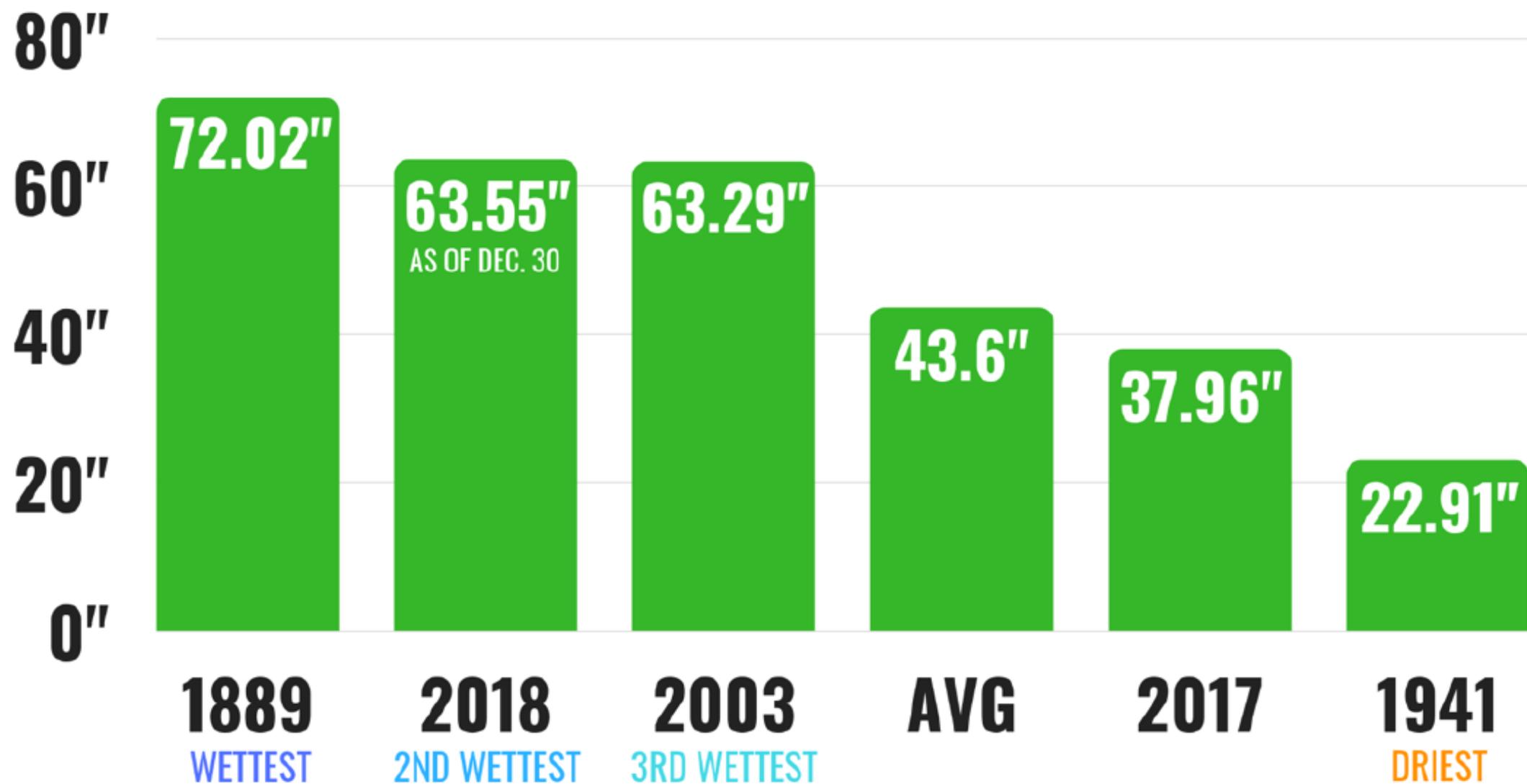
Created on: December 30, 2018 - 19:44 UTC

Valid on: December 30, 2018 12:00 UTC



Percent





## RICHMOND'S ANNUAL PRECIPITATION



Kookum Creek,  
Anchorage, Alaska – 2014  
Passenger Train Washout

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# 2018 HURRICANE SEASON





# Fires & High Temps

Chattanooga Fire Department  
Nov 2016 – Great Smokey Mountain Wildfires  
Death toll reaches 11

Chattanooga



Caltrans District 1 added 4 new photos.

September 17 ·

Like Page

You ever wonder what happens to plastic culvert piping when a wildfire is burning everything around it? Wonder no more.

Some culverts along Route 29 and Route 175 liquefied from the heat of the fire; in the first two photos, the plastic piping sits in a puddle at the bottom of the culvert. The earth around the culvert retains its shape.

In other cases, the pipes partially melted, impacting drainage and the integrity of the culvert.



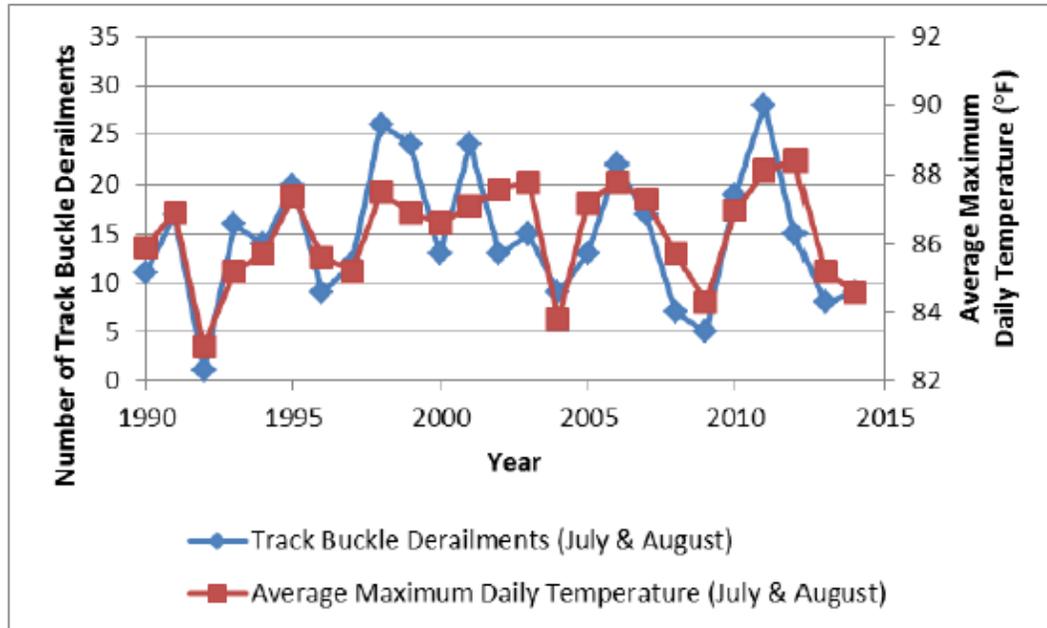
Cranston Fire burning on July 25 near Idyllwild, California. The blaze spread quickly, destroying houses and buildings before fire-fighters could contain it.

PHOTOGRAPH  
STUART  
PALLEY



VA Rt 288 – Chesterfield County 2016





**Figure 2. Number of track buckle derailments and the average maximum daily temperature for the contiguous United States for July and August of each year from 1990 through 2014**



U.S. Department of  
Transportation  
Federal Railroad  
Administration

**Quantification of the Effectiveness of Low Solar Absorptivity Coatings for Reducing Rail Temperature**

# Snow & Freezing



1. 2009	17.8"
2. 1969	16.4"
3. 2018	15.0"
4. 1929	15.0"
5. 1930	14.0"

- Jan 7: Richmond's low of 3 below zero was the coldest reading since 1985.
- Jan 12: A rapid shift in the weather pattern allowed 70s and severe storms to return just five days later – 1<sup>st</sup> Tornado of 2018
- Jan 17: Light snow struck again, followed by another dramatic thaw.

# “Investigating Frost Heave Deterioration at Pavement Joint Locations”

- ASCE Library



(a)



(b)



(c)

$$\epsilon_{\text{(Thermal)}} = \alpha (\Delta T)$$

Where:

$\alpha$  = Coefficient of Thermal Expansion

$\Delta T$  = Change in Temperature (°F)



Thermal strain occurs when changes in temperature cause changes in the dimensions of an object

- These changes happen simultaneously in all directions
- Thermal strain in each direction is the same
- More you heat/cool an object, the larger the magnitude of strain

Material	$\alpha$ ( $\times 10^{-6}$ in./°F)	$\Delta_{\text{Length}}$ (100°F per 20')	$\Delta_{\text{Circ}}$ (100°F per 60" Dia.)
Steel*	6.1-6.7	0.12 inches	0.09 inches
Concrete*	4.1-7.3	0.12 inches	0.09 inches
<b>HDPE**</b>	<b>80-100</b>	<b>1.92 inches</b>	<b>1.50 inches</b>

\*<https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/pccp/thermal.cfm>

\*\*[plasticpipe.org](http://plasticpipe.org)



County Rd 450 – East Texas Washout – 2016

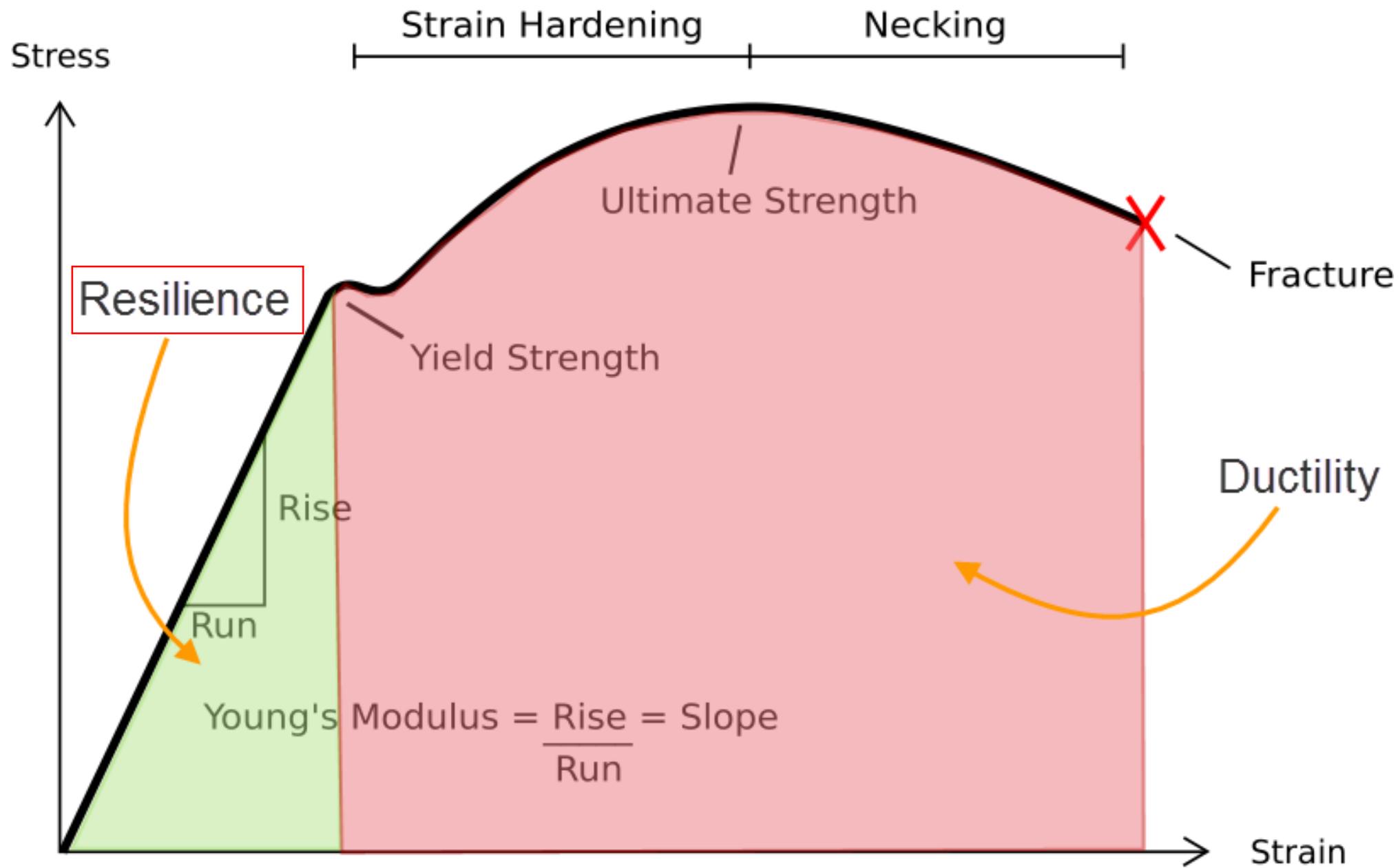
# Resilience

Ability to

**PREPARE, PLAN FOR, ABSORB, RECOVER FROM**, or more  
**SUCCESSFULLY ADAPT** to adverse events.

AASHTO – American Association of State Transportation Officials





# 100 Resilient Cities Network

- Norfolk, VA has recently released its resilience strategy
- “Robust design is **well-conceived**, **constructed** and **managed** and includes making provision to ensure failure is predictable, safe, and not disproportionate to the cause.
- For example, **protective infrastructure** that is **robust** will **not fail** catastrophically when **design thresholds are exceeded.**”

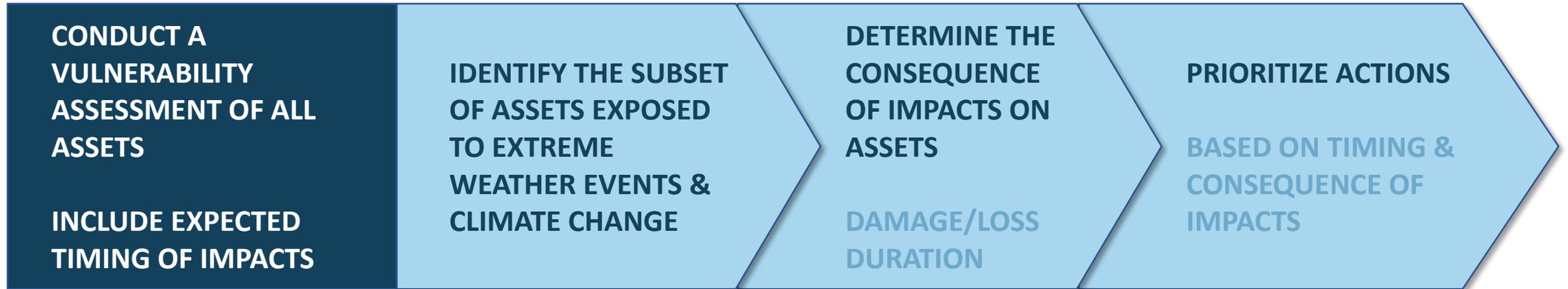




Binghamton, NY August 14, 2018:

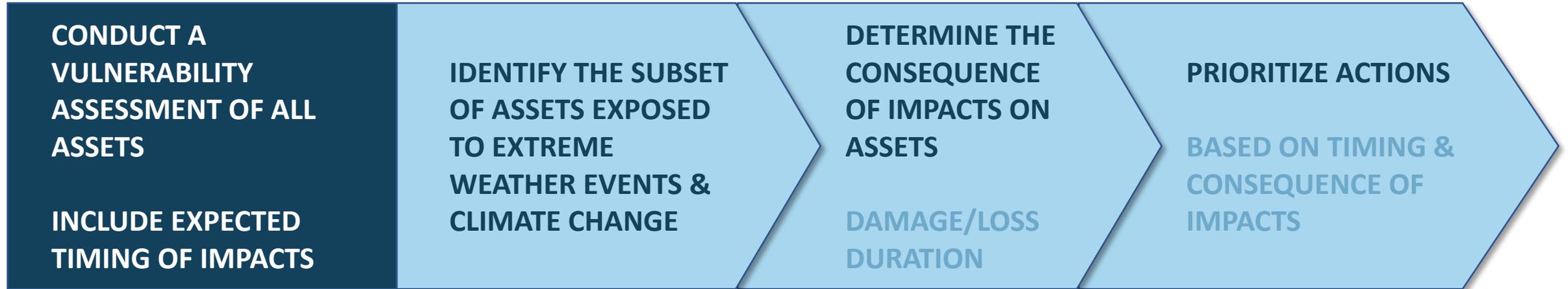
- Heavy storms severely damaged Hiner Rd & Upper Fairview Ave
- Costs to repair estimated at \$3-\$5 million
- Precast box culvert on Hiner Rd remained completely intact
- Resilient box culvert allowed road to be reopened to emergency personnel in short period.

# Vulnerability & the State Highway System: CalTrans



- **Exposure:** Identify those assets which are susceptible to potential damage or reduced service life from expected future conditions
- **Consequence:** Determine what damage might occur to system assets – in terms of loss of use or cost of repair
- **Prioritization:** Determine how to most effectively make capital programming decisions to address those identified risks.

# Vulnerability & the State Highway System: CalTrans



This approach requires participation of a wide range of professionals – from planning, asset management, operations, maintenance, design, emergency response, economics, etc

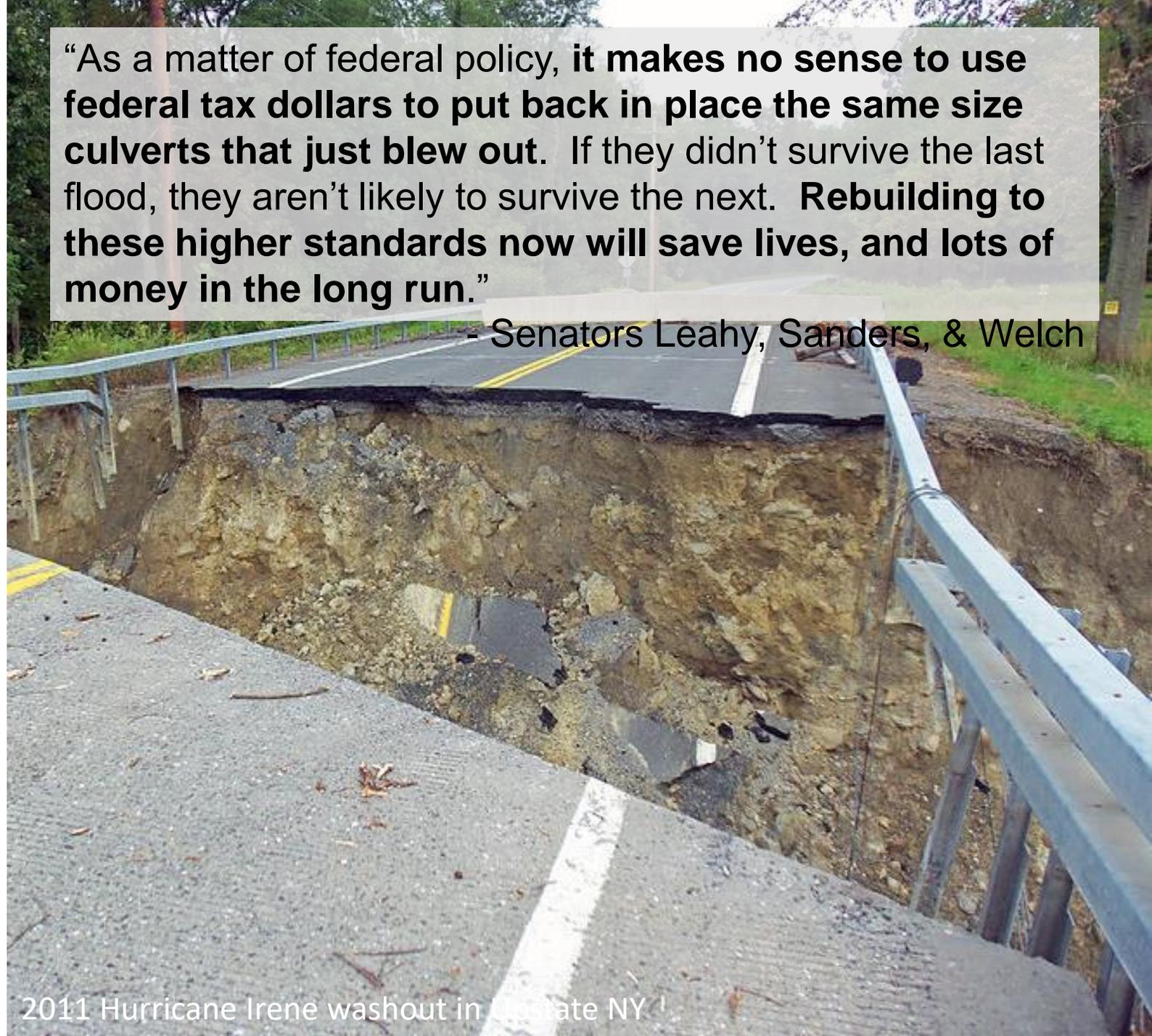
# 2011 Hurricane Irene:

- More than 2000 culverts damaged in Vermont alone
- One 14' CMP was washed out and VTrans chose to replace it with a precast 28x7 3-sided box culvert
- FEMA deemed that an “upgrade” and refused reimbursement.
- Town of Townshend & VTrans officials petitioned FEMA twice to accept the state’s new flood hazard mitigation policies.
- At 2<sup>nd</sup> review, FEMA found the increased capacity and resilient structure to meet the Federal 406 Hazard Mitigation designation.

<https://www.fema.gov/appeal/220548>

**“As a matter of federal policy, it makes no sense to use federal tax dollars to put back in place the same size culverts that just blew out. If they didn’t survive the last flood, they aren’t likely to survive the next. Rebuilding to these higher standards now will save lives, and lots of money in the long run.”**

- Senators Leahy, Sanders, & Welch



2011 Hurricane Irene washout in Upstate NY

# Vulnerability & the State Highway System:

FHWA

**23 CFR 667** – Periodic Evaluation of Facilities Repeatedly Requiring Repair and Reconstruction Due to Emergency Events

- Each State, acting through its department of transportation (**State DOT**), **shall conduct statewide evaluations** to determine if there are **reasonable alternatives to roads, highways, and bridges** that have required repair and reconstruction activities on two or more occasions due to emergency events.

**23 CFR 668** – Emergency Relief Program

- To establish policy and provide program guidance for the administration of emergency funds for the repair or reconstruction of Federal-aid highways, which are found to have suffered serious damage by natural disasters over a wide area or serious damage from catastrophic failures.



# Evaluate Repeat Reconstruction:

Mines Rd, Lowell, VT  
Brian, Angel, & Alex Richardson





*You Can't Design for Everything...*

Julie Heilman, P.E.  
State Hydraulic Engineer

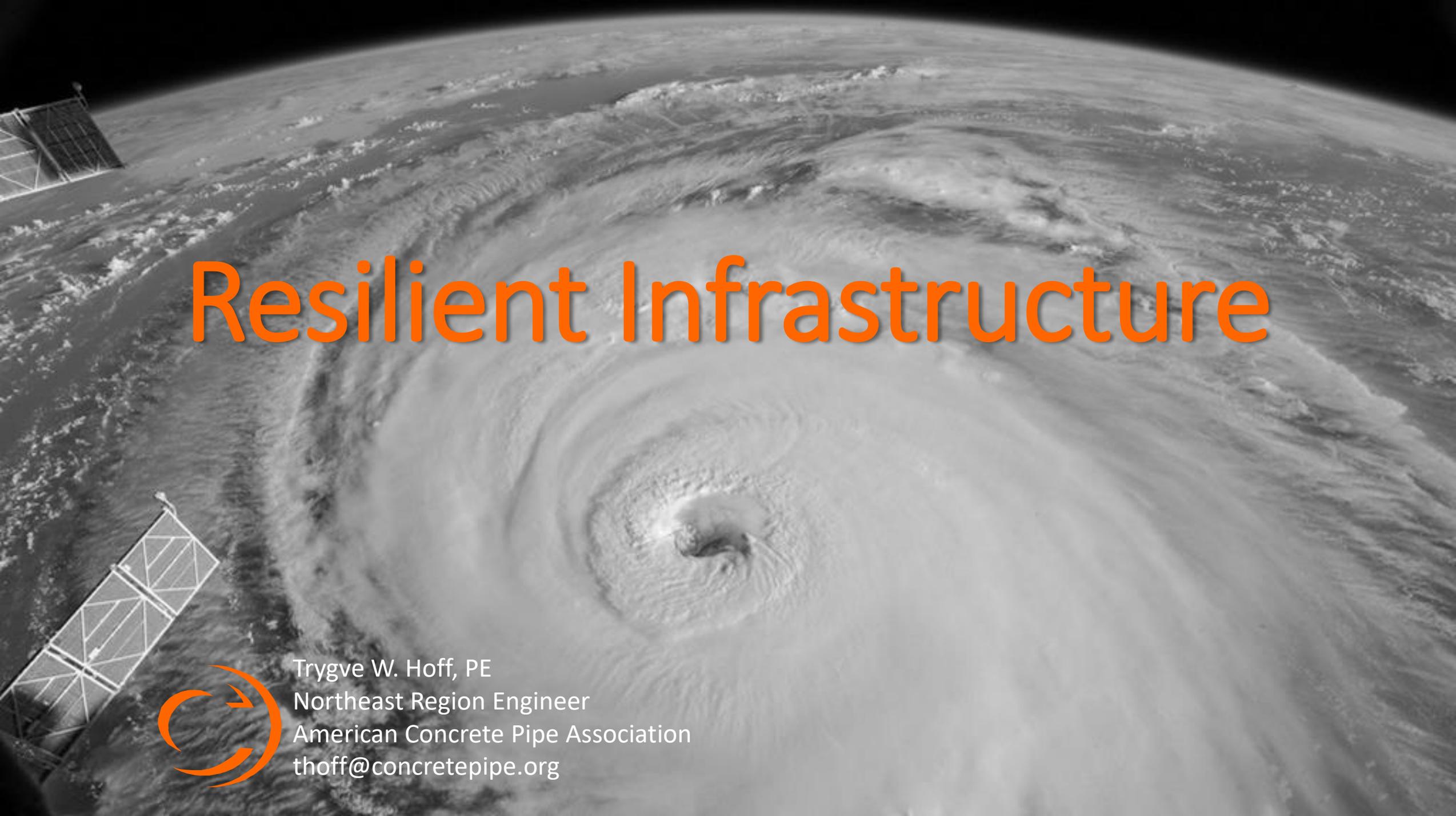


Washington State  
Department of Transportation



*...Except Resilience*

Julie Heilman, P.E.  
State Hydraulic Engineer

An aerial, grayscale photograph of a large hurricane or tropical storm over the ocean. The eye of the storm is clearly visible in the center, surrounded by dense, swirling clouds. In the upper left corner, a portion of a satellite or space station is visible, showing solar panels and structural elements.

# Resilient Infrastructure



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