Short Course: INFRASTRUCTURE RESILIENCE AND PLANNING UPDATE

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U.S. Army Corps of Engineers
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25 YEARS OF ESTCP
2019 | Enhancing DoD's Mission Effectiveness

Agenda

- 0830-0845 Introductions/administrative details
- 0845-0900 Sources of authoritative climate information
- 0900-0920 Sea level change and Q/A
- 0920-0940 Climate-impacted hydrology and Q/A
- 0940-1000 Installation climate resilience and Q/A

INFRASTRUCTURE RESILIENCE AND PLANNING UPDATE

- **Instructor:** Dr. Kathleen D. White, U.S. Army Corps of Engineers

This short course provides an update to the tools available for resilient infrastructure planning with a particular focus on tools available to DoD installation planning practitioners at coastal installations.

Topics include an introduction sea level change tools, an exploration of the statistical adjustment approaches to climate derived hydrology data, what those adjustments and diagnostics are, and how to apply the methods available, the background context on nonstationarity research, and an introduction to the framework based on the shift in assumptions from hydrologic stationarity to nonstationarity and outlines the major steps of the framework.

The course will provide participants with an understanding of the tools currently available and their use.

INFRASTRUCTURE RESILIENCE AND PLANNING UPDATE

- Instructor Short Bio:

Dr. Kate White leads the US Army Corps of Engineers (USACE) Climate Preparedness and Resilience Community of Practice within the USACE Headquarters, Engineering and Construction Directorate.

Dr. White holds B.S. and M.S. degrees in Civil Engineering and a Ph.D. in Civil and Environmental Engineering.

A registered professional engineer with over 31 years at the USACE, she develops policy, technical guidance, methods, and tools for climate preparedness and resilience, with an emphasis on water resources management issues involving extreme events and natural hazards.

She received a 2013 GreenGov Presidential Award as Climate Champion and was selected as the USACE 2014 Engineer of the Year.

Specific Course Objectives

1. Learn where to find authoritative information on changing climate pertinent to infrastructure resilience.

2. Become familiar with changing sea level and several on-line resources to visualize observed and projected sea level change.

3. Understand basic concepts of stationary and nonstationary hydrologic conditions.

4. Gain an introduction to the basics of climate preparedness and resilience for military infrastructure.

Sources of Authoritative Climate Information

- The U.S. Global Change Research Program (GCRP) developed and produced the Fourth U.S. National Climate Assessment (NCA4), vols I and II
- 1989 GCRP began as Presidential Initiative
- 1990 Created by Congress in U.S. Global Change Research Act “to assist the nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change”
- Work is directed and overseen by Principals representing the 13 GCRP member agencies as the White House Office of Science and Technology Policy Subcommittee on Global Change Research (OSTP / SGCR)

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National Climate Assessment

- The National Climate Assessment is required by the Global Change Research Act, section 106:
  - “Not less frequently than every 4 years [USGCRP] shall prepare and submit to the President and Congress an assessment which:
  - Integrates, evaluates, and interprets the findings of [USGCRP] and discusses the scientific uncertainties associated with such findings
  - Analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity
  - Analyzes current trends in global change, both human- induced and natural, and projects major trends for the subsequent 25 to 100 years.”

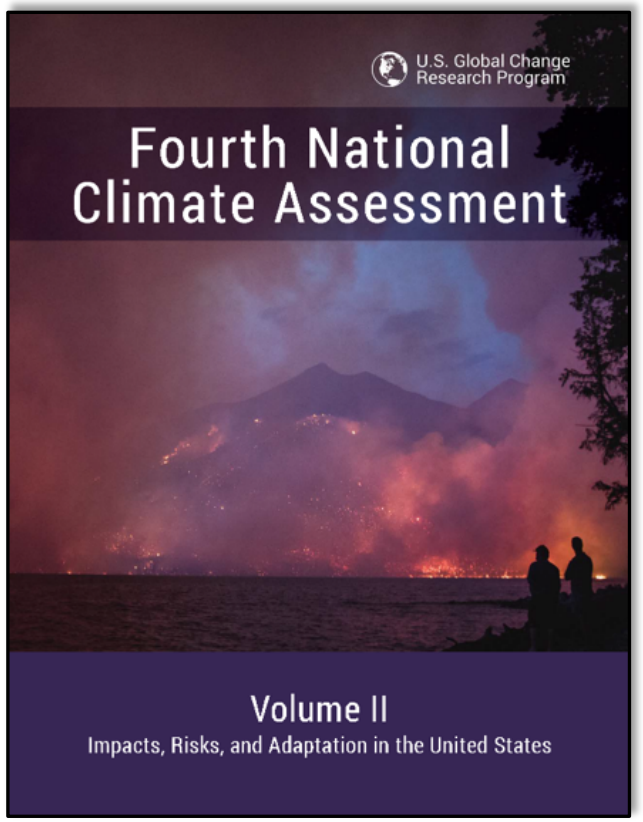
NCA4, vol I - Climate Science Special Report

- Released 3 Nov 2017
- Key advances:
  - Detection and attribution
  - Extreme events (tropical cyclones, tornadoes, atmospheric rivers)
  - Downscaled information (including sea level rise)
  - Potential surprises
  - Climate model weighting
- Also summarized in “Our Changing Climate,” Chapter II in NCA4, vol II

available at: science2017.globalchange.gov

NCA4, vol II - Impacts, Risks, and Adaptation in the United States

- Released 23 Nov 2018
- Is policy relevant, but not policy prescriptive
- Places strong emphasis on regional information
- Assesses range of potential impacts, helping decision makers better identify risks to avoid or reduce
- Uses case studies to provide additional context and opportunities to showcase community success stories



available at: nca2018.globalchange.gov

NCA4 Regions and Likelihood Terminology

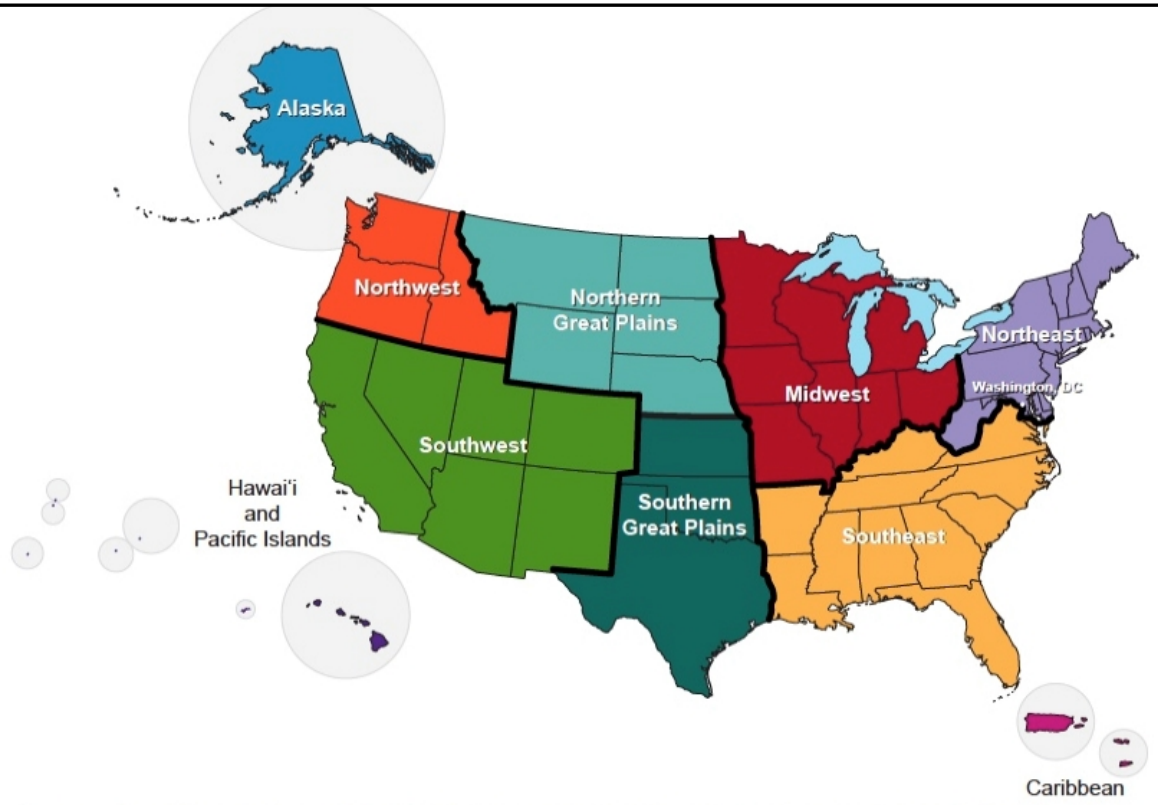


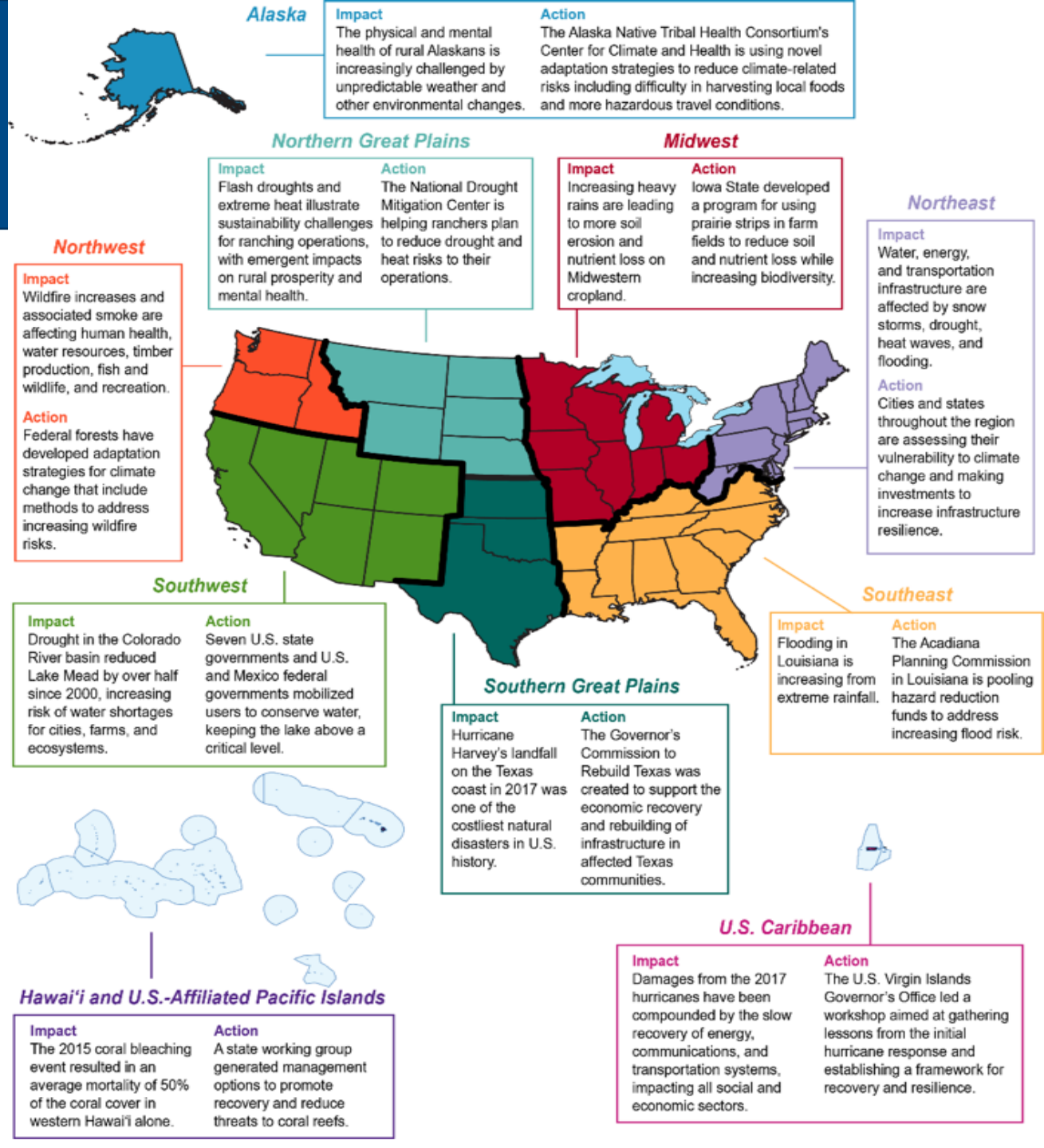
Figure 1. Map of the ten regions of the United States used throughout the Climate Science Special Report. Regions are similar to that used in the Third National Climate Assessment except that 1) the Great Plains are split into the Northern Great Plains and Southern Great Plains, and 2) the Caribbean islands have been split from the Southeast region. (Figure source: adapted from Melillo et al. 2014[2]).

Confidence Level	Likelihood
Very High	**Virtually Certain**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	99%–100%
High	**Extremely Likely**
Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	95%–100%
Medium	**Very Likely**
Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	90%–100%
Low	**Likely**
Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts	66%–100%
	About as Likely as Not
	33%–66%
	Unlikely
	0%–33%
	Very Unlikely
	0%–10%
	Extremely Unlikely
	0%–5%
	Exceptionally Unlikely
	0%–1%

Figure 2. Confidence levels and likelihood statements used in the report. (Figure source: adapted from USGCRP 2016[5] and IPCC 2013[1]; likelihoods use the broader range from the IPCC assessment). As an example, regarding "likely," a 66%–100% probability can be interpreted as a likelihood of greater than 2 out of 3 chances for the statement to be certain or true. Not all likelihoods are used in the report.

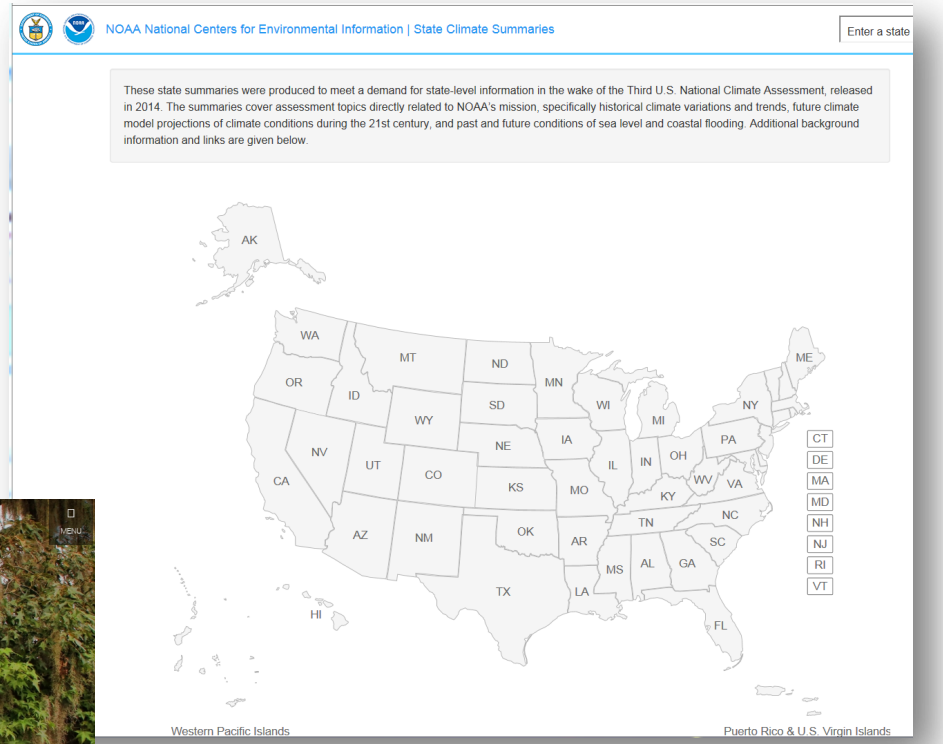
NCA4 vol II Regional Assessments emphasize regional risks and actions

- NCA4 is not simply an update to NCA3 from 2014
- New climate-related impacts in each region since NCA3 (2014), and new response actions to address related risks and costs
- Greater visibility to **emerging topics**:
  - Effects of climate change on U.S. international interests, including trade, national security, and humanitarian assistance
  - Air quality and climate change
  - Complex, interconnected human and natural systems



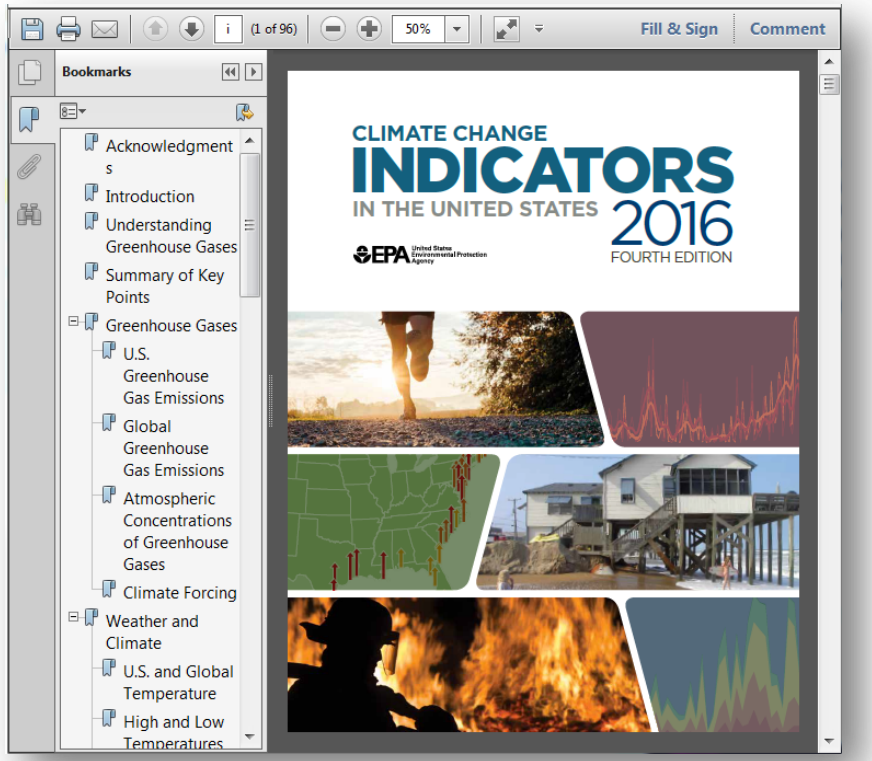
NOAA State Climate Summaries, 2017

- NOAA State Climate Summaries https://statesummaries.ncics.org/
- Select state
- Select key messages, narrative (same as text in key messages), and downloads (web graphics and supplemental graphics)



EPA Report on Climate Change Indicators, 2016

- EPA Report on Climate Change Indicators in the US, 2016 https://www.epa.gov/sites/production/files/2016-08/documents/climate_indicators_2016.pdf
- Applicable sections are
  - Weather and Climate
  - Oceans
  - Snow and Ice
  - Ecosystems
  - To a lesser extent, Health and Safety
- Some interesting background information and potentially localized data that could provide useful background



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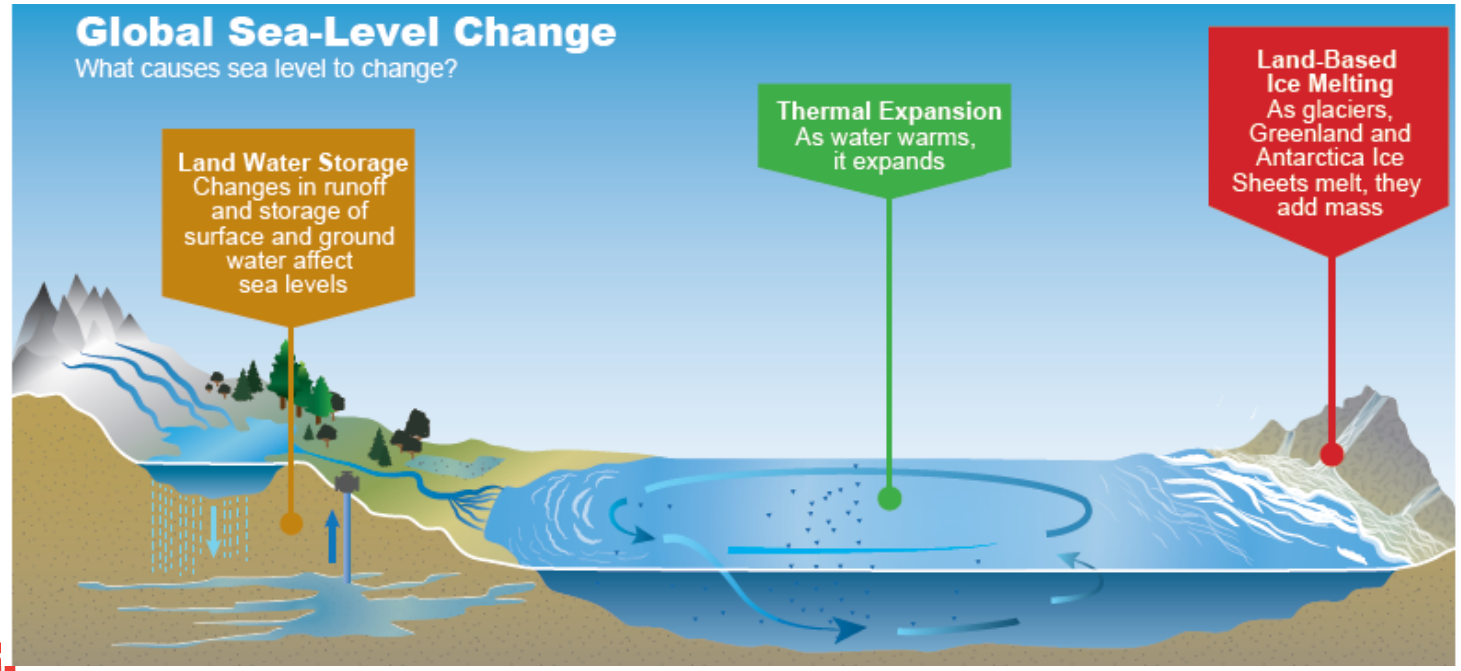
Changing Sea Level

Sea Level Change

- ***Global Drivers***
- Thermal Expansion
- Land Ice Melt-Discharge

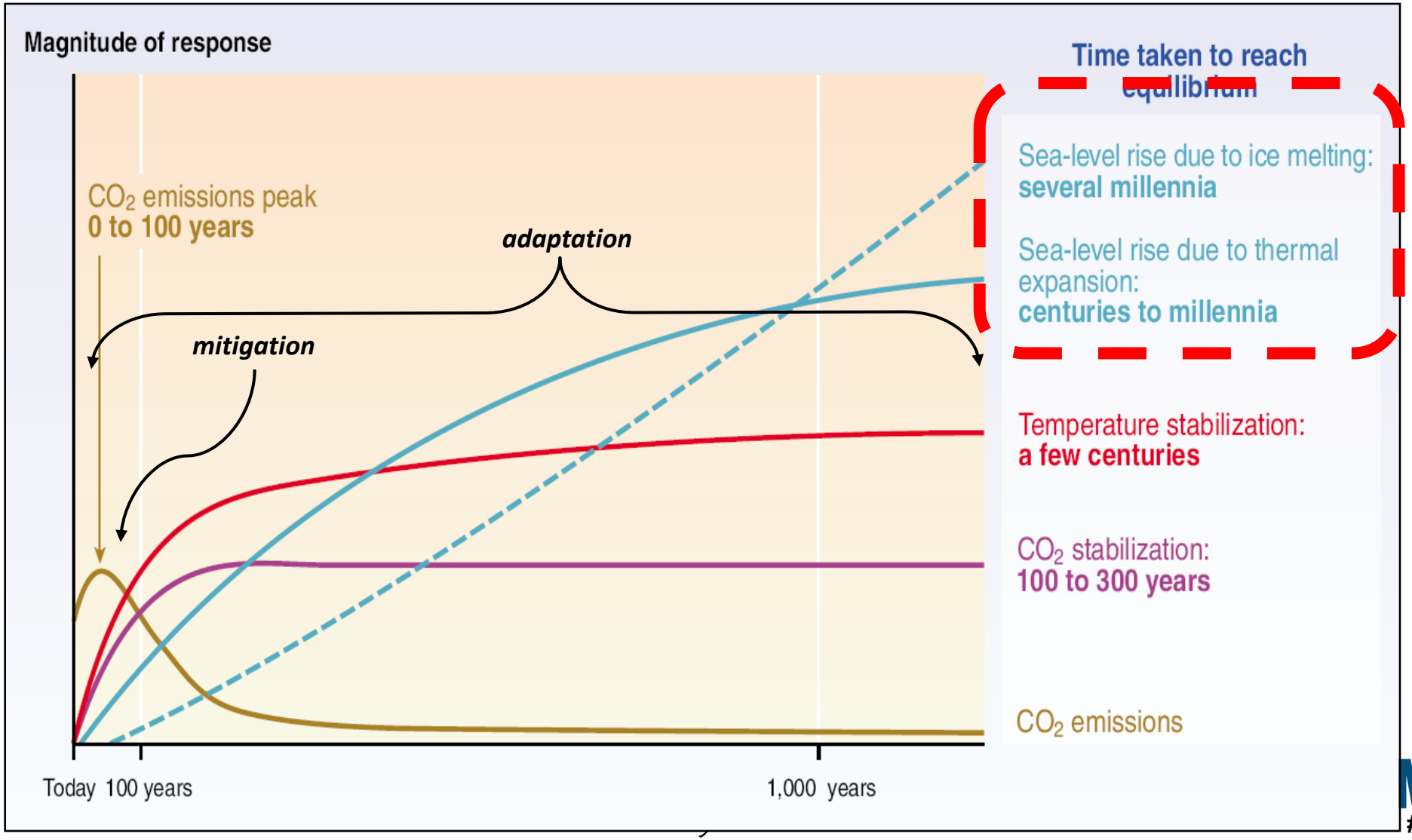
- ***Regional to Local Drivers***
- Vertical land movement
- Seasonal cycles
- Ocean – atmospheric variability
- Ocean circulation
- Storm surge - tsunami
- Wind waves
- Tides



(NRC, 2012)

Hall et al., 2016 Regional Sea Level Scenarios for Coastal Risk Management, DoD Strategic Environmental Research and Development Program

Climate Change Commitment: We are already committed to centuries of changing sea level



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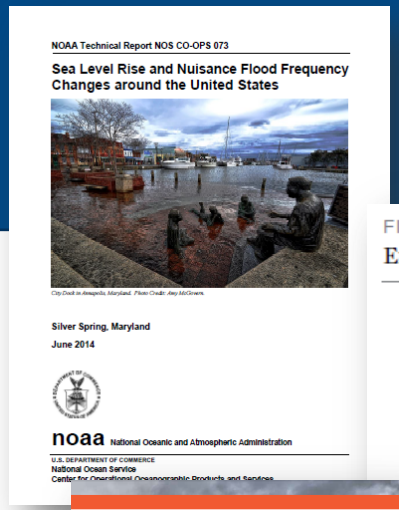
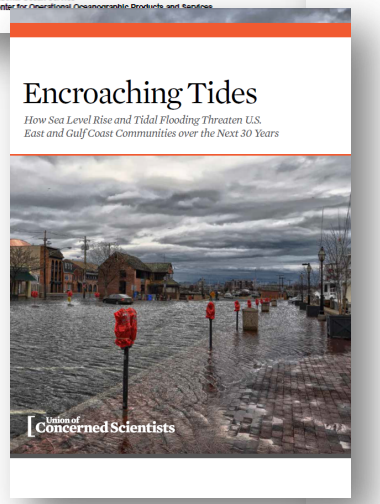
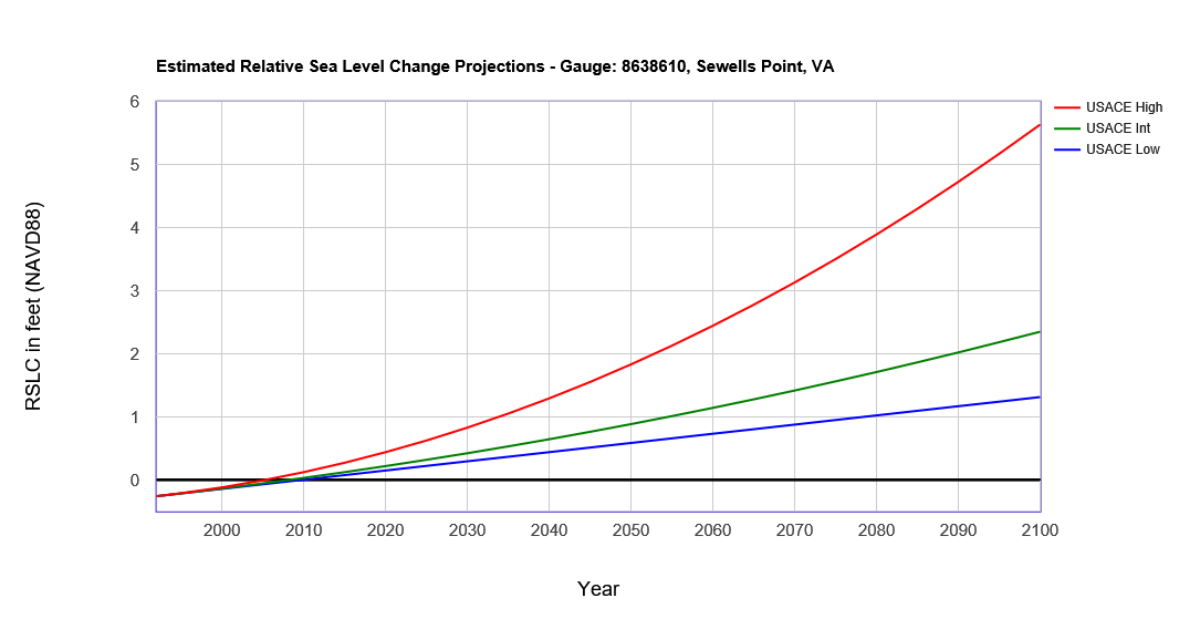
WHEN, NOT IF

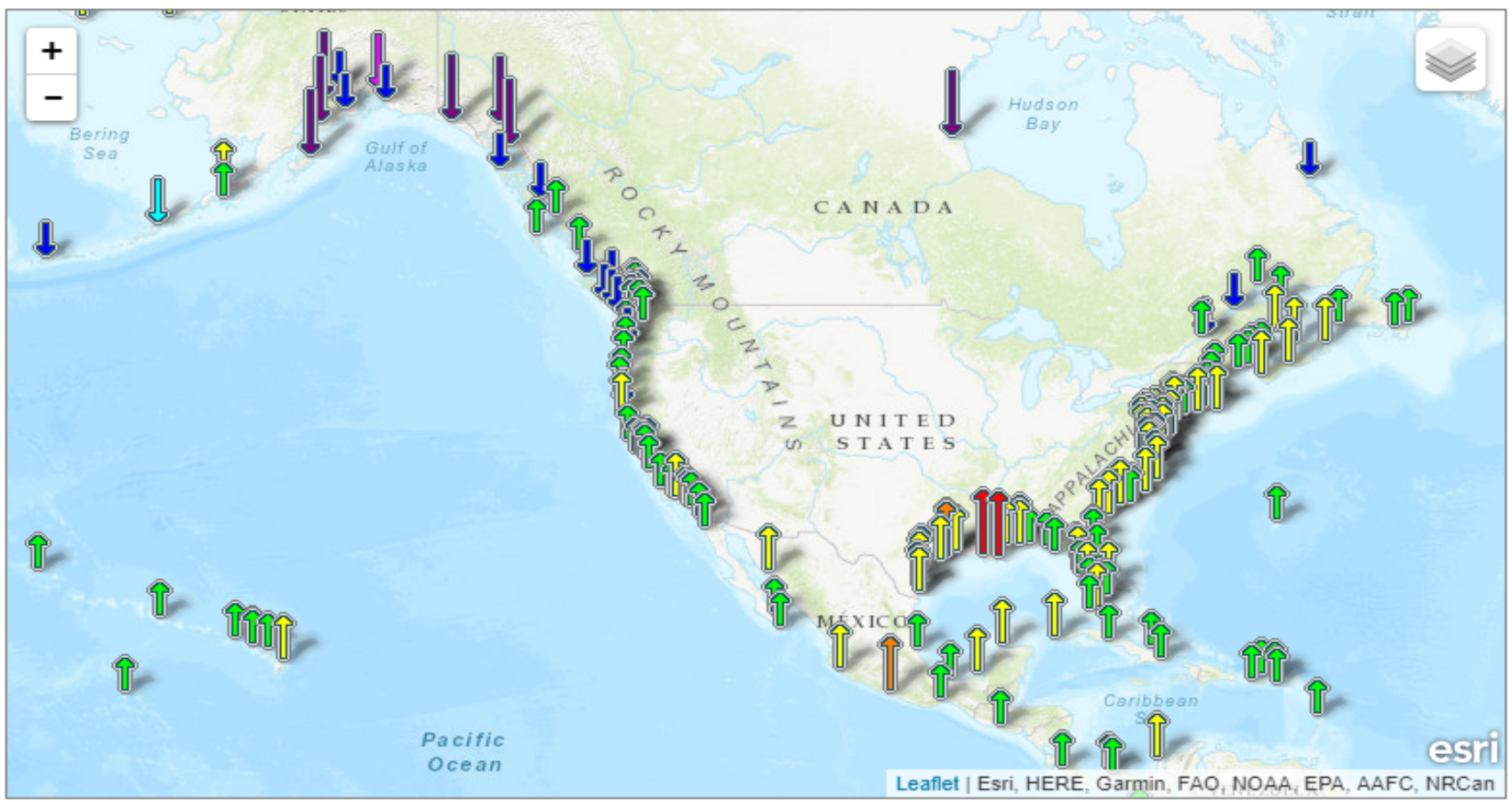
- Chronic flooding is increasing and will continue to increase
- USACE approach is “When, not if”
- Scenario approach allows us to prepare for plausible future timing without “guessing” how sea level varies
- The scenarios help us to avoid over-investment today for far future needs or under-investment now that results in high response recovery costs later







Regional and Local Sea Level Change Variation



The map above illustrates relative sea level trends , with arrows representing the direction and magnitude of change. Click on an arrow to access additional information about that station.

Relative Sea Level Trends

mm/yr (feet/century)

Above 9 (Above 3)	6 to 9 (2 to 3)	3 to 6 (1 to 2)	>0 to 3 (0 to 1)	-3 to 0 (-1 to 0)	-6 to -3 (-2 to -1)	-9 to -6 (-3 to -2)	Below -9 (Below -3)

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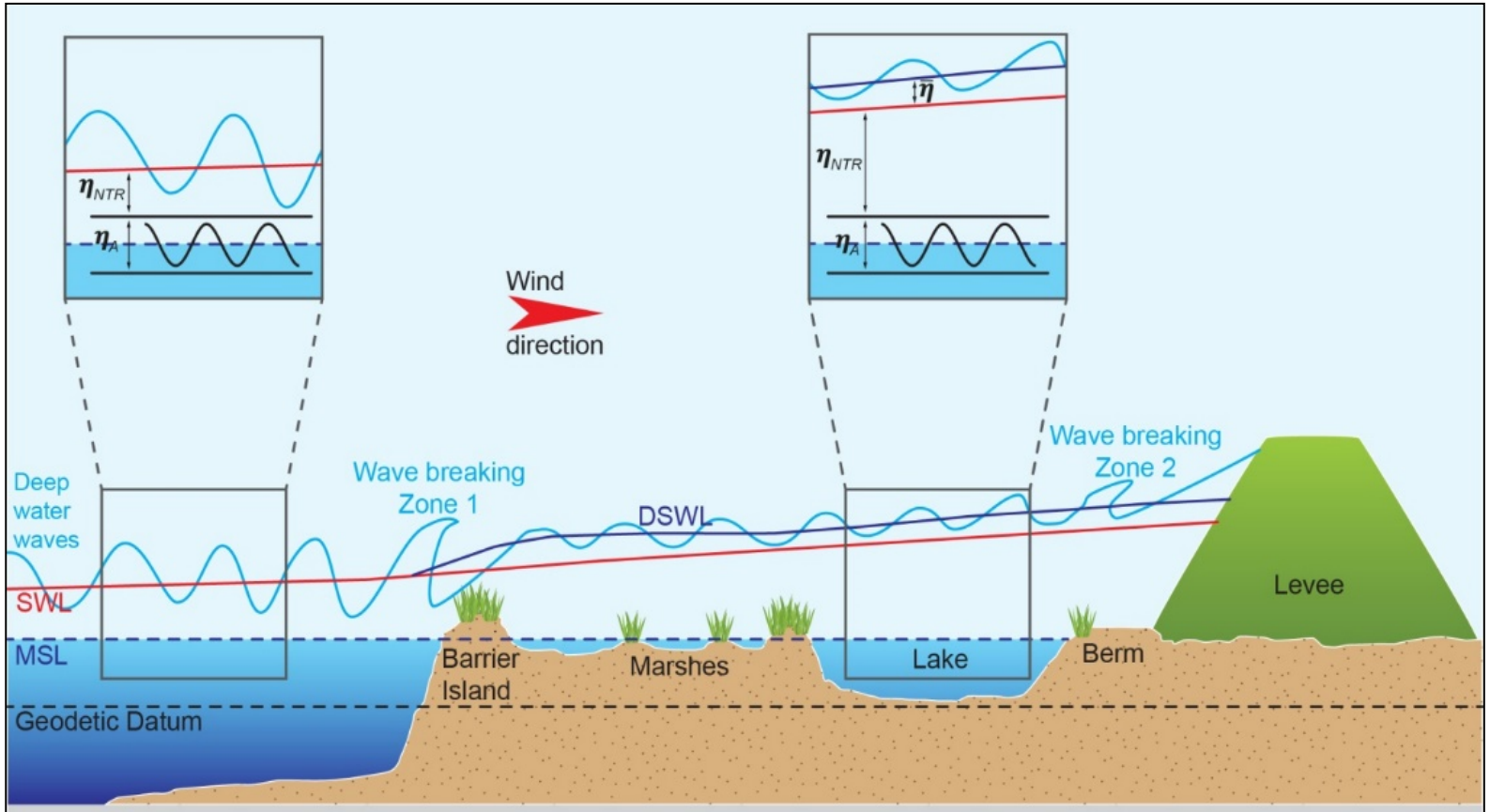
Changing Sea Levels Affect Total Water Surface Elevations Over the Ground



Key

η_{NTR}	non tidal residual	*MSL*	mean sea level	*DSWL*	dynamic still water level
η_A	astronomical tide	*SWL*	still water level	*R*	wave runup
$\bar{\eta}$	wave setup	*S*	swash	*TWL*	total water level

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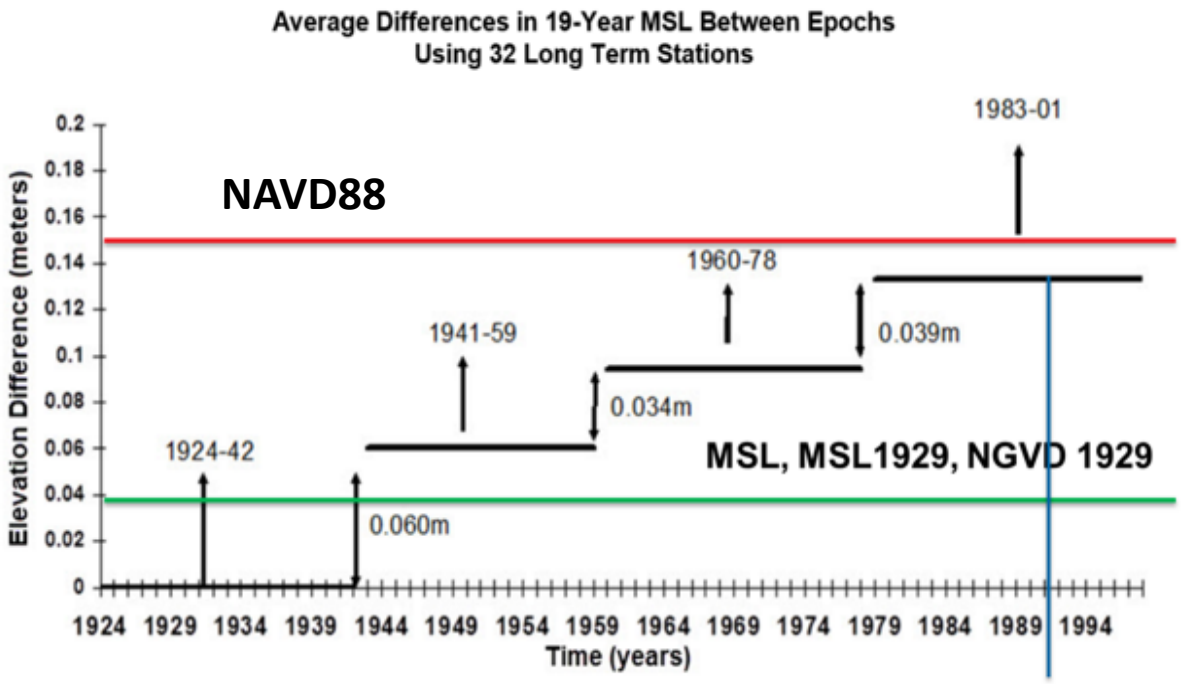
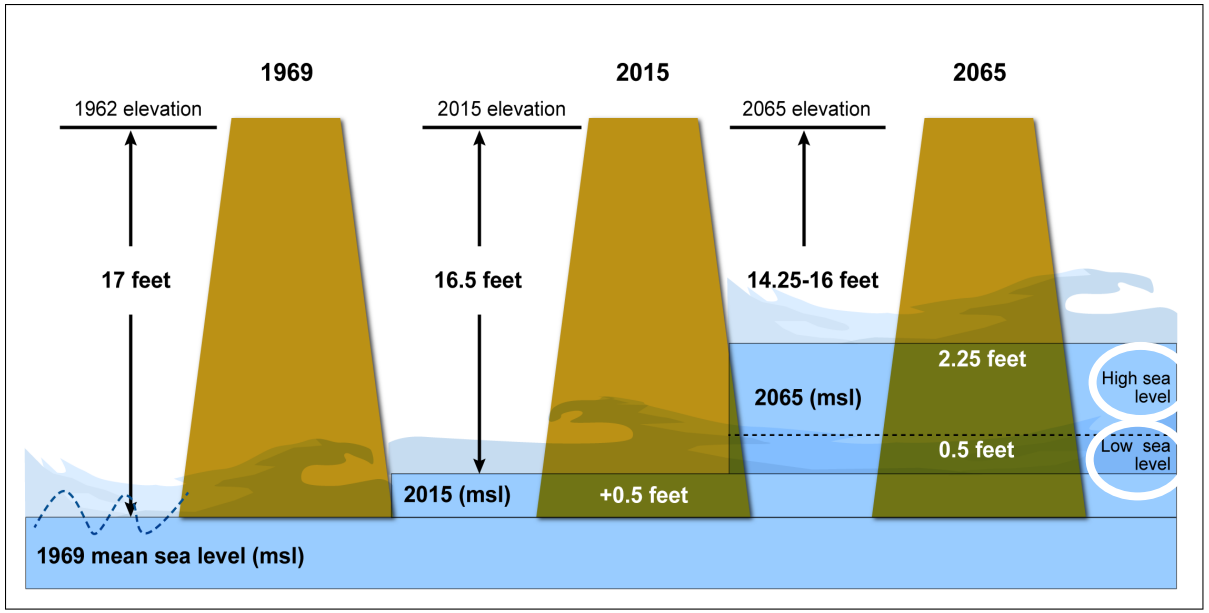
Computing water surface elevations over the ground in coastal areas: Datums, Datums, Datums

- Datum Compliance is required for projects, especially coastal projects – many are noncompliant
- Why? People can die when datums are incorrect or conversions are wrong - ref. Katrina
  - ER 1110-2-8160 Engineering and Design: Policies for Referencing Project Evaluation Grades to Nationwide Vertical Datums
  - EM 1110-2-6056, Standards and Procedures for Referencing Project Evaluation Grades to Nationwide Vertical Datums

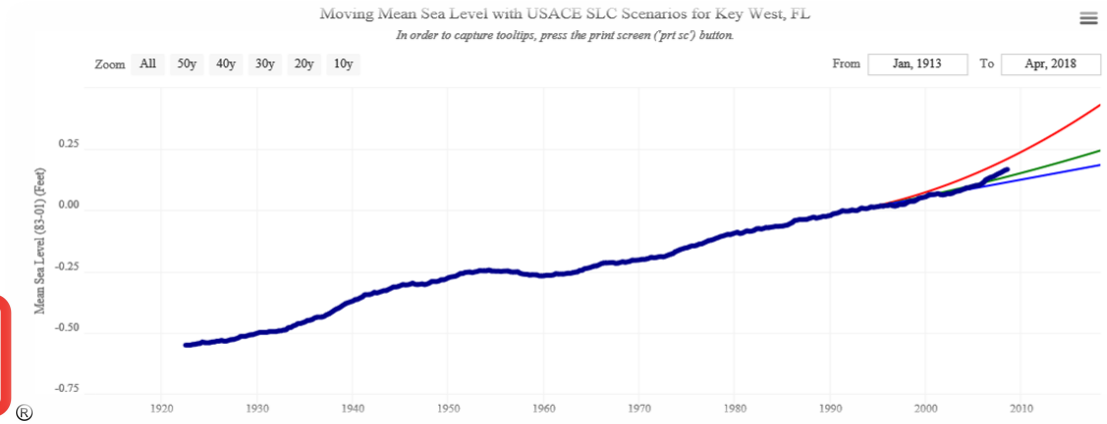


Midpoint of Current Tidal Datum

Changing Sea Level Affects Existing Infrastructure



Source: GAO representation of U.S. Army Corps of Engineers data. | GAO-15-660

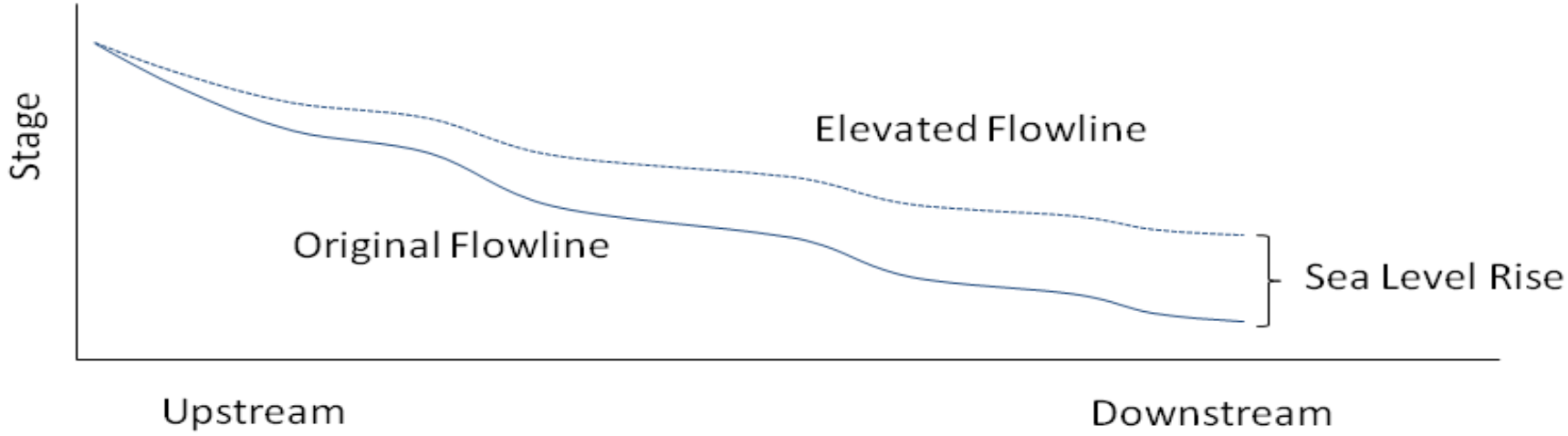


Scenarios:
High
Intermediate
Low

- 2013, ER 1100-2-8162 (EC 1165-2-211/212) – use 3 scenarios
- 2014, ETL 1100-2-1, adaptation to changing sea levels, uses tiered approach with level of effort commensurate with scale of decision and consequences
- 2019, EP 1100-2-1 continuing guidance for ETL 1100-2-1, which expired June 2019

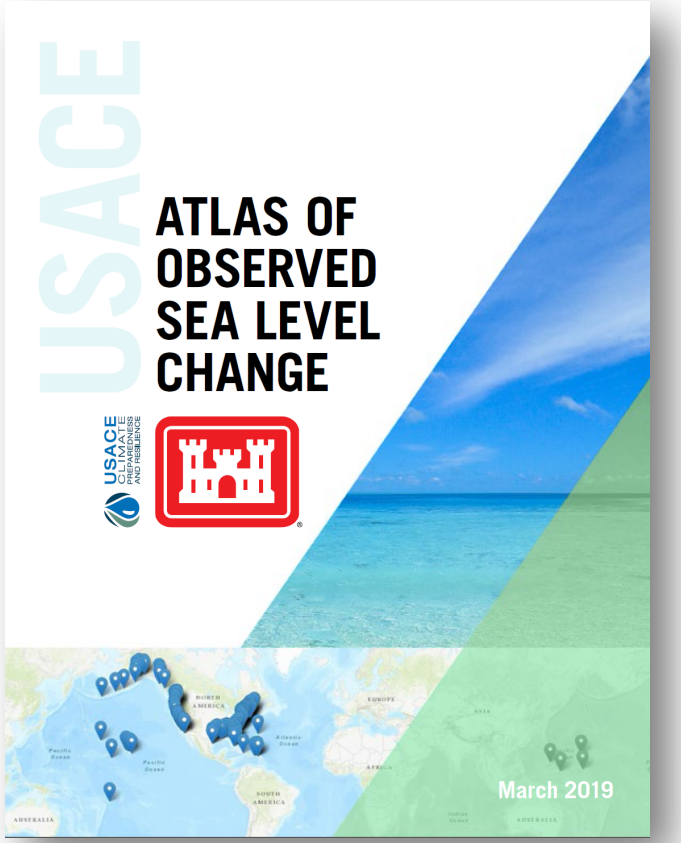
Project Impact Example: Sea Level Impact on Rivers

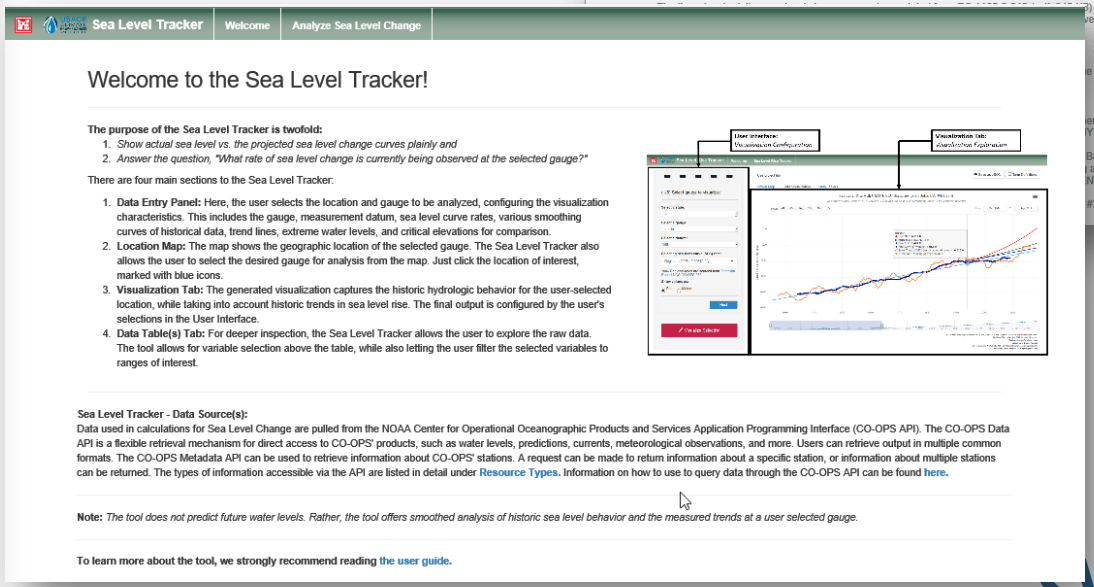
- Raising the downstream boundary increases river stage for the same discharge
  - EM 1110-2-1416, section 6-8.f. Tidal conditions. “When the river profile computation begins at the outlet of a stream influenced by tidal fluctuations, the maximum predicted high tide, including wind-wave set up, is taken as the starting elevation at a station usually located at the mouth of the stream.”
  - ER 1100-2-8162: “As used in this ER, locations with oceanic astronomical tidal influence, as well as connected waterways with base-level controlled by sea level. In the latter waterways, influence by wind driven tides may exceed astronomical tidal influence. Coastal areas include marine, estuarine, and riverine waters and affected lands.”

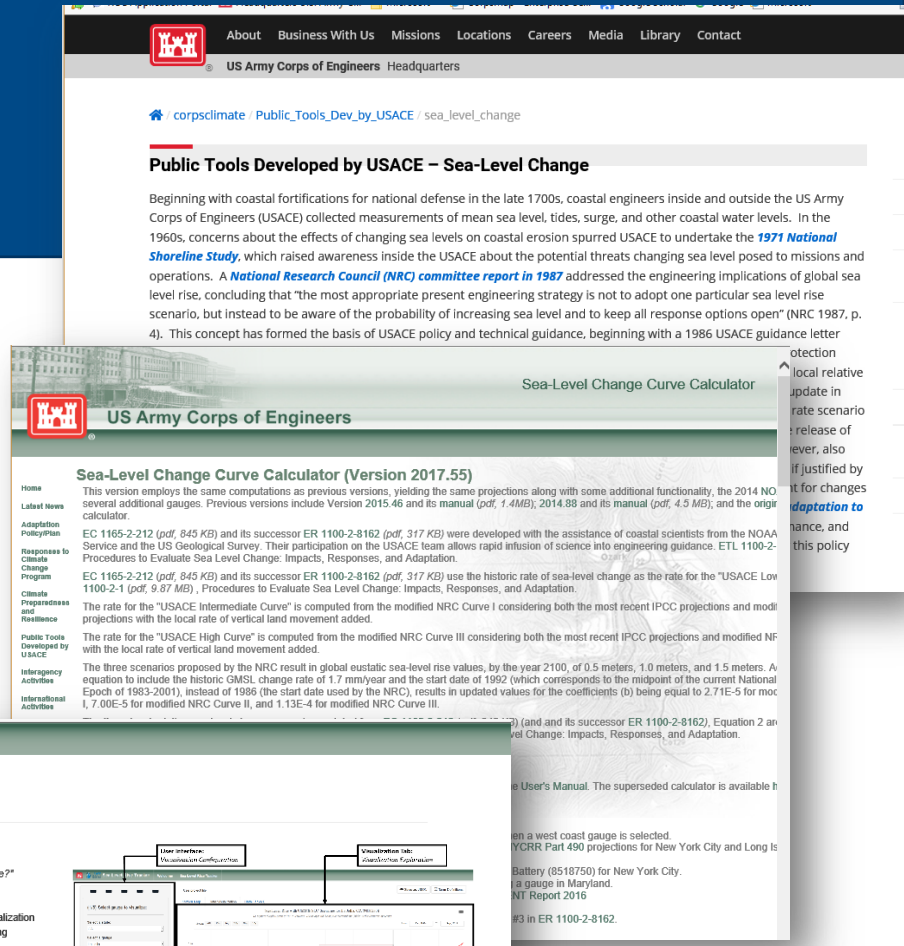


Sea level change tools

- Sea level change calculator - 2013
- Sea level change tracker - 2018
- Atlas of sea level change - 2019



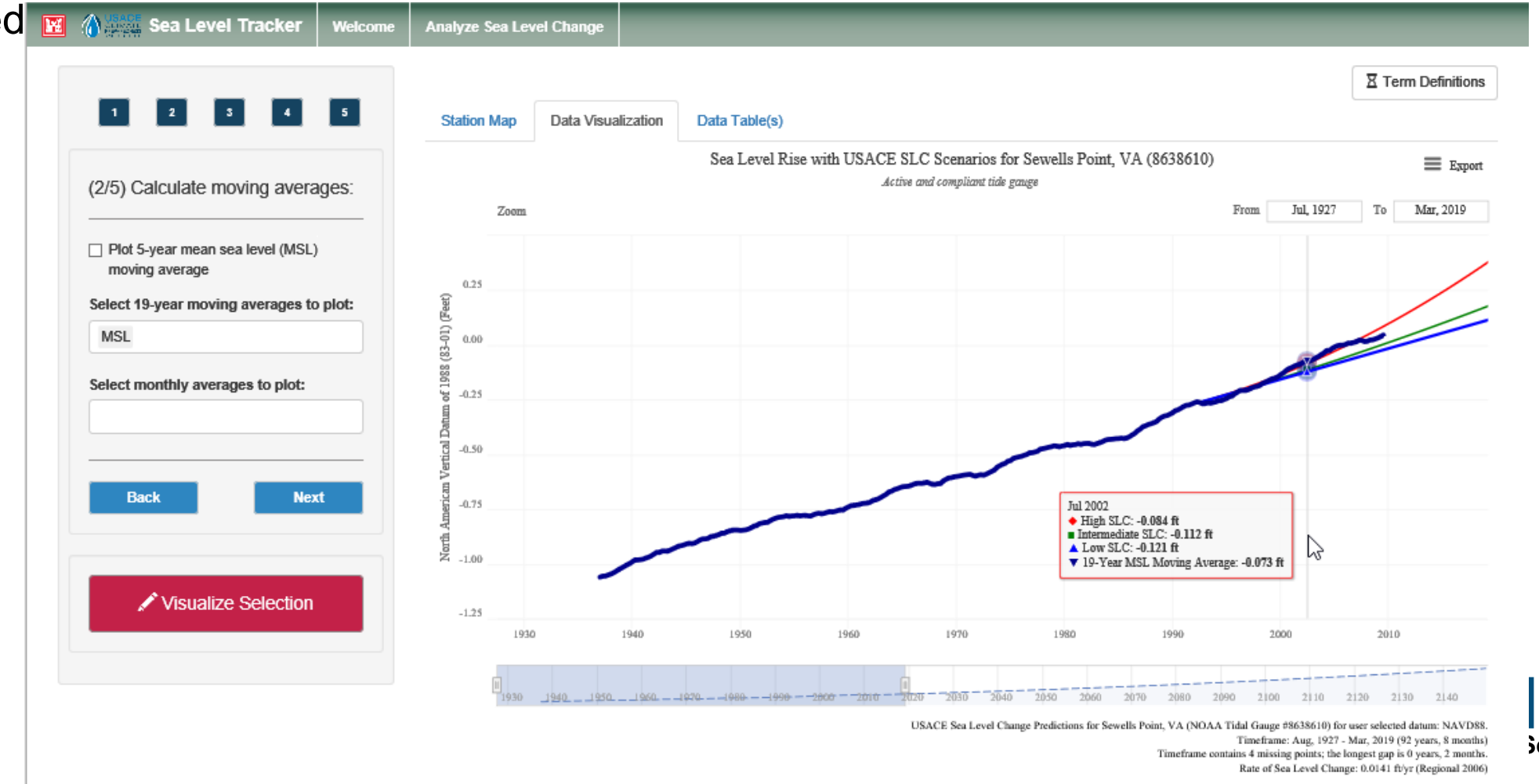




https://www.usace.army.mil/corpsclimate/Public_Tools_Dev_by_USACE/sea_level_change/

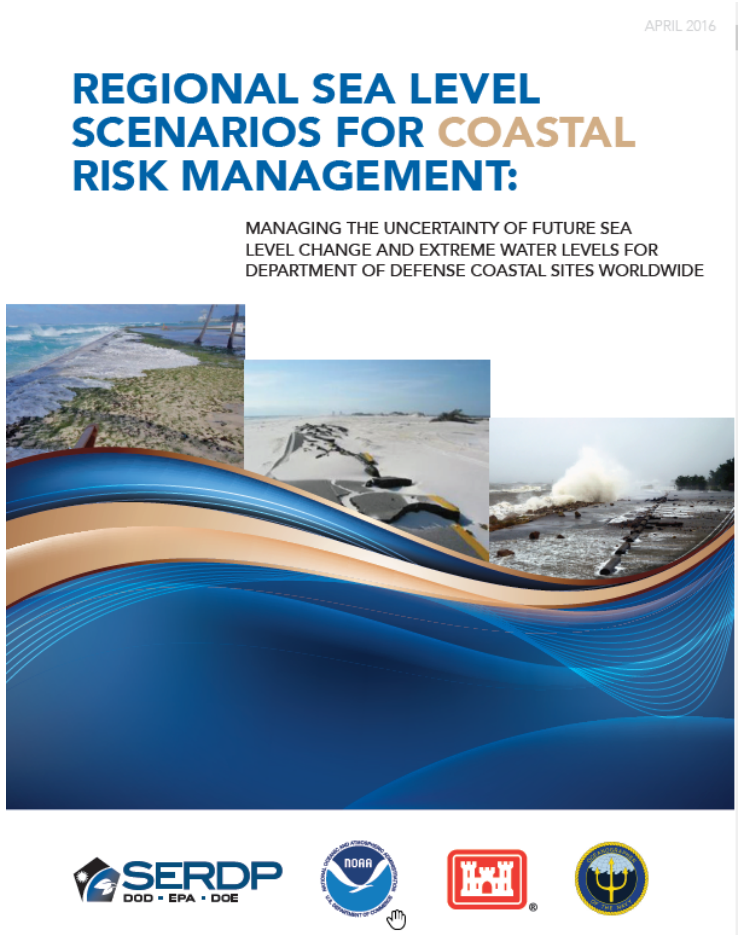
Sea Level Tracker Example Output

- Capability to show monthly values, other tidal statistics (e.g., MHHW, MLLW), extreme water levels (annual through 1% AEP) and critical elevation thresholds to show when and if they are exceed



DOD DoD Group (CARSWG)

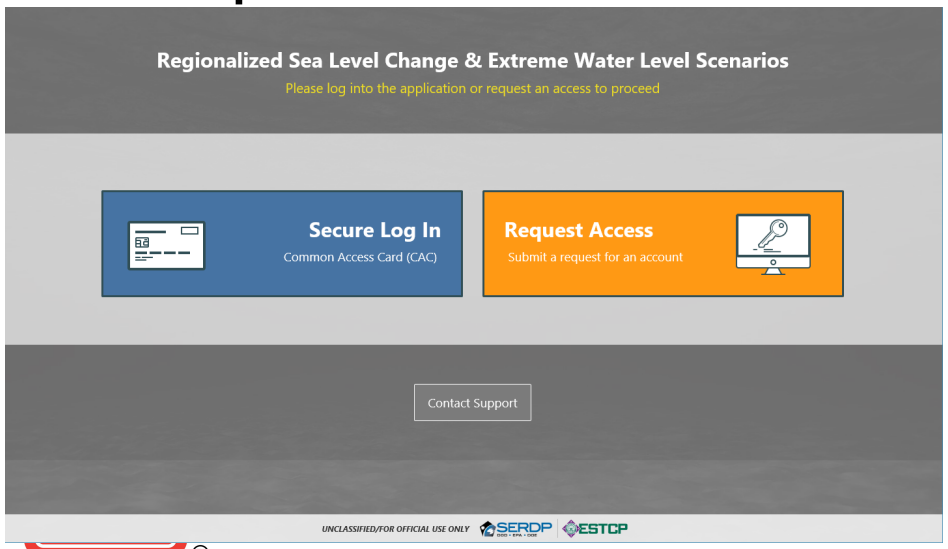
- Multi-agency team of researchers developed the report and an accompanying online database to provide regionalized sea level and extreme water level scenarios for three future time horizons (2035, 2065, and 2100) for 1,774 military sites worldwide
- These scenarios are plausible and scientifically credible future sea level and extreme water level values.

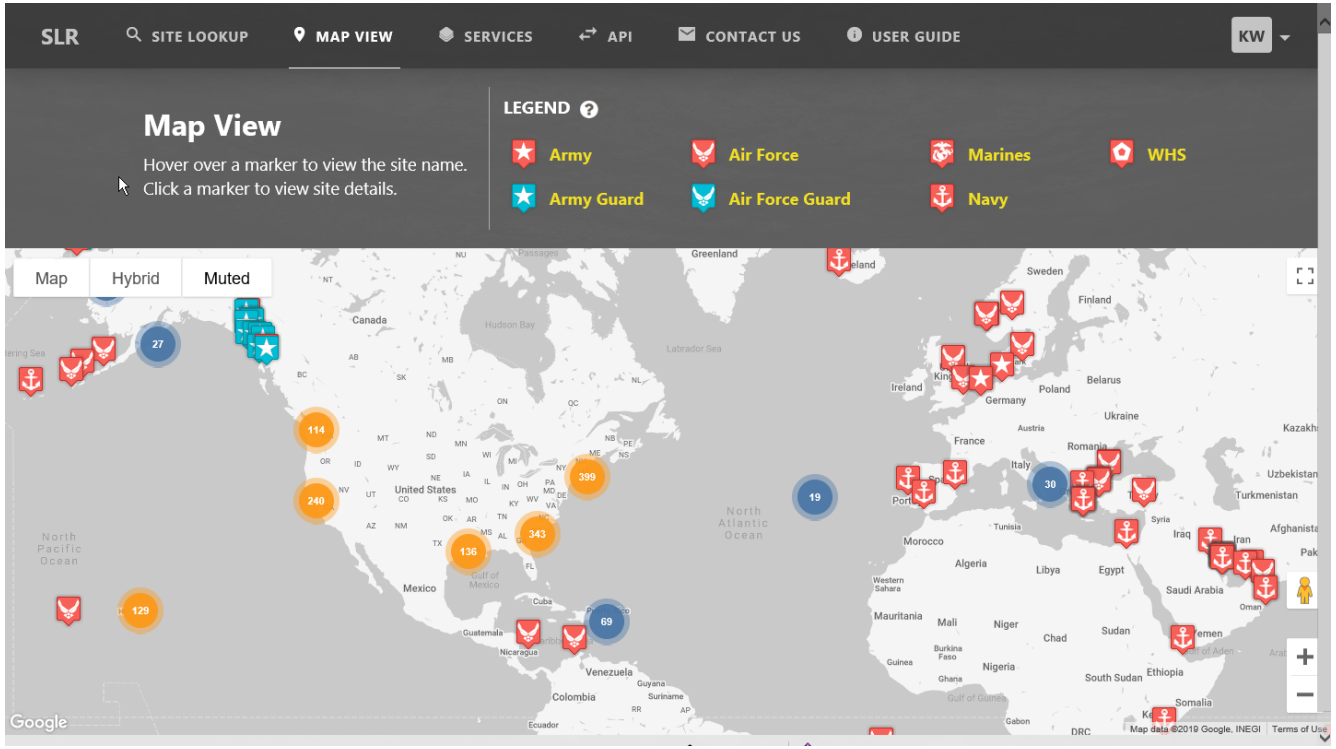


https://www.serdp-estcp.org/News-and-Events/News-Announcements/Program-News/DoD-Report-on-Regional-Sea-Level-Scenarios

DOD Regional Sea Level Scenarios Database

- Database is CAC-accessible (url below)
- Need to request access ahead of time
- Site lookup by name or map view





https://sealevelscenarios.serdp-estcp.org/

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DOD Scenarios Example: Alaska

SLR | http://ec2-34-205-128-255.compute-1.amazonaws.com:8080/roi/ | RVICES | API | CONTACT US | USER GUIDE

Map View

Hover over a marker to view the site name.
Click a marker to view site details.

LEGEND

- Army
- Air Force
- Marines
- WHS
- Army Guard
- Air Force Guard
- Navy

Map | Hybrid | Muted

Beaufort Sea
Chukchi Sea
ALASKA
YUKON
NORTHWEST TERRITORIES
Canada
Bering Sea
Nome
Google

24
15

ny Guard
NG Nome Armory OMS
Site RpsuId
6503
Site Code
02C55
Installation Name
Alaska National Guard
Installation Code
020NG
VIEW SITE

NG Nome Armory OMS

RPSUId 6503 Installation ALASKA NATIONAL GUARD
Latitude 64.496512 Longitude -165.397212 Elevation unavailable
Reference Datum unavailable Mean Sea Level is unavailable Mean Higher High Water is unavailable

Sea Level Change | Meters | Feet

Regionalized Sea Level Change Scenarios

Adjustments relative to global **mean sea level** (referenced to 1992, the 1983-2001 tidal epoch)
User choices include selection of the appropriate time horizon, global sea level scenarios, and unit (meters or feet).

Global Scenario	2035	2065	2100
Lowest	0.1	0.1	0.1
Highest	**0.2**	**0.9**	**2.0**

Base Unit → Meters

2035 Scenarios | 2065 Scenarios | 2100 Scenarios

Global Scenario	Global SLR	Site-Specific Adjustments			Total Site-Specific Adjustments	Global SLR + Site-Specific Adjustments
		Vertical Land Movement	Ocean Circulation	Ice Melt Effects		
Lowest (0.2)	0.1	0.0	0.0	0.0	0.0	0.1
Low (0.5)	0.1	0.0	0.0	0.0	0.0	0.1
Medium (1.0)	0.2	0.0	0.0	0.0	0.0	0.2
High (1.5)	0.2	0.0	0.0	-0.1	-0.1	0.1
Highest (2.0)	0.3	0.0	0.0	-0.1	-0.1	0.2

Base Unit → Meters

Example: NG Nome Armory OMS

NG Nome Armory OMS

RPSUId 6503 Installation ALASKA NATIONAL GUARD

Latitude 64.496512 Longitude -165.397212 Elevation unavailable

Reference Datum unavailable Mean Sea Level is unavailable Mean Higher High Water is unavailable

Sea Level Change

Meters Feet

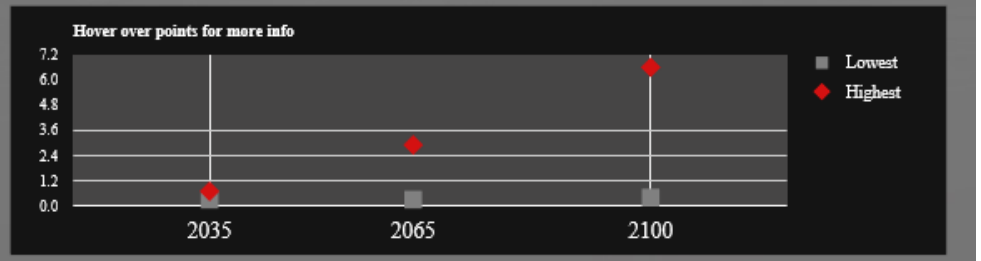
Regionalized Sea Level Change Scenarios

Adjustments relative to global **mean sea level** (referenced to 1992, the 1983-2001 tidal epoch)

User choices include selection of the appropriate time horizon, global sea level scenarios, and unit (meters or feet).

Global Scenario	2035	2065	2100
Lowest	0.3	0.3	0.4
Highest	**0.7**	**2.9**	**6.6**

Base Unit → Feet

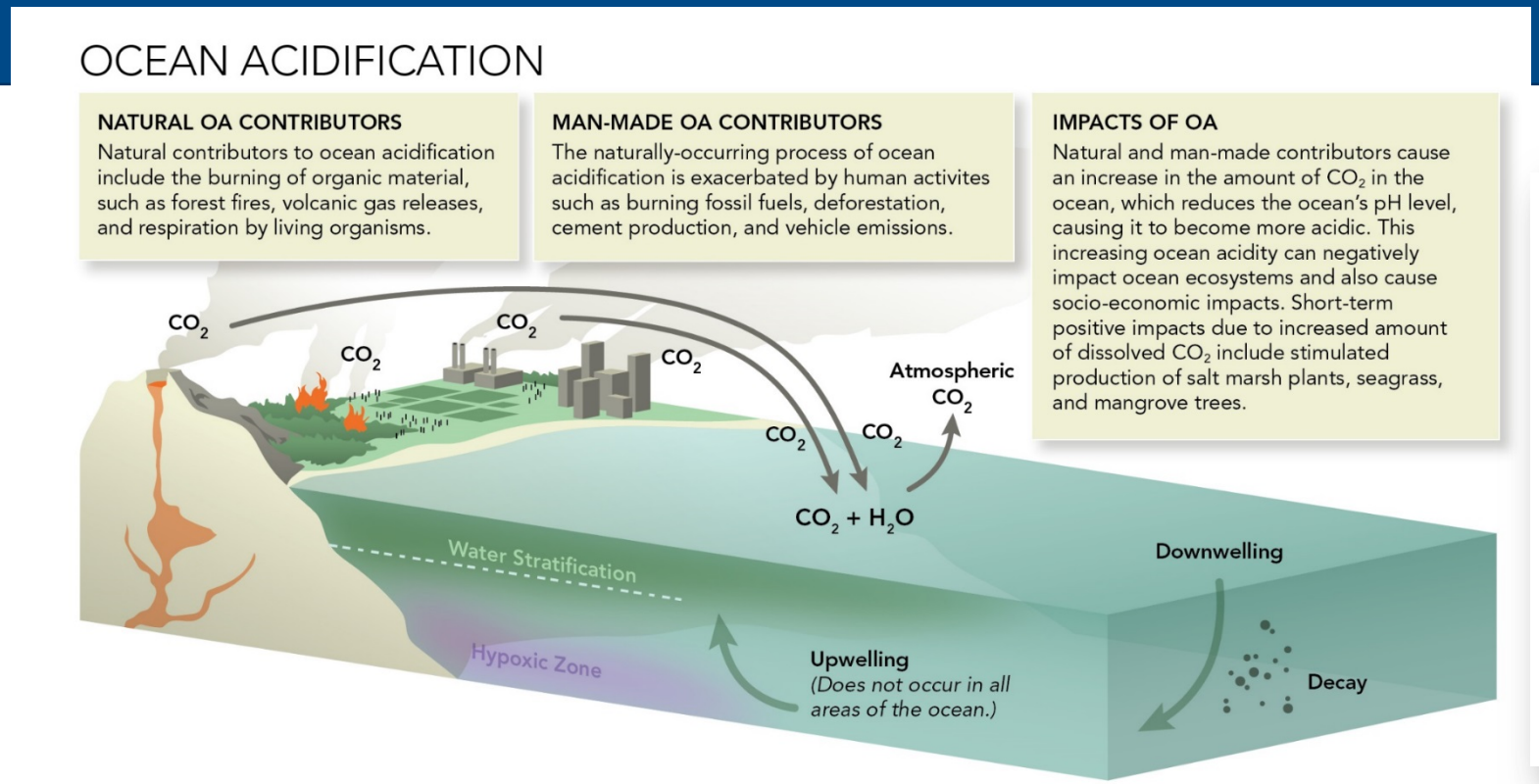


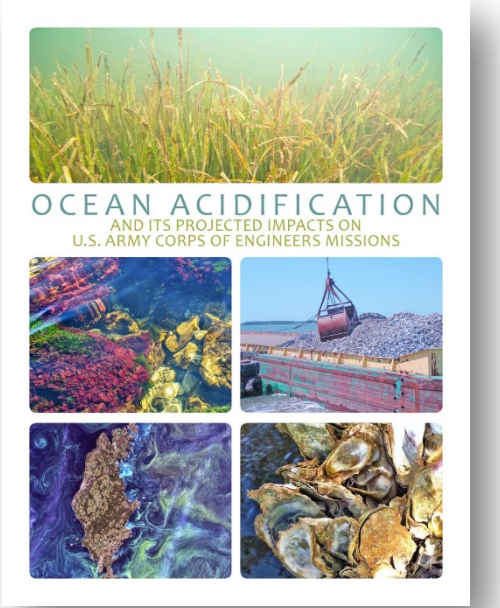
2035 Scenarios | 2065 Scenarios | 2100 Scenarios

Global Scenario	Global SLR	Site-Specific Adjustments			Total Site-Specific Adjustments	Global SLR + Site-Specific Adjustments
		Vertical Land Movement	Ocean Circulation	Ice Melt Effects		
Lowest (0.7)	0.3	0	0	0	0	0.3
Low (1.6)	0.7	0	0	-0.3	-0.3	0.4
Medium (3.3)	1.3	0	0	-0.3	-0.3	1.0
High (4.9)	2.0	0	0.3	-0.3	0.0	2.0
Highest (6.6)	2.6	0	0.3	0	0.3	2.9

Base Unit → Feet

Ocean Acidification, the "Other CO_2 Problem"





- Natural waters with low pH can become "aggressive" towards concrete structures
- pH of about 6.5 is the threshold for damaging effects
- pH < 6.5, acidified water attacks and begins to dissolve the Portland cement which binds concrete

Climate-Impacted Hydrology

Extreme Precipitation

Extreme Precipitation Has Increased Across Much of the United States

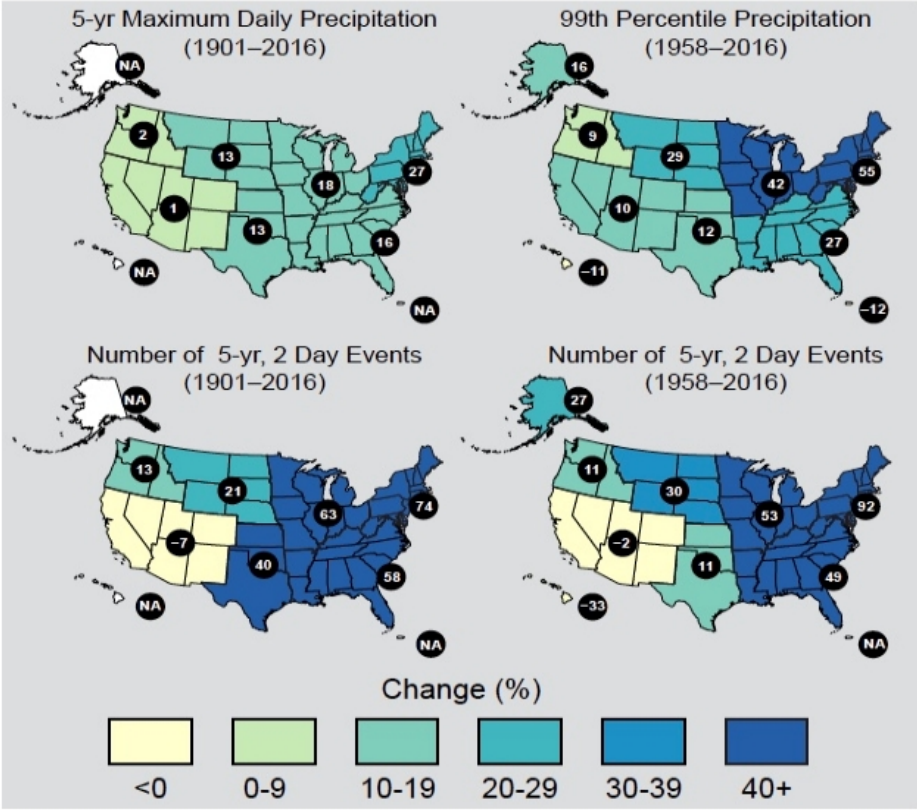


Figure ES.6: These maps show the percentage change in several metrics of extreme precipitation by NCA4 region, including (upper left) the maximum daily precipitation in consecutive 5-year periods; (upper right) the amount of precipitation falling in daily events that exceed the 99th percentile of all non-zero precipitation days (top 1% of all daily precipitation events); (lower left) the number of 2-day events with a precipitation total exceeding the largest 2-day amount that is expected to occur, on average, only once every 5 years, as calculated over 1901–2016; and (lower right) the number of 2-day events with a precipitation total exceeding the largest 2-day amount that is expected to occur, on average, only once every 5 years, as calculated over 1958–2016. The number in each black circle is the percent change over the entire period, either 1901–2016 or 1958–2016. Note that Alaska and Hawai'i are not included in the 1901–2016 maps owing to a lack of observations in the earlier part of the 20th century. *(Figure source: CICS-NC / NOAA NCEI). Based on figure 7.4 in Chapter 7.*

Drought

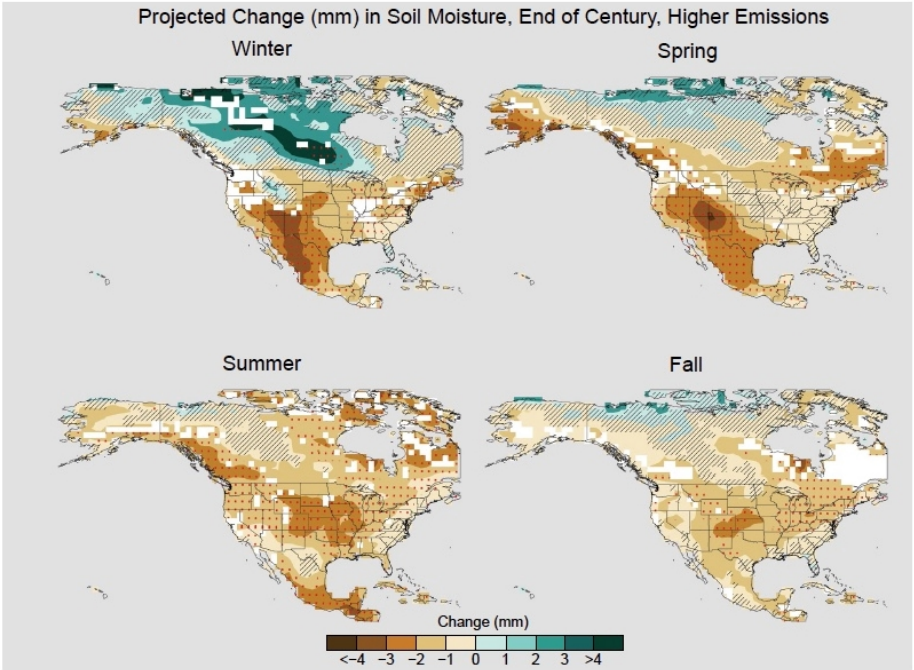
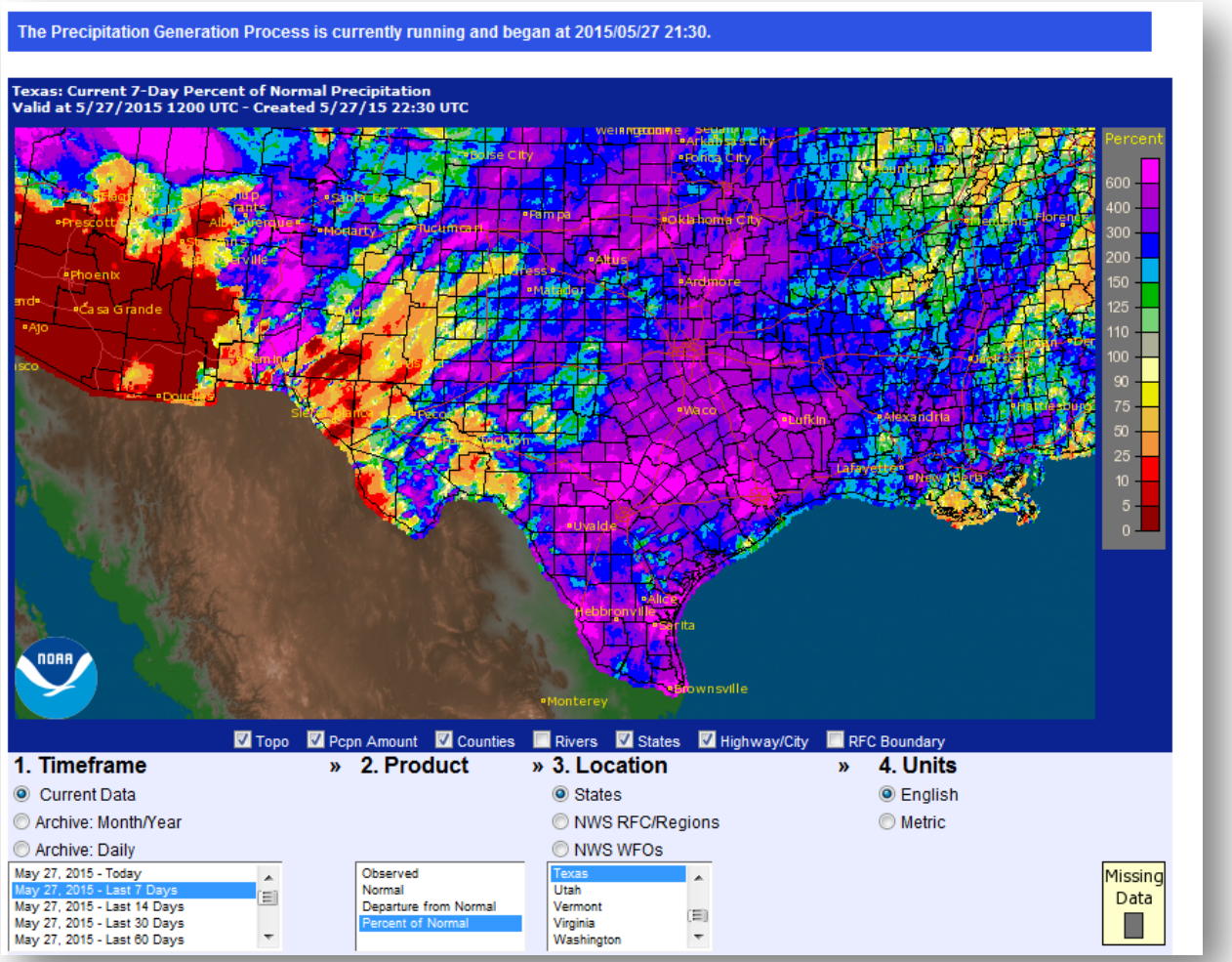


Figure 8.1: Projected end of the 21st century weighted CMIP5 multimodel average percent changes in near surface seasonal soil moisture (mrsos) under the higher scenario (RCP8.5). Stippling indicates that changes are assessed to be large compared to natural variations. Hashing indicates that changes are assessed to be small compared to natural variations. Blank regions (if any) are where projections are assessed to be inconclusive (Appendix B). (Figure source: NOAA NCEI and CICS-NC).

Table 8.1. A list of U.S. droughts for which attribution statements have been made. In the last column, "+" indicates that an attributable human-induced increase in frequency and/or magnitude was found, "–" indicates that an attributable human-induced decrease in frequency and/or magnitude was found, "0" indicates no attributable human contribution was identified. As in Tables 6.2 and 7.1, several of the events were originally examined in the Bulletin of the American Meteorological Society's (BAMS) State of the Climate Reports and reexamined by Angélil et al.[18] In these cases, both attribution statements are listed with the original authors first. (Source: M. Wehner)

Authors	Event Year and Duration	Region or State	Type	Attribution Statement
Rupp et al. 2012[130] / Angélil et al. 2017[18]	MAMJJA 2011	Texas	Meteorological	+/+
Hoerling et al. 2013[16]	2012	Texas	Meteorological	+
Rupp et al. 2013[19] / Angélil et al. 2017[18]	MAMJJA 2012	CO, NE, KS, OK, IA, MO, AR & IL	Meteorological	0/0
Rupp et al. 2013[19] / Angélil et al. 2017[18]	MAM 2012	CO, NE, KS, OK, IA, MO, AR & IL	Meteorological	0/0
Rupp et al. 2013[19] / Angélil et al. 2017[18]	JJA 2012	CO, NE, KS, OK, IA, MO, AR & IL	Meteorological	0/+
Hoerling et al. 2014[17]	MJJA 2012	Great Plains/Midwest	Meteorological	0
Swain et al. 2014[24] / Angélil et al. 2017[18]	ANN 2013	California	Meteorological	+/+
Wang and Schubert 2014[29] / Angélil et al. 2017[18]	JS 2013	California	Meteorological	0/+
Knutson et al. 2014[131] / Angélil et al. 2017[18]	ANN 2013	California	Meteorological	0/+
Knutson et al. 2014[131] / Angélil et al. 2017[18]	MAM 2013	U.S. Southern Plains region	Meteorological	0/+
Diffenbaugh et al. 2015[28]	2012–2014	California	Agricultural	+
Seager et al. 2015[13]	2012–2014	California	Agricultural	+
Cheng et al. 2016[15]	2011–2015	California	Agricultural	–
Mote et al. 2016[31]	2015	Washington, Oregon, California	Hydrological (snow water equivalent)	+

Compound events: Droughts and Floods



Cumulative rainfall 20-27 May 2015

Heavy precipitation May-June 2015 Within Multiyear Drought

Utilizing > 50% Flood Control Storage: 37 projects
Utilizing > 100% Flood Control Storage: 11 projects

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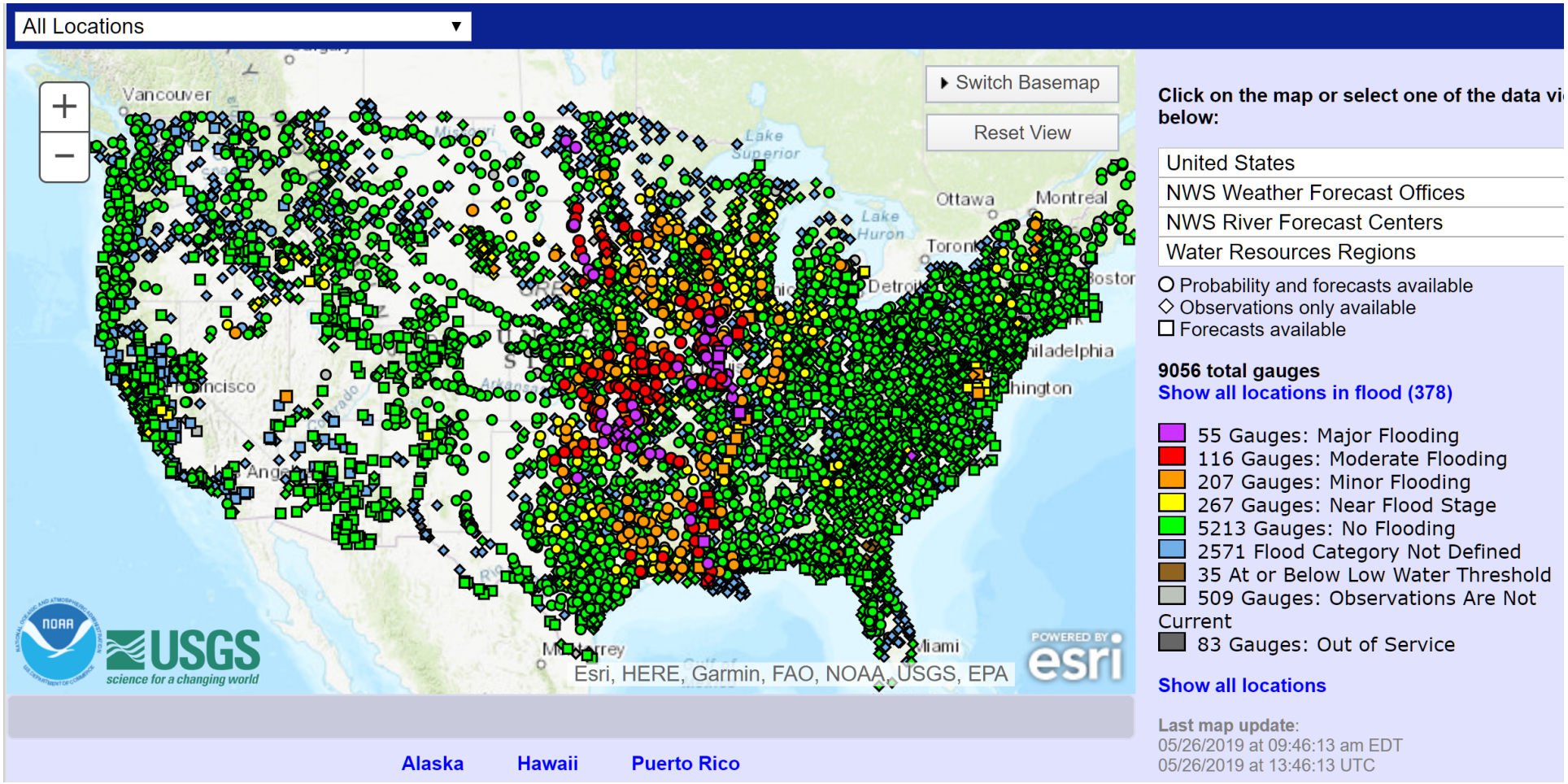
Sunday 26 May 2019: successive events



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Correlated events we are facing

- Successive precipitation events
- Floods and droughts
- Aridity or wildfire and precipitation causing sedimentation
- Precipitation and sea level rise
- Snowmelt and precipitation
- Precipitation and storm surge
- Others:
  - Decreased arctic sea ice and thawing permafrost increasing coastal erosion
  - Increasing ocean acidification that alters metal mobilization and also impacts habitat
  - Temperature or salinity impacts that encourage invasive species in a wetland marsh that previously provided some wave attenuation…

Key factor in water decision-making: stationary or not?

The Stationarity Assumption

The assumption that natural systems fluctuate within an unchanging envelope of variability – that any variable (e.g., annual streamflow or annual flood peak) has a time-invariant (or 1-year–periodic) probability density function (pdf).

In other words, that hydrologic processes are relatively unchanging in time.

Historic Data Driven

The Traditional Approach

The assumption of stationarity has been a cornerstone of hydrologic engineering design because hydrologic engineers do not plan only for the past or the present, but for the future (i.e., over the design life of the structure or project).

Longer Data Record = Better Sample = Better Flow-Frequency curve

- If one assumes stationarity, one can conditionally assume that historic trends will reflect future patterns and expectations, as detected hydrologic processes are unchanging in time. Herein, better historical data and analysis leads to stronger conclusions on the future.
- This approach to analysis relies solely on the statistical properties of the observed record.
- This assumption has been taken in standard federal guidelines for flood flow frequency (e.g., Bulletin 17B and Bulletin 17C)

Now, what happens if the data collected in the past no longer resembles what lies ahead?

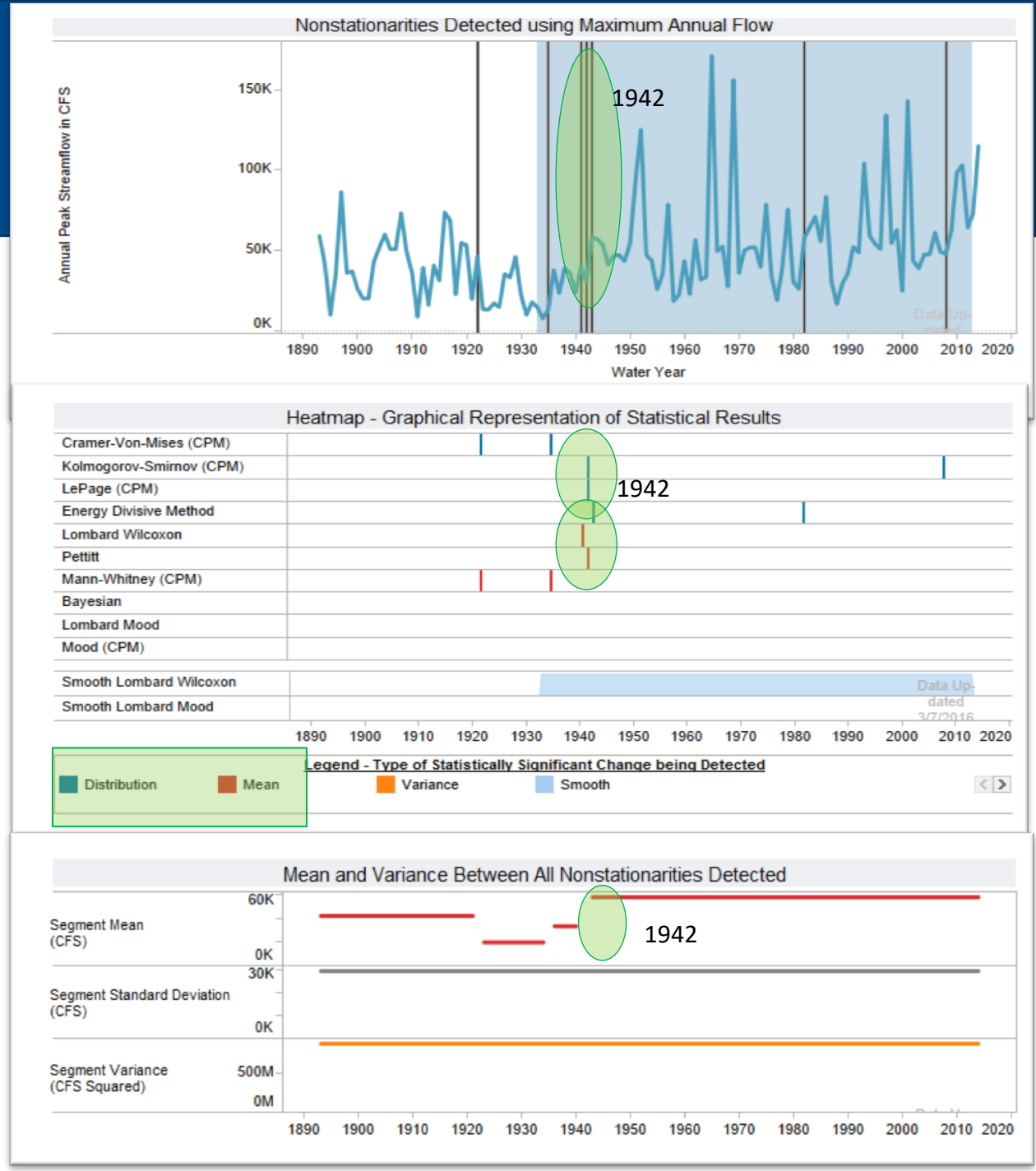
Stationarity is Dead (Milly et al., 2008): since climate change must by its nature change flow frequencies, we can no longer credibly assume that flow frequencies are unchanging as the climate changes.

- This seminal paper and subsequent research have gone on to show that the stationary assumption, while accurate at times, is not universally applicable and must be integrated with caution in future planning and predictive trend analysis.

When making engineering decisions, nonstationarity detection is now a critical phase in the analytic process

Detecting "Strong" Nonstationarities

- **ETL 1100-2-3**
- **Consensus** – Agreement between multiple statistical methods that detect the <u>same type</u> of nonstationarity
- **Robust** – Agreement between multiple statistical methods that detect <u>different types</u> of nonstationarity
- **Magnitude** – The size of the change in the streamflow before and after the detected nonstationarity
- Next step: monotonic trend analysis
- Then: attribution
- Then: project



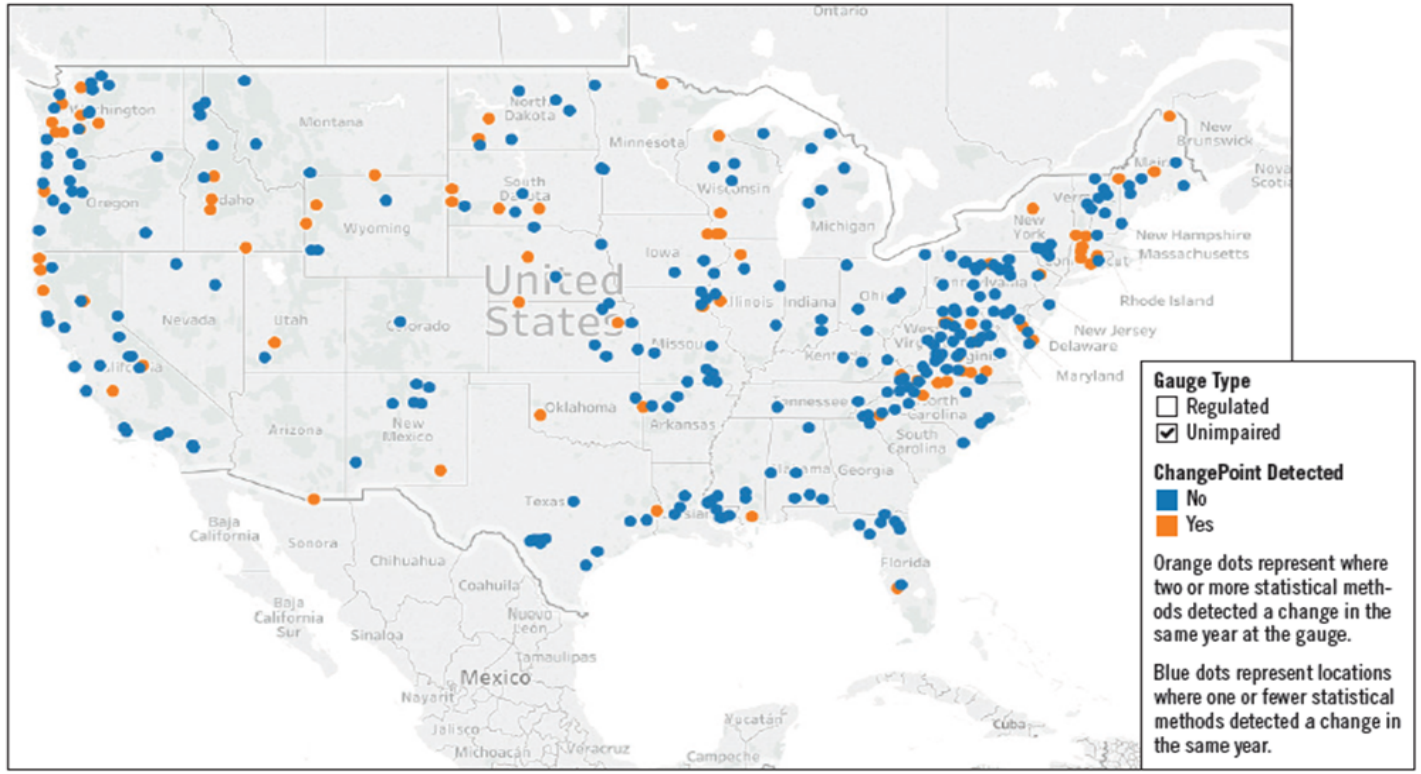
https://www.usace.army.mil/corpsclimate/Public_Tools_Dev_by_USACE/Climate-Impacted_Hydrology/

Example: Regional nonstationarity detection for unimpaired stream gauges

Dataset

*Stream data was pulled from USGS **(the Gages II data)** and reduced to just those streams which are defined to be **unimpaired**.*

- For each stream in the data set, annual instantaneous peak flow was used as a measure of stream behavior
- Stream were flagged as having a nonstationarity if two or more statistical methods detected a change in the same year at that gauge
  - This is shown in the plot below, where blue gauges did not have a nonstationarity with consensus and the orange did
- The resulting data set held a variety of features, but the analysis here focused on presence of nonstationarity, and latitude / longitude
- Next, we wanted to know if any of the nonstationarities represented an unusual condition.



Objective

While identifying nonstationarities at specific gauges is of critical importance in the analysis of that gauge, it is also of importance to understand global trends and relationships in nonstationarities across multiple gauges.

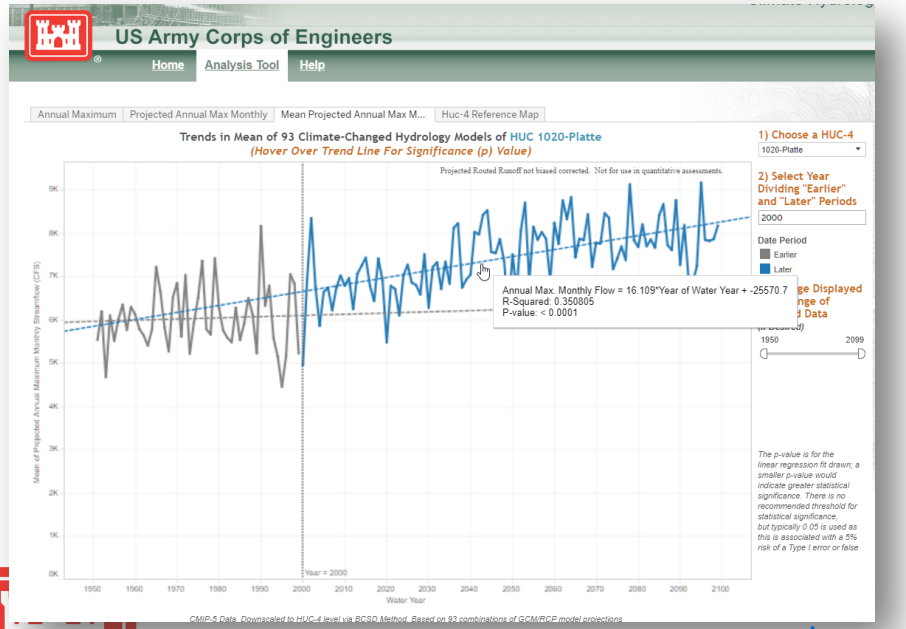
- Here, particular attention was paid to the relationship between geographic location of the gauge and the tendency of that gauge to have a nonstationarity.

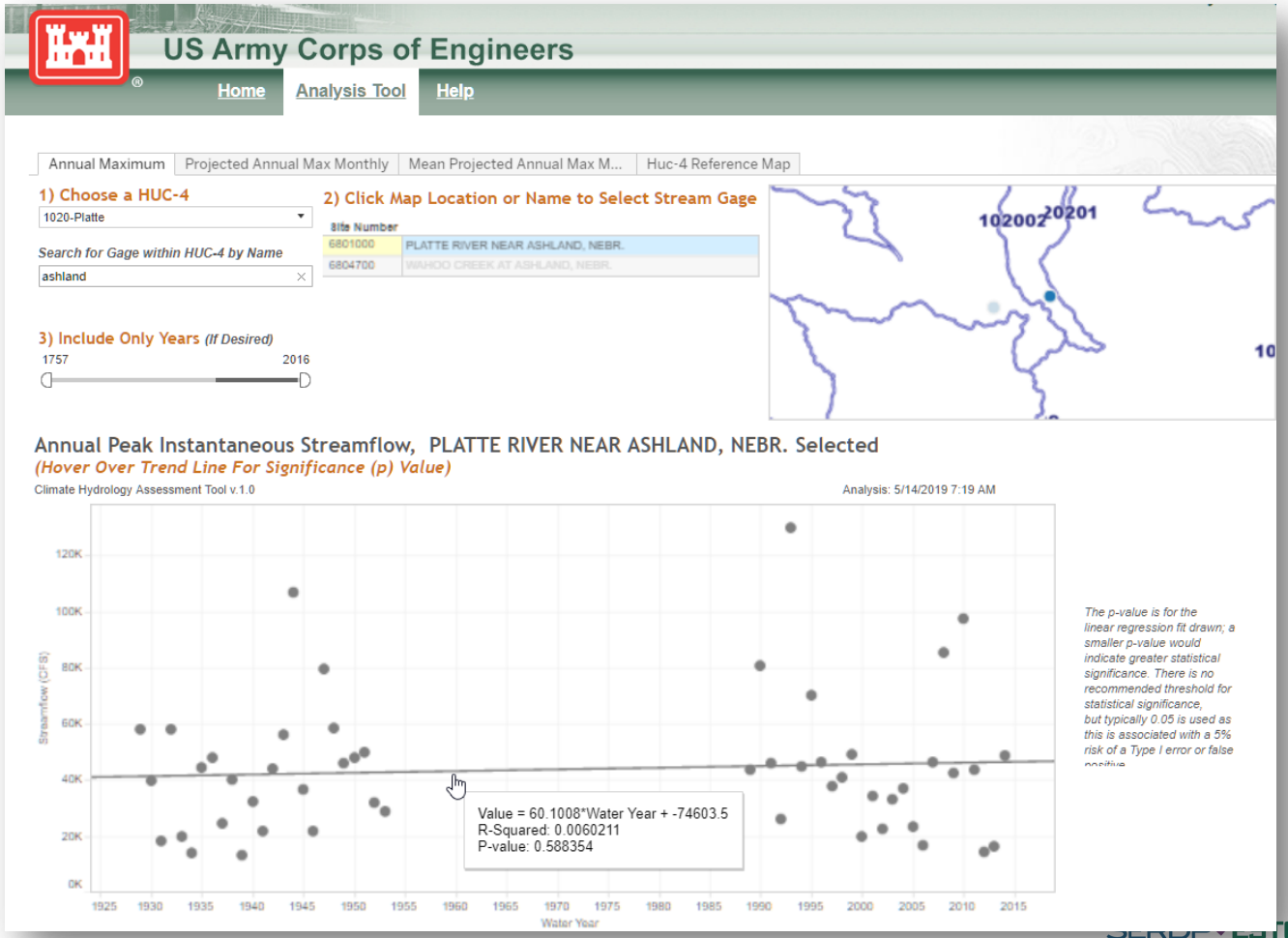
While many different predictors were considered, using a variety of models and techniques, the small sample size limited the significance of predictive conclusions using non-geographic features.

Tool for single streamgage analysis:
https://www.usace.army.mil/corpsclimate/Public_Tools_Dev_by_USACE/Climate-Impacted_Hydrology/

Trends: Climate Hydrology Assessment Tool (CHAT)

- Platte River near Ashland
- Statistically significant slight upward trend in annual peaks
- Increasing trend in future, also statistically significant





https://www.usace.army.mil/corpsclimate/Public_Tools_Dev_by_USACE/Climate-Impacted_Hydrology/

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ECB 2018-14 Risks

- Projected benefits or reductions in risk due to climate should also be briefly discussed
- Table B-1 provides examples that might be included in a decision document or climate appendix for the measures and features of a given resilience measure alternative

Table B-1. Example table identifying climate risks.

Feature or Measure	Trigger	Hazard	Harm	Qualitative Likelihood
Levee	Increased precipitation from larger, slower-moving storms	Future flood volumes may be larger than present Large flood volumes may occur more frequently	Flood waters may remain on the levee for longer durations, and more frequently, potentially damaging levee	Likely
Drought resilience measure	Decreased precipitation or increased severity of drought	Future droughts may be more severe than at present Future droughts might occur at increasing frequency	Water availability and quality may be decreased, impacting water supply storage or water quality within and downstream of reservoir	Likely
Weir at upstream end of flood bypass channel	Increased precipitation from larger, slower-moving storms	Future flood volumes may be larger than present Large flood volumes may occur more frequently	Weir may be overtopped more frequently than at present, resulting in more frequent flows in the floodway	Likely
Off-channel wetland restoration feature	Decreased winter precipitation and higher winter temperatures	Lower stream flows year round Reduced freshet volume and duration	Water may no longer inundate restoration feature during all or part of year, resulting in loss of habitat and reducing project benefits	Highly Likely

Installation Climate Resilience

Decision making for Climate preparedness and resilience

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Moving from theory to practice

In theory, theory and practice are the same.
In practice, they are not.

- Attributed to Albert Einstein

Or maybe it was Yogi Berra

Decision-Makers' Perspective – Actionable science, not necessarily latest or most complex science

"All models are wrong; some are useful." George EP Box

- Decision-makers especially need to consider surprises or cases where a weak signal could result in large consequence – these are situations where models provide only part of needed information
- Decision-makers begin with the requirements for acceptable performance and reliability of their asset/project/system and *then*
  - ID the impacts or combinations of impacts that increase vulnerability and decrease performance and reliability
  - Assess likelihood of occurrence
  - Use this knowledge to plan and implement measures to prepare, absorb, recover wisely, and adapt or transform to reduce future occurrences
- The information supporting the assessment does not necessarily have to be complex but it does have to be actionable

What information matters to decision-makers?

- Depends on investment horizon, decision-scale, and risk tolerance
- Special consideration for spatial and temporal scales – tradeoff between precision and accuracy
- Short term horizon:
  - New or existing asset/project, or both?
  - Is asset vulnerable now? Does schedule rely on uninterrupted work?
  - Under what conditions does the asset/project perform?
- Mid-term:
  - Do observed and/or projected changes increase vulnerability?
  - Are the consequences more severe?
  - Are fiscal exposure and legal liability increasing?
- Long-term:
  - What adaptation pathway or transformation is necessary?
  - What is the lead time necessary to adapt/transform?

Identify performance requirements
- Critical thresholds and triggers that impact performance

Performance assessment
- Assess performance under plausible future conditions
- ID consequences of nonperformance

Likelihood of plausible future conditions
- Qualitative/quantitative
- Range of timing of critical variables
- Monitoring strategy

Adaptation
- Suite of alternatives
- Lead time to take action
- Economic , environmental, social, engineering analyses

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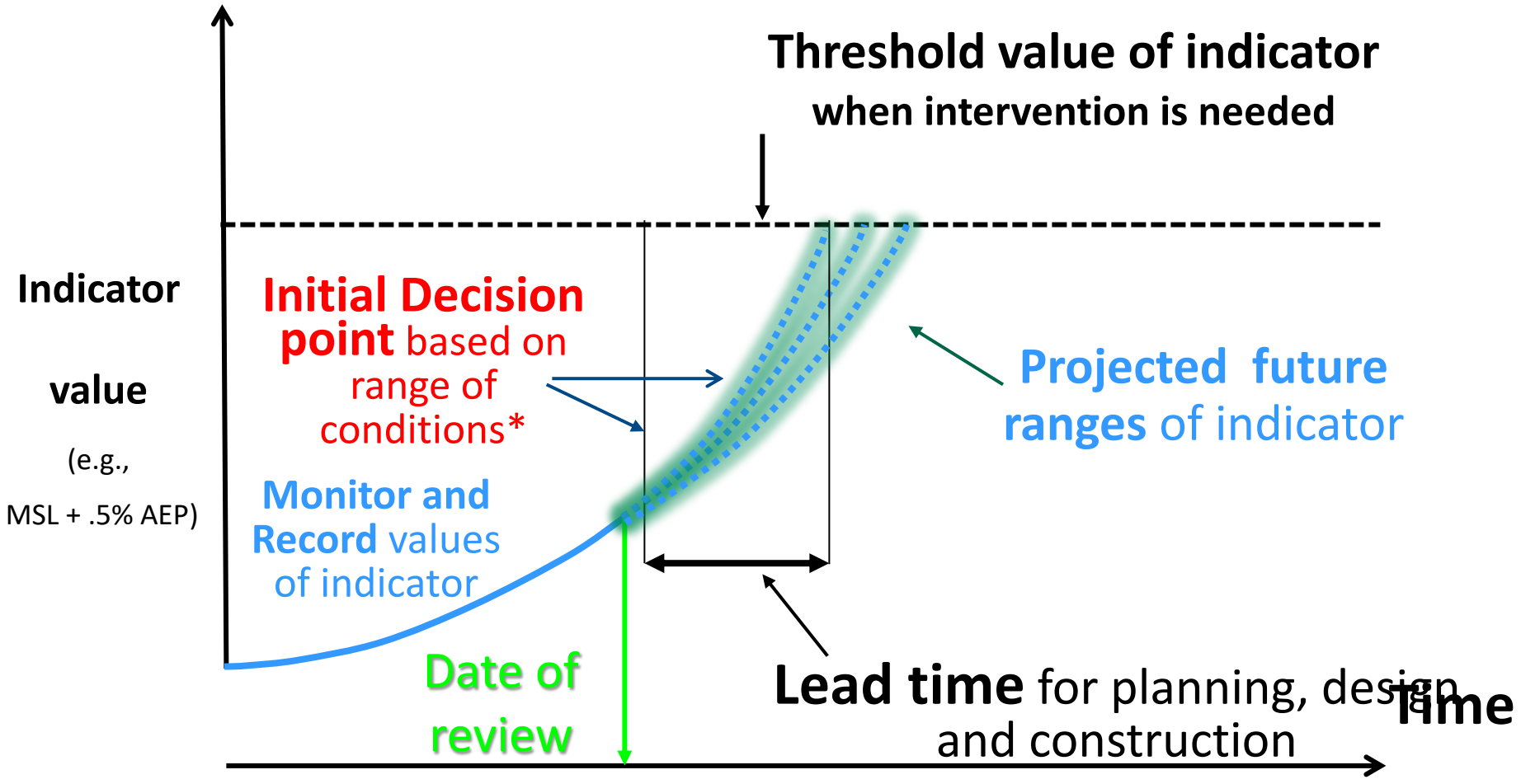
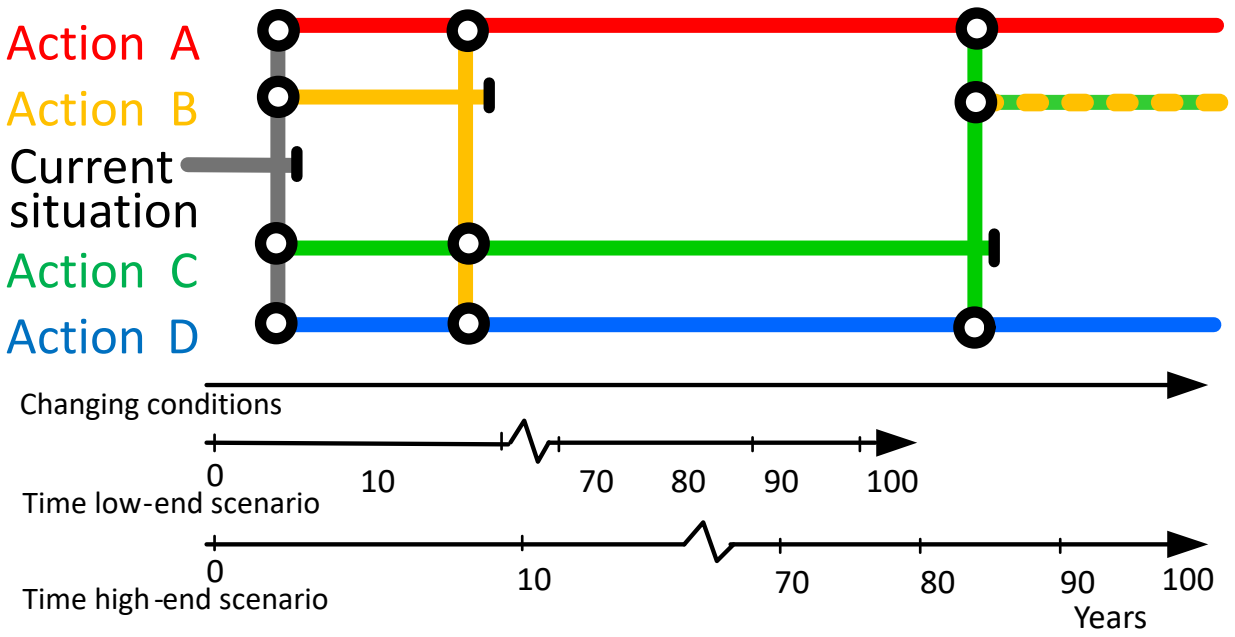
SLC and Thresholds



* Can be adjusted based on monitoring closer to decision point

Determine Adaptation Pathways At the Start (Adaptation ≠ Adaptive management)



Time horizon 100 years

Pathway	Costs	Benefits	Co-benefits
1	+++	+	0
2	+++++	0	0
3	+++	0	0
4	+++	0	0
5	0	0	-
6	++++	0	-
7	+++	0	-
8	+	+	- - -
9	++	+	- - -

Transfer station to new policy action

Adaptation Tipping Point of a policy action (Terminal)

Policy action effective

Source: Haasnoot et al. (2013), etc.

Key Takeaways from 2018

- Phased approach consistent with NAVFAC CC Planning Handbook **gives structure to level of effort of analysis**
- **Start with the systems of systems** that include the social, environmental, and economic requirements and constraints to decision-making
- Understand the range of conditions under which performance is acceptable now and in the future to help **focus on conditions causing vulnerabilities**
- **We can’t engineer our way out of every situation: transformation may become necessary**

Key Takeaways:

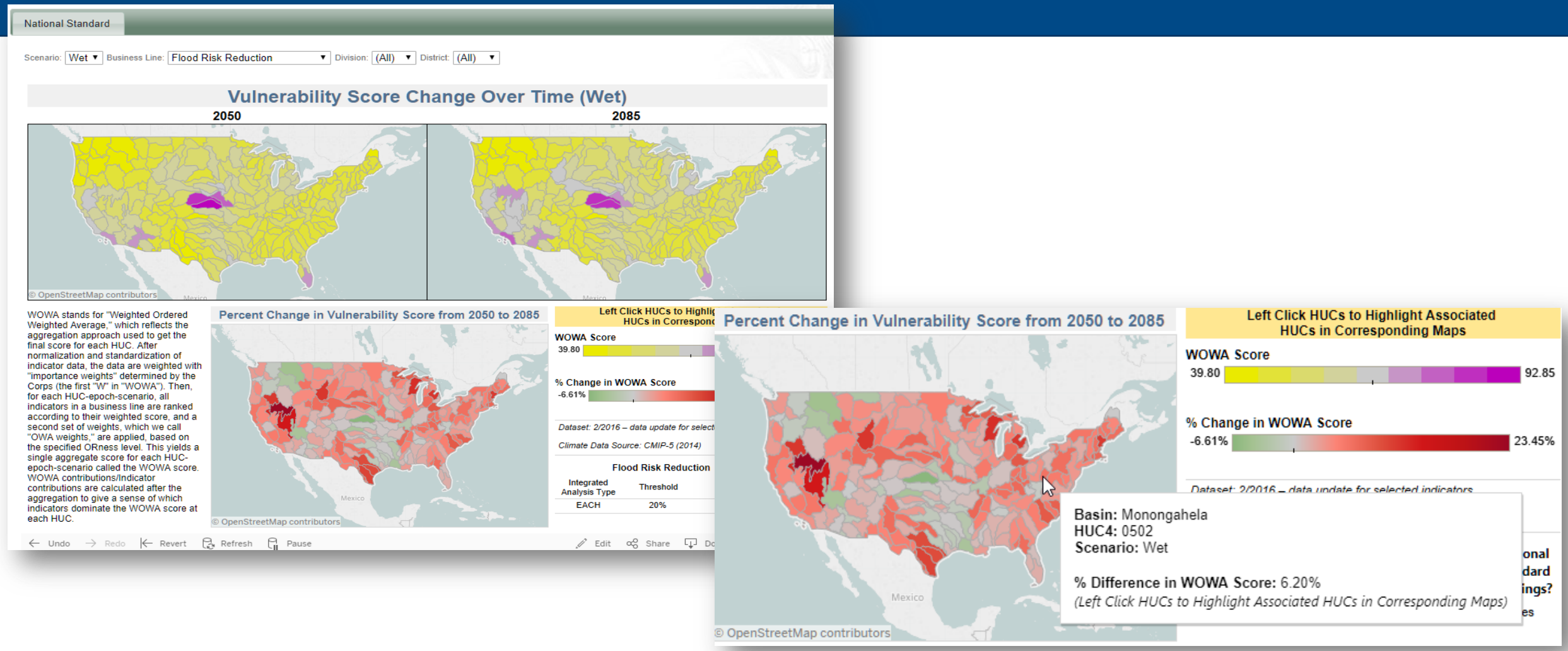
1. Authoritative information on changing climate pertinent to infrastructure resilience is presented in the Fourth National Climate Assessment (Volumes 1 and 2) and agency climate preparedness and resilience sites, including the NOAA state climate summaries.

2. Several agency web sites serve as resources for understanding and visualizing observed and projected sea level change, including the NOAA Sea Level Trends and Sea Level Rise Viewer and the USACE Sea Level Change Calculator and Sea Level Tracker.

3. Hydrologic nonstationarity caused by changing land use and land cover, river regulation, or climate can be detected using several statistical tests which detect abrupt or smooth changes in a hydrologic time series.

4. Climate preparedness and resilience for military infrastructure improvesreliability of missions and operations and reduces response and recovery costs.

Preview: Vulnerability Change Over Time



Short Course: INFRASTRUCTURE RESILIENCE AND PLANNING UPDATE

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