US ARMY CORPS OF ENGINEERS POLICY, GUIDANCE, AND APPROACHES TO FLOOD RISK IMPACTED BY CLIMATE CHANGE

WILL VEATCH, PHD, PH

Lead, Climate Preparedness and Resilience, USACE

NATIONAL SCIENCE FOUNDATION RESEARCH INFRASTRUCTURE WORKSHOP

29 June 2023

U.S. ARMY

USACE CLIMATE PREPAREDNESS AND RESILIENCE

USACE APPROACH TO CLIMATE-CHANGED FLOOD RISK

- USACE Civil Works Overview
- USACE Climate Preparedness and Resilience Policy
- What is (Climate) Resilience?
- Climate Change as a Deep Uncertainty
- Tools and Guidance for Climate Impacts to Riverine Flood Risk

USACE CIVIL WORKS PROGRAM: MISSIONS

USACE operates, maintains, and manages more than $232B worth of the Nation's water resource infrastructure assets.

- **NAVIGATION**: 926 coastal harbors & 40,200 km of waterways
- **HYDROPOWER**: 25% of nation's hydropower
- **FLOOD RISK MANAGEMENT & SHORE PROTECTION**: 14,000 km of levees & 640 km of shore protection
- **ECOSYSTEM RESTORATION** 143,000 km of tidal coastline
- **WATER SUPPLY**
- **REGULATORY**: (Wetlands / US Waters)
- **RECREATION**: 376 M visitors to USACE projects annually
- **DISASTER RESPONSE**


Beach Erosion, Nags Head, NC


Miami Beach Nourishment, FL)


Everglades


Dredge ESSAYONS (Coos Bay, OR)


Lake Seminole (Mobile District)

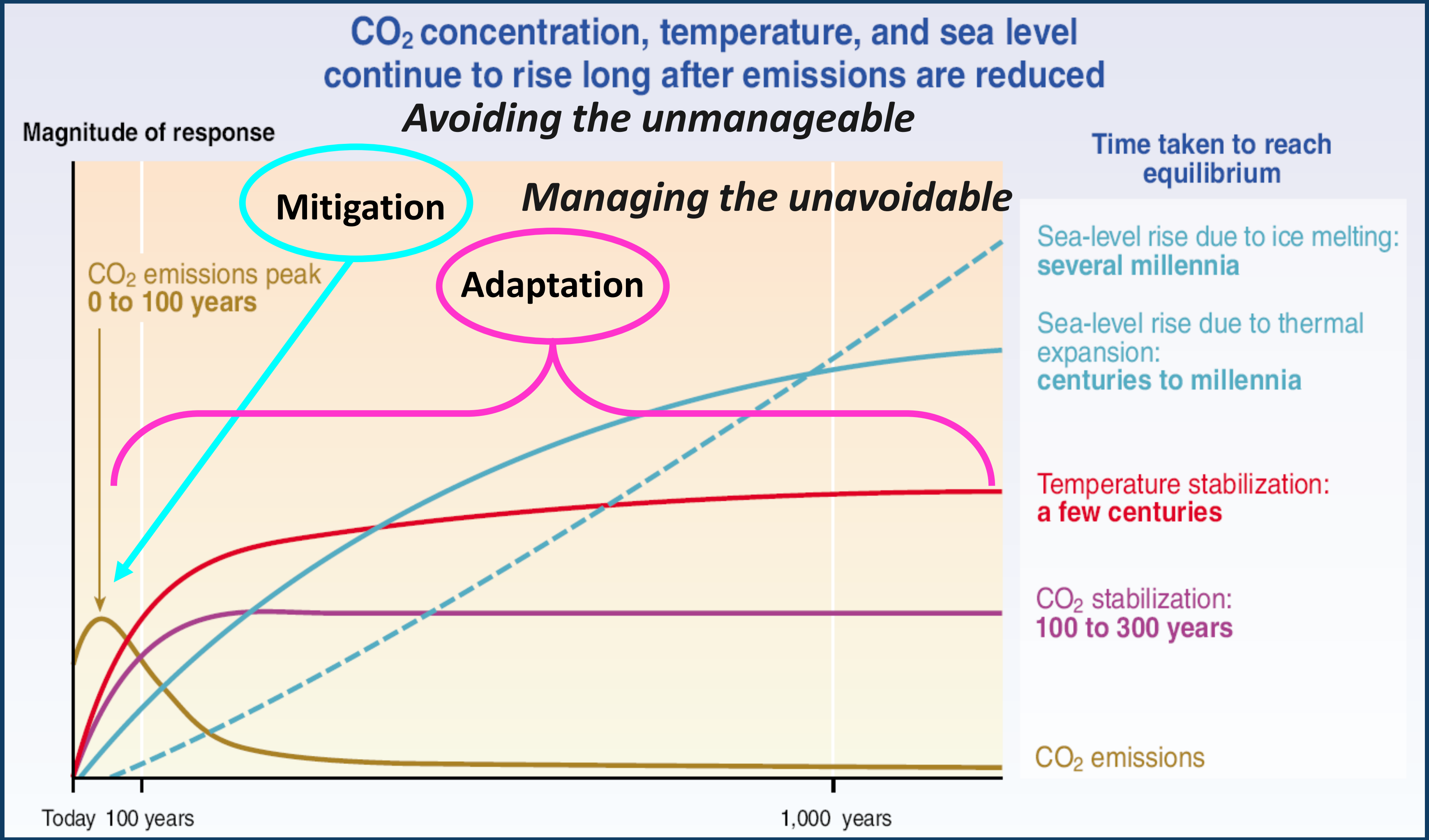

Bonneville II Powerhouse (Washington)

MITIGATION VS. ADAPTATION

Climate change mitigation is about CARBON

Climate change adaptation is about WATER

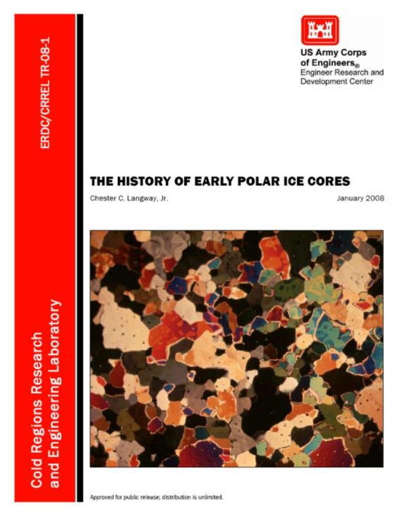
MITIGATION VS. ADAPTATION

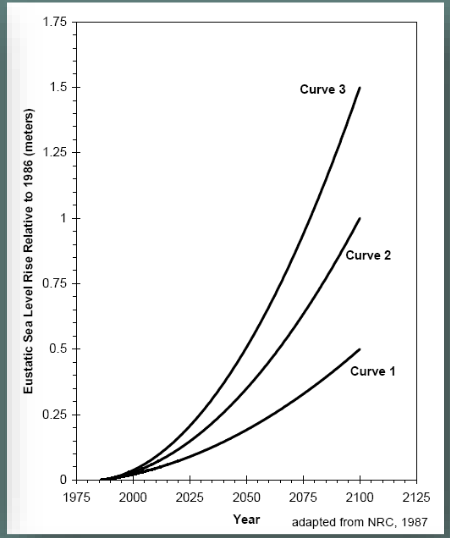


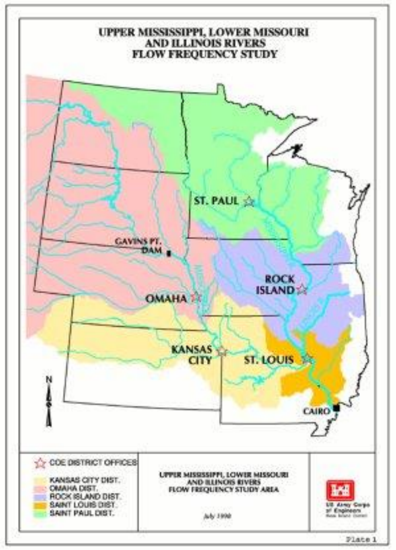
USACE CLIMATE PREPAREDNESS AND RESILIENCE HISTORY

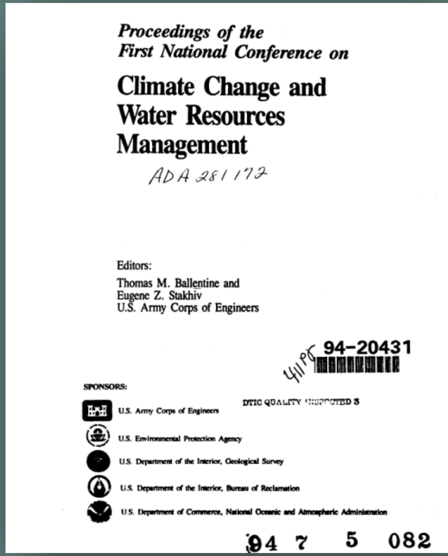
USACE has a long history in climate change

- 1950s – present ice core drilling Greenland and Antarctica
- 1970s led White House drought commission
- 1980s addressed changing sea level
- 1990s economics of climate change
- 2000s effects on water resources, updated policy/guidance
- 2010s planning and implementing climate resilience measures
- 2020s interagency leaders in mainstreaming adaptation and resilience


ERDC/CRREL TR-08-1
Cold Regions Research and Engineering Laboratory
US Army Corps of Engineers
Engineer Research and Development Center
THE HISTORY OF EARLY POLAR ICE CORES
Chester C. Langway, Jr.
January 2008






Proceedings of the First National Conference on
Climate Change and Water Resources Management
ADA 281 172
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Eugene Z. Stakhiv
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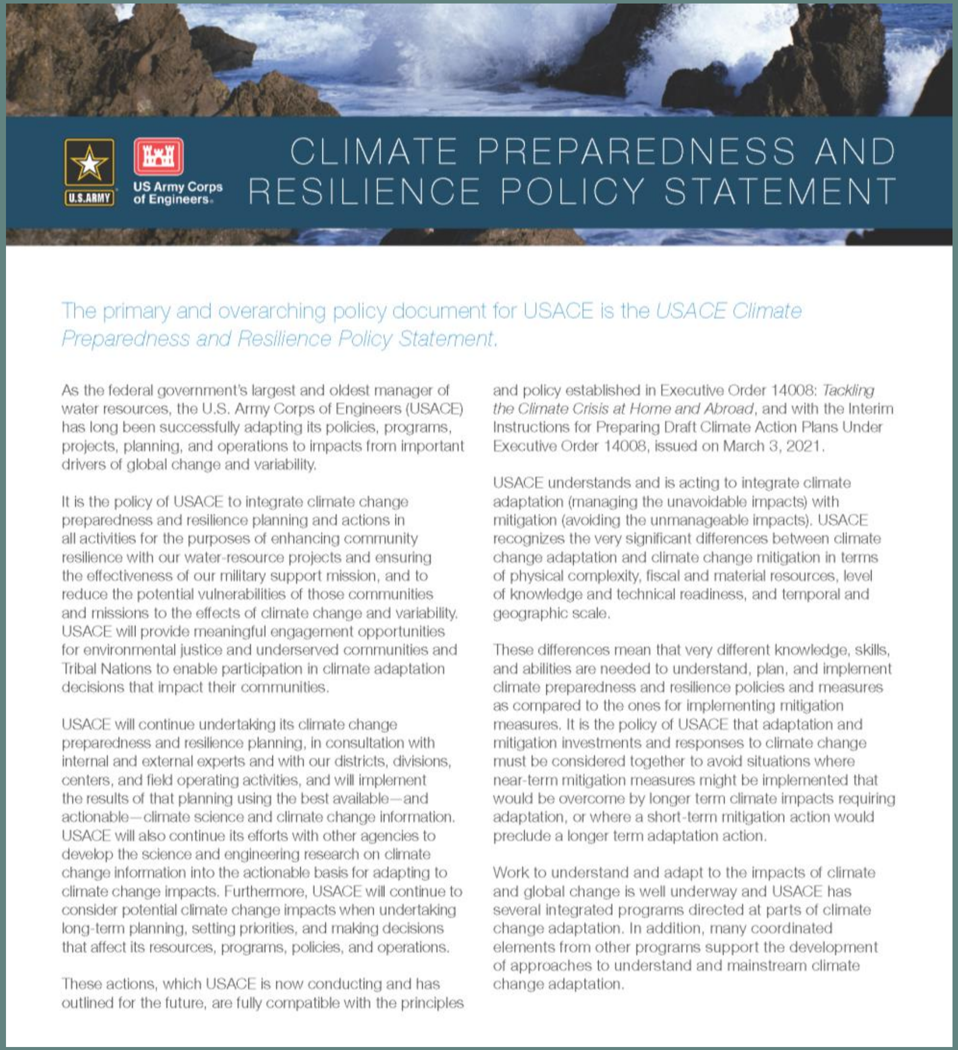
2021 USACE CLIMATE PREPAREDNESS AND RESILIENCE POLICY STATEMENT

> It is the policy of USACE to integrate climate change preparedness and resilience planning and actions in **all activities** for the purposes of enhancing community resilience with our water-resource projects and ensuring the effectiveness of our military support mission…

> **"… using the best available – and actionable – climate science and climate change information."**

> **"… it will be considered at every step in the project life cycle for all USACE projects, both existing and planned, … to reduce vulnerabilities and enhance the resilience of our water-resource projects."**



US Army Corps of Engineers

CLIMATE PREPAREDNESS AND RESILIENCE POLICY STATEMENT

The primary and overarching policy document for USACE is the USACE Climate Preparedness and Resilience Policy Statement.

As the federal government's largest and oldest manager of water resources, the U.S. Army Corps of Engineers (USACE) has long been successfully adapting its policies, programs, projects, planning, and operations to impacts from important drivers of global change and variability.

It is the policy of USACE to integrate climate change preparedness and resilience planning and actions in all activities for the purposes of enhancing community resilience with our water-resource projects and ensuring the effectiveness of our military support mission, and to reduce the potential vulnerabilities of those communities and missions to the effects of climate change and variability. USACE will provide meaningful engagement opportunities for environmental justice and underserved communities and Tribal Nations to enable participation in climate adaptation decisions that impact their communities.

USACE will continue undertaking its climate change preparedness and resilience planning, in consultation with internal and external experts and with our districts, divisions, centers, and field operating activities, and will implement the results of that planning using the best available—and actionable—climate science and climate change information. USACE will also continue its efforts with other agencies to develop the science and engineering research on climate change information into the actionable basis for adapting to climate change impacts. Furthermore, USACE will continue to consider potential climate change impacts when undertaking long-term planning, setting priorities, and making decisions that affect its resources, programs, policies, and operations.

These actions, which USACE is now conducting and has outlined for the future, are fully compatible with the principles and policy established in Executive Order 14008: *Tackling the Climate Crisis at Home and Abroad*, and with the Interim Instructions for Preparing Draft Climate Action Plans Under Executive Order 14008, issued on March 3, 2021.

USACE understands and is acting to integrate climate adaptation (managing the unavoidable impacts) with mitigation (avoiding the unmanageable impacts). USACE recognizes the very significant differences between climate change adaptation and climate change mitigation in terms of physical complexity, fiscal and material resources, level of knowledge and technical readiness, and temporal and geographic scale.

These differences mean that very different knowledge, skills, and abilities are needed to understand, plan, and implement climate preparedness and resilience policies and measures as compared to the ones for implementing mitigation measures. It is the policy of USACE that adaptation and mitigation investments and responses to climate change must be considered together to avoid situations where near-term mitigation measures might be implemented that would be overcome by longer term climate impacts requiring adaptation, or where a short-term mitigation action would preclude a longer term adaptation action.

Work to understand and adapt to the impacts of climate and global change is well underway and USACE has several integrated programs directed at parts of climate change adaptation. In addition, many coordinated elements from other programs support the development of approaches to understand and mainstream climate change adaptation.

https://usace.army.mil/CorpsClimate/

USACE CLIMATE ACTIONS PER 2021 CLIMATE ACTION PLAN

ACTION 1

MODERNIZE

USACE Programs and Policies to Support Climate-Resilient Investments

ACTION 2

MANAGE

USACE Lands and Waters for Climate Preparedness and Resilience

ACTION 3

ENABLE

State, Local, and Tribal Government Preparedness

ACTION 4

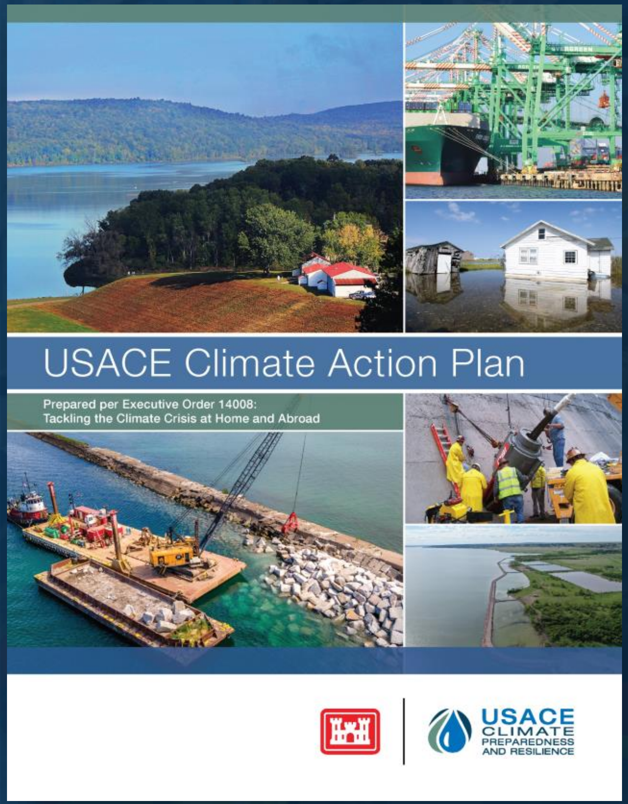
PROVIDE

Actionable Climate Information, Tools, and Projections

ACTION 5

PLAN

for Climate Change-Related Risks to USACE Missions and Operations



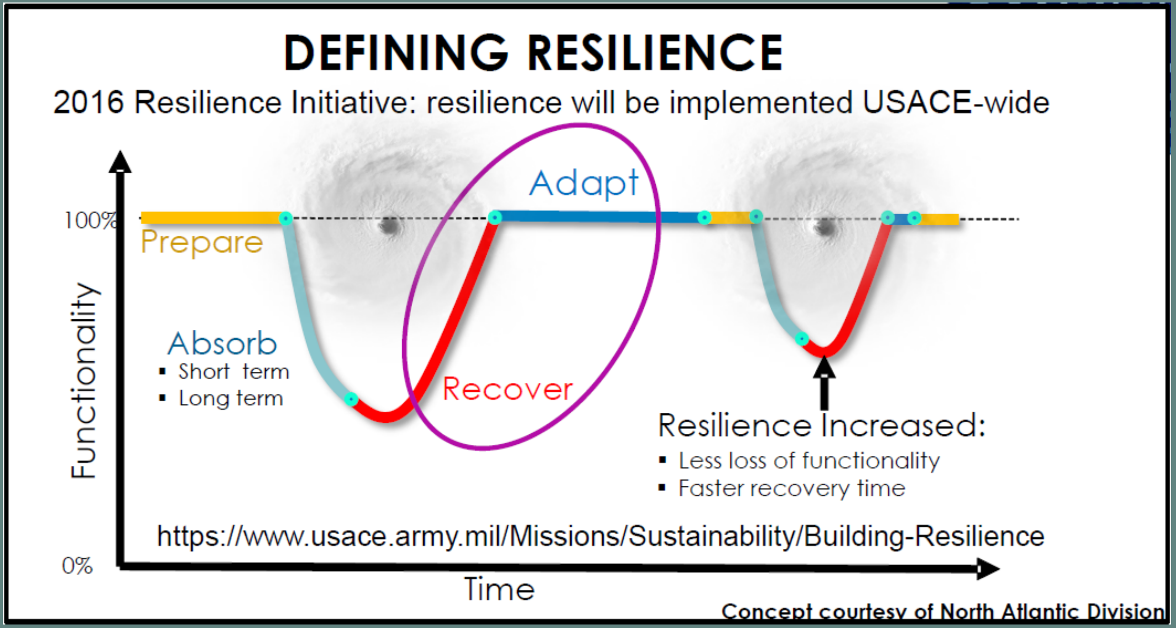
WAIT, WHAT ARE ADAPTATION AND RESILIENCE?

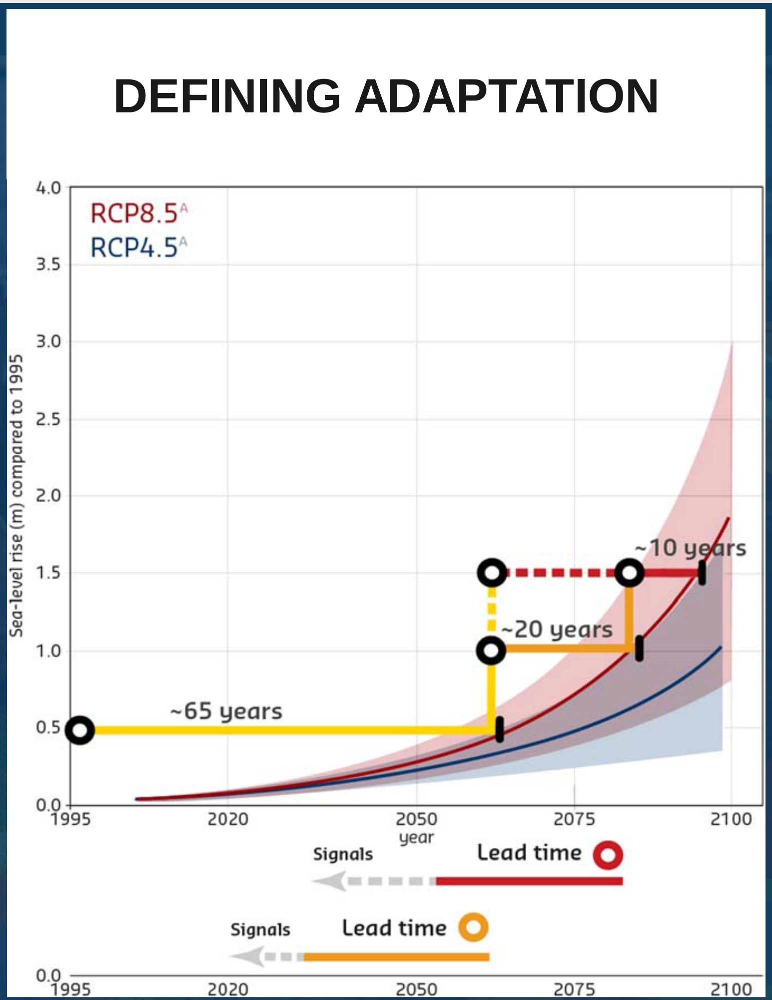
ADAPTATION

"Adjustment in natural or human systems in anticipation of or response to a changing environment in a way that effectively uses beneficial opportunities or reduces negative effects." Adaptation is an **action**.

RESILIENCE

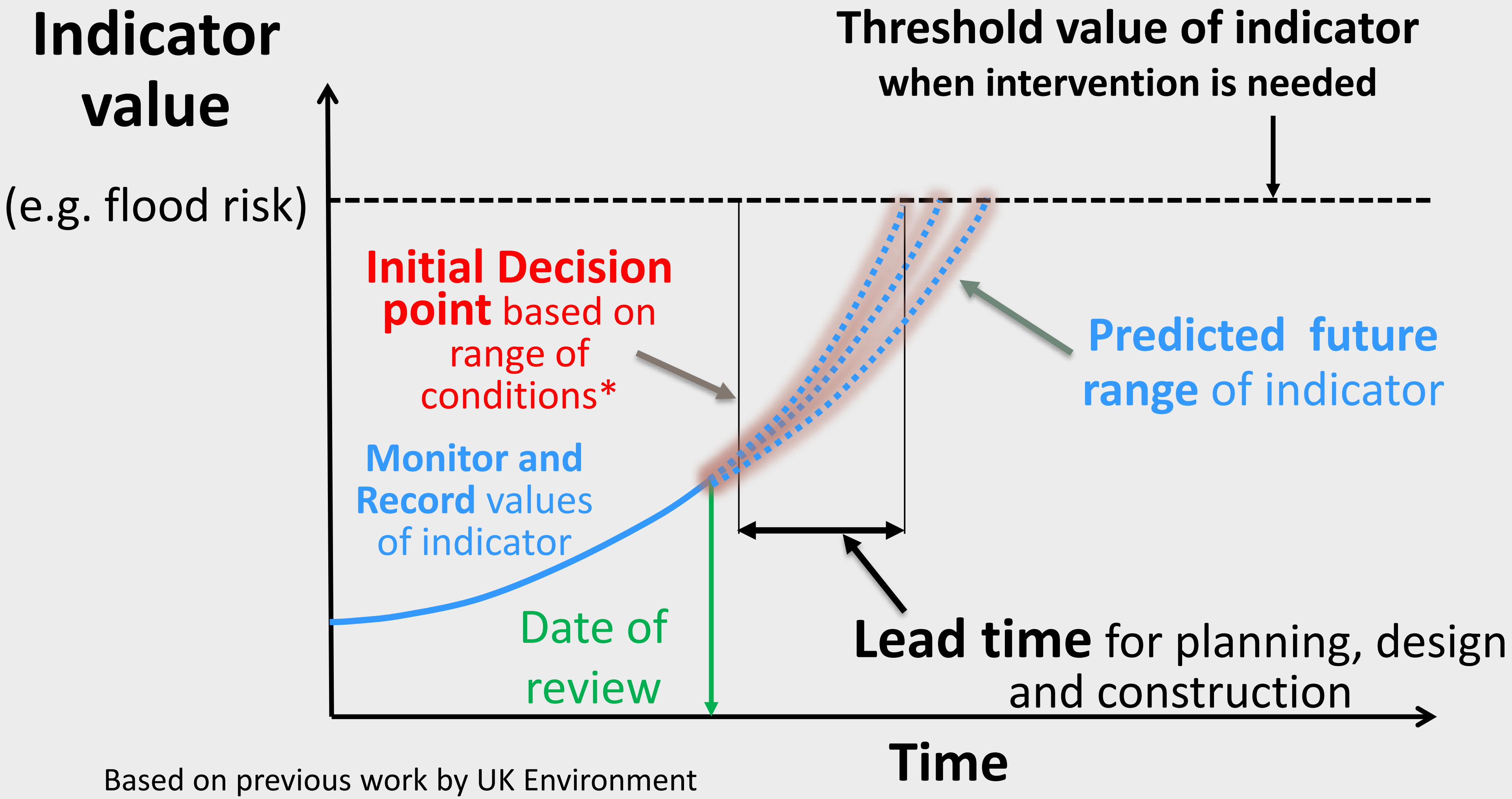
"The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions." Resilience is a **trait**.
– EO 13653: "Preparing the United States for the Impacts of Climate Change"





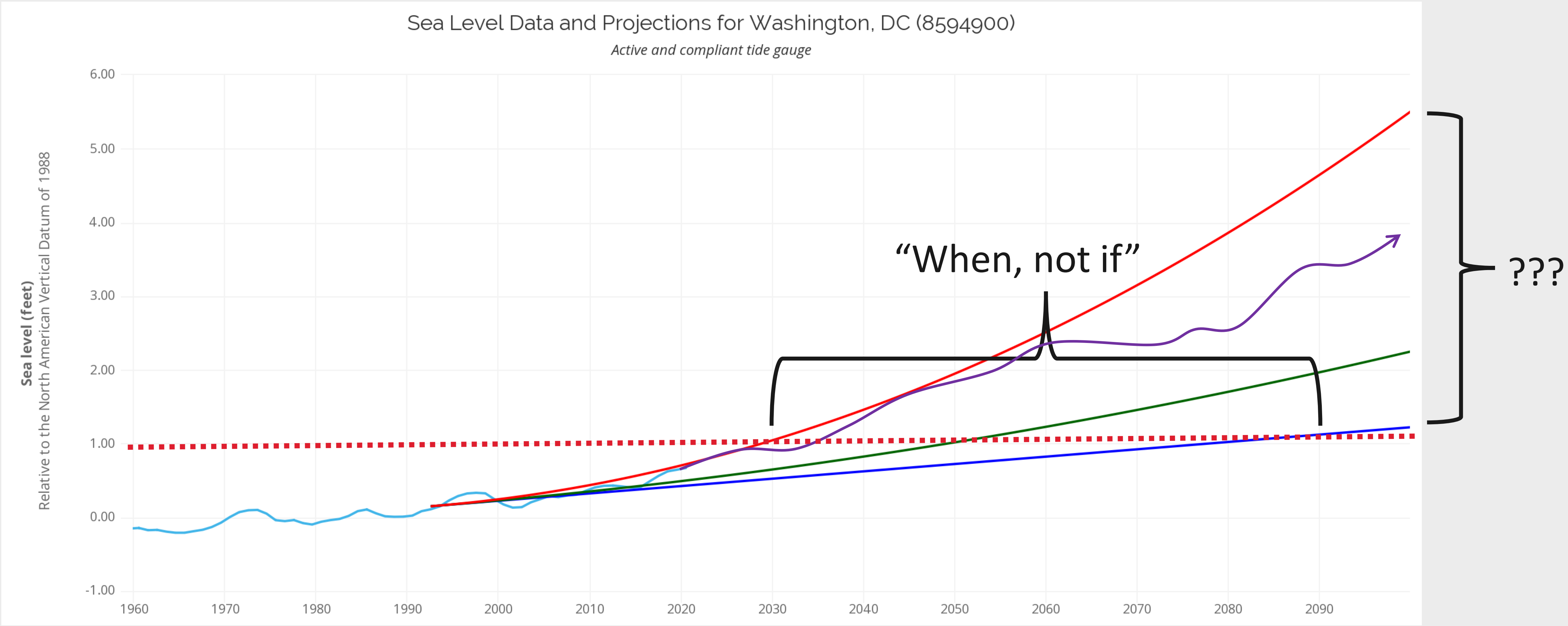
Haasnoot et al. "Adaptation to uncertain sea-level rise; how uncertainty in Antarctic mass-loss impacts the coastal adaptation strategy of the Netherlands." *Environmental Research Letters* (2020)

THRESHOLDS, LEAD TIMES, AND DECISION POINTS

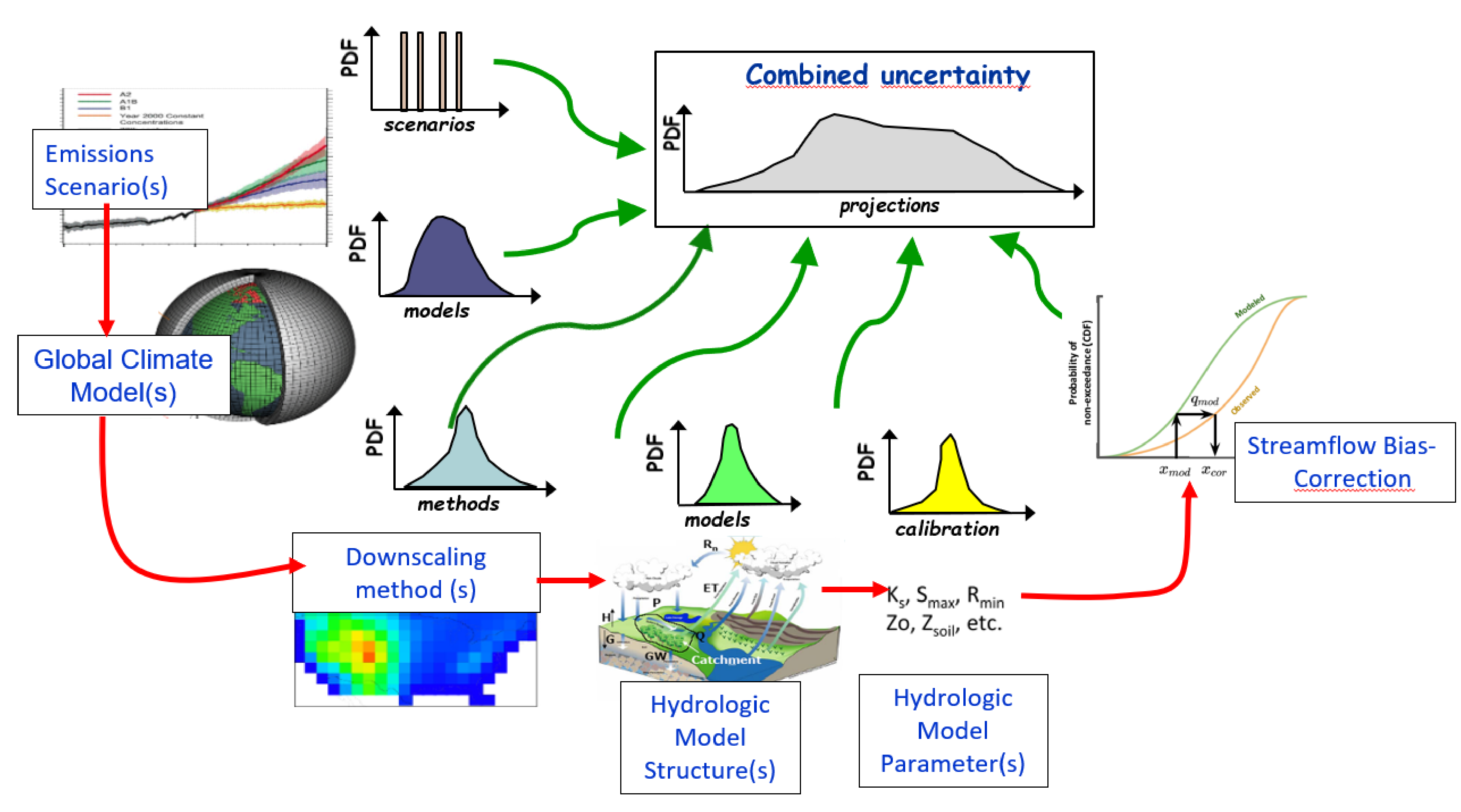


Based on previous work by UK Environment

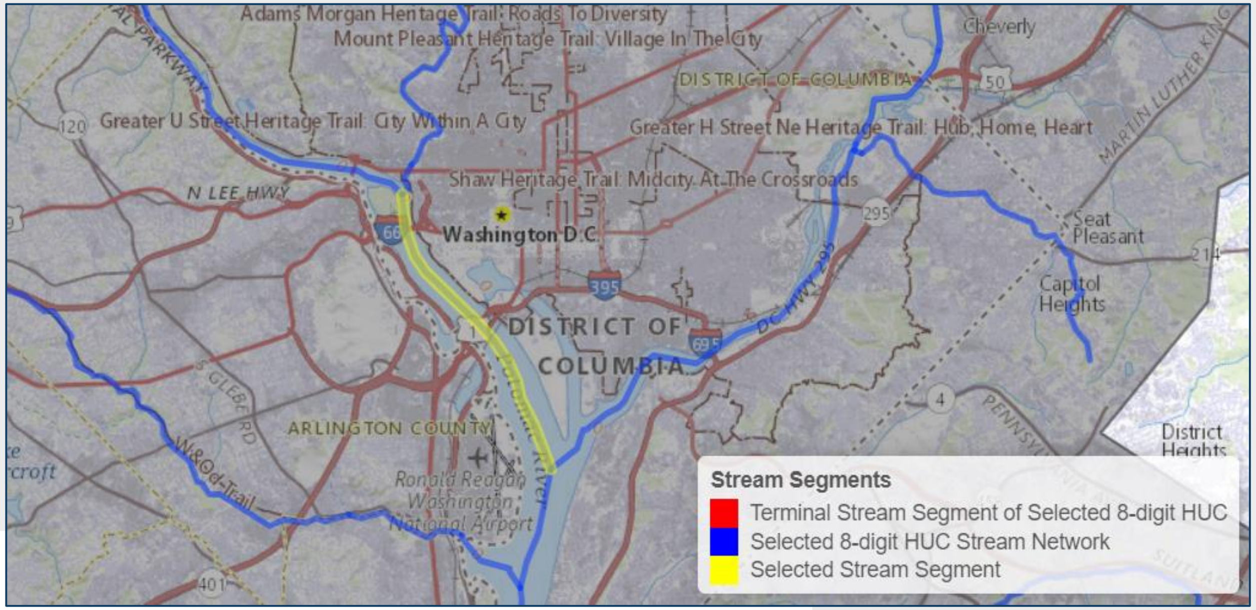
(RELATIVELY) EASY EXAMPLE: SEA LEVEL CHANGE

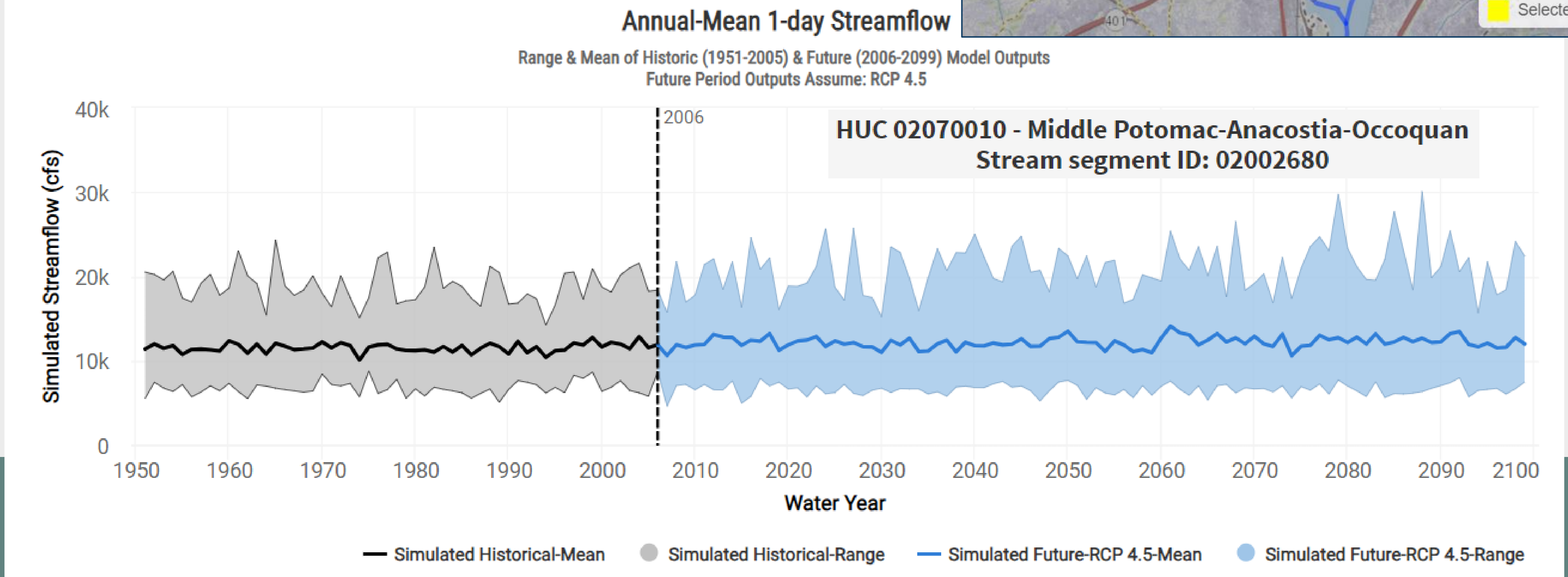


HARDER EXAMPLE: RIVERINE FLOOD RISK



HARDER EXAMPLE: RIVERINE FLOOD RISK

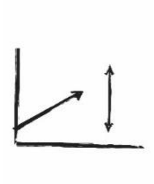
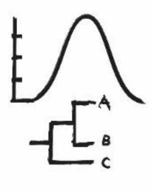
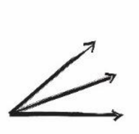
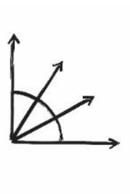
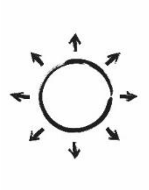




DECISION-MAKING UNDER (DEEP) UNCERTAINTY

Climate Preparedness

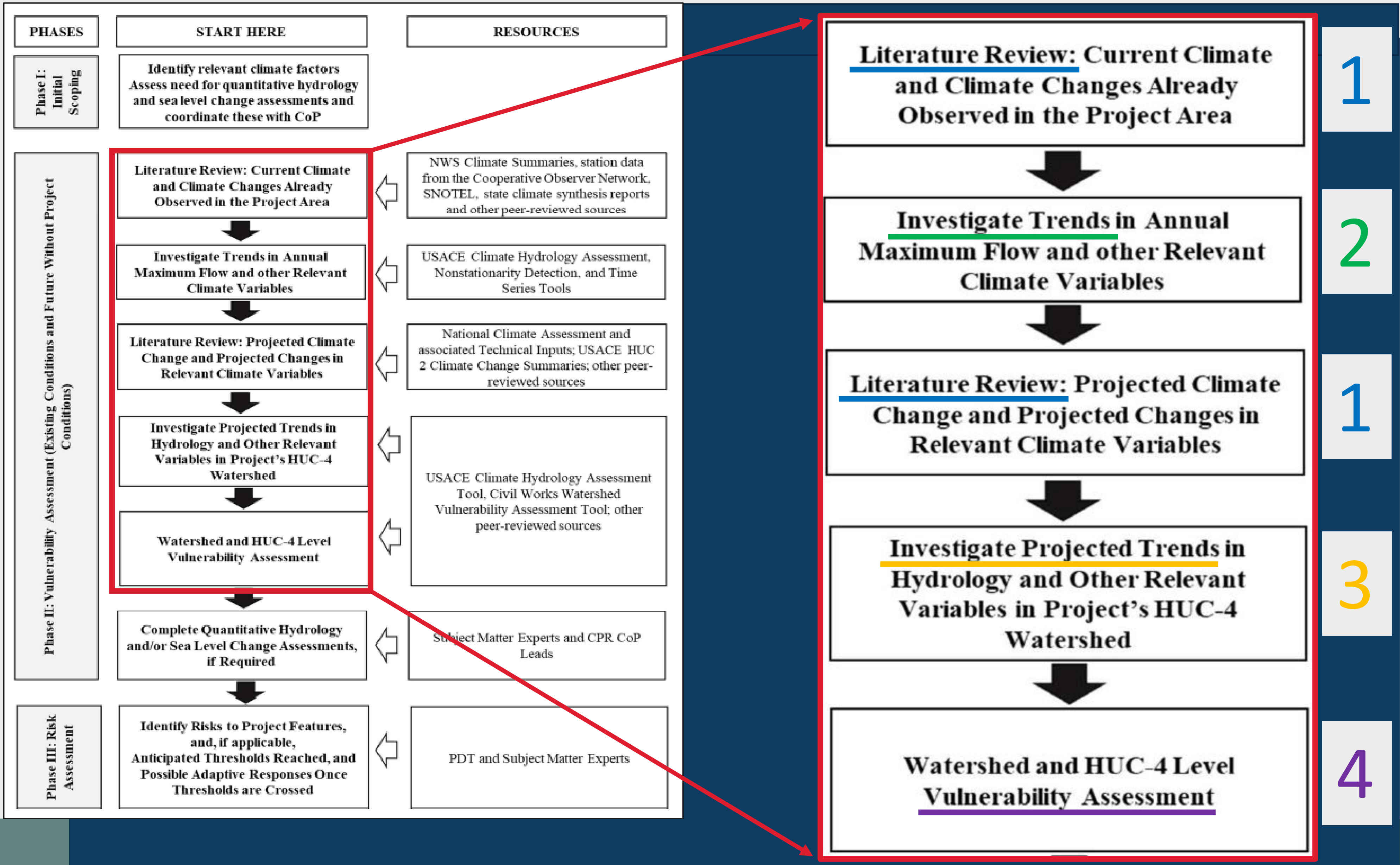
Very Certain

	Level 1	Level 2	Level 3	Level 4	Level 5
Context	A clear enough future (with sensitivity) 	Alternate futures (with probabilities) 	Alternate futures (with ranking) 	A multiplicity of plausible futures (unranked) 	Unknown future 
System model	A single system model	A single system model with a probabilistic parameterization	Several system models, one of which is most likely	Several system models, with different structures	Unknown system model; know we don't know

Total Ignorance

W.E. Walker, R.J. Lempert, J.H. Kwakkel (2013) Uncertainty in Model-Based Decision Support. Presented at First Workshop on Decision-Making Under Deep Uncertainty, Washington, DC 5-6 Nov 2013.

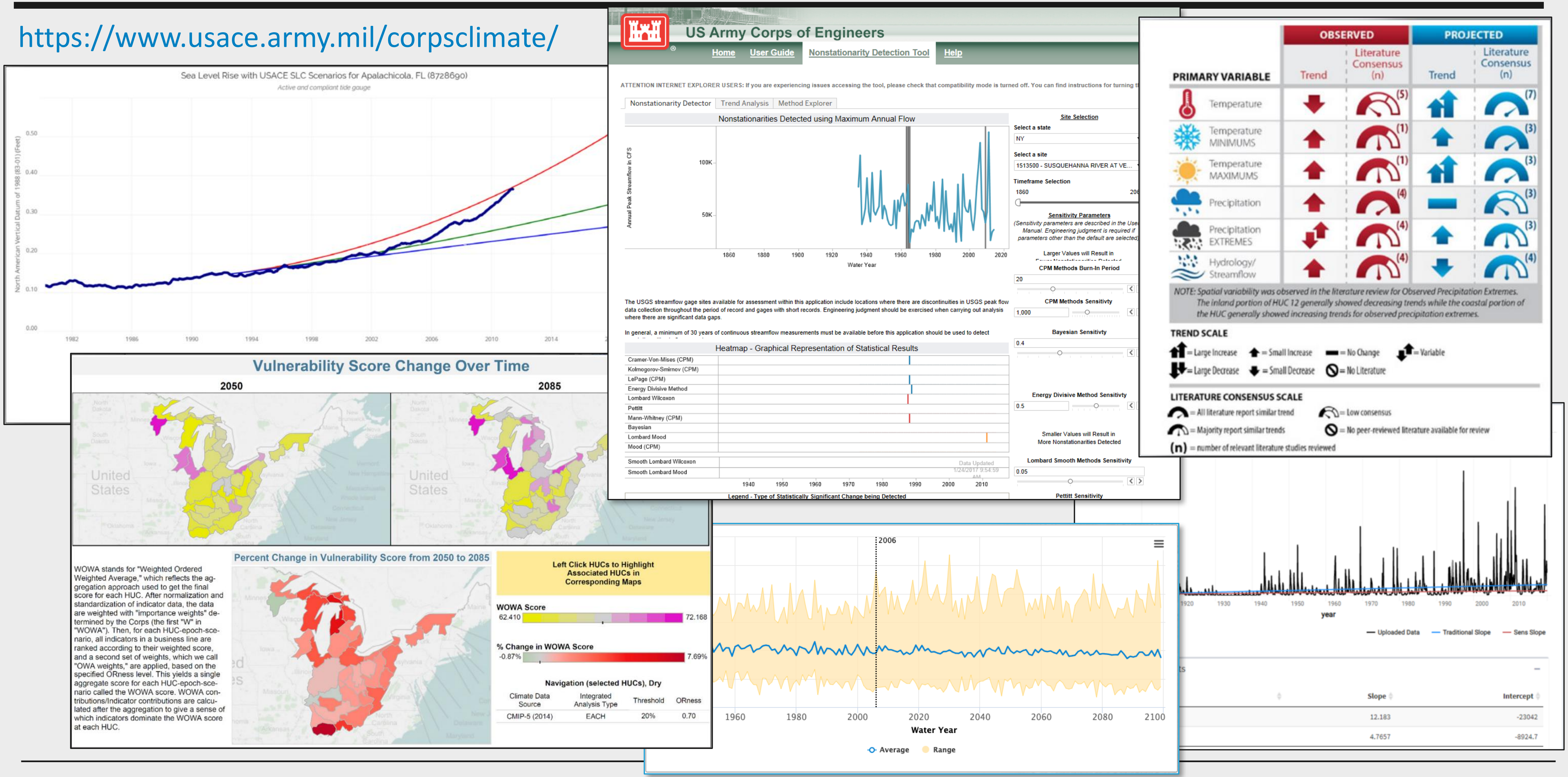
WE CAN'T PREDICT THE FUTURE, BUT WE CAN PROVIDE INFORMATION



Engineering and Construction Bulletin 2018-14: Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects

TOOLS AND GUIDANCE MAKE CLIMATE SCIENCE ACTIONABLE

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



TECHNICAL GUIDANCE

DEPARTMENT OF THE ARMY
Corps of Engineers
411 G Street, NW
Washington, DC 20314-1000

ER 1100-2-8162

CECW-CE
CECW-P

Engineer Regulation
No. 1100-2-8162

15 June 2019

Global Changes
INCORPORATING SEA LEVEL CHANGE IN CIVIL WORKS PROGRAMS

1. Purpose. This Regulation provides United States Army Corps of Engineers (USACE) guidance for incorporating the direct and indirect physical effects of projected future sea level change across the project life cycle in managing, planning, engineering, designing, constructing, operating, and maintaining USACE projects and systems of projects.

2. Applicability. This Regulation applies to all USACE elements having Civil Works responsibilities and is applicable to all USACE Civil Works activities. This guidance is effective immediately and supersedes all previous guidance on this subject.

3. Distribution Statement. This publication is approved for public release; distribution is unlimited.

4. References. Required and related references are at Appendix A. A glossary is included at the end of this document.

5. Geographic Extent of Applicability.

a. USACE water resources management projects are planned, designed, constructed, and operated locally or regionally. For this reason, it is important to distinguish between global mean sea level (GMSL) and local (or "relative") mean sea level (MSL). At any location, changes in local MSL reflect the integrated effects of GMSL change plus changes of regional geologic, oceanographic, or atmospheric origin as described in Appendix B and the Glossary.

b. Potential relative sea level change must be considered in every USACE coastal activity as far inland as the extent of estimated tidal influence. Fluvial studies that include backwater profiling should also include potential relative sea level change in the starting water surface elevation for such profiles, where appropriate. The project vertical datum must be the latest vertical reference frame of the National Spatial Reference System, currently North American Vertical Datum of 1988, to be held as constant for tide station comparisons, and a project datum diagram must be prepared per Engineer Manual 1110-2-6056.

This regulation supersedes ER 1100-2-8162, dated 31 December 2013

1

ER 1100-2-8162: Incorporating Sea Level Change in Civil Works Programs

EP 1100-2-1: Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation

ECB-2018-14: Incorporating Climate Change Impacts to Inland Hydrology in Civil Work Studies, Designs, and Projects

EP 1100-1-5: USACE Guide to Resilience Practices

ECB 2020-6: Implementation of Resilience Principles in the Engineering and Construction Community of Practice

EC 1100-1-113: Incorporating Study-Specific Projections of Climate-Changed Meteorology and Hydrology

https://www.publications.usace.army.mil/
https://www.wbdg.org/

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USACE APPROACH TO CLIMATE-CHANGED FLOOD RISK

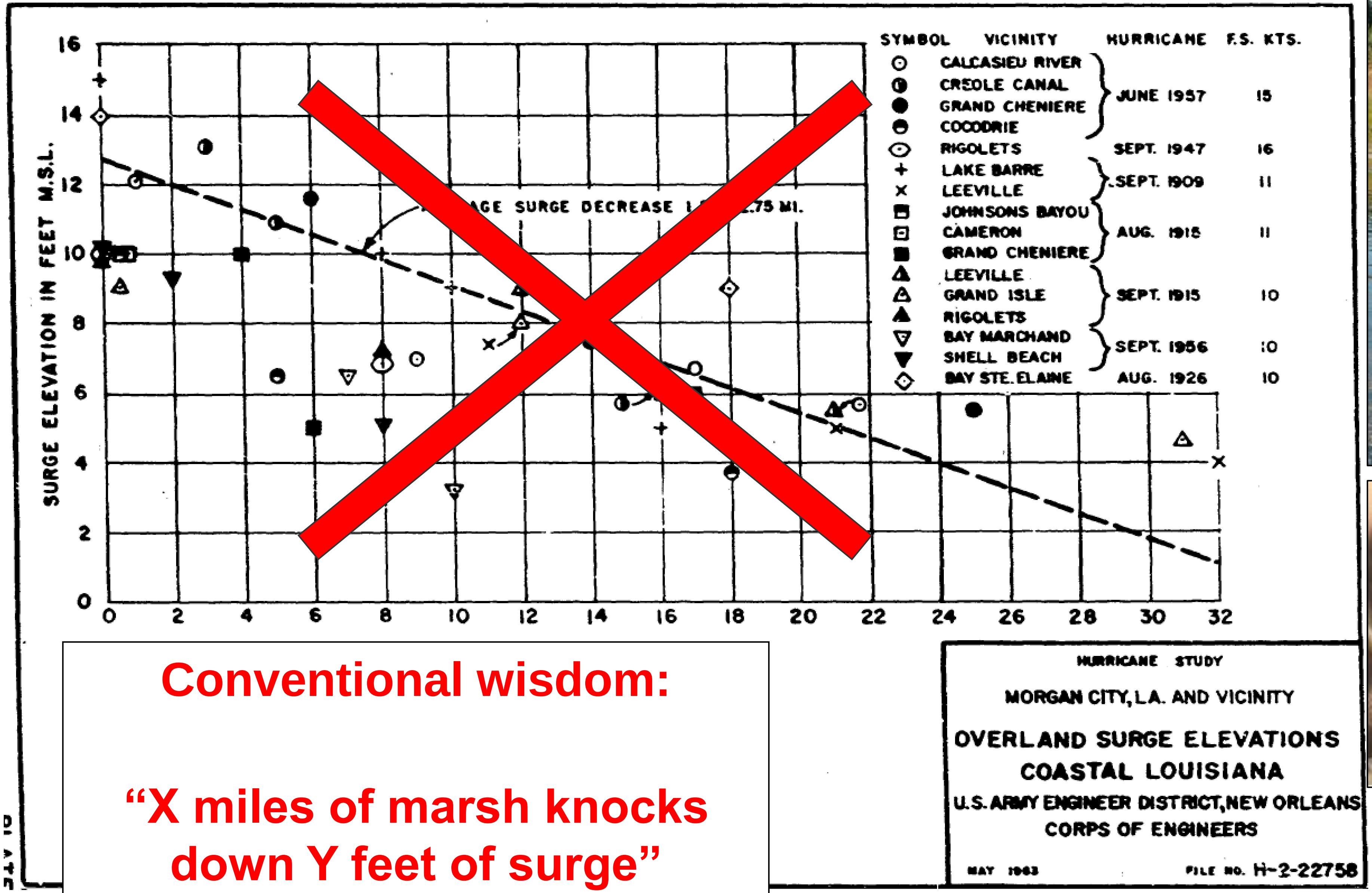
- Climate change is **happening now** and will continue
- Climate **mitigation** and **adaptation** are both critical
- USACE policy **requires** that climate change be **considered** in planning
- Inability to **predict** ≠ total **ignorance**
- Guidance and tools **translate** science into action

Flooding in a small Virginia fishing community experiencing subsidence and relative sea level rise

SUPPLEMENTARY MATERIAL

GET IN TOUCH WITH OUR TEAM TO LEARN MORE.

NATURE-BASED SOLUTIONS FOR CLIMATE RESILIENCE



Conventional wisdom:

“X miles of marsh knocks down Y feet of surge”

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THE TRUTH IS COMPLICATED

Contents lists available at ScienceDirect

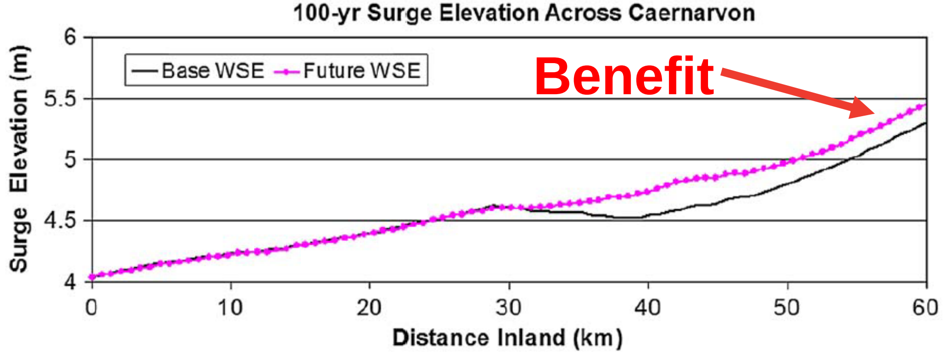
Ocean Engineering

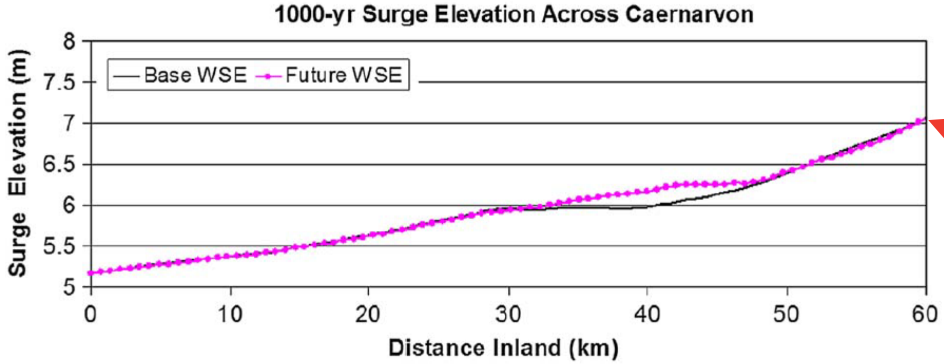
journal homepage: www.elsevier.com/locate/oceaneng

The potential of wetlands in reducing storm surge

Ty V. Wamsley [a,*], Mary A. Cialone [a], Jane M. Smith [a], John H. Atkinson [b], Julie D. Rosati [a]

[a] Coastal & Hydraulics Laboratory, US Army Engineer Research & Development Center, 3909 Halls Ferry Rd., Vicksburg, MS 39180, USA
[b] Arcadis-US, Boulder, CO, USA





No benefit

Fig. 9. The 100- and 1000-yr surge level across Caernarvon for the base and future condition.

PHYSICS TODAY

Modeling the physics of storm surges

Donald T. Resio and Joannes J. Westerink

Despite the potentially catastrophic consequences of storm surges, the physics of surge generation and propagation has historically been poorly understood, and many misconceptions about surges still exist.

Wetlands don't always mitigate surges

Modelers and community planners alike want to know the degree to which marshes and coastal forests slow inland surge penetration. A commonly stated rule of thumb says that a storm surge is attenuated at a rate of 1 m for every 14.5 km of marsh as the surge propagates inland from the shore. That estimate is based on a US Army report that examined inland penetration for seven storms occurring between 1909 and 1957 throughout southern Louisiana.[2] However, the data display considerable scatter and suggest that the attenuation rate for those storms ranges from −1 m per 20 km to −1 m per 7 km.

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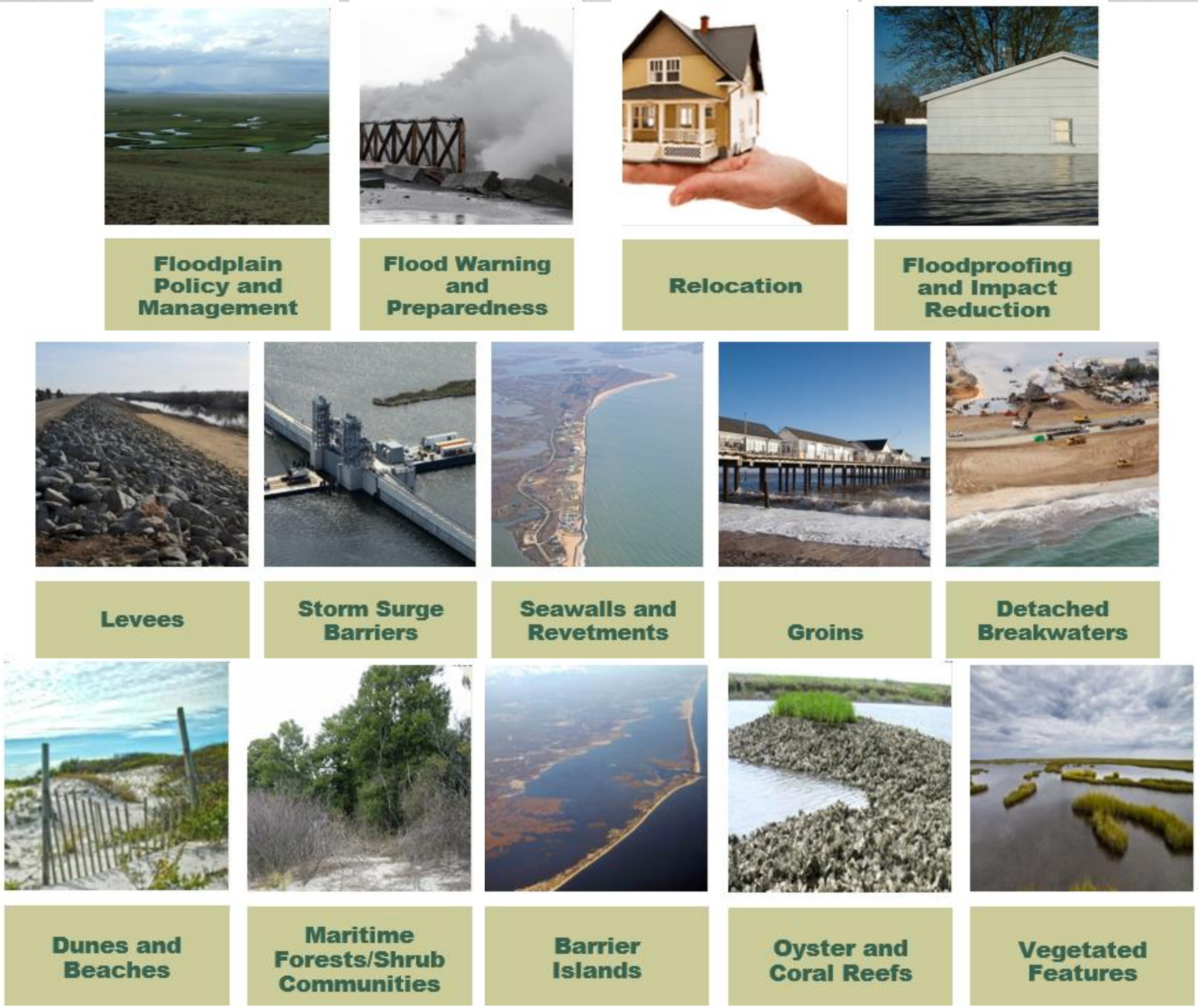

Bridges, Todd S., et al. *Use of natural and nature-based features (NNBF) for coastal resilience*. US Army Engineer Research and Development Center, Environmental Laboratory, Coastal and Hydraulics Laboratory, 2015.

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NATIONAL PROJECTION DATABASE

Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections

This site is best viewed with Chrome (recommended) or Firefox. Some features are unavailable when using Internet Explorer. Requires JavaScript to be enabled.

Trouble accessing the FTP? Many web browsers no longer support FTP URLs.

Welcome | About | Tutorials | Projections: Subset Request | Projections: Complete Archives | Feedback | Links

Downscaled CMIP5 climate and hydrology projections' documentation and release notes available here.

Summary

This archive contains fine spatial resolution translations of climate projections over the contiguous United States (U.S.) developed using three downscaling techniques (monthly BCSD Figure 1, daily BCCA Figure 2, and daily LOCA Figure 3), CMIP3 hydrologic projections over the western U.S., and two sets of CMIP5 hydrology projections, corresponding to monthly BCSD climate projections, and corresponding to daily LOCA climate projections, both over the contiguous U.S. as well as Canadian portions of the Columbia River and Missouri River Basins.

Archive content is based on global climate projections from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset referenced in the Intergovernmental Panel on Climate Change Fourth Assessment Report, and the phase 5 (CMIP5) multi-model dataset that is informing the IPCC Fifth Assessment.

For information about downscaled climate and hydrology projections development, please see the About page.

Purpose

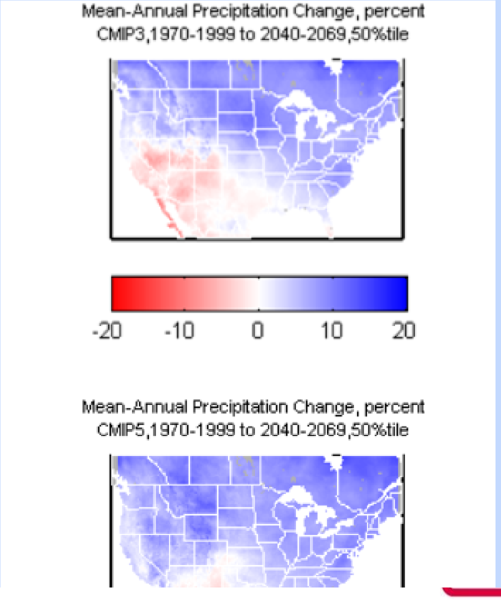
The archive is meant to provide access to climate and hydrologic projections at spatial and temporal scales relevant to some of the watershed and basin-scale decisions facing water and natural resource managers and planners dealing with climate change. Such access permits several types of analyses, including:

- assessment of potential climate change impacts on natural and social systems (e.g., watershed hydrology, ecosystems, water and energy demands).
- assessment of local to regional climate projection uncertainty.
- risk-based exploration of planning and policy responses framed by potential climate changes exemplified by these projections.

Archive History

- November 2007: Archive launched, initially serving 112 projections of monthly BCSD CMIP3 temperature and precipitation projections over the contiguous U.S. for the period 1950-2099.

Figure 1. Central Tendency Changes in Mean-Annual Precipitation over the contiguous U.S. from 1970-1999 to 2040-2069 for BCSD3, BCSD5, and Difference.



https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/

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Compound Floods

REVIEWS

NATURE REVIEWS | EARTH & ENVIRONMENT

A typology of compound weather and climate events

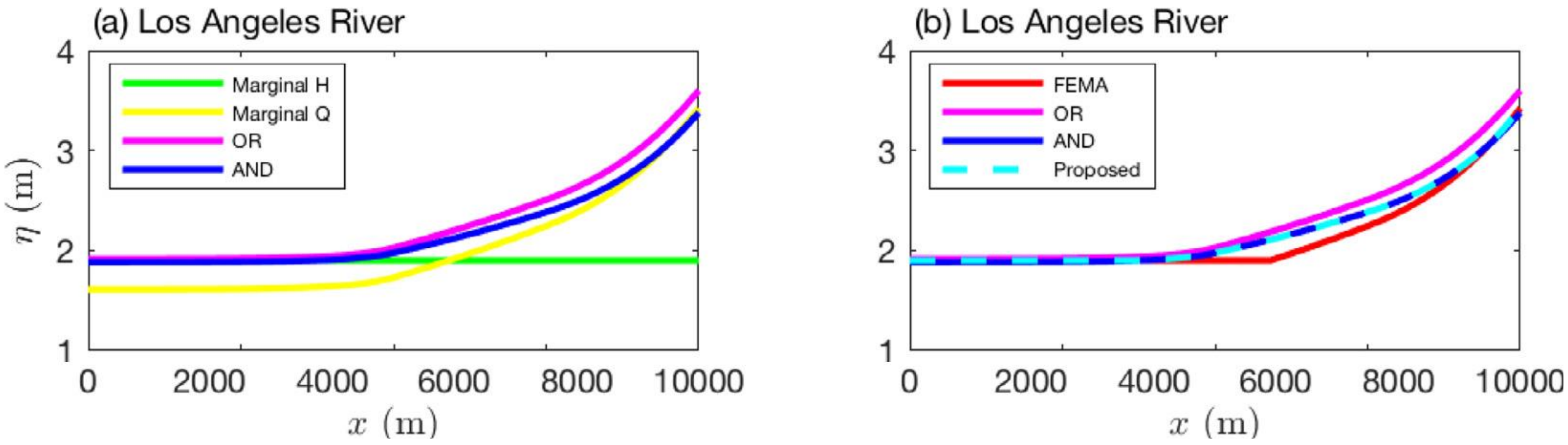
Jakob Zscheischler[1,2], Olivia Martius[1,3,4], Seth Westra[5], Emanuele Bevacqua[6], Colin Raymond[7,8], Radley M. Horton[9], Bart van den Hurk[10,11], Amir AghaKouchak[12,13], Aglaé Jézéquel[14,15], Miguel D. Mahecha[16,17], Douglas Maraun[18], Alexandre M. Ramos[19], Nina N. Ridder[20], Wim Thiery[21] and Edoardo Vignotto[22]

NATURE CLIMATE CHANGE | VOL 10 | JULY 2020 | 583 | www.nature.com/natureclimatechange

editorial

Moving beyond isolated events

Research addressing compound and connected events, and their integrated risk to the natural and built world, is gaining momentum. Paradigms are now evolving to classify and analyse the processes forming such links — whether physical or societal, direct or indirect — and the role of climate change in their ultimate impacts.



Moftakhari et al. "Linking statistical and hydrodynamic modeling for compound flood hazard assessment in tidal channels and estuaries." *Advances in Water Resources* 128 (2019)

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THE NONSTATIONARITY DETECTION TOOL

Background

Assess stationarity in **annual instantaneous peak stream flow** & **gage height** data series

Data pulled **from USGS streamflow gages** and updated every six months

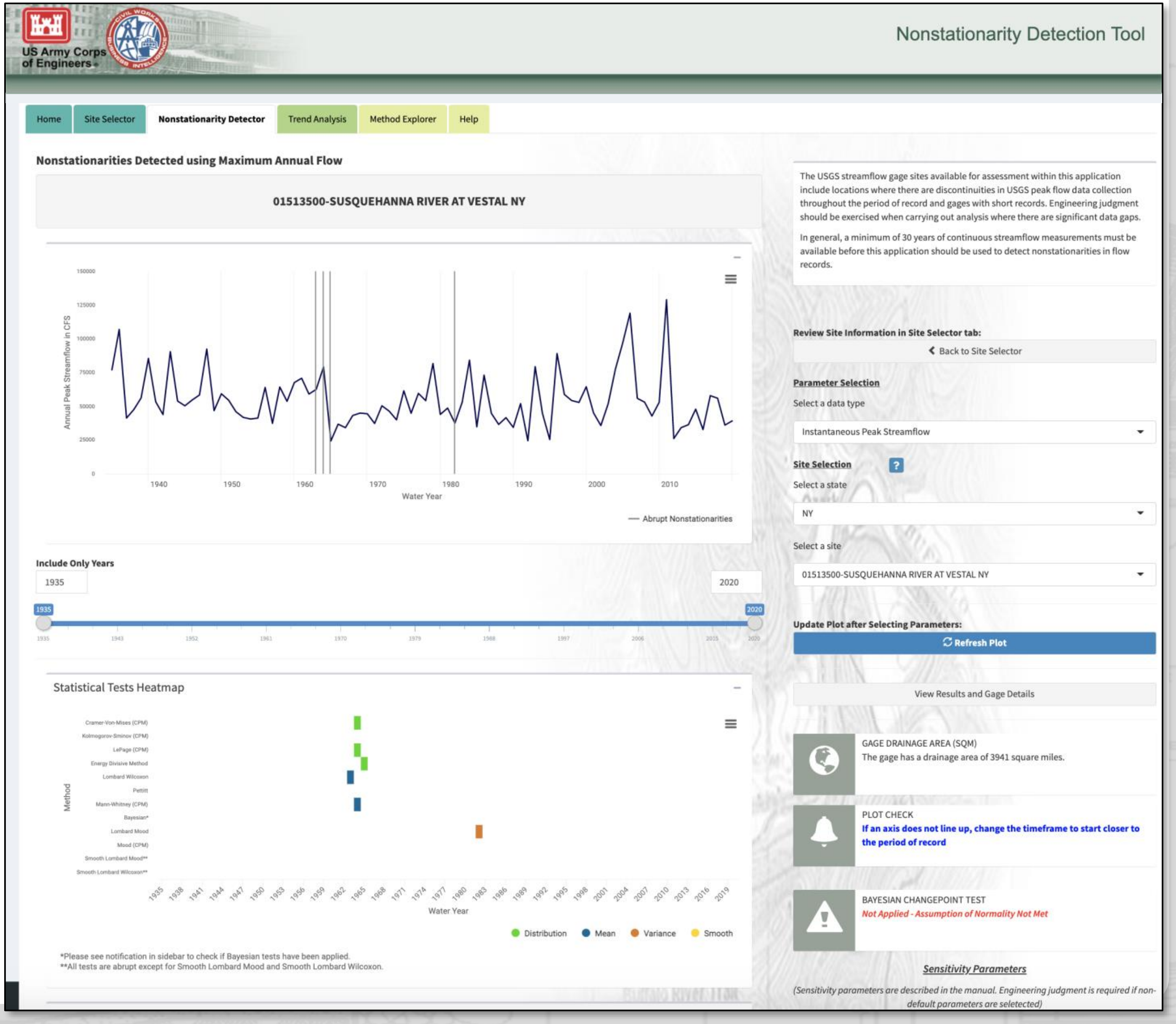
Only gages with **at least 30 years of data** is included for analysis to ensure robustness

Formal technical guidance is included in **Engineering Technical Letter 1100-2-3**

Core Capabilities

Nonstationarity Detection

Trend Analysis



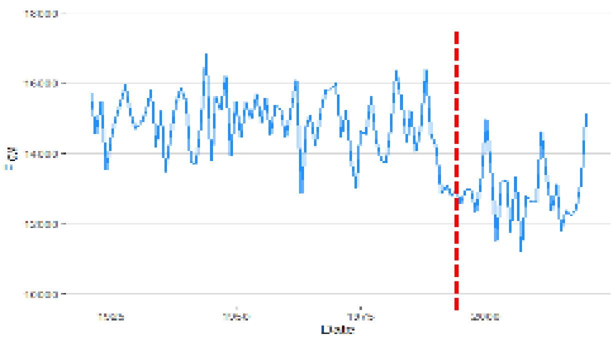
NONSTATIONARITIES TAKE MANY FORMS

Types of Nonstationarities

There are three main types of nonstationarities we are concerned about (below). Note, nonstationarities can be abrupt and sudden (detected as change points) or smooth and gradual changes (trends over time)

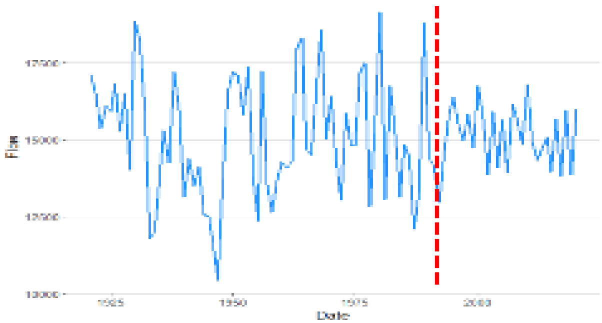
Mean

Change in the "central tendency" of the data



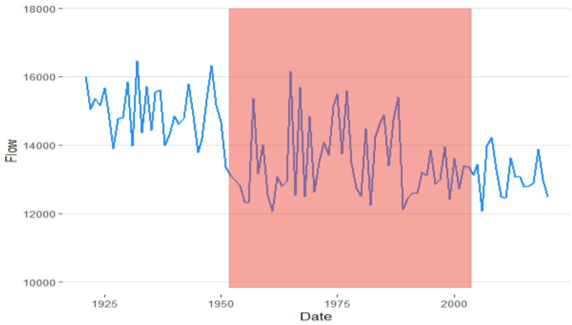
Variance

Change in the "volatility" of the data



Distribution

Change in **both** characteristics of the data



To detect nonstationarities, it is recommended to use many tests at the same time, as each has its own unique tradeoffs

Consensus: Multiple different tests detect the same kind of change

Robustness: Several types of changes are detected all at once

Magnitude: Changes are substantive enough to impact engineering decisions

*While presence of all three criteria is of particular value, consensus of multiple significant nonstationarities often constitutes a **strong nonstationarity***

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MEAN AND VARIANCE TESTS

Most tests work by iteratively stepping through the data and breaking the observed record into two sub-records at each year. The tests then compare measures in the two samples.

Mean

Lombard Wilcoxon

Nonparametric test which nests the *Wilcoxon score function within the Lombard test statistic* to detect both smooth and abrupt shifts in mean

Pettitt

Nonparametric test that identifies changepoints by *testing whether two samples come from the same population*

Mann-Whitney

Nonparametric test that *compares the average magnitude of randomly selected values* pulled from both samples of data

Bayesian CPD

Parametric test that uses *MCMC sampling to test if the series can be broken into partitions with a constant mean*

Variance

Mood

A nonparametric case of a Pearson's Chi-test that *evaluates change points based on volatility in medians* between defined samples

Lombard Mood

Nonparametric test which nests the *Mood score function within the Lombard test statistic* to detect both smooth and abrupt shifts in variance by time

DISTRIBUTION TESTS

Nonstationarities in distribution can reflect a significant change in a distribution's parameters or a shift to an entirely new distribution that may have drastically different characteristics

Cramer-Von-Mises

Nonparametric test that compares two distributions by evaluating a test statistic of *distributional distance*

Kolmogorov-Smirnov

Nonparametric test that compares two distributions by evaluating a test statistic of *distributional distance*

LePage

Simultaneously *tests mean and variance statistics* in the two samples, where inequality indicates a shift

Energy Divisive

Nonparametric test that *partitions the dataset into two subsets at the most likely changepoint*, then it partitions those subsets into further subsets, and continues partitioning until the differences between the subsets are no longer significant.

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TREND SIGNIFICANCE TESTS

Whether there is a relationship between the data and time (i.e., a trend in the time series) can be tested as well, but again, many tests should be used concurrently as each has its own strengths and weaknesses. Apply trend analysis tests to full period of record and subsets of data prior to and after each strong nonstationarity detected.

Correlation Tests

Spearman's

Tests whether **Spearman's rho** (correlation) is statistically significantly different from 0. More widely used.

Mann-Kendall

Tests whether **Kendall's tau** (correlation) is statistically significantly different from 0. Less commonly used.

t-Test

Tests which compares the strength of the signal in mean to the variation of the data. The smaller the magnitude of the **p-value**, the greater chance of a trend.

Slope Tests

Simple Linear Regression

Tests whether **best-fit trendline** slope is statistically significantly different from 0

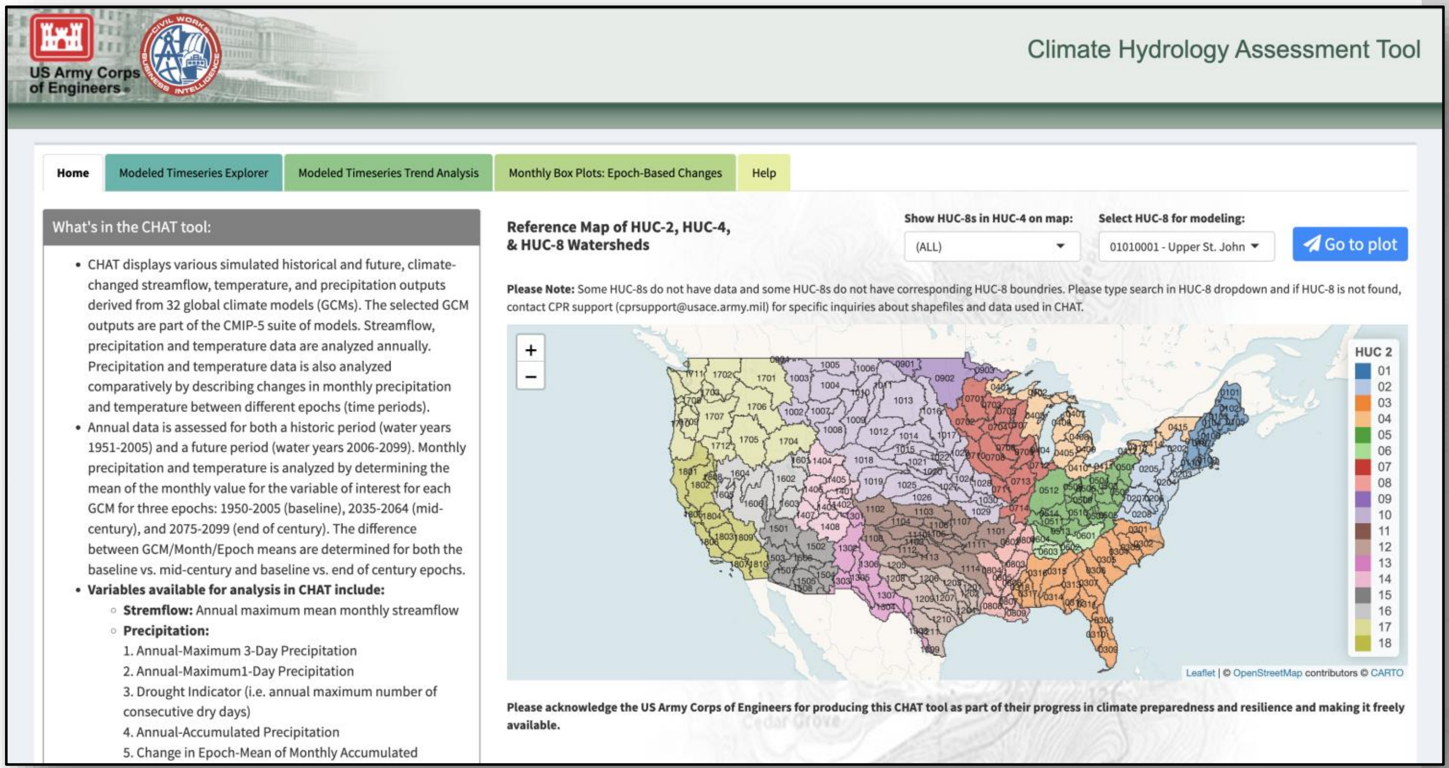
Sen's

Tests whether the Sen's slope, which takes the **average across all slopes between pairs of data** throughout the series, is statistically significantly different from 0

THE CLIMATE HYDROLOGY ASSESSMENT TOOL

Background

- Displays simulated **streamflow, temperature and precipitation data.**
- Analyzes trends across **climate modeled hindcasts and projections**
- **Compares climate modeled trends** for both simulated historical and projected futures
- Operationalizes elements of the flow discussed in **ECB 2018-14**



Core Capabilities

- Global Climate Model (GCM) based hydrologic Timeseries & Inter-model Spread
- Trend Analysis of Simulated Hindcast & Future Period Hydrology

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CONSIDERING PATTERNS

*While the NSD tool focuses on change points and the presence of a trend in observed data, **CHAT** allows for analysis of the magnitude and significance of the trends in simulated, unregulated historical and projected, future data (with interactive visualizations)*

The Data

Uses simulated historical and projected future climate-modeled data derived from 32 state-of-the-art Global Climate Models for two RCPs: 4.5 & 8.5

Simulated annual-maximum average monthly runoff for each 8-digit HUC watershed

Annual water year-based resolution (Oct 1 – Sep 30)

Analytic Capabilities

Trend Tests: p-value tests of whether a trend is present (typically use a significance threshold <0.05)

Trend Measurement: Fits and visualizes trend lines over the data using simple linear regression, reporting slope magnitude

Timeframe-based Analysis: Separate trend fits and significance tests for the simulated historical (1951-2005) and projected, future (2006-2099) time periods.

NEW DATA INCLUDED IN THE LATEST CHAT

CHAT is actively integrating meteorological (temperature and precipitation) climate model parameters to complement streamflow information.

The Data

New parameters will derive from the same simulated historical and projected future climate-modeled data derived from 32 state-of-the-art Global Climate Models

Simulated meteorological parameters for each 8-digit HUC watershed

Annual water year-based resolution (Oct 1 – Sep 30)
+
New Epoch-based resolution

Parameters

Precipitation:

- Annual-maximum of daily accumulated precipitation
- Annual-maximum of 3-day mean of daily accumulated precipitation
- Annual-maximum of 3-day sum of daily accumulated precipitation
- "Drought": Annual maximum number of consecutive dry days
- Annual-sum of daily accumulated precipitation
- Epoch-mean differences in monthly-sum of daily accumulated precipitation

Temperature:

- Annual-average of daily average temperature
- Annual-maximum of daily maximum temperature
- Epoch-mean differences in monthly average of daily average temperature
- Epoch-mean differences in monthly maximum of daily maximum temperature

ANALYZING FUTURE PROJECTIONS

CHAT allows the user to consider future conditions with climate model projections across two combined emissions scenarios (RCP 4.5 and RCP 8.5)

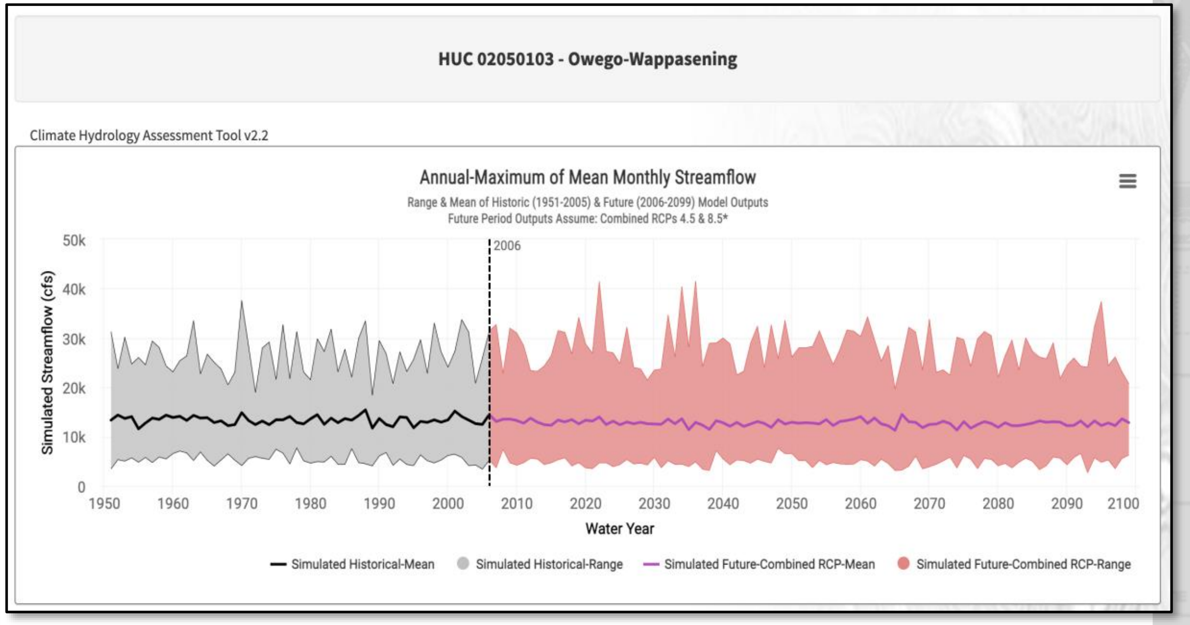
Summary

Climate data are generated from **a wide range of global climate model and emission scenario combinations** from the CMIP5 project (available at: https://gdo-dcp.ucllnl.org/)

Global climate models are **downscaled using the Localized Constructed Analogs (LOCA) method**

Data is then fed through the **Variable Infiltration Capacity (VIC) model** (which is a macroscale hydrologic model)

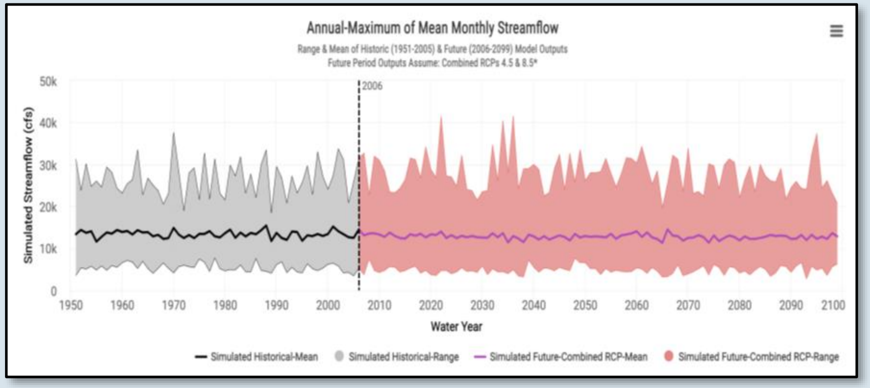
VIC output is used to create **daily, 8-digit HUC streamflow data that are subsequently aggregated to annual maximums of average monthly streamflow**



Climate model data is presented for the VIC model stream segment that most closely represents the cumulative flow at the terminal routing segment transecting the downstream 8-digit HUC watershed boundary. Historic climate hindcast data (shown above) should not be treated the same as historic, observed data, and projected future data should not be compared directly to observed data.

ANALYZING FUTURE PROJECTIONS (CONT.)

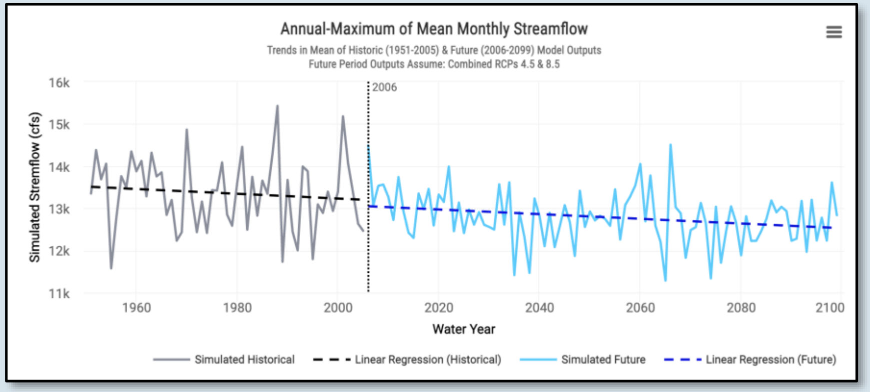
CHAT allows the user to consider future conditions with climate model projections for a selected 8-digit HUC watershed in two tabs



Modeled Streamflow Explorer

This tab visualizes an annual maximum monthly timeseries of climate change driven hydrological model outputs.

- *Climate models are based on a wide array of assumptions, resulting in a **range** of projected flows at the 8-digit HUC level per year. This reflects the **uncertainty.***
- *As a **general central tendency over time**, the **mean** of the models can be referenced.*



Modeled Streamflow Trend Analysis

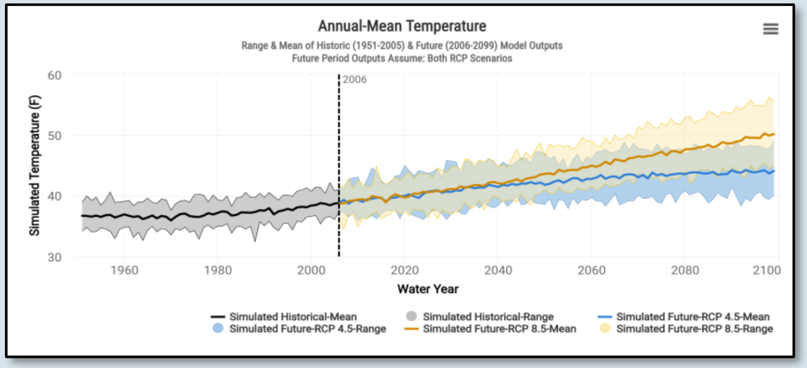
This tab fits linear regression models to simulated historical (1951-2005) and projected future (2006-2099) data separately.

- *Each trend can be assessed by the model **slope, R-squared,** and **trend significance** (p-value based on three statistical tests).*
- *These trends can be directly compared as a proxy for climate change impact.*

*All climate outputs provide **unregulated flows.** This makes comparison to observed data challenging unless observed data comes from a "pristine" or unregulated watershed.*

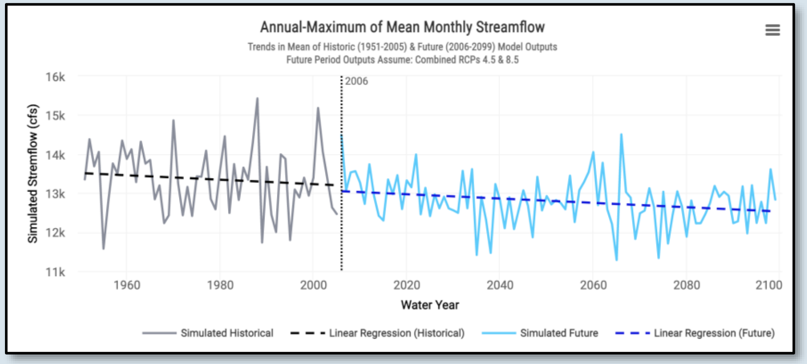
NEW FEATURES OF CHAT

CHAT recently integrated meteorological (temperature and precipitation) climate model variables to complement the streamflow variable.



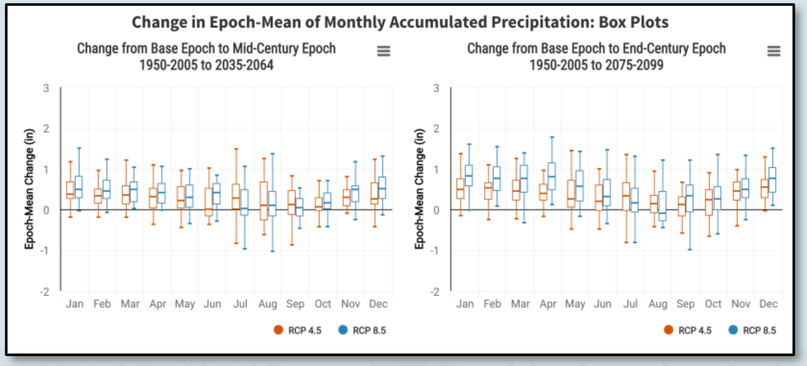
Modeled Timeseries Explorer

*This tab displays annual timeseries and inter-simulation range visualizations of modeled **hydrological and meteorological variables** for the selected HUC-8 watershed. Temperature and precipitation variables are available for **each RCP scenario separately or overlaid together** (as shown at left).*



Modeled Timeseries Trend Analysis

*This tab shows a trend analysis of a **selected variable (temperature, precipitation or streamflow)** for the simulated historical data and projected future data and presents the results of several statistical tests for monotonic trends in the data.*



Monthly Box Plots: Epoch-Based Changes

*This tab displays modeled **monthly epoch-based changes** for various meteorological variables for the selected HUC-8 watershed. These figures depict the change in the mean simulated variable values between two climatological time periods called "epochs".*

NEXT STEPS FOR CHAT

CHAT is also targeting a transition from 8-digit HUC oriented selection to stream segment-oriented selection of simulated streamflow data.

Current vs Planned

Regional:
CHAT currently renders data for the terminal or outlet stream segment associated with the user-selected 8-digit HUC watershed.

Local:
A future iteration of CHAT will allow finer-scale selection by rendering data for a user-selected stream segment.

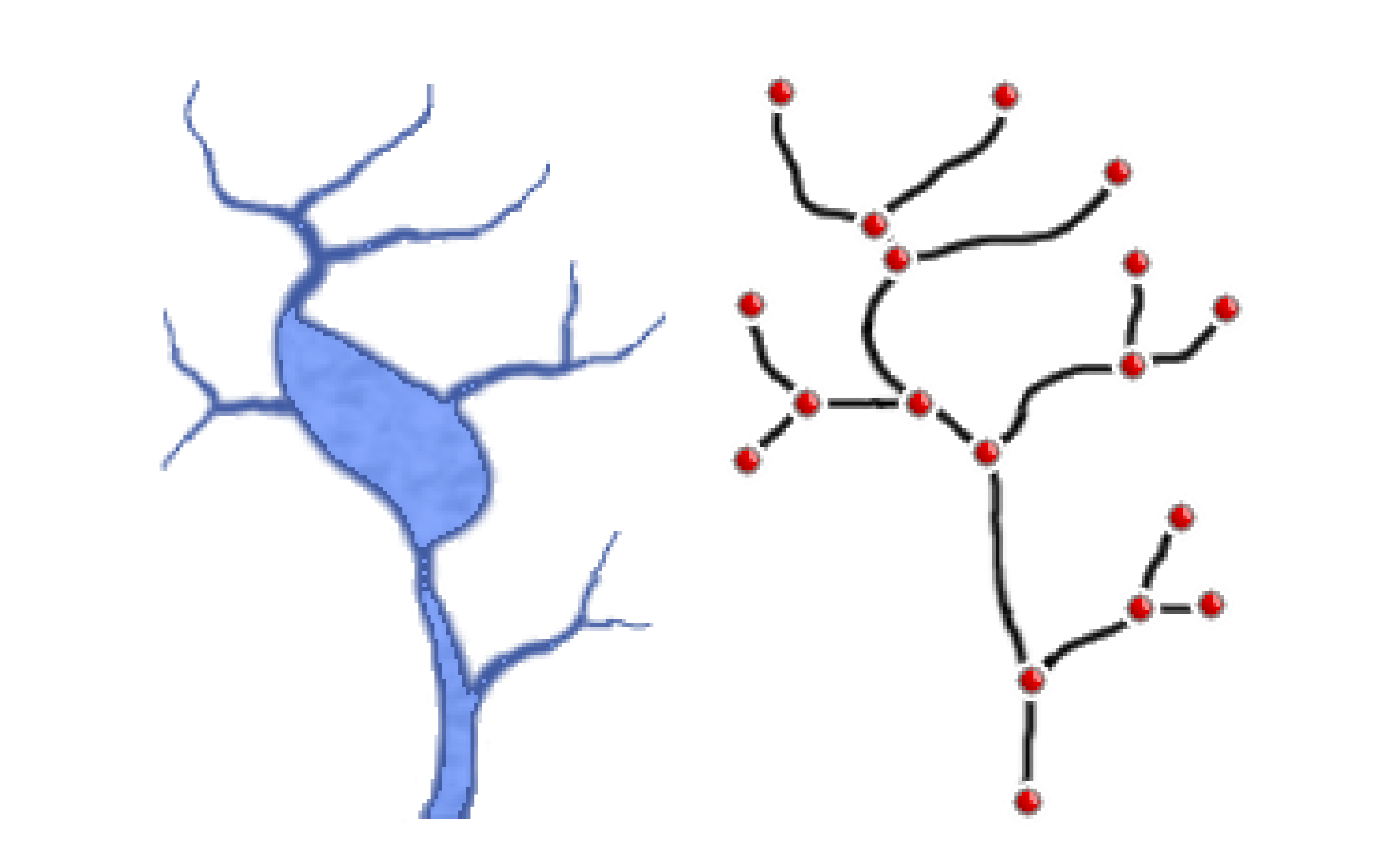


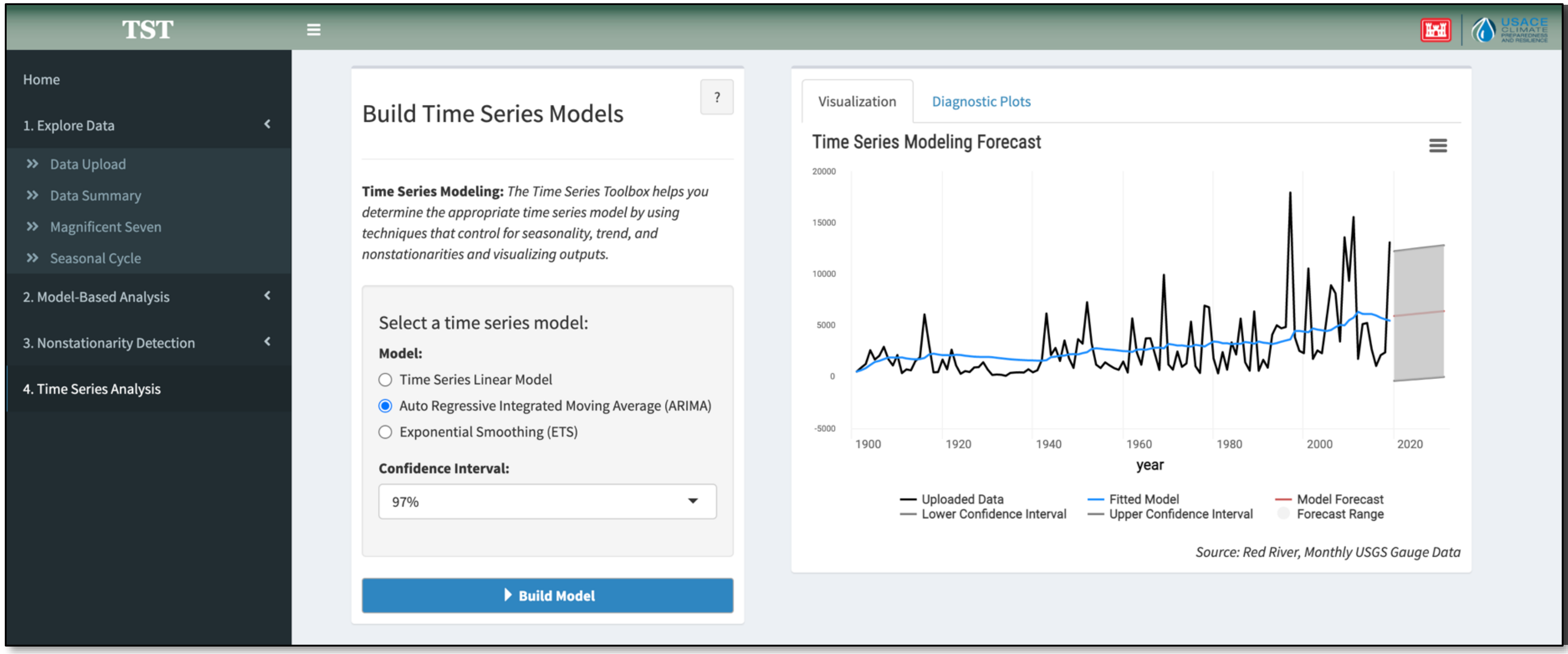
Image Credit: https://en.wikipedia.org/wiki/Strahler_number

THE TIME SERIES TOOLBOX

Background

Origin Story: Originally developed for the data science team to support ad-hoc analytic requests, but with increased investment overtime, it's become a *flexible tool for the broader user community* to conduct their own analysis.

Provides the same function as NSD but on any dataset, while simultaneously including additional features that may be of value and of interest to users (e.g., breakpoint or seasonality analysis).



Core Capabilities

- *Data Visualization / Exploration*
- *Trend & Seasonality Analysis*
- *Seasonal Cycle Analysis*
- *Nonstationarity & Breakpoint Tests*
- *Time Series Modeling*

TIME SERIES TOOLBOX FEATURES

Many users require flexible tooling for customized analysis of their own data. To support these operational needs, USACE has developed the Time Series Toolbox to aid in the repeatable, quantitative analysis of time series data.

Core Capabilities

DATA EXPLORATION

- *Allows users to **upload custom datasets** for visual inspection, summary statistic analysis, and customizable preprocessing*
- *Allows users to rapidly understand patterns and core characteristics in their data set*
- *Displays Magnificent Seven summary statistics to characterize the uploaded data*

TREND ANALYSIS

- *Fits customizable trend lines to data, with supporting visuals*
- *Uses hypothesis testing to measure the significance of the measured trends*

SEASONAL DECOMPOSITION

- *Performs a series of statistical methods to detect, extract, and decompose seasonal patterns*

NONSTATIONARITY

- *Analyzes the data for nonstationarity and displays this analysis in three different graphs*

MODELING

- *Explores three time series models to extract both model fit statistics and the model's forecasts for the uploaded data*

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DATA EXPLORATION

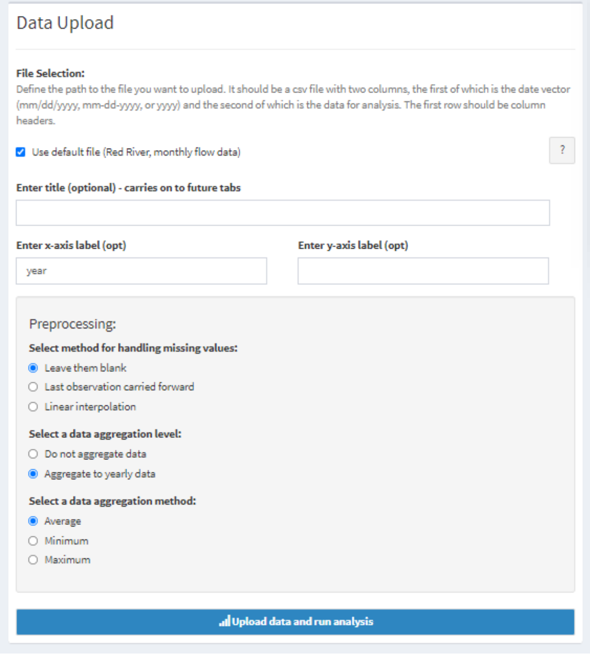
The Time Series Toolbox enables the user to upload a dataset of interest. The Data Summary, Magnificent Seven and Seasonal Cycle subtabs offer various metrics and visualizations for users to better understand and analyze their dataset.

Upload Data & Data Summary: Explore Tab - csv file

Pre-Processing Options: Fill-in Missing Data/ Data Aggregation

Magnificent 7: Summary Statistics

Seasonal Cycle: Monthly metrics of mean, min., & max.



Research suggests that these measures are both effective & efficient in classifying climate data & understanding hydrologic behavior.

1) **L-Mean**: Average value
2) **LCV** (Coefficient of L-Variance): Relative variability
3) **L-Skewness**: Asymmetry - probability distribution
4) **L-Kurtosis**: Tail density - probability distribution
5) **AR1**: Autoregressive lag-one correlation coefficient
6) **Amplitude**: Best Fit Annual sinusoidal curve height
7) **Phase**: Angle of annual sinusoidal curve at time zero

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TREND & NONSTATIONARITY ANALYSIS

The Time Series Toolbox allows users to detect if there are any nonstationarities and/or monotonic trends present in the data, which can significantly impact decision-making around future series behavior.

Methods Used in the Time Series Toolbox

Trend Analysis (SAME AS NSD Tool):

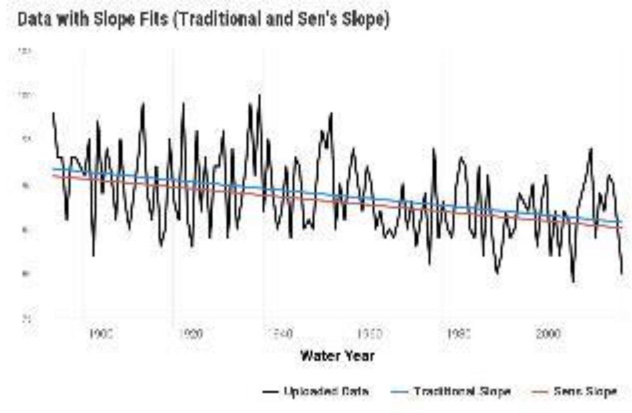
- Traditional & Sen's Slope (Increasing/Decreasing?)
- t-Test, Mann-Kendall, Spearman (p-value<0.05?)

Nonstationarity Analysis (SAME AS NSD Tool):

- 12 Statistical Tests (11 Nonparametric + 1 Parametric)
- Abrupt & Smooth Nonstationarities: Mean, Variance, Distribution
- Three Panes: Data Visualization, Consensus/Robustness, Magnitude

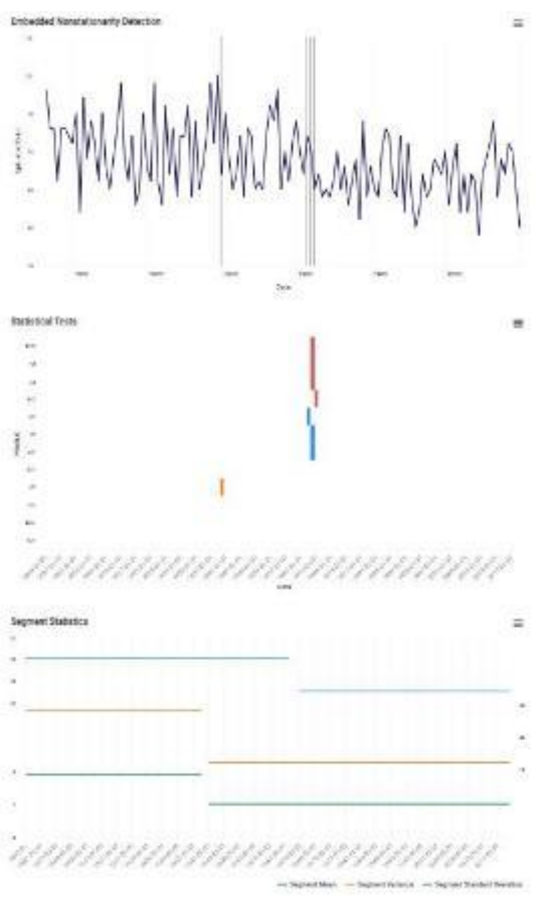
Monotonic Trends:

- Directionality of Trends
- Statistical Significance
- Multiple Tests



Nonstationarity Detection:

- Visualization & summary of nonstationarity analysis of time series data
- Statistical Significance
- Strong Nonstationarities
- Selected Tests are optimized for annual peak flow data, using these tests for other data types might not be appropriate



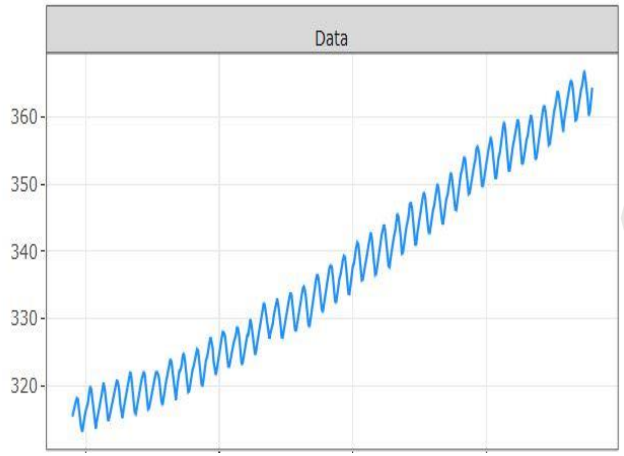
SEASONAL DECOMPOSITION

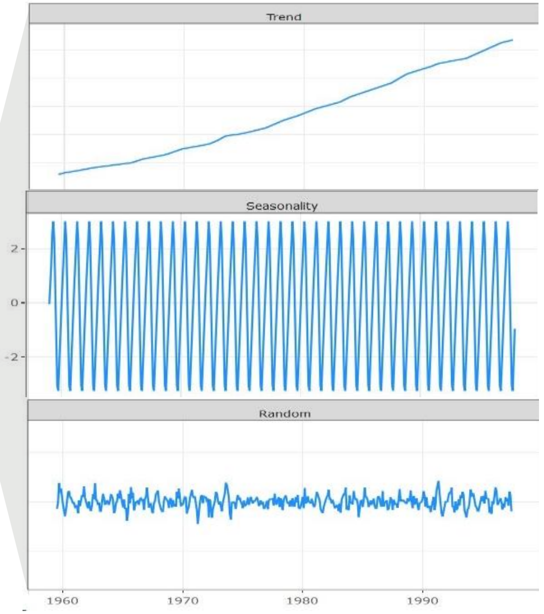
Seasonal decomposition refers to a series of statistical methods that attempt to separate out three of the different components (trend, seasonality, and error) embedded within time series data.

$$Data = Trend + Seasonality + Error$$

Trend	Seasonality	Error
Consistent increases or decreases in the data	Recurring patterns across regular windows of time	Any changes once the former are removed

Original Data (CO_2 levels)





Methods Used in the Time Series Toolbox

Moving Average Decomposition: Moving averages are fit to the data to identify both trends and seasonality

STL (Seasonal-Trend Decomposition by LOESS): LOESS (Local Polynomial Regression) curves are fit to the data to identify both trends and seasonality

BREAKPOINT ANALYSIS

Breakpoints can be used to "segment time series data." Model prediction and characterization are improved if an analyst can build separate, individual models within distinct segments of the data.

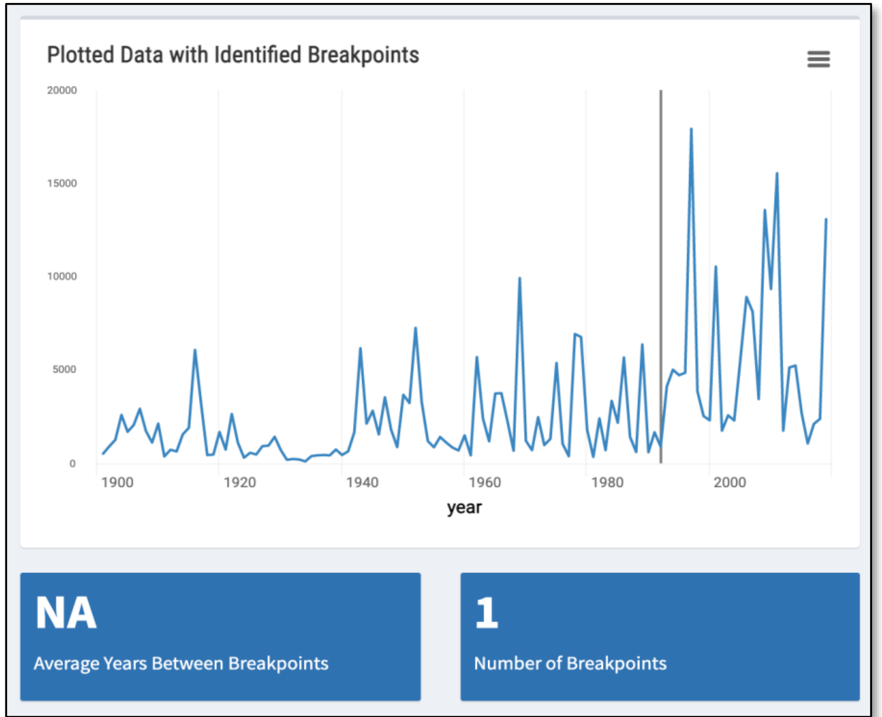
Fit Regression Models to Data: Calculate model fit error → **Test for Change Points:** Across regression fit errors → **Detect Breakpoints:** Flag significant changes in error → **Segmented Analysis and Model Development**

Methods Used in the Time Series Toolbox

Hypothesis tests on model errors use a range of parameters for evaluations. Multiple tests should be considered for robust analysis.

CUMSUM (Cumulative Sums of Squared Errors) uses the running total of the squared errors as the test parameter

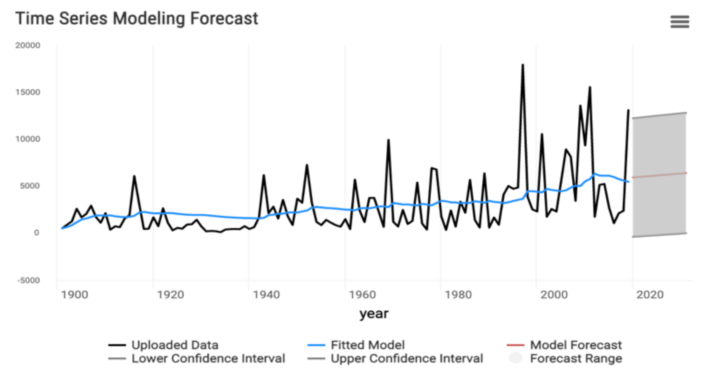
MOSUM (Moving Sums of Squared Errors) uses the moving sum of the squared errors as the test parameter



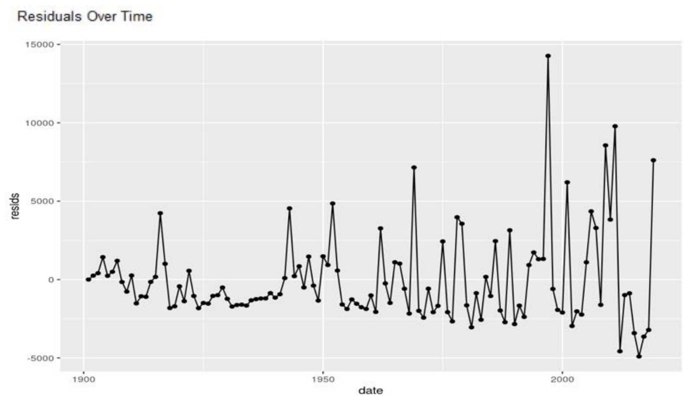
TIME SERIES MODELS

Time series models are powerful tools for characterizing data. They can be used in short-term forecasting, error handling, interpretation, and decomposition, while also helping diagnose how consistently the data behaves over time.

Time Series Models: Offer near-term predictions on data, with some measure of confidence on those predictions



Residual Analysis: Help provide a sense of how "predictable" the data is over time, which can be very insightful



Methods Used in the Time Series Toolbox

Linear Models: A linear regression model that also accounts for the trend and seasonality present in the data

ARIMA (Auto Regressive Integrated Moving Average): A model that describes the data through a combination of recurring historical patterns (autoregressive) and overall trends (moving average)

ETS (Exponential Smoothing): A model that describes the data using weighted moving averages where the most recent data is weighted more than historical data

OVERVIEW OF STATISTICAL TESTS

Statistical Test	Parametric?	Single or Multiple Nonstationarities?	Type of Nonstationarity	Smooth or Abrupt
R-Package: The Change Point Model (CPM)				
Cramer-von-Mises	No	Multiple	Distributional	Abrupt
Kolmogorov Smirnov	No	Multiple	Distributional	Abrupt
Mann-Whitney	No	Multiple	Mean	Abrupt
Lapage	No	Multiple	Distributional	Abrupt
Mood	No	Multiple	Variance	Abrupt
The Lombard Model				
Wilcoxon	No	Single	Mean	Both
Mood	No	Single	Variance	Both
Other Methods				
Pettitt	No	Single	Mean	Abrupt
Bayesian Changepoint	Yes	Multiple	Mean	Abrupt
Energy Based Divisive	No	Multiple	Distributional	Abrupt