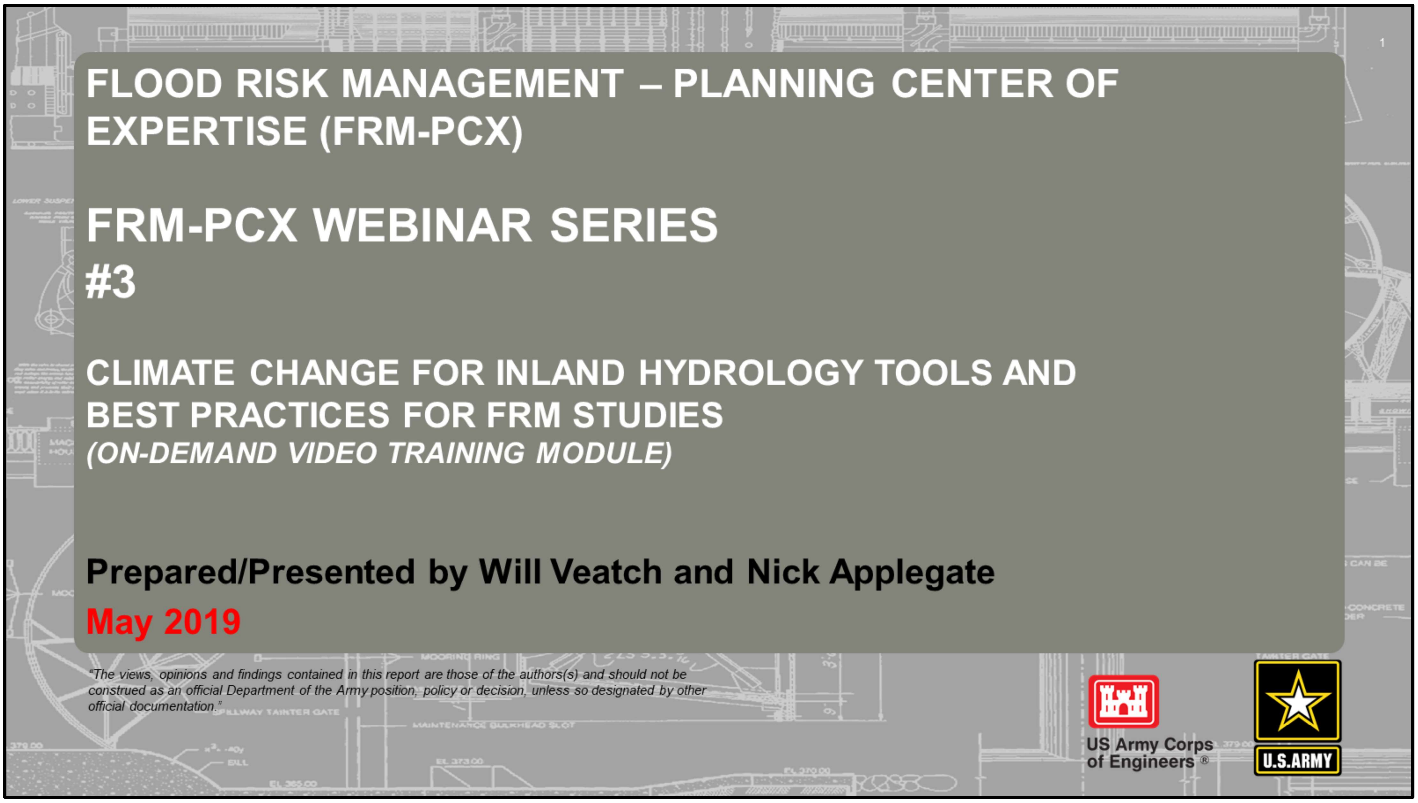
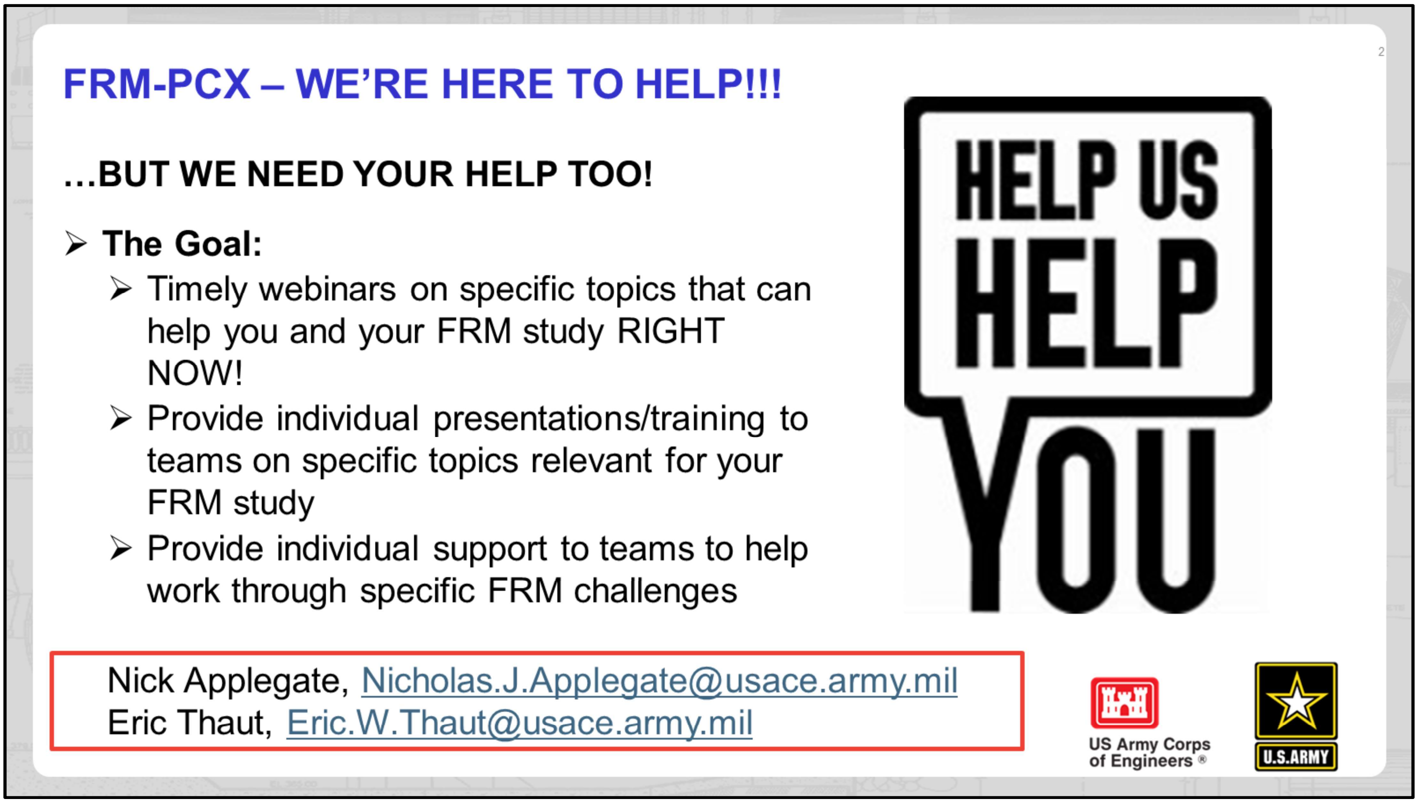


- There are many kinds of climate changes that could affect USACE projects. For example, extreme heatwaves could be important in MILCON where soldiers are not allowed to drill outdoors is excessive heat and hospitals need to be ready to install more air handlers. But for FRM the most important climate changes are likely to be focused on altered inland hydrology, especially flood frequency.



- **WE NEED YOUR HELP!!!**

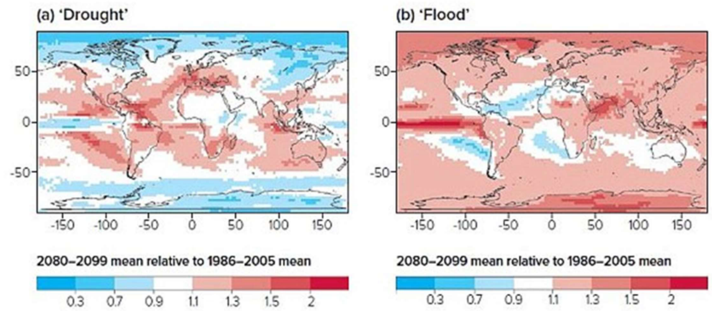
- We need you to reach out and ask for help.
- And tell us what your challenges are!
- We can provide advice and assistance free-of-charge either and/or find the right SME to help.

- **Here's our goal…**
  - ➢ Timely webinars on specific topics that can help you and your FRM study RIGHT NOW!
  - ➢ Provide individual presentations/training to teams on specific topics relevant for your FRM study
  - ➢ Provide individual support to teams to help work through specific FRM challenges
    - ➢ I'm in a newly created position with the PCX to do just this! You don't need to provide me a labor charge code! Please reach out, invite me to a meeting, or even just run some of your recent decisions, assumptions or results by me to make sure we aren't missing anything.

➢ Please reach out to either myself or the Deputy Director with any questions.

PRESENTATION SUMMARY – INLAND CLIMATE CHANGE FOR INLAND FRM PLANNING

- What is Inland Climate Change?
- Why is Inland Climate Change important for FRM Studies?
- Inland Climate Change Overview – Policy and Guidance
- Inland Climate Change Tools and how/when to use them



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EXECUTIVE SUMMARY OF CLIMATE CHANGE TOOLS AND BEST PRACTICES FOR INLAND FRM

- Inland climate change effects are more uncertain than coastal
- **POLICY**: Requirement is for a qualitative assessment of potential vulnerabilities
  - This may change as science matures
  - Quantitative adjustments require approval from CPR CoP
- **STEP 1**: Start with literature review
- **STEP 2**: Assess observed record using *Nonstationary Detector*
  - If found and attributable, follow existing guidance
  - If not attributable, make risk-informed choices to censor or re-regulate record, ask for assistance if needed

- **STEP 3**: Use *Climate Hydrology Assessment Tool (CHAT) tool* to project future flows, assess project risks
- **STEP 4**: *Vulnerability tool* indicates if project site, business line combination is relatively more vulnerable, and **why**
- **The "So What":** Informs formulation, documents risks in project report, clear communication with public, partners, stakeholders

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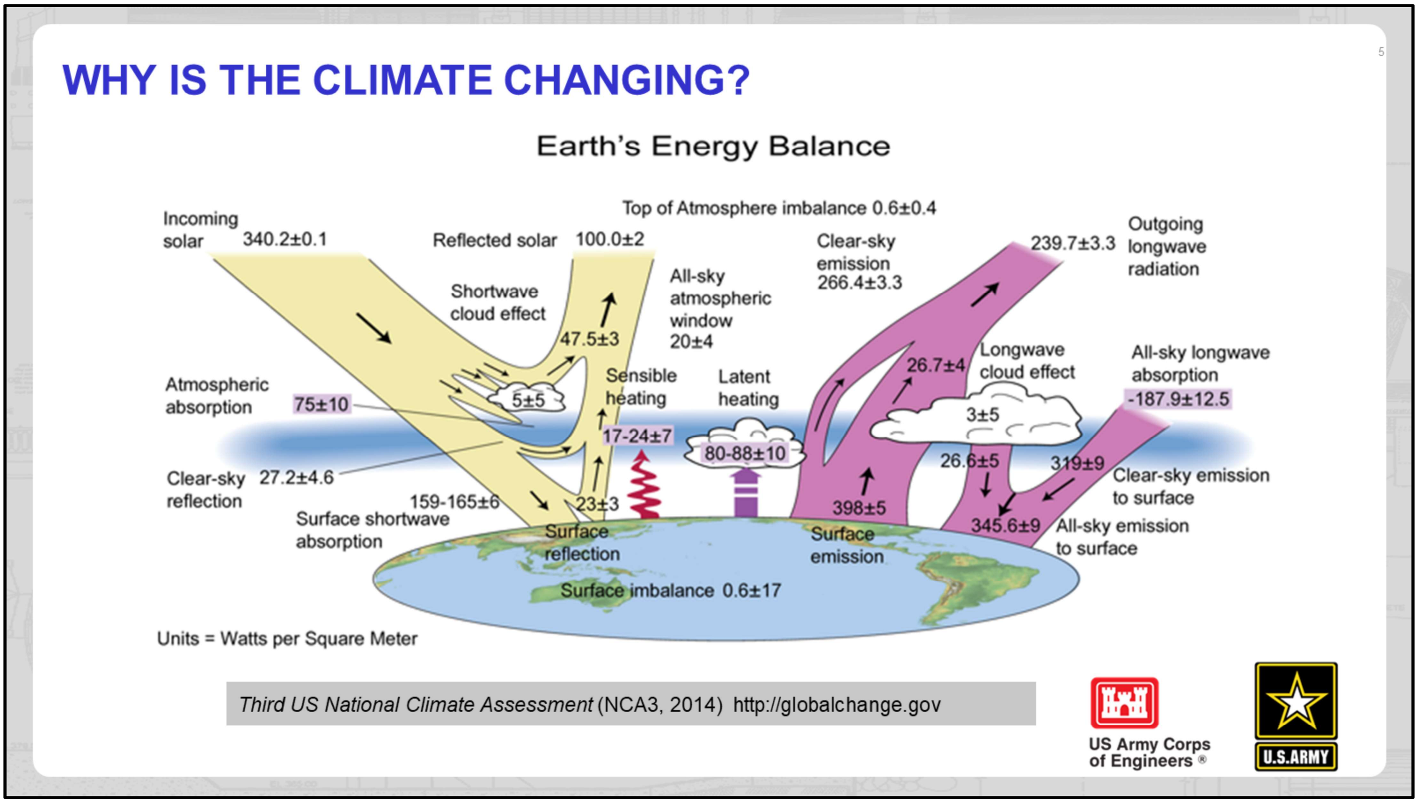
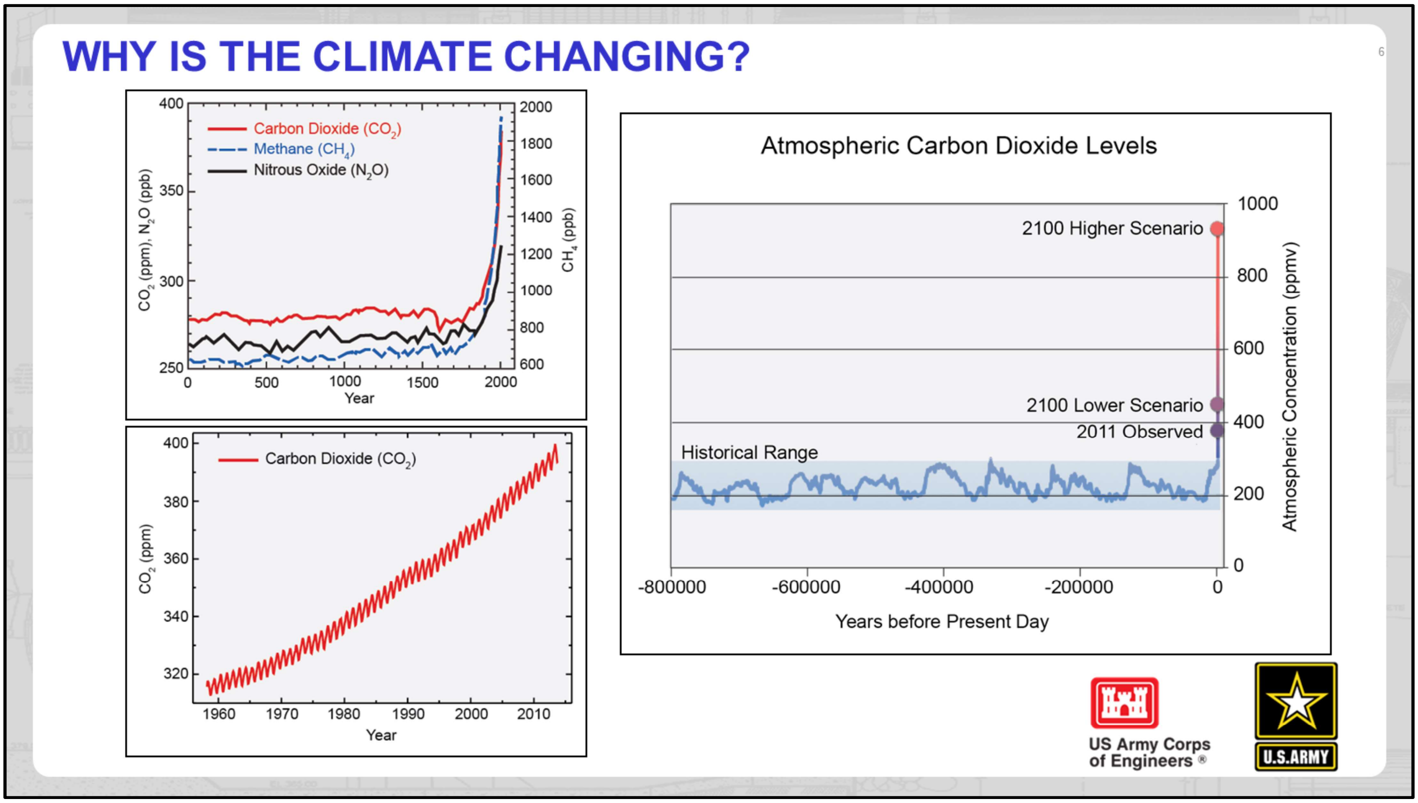


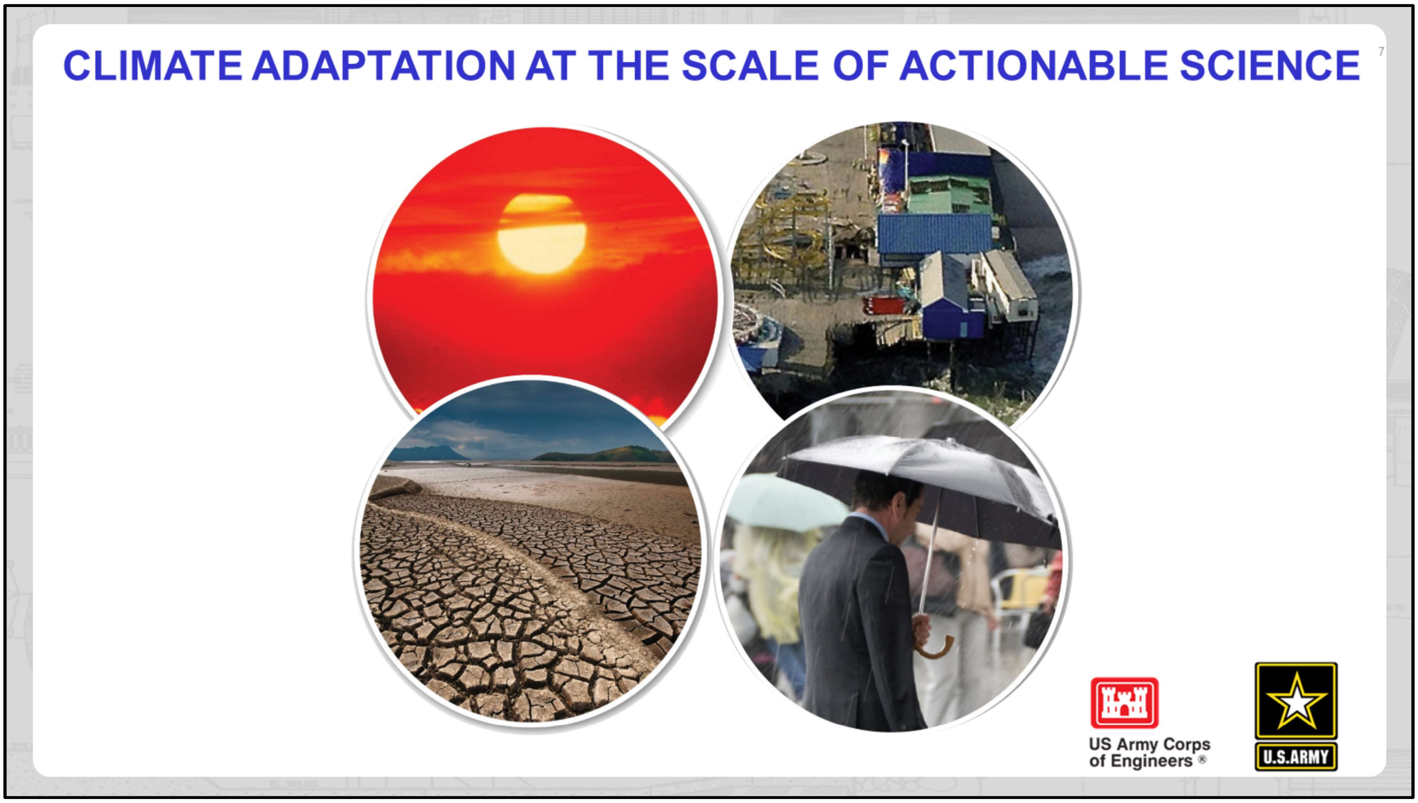
- **There are many components to the energy balance of the Earth.** Longwave radiation, shortwave radiation, sensible heat, latent heat, absorption and re-emission.
  - But it all boils down to the **overall balance**, the excess or deficit, that determines whether the climate will change or stay in a dynamic equilibrium
  - The Earth's energy budget is presently out of balance **by about 0.6 W/m^2**. That might not sound like much compared to a 100 watt light bulb, but of course, the Earth has a lot of square meters.
  - **Human burning of fossil fuels has enhanced the greenhouse effect and made the energy going out ever so slightly less than the energy going in, causing the atmosphere to warm.**

- USACE **climate adaptation policy** is actually agnostic about the cause of the warming, although the science is pretty settled on the causes by now. (USACE, and the DoD, have other policies about climate **mitigation**, but that's not the topic of this webinar).
  - No matter **why** the climate is changing, **it is changing.** And for USACE projects to perform as intended, our designs must incorporate that change



- The concentration of heat-trapping gases in the atmosphere like carbon dioxide, methane, and nitrous oxide **has increased dramatically and recently**.
    - CO_2 concentrations have increased about **25% just since 1960**.
    - Concentrations are **well above even the uncertainty in measurements** from the last several hundred thousand years

- The climate consequences of these changes in greenhouse gases **will take centuries to millennia to play out**.
    - Therefore **we have high confidence** that the changes won’t be reversed anytime soon, like on the scale of a USACE project lifecycle.



- Climate adaptation activities are most focused when assessing the impacts of changes that we have high confidence will continue. Four kinds of impacts are especially certain:
    - Extreme heatwaves will be more common (and extreme cold less common) as the Earth's average temperature increases [upper left]
    - Coastal flooding will be more common, driven primarily by global mean sea level rise [upper right]
    - Droughts will be more common because a warmer atmosphere can hold more water and is therefore more efficient at drying the land surface [lower left]
    - Heavy rainfall will be more common, again due to the atmosphere being more able to hold and transport larger volumes of water [lower right]
- In contrast to these changes, there are many processes and associated uncertainties affecting changes in river flow (fluvial geomorphology, ecohydrology, and human activities just to name a few). Therefore our adaptation activities in this arena are relatively are broad and general, for now.

USACE APPROACH: CLIMATE IMPACTS TO INLAND HYDROLOGY

- Potential climate changes represent uncertainty in FWOP and FWP conditions
- Projects must perform as intended despite uncertainty
- Inland changes are more complex than sea level change
  - Sea level mostly just goes up; the rate of change is uncertain
  - Inland changes can have varied directionalities, feedbacks, tipping points
- At this time, inland changes addressed with a qualitative assessment of potential project vulnerabilities
  - Requirements may change as science matures
  - Quantitative adjustment allowed with prior approval

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- In contrast to sea level change, which requires a quantitative adjustment of future conditions in design, inland hydrological changes are much more complex and uncertain. As a result, we are only required to perform a qualitative assessment of potential project vulnerabilities.

FUTURE WITHOUT-PROJECT CONDITION SCENARIO(S) (FWOP)

- Single most important scenario!
  - Basis of comparison for alternatives
- Primarily a qualitative effort for initial iterations
  - Identify data gaps and where to focus gathering additional data for quantitative analysis

- Assumptions – trends, actions by others
  - Will FRM problems get worse or better without Federal action?
  - *How might climate change impact the future?*
- May have more than one future without project scenario
  - Best practice is to identify **one** "most-likely" FWOP to identify TSP and then compare back to other possible FWOPs.

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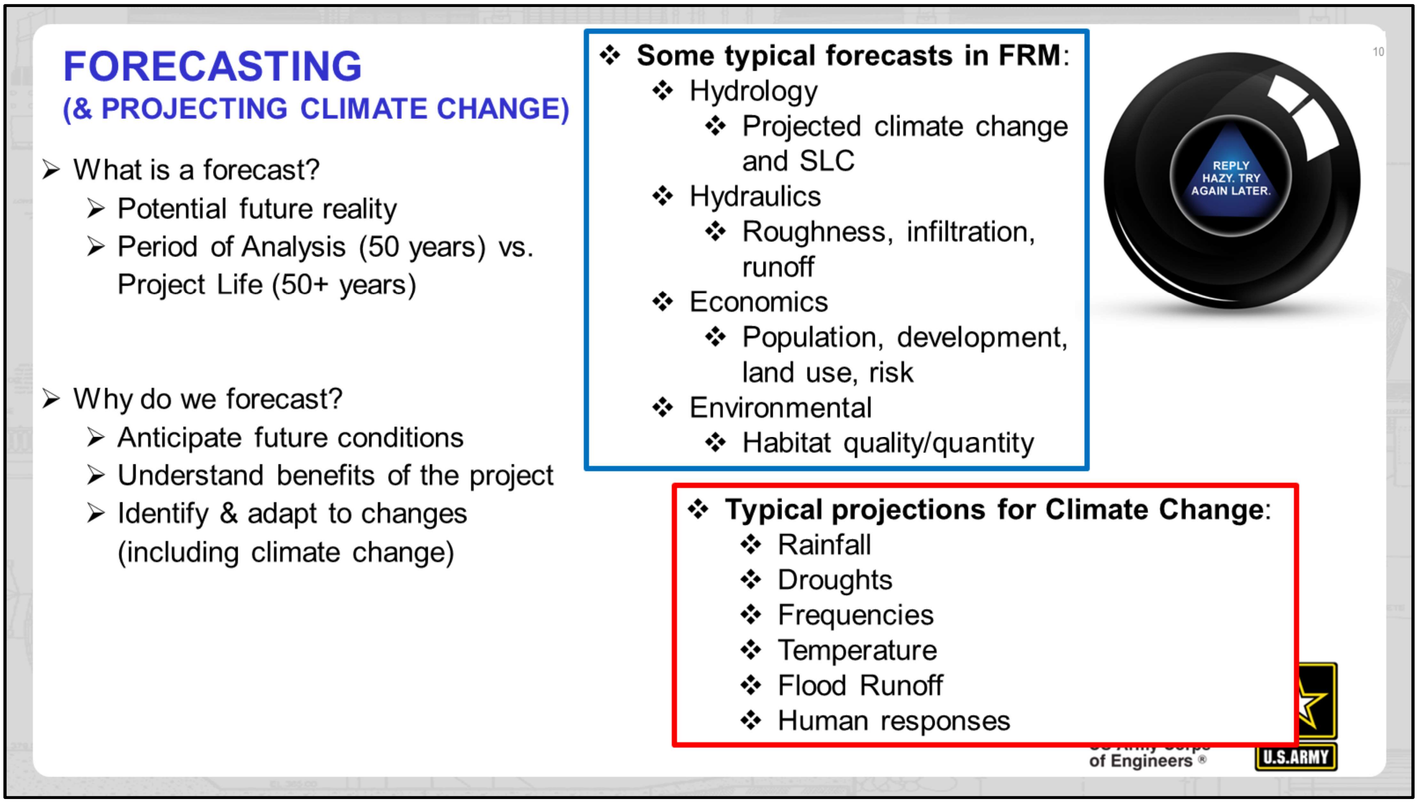
- The single most important scenario that we will forecast and compare against our alternatives.
- Qualitative in initial planning iterations and scoping phase
  - Primarily based on existing information
- Becomes more quantitative in later iterations when moving towards the TSP.
  - Quantitative incorporation of Climate Change in FWOP need prior approval from Climate Preparedness and Resilience (see slide 12)

- **There's a great deal of uncertainty in the future, so we can't predict it perfectly. Therefore, there's multiple different future realities that we have to think about.**
  - **However, to the best of our ability we want to narrow these possibilities because the Future Without Project is the baseline to define our problem and the baseline that we compare all alternatives to. So, the more possible futures you have, the more evaluations and comparisons you have to do.**
  - **Make reasonable assumptions, that you can document and get buy-off from the vertical chain and review team throughout the process for significant assumptions.**
  - **Climate Change will require us to look qualitatively at projecting potential future impacts**
  - **Sea Level Change will always require us to look at multiple future's at least in terms of doing a sensitivity analysis. See FRM-PCX Webinar #4 for more detail on SLC.**

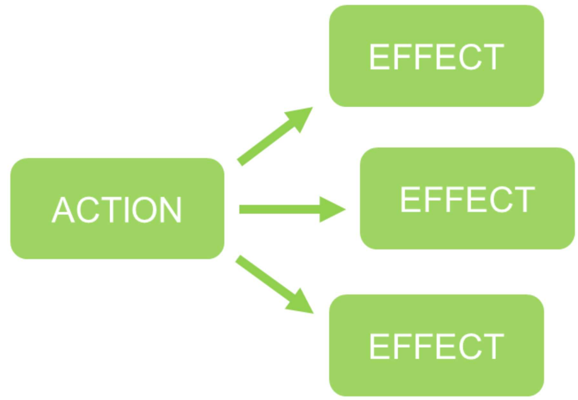


- **Period of Analysis** = The time horizon for project benefits, deferred installation costs, and OMRR&R costs. Use the same period of analysis for all alternative plans.
  - Doesn't have to be full 50 years, future year can be more reasonable based on development plans, etc. And than truncated. Just need to document why these assumptions were made and why they are reasonable.
    - Base Year vs. Future Year
- **Project Life** = how long we think proposed projects will last and perform.
  - In terms of Climate Change and SLC we are concerned about how the project performs over the project life, not just the period of analysis.

We need to be transparent about our assumptions and convey to decision-makers what the risk is to our decision should any of these conditions prove to be different than our forecasts and projections.

FUTURE WITH PROJECT SCENARIO(S)

- Most likely future condition if a plan of action is taken
  - Hydrology, Hydraulics, Economics, Geotech, Environmental
  - Will there be downstream or upstream impacts?
  - What is the residual risk?
  - *How robust is the plan to an uncertain future?*
- Purpose of the with-condition scenario is provide the narrative for evaluating the plan's effects
- Different with-condition for each plan
- Account for changes and uncertainty in the with condition scenarios
- Document assumptions along the way and TELL YOUR PLANNING STORY!



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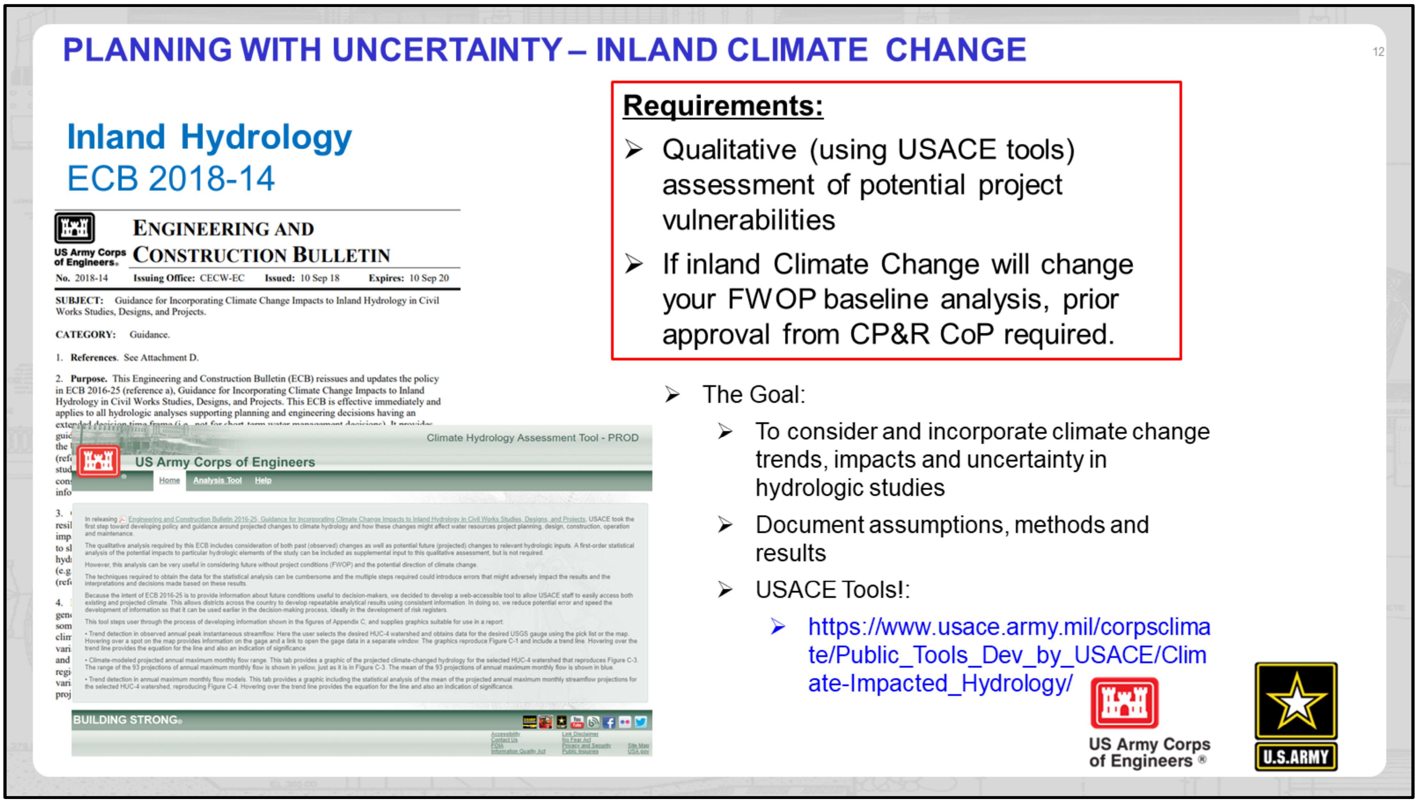
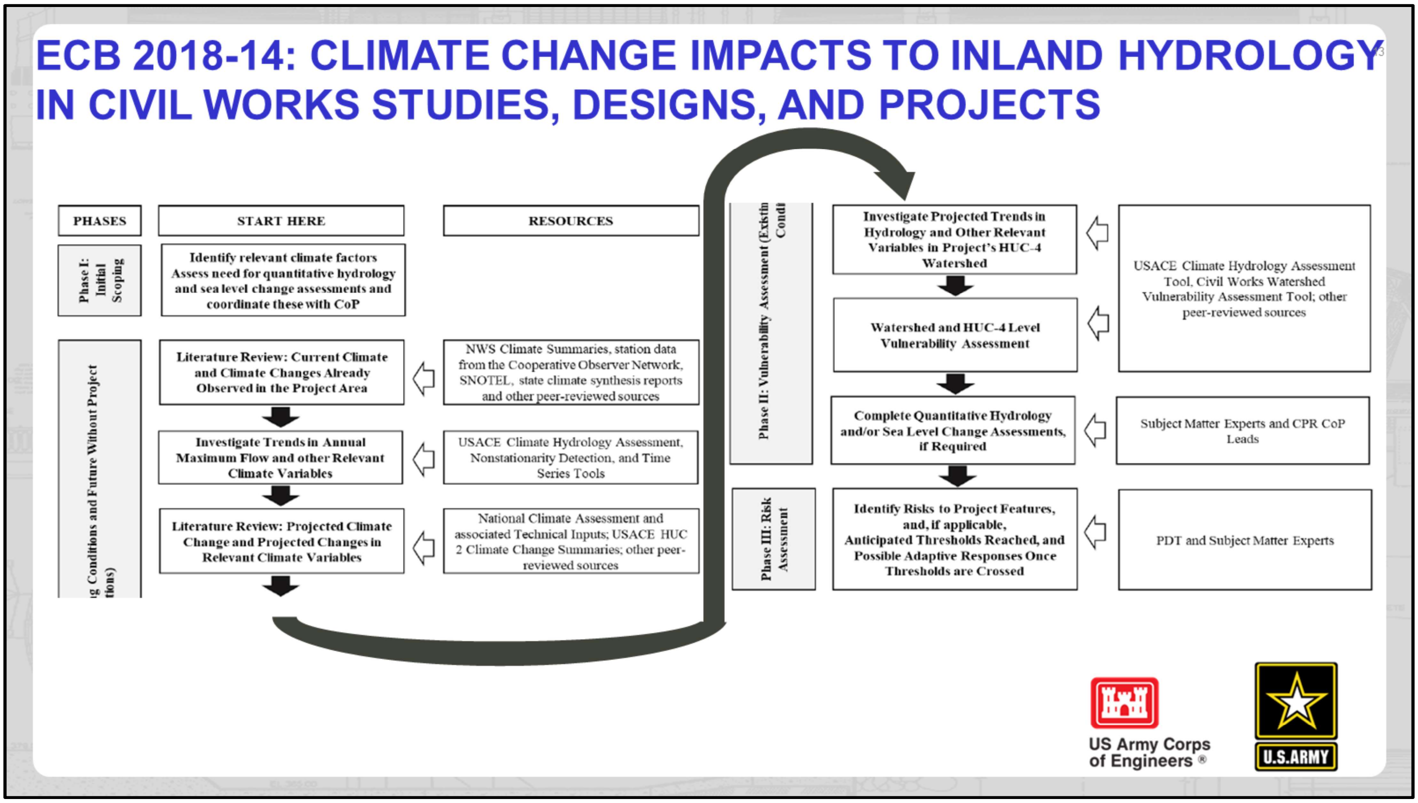
- We want to look at how the with project scenarios perform considering the range of climate change impacts. At a minimum, we do this qualitatively using the tools described later in this presentation.



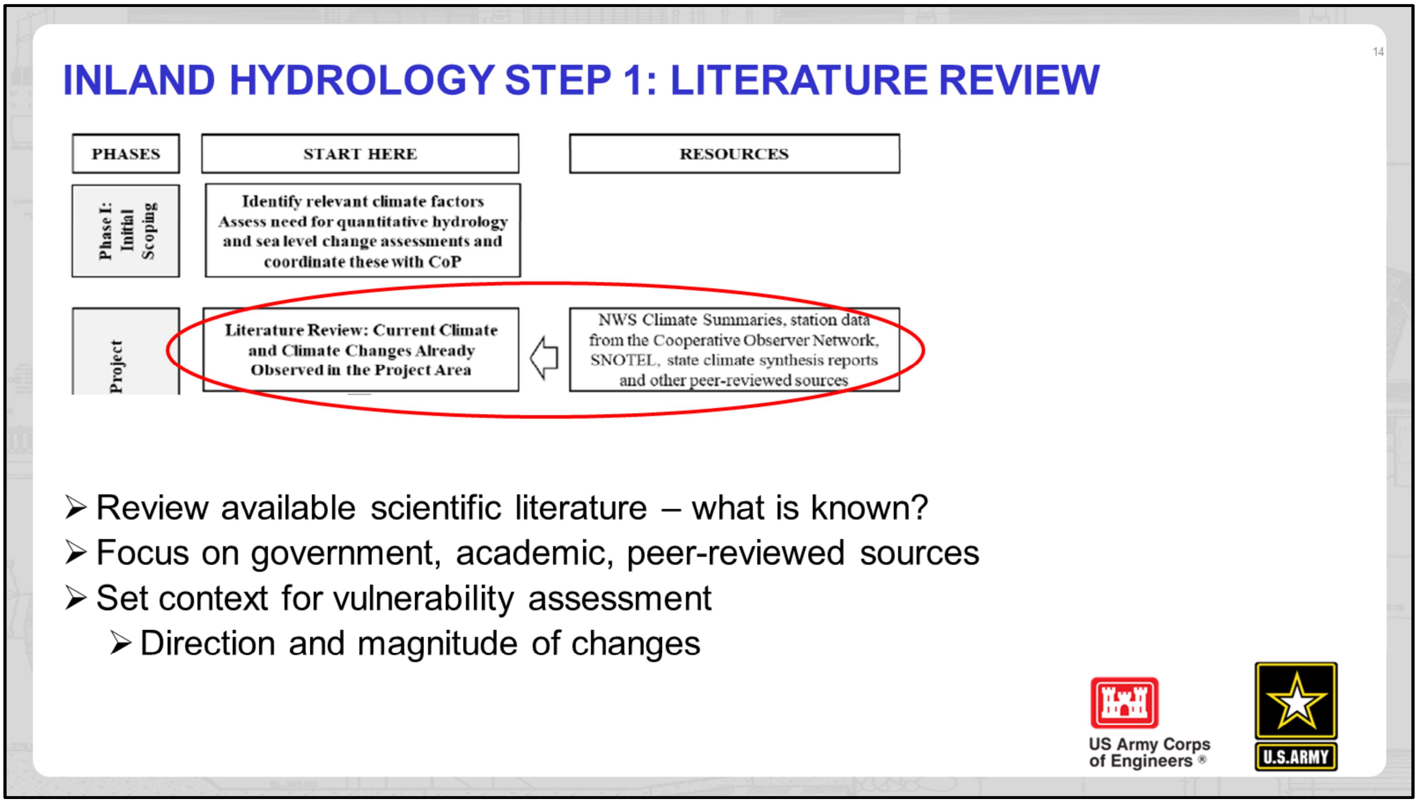
- Start this as soon as possible! Early in the study reach out to your CP&R rep.

- Changes to inland hydrology, to include changes in river flow frequency and rainfall intensity, are more complex than SLC so we are less sure about the direction of change, although they make theoretical sense based on climate science. So in that arena we only require, for now, a qualitative assessment of potential changes and potential project vulnerabilities; we do not require any change to the normal H&H engineering process. If a team desires to use an altered FWOP based on an assumption or projection of altered hydrology, they have to get prior approval from Kate White and/or Jeff Arnold.

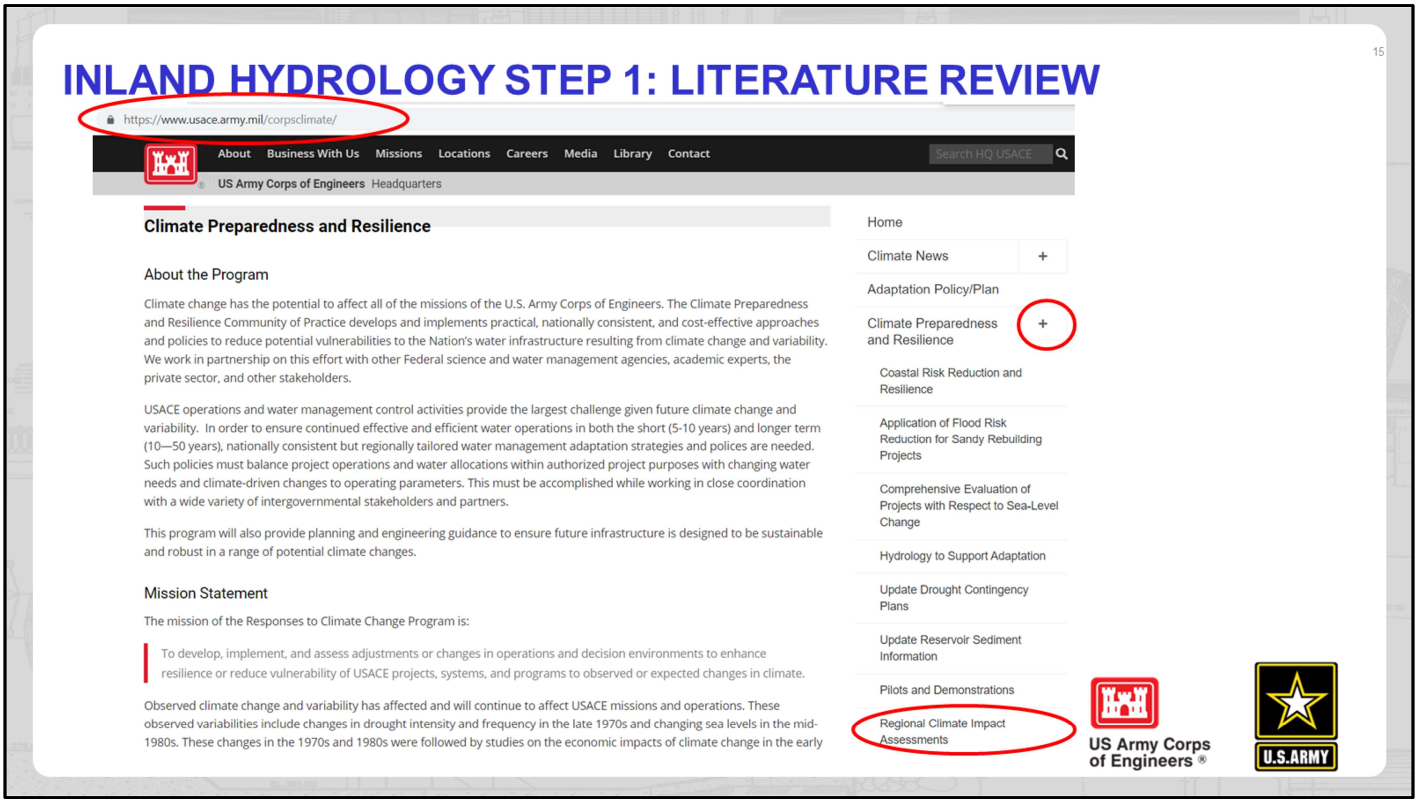
- 4 Tools available for use:
- Climate Hydrology Assessment Tool, Nonstationarity Detector, Vulnerability Assessment, and Timeseries Toolbox. According to the ECB there isn't an ironclad rule to use any of them (and an ECB isn't an ER anyway so it doesn't really require in the same sense) but running the NSD, CHAT, and VA are going to be much, much easier than doing any of that stuff on your own. It' more difficult to satisfy the requirements of climate ATR as laid out in the review guide and the ECB without using those three tools.



- The qualitative assessment described in ECB 2018-14 contains four major components, detailed in this diagram which appears at the end of the ECB (the flowchart was broken in two for this presentation). The chart shows each step along with the relevant resources and outputs. These four general steps are:
    - Review available scientific literature on climate change in the project area
    - Investigate observed changes in past data
    - Investigate projected changes in modeled future climate data
    - Assess potential project vulnerabilities based on future projections
- Each step will be detailed in the following slides

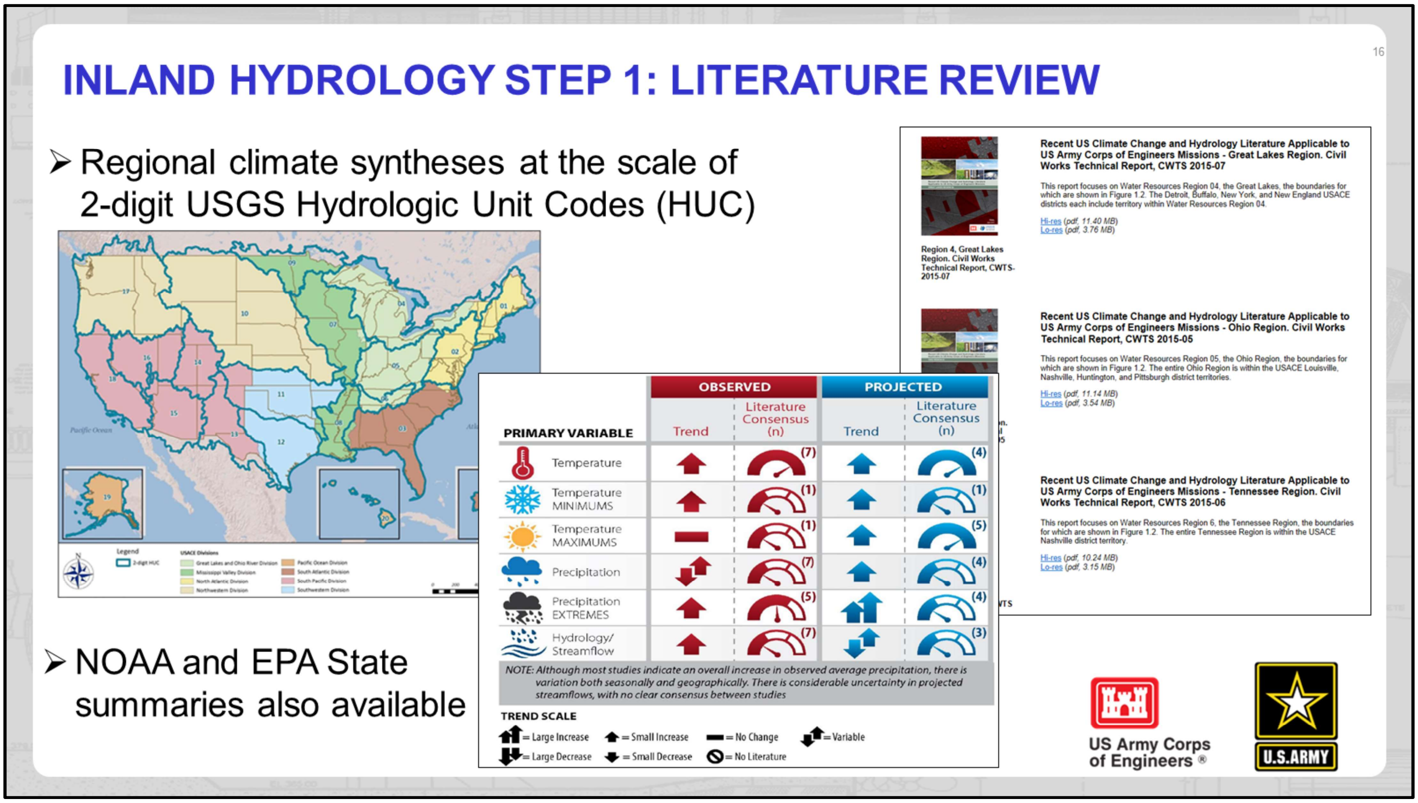


- The first step is a literature review. This review should focus on government, academic, and other peer-reviewed sources. However, less formal sources like popular media articles and blogs can provide citations of scientific literature which can then be reviewed.
- Both published papers and raw data can provide useful insights.
- The main idea is to find out what is already known rather than having to reinvent the wheel



- The simplify the literature review process, CPR CoP has collected published literature as of 2015 into 21 literature syntheses by region. These can be accessed from the CorpsClimate website as shown.

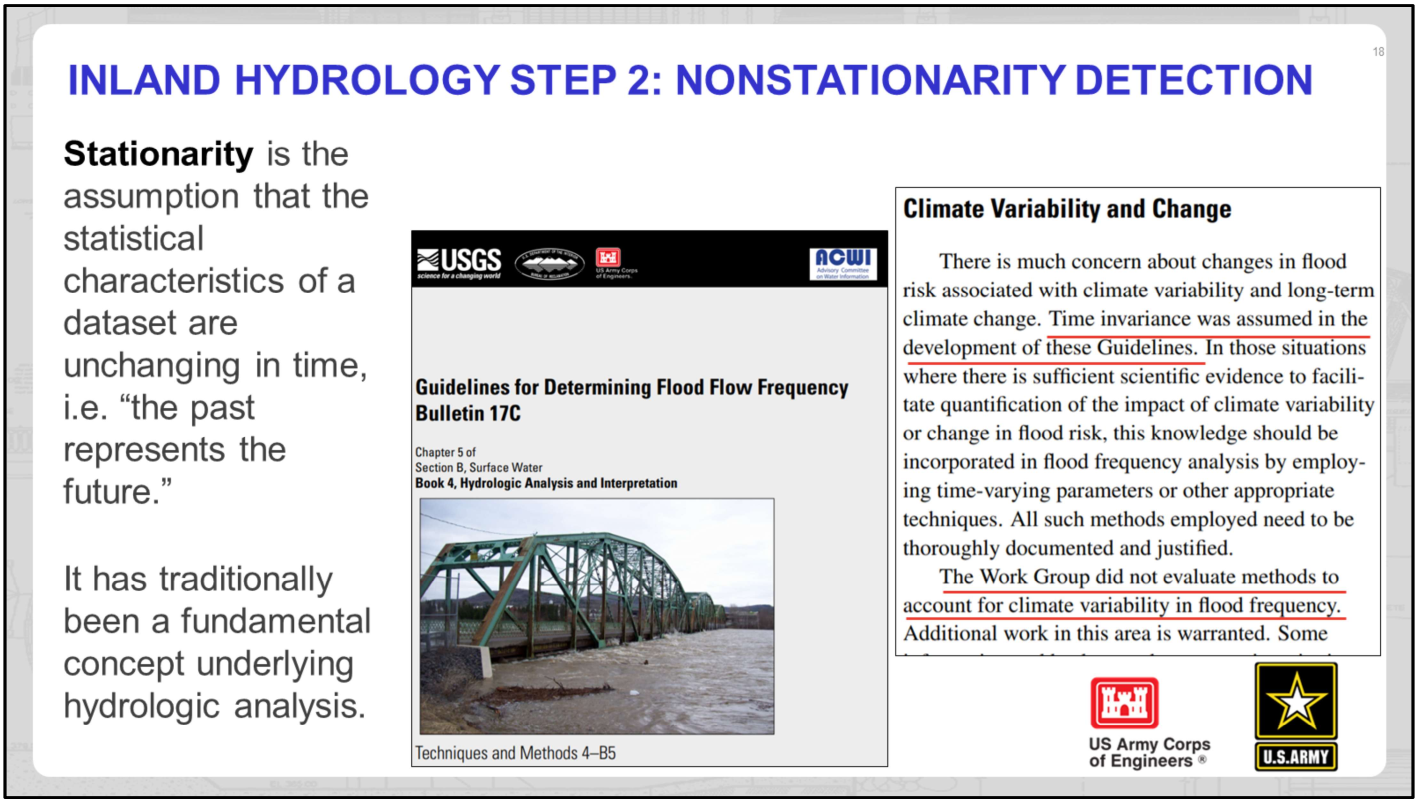
- Another great reference is National Climate Assessment (NCA) Volumes 1 and 2.



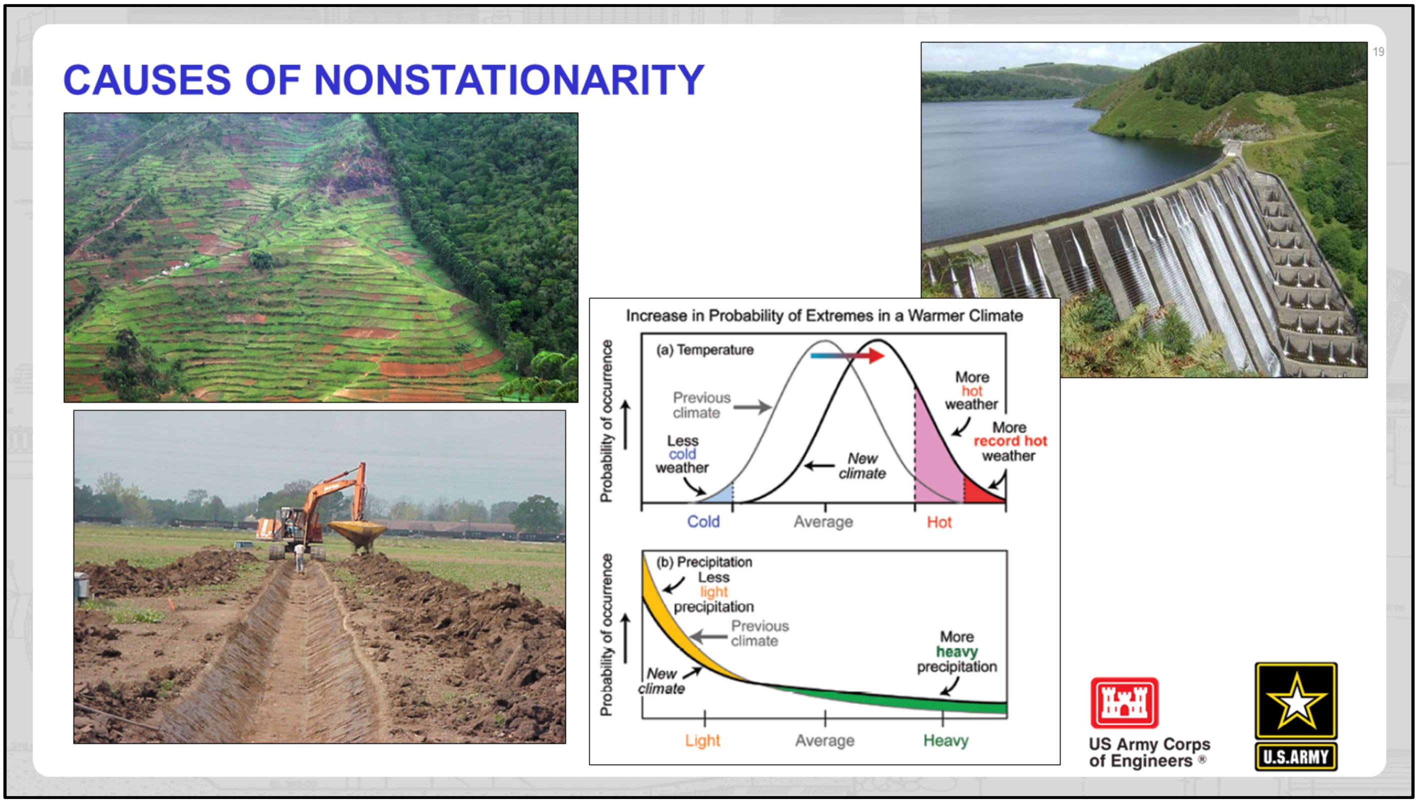
- The 21 regional climate syntheses (impact assessments) are organized by HUC-2 watersheds as shown in the map. These are very large watersheds (Missouri River Basin, Columbia River Basin, etc.) compared to an FRM project site but are a reasonable scale for summarizing published findings. Remember that we don't want to be overly precise where we can't also be accurate.
- Each summary describes observed and projected changes, showing the magnitude and direction in a summary table along with the degree of scientific consensus for each change. In this example there is strong consensus for increasing temperature both past and future but less consensus on changes in precipitation

INLAND HYDROLOGY STEP 2: NONSTATIONARITY DETECTION

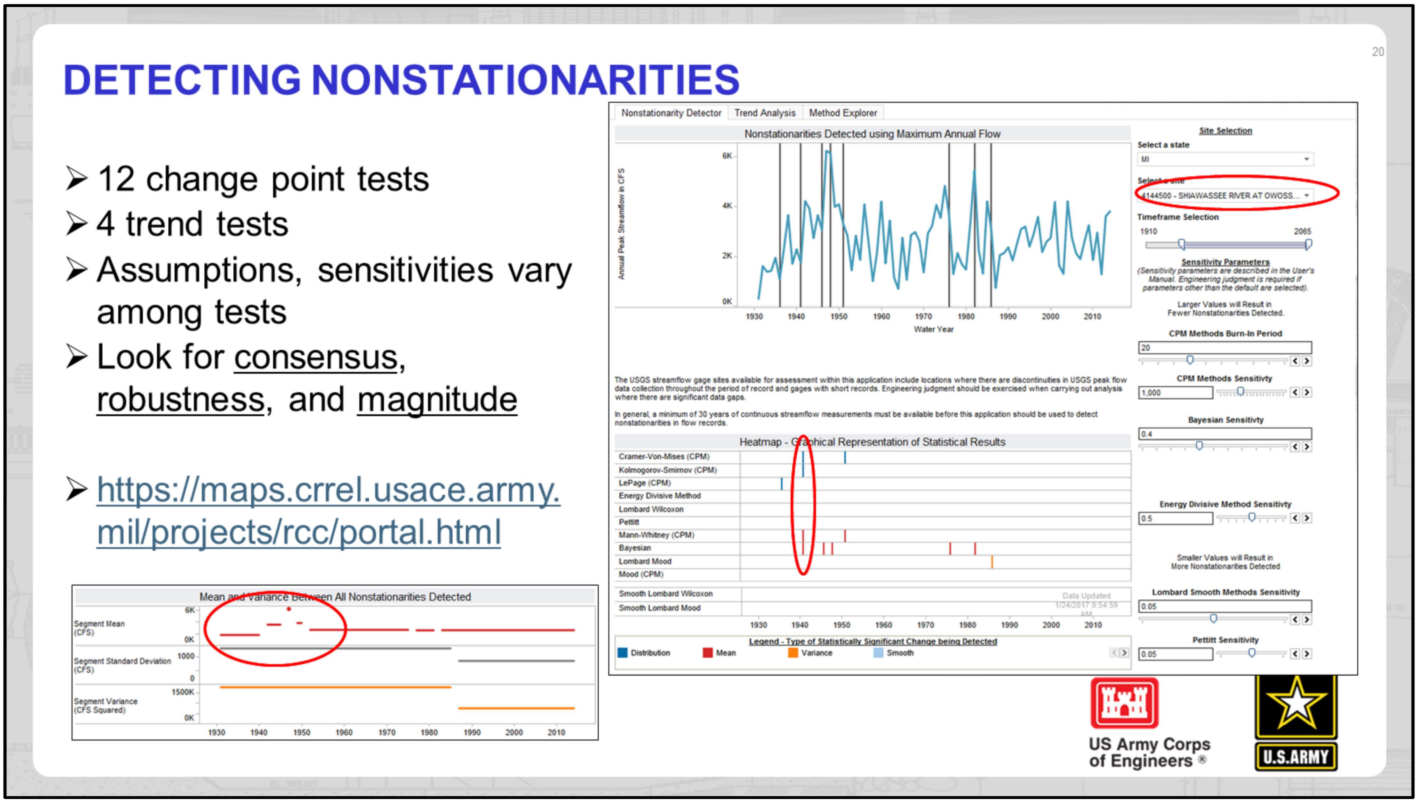
- The second step of the qualitative assessment is an investigation of past data for nonstationarities.
- Nonstationarity simply means that something has changed in the hydrological patterns at the project site.
- In the example on screen, the former fishing fleet of the Aral Sea now provides shade for desert camels. If we were building an FRM project at this site, we would want to account for this change rather than simply using the entire record of observed data as though the Sea were unchanged



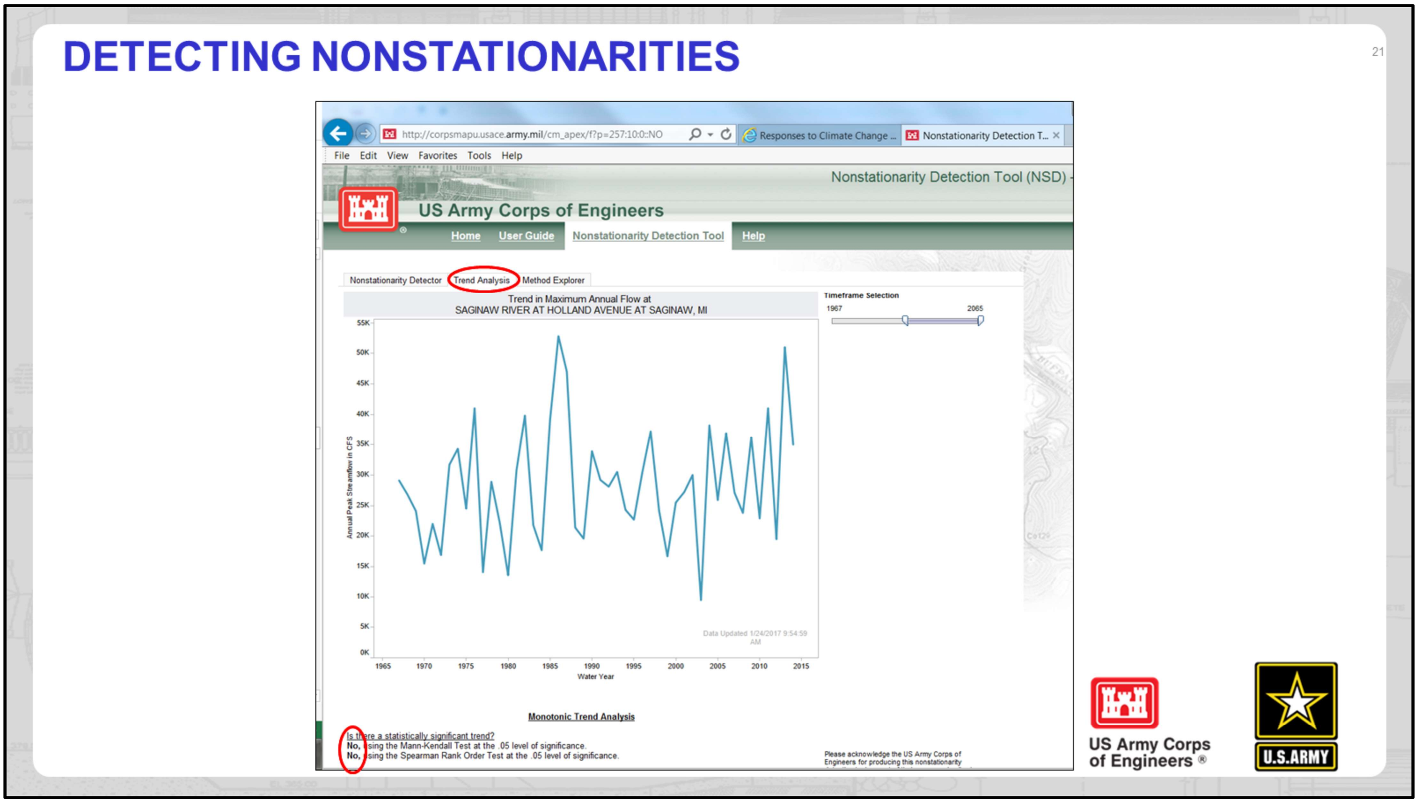
- The stationarity assumption traditionally underlies hydrological analyses by allowing us to assume that observed data from the past represents the future (and the present).
- Standard guidelines for flood flow frequency, such as Bulletin 17C of the Subcommittee on Hydrology, assume stationarity in statistical characteristics (mean, variance, skewnes) of observed flood data



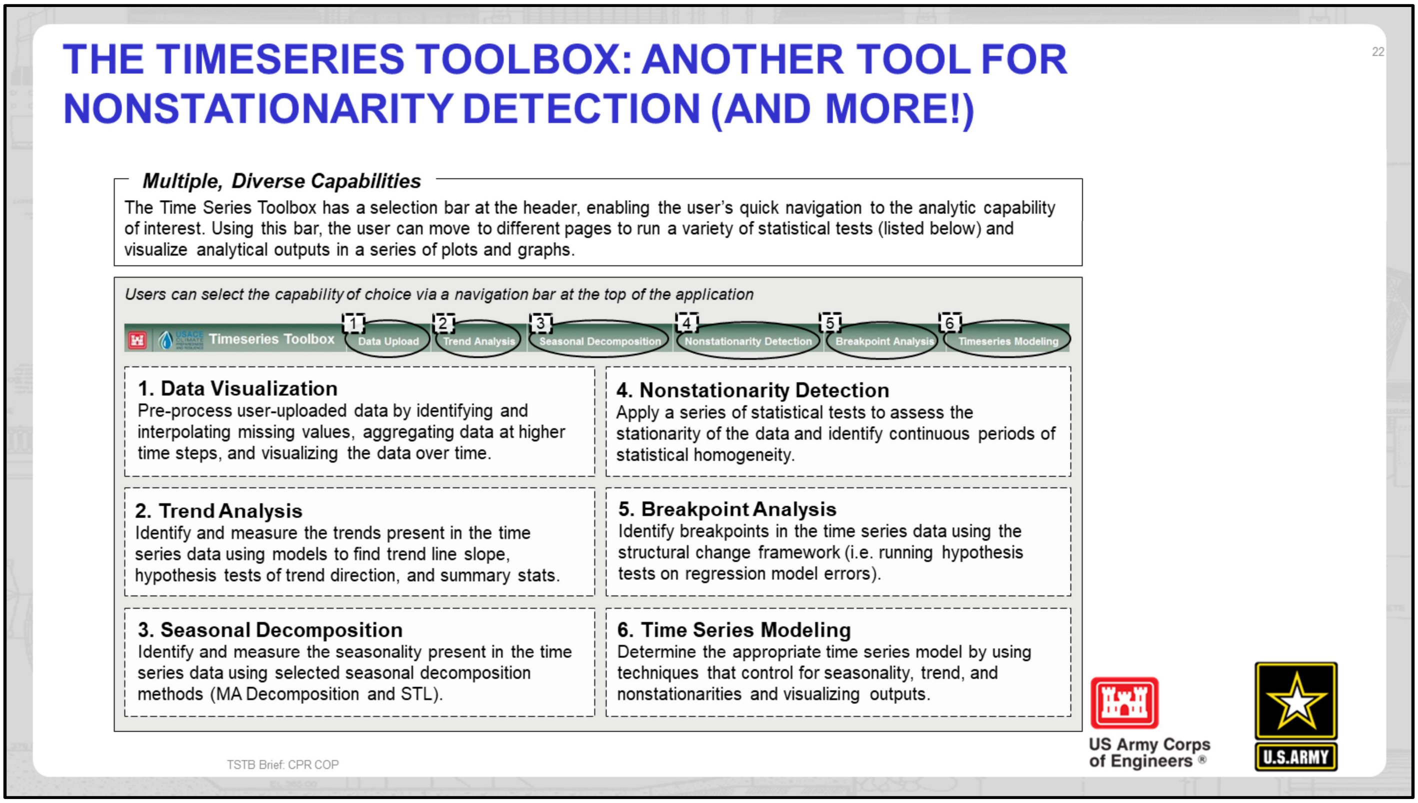
- There are several potential causes of nonstationarities. These include:
  - Land use change, such as conversion of forest to farmland, alters the fraction of precipitation that is partitioned into runoff versus interception or infiltration [upper left]
  - Drainage projects, such as surface ditches and subsurface drains, can change how quickly rivers respond to precipitation input [lower left]
  - Water resource infrastructure like dams, levees, and bypasses create nonstationarities <u>on purpose</u>. A dam that doesn't change flow/stage frequencies isn't working [upper right]
  - Finally, climate change can cause nonstationarity in hydrology by changing precipitation and evapotranspiration patterns



- Many statistical tests for nonstationarities exist, but most USACE engineers and planners aren't statisticians and don't want to be. So CPR CoP created a nonstationarity detection web tool to make these tests easier and quicker to perform.
- The NSD tool only checks annual peak streamflow datasets at USGS streamgages
- The tool offers 12 tests for sudden changes and four tests for smooth trends over time
  - Why so many tests? Because they each have their own assumptions, strengths, and weaknesses. Some can find only one change in the record, others can find many; some require that we assume the data has some underlying distribution, others are nonparametric; some tests find the last year before a change and others find the first one after it
- Because there are so many tests, we are likely to find at least a change or two in almost any record we assess. To decide if a detected change is serious enough to bother with, we look for:
  - Consensus, meaning multiple tests found the same change at (about) the same time
  - Robustness, or multiple kinds of changes (e.g. change in the mean and also variance, or mean and distribution) which indicates something fundamental has happened to cause this multifaceted change. The right panel shows four tests detected two kinds of changes (distribution and mean, indicated by blue and red vertical bars) in the early 1940s at this gage, which seems worth investigating. The other flagged changes were only found by one test each so they are less concerning.
  - Magnitude: some changes can be statistically significantly different from zero, but do they really matter to the project? This is where local expertise and expert judgment are key. The lower left panel shows a change in average annual peak flow from about 2000 cfs to about 4000 cfs. Does this magnitude of change matter? That is a decision for the project team.
- The right side of the right panel shows all the options and adjustments available to the user, which we don't have time to describe here. But they are explained in the user guide.



- In addition to change point tests, the NSD tool also detects smooth trends in annual peak streamflow
- This functionality is accessed from the second tab in the tool, “Trend Analysis”
- In this example, no trend was found using either the Mann-Kendall or the Spearman Rank Order tests (at the $p < 0.05$ significance level)



- The NSD tool only shows analysis of annual peak streamflow at USGS gages. What if the project site has a non-USGS gage or the team would like to assess other datasets such as low flows, volumes, stages, or rainfall?
- We created the Timeseries Toolbox for this purpose. It has all of the functionality of the NSD tool plus more capabilities such as time series modeling and seasonal decomposition, and you can upload any dataset you want!
- The downside is that the tool may take a few minutes to run because it is doing the tests realtime rather than serving up pre-run results. You can speed things up by aggregating data if appropriate (extracting annual peaks rather than uploading daily data, for example)

WHAT TO DO IF YOU FIND A NONSTATIONARITY?

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- If the change can be attributed to infrastructure changes, land-use changes, land cover changes:
  - Follow existing guidance e.g. EM 1110-2-1417, Ch. 18
- If change cannot be attributed:
  - Engage CPR SMEs for assistance
  - Consider truncating record **with caution**: reducing record length increases uncertainty bands for economic analysis
  - Consider an envelope approach to pre- and post-change frequency curves

What's the risk?

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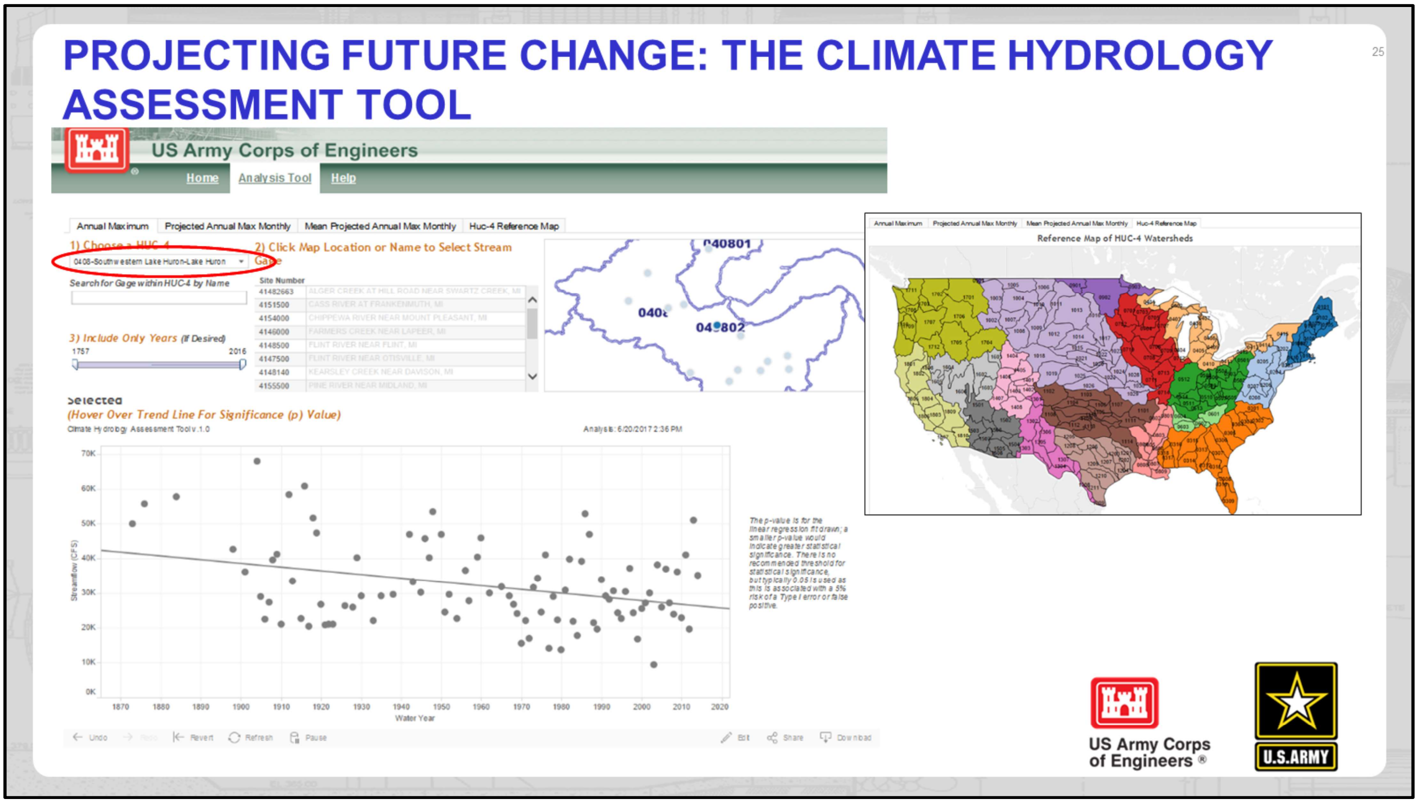
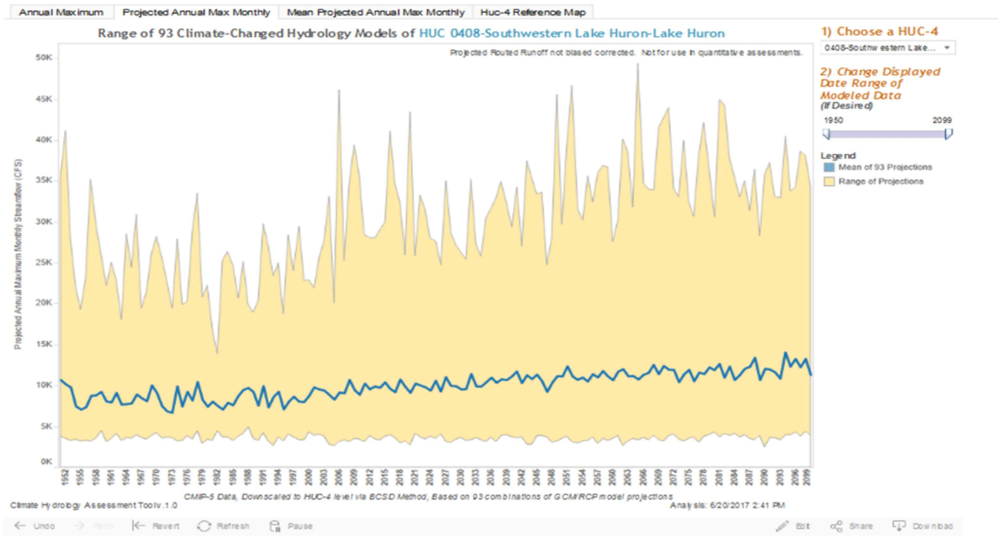
- If a nonstationarity is detected, then what?
- The first question is whether the change can be attributed. If the change is due to the installation of a dam or the urbanization of a watershed, for example, then existing guidance has been available for a long time, and should be followed. It's unlikely that USACE FRM planning teams are not aware of an upstream dam but sometimes the NSD tool can detect a revision to water control manual or other alteration that might have been forgotten over the years
- If the detected change cannot be attributed, then several options exist to assist further investigations. It might seem sensible to throw out the earlier data that no longer applies to the present conditions, **BUT** recognize that this reduction in sample size will increase uncertainty and widen the confidence bands in FDA, with consequences for economic outputs.
- An envelope approach might also make sense, in which two frequency curves are generated and the higher of the two is used for any given exceedance probability. But again this may create unintended consequences such as sharp discontinuities in net benefits
- CPR CoP SMEs are available to assist if you aren't sure how to proceed

- After checking past data for observed changes, the third part of the analysis involves assessment of projected future changes
- USACE and partner agencies have collaborated to produce projected mean monthly streamflow datasets through the year 2099
    - Annual maxima of these mean monthly flows were then extracted for analysis
    - These projections are at the scale of the HUC-4 watershed
    - Temperature and precipitation from General Circulation Models (GCMs) are used to force the VIC hydrology model to generate flows, **BUT** the model is not locally calibrated and does not include the effects of regulation by dams, etc. As a result the projected flows are not correct; instead they give a sense of how future flows may be expected to change in magnitude and direction in a relative sense



- The front page of the CHAT tool allows the user to select a gage from the pulldown menu or by searching by name. It also shows the HUC-4 watershed map and a simple linear regression of observed past annual peak streamflows for context

PROJECTING FUTURE CHANGE: THE CLIMATE HYDROLOGY ASSESSMENT TOOL



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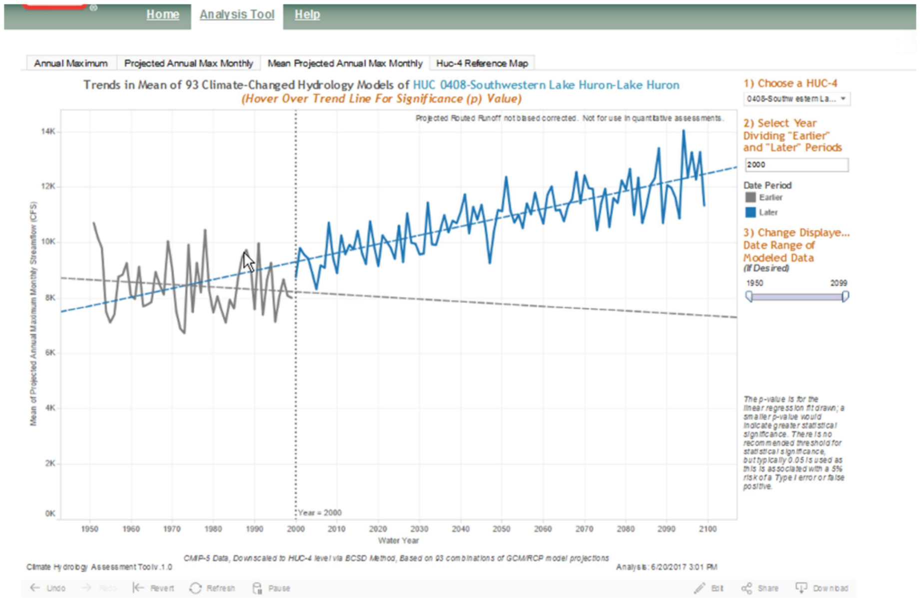
- The second tab shows the projected flows. There are 93 different traces of projected future flows because there are 93 combinations of GCMs and future emissions scenarios (also knows as Representative Concentration Pathways or RCPs). This produces a spaghetti-like jumble of traces, so to make things simpler we just show the upper and lower bounds of the spaghetti and the mean (in blue).
- Clearly there is a lot of uncertainty in future flows, this is part of the point! We see an increase in flow on average, but a large range of conditions that could potentially impact project function.

PROJECTING FUTURE CHANGE: THE CLIMATE HYDROLOGY ASSESSMENT TOOL

27



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- The third tab shows the projection mean from the previous plot, with a divider between "earlier" and later data set by default at the year 2000. This allows the user to see how the projected changes might be expected to trend for various time periods in the past and future.
- Note that projections in the past do not match observations due to the lack of local calibration, lack of regulation, and idiosyncrasies of individual events in the past.
- The user can hover over the line for p-values and regression formulas

INLAND HYDROLOGY STEP 4: PROJECTING FUTURE ISSUES: THE VULNERABILITY ASSESSMENT TOOL

Input Variable	Description/Value
Indicator	27
HUC-4 watershed	202 across US
Epoch	2035-2065 (“2050”) or 2070-2100 (“2085”)
Scenario	Wet or Dry
USACE Business Line	8 of them
ORness	0.5 to 1.0
Integrated Analysis Type	“Each” or “All”
Vulnerability Threshold	0 to 1 (percentile)

Output Variable
VULNERABILITY (0 to 100)

Vulnerability a.k.a.
W.O.W.A. score
(what is vulnerability?)

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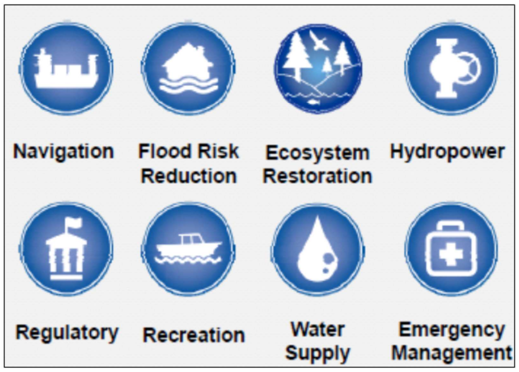
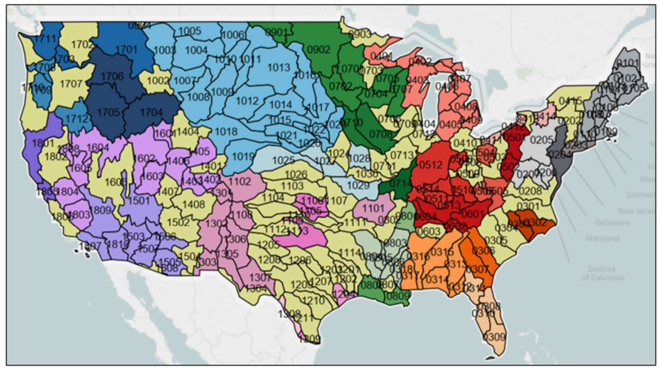
- After reviewing literature, assessing observed changes, and investigating future projections, the final step is to assess potential project vulnerabilities. This is made simpler by the Vulnerability Assessment tool.
- This is the most complex tool and in past CPR trainings has merited an entire day of training, so we’ll only be able to give a quick overview here
- The VA tool works by combining 27 indicators depending on the chosen watershed and business line. Like the CHAT, it works at the scale of the HUC-4 watershed (it uses the same projections as the CHAT)
- Vulnerability is assessed for two time epochs (“2050” and “2085”) and two groupings of scenarios (“wet” and “dry”)
- The indicators are combined into an overall score using a weighted order, weighted average (WOWA). The algorithm details don’t really matter, the bottom line is higher scores indicate higher vulnerability

PROJECTING FUTURE ISSUES: THE VULERNABILITY ASSESSMENT TOOL

- Objective: Assess the vulnerability of USACE's missions, operations, and programs to climate change impacts
- Support USACE's climate change adaptation planning activities





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- Any of eight USACE business lines can be assessed, but in this case we're only interested in FRM

PROJECTING FUTURE CHANGE: THE CLIMATE HYDROLOGY ASSESSMENT TOOL

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Indicator	Category	Type	Unit
130: Population in 500-year floodplain	Supporting	Function of Time	people
156: Change in sediment load due to change in future precipitation	Ecological	Function of Time and Scenario	–
175C: Annual covariance of unregulated runoff (cumulative)	Hydrological	Function of Time and Scenario	–
175L: Annual covariance of unregulated runoff (local)	Hydrological	Function of Time and Scenario	–
192: Percent of land that is urban/ suburban	Supporting	Function of Time	% of HUC area
221C: Monthly covariance of runoff (cumulative)	Hydrological	Function of Time and Scenario	–
221L: Monthly covariance of runoff (local)	Hydrological	Function of Time and Scenario	–
277: Percent change in runoff divided by percent change in precipitation	Hydrological	Function of Time and Scenario	–
297: Macroinvertebrate index of biotic condition	Ecological	Constant	–

Indicator	Category	Type	Unit
571C: Low flow (monthly flow exceeded 90% of time; cumulative)	Hydrological	Function of Time and Scenario	c.f.s.
571L: Low flow (monthly flow exceeded 90% of time; local)	Hydrological	Function of Time and Scenario	c.f.s.
570C: Flood flow (monthly flow exceeded 10% of time; cumulative)	Hydrological	Function of Time and Scenario	c.f.s.
570L: Flood flow (monthly flow exceeded 10% of time; local)	Hydrological	Function of Time and Scenario	c.f.s.
590: Acres of urban area within 500-year floodplain	Supporting	Function of Time	acres
65C: Mean annual runoff (cumulative)	Hydrological	Function of Time and Scenario	c.f.s.
65L: Mean annual runoff (local)	Hydrological	Function of Time and Scenario	c.f.s.
700C: Low flow reduction factor (cumulative)	Hydrological	Function of Time and Scenario	–
700L: Low flow reduction factor (local)	Hydrological	Function of Time and Scenario	–

Indicator	Category	Type	Unit
8: Percent of freshwater plant communities at risk	Ecological	Constant	%
95: Drought Severity Index	Hydrological	Function of Time and Scenario	–
441: Area in 500-year floodplain	Supporting	Constant	square miles
443: Number of people below poverty line	Supporting	Function of Time	people
447: Percent of people disabled	Supporting	Constant	people
448: Disaster resilience due to experience	Supporting	Constant	declarations
450: Number of communities with flood insurance	Supporting	Constant	communities
568C: Flood magnification factor (cumulative)	Hydrological	Function of Time and Scenario	–
568L: Flood magnification factor (local)	Hydrological	Function of Time and Scenario	–

CATEGORY	TYPE
Hydrological	Constant
Ecological	Function of Time
Supporting	Function of Time and Scenario

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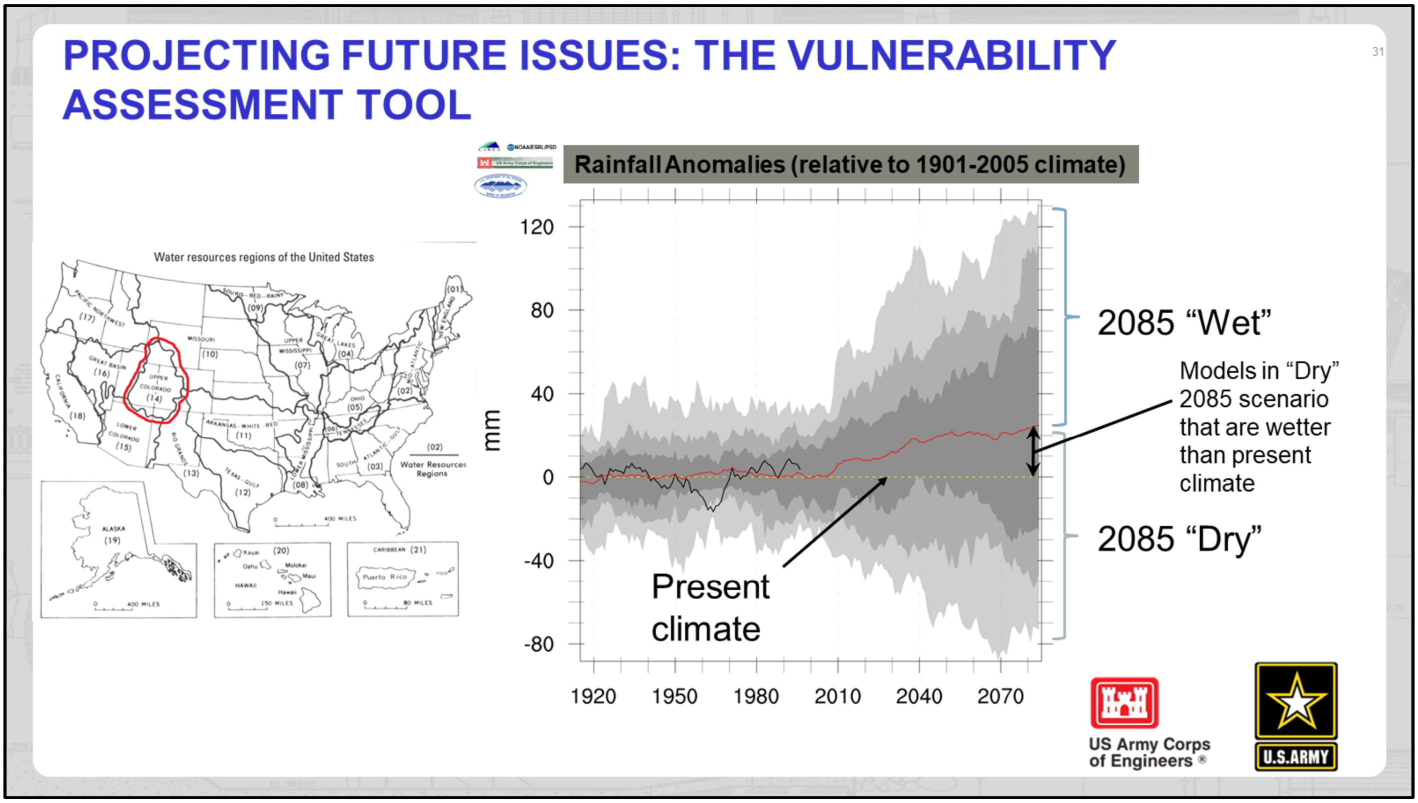
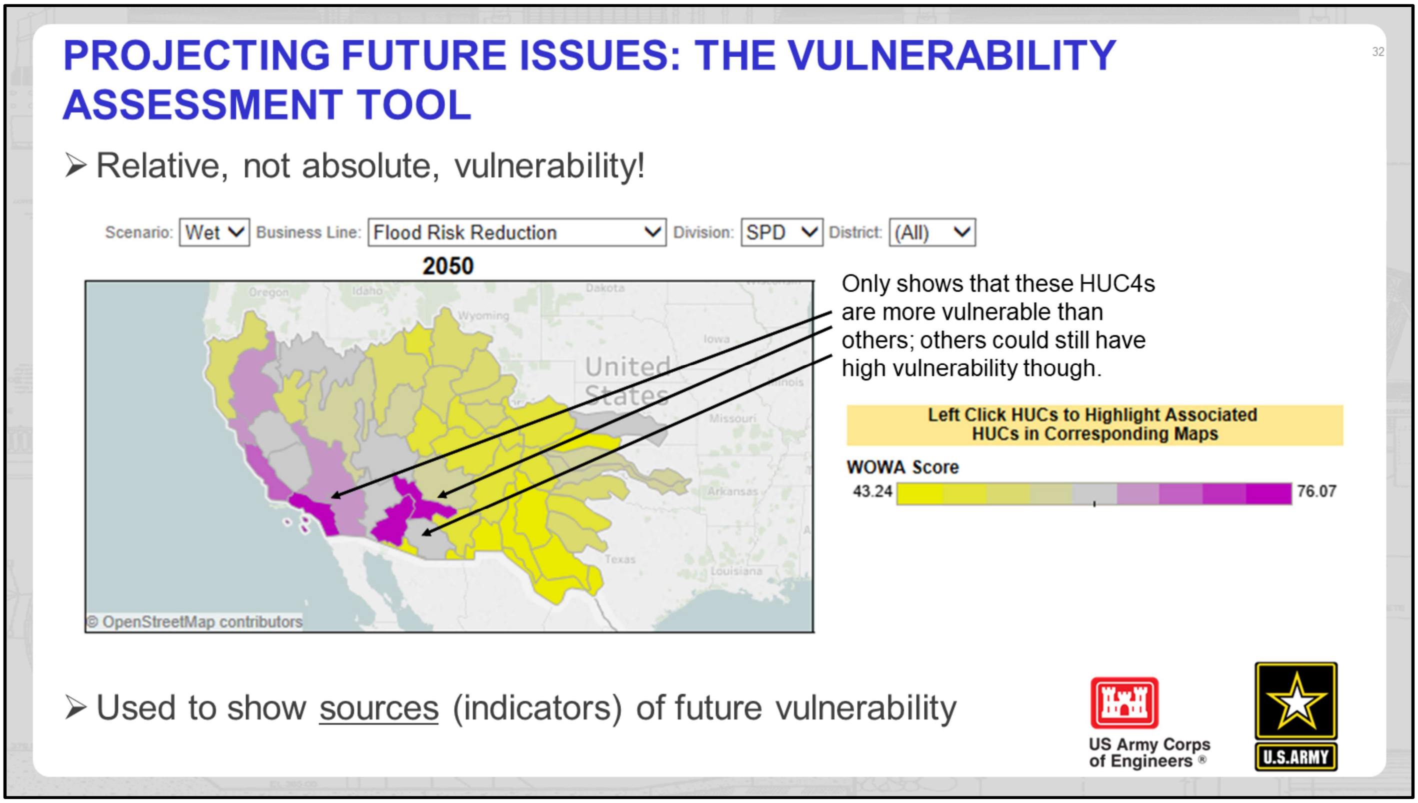
- The 27 indicators are shown above. These are combined differently depending on the business line and according to user preferences (most users will stick with default settings).
- Some indicators are changing over time, such as population in the floodplain, while others are static, like percentage of disabled people
- Some indicators change depending on climate projections, like mean annual runoff or 10% ACE flood flow
- FRM vulnerability is based on five indicators:
    - 175C cumulative annual covariance of runoff to precipitation
    - 277 projected change in runoff by unit precipitation
    - 568C cumulative flood magnification factor (elasticity)
    - 568L same as above but local watershed only, ignoring upstream effects
    - 590 urban area in 500 year floodplain



- When assessing vulnerability, the user will select whether to assess the "wet" or "dry" set of traces. Note that this division is relative to each other, not present climate
- Some future "dry" traces can be wetter than the present climate (and vice versa)



- The definition of vulnerability in an objective sense gets philosophical, so we sidestep that by assessing relative vulnerability instead.
- A finding that the selected project is relatively vulnerable, compared to the rest of the USACE portfolio, would be cause for future investigation
- Just because the relative vulnerability of a given HUC is high (or low) compared to the other watersheds doesn't mean that there is (or is not) cause for concern. But in general we look to see whether a proposed project would be among the 20% most vulnerable if built
- The tool allows the user to **investigate which indicators are contributing to the observed vulnerability**. This is more important than the WOWA score or the relative vulnerability because it points to potential adaptation options.

EXECUTIVE SUMMARY OF CLIMATE CHANGE TOOLS AND BEST PRACTICES FOR INLAND FRM

- Inland climate change effects are more uncertain than coastal
- **POLICY**: Requirement is for a qualitative assessment of potential vulnerabilities
  - This may change as science matures
  - Quantitative adjustments require approval from CPR CoP
- **STEP 1**: Start with literature review
- **STEP 2**: Assess observed record using *Nonstationary Detector*
  - If found and attributable, follow existing guidance
  - If not attributable, make risk-informed choices to censor or re-regulate record, ask for assistance if needed
- **STEP 3**: Use *Climate Hydrology Assessment Tool (CHAT) tool* to project future flows, assess project risks
- **STEP 4**: *Vulnerability tool* indicates if project site, business line combination is relatively more vulnerable, and **why**
- **The "So What":** Informs formulation, documents risks in project report, clear communication with public, partners, stakeholders

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QUESTIONS / FEEDBACK?

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Please contact us with:

- Questions?
- Comments?
- More/less helpful than a live webinar?
- Recommendations for improvement?

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