

A GEOTECHNICAL ENGINEER'S GUIDE TO CLIMATE CHANGE

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March 18, 2025

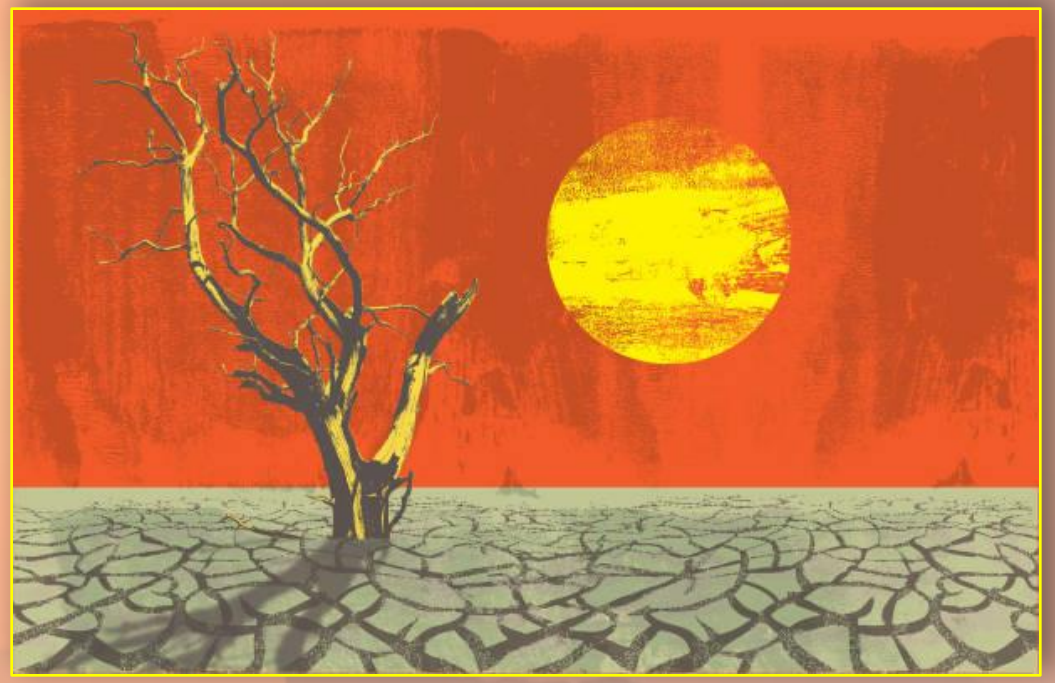
Climate change and weather extremes bring chaos

Threatens food and water supplies

Destroys ecosystems

Damages infrastructure

Imperils public health, safety, and welfare



Where the sun beats, and the dead tree gives no shelter.

The Waste Land, T.S. Eliot (1922)



It is time for civil engineers to turn climate talk into climate action.

Rachel Skinner, Past President
Institution of Civil Engineers



The climate crisis is an emergency – treat it like one

Bring climate change into every conversation

Consider climate change in every project

Design and build for the right outcomes

Stress test all projects against a wide range of climate extremes

Embrace radical change

Refuse business as usual

2021



https://www.ice.org.uk/media/3wypvqnx/ice-state-of-the-nation-2021.pdf


“Hello, is anyone listening?”


Is the past prolog?

The 1980s ushered in a game changer for the geotechnical engineering profession





LOVE CANAL, U.S.A.

By Michael H. Brown

Not until the nightmare in Niagara Falls unfolded did Americans realize the horrors of

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

SUPERFUND CLEANUP SITES

Hazardous and toxic wastes

Increased public awareness applied pressure for government action

Governmental action and funding jump-started growth in a new market (e.g., Superfund)

Forward-thinking geotechnical firms seized new market opportunities

The profession responded by honing existing technologies and developing new ones to meet market needs



Hazardous and toxic wastes

Universities implemented research to improve how we analyzed and treated hazardous and toxic wastes

Geoenvironmental engineering rapidly became recognized as a subdiscipline

ASCE changed the name of one of its flagship publications





Hazardous and toxic wastes

New threats exposed consulting firms to claims of negligence and professional liability

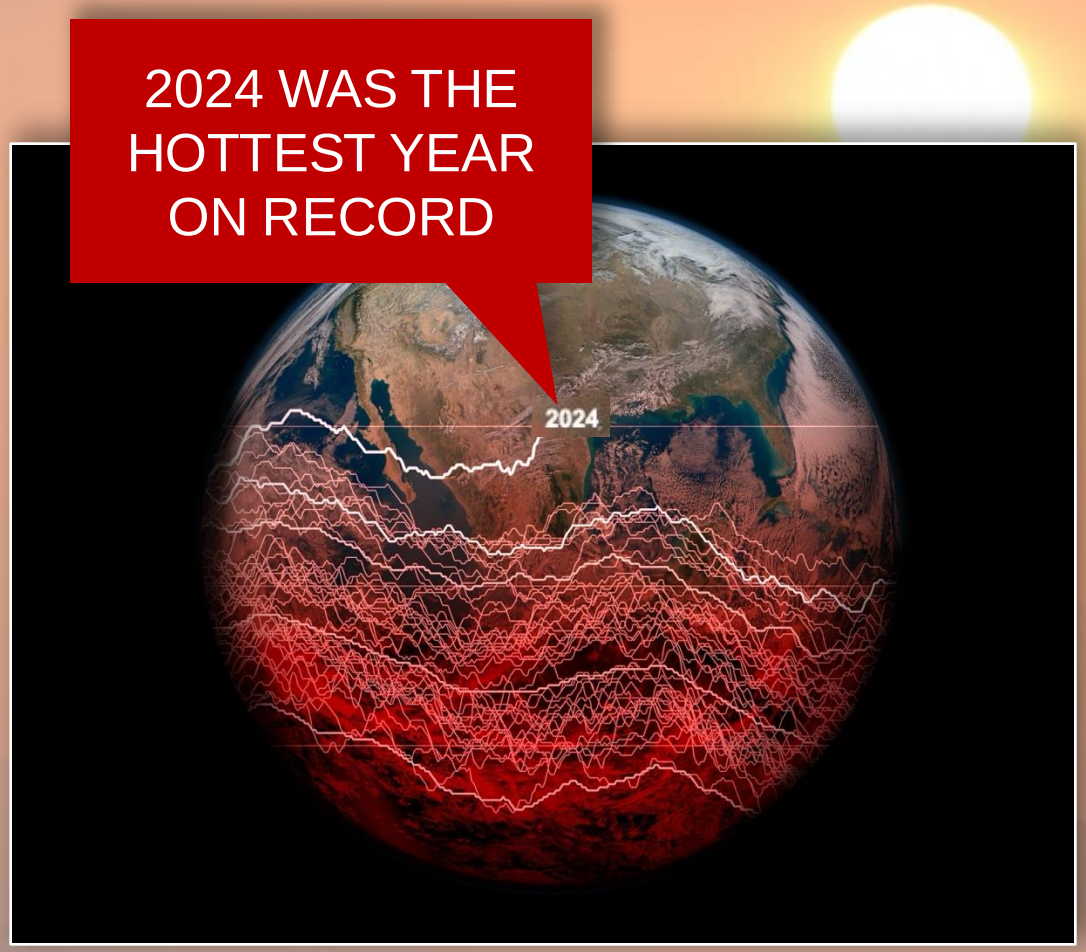
Concern for professional liability led to development of loss prevention aids and education

HWAC

GBA GEOPROFESSIONAL BUSINESS ASSOCIATION



The climate crisis a similar game-changer



Public awareness and need for government action are growing

Will government action stimulate a new market?

Is there a market opportunity for geotechnical engineers?

What existing and new technologies are required to compete?

If we do nothing, will we face claims of negligence and professional liability?

What loss prevention aids and education are needed to protect geotechnical engineers?

Hazardous wastes vs. climate change

Recognition of climate change as a new market is developing more slowly – but *it's happening!*

Not all geotechnical engineers embraced geoenvironmental engineering – we have *no choice*, we all must be involved



The climate crisis is the *biggest challenge* and the *greatest opportunity* that geotechnical engineers have ever faced

We design and build infrastructure that shapes people's lives

We are responsible for ensuring the health, safety, and welfare of people who rely on infrastructure

Changing climate stressors threaten safe and reliable infrastructure performance

We must use our problem-solving skills and influence to lead transformational change

We must use this opportunity to create new markets for our services

If we don't, we face serious exposure from claims of negligence and professional liability



The climate crisis is a game-changer

Geoprofessionals are well positioned to respond to the climate crisis

We are first onsite making recommendations for

- Site development
- Construction
- Foundation design

We are comfortable dealing with materials and conditions that

- Are often difficult to predict
- Change with time
- Require engineering judgment

We are familiar with managing uncertainty and analyzing risk

We are expert at identifying geo-hazards and applying risk and life-cycle cost analyses to reduce risk

We pioneered the observational method (now called adaptive management)




SPILLWAY FAILURE


LEVEE SAFETY


PAVEMENT DISTRESS


SOIL DESICCATION


EROSION


IMPAIRED WATER SUPPLY


PERMAFROST THAW


SEA LEVEL RISE
2050
sea level
2030
sea level


LANDSLIDES


NUISANCE FLOODING


DAM SAFETY


INLAND AND COASTAL FLOODING





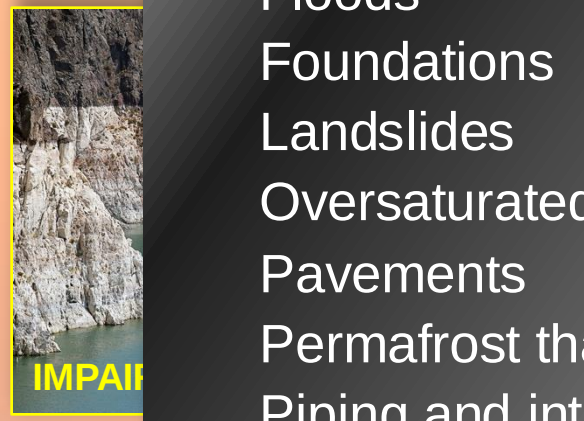


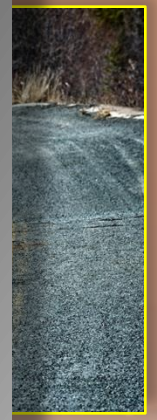


GEOTECHNICAL ISSUES

- Aquifer depletion
- Dams and levees
- Erosion
- Expansive soils
- Floods
- Foundations
- Landslides
- Oversaturated fill and backfill
- Pavements
- Permafrost thaw
- Piping and internal erosion
- Seawalls
- Sea level rise
- Soil desiccation
- Water supply

















Ready or not, we are in a climate crisis

Practitioners

- Are you warning clients about the adverse effects of a changing climate?
- If not, are you concerned about your professional liability?

Clients

- Are you asking your advisors about climate change effects on project performance?

Educators

- Are you teaching your students how to deal with climate change?

Researchers

- Are you seeking ways to improve infrastructure resilience?



Today's objectives

Is the past prolog?

What's happening?

Why should we care?

What's the challenge?

What can we do?

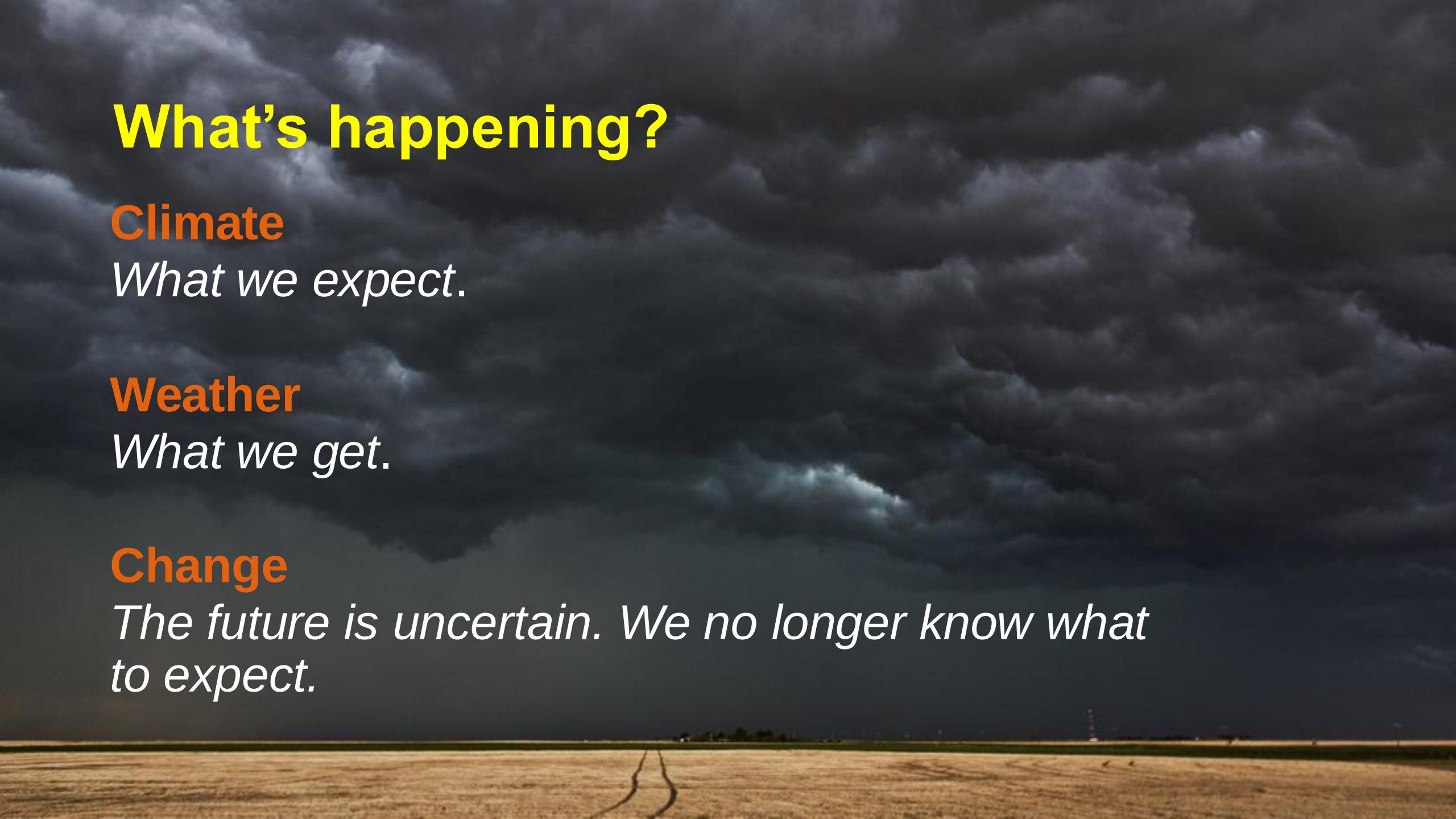
What should we do?

What could go wrong?

Summary




What’s happening?



What's happening?

Climate

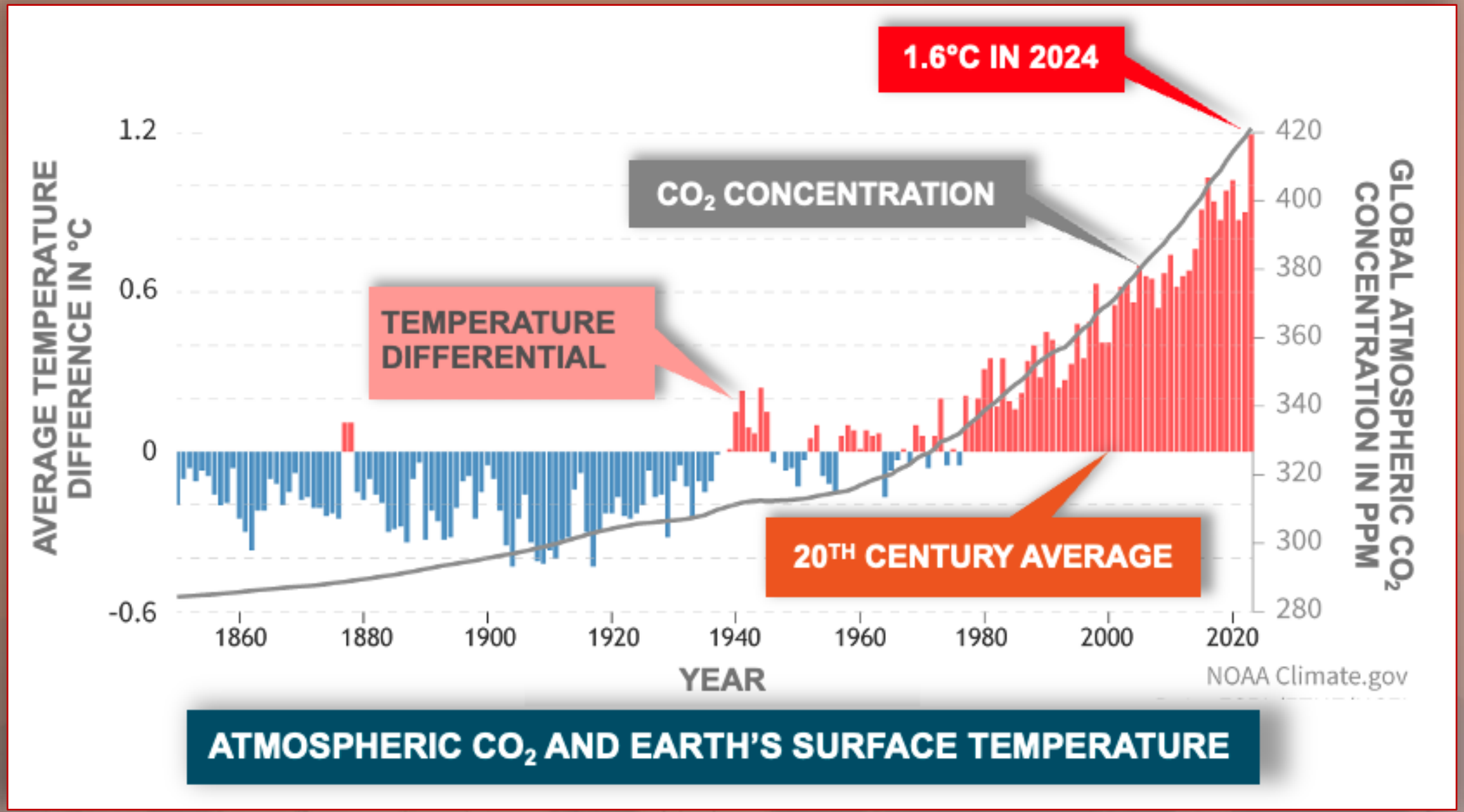
What we expect.

Weather

What we get.

Change

The future is uncertain. We no longer know what to expect.


1.6°C IN 2024
CO2 CONCENTRATION
TEMPERATURE DIFFERENTIAL
20TH CENTURY AVERAGE
AVERAGE TEMPERATURE DIFFERENCE IN °C
1.2
0.6
0
-0.6
GLOBAL ATMOSPHERIC CO2 CONCENTRATION IN PPM
420
400
380
360
340
320
300
280
1860
1880
1900
1920
1940
1960
1980
2000
2020
YEAR
NOAA Climate.gov
ATMOSPHERIC CO2 AND EARTH'S SURFACE TEMPERATURE

2024 in review, it keeps getting warmer

The average global temperature *exceeded 1.6°C (2.9°F)*

2024 was 0.12°C (0.22°F) warmer than 2023

July 22, 2024, was the *hottest day* on record

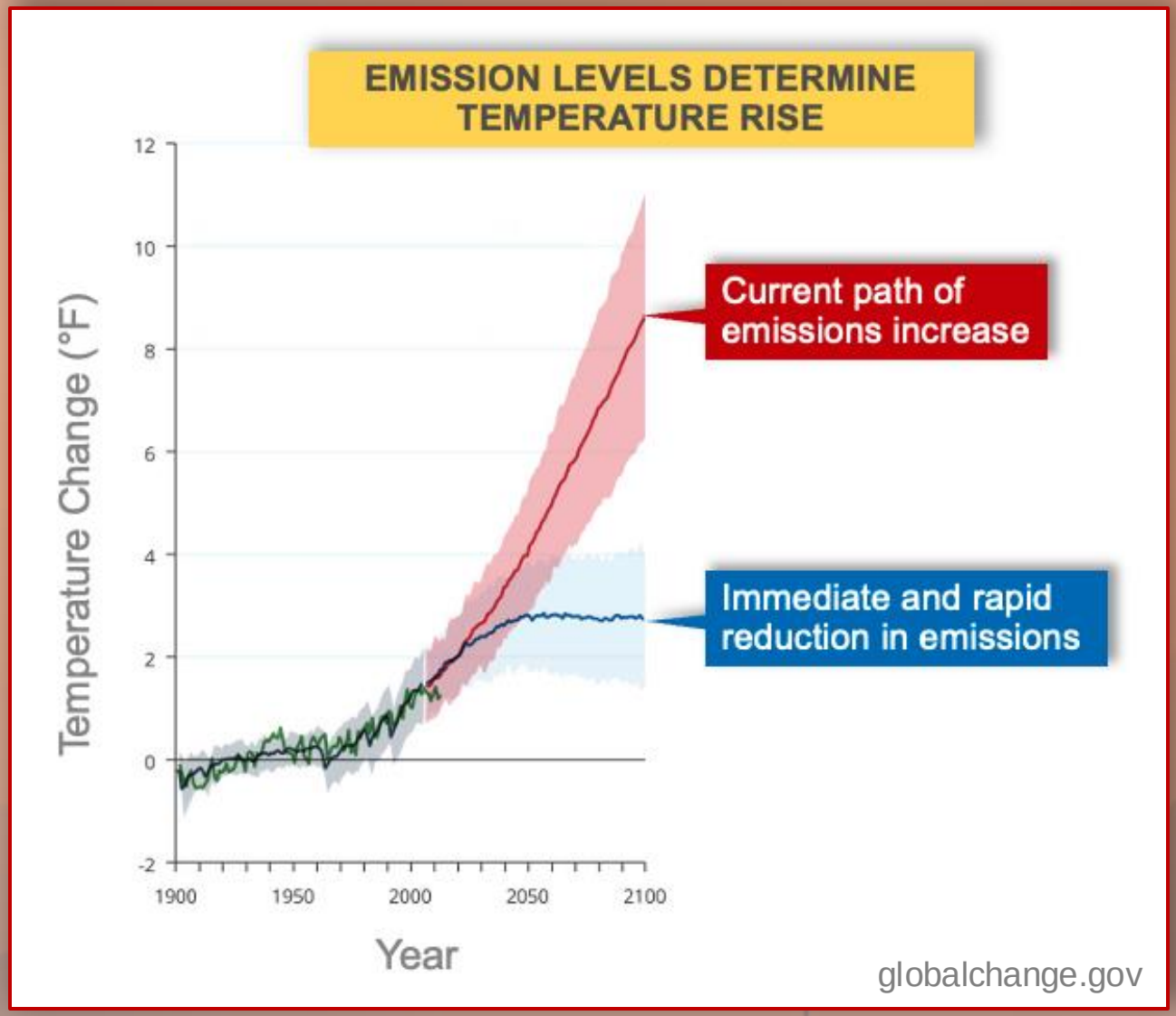
2015-2024 was the *hottest decade* on record

Point of No Return

"... the time-frame of climate breakdown is hard to pin down... any overshoot of the 1.5°C *dangerous climate change guardrail* is extremely risky."

Bill McGuire, Professor Emeritus
University College London





WILD CARDS

Will we be motivated to act?

How successful will we be in reducing emissions?

Can we curtail our dependence on fossil fuels?


Why should we care?

We should care because…

We hold paramount the health, safety, and welfare of the public

We want infrastructure to:

- Be safe
- Perform as intended
- Be resilient to unusual loads
- Be sustainable



Changing climate stressors affect infrastructure performance

Heatwaves cause service interruptions, physical damage, and premature deterioration

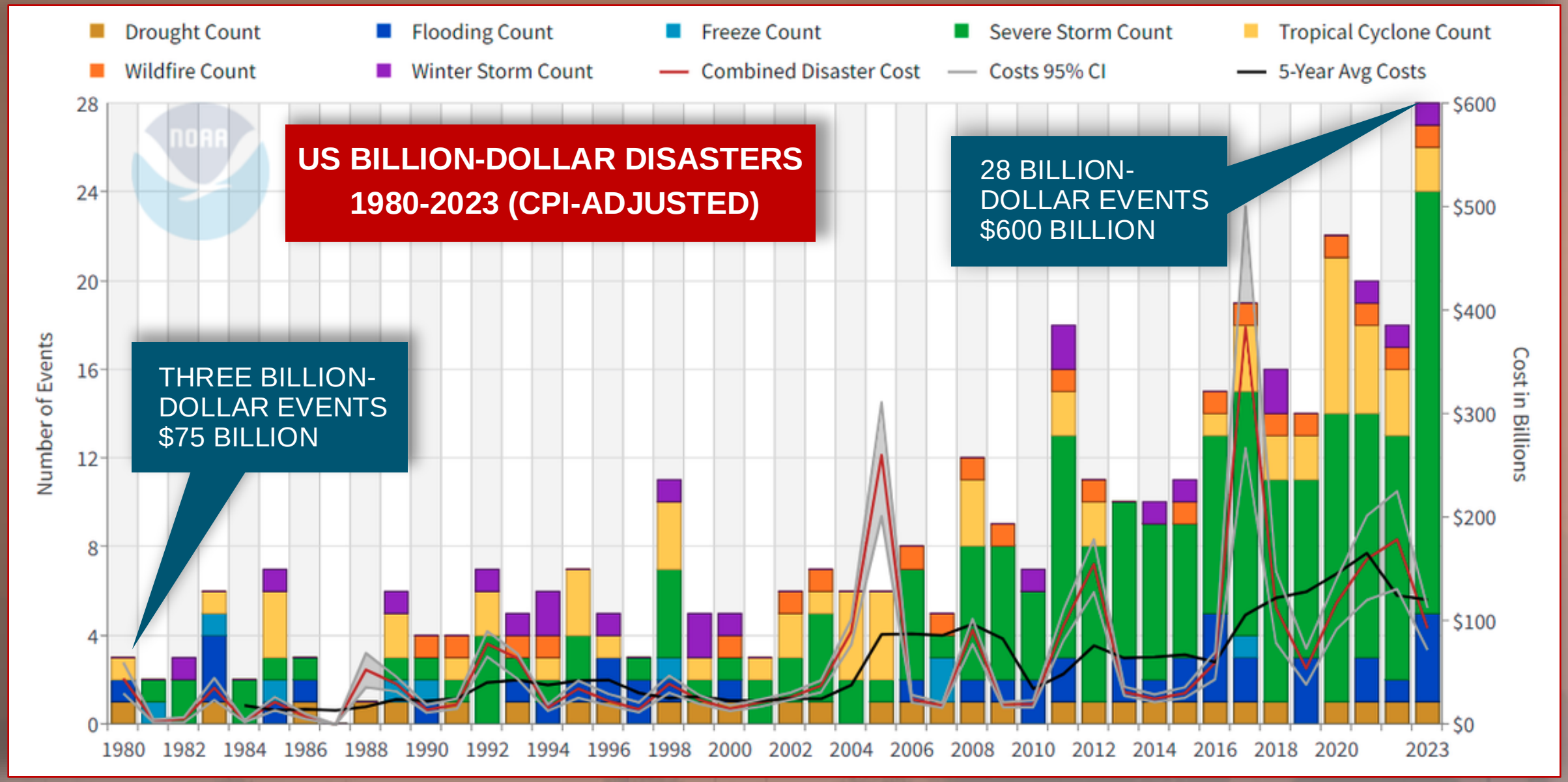
The **frequency of severe wind** is increasing and the geography susceptible to wind hazards is widening

Changing precipitation patterns cause drought in some areas and increase flooding elsewhere

Coastal flooding is made worse by **sea level rise**





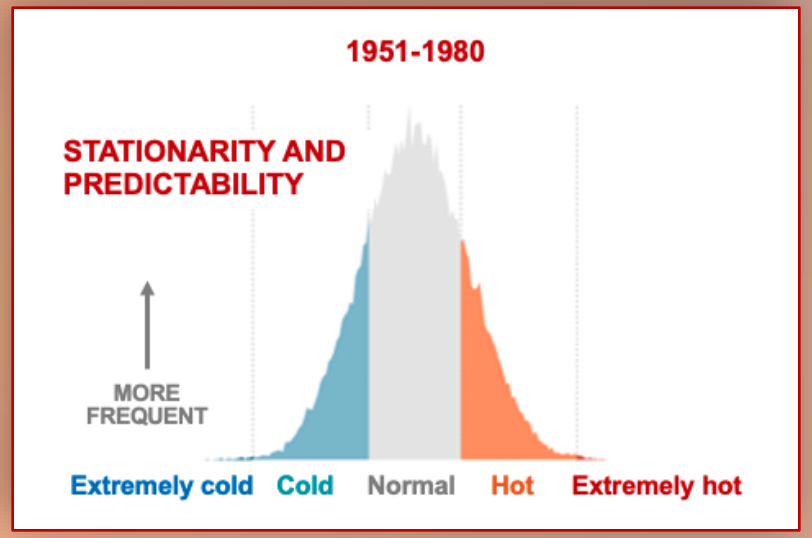

Drought Count
Flooding Count
Freeze Count
Severe Storm Count
Tropical Cyclone Count
Wildfire Count
Winter Storm Count
Combined Disaster Cost
Costs 95% CI
5-Year Avg Costs
US BILLION-DOLLAR DISASTERS
1980-2023 (CPI-ADJUSTED)
28 BILLION-DOLLAR EVENTS
$600 BILLION
THREE BILLION-DOLLAR EVENTS
$75 BILLION
Number of Events
Cost in Billions
0
4
8
12
16
20
24
28
$0
$100
$200
$300
$400
$500
$600
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2023


What’s the challenge?

We have moved from stationarity to non-stationarity

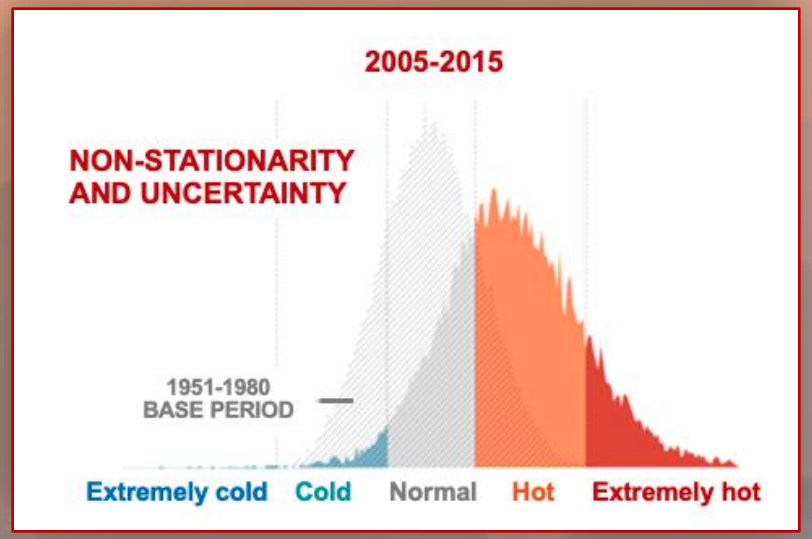
Stationarity (conditions we expect)

- Though weather changes daily, the climate in a region will remain constant
- Enabled design of safe, reliable, and long-lived infrastructure using historical climate conditions to predict the future

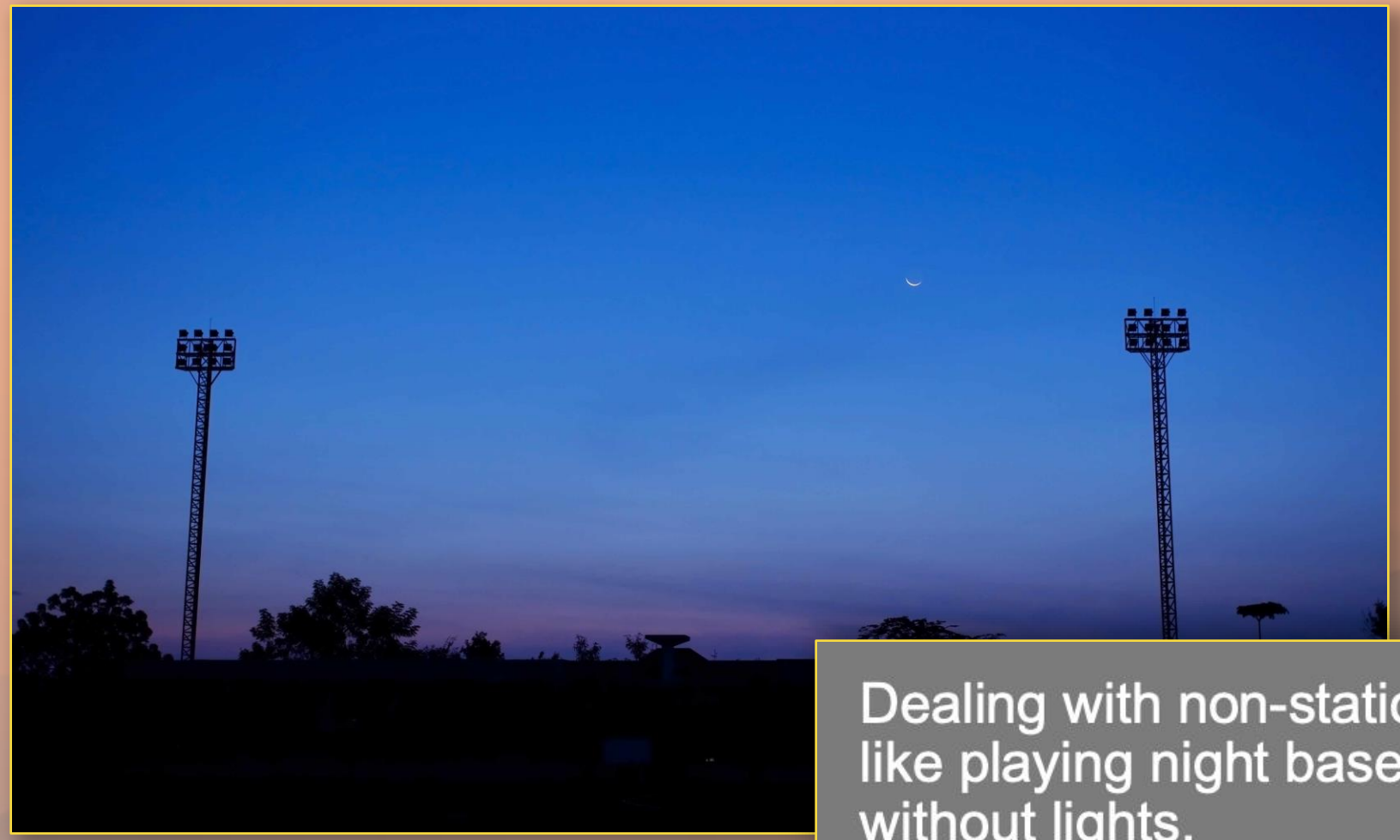


Non-stationarity

- Climatic conditions are no longer constant
- Effects of non-stationarity are uncertain
- Using historical climate conditions is no longer reliable
- Future conditions are more difficult to predict



The past is no longer prolog



Dealing with non-stationarity is like playing night baseball without lights.

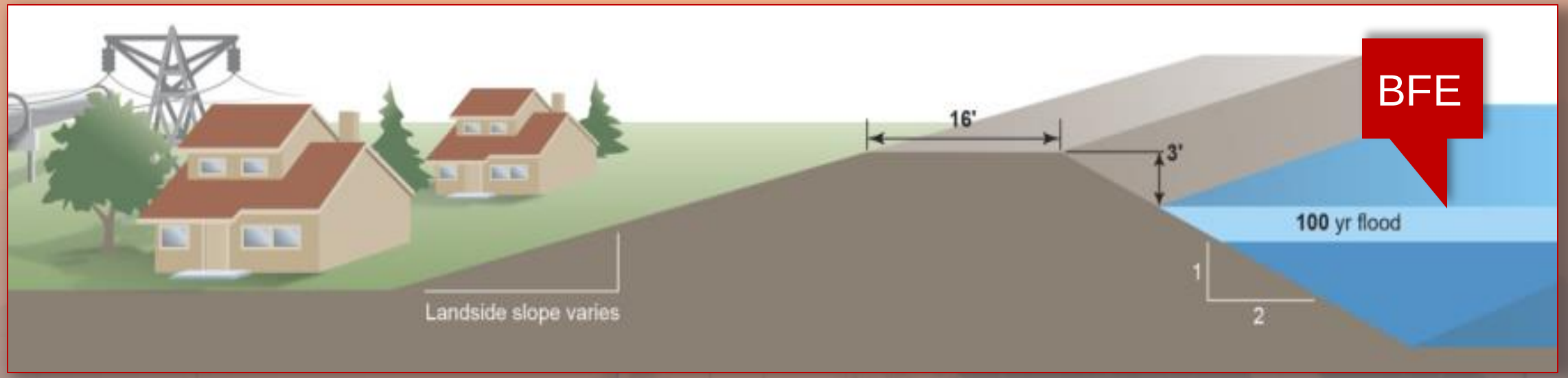
Ed Link, University of Maryland



Policy-driven standards may no longer be valid

The “100-year flood” may occur more frequently in some locales

- Base Flood Elevation (BFE) is the **elevation** of flooding that has a one-percent probability of occurring in any given year (“100-year flood”)
- Basis of the National Flood Insurance Program (NFIP) and for most FEMA levee certifications

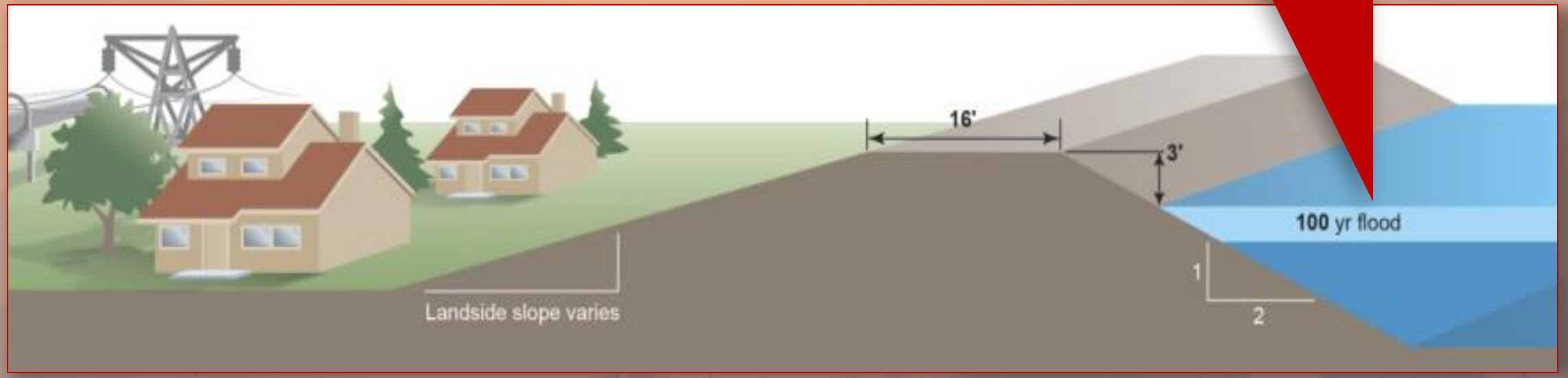


Policy-driven standards may no longer be valid

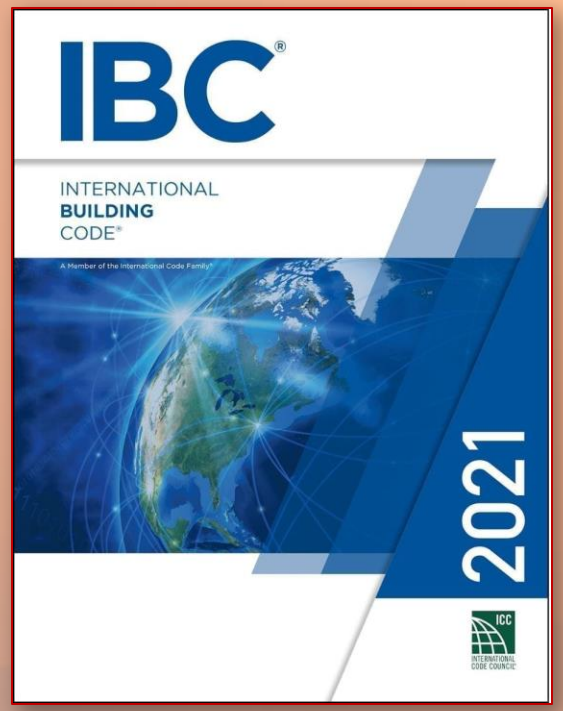
Will the 100-year BFE occur more frequently, say 50-years or even 25-years?

How will this affect the NFIP, levee certifications, and other flood-related policies and practices?

Will climate change cause this to be the BFE of the 50-year or 25-year flood?



Building codes will need to be updated



"The design rainfall rate shall be based on … rainfall rates determined from approved local weather data."

SECTION 1611
RAIN LOADS

1611.1 Design rain loads.

Each portion of a roof shall be designed to sustain the load of rainwater that will accumulate on it if the primary drainage system for that portion is blocked plus the uniform load caused by water that rises above the inlet of the secondary drainage system at its design flow. The design rainfall shall be based on the 100-year hourly rainfall rate indicated in Figure 1611.1 or on other rainfall rates determined from *approved* local weather data.

Building codes will need to be updated



Climate change is rapidly making local rainfall records obsolete

If precipitation rates increase in a particular area

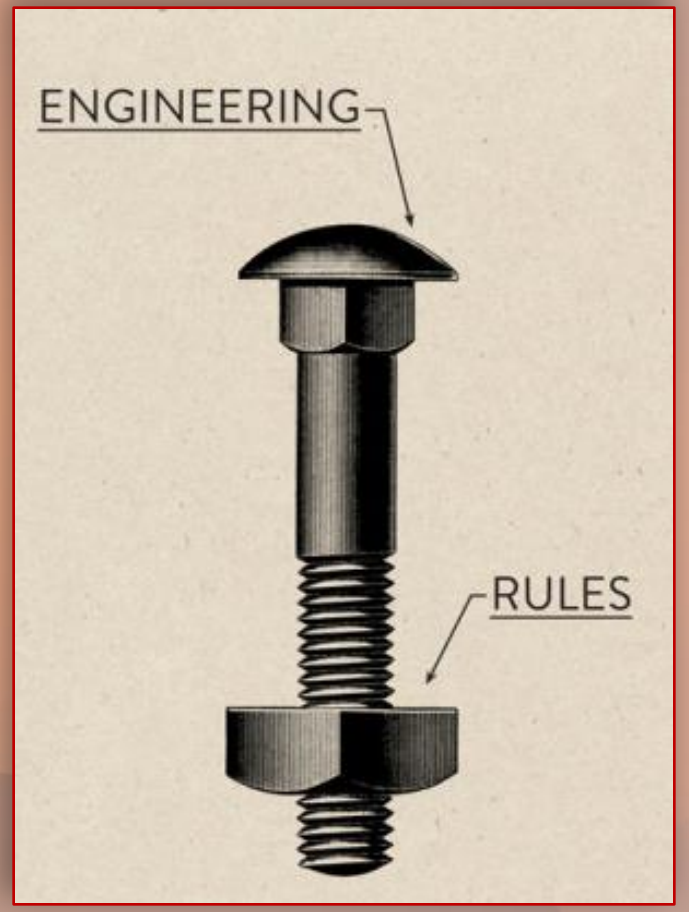
- Using a more conservative rate makes good sense
- But, how conservative should we be?
- What if we guess wrong?

The challenge of non-stationarity

Blindly following current codes, standards, and design guidelines may no longer result in safe and reliable performance over the life of the project

If there is a discrepancy or confusion when applying building codes:

- How will the standard of care be defined?
- Who will determine the standard of care?



What is our ethical responsibility in a dynamic environment?


What can we do?

What can we do?

We have three choices – mitigate, adapt, or suffer.

We're going to do some of each. What is the mix going to be?

The more mitigation we do, the less adaptation will be required, and the less suffering there will be.

Dr. John Holdren, Former White House Science Advisor



What can we do?

We have three choices – mitigate, adapt, or suffer.

I want you to act as you would in a crisis. I want you to act as if the house is on fire, because it is.

Greta Thunberg, Climate Activist



People suffer from weather extremes

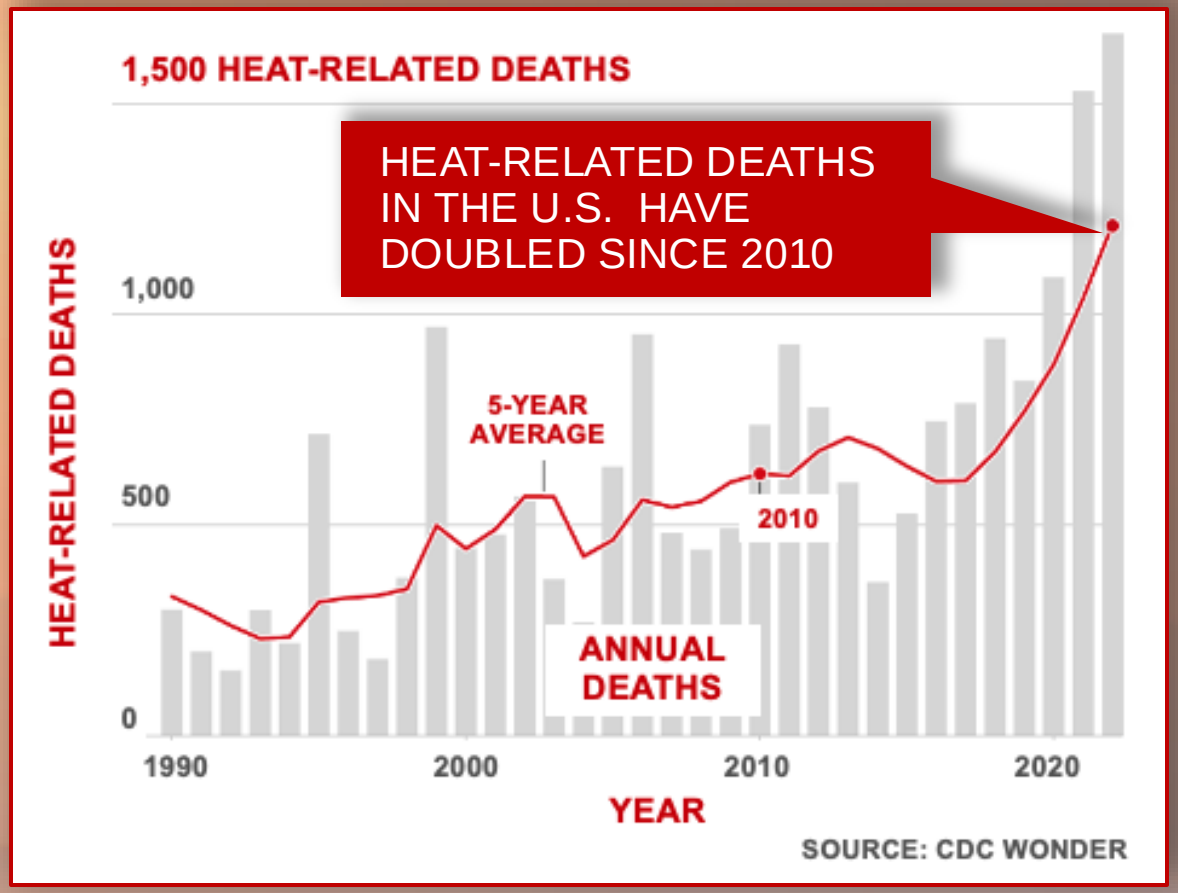
Is 70 degrees F that much different than 68 degrees F?

489,000 people died in heat waves globally in 2019

Extreme heat has cost $16 trillion since 1990

260,000-600,000 people die each year from smoke from wildfires

Can 8 billion people survive by simply cranking up the AC?



HEAT WAVES PREY ON VULNERABLE PEOPLE

Climate change is causing global diaspora

Estimate >200 million climate refugees by 2050

Triggered by

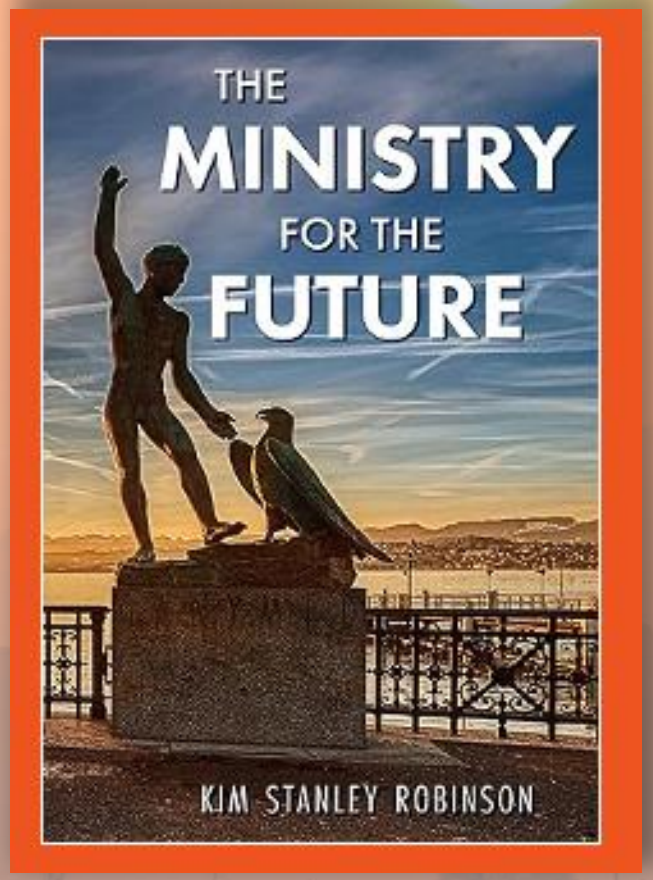
- Heat
- Famine
- Drought
- Sea level rise

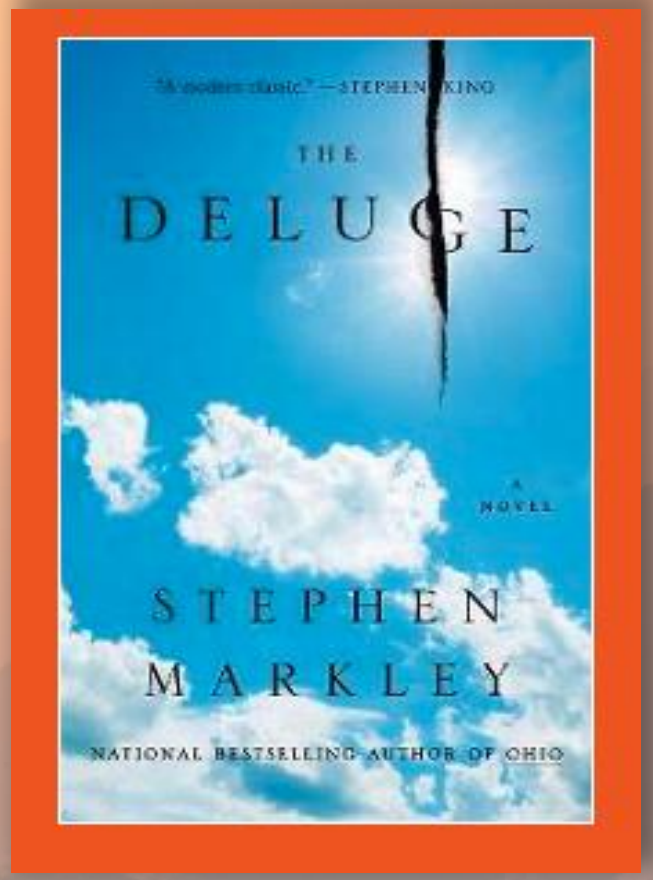
Climate change will fuel civil unrest



What can we do?

We have three choices – mitigate, adapt, or suffer.





What can we do?

We have three choices – mitigate, adapt, or suffer.

Either you abandon fossil fuels, or you find a way to get that carbon back.

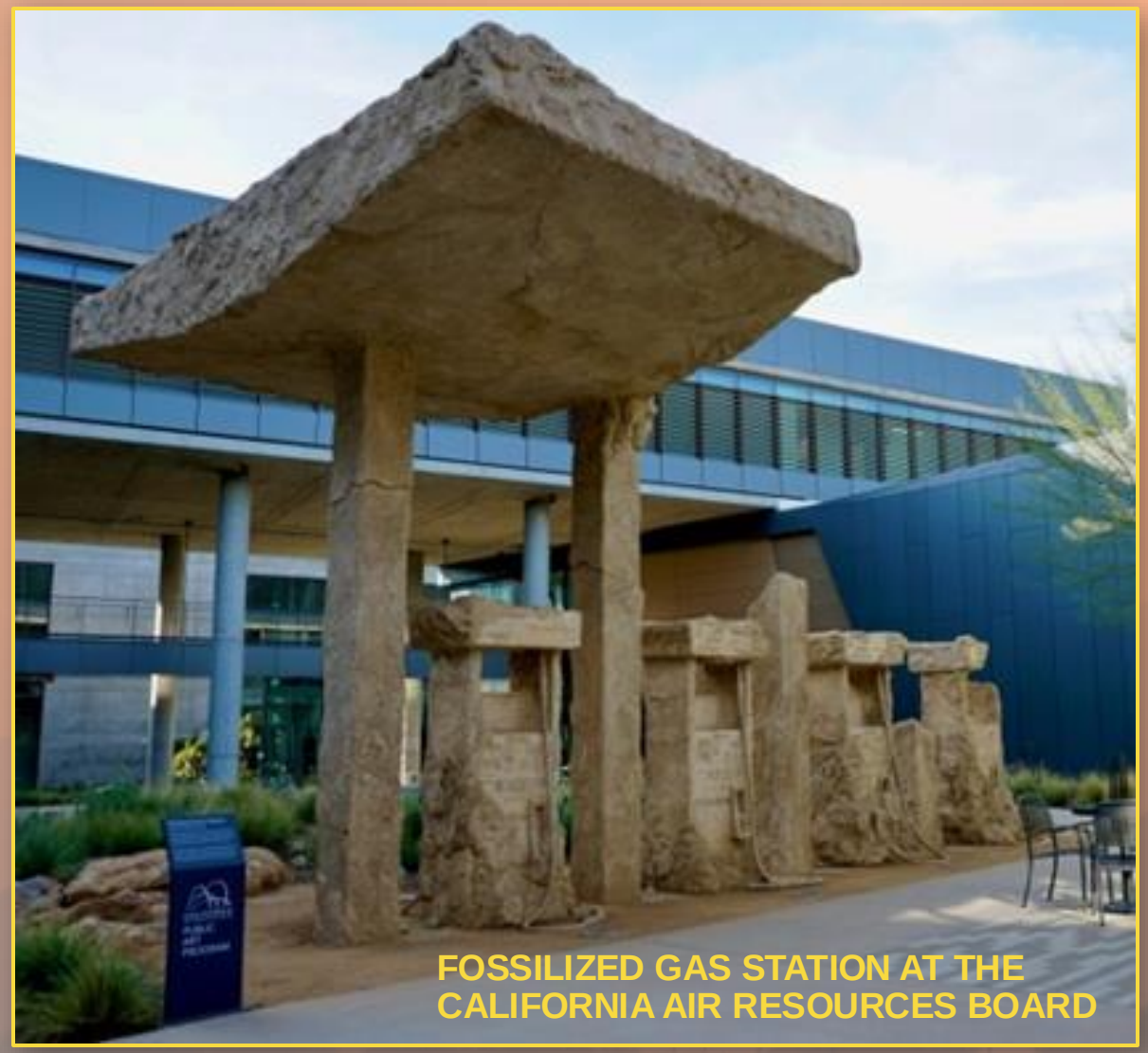
Klaus Lackner, Professor, Arizona State University



Climate change mitigation technologies

- GHG management
- Geoengineering

Mitigation: GHG management



FOSSILIZED GAS STATION AT THE CALIFORNIA AIR RESOURCES BOARD

GOALS

Net zero by 2050

Avert the worst impacts of climate change

Preserve a livable planet

METHODS

Reduce emissions

Increase carbon capture

Mitigation: Geoengineering

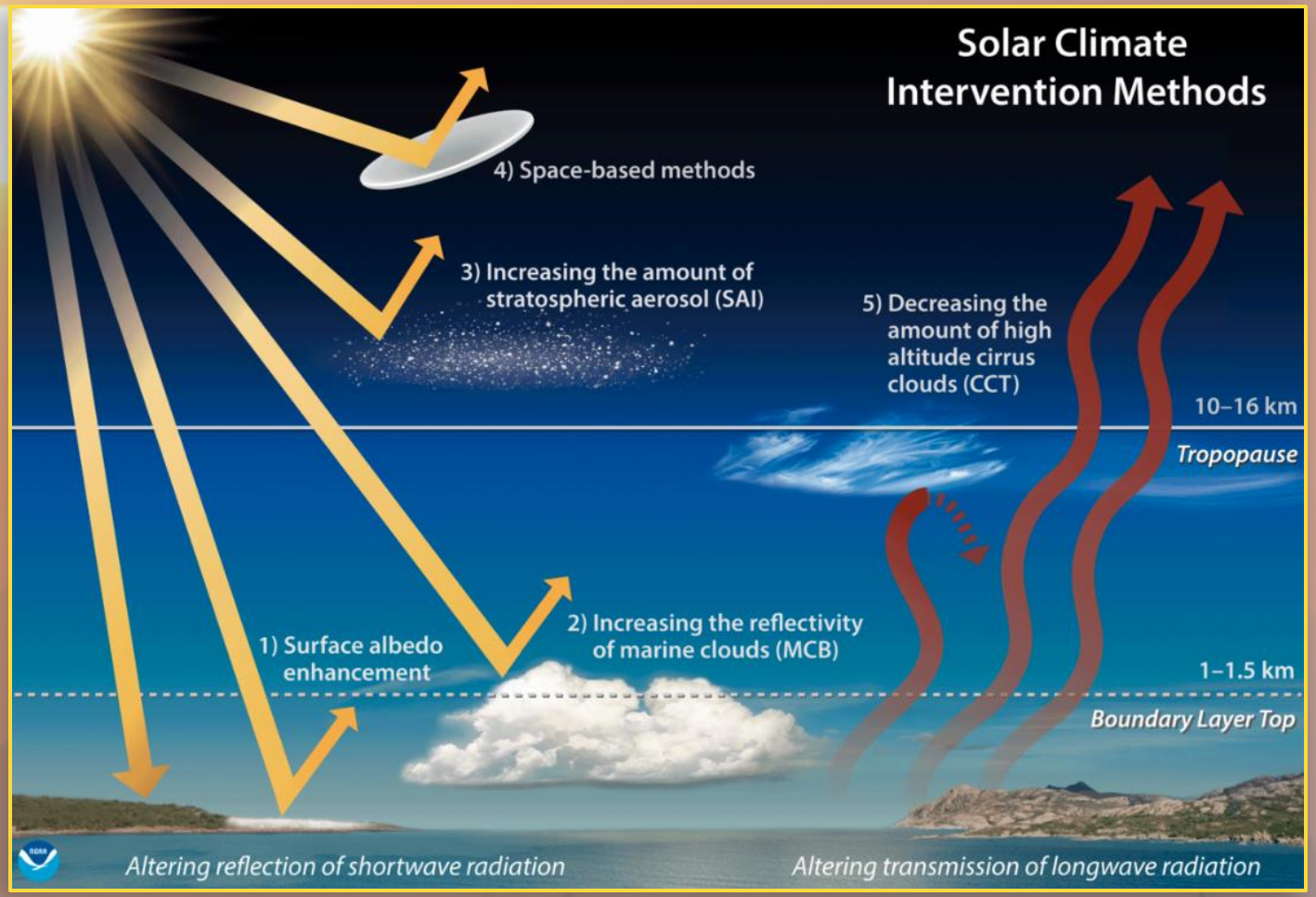
INCREASE SURFACE ALBEDO

Increase marine cloud reflectivity

REDUCE SOLAR INPUT (Star Wars)

Put reflectors in orbit

Inject aerosols into the atmosphere



Can technology save us?

It’s immature and in most cases unproven

It’s very expensive

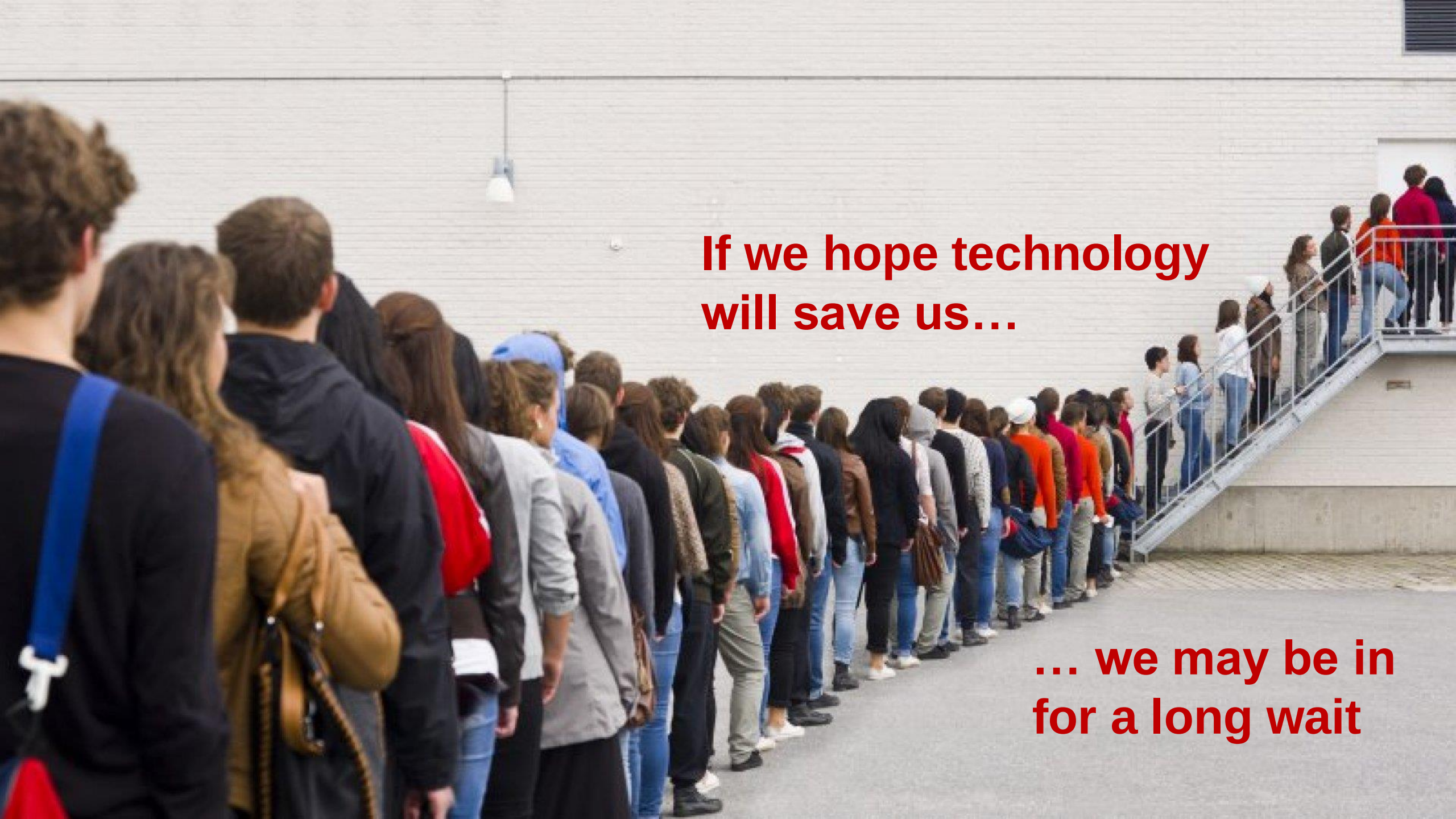
We may not be able to control it – i.e., the cure may be worse than the disease



The moral hazard

Research may popularize the idea that geoengineering is a magical fix

If we believe a cure is around the corner, we may give up trying to reduce emissions


If we hope technology will save us…
… we may be in for a long wait

What can we do?

We have three choices – mitigate, adapt, or suffer.

Adaptation is a vital part of a response to the challenge of climate change.

Sir Nicholas Stern, Professor, London School of Economics



Climate adaptation (US EPA)

- Preparing for and accommodating current and projected effects of warmer temperatures, extreme weather events, and sea level rise
- Adapting to changes we can no longer avoid rather than preventing them entirely

Adapting to the climate crisis

What are the effects of changing climate stressors on infrastructure?

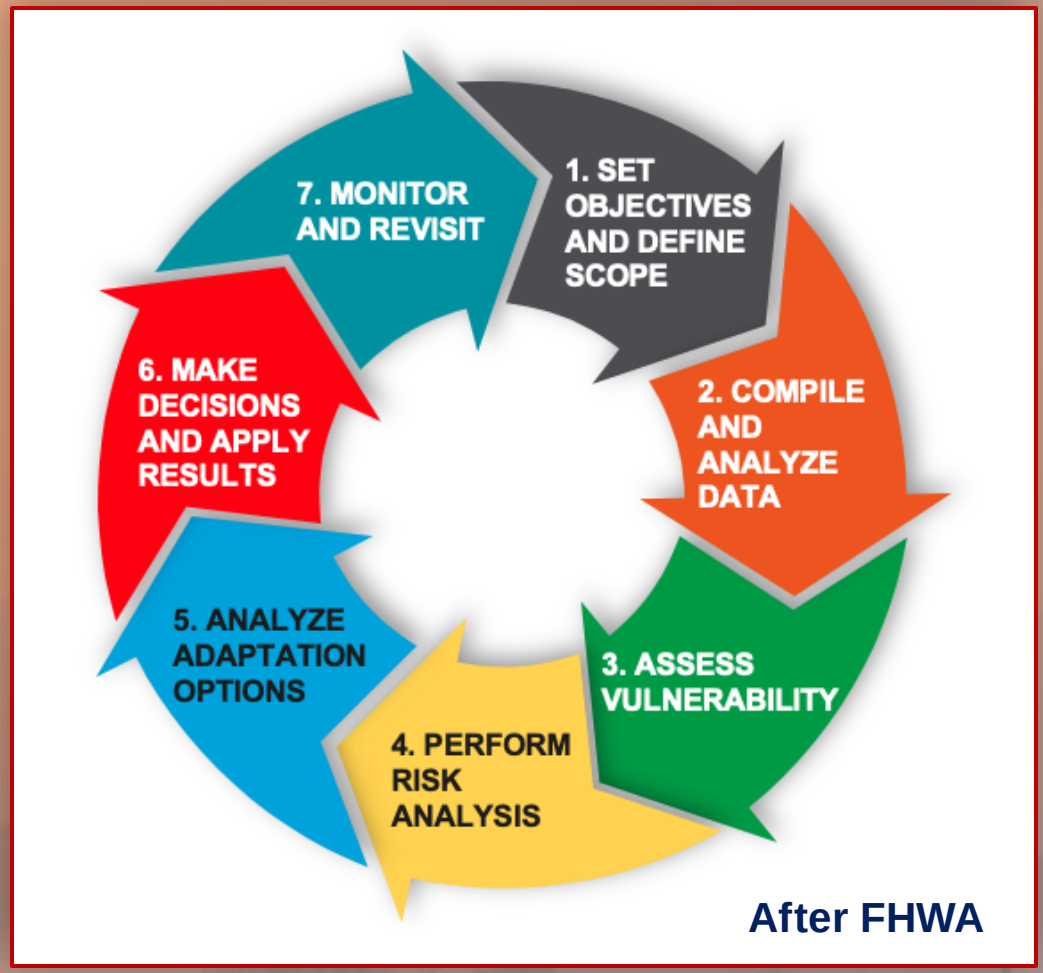
When will they occur? How bad will they be?

We cannot rely on stationarity – what should we do?

What are the infrastructure vulnerabilities of concern?

What are the consequences if our predictions are wrong?

How do we accommodate change that differs from what we predict?



Adaptation options for a changing climate (from FHWA)

Retreat

Relocate

Isolate

Improve

- Robustness
- Redundancy
- Resilience

Revise, adapt, accommodate

RETREAT



RELOCATE





ISOLATE

Adaptation options for a changing climate

Retreat

Relocate

Isolate

Improve

- Robustness
- Redundancy
- Resilience

Revise, adapt, accommodate



ROBUSTNESS: ADD STRENGTH



REDUNDANCY: USE BELT AND SUSPENDERS



RESILIENCE: IMPROVE THE CAPACITY TO WITHSTAND OR RECOVER

Adaptation options for a changing climate

Retreat

Relocate

Isolate

Improve

- Robustness
- Redundancy
- Resilience

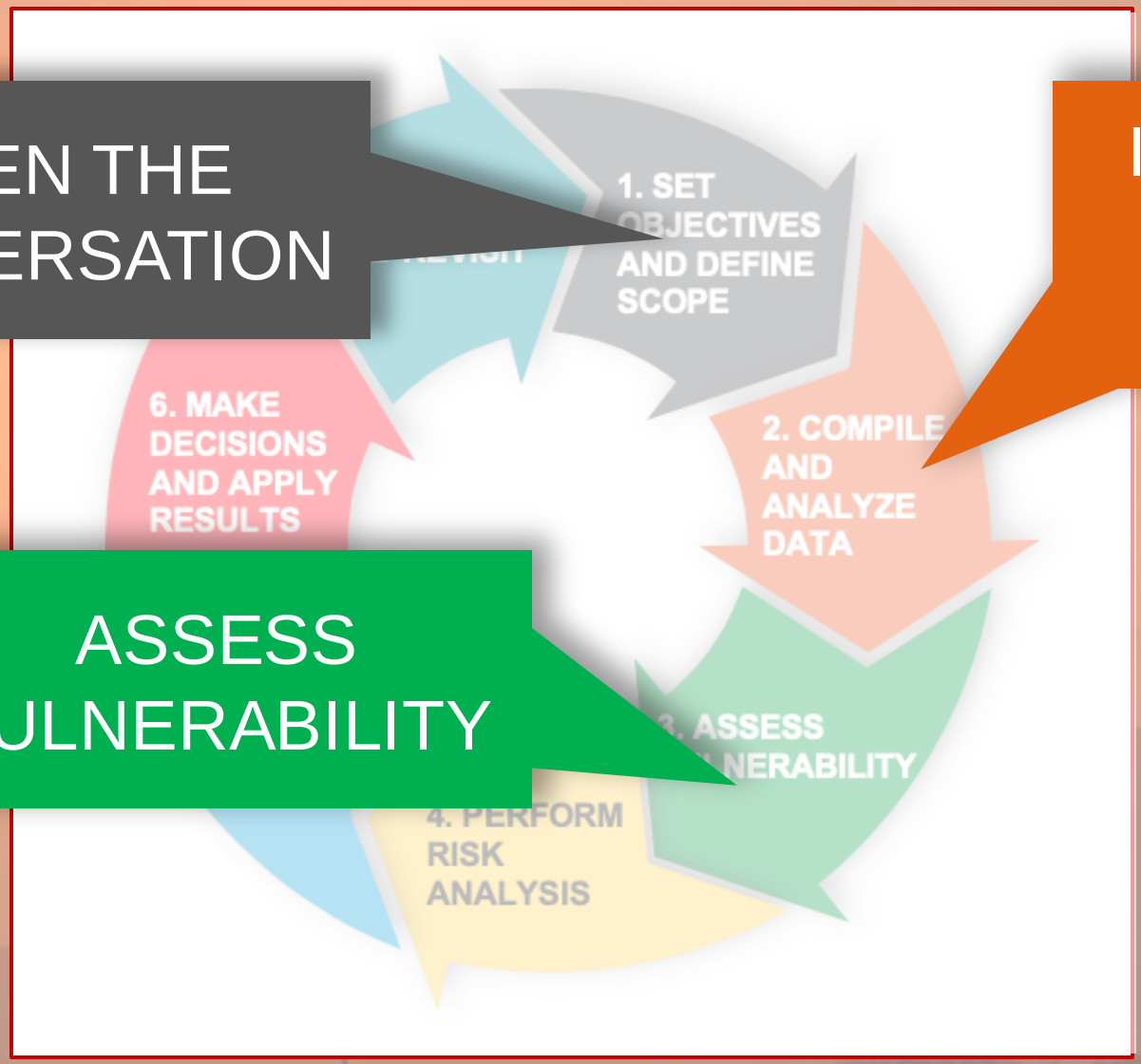
Revise, adapt, accommodate



OPEN THE CONVERSATION

INVESTIGATE CLIMATE HAZARDS

ASSESS VULNERABILITY



Open the conversation

Projects built to current climate-related standards are less safe because of non-stationarity

Current standards have not kept pace, confusing how to proceed

Developing new codes and standards is a deliberate, time-consuming process

Bring climate change into every conversation.

Institution of Civil Engineers



Until there is widespread acceptance of climate change, opening the conversation may be challenging

Conversation openers:

- US EPA
- US Army Corps of Engineers
- American Institute of Architecture

Climate hazards and vulnerability

US EPA Climate Risk Assessment Resources

Provides worksheet to assess a project's climate risk

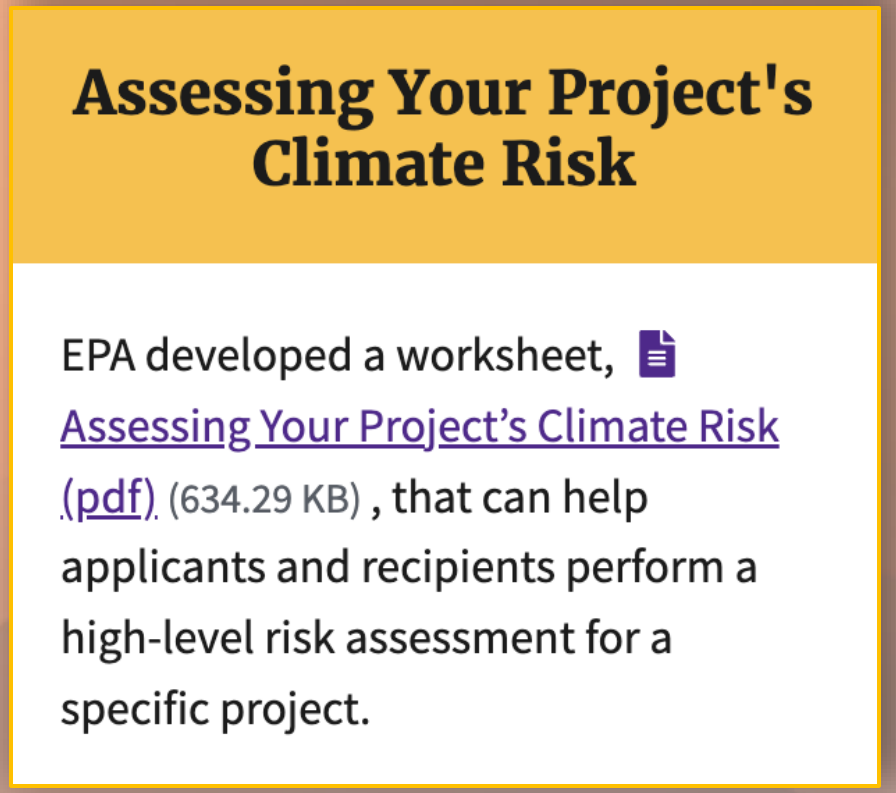
Guides the conduct of a basic climate risk assessment

Considers risk to project components and their resilience to climate impacts

Supports a climate risk assessment based on current climate hazards and future hazard predictions

Helps identify adaptation actions to improve resilience or adaptive capacity

https://www.epa.gov/system/files/documents/2024-06/cdti_risk_assessment_worksheet_final_5-21-2024.pdf



Climate hazards and vulnerability

USACE ECB 2018-14

Requires consideration of climate change on all projects

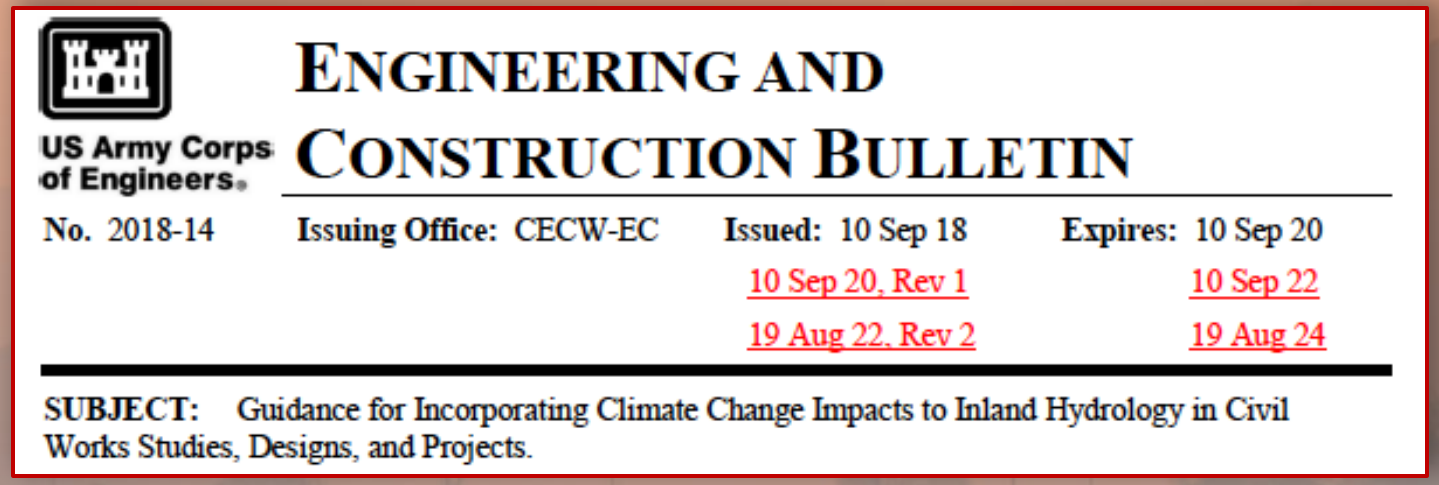
Assumption of stationarity is no longer appropriate

Focus is on relevant climate stressors

Identifies and communicates threats from climate change

May affect the design and the potential for future modifications

Complexity of analysis depends on level of uncertainty



US Army Corps of Engineers

ENGINEERING AND CONSTRUCTION BULLETIN

No. 2018-14 **Issuing Office:** CECW-EC **Issued:** 10 Sep 18 **Expires:** 10 Sep 20

10 Sep 20, Rev 1 10 Sep 22

19 Aug 22, Rev 2 19 Aug 24

SUBJECT: Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects.

https://wbdg.org/FFC/ARMYCOE/COEECB/ecb_2018_14_rev_3.pdf

Climate hazards and vulnerability

AIA's hazards guide

Identify threats from potential geologic hazards and changing climate stressors

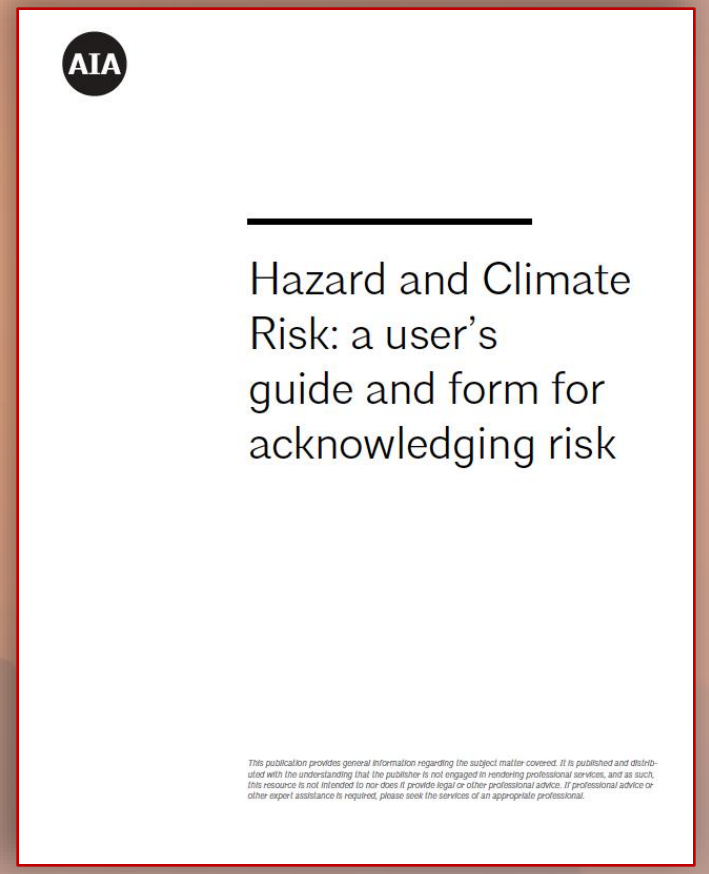
Estimate future climate conditions

Develop a hazard risk profile, including climate hazards

- Estimate expected frequency and impact
- Prepare risk rating

Identify performance requirements for resilience

Obtain acknowledgment from the client and project team



https://content.aia.org/sites/default/files/2021-12/Users_Guide_to_the_Hazard_and_Climate_Risk_Acknowledgement_Form_v2.pdf

Hazards screening

Opens the door to talking about climate change with clients

Initiates discussion of non-stationarity

Sets the stage for getting to the right outcome

Underscores the value of resilience

Creates the opportunity to offer new services

Encourages discussion of negligence and professional liability

Provides an opportunity for buy-in by the owner, stakeholders, and the project team

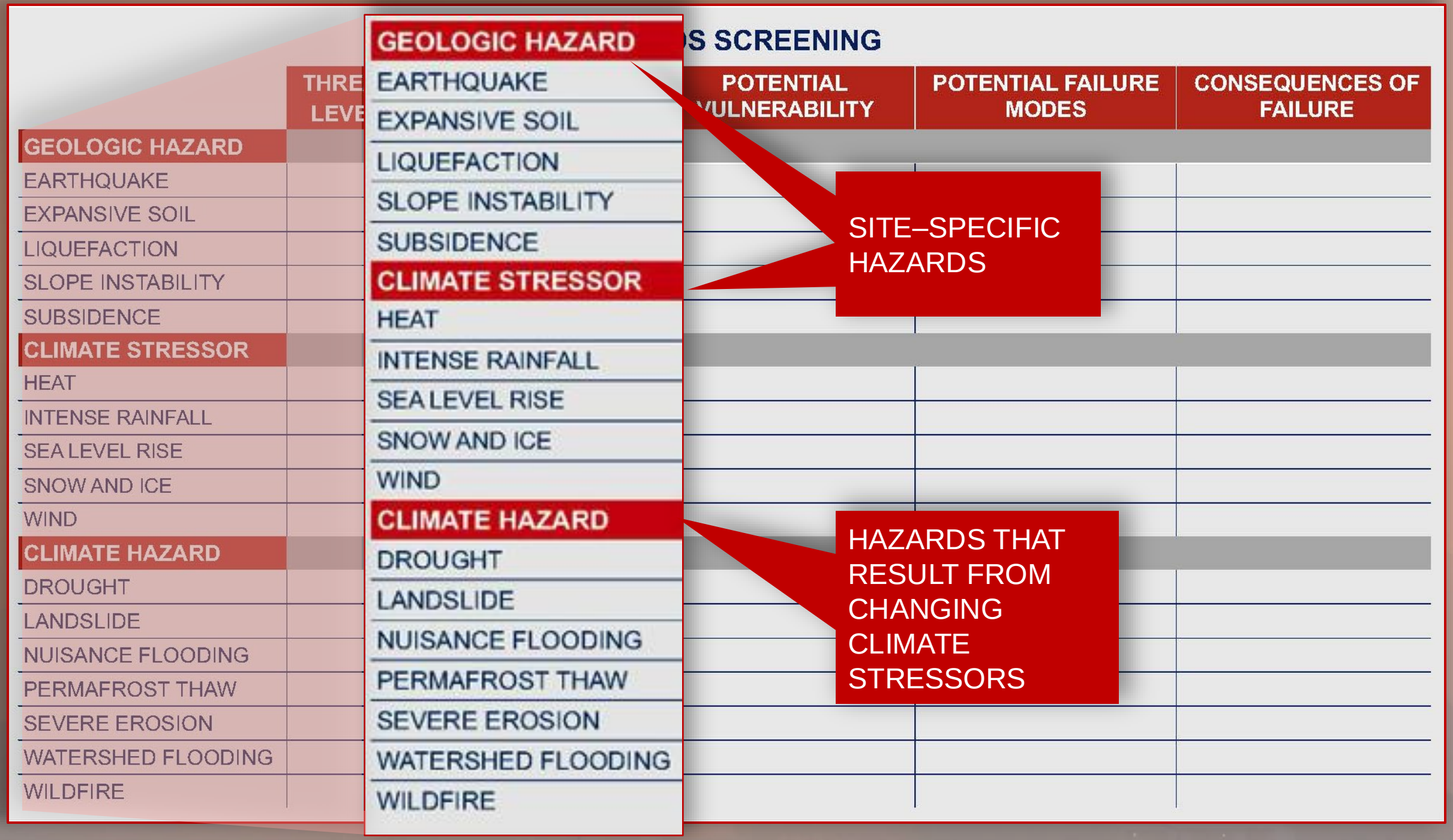
If you don't have time to build it right, when will you have time to build it twice?



Swizec Teller, Geek with a hat

HAZARDS SCREENING

	THREAT LEVEL	PROJECT COMPONENT	POTENTIAL VULNERABILITY	POTENTIAL FAILURE MODES	CONSEQUENCES OF FAILURE
GEOLOGIC HAZARD					
EARTHQUAKE					
EXPANSIVE SOIL					
LIQUEFACTION					
SLOPE INSTABILITY					
SUBSIDENCE					
CLIMATE STRESSOR					
HEAT					
INTENSE RAINFALL					
SEA LEVEL RISE					
SNOW AND ICE					
WIND					
CLIMATE HAZARD					
DROUGHT					
LANDSLIDE					
NUISANCE FLOODING					
PERMAFROST THAW					
SEVERE EROSION					
WATERSHED FLOODING					
WILDFIRE					


S SCREENING
THRE
LEVE
POTENTIAL
VULNERABILITY
POTENTIAL FAILURE MODES
CONSEQUENCES OF FAILURE
GEOLOGIC HAZARD
EARTHQUAKE
EXPANSIVE SOIL
LIQUEFACTION
SLOPE INSTABILITY
SUBSIDENCE
CLIMATE STRESSOR
HEAT
INTENSE RAINFALL
SEA LEVEL RISE
SNOW AND ICE
WIND
CLIMATE HAZARD
DROUGHT
LANDSLIDE
NUISANCE FLOODING
PERMAFROST THAW
SEVERE EROSION
WATERSHED FLOODING
WILDFIRE
SITE–SPECIFIC HAZARDS
HAZARDS THAT RESULT FROM CHANGING CLIMATE STRESSORS

HAZARDS SCREENING

	THREAT LEVEL	PROJECT COMPONENT	POTENTIAL VULNERABILITY	POTENTIAL FAILURE MODES	CONSEQUENCES OF FAILURE
GEOLOGIC HAZARD					
EARTHQUAKE					
EXPANSIVE SOIL					
LIQUEFACTION					
SLOPE INSTABILITY					
SUBSIDENCE					
CLIMATE STRESSOR					
HEAT					
INTENSE RAINFALL					
SEA LEVEL RISE					
SNOW AND ICE					
WIND					
CLIMATE HAZARD					
DROUGHT					
LANDSLIDE					
NUISANCE FLOODING					
PERMAFROST THAW					
SEVERE EROSION					
WATERSHED FLOODING					
WILDFIRE					

NOT APPLICABLE

LOW

MEDIUM

HIGH

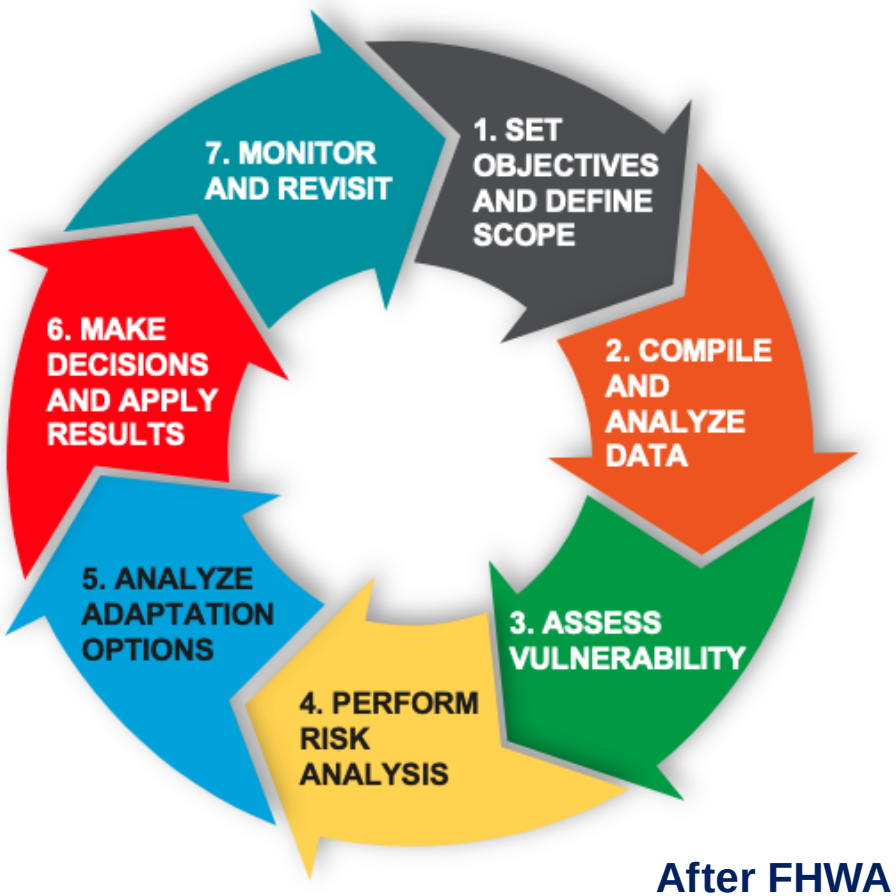
HAZARDS SCREENING

	THREAT LEVEL	PROJECT COMPONENT	POTENTIAL VULNERABILITY	POTENTIAL FAILURE MODES	CONSEQUENCES OF FAILURE
GEOLOGIC HAZARD					
EARTHQUAKE					
EXPANSIVE SOIL					
LIQUEFACTION					
SLOP					
SUBS					
CLIM					
HEAT					
INTEN					
SEA L					
SNOW					
WIND					
CLIM					
DROUGHT					
LANDSLIDE					
NUISANCE FLOODING					
PERMAFROST THAW					
SEVERE EROSION					
WATERSHED FLOODING					
WILDFIRE					

PROJECT COMPONENT	POTENTIAL VULNERABILITY	POTENTIAL FAILURE MODES	CONSEQUENCES OF FAILURE


What should we do?

Project example



After FHWA

Proposed new water treatment plant

Publicly owned utility in south-central Wisconsin

Located on gently rolling terrain in the floodplain of a small stream

Because of space limitations, a floodwall is planned to reduce flood risk

As the sole water supply for a small community, it classifies as critical infrastructure

The owner expects a 50-year service life

Owner’s goal is to minimize capital costs


PROPOSED WATER TREATMENT PLANT


PROPOSED FLOODWALL

Characterizing the need for resilience

What is the estimated service life of the facility?

Is the facility critical infrastructure?

Does a climate-change-induced failure:

- Present a life-safety risk?
- Affect the performance of other infrastructure?
- Cause other infrastructure to fail?

How important is continuity of operations? How long can the facility be out of service?

How difficult and costly will it be to repair or retrofit?

What is risk tolerance of the owner, stakeholders, and the affected public?

CRITICAL INFRASTRUCTURE

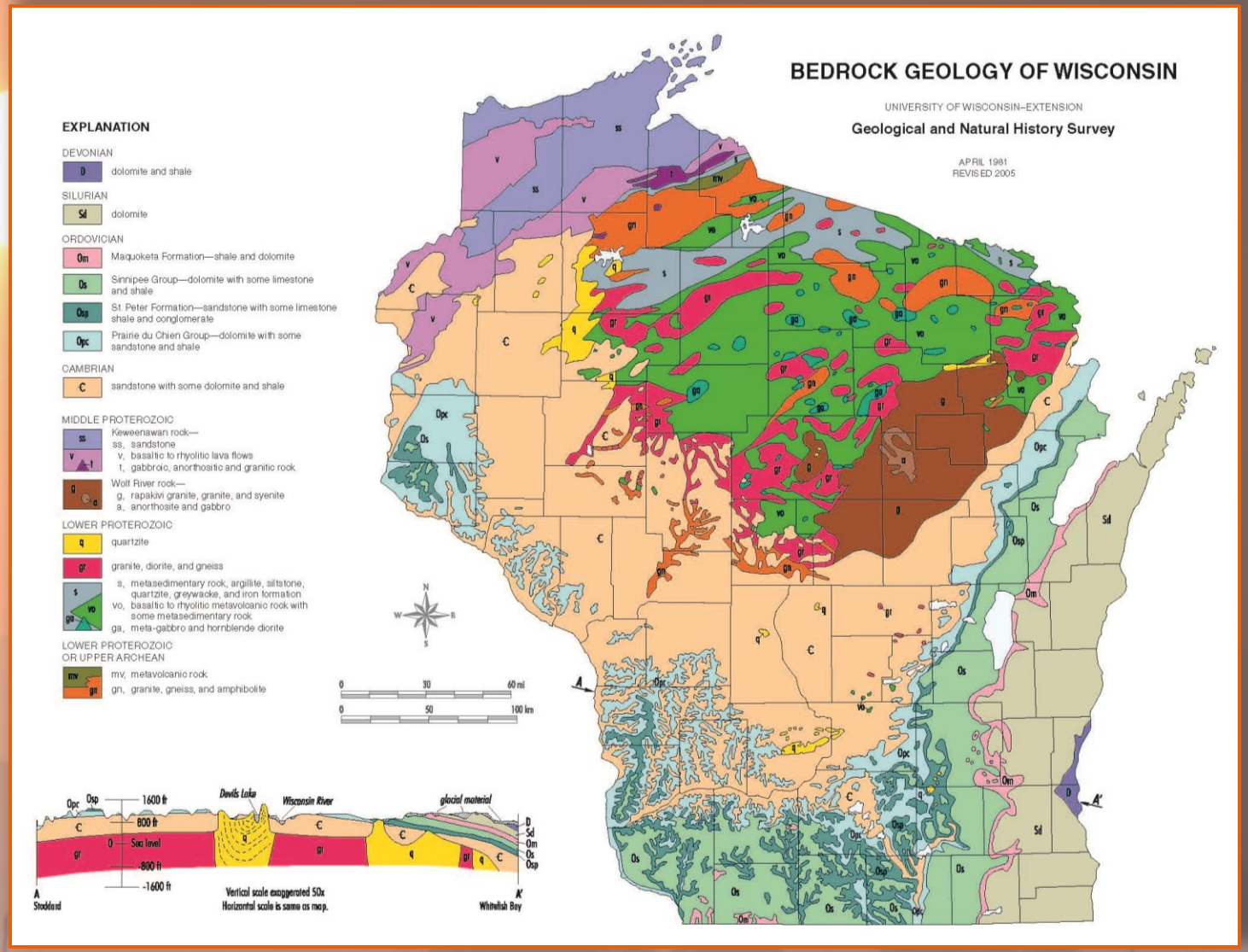
Facilities and assets so vital that their destruction or incapacitation would disrupt the public's security, economy, safety, health, or welfare.

Geologic hazards and vulnerability

Low seismic risk

Not susceptible to slope instability or other geologic hazards

Foundation soil is piping susceptible



Climate hazards

What are the *climate stressors* of concern?

How are *climate stressors* changing?

What are the *climate hazards* of concern?



Climate Resilience Evaluation
epa.gov/crwu/climate-resilience-evaluation-and-awareness-tool
Relaunch to update
msn | Google Maps | asce | hyatt | umpqua | amazon | southwest | Gmail | orvis | nwm | weather | allstate id | az republic | YouTube | dictionary | All Bookmarks
An official website of the United States government Here's how you know
EPA United States Environmental Protection Agency
Search EPA.gov
Environmental Topics | Laws & Regulations | Report a Violation | About EPA

Creating Resilient Water Utilities (CRWU)

- Resilient Strategies Guide
- Climate Resilience Evaluation and Awareness Tool
- Climate and Weather Data Maps
- Adaptation Case Studies
- Adaptation Planning in Action Videos
- Risk Assessments
- Community Co-Benefits StoryMap
- Training and Engagement Center
- Climate Adaptation Funding
- Climate Finance Working Group

Contact Us about Creating Resilient Water Utilities (CRWU)

Climate Resilience Evaluation and Awareness Tool

Oops, something went wrong. Check your browser's developer console for more details.

What is Climate Resilience Evaluation and Awareness Tool?

Climate Resilience Evaluation and Awareness Tool (CREAT) is a tool that assists water sector utilities in assessing climate-related risks to utility assets and operations. Throughout CREAT's five modules, users consider climate impacts and identify adaptation options to increase resilience. The modules are:

1. **Climate Awareness:** Provide basic utility information; increase awareness of climate impacts;
2. **Scenario Development:** Understand utility risk; design scenarios of threats based on climate data;
3. **Consequences and Assets:** Outline potential consequences; catalog critical assets;
4. **Adaptation Planning:** Inventory current actions that provide resilience; design adaptation plans; and
5. **Risk Assessment:** Assess risk from a changing climate; compare risk reduction of adaptation plans.

Visit CRWU's Training and Engagement Center to view CREAT's Welcome Video as well as the How-To Videos for completing its Modules.

Related Information

- CREAT methodology guide
- Access CREAT data
- CREAT Training Videos
- CREAT Climate Scenarios Projection Map
- Streamflow Projections Map
- EPA National Stormwater Calculator

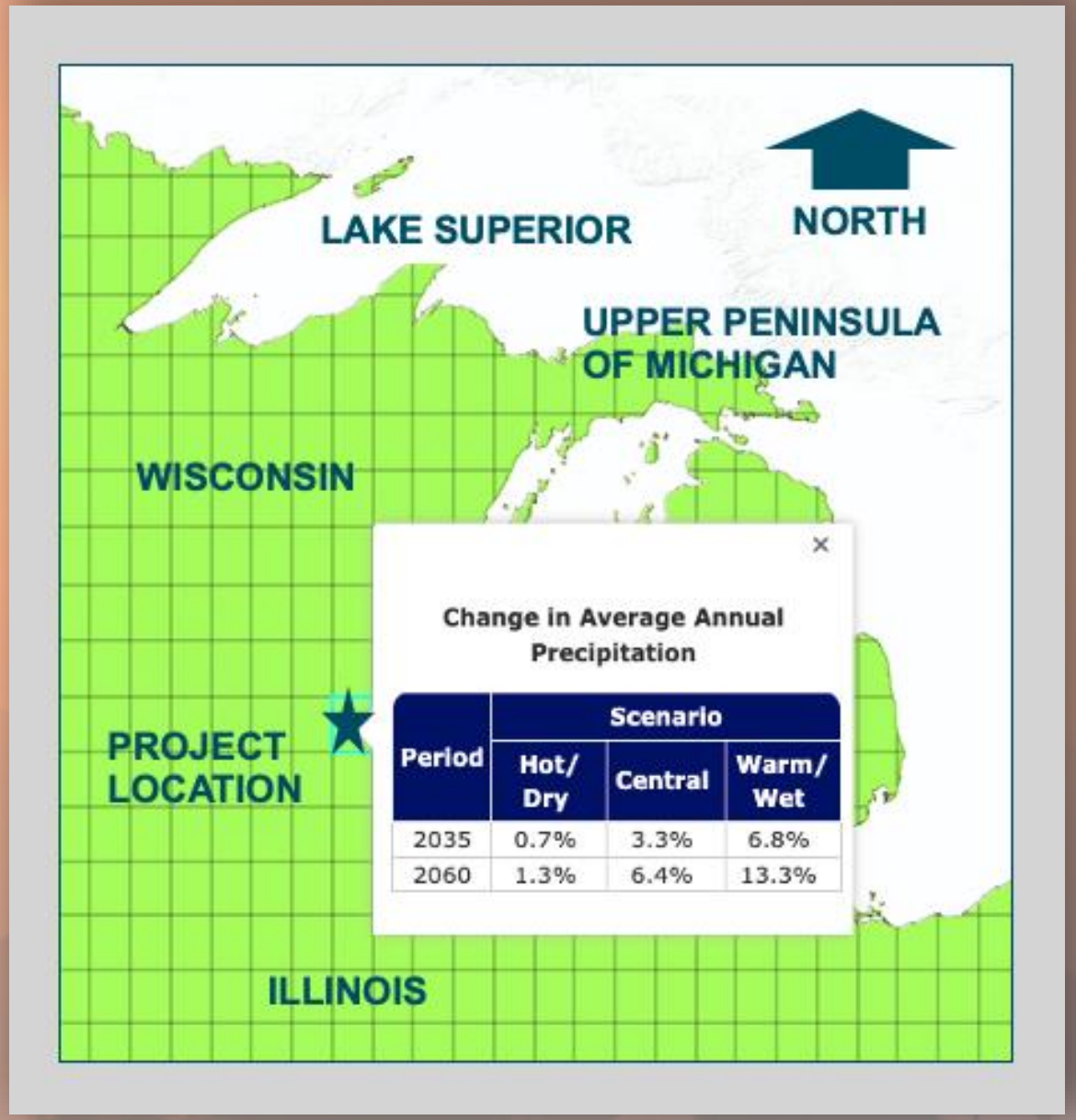
Climate stressors and hazards of concern

Climate stressors of concern include heat and intense precipitation (both rain and snow)

Climate hazards of concern include watershed flooding and nuisance flooding

https://epa.maps.arcgis.com/apps/MapSeries/index.html?appid=3805293158d54846a29f750d63c6890e

US EPA's CREAT Climate Change Scenarios Projection Map



Climate stressors and hazards of concern

CLIMATE CHANGE SCENARIOS (SOUTH-CENTRAL WISCONSIN)	YEAR	SCENARIO		
		HOT/DRY	CENTRAL	WARM/WET
CHANGE IN AVERAGE ANNUAL TEMPERATURE	2035	3.5°F (1.9°C)	2.9°F (1.6°C)	2.6°F (1.4°C)
	2060	6.8°F (3.8°C)	5.7°F (3.2°C)	5.1°F (2.8°C)
NUMBER OF DAYS OVER 100° F (55.5° C)	2035	1	1	1
	2060	5	3	3
CHANGE IN AVERAGE ANNUAL PRECIPITATION	2035	0.7%	3.3%	6.8%
	2060	1.3%	6.4%	13.3%
		SCENARIO		
		STORMY	LESS STORMY	
CHANGE IN 100-YEAR STORM INTENSITY	2035	10.0%	3.5%	
	2060	19.5%	6.9%	

Climate stressors and hazards of concern

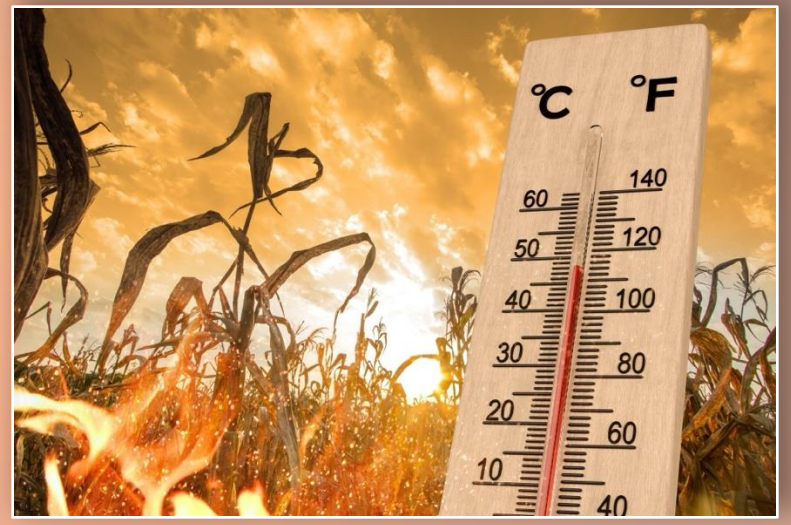
In all cases, projections are for warmer, wetter weather

Predicted *heat increase of 5.1-6.8 degrees F by 2060*

- Designers of electrical and mechanical systems may conclude that following current codes and standards may be satisfactory

Predicted *increase in 100-year storm intensity of 6.9-19.5 percent*

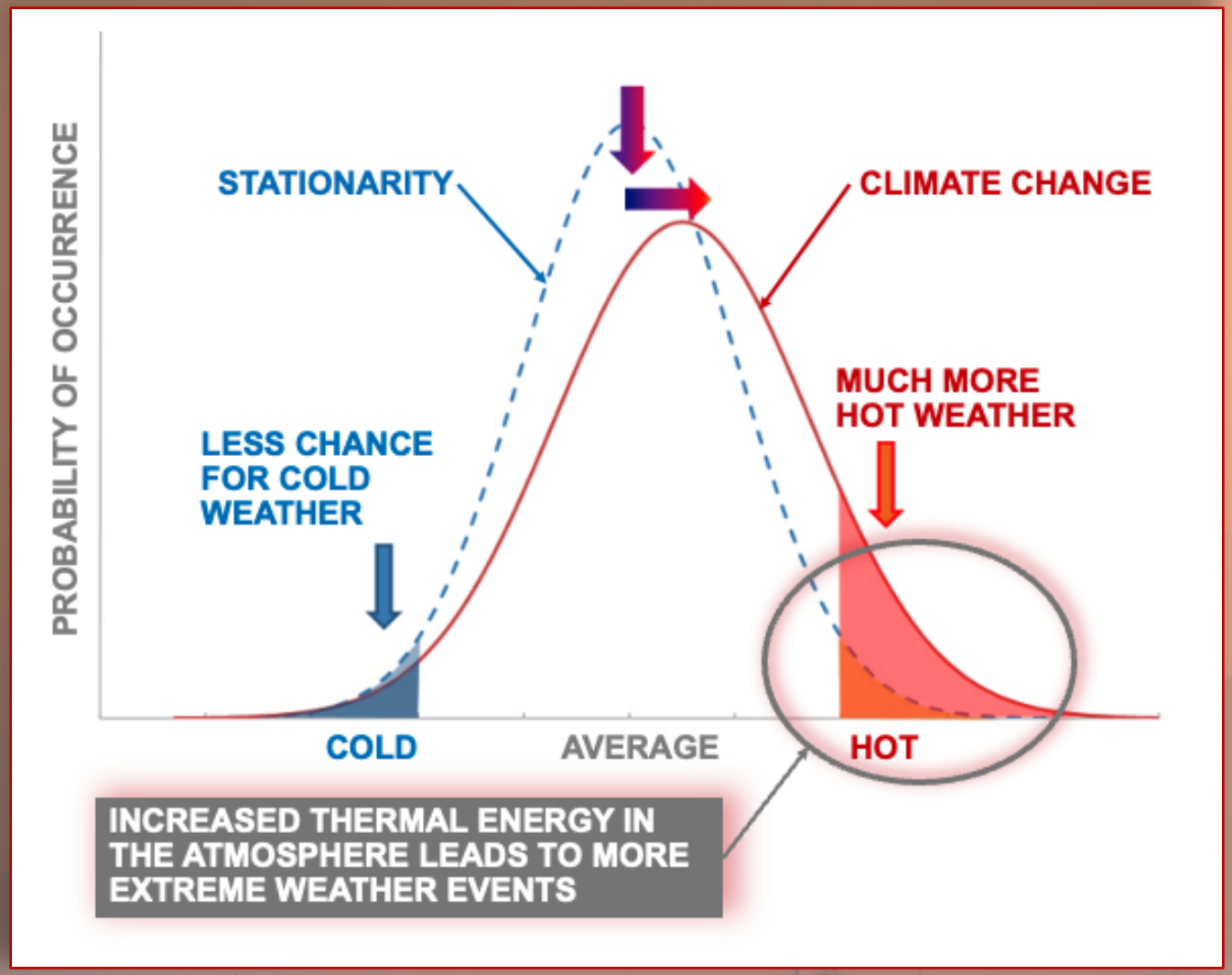
- Must be considered in structural design and flood risk





Climate stressor projections do NOT show the potential for extreme weather events that could overwhelm project components designed using current codes and standards

Extreme weather events



Stationarity

The US EPA defines *extreme weather* as rarer than the 10 percent or 90 percent probability density function

Non-stationarity

Weather events currently considered to be extreme are likely to become more commonplace

What are the system and component vulnerabilities?

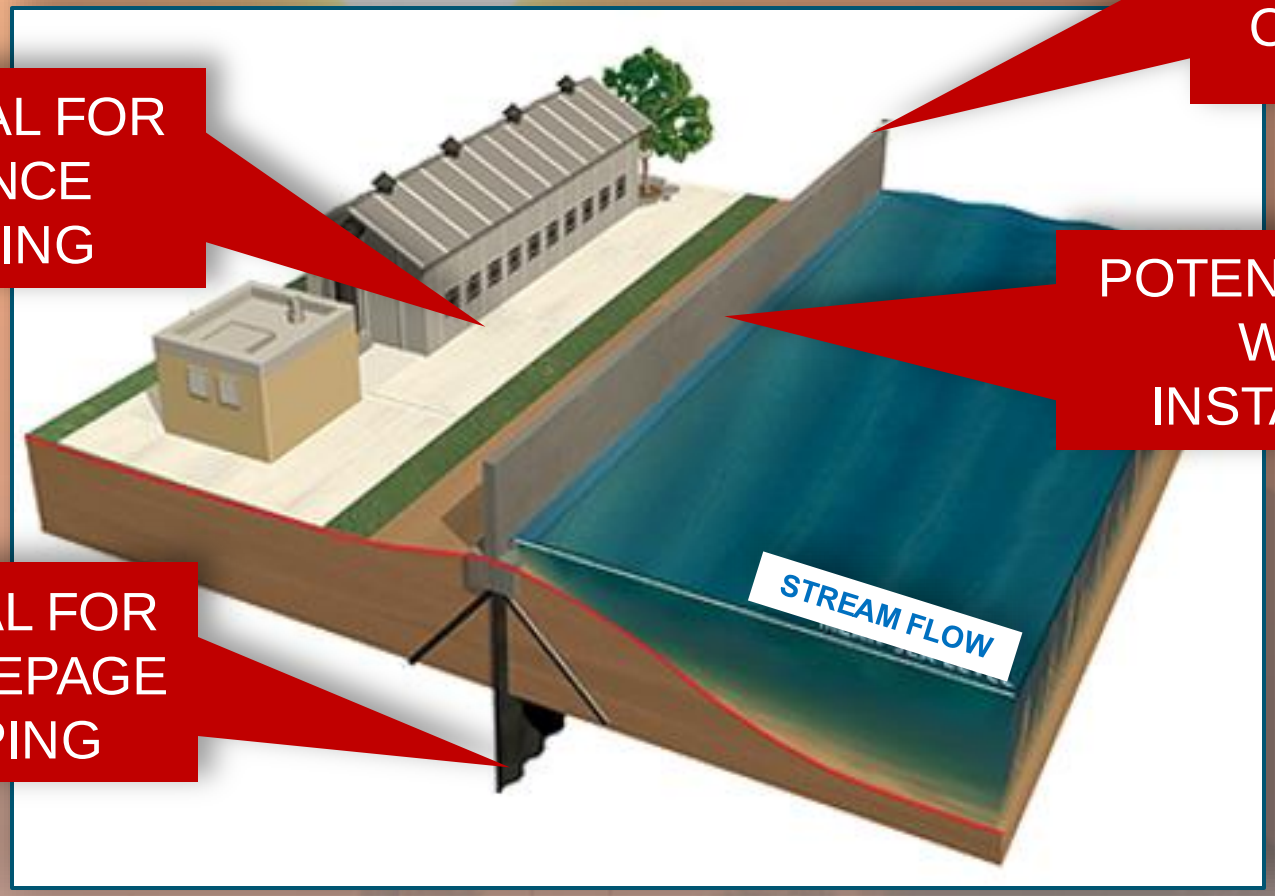


POTENTIAL FOR POOLING RAINWATER ON FLAT ROOFS

POTENTIAL FOR STRUCTURAL COLLAPSE FROM RAINWATER OR SNOW LOADS



What are the system and component vulnerabilities?



POTENTIAL FOR OVERTOPPING

POTENTIAL FOR NUISANCE FLOODING

POTENTIAL FOR WALL INSTABILITY

POTENTIAL FOR UNDERSEEPAGE AND PIPING

HAZARDS SCREENING, WATER TREATMENT PLANT, WISCONSIN

	THREAT LEVEL	PROJECT COMPONENT	POTENTIAL VULNERABILITY	POTENTIAL FAILURE MODES	CONSEQUENCES OF FAILURE
CLIMATE STRESSOR					
HEAT	M	Mechanical and electrical equipment	Equipment malfunction Equipment overload	Energy inefficiency Equipment failure	Cost of service interruption Cost of retrofit, repair, or reconstruction
INTENSE RAINFALL	H	Roof system Roof drainage Building structure	Roof pooling Structural overload	Roof leakage Roof collapse	Cost of service interruption Cost of retrofit, repair, or reconstruction
SNOW AND ICE	H	Roof system Roof drainage Building structure	Snow melt/roof ponding Structural overload Ice dams/pooling	Roof leakage Roof collapse	Cost of service interruption Cost of retrofit, repair, or reconstruction
CLIMATE HAZARD					
NUISANCE FLOODING	H	Electrical/mechanical equipment Internal drainage system Parking lot pavement	Internal drainage system overload Pavement/subgrade damage	System malfunction System failure Internal drainage system failure Pavement damage Pavement failure	Cost of service interruption Cost of retrofit, repair, or reconstruction
WATERSHED FLOODING	H	Floodwall	Inadequate height of floodwall Floodwall instability Underseepage	Site flooding from: • Overtopping • Floodwall collapse • Piping failure	Cost of service interruption Cost of retrofit, repair, or reconstruction

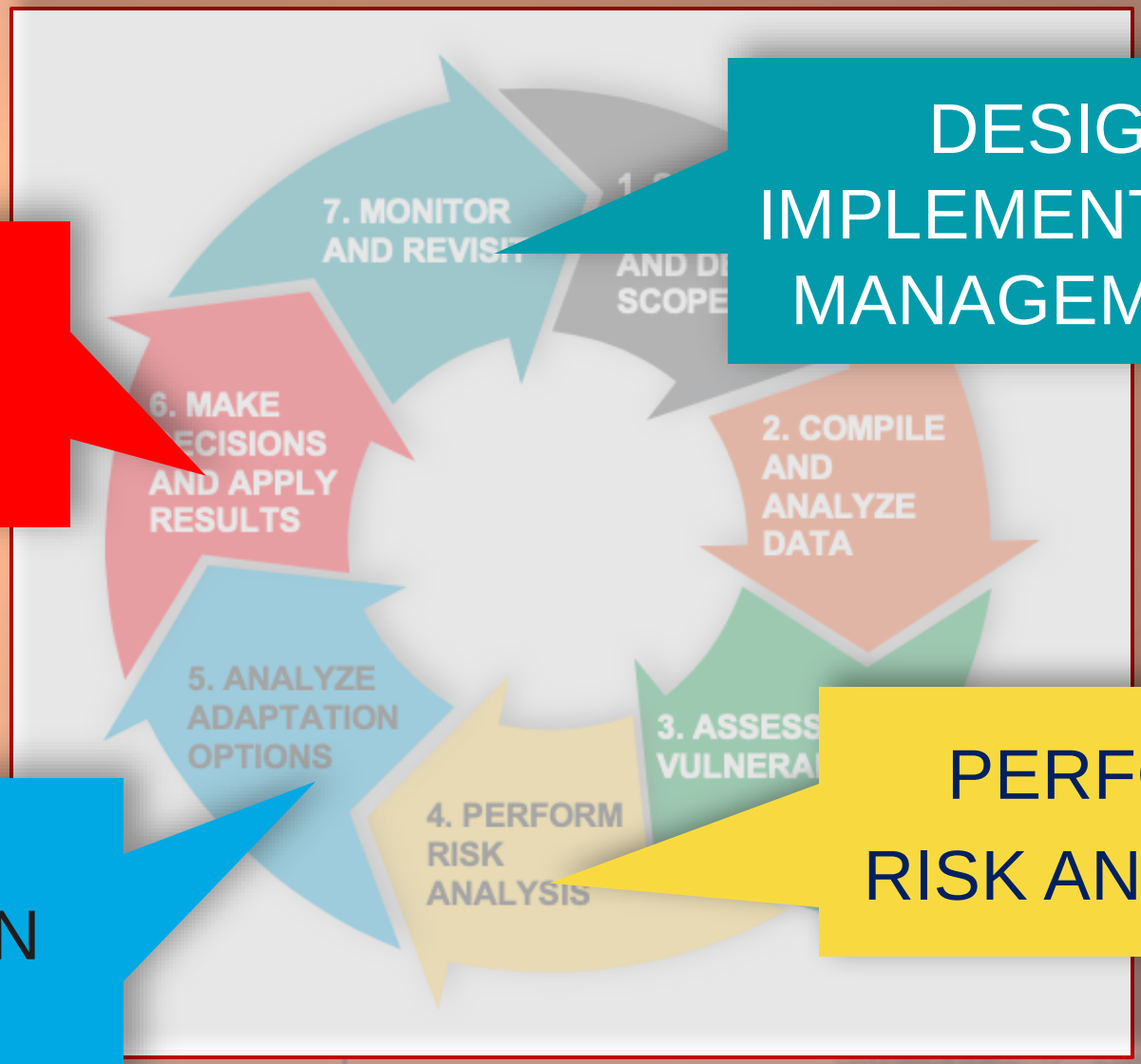
HAZARDS SCREENING, WATER TREATMENT PLANT, WISCONSIN

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		Roof system	Snow melt/roof ponding		Cost of service
		Parking lot pavement		Pavement failure	
WATERSHED FLOODING	H	Floodwall	Inadequate height of floodwall Floodwall instability Underseepage	Site flooding from: • Overtopping • Floodwall collapse • Piping failure	Cost of service interruption Cost of retrofit, repair, or reconstruction

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HAZARDS SCREENING, WATER TREATMENT PLANT, WISCONSIN

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DESIGN AND IMPLEMENT ADAPTIVE MANAGEMENT PLAN

ANALYZE LIFE-CYCLE COSTS

EVALUATE ADAPTATION OPTIONS

PERFORM RISK ANALYSIS

Analyzing risk

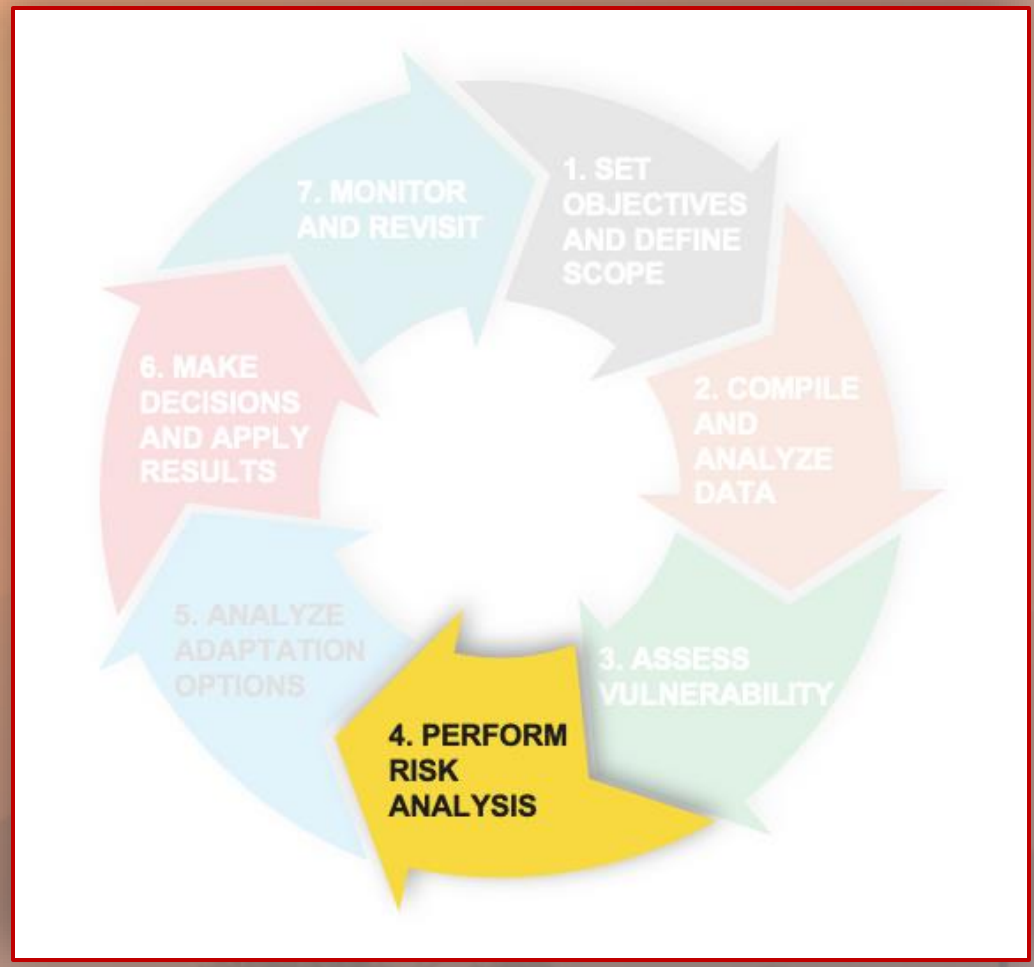
Hazards screening identifies:

- *Potential failure modes* from changing climate stressors
- *Consequences* of failure

Estimate the *probability* of failure

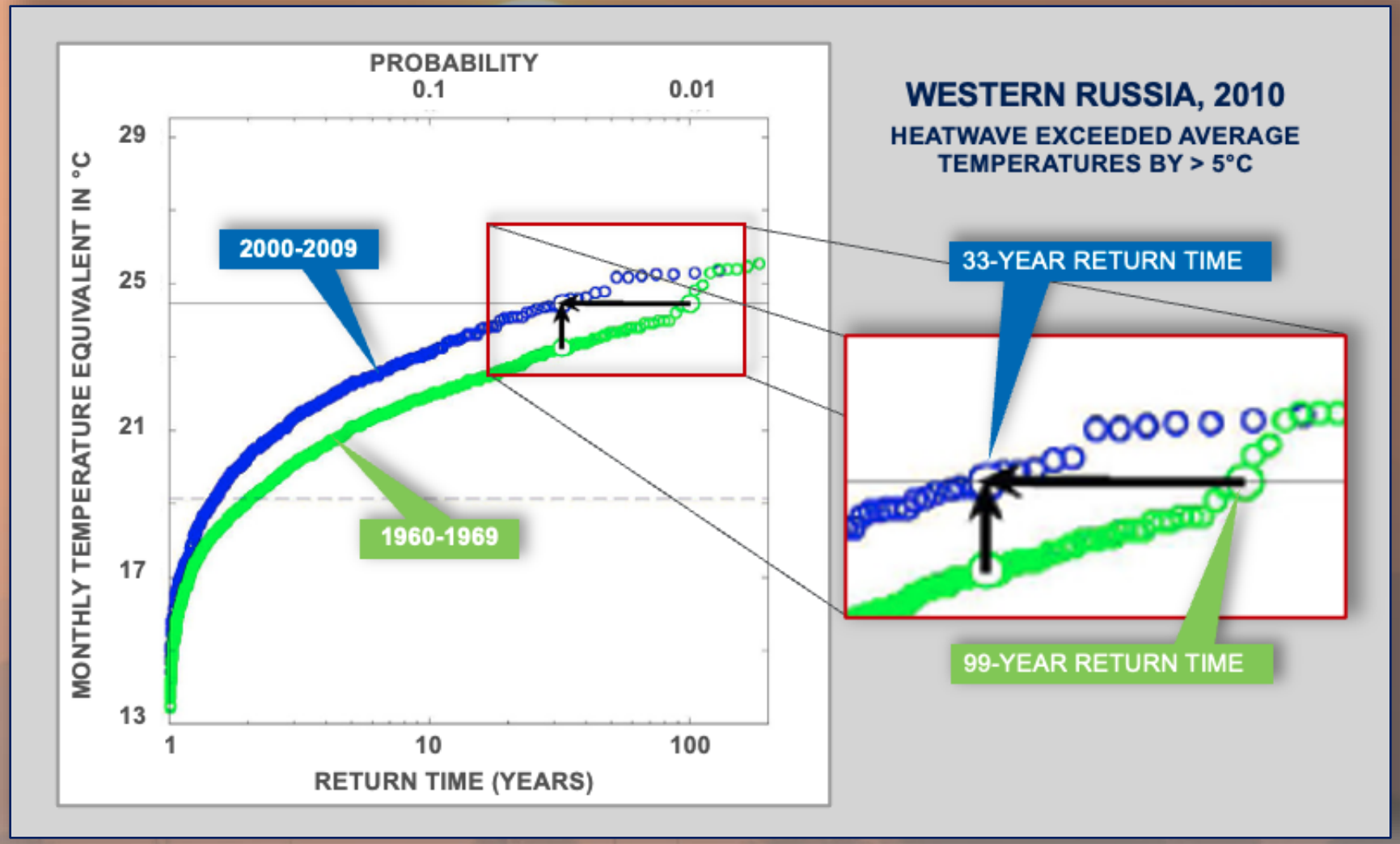
Calculate the risk
Risk = probability x consequences

How do we estimate probability under conditions of non-stationarity?



Assessing probability

https://nap.nationalacademies.org/download/21852



Assessing probability

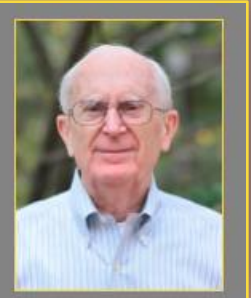


EXPERT ELICITATION

LIKELIHOOD OF FAILURE	ESTIMATED LIKELIHOOD
REMOTE	F < 1/1,000,000
LOW	F < 1/100,000
MODERATE	F < 1/10,000
HIGH	F < 1/1,000
VERY HIGH	F > 1/1,000

The scenario approach is vulnerable to "too-small" thinking, exploring only changes that appear realistic rather than extreme conditions.

Gerry Galloway, University of Maryland





https://iwrlibrary.sec.usace.army.mil/searchResults?series=Best%20Practices-Manual

Evaluating adaptation alternatives

What are the possible *future conditions*?

What actions can reduce risk now or in the future?

How much will risk reduction cost?

We can never eliminate risk: Is the residual risk tolerable?



Adaptation alternatives

Install electrical and mechanical equipment that can easily be upgraded

Use conservative designs

- Roof drainage system to reduce pooling on flat roofs
- Building structure to support unusual loads
- Internal drainage system to handle extreme events

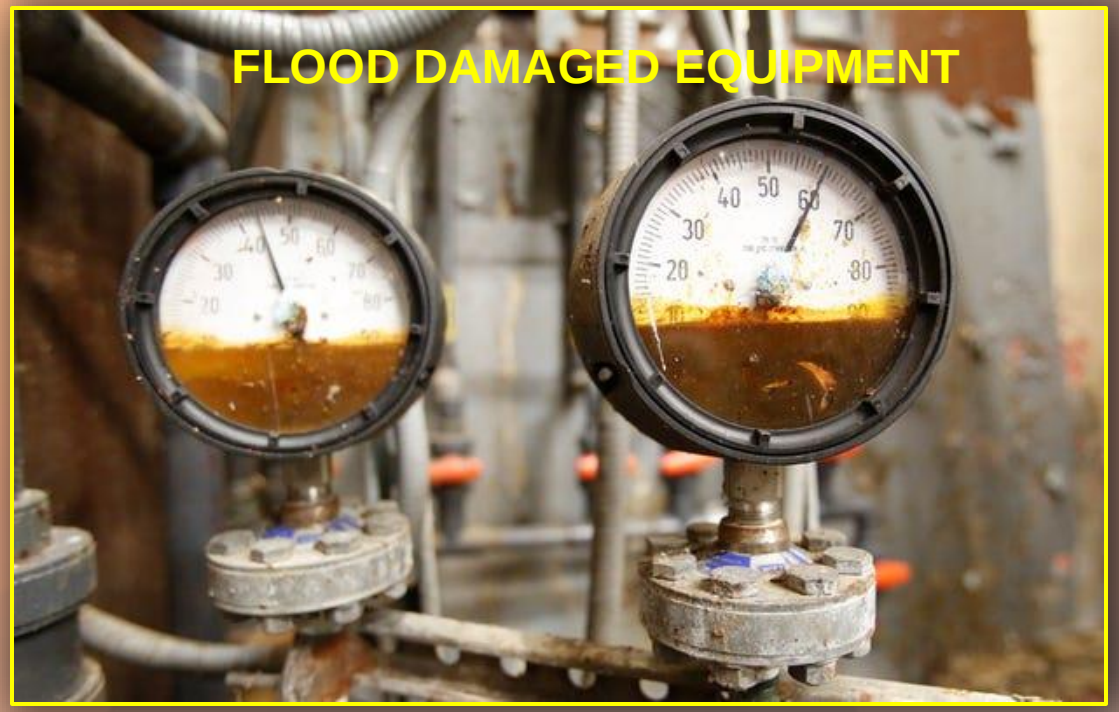


Adaptation alternatives (contd.)

Provide for aggressive roof and parking lot drainage system maintenance

Overbuild the foundation for the floodwall so that, if required, the wall could be raised

Use a cutoff wall even if it's not needed based on current conditions to reduce the chance of a piping failure



Evaluating adaptation alternatives

Which is more cost-effective?

- Use *conservative designs* for weather extremes that may or may not occur
- Use current codes and standards and *adapt as required*

Future reconstruction to fix damaged components will disrupt service and will be expensive



Life-cycle cost analysis

Adaptation options

- Over-build now?
- Retrofit later?

Life-cycle cost analysis

- Enables comparing economic performance of alternative designs over the project's life
- Considers initial investment plus long-term costs of operation as well as costs to repair, retrofit, or reconstruct

Owner's dilemma: Make decisions based on least capital cost or life-cycle cost?



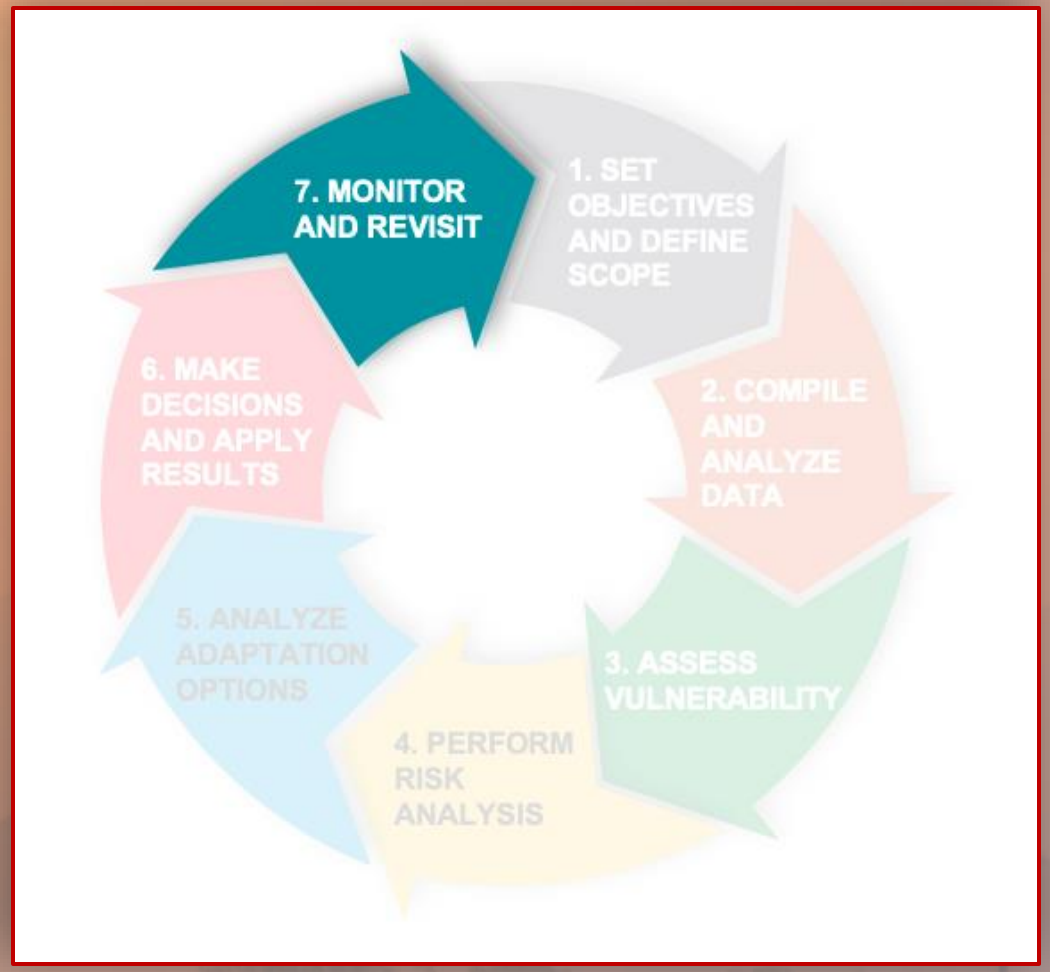
Monitor and Revisit

Ignoring climate change and doing business as usual is faith-based engineering

However, assuming worst-case conditions may be imprudent and wasteful

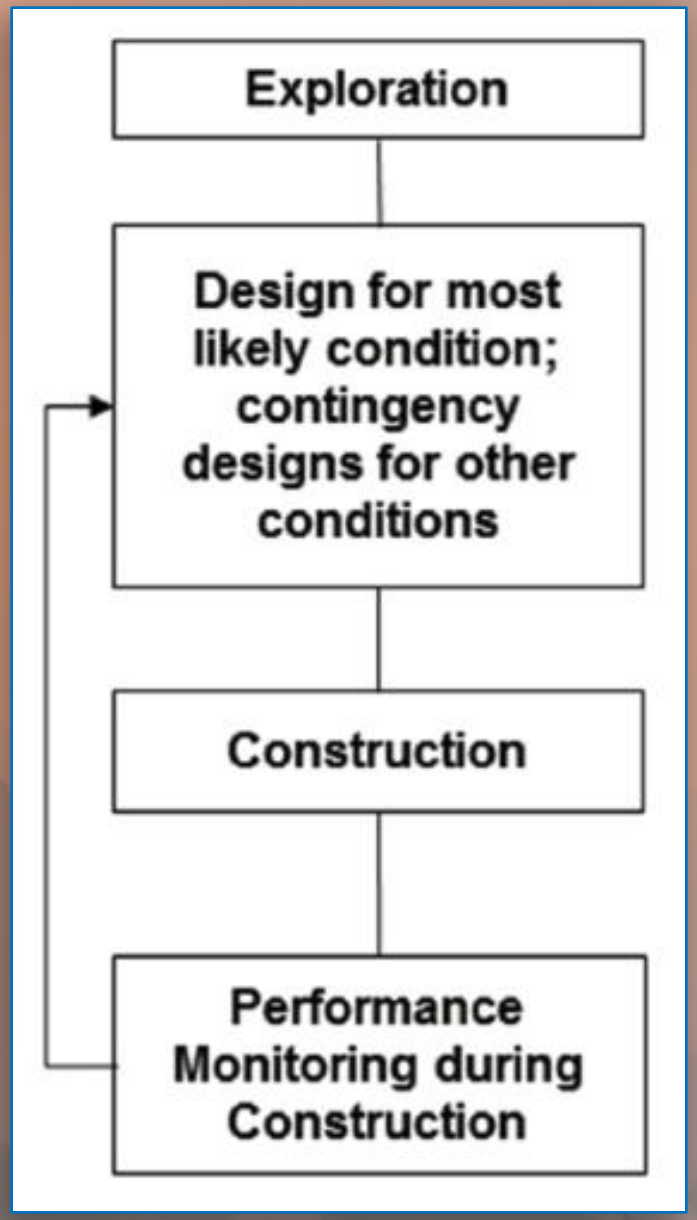
Adaptative management enables adjusting to conditions that differ from the best predictions of changing climate stressors

Continuing with business as usual and hoping for the best outcome is faith-based engineering



Adaptive management plans are like the Observational Method





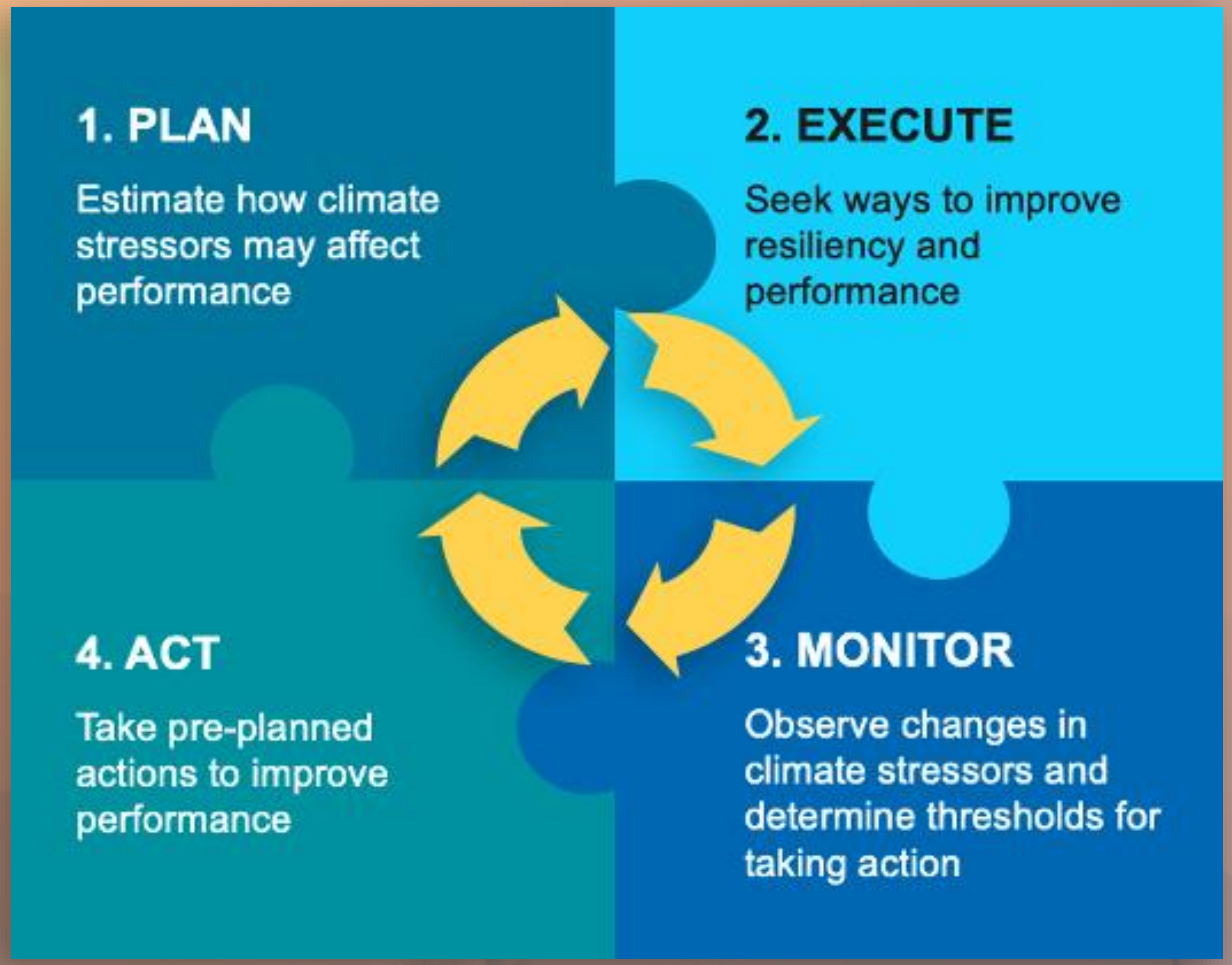
Adaptive management plans

Provide a flexible decision-making process

Designed to achieve specified objectives

Use ongoing knowledge acquisition, monitoring, and evaluation

Enable continuous improvements in project implementation



Devising an adaptive management plan

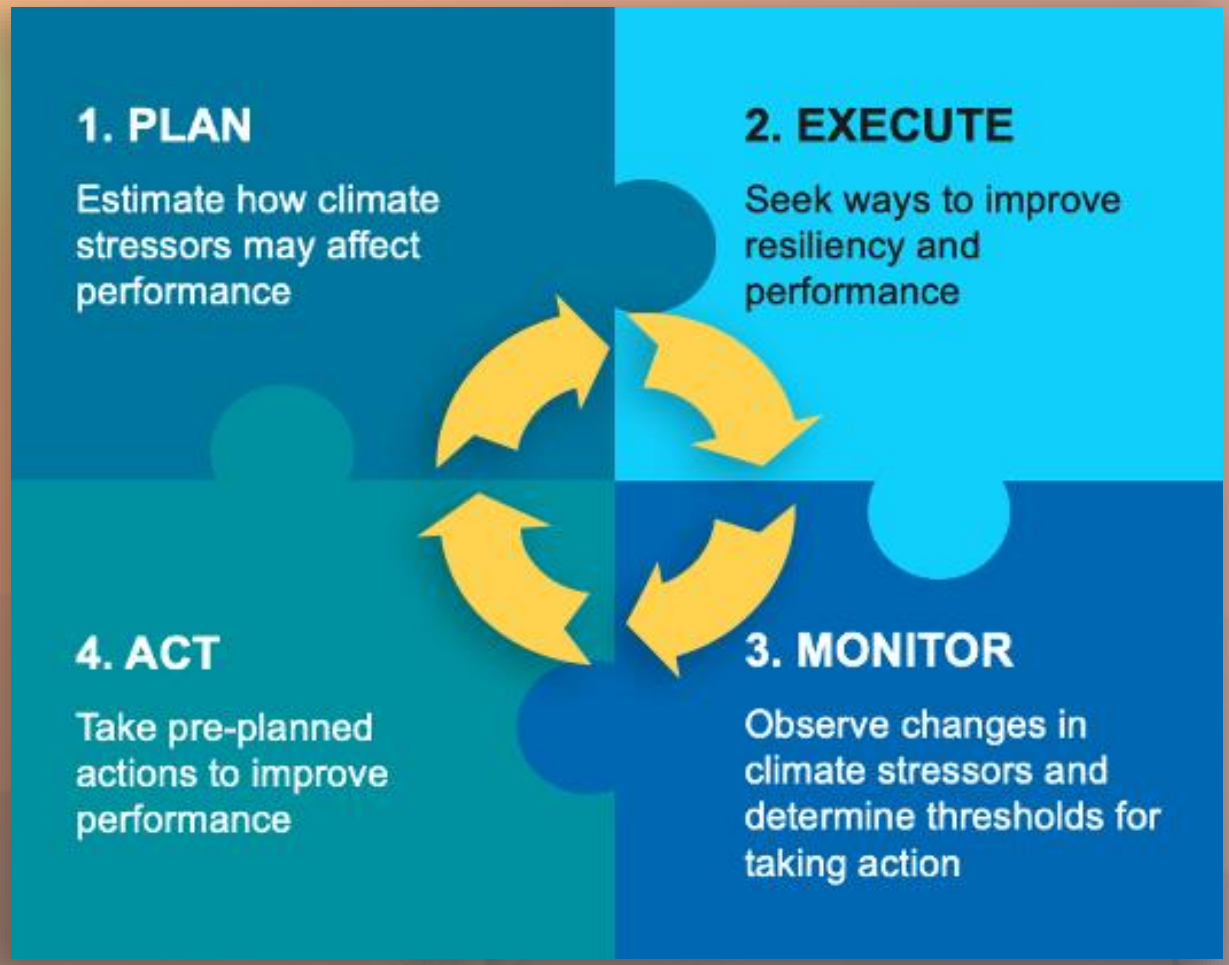
Risk analysis

- Establishes performance expectations
- Guides future adaptation

The future is uncertain – climate stressors will likely differ from best predictions

An AMP requires

- A plan to monitor climate stressors and component performance
- A plan of action if conditions differ
- The resources to monitor
- The thresholds for action
- The resources to act, if required



ADAPTIVE MANAGEMENT PROGRAM

	PROJECT COMPONENT	POTENTIAL VULNERABILITY	MONITORING NEEDS	POSSIBLE ACTIONS
CLIMATE STRESSOR				
HEAT	Mechanical and electrical equipment	Equipment malfunction Equipment overload	Temperature and temperature trends Equipment performance Energy efficiency	Upgrade or replace equipment to increase capacity and improve efficiency
INTENSE RAINFALL	Roof system Roof drainage Building structure	Roof pooling Structural overload	Extreme rainfall events Drain maintenance and performance Structural performance	Repair drains Improve maintenance Retrofit structural system
SNOW AND ICE	Roof system Roof drainage Building structure	Snow melt/roof ponding Structural overload Ice dams/pooling	Extreme rainfall events Drain maintenance and performance Structural performance	Repair drains Improve maintenance Retrofit structural system
CLIMATE HAZARD				
NUISANCE FLOODING	Electrical/mechanical equipment Internal drainage system Parking lot pavement	Internal drainage system overload Pavement/subgrade damage	Extreme rainfall events Drainage system maintenance and performance Pavement system and performance	Repair or replace drainage system Repair or replace pavement
WATERSHED FLOODING	Floodwall	Inadequate height of floodwall Floodwall instability Underseepage	Extreme rainfall events Flood depths and frequency Wall performance Seepage	Raise wall Reinforce wall Add seepage control measures

ADAPTIVE

	PROJECT COMPONENT			IBLE ACTIONS
CLIMATE STRESSOR				
HEAT	Mechanical and electrical equipment	**Temperature** and temperature trends Equipment performance **Energy efficiency**	**Upgrade or replace** equipment to increase capacity and improve efficiency	**de or replace** ent to increase y and improve cy
INTENSE RAINFALL	Roof system Roof drainage Building structure	Extreme **rainfall** events Drain **maintenance and performance** Structural performance	Repair drains **Improve maintenance** **Retrofit structural system**	drains **e maintenance** **t structural**
SNOW AND ICE	Roof system Roof drainage Building structure	Extreme rainfall events Drain maintenance and performance Structural performance	Repair drains Improve maintenance Retrofit structural system	drains e maintenance structural
CLIMATE HAZARD				
NUISANCE FLOODING	Electrical/mechanical equipment Internal drainage system Parking lot pavement	Extreme rainfall events **Drainage system maintenance and performance** **Pavement system and performance**	**Repair or replace** drainage system Repair or replace pavement	**or replace** e system or replace ent
WATERSHED FLOODING	Floodwall	Extreme rainfall events **Flood depths and frequency** Wall performance **Seepage**	**Raise wall** Reinforce wall **Add seepage control measures**	**wall** ce wall **epage control** **res**

ADAPTIVE MANAGEMENT PROGRAM

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WATERSHED FLOODING	Floodwall	Inad flooc Flood Underseepage	Wall performance **Seepage**	**ise wall** inforce wall **Add seepage control measures**

OVER-BUILD IN ADVANCE OF NEED

FOUNDATION DESIGNED TO ACCOMMODATE A HIGHER WALL




What could go wrong?

This is an emergency – treat it like one.
Consider climate change in every project.
Institution of Civil Engineers

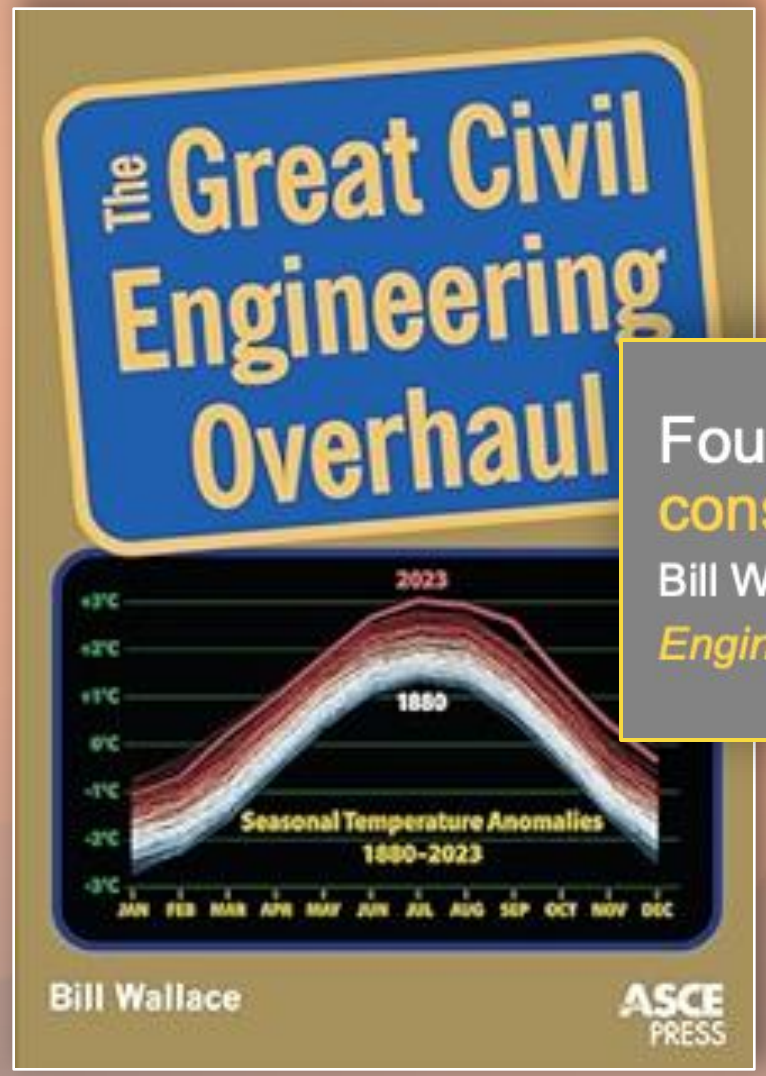




Climate records broken

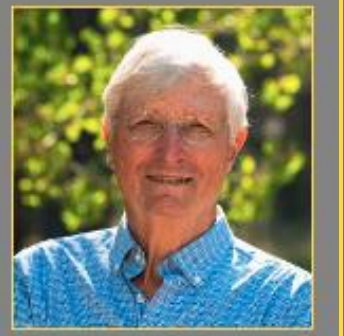
BBC NEWS

How can we motivate action?



Four things that may encourage us to consider climate change in every project.

Bill Wallace, Author of *The Great Civil Engineering Overhaul*



https://sp360.asce.org/personifyebusiness/Merchandise/Product-Details/productId/313258560

It's the right thing to do.	Most owners and stakeholders may not care. Considering climate change is not yet standard practice.
The risk to future generations if we don't take climate change seriously. The Tragedy of the Horizon: "The impact of climate change is … beyond the time horizon of most policymakers diminishing their urgency to act."	While an altruistic consideration, the tragedy of the horizon hampers action. Here's the real tragedy: The effects of climate change are happening now and will only worsen in the future.
The potential for cost savings from creative and sustainable solutions.	May be seen as more conservative and more costly. Need to overcome the mindset of basing decisions on lowest first cost.
Fear of claims and litigation arising from the adverse effects of climate change on project performance.	The default standard of care is based on adherence to current codes, standards, and design guidelines. Will the standard of care evolve as the changing climate degrades infrastructure performance and imperils public safety?

Potential ramifications for the design engineer

Negligence, failure to meet the standard of care

Claims by the client

- Failure to adapt to changing climate stressors
- Inaccurate estimates of the elevation and duration of flooding
- Inadequate floodwall design
- Structural damage (under-design)
- Inadequate drainage design
- Consequential damages

Third-party claims

- Injury or death (e.g., structural collapse)
- Slip-and-fall
- Personal damages



In ongoing legal battle, judge says I-12 barriers contributed to 2016 flooding in Walker

June 04, 2020 5:13 PM in News Source: WBRZ By: Jeremy Krail





The 2016 “no-name” storm caused three times the rainfall that occurred during Hurricane Katrina

In ongoing legal battle, judge says I-12 barriers contributed to 2016 flooding in Walker

June 04, 2020 5:13 PM in News Source: WBRZ By: Jeremy Krail



Storm estimated to be a 1000-year rainfall event

Median barrier on I-12 acted as a dam ponding runoff that flooded Walker

$20 billion in damages

A 2020 ruling concluded that design firms can be sued for negligence even though the barrier was built to *state standards (50-year storm event)*

423 Residential Homeowners File Suit Against Costello, Inc. For Faulty Design Of The Riverstone Subdivision Community

April 6, 2018



Flooding in the wake of Hurricane Harvey

Claim filed against designer of levee and pumping systems

Design based on 100-year base flood elevation

Plaintiffs claimed that design failed to consider five previous events with greater rainfall

Hurricane Harvey was the third 500-year event in three years

Summary



Putting it all together…

- Open the conversation on climate change
- Screen for hazards (geologic, climate stressors, and climate hazards)
- Identify adaptation alternatives
- Perform risk and life-cycle cost analyses
- Select preferred alternative
- Prepare and implement an adaptive management plan

HAZARDS SCREENING

	THREAT LEVEL	PROJECT COMPONENT	POTENTIAL VULNERABILITY	POTENTIAL FAILURE MODES	CONSEQUENCES OF FAILURE
GEOLOGIC HAZARD					
EARTHQUAKE					
EXPANSIVE SOIL					
LIQUEFACTION					
SLOPE INSTABILITY					
SUBSIDENCE					
CLIMATE STRESSOR					
HEAT					
INTENSE RAINFALL					
SEA LEVEL RISE					
SNOW AND ICE					
WIND					
CLIMATE HAZARD					
DROUGHT					
LANDSLIDE					
NUISANCE FLOODING					
PERMAFROST THAW					
SEVERE EROSION					
WATERSHED FLOODING					
WILDFIRE					



The climate is changing…

Heat retained by GHGs is causing a climate crisis

Weather extremes, wildfires, and sea level rise are affecting the performance and reliability of infrastructure

Climate change effects on infrastructure threaten the public's health, safety, and welfare

Geotechnical engineers have a special responsibility because we design and build the infrastructure that shapes the way that people live

Non-stationarity is the new reality and the future is uncertain

Some building codes and policy-driven standards may no longer be reliable

Blindly following codes, standards, and current practices may no longer result in safe and reliable performance

Keep calm, many practices won't change

Like it or not…

The climate crisis is an emergency and a game-changer for geotechnical engineers

Enhance knowledge, skills, and attitudes

Recognize ethical responsibilities

Bring climate change into every conversation

Consider climate change in every project

Seize opportunities to advise clients about the effects of a changing climate

Apply risk and life-cycle cost analyses and adaptive management

Design and build for the right outcomes

Stress test all projects against a wide range of climate extremes

Improve awareness of potential liability

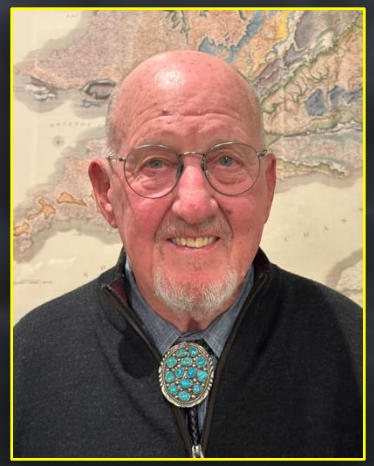
Refuse business as usual

- Avoid faith-based engineering
- Don’t work for climate deniers

Embrace radical change

Share your successes (and your setbacks)

Thank you!



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