"Partners in Planning"

Climate Science in Floodplain Management

Kristina Murphy, EIT, CFM

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Objectives

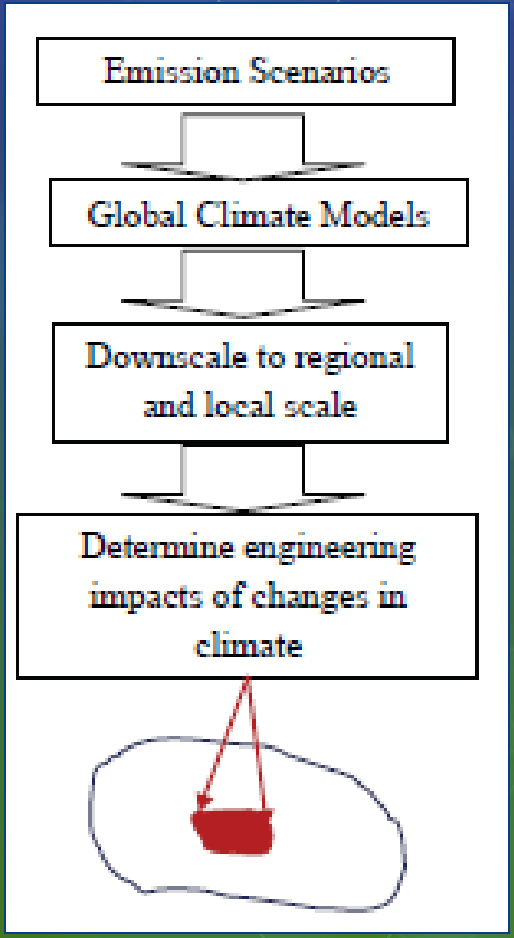
Climate science and climate resilience are terms that have recently made their way into a number of federal documents and grant programs, including the Biggert-Waters reform act to the National Flood Insurance Program and the Federal Flood Risk Management Standard. These changes may affect floodplain management for our communities and clients.

- **What are the benefits of the climate science approach?**
- **What are the projected effects and impacts to floodplains from climate change?**
- **What is the Federal Emergency Management Agency's (FEMA) policy on climate change?**
- **What information will we have to address?**
- **How are planning and transportation agencies incorporating climate science into their programs?**
- **What climate data, technical references, and studies are available to assess and plan for future flood risk from extreme events and shifts in the climate?**

Benefits of the Climate Science Approach

Engineers currently use historic data for designing infrastructure expected to persist for 20 to 50 years in the future. Past records do not contain all the possibilities of extremes and trends of the future.

The climate science approach uses available climate model output to assist with predicting future trends for planning and design.

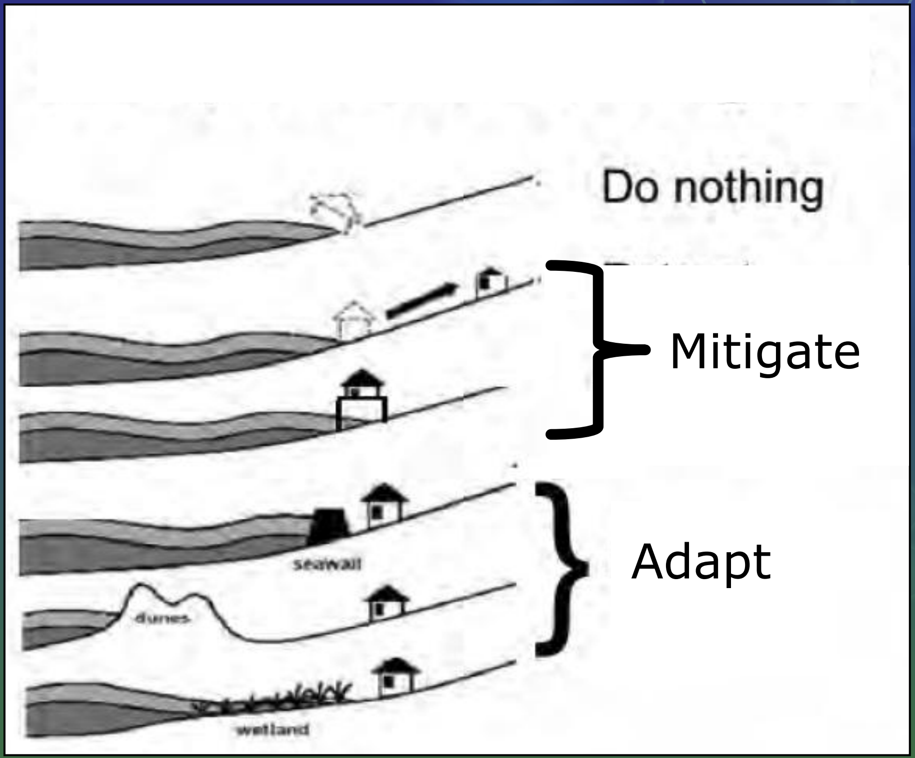


Benefits of the Climate Science Approach

- The climate science approach supports adaptation and mitigation, which reduces vulnerability and increases resilience to extreme and/or more frequent events.

- Resilience: the ability to adapt to changing conditions and rapidly recover from disruptions.

- Build better rather than repeatedly rebuild.



- Adapt: change to be better suited for the environmental conditions.
- Mitigate: actions to improve resilience and reduce vulnerabilities to future risks.

Benefits of the Climate Science Approach

- Limit property and infrastructure damages
- Limit economic losses
- Public safety, avoid casualties
- Avoid loss of essential services (utilities)
- Avoid loss of function of critical facilities and roads
  - Displacements, disruptions
  - Road detours, closures
- Emergency response (evacuations, rescues)
- Reduce costs to repair or rebuild from more frequent and/or extreme events
- Responsible spending of tax payer money

Chicago O'Hare Airport

One large event can result in total loss of use.

Highway 34 & Big Thompson Creek, Colorado

Benefits of the Climate Science Approach

"Future" Conditions Analyses

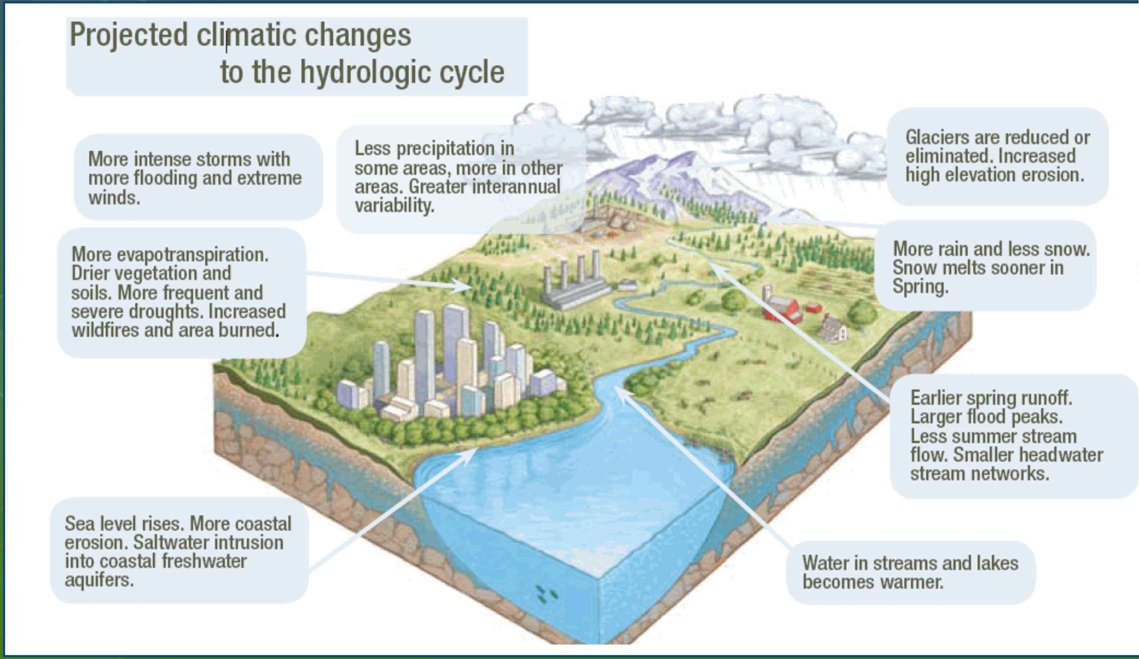
- **Future precipitation + Future land use → Future flows → Future floodplains**
  - Elevate critical buildings (hospitals, wastewater treatment plants)
  - Elevate critical roads; size culverts and bridges to withstand future extreme events
  - Reduce and limit erosion and property and infrastructure damages
  - Avoid high-risk areas
  - Evaluate open space preservation requirements and set-backs
  - Avoid putting properties "into" the Special Flood Hazard Area (SFHA) when updating modeling and mapping
- **Future precipitation + Future land use → Future flows → Future utilities**
  - Account for future increases to the design storm
  - Size storm sewers and culverts to meet design life flows
  - Pipe outlet (tail-water) considerations
  - Pipe surcharging in known problem areas
- **Cost benefit analysis of increased protection**
- **Plan and budget for future retrofits**

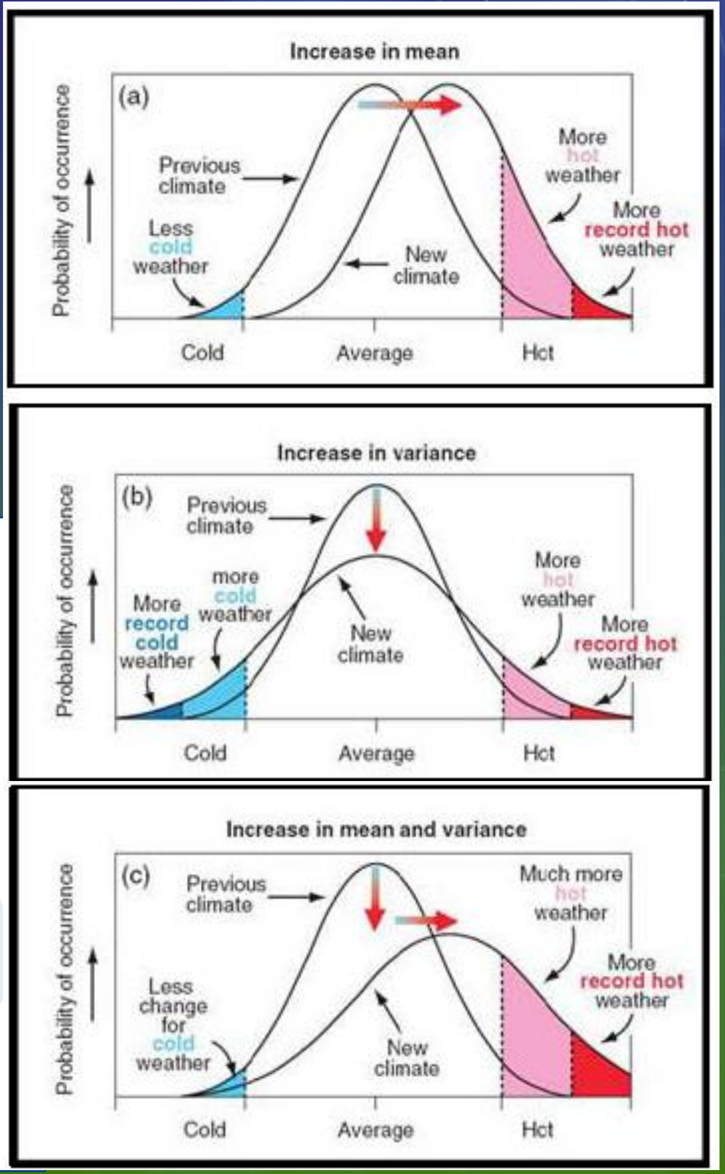
Interstate 25, Denver, Colorado

Climate Science Background

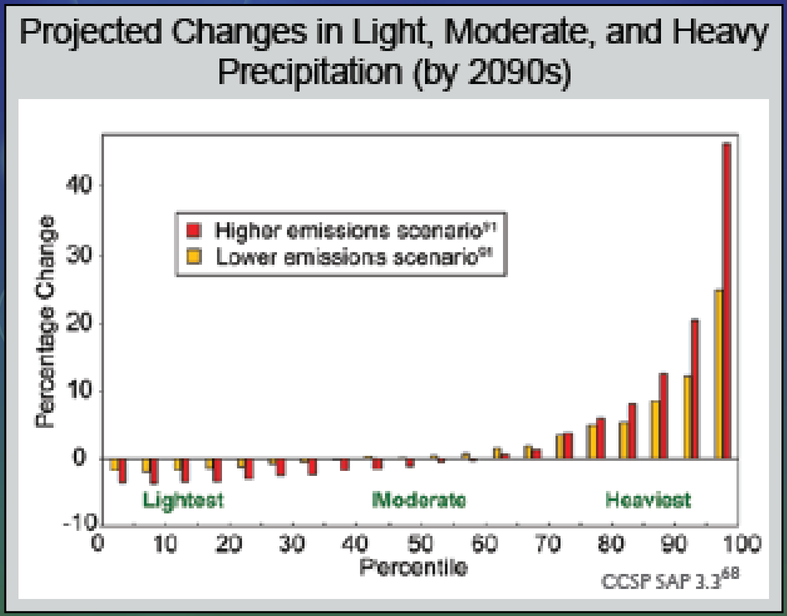
Climate is the average of weather at a particular location. Large or abrupt shifts in frequency of extreme events are of concern.

- Average temperature increase of 2^{o}C is predicted.
- 1^{o}C warmer atmosphere can hold 7% more water vapor.



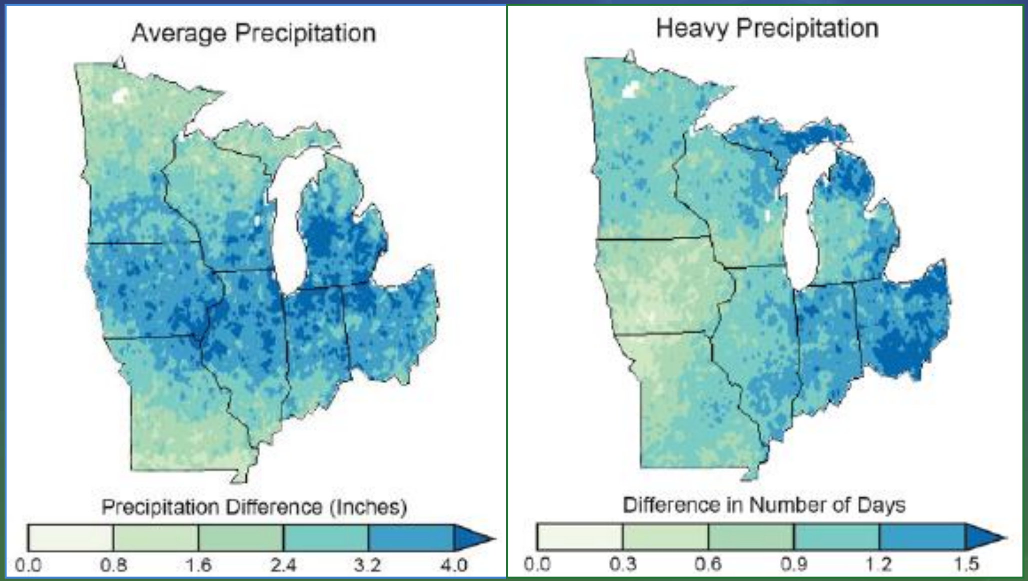


Climate Change Effects on Precipitation



Projected changes increase exponentially for the heaviest precipitation and slightly decrease for the lightest precipitation.

Projections for 2041-2070 compared to 1971-2000
for CMIP3 A2 emissions scenario

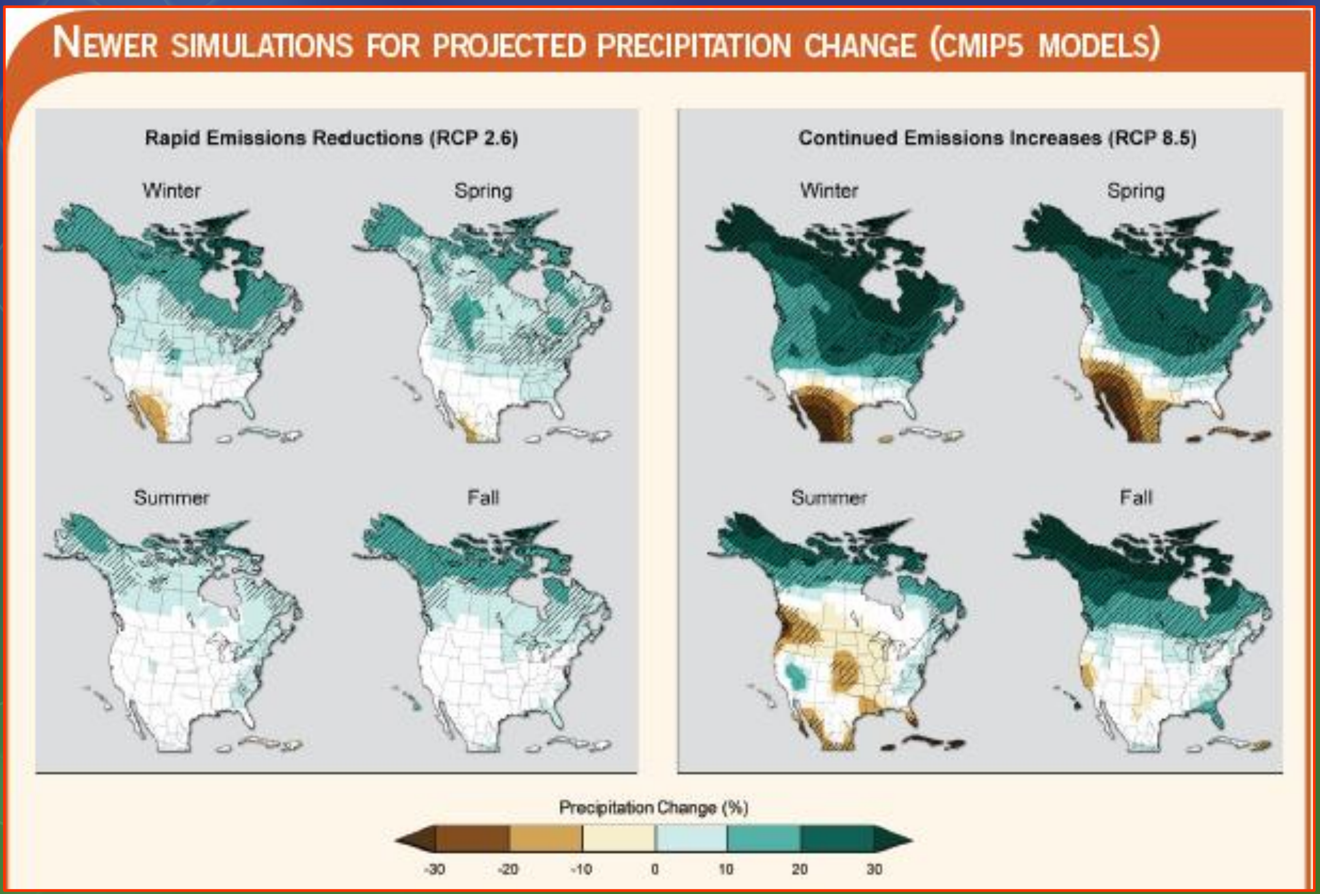


Dynamics of where and when precipitation will fall is complex, resulting in geographic variability.

Source: NCA 2014

Climate Change Effects on Precipitation

Projected Changes from Climate Change Models

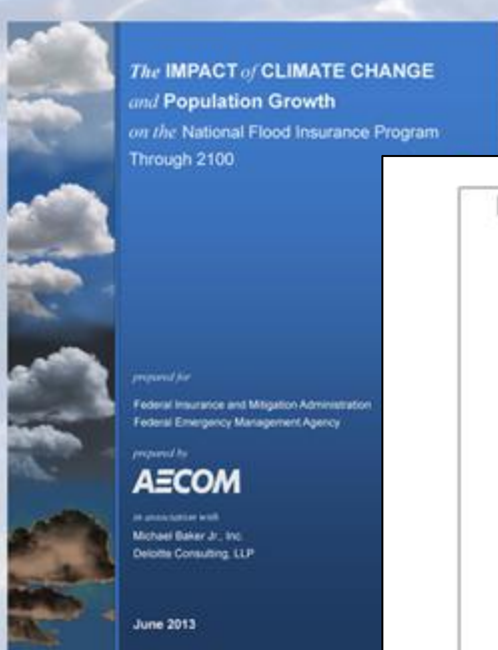


Seasonal precipitation change projections for 2071-2099 compared to 1970-1999

Source: NCA 2014

- **Increased intense precipitation → flooding**
- Increased frequency and severity of droughts
- Increased alternating wet and dry periods
- Changes in solid vs. liquid precipitation and snow-melt timing

Climate Change Impacts to Floodplains



www.aecom.com/deployedfiles/Internet/News/Sustainability/FEMA%20Climate%20Change%20Report/Climate_Change_Report_AECOM_2013-06-11.pdf

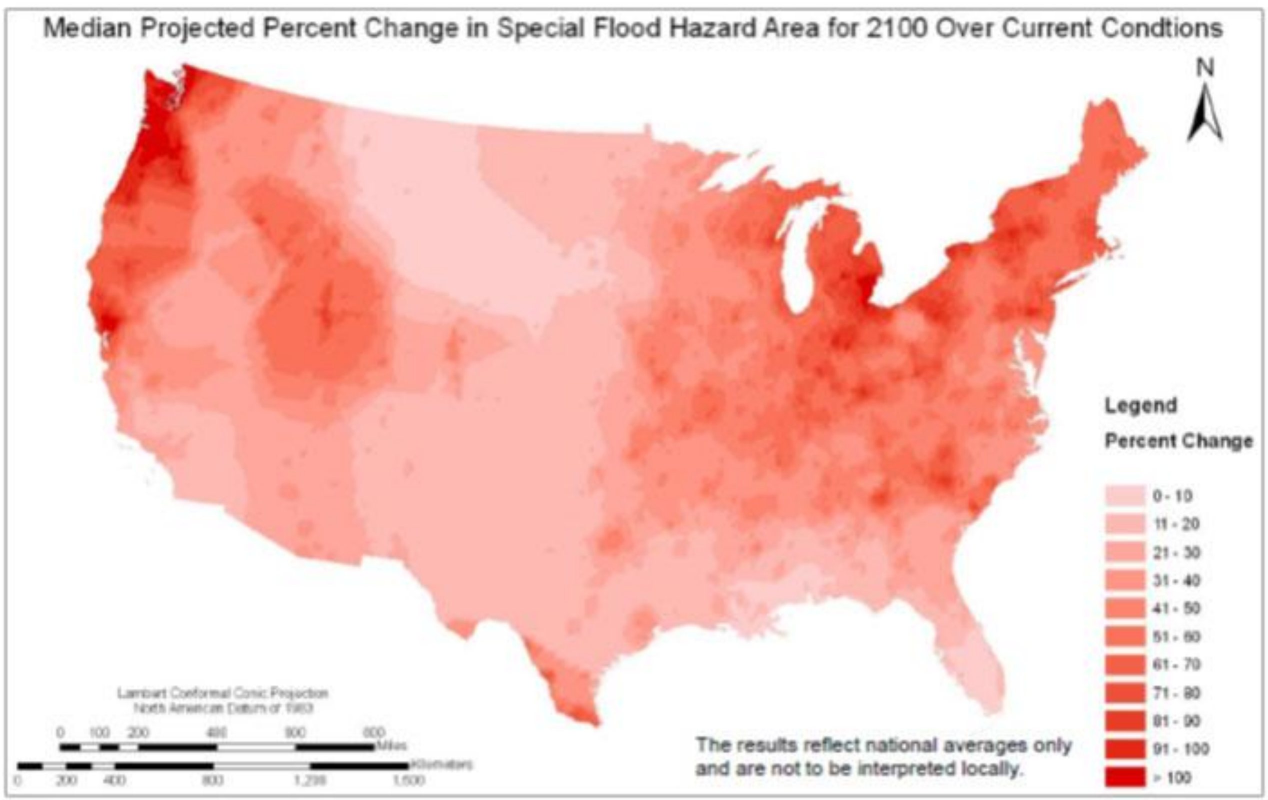


Figure 4-10. The median (50th percentile) relative change of the SFHA at epoch 5 (2100). Changes are with respect to current conditions.

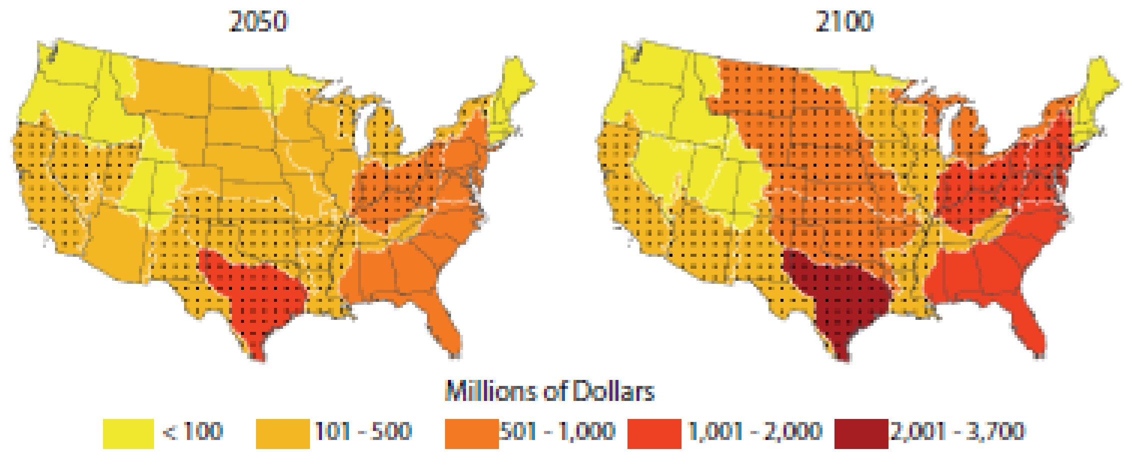
Considered changes to precipitation, land use, and sea level rise.

Climate Change Impacts to Floodplains

- By 2100, the 1% annual chance (100-year) floodplain depth and lateral size is projected to increase, on average, by 45% above current levels across the nation.
  - ***About 30% of these increases in floodplain area and flood depth may be attributed to normal population growth (i.e. land use) while the remaining <u>70% represents the influence of climate change</u>.***
- By 2100, the population within riverine and coastal floodplains will increase by 130-155%.
  - The total number of policyholders participating in the NFIP may increase approximately 80-100%.
  - The average premium per policy will increase by about 10-70%.

Figure 1. Estimated Flood Damages Due to Unmitigated Climate Change

Estimated flood damages under the Reference scenario in 2050 and 2100 for the IGSM-CAM climate model (millions 2014$). Results are presented for the 18 2-digit hydrologic unit codes (HUCs) of the contiguous U.S. Stippled areas indicate regions where the projected damages are significantly different from the historic period (at a 90% confidence interval).



Source: EPA CIRA

Climate Models

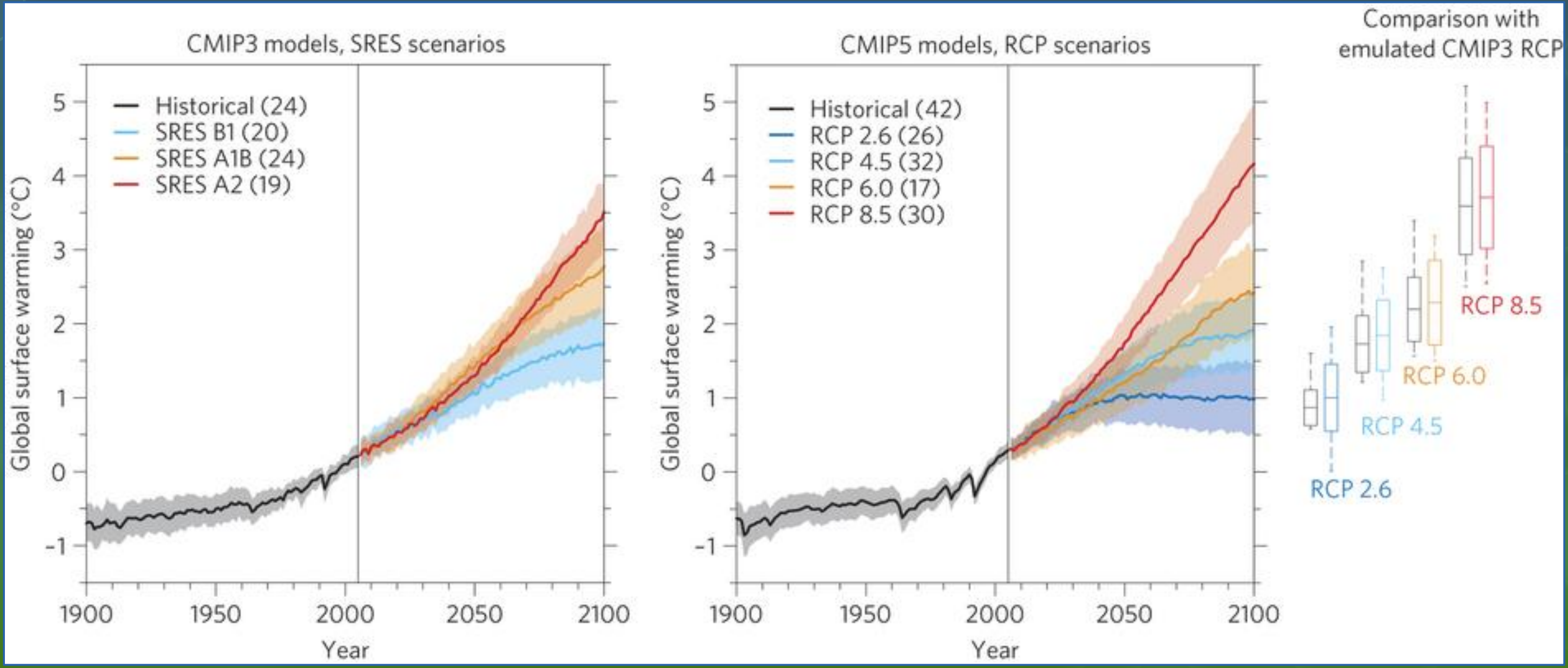
- Climate models are not the same models used to forecast daily weather.
- Climate models represent large-scale land-ice-ocean-atmosphere circulations. Limitations include:
  - Models do not account for outlier (rare) events.
  - Models assume that feedback loops will remain consistent (stationarity).
- Due to grid size resolution, models miss small-scale storms, such as thunderstorms and tornadoes.
- All models contain unknowns and approximations resulting in uncertainty.
- Precipitation results from various scenario runs lack agreement which implies greater uncertainty.

Climate Models

What climate change model output data is available?

Global Circulation Models (GCMs) and Regional Climate Models (RCMs)

- Projections → Coupled Model Intercomparison Project (CMIP) – versions 3 and 5
- Emissions Scenarios
  - CMIP3 (2010) → Special Report on Emissions Scenarios (SRES)
  - CMIP5 (2013) → Representative Concentration Pathways (RCPs)



Climate Models

What climate model data is available? (continued)

Sampling of CMIP5 Model Runs from Various Government Agencies

CMIP5 Projection Model Runs	WCRP CMIP5 Climate Model ID	RCP 2.6 runs[2]	RCP 4.5 runs	RCP 6.0 runs	RCP 8.5 runs
National Center for Atmospheric Research	CCSM4	1-2, 3-5	1-2, 3-5	1-2, 3-5	1-2, 3-5
NOAA Geophysical Fluid Dynamics Laboratory	GFDL-CM3	1	1	1	1
	GFDL-ESM2G	1	1	1	1
	GFDL-ESM2M	1	1	1	1
NASA Goddard Institute for Space Studies	GISS-E2-H-CC		1		
	GISS-E2-R	1	1-5	1	1
	GISS-E2-R-CC		1		

Model Runs Available from U.S. Bureau of Reclamation's Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections (DCHP)

Provides daily and monthly downscaled climate model data for continental United States

Daily data attributes:

- **Variables**: precipitation, minimum surface air temperature, maximum surface air temperature
- **Time**: 1961-2000, 2046-2065, 2081-2100 (CMIP3); 1950-2099 (CMIP5)
- **Resolution**: 1/8° grids (~56 sq. miles)
- **Downscaling**: Bias-Correction Constructed Analogues (BCCA)
- **Models**: 9 for CMIP3, 21 for CMIP5

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

Federal Initiatives

- President's Climate Action Plan - 2013
- Executive Order 13653: Preparing the U.S. for the Impacts of Climate Change - 2013
- Task Force on Climate Preparedness and Resilience - 2014
- Federal Emergency Management Agency (FEMA)
  - Climate Change Adaptation Policy Statement - 2012
- U.S. Environmental Protection Agency (EPA)
  - National Stormwater Calculator – Climate Assessment Tool
- U.S. Geological Survey (USGS)
  - National Climate Change Viewer
- Army Corps of Engineers
  - Committee on Climate Preparedness and Resilience (CCPR) – Adaptation Plan
- Federal Highway Administration (FHWA)
  - Pilot projects, tools, and studies

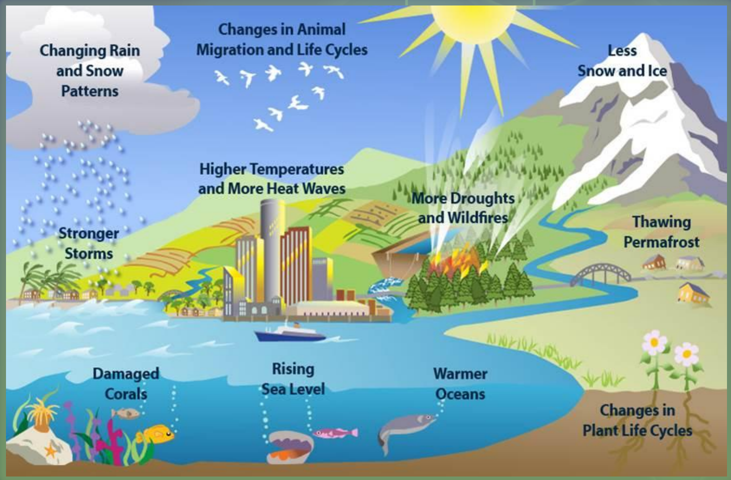
Links

- FEMA
  - www.fema.gov/climate-change
- U.S. Environmental Protection Agency (EPA)
  - http://toolkit.climate.gov/tool/national-stormwater-calculator%E2%80%94climate-assessment-tool
  - www3.epa.gov/climatechange/science/future.html
  - www3.epa.gov/climatechange/adaptation/
- USGS
  - http://www.usgs.gov/climate_landuse/
- Army Corps
  - http://www.usace.army.mil/Missions/Sustainability/BuildingClimateResilience.aspx
- Federal Highway Administration (FHWA)
  - www.fhwa.dot.gov/engineering/hydraulics/hydrology/change.cfm
  - www.fhwa.dot.gov/environment/climate_change/adaptation/
- U.S. Department of Transportation (DOT)
  - www.climate.dot.gov

FEMA Climate Change Policy

FEMA Climate Change Adaptation Policy Statement

- Challenges posed by climate change:
  - More intense storms
  - Frequent heavy precipitation
  - Heat waves
  - Drought
  - Extreme flooding
  - Higher sea levels



- Specific areas where climate change could influence FEMA's capabilities and need for services:
  - Impacts on mitigation, preparedness, response, and recovery operations
  - Resiliency of critical infrastructure and various emergency assets
  - Climate change could trigger indirect impacts that increase mission risks

www.fema.gov/media-library-data/20130726-1919-25045-6267/signed_climate_change_policy_statement.pdf

FEMA Climate Change Policy

Actions to integrate climate change adaptation considerations into the Agency's programs, policies, and operations:

- Establish partnerships with other agencies and organizations that possess climate science and climate change adaptation expertise.
- **Continue to study the impacts of climate change on the National Flood Insurance Program (NFIP) and incorporate climate change considerations in the NFIP reform effort.**
- **Evaluate how climate change considerations can be incorporated into grant investment strategies with specific focus on infrastructure; evaluate methodologies or tools such as benefit/cost analysis.**
- **Understand how climate change will impact local communities and engage them in addressing those impacts.**
- Promote building standards and practices, both within FEMA programs and in general, that consider the future impacts of climate change.
- Evaluate the potential impact of climate change may have on existing risk data and the corresponding implications for Threat Hazard Identification Risk Assessment (THIRA) development and operational planning.
- Continue to pursue a flexible, scalable, well equipped, and well trained workforce that is educated about the potential impacts of climate change.

Biggert-Waters Act

- Requires a Technical Mapping Advisory Council (TMAC) to issue guidance on how to incorporate best available climate science into flood insurance rate maps. **www.fema.gov/technical-mapping-advisory-council**

- "Rise in sea level and future development on flood risk."

- Detailed specific scientific considerations should be included when updating flood risk maps, including any relevant information on:
  - coastal inundation and storm surge modeling;
  - stream flows, watershed characteristics, and topography;
  - land subsidence, coastal erosion areas, and changing lake levels; and
  - best available science regarding future changes in sea level rise, precipitation, and hurricane intensity.

Source: Government Accountability Office Report

Technical Mapping Advisory Council (TMAC)

Future Conditions Risk Assessment and Modeling Report

Recommendation 1: Provide future conditions flood risk products, tools, and information for coastal, Great Lakes, and riverine areas. The projected future conditions should use standardized timeframes and methodologies wherever possible to encourage consistency and should be adapted as actionable science evolves.

Recommendation 4: Provide future conditions flood risk products and information for riverine areas that include the impacts of: future development, land use change, erosion, and climate change, as actionable science becomes available. Major elements are:

- Provide guidance and standards for the development of future conditions riverine flood risk products.
- Future land use change impacts on hydrology and hydraulics can and should be modeled with land use plans and projections, using current science and build upon existing model study methods where data are available and possible.
- Future land use should assume built-out floodplain fringe and take into account the decrease of storage and increase in discharge.
- No actionable science exists at the current time to address climate change impacts to watershed hydrology and hydraulics. If undertaken, interim efforts to incorporate climate change impacts in flood risk products and information should be based on existing methods, informed by historical trends, and incorporate uncertainty based upon sensitivity analyses.

Where sufficient data and knowledge exist, incorporate future riverine erosion (channel migration) into flood risk products and information.

Technical Mapping Advisory Council (TMAC)

Future Conditions Risk Assessment and Modeling Report

Datasets of climate model output translated into engineering formats for precipitation are not currently available. Sea level rise data is available.

Sub-Recommendation		Timing
5-15	FEMA should use observed riverine trends to help estimate what future conditions might look like. In watersheds where floods of interest may decrease in magnitude and frequency then use existing riverine study results as the basis for flood hazard mapping. In watersheds where floods exhibit increase in magnitude or frequency then use best available science to determine future hydrology and flood hazards.	Short-term
5-16	FEMA should work with other Federal agencies via the Advisory Committee on Water Information sub-committee on hydrology to produce a new method to estimate future riverine flood flow frequencies. This method should contain ways to consistently estimate future climate-impacted riverine floods and address the appropriate range of flood frequencies needed by the NFIP.	Long-term

One important gap identified is to improve the riverine climate-informed science option is to convene a working group that produces a new method to estimate projected future flood flow frequencies.

Source: http://www.fema.gov/media-library/assets/documents/111853

Federal Flood Risk Management Standard (FFRMS)

FFRMS will require any construction funded by federal money, including disaster relief grants, to meet these standards.

When complying with this Executive Order (13690), the floodplain shall be established using one of the following approaches:

- ***Climate Informed Science Approach*** – The elevation and flood hazard area that result from using a climate-informed science approach that uses the best-available, actionable hydrologic and hydraulic data and methods that integrate current and future changes in flooding based on climate science. For critical actions, the elevation determined must be higher than the elevation under the freeboard value approach.
- ***Freeboard Value Approach*** – The elevation and flood hazard area that result from using the freeboard value, reached by adding an additional 2 feet to the base flood elevation for non-critical actions and from adding an additional 3 feet to the base flood elevation for critical actions.
- ***"500-year" Elevation Approach*** – The area subject to flooding by the 0.2-percent-annual-chance flood.

Guidelines released October 8, 2015 state that the Climate Informed Science Approach is preferred.

Planning & Transportation

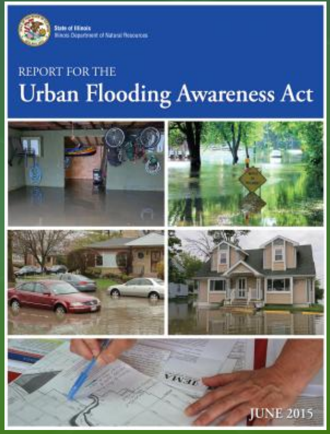
- Effective March 2016, Hazard Mitigation Plans (HMPs) do not have to use the term "climate change" but must include:
  - Probabilities of future hazard events, including projected changes in occurrences for each natural hazard (floods, droughts, temperatures) in terms of location, extent, intensity, frequency, and/or duration; and,
  - Considerations of changing future conditions, including long-term changes in weather patterns and climate on the identified hazards.
- Federal Highway Authority
  - Order 5520 funds climate analysis in projects
  - Hosted International Conference on Surface Transportation System Resilience to Climate Change and Extreme Weather Events – September 2015

Source: www.fema.gov/hazard-mitigation-planning-frequently-asked-questions

State References

Report for the Urban Flooding Awareness Act (June 2015)

- Chapter 2: Climate Trends and Climate Change
- No longer rely on analyses of past data to estimate future events. Necessary to account for the nonstationary nature of precipitation and flooding.
- Key Findings:
  - Precipitation has increased by 10% in the last century. Much of this increase has been from the more intense storms of over an inch. This pattern of more intense storms is expected to continue.
  - Although there is significant uncertainty in projections, increases in the frequency and intensity of extreme precipitation events and urban flooding are projected.
- Recommendations:
  - Update rainfall frequency distributions every 15 years.
  - When planning stormwater infrastructure modifications and enhancements, local governments should include future precipitation projections and land use where available.



State References

General NPDES Permit No. ILR40:

- Public Education and Outreach on Storm Water Impacts
  - Educational materials shall include information on the potential impacts and effects on storm water discharge due to climate change.
- Post-Construction Storm Water Management in New Development and Redevelopment
  - Strategies shall include effective water quality and watershed protection elements and shall be amenable to modification due to climate change.
  - Evaluation of existing flood control techniques to determine potential impacts and effects due to climate change.
  - Develop and implement a process to assess the water quality impacts in the design of all new and existing flood management projects. This process will include assessment of any potential impacts and effects on flood management projects due to climate change.
- Comments and Response to Draft Permit:
  - Commenters are concerned that local entities lacked the expertise to predict the potential impacts of climate change on weather patterns affecting their communities.
  - Illinois EPA's intent is to have communities begin to prepare initial planning efforts for extreme weather events and to educate the public on potential impacts from climate change.

Technical References

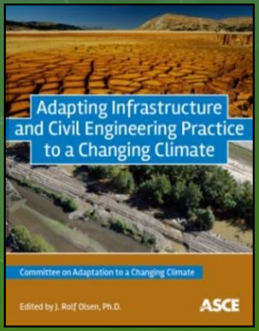
- **National Climate Assessment (NCA)** http://nca2014.globalchange.gov
  - Released in 2014
  - Chapters by regions and sectors:
    - Water
    - Energy
    - Transportation
    - Urban
    - Land Use and Land Cover Change
- National Research Council (NRC) www.nap.edu
- Intergovernmental Panel on Climate Change (IPCC) www.ipcc.ch
- U.S. Global Change Research Program www.globalchange.gov
- Federal Climate Clearinghouse www.climate.gov

Technical References

- **Federal Highway Administration (FHWA)**
  - "Regional Climate Change Effects: Useful Information for Transportation Agencies" www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/climate_effects/
  - "HEC 17: Highways in the River Environment – Floodplains, Extreme Events, Risk and Resilience" (Spring 2016)
- **U.S. Environmental Protection Agency (EPA)**
  - "Climate Change in the U.S.: Benefits of Global Action" www.epa.gov/cira
  - "Climate Change Indicators in the U.S." www3.epa.gov/climatechange/science/indicators/
  - "Community-Based Adaptation to a Changing Climate" www.epa.gov/localadaptationtraining/community-basedadaptation_handout.pdf
- **U.S. Geological Survey (USGS)**
  - "Climate Change and Water Resources Management: A Federal Perspective" http://pubs.usgs.gov/circ/1331/
  - "U.S. Geological Survey Climate and Land Use Change Science Strategy – A Framework for Understanding and Responding to Global Change" http://pubs.usgs.gov/circ/1383a/

Technical References

- Association of State Floodplain Managers (ASFPM)
  - Foundation Forum "Climate-Informed Sciences and Flood Risk Management – Opportunities and Challenges" (9/17/15) http://www.asfpmfoundation.org/flood-policy-forums/2015-forum
- American Planning Association (APA)
  - "Policy Guide on Planning & Climate Change" (4/11/11) www.planning.org/policy/guides/pdf/climatechange.pdf
- American Society of Civil Engineers (ASCE)
  - Committee on Adaptation to a Changing Climate www.asce.org/climate-change/committee-on-adaptation-to-a-changing-climate/
  - "Adapting Infrastructure and Civil Engineering Practice to a Changing Climate" (June 2015) http://ascelibrary.org/doi/pdf/10.1061/9780784479193
  - Recommends low regret options and quantifying uncertainty.



Studies

Federal Highway Administration

- Climate Change Resilience Pilot Projects and Webinars
  - Climate Change & Extreme Weather Vulnerability Assessment Framework
- Climate Change Adaptation Tools
  - CMIP Climate Data Processing Tool
  - Vulnerability Assessment Scoring Tool
- Transportation Engineering Approaches to Climate Resiliency (TEACR) Study
  - Gap Analysis report
- The Impact of Climate Change on Stream Stability Study
  - Focused on smaller precipitation events of longer duration and/or greater frequency of occurrence.

Other concerns: temperatures and winds, operation and maintenance

Studies

Creating Resilience to Climate Change: Cost-Effective Land Conservation in the Floodplain

Year Initially Funded: 2012

Sector (s) N/A

Location N/A

Annual Project Report:

The PIs will adapt a widely used GIS-based model of flooding (Hazus, a tool developed by FEMA and routinely used for flood loss modeling) to include climate change and site-specific data on economic exposure, and then link this model with a benefit-cost analysis of alternative land use adaptation policies.

Principal Investigator (s): Walls

Communication of Climate Change Data for Community Assessment of Impacts of Severe Storms on Urban and Stormwater Infrastructure and Flood Risk

Year Initially Funded: 2014

Sector (s) Extreme Events

Location Illinois

Annual Project Report:

The PIs propose to demonstrate a method to formulate climate data in a format that can be readily used to assess future climate scenarios for extreme events in commonly used models for sizing stormwater infrastructure and identifying flooding potential. Future climate data will be analyzed to prepare precipitation isohyetals for selected design storm frequencies which can be readily used to model future climate conditions stormwater runoff and flood risk.

Principal Investigator (s): Sally McConkey, Markus Momcilo (Center for Watershed Science, IL State Water Survey)

Conclusions

- Consider future conditions to ensure we meet the design life, especially for critical infrastructure and known problem areas.
- Climate models are the best available information that we have to assess future conditions.
- Use future conditions precipitation with future conditions land use in models to determine future floodplains to:
  - Preserve floodplains;
  - Reduce and limit property and infrastructure damages;
  - Reduce flood insurance premiums;
  - Avoid putting people "into" the floodplain; and,
  - Reduce the need for grand-fathering and future buy-outs.
- Translated climate model output is available for sea level rise. Future precipitation is not available.
- Climate data is currently required for Hazard Mitigation Plans. Federal and state government are promoting climate science approaches.

Questions or comments?

Contact information:

Kristina Murphy

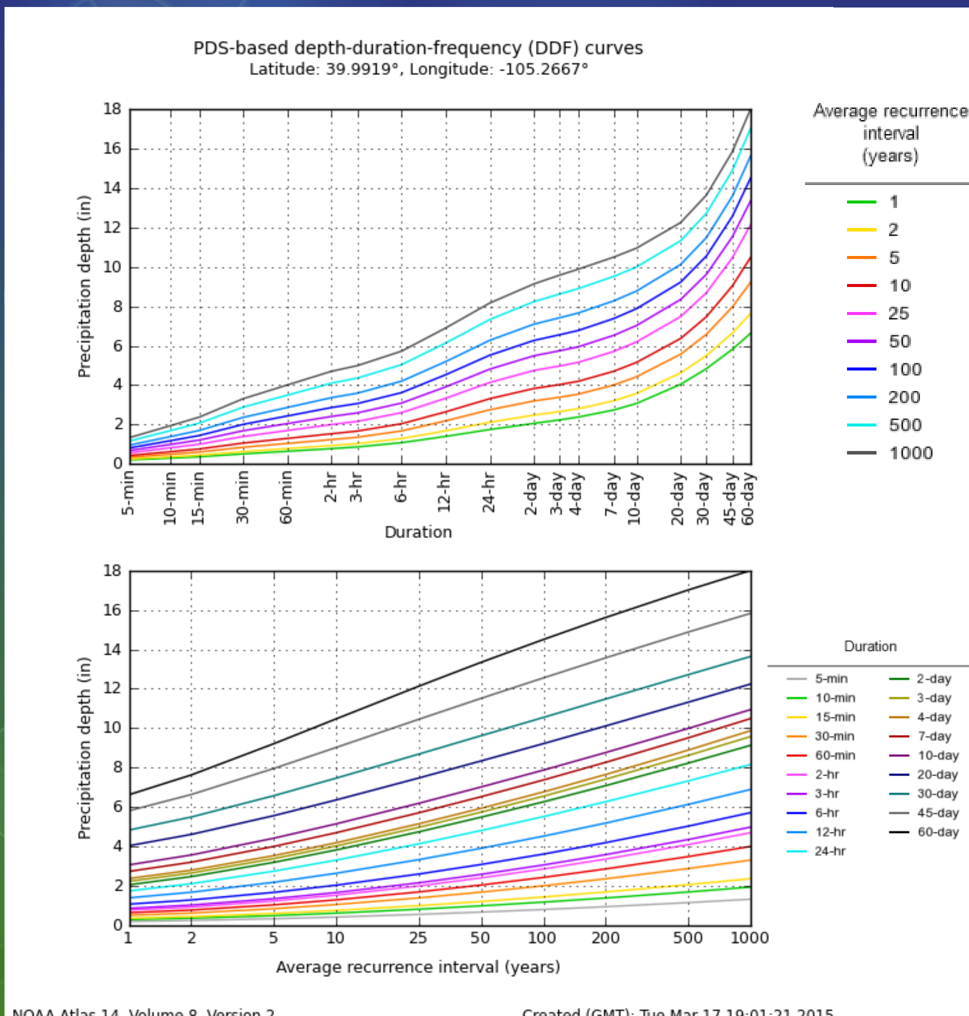
(630) 363-4731

Kristina.Murphy@dupageco.org

Recommendations

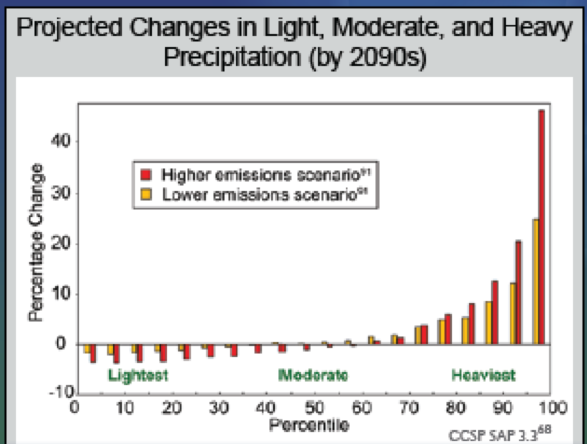
"Future" Precipitation Depth Duration Frequency (DDF) Curves

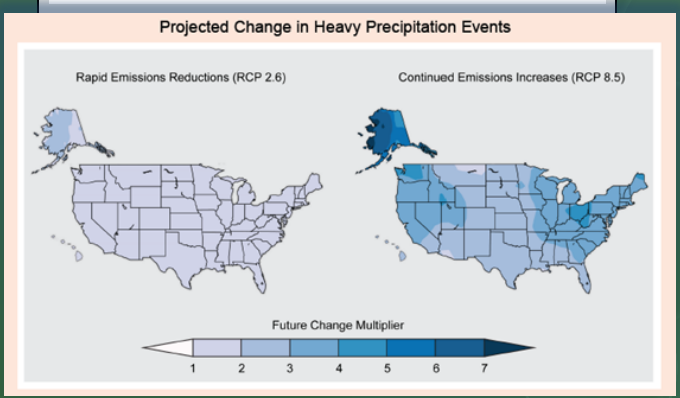
NOAA Atlas 14 at Boulder, CO



Graphic Credit: DOC NOAA NWS OHD HDSC

Future DDF Curves would reflect changes over the entire recurrence interval.





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Apply to regional analyses rather than point data.

Recommendations

- Seek assistance from climate scientists. Decide on which climate model projections and scenarios to use and acceptable methodologies to translate the data into standard engineering formats.
- Understand limitations of climate models
  - Quantify uncertainty
- Data requirements:
  - Need data for analysis, not percentages, in addition to viewers and tools
  - Need data to correspond to annual probability of occurrence
  - Need data corresponding to typical design life (10, 20, 50 years)
  - Create confidence levels to link decision-making to likelihood of occurrence (imminent vs. unlikely) → no regret actions
  - Need to translate data into a nationwide 'future' precipitation depth-duration-frequency (DDF) curves dataset
  - Need data for Alaska
- Add to common applications (USGS StreamStats)
- Revise floodplain ordinances to accommodate alternative analysis and designs for future retrofits