Web session etiquette. Please:

• If you are using a phone, turn off your computer speakers to avoid feedback and terrible noises.

• Mute your line unless you are speaking to the group.
Today’s Agenda

Discussion:
- Step 4 review
- Discussion: how are you adapting your forests to a changing climate?

Lecture:
- Step 5: Monitoring
- Website demo and homework
Step 4: IDENTIFY adaptation approaches and tactics for implementation.

Key Question:

What actions can enhance the ability of the ecosystem to adapt to anticipate changes and meet management goals?
Adaptation Strategies & Approaches

A “menu” of possible actions that allows you to decide what is most relevant for a particular location and set of conditions.

Find in: Step 4 of online workbook, Chapter 3-4 of FAR, or www.adaptationworkbook.org/niacs-strategies
www.adaptationworkbook.org/niacs-strategies/urban
Adaptation Strategies and Approaches

Big ideas
- Increase **resistance**
- Build **resilience**
- Facilitate **transition**

See Step 4 Course Materials for a recorded presentation that provides more details
Broad adaptation responses

- Sustain fundamental ecological functions
- Reduce the impact of existing biological stressors
- Maintain and enhance species and structural diversity
- Facilitate community adjustments through species transitions
Adaptation Strategies & Approaches

More specific actions

- Promote diverse age classes
- Maintain and restore diversity of native tree species
- Identify and move species to sites that are likely to provide future habitat
Adaptation Strategies & Approaches

Prescriptive actions selected by producer that are designed for individual site conditions and management objectives

→ YOU DECIDE!
Adaptation Strategies & Approaches

Management Goals & Objectives

Climate Change Impacts

Challenges & Opportunities

Intent of Adaptation (Option)

Make Idea Specific (Strategy, Approach)

Action to Implement (Tactic)

Why it’s important: Helps connect the dots from broad concepts to specific actions for implementation.
Step 4: IDENTIFY adaptation approaches and tactics for implementation.
**Key Strategies You Selected:**

### Urban Forest

1. Sustain or restore fundamental ecological functions  
2. Reduce the impact of biological stressors  
3. Reduce the risk and long-term impacts of severe disturbances  
4. Maintain or create refugia  
5. Maintain and enhance species and structural diversity  
6. Increase ecosystem redundancy across the landscape  
7. Promote landscape connectivity  
8. Maintain and enhance genetic diversity  
9. Facilitate composition adjustments through species transitions  
10. Realign urban ecosystems after disturbance

### Watershed

1. Sustain fundamental hydrologic processes  
2. Maintain and enhance water quality  
3. Maintain or restore forests and vegetative cover  
4. Facilitate forest ecosystem adjustments through species transitions  
5. Accommodate altered hydrologic processes  
6. Design and modify infrastructure to accommodate future conditions
What Options did you select?
Tactics you evaluated but did not select?
What are some new tactics or strategies you developed that you were not doing before?
Were there challenges you had that could not be addressed?

Do others have ideas?
Were there tactics you developed that did not align with any of the strategies or approaches?
Any innovative ideas you’ve heard about that others are doing?
Step 5: MONITOR and evaluate effectiveness of implemented actions.
Today’s Agenda

Discussion:
- Step 4 review
- Discussion: how are you adapting your forests to a changing climate?

Lecture:
- Step 5: Monitoring
- Website demo and homework
1. DEFINE area of interest, management objectives, and time frames.

2. ASSESS climate change impacts and vulnerabilities for the area of interest.

3. EVALUATE management objectives given projected impacts and vulnerabilities.

4. IDENTIFY and implement adaptation approaches and tactics.

5. MONITOR and evaluate effectiveness of implemented actions.

Menu of Adaptation Strategies & Approaches

Vulnerability assessments, scientific literature, and other resources

Today – Step 5!
A FEW THOUGHTS ABOUT MONITORING...

Be VERY CLEAR about your objectives! What question you are asking guides your monitoring approach:

Scientific research = Is this outcome statistically significant compared to a control? Could we expect similar results elsewhere?

Impact/ response monitoring = What changes are occurring?

Implementation monitoring = Did we do the action?

Effectiveness monitoring = Did our actions actually have the desired effect?
Course Material Landing Page
Step 5: Monitor and evaluate effectiveness of implemented actions

Monitoring is critical for understanding if management actions are effective over time, or if management should be altered in the future to account for new information. The final step of the Adaptation Workbook is to identify monitoring items that may be used to answer these kinds of questions.

The outcome of this step is a list of monitoring questions that will help you evaluate the effectiveness of your adaptation actions. Try to think of at least one monitoring question for each of your management objectives. You should especially consider monitoring questions that will help assess the effectiveness of your recommended adaptation tactics.

Time and resources can often limit monitoring efforts, so focus on creating a monitoring plan that is realistic and feasible.

For example:

If you’re assisting with the green infrastructure design for a new development and your objective is to reduce stormwater runoff by 50%, you may have designed an adaptation tactic to incorporate pervious pavements and structural soils for stormwater interception. An appropriate monitoring variable would be inflow and outflow of water through the system during storm events.
Add a Monitoring Variable
Add a Monitoring Variable

Identify items that will help evaluate whether you have achieved your management objectives or if you are making progress toward those objectives. For example, you may care about survival of planted seedlings if your project will include tree planting.

Criteria For Evaluation
Identify a value or threshold that is meaningful for this monitoring item. For example, you may have a goal of 70% seedling survival after 3 years if your project will include tree planting.

Monitoring Implementation
Describe how and when will this information be gathered. For example, you may monitor seedling survival every June for 5 years after planting.
**Step 5:** MONITOR and evaluate effectiveness of implemented actions.

**Monitoring Variable**

| Items that can tell you whether you have achieved your management goals & objectives. |
|---|---|
| If possible, use an item that also helps evaluate a particular tactic. |
| **For example:** |
| • Planted seedling survival |
**Step 5:** MONITOR and evaluate effectiveness of implemented actions.

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>What is success?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>What you’re monitoring or measuring. <strong>What are the units on your data?</strong></td>
</tr>
<tr>
<td></td>
<td><strong>For example:</strong></td>
</tr>
<tr>
<td></td>
<td>• 60% survival of non-local genotypes.</td>
</tr>
</tbody>
</table>
Step 5: MONITOR and evaluate effectiveness of implemented actions.

Monitoring Implementation

How the monitoring will actually get done.

Use existing monitoring when possible!

For example:

- Regular post-planting stocking surveys.
- Supplemental surveys at 10 years.
Add a Monitoring Variable

Monitoring Variable
- Survival of newly planted street trees

Criteria For Evaluation
- 70% survival at 5 years

Monitoring Implementation
- Homeowner calls, annual checks

Save
Apply to Objectives

Monitoring Variables
1 monitoring variables

Monitoring Variable: Survival of newly planted street trees

Applicable to 2 objectives

- Monitoring Variable
  Survival of newly planted street trees

- Criteria For Evaluation
  70% survival at 5 years

- Monitoring Implementation
  Homeowner calls, annual checks.

Does this monitoring variable apply to these objectives?

- No
- Yes

Management Topic: Park - Goal

Objective: Have no more than 20 percent of a family, 10 percent of a genus and 5 percent of a species

Management Topic: Park - Goal

Objective: Increase the percent of species that are native or expected to gain habitat in the area.
Homework

Homework 5

What are the key questions you’ll want to be able to answer to determine the effectiveness of your recommended tactics for climate change adaptation? What are the metrics needed to answer these questions, and how/when will you collect the necessary measurements?

Monitoring and Evaluating Effectiveness: rate how strongly you agree/disagree with the following statements.

I can identify monitoring metrics to assess the effectiveness of my management tactics.

I understand how the measurements collected through my monitoring plan could help me adjust future management.

What information do you already have to help you measure the effectiveness of your climate adaptation tactics?
EXAMPLES
**Step 5:** MONITOR and evaluate effectiveness of implemented actions.

Twentymile Creek and Marengo River Priority Watershed project

<table>
<thead>
<tr>
<th>Monitoring Item</th>
<th>Monitoring Metric</th>
<th>Criteria for Evaluation</th>
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<tbody>
<tr>
<td>Brook Trout pop (+other spp)</td>
<td># fish (size, pop, catch/effort)</td>
<td>Maintaining or increasing populations</td>
</tr>
<tr>
<td>Channel stability</td>
<td>Detecting changes to Bankfull width, depth, and area</td>
<td>Maintaining stable channels – no change in width: depth ratio</td>
</tr>
<tr>
<td>Water temperature</td>
<td>Summer max, max weekly mean</td>
<td>Cold: &lt; 23 C for annual max</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cool: &lt; 26 C for annual max</td>
</tr>
</tbody>
</table>

[forestadaptation.org/node/243](http://forestadaptation.org/node/243)
Step 5: MONITOR and evaluate effectiveness of implemented actions.

City of Columbia, MO: Street Tree Management Plan

<table>
<thead>
<tr>
<th>Monitoring Item</th>
<th>Monitoring Metric</th>
<th>Criteria for Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Street Tree Survival</td>
<td>% survival at 3 years</td>
<td>70% street tree survival at 3 years.</td>
</tr>
<tr>
<td>Species Diversity</td>
<td>Biannual inventory of the percentage of trees that belong to a family</td>
<td>no more than 10% of street trees may belong to a single family</td>
</tr>
<tr>
<td>Invasive species</td>
<td>Presence/absence of invasive vegetation at recently disturbed sites after 1 year</td>
<td>Absence of invasive species</td>
</tr>
</tbody>
</table>

https://forestadaptation.org/ColumbiaMO
### Monitoring Item

- Whip and seedling survival
- Survival of balled and burlapped trees and larger plantings
- % tree canopy

### Monitoring Metric

- Survival (mapped using Treekeeper)
- Survival (mapped using Treekeeper)
- Urban tree canopy assessment (remote sensing)

### Criteria for Evaluation

- 50% survival at 3 years.
- 85% after 3 years.
- 25% by 2025, 30% by 2030, 35% by 2035, 40% by 2040, 45% by 2045.

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**City of Goshen, IN: Goshen Tree Benefits Campaign**

[https://forestadaptation.org/GoshenIN](https://forestadaptation.org/GoshenIN)
Cambridge, MA: Cartegraph GIS Inventory
Street Tree Vulnerability Assessment

http://www.cambridgema.gov/CDD/Projects/Climate/~media/42F2847A3DCB4706BB5981D66D0AB157.ashx
LiDAR Mapping
Citizen Science in Lombard, Philadelphia, Grand Rapids, and Malmo Sweden

Novice:
- 1 year of experience or less (volunteers, interns)

Intermediate:
- 1-3 years experience (volunteers, interns)

Expert:
- experienced urban forest researchers and certified arborists

Roman et al. 2017
Methods

▪ Volunteers received 6-7 hours of training led by experts

▪ Field guide provided

▪ Field work carried out without supervision

▪ Trees observed by 1 expert, 3 novices, and 3 intermediates
  • Results compared between novice/intermediate and expert

▪ Field crew questionnaire
  • Characteristics, level of training of participants

Roman et al. 2017
Citizen science is good for:

- Classifying site type and land use
- Dieback rating (especially low, high)
- Genus ID (especially common ones like Acer, Gleditsia, Tilia)
- Number of stems
- DBH within 1 inch (2.54 cm)
Did not work as well for:

- Crown transparency
- Wood condition
- Classifying trees in middle dieback categories
- Species ID
- Identifying less common genera (Amelanchier, Prunus, Syringa)
- Species within genera
- DBH of multistemmed trees
- Radial growth monitoring

Roman et al. 2017
My City’s Trees: Urban FIA

http://tfsfrd.tamu.edu/mycitystrees
Zoom in on a city

http://tfsfrd.tamu.edu/mycitystrees
Get Inventory Summaries

http://tfsfrd.tamu.edu/mycitystrees
Urban Forest Benefits

Austin

Selected Area

Austin is comprised of 195,223 acres with a population of 790,390 people. The city is divided into 8 land cover classes. This report contains information for a selected area consisting of the following 8 classes: Developed - Open, Developed - Low, Developed - Medium, Developed - High, Deciduous/Mixed Forest, Evergreen Forest, Shrub/Herbaceous, and Water/Barren. These classes cover 195,223 acres, which is 100 percent of the city. A total of 790,390 people live in the selected area, which is 100 percent of the entire city population. A total of 206 locations were sampled in the urban forest inventory, of which 206 plots were located in the selected area.

Figure 1. Map of Austin and selected land cover classes.

Table 1. Distribution of area and population by selected land cover classes.

<table>
<thead>
<tr>
<th>Class</th>
<th>Area (acres)</th>
<th>Percent of City Area (%)</th>
<th>Population (people)</th>
<th>Percent of City Population (%)</th>
<th>Plots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developed - Open</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>51</td>
</tr>
</tbody>
</table>
I-Tree Landscape

https://landscape.itreetools.org/maps/
USA National Phenology Network

https://www.usanpn.org/data/visualizations
USA National Phenology Network

Activity Curves

2013: Red maple - Breaking leaf buds

https://www.usanpn.org/data/visualizations
Caroline Lake State Natural Area Adaptation Demonstration

Major concerns: Forest composition could become less diverse given climate changes

How can we better use forest inventory data to tell us:
- Are forests at risk from climate change?
- Are management actions reducing risk?

Matt Dallman (TNC), find project at [forestadaptation.org/node/659](http://forestadaptation.org/node/659)
### Northern Hardwood Stand:

<table>
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<tr>
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<th>Basal Area</th>
<th>Stems Per Acre</th>
<th>Freq. (%)</th>
<th>Proportion of Stand (IV %)</th>
<th>Future: Current Habitat Change Class</th>
<th>At-risk Proportion of Stand (%)</th>
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</tr>
<tr>
<td>White ash</td>
<td>33.1</td>
<td>30.7</td>
<td>96.2</td>
<td>17.9</td>
<td>Increase</td>
<td>1.9</td>
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<tr>
<td>American basswood</td>
<td>18.5</td>
<td>23.7</td>
<td>73.1</td>
<td>12.3</td>
<td>No Change</td>
<td>1.4</td>
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<td>10.0</td>
<td>16.1</td>
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<td>1.1</td>
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<tr>
<td>Red maple</td>
<td>4.2</td>
<td>8.6</td>
<td>42.3</td>
<td>5.0</td>
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<td>0.0</td>
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</tr>
<tr>
<td>Northern red oak</td>
<td>1.5</td>
<td>0.7</td>
<td>42.3</td>
<td>3.2</td>
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<td>0.0</td>
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<tr>
<td>American elm</td>
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<td>34.6</td>
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<td>Paper birch</td>
<td>1.9</td>
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<td>0.0</td>
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## Climate-informed inventory: New Risk Metrics

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## Climate-informed inventory: New Risk Metrics

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#### Low (PCM B1)

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<td>Northern red oak</td>
<td>1.5</td>
<td>0.7</td>
<td>42.3</td>
<td>3.2</td>
<td>Increase</td>
<td>0.0</td>
<td>1.1</td>
<td>No Change</td>
<td>0.0</td>
</tr>
<tr>
<td>American elm</td>
<td>0.4</td>
<td>0.4</td>
<td>34.6</td>
<td>2.4</td>
<td>Increase</td>
<td>0.0</td>
<td>3.2</td>
<td>Large Increase</td>
<td>0.0</td>
</tr>
<tr>
<td>Paper birch</td>
<td>1.9</td>
<td>5.3</td>
<td>11.5</td>
<td>2.0</td>
<td>Decrease</td>
<td>2.0</td>
<td>0.2</td>
<td>Large Decrease</td>
<td>2.0</td>
</tr>
<tr>
<td>Black ash</td>
<td>1.5</td>
<td>2.6</td>
<td>7.7</td>
<td>1.2</td>
<td>Decrease</td>
<td>1.2</td>
<td>0.6</td>
<td>Decrease</td>
<td>1.2</td>
</tr>
<tr>
<td>Black cherry</td>
<td>0.4</td>
<td>0.2</td>
<td>15.4</td>
<td>1.1</td>
<td>Large Increase</td>
<td>0.0</td>
<td>1.4</td>
<td>Increase</td>
<td>0.0</td>
</tr>
<tr>
<td>Eastern hemlock</td>
<td>1.2</td>
<td>1.9</td>
<td>3.8</td>
<td>0.8</td>
<td>Increase</td>
<td>0.0</td>
<td>0.4</td>
<td>Large Decrease</td>
<td>0.8</td>
</tr>
<tr>
<td>Quaking aspen</td>
<td>0.8</td>
<td>0.6</td>
<td>7.7</td>
<td>0.8</td>
<td>Decrease</td>
<td>0.8</td>
<td>0.2</td>
<td>Large Decrease</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>160.2</strong></td>
<td><strong>220.3</strong></td>
<td><strong>100.0</strong></td>
<td></td>
<td></td>
<td><strong>Proportion at-risk:</strong> 11.0</td>
<td></td>
<td></td>
<td><strong>Proportion at-risk:</strong> 63.0</td>
</tr>
</tbody>
</table>

#### High (GFDL A1F1)

The table above presents the basal area, stems per acre, frequency of stand, and future habitat change class for various species in a northern hardwood stand. The at-risk proportion of the stand is also highlighted, indicating the potential impact of climate change on these species.

The northern hardwood stand is characterized by a diverse composition of species, each with its own basal area and stem density. The future habitat change is assessed based on current habitat conditions, with classifications ranging from no change to large decrease. The at-risk proportion is a critical metric for conservation efforts, indicating the percentage of the stand that is at risk due to climate change.
Climate-informed inventory: Risk Maps

Risk by stand: overstory
“100 year” storms and floods

- Current streamflow
- Using stream channel capacity to manage future risks to infrastructure
- Terminology
- Future projected 100y flow
- Tools you can use

Wobus et al, 2017; Mills et al, 2018
Annual Average Streamflow in the United States, 1940–2014


For more information, visit U.S. EPA’s “Climate Change Indicators in the United States” at www.epa.gov/climate-indicators.
Three-Day High Streamflows in the United States, 1940–2014


For more information, visit U.S. EPA’s “Climate Change Indicators in the United States” at www.epa.gov/climate-indicators.
Increases and decreases in frequency and magnitude of river flood events generally coincide with increases and decreases in the frequency of heavy rainfall events.


For more information, visit U.S. EPA’s “Climate Change Indicators in the United States” at www.epa.gov/climate-indicators.
Climate change and flooding

A changing climate... Non stationary conditions

- Warming temperatures
  - Earlier snowmelt in the spring
  - Storm systems generate more rain because warm air holds more moisture than cold air.
- Seasonal floods are expected to arrive earlier in the spring
- More heavy summer rainfall events

While no single storm or flood can be attributed directly to global warming, changing climate conditions are at least partly responsible for past trends and the increasing frequency of major flood events.

Take home Message: Reimagine “normal” storms, and “normal” flows.
Future Climate: Precipitation

More rain in winter and spring

High Certainty:

- More rainfall annually & some seasons
- Potential for more frequent & intense heavy rains
- Reduced snowpack, earlier melting

2070-2099 percent change relative to the 1976–2005 average. RCP8.5. Stippling indicates that changes are assessed to be large compared to natural variations.

Future Climate: Increases in extreme events

- Sight increase in the very lightest precipitation days
- Large increase in the heaviest days
- “Uncertainty for each specific duration grows as the return period increases, specifically for short-duration storms.” - Sarhadi and Soulis, 2017).

doi.org/10.1002/2016GL072201

Heavy precipitation 2006–2100

Model avg (CMIP5 14-16 models)

Future Climate: Increases in extreme events

Frequency & intensity of hourly heavy precip. will increase 1-2 times.

Winter (DJF)  
Summer (JJA)

Future increases in 99th% of hourly precipitation event intensities by 2100  
Relative to January 2001 - 2013

Prein et al 2017. doi:10.1038/nclimate3168.
Streams change over time: Channel capacity

- Traditional hydrological modelling assumes that the catchment does not change...

- Understanding the **natural capacity** of your stream can reduce risks and mitigate infrastructure losses
  - Channel geometry (width, mean, depth, cross-sectional area) and discharge
  - Future changes in streamflow are expected to alter channel morphology

- **Bankfull discharge** is the streamflow that occurs when the stream fills its channel and any additional discharge will result in the stream overflowing its banks.
  - 1-2 year flow
  - Moves the most sediment over time and shapes the stream channel
  - “Channel forming flow”
Understanding local channel capacity can help managers recognize areas prone to natural stream-erosion.
“If culverts built today cannot accommodate future channel conditions, then climate change could indirectly create barriers ..and consequent loss habitats” Wilhere et al 2017

Chequamegon-Nicolet National Forest: Marengo and Twentymile Creek Watersheds
forestadaptation.org/cnnf-water

“Find #s based on current -

Find resources to help incorporate climate change into future infrastructure decisions

https://doi.org/10.1016/j.ecoleng.2017.04.009
**100-Year** –
Event that occurs on average every 100 years

- Average Recurrence Interval
- Commonly used term, included in NOAA Atlas 14

**1% Annual Chance** –
Event that has a 1% chance of being exceeded in any year

- Average Exceedance Probability (AEP)
- Common term used to delineate special flood hazard areas in federal flood insurance rate maps
- FEMA & USGS use this term

**1% AEP flood:** With observed or modeled data, a 1% AEP flood defines both a flow volume (E.g. 10,000 cubic feet per second) and an expected return interval or frequency for that flow volume (on average, once every 100-y)
Does a 100-year storm always cause a 100-year flood?

**No.** Several factors can independently influence the cause-and-effect relation between rainfall and streamflow.
- **Extent of rainfall in the watershed**
- **Soil saturation before the storm**
- **Watershed size and duration of the storm**

**Recurrence intervals and probabilities of occurrences**

<table>
<thead>
<tr>
<th>Recurrence interval, in years</th>
<th>Probability of occurrence in any given year</th>
<th>Percent chance of occurrence in any given year</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1 in 100</td>
<td>1</td>
</tr>
<tr>
<td>50</td>
<td>1 in 50</td>
<td>2</td>
</tr>
<tr>
<td>25</td>
<td>1 in 25</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>1 in 10</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>1 in 5</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>1 in 2</td>
<td>50</td>
</tr>
</tbody>
</table>

Learn more ➔ https://water.usgs.gov/edu/100yearflood.html
Predicting future flood risks in the 100-y floodplain

Modeling approach:

- Modeled both the **frequency**, and **magnitude** of high flow events with a 1% annual exceedance probability (AEP) threshold by 2100

- Quantify damages from “100-year” (1% annual exceedance probability, or AEP) floods nationwide
  
  - Only modeled 100-yr – yet, larger floods will be more damaging

- **1,000 model runs** for high emissions (RCP 8.5), low (RCP 4.5) to develop trends

Wobus et al, 2017

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Climate change impacts on flood risk and asset damages within mapped 100-year floodplains of the contiguous United States

Cameron Wobus, Ethan Gutmann, Russell Jones, Matthew Rissing, Naoki Mizukami, Mark Lorie, Hardee Mahoney, Andrew W. Wood, David Mills, and Jeremy Martinich

1 Abt Associates, 1881 Ninth Street, Suite 201, Boulder, CO 80302, USA
2 National Center for Atmospheric Research, 3450 Mitchell Lane, Boulder, CO 80301, USA
3 US Environmental Protection Agency, Climate Change Division, 1200 Pennsylvania Ave NW, Washington, DC 20460, USA

- Used National Flood Insurance Program (NFIP) – geospatial data on 100yr floodplains - “regulatory floodplain” that requires flood insurance

Bigger flow volume for more frequent events

The 100 m$^3$s$^{-1}$ flow baseline 1% AEP flood becomes twice as frequent by end of century (shift from 100-y to 50-y average return interval – RCP 4.5)

Larger flow volumes

100-y return interval [1% AEP event] becomes 25% larger in 2090 – RCP 4.5

*Example of change in inland flooding for one river reach.

- Modeled future flows
- Found flow and flood magnitude increased in some cases.

Mills et al, 2017, Wobus et al 2017
Ensemble mean, 29 models
Change in frequency of annual 1% (100 year) event from baseline, by 2100

**Red:** Extreme increases in frequency for the baseline flood (> 1)

**Blue:** Largest decreases in frequency (< 1)

**Increases in frequency**

10 times current baseline

**Decreases in frequency**

Mills et al, 2017, Wobus et al 2017
Ensemble mean, 29 models
Projected change in the frequency of baseline 1% annual exceedance probability (AEP) floods. Map shows 2090 - RCP 8.5 (High emissions, business as usual scenario).

Mills et al, 2017, Wobus et al 2017
Ensemble mean, 29 models

Increases in frequency (>1)  Decreases in frequency (<1)
Projected Flood damages ($ cost)

(Wobus et al, 2017)

- **High emissions:** Flood damages exceed low emissions by ~$3B/year in 2100
- Gray lines show results from 1,000 simulations for RCP 4.5 and RCP 8.5
- Emissions scenarios diverge primarily after 2050

*in 2014 dollars*
Stream channels are dynamic, and change over time...

- Any changes in a river channel’s capacity (i.e., the depth, width, and roughness) may significantly alter the frequency of local flooding above set flood levels (even in the absence of any changes in discharge) (Slater et al, 2015)
  - Stream channels evolve, aggrade, degrade, narrow, widen.

- Particularly in locations that have experienced major changes in channel capacity due to urbanization or water regulation

Read more on this concept:
What can we do?

- Leave?
- Pretend it’s not happening?
- Embrace uncertainty

- Reframe our idea of “future conditions”
- Get out in front and address the problem in planning... now
Where to start

- Understand the channel capacity at your site
- Learn how to incorporate ecological considerations into road-stream crossing designs to accommodate changing hydrology

**USDA FS Stream Simulation tool**

Where to start: Evaluate storm frequency – tool: NOAA Atlas 14

- NOAA has updated precipitation frequency (PF) estimates for the U.S \((P_{min}, P_{max}, P_{avg})\)

- **Updates are noteworthy:**
  - Atlas 14 includes most recent 30 years of precipitation data
  - And includes more weather stations than previous efforts.

- Gridded precipitation-frequency estimates at 30 arc-seconds resolution

- Provides estimates of 500-yr and 1000-yr events

http://hdsc.nws.noaa.gov/hdsc/pfds/
Where to start: Evaluate storm frequency - NOAA Atlas 14

- Atlas 14 can replace older technical reports when making infrastructure sizing and design decisions for conveyance and detention.

- Likely - Precipitation Frequency estimates used for stormwater management do not accurately reflect the depths falling during precipitation events –
  
  - Climate change projections indicate rainfall volumes will continue to increase over the next 50 years
  
  - Start with Atlas 14, incorporate other considerations.

http://hdsc.nws.noaa.gov/hdsc/pfds/
Expected “normal” rainfall amount

**Case study**: Ann Arbor, MI
(Older technical report vs. Atlas 14)

Bulletin 71/Atlas 14

<table>
<thead>
<tr>
<th>[% change]</th>
<th>1-Yr</th>
<th>2-Yr</th>
<th>5-Yr</th>
<th>10-Yr</th>
<th>25-Yr</th>
<th>50-Yr</th>
<th>100-Yr</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1-hr</strong></td>
<td>0.88/0.969 [10%]</td>
<td>1.06/1.14 [8%]</td>
<td>1.29/1.44 [12%]</td>
<td>1.47/1.70 [16%]</td>
<td>1.69/2.07 [22%]</td>
<td>1.87/2.38 [27%]</td>
<td>2.05/2.69 [31%]</td>
</tr>
<tr>
<td><strong>12-hr</strong></td>
<td>1.63/1.82 [12%]</td>
<td>1.97/2.06 [5%]</td>
<td>2.39/2.50 [5%]</td>
<td>2.72/2.90 [7%]</td>
<td>3.13/3.54 [13%]</td>
<td>3.46/4.09 [18%]</td>
<td>3.79/4.68 [23%]</td>
</tr>
<tr>
<td><strong>24-hr</strong></td>
<td>1.87/2.09 [12%]</td>
<td>2.26/2.35 [4%]</td>
<td>2.75/2.83 [3%]</td>
<td>3.13/3.26 [9%]</td>
<td>3.60/3.93 [9%]</td>
<td>3.98/4.50 [13%]</td>
<td>4.36/5.11 [17%]</td>
</tr>
</tbody>
</table>

**Huron River Watershed – Stormwater Guide**

Atlas 14 prediction: Changes storm estimates
**NOAA Atlas 14 Versus TP40 Precipitation Depths**

**100-Yr, 24-Hr Precipitation Depths**

**Percent Change From TP40 to NOAA Atlas 14 (Mean)**

- **Ashland County:**
  - NOAA Atlas 14 (Mean): 7.37”
  - TP40: 5.40”
  - Increase 36.5%

- **Shawano County:**
  - NOAA Atlas 14 (Mean): 5.40”
  - TP40: 5.40”
  - No Change

- **Grant County:**
  - NOAA Atlas 14 (Mean): 7.69”
  - TP40: 6.20”
  - Increase 24.0%

- **Ozaukee County:**
  - NOAA Atlas 14 (Mean): 6.38”
  - TP40: 5.40”
  - Increase 18.1%
Tool: USGS Future Flow – NY state only

- Get future flow predictions for your watershed
- Flood regressions and climate change scenarios – future peak flows
- Estimate flows (cfs, and % change)

https://ny.water.usgs.gov/maps/floodfreq-climate/
To-do list for next week:

- **Complete Step 5**: Monitor and evaluate effectiveness
- **Complete the Homework section** after Step 5
- **Recommended readings**:
  - Roman et al. 2017
  - Janowiak et al. 2017
- **Come to Session 6 (Tuesday, December 11)** ready to discuss your monitoring!

**Thanks everyone!**
Troubleshooting? Stay on the line.