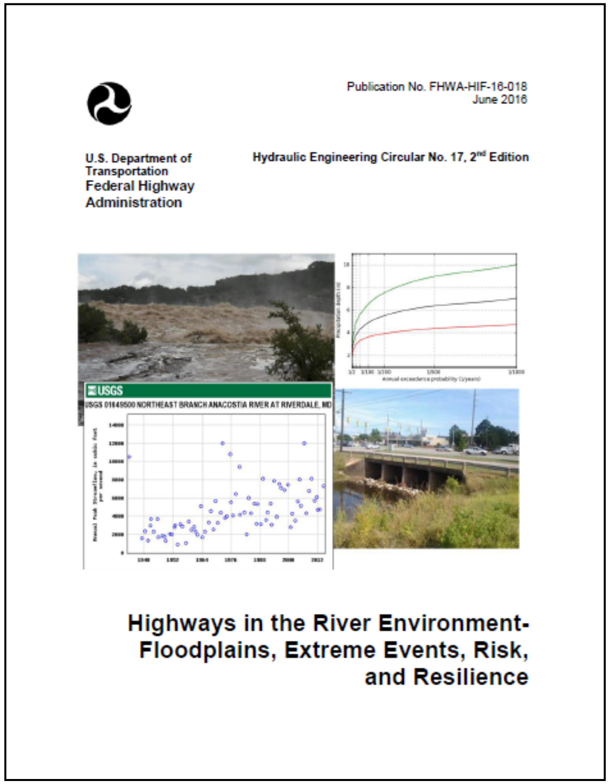
HEC 17:

Highways in the River Environment
::
Floodplains, Extreme Events, Risk and Resilience



Publication No. FHWA-HIF-16-018
June 2016

U.S. Department of Transportation
Federal Highway Administration

Hydraulic Engineering Circular No. 17, 2nd Edition

Highways in the River Environment-
Floodplains, Extreme Events, Risk,
and Resilience

Webinar B: Chapters 5 and 6

Presenters: Brian Beucler, Rob Kafalenos, Rob Hyman

Webinar Logistics

- Mute Phone
  - Press *6
- Questions During Presentation
  - Type in Chat Box
  - Designated times
- Presentation Recorded
  - Slides available at end of webinar
  - Posted to FHWA site

Webinar Schedules

Webinar A: Introduction, Floodplains, Riverine Flood Events, Non-Stationarity (Chapters 1-4)

January 25, 2017, 10 am to 12 pm (Eastern Std Time)

https://www.fhwa.dot.gov/engineering/hydraulics/media.cfm

Webinar B: Climate Modeling and Risk and Resilience (Chapters 5 & 6)

February 8, 2017, 11 am to 1 pm (Eastern Std Time)

https://www.fhwa.dot.gov/engineering/hydraulics/media.cfm

Webinar C: Analysis Framework and Case Studies (Chapters 7 & 8)

February 22, 2017, 11 am to 1 pm (Eastern Std Time)

https://collaboration.fhwa.dot.gov/dot/fhwa/WC/Lists/Seminars/DispForm.aspx?ID=1296

**register by Feb 16*

People Presenting

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FHWA HQ
Principal Hydraulic Engineer

Cynthia Nurmi
FHWA Resource Center
Hydraulic Engineer

Rob Kafalenos
FHWA HQ :: Environmental
Protection Specialist

Rob Hyman
FHWA HQ :: Environmental
Protection Specialist

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FHWA HQ
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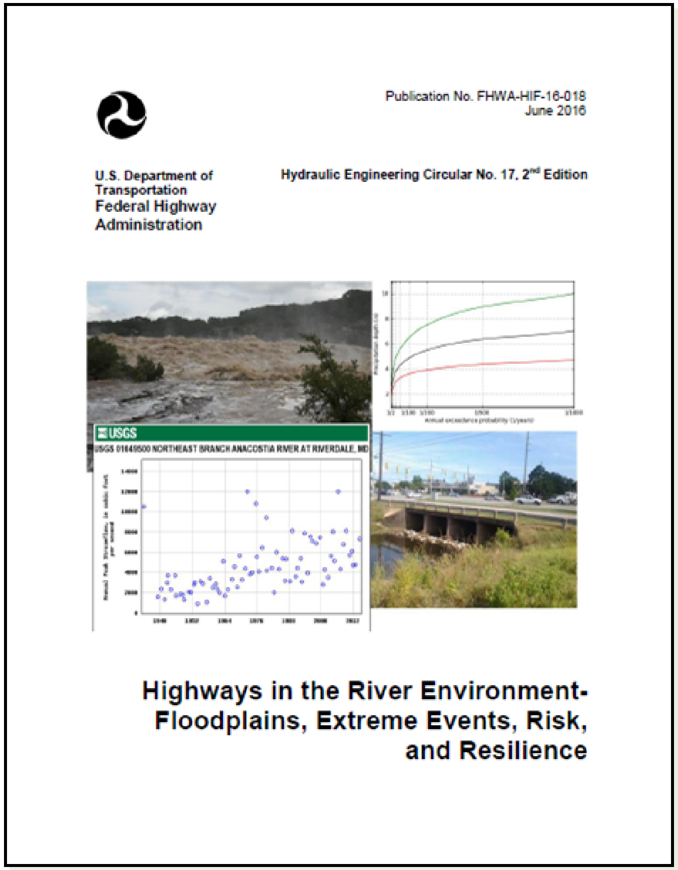
- **Roger T. Kilgore**
  - ***Kilgore Consulting & Management***
- **George (Rudy) Herrmann**
  - ***Desert Sky Engineering and Hydrology***
- **Wil Thomas**
  - ***Michael Baker International***
- **David B. Thompson**
  - ***Thompson Hydrologics***

Why HEC-17?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**Highways in the River Environment-
Floodplains, Extreme Events, Risk,
and Resilience**

Intent

- ***Provide***
  - **Best currently available science, technology and information**
  - **National consistency and relevance to our highway programs**
- ***Focus Areas***
  - **Floodplains**
  - **Extreme Events**
  - **Risk**
  - **Resilience**
- ***Assist***
  - **Our transportation partners**
  - **FHWA**
  - **Other agencies**

Chapter

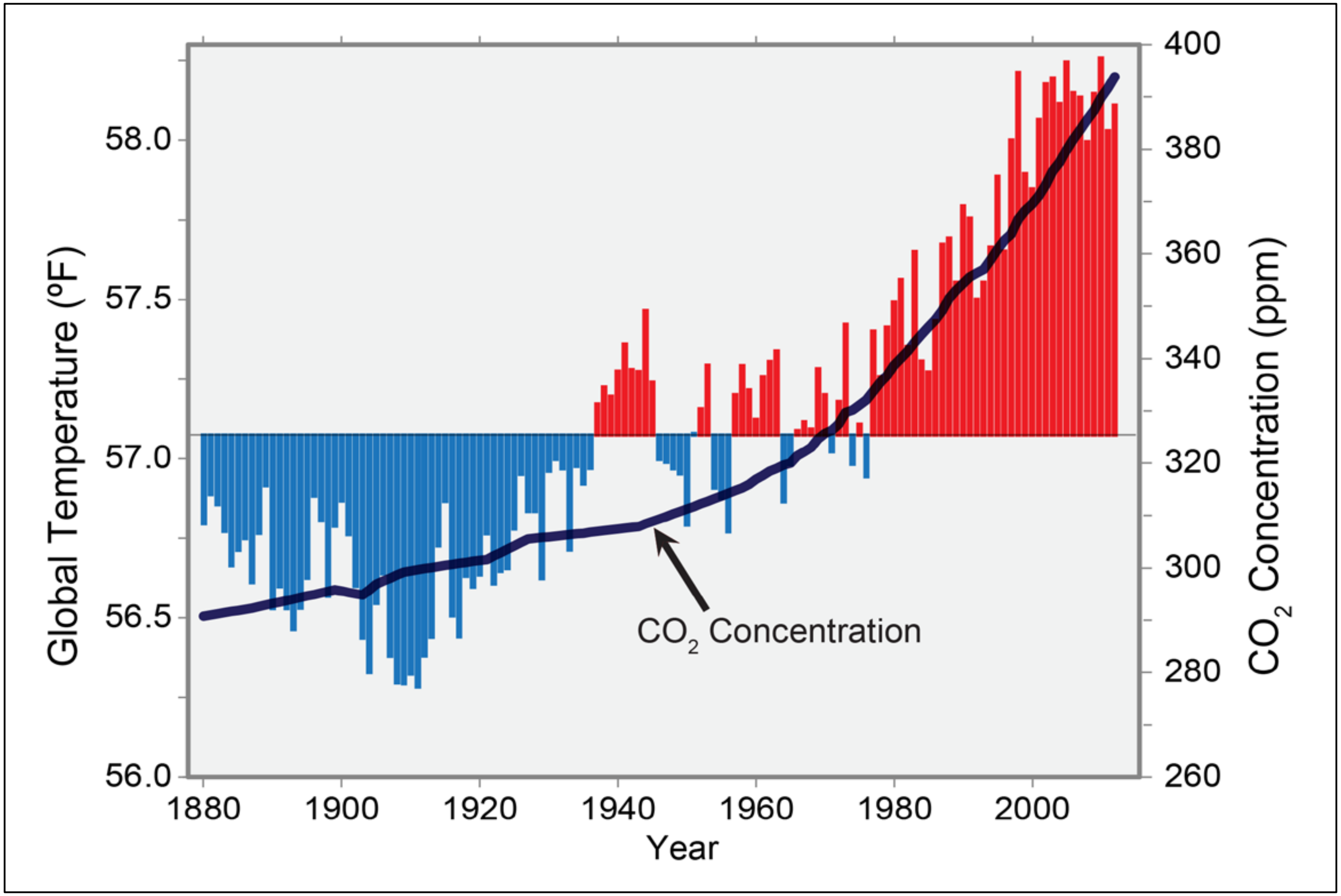
5

Climate Modeling

Nonstationarity and Climate

- Chapter 4: Nonstationarity
- Chapter 5: Climate Modeling (Today’s focus)

Observed Trends: Temperature and CO_2



Weather and Climate

- **What's the difference between <u>weather</u> and <u>climate</u>?**

- **Weather <u>prediction</u> vs climate <u>projections</u>**
  - ***Weather forecast: 2 in. rain next Saturday***
  - ***Projection: Average temperature is expected to increase by 2-4° F by mid-century***

Variability in the Weather

- **Causes of variability include:**
  - ***El Nino***
  - ***La Nina***
  - ***Volcanic eruptions***

Causes of Changes in Climate

- **Greenhouse gas emissions**
  - ***Carbon Dioxide (CO_2)***
  - ***Methane (CH_4)***
  - ***Nitrous Oxide (N_2O)***
  - ***Hydrofluorocarbons (HFCs)***

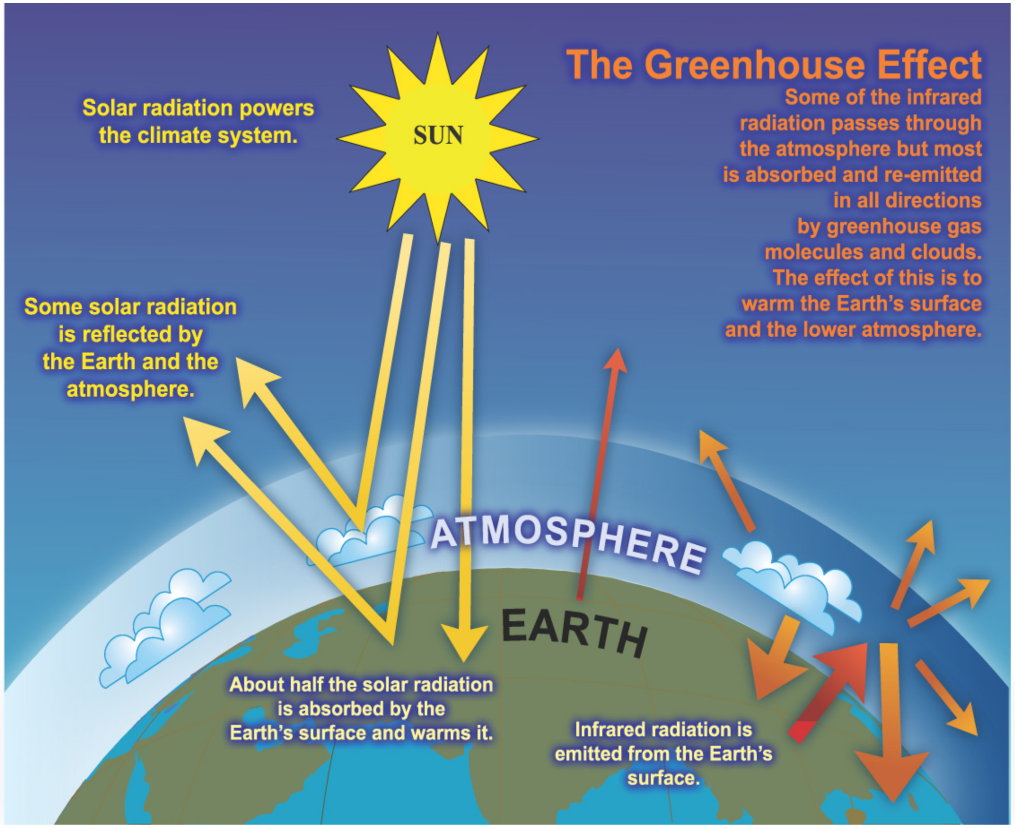
- **Long lived pollutants**

Radiative Forcing (watts/M^2)

- Measure of the change in the earth's energy balance—the balance of incoming (sunlight) and outgoing energy (heat)

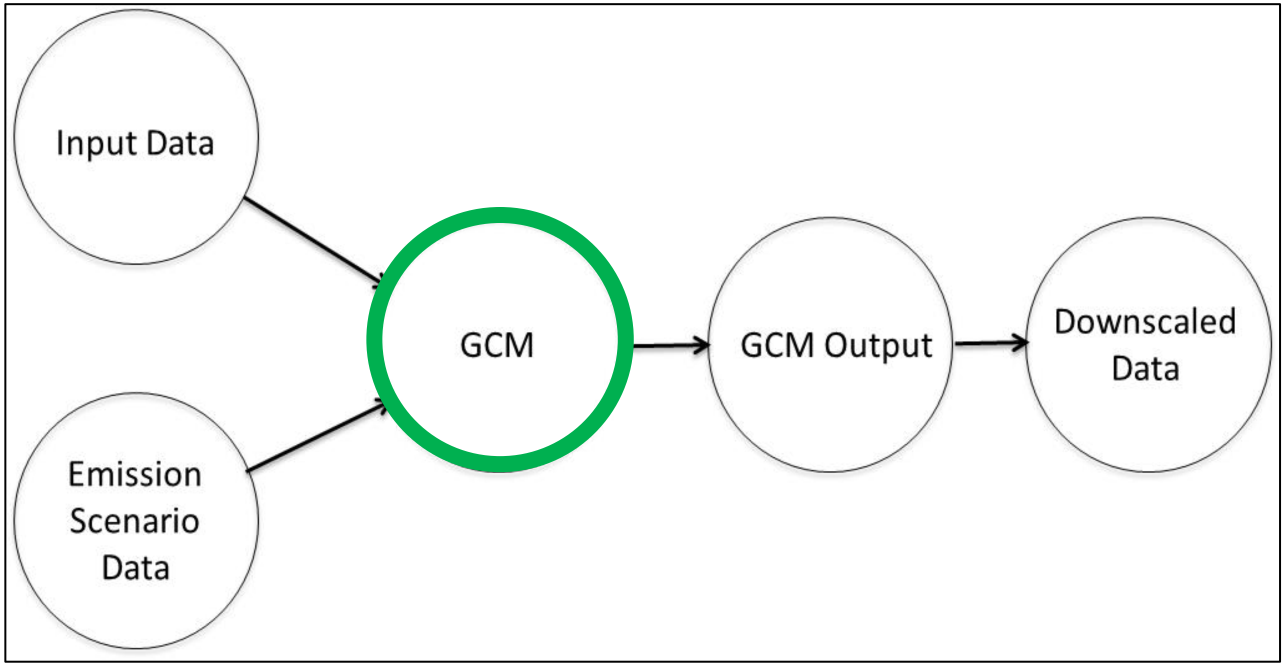
- Greenhouse gases:

  positive forcing

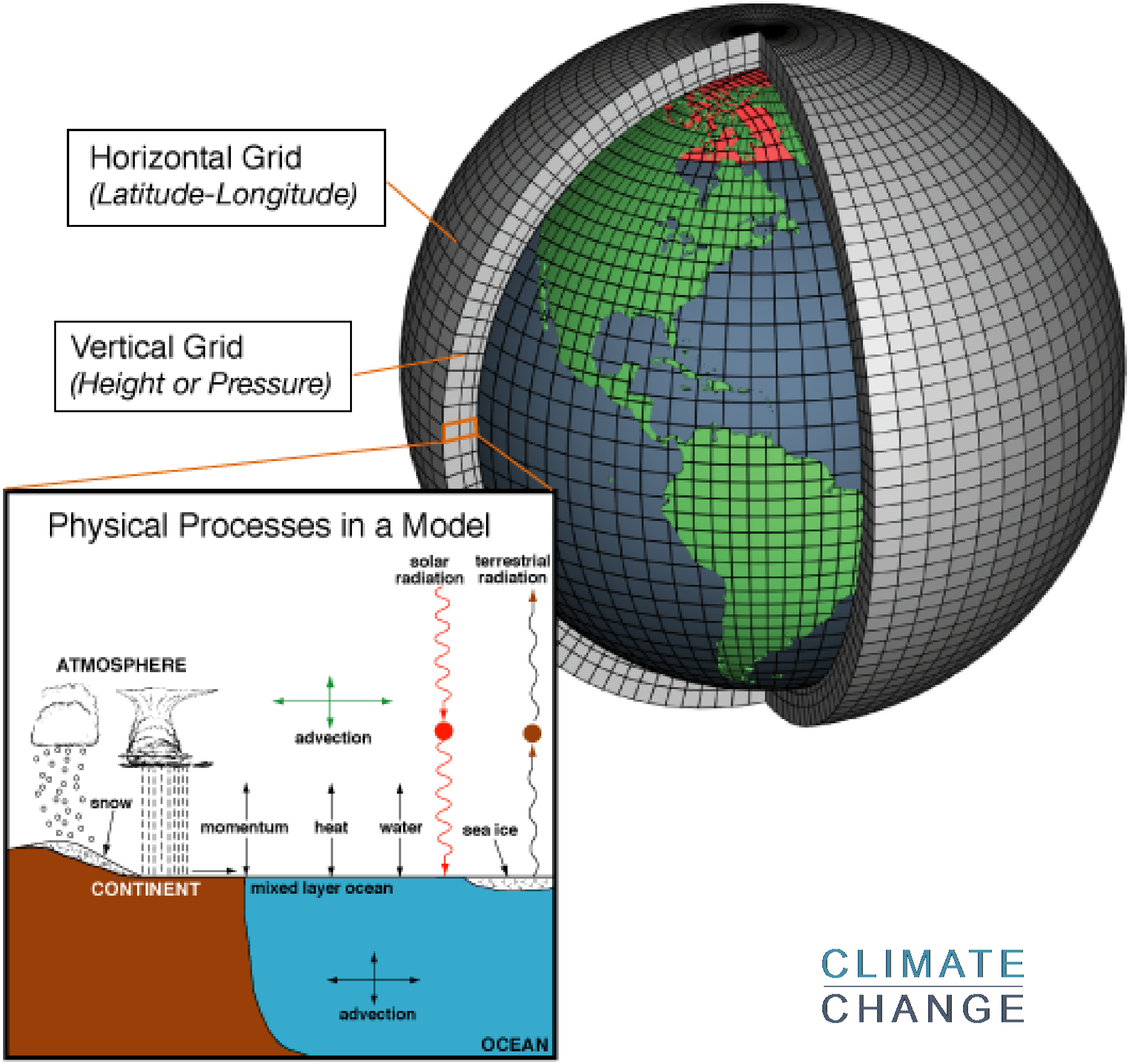


IPCC, The Physical Science Basis, 2007

Projections of Future Conditions



Global Climate Models (GCMs)



Horizontal Grid
(Latitude-Longitude)

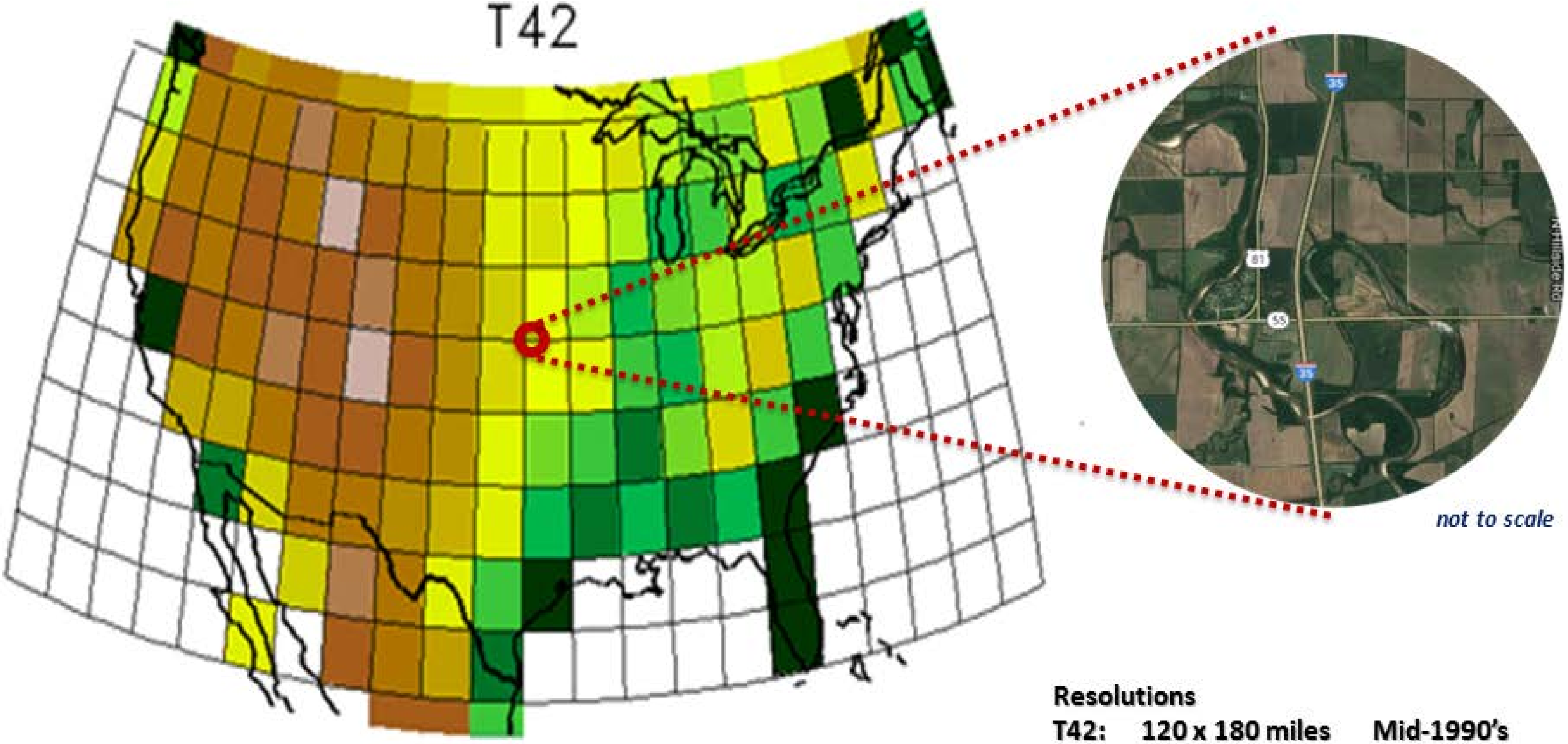
Vertical Grid
(Height or Pressure)

Physical Processes in a Model

CLIMATE
CHANGE

Is Climate Model Output Sufficient for Engineering Applications?

While advancing in complexity, global climate models currently lack required fidelity needed by engineers



not to scale

Resolutions

T42:	**120 x 180 miles**	**Mid-1990's**
T85:	**60 x 90 miles**	**Current**
T170 & T340		***Future***

Resolution map: Warren Washington, NCAR
http://scied.ucar.edu/longcontent/climate-modeling

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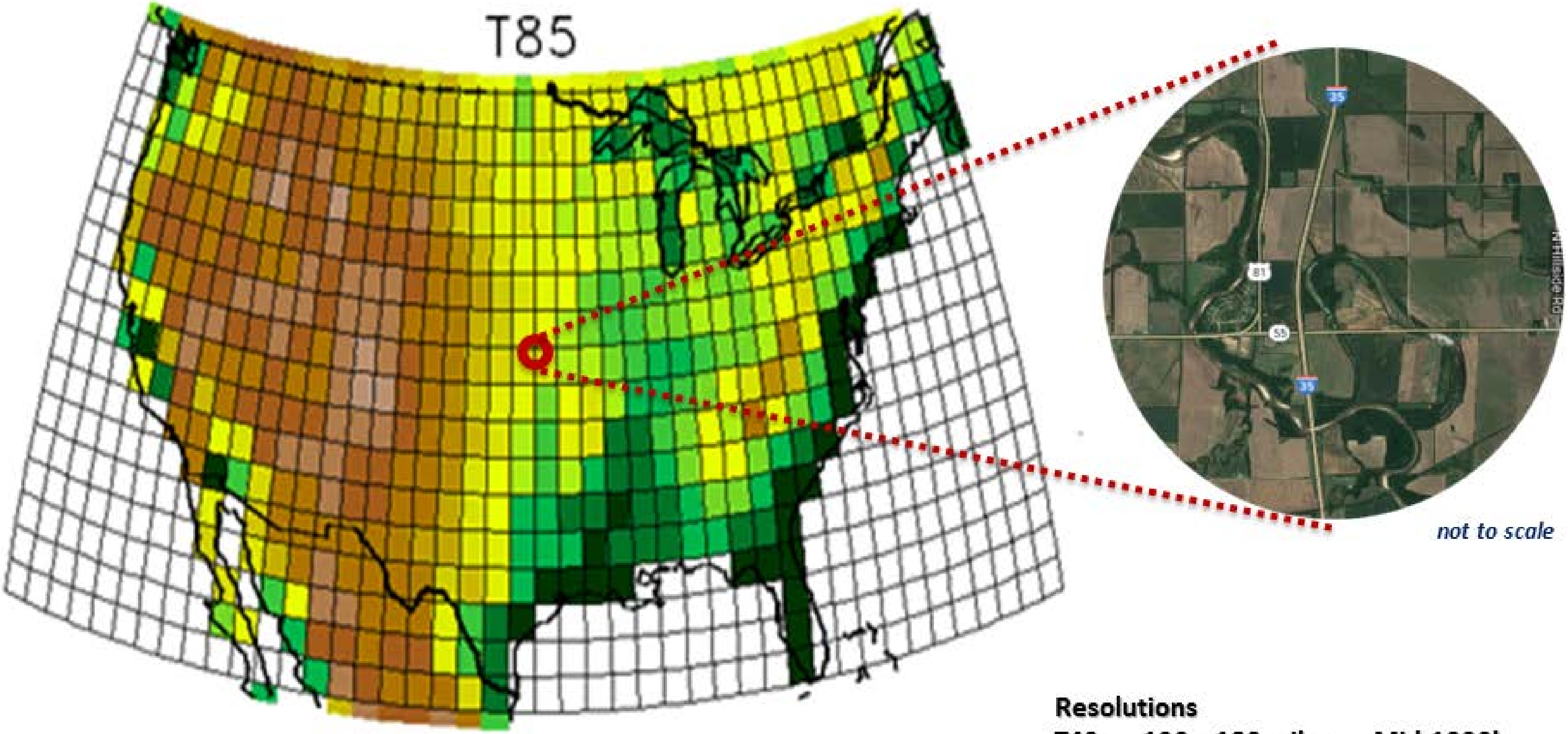

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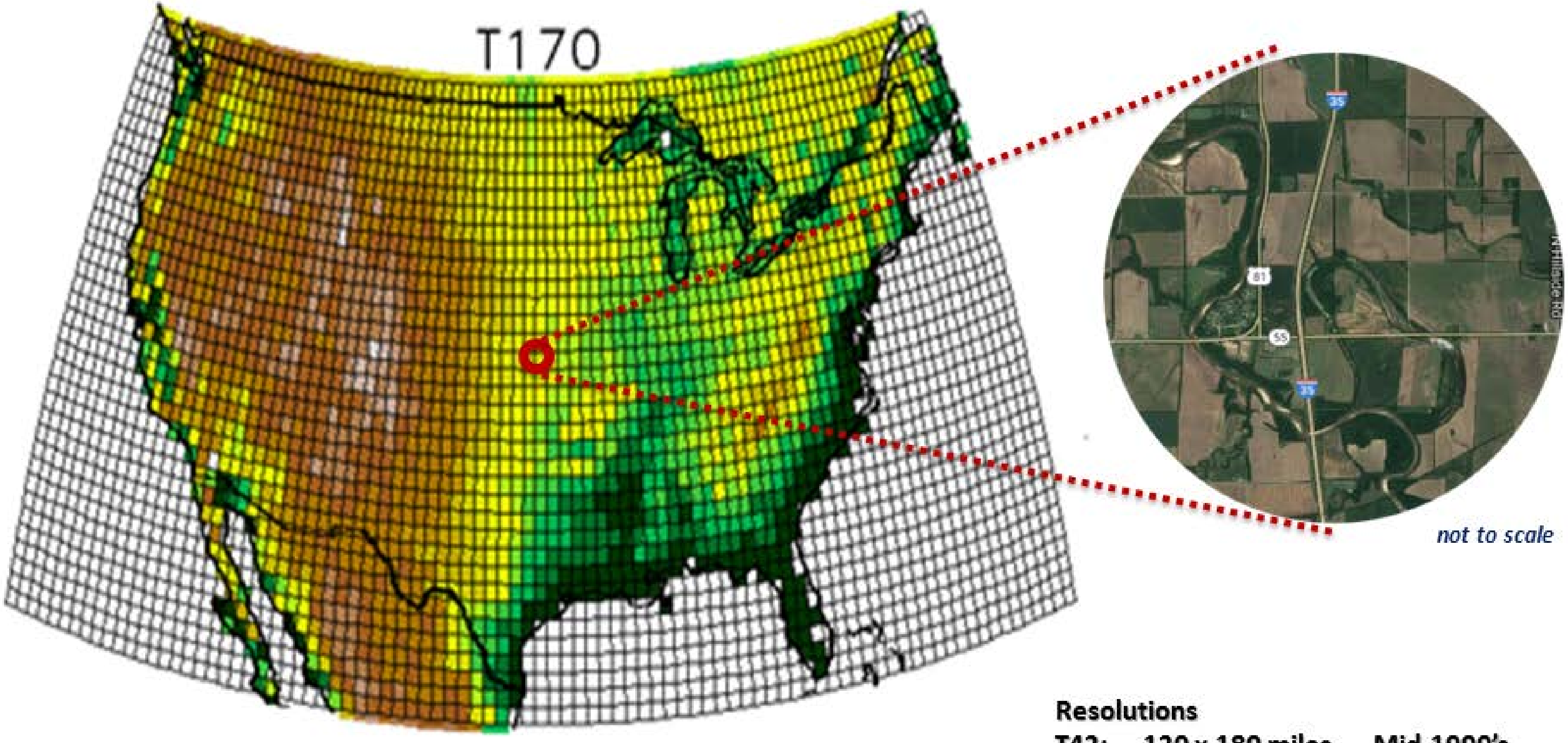

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Global Climate Models (GCMs)

- **What data do climate models produce?**
  - ***Temperature, precipitation projections***

- **How many models are there?**
  - ***Dozens***

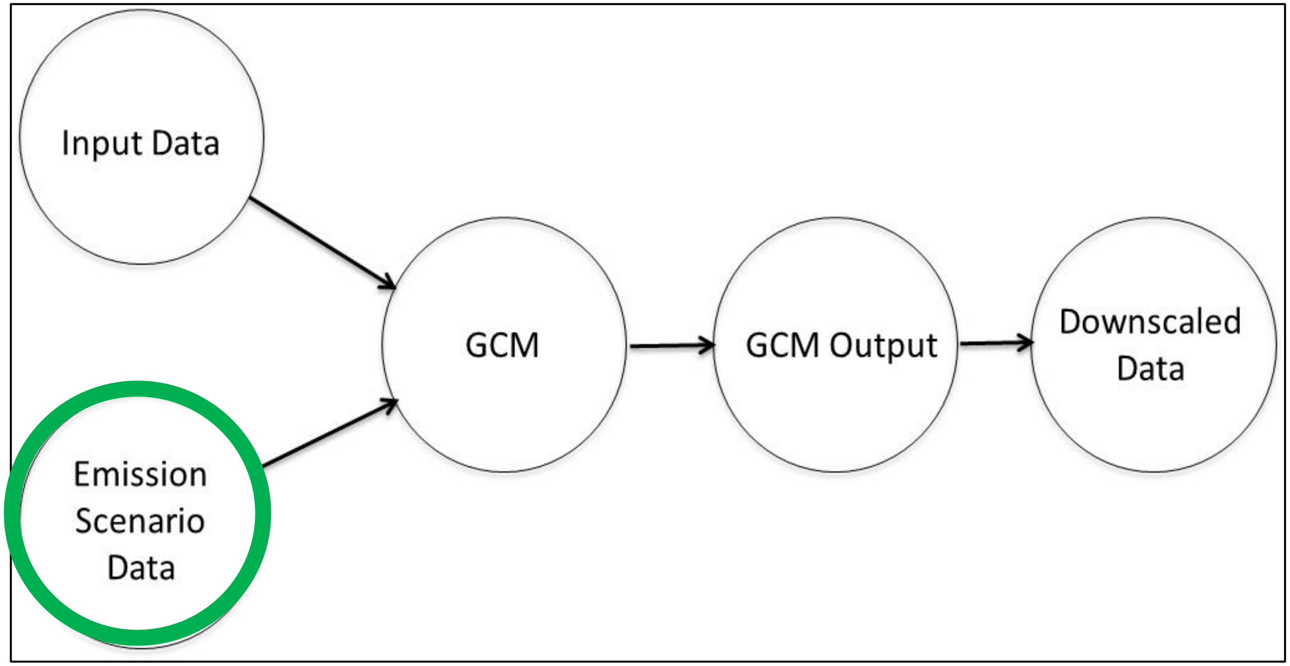
Climate models

- **How can I get a GCM on my phone or laptop??**

- **Which model should I choose?? [trick question]**
  - ***Ensemble of models***

- **Scale of GCM results**
  - ***Thousands of square miles***

Developing Projections



Emissions Scenarios

What is a scenario?

- ❖ ***Tells the model future GHG concentrations***
- ❖ ***Affects the strength of the forcings calculated by the model***

Based on assumptions about the future

- ❖ ***Economic growth***
- ❖ ***Technological development***
- ❖ ***Fossil fuel, renewable energy***
- ❖ ***Population growth rates***

Two Sets of Scenarios:

- ❖ ***Representative Concentration Pathways (RCP)***
- ❖ ***Special Report on Emissions Scenarios (SRES)***

Representative Concentration Pathways (RCP) Scenarios

RCP Scenario	Description
RCP 8.5	**Rising radiative forcing leading to 8.5 W/m^2 (~1370 ppm CO_2 equivalent) by 2100.**
RCP 6.0	**Stabilization, 6 W/m^2 (~850 ppm CO_2 equivalent) at stabilization after 2100**
RCP 4.5	Stabilization, 4.5 W/m^2 (~650 ppm CO_2 equivalent) after 2100
RCP 2.6	Peak at ~3 W/m^2 (~490 ppm CO_2 equivalent) before 2100 and then declines.

FHWA recommends: RCP 6.0, RCP 8.5

Special Report on Emissions Scenarios (SRES)

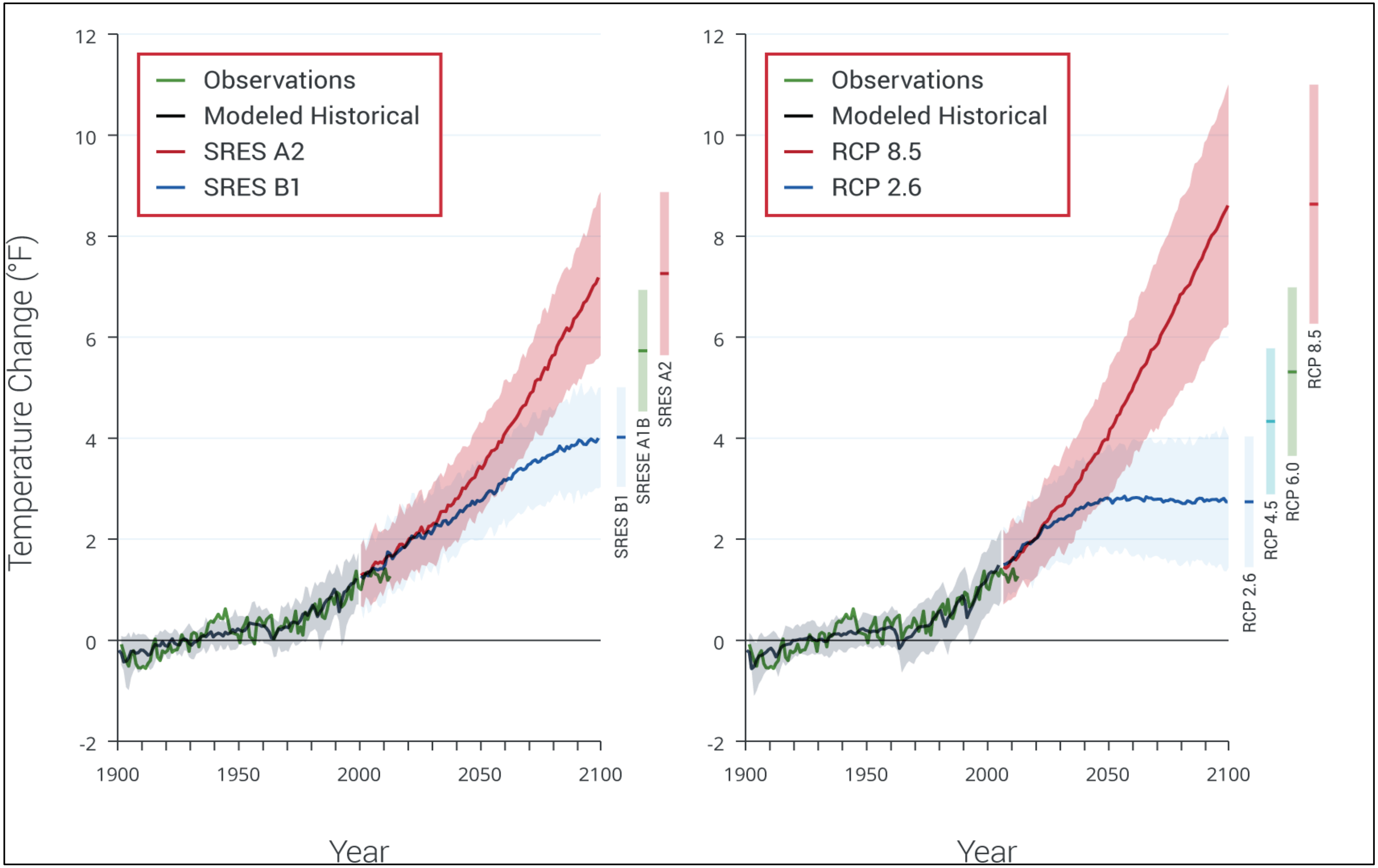
SRES Scenarios

- **Developed in 2000**
- **Used in multiple model runs and studies**
- **CO_2 concentrations: 550-750 ppm, or higher**

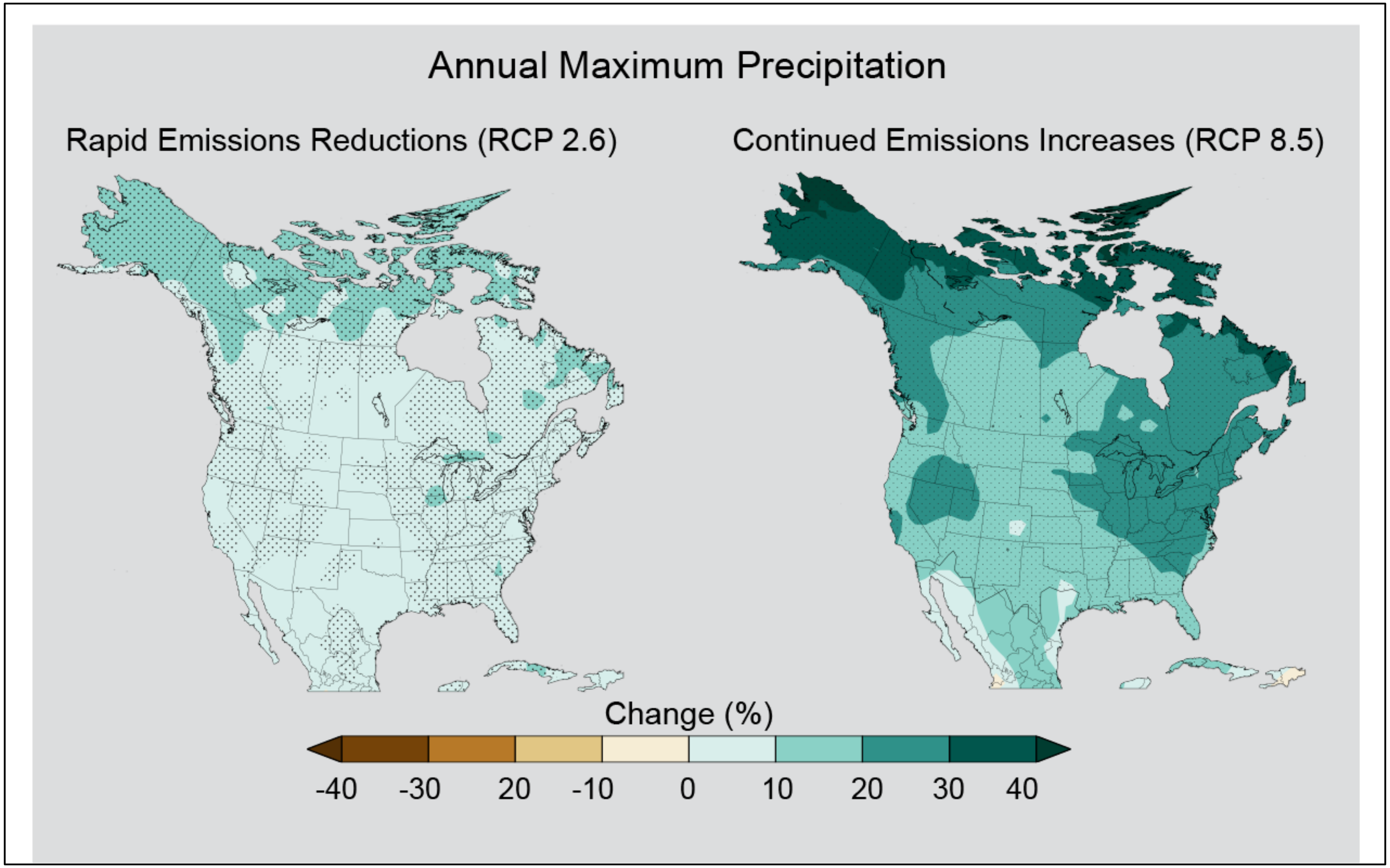
Coupled Model Intercomparison Project (CMIP) database

- **CMIP5 – results for RCP scenarios/models**
- **CMIP3 – Results for the SRES scenarios/models**

Global Temperature Increase: SRES, RCP Scenarios

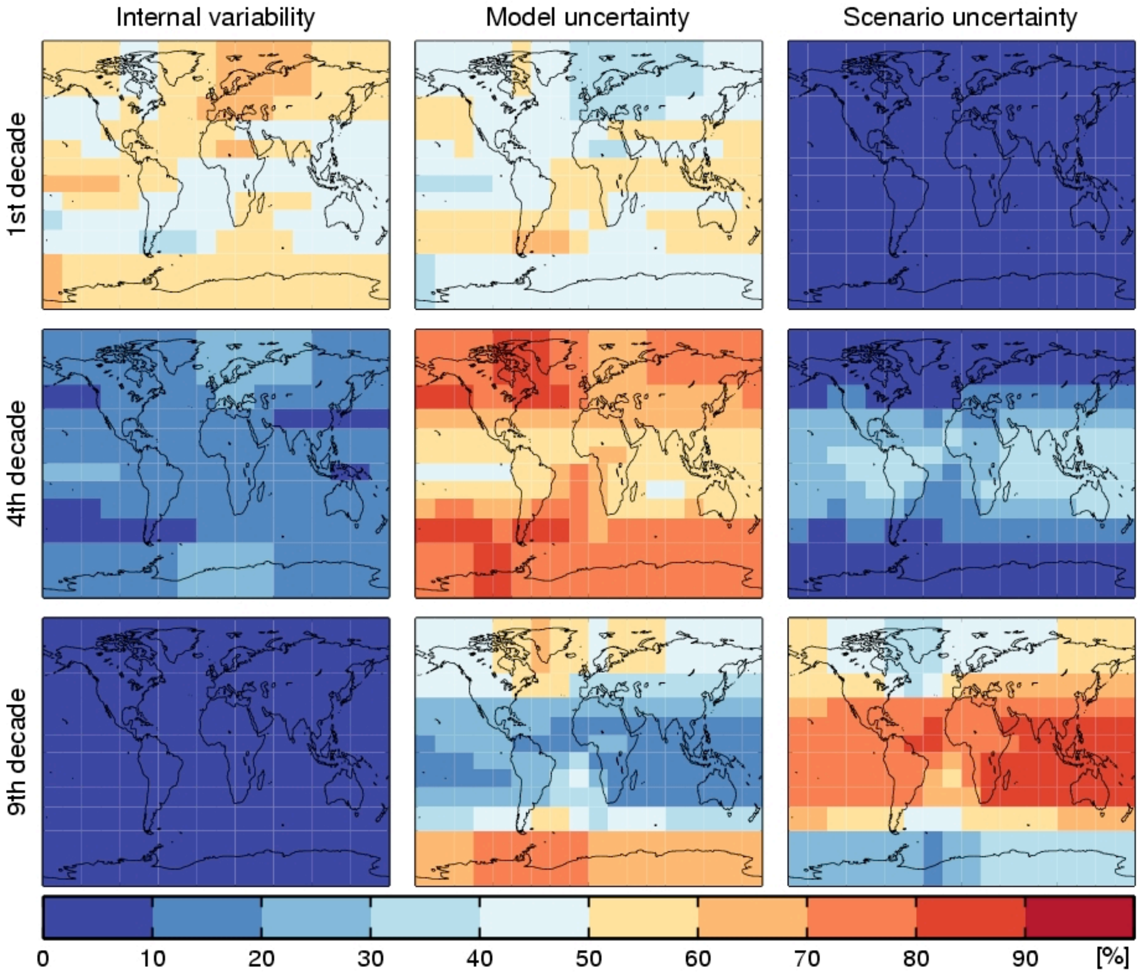


Annual Max Precipitation



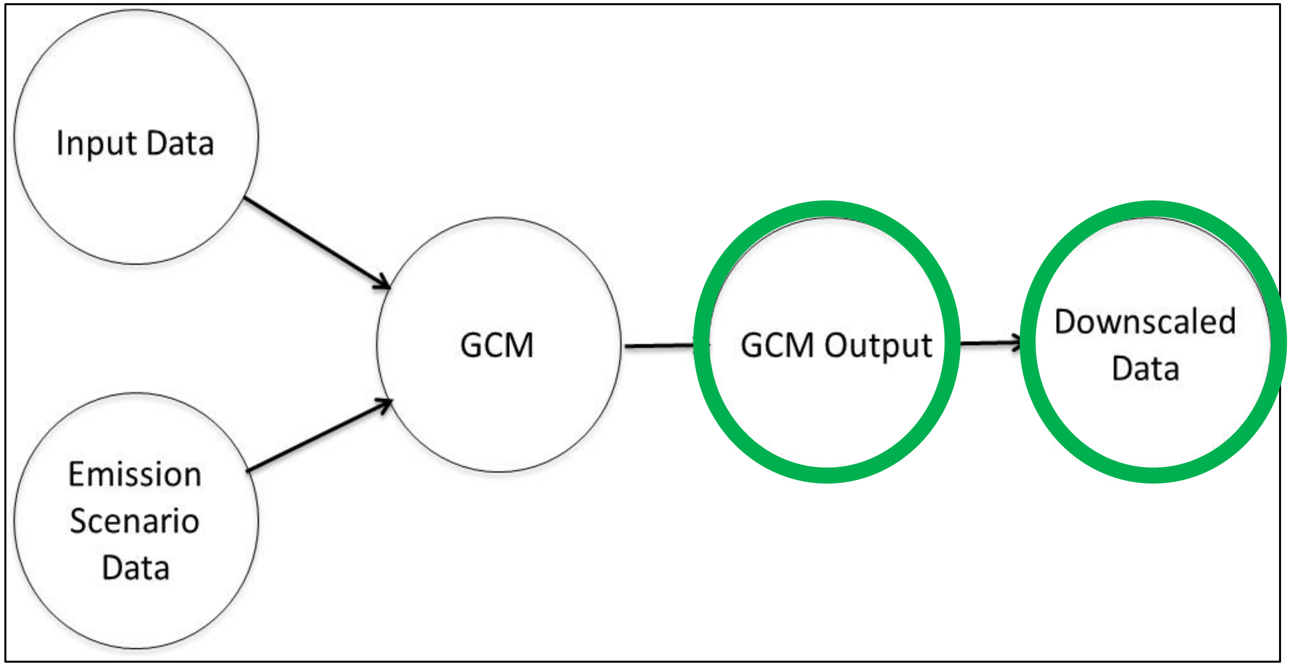
Three Sources of Uncertainty

- **Natural variability**
- **Scientific or Model Uncertainty**
- **Scenario Uncertainty**

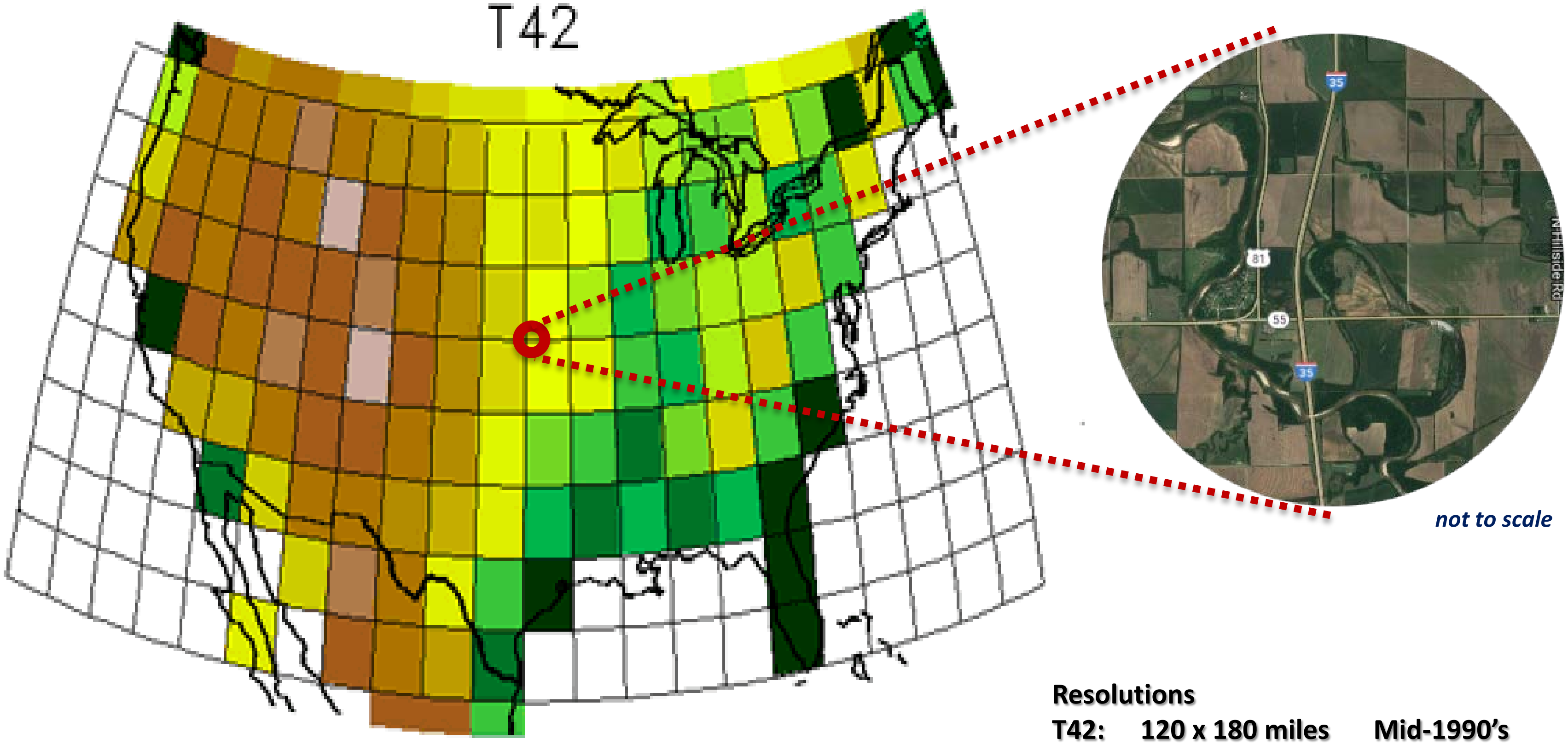


Gulf Coast 2 / Hawkins and Sutton, 2009

Developing Projections



Climate Model Output is too Coarse for Engineering Applications



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Resolution map: Warren Washington, NCAR
http://scied.ucar.edu/longcontent/climate-modeling

Downscaling

- Used to develop projections at a smaller scale
- Two types:
  - *Statistical downscaling*
    - Used in FHWA recommended databases
  - *Dynamic downscaling*

Downscaling

- Statistical Downscaling -- Relies on statistical relationships between local weather and larger weather patterns
- Several different statistical processes:
  - *Bias Corrected Constructed Analogs (BCCA)*
  - *Bias Corrected Spatially Downscaled (BCSD)*
  - *Asynchronous Regional Regression Model (ARRM)*
  - *Localized Constructed Analogs (LOCA)*

- Dynamic Downscaling

Sources of Downscaled Data

- **Downscaled Climate and Hydrology Projections (DCHP)**
  - ***Uses Coupled Model Intercomparison Project (CMIP) model runs***
  - ***Statistically downscaled data from multiple models/scenarios***
  - ***Supported by multiple federal agencies***
  - ***http://Gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html***

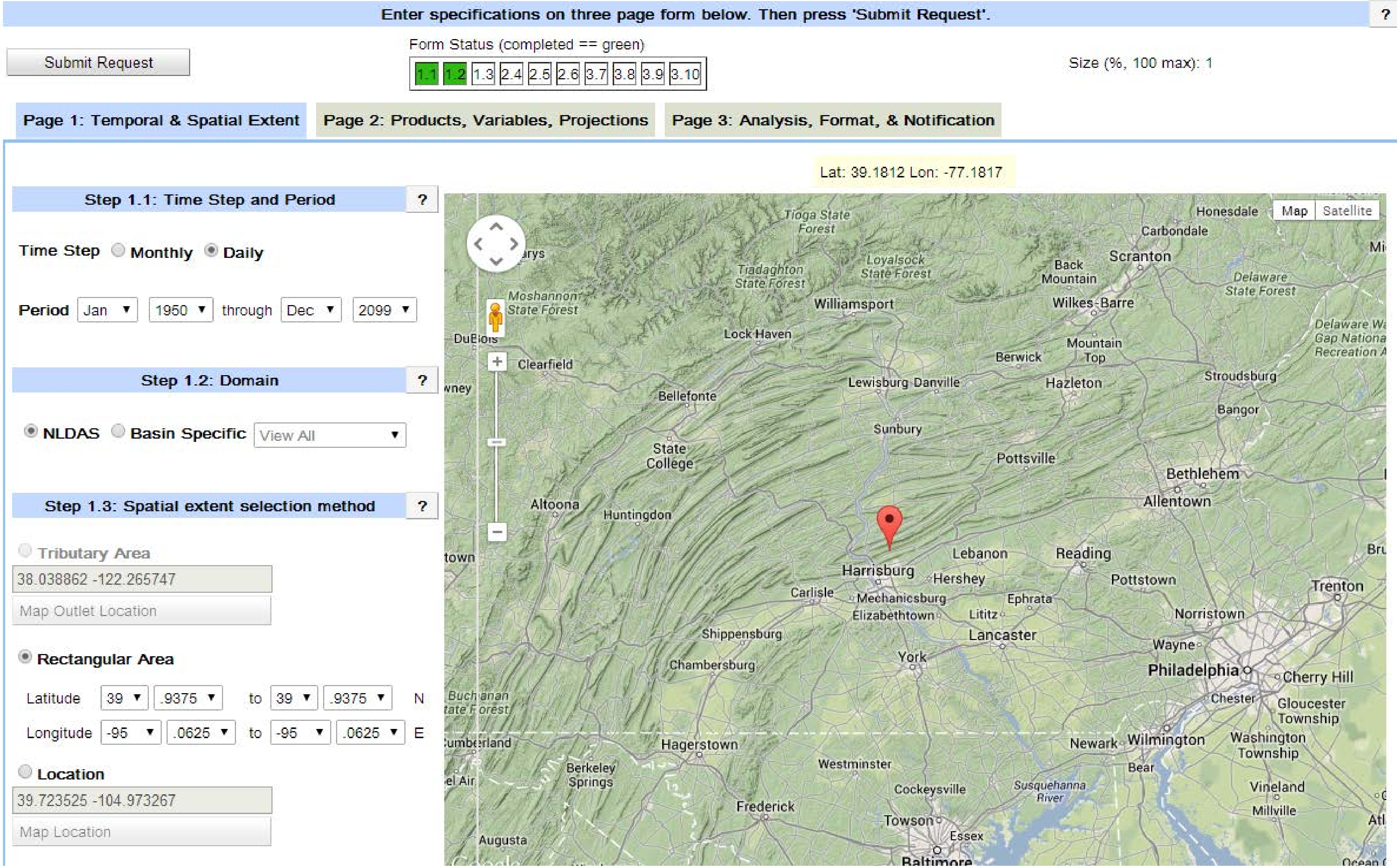
RECLAMATION USGS

Santa Clara University

CLIMATE CENTRAL

SCRIPPS INSTITUTION OF OCEANOGRAPHY

Request Data for your Location from the DCHP Website



Enter specifications on three page form below. Then press 'Submit Request'.

Submit Request

Form Status (completed == green)

1.1	1.2	1.3	2.4	2.5	2.6	3.7	3.8	3.9	3.10
🟩	🟩								

Size (%, 100 max): 1

Page 1: Temporal & Spatial Extent | Page 2: Products, Variables, Projections | Page 3: Analysis, Format, & Notification

Lat: 39.1812 Lon: -77.1817

Step 1.1: Time Step and Period

Time Step ○ Monthly ● Daily

Period Jan 1950 through Dec 2099

Step 1.2: Domain

● NLDAS ○ Basin Specific View All

Step 1.3: Spatial extent selection method

○ Tributary Area

38.038862 -122.265747

Map Outlet Location

● Rectangular Area

Latitude 39 .9375 to 39 .9375 N

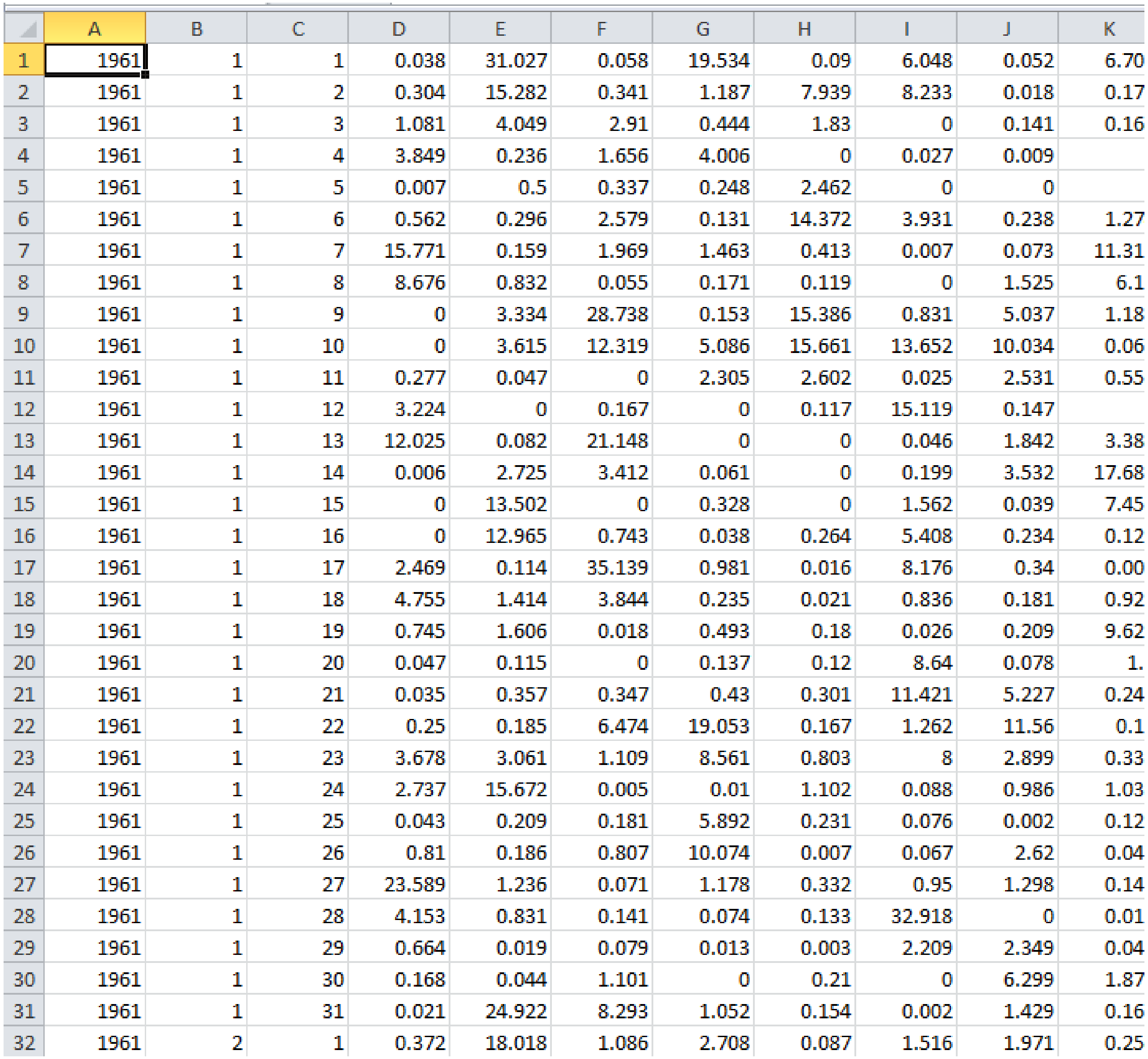
Longitude -95 .0625 to -95 .0625 E

○ Location

39.723525 -104.973267

Map Location

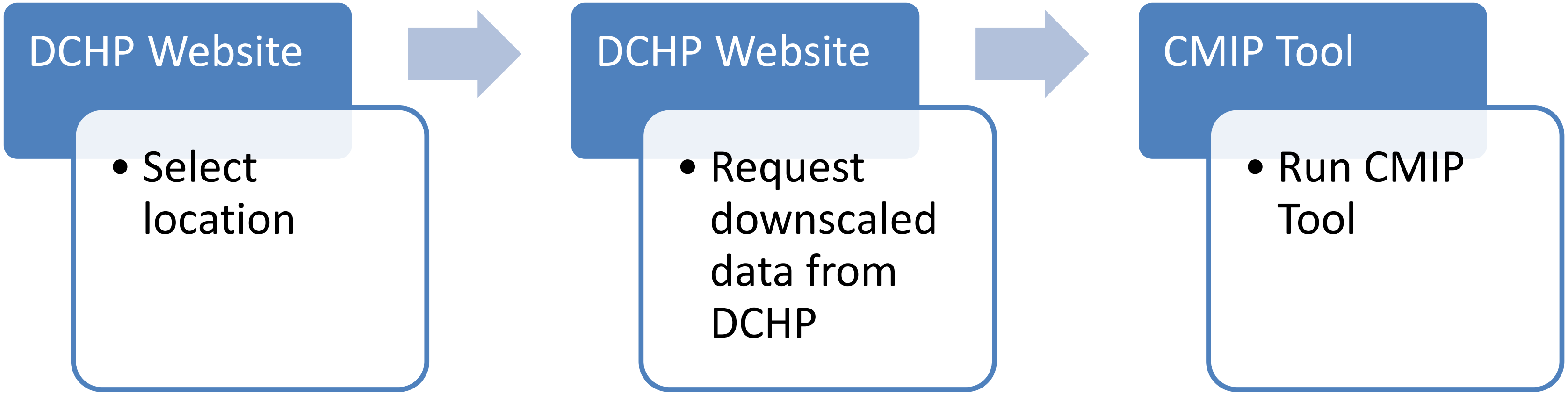
Raw DCHP Data



	A	B	C	D	E	F	G	H	I	J	K
1	1961	1	1	0.038	31.027	0.058	19.534	0.09	6.048	0.052	6.70
2	1961	1	2	0.304	15.282	0.341	1.187	7.939	8.233	0.018	0.17
3	1961	1	3	1.081	4.049	2.91	0.444	1.83	0	0.141	0.16
4	1961	1	4	3.849	0.236	1.656	4.006	0	0.027	0.009	
5	1961	1	5	0.007	0.5	0.337	0.248	2.462	0	0	
6	1961	1	6	0.562	0.296	2.579	0.131	14.372	3.931	0.238	1.27
7	1961	1	7	15.771	0.159	1.969	1.463	0.413	0.007	0.073	11.31
8	1961	1	8	8.676	0.832	0.055	0.171	0.119	0	1.525	6.1
9	1961	1	9	0	3.334	28.738	0.153	15.386	0.831	5.037	1.18
10	1961	1	10	0	3.615	12.319	5.086	15.661	13.652	10.034	0.06
11	1961	1	11	0.277	0.047	0	2.305	2.602	0.025	2.531	0.55
12	1961	1	12	3.224	0	0.167	0	0.117	15.119	0.147	
13	1961	1	13	12.025	0.082	21.148	0	0	0.046	1.842	3.38
14	1961	1	14	0.006	2.725	3.412	0.061	0	0.199	3.532	17.68
15	1961	1	15	0	13.502	0	0.328	0	1.562	0.039	7.45
16	1961	1	16	0	12.965	0.743	0.038	0.264	5.408	0.234	0.12
17	1961	1	17	2.469	0.114	35.139	0.981	0.016	8.176	0.34	0.00
18	1961	1	18	4.755	1.414	3.844	0.235	0.021	0.836	0.181	0.92
19	1961	1	19	0.745	1.606	0.018	0.493	0.18	0.026	0.209	9.62
20	1961	1	20	0.047	0.115	0	0.137	0.12	8.64	0.078	1.
21	1961	1	21	0.035	0.357	0.347	0.43	0.301	11.421	5.227	0.24
22	1961	1	22	0.25	0.185	6.474	19.053	0.167	1.262	11.56	0.1
23	1961	1	23	3.678	3.061	1.109	8.561	0.803	8	2.899	0.33
24	1961	1	24	2.737	15.672	0.005	0.01	1.102	0.088	0.986	1.03
25	1961	1	25	0.043	0.209	0.181	5.892	0.231	0.076	0.002	0.12
26	1961	1	26	0.81	0.186	0.807	10.074	0.007	0.067	2.62	0.04
27	1961	1	27	23.589	1.236	0.071	1.178	0.332	0.95	1.298	0.14
28	1961	1	28	4.153	0.831	0.141	0.074	0.133	32.918	0	0.01
29	1961	1	29	0.664	0.019	0.079	0.013	0.003	2.209	2.349	0.04
30	1961	1	30	0.168	0.044	1.101	0	0.21	0	6.299	1.87
31	1961	1	31	0.021	24.922	8.293	1.052	0.154	0.002	1.429	0.16
32	1961	2	1	0.372	18.018	1.086	2.708	0.087	1.516	1.971	0.25

CMIP Climate Data Processing Tool

- **FHWA developed tool to help crunch the data**
  - ***Excel spreadsheet that processes DCHP datasets***
  - ***Calculate variables relevant to transportation agencies***



DCHP Website

- Select location

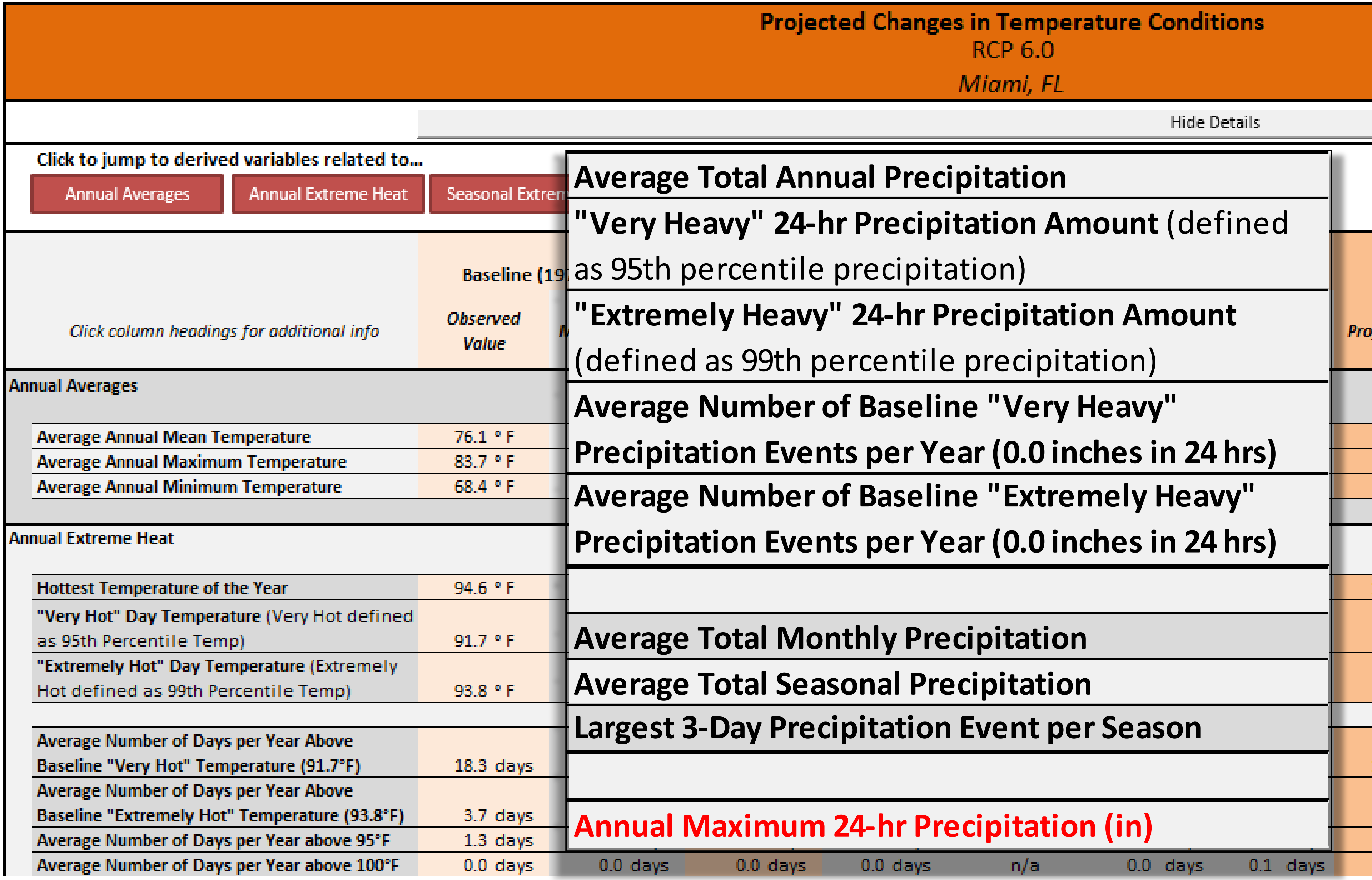
DCHP Website

- Request downscaled data from DCHP

CMIP Tool

- Run CMIP Tool

CMIP Climate Data Processing Tool – Output



Projected Changes in Temperature Conditions
RCP 6.0
Miami, FL

Hide Details

Click to jump to derived variables related to...

Baseline (19

Click column headings for additional info	*Observed Value*						
Annual Averages							
Average Annual Mean Temperature	76.1 ° F						
Average Annual Maximum Temperature	83.7 ° F						
Average Annual Minimum Temperature	68.4 ° F						
Annual Extreme Heat							
Hottest Temperature of the Year	94.6 ° F						
"Very Hot" Day Temperature (Very Hot defined as 95th Percentile Temp)	91.7 ° F						
"Extremely Hot" Day Temperature (Extremely Hot defined as 99th Percentile Temp)	93.8 ° F						
Average Number of Days per Year Above Baseline "Very Hot" Temperature (91.7°F)	18.3 days						
Average Number of Days per Year Above Baseline "Extremely Hot" Temperature (93.8°F)	3.7 days						
Average Number of Days per Year above 95°F	1.3 days						
Average Number of Days per Year above 100°F	0.0 days	0.0 days	0.0 days	0.0 days	n/a	0.0 days	0.1 days

Average Total Annual Precipitation

"Very Heavy" 24-hr Precipitation Amount (defined as 95th percentile precipitation)

"Extremely Heavy" 24-hr Precipitation Amount (defined as 99th percentile precipitation)

Average Number of Baseline "Very Heavy" Precipitation Events per Year (0.0 inches in 24 hrs)

Average Number of Baseline "Extremely Heavy" Precipitation Events per Year (0.0 inches in 24 hrs)

Average Total Monthly Precipitation

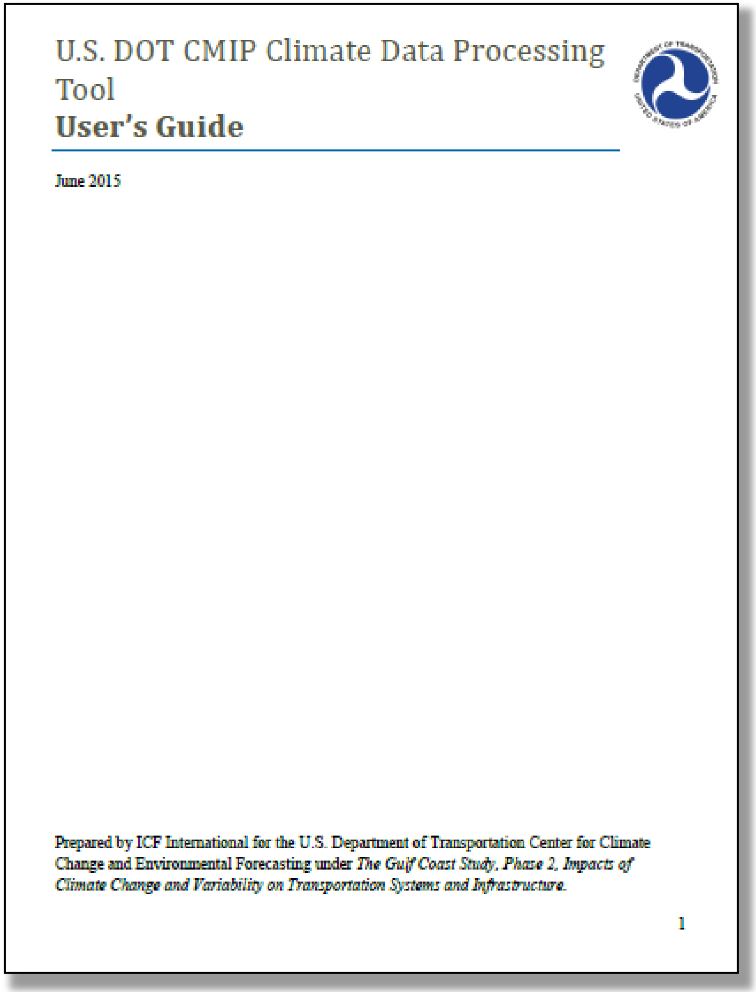
Average Total Seasonal Precipitation

Largest 3-Day Precipitation Event per Season

Annual Maximum 24-hr Precipitation (in)

CMIP Climate Data Processing Tool

- Tool user guide steps through entire process
- Online webinars describe how to use tool in detail
- Tool is free to download and use



U.S. DOT CMIP Climate Data Processing Tool
User's Guide

June 2015

Prepared by ICF International for the U.S. Department of Transportation Center for Climate Change and Environmental Forecasting under *The Gulf Coast Study, Phase 2, Impacts of Climate Change and Variability on Transportation Systems and Infrastructure.*

1

www.fhwa.dot.gov/environment/sustainability/resilience/tools/

Other Sources of Downscaled Data

- **USGS Geo Data Portal**
  - ***Statistically downscaled data from multiple sources***
  - ***http://cida.usgs.gov/gdp/***
- **North American Regional Climate Change Assessment Program (NARCCAP)**
  - ***Dynamically downscaled data for SRES A2 scenario***
  - ***www.narccap.ucar.edu/***

Questions?

Chapter

6

Risk and Resilience

Why a Chapter on Risk and Resilience?

- **23 CFR 650 Subpart A**
  - ***"Location studies shall include discussion of …The risks associated with the implementation of the action,…"***
- **FHWA Order 5520**
  - ***"…developing engineering solutions…that address risk and promote resilience…"***
- **Risk-based asset management**
- **Balance social, economic, environmental interests**
- **Design standards provide consistency**
- **Expand thinking about design to include:**
  - ***Evolving service lives, function, multiple events, retrofits***
  - ***Changing watershed and climate (nonstationarity)***

Terminology

Risk

Resilience

Design Criteria

Design Event

Design Life

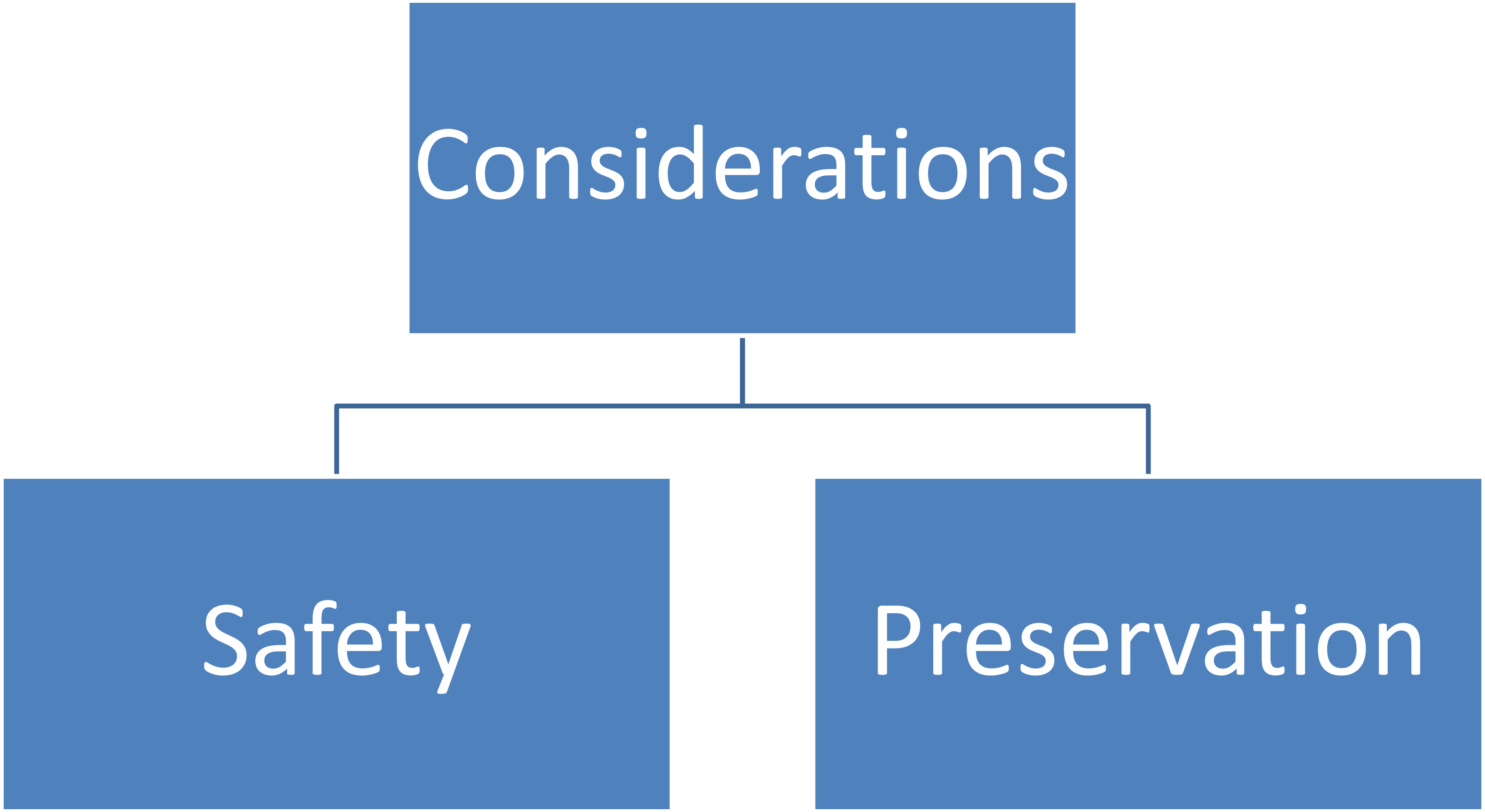
Service Life

Functional Classification

Probability of Occurrence

Exceedance

Design Events



Considerations

Safety

Preservation

Risk

R
I
S
K

=

Probability

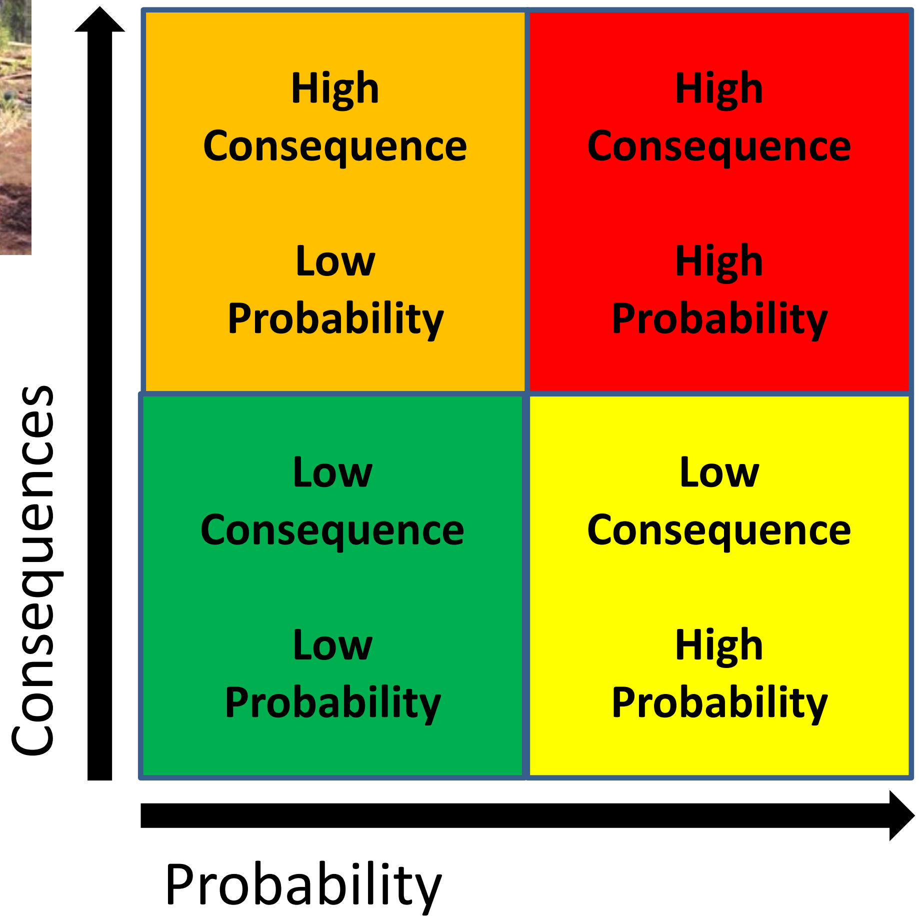
Design Event
Check Event
AEP
Return Period
Design Life
Service Life
Range of Events
Nonstationarity

X

Consequences

Damage
Overtopping
Exceed Design
Maintenance
Higher Costs
Loss of Life
Loss of Service
Scour (?!?)

Backpacking Risk



High Consequence Low Probability	High Consequence High Probability
Low Consequence Low Probability	Low Consequence High Probability

Consequences

Probability

Low Consequences?

High Consequences

The Recorder

Special report

75 cents
April, 1987

Thruway disaster

Associated Press: James McKnight

Bridge down...

It was a rainy Sunday morning — the first Sunday in April.

The Mohawk River was running high. So was the Schoharie Creek, which feeds into it near Fort Hunter.

Tragedy struck shortly after 10:30.

Without warning, the Thruway bridge over the Schoharie collapsed. Unaware of the gap where moments before an 80-foot-high bridge had been, as many as five vehicles plunged into the muddy water below.

Ten people are believed to have died in the accident.

Word spread quickly up and down the valley. It spread from neighbor to neighbor, village to town.

"Have you heard?"

"What happened?"

"Is anybody hurt ..."

The news traveled on and on. Soon, the nation knew.

The story is still unfolding, and will be for months.

Traffic is snarled. Investigations into what actually caused the bridge to go down have begun. Local merchants and other business interests ponder what will happen next.

In this special report, The Recorder's newsroom staff has captured the story in words and photographs.

It is a story of tragedy, of course. But it also is a story of cooperation, heroism and a determination to pick up the pieces.

Design Criteria Example

Roadway Classification*	Annual Exceedance Probability (percent)	Return Period (years)
Interstate, Freeways (Urban/Rural)	2%	50
Principal Arterial	2%	50
Minor Arterial System, ADT>3000 VPD	2%	50
Minor Arterial System, ADT=<3000 VPD	4%	25
Collector System with ADT>3000 VPD	4%	25
Collector System with ADT=<3000 VPD	10%	10
Local Road System	20%-10%	5-10

*Average Daily Traffic (ADT): Vehicles per Day (VPD)

Performance over Design Life

$$P = 1 - \left(1 - \frac{1}{T}\right)^{n}$$

Eq. 6.1

$\boldsymbol{P}$ = probability that the design flood level will be equaled or exceeded in n years

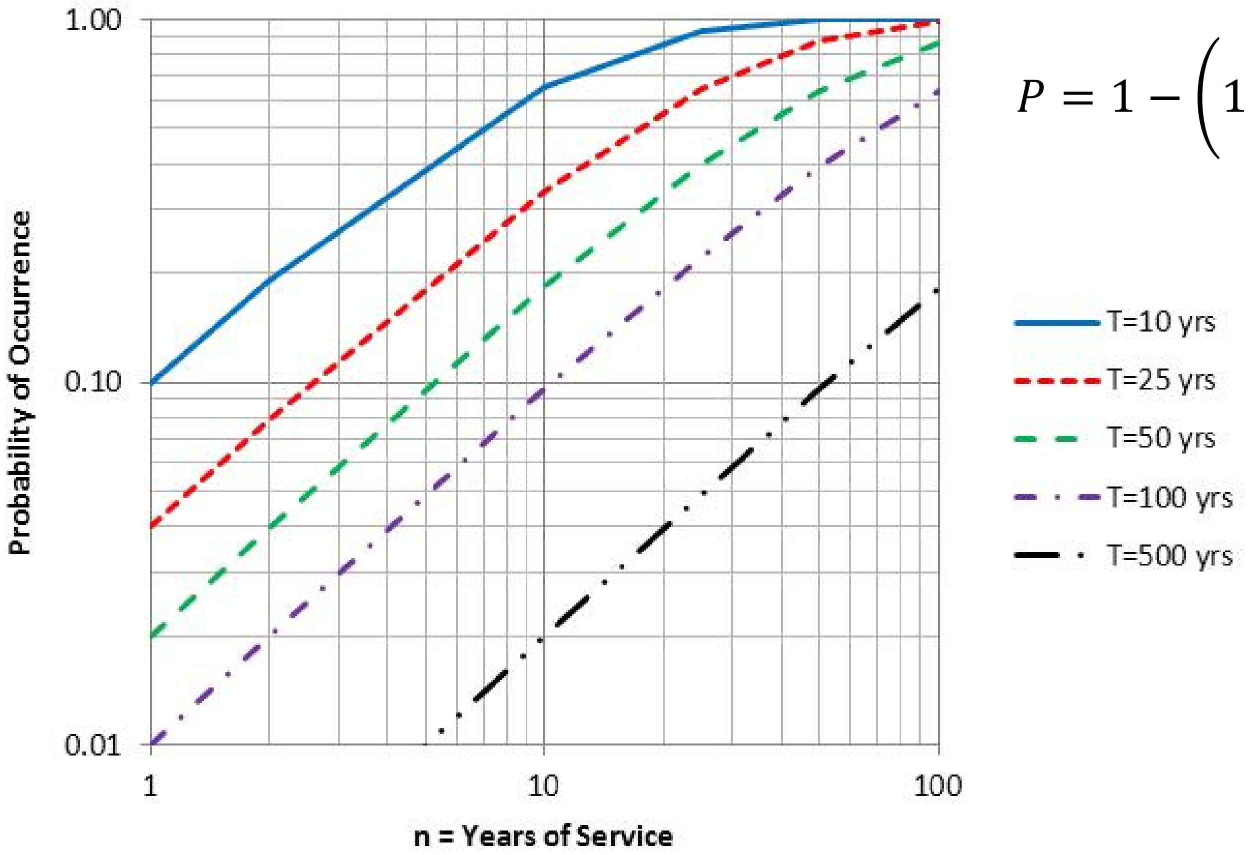
$\boldsymbol{n}$ = design or expected service life, years

$\boldsymbol{T}$ = the return period of the design storm, years

$$P = 1 - \left(1 - \frac{1}{50}\right)^{75} = 0.78\ (78\ percent)$$

Odds of Q50 flooding bridge over 75 year life is 78%!

Performance over Design Life



$$P = 1 - \left(1 - \frac{1}{T}\right)^{n}$$

Evolving Conditions over Service Life

- **Changes in functional classification**
  - ***Upgrade from secondary to primary road***

- **Nonstationarity**
  - ***Change in land use (urbanization, flood control projects)***
  - ***Change in precipitation patterns***
  - ***Change in watershed characteristics (cover, wildfire!)***

- **See example problem HEC 17 page 6-6:**
  - ***Uses Eq. 6.1***
  - ***Flood probability increases over time***

Example problem HEC 17 page 6-6

- ***Regression includes Mean Annual Precipitation (MAP)***
- ***MAP projected to increase* over 100 year service life***

AEP Return Period	0.5 Q2	0.2 Q5	0.1 Q10	0.04 Q25	0.02 Q50	0.01 Q100
Flow with Current MAP (ft^3/s)	2,280	5,240	7,800	12,000	15,800	20,500
Flow with Future MAP (ft^3/s)	3,110	7,020	10,200	15,500	20,300	26,000

$$P = 1 - \left(1 - \frac{1}{50}\right)^{100} = 0.87 \qquad P = 1 - \left(1 - \frac{1}{25}\right)^{100} = 0.98$$

- ***Probability of 15,800 cfs event 87% → 98% over 100 years***
- ****If MAP decreases, P decreases too***

Modifying Existing Facilities

- **Examine remaining service life**

- **If remaining life is short (<30 yrs)**
  - ***Additional risk due to "nonstationarity" is minimal***

- **If remaining life is long (>30 yrs)**
  - ***Consider additional risk due to "nonstationarity"***

Modifying Existing Facilities

Ugh Oh?

We're Good?

Look at a Range of Events

- In addition to design flood…

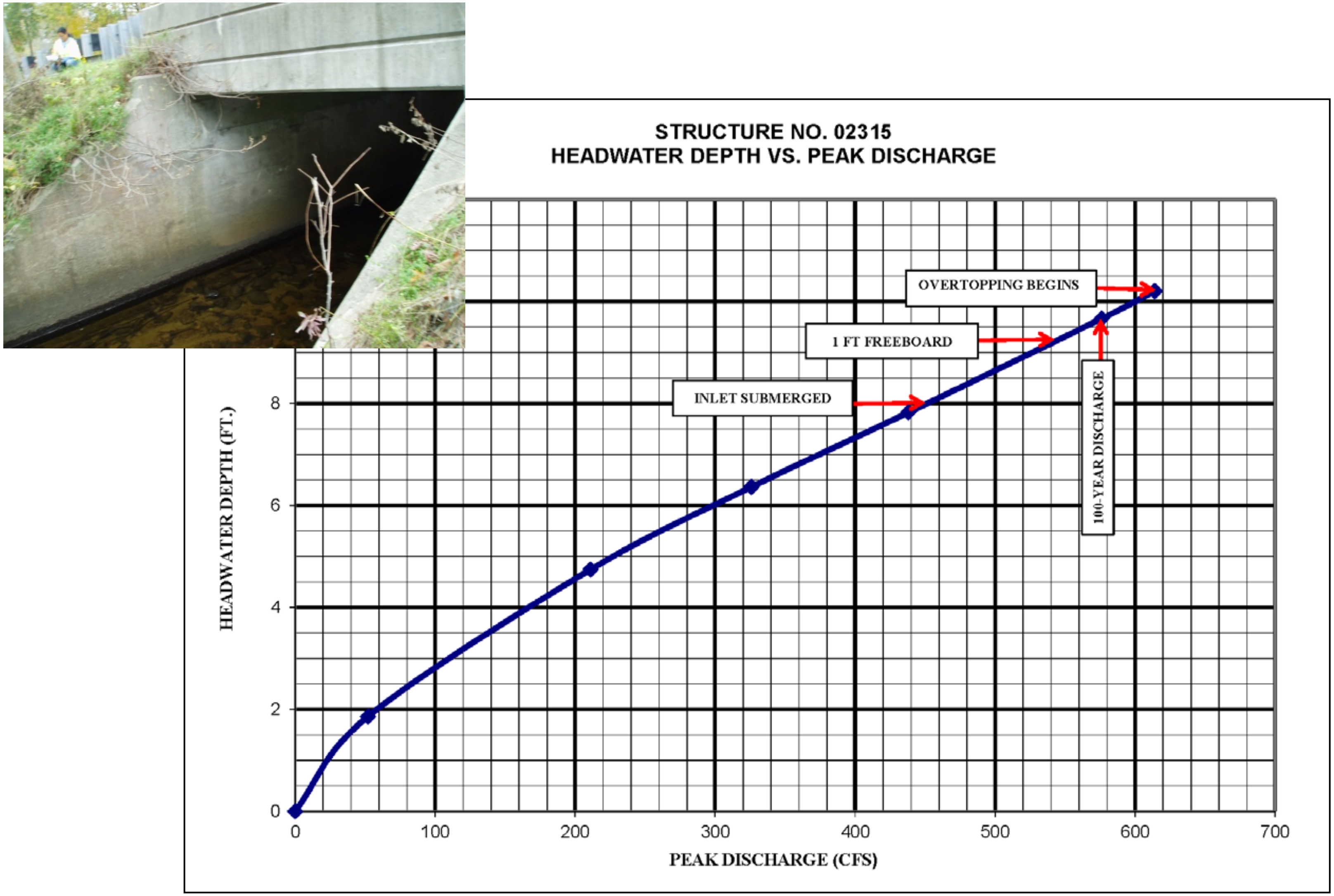
- Check floods above design flood
- Backwater impacts to upstream properties
- Impacts to FEMA regulated floodplains
- Performance curves…shapes convey resilience
- Smaller floods…siltation? Maintenance issues?
- Wide floodplains…channel meandering patterns?
- Temporary construction flood diversions required?

Resilience

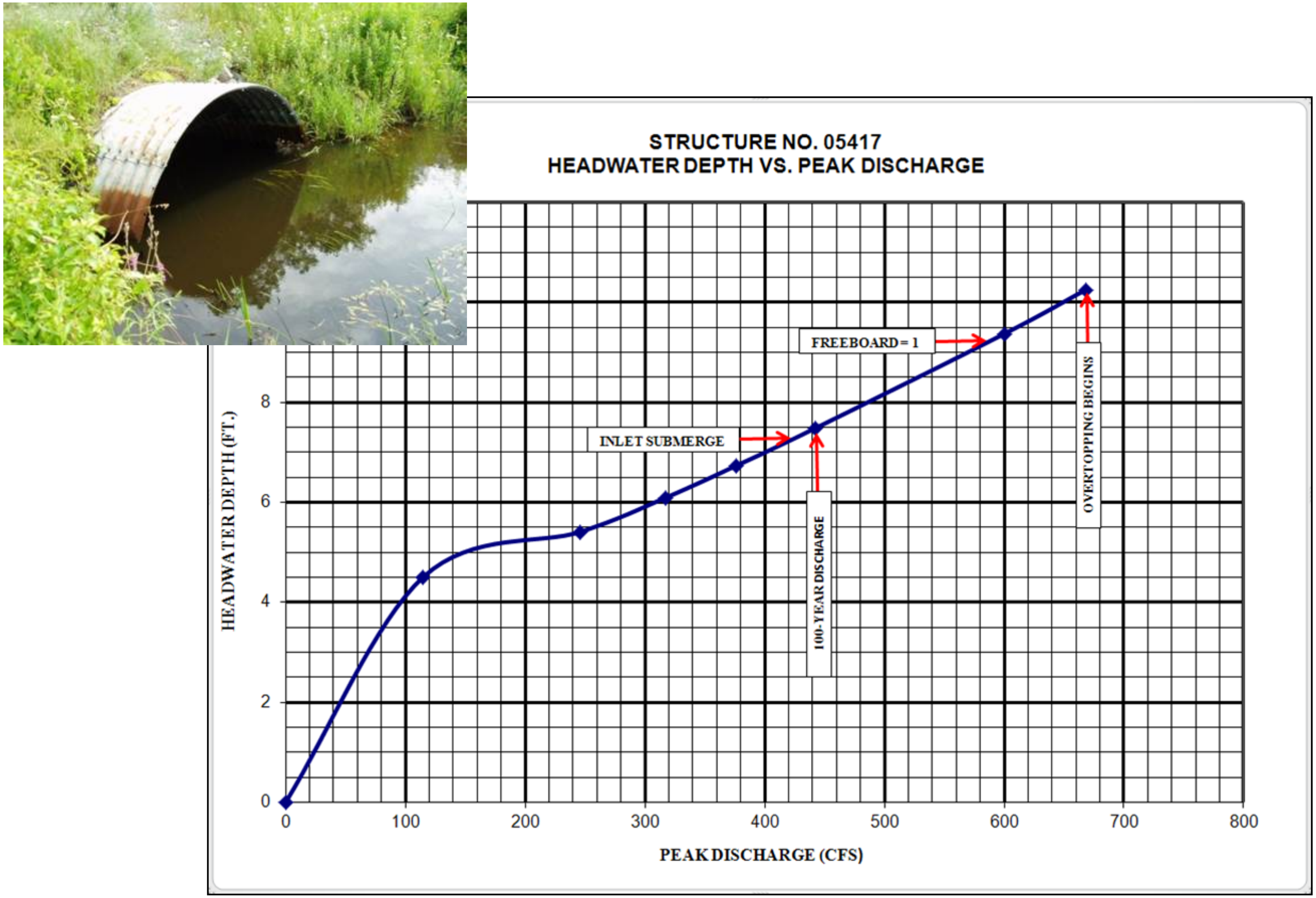
The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.

FHWA Order 5520, December 15, 2014

Performance Curve: Little Existing Resilience



Performance Curve: Lots of Existing Resilience



Exceeding Design Criteria

- **Design discharge exceedances from:**
  - ***Random, but natural, high discharges***
  - ***Changes in watershed/climate***
  - ***Incorrect estimate of design discharge***

- **Does exceedance create risk to safety or the asset?**

- **23 CFR 650.115: Consider costs, economic, engineering, social, environmental concerns**

Consider Impacts to Surrounding Vicinity

Structural Damage

- Usually result of exceeding hydraulic capacity…not necessarily exceeding design criteria
- Can we anticipate/design for these exceedances?

Recognizing Risk / Designing with Resilience

- **Need to recognize potential for evolving (rather than static) risks and build in resilience**

- **This is NOT changing design criteria, rather recognizing design discharge may evolve over time**

- **Example: A "resilient" bridge design:**
  - ***accommodates the planned design discharge***
  - ***survives higher discharges w/o catastrophic failure,***
  - ***returns to service cheaply/quickly if overtopped***
  - ***is elevated above damaging waves including debris***

Questions?