HEC 17:

Highways in the River Environment

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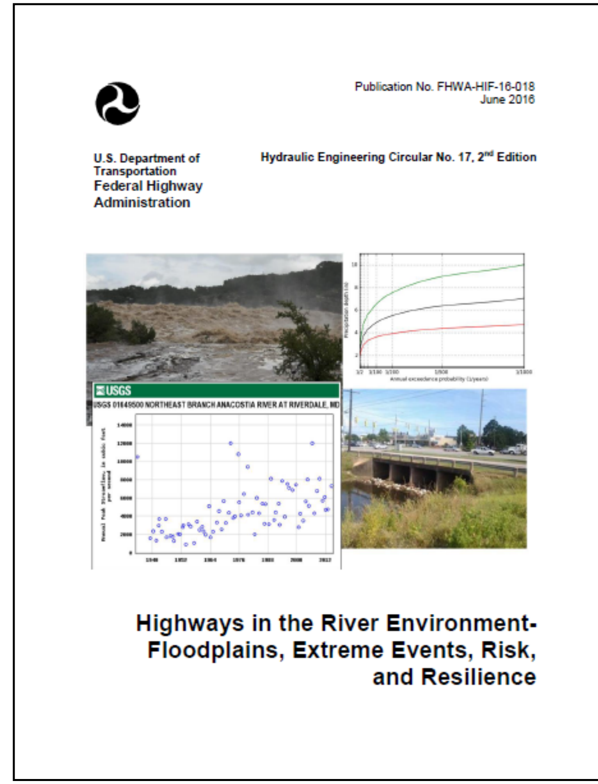
Floodplains, Extreme Events, Risk and Resilience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USGS
USGS 01649500 NORTHEAST BRANCH ANACOSTIA RIVER AT RIVERDALE, MD

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

Webinar C: Chapters 7 and 8

Presenters: Joe Krolak, Brian Beucler, Rob Kafalenos, Cynthia Nurmi, 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://www.fhwa.dot.gov/engineering/hydraulics/media.cfm

People Presenting

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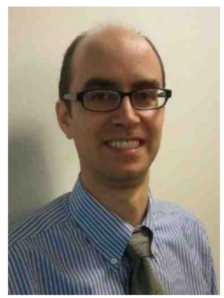

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- **Roger T. Kilgore**
  - ***Kilgore Consulting & Management***
- **George (Rudy) Herrmann**
  - ***Desert Sky Engineering and Hydrology***
- **Wil Thomas**
  - ***Michael Baker International***
- **David B. Thompson**
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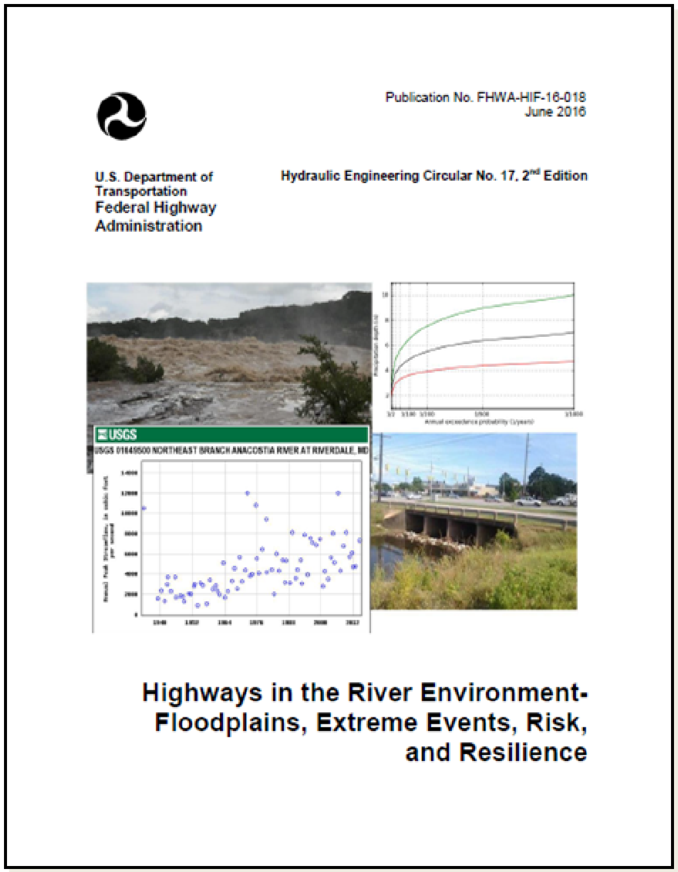
Peer Exchange Panel

- **Karen Metchis & Chris Weaver**
  - ***USEPA***
- **Kate White & Jeff Arnold**
  - ***USACE***
- **Robert Mason, Robert Hirsch & Tim Cohn**
  - ***USGS***

Helped to inform FHWA on Federal insights …

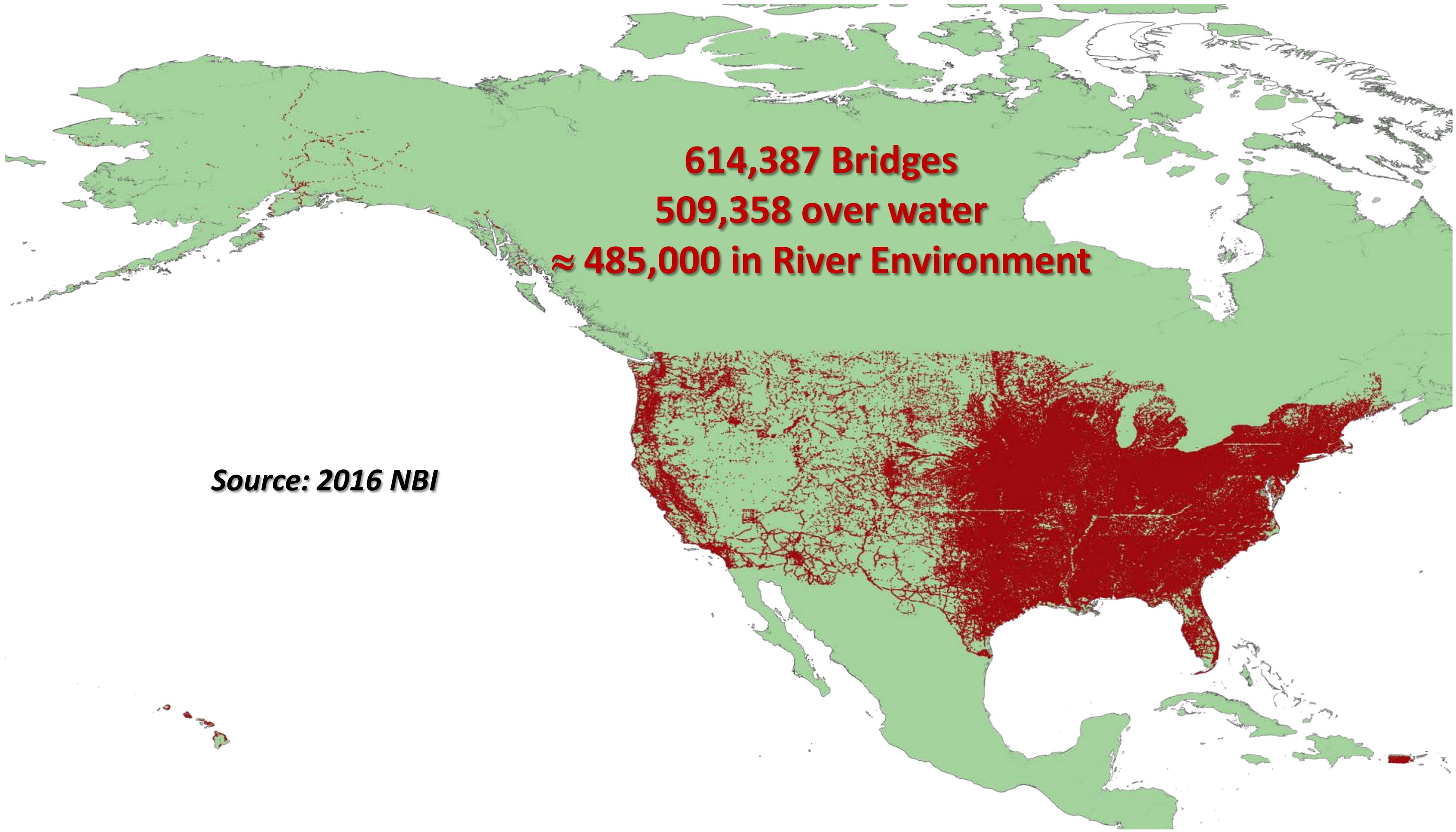
Why HEC-17?



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**

Why the River Environment?



Missing: nationally applicable riverine information on focus areas

What Do We Know?

What Don’t We Know?

Pulling It All Together

- **Floodplain Policy** *Chapter 2*
  - ***Best actionable engineering / science methods and data***
- **Riverine Flooding** *Chapter 3*
  - ***Traditional hydrologic approaches***
- **Nonstationarity** *Chapter 4*
  - ***Sources of nonstationarity***
- **Climate Science and Modeling** *Chapter 5*
  - ***Weather vs Climate, scenarios, ensembles, uncertainty***
  - ***Large scale models driven by greenhouse gas forcings***
  - ***Downscaling required, FHWA CMIP tool recommended***
- **Risk and Resilience** *Chapter 6*
  - ***Risk "evolution", exceeding design criteria vs damage***
  - ***Resilient designs***

Chapter

7

Analysis Framework

Before we Begin…

- **Observations vs Projections**
  - ***Observations are measurements taken looking back in time***
  - ***Projections are future estimates of "observations yet to occur"***
  - ***Observations are of fine spatial/temporal scale***
  - ***Projections are of coarse spatial/temporal scale***
- **Precipitation vs Flow**
  - ***Precipitation falls from the sky onto watersheds…GCMs give precip***
  - ***Flow determined by conditions in watersheds…we need flow***
  - ***Chapter 7 deals <u>mainly</u> with precipitation nonstationarity***
- **Climate Science vs Hydrology**
  - ***Climate science set up to answer broader global longer term questions***
  - ***Hydrology focuses on specific sites, answers specific local questions***
  - ***Both fields work with uncertainty***

Analysis Framework

- **Recognizes Uncertainties**
  - ***Data uncertainty (variability and emissions scenarios)***
  - ***Model uncertainty (hydrologic and GCM's)***

- **Levels of Analysis**
  - ***Historic observations vs future projections***
  - ***Effort grows and shifts to projections as risk increases***
  - ***Incorporation of projections into various hydrologic models***
  - ***Watershed size vs level of analysis***
  - ***Service life considered using confidence intervals***
  - ***Skillset/membership of design teams shifts as risk increases***

- **Programmatic Information**
  - ***How to approach multitudes of assets***
  - ***Regional studies can lead to simplifying assumptions***

Five Levels of Analysis

1 - Historical Discharges

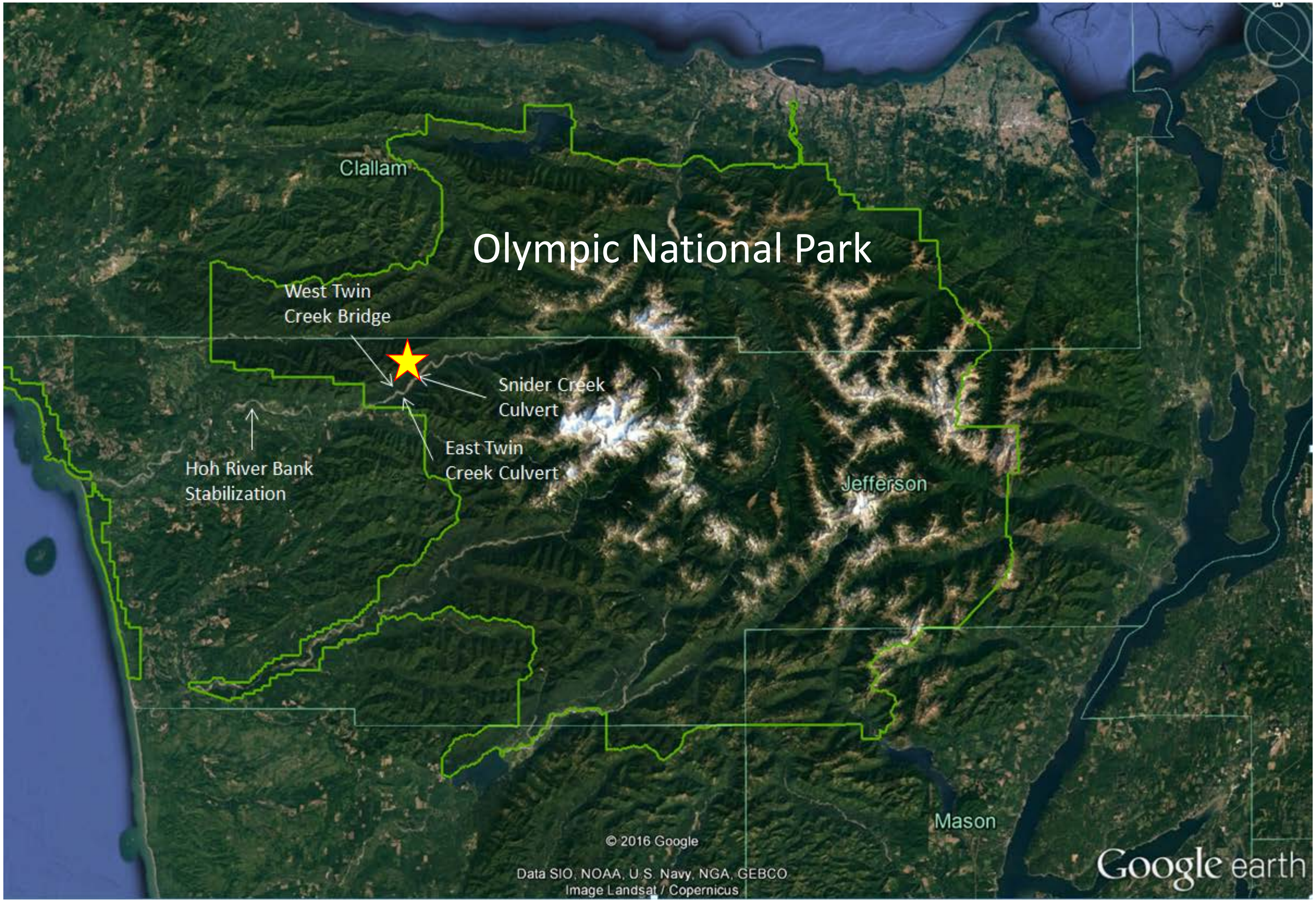
2 - Historical Discharges + Confidence Limits

3 - Precipitation Projection Trend Test

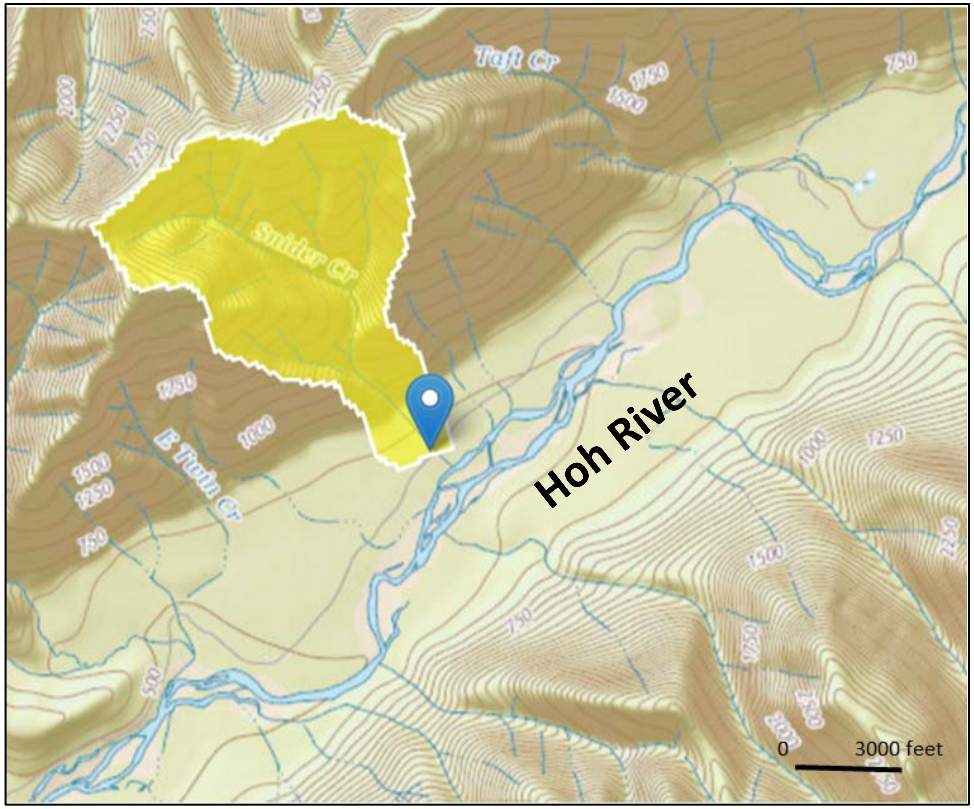
4 - Projected Discharges using CMIP tool

5 - Customized Projected Discharges w/Climate Scientist

Let’s Run through an Example

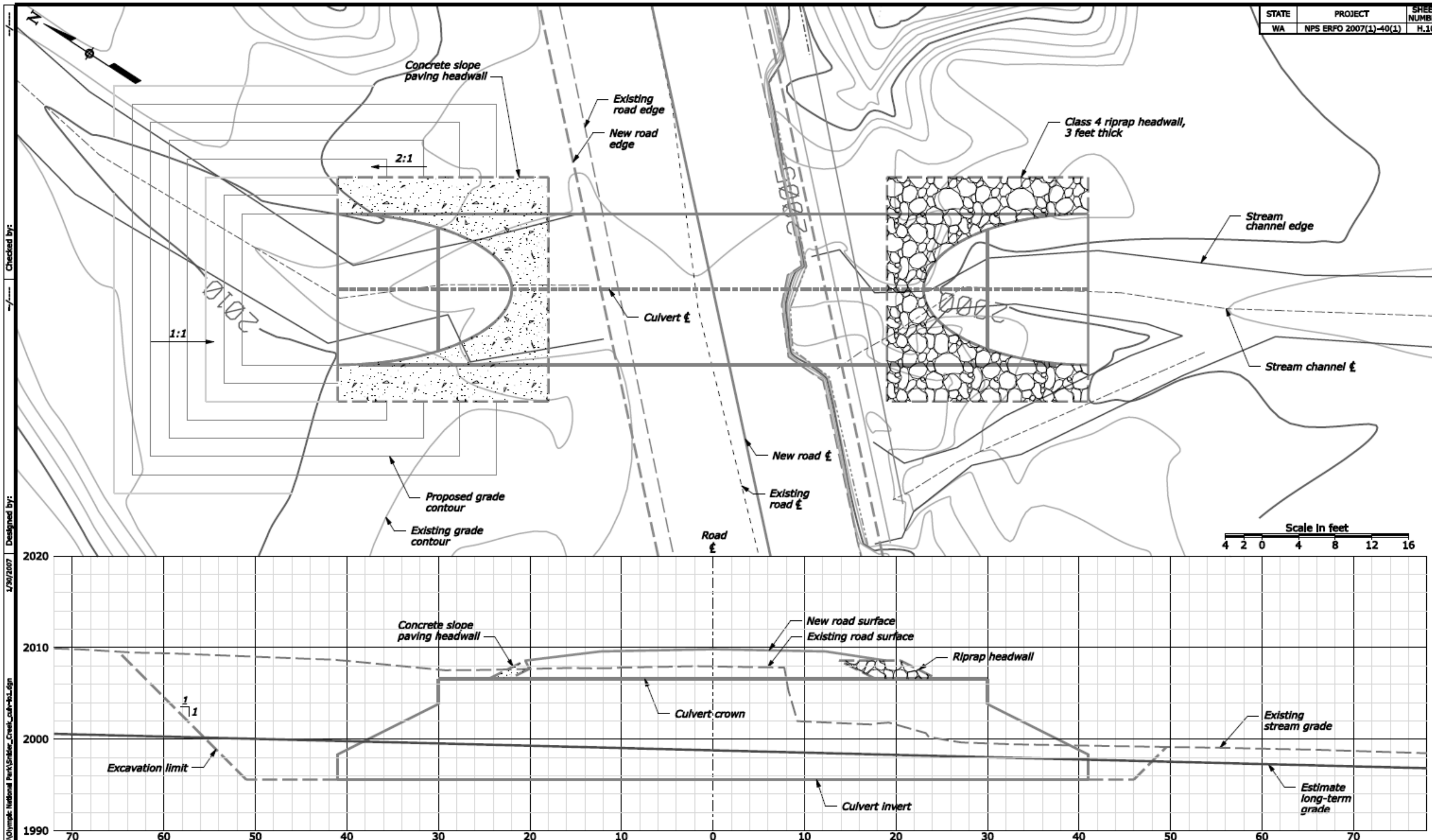


Snider Creek Culvert



Snider Creek Culvert Stats

- Upper Hoh Road crosses an alluvial fan
- Emergency-funded construction 2007, replaced 36 inch culvert
- 16.5 ft x 11.0 ft structural plate arch
- Oversized to provide debris and sediment passage
- Embedded to mitigate for long term degradation
- Upstream slope 5%, downstream slope 3%
- Active channel width 16 ft, bankfull depth 3 ft
- Drainage area 1.1 square miles



HYDRAULIC INFORMATION

Q_2: 165 CFS OHW: 2.7 FT
Q_{50}: 346 CFS HW_{50}: 4.6 FT
FISH SPECIES:
INSTREAM WORK WINDOW:
ACTIVE CHANNEL WIDTH: 12 FT

PIPE

TYPE: STRUC-PLATE ARCH SPAN: 16'-6" RISE: 11'-0"
LENGTH: 82 FT WALL THICKNESS: 0.140 IN
PIPE SLOPE: 0.0 FT/FT FLOWLINE SLOPE: NA
INFILL TYPE: NONE SBM TYPE: NONE

INLET

INV N/E/EL: 30509.8/15482.7/1995.6
BURIAL DEPTH: 0
LOWER BEVEL HEIGHT: 33 IN
BEVEL: STEP, 2(h):1(v)
HEADWALL: CONC. SLOPE PAVE

OUTLET

INV N/E/EL: 30441.2/15527.5/1995.6
BURIAL DEPTH: 0
LOWER BEVEL HEIGHT: 33 IN
BEVEL: STEP, 2(h):1(v)
HEADWALL: RIPRAP

SNIDER CREEK
AOP CULVERT
PLAN AND PROFILE

1

StreamStats Results

StreamStats Version 3.0

Flow Statistics Ungaged Site Report

Date: Mon Feb 20, 2017 3:44:12 PM GMT-5
Study Area: Washington
NAD 1983 Latitude: 47.8438 (47 50 38)
NAD 1983 Longitude: -123.9671 (-123 58 02)
Drainage Area: 1.1 mi2

Peak-Flow Basin Characteristics			
100% Region 1 (1.1 mi2)			
Parameter	Value	Regression Equation Valid Range	
		Min	Max
Drainage Area (square miles)	1.1	0.15	1294
Mean Annual Precipitation (inches)	141	45	201

Peak-Flow Statistics						
Statistic	Value	Unit	Standard Error (percent)	Equivalent years of record	90-Percent Prediction Interval	
					Min	Max
PK2	177	cfs	32	1		
PK10	280	cfs	33	2		
PK25	329	cfs	34	3		
PK50	371	cfs	36	3		
PK100	415	cfs	37	4		
PK500	516	cfs				

http://pubs.er.usgs.gov/usgspubs/wri/wri974277 (http://pubs.er.usgs.gov/usgspubs/wri/wri974277)
Sumioka_ S.S._ Kresch_ D.L._ and Kasnick_ K.D._ 1998_ Magnitude and Frequency of Floods in Washington: U.S. Geological Survey Water-Resources Investigations Report 97-4277_ 91 p.

Accessibility FOIA Privacy Policies and Notices
U.S. Department of the Interior | U.S. Geological Survey
URL: http://streamstatsags.cr.usgs.gov/v3_beta/FTreport.htm
Page Contact Information: StreamStats Help
Page Last Modified: 08/09/2016 14:34:10 (Web2)
Streamstats Status News
USA.gov

- Q50 = 371 cfs
- Std Error = 36%
- M.A.P. = 141 inches
- HW/D < 1
- Note the reference document

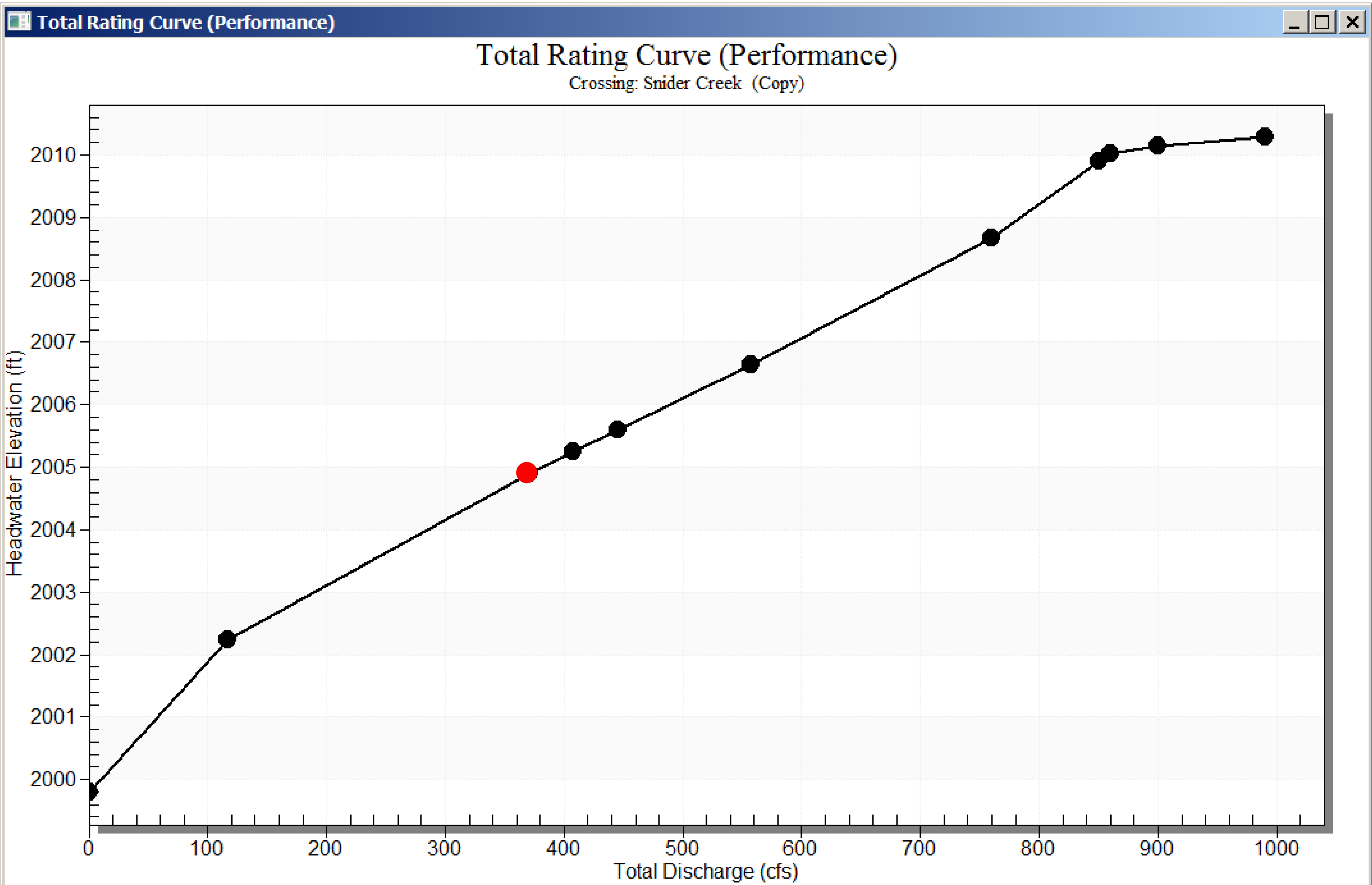
1

Hydraulic Results

Hydraulic Parameters	Design Flow Q50	Q50 + 20%	Q50 + 50%	Flow at Barrel Top	Roadway Overtops
Flow in cfs	371	445	557	760	860
Headwater Elevation (ft)	2004.9	2005.6	2006.6	2008.6	2010.0
Headwater Depth (ft)	5.1	5.8	6.8	8.8	10.2
Clearance / Freeboard (ft)	1.8 / 5.1	1.1 / 4.4	0.1 / 3.4	-1.9 / 1.4	-3.3 / 0
Headwater-to-Diameter Ratio, HW/D	0.74	0.84	0.99	1.28	1.47
US Bed Elevation @ Invert (ft)	1999.8				
US Top of Barrel Elevation (ft)	2006.7				
Open Diameter considering Embedment (ft)	6.9				

- **This is a very resilient culvert**
- **Q50 HW/D = 0.74 < 1, 5.1 ft until road overtops**

1 Performance Curve, Q50=371 cfs



2

Determine Confidence Limits

- **Confidence Limits for Regression Equations**
  - ***Step 1: Estimate design flow***
  - ***Step 2: Compute log of design flow***
  - ***Step 3: Compute standard error in log units***
  - ***Step 4: Compute confidence limits in log units***
  - ***Step 5: Compute confidence limits in flow units***
  - ***Step 6: Assess/design plan/project***
- **Assume greater than 75 years remaining service life**
  - ***From Table 7.5, use 90% confidence interval***
  - ***Wide interval reflects larger uncertainty over longer life***

2

Determine Confidence Limits

- ***Step 1: Estimate design flow***

$$Q_T = a(A)^b(P)^c, A = \text{area}, P = \text{M. A. P.}, abc = \text{regression coefs}$$

$$Q_{50} = 0.666(1.1)^{0.921}(141)^{1.26} = 371 \text{ cfs}$$

- ***Step 2: Compute log of design flow***

$$Y_T = \log_{10}(Q_T) = \log_{10}(371) = 2.569$$

- ***Step 3: Compute standard error in log units***

$$SE_{log10} = \left[\frac{1}{5.302}\ln\left\{\left(\frac{SE_{\%}}{100}\right)^2 + 1\right\}\right]^{0.5}$$

$$= \left[\frac{1}{5.302}\ln\left\{\left(\frac{36}{100}\right)^2 + 1\right\}\right]^{0.5} = 0.152$$

2

Determine Confidence Limits

- ***Step 4: Compute confidence limits in log units***

Table 7.6: For confidence interval of 90 percent, Kc = 1.645

$$Y_{T,U} = Y_T + K_c SE_{log10} = 2.569 + 1.645(0.152) = 2.819$$
$$Y_{T,L} = Y_T - K_c SE_{log10} = 2.569 - 1.645(0.152) = 2.319$$

- ***Step 5: Compute confidence limits in flow units***

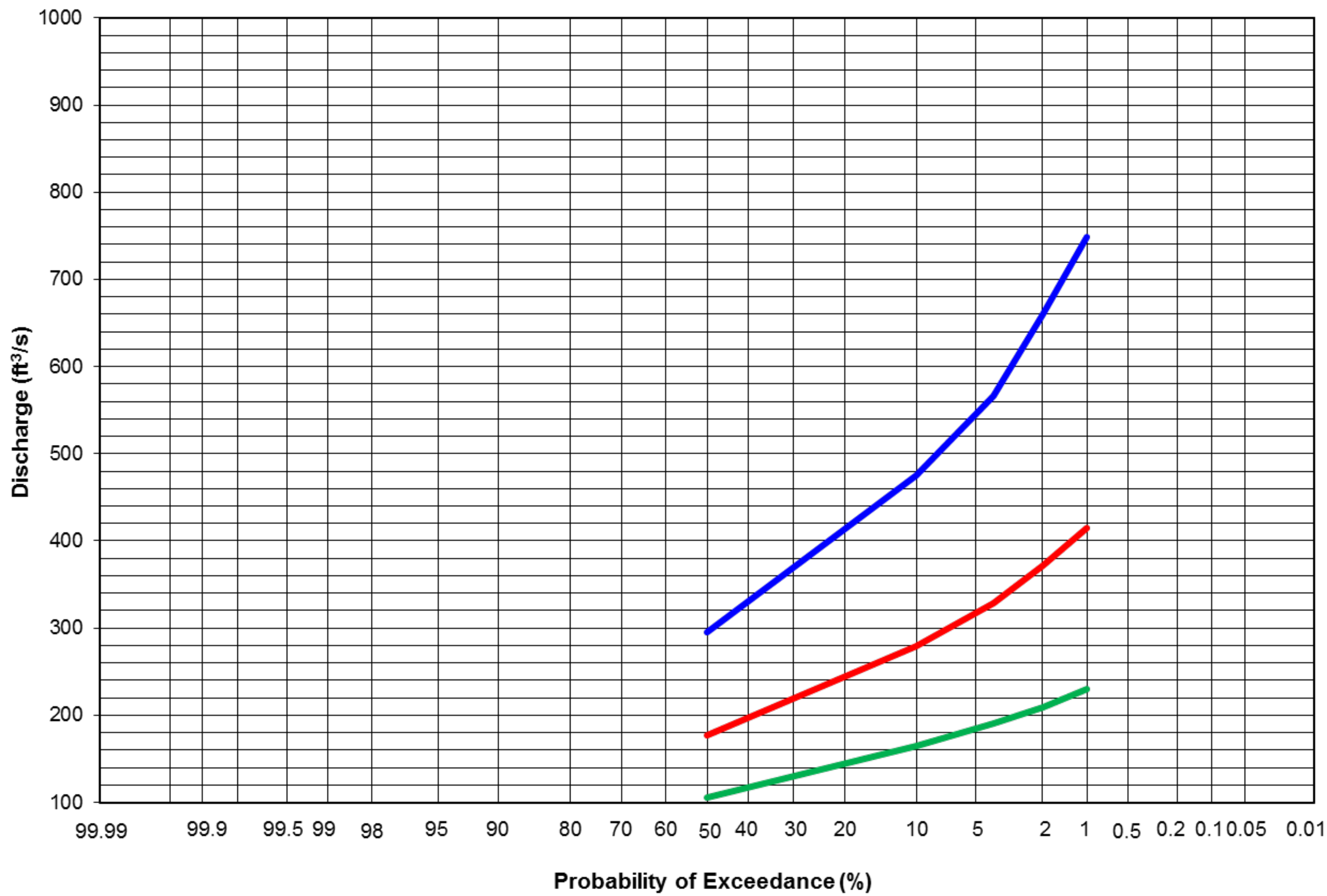
$$Q_{T,U} = 10^{Y_{T,U}} = 10^{2.819} = 659 \text{ cfs}$$
$$Q_{T,L} = 10^{Y_{T,L}} = 10^{2.319} = 208 \text{ cfs}$$

- ***Step 6: Assess/design plan/project***

Go back to Hydraulic Results Table

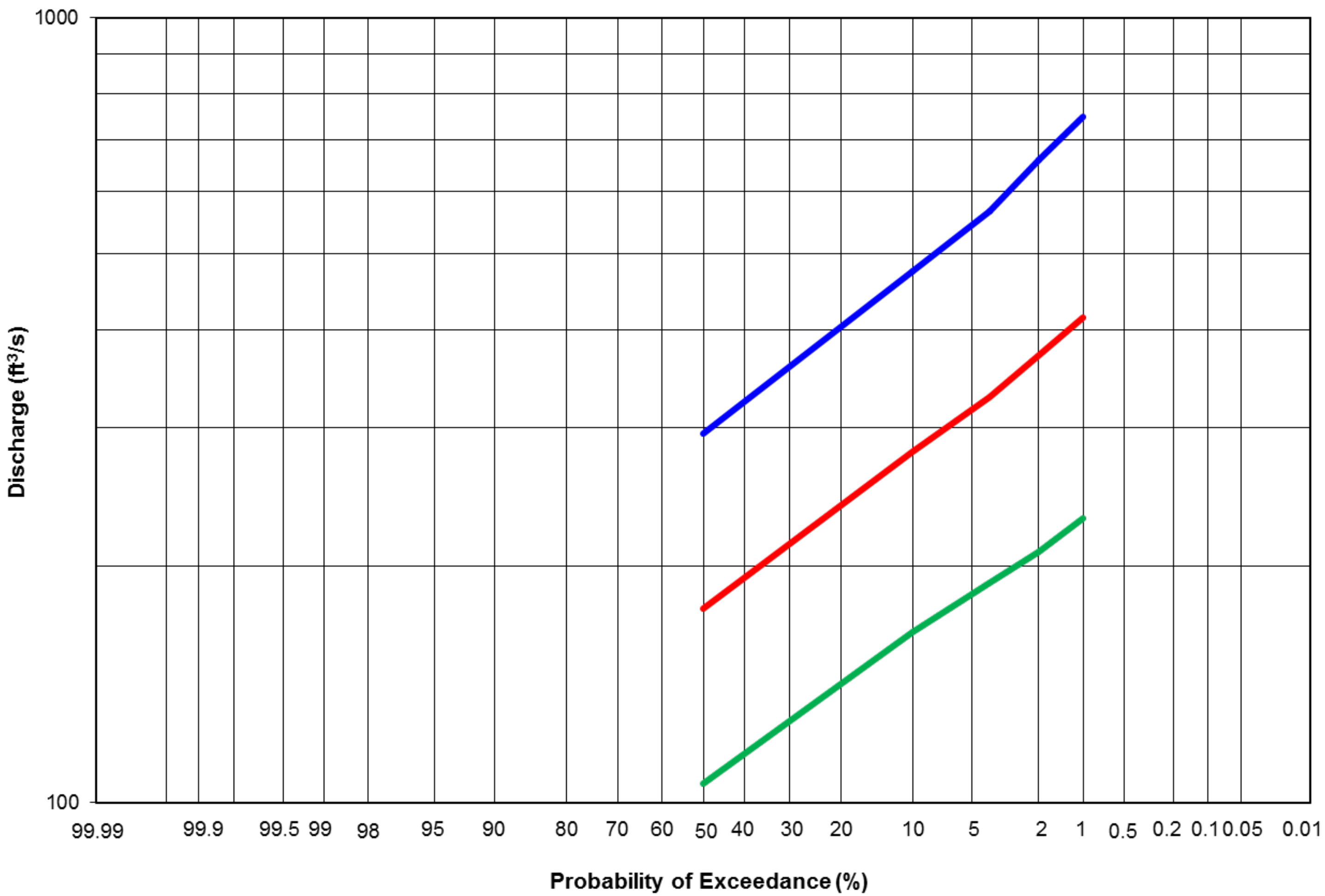
2

Confidence Limits Log-Normal



2

Confidence Limits Log-Log



2

Hydraulic Results

Hydraulic Parameters	Design Flow Q50	Q50 + 20%	Q50 + 50%	Flow at Barrel Top	Roadway Overtops
Flow in cfs	371	445	557	760	860
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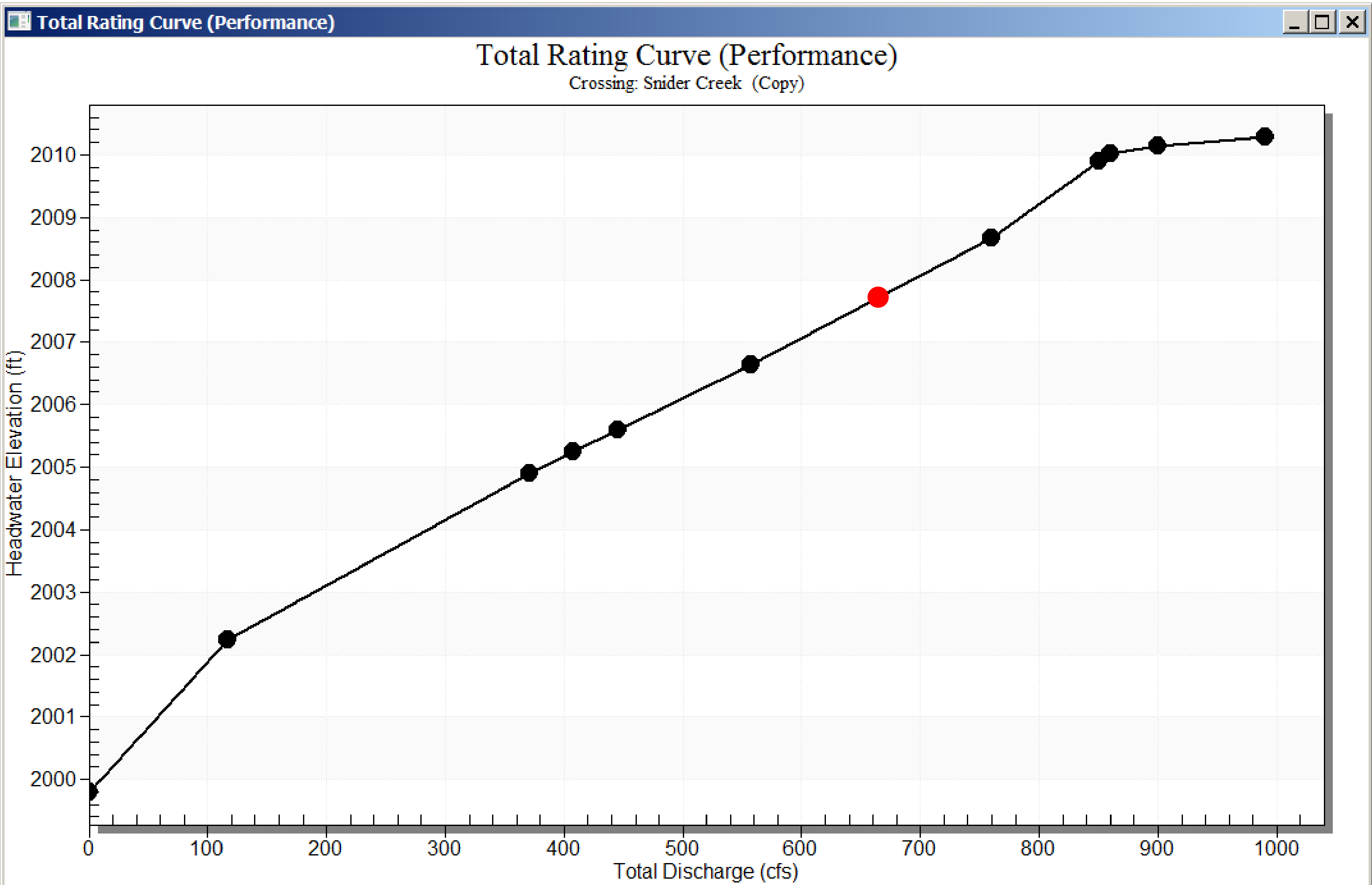
Headwater-to-Diameter Ratio, HW/D	0.74	0.84	0.99	1.28	1.47
US Bed Elevation @ Invert (ft)	1999.8				
US Top of Barrel Elevation (ft)	2006.7				
Open Diameter considering Embedment (ft)	6.9				

- **At upper limit Q50 = 659 cfs …less resilient culvert**
- **Barrel inundated but no roadway overtopping**
- **HW/D > 1**

2

Performance Curve, Q50=659 cfs



3 Precipitation Projection Trend Test

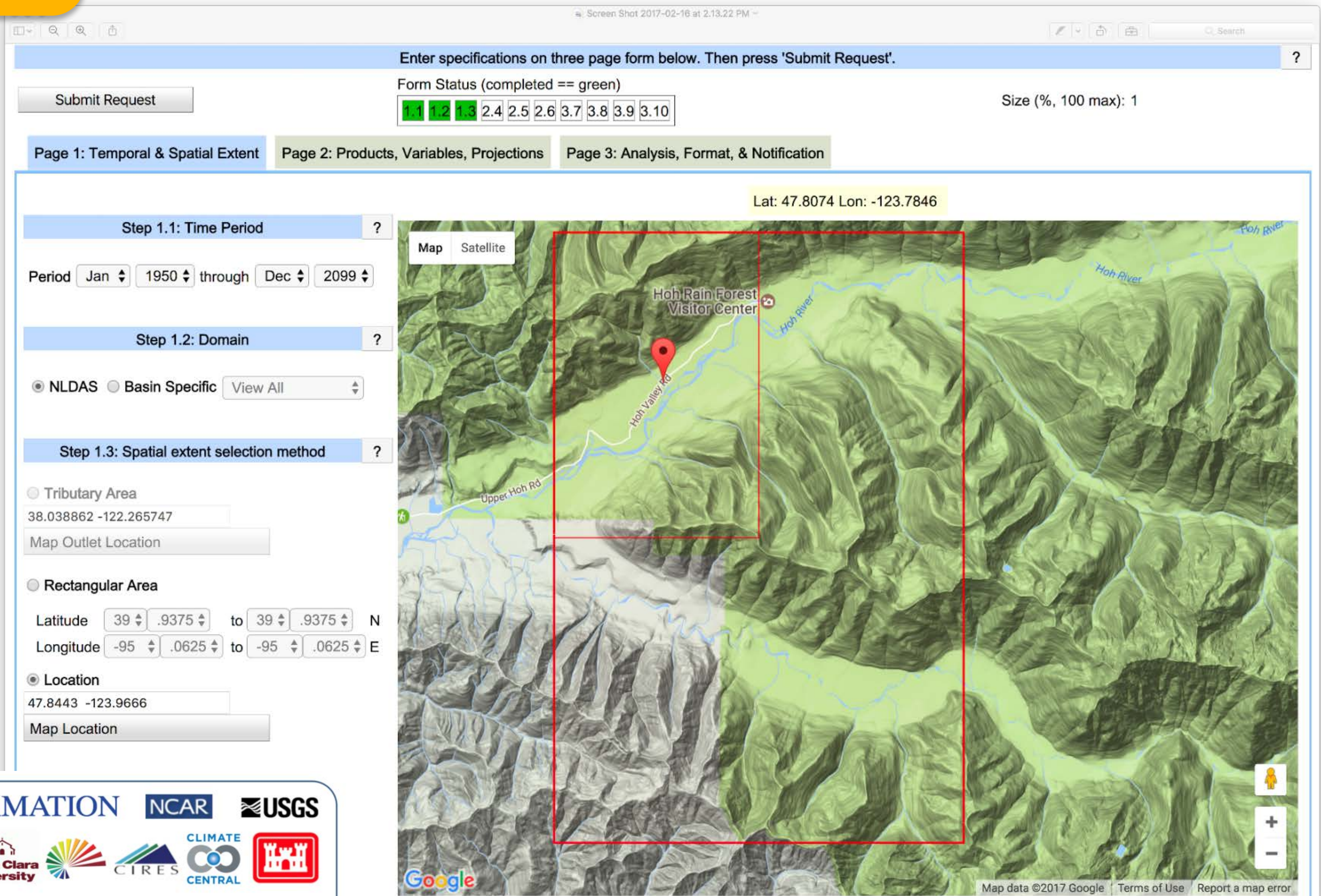
- **Projected vs. Historical T-year, 24 hour, Precipitation**
  - ***If trend weak, stay with level 2***
  - ***If trend strong, consider looking at level 4***
- **Test requires DCHP precipitation projection data**
  - ***Step 1: Average the modeled daily precip across all cells***
  - ***Step 2: Determine maximum annual value for each year***
  - ***Step 3: Select baseline and future periods***
  - ***Step 4: Compute baseline & future T-year 24 hr precip per model***
  - ***Step 5: Estimate projected T-year 24 hr precip per model***
  - ***Step 6: Compute mean for projected T-year 24 hr precipitation***
  - ***Step 7: Evaluate for further analyses using Climate Change Indicator***

3 Precipitation Projection Trend Test

- ***Using RCP 8.5 and CMIP 5 BCCAv2 daily downscaled data***
- ***We have 20 models***
- ***Step 1: Average the modeled daily precip across all cells***
  Used one cell to save time, see next slide
- ***Step 2: Determine maximum annual value for each year***
  Computed w/CMIP tool for calendar yrs 1950 to 2000
- ***Step 3: Select baseline and future periods***
  Baseline 1950-2000, Future 2050-2099

3

Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections



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Santa Clara University CIRES CLIMATE CENTRAL

SCRIPPS INSTITUTION OF OCEANOGRAPHY

3 Precipitation Projection Trend Test

❖ ***Step 4: Find baseline & future T-year 24 hr precip per model***

Fitted AMS to Log Pearson Type III distribution (vs GEV)

This sheet provides a time series of annual maximum daily precipitation amounts from 1950-2099. See file 'CMIP5 1950-2099 Precipitation Data' for underlying calculatic

Observed Data			Model Projections											
				Annual Maximum 24-hr Precipitation (in)										
					Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Mo
Year	Annual Maximum 24		Year	Multi-Moc	access1-0.	bcc-csm1-	canesm2.:	ccsm4.1.r	cesm1-bg	cnrm-cm5	csiro-mk3	gfdl-cm3.:	gfdl-esm2	gfd
1950	3.61		1950	4.09	5.58	5.02	3.63	4.63	4.00	4.15	3.38	3.88	3.88	
1951	6.11		1951	3.72	3.90	3.05	2.60	3.35	5.27	5.54	3.32	3.06	3.54	
1952	3.78		1952	3.79	3.10	5.04	4.76	2.98	4.14	3.15	2.61	4.72	3.73	
1953	5.17		1953	3.89	6.22	3.32	4.40	3.65	3.51	4.71	5.10	4.54	4.33	
1954	4.91		1954	3.90	3.65	4.16	3.63	4.62	3.30	3.36	4.81	3.34	3.32	
1955	4.62		1955	3.75	3.69	4.91	3.78	3.21	3.71	2.65	4.20	2.93	4.71	
1956	6.67		1956	4.03	2.66	4.00	3.59	3.36	3.36	8.52	4.01	6.82	3.22	
1957	4.90		1957	3.85	3.46	2.98	3.82	3.12	3.48	3.95	3.89	3.91	4.31	
1958	4.06		1958	4.02	6.15	2.86	3.83	3.50	5.00	4.63	3.27	4.46	3.23	
1959	5.83		1959	4.13	5.00	3.72	4.97	4.65	4.20	3.80	4.51	3.45	4.88	
1960	5.07		1960	4.64	3.94	4.20	4.82	5.35	3.47	4.13	5.61	5.68	4.50	
1961	7.12		1961	3.86	3.59	3.08	3.06	5.65	3.04	2.92	3.15	3.39	4.31	
1962	5.21		1962	3.80	4.06	2.86	3.93	3.21	3.17	3.27	3.84	3.56	5.19	
1963	4.13		1963	3.82	6.11	3.95	3.32	3.59	3.53	3.19	3.96	3.75	4.17	
1964	3.01		1964	3.98	3.97	3.46	3.57	4.90	4.70	4.53	4.02	4.12	3.19	
1965	4.52		1965	3.72	3.72	3.54	2.83	3.31	3.97	5.37	3.30	4.09	4.18	
1966	4.22		1966	3.59	3.52	3.51	2.81	2.88	3.77	2.84	3.99	3.66	3.76	

3 Precipitation Projection Trend Test

- ***Step 5: Estimate projected T-year 24 hr precip per model***
  - *Compute difference between future and baseline T-year, 24 hr precip per model*
  - *Add this difference to the observed T-year 24 hr precip for each model*

- ***Step 6: Compute mean for projected T-year 24 hr precipitation***
  - *Compute mean of projected T-year 24 hr precip from all the models (in our case 20 models)*
  - *This is your $P_{24,T,P}$ term*

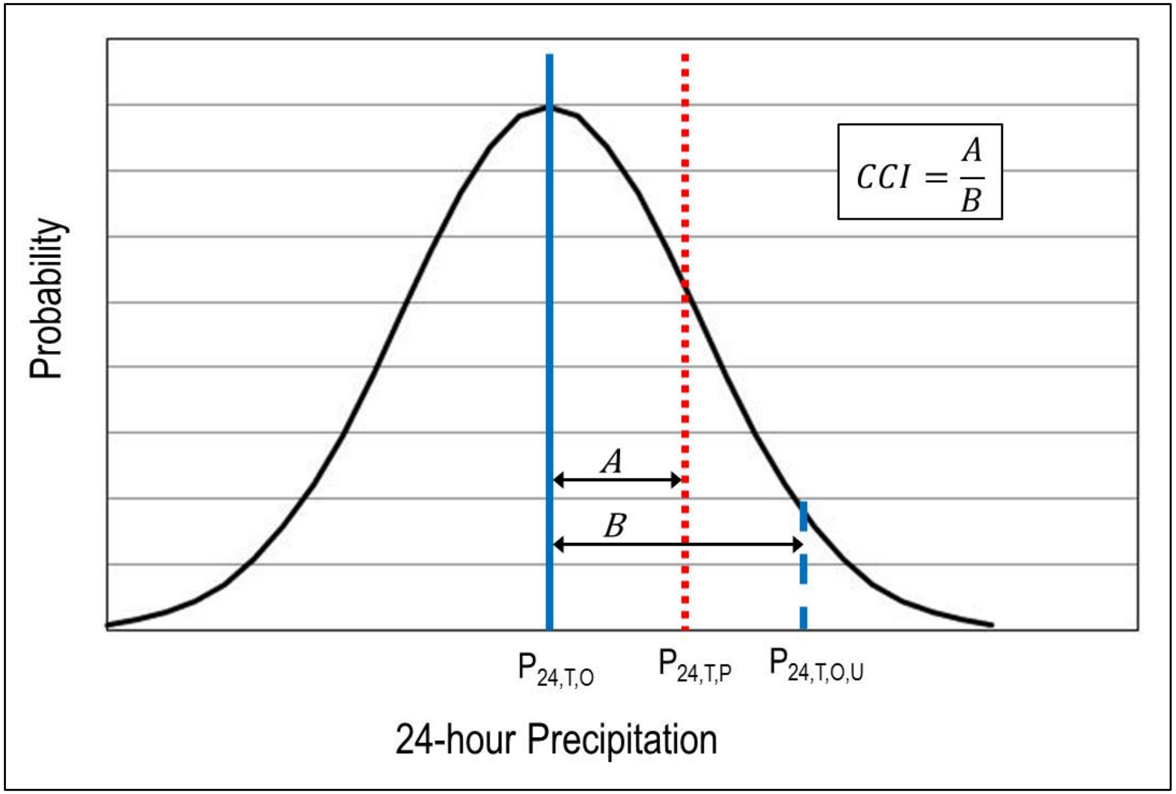
3

Climate Change Indicator

$$CCI = \frac{P_{24,T,P} - P_{24,T,O}}{P_{24,T,O,U} - P_{24,T,O}}$$

CCI = Climate change indicator
$P_{24,T,P}$ = Projected T-year 24-hour precipitation
$P_{24,,T,O}$ = Observed T-year 24-hour precipitation
$P_{24,T,O,U}$ = Upper 90% confidence limit T-year 24-hour precipitation for the observed data

- **If CCI < 0.4, trend is weak, historic OK**
- **If CCI > 0.8, trend is strong, consider further analysis w/ future projections**



4

Projected Discharges and Confidence Limits

- **Projected discharges explicitly incorporate future precipitation projections**
  - ***Methods vary for rainfall/runoff vs statistical***
- **Will temperature will shift fraction of snow vs rain?**
- **Consider other sources of nonstationarity**
  - ***Landuse: Database of impervious areas from EPA***
- **Calculate and evaluate projected confidence limits**
  - ***Compare to historical confidence limits from Level 2***
- **Though not required climate scientist and hydrologist can help**

4

Projected Discharges and Confidence Limits

- **Incorporating projections into rainfall/runoff hydrology**
  - ***For precip inputs with sub-daily durations, may use historic ratio of daily, T-year precipitation to sub-daily T-year precipitation from NOAA Atlas 14***
  - ***Minnesota Pilot project (to be described later) demonstrates rainfall runoff methods***
- **Our example uses statistical hydrology**
  - ***Regression equation with precipitation variable (M.A.P.)***
- **Steps to our Level 4 analysis**
  - ***Step 1: Determine future mean annual precipitation (M.A.P.)***
  - ***Step 2: Check regression equation limitations***
  - ***Step 3: Compute future discharge (incl. other nonstationarities)***
  - ***Step 4: Compute and evaluate projected confidence limits***

4

Projected Discharges and Confidence Limits

❖ ***Step 1: Determine future mean annual precipitation (M.A.P.)***

Determine from CMIP tool output

Projected Changes in Precipitation Conditions
RCP 8.5
Snider Creek

Hide Details

Click column headings for additional info	**Baseline (1950-1999)**		**2050-2099 (2050-2099)**				
	Observed Value	***Modeled Value***	***Projected Value***	***Change from Baseline***	***% Change from Observed***	***Model Uncertainty Range (100% Confidence Interval)*** ***Low***	***High***
Average Total Annual Precipitation	147.6 inches	147.1 inches	157.1 inches	9.5 inches	6%	151.1 inches	163.1 inches
"Very Heavy" 24-hr Precipitation Amount (defined as 95th percentile precipitation)	2.0 inches	1.7 inches	2.1 inches	0.1 inches	5%	2.0 inches	2.2 inches
"Extremely Heavy" 24-hr Precipitation Amount (defined as 99th percentile precipitation)	3.4 inches	2.8 inches	3.6 inches	0.3 inches	8%	3.4 inches	3.8 inches
Precipitation Events per Year (2.0 inches in 24 hrs)	13.6 times	17.7 times	17.9 times	4.3 times	31%	16.0 times	19.8 times
Precipitation Events per Year (3.4 inches in 24 hrs)	2.7 times	3.6 times	4.8 times	2.1 times	77%	4.0 times	5.7 times

4

Projected Discharges and Confidence Limits

❖ ***Step 2: Check regression equation limitations***

From StreamStats output and State regression manual:

45 inches > 157.1 inches > 201 inches

Step 3: Compute future discharge (incl. other nonstationarities)

From WFL report (Hamlet et. al. 2013): Snider Creek is a rain dominant basin and will remain so in the future

Olympic National Park not expected to see significant land use changes (exception would be wildfire…a short term situation)

$$Q_T = a(A)^b(P)^c, A = \text{area}, P = \text{M.A.P.}, abc = \text{regression coefs}$$

$$Q_{50} = 0.666(1.1)^{0.921}(157.1)^{1.26} = 425 \text{ cfs}$$

4 Find Projected Confidence Limits

- ***Step 4a: Estimate design flow***

$$Q_{50} = 0.666(1.1)^{0.921}(157.1)^{1.26} = 425 \text{ cfs}$$

- ***Step 4b: Compute log of design flow***

$$Y_T = \log_{10}(Q_T) = \log_{10}(425) = 2.628$$

- ***Step 4c: Compute standard error in log units***

$$SE_{\log 10} = \left[\frac{1}{5.302}\ln\left\{\left(\frac{SE_{\%}}{100}\right)^2 + 1\right\}\right]^{0.5}$$

$$= \left[\frac{1}{5.302}\ln\left\{\left(\frac{36}{100}\right)^2 + 1\right\}\right]^{0.5} = 0.152$$

4 Determine Confidence Limits

❖ ***Step 4d: Compute confidence limits in log units***

Table 7.6: For confidence interval of 90 percent, Kc = 1.645

$$Y_{T,U} = Y_T + K_c SE_{log10} = 2.628 + 1.645(0.152) = 2.878$$
$$Y_{T,L} = Y_T - K_c SE_{log10} = 2.628 - 1.645(0.152) = 2.378$$

❖ ***Step 4e: Compute confidence limits in flow units***

$$Q_{T,U} = 10^{Y_{T,U}} = 10^{2.878} = 755 \text{ cfs}$$
$$Q_{T,L} = 10^{Y_{T,L}} = 10^{2.378} = 239 \text{ cfs}$$

❖ ***Step 4f: Assess/design plan/project***

Go back to Hydraulic Results Table

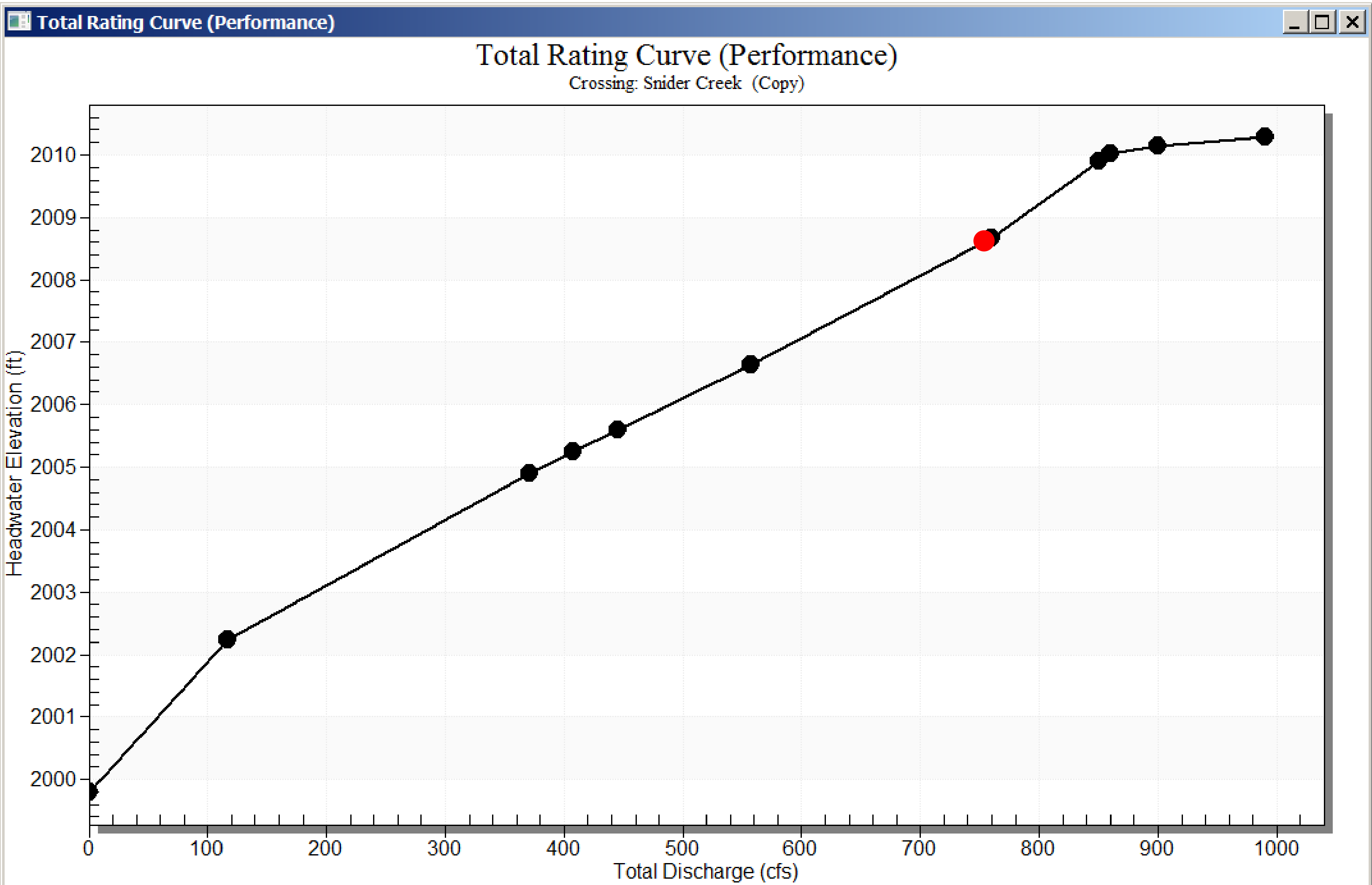
4

Hydraulic Results

Hydraulic Parameters	Design Flow Q50	Q50 + 20%	Q50 + 50%	Flow at Barrel Top	Roadway Overtops
Flow in cfs	371	445	557	760	860
Headwater Elevation (ft)	2004.9	2005.6	2006.6	2008.6	2010.0
Headwater Depth (ft)	5.1	5.8	6.8	8.8	10.2
Clearance / Freeboard (ft)	1.8 / 5.1	1.1 / 4.4	0.1 / 3.4	-1.9 / 1.4	-3.3 / 0
Headwater-to-Diameter Ratio, HW/D	0.74	0.84	0.99	1.28	1.47
US Bed Elevation @ Invert (ft)	1999.8				
US Top of Barrel Elevation (ft)	2006.7				
Open Diameter considering Embedment (ft)	6.9				

- **At upper limit Q50 = 755 cfs …even less resilient**
- **Barrel inundated, roadway closer to overtopping**
- **If no precip. term in regression?...consider Level 5**

4 Performance Curve, Q50=755 cfs



5

Level 5 Example: Iowa DOT

Iowa Bridge and Roadway Vulnerability Assessment Pilot (2015)

5

Project Partners

- **Lead: Iowa DOT**
  (Dave Claman, Hydraulic Engineer)

- **Iowa State University**
  (Christopher J. Anderson, Eugene S. Takle)
  - ***Climate science and climate projections expertise***
  - ***Lead and contributing authors to IPCC AR4, NCA Agriculture***

- **University of Iowa IIHR**
  (Witold F. Krajewski, Ricardo Mantilla)
  - ***Hydrology and hydraulics engineering and modeling***
  - ***Iowa Flood Center: ifis.iowafloodcenter.org***

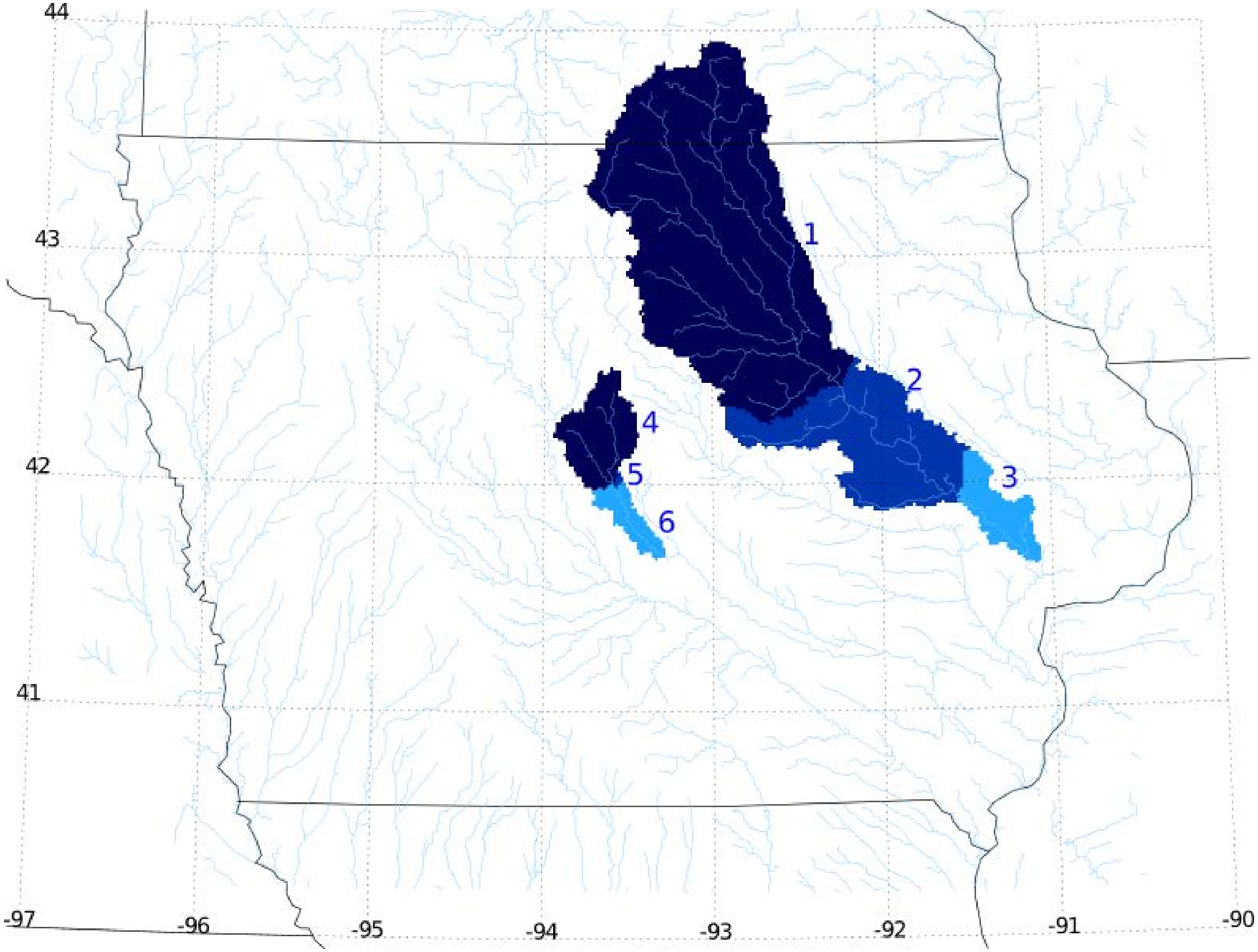
5

What makes this a Level 5?

- **Climate scientist**
- **Advanced hydrologic modeling**
  - **Selected alternative climate data sets**
    - ***Asynchronous Regional Regression Model (ARRM)***
  - **CUENCAS hydrological model, distributed rainfall-runoff hillslope model**
  - **Limited to flood season**

5

Two river basins examined: Cedar, South Skunk



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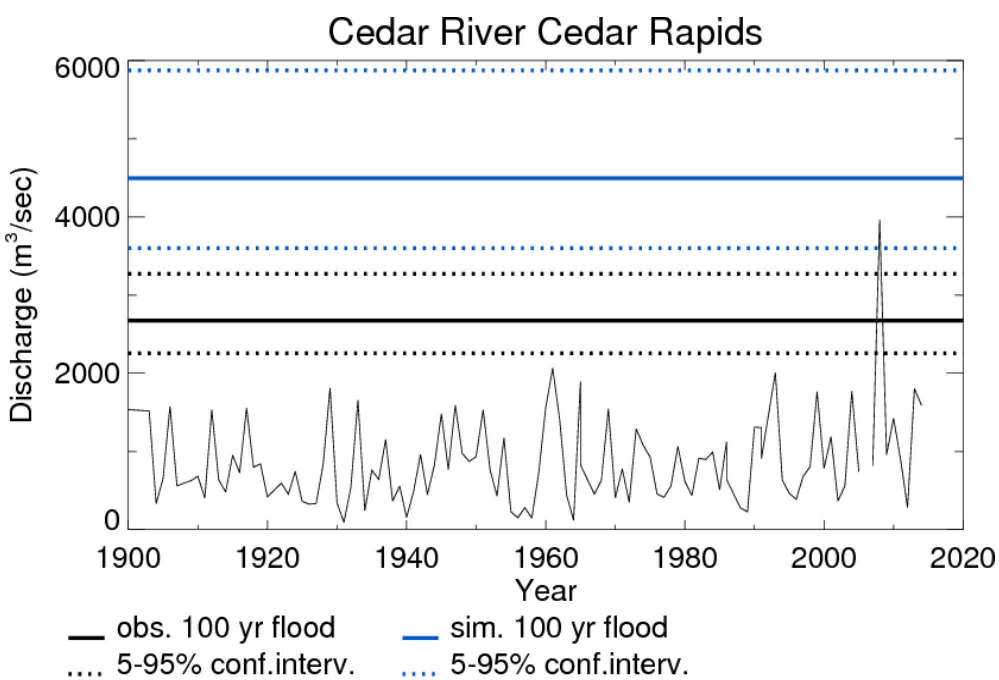
Modeling

- Linked precipitation projections to streamflow in Skunk and Cedar River Basins
- Generated continuous 140 year streamflow simulation (1960-2100)
- Modeled projected 100-yr flood levels for 6 locations



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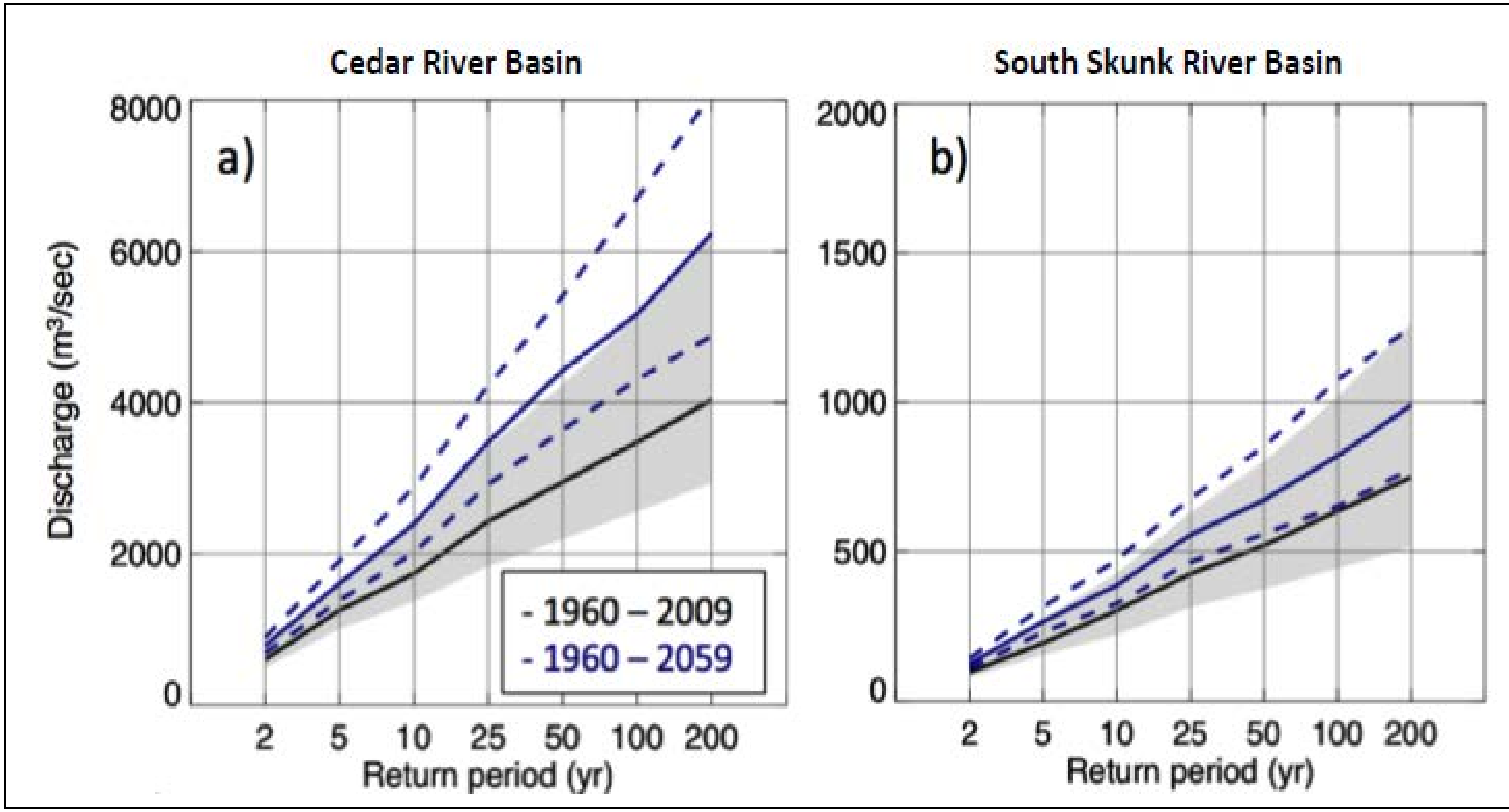
Flood Frequency Curves



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Insights

- Determined using this type of climate data was best for basins 250 km^2 and greater
- Four of six locations found vulnerable to future flooding (100-yr flows)
- Flood projections are more model-specific than emission scenario-specific

Questions?

Chapter

8

Case Studies

Case Studies

- Bridge 02315 (Barkhamsted, Connecticut)
- USGS Regression Analysis for New York and Vermont
- Minnesota Pilot Project
- Gulf Coast 2: Airport Boulevard Culvert (Mobile, AL)
- Cedar and South Skunk River Iowa Pilot Project

Minnesota Pilot Project

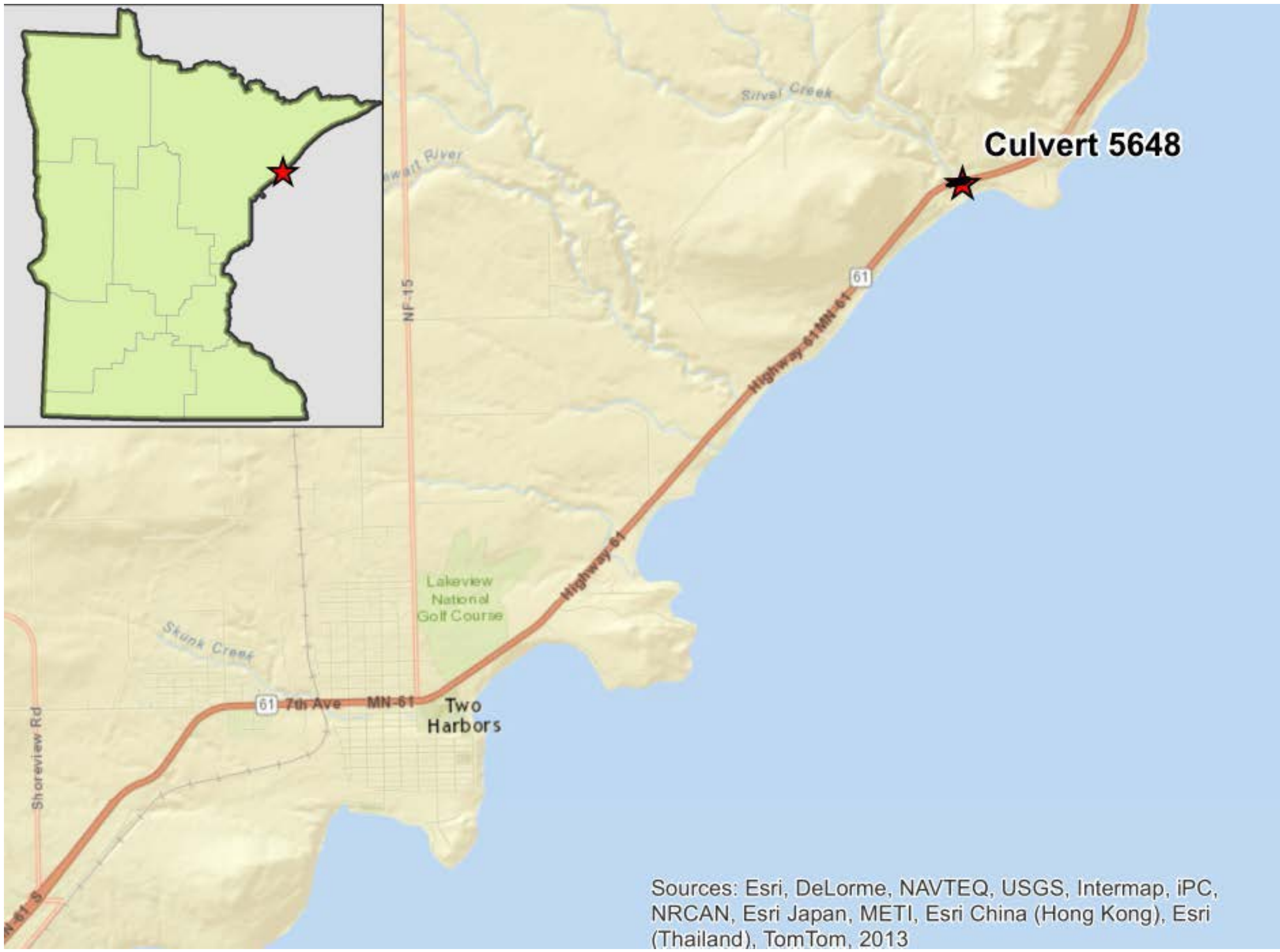
High Level System-wide Assessment

- Metrics to qualitatively assess
  - Sensitivity
  - Exposure
  - Adaptive Capability
- Ranked assets
- Team

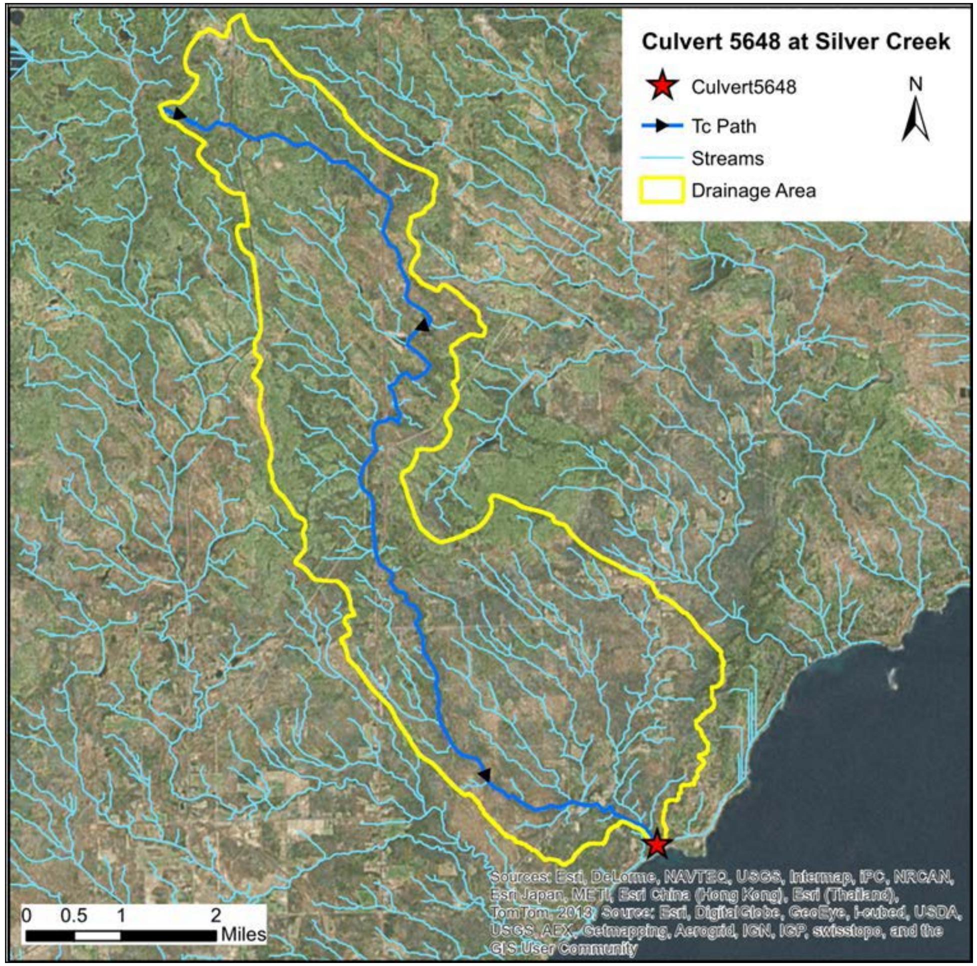
Case Studies

- MN 61 Culvert #5648
- US 63 Culvert #5722

MN61 Culvert 5648 over Silver Creek



Watershed


Culvert 5648 at Silver Creek
Culvert5648
Tc Path
Streams
Drainage Area
N
0 0.5 1 2
Miles
Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2013; Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

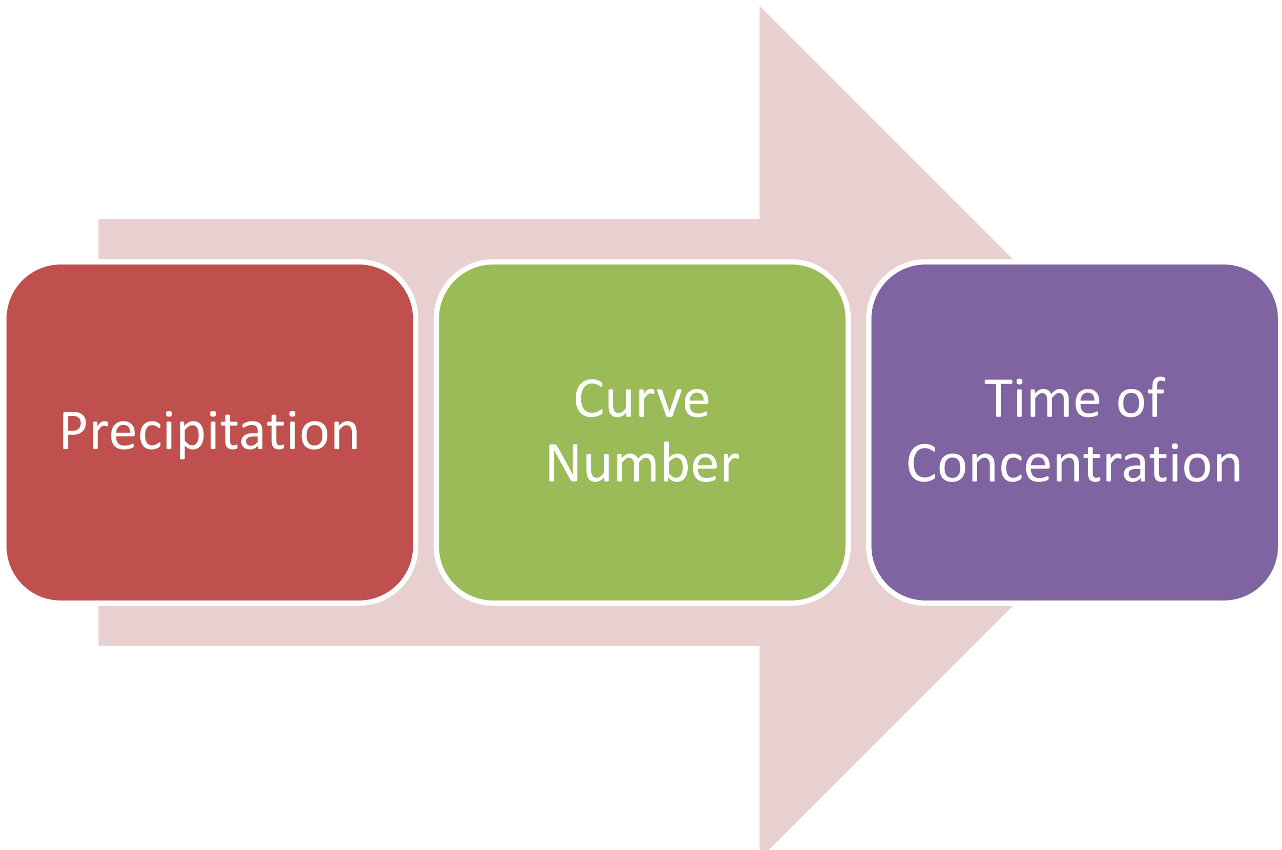
Existing Culvert

- 2 10’x10’ by 90’ long
- Built 1936
- Cracks, Spalling, Exposed Rebar

Hydrologic Methods

- NRCS Method
- USGS Regression

NRCS Input



Precipitation

NOAA Atlas 14

- Best available and actionable historic data

Climate Projections

Precipitation

Scenarios

- Low emissions scenario: RCP4.5
- Medium emissions scenario: RCP6.0
- High emissions scenario: RCP8.5

GCMs

- 22 models

Output

- 24 hour precipitation depths

Time Period

- 2040
- 2070
- 2100

Bias Correction

- Compare historical rainfall and climate projections

Bias Correction

Table 4: 24-Hour Precipitation Depths at Culvert 5648, Low Scenario

24-Hour Storm Return Period	Atlas 14 Precipitation Depth (in)[1]	Low Scenario Precipitation Depth (in)					
		2040		2070		2100	
		% Increase	Depth	% Increase	Depth	% Increase	Depth
2-year storm	2.48	3.08%	2.56	4.72%	2.60	5.48%	2.62
5-year storm	3.26	3.12%	3.36	4.77%	3.42	5.55%	3.44
10-year storm	3.89	3.22%	4.02	4.93%	4.08	5.74%	4.11
25-year storm	4.8	3.43%	4.96	5.25%	5.05	6.11%	5.09
50-year storm	5.53	3.63%	5.73	5.55%	5.84	6.46%	5.89
100-year storm	6.31	3.85%	6.55	5.90%	6.68	6.86%	6.74
500-year storm	8.26	4.47%	8.63	6.85%	8.83	7.96%	8.92

[1] *Source: NOAA, 2014b*

Land Use

Existing

- National Land Cover Datase
- CN = 75

Future

- Current zoning
- CN = 77

Time of Concentration

Existing

- 9 hours

Future

- 9 hours

Flows

Table 8: TR-20 Projected Peak Flows at Culvert 5648

24-Hour Storm Return Period	Existing Discharges (cfs)	Low Scenario Discharges			Medium Scenario Discharges			High Scenario Discharges		
		2040 (cfs)	2070 (cfs)	2100 (cfs)	2040 (cfs)	2070 (cfs)	2100 (cfs)	2040 (cfs)	2070 (cfs)	2100 (cfs)
2-year storm	770	1070	1100	1120	1090	1160	1230	1180	1370	1550
5-year storm	1350	1760	1810	1830	1800	1900	2000	1930	2190	2460
10-year storm	1880	2360	2420	2450	2420	2540	2660	2580	2920	3250
25-year storm	2690	3260	3350	3390	3340	3500	3670	3550	4010	4460
50-year storm	3370	4010	4120	4170	4113	4300	4500	4360	4920	5480
100-year storm	4140	4810	4940	5000	4930	5170	5420	5240	5940	6610
500-year storm	6090	6870	7060	7150	7040	7410	7800	7520	8590	9630

Design Limitations

- Headwater
- Upstream Properties
- Fish Passage
- Outlet Velocities

Culvert Design Options

- 14x14 2-cell Culvert
- 16x14 2-cell Culvert
- 52-foot long single span bridge
- 57-foot long single span bridge

Economic Analysis

Table 13: Projected Life Cycle Costs for Culvert 5648 Adaptation Options *With* Social Costs, Medium Scenario

	Period 1 2025-2055	Period 2 2056-2085	Period 3 2086-2100	Initial Construction Costs	Total Damage/ Repair Costs by 2100	Total Life Cycle Cost by 2100
Base Case: Replace in Kind	122,352	111,568	40,147	$643,069	$274,067	**$917,136**
Option 1: Two Cell Culvert	18,226	9,041	14,708	$697,413	$41,975	**$739,388**
Option 2: 52-Foot Bridge	72,592	55,207	30,455	$1,023,476	$158,254	**$1,181,730**
Option 3: 57-Foot Bridge	25,839	11,130	3,808	$1,095,934	$40,777	**$1,136,711**

Note: Options with the best life cycle cost-effectiveness are highlighted in green.

Table 14: Projected Life Cycle Costs for Culvert 5648 Adaptation Options *With* Social Costs, High Scenario

	Period 1 2025-2055	Period 2 2056-2085	Period 3 2086-2100	Initial Construction Costs	Total Damage/ Repair Costs by 2100	Total Life Cycle Cost by 2100
Base Case: Replace in Kind	290,776	125,251	46,990	$643,069	$463,017	**$1,106,086**
Option 1: Two Cell Culvert	20,990	111,568	36,756	$697,413	$169,314	**$866,727**
Option 2: 52-Foot Bridge	58,740	26,785	41,520	$1,023,476	$127,045	**$1,150,521**
Option 3: 57-Foot Bridge	27,913	23,937	39,611	$1,095,934	$91,461	**$1,187,395**

Note: Options with the best life cycle cost-effectiveness are highlighted in green.

Questions?

Next Steps

- **HEC-17 2nd Edition is evolving document**
  - ***Science and climate modeling continues to advance***
  - ***Methods will evolve with the science***
  - ***HEC-17 represents attempt to modify current practice, rather than start from scratch***

New Research in Progress

- **Updating Precipitation Frequency Estimates under Non-Stationary Climate Conditions**
  - ***Develop methods to integrate non-stationary climate effects into precipitation frequency estimates (like NOAA Atlas 14)***
  - ***NWS/FHWA***
- **Flood Frequency Estimation for Hydrologic Design under Changing Conditions**
  - ***Adjust flood-frequency analysis for observed and projected change for rivers showing trends in peak flows***
  - ***USGS/FHWA***
- **Potential Impact of Climate Change on US Precipitation Frequency Estimates**
  - ***Examine historical trends in exceedances of precipitation frequency thresholds in different regions***
  - ***Bonnin & Co. LLC***

More Research In Progress

- **Climate Change Effects on Stream Geomorphology: Maple River Stream Instability Study**
  - ***Evaluate future channel instability at site in Iowa given historic instability and climate change***
  - ***TetraTech***
- **Sensitivity of Drainage Infrastructure to Climate Change**
  - ***Hydraulic analysis of increased precipitation on drainage infrastructure, including quantifying cost of inaction***
  - ***FHWA Federal Lands Highway Divisions***

Even More Research!

- **NCHRP 15-61: Applying Climate Change Information to Hydrologic and Hydraulic Design of Transportation Infrastructure**
  - ***Design guide of national scope***
  - ***Provide hydraulic engineers with the tools needed to amend practice to account for climate change***
  - ***Builds on HEC-17***
  - ***Completion 2018***

Links to Other Resilience Related Work

- Transportation Engineering Approaches to Climate Resilience (TEACR)
- Hurricane Sandy project
- Green Infrastructure Pilots
- Adaptation Pilots
- Gulf Coast 2 Study

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

Questions?