Incorporating Climate Change Projections into Culvert Design

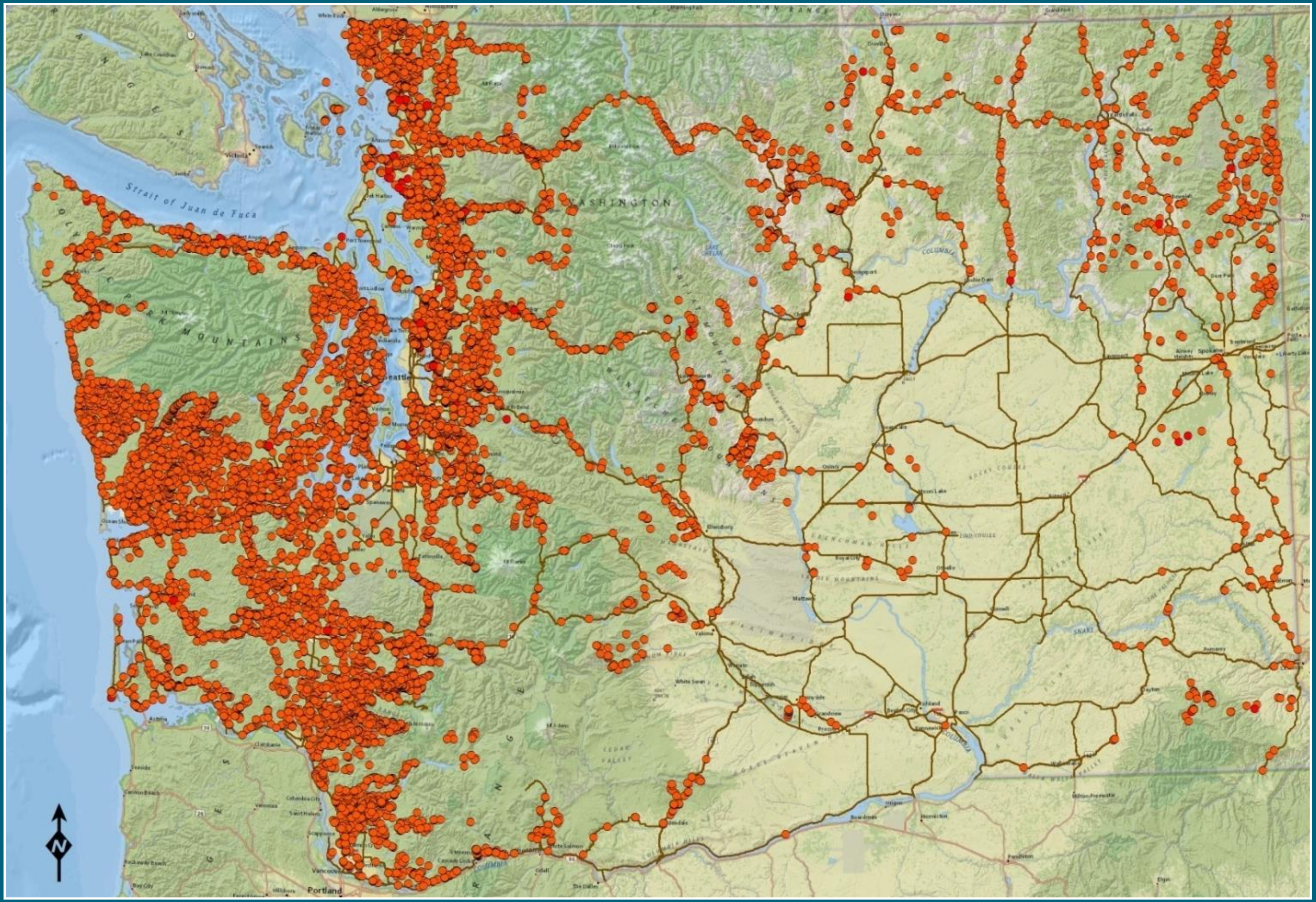
A project funded by the North Pacific Landscape Conservation Cooperative

June 14, 2017

Prediction: a Lot of New Culverts

13,500 known culvert barriers in database

35,000 estimated culvert barriers state-wide



≈$33 billion to replace 13,500 culverts

WDFW's Role in Ensuring Fish Passage

- Provides design guidance for the protection of fish life and fish habitat.

- Issues permits for the installation of culverts. Enforces regulations.

- Designs culverts for its own lands and other clients. Reviews designs.

Project Team

Jane Atha, Geomorphologist, WDFW

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Jennie Hoffman, Adaptation Insight

Major Steps

1. Assess climate sensitivity of current culvert design process.

2. Project changes in instream flow due to climate change.

3. Convert stream flow projections into stream channel width – an important culvert design parameter.

4. Develop approaches for applying findings in policy and practice.

Geomorphic Culvert Design

- "Simulate" geomorphic processes
- Channel inside ≈ Channel outside
- Fish passage inside ≈ Fish passage outside

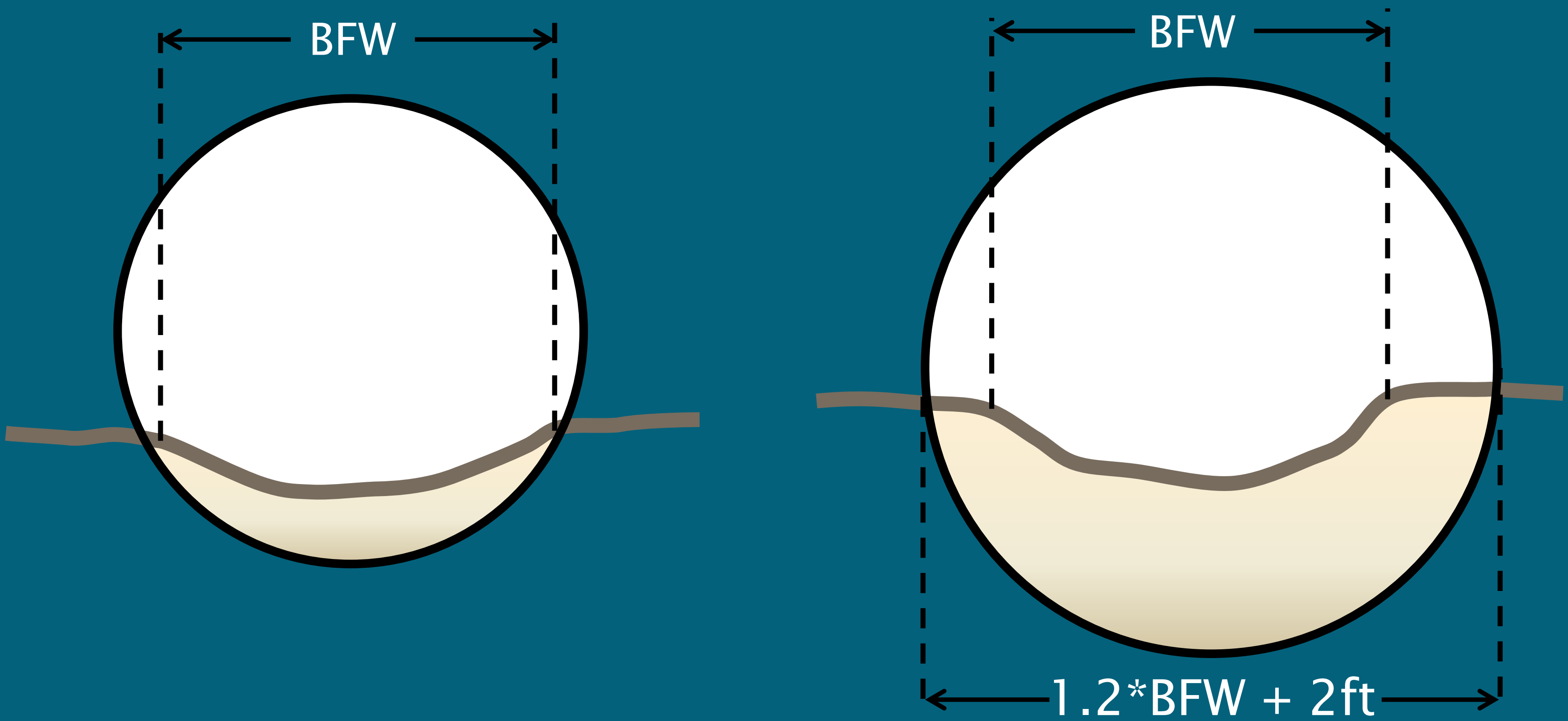
Downstream Hydraulic Geometry

$$\text{width} \propto Q^b$$

- Channel characteristics change in proportion to some power of water discharge, Q.

Culvert Design

Bankfull width (BFW) is a key parameter

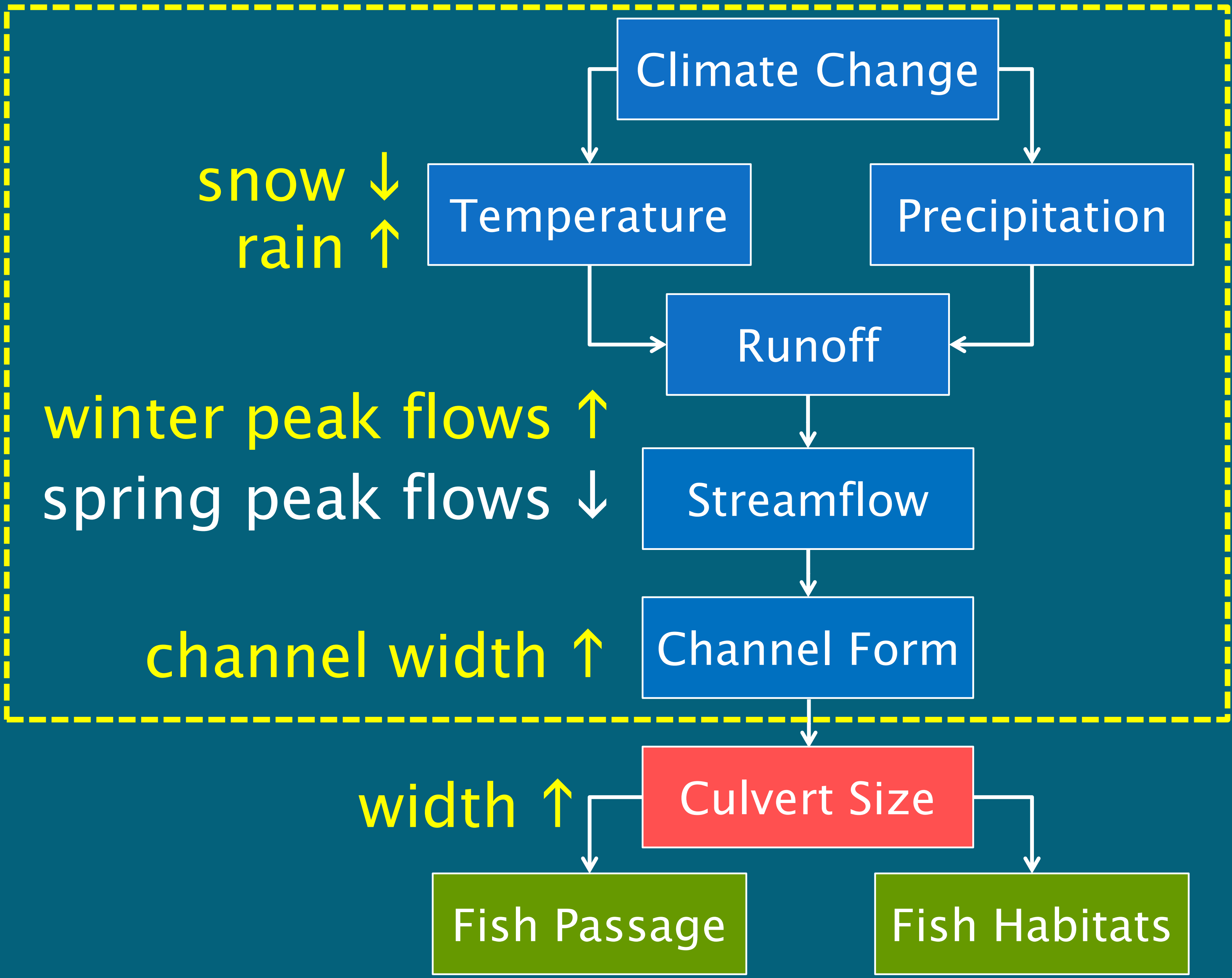


No-slope
(<10 ft BFW, gradient <3%)

Stream Simulation
(<15 ft BFW)

Width Matters

Projecting Future Changes in Bankfull Width Due to Climate Change


Climate Change
snow ↓
rain ↑
Temperature
Precipitation
Runoff
winter peak flows ↑
spring peak flows ↓
Streamflow
channel width ↑
Channel Form
width ↑
Culvert Size
Fish Passage
Fish Habitats

Modelling Process

UW

Global Climate Models
future projections: temp. and precip.

↓

Hydrologic model projects runoff

↓

WDFW

Estimate bankfull flow

↓

Predict bankfull width

Global Climate Models

- Projections from 10 independent models
- 1 global emissions scenario: moderate A1B
- Down-scaled and bias-corrected for PNW
- Climate projections for 2 future time periods

  2030–2059 (2040s)
  2070–2099 (2080s)

Hydrological Model

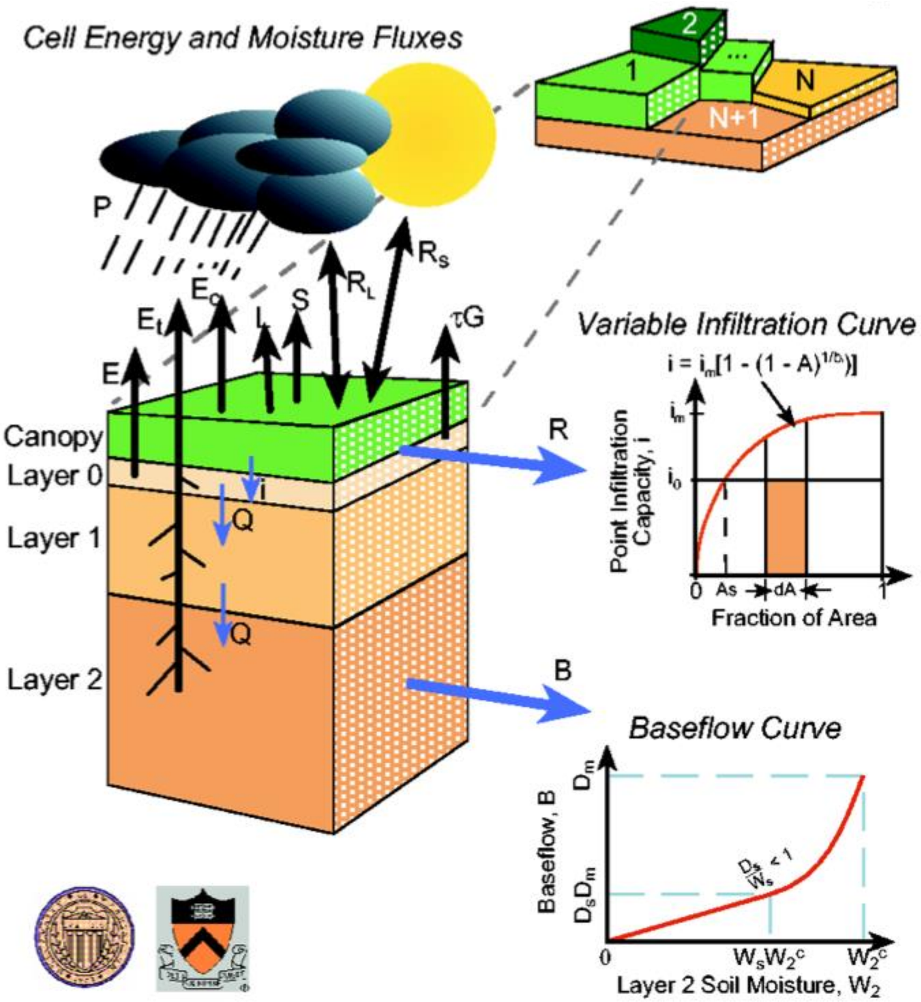
Global Climate Model Outputs

Temperature ➡

Precipitation ➡

Future Mean Daily Flow ⬅

Variable Infiltration Capacity Model (VIC)



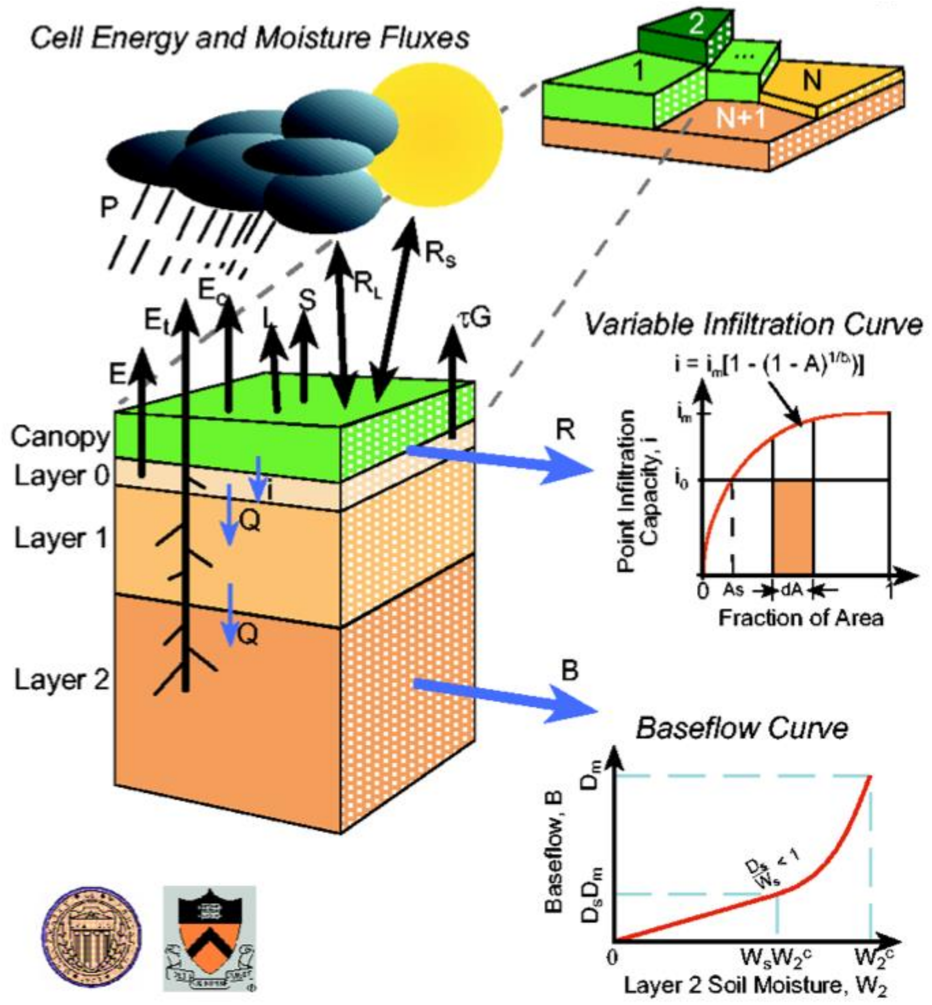
Hydrological Model

Historical Weather Data

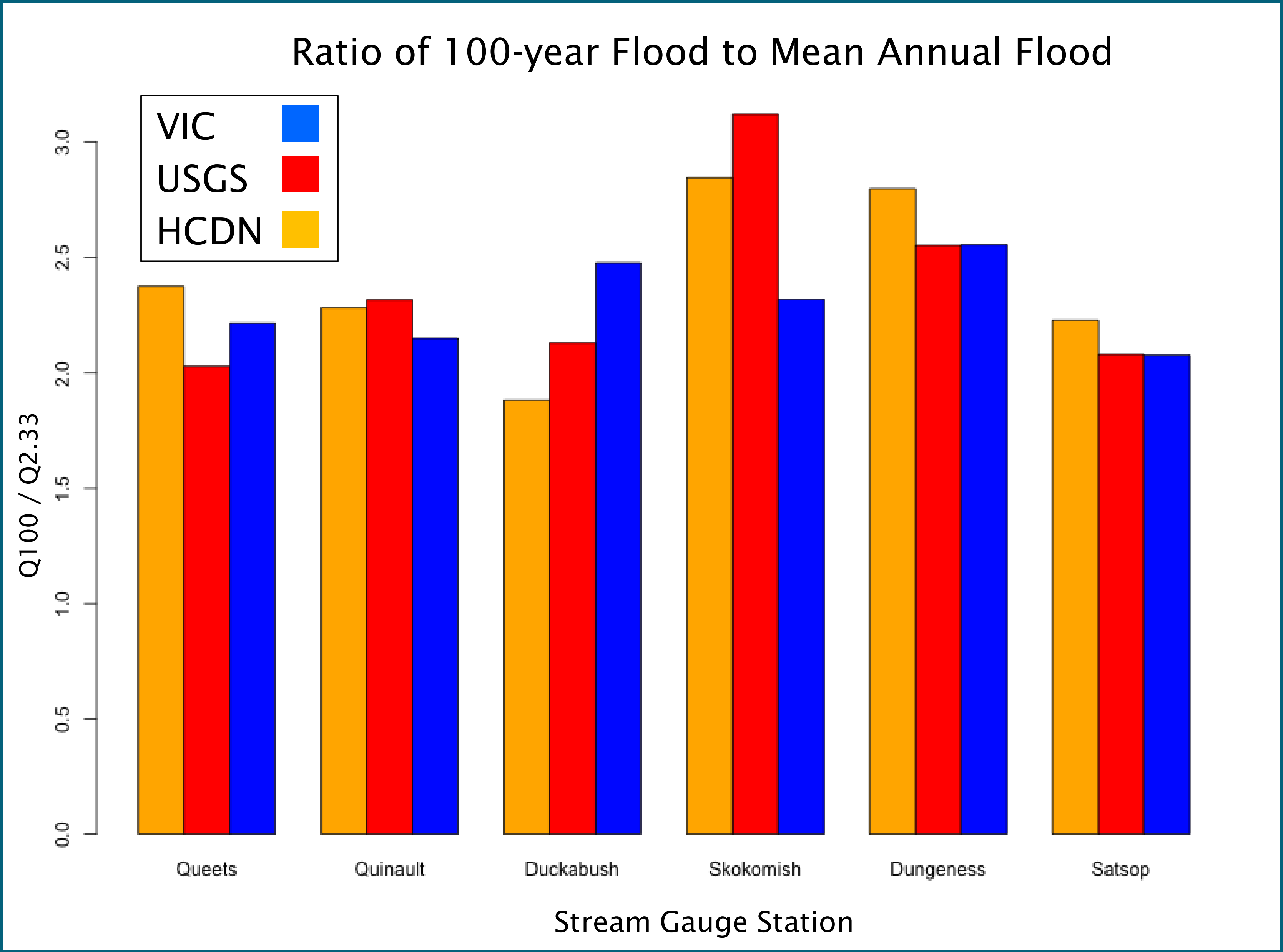
- Temperature
- Precipitation

Historical Mean Daily Flow

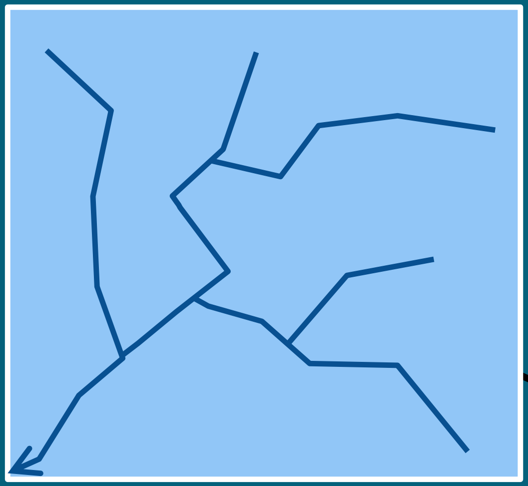
Variable Infiltration Capacity Model (VIC)



Validation of Flow Projections

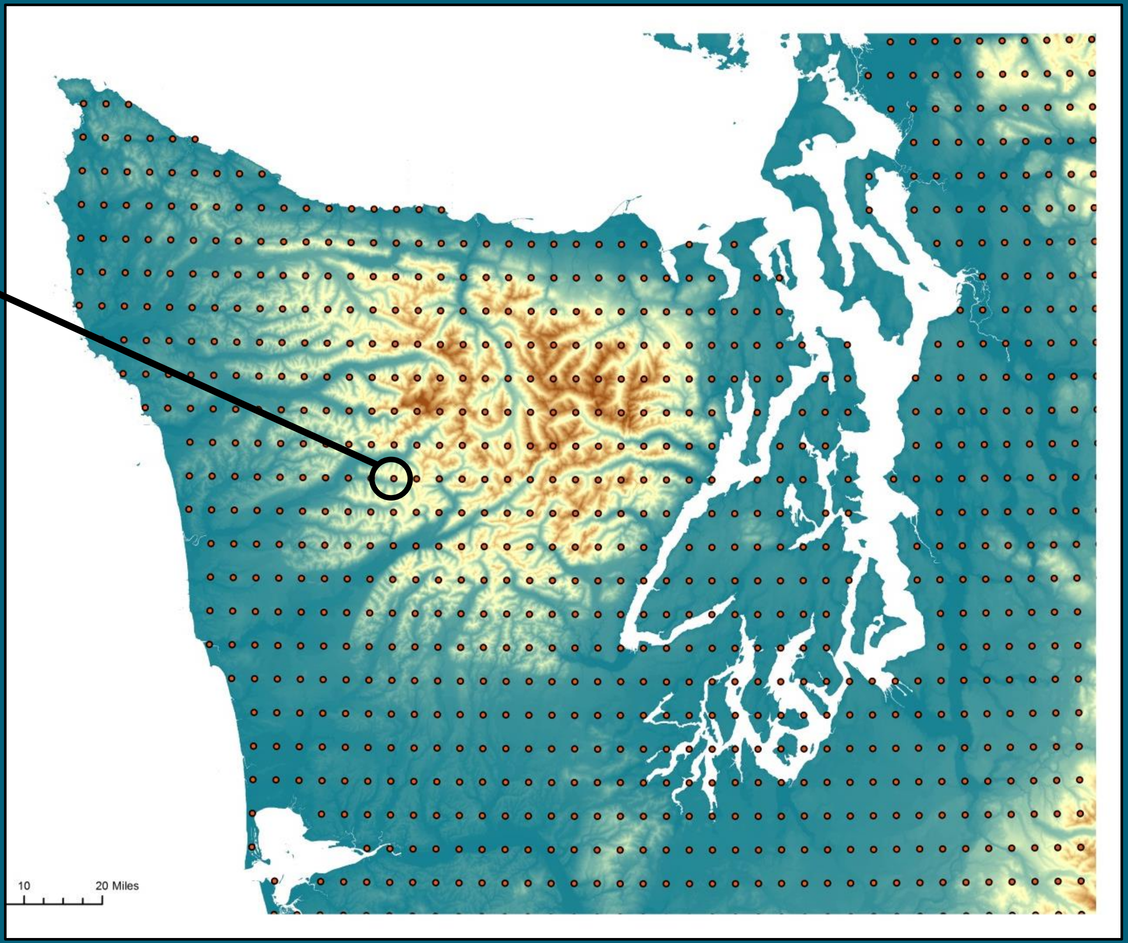


VIC Grid Cells

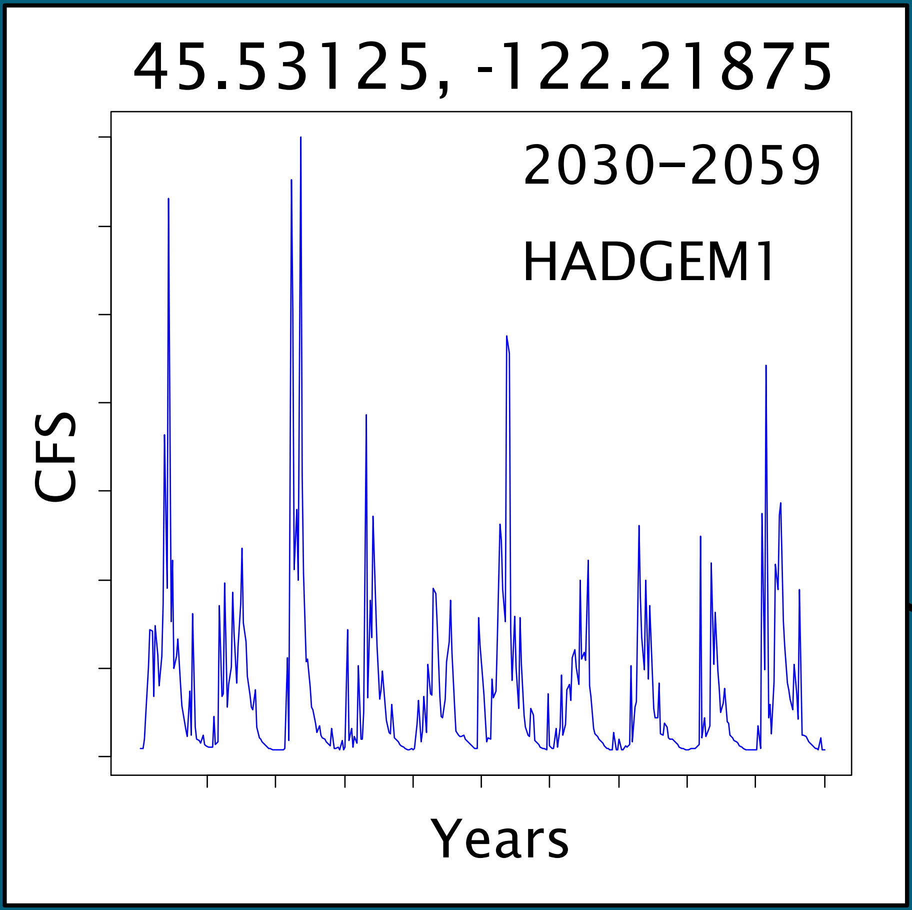


1/16 degree
≈ 5 x 7 km
≈ 12.6 mi²

5,270 grid cells
in Washington

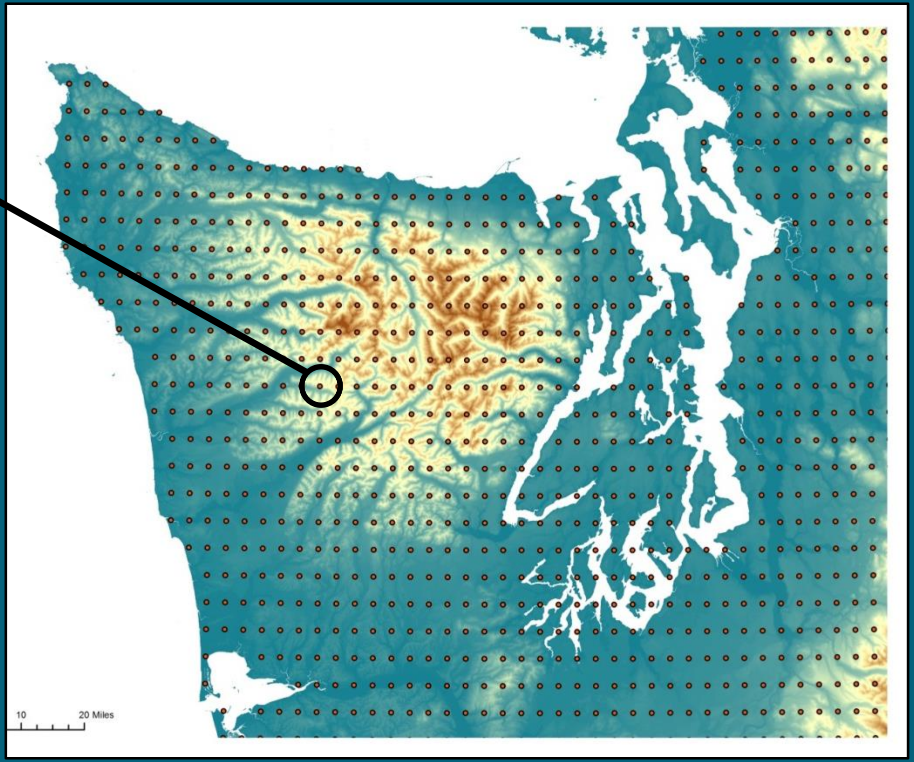


VIC Output



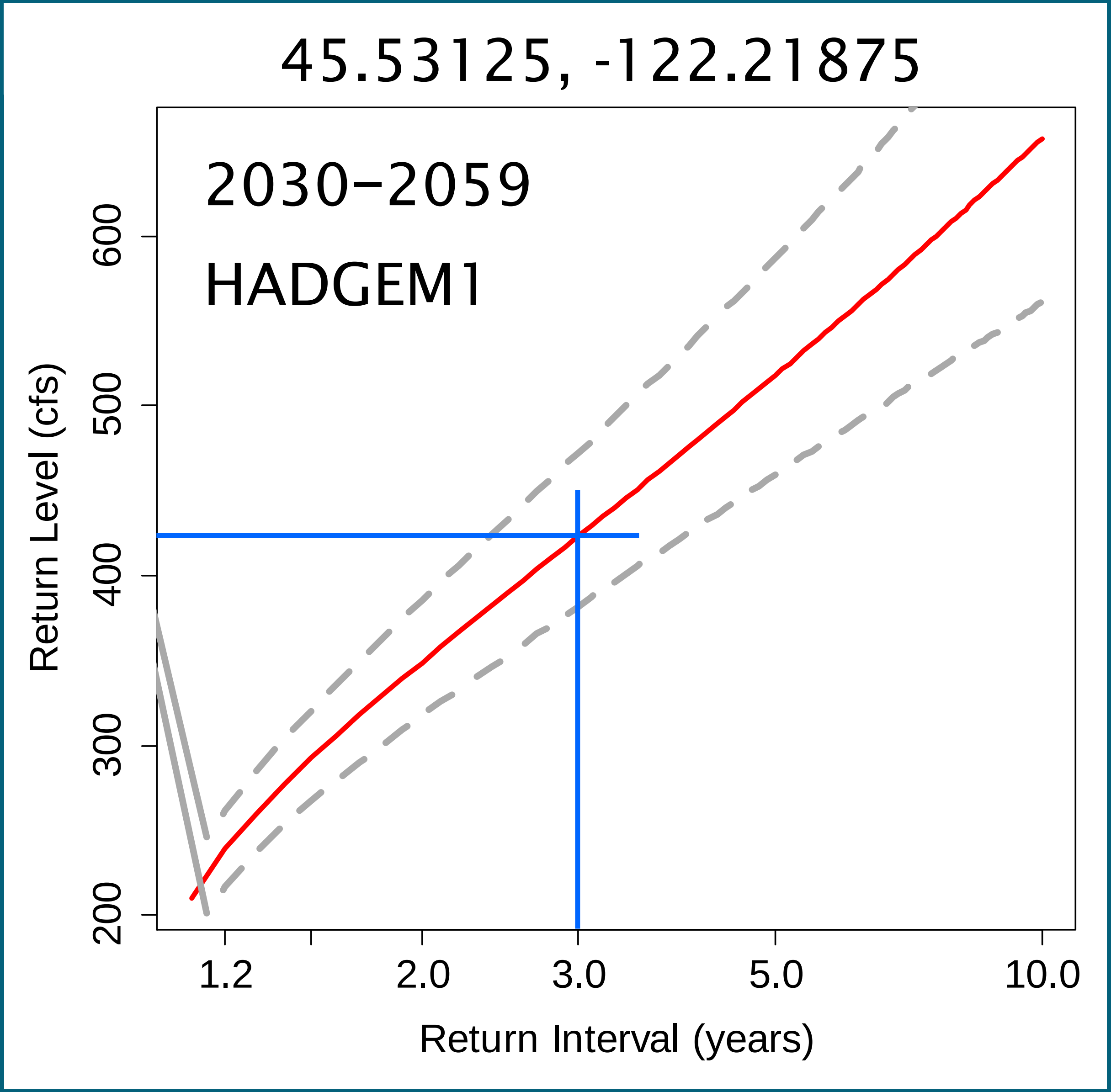
2 future periods
for 10 models

historical period
1916–2006

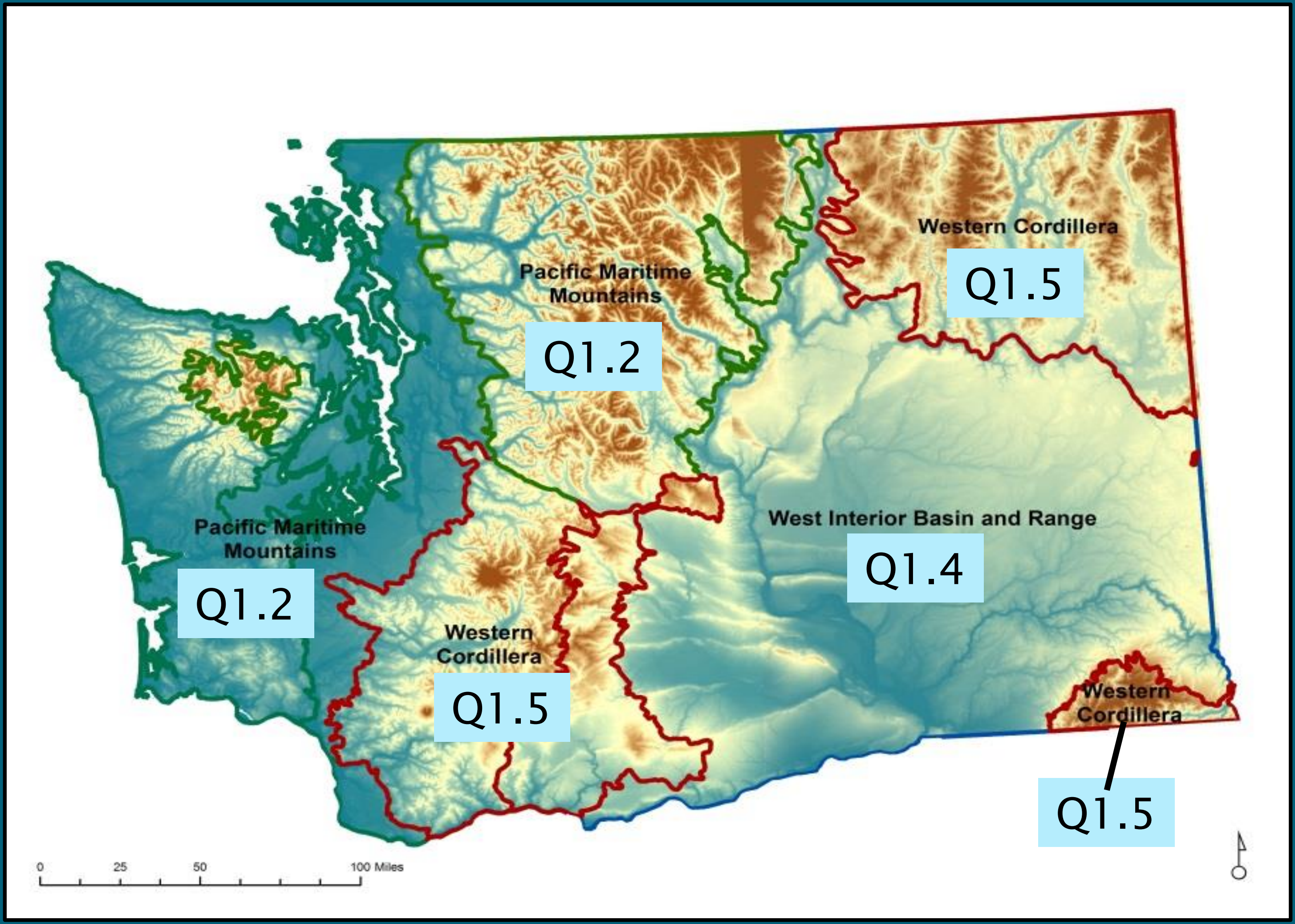


5,270 time series
of mean daily flow

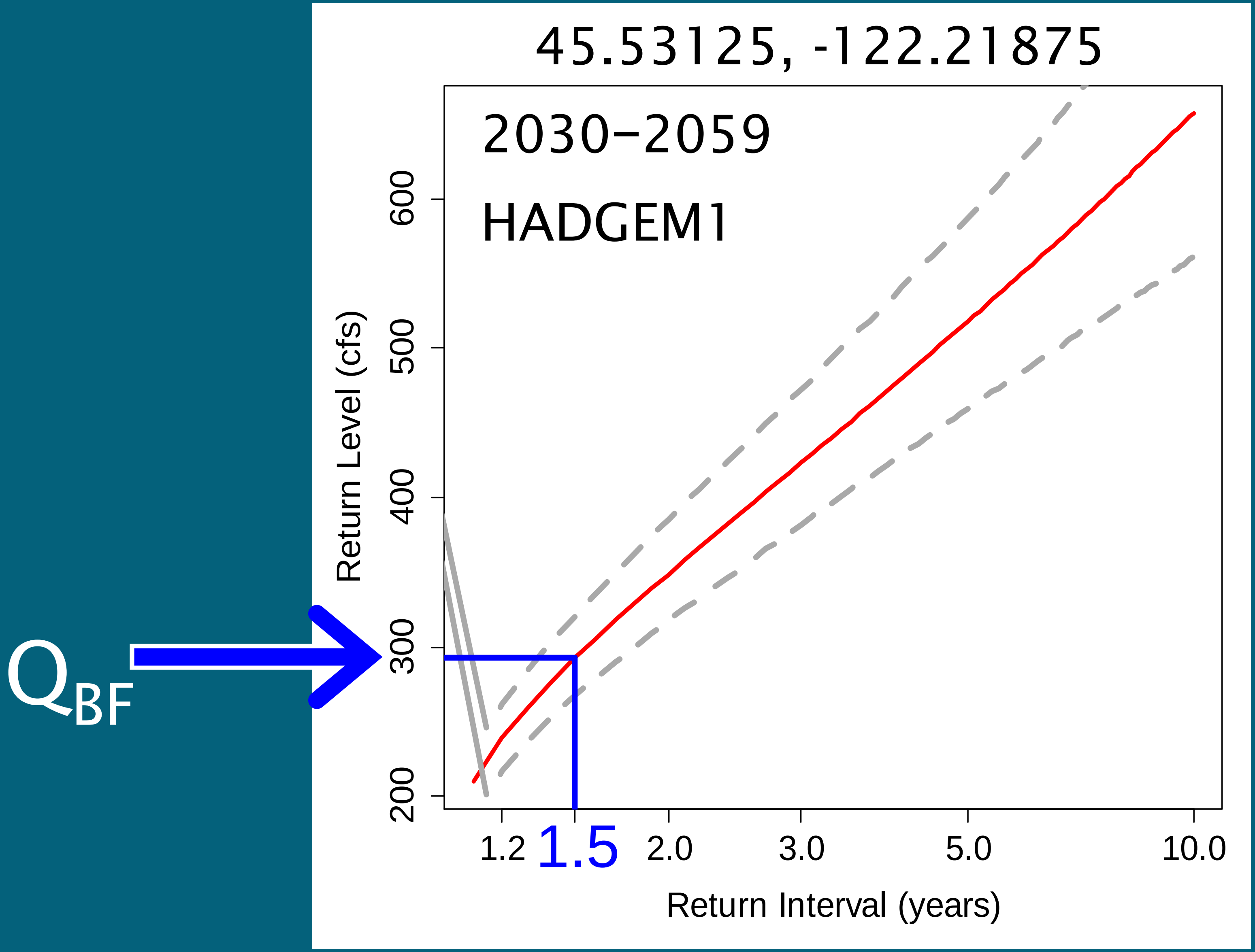
Flood Frequency Curve



Bankfull Flow Recurrence Intervals



Estimating Bankfull Discharge (Q_{BF})



Predicting Bankfull Width

BANKFULL DISCHARGE RECURRENCE INTERVALS AND REGIONAL HYDRAULIC GEOMETRY RELATIONSHIPS: PATTERNS IN THE PACIFIC NORTHWEST, USA[1]

Janine M. Castro and Philip L. Jackson[2]

$$\text{Bankfull width} = aQ^{b}$$

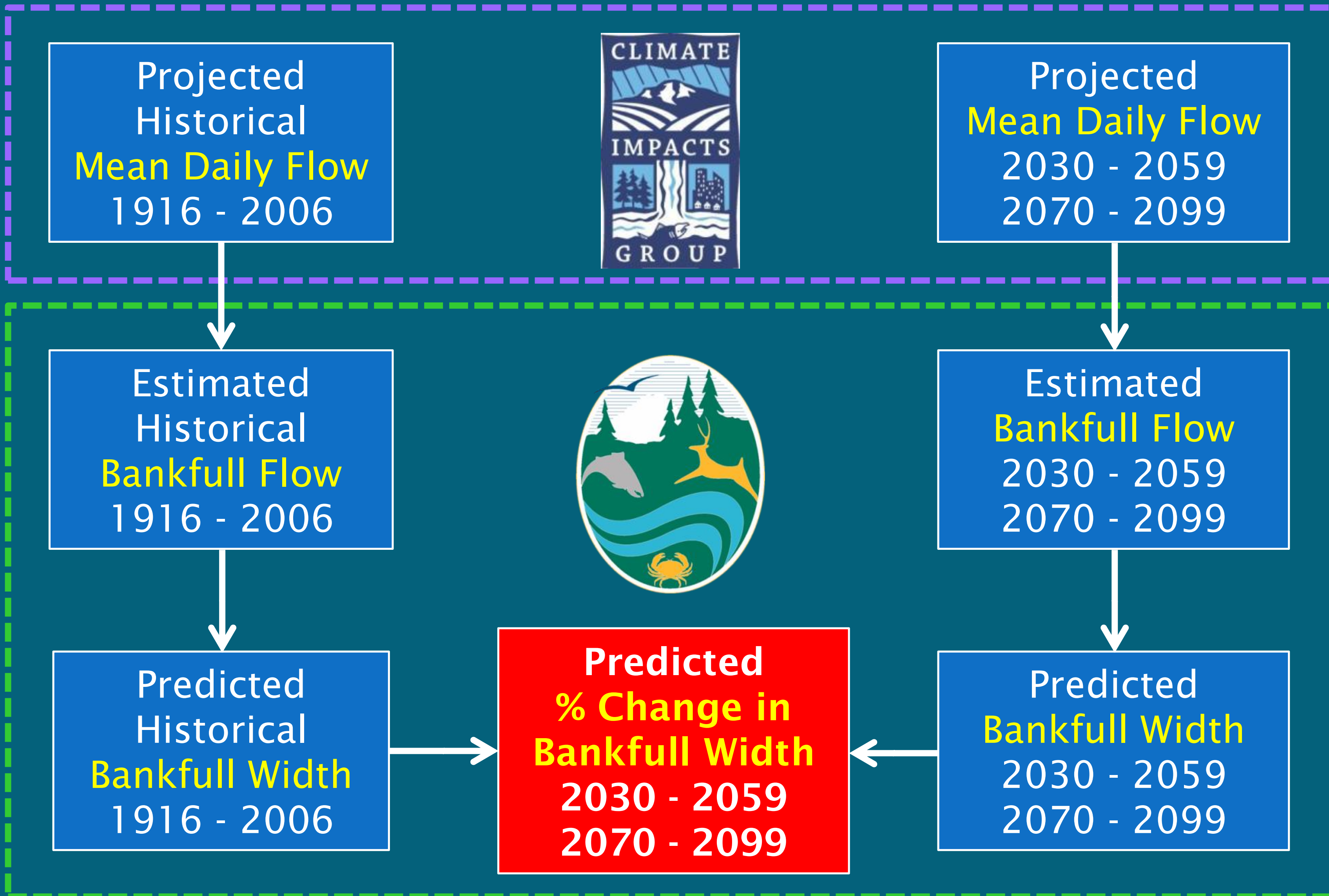
$$Q = Q_{BF}$$

$$Q_{BF} = Q_{1.2} \text{ or } Q_{1.4} \text{ or } Q_{1.5}$$

a and *b* determined empirically

$r^2 = 0.76$ to 0.87

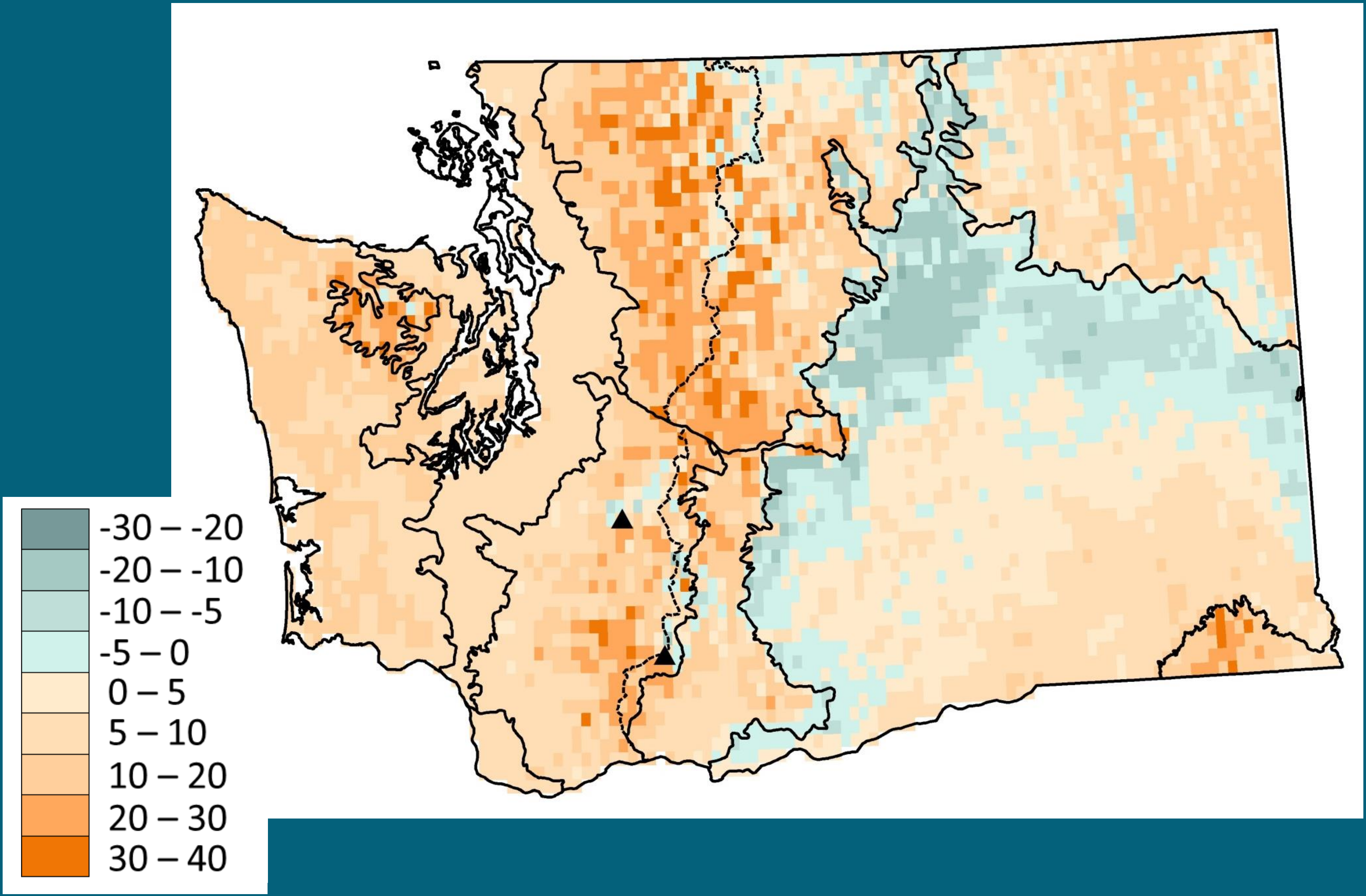
% Change in Bankfull Width



Projected Changes in BFW

- Where?
- How large?
- How likely?

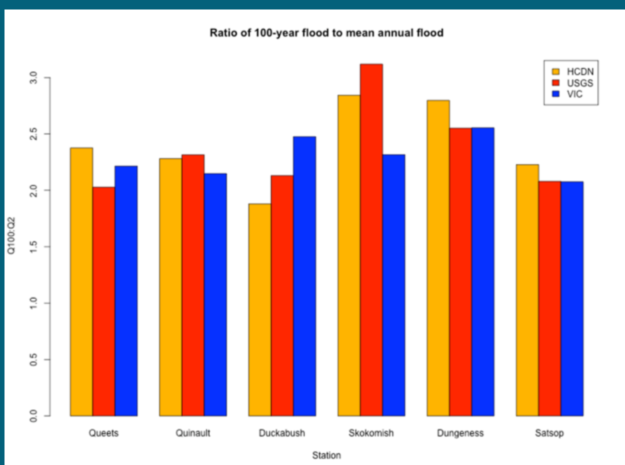
Mean % Change BFW in 2080s



Dealing with Uncertainty

10 GCMs

Global Climate Models
future projections: temp. and precip.



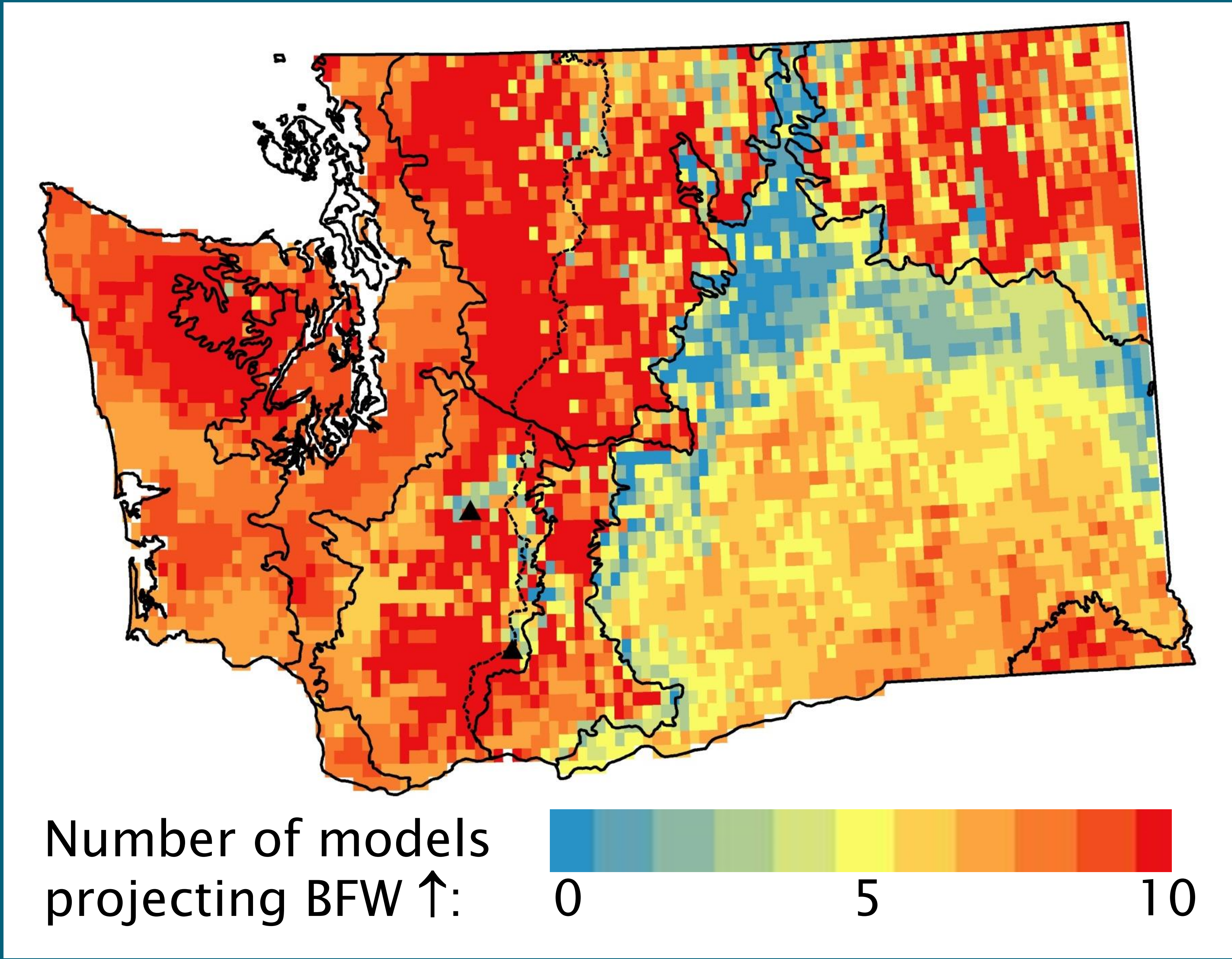
Hydrologic model projects runoff

Estimate bankfull flow

$r^2 > 0.75$

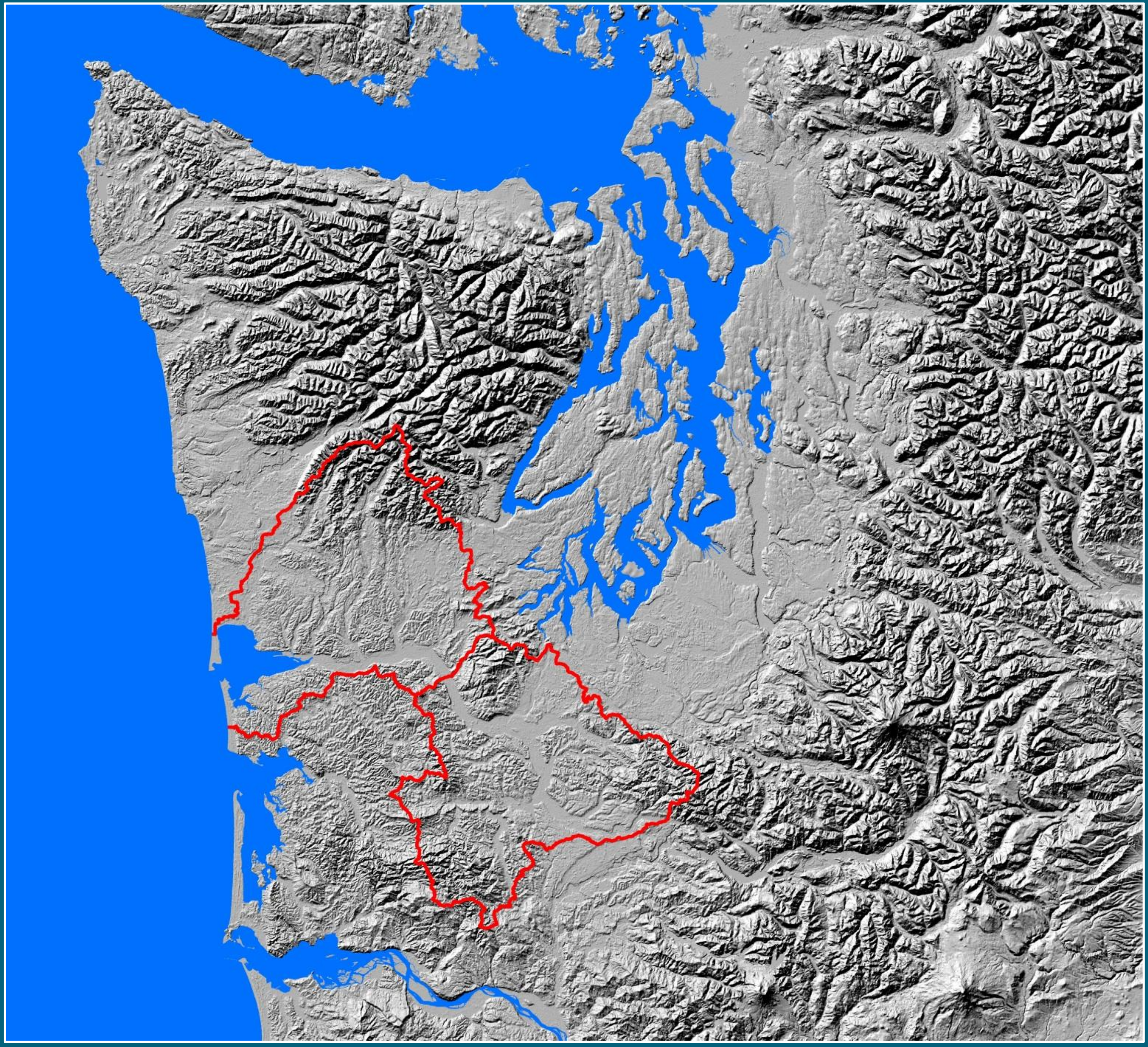
Predict bankfull width

Uncertainty in 2080s

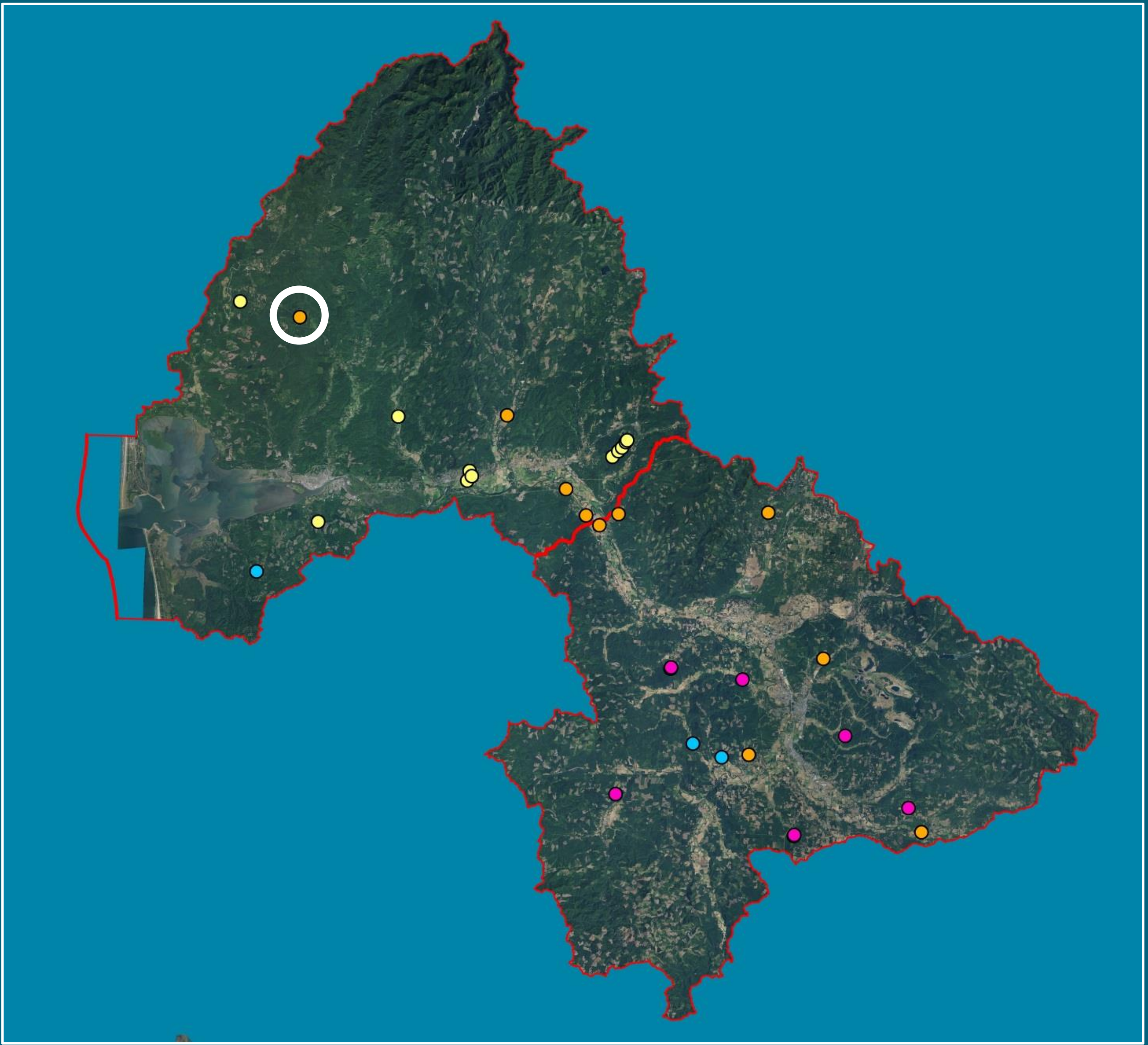


Incorporating Climate-based Bankfull Width Projections into Culvert Design

Chehalis River Basin



Culvert Projects in Chehalis River Basin

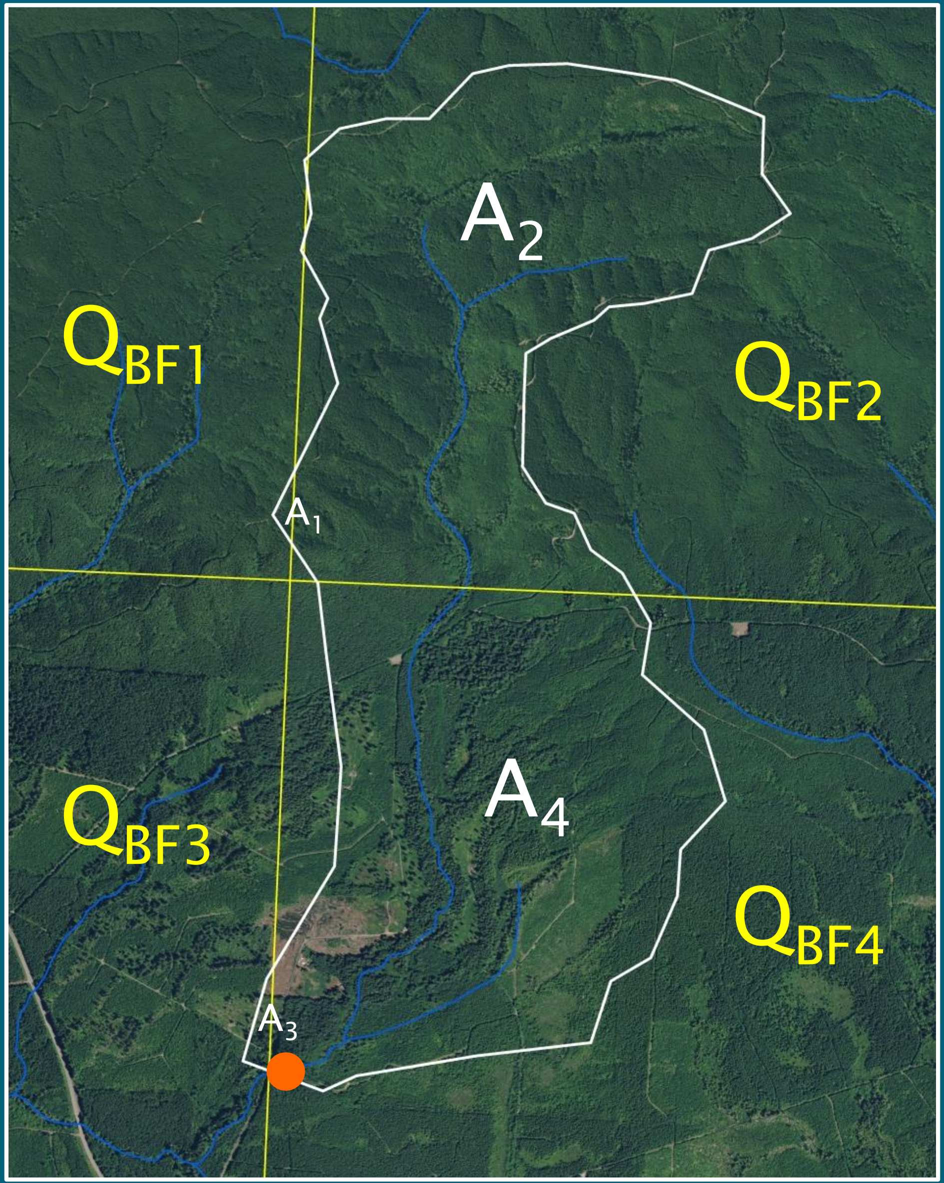


Polson Camp Road on Big Creek

Area = 1.85 mile^2
BFW ≈ 12 ft

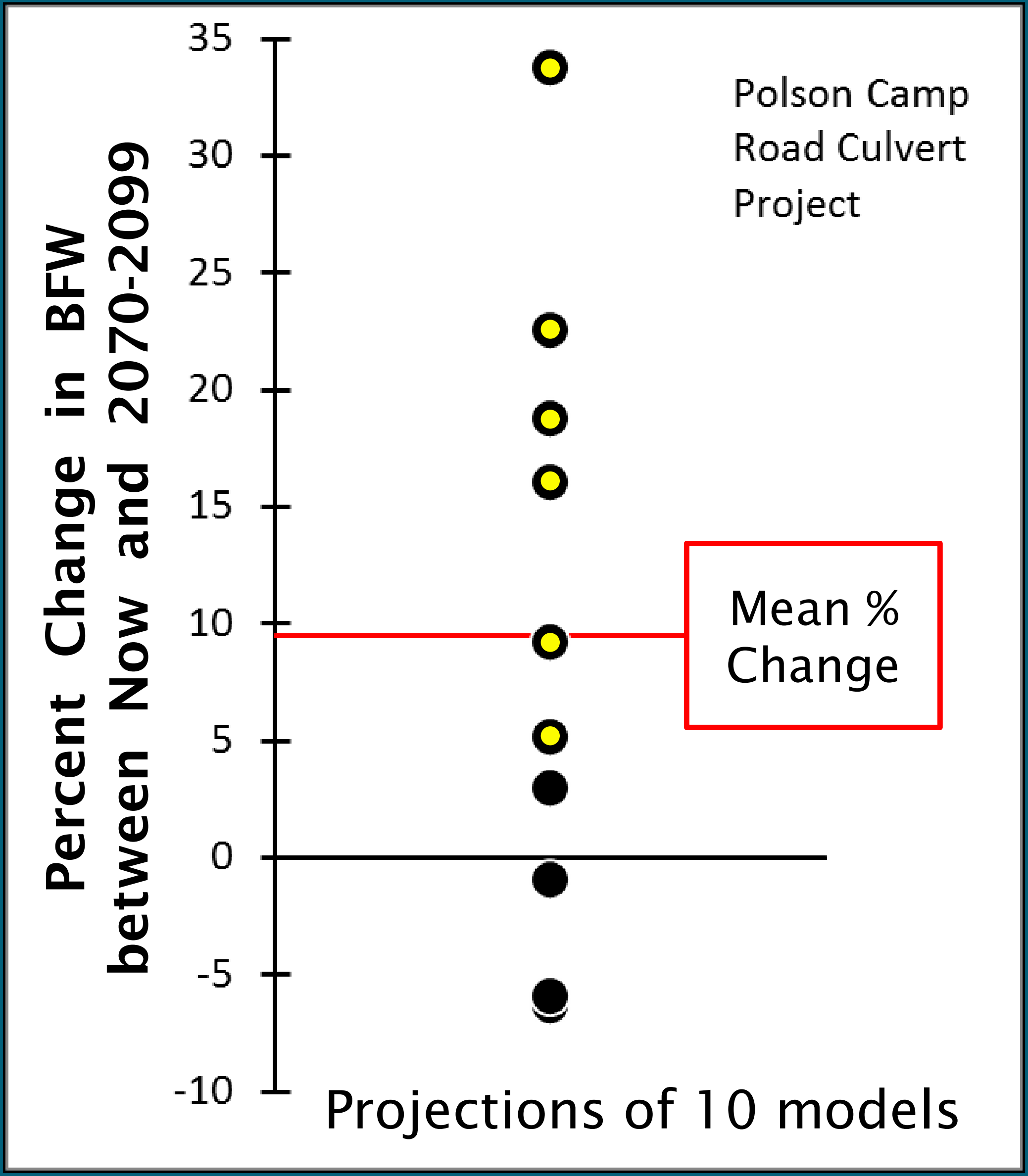
Area weighted average of
- Q_{BF1}
- Q_{BF2}
- Q_{BF3}
- Q_{BF4}

11 bankfull widths



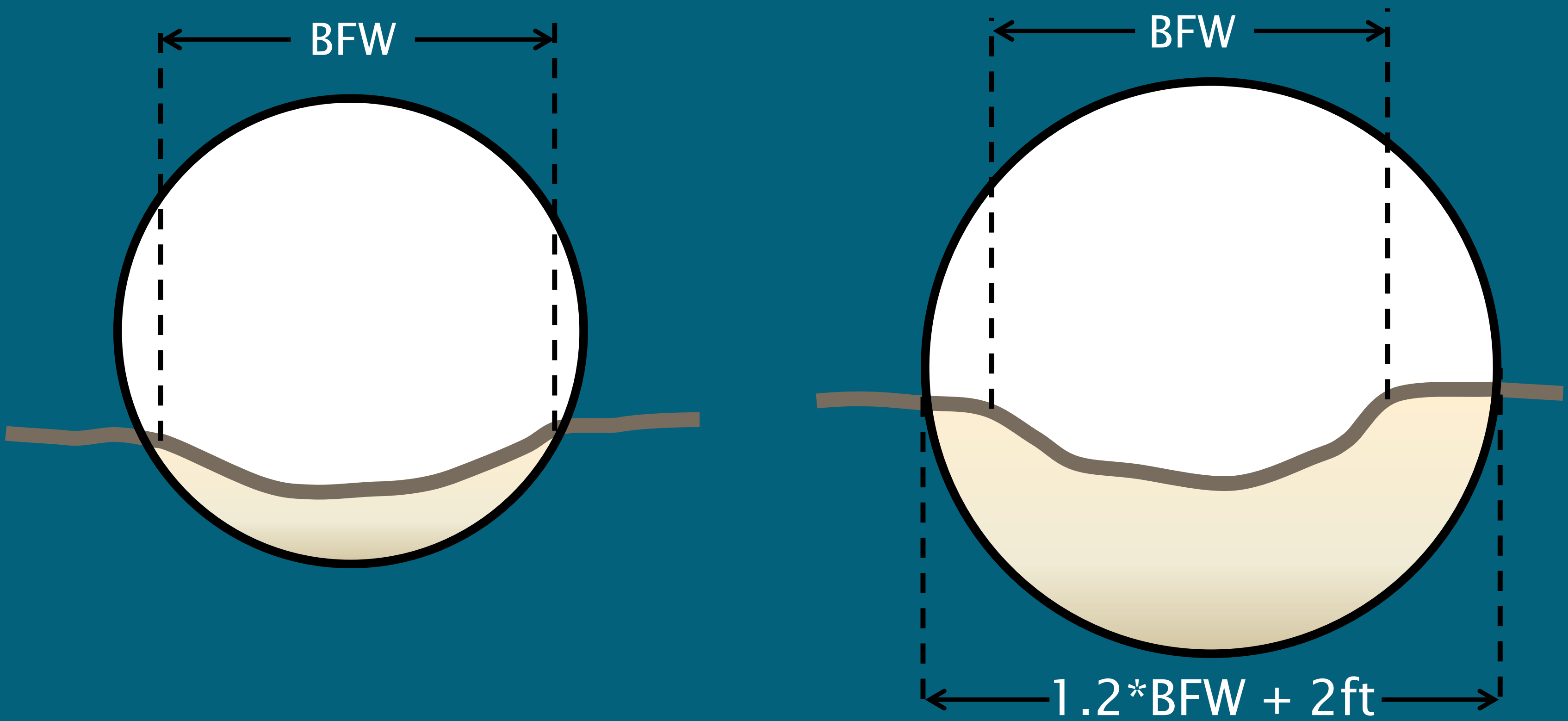
% Change in Bankfull Width

- range of projected change in BFW between -6 and 34%
- mean projected change in BFW = +9.5%
- 7 of 10 models project an increase in BFW
- 6 of 10 models project an increase greater than 5%



How someone might use it

Bankfull width (BFW) is a key parameter

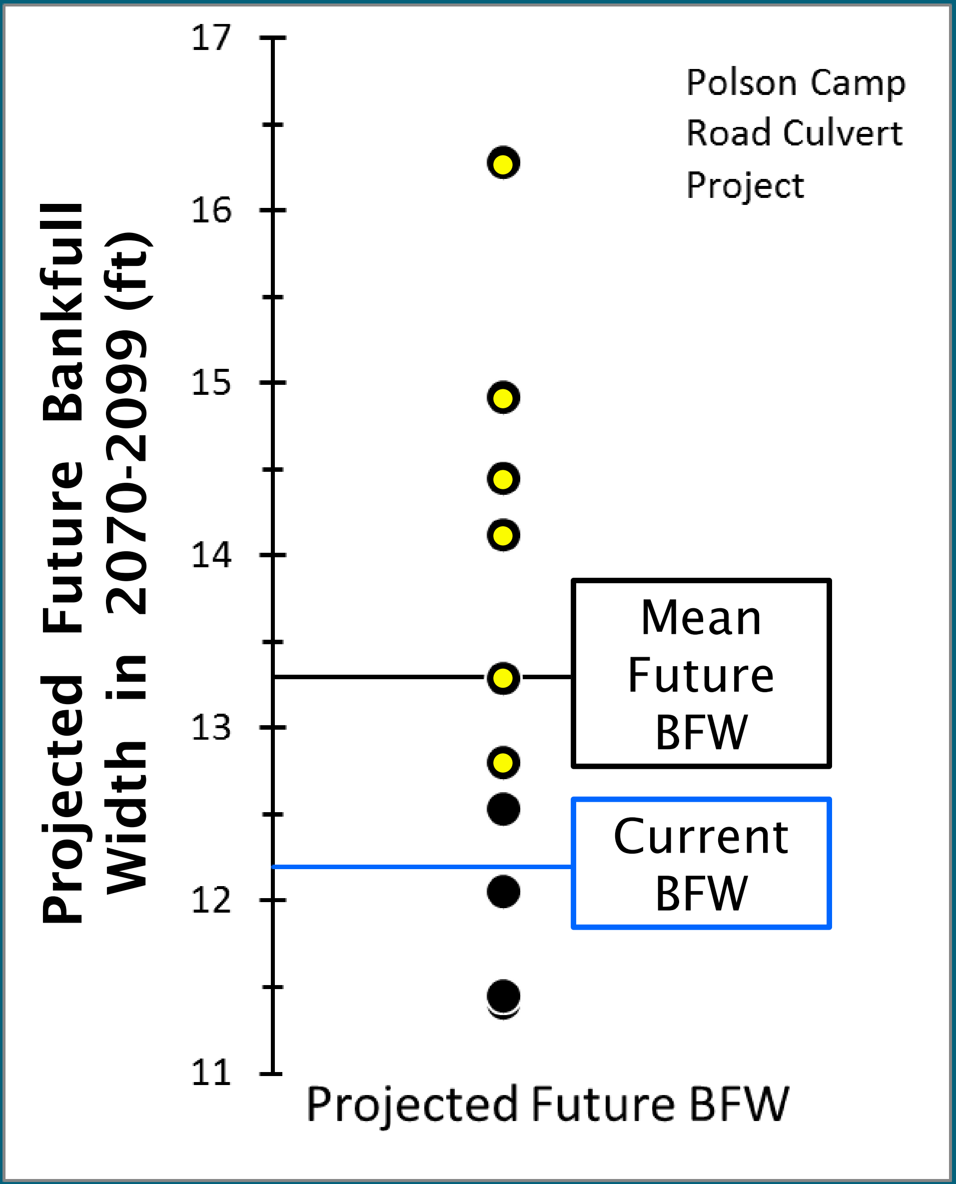


No-slope
(<10 ft BFW, gradient <3%)

Stream Simulation
(<15 ft BFW)

How someone might use it

- current BFW = 12.2 ft
- mean % change in BFW = 9.5%
- mean future BFW = 13.3 ft
- 6 of 10 models project an increase greater than ½ ft

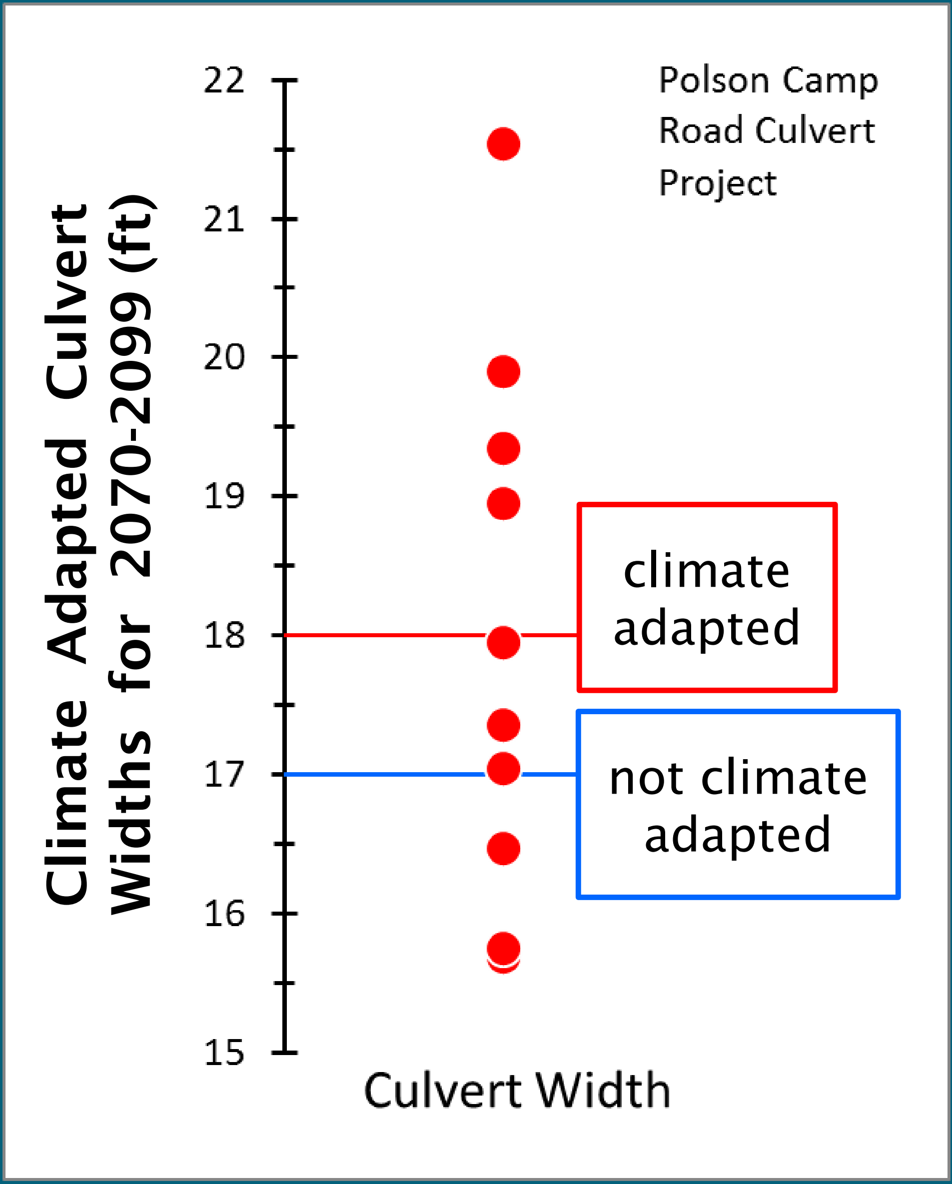


How someone might use it

Stream Simulation Culvert

- current BFW = 12.2 ft
- culvert width = 17 ft

- mean future BFW = 13.3 ft
- "climate adapted" culvert width = 18 ft



Construction Cost of Wider Culvert

Assume:

- one-lane, gravel road
- stream simulation design
- round, steel culvert
- and many other details

BFW (ft)	1.2 x BFW + 2 ft	Culvert Diam (ft)	Est. Project Cost	Cost Increase	% Cost Increase
12.2	16.6	17	$117,030	$0	0
13.3	18.0	18	$124,125	$7,095	6
13.8	18.6	19	$144,303	$27,273	23

Potential Costs of Undersized Culvert

- Increased maintenance
- More repairs
- Early replacement
- Damage to aquatic resources

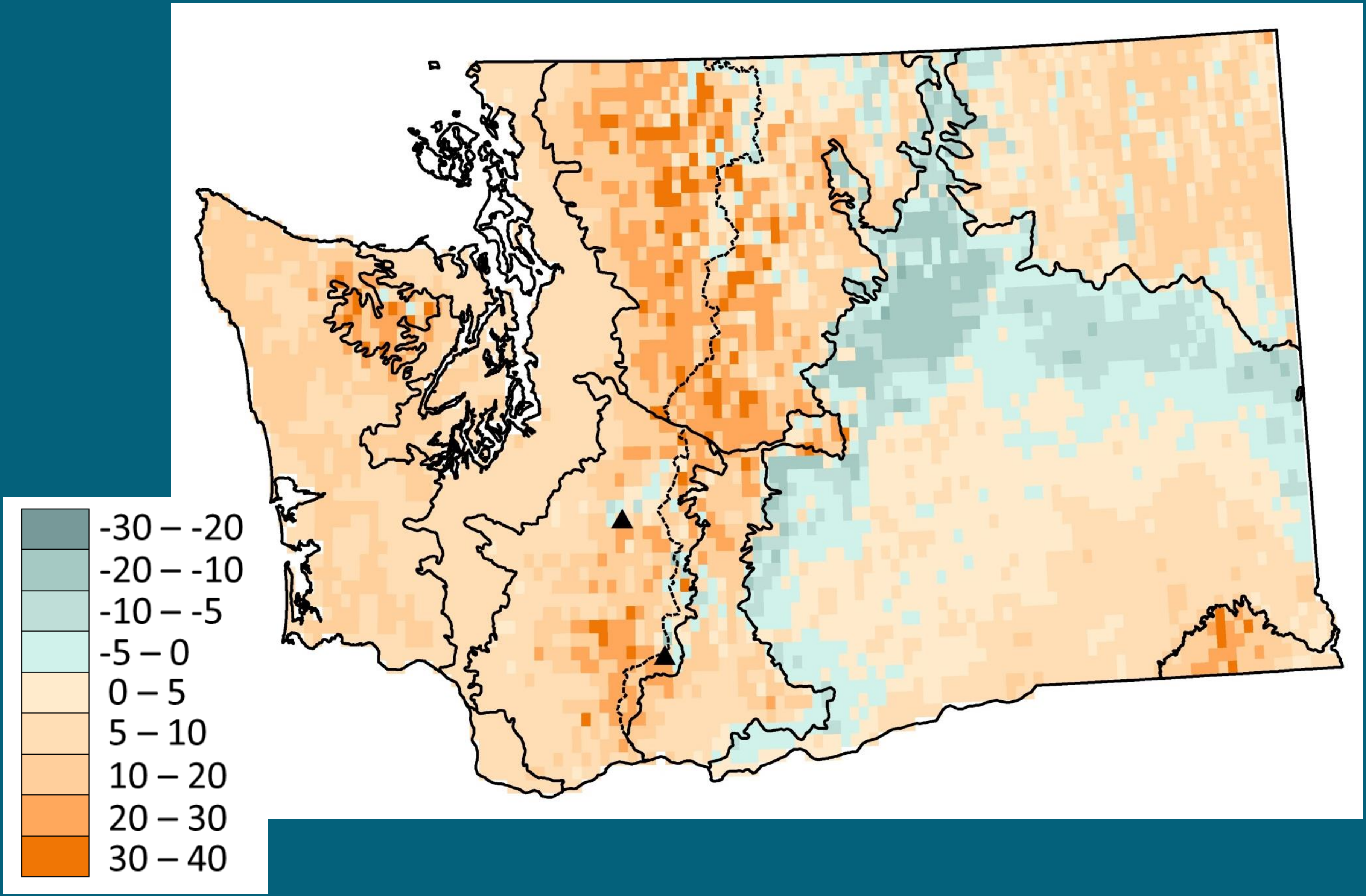
Not yet quantified

What is a Manager to do?

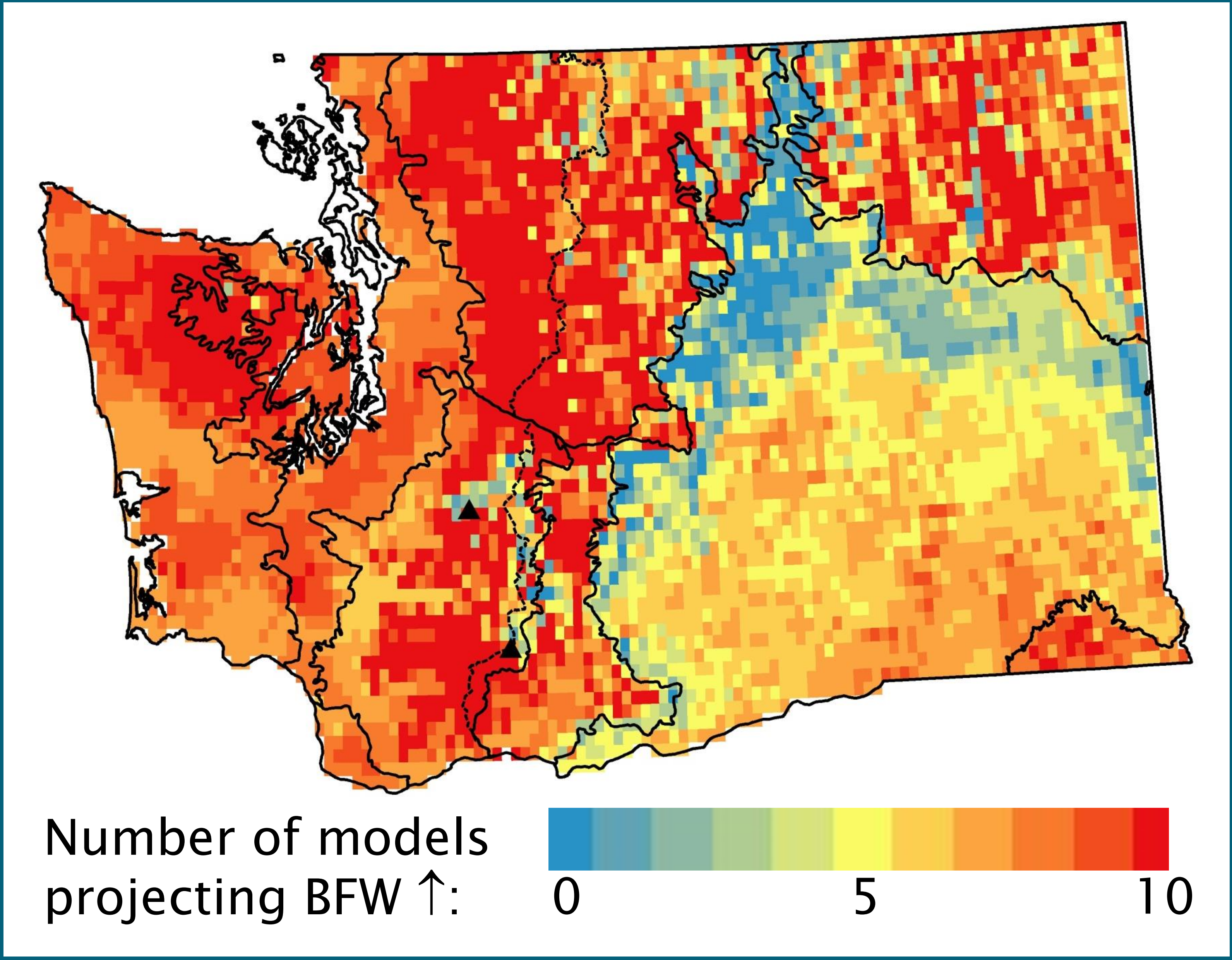
- Manage Risk
  - What risk is “actionable” ?

- Risk
  - how bad (damage, impact, cost)
  - how likely (probability, uncertainty)

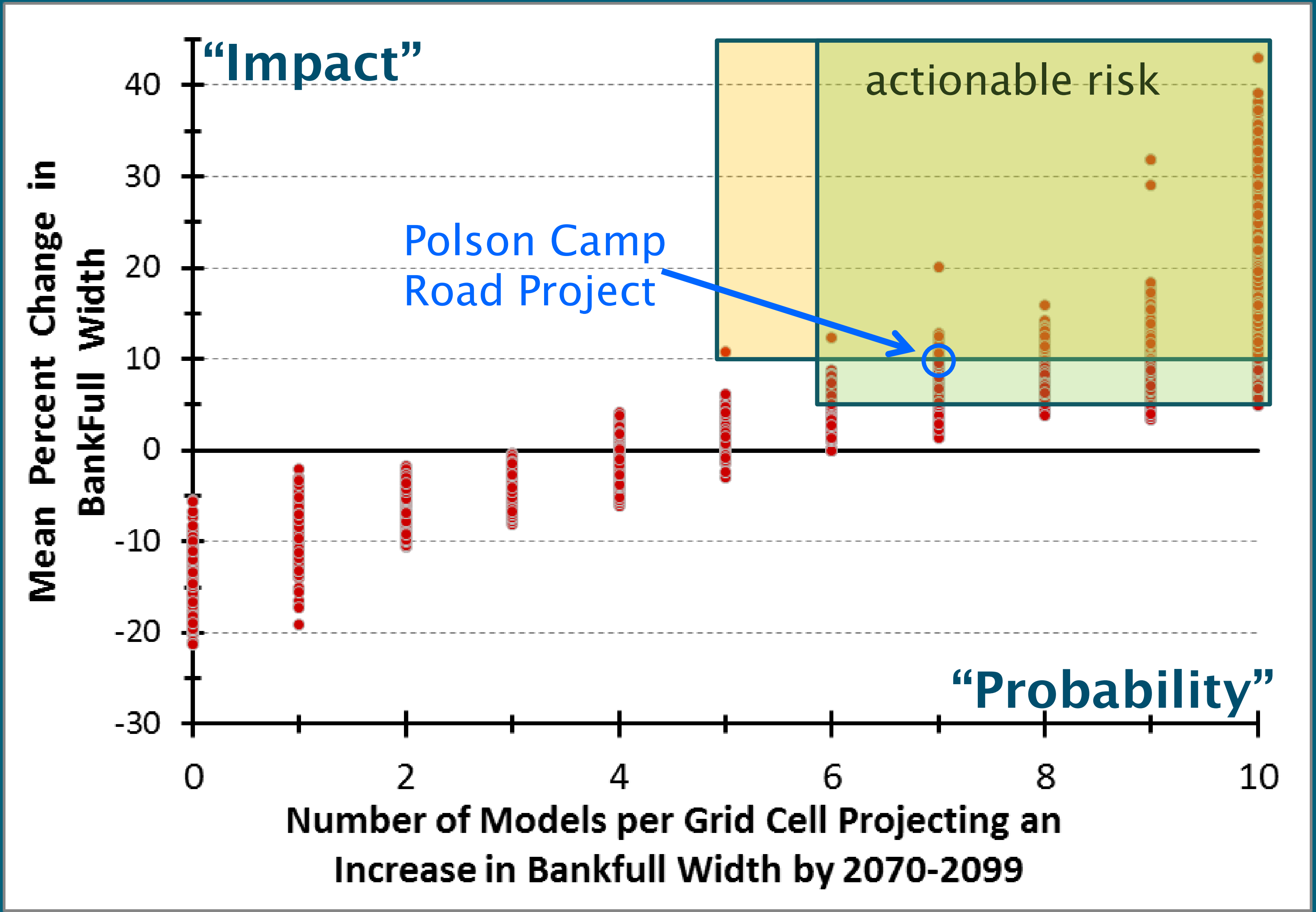
Magnitude: Mean % Change BFW



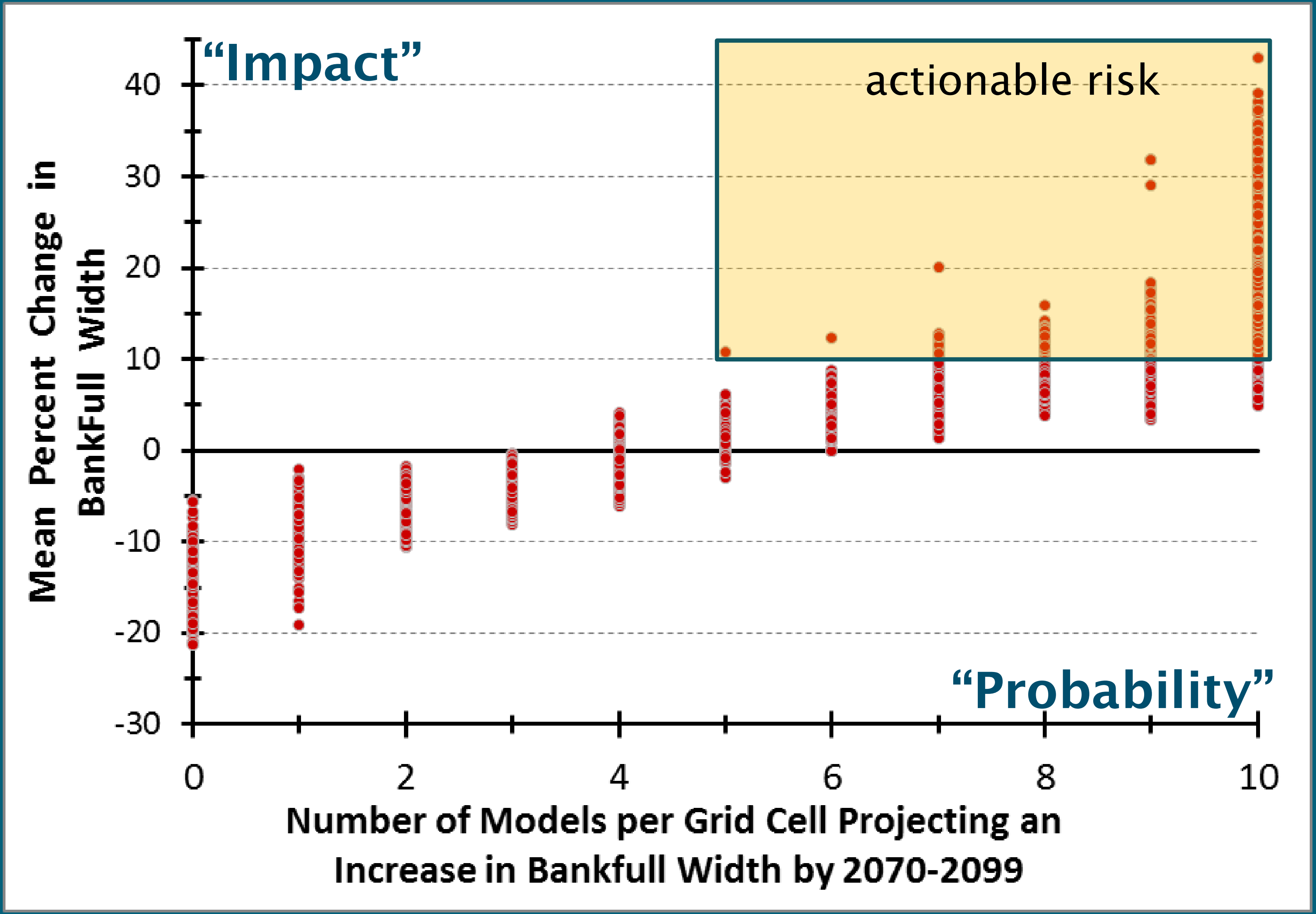
How Likely: Model Agreement



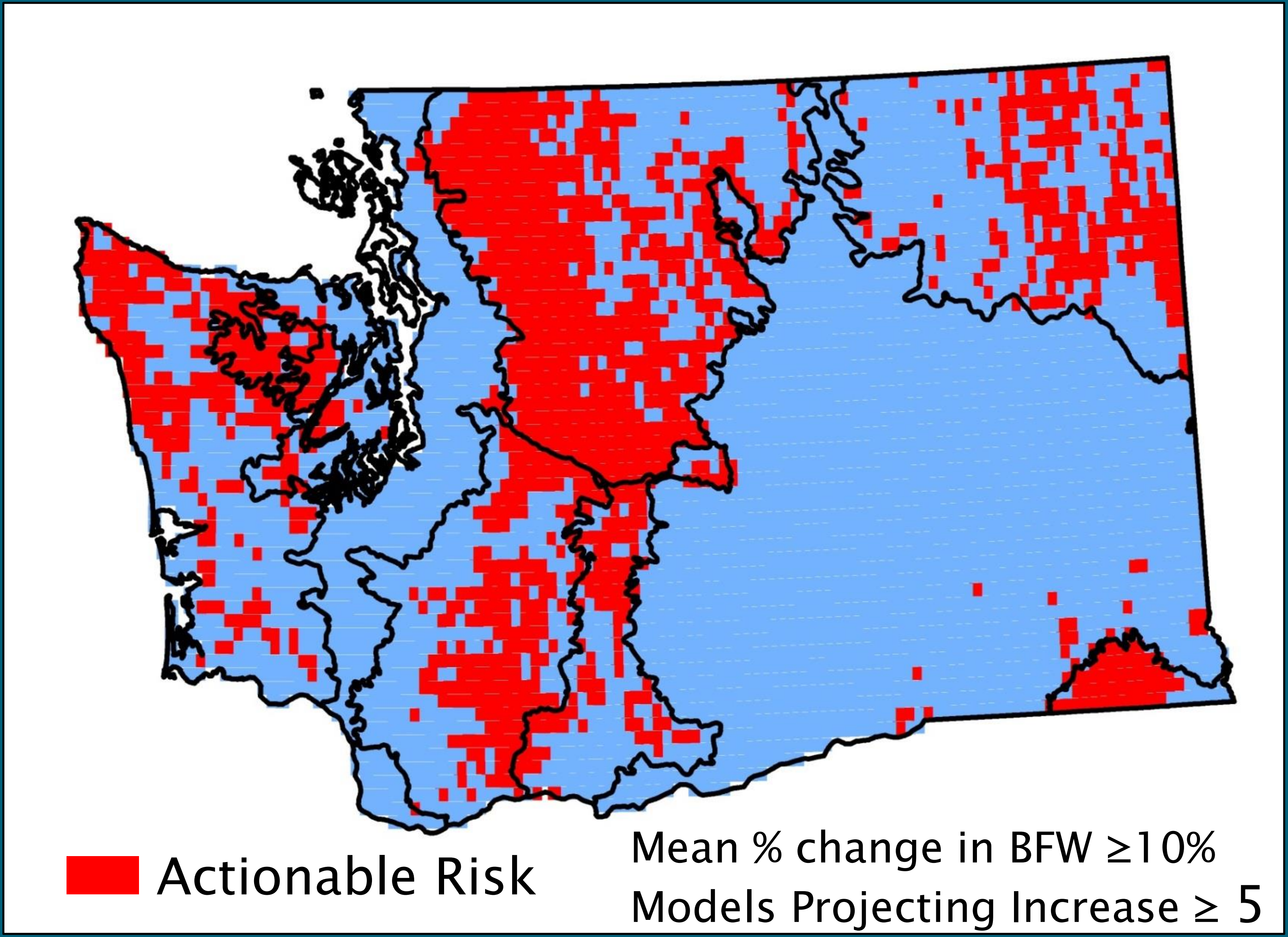
Actionable Risk in 2080s



Actionable Risk in 2080s



One Version of Actionable Risk 2080s



The Bottom Line

- Bankfull width is projected to increase in many watersheds due to climate change.
- Many culverts may be at risk of being undersized.
- We now have a spatially-explicit, state-wide assessment of the magnitude and likelihood of change in bankfull width.
- We are developing a framework for addressing uncertainty inherent in climate change projections.

Next Steps for WDFW

1. Learn from collaboration on climate-adapted culverts in Chehalis Basin projects.
2. Work with managers of WDFW lands to incorporate climate projections into culvert projects.
3. Publish results in peer-reviewed journal.
4. Explore development of guidance for voluntary use of bankfull width projections.
5. Develop internet site that provides easier access to information.

Thank You