Climate Change & the Tongass NF: Potential Impacts on Salmon Spawning Habitat

Matt Sloat, Gordie Reeves,
Kelly Christiansen

US Forest Service
PNW Research Station

Funding provided by:

The Nature Conservancy

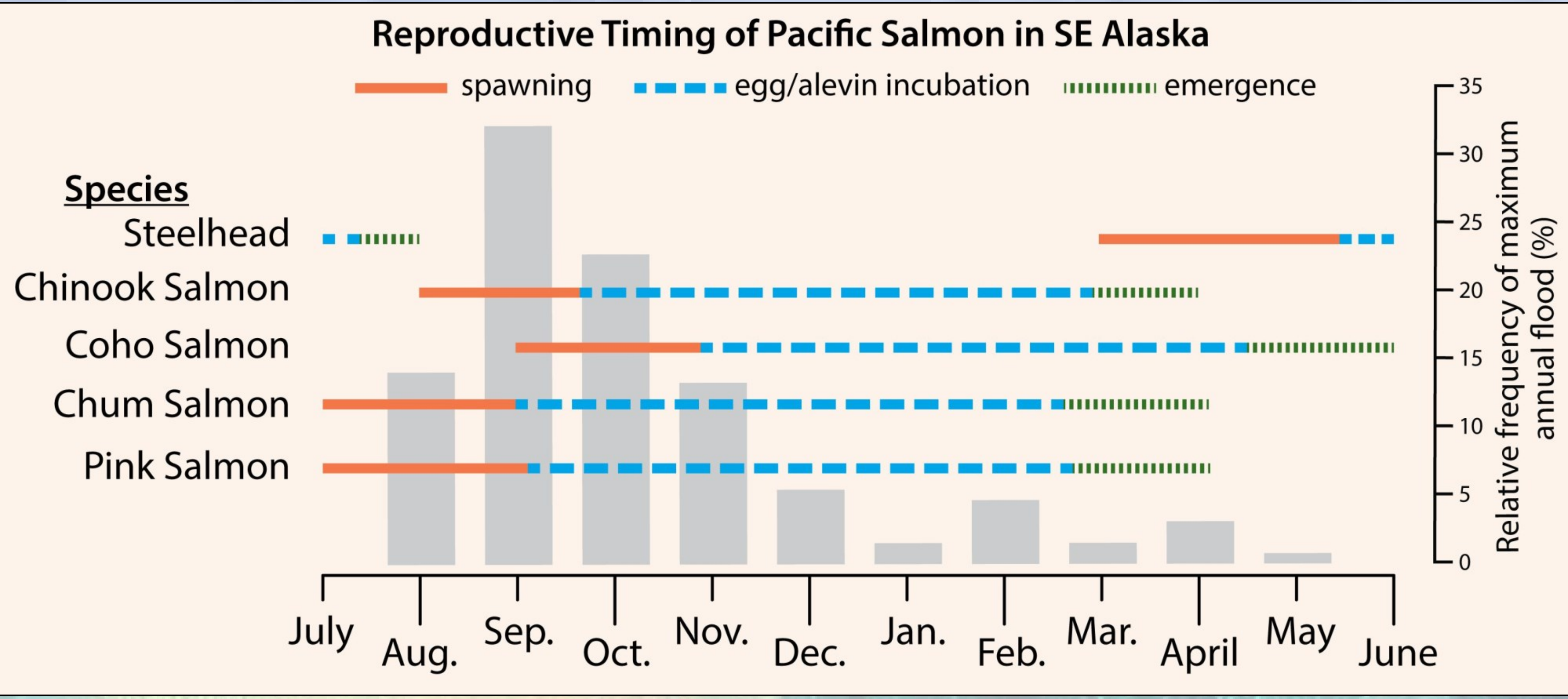
Protecting nature. Preserving life.™

Gordon and Betty MOORE FOUNDATION

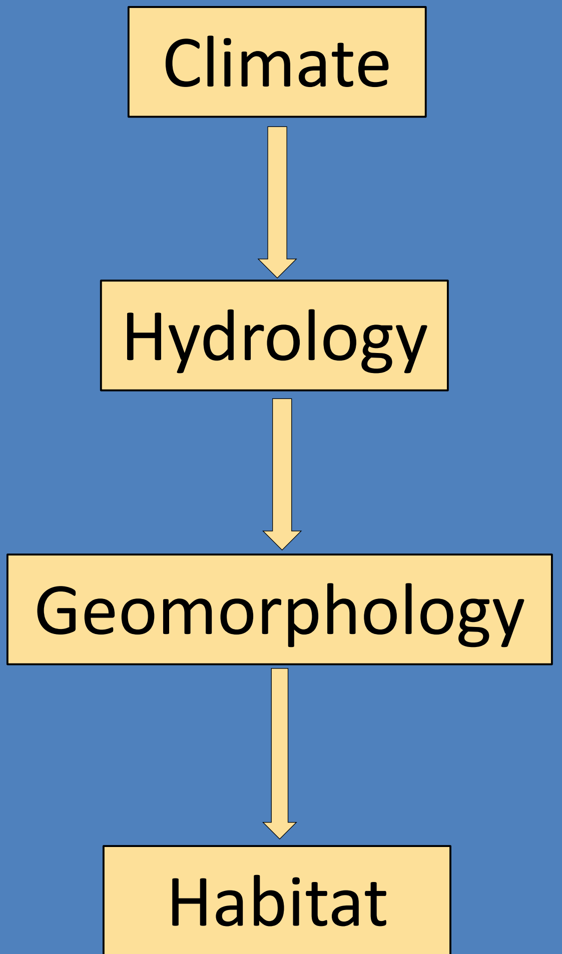
Additional assistance provided by:
TNF, UCSB Marine Science Institute, UC Davis, Oregon State University, and USFS PNW RS.

Objectives:

- Determine the vulnerability of watersheds on the Tongass National Forest to the potential impacts of climate change.
- Focus on changes in flood disturbance in response to trends for a warmer, wetter climate.
- Determine the impact of increases in mean annual flooding on spawning habitat for Pacific salmon.



Reproductive Timing of Pacific Salmon in SE Alaska
spawning
egg/alevin incubation
emergence
Species
Steelhead
Chinook Salmon
Coho Salmon
Chum Salmon
Pink Salmon
July
Aug.
Sep.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
April
May
June
35
30
25
20
15
10
5
0
Relative frequency of maximum annual flood (%)


Climate
Hydrology
Geomorphology
Habitat

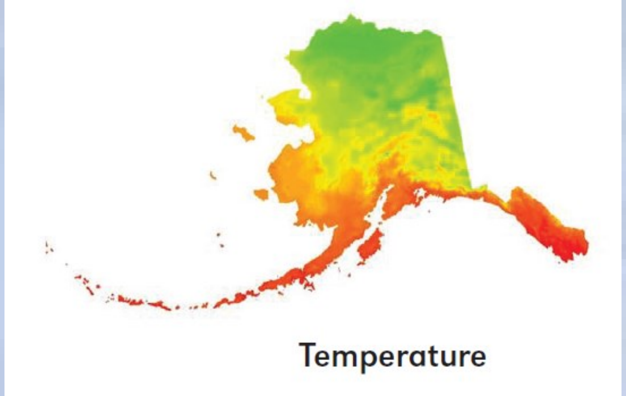
Historic climate

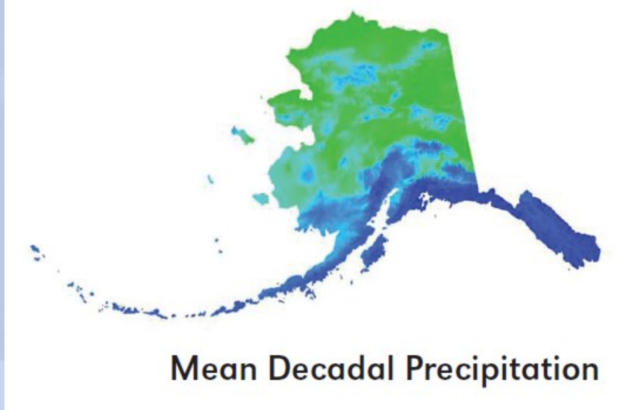
Future climate models

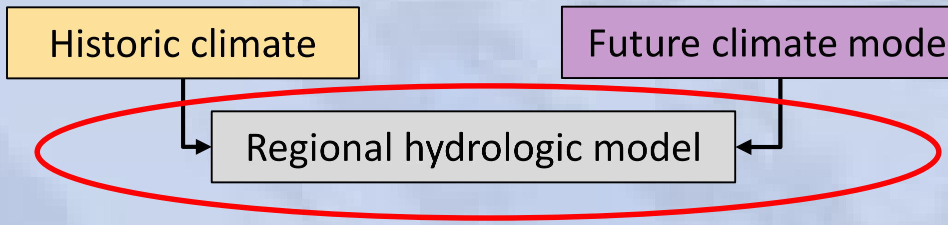
Regional hydrologic model

SNAP

Scenarios Network for Alaska Planning







$$Q_2 = 0.004119 * A^{0.8361} * (ST+1)^{-0.3590} * P^{0.9110} * (J+32)^{1.635}$$

Q_2 = Mean annual flood magnitude
A = Drainage area
ST = Area of lakes
P = Mean annual precipitation
J = Mean January temperature

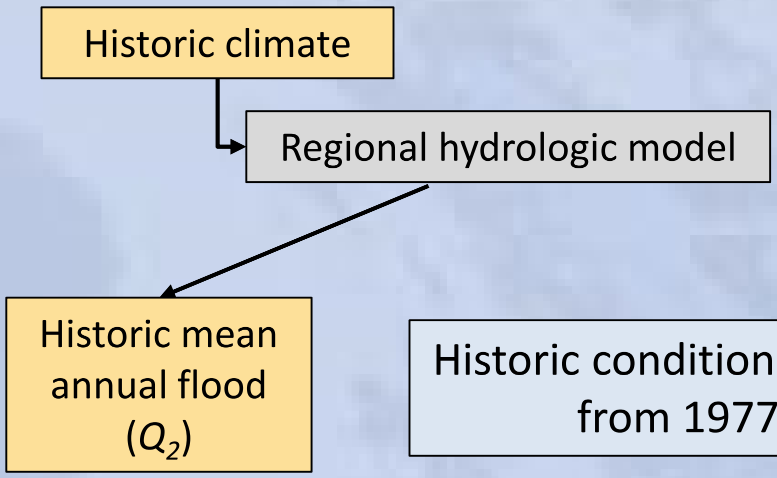
Curran et al. (2003) *Estimating the magnitude and frequency of peak streamflows for ungagged sites on stream in Alaska . . . USGS Water Resources Investigations Report 03-4188.*

Why focus on mean annual floods?

RIVERS ARE THE AUTHORS OF THEIR OWN GEOMETRY

- Given enough time, rivers **construct their own channels**.
- A river channel is characterized in terms of its ***bank-full geometry***.
- ***Bank-full geometry*** is defined in terms of river width and average depth at ***bank-full discharge***.
- ***Bank-full discharge*** (~Q_2) is the flow discharge when the river is just about to spill onto its floodplain.

Gary Parker 2007

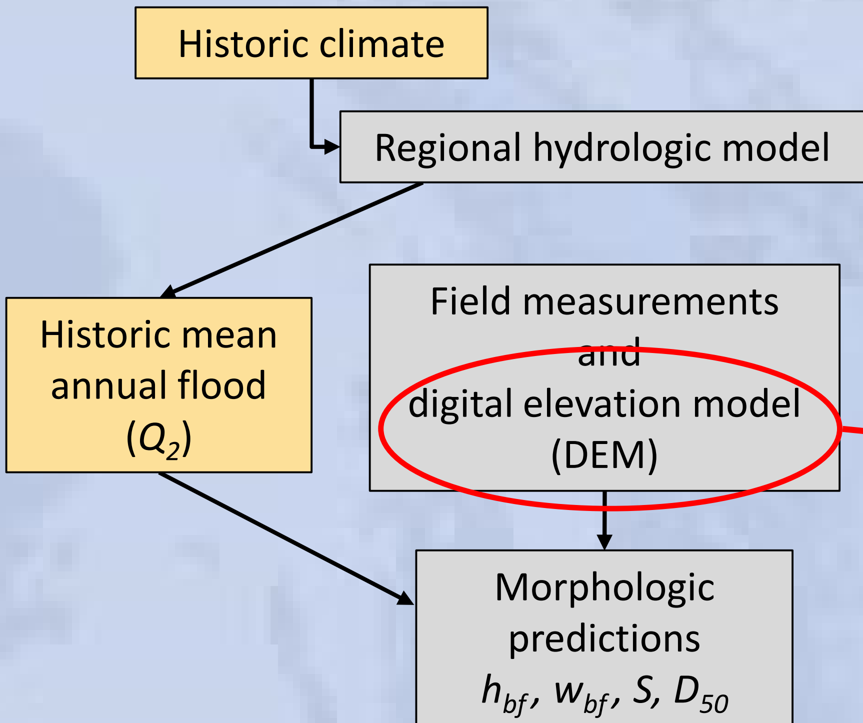


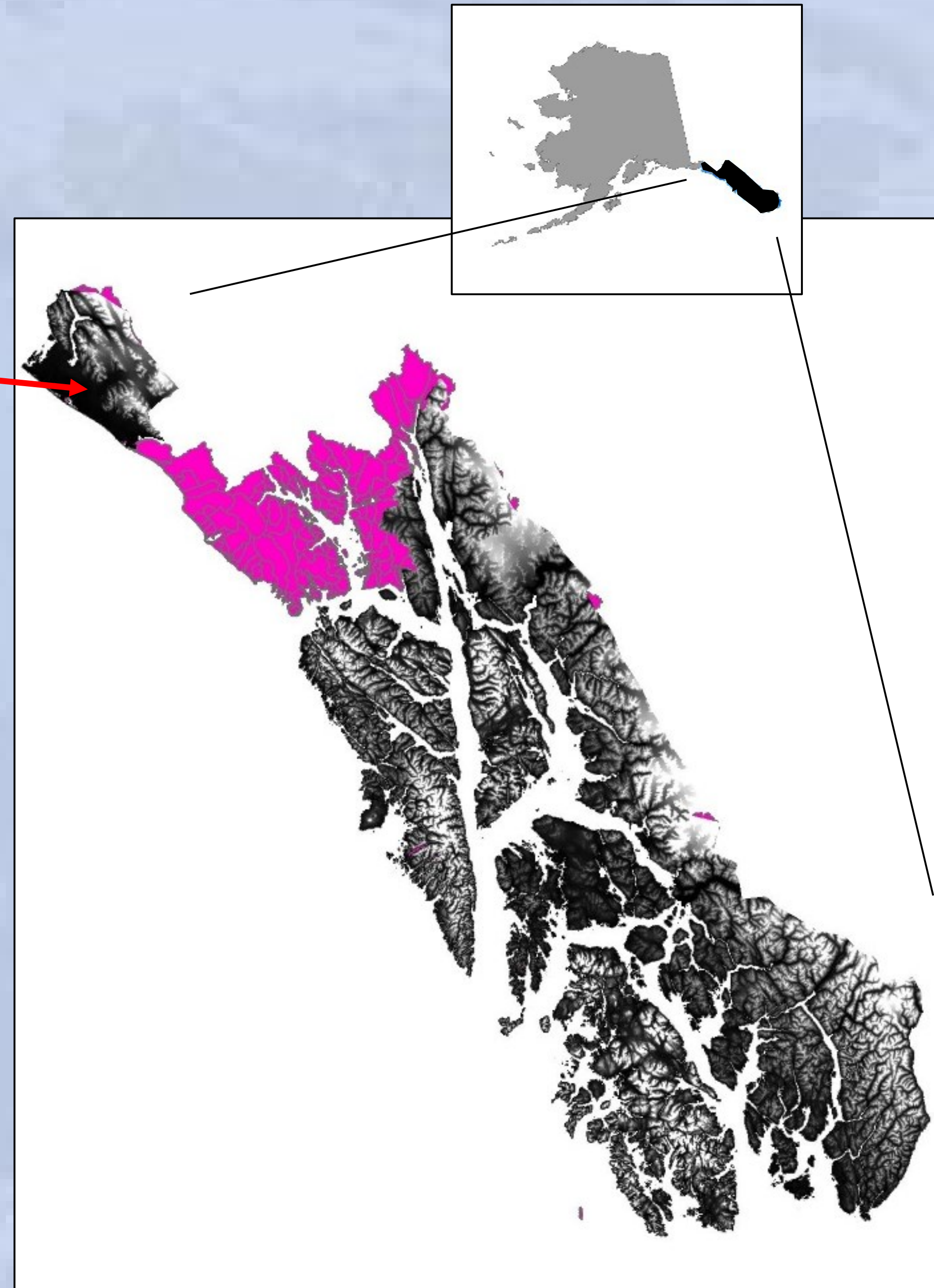
Historic conditions characterized from 1977 – 2000

$$Q_2 = 0.004119 * A^{0.8361} * (ST+1)^{-0.3590} * P^{0.9110} * (J+32)^{1.635}$$

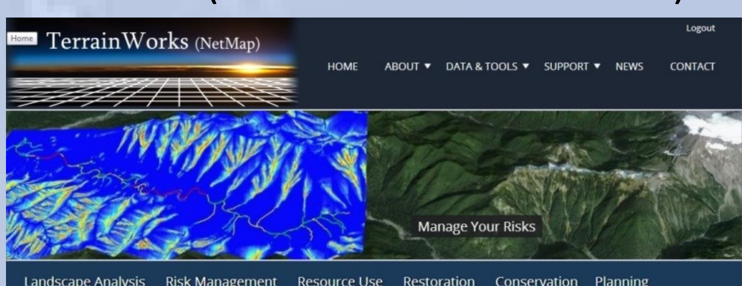
Q_2 = Mean annual flood magnitude
A = Drainage area
ST = Area of lakes
P = Mean annual precipitation
J = Mean January temperature

Curran et al. (2003) *Estimating the magnitude and frequency of peak streamflows for ungagged sites on stream in Alaska . . . USGS Water Resources Investigations Report 03-4188.*





NetMap's attributed and routed stream layer in southeast Alaska was used to delineate fish habitats and to calculate hydrographic and morphological variables (www.terrainworks.com)



Historic climate

Regional hydrologic model

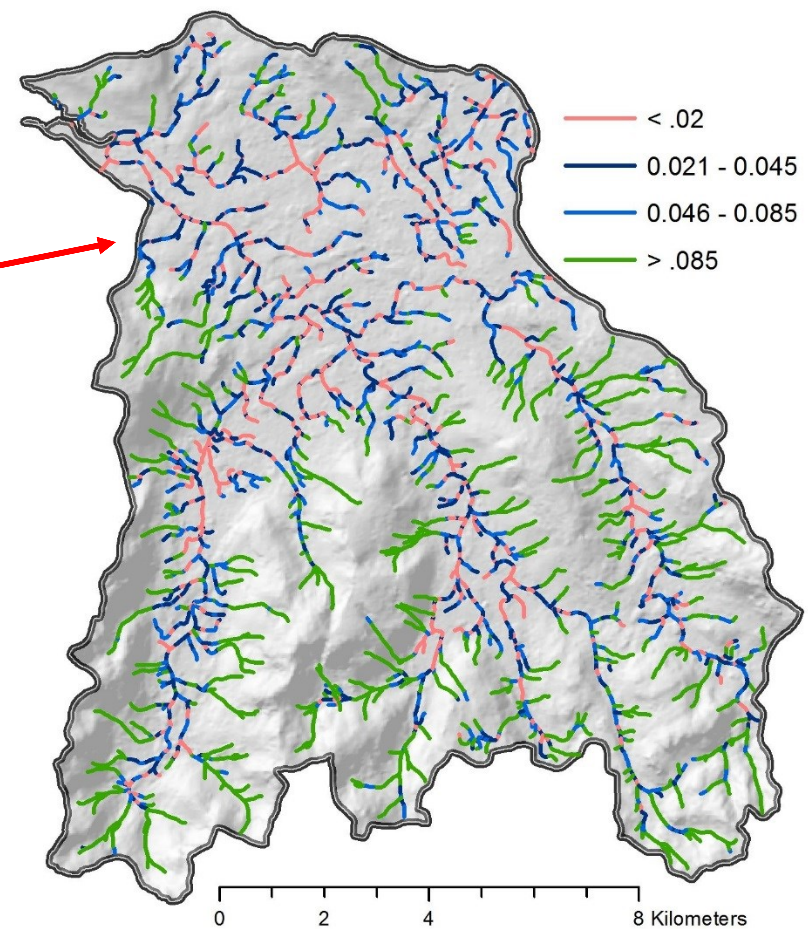
Historic mean annual flood (Q_2)

Field measurements and digital elevation model (DEM)

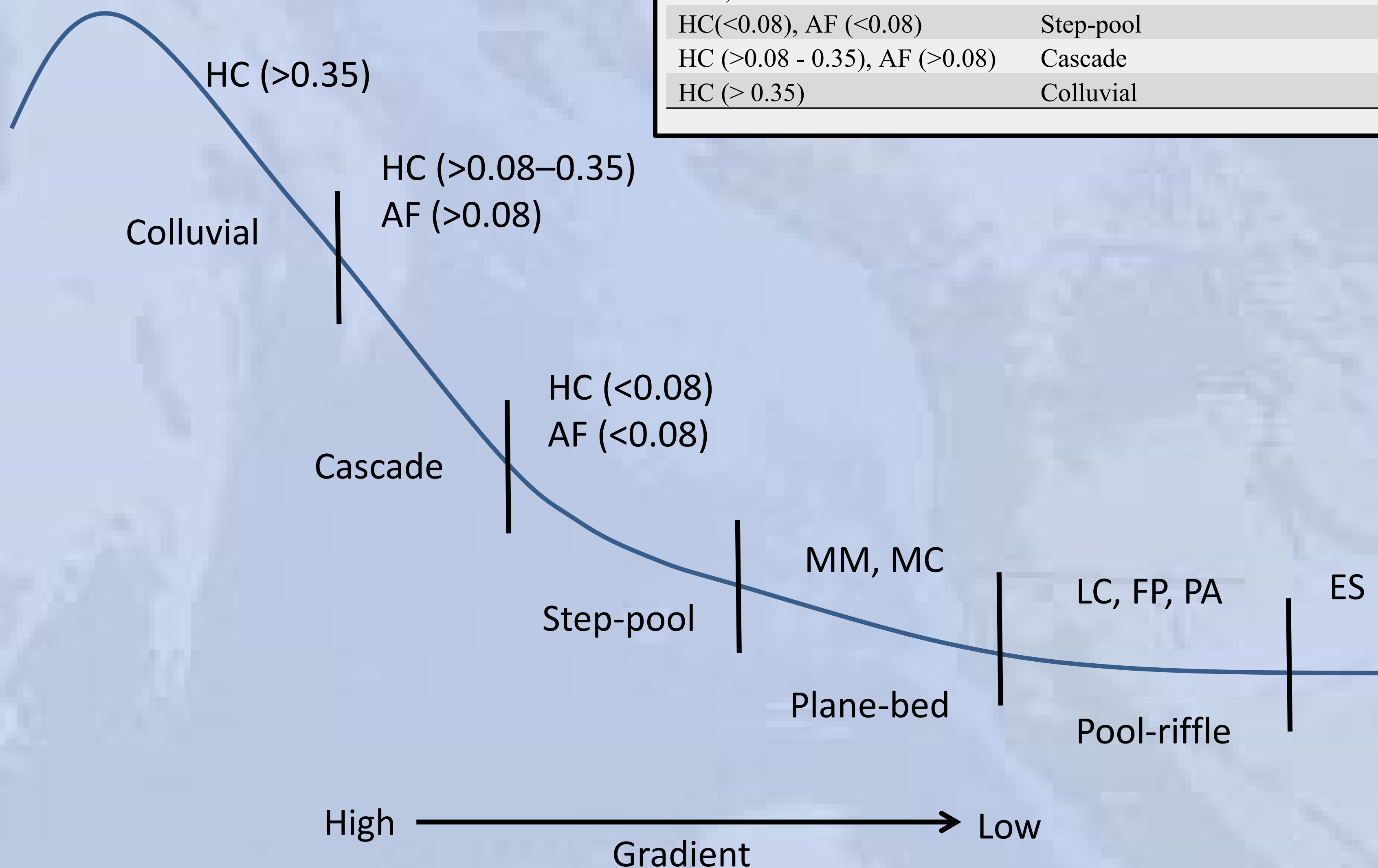
Morphologic predictions

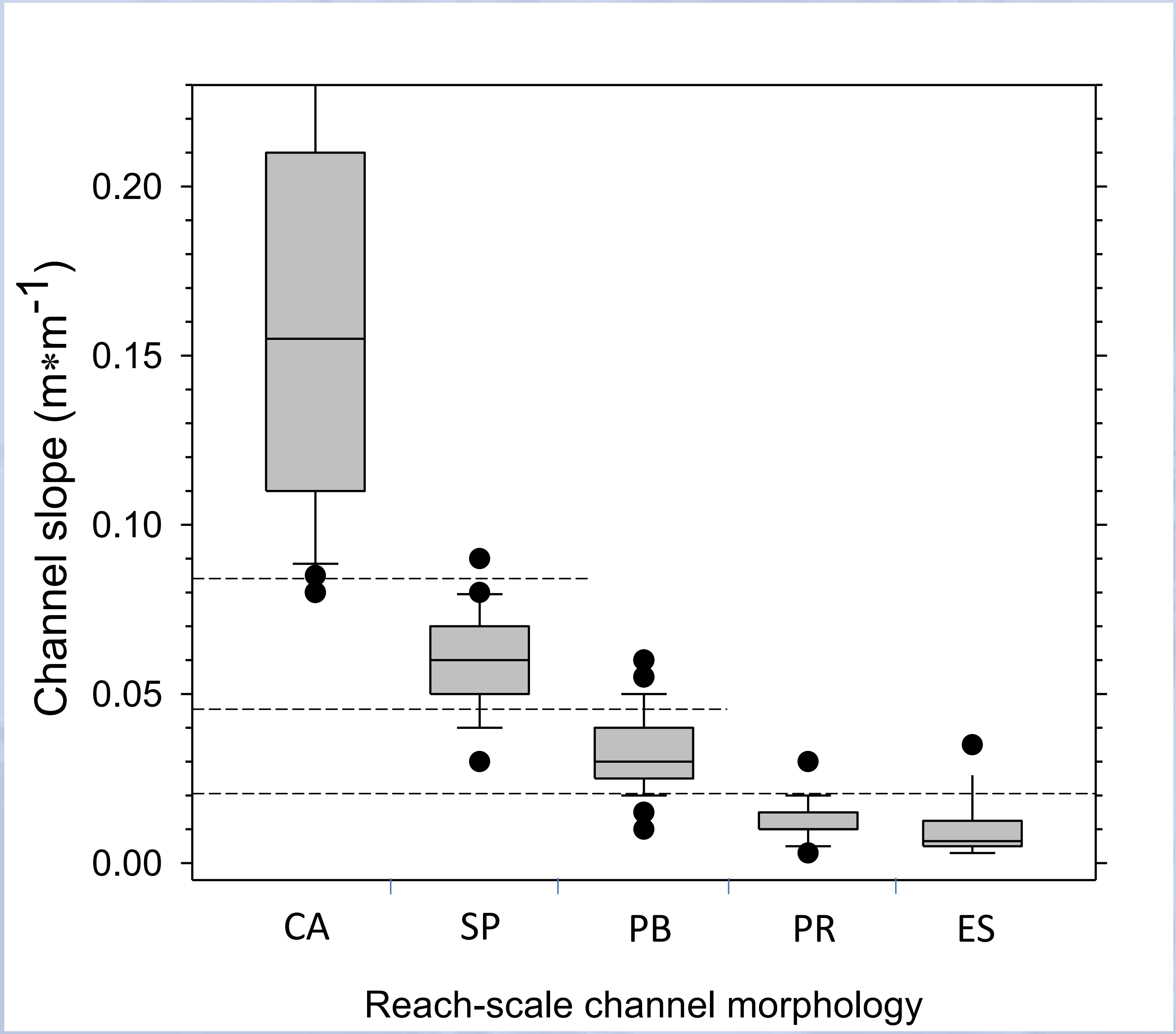
h_{bf}, w_{bf}, S, D_{50}

DEM-derived channel slope



Channel process groups (Paustian et al. 1992)	Channel reach types (Montgomery and Buffington 1997)
LC, FP, PA	Pool-riffle
MM, MC	Plane-bed
HC(<0.08), AF (<0.08)	Step-pool
HC (>0.08 - 0.35), AF (>0.08)	Cascade
HC (> 0.35)	Colluvial





Channel slope (m*m^{-1})
0.20
0.15
0.10
0.05
0.00
CA
SP
PB
PR
ES
Reach-scale channel morphology

Reach-level channel response potential to changes in sediment supply and discharge (modified from Montgomery and Buffington 1997)

	Width	Depth	Roughness	Scour depth	Grain size	Slope	Sediment storage
Pool riffle	+	+	+	+	+	+	+
Plane bed	p	+	p	+	+	+	p
Step pool	o	p	p	p	p	p	p
Cascade	o	o	p	o	p	o	o

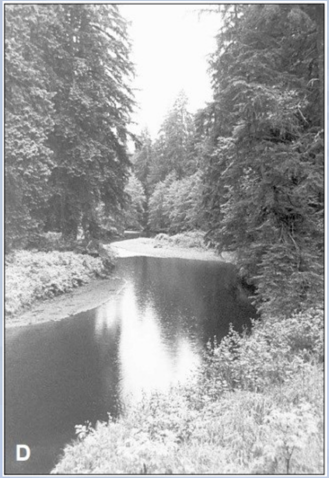
Notes: +—likely, o—unlikely, p—possible.

Cascade

Step-pool

Plane-bed

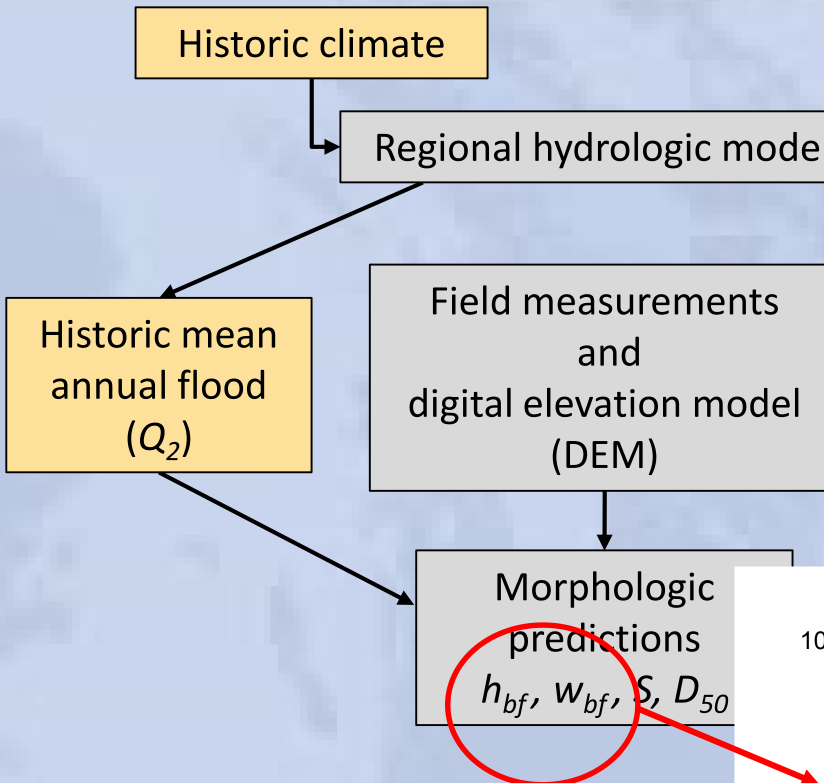
Pool-riffle

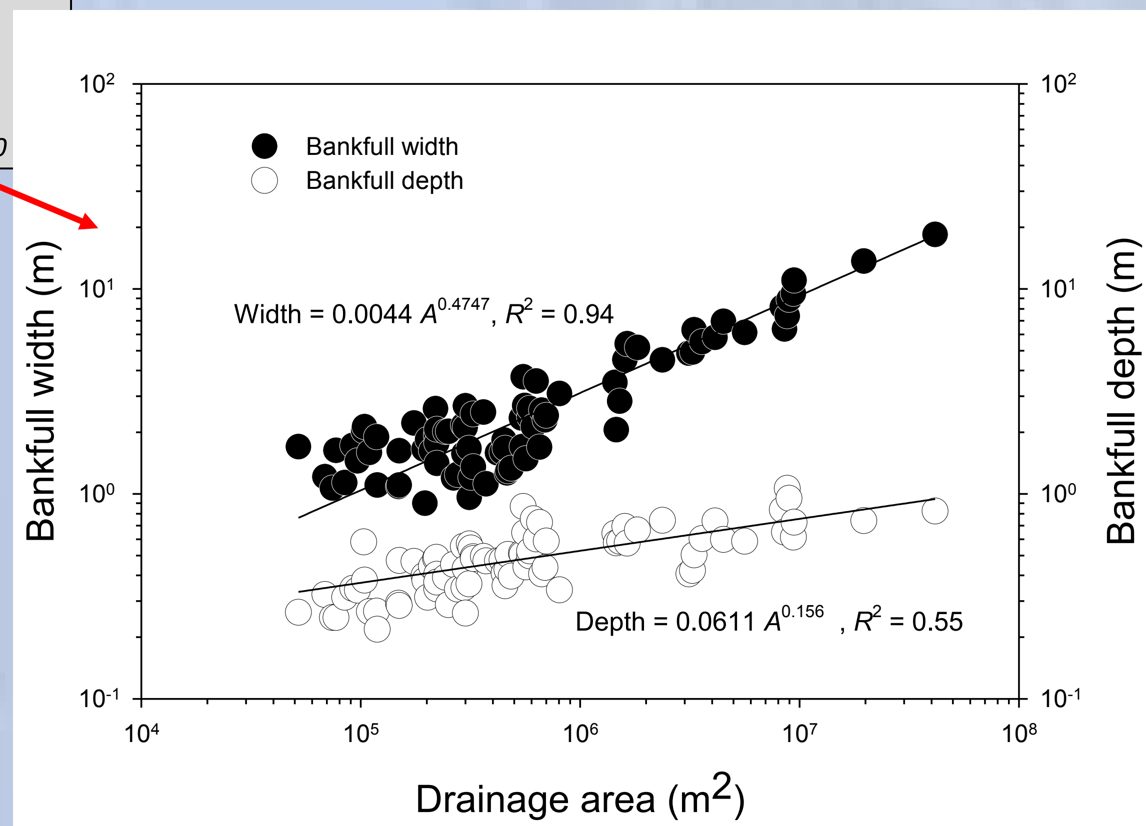


Transport → Response

High → Low

Slope





Zynda, T. (2005). Development of regional hydraulic geometry relationships and stream basin equations for the Tongass National Forest, Southeast Alaska. Unpublished Master's Thesis, Michigan State University, Lansing MI.

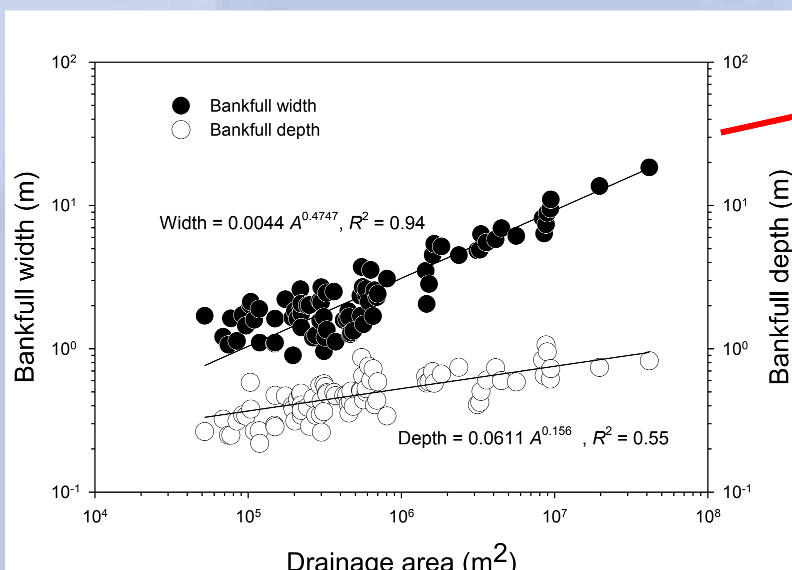
Historic climate

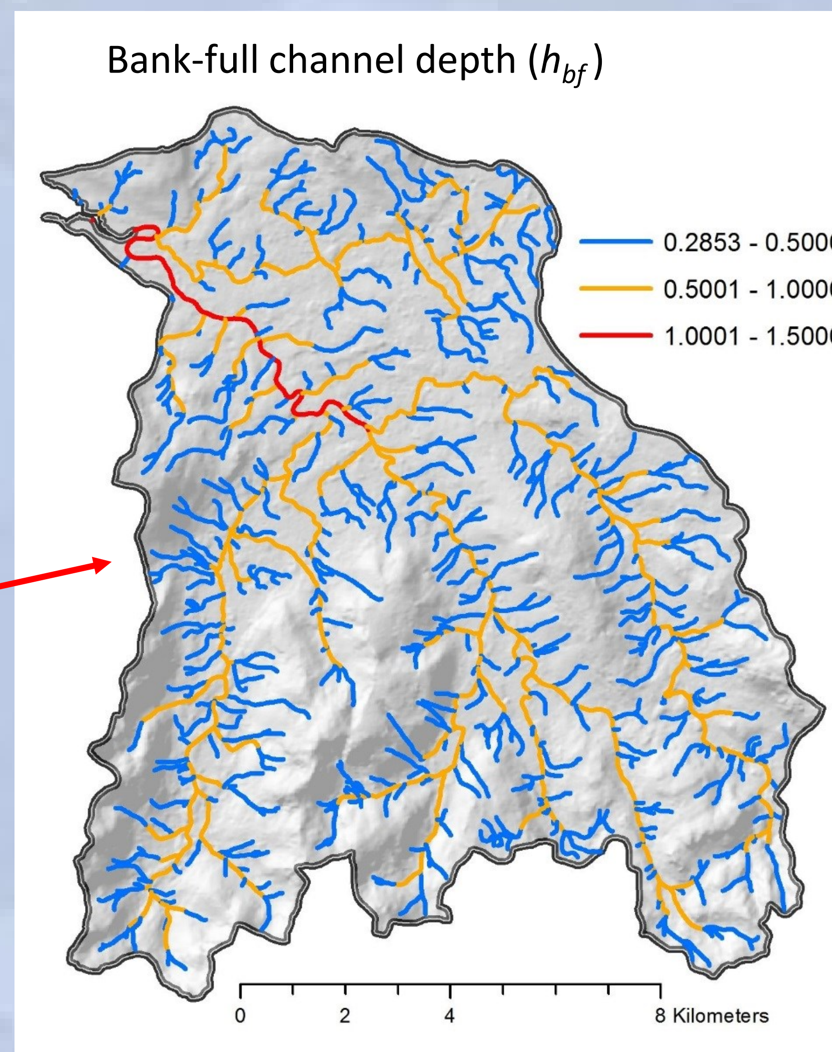
Regional hydrologic model

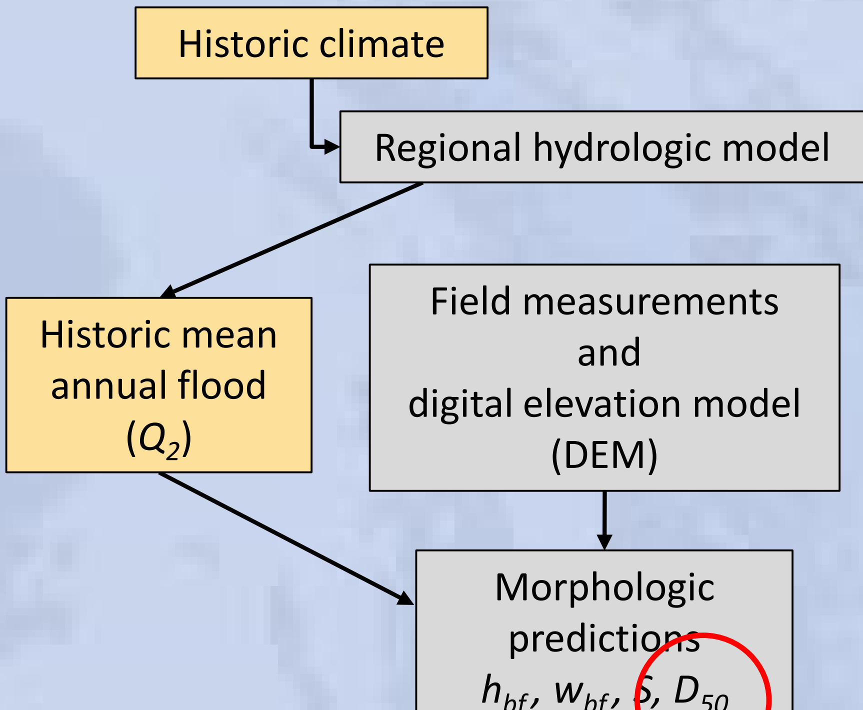
Historic mean annual flood (Q_2)

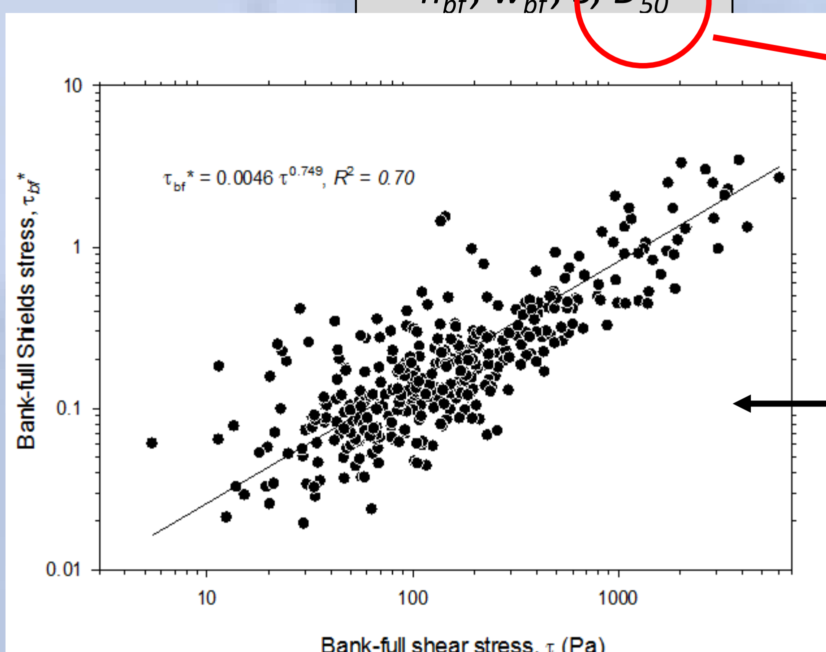
Field measurements and digital elevation model (DEM)

Morphologic predictions h_{bf}, w_{bf}, S, D_{50}









Surface substrate size characterized by median grain size (D_{50}) and predicted by :

$$D_{50} = (\rho h S)^{1-n}/(\rho_s-\rho)kg^n$$

(Buffington et al. 2004)

where k and n are empirical constants relating bank-full Shields stress and total bank-full shear stress in southeast AK streams.

Historic climate

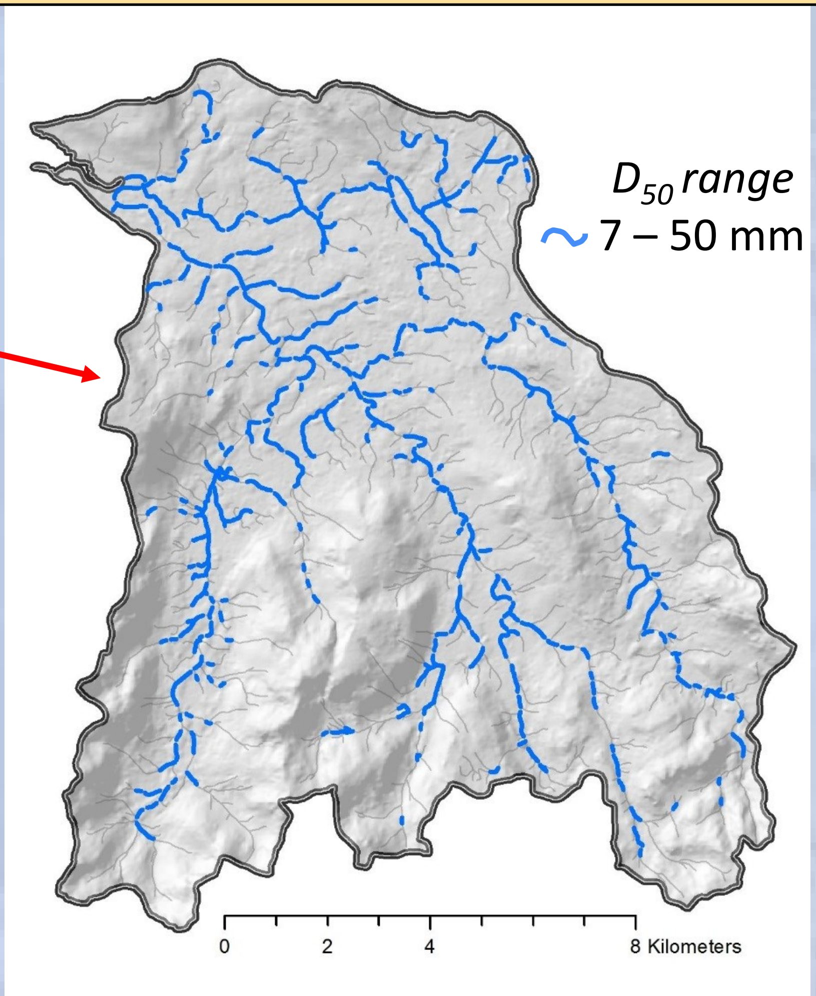
Regional hydrologic model

Historic mean annual flood (Q_2)

Field measurements and digital elevation model (DEM)

Morphologic predictions h_{bf}, w_{bf}, S, D_{50}

Spatially explicit prediction of median gravel size is used to assess the extent of reaches with suitable size gravel for salmon spawning



Historic climate

Regional hydrologic model

Historic mean annual flood (Q_2)

Field measurements and digital elevation model (DEM)

Morphologic predictions h_{bf}, w_{bf}, S, D_{50}

historic morphology

Reach-averaged excess Shields stress (τ^*/τ^*_c)

$$\tau^* = \rho g h S / (\rho_s - \rho) g D_{50}$$

$$\tau^*_c = 0.15\, S^{0.25}$$ (Lamb et al. 2008)

Critical scour probability

$$\text{Pscour}(\geq 30 \text{ cm}) = e^{(-30\,(3.33 e^{(-1.52\, \tau^*/\tau^*c)})}$$

(Haschenburger 1999; Goode et al. 2013)

Historic climate

Regional hydrologic model

Historic mean annual flood (Q_2)

Field measurements and digital elevation model (DEM)

Morphologic predictions
h_{bf}, w_{bf}, S, D_{50}

historic morphology

Reach-averaged excess Shields stress
(τ^*/τ^*_c)

Critical scour probability

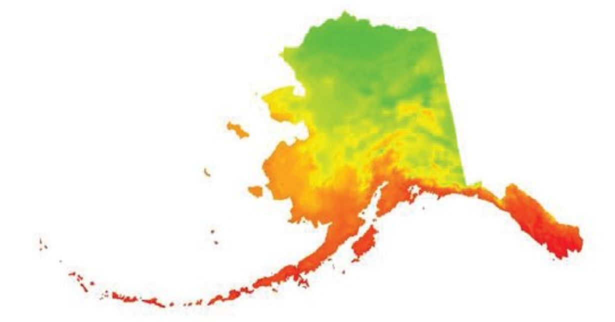
Suitable spawning reaches (D_{50}: 7 – 50 mm; $h_{bf} \geq 0.5$ m; $w_{bf} \geq 2$ m; Probability of scour mortality <0.50)

Historic climate

Future climate models

Regional hydrologic model

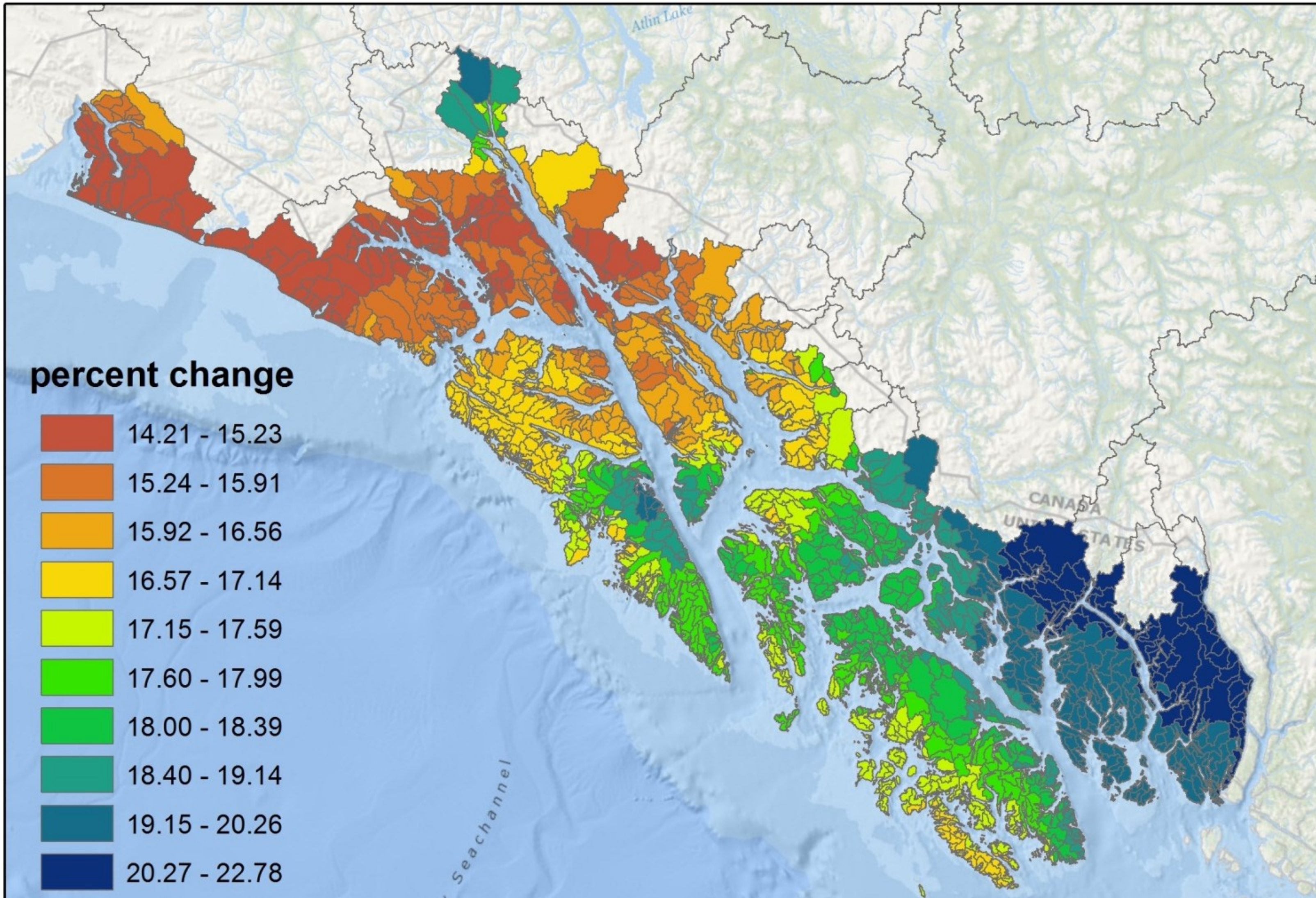
SNAP
Scenarios Network for Alaska Planning



Temperature

Mean Decadal Precipitation

Precipitation change - current to 2080-89



Future climate models

Regional hydrologic model

Future mean annual flood (Q_2)

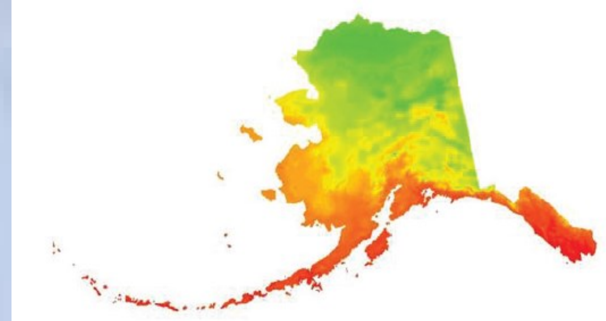
- Future conditions were considered at 2 time-steps:

  2040 – 2049

  2080 – 2089

SNAP

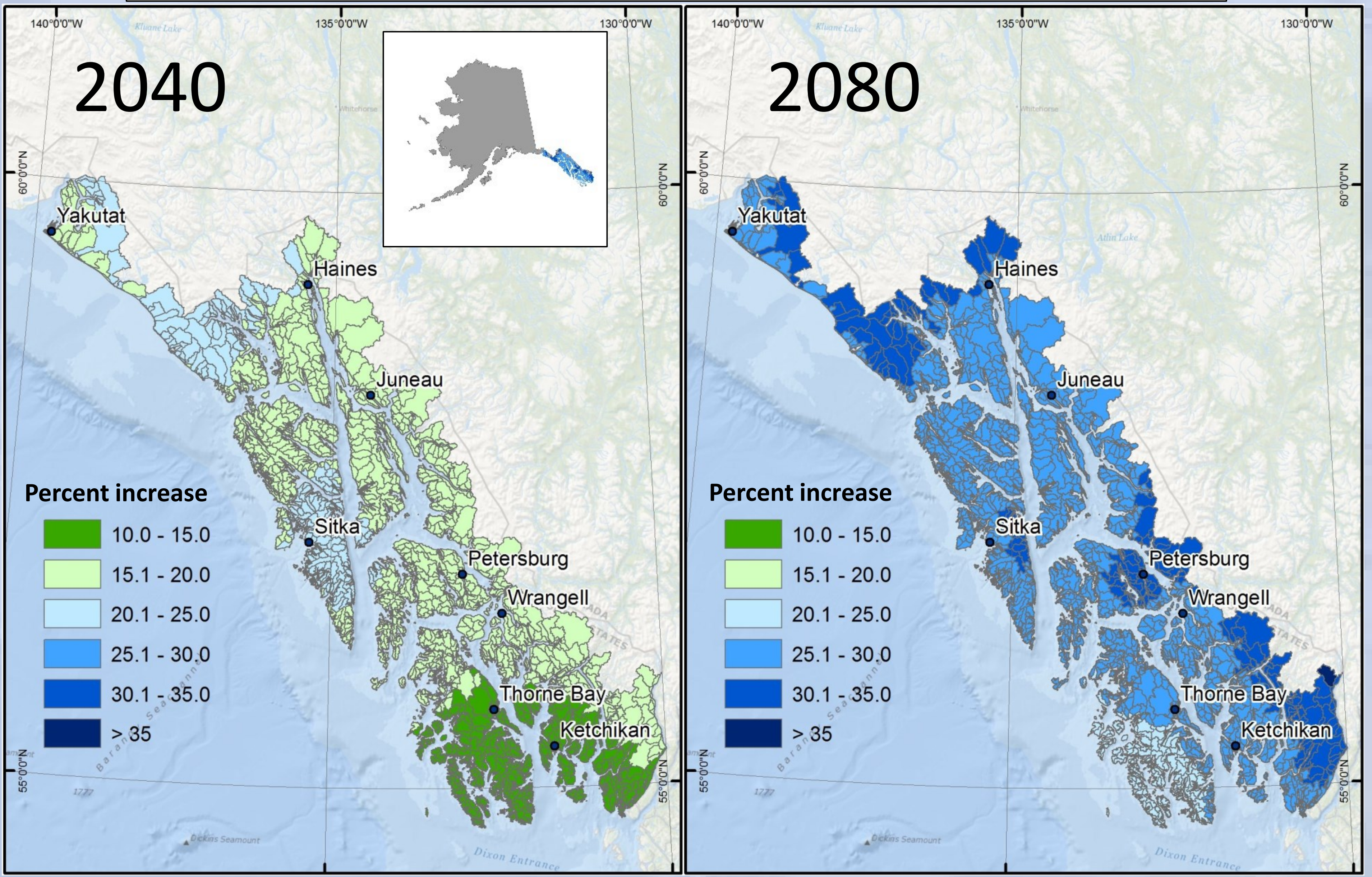
Scenarios Network for Alaska Planning



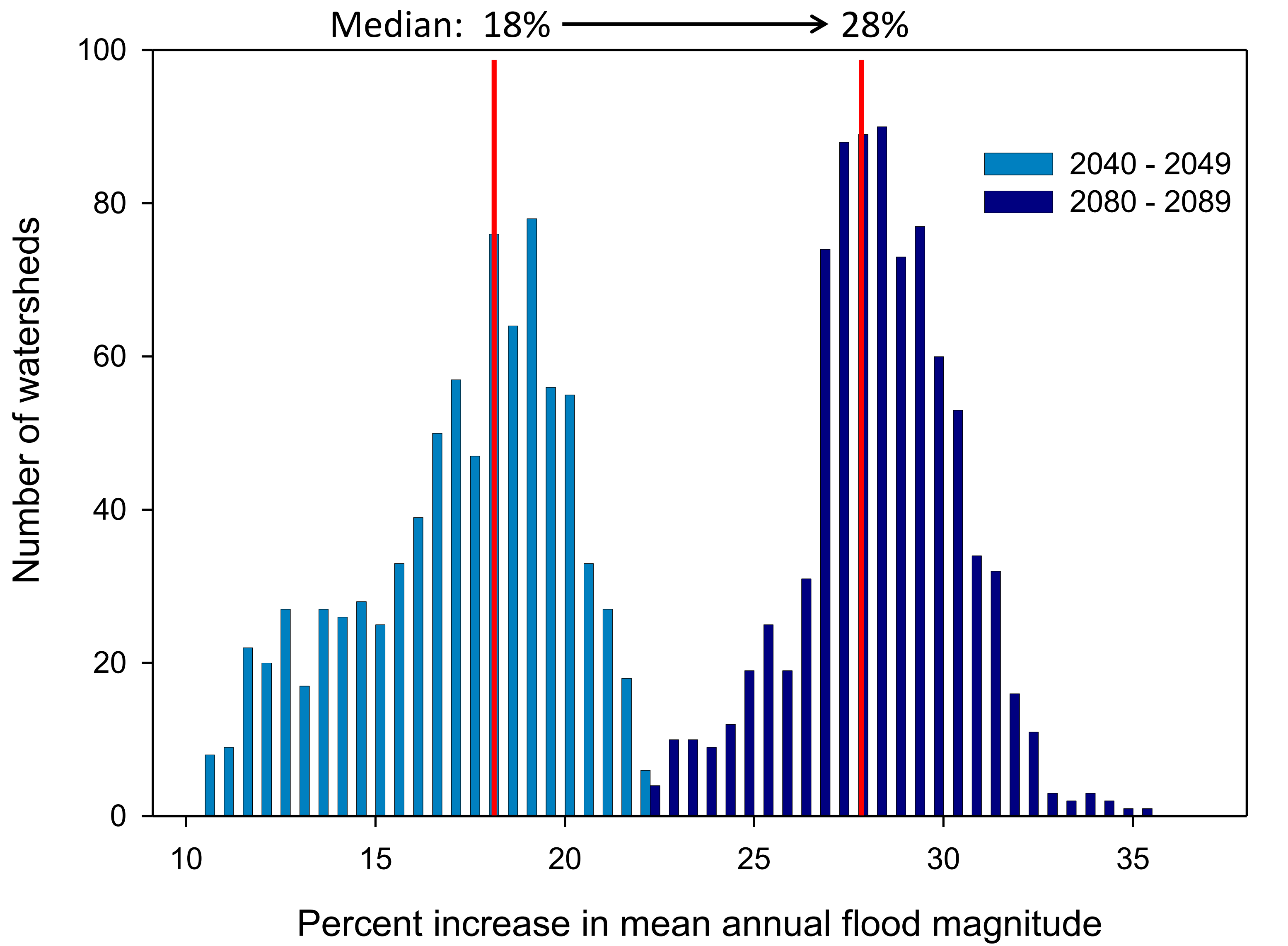
Temperature

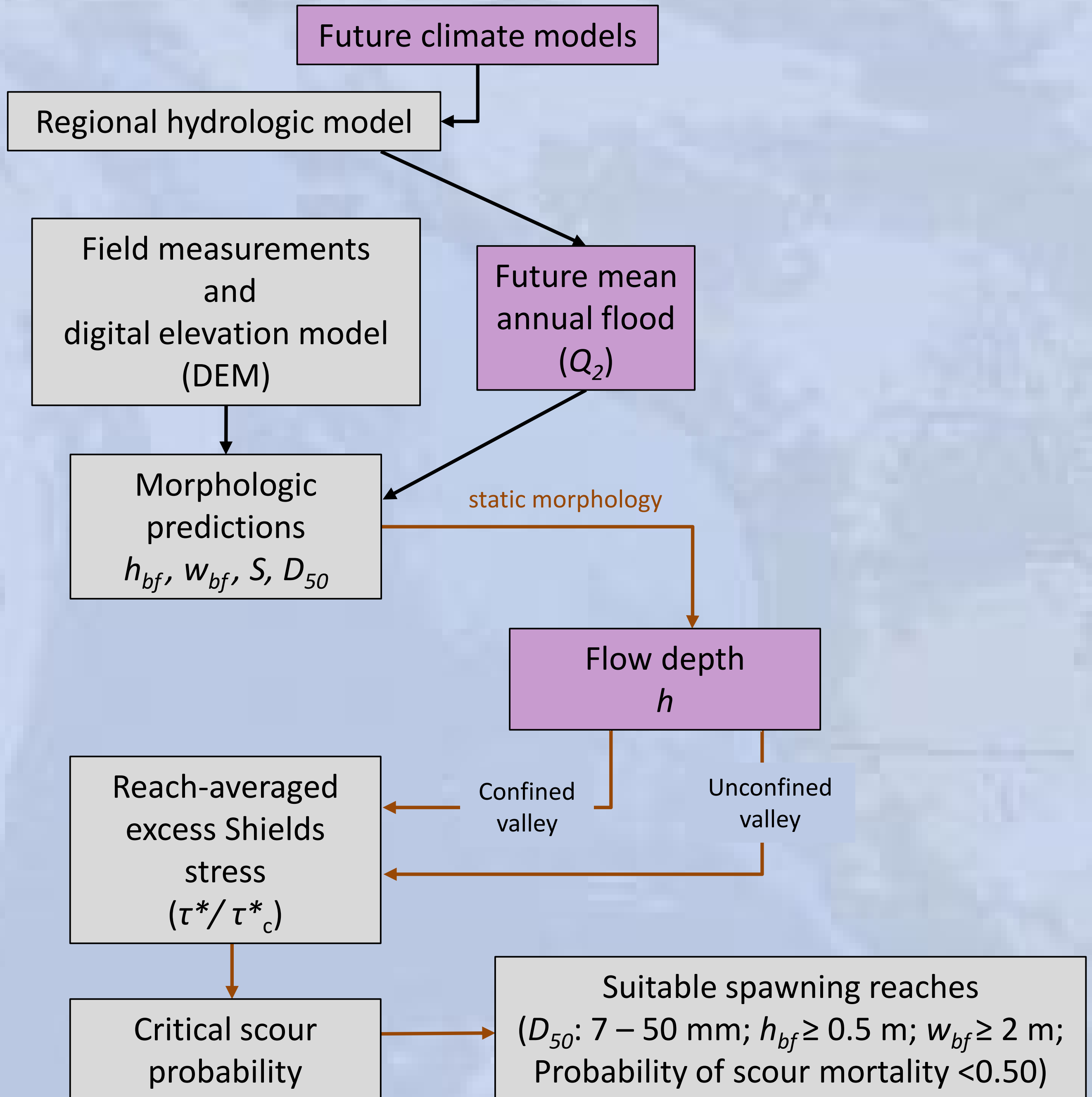
Mean Decadal Precipitation

A warmer, wetter future for SE AK will produce larger mean annual floods (Q_2)



A warmer, wetter future for SE AK will produce larger mean annual floods

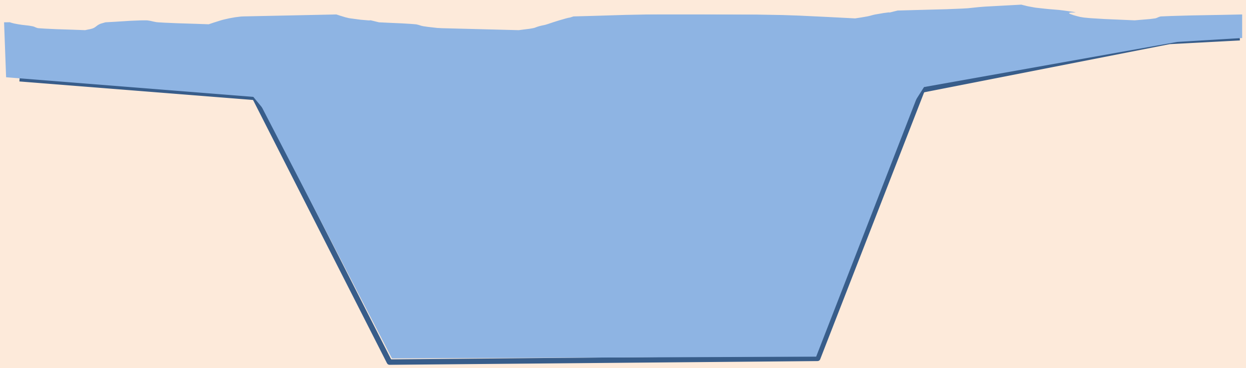


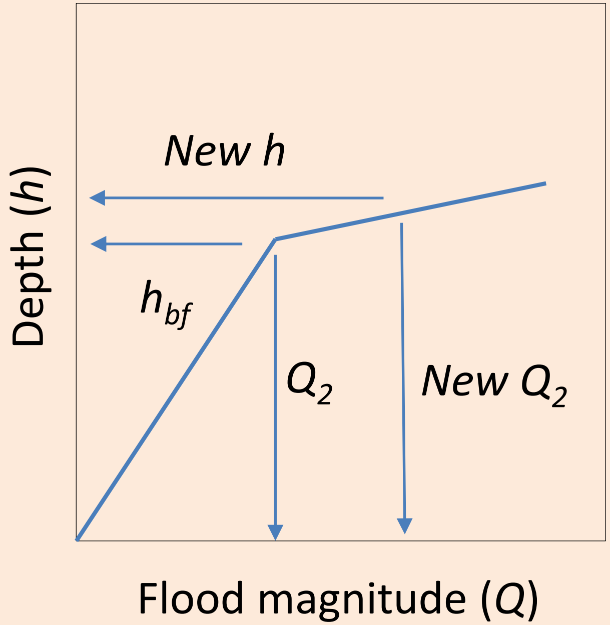

Future climate models
Regional hydrologic model
Field measurements and digital elevation model (DEM)
Future mean annual flood (Q_2)
Morphologic predictions
h_{bf}, w_{bf}, S, D_{50}
static morphology
Flow depth
h
Confined valley
Unconfined valley
Reach-averaged excess Shields stress
(τ^*/τ^*_c)
Critical scour probability
Suitable spawning reaches
(D_{50}: 7 – 50 mm; $h_{bf} \geq 0.5$ m; $w_{bf} \geq 2$ m;
Probability of scour mortality <0.50)

Static channel morphology
Unconfined channels

$$h_{new} \approx h_{bf}$$

(McKean and Tonina 2013)

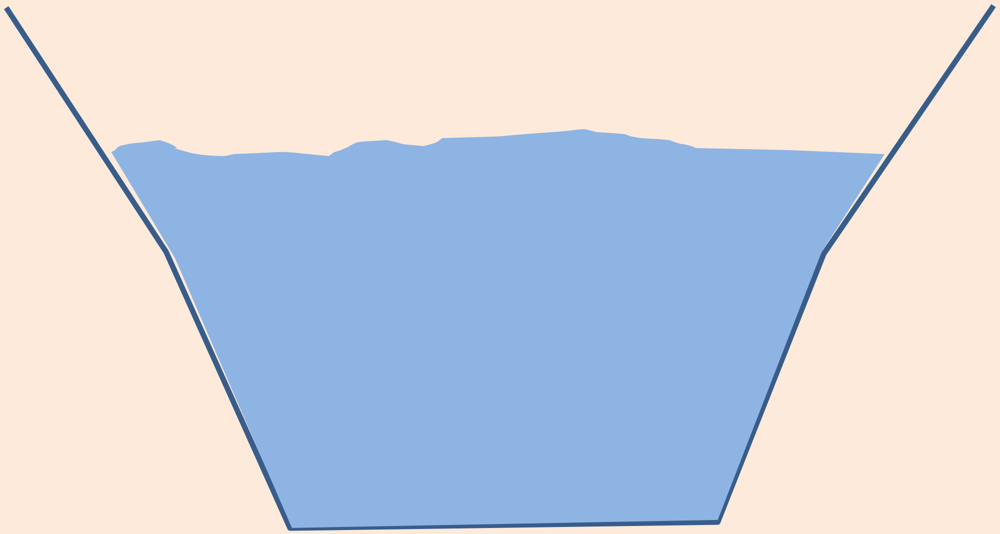


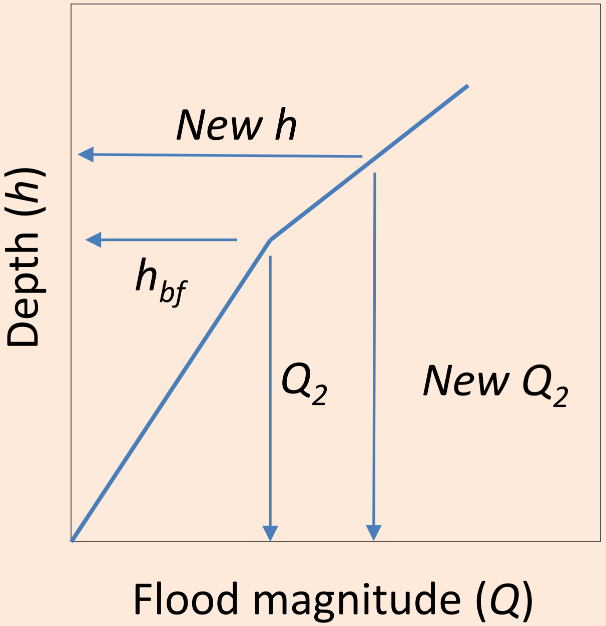


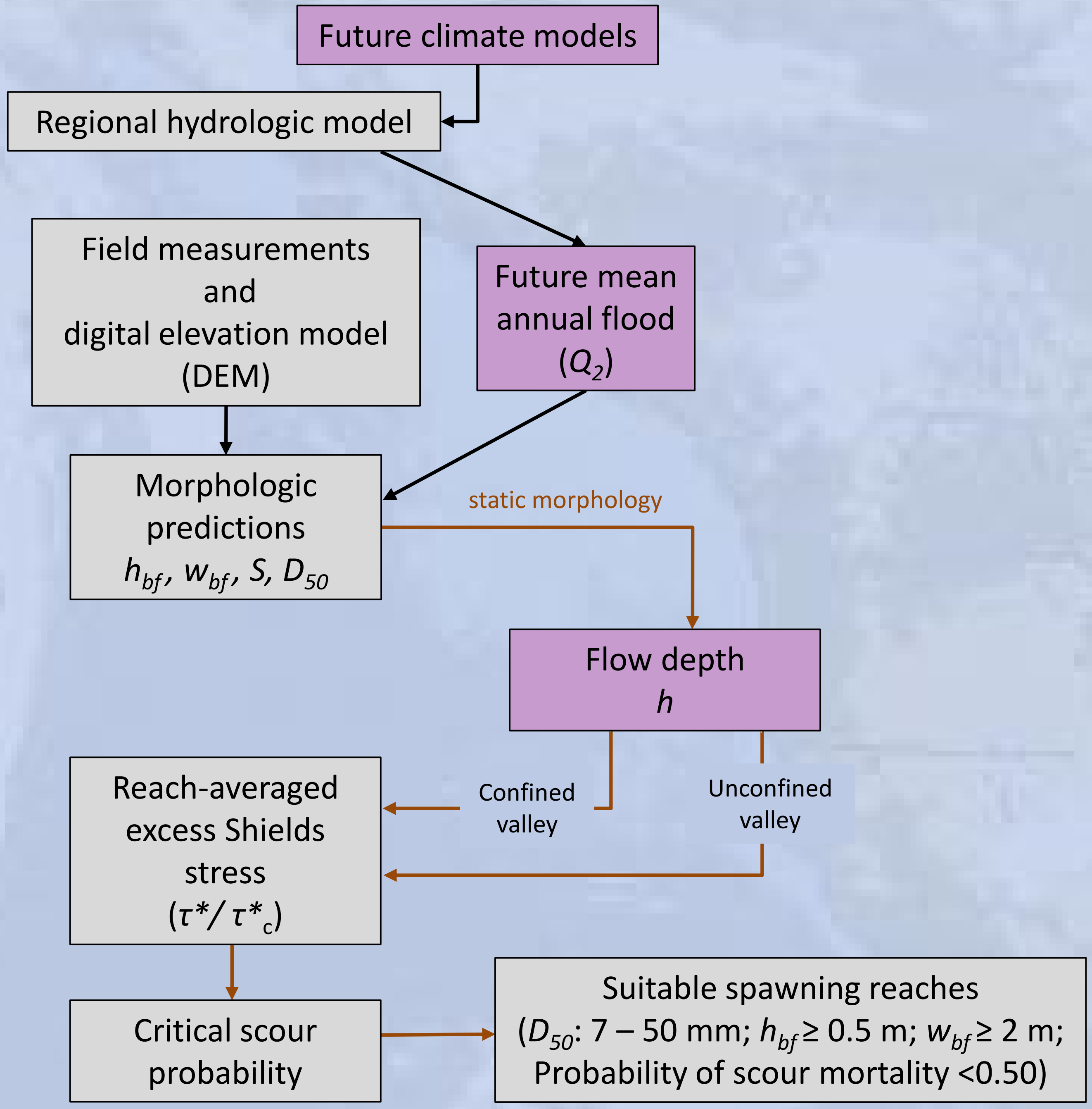
Static channel morphology
Confined channels

$$Q_{bf} = 3.732 * w_{bf} * h_{new} * \sqrt{(g * h_{new} * S)} * (h_{new}/D_{50})^{0.2645}$$

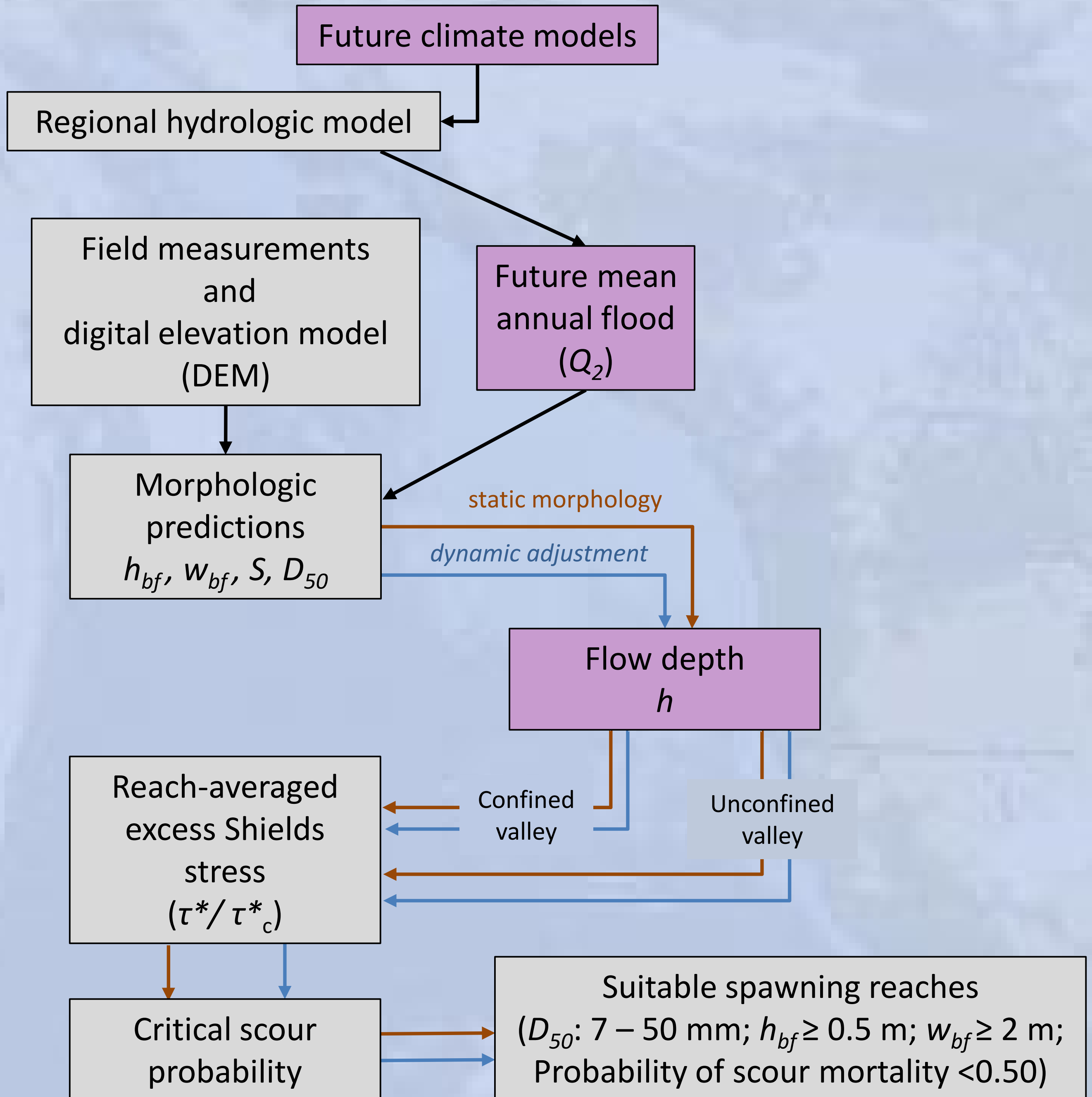
(Parker et al. 2007)







Future climate models
Regional hydrologic model
Field measurements and digital elevation model (DEM)
Future mean annual flood (Q_2)
Morphologic predictions h_{bf}, w_{bf}, S, D_{50}
static morphology
Flow depth h
Confined valley
Unconfined valley
Reach-averaged excess Shields stress (τ^*/τ^*_c)
Critical scour probability
Suitable spawning reaches (D_{50}: 7 – 50 mm; $h_{bf} \geq 0.5$ m; $w_{bf} \geq 2$ m; Probability of scour mortality <0.50)



Future climate models
Regional hydrologic model
Field measurements and digital elevation model (DEM)
Future mean annual flood (Q_2)
Morphologic predictions
h_{bf}, w_{bf}, S, D_{50}
static morphology
dynamic adjustment
Flow depth
h
Confined valley
Unconfined valley
Reach-averaged excess Shields stress
(τ^*/τ^*_c)
Critical scour probability
Suitable spawning reaches
(D_{50}: 7 – 50 mm; $h_{bf} \geq$ 0.5 m; $w_{bf} \geq$ 2 m;
Probability of scour mortality <0.50)

Mutual adjustment of stream channel parameters to changing discharge

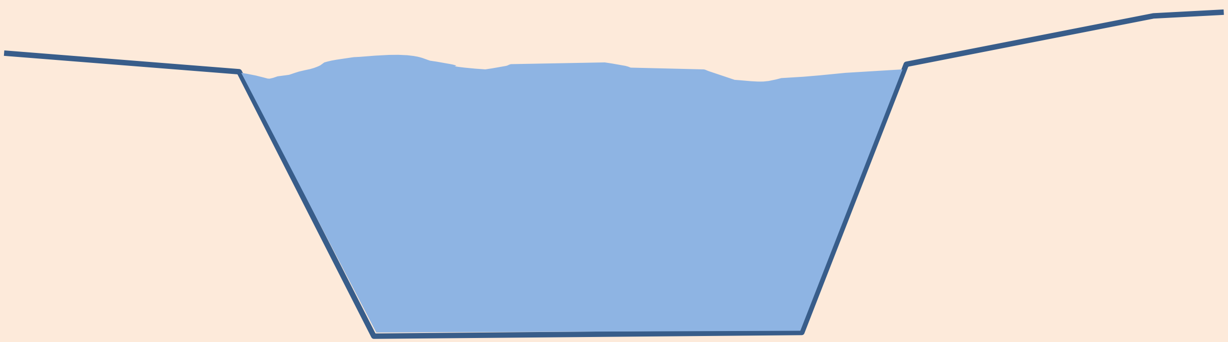
• ***Slope does not change*.** Readjusting river valley slope involves moving large amounts of sediment over long reaches, and typically requires long geomorphic time (thousands of years or more).

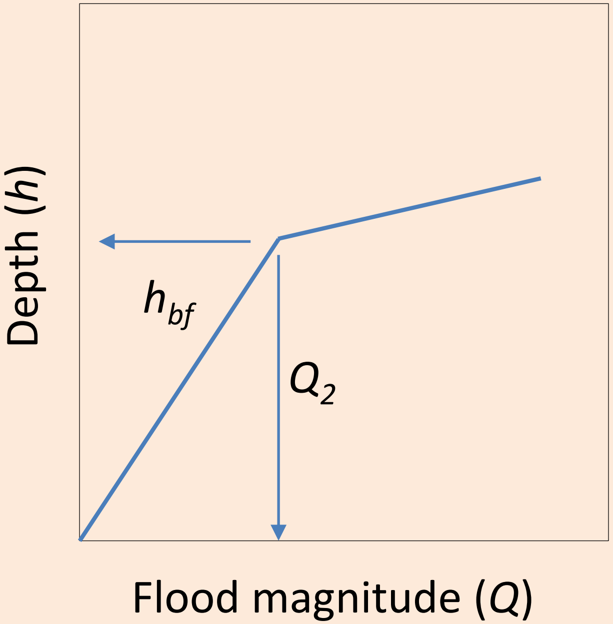
• ***Bank-full width and depth change.*** Rivers can readjust their bank-full depths and widths over relatively short geomorphic time (decades to centuries).

• ***D_{50} changes*.** Rivers can readjust surface grain size over short geomorphic time (years to decades).

Gary Parker 2007

Dynamic channel morphology
Unconfined channels

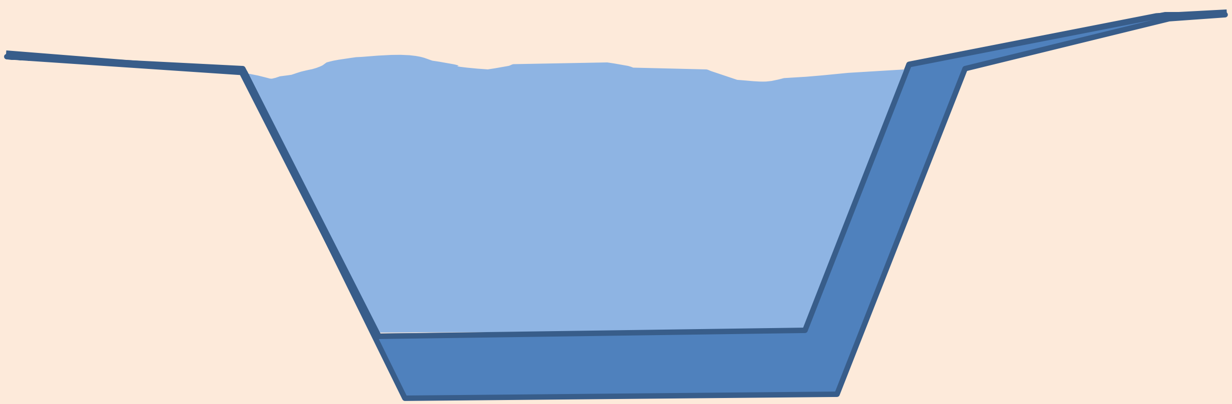


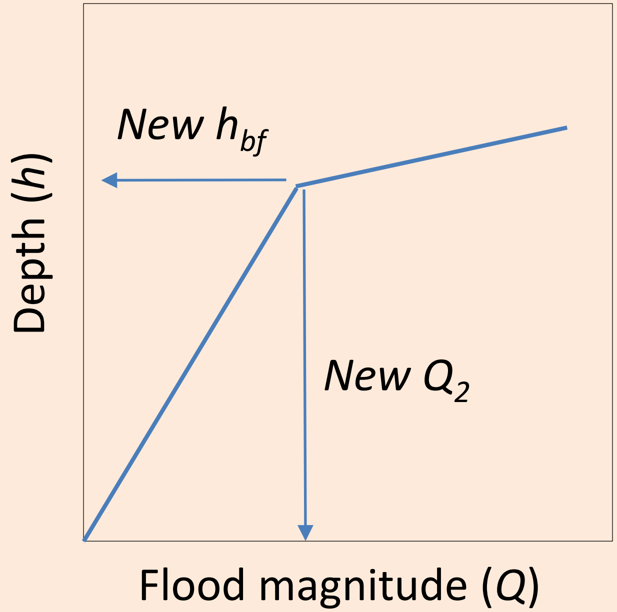


Dynamic channel morphology
Unconfined channels

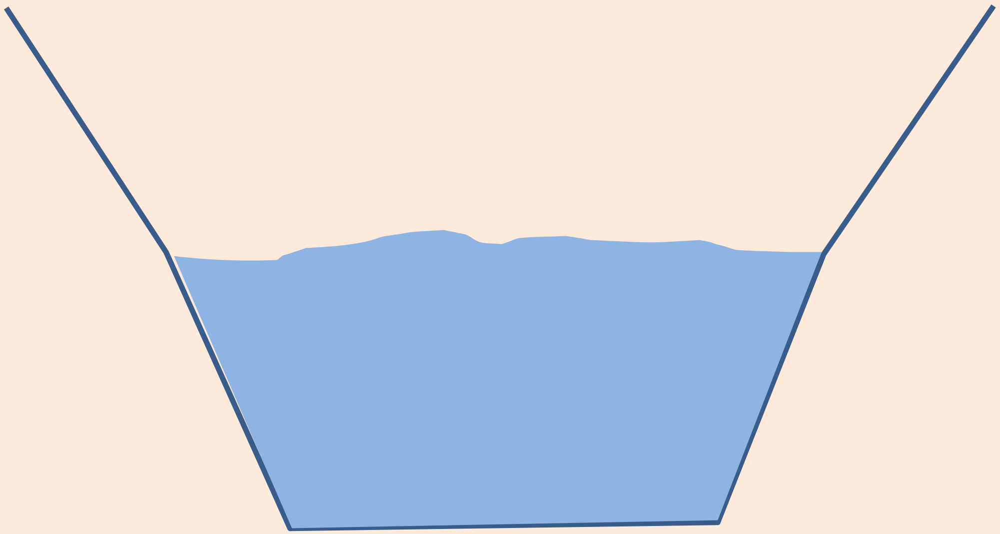
$$h_{new} = Q_{bf}^{2/5}/g^{1/5}$$

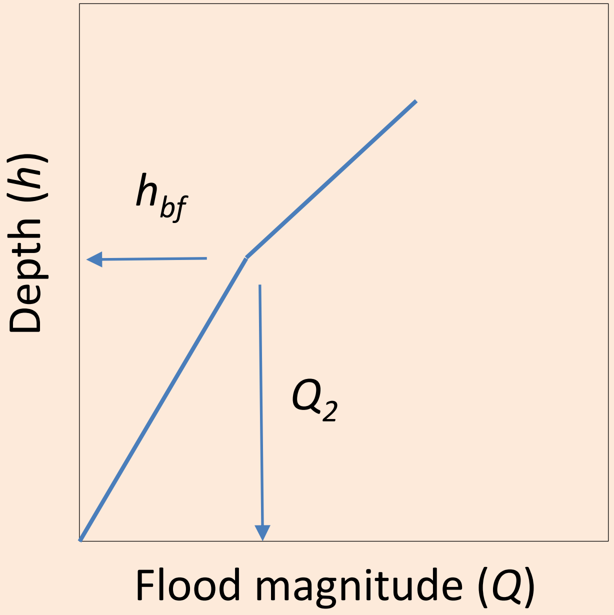
(Parker et al. 2007)





Dynamic channel morphology
Confined channels

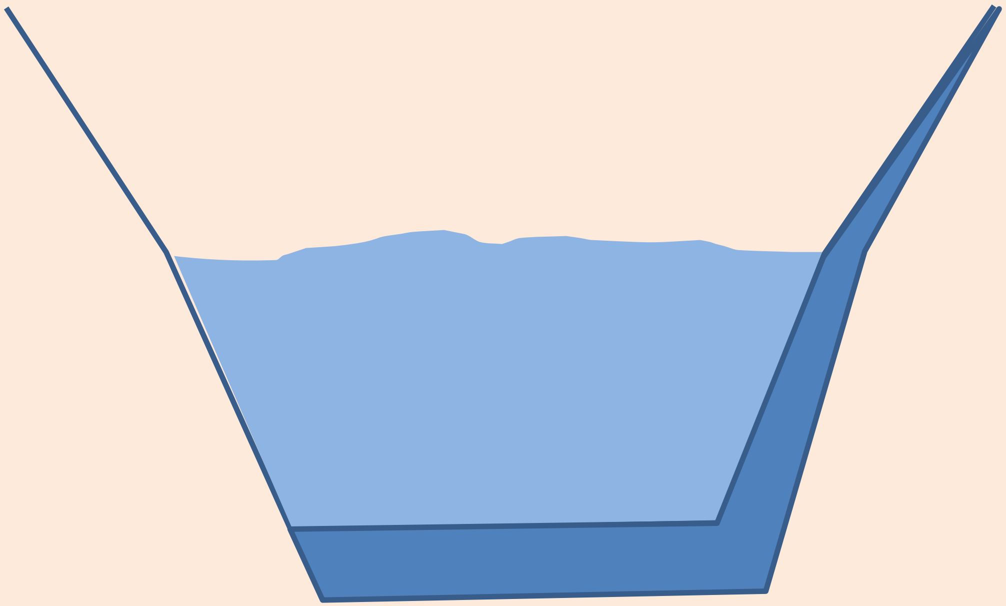


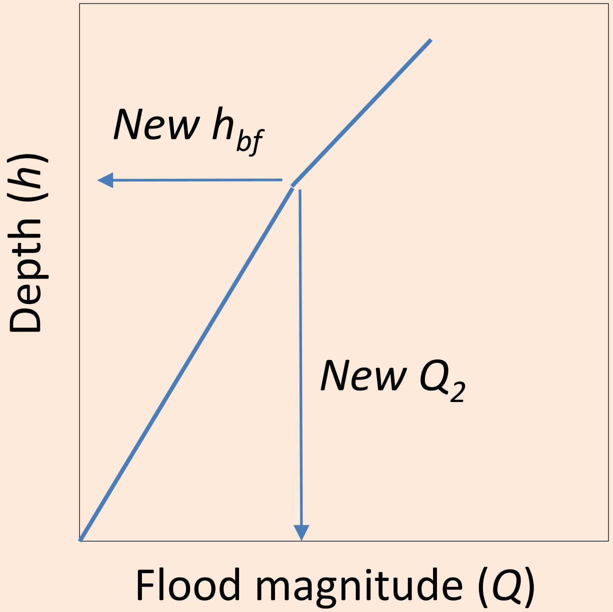


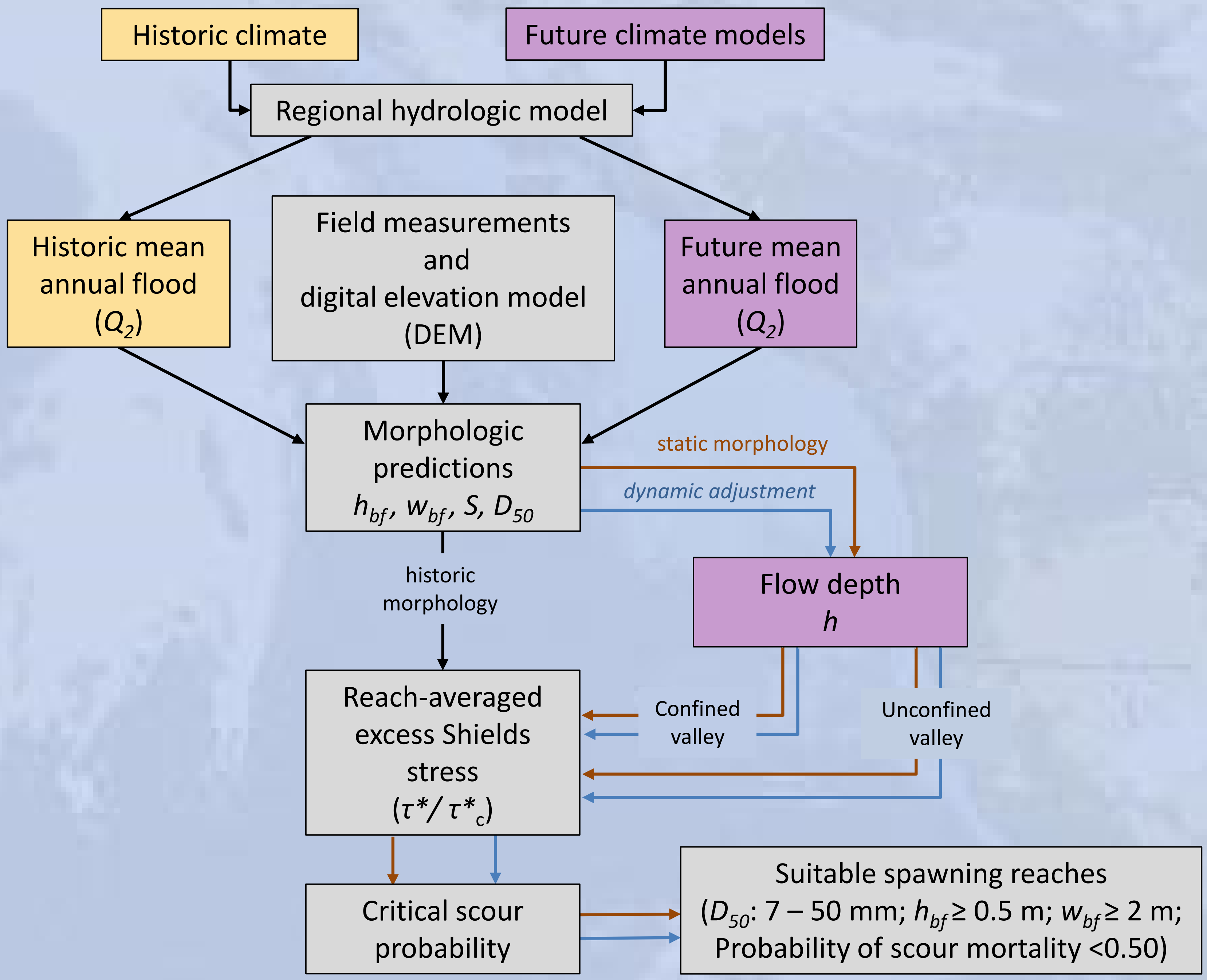
Dynamic channel morphology
Confined channels

$$h_{new} = Q_{bf}^{2/5}/g^{1/5}$$

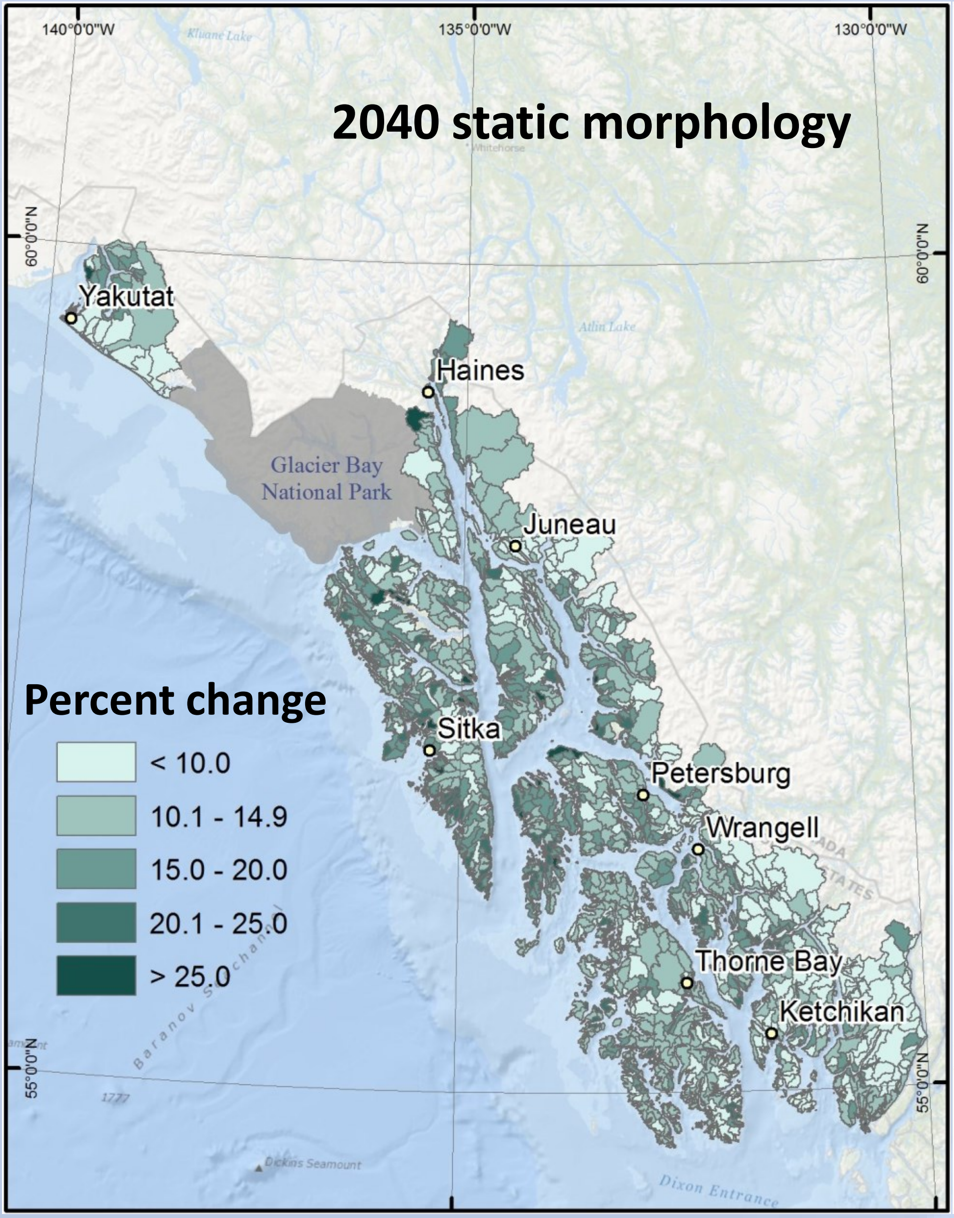
(Parker et al. 2007)

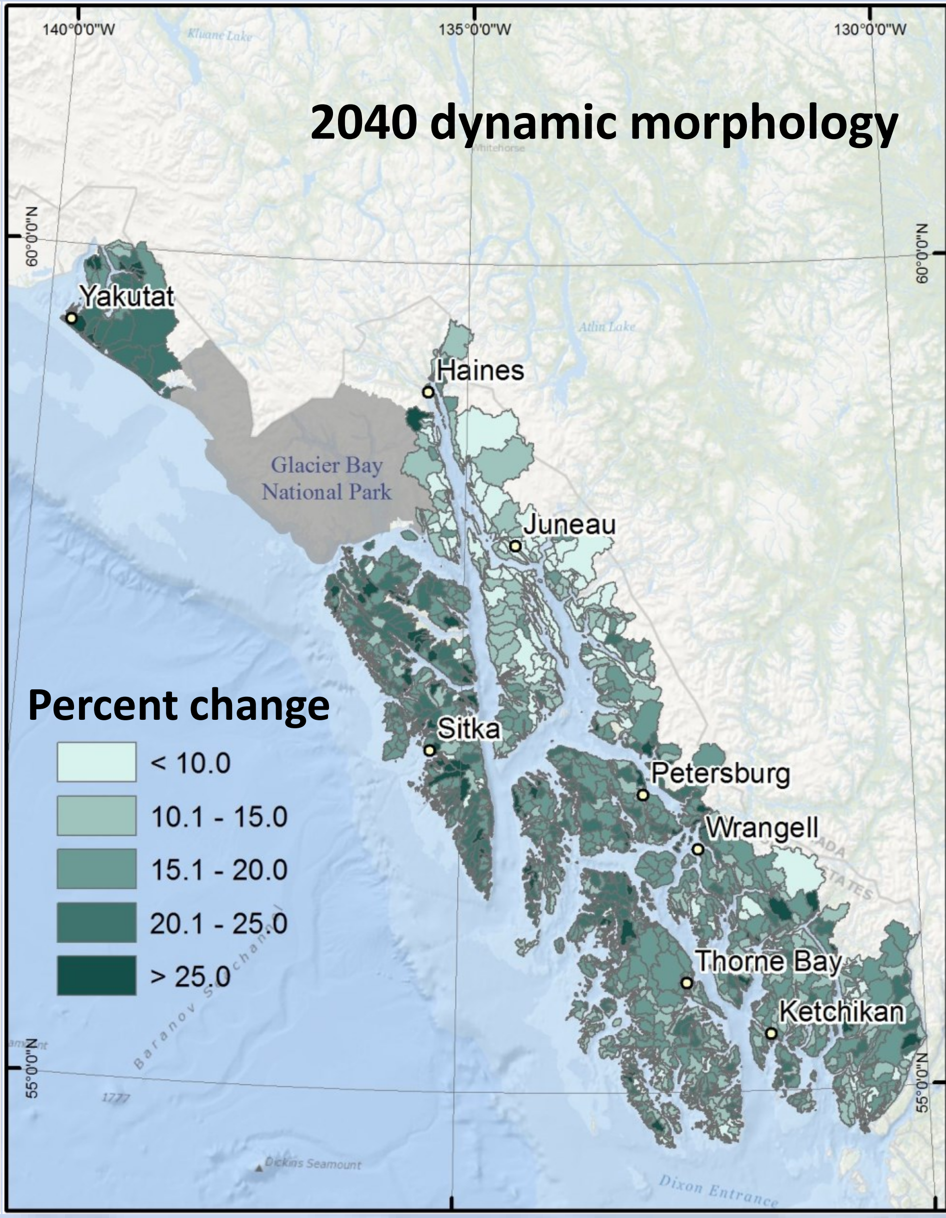




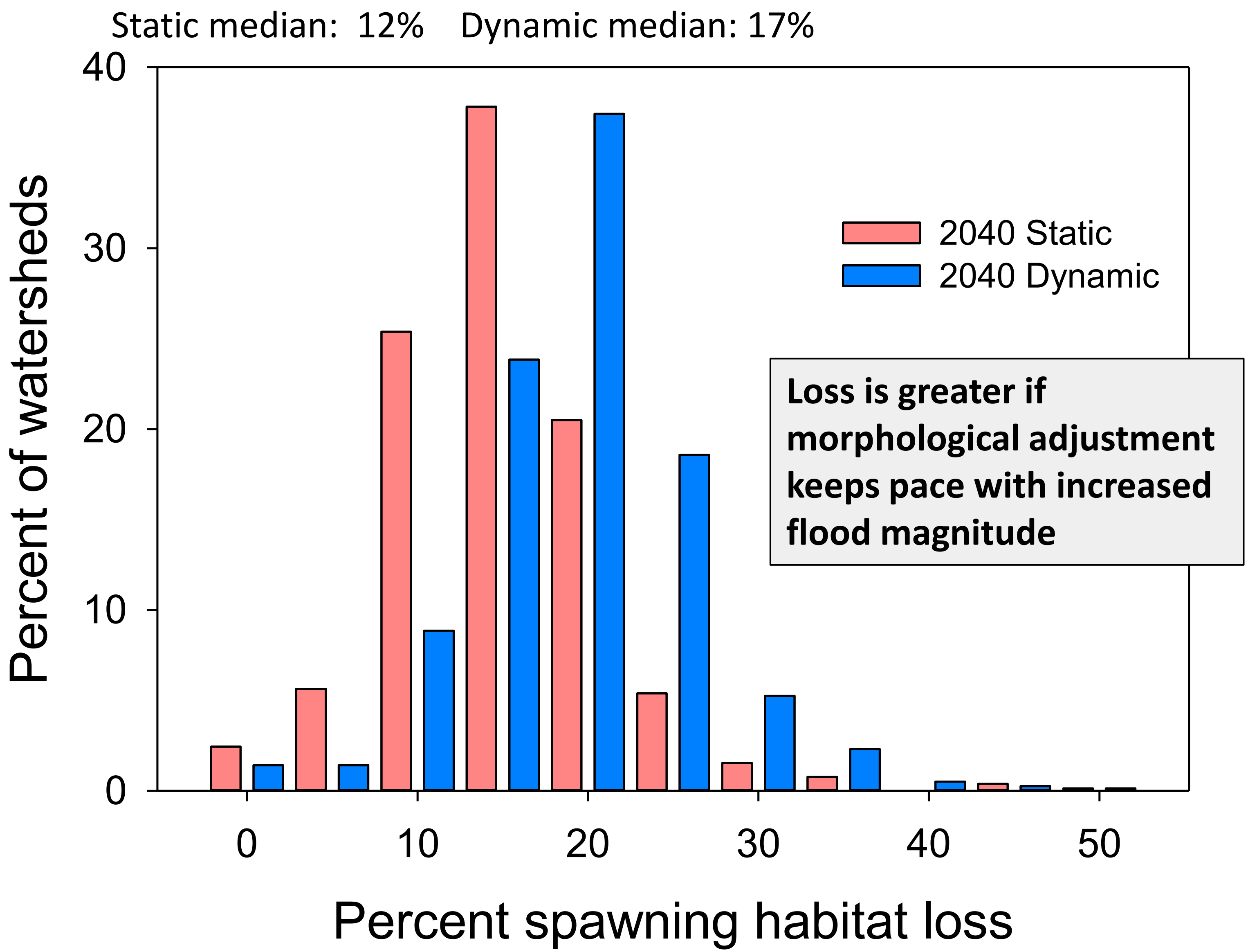

Historic climate
Future climate models
Regional hydrologic model
Historic mean annual flood (Q_2)
Field measurements and digital elevation model (DEM)
Future mean annual flood (Q_2)
Morphologic predictions h_{bf}, w_{bf}, S, D_{50}
static morphology
dynamic adjustment
historic morphology
Flow depth h
Confined valley
Unconfined valley
Reach-averaged excess Shields stress (τ^*/τ^*_c)
Critical scour probability
Suitable spawning reaches (D_{50}: 7 – 50 mm; $h_{bf} \geq 0.5$ m; $w_{bf} \geq 2$ m; Probability of scour mortality <0.50)

Spawning habitat response to increased flood magnitude: 2040

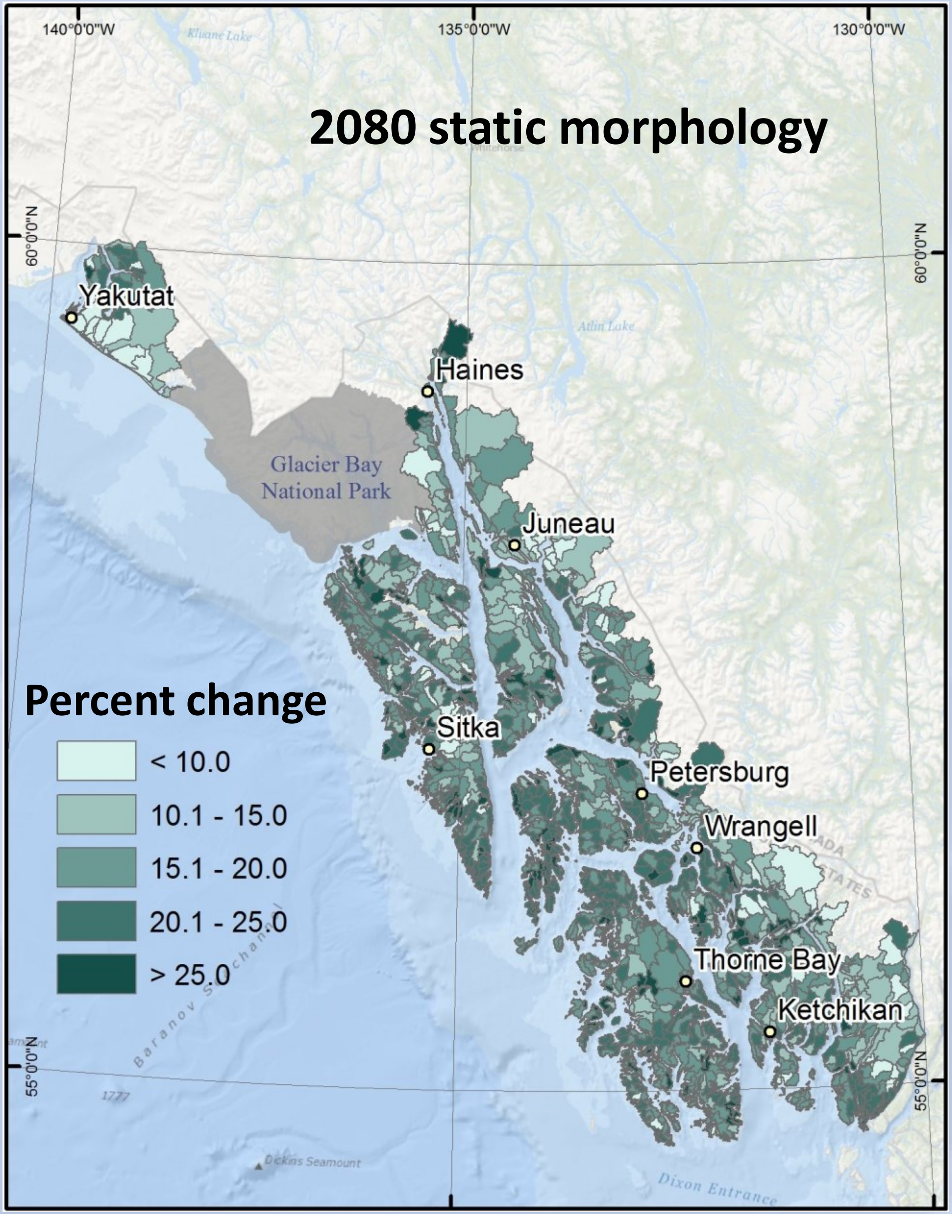


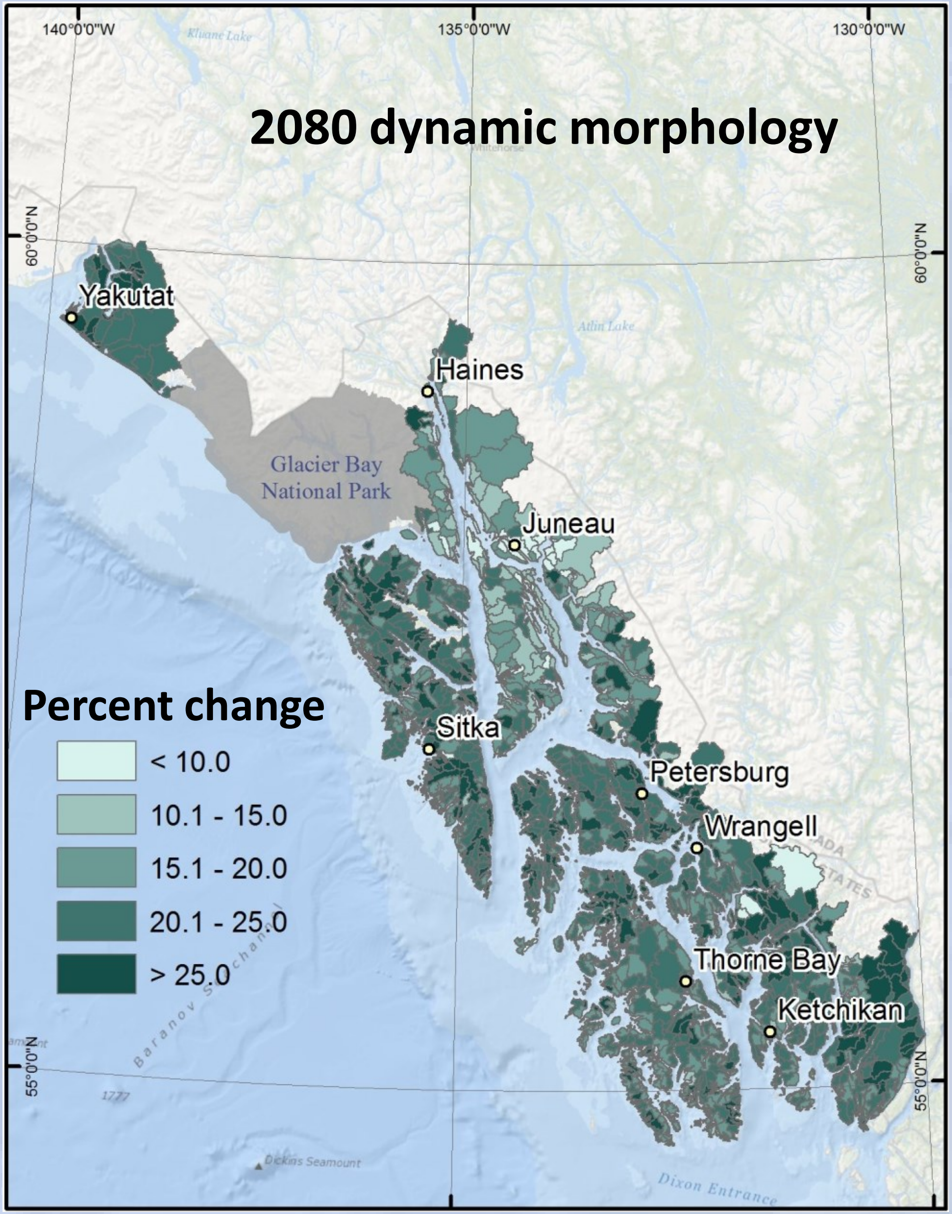


Spawning habitat response to increased flood magnitude: 2040

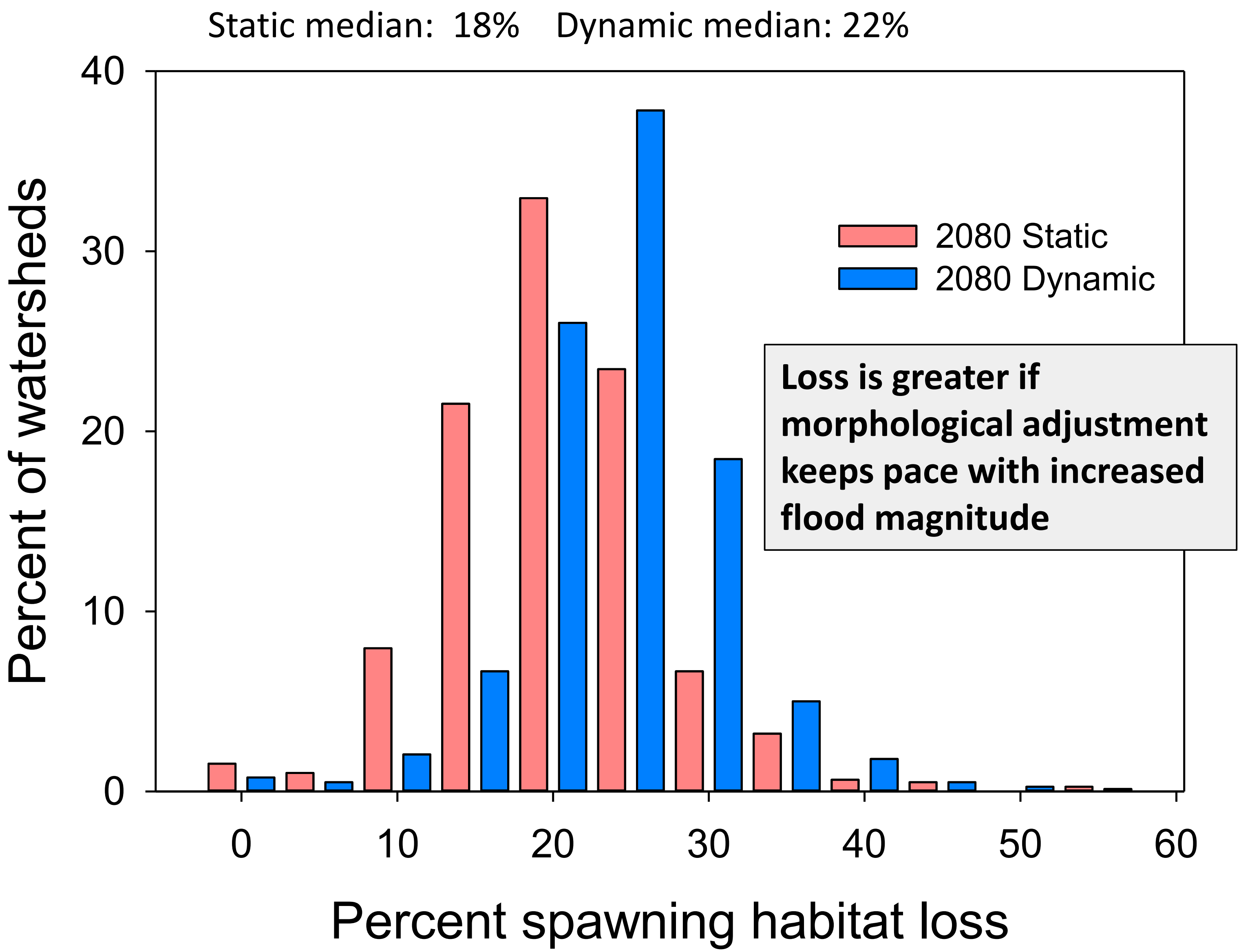


Spawning habitat response to increased flood magnitude: 2080

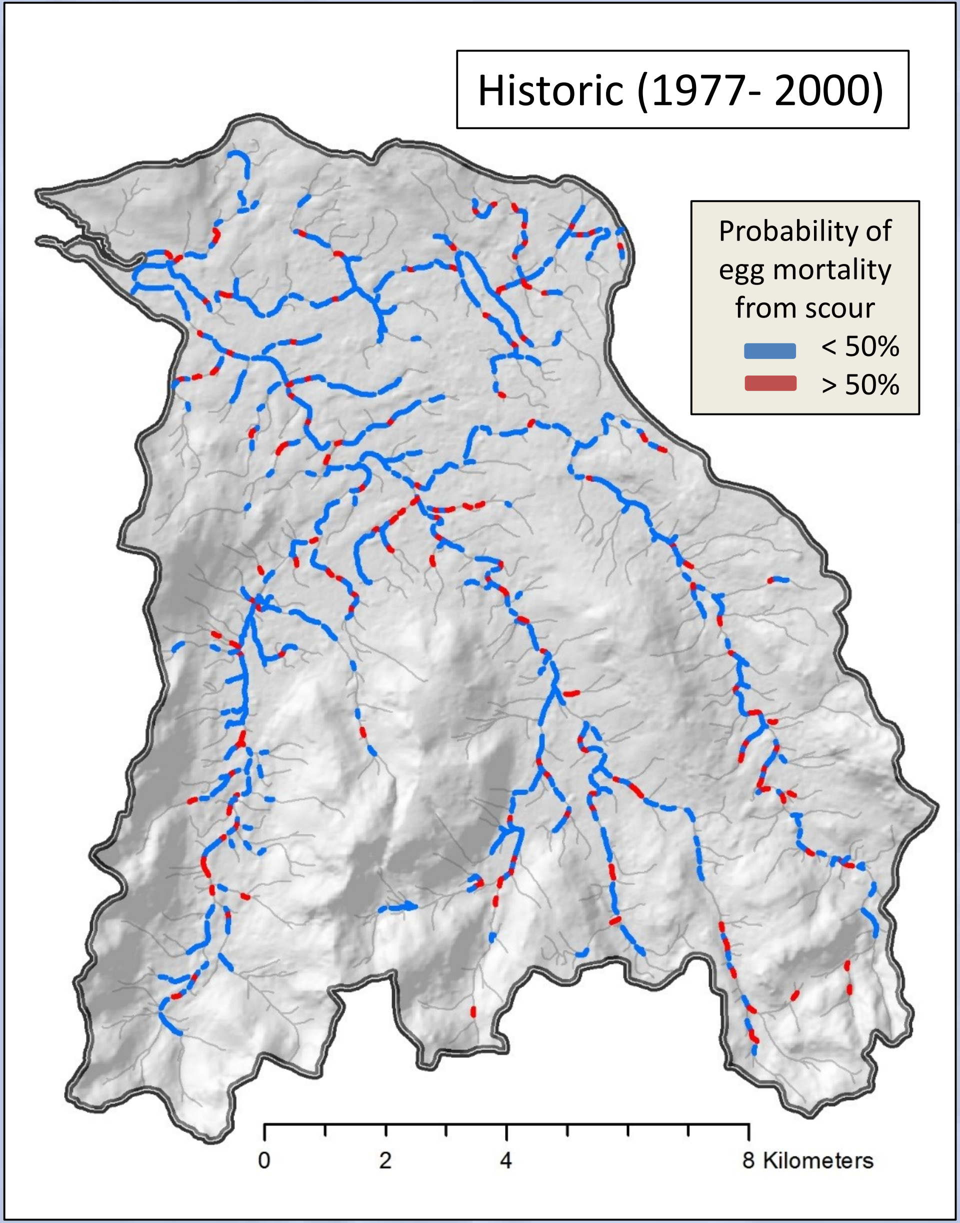




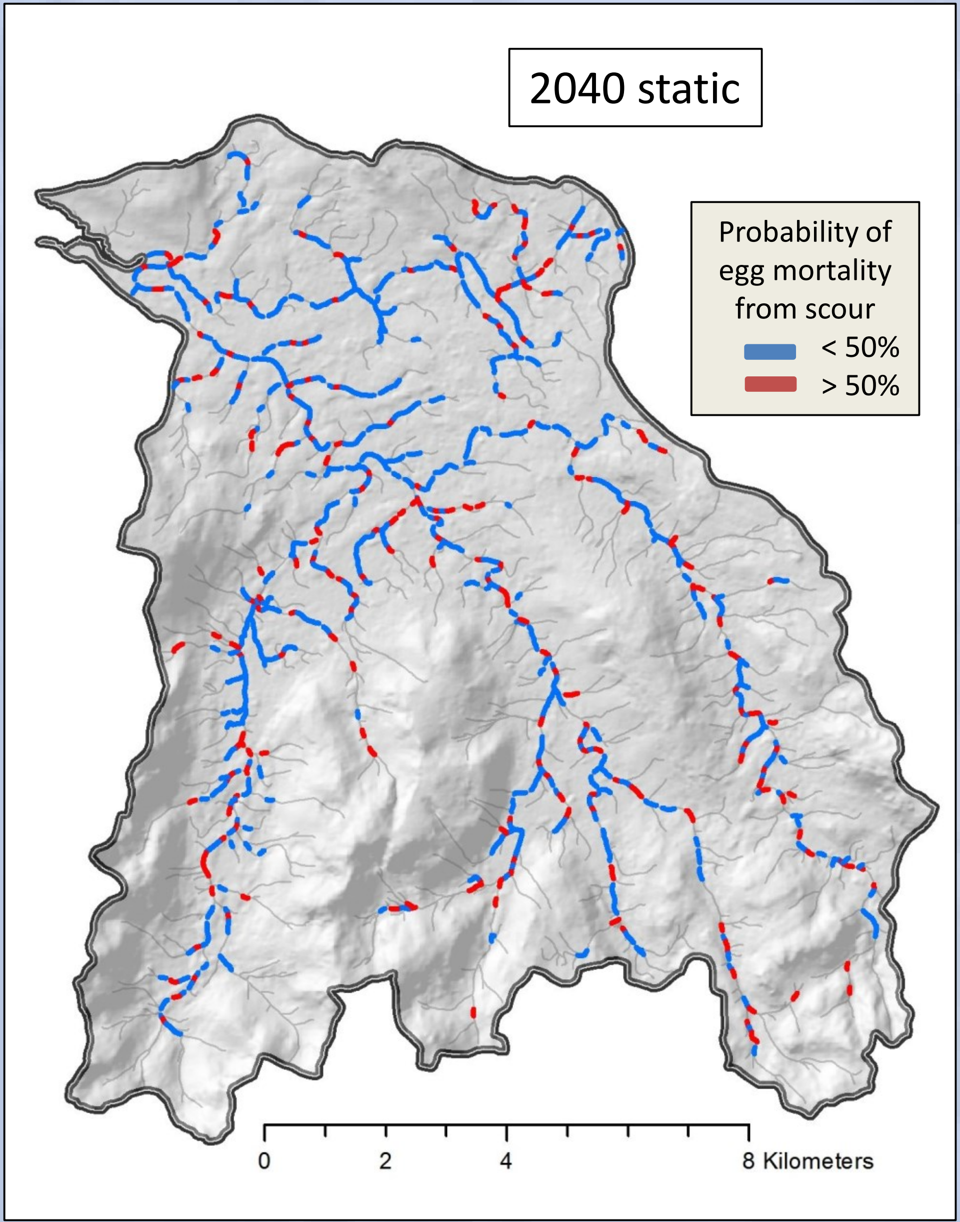
A warmer, wetter future for SE AK will produce larger mean annual floods



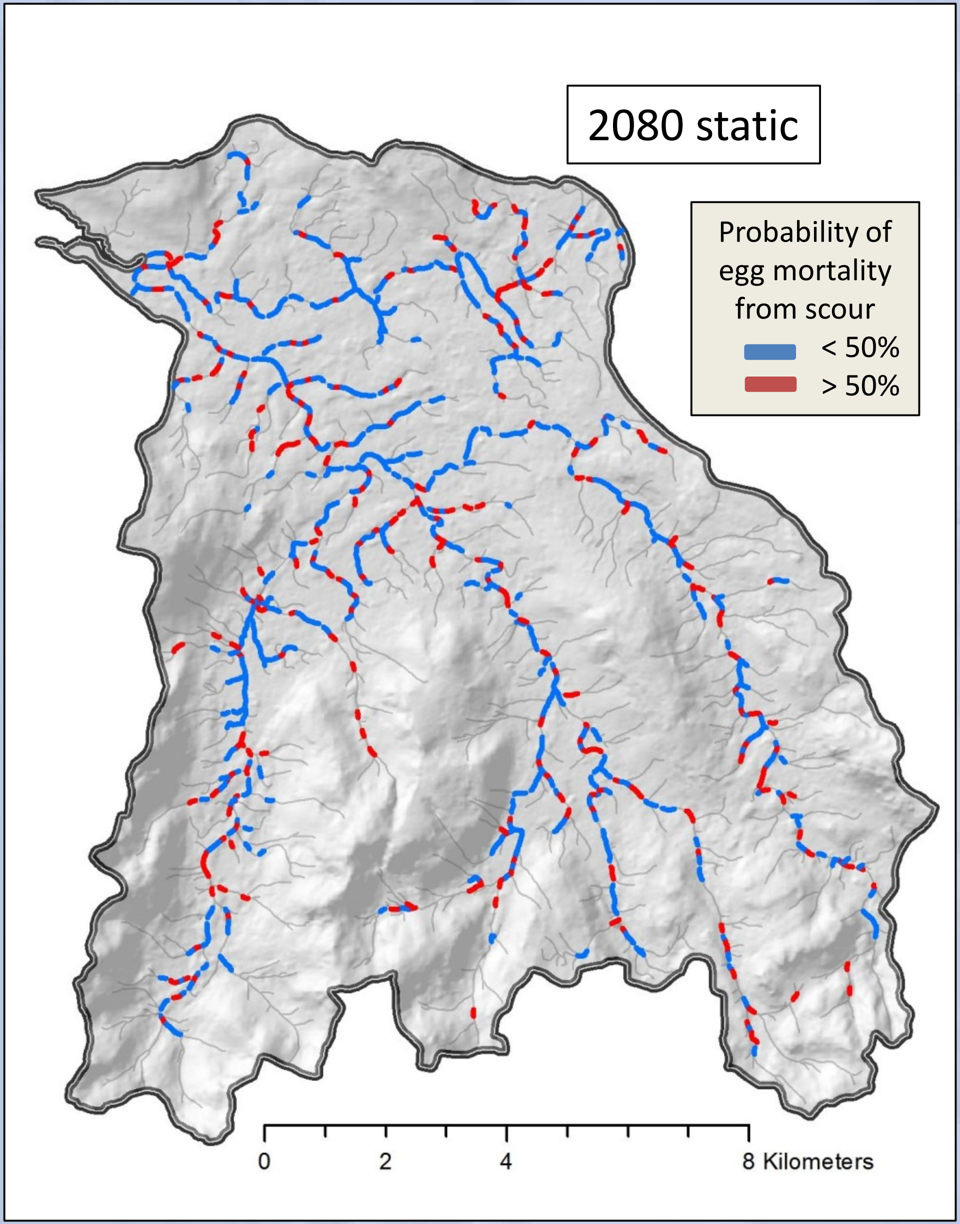
D_{50}: 78 km
Scour > .50: 19 km
59 km



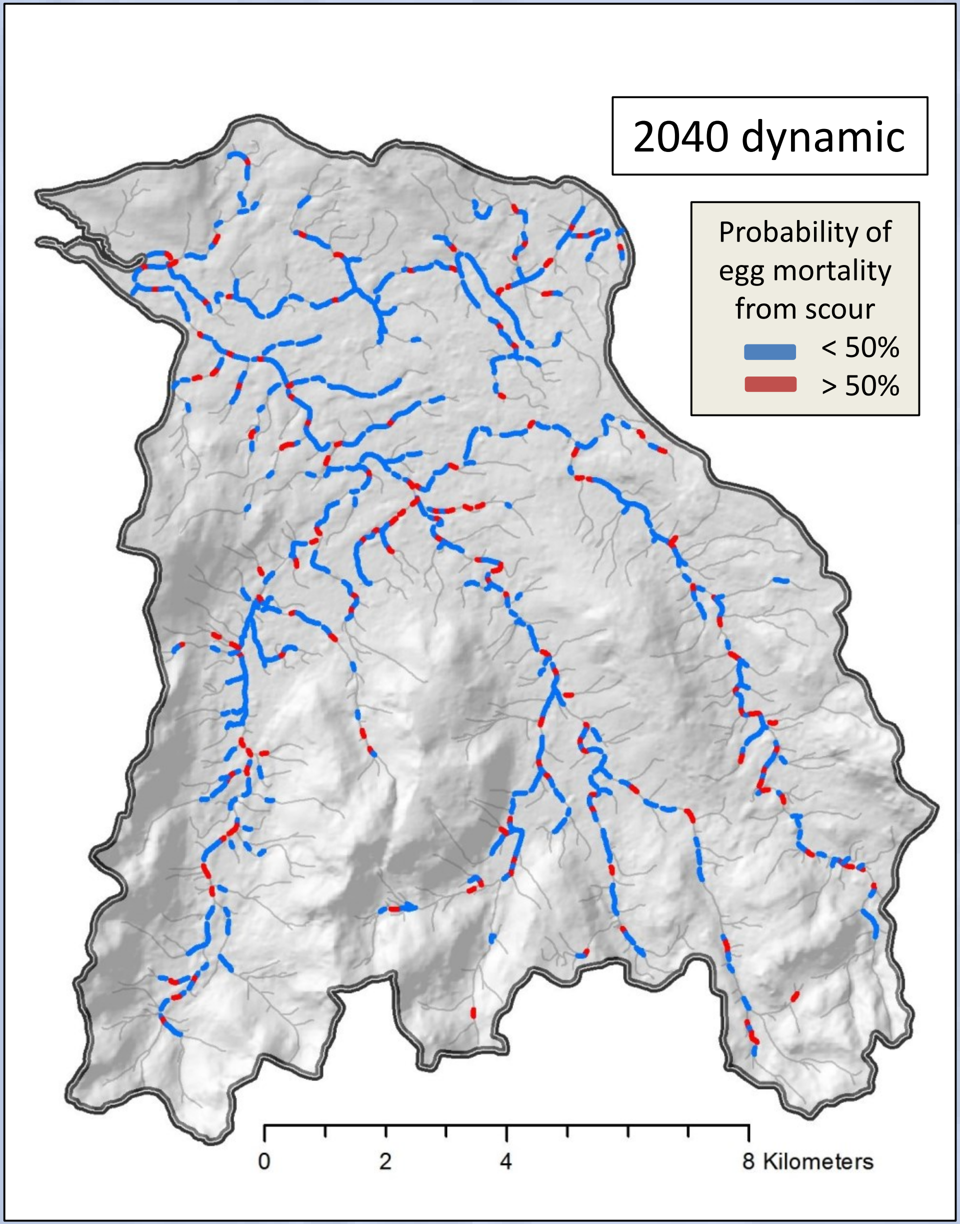
D_{50}: 78 km
<u>Scour > .50: 26 km</u>
52 km



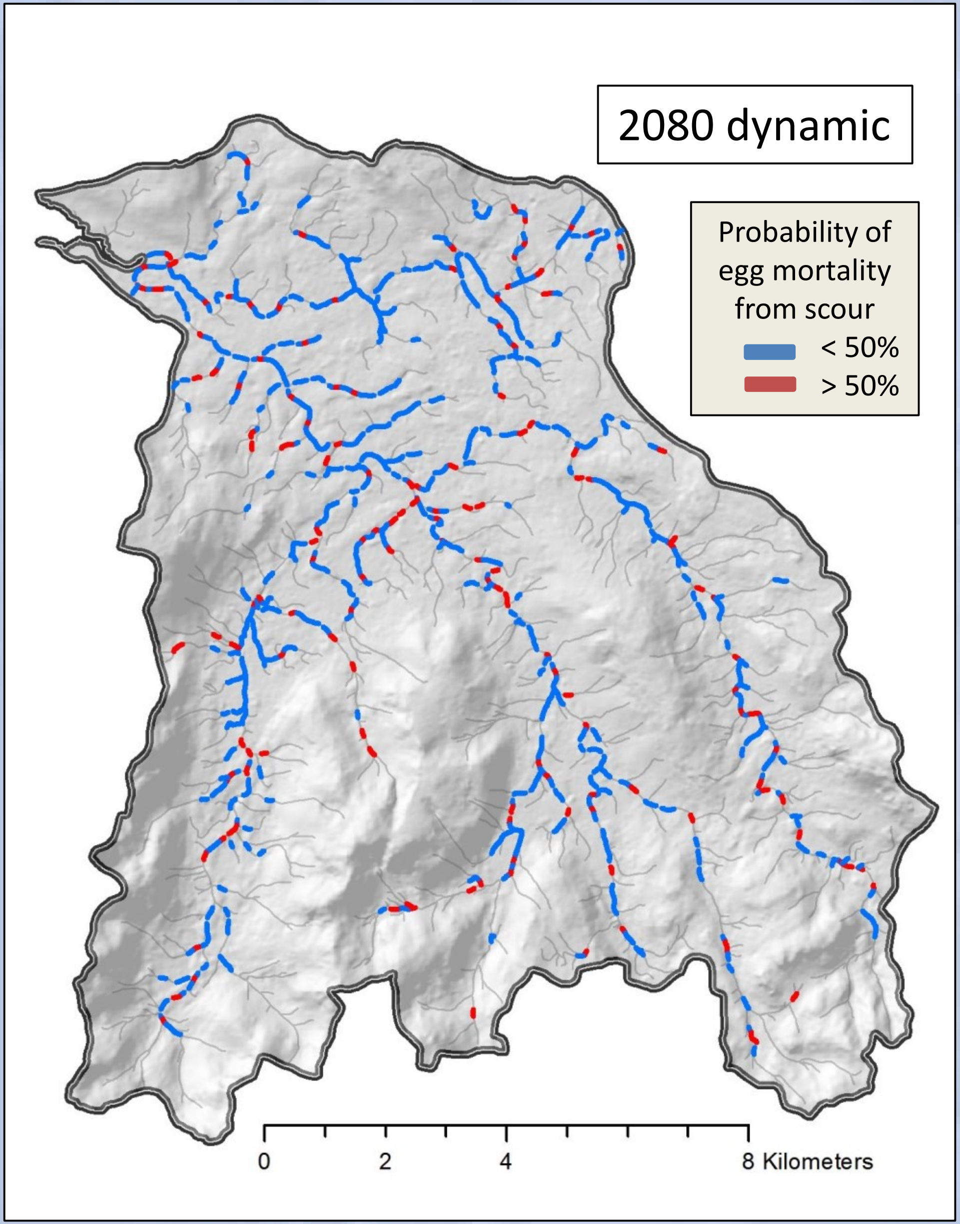
D_{50}: 78 km
<u>Scour > .50: 30 km</u>
48 km

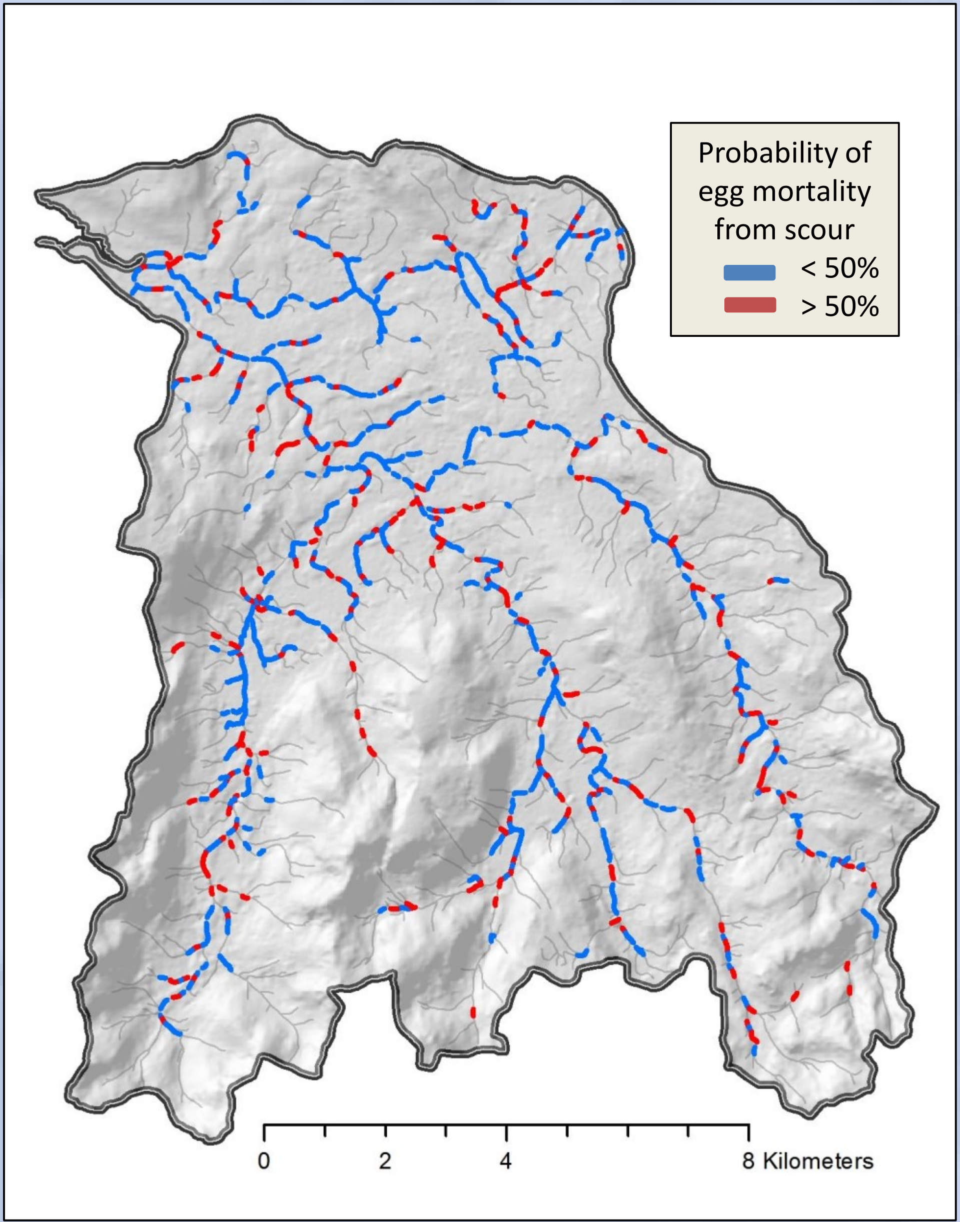


D_{50}: 76 km
<u>Scour > .50: 24 km</u>
52 km



D_{50}: 73 km
Scour > .50: 26 km
47 km





This framework provides tools for:

- Identifying watersheds, streams, and reaches with high resilience to impacts of climate change.
- Monitoring trends in salmon spawning habitat.
- Prioritizing areas for habitat improvement (e.g., lwd placement, flood plain connectivity).
- Guiding more detailed watershed assessments and salmon population models.

Conclusions:

- Mean annual flood magnitudes may increase ~ 28% by 2080 (high spatial variability).

Conclusions:

- Mean annual flood magnitudes may increase ~ 28% by 2080 (high spatial variability).

- Larger floods will potentially reduce salmon spawning habitat by ~ 18 – 22%, but there is high spatial variability due to geomorphic context.

Conclusions:

- Mean annual flood magnitudes may increase ~ 28% by 2080 (high spatial variability).

- Larger floods will potentially reduce salmon spawning habitat by ~ 18 – 22%, but there is high spatial variability due to geomorphic context.

- The spatially-explicit framework we describe provides tools that can help managers reduce or avoid habitat loss through climate adaptation strategies.

Conclusions:

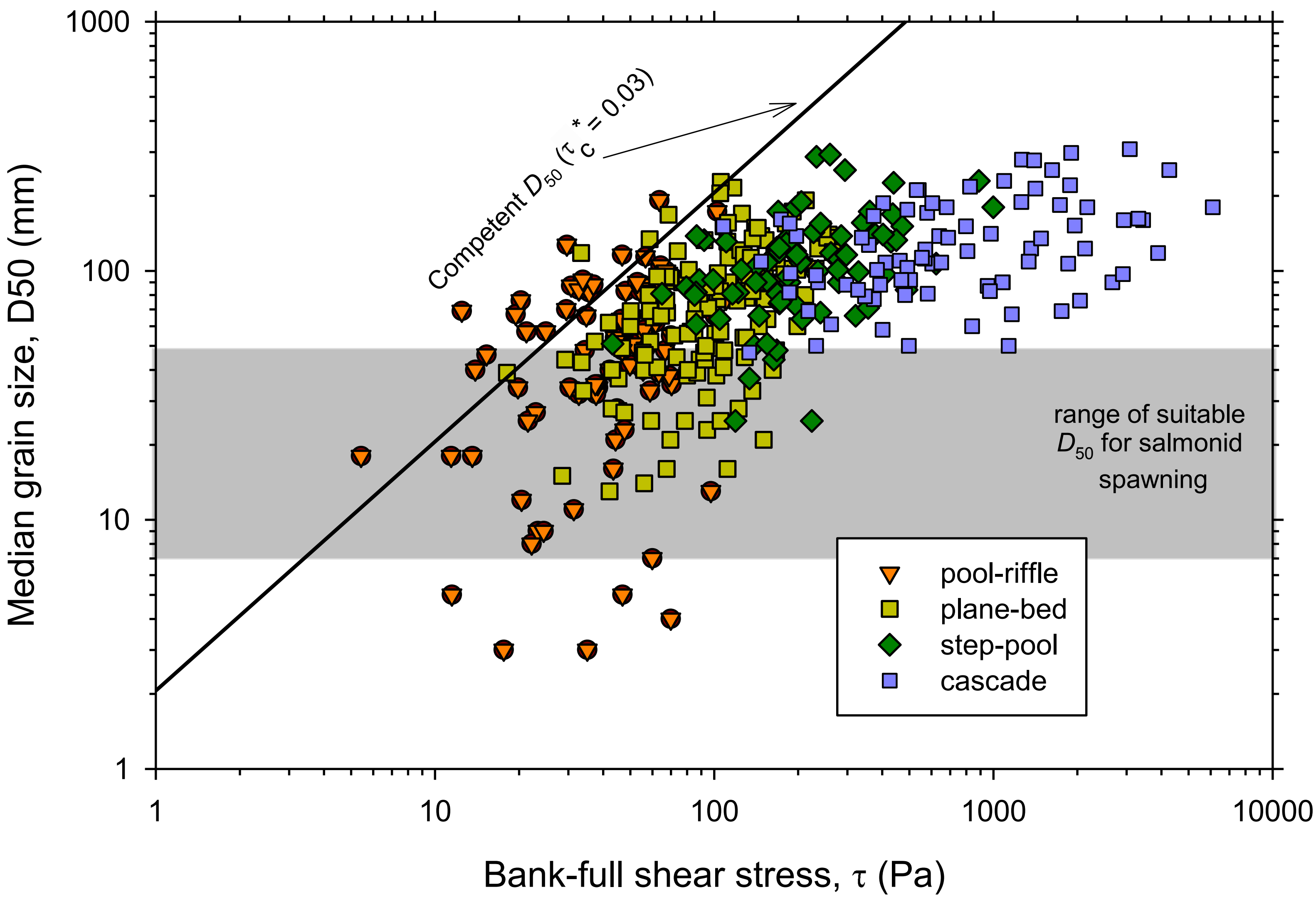
- Mean annual flood magnitudes may increase ~ 28% by 2080 (high spatial variability).

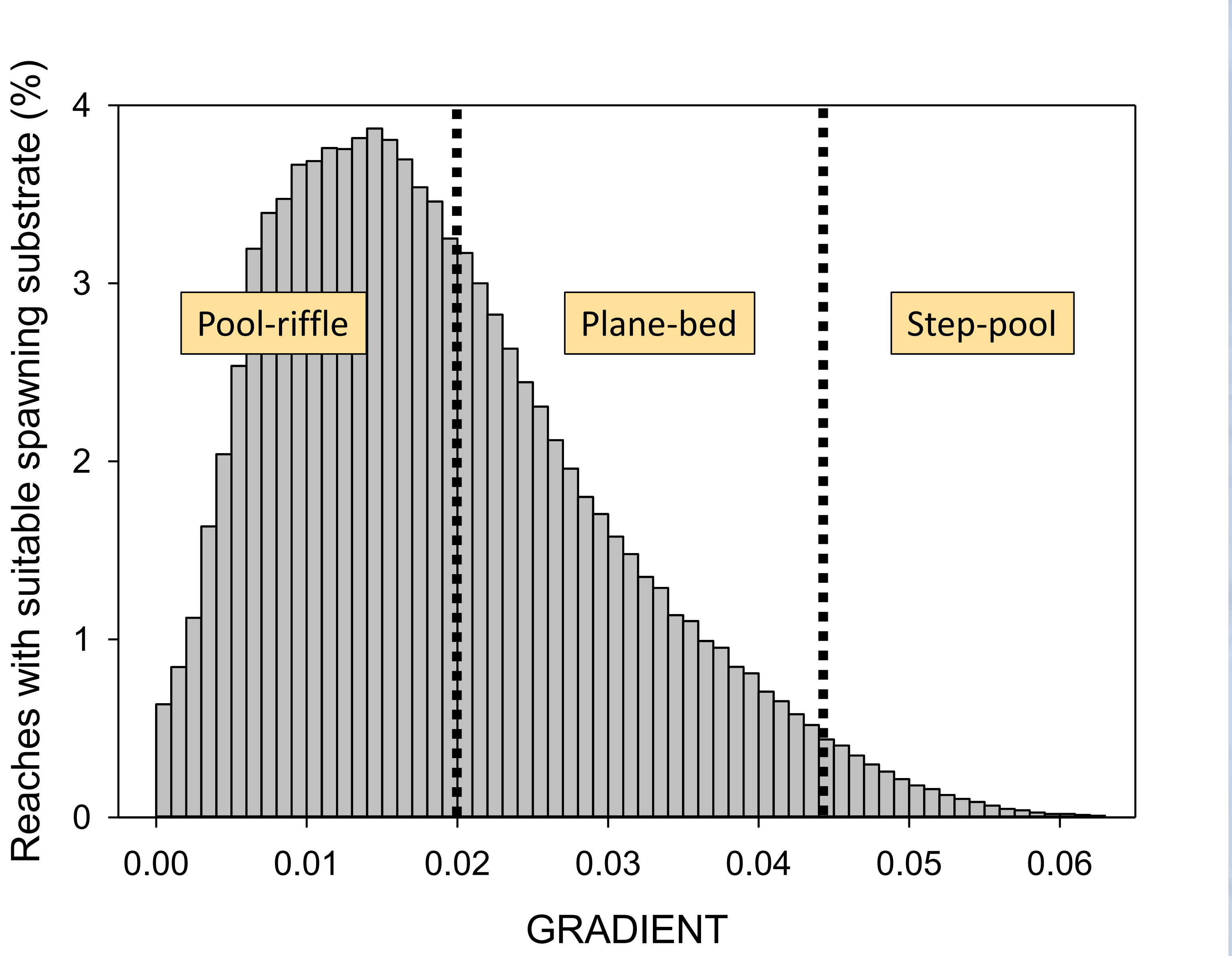
- Larger floods will potentially reduce salmon spawning habitat by ~ 18 – 22%, but there is high spatial variability due to geomorphic context.

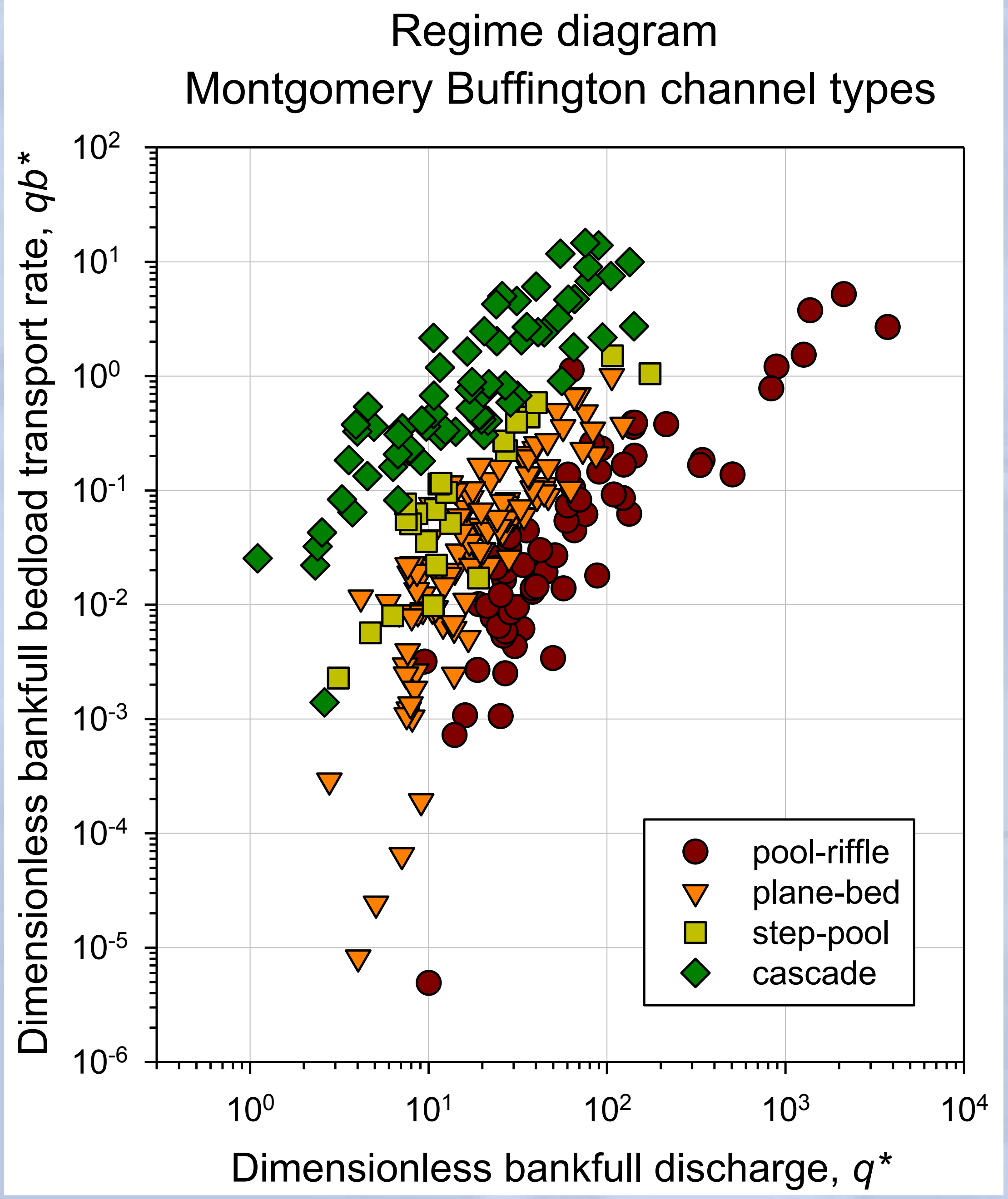
- The spatially-explicit framework we describe provides tools that can help managers reduce or avoid habitat loss through climate adaptation strategies.

- Salmon population responses to changes in spawning habitat will vary among the species considered (e.g., differences in phenology, spatial distribution, life history).

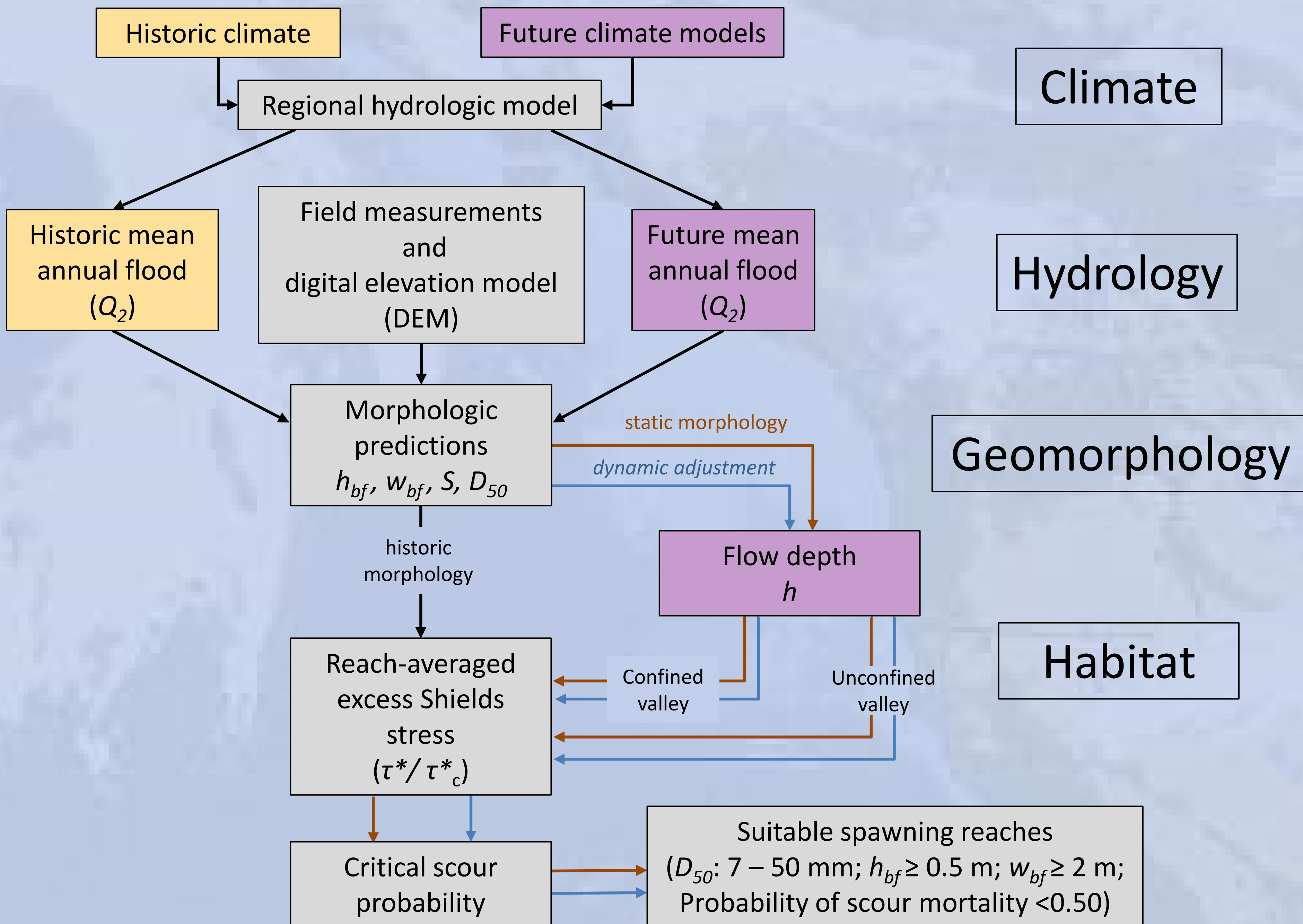
Reach average median surface grain size and bank-full shear stress




Reaches with suitable spawning substrate (%)
4
3
2
1
0
Pool-riffle
Plane-bed
Step-pool
0.00
0.01
0.02
0.03
0.04
0.05
0.06
GRADIENT



Regime diagram
Montgomery Buffington channel types
Dimensionless bankfull bedload transport rate, qb*
Dimensionless bankfull discharge, q*
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^0
10^1
10^2
10^3
10^4
pool-riffle
plane-bed
step-pool
cascade



Historic climate
Future climate models
Regional hydrologic model
Climate
Historic mean annual flood (Q_2)
Field measurements and digital elevation model (DEM)
Future mean annual flood (Q_2)
Hydrology
Morphologic predictions h_{bf}, w_{bf}, S, D_{50}
static morphology
dynamic adjustment
Geomorphology
historic morphology
Flow depth h
Reach-averaged excess Shields stress (τ^*/τ^*_c)
Confined valley
Unconfined valley
Habitat
Critical scour probability
Suitable spawning reaches (D_{50}: 7 – 50 mm; $h_{bf} \geq 0.5$ m; $w_{bf} \geq 2$ m; Probability of scour mortality <0.50)

River bankfull discharge is a key parameter for estimating channel geometry. A knowledge of bankfull discharge is necessary for the evaluation and implementation of many river restoration projects.

The best way to measure bankfull discharge is from a stage-discharge relation. Bankfull discharge is often estimated in terms of a flood of a given recurrence frequency (e.g. 2-year flood, or a flood with a peak flow that has a 50% probability of occurring in a given year; Williams, 1978).

In some cases, however, the information necessary to estimate bankfull discharge from a stage-discharge relation or from flood hydrology may not be available.