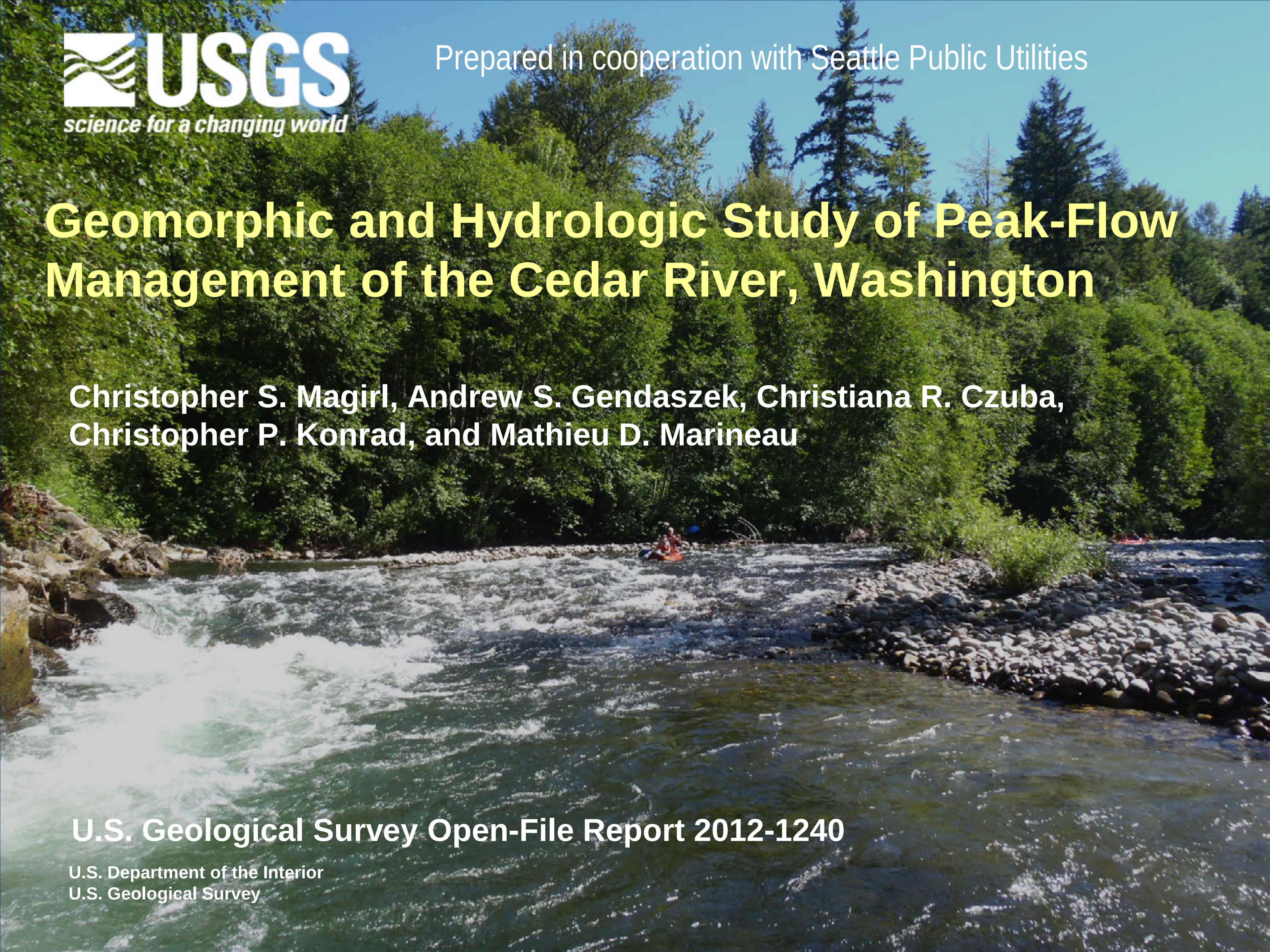


Prepared in cooperation with Seattle Public Utilities

Geomorphic and Hydrologic Study of Peak-Flow Management of the Cedar River, Washington

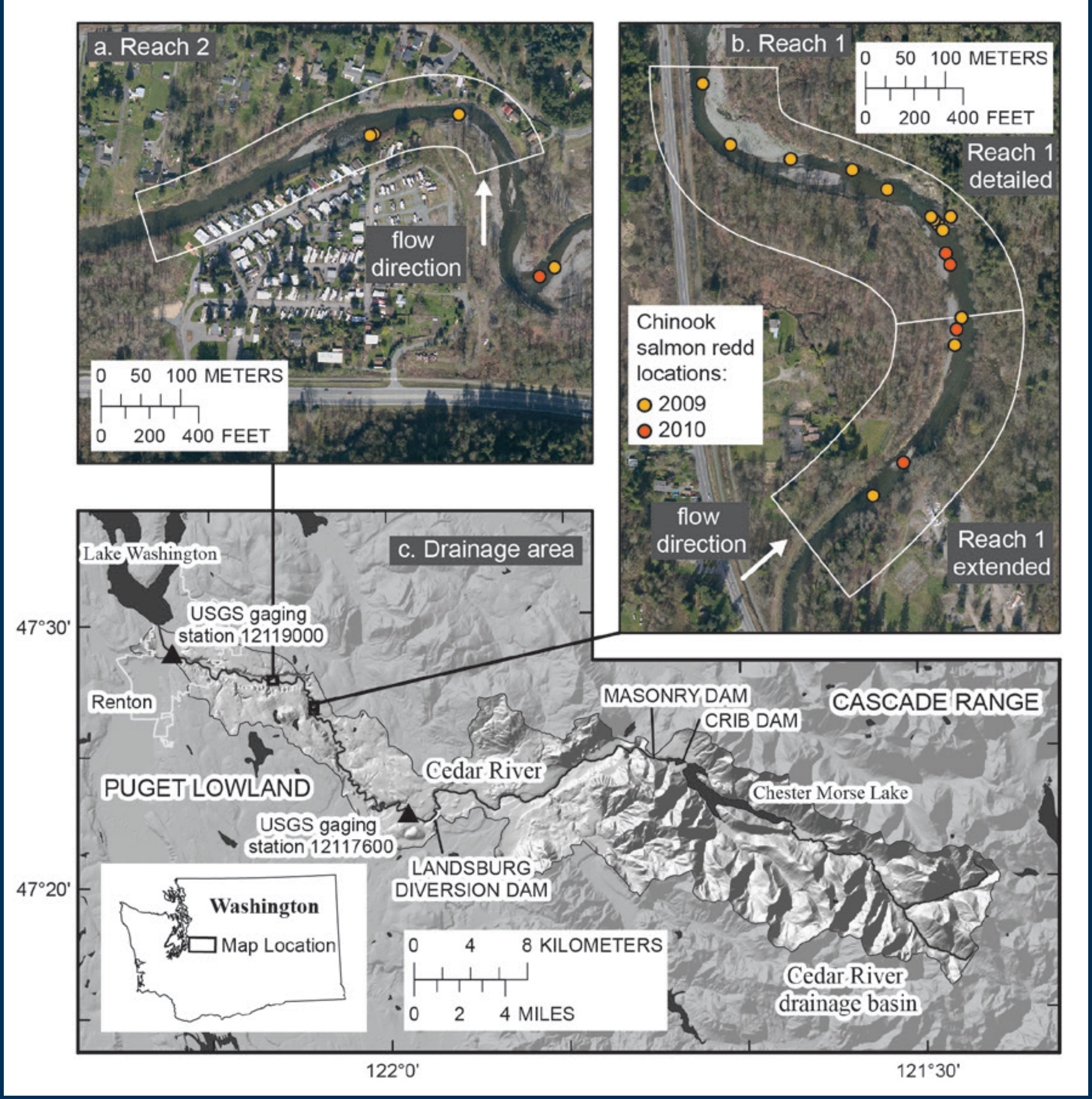
Christopher S. Magirl, Andrew S. Gendaszek, Christiana R. Czuba, Christopher P. Konrad, and Mathieu D. Marineau

U.S. Geological Survey Open-File Report 2012-1240

U.S. Department of the Interior
U.S. Geological Survey

Cedar River Watershed

- **Cedar River regulated at Chester Morse Lake**
- **Municipal water supply for Seattle**
- **Supports spawning and rearing of anadromous salmonids**



from Czuba and others (pub. C)

Study Objectives

- Define geomorphic state of the Cedar River
- Understand river response and habitat health for peak-flow management practices
  - How does peak-flow management (magnitude, duration, and frequency of floods) affect the geomorphology of the Cedar River and scour of salmon redds (that is, fish-created depressions in the gravel bed containing salmon eggs)?

USGS

Project Tasks and Deliverables

- *Task 1:* Conceptual model & Cedar River geomorphology [A, D]
- *Task 2:* Geomorphically resetting flood / 2009 flood [A]
- *Task 3:* 2D Hydrodynamic modeling [C]
- *Task 4:* Redd scour study [B, C]
- *Task 5:* Key metrics for long-term monitoring [D]

Project background *http://wa.water.usgs.gov/projects/cedarriverpeakflows/*

Deliverables:

A. Journal article: Gendaszek and others, Cedar River Geomorphology
B. Journal article: Gendaszek and others, Scour Study (Accelerometers, scour chains)
C. Journal article: Czuba and others, Hydrodynamic Modeling
D. USGS Open-File Report: Summary of entire study (this presentation)

Deliverables:

The results of the study will be published in three journal articles, a summary USGS Open-File Report (this presentation), and two proceedings papers. Below are the tentative (as of November 2012) references for each publication:

[pub. A] Gendaszek, A.S, Magirl, C.S., and Czuba C.R., (in press, manuscript accepted), “Geomorphic response to flow regulation and channel and floodplain alteration in the gravel-bedded Cedar River, Washington, USA,” *Geomorphology,* doi:10.1016/j.geomorph.2012.08.017.

[pub. B] Gendaszek A.S., Magirl, C.S., Konrad, C.P., and Czuba, C.R., (in prep), “Temporal and spatial patterns of bed movement, scour, and fill in a gravel-bedded river detected with buried accelerometers,” *to be submitted to Journal of Hydrology.*

[pub. C] Czuba C.R., Magirl, C.S., Czuba, J.A., Gendaszek, A.S., and Konrad, C.P., (in prep), “Hydrodynamic modeling of potential salmon-redd disturbance during managed peak flows on the Cedar River, Washington,” *to be submitted to Journal of Hydrology.*

[pub D] Magirl, C.S., Gendaszek, A.S., Czuba, C.R., Konrad, C.P., and Marineau, M.D., 2012, Geomorphic and hydrologic study of peak-flow management of the Cedar River, Washington, U.S. Geological Survey Open-File Report 2012-1240.

[pub E] Gendaszek, A.S., Magirl, C.S., Konrad, C.P., Czuba, C.R., and Marineau, M.D., 2012, Using buried accelerometers to measure the timing of bed movement, scour, and fill in gravel-bedded rivers, in Hydraulic Measurements and Experimental Methods Conference, Snowbird, Utah, 2012, Proceedings: Snowbird, Utah, American Society of Civil Engineers, 6 p. *http://wa.water.usgs.gov/projects/cedarriverpeakflows/data/Gendaszek_et_al_HMEM_2012.pdf*

[pub F] Marineau, M.D., Gendaszek, A.S., Magirl, C.S., Czuba, C.R., and Czuba, J.A., 2012, Surrogate bedload monitoring using hydrophones for a flood-season deployment on the gravel-bedded Cedar River, Washington, in Hydraulic Measurements and Experimental Methods Conference, Snowbird, Utah, 2012, Proceedings: Snowbird, Utah, American Society of Civil Engineers, 6 p. *http://wa.water.usgs.gov/projects/cedarriverpeakflows/data/Marineau_et_al_HMEM_2012.pdf*

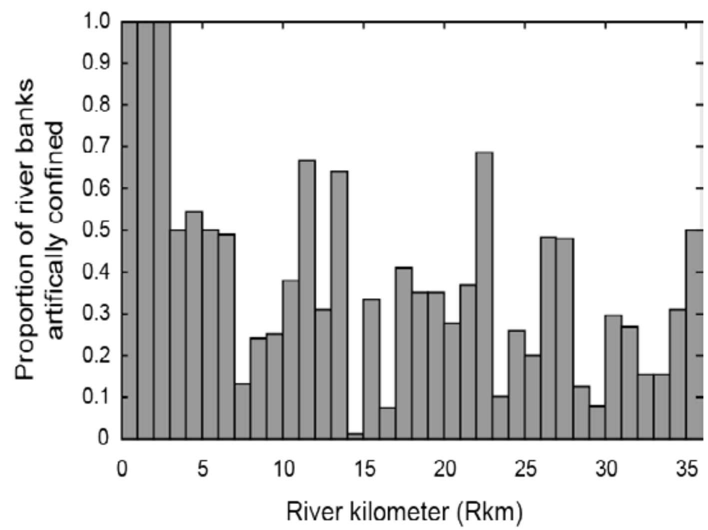
Peak-flow hydrology of the Cedar River

- Largest flows typically occur from November to March from heavy precipitation
- Peak of record (before regulation) was 402 m^3/s (14,200 ft^3/s) on November 19, 1911 (measured near Landsburg, #12117500)
- The largest peak flow since regulation was 306 m^3/s (10,800 ft^3/s) on November 24, 1990.

Recurrence interval (year)	Pre-regulation discharge (m^3/s)	95 % confidence lower limit (m^3/s)	95 % confidence upper limit (m^3/s)	Post-regulation discharge (m^3/s)	95 % confidence lower limit (m^3/s)	95 % confidence upper limit (m^3/s)
2	129	96.5	172	68.9	63.2	75.0
5	224	169	335	108	98.6	120
10	303	220	497	140	126	159
25	420	290	778	189	166	222
50	520	346	1050	232	200	278
100	633	406	1390	281	238	344

Geomorphology

- Assess the present geomorphic condition of the Cedar River
  - Residual pool depth
  - Stream power
  - Substrate
  - Current function
- Assess twentieth-century channel change
  - Channel width
  - Channel migration
  - Aggradation trends



Proportion of river banks artificially confined by revetments or other bank stabilization structures in 2010.

from Gendaszek and others (pub. A)

Stream-Power Analysis of Present River

- Three wide, unconfined reaches
- Decreasing slope downstream
- Decreasing substrate size downstream
- Decreasing stream power downstream
- Local stream-power minima at wide reaches
- ‘Rkm’ is river kilometer

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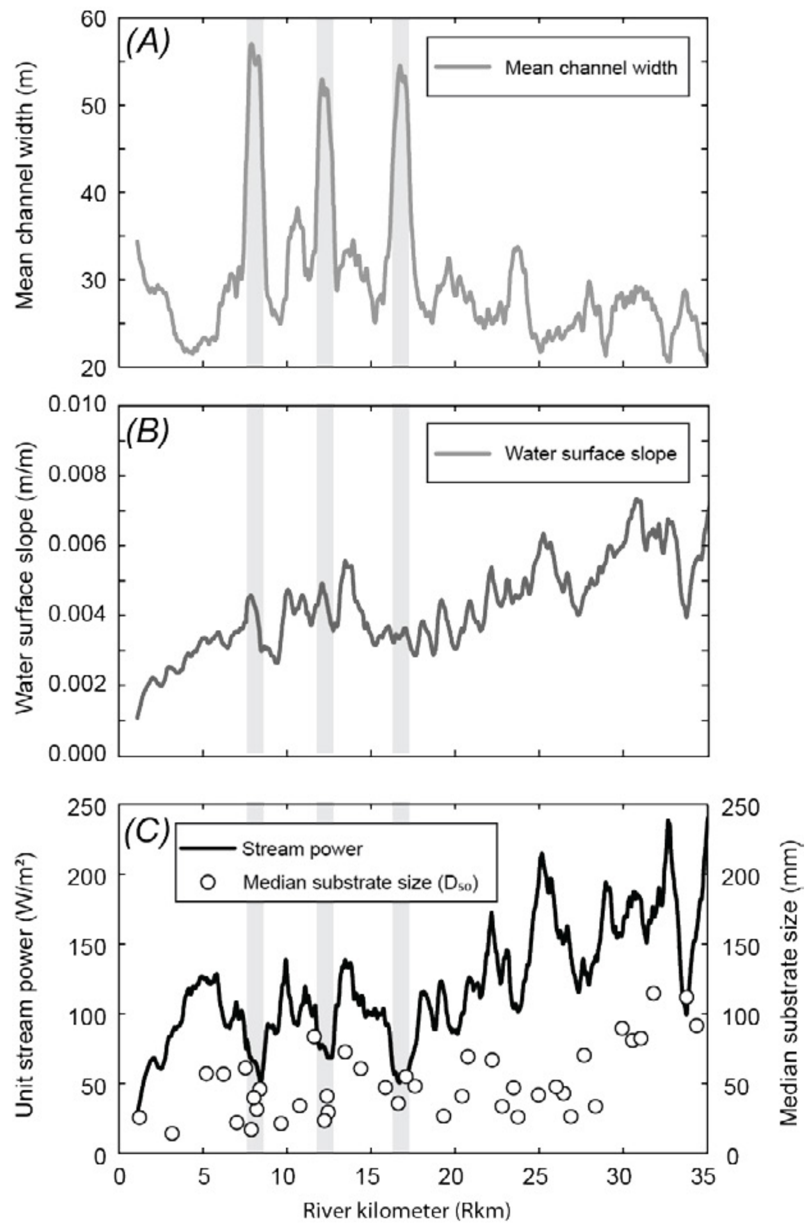
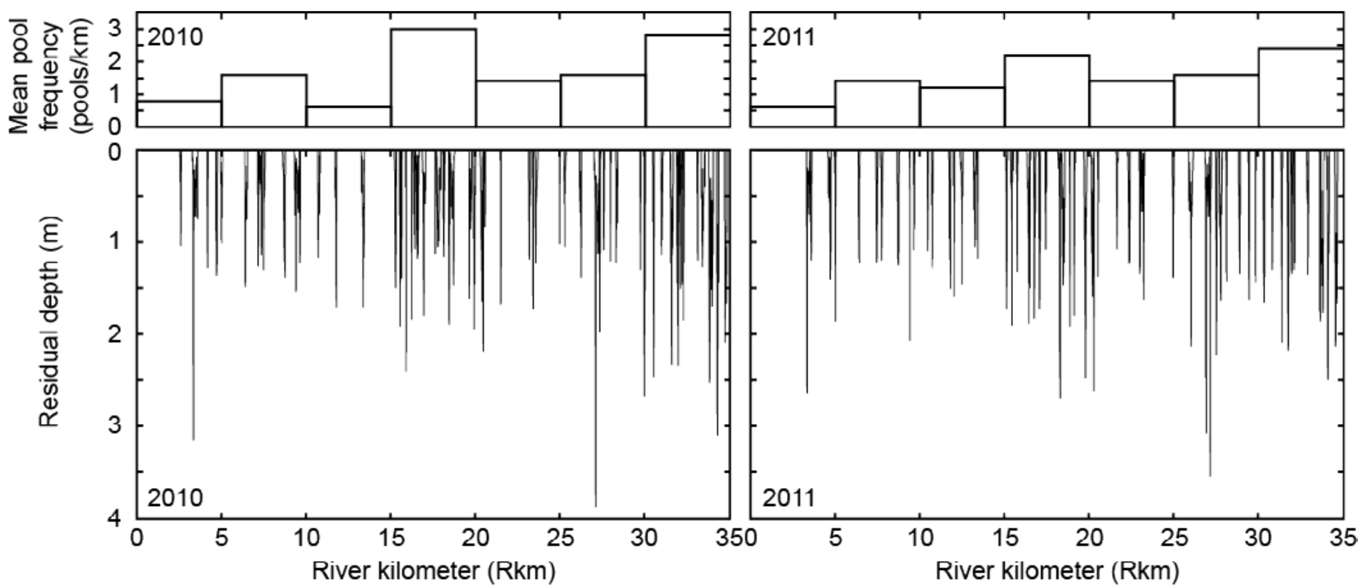
from Gendaszek and others (pub. A)



Longitudinal variation in (A) active-channel width, (B) water-surface slope, and (C) stream power and median substrate size (D_{50}) of the Cedar River between Rkm 0 and 35. Gray areas indicate longitudinal extent of unconfined reaches.

Longitudinal Profile Analysis

- Residual pool depth (depth of each pool if discharge was zero, see Gendaszek and others, pub. A) measured in 2010 and 2011 shows that many pools were deeper than 1 meter
- Residual pool frequency changed little between 2010 and 2011



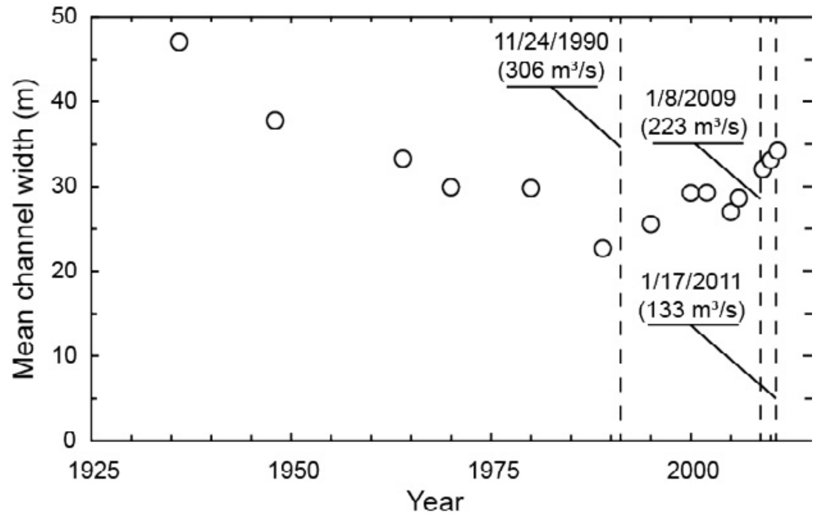
Residual pool depth and frequency between Rkm 0 and 35 surveyed in April 2010 and July 2011.

from Gendaszek and others (pub. A)

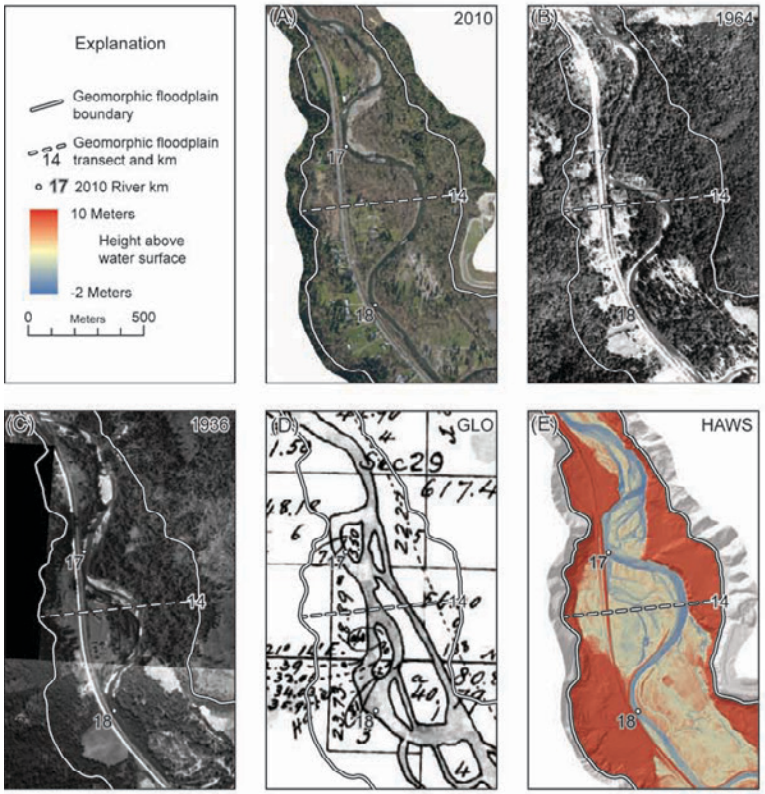
USGS

Historical Channel Change

- Decrease in channel width up to 1989; slight increase to present
- Decrease in channel complexity over time: channel form changed from island anastomosing to straight channel



Mean channel width for the Cedar River downstream of the Landsburg diversion dam measured from 13 orthoimagery sets from 1936 to 2011. The time of notable peak streamflows measured near Landsburg at USGS streamflow gaging station 12117500 is shown by vertical dashed lines.



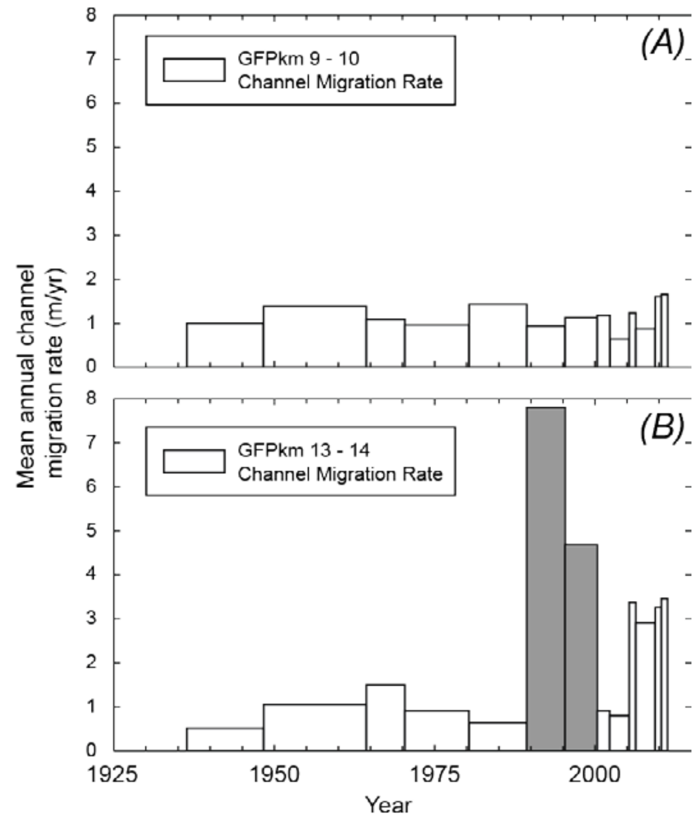
Progression of planform geomorphic features in representative study reach: (A) 2010 orthoimagery, (B) 1964 orthoimagery, (C) 1936 orthoimagery, (D) 1865-1880 General Land Office survey, and (E) height above water surface.

from Gendaszek and others (pub. A)

USGS

Historical Channel Change: Channel Migration

- **Limited channel migration observed in confined reaches *(A)***
- **Limited channel migration in unconfined reaches until late twentieth century *(B)***
- **'GFPkm' is geomorphic flood-plain kilometer**

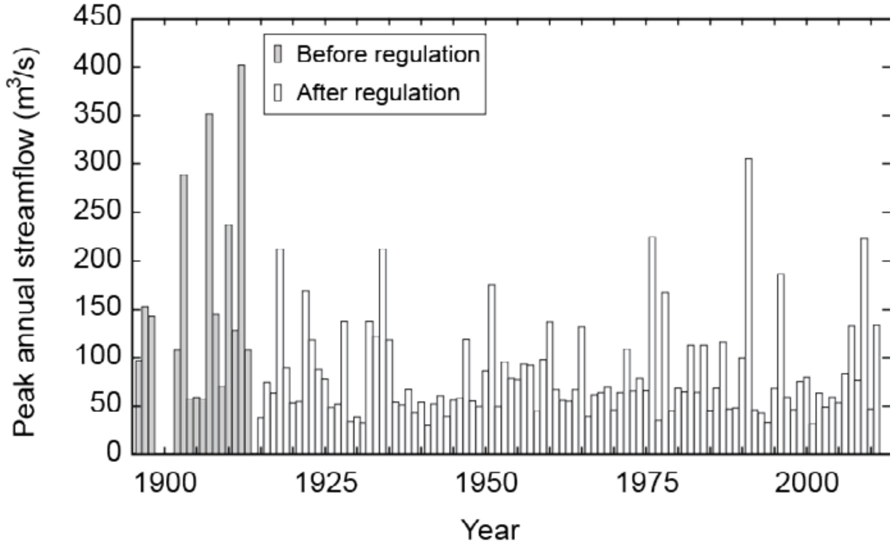


Mean annual channel migration rate (A) between GFPkm 9 and 10 and (B) GFPkm 13 and 14. Migration rates greater than the total error from orthorectification and digitization are shaded gray.

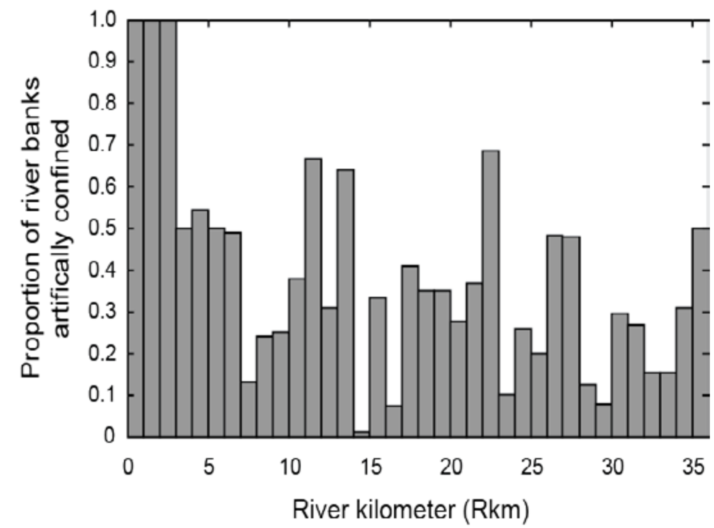
from Gendaszek and others (pub. A)

Historical Channel Change: Channel Migration

- **Reduction in channel-migration rate was due to reduced flood peaks from flow regulation and increased confinement from the construction of levees and revetments**



Annual peak streamflow of the Cedar River near Landsburg (U.S. Geological Survey streamflow-gaging station 12117500) for water years 1896-1898, 1902-1913, and 1915-2011. Peak annual streamflows before regulation in 1914 are shaded.



Proportion of river banks artificially confined by revetments or other bank stabilization structures in 2010.

from Gendaszek and others (pub. A)

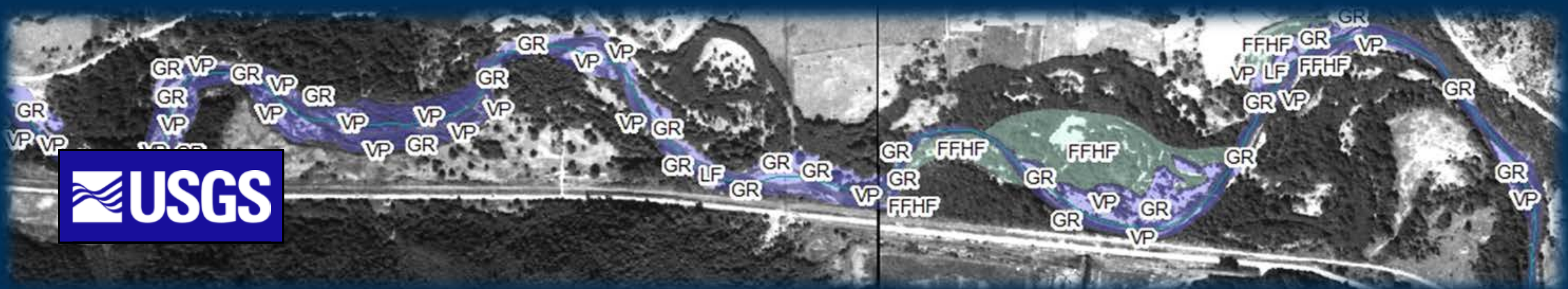
USGS

Geomorphology—Primary conclusions

- The geomorphic form of the Cedar River has been significantly altered by changes to flow regime by upstream regulation, development in the flood plain, and the construction of revetments and levees to confine channel migration

- The formerly wide, anastomosing channel (though not meandering) narrowed by over 50 percent from an average of 47 m in 1936 to 23 m in 1989 and became progressively single threaded; subsequent high flows and revetment removal contributed to an increase in mean channel width to about 34 m by 2011

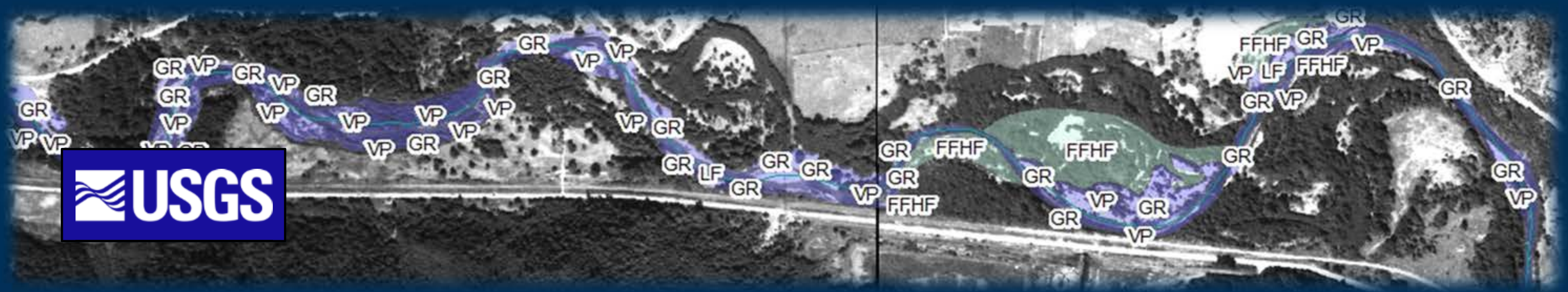
- Channel migration rates between 1936 and 2011 were less than 1 m/yr throughout most of the Cedar River's length, but up to 8 m/yr in reaches not confined by revetments or valley walls



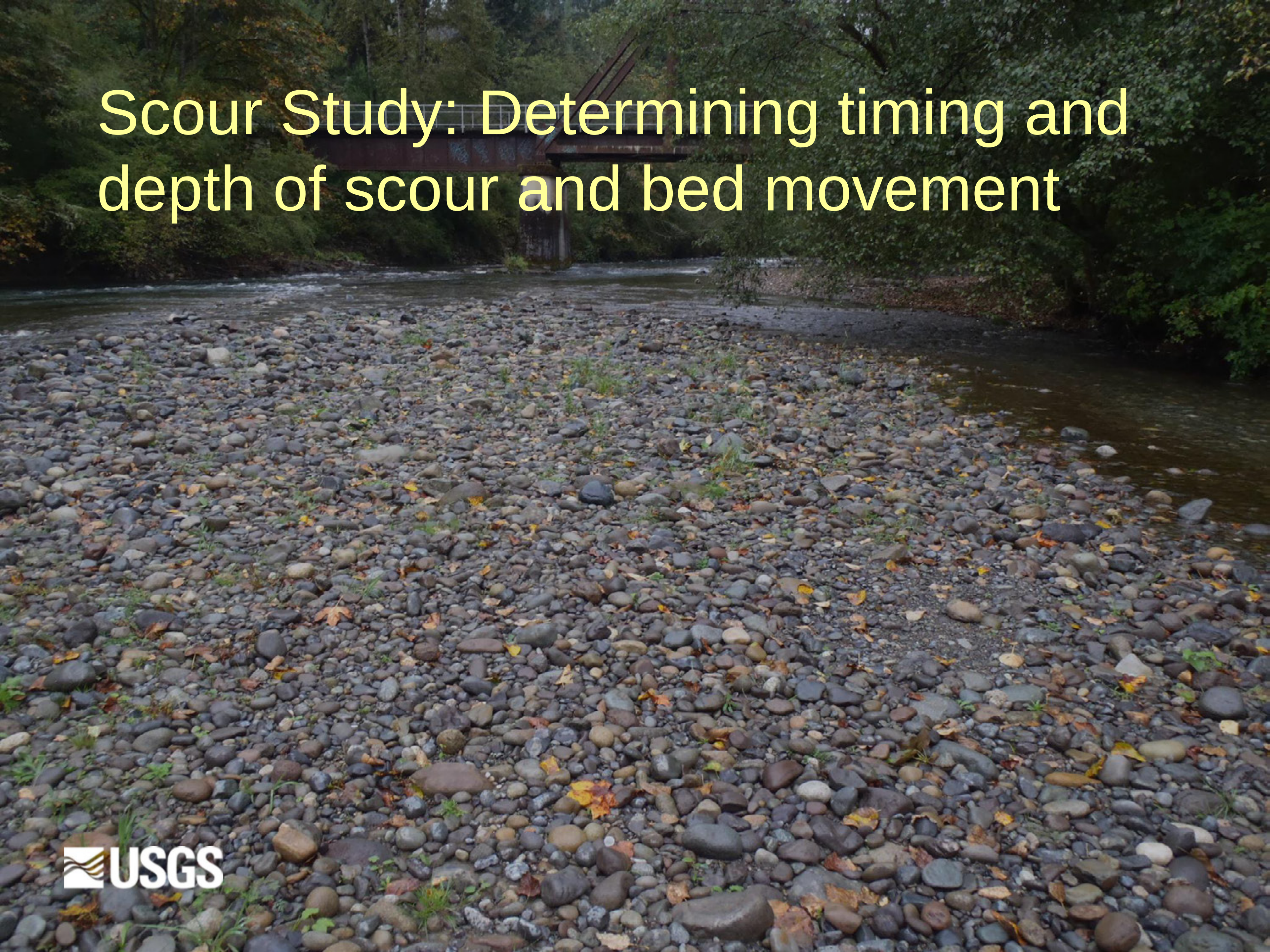
Geomorphology—Primary conclusions (continued)

- While high flows are important for maintaining channel dynamics in the Cedar River, their effectiveness is currently limited by revetments, limited sediment supply, and the lack of large wood available for recruitment to the channel

- Channel-forming flows (10- to 20-year floods), which provide benefit to other river systems, appear to result in a net decrease of ecological function for the Cedar River because of the presence of bank armoring: Spawning gravels appear to be evacuated and deposited in topographically high bars away from the low-flow channel where salmon could use them; large wood also gets transported from the system and similarly deposited in assemblages away from the low-flow channel



Scour Study: Determining timing and depth of scour and bed movement



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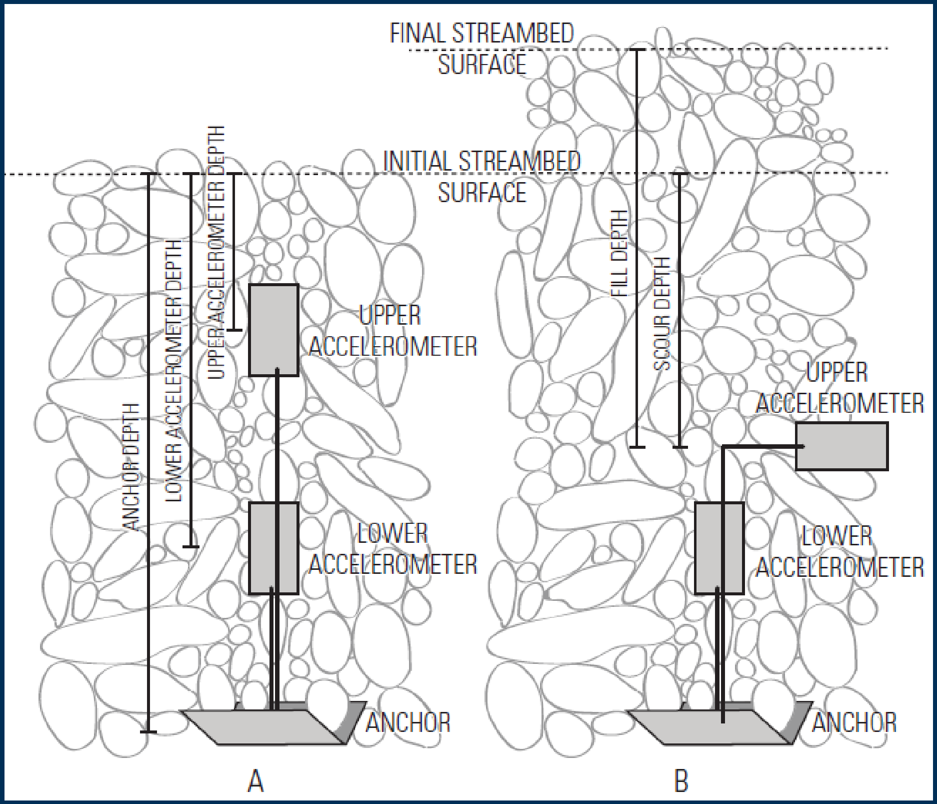
Determining Timing and Depth of Scour

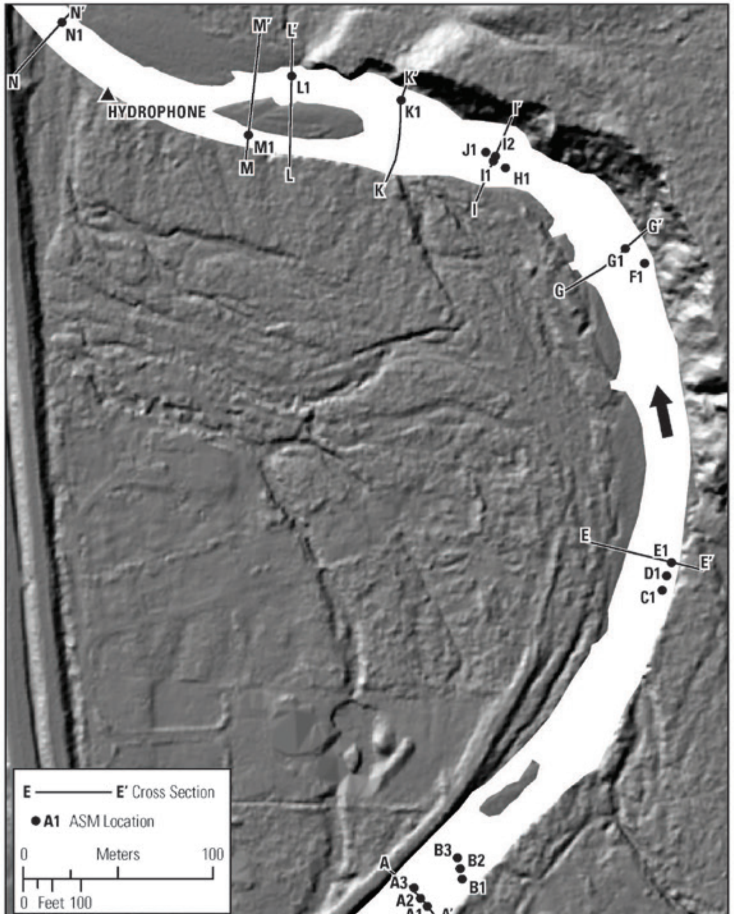
- **New method developed using buried accelerometers**
- **48 accelerometers deployed at 26 accelerometer-scour-monitor (ASM) locations in Chinook and sockeye salmon spawning habitat in fall 2010**
- **Accelerometers record their tilt relative to 3 axes. Changes in tilt interpreted as disturbance of the gravel bed, indicating temporal dynamics of scour and fill during flood season**



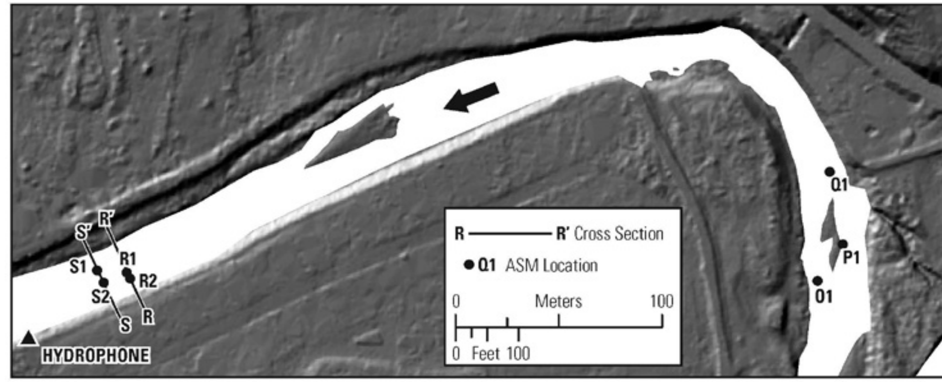
from Gendaszek and others (pub. B)

USGS

Temporal Dynamics of Scour and Fill



Location of accelerometer scour monitors and hydrophones in Reach 1



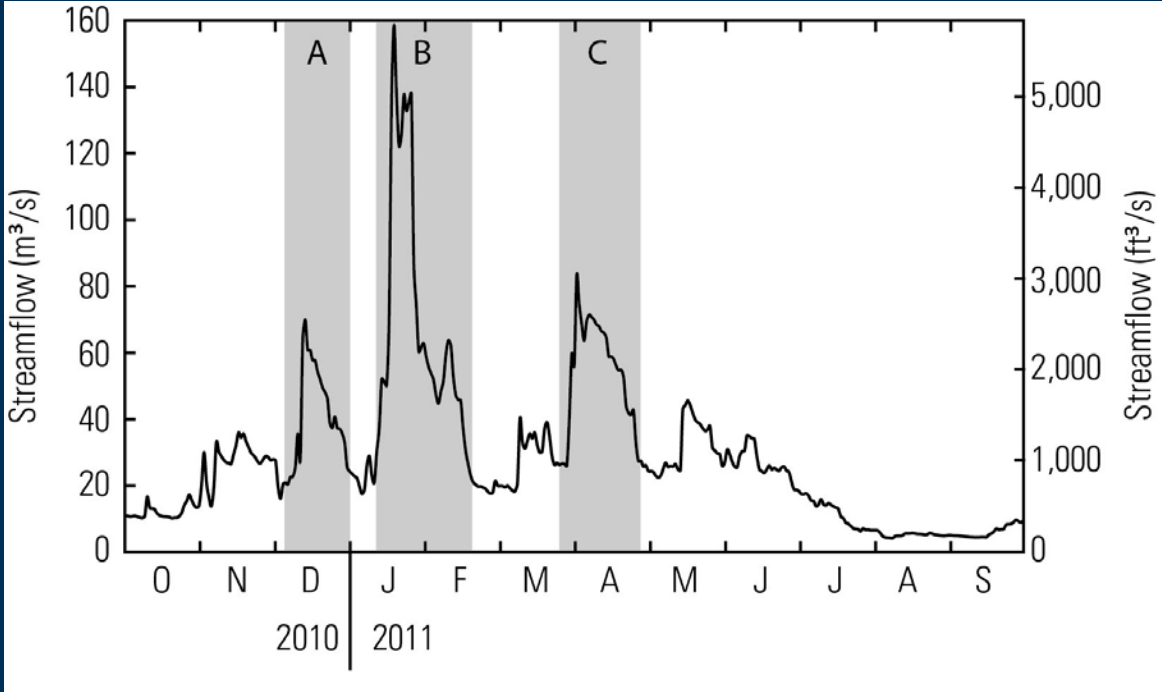
Location of accelerometer scour monitors and hydrophones in Reach 2

from Gendaszek and others (pub. B)

Three distinct high-flow events occurred during the 2010-2011 flood season

Event	Dates	Peak Discharge, Renton / Recurrence Interval (RI)
High-flow event A	Dec 2010	2,820 ft^3/s (80 m^3/s) / 1.4-year RI
High-flow event B	Jan – Feb 2011	5,930 ft^3/s (168 m^3/s) / 7-year RI
High-flow event C	Mar 2011	3,130 ft^3/s (89 m^3/s) / 1.7-year RI

from Gendaszek and others (pub. B)



Mean daily streamflow of the Cedar River at Renton. High-flow events A, B, and C are shaded

USGS

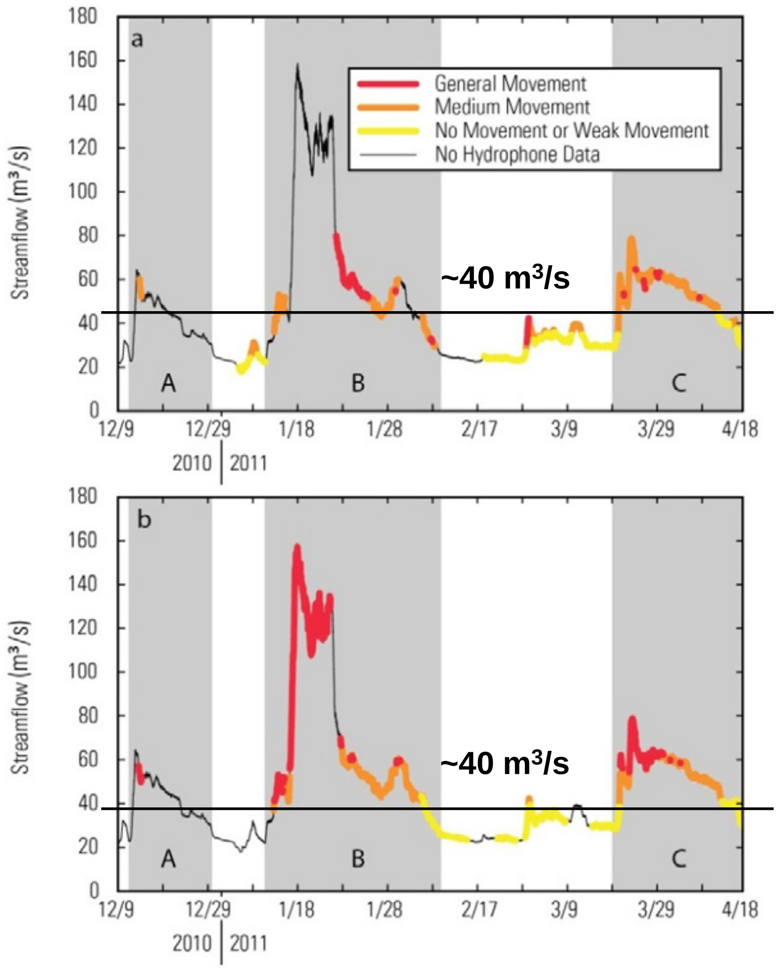
Sediment Acoustic Monitoring Using Hydrophones

- **Record hourly audio data at Belmondo (unconfined reach) and confined reach**
- **Detect movement of bedload through passive acoustic monitoring**
- **Intensity and frequency of shocks qualitatively correlated with bedload movement**
- **Methodological details available in**

  Marineau, M.D., Gendaszek, A.S., Magirl, C.S., Czuba, C.R., and Czuba, J.A., 2012, Surrogate bedload monitoring using hydrophones for a flood-season deployment on the gravel-bedded Cedar River, Washington, in Hydraulic Measurements and Experimental Methods Conference, Snowbird, Utah, 2012, Proceedings: Snowbird, Utah, American Society of Civil Engineers, 6 p.
  http://wa.water.usgs.gov/projects/cedarriverpeakflows/data/Marineau_et_al_HMEM_2012.pdf

USGS

Hydrophone data



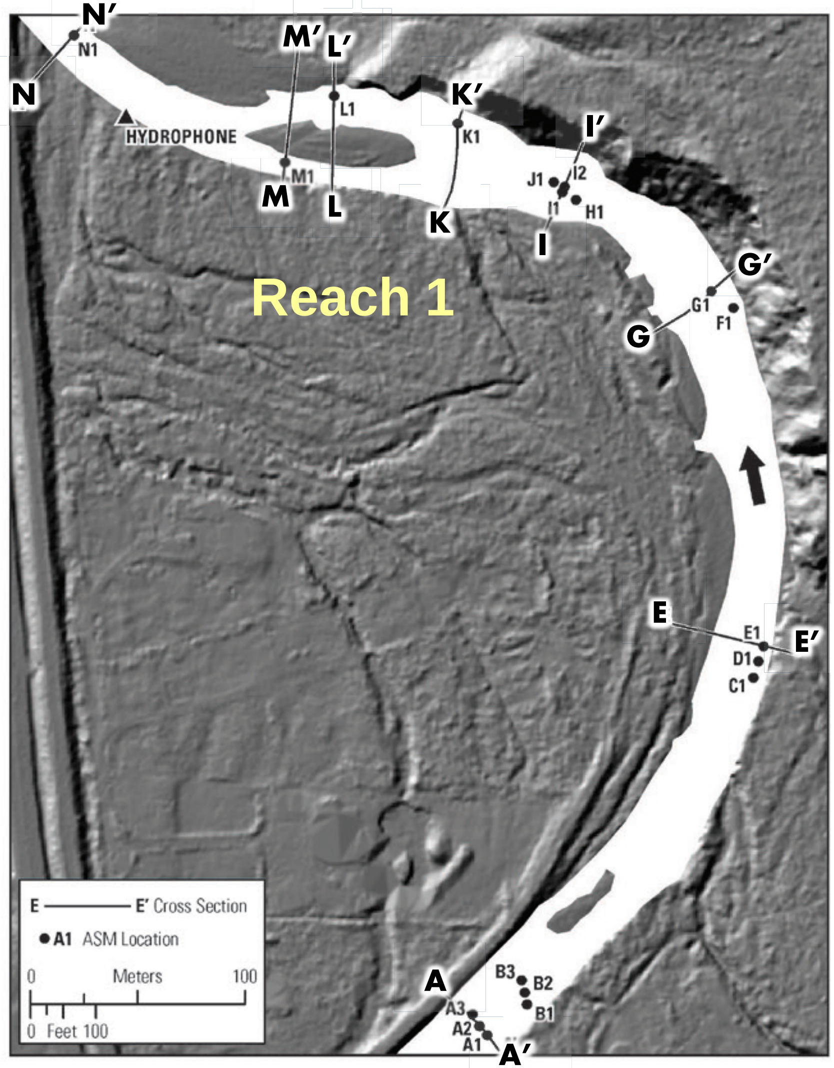
Classification of bedload movement from hydrophone data at (a) unconfined reach and (b) confined reach between December 2010 and March 2011 as projected onto streamflow. High-flow events A, B, and C are shown in gray.

- Bedload begins to move at about 40 m^3/s (1,400 ft^3/s), but there is no way to determine if bedload originated from the bed material in the vicinity of the hydrophones or from another source upstream

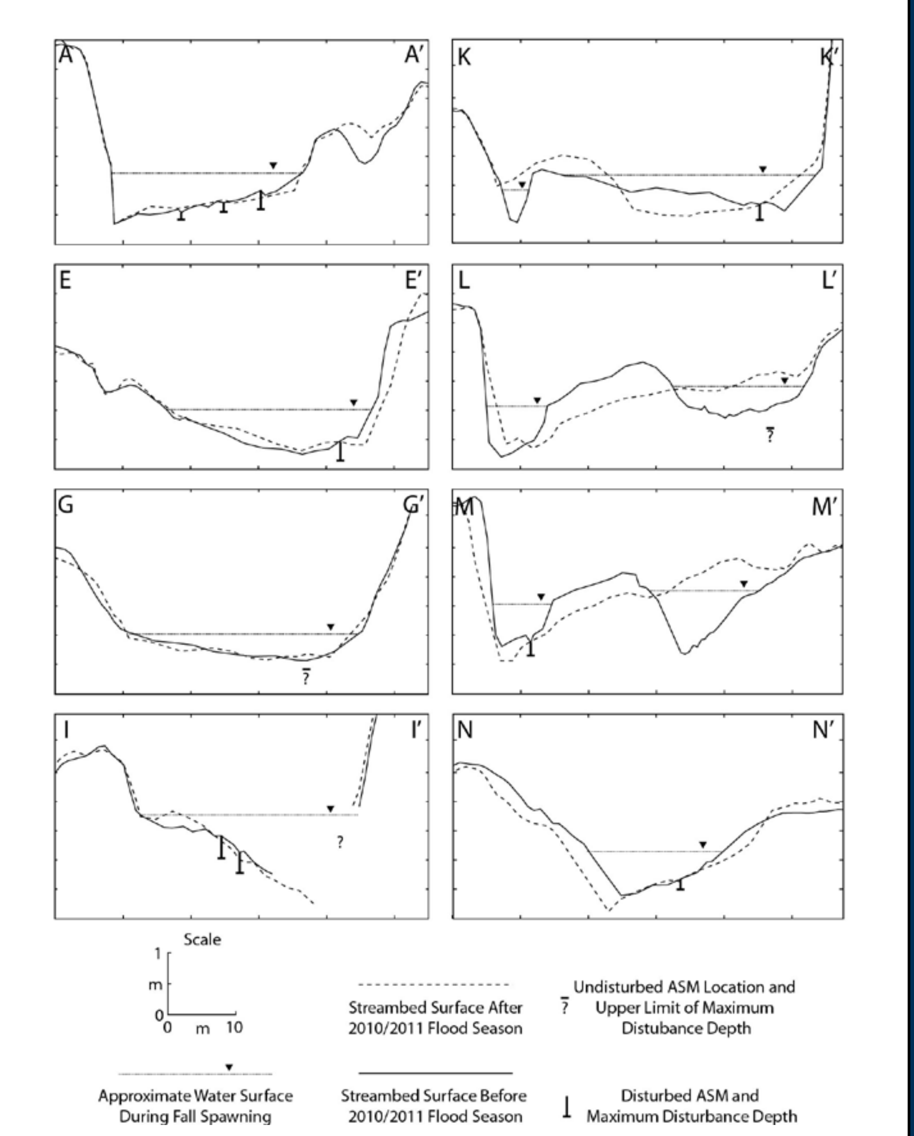
- Data resolution insufficient to determine if there is a significant difference between the two reaches

USGS

Cross-sectional patterns of scour: Reach 1

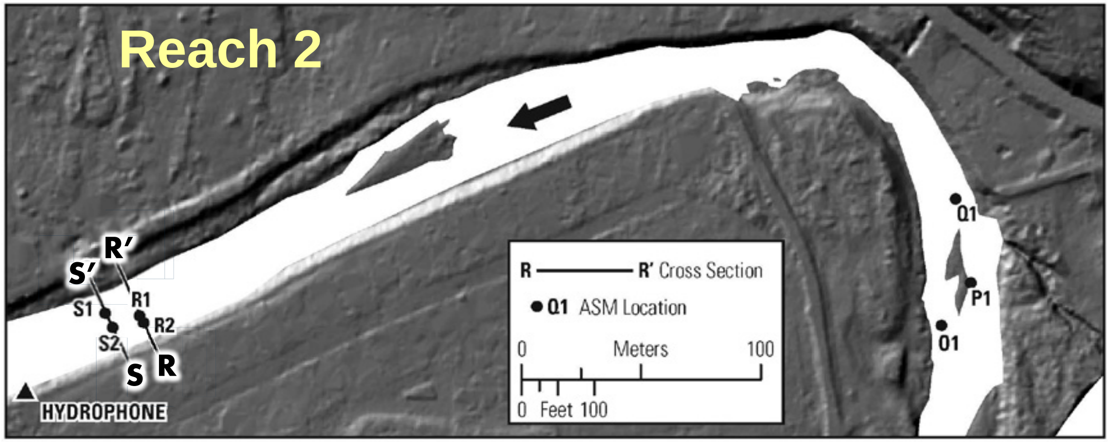


Location of accelerometer scour monitors and hydrophones in Reach 1

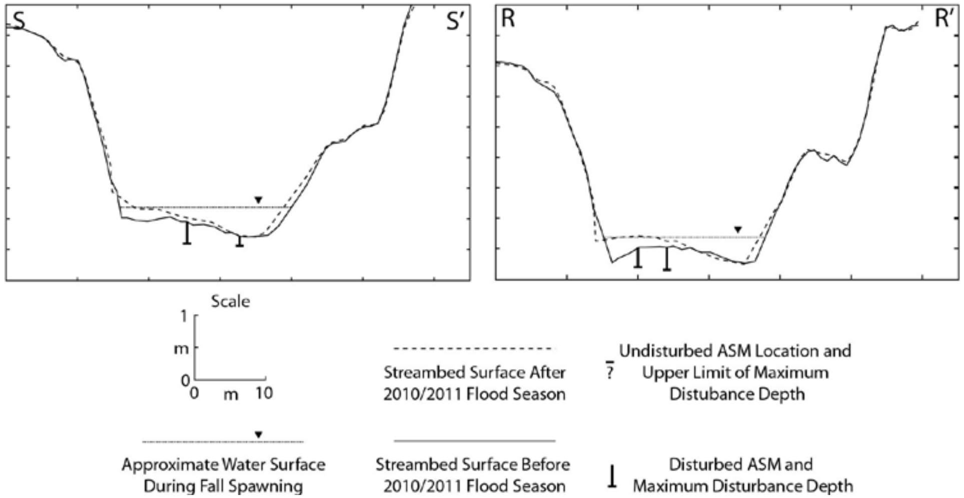


from Gendaszek and others (pub. B)

Cross-sectional patterns of scour: Confined Reach 2



Location of accelerometer scour monitors and hydrophones in Reach 2



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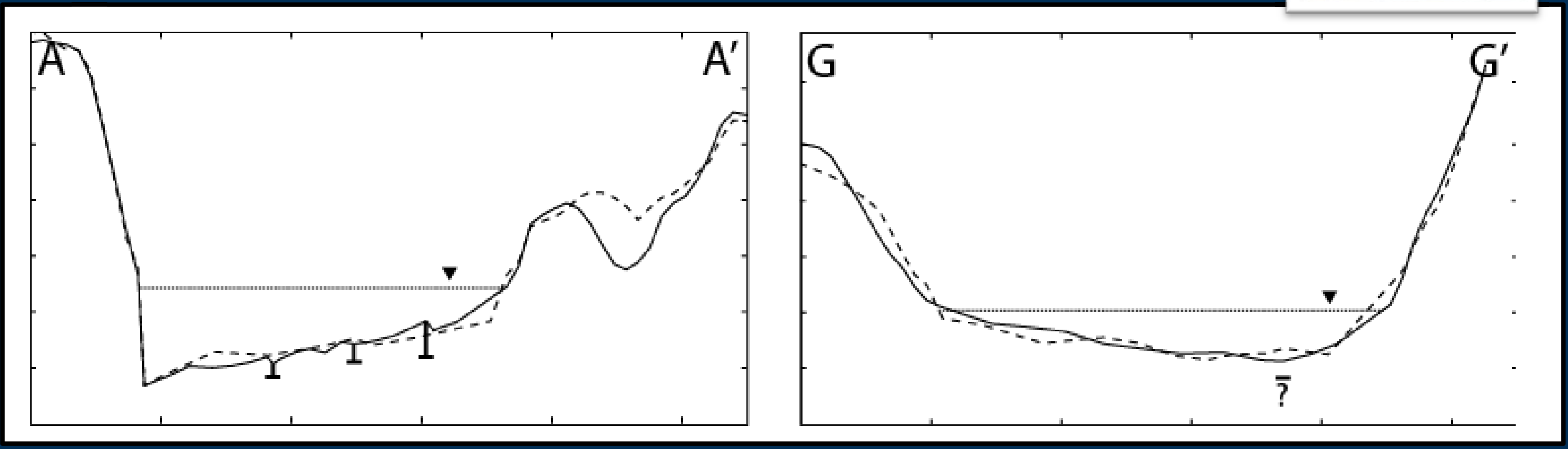
from Gendaszek and others (pub. B)

Cross-sectional patterns of scour

- **Assessment of the bed topography before and after a flood cannot be used to infer depth of scour**



from Gendaszek and others (pub. B)

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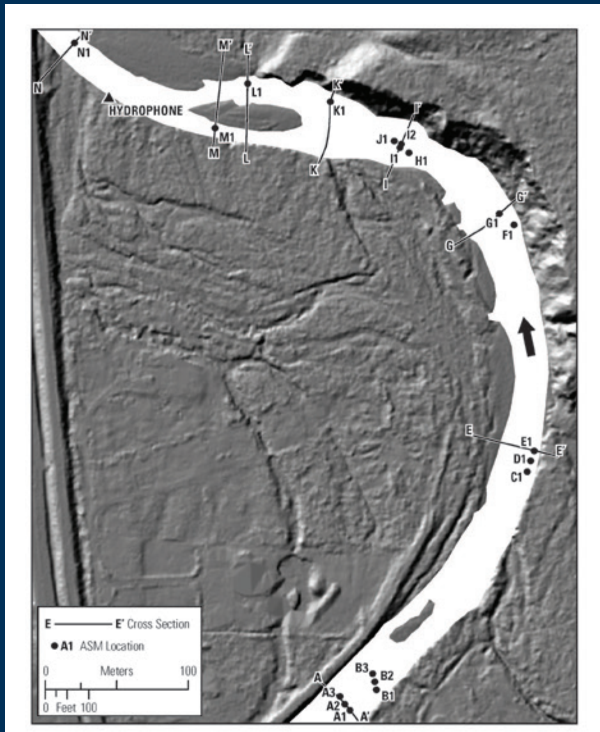
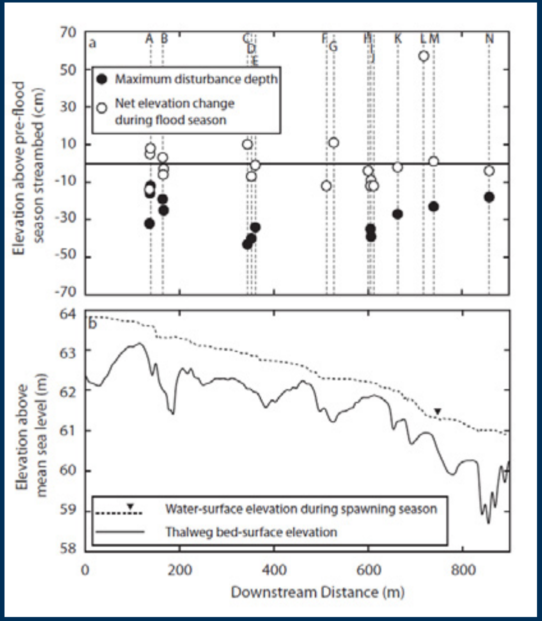
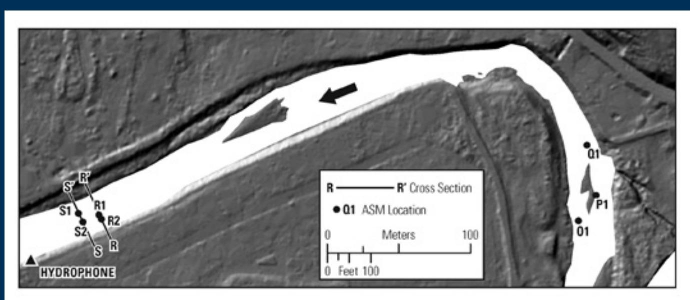
Longitudinal patterns of scour

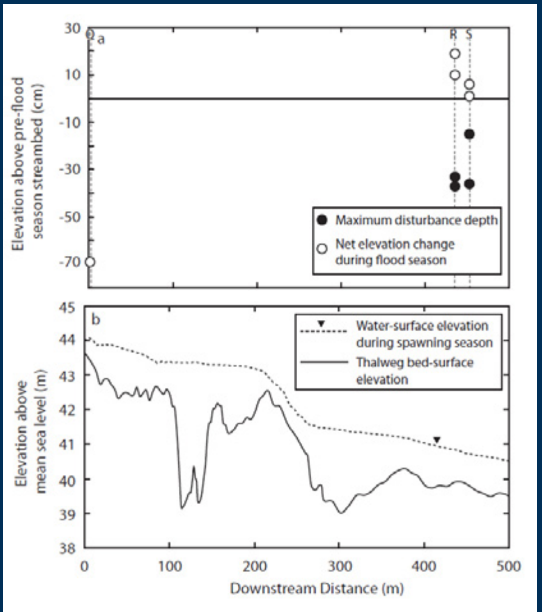


Reach 1





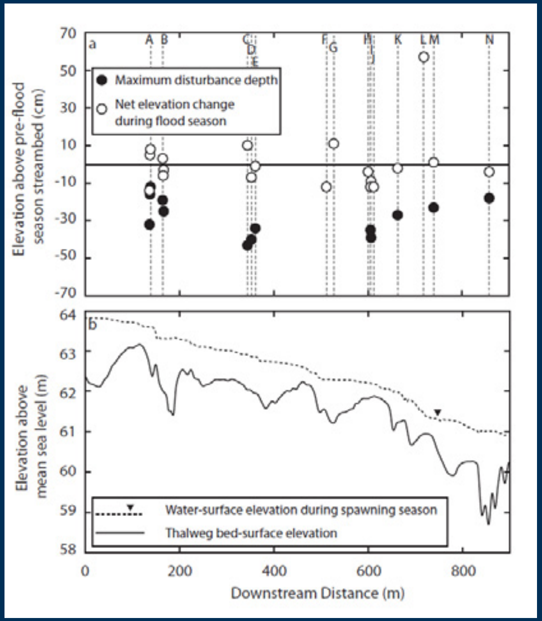
Reach 2

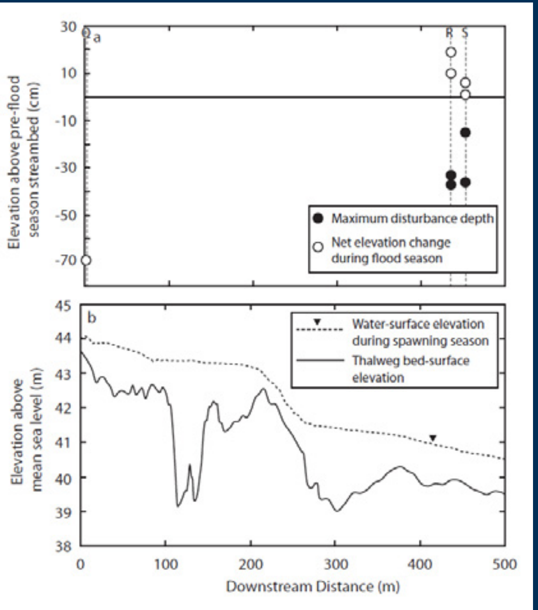


from Gendaszek and others (pub. B)

Longitudinal patterns of scour

- One ASM disturbed in event A; 17 ASMs disturbed in event B; 0 disturbed in event C
- No discernible spatial patterns of scour
- Data from 4 scour chains showed depth of scour measured by the chains to be similar to depth of scour measured by ASMs
- Fill, in most locations, emplaced a bed surface similar to the pre-flood surface; in general, the difference in bed-elevation change over the flood season was less than the depth of scour





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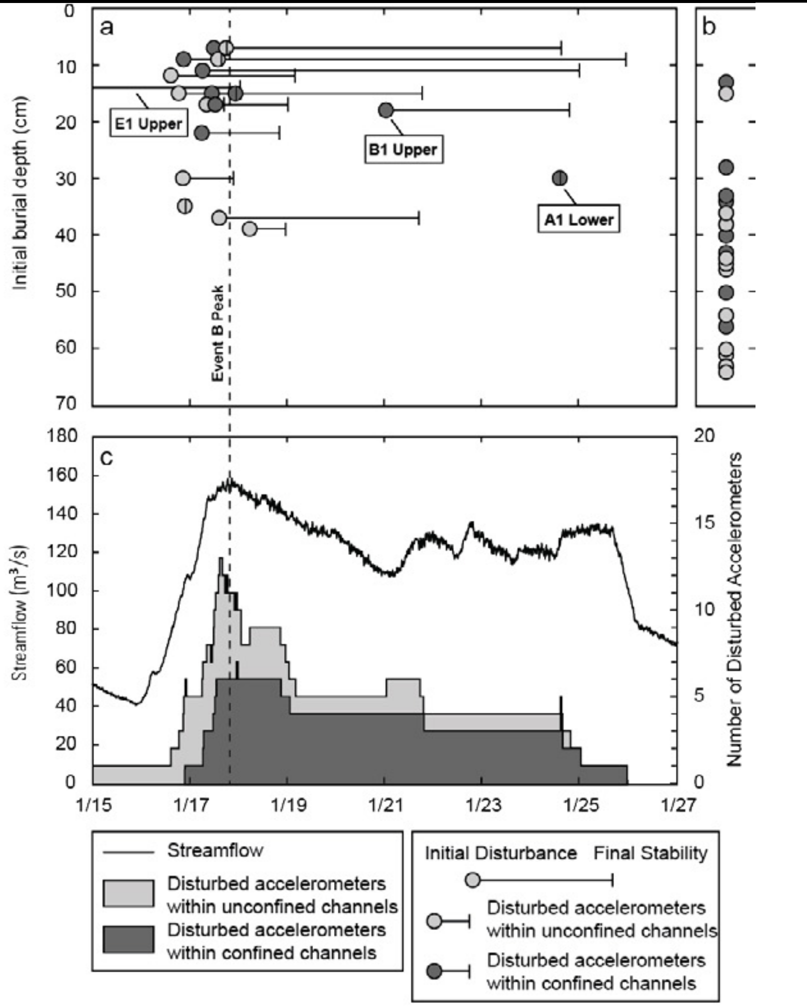
from Gendaszek and others (pub. B)



(a) Timing of accelerometer disturbance and initial accelerometer burial depth during high-flow event B. Accelerometer E1 Upper was initially disturbed during high-flow event A. Accelerometers B1 Upper and A1 Lower were initially disturbed days after the peak of event B. (b) Initial burial depth of accelerometers not disturbed during high-flow event B. (c) Streamflow and cumulative disturbed accelerometers in confined and unconfined study reaches during high-flow event B.

USGS

from Gendaszek and others (pub. B)

ASM data

- Most disturbance occurred on the rising limb of the hydrograph
- A few accelerometers were first disturbed during the sustained high flow
- A general pattern of bed stabilization during high-flow event B
- There was no disturbance (scour) deeper than 39 cm at ASM locations

Total depth of scour

	Confined reaches (n=9)	Unconfined reaches (n=8)	All ASMs (n=17)
Mean scour	**25 ± 10 cm**	**32 ± 9 cm**	**28 ± 10 cm**

- **No statistical difference in depth of scour between confined and unconfined reaches**
- **Scour started at about 2,000 ft^3/s, consistent with finding by Cascade Environmental Services (1991)**

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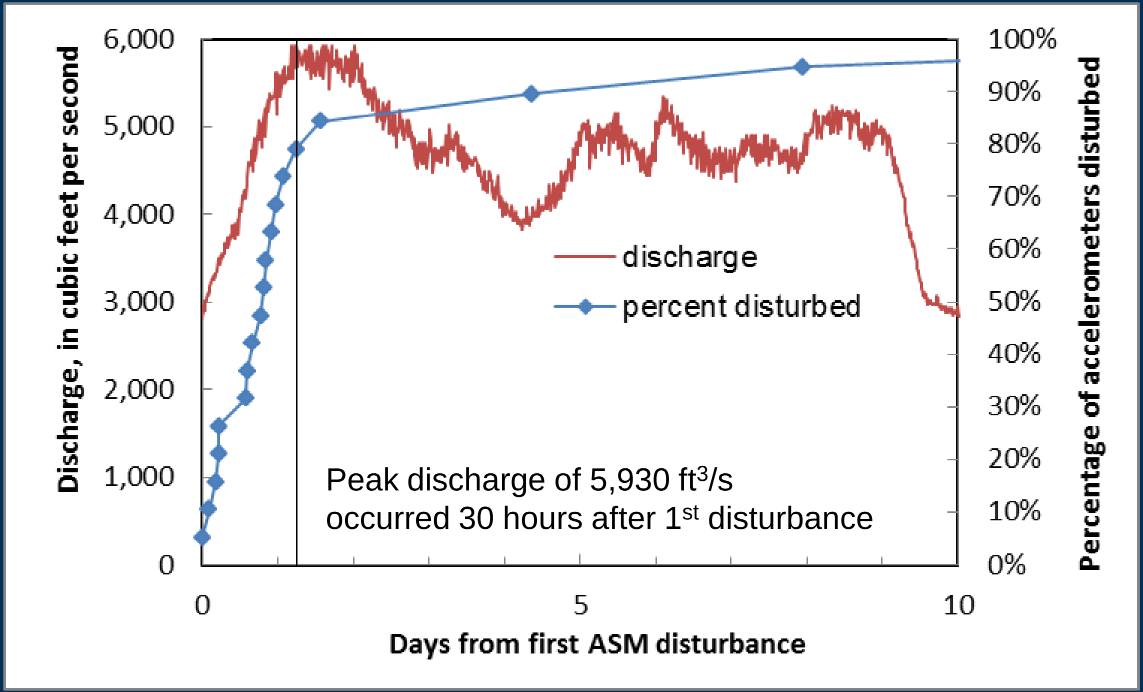
Temporal patterns of scour



- During high-flow event B, first disturbance of accelerometer occurs when discharge is 2,830 ft^3/s
- Of 19 accelerometers disturbed during high-flow event B, 84% were first disturbed before the peak of the hydrograph
- Only 16% of accelerometers were disturbed during the following 8 days of sustained high flow

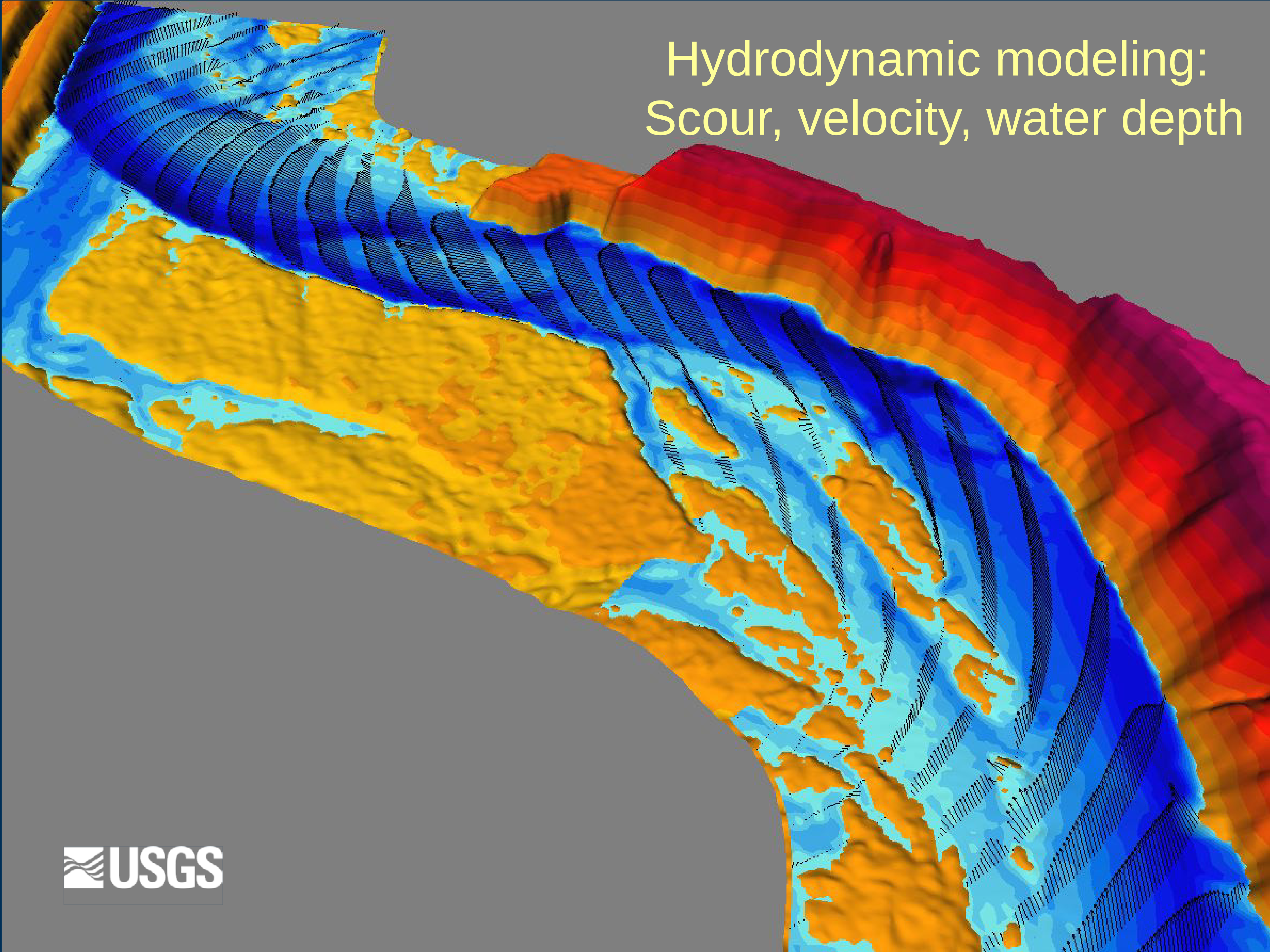
USGS

Insight into scour processes

- **Scour into the gravel bed occurs predominantly during the rising limb of the hydrograph, and scour to a given depth (that is, redd pocket) occurs in a matter of hours**
- **However, a limited number of locations did scour days after the flood peak in response to morphologic evolution of the river channel**
- **In terms of managing flow for differences in magnitude and duration, the scour response occurs faster than the ability to change flows; also, maintaining high flow just after a peak does not cause additional widespread scour**

USGS

Hydrodynamic modeling: Scour, velocity, water depth



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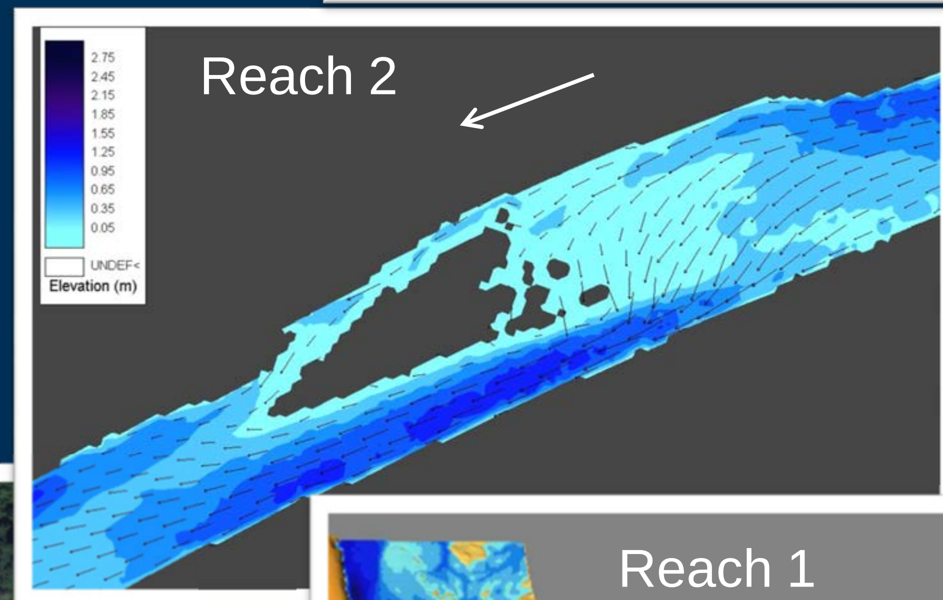
Hydrodynamic Modeling

- Simulate inundation, velocity, and bed shear stress in study reaches for increasing discharges
- Model results were related to field-scour data to predict spatial patterns of disturbance to the depth of salmon egg pockets

USGS

Hydrodynamic Modeling

iRIC – FaSTMECH 2-D model

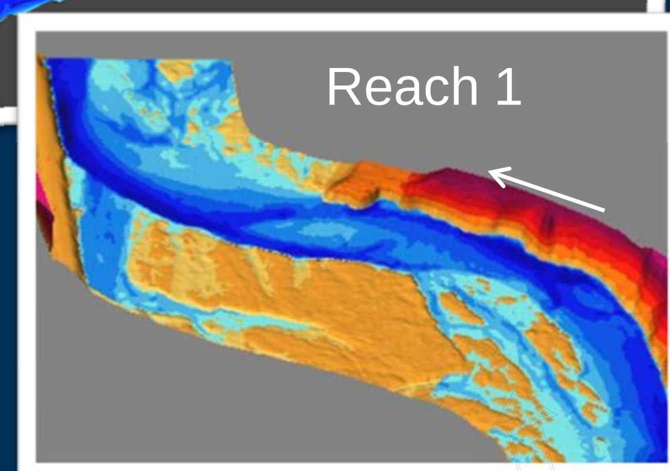


Boundary Conditions:

- **Discharge**
- **Stage**

Predict:

- **Water-surface elevation**
- **Velocity**
- **Depth**
- **Shear stress**



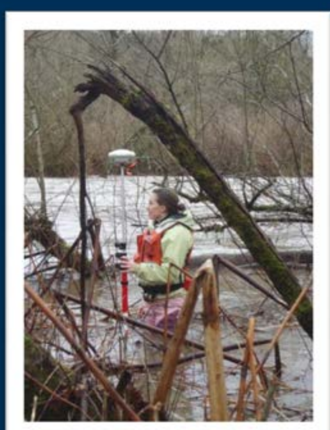
USGS

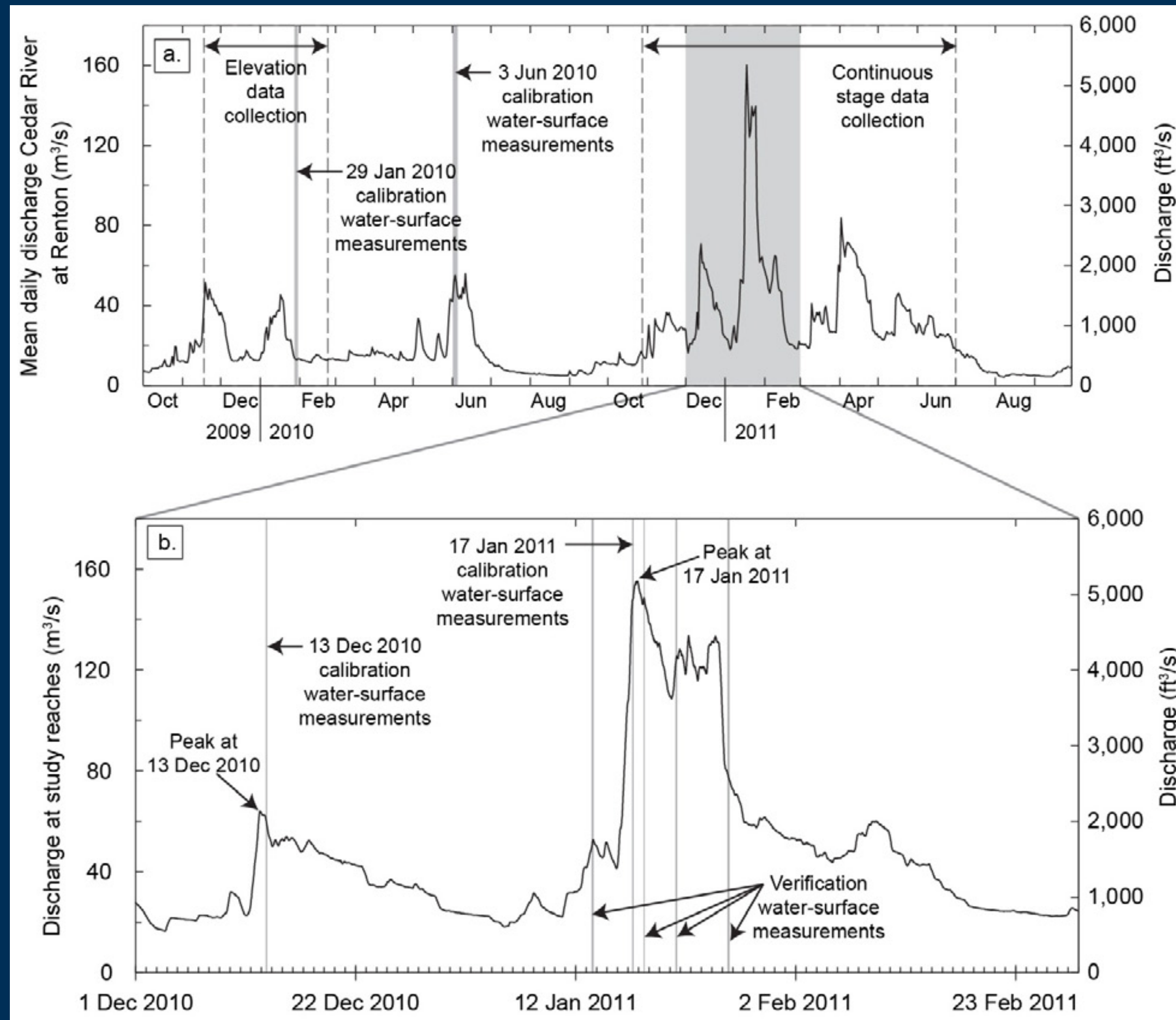
iRIC: ***http://wwwbrr.cr.usgs.gov/projects/GEOMORPH_Lab/project-MDSWMS.html***

Calibration and Verification Flows during Study Period

January high flow event:

- **Peak discharge = 168 m^3/s (5,930 ft^3/s)**
- **~7-year flow**





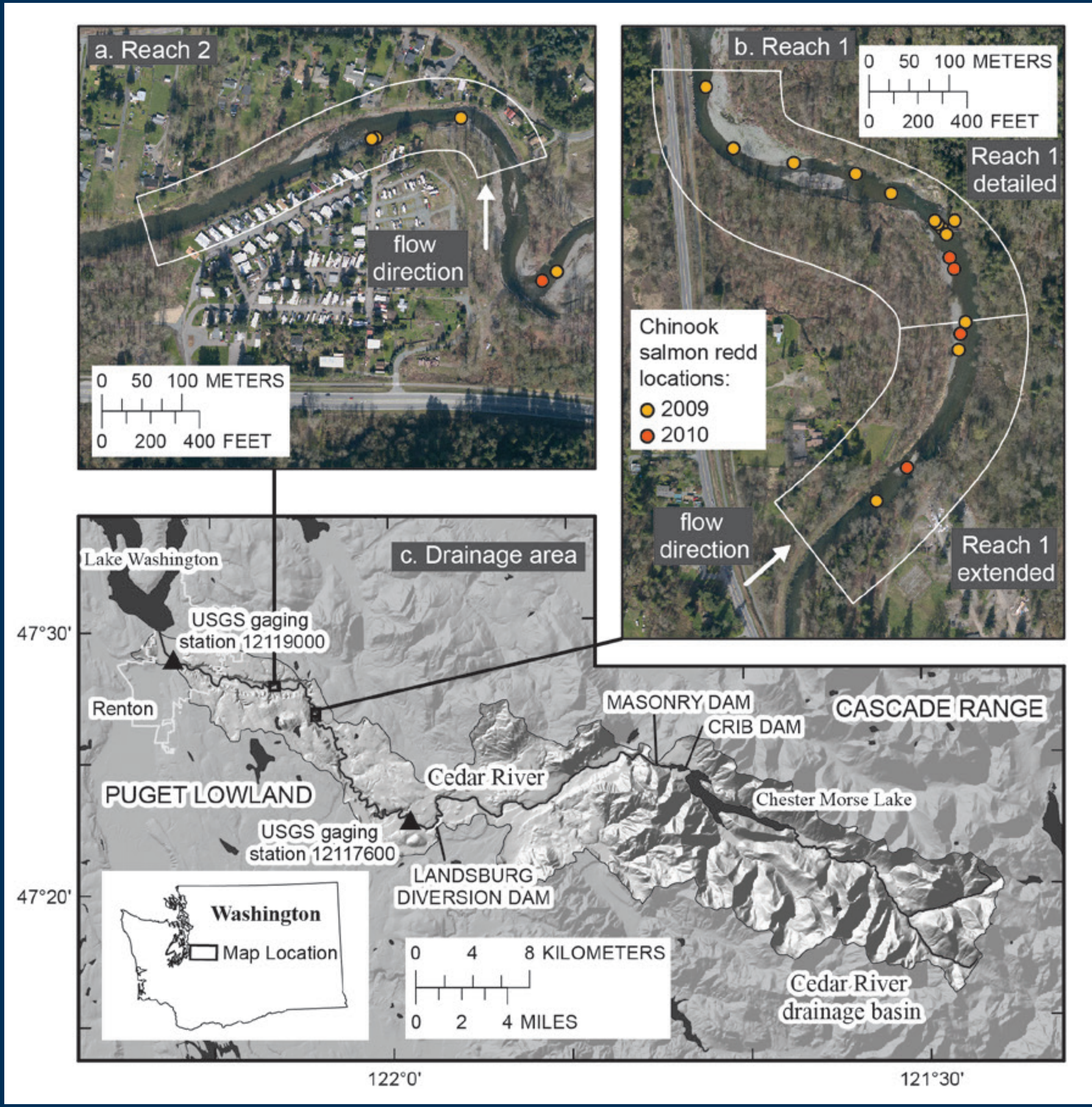
USGS

from Czuba and others (pub. C)

Representative Reaches

Chosen for:

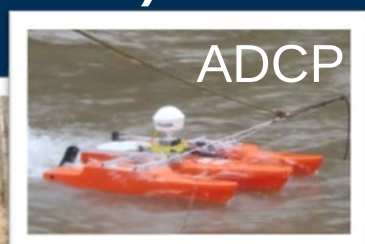
- **Safety**
- **Access**
- **Redd suitability**
- **Confined vs. Unconfined**

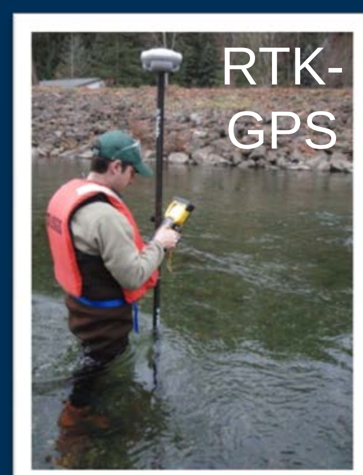


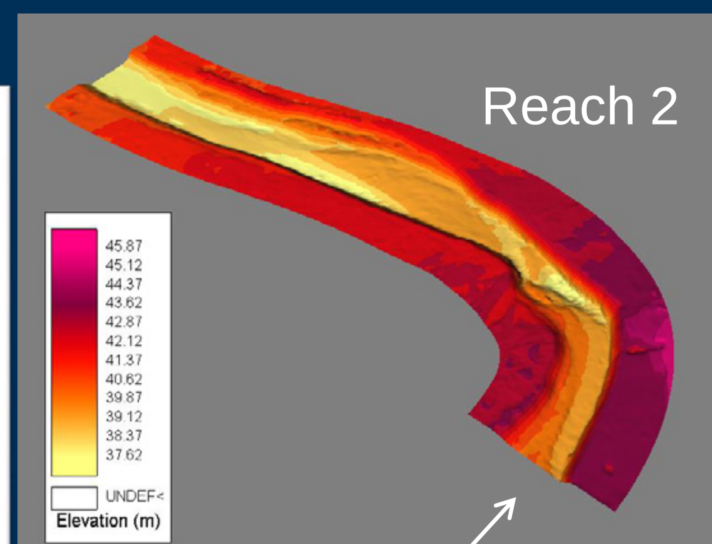
from Czuba and others (pub. C)

Bathymetry Data Collection and Model Construction

- **Real-Time Kinematic Global Positioning System (RTK-GPS)**
- **Acoustic Doppler Current Profiler (ADCP)**
- **Light detection and ranging (LiDAR)**

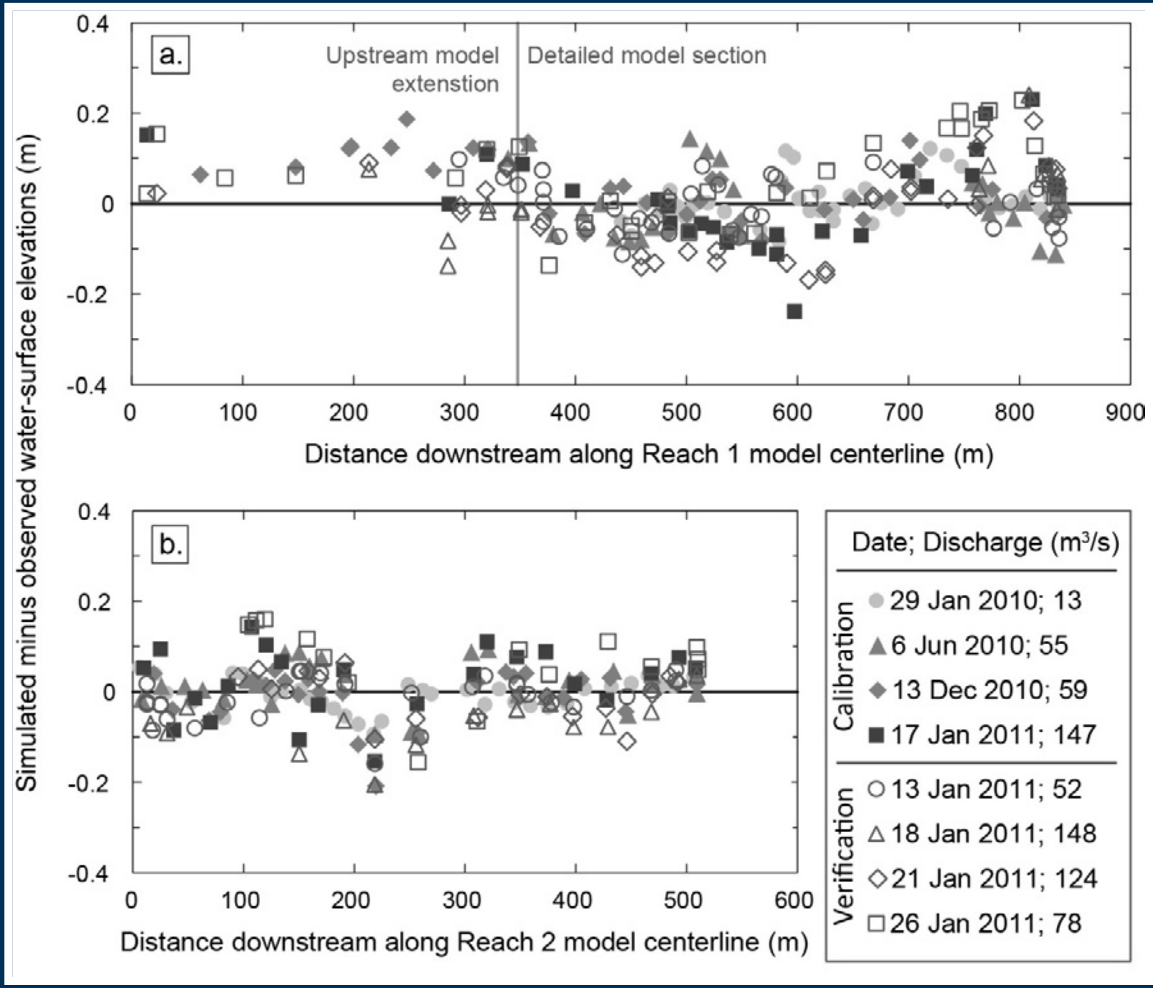






Model Calibration and Verification

- **Comparison of simulated and observed water-surface elevations**



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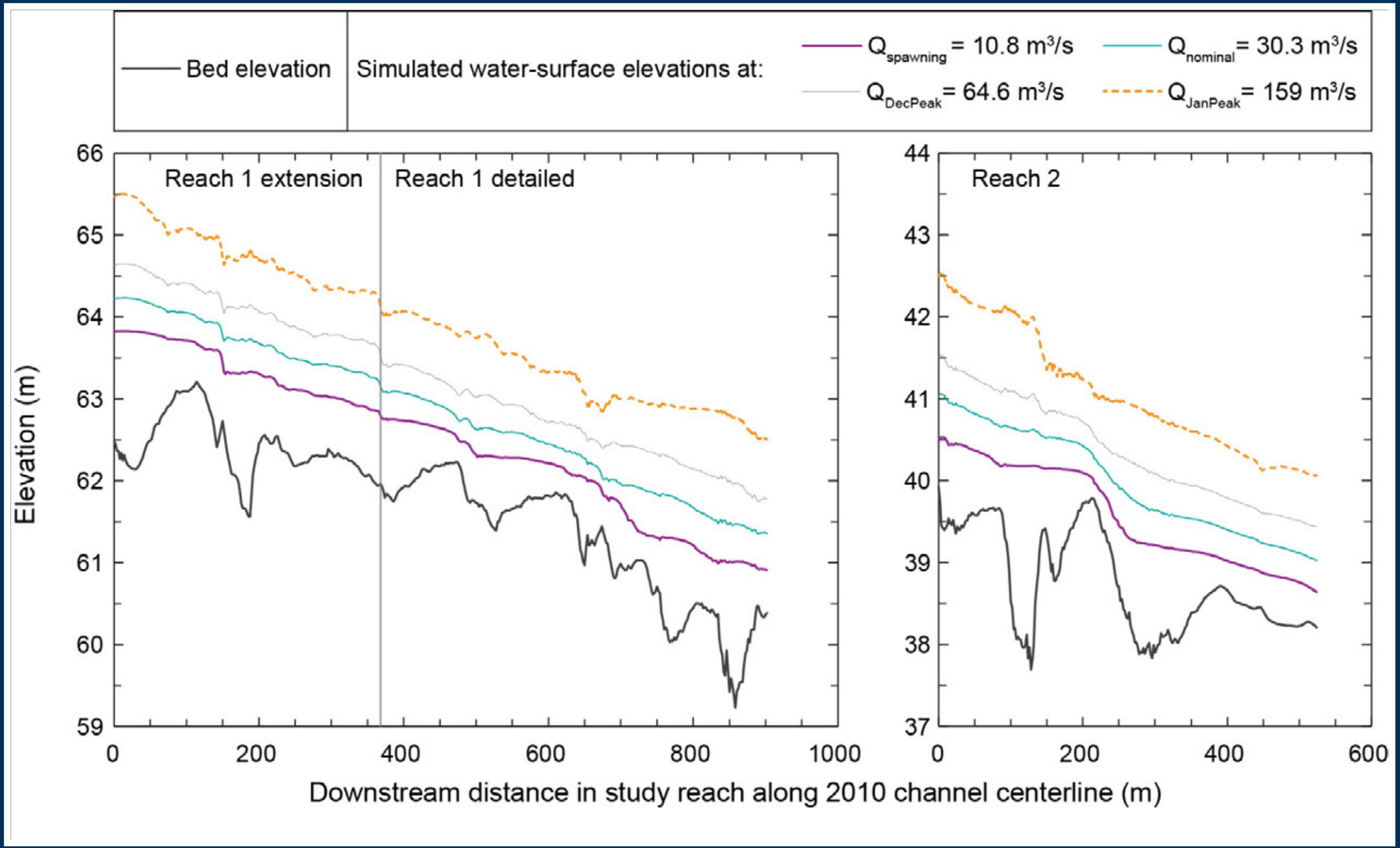
from Czuba and others (pub. C)

Model Simulations

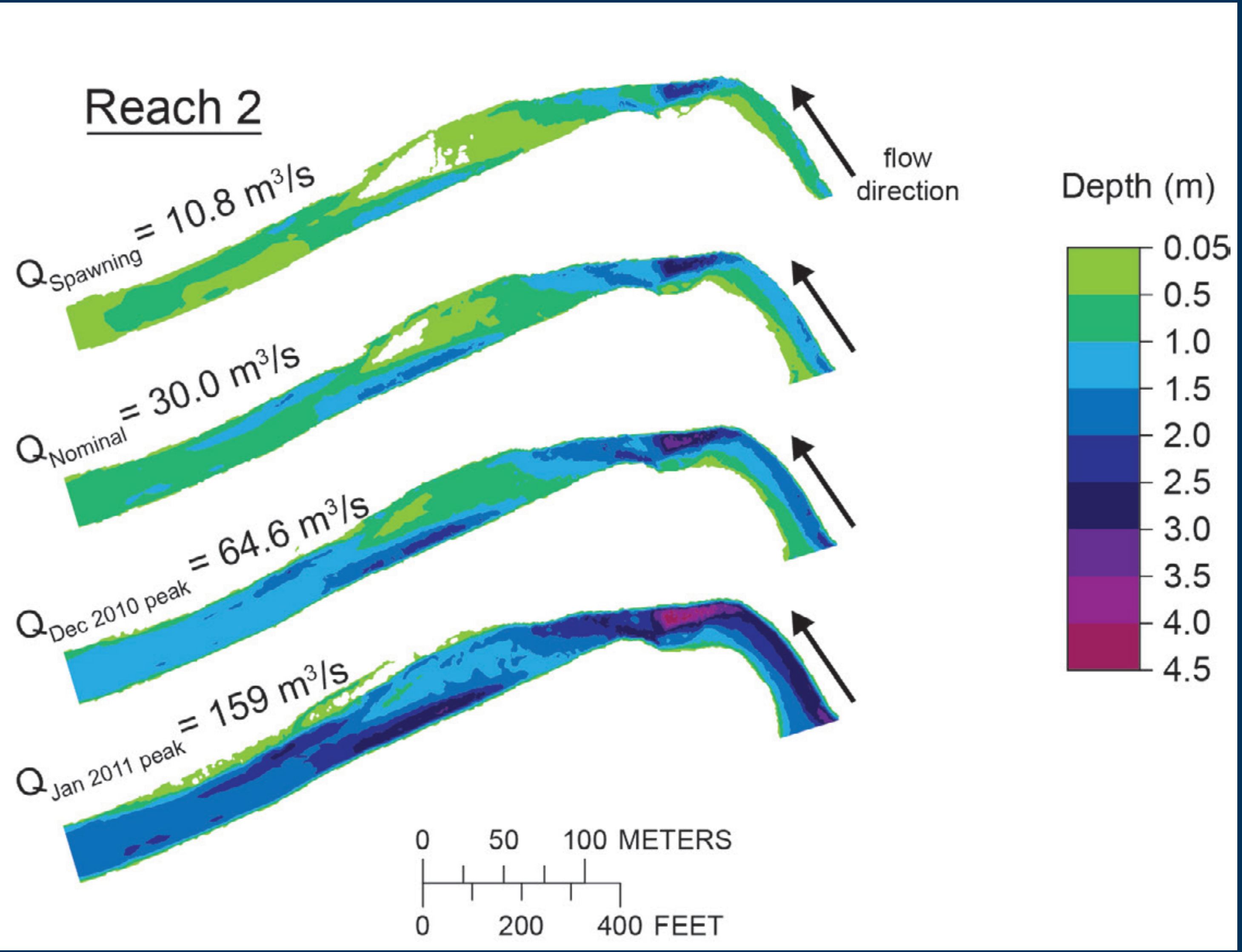
Flow event		Discharge at study reach for model simulations		High-flow event discharges at Renton gaging station (USGS 12119000)	
		m^3/s	ft^3/s	m^3/s	ft^3/s
$Q_{Spawning}$	2010 Spawning Discharge	10.8	380	-	-
$Q_{Nominal}$	Nominal Discharge	30	1,060	-	-
$Q_{Dec\ 2010\ peak}$	13 Dec 2010 Peak	64.6	2,280	79.9	2,820
$Q_{Jan\ 2011\ peak}$	17 Jan 2011 Peak	159	5,600	168	5,930
Q_{1A}	Scenario 1A	52.3	1,850	56.6	2,000
Q_{1B}	Scenario 1B	78.5	2,770	85	3,000
Q_{1C}	Scenario 1C	105	3,700	113	4,000
Q_{1D}	Scenario 1D	131	4,620	142	5,000

Simulated Water-Surface Profiles



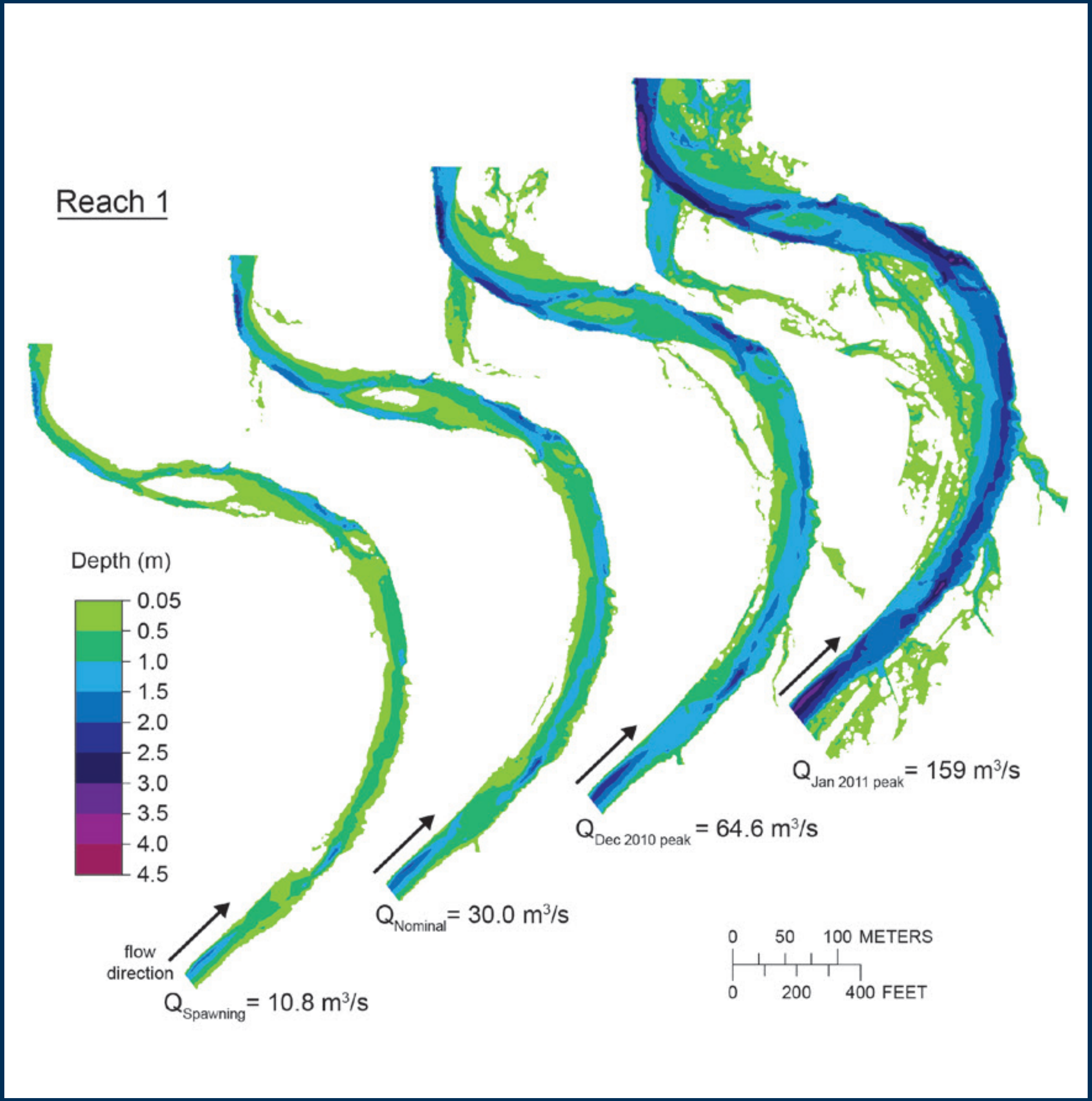
from Czuba and others (pub. C)

Simulated Flow Depths



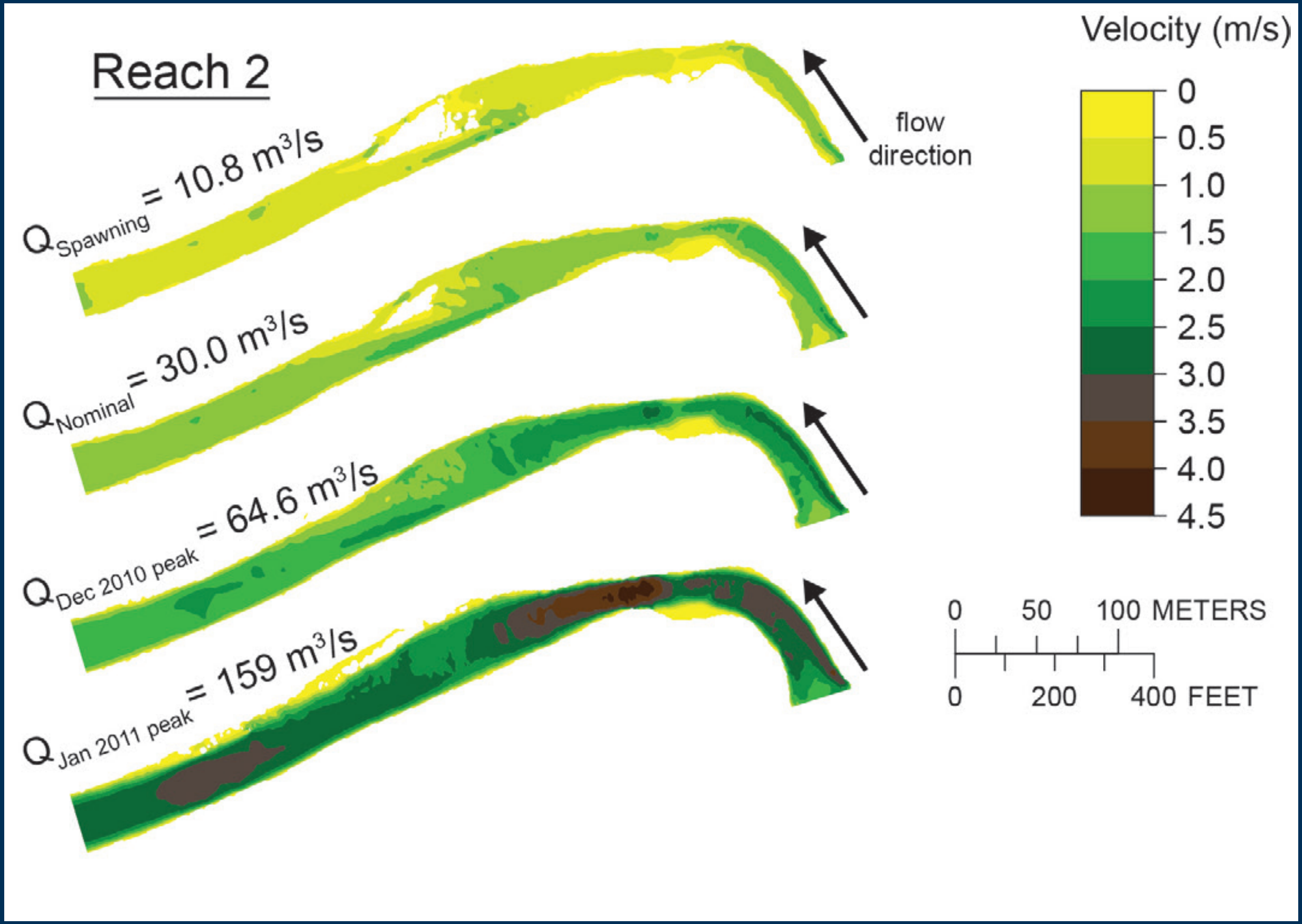
from Czuba and others (pub. C)

Simulated Flow Depths



from Czuba and others (pub. C)

Simulated Flow Velocities



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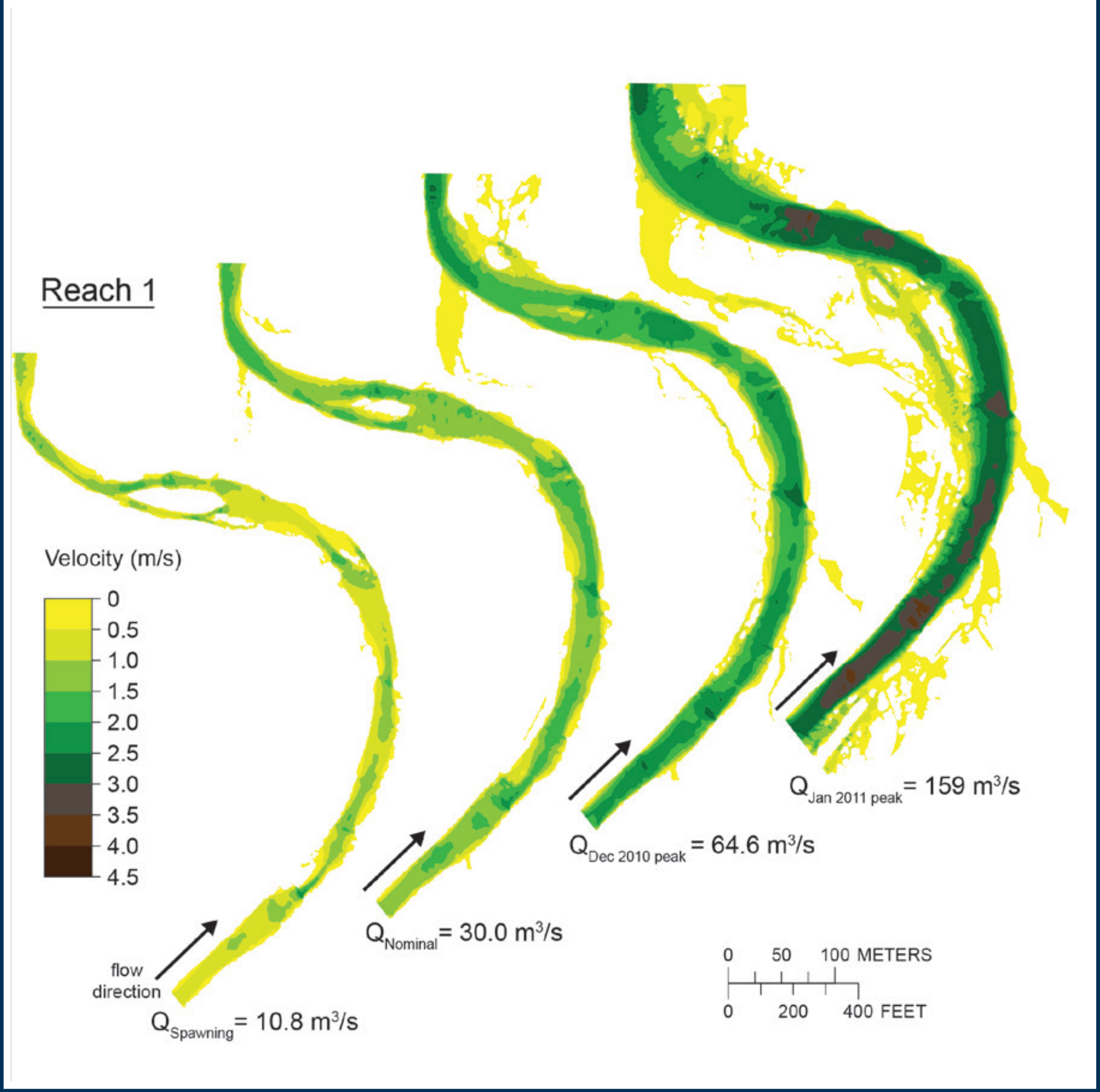
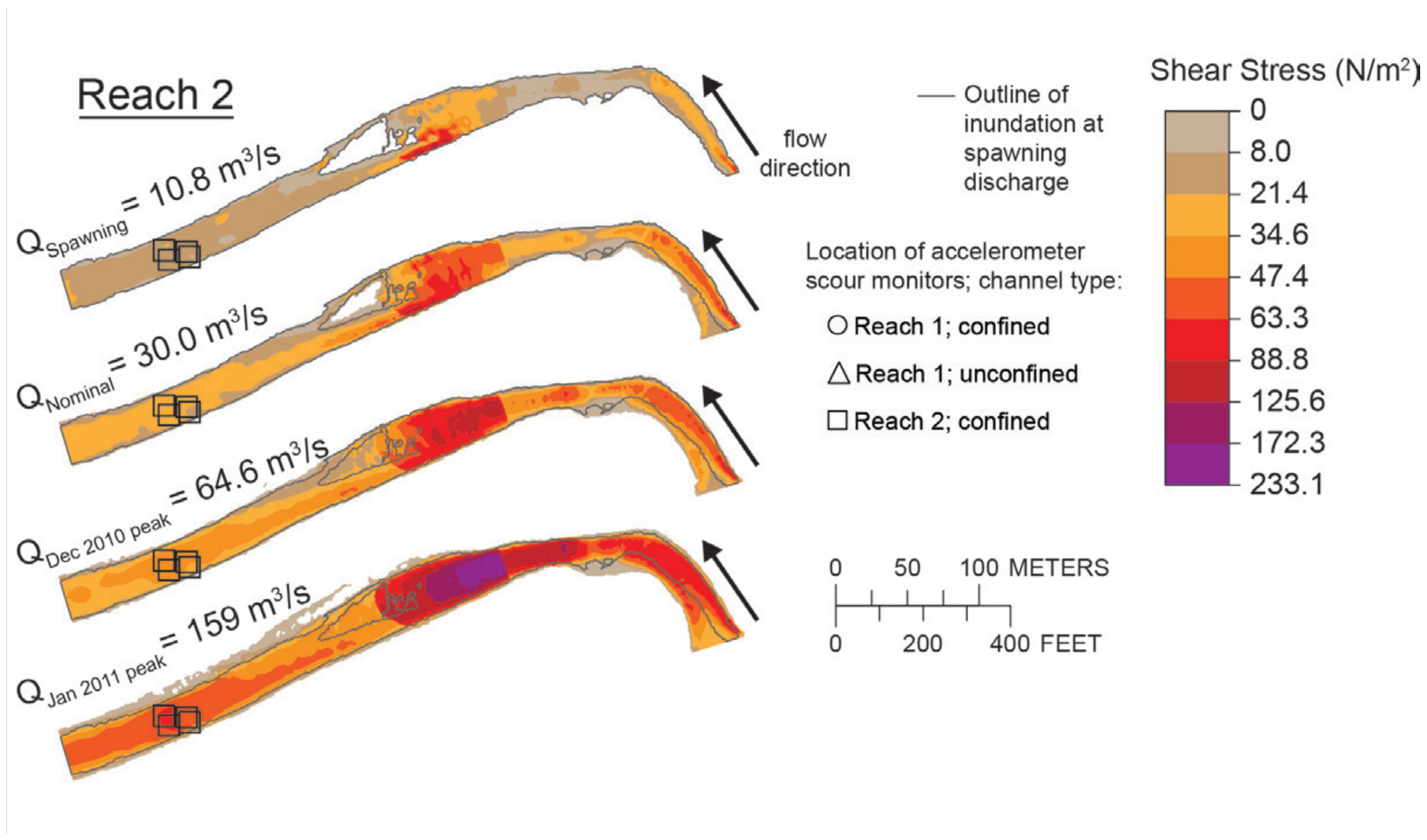
Simulated Flow Velocities



from Czuba and others (pub. C)

Simulated Shear Stress



from Czuba and others (pub. C)

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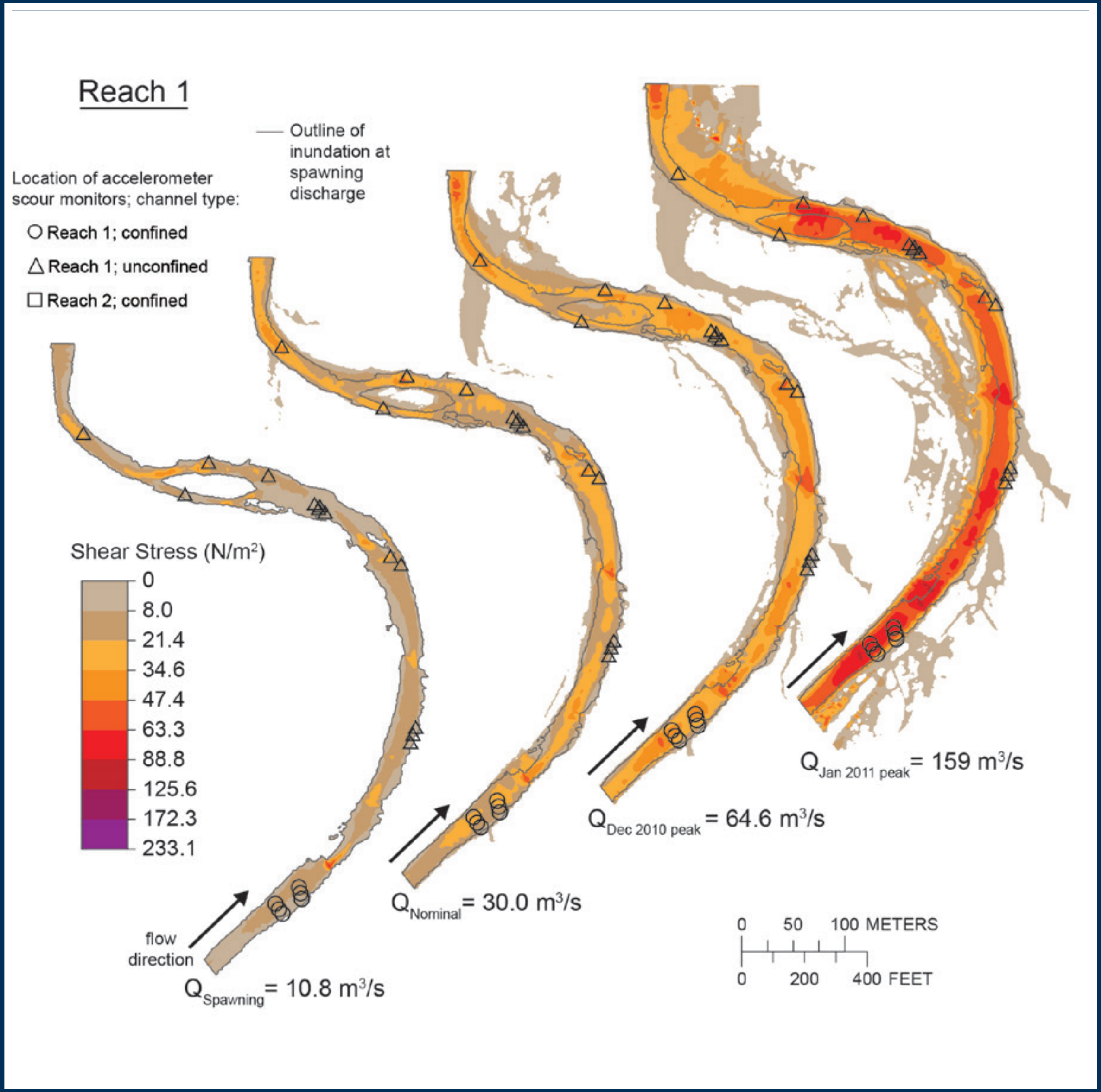
Simulated Shear Stress



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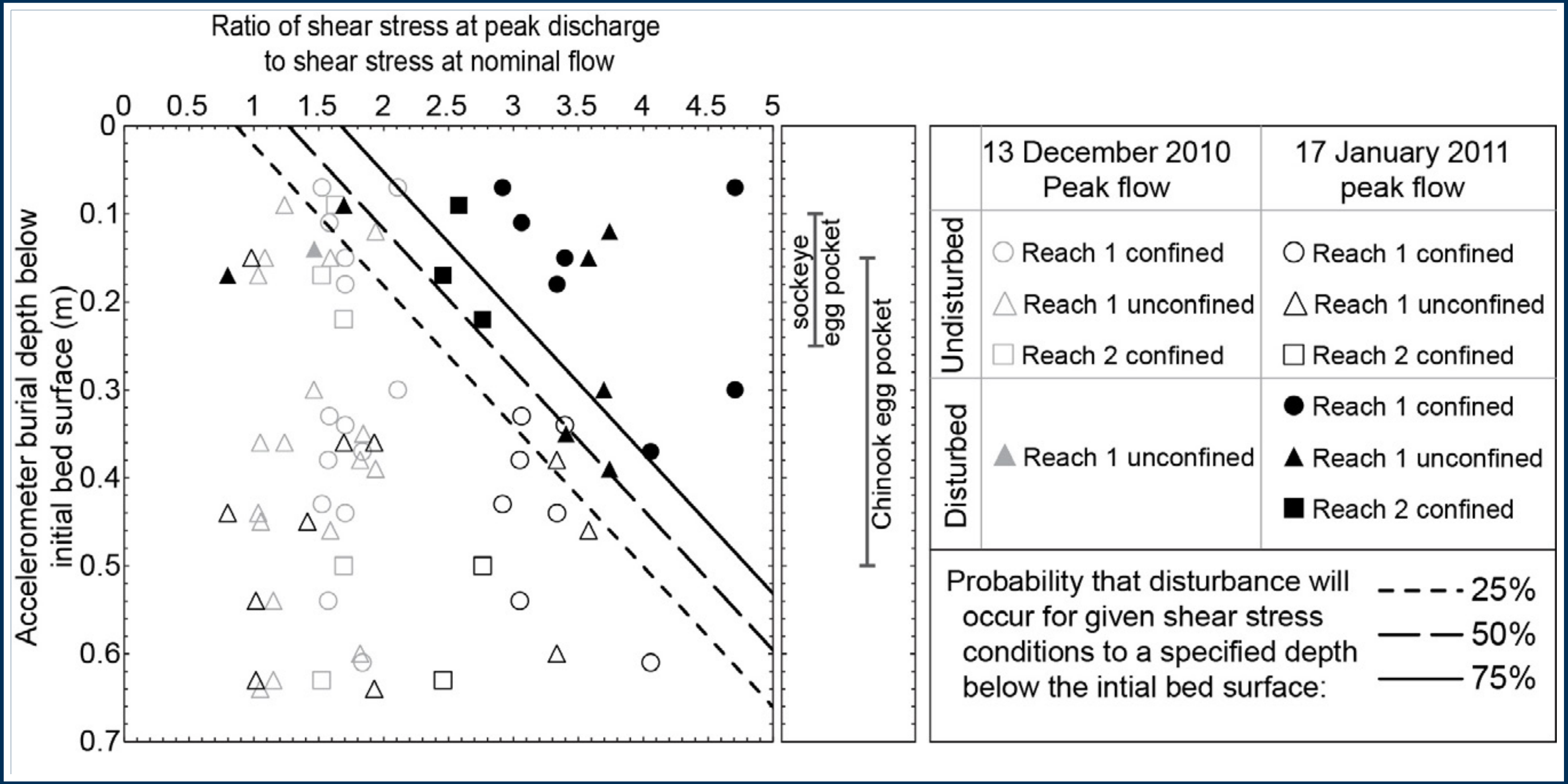
from Czuba and others (pub. C)

Logistic regression for model results and accelerometer response

- **To predict spatial response of bed to peak shear stress at burial depths of egg pockets**



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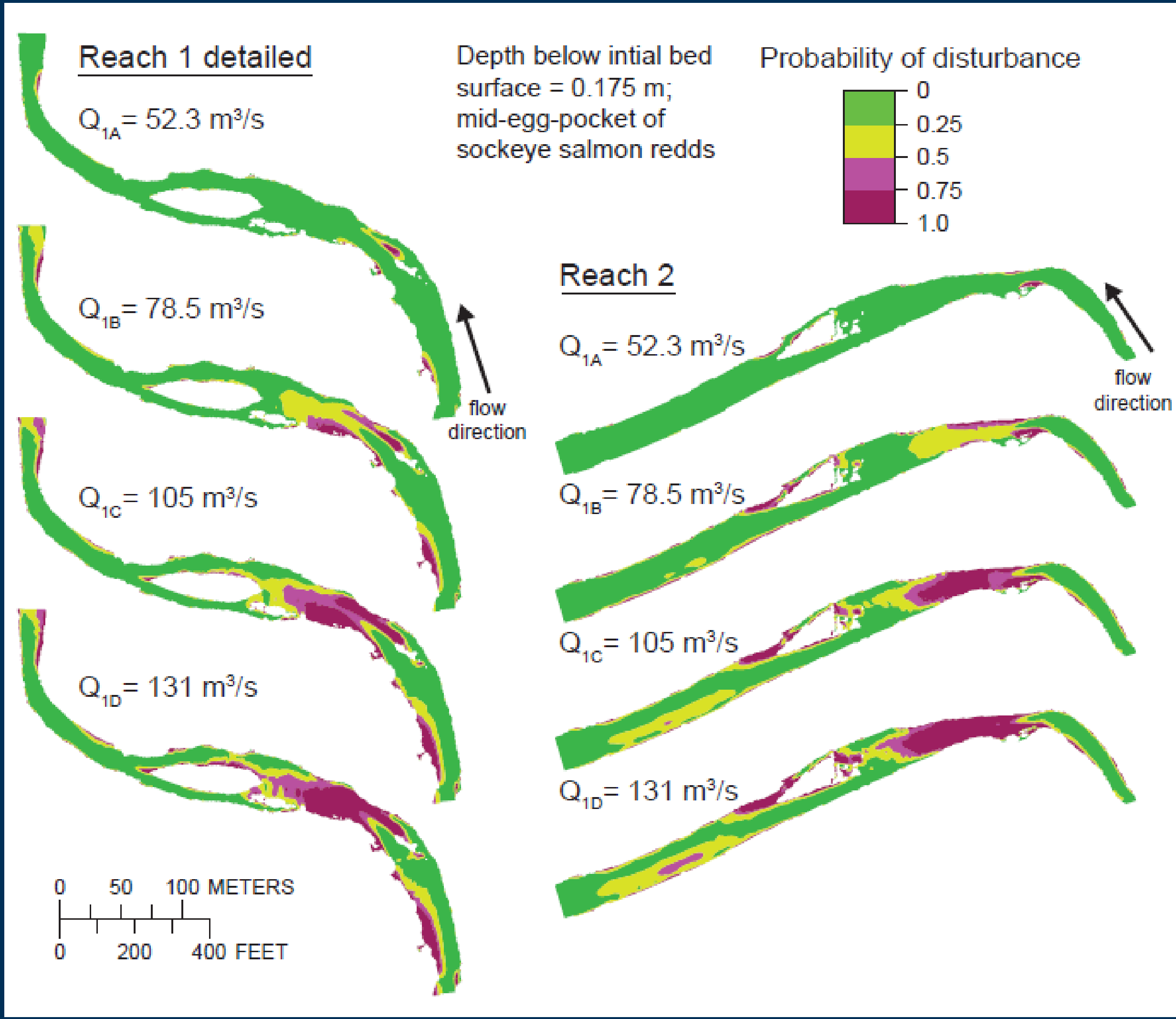
Application of logistic regression

- **Spatial mapping of logistic regression to predict bed disturbance at increasing discharge**

- **Example for the burial depth equal to the middle of sockeye salmon egg pocket**



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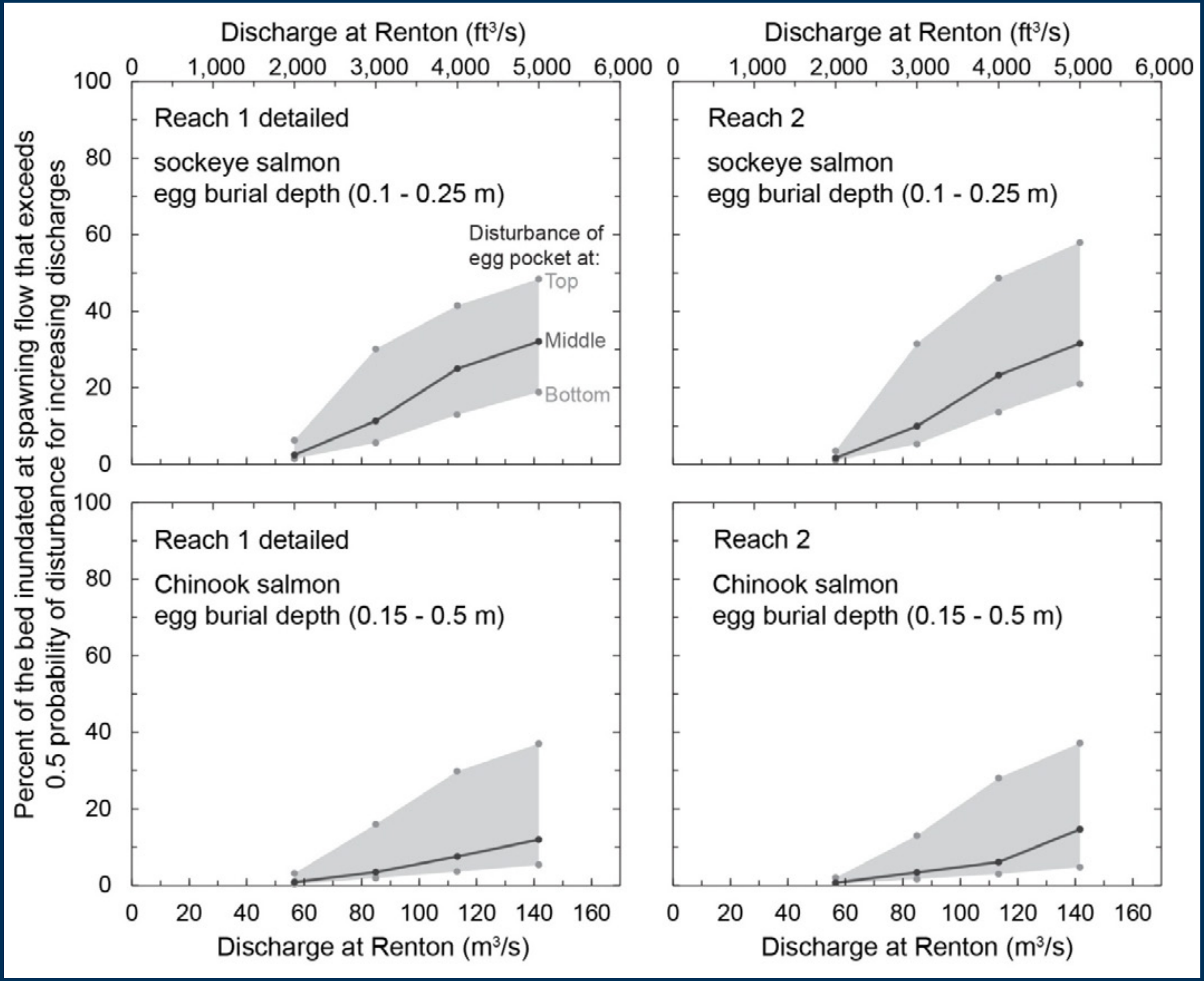
Spatial summary of bed disturbance



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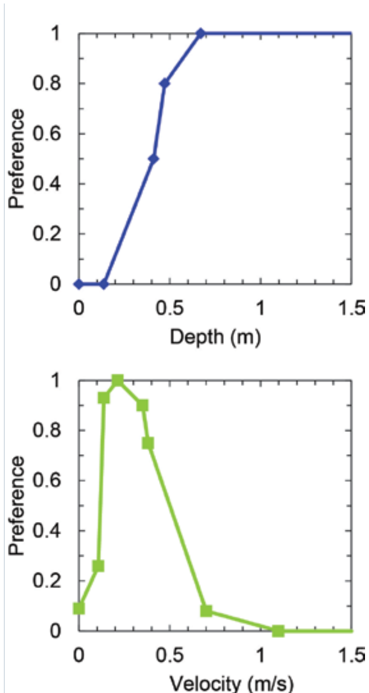
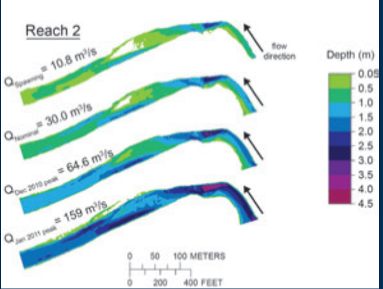
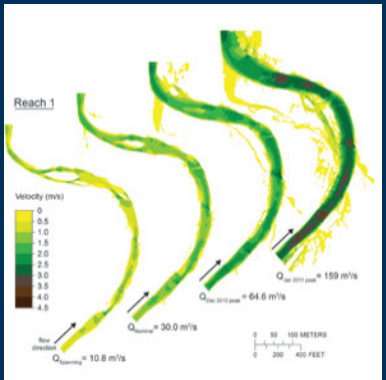
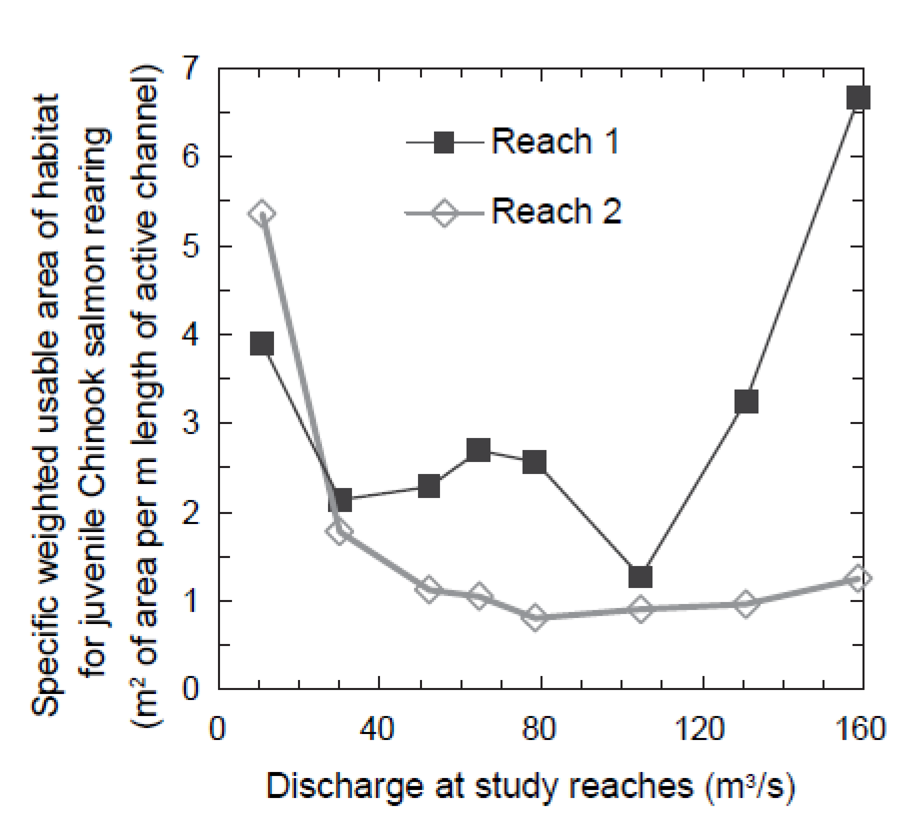
Habitat suitability



Chinook salmon juvenile rearing depth and velocity preference







Insight from modeling

- Confined reaches generally have greater water depth, water velocity, and shear stress
- Bed disturbance to the depth of egg pockets is relatively similar between confined and unconfined reaches, presumably because the river has adjusted to its localized hydraulic conditions
- Unconfined reaches provide additional benefits to river function including flood attenuation and habitat refugia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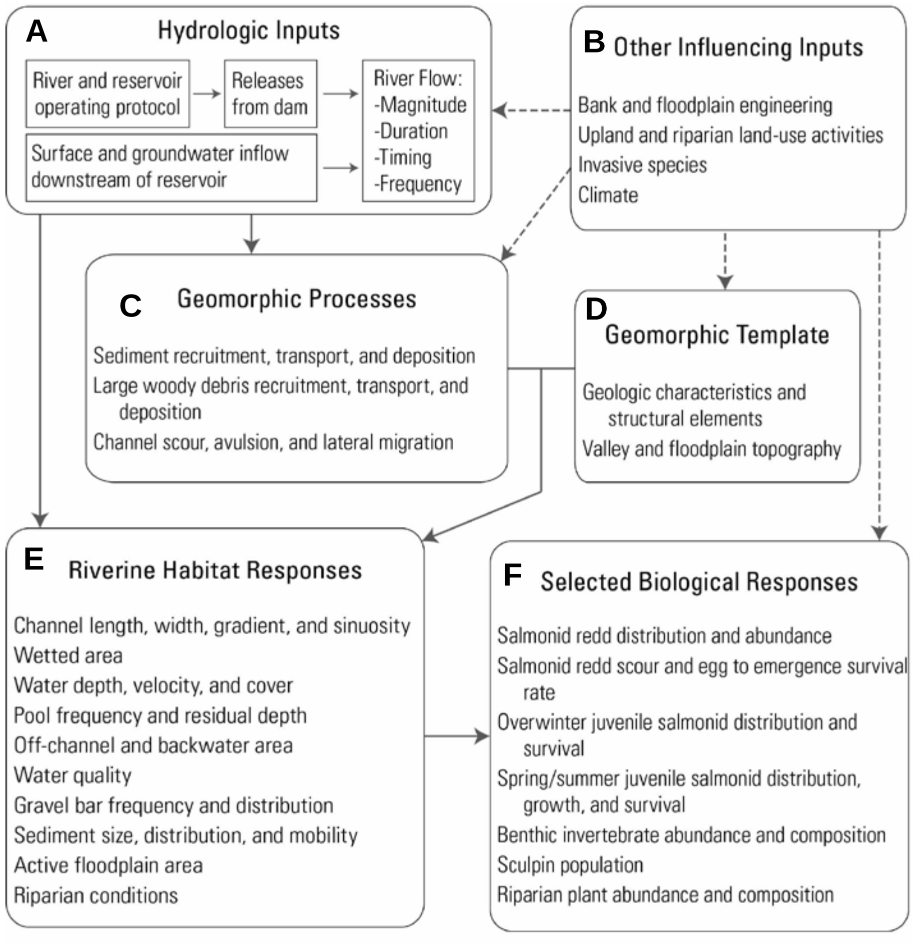
Insight from modeling (cont'd)

- Not all areas of the bed are disturbed at the largest flows
- As discharge increases from 56.6 m^3/s (2,000 ft^3/s) to 142 m^3/s (5,000 ft^3/s), the disturbance probability of the streambed to the depth of the top of salmonid egg pockets increases linearly from approximately 4 – 6% to 50 – 60% and from 2 – 3% to 40% for sockeye and Chinook salmon, respectively

Conceptual model, monitoring metrics, and peak-flow management

Conceptual Model

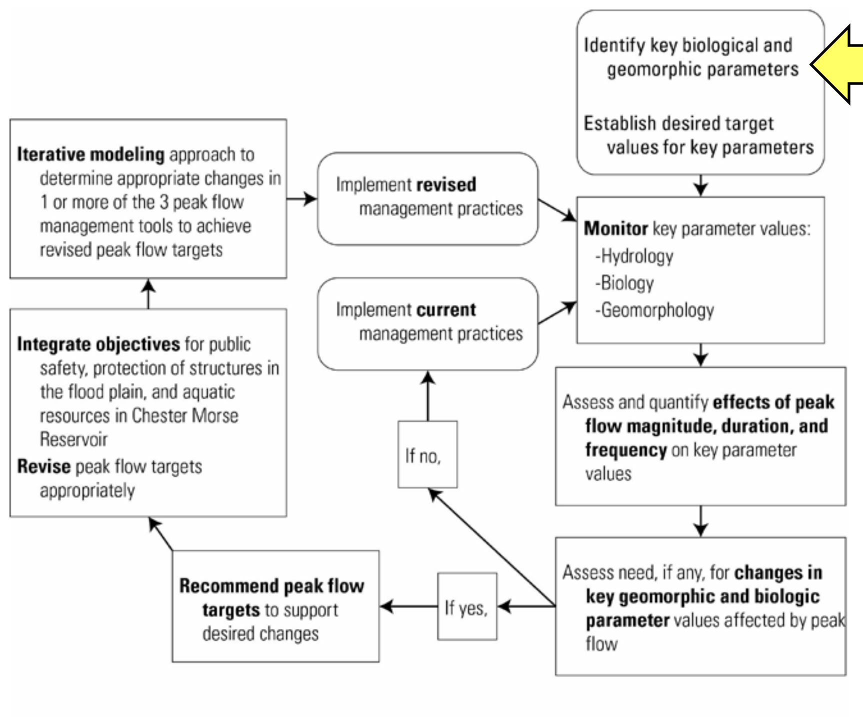
- Conceptual model developed to identify possible links between measureable geomorphic parameters and ecological responses
- Scientific monitoring and research in the Cedar River can be planned using the conceptual model for guidance
- The Cedar River adaptive-management framework uses information and data collected within the conceptual model



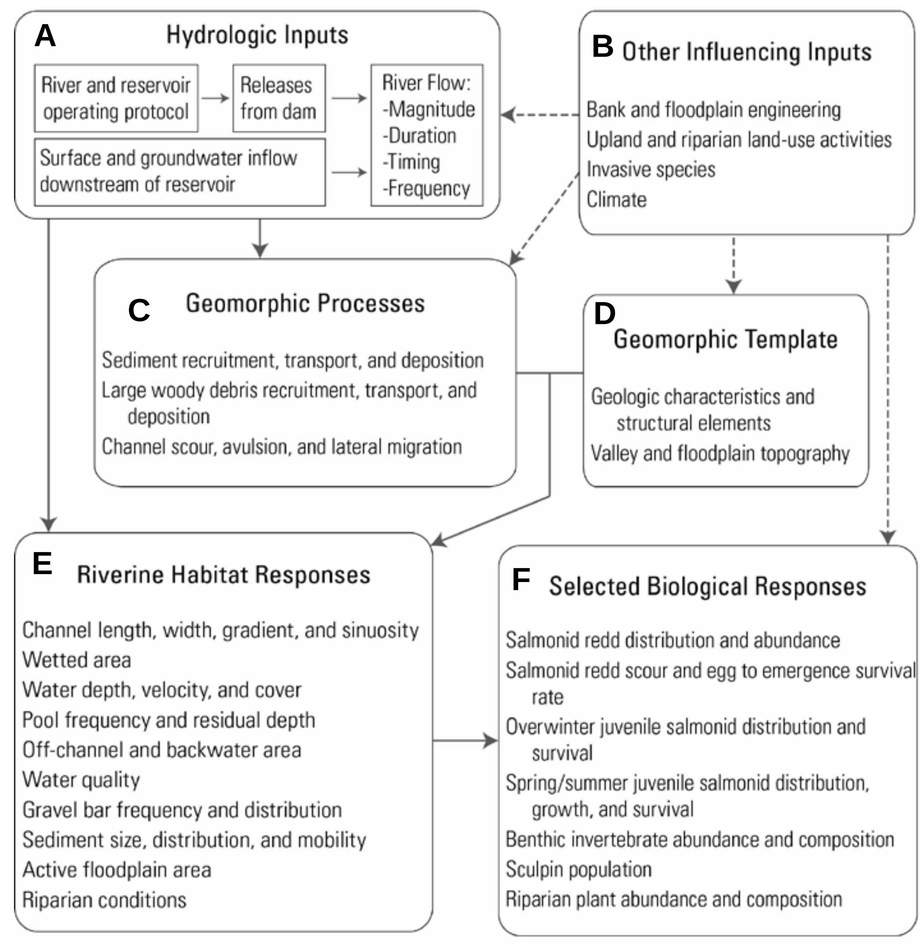
Peak-flow conceptual model for the Cedar River, Washington

USGS

Linking Adaptive Management and Conceptual Model



Seattle Public Utilities' schematic overview of peak-flow adaptive-management practices for the Cedar River, Washington



Peak-flow conceptual model for the Cedar River, Washington

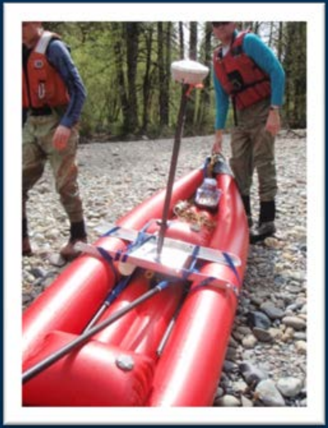
- **Scientific information feeds into Seattle Public Utilities' Cedar River adaptive-management plan**

USGS

Monitoring Metrics:
The final deliverable in the study was to identify key geomorphic parameters to monitor in the future

Steps:

- **First, USGS scientists identified 14 possible long-term monitoring activities (with subtasks)**
- **Next, using an expert elicitation, the Cedar River Instream Flow Commission (IFC) and USGS scientists worked together to evaluate the usefulness of each potential monitoring metric**
- **USGS finalized the list and estimated effort (that is, relative cost) required for each monitoring task**



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Possible monitoring metrics

Task	Metric	Units	Pools	Gravel	Habitat/Veg/LWD	Planform geomorph	Inverts
1. Conduct periodic surveys to measure pool frequency and depth	Pools freq and depth	count/km; m	x				
2. Conduct periodic surveys to map total area of available spawning gravels (sediment size)	Area containing spawnable gravels	m^2		x			
3. Conduct periodic surveys to measure grain size of active redds (what the fish actually use)	Redd grain size	cm		x			
4. Measure and track exposed gravel bars (from field work, LiDAR, aerial imagery)	Exposed gravel bars	m^2; m^3; m		x			
a. Height, area at low flow							
b. Grain size							
c. Sand percentage							
5. Monitor seasonal redd scour using best available techniques at specific sites	Scour	m		x			
6. Establish and track a sediment budget							
a. Monitor dredging activities	Dredging	m^3/yr		x			
b. Inventory landslides in river corridor	Landslides	m^3		x			
c. Survey accumulation of bedload through stage/discharge relations	Aggradation	m		x			
d. Identify and track sources and sinks of sediment	Sediment budget	tons/yr		x			
7. Establish bedload-monitoring gaging station(s)	Bedload	kg/yr		x			
8. Conduct periodic surveys to map off channels (access, number, quality, etc.)	Side channels	count; quality			x		
9. Measure and track large woody debris	LWD	count, quality			x		
10. Measure channel complexity	Channel complexity	tbd			x		
11. Maintain an inventory of revetments along river corridor	Revetments	count; location				x	
12. Track benthic invertebrates and algae at specific monitoring sites (food web)	Inverts	count, quality, assemblage					x
13. Conduct reach-specific monitoring							
a. Map suitable spawning areas (sediment size, water depth, water velocity)	Area containing spawnable gravels	m^2		x			
b. Map texture and grain size: look for trends;	Grain size	m		x			
c. Survey wood precisely	LWD	count, quality			x		
d. Map side channels in the floodplain	Side channels	count; quality			x		
e. Map vegetation and shade to river	Riparian vegetation	count; quality			x		
f. Map gravel bars	Exposed gravel bars	m^2; m^3; m		x			
14. Monitor planform geomorphology of the lower river (LiDAR/GIS)							
a. Active channel width	Active channel width	m				x	
b. Low flow channel width	Low-flow channel width	m				x	
c. Vegetation distribution	Riparian vegetation distribution	count; quality			x		
g. Canopy height (1st-last returns)	Riparian vegetation height	m			x		
d. Quantify secondary channels	Side channels	count; quality			x		
e. Sinuosity	Sinuosity	m/m				x	
f. Channel migration	Channel migration rate	m/yr				x	

Monitoring Metrics:
Evaluating the candidate metrics

Key questions when evaluating each potential monitoring metric:

1. Where does this metric fit into the Conceptual Model (box A, B, C, D, E, or F)?
2. How strongly is this metric influenced by peak flows?
   [1 = not influenced … 5 = strongly influenced]
3. Do we understand the sensitivity of this metric to peak-flow management?
   [1=not at all … 5 = well understood]
4. Do we understand the benefits to fish from this metric?
   [1=not at all … 5 = well understood]
5. Would data from this metric change the way peak flows are managed?
   [1=not at all … 5 = a lot]
6. Is this task a *must*, a *want*, or *don't want*?

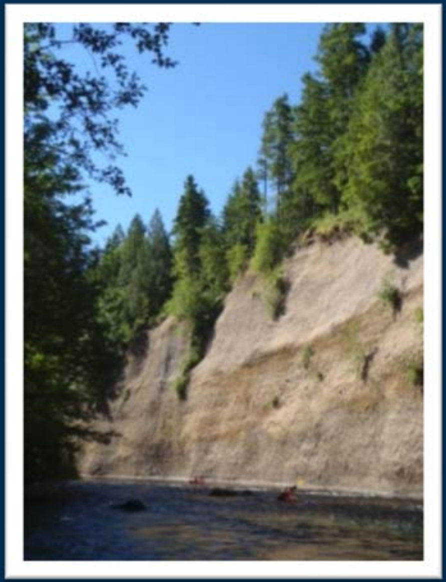
USGS

Expert elicitation: Scoring results

Task	Where does this fit into conceptual model? [A - F]	Influenced by peak flows?	Understand the sensitivity to peak-flow management?	Understand effects to fish?	Would this change management?	*Mean of all scores*	*Value: Mean of Q2 and Q5 only*	*Understanding: ave of Q3 and Q4*	Is this a must, a want, or don't want?	Relative cost?
5. Monitor seasonal redd scour using best available techniques at specific sites	E - C - F	5	3	5	5	*4.5*	*5*	*4*	**must**	medium
9. Measure and track large woody debris	C	4	4	5	4	*4.25*	*4*	*4.5*	**must**	low
2. Conduct periodic surveys to map total area of available spawning gravels (sediment size)	C - E - F	5	2	4	5	*4*	*5*	*3*	**must**	low
8. Conduct periodic surveys to map off channels (access, number, quality, etc.)	C - E - F	4	3	5	4	*4*	*4*	*4*	**must**	low
6. Establish and track a sediment budget	C - E	4	4	2	4	*3.5*	*4*	*3*	want	high
7. Establish bedload-monitoring gaging station(s)	C - E	4	4	2	4	*3.5*	*4*	*3*	want	high
4. Measure and track exposed gravel bars (from field work, LiDAR, aerial imagery)	E-F-C	4.5	4	2	3	*3.375*	*3.75*	*3*	want	low
14. Monitor planform geomorphology of the lower river (LiDAR/GIS)	D - C - E	3	4	3	4	*3.5*	*3.5*	*3.5*	want	med
1. Conduct periodic surveys to measure pool frequency and depth	E	4	3	4	3	*3.5*	*3.5*	*3.5*	want	low-med
10. Measure channel complexity	C - E - F	3	2	4	3	*3*	*3*	*3*	want	med
13. Conduct reach-specific monitoring	A - B - C - D - E - F	3	2	3	4	*3*	*3.5*	*2.5*	want	med-high
3. Conduct periodic surveys to measure grain size of active redds (what the fish actually use)	C - E - F	1	3	5	2	*2.75*	*1.5*	*4*	want (at least once)	low
12. Track benthic invertebrates and algae at specific monitoring sites (food web)	F	3	1	2	3	*2.25*	*3*	*1.5*	want	med-high
11. Maintain an inventory of revetments along river corridor	B	1	5	5	1	*3*	*1*	*5*	general interest; others collect	low

High-priority monitoring activities

- Monitor seasonal redd scour
- Measure and track large woody debris
- Map areas of spawnable gravels
- Map off-channel habitat and quality



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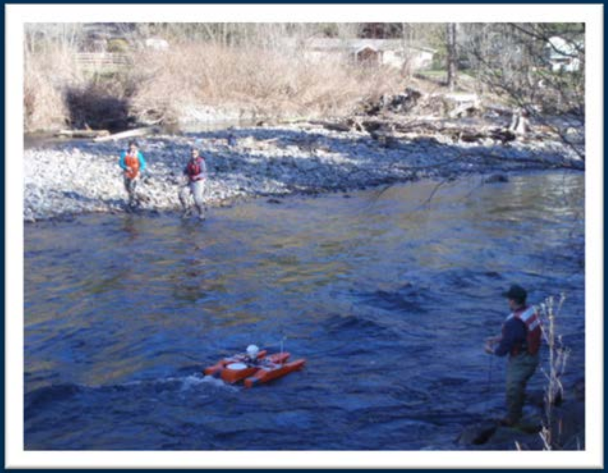
Medium-priority monitoring activities

- Establish sediment budget (potentially expensive)
- Monitor bedload movement (expensive)
- Measure and track gravel bars
- Monitor planform geomorphology
- Monitor pool frequency and depth
- Monitor channel complexity
- Reach-specific monitoring
- Measure grain size of active redds
- Track invertebrates / food web

Acknowledgments

Jon Czuba, Halley Kimball, Casey Gish, Trevor Magirl, Raegan Huffman all helped with field data collection. Jon Richards developed much of the computer code used to operate the hydrophones.



Thank you, Instream Flow Commission, for your expertise and support