Stream Power and Geomorphic Change during the 2013 Colorado Front Range Flood

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10/2013

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Collaborators:

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Overview of Problem

- It is common practice to constrain streams along highway corridors by road embankments, especially in narrow valleys
- During large floods, these highways are vulnerable to failure

Big Thompson River & US-34, on the Roosevelt National Forest, Colorado
Q = 430 m^3/s (15,000 cfs)
ω = 2700 W/m2
(10/21/2013; graphic created in ArcGlobe)

Overview of Problem

- It is also common practice to build homes and business immediately adjacent to stream channels
- Oftentimes these structures are placed in erosion hazard zones

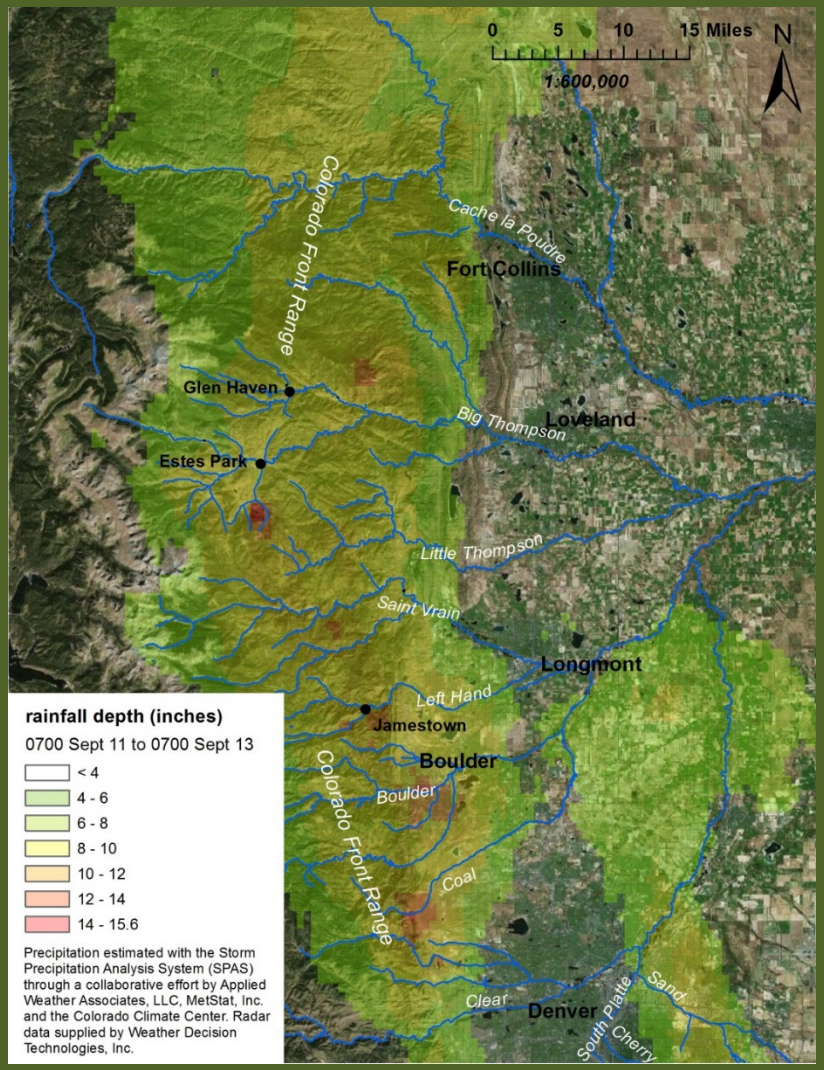
Drake, Colorado
Image source: NRCS exigent EWP

Overview of Problem

- Tools are needed to manage these stream corridors more thoughtfully
  - Erosion hazard zones
  - Sufficient floodplain extent for providing width and form for conveyance and ecological function

Before and after view of the 2005 flood damage in St. George, Utah (FEMA 2007). Green lines are 100-yr floodplain boundary and orange lines are mapped erosion hazard boundaries. extracted from Jagt et al. 2016

Colorado Front Range Flood



Overview

- September 2013
- Heavily impacted stream corridors in the Front Range Foothills and adjacent high plains

Precipitation

- 15 to 18 inches in high-impact areas
- Majority during a 36 hour period: Sept 11-12, 2013
- Rainfall depths similar to average annual precipitation

Flood Response

Borga et al. 2014, Alfieri et al. 2012

- Flood response due to the most intense rainfall periods varied on both spatial and temporal scales
- Landslides and debris flows
  - minutes to hours scale
  - on mountain slopes

2.5 mile long debris flow on east side of Twin Sisters Peak 11/8/2013

Flood Response

Borga et al. 2014, Alfieri et al. 2012

- Small to medium-size foothills streams flooded on an hours to day scale
- Primary riverine floods peaking on a day to days scale
  - South Platte at Fort Morgan peak on 9/15

Big Thompson River
9/13/2013 @ 1549

Flood Impacts

N.F. Big Thompson,
Glen Haven

10/16/2013

Flood Impacts

Confluence of N.F. Big Thompson and Big Thompson, Drake

Flood Impacts

Geomorphic adjustments included:

- localized streambank erosion
- hillslope and terrace failures
- reach-scale channel widening
- sediment deposition
- rapid downstream meander migration
- channel avulsions and braiding

Big Thompson River at canyon mouth
Sylvan Dale Ranch
(9/24/2013; graphic created in ArcGlobe)

Flood Impacts

Magnitude of flood impact dependent upon variability in driving and resisting mechanisms to geomorphic adjustment

- Example variables for driving forces:
  - peak discharge
  - total and unit stream power
  - flow duration
  - channel and floodplain slope and form
  - differential unit stream power
- Example resisting mechanisms:
  - flow resistance
  - bank and bed composition
  - vegetation type and extent
  - rip rap / retaining walls

$$\omega = \frac{\Omega}{w} = \frac{\gamma Q S_f}{w}$$

Study Approach

- Developed classification scheme for increasing geomorphic adjustment
- Computed variables describing driving forces
  - unit stream power (@ peak flow)
  - total stream power (@ peak flow)
  - channel confinement

North St. Vrain Creek (4/9/2014)

Study Approach

Class descriptors of increasing geomorphic adjustment (blind quality assurance process utilized)

1. No detected geomorphic change
2. Infrequent eroded streambanks (<25% streambank length)
3. Numerous eroded streambanks (>25% streambank length)
4. Substantially widened channel over the majority of the reach length
5. Major geomorphic change, with avulsions, braiding, or roadway embankments and high terraces eliminated or substantially eroded
6. Narrow valley form (canyon) limits geomorphic adjustment potential, with no substantial pre-flood floodplains detected

Study Approach

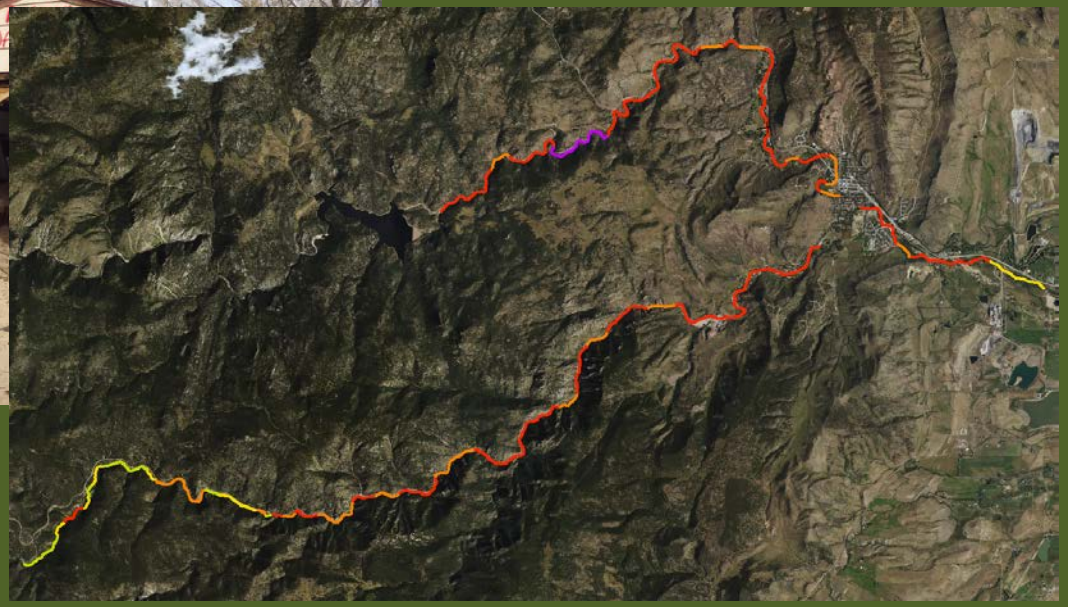
Examples of geomorphic change class 5 and 4

- paired pre- and post-flood imagery

Results

Geomorphic change class and stream power were assessed in the South Platte River basin in and adjacent to the Colorado Front Range foothills

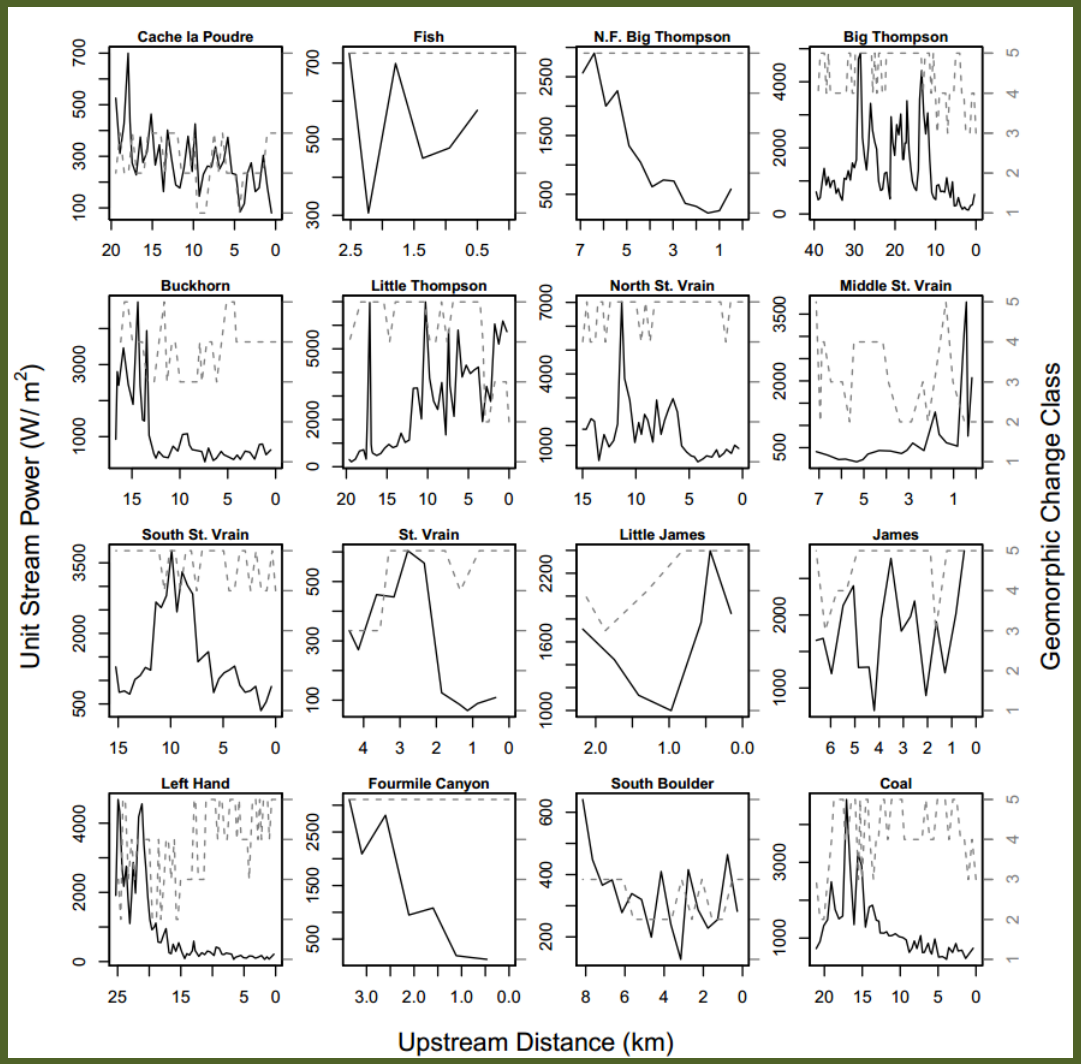
- 531 reaches on 226 km of 16 impacted streams
- Reach lengths: 71 to 500 m (average = 426 m)
- Watershed areas: 4.3 to 2900 km^2
- Channel slopes: 0.2 to 10.5%



St. Vrain

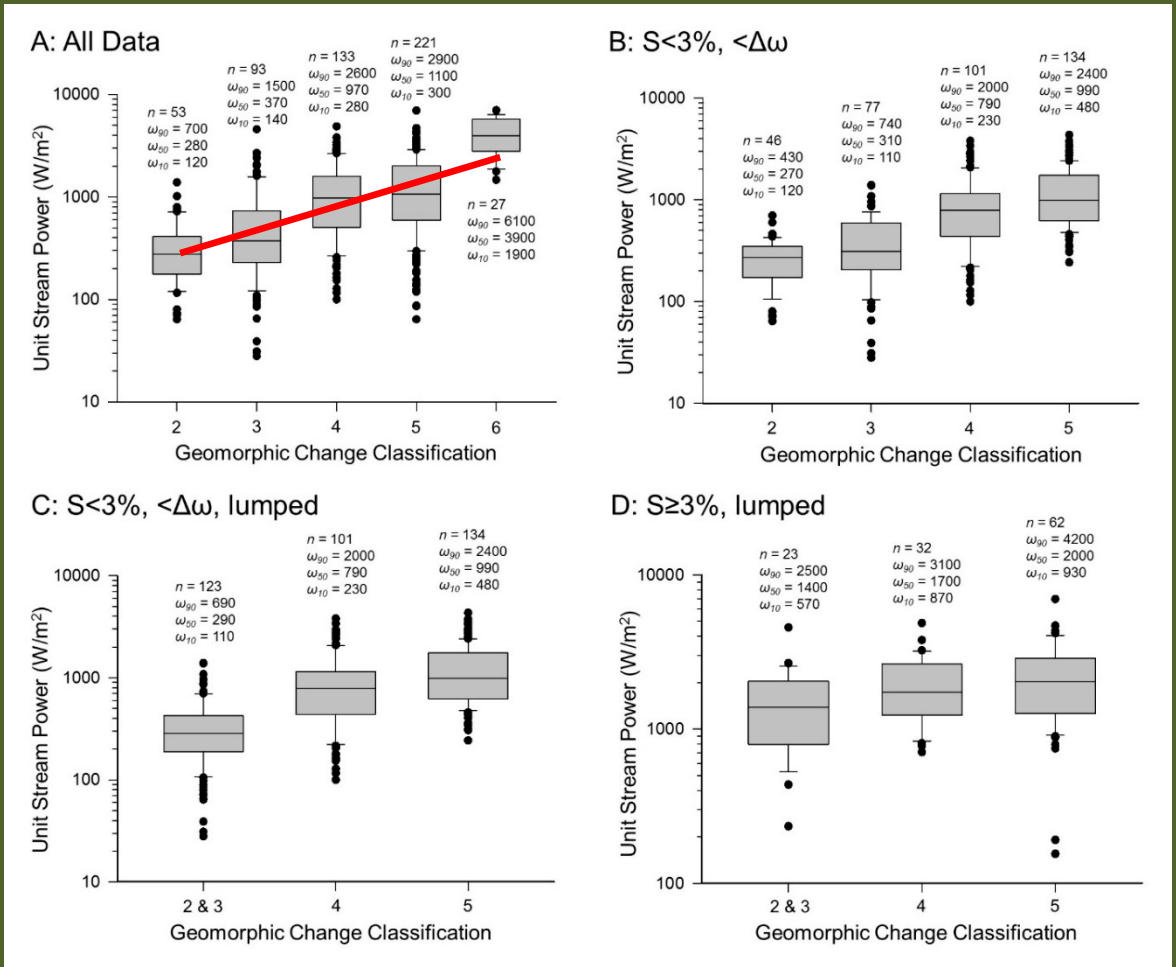
Results

- Peak flow unit streampower of up to 7000 W/m^2
- Geomorphic adjustment varied from extreme to minor or not detected
- With transition from higher-gradient confined reaches to lower-gradient, less-confined reaches: progressive decrease in unit stream power



Results

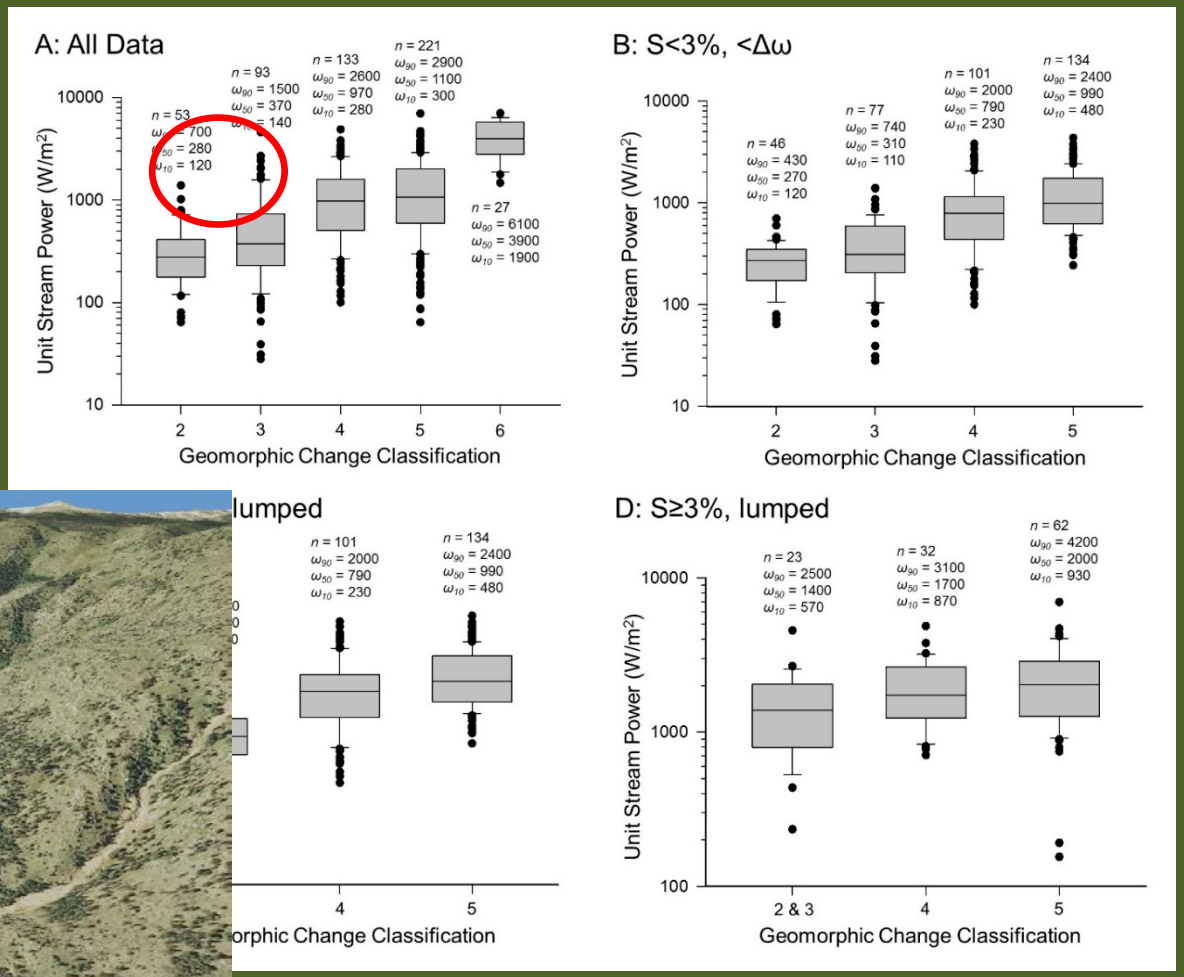
Generally, unit stream power was positively related to geomorphic change (part A)

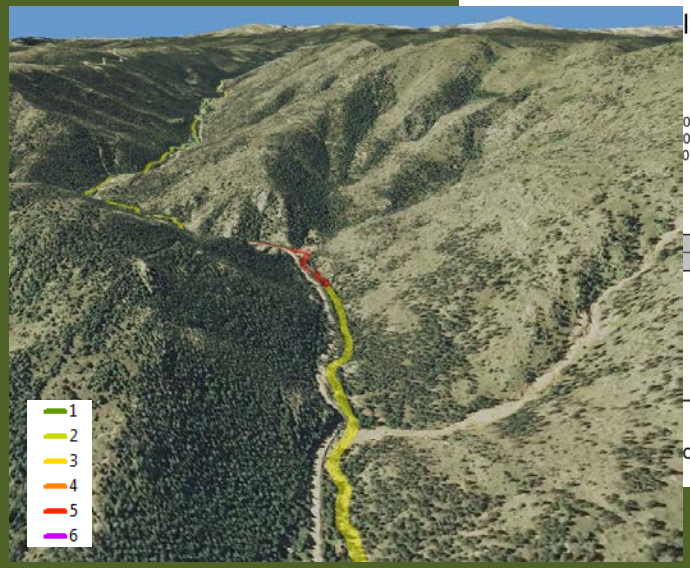


Results

Reaches with less geomorphic adjustment at higher stream power were higher gradient (> 3%)

- step-pool channels with higher flow resistance and bed armoring



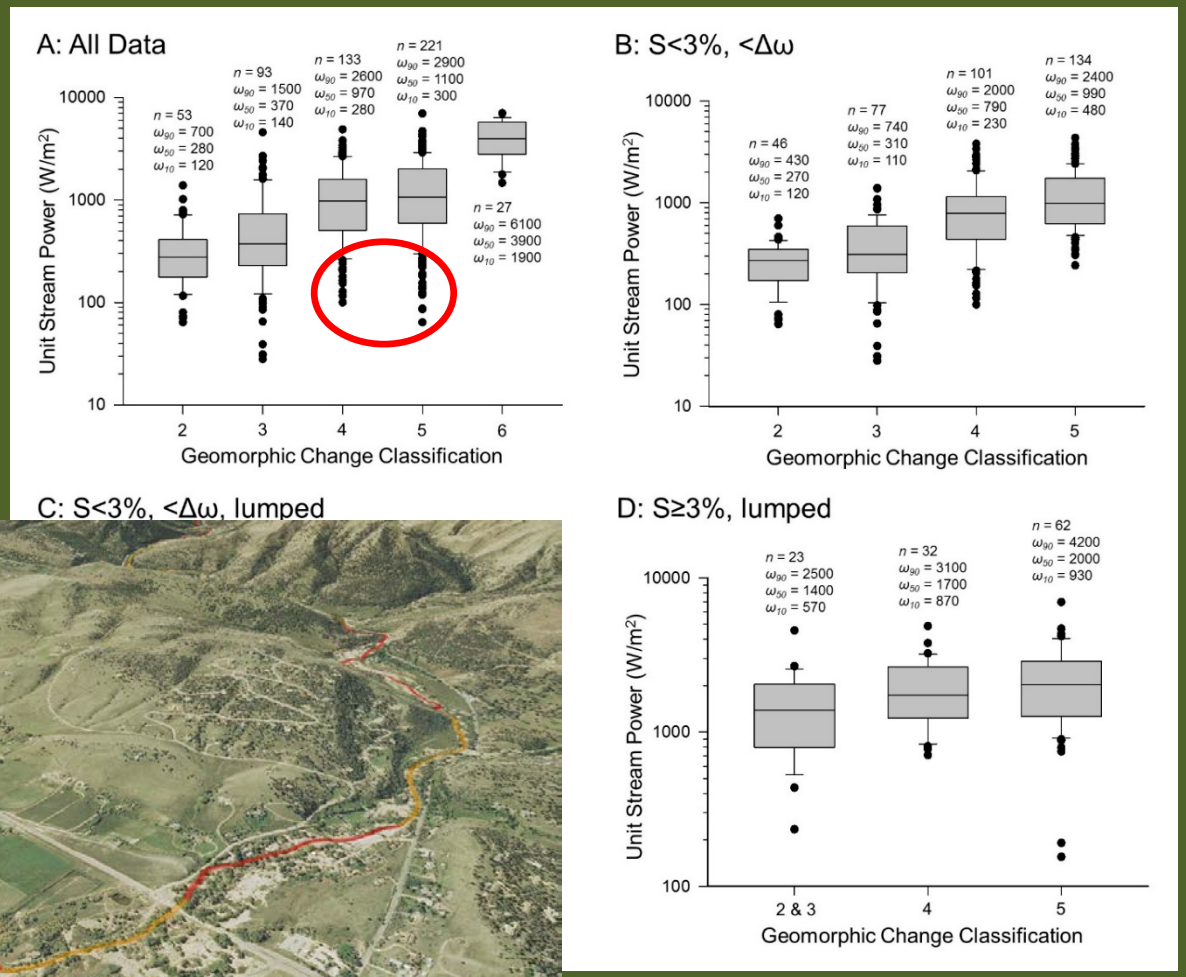


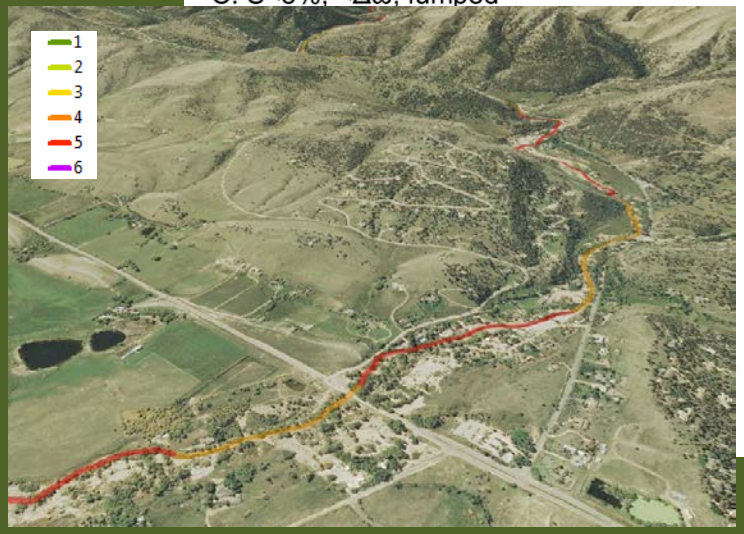
Left Hand Creek, graphic created in ArcGlobe

Results

Some reaches had relatively low stream power but large amounts of geomorphic change

- downstream of canyon mouths
- large reductions in unit stream power and sediment transport conveyance capacity

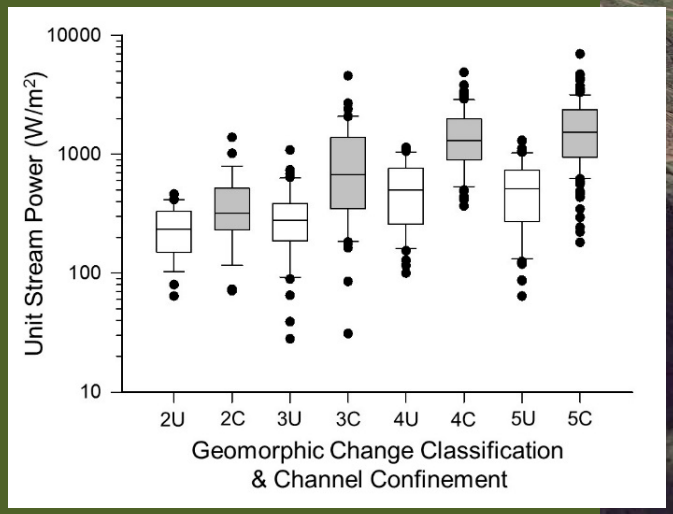




Left Hand Creek, graphic created in ArcGlobe

Results

For each geomorphic response class, unit stream power was smaller for unconfined reaches than confined reaches



Big Thompson River at canyon mouth
Sylvan Dale Ranch
(9/24/2013; graphic created in ArcGlobe)

Results

Cumulative Logit Modeling

- Models fit to entire dataset poorly predicted the geomorphic response
  - <50% accurate
- Models fitted to subsetted dataset (S<3%, 4&5 lumped) performed well
  - 68% to 74% accurate
- Models based on two classes (2&3, and 4&5 lumped) performed best
  - 72% to 83% accurate

Model	Predictor Variables[1]	Dataset[2]	Model Sensitivity by Geomorphic Change Category (%)[3]				Model Accuracy (%)[4]
			2	3	4	5	
1	usp + usp:conf	1	4	19	10	85	44
2	sp + sp:conf.cat	1	0	29	33	78	49
3	usp + 'usp:conf.cat	2	0	50	9	75	43
4	sp + sp:conf.cat	2	2	58	32	75	52
5	sp + sp:conf + dSP	3	33	35	92		74
6	usp + conf.cat + dUSP	3	18	26	92		70
7	sp	3	15	32	93		71
8	usp	3	7	21	93		68
9	sp + sp:conf + grad.sp	4	71		86		81
10	usp + conf.cat + dUSP	4	63		84		77
11	sp	4	67		89		82
12	usp	4	63		85		78
13	sp + sp:conf	5	60		90		81
14	usp*conf + dUSP	5	47		91		78
15	sp	5	60		92		83
16	usp	5	37		91		75
17	slope + conf	5	12		97		72

(1) See table 1 for predictor variable definitions. The operator "*" denotes both an additive and an interaction affect between the two variable. The operator ":" denotes an interaction effect between two variable.

(2) Dataset 1 is the complete dataset; dataset 2 only contains reaches with slopes < 3%; dataset 3 is the same as 2 but with geomorphic change Fcategories 4 & 5 lumped into one response category; dataset 4 is the same as 2 but with categories 2 & 3 lumped and categories 4 & 5 lumped (two response categories); and dataset 5 is the complete dataset with the same two response categories as in dataset 4.

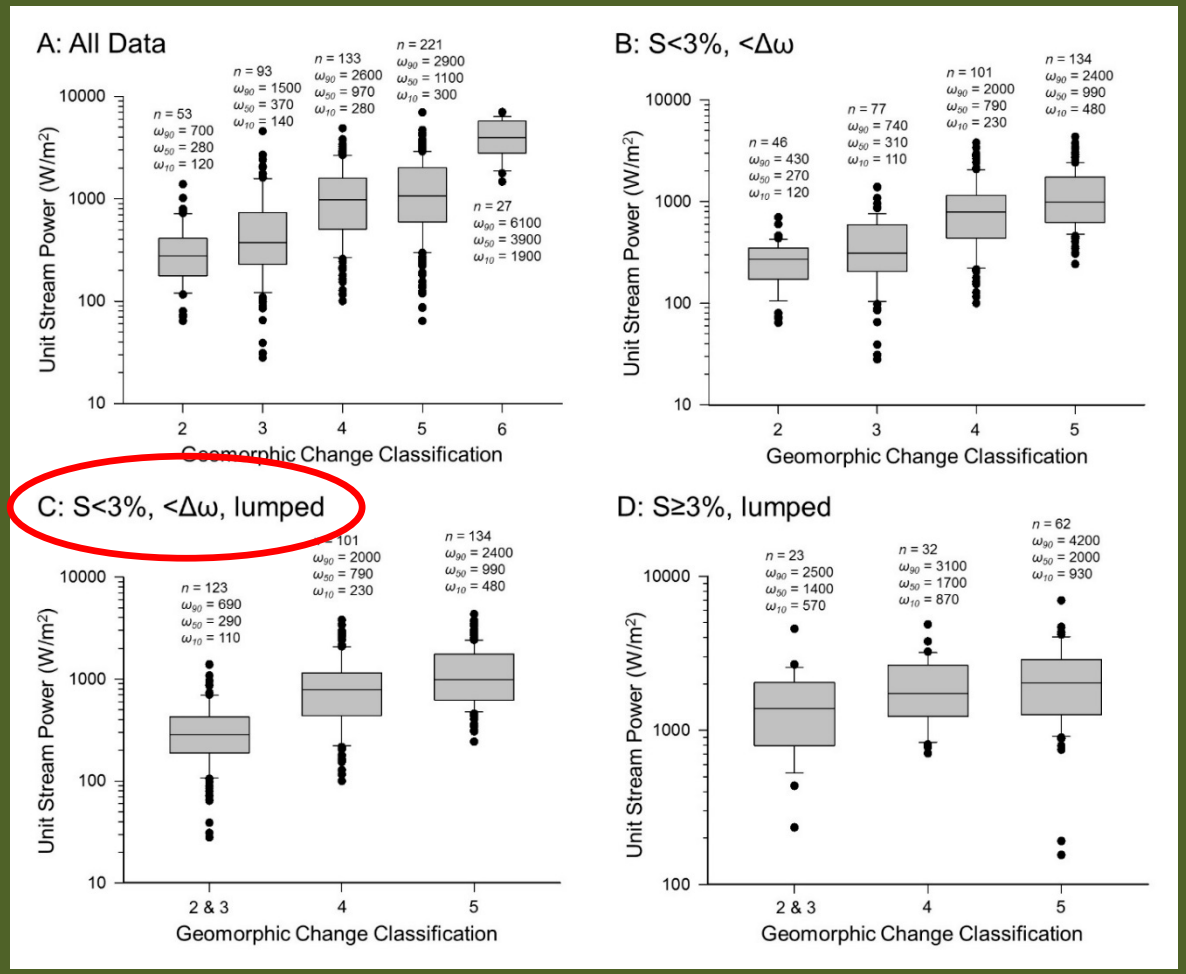
(3) Model sensitivity is define as the percent of correctly-predicted geomorphic response within each response category based on a leave-one-out analysis.

(4) Model accuracy is the percent of geomorphic response category classes correctly predicted overall based on a leave-one-out analysis.

Results

Noting mechanisms behind outliers, dataset was subsetted to:

- Exclude reaches with slopes >3% (mechanistic shift due to step pool bedforms)
- Exclude reaches with large reductions in stream power (shift in geomorphic instability mechanism)
- Insignificantly different classes grouped
- n = 358



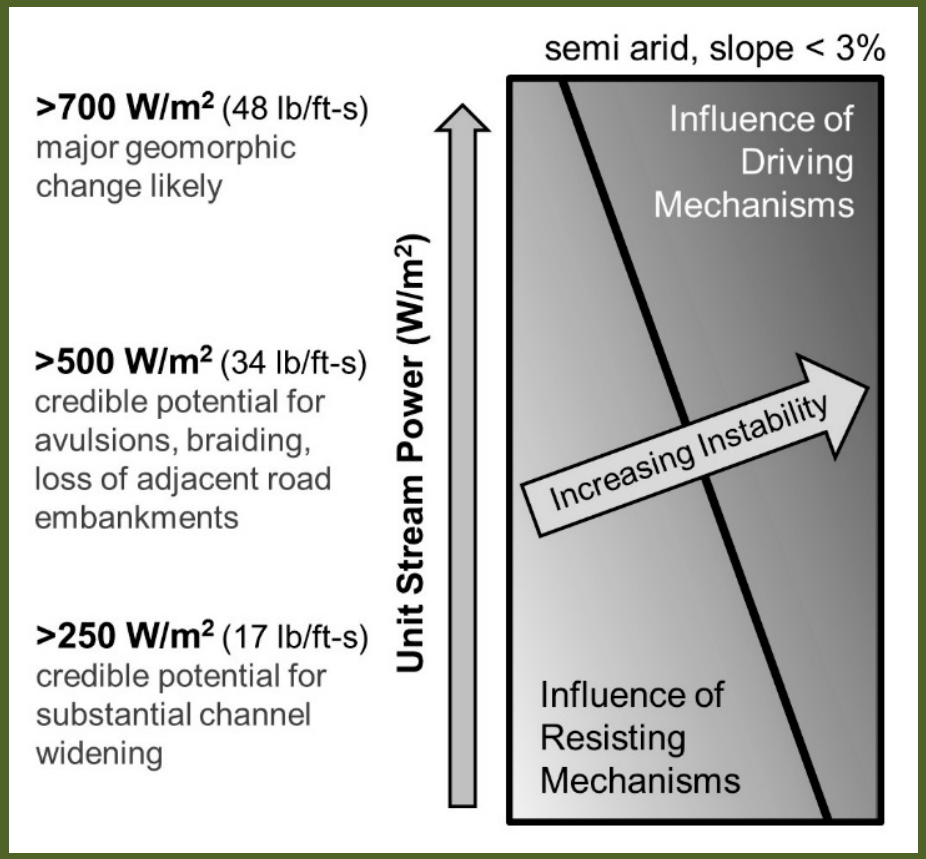
Threshold Results

With an assumption that the 10th and 90th percentiles are reasonable boundaries for quantifying where geomorphic change is most likely:

- **>250 W/m²**: credible potential for channel widening
- **>500 W/m²**: credible potential for avulsions, braiding, loss of roadway embankments
- **>700 W/m²**: major geomorphic change likely

Key assumptions:

- Slope < 3%
- Geomorphic adjustment due to erosional processes (not depositional)



Conclusions

- Key variables for predicting geomorphic response:
  - stream power or unit stream power
  - unit stream power gradient
  - valley confinement
- Thresholds for variable geomorphic adjustment quantified
  - Should be applicable for prediction in an along the Colorado Front Range and could potentially be extrapolated to other semi-arid landscapes
  - Standard HEC-RAS analysis can be used to assess potential for geomorphic instability

James Creek in Jamestown
10/29/2013

Conclusions

- Slopes >3% resisted geomorphic change at higher unit stream power
  - Enhanced flow resistance induced from bedform flow dynamics (from large clasts and large in-channel wood)
  - Bed armoring
- In places, channel instability from deposition resulted in major reach-scale geomorphic adjustment at relatively low unit stream power
  - Lower-gradient, unconfined reaches downstream of confined and steeper reaches
  - Impacts over several kilometers downstream

James Creek in Jamestown
10/29/2013

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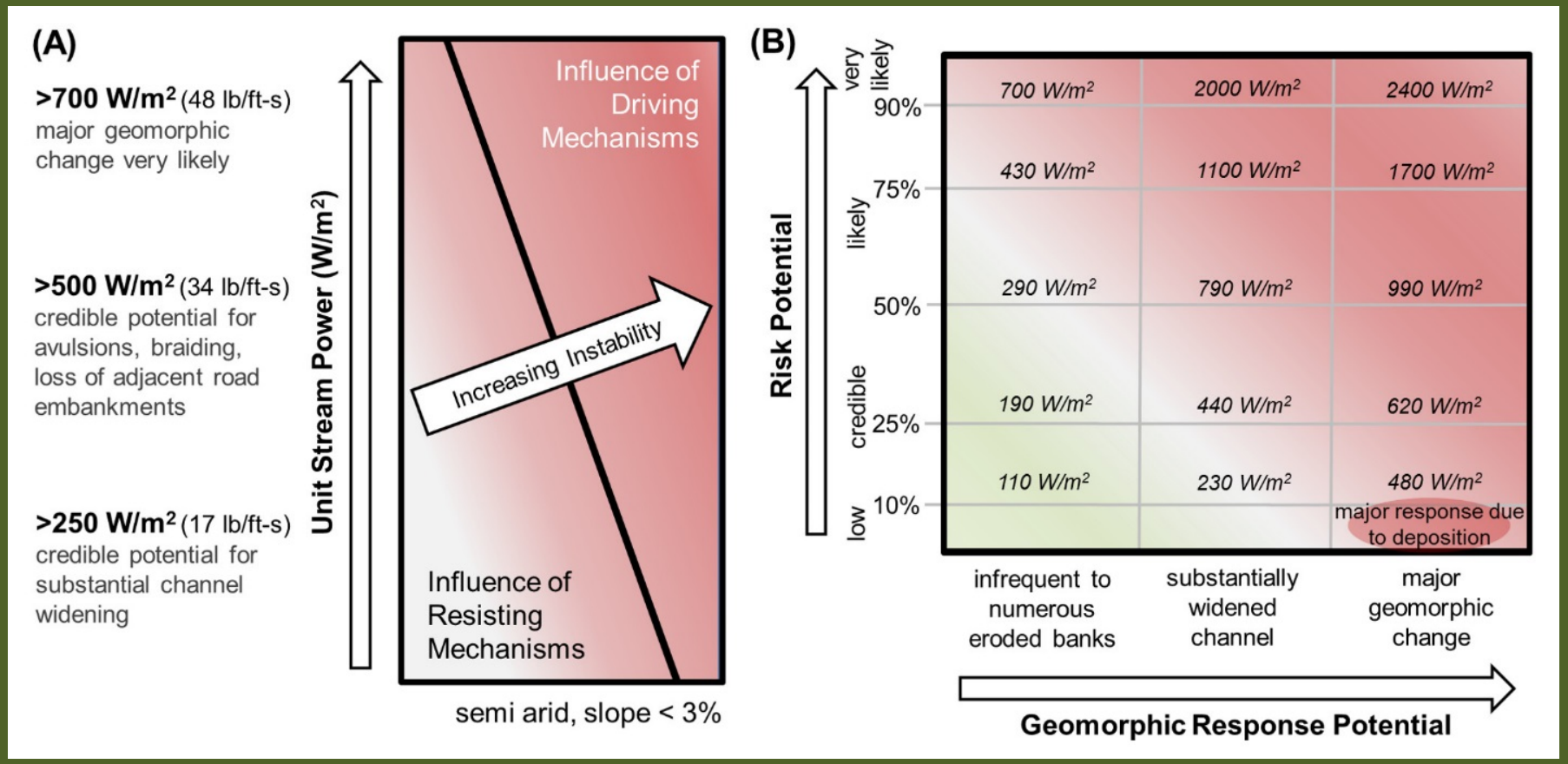
Questions?

EXTRA: Thresholds Matrix