# *How do fires affect the way sediment and wood are conveyed to small- and large-order streams and what are the effects on channel morphology and aquatic habitat?*

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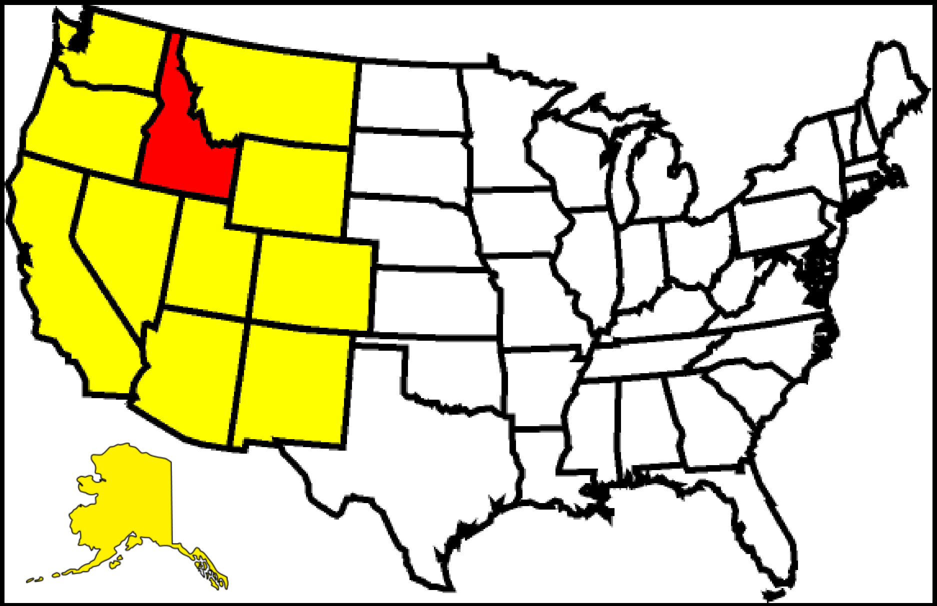
# *Take-home messages*

- Location matters
  - Risk & type of post-fire disturbance depends on location in the channel network.
- Pros & cons to fire
  - Fires cause damage, but they also have important ecological benefits; aquatic organisms have evolved with these landscape disturbances and show adaptation to them.

# *Outline*

- Overview of fire effects, and the types & causes of post-fire erosion
- Geomorphic process domains & styles of wood input
- Effects of fire on channel morphology & aquatic habitat

# *Study Area*



- Mountain basins of western U.S.
- Case studies from northern Rocky Mountains, Idaho Batholith

# *Physical Effects of Fire*

- loss of vegetation (alters rainfall interception, surface roughness, root strength)
- ground heating (causes hydrophobic soils, decreased soil permeability, particle breakdown)

Result: altered basin hydrology

- increased surface runoff
- flashier flows
- more erosive power both on hillslopes & in channels

# *Types of Postfire Erosion*

*Surface erosion*
- sheetwash & rilling

*Mass wasting*
- landslides

*Sediment–water flows*
- debris flows
- hyperconcentrated flows
- flash floods

# *Surface Erosion: Sheetwash & Rilling*

Location: hillslopes

Process: overland flow due to soil saturation, or rainfall rates greater than soil infiltration capacity

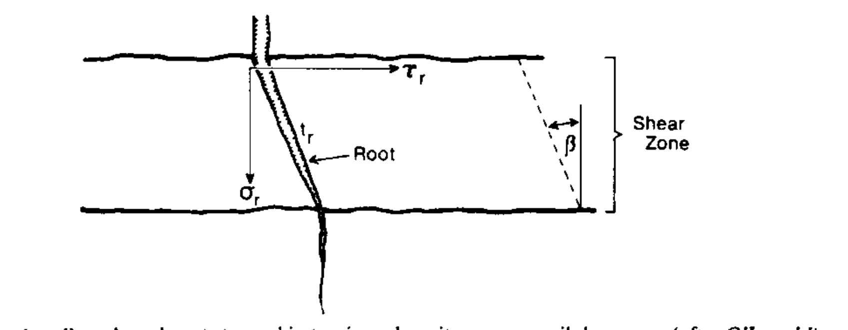
rainfall (I) > infiltration (i) ⇒ surface runoff

- sheetwash = unchanneled flow
- rilling = channeled flow, but not fluvial

# *Mass Wasting: Landslide Erosion*

Location: planar & convergent hillslopes

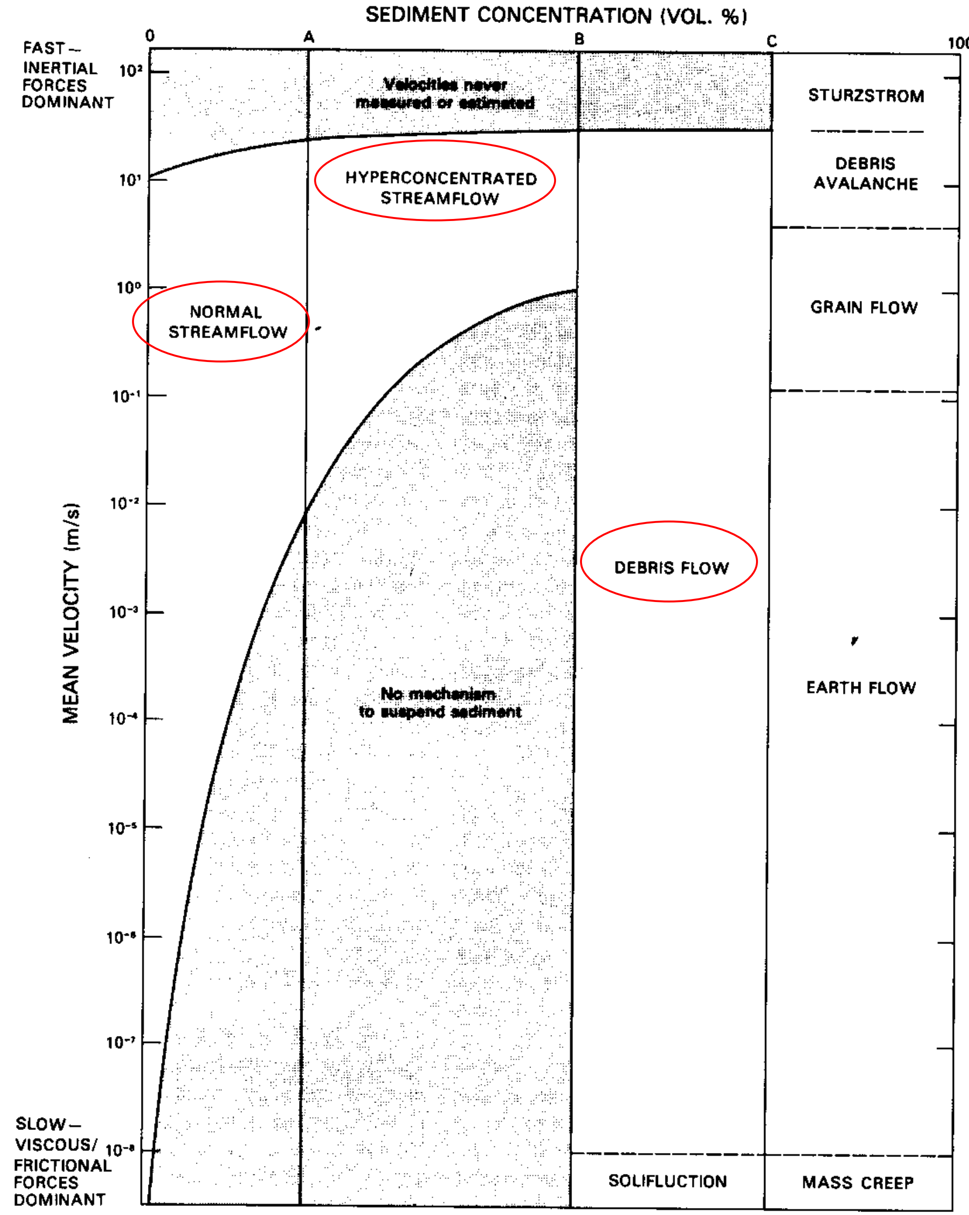
Process: *en masse* failure of coherent soil wedge due to steep slopes, adverse pore pressure within the soil, and insufficient soil/root cohesion




A well-anchored root stressed in tension where it crosses a soil shear zone (after *O'Loughlin and Ziemer* [1982]).

# *Sediment–Water Flows*

- channelized flow of water–sediment mixture
- rheology and erosive power varies with relative content of water vs. sediment




| | | | | |
|---|---|---|---|---|
| FLUID TYPE | NEWTONIAN | NON-NEWTONIAN | | |
| INTERSTITIAL FLUID | WATER | WATER+FINES | | WATER+AIR +FINES |
| FLOW CATEGORY | STREAMFLOW | | SLURRY FLOW | GRANULAR FLOW |
| FLOW BEHAVIOR | LIQUID | PLASTIC | | |

(Pierson & Costa 1987)

# *Debris Flows*

- Muddy, viscous slurry of water and sediment (silt to boulders) & wood

# *Types of Debris Flows*

*Landslide-initiated*

- Process: liquefaction of landslide as it moves, or liquefaction of downslope soil when landslide impacts it
- Location: hillslopes & head of channel network (initiation in 0-1st order channels)

# *Types of Debris Flows*

*"Bulking"*

- Process: rheologic transition from fluid overland flow to viscous debris flow by "bulking" (downstream addition of sediment or removal of water)
- Location: ~4th-6th order channels

# *Hyperconcentrated Flows*

- Process: rapid input of sediment relative to local discharge (e.g., gullying, bank failure, landslide, debris flow)
- Location: commonly in $1^{st}$ - $\sim5^{th}$ order channels

# *Mechanics of Erosion (simplified)*

Erosion occurs when applied shear stress exceeds critical stress for soil/sediment motion

$$\tau > \tau_c$$

Shear stress depends on topographic slope ($S$) and water depth ($h$)

$$\tau = \rho g h S$$

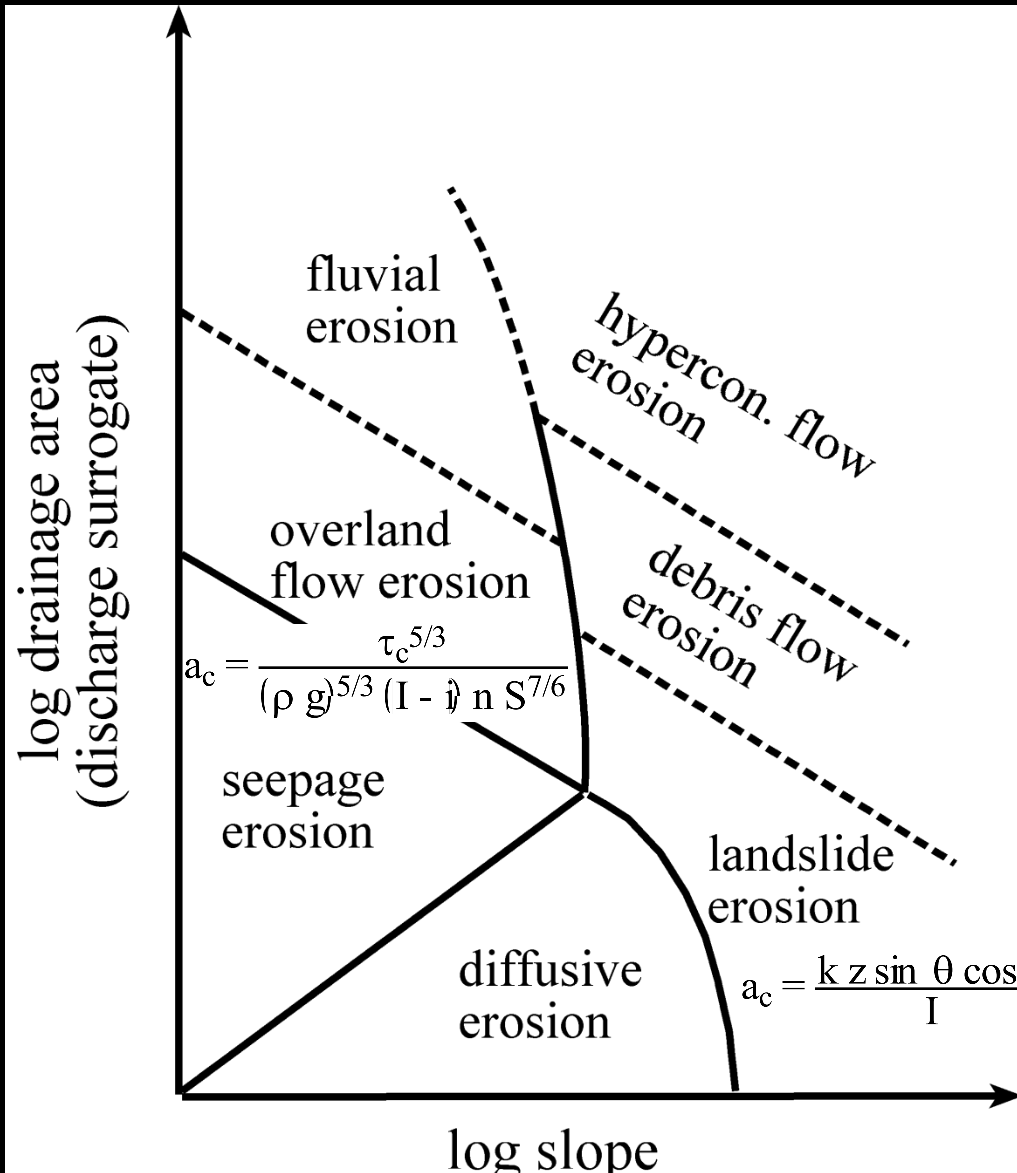
Flow depth is a power-function of drainage area

$$h = \alpha A^{\beta}$$

Critical shear stress is a function of soil/sediment properties (sediment size, cohesion, frictional resistance, etc.)

**Erosion = *f* (*S*, *A*, sediment/soil characteristics)**

# *Erosional Process Domains*



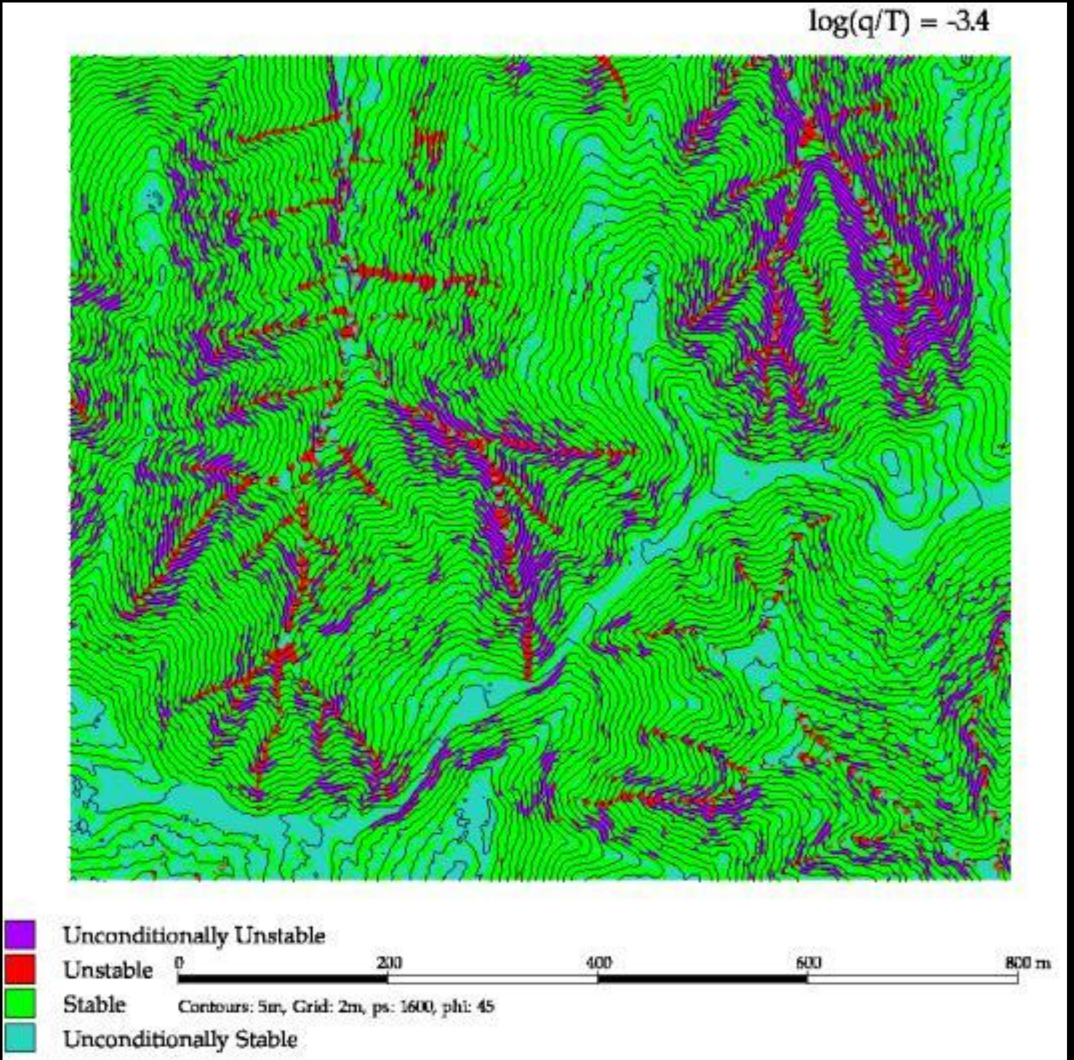

- Each erosional process has a specific domain (slope–drainage area combinations needed to support that style of erosion)
- Process boundaries based on theoretical equations

(modified from Montgomery & Dietrich 1994)

# Application

- use DEMs to map erosional process domains [*f* (*A*,*S*)]
- assess associated hazards for infrastructure & natural resources

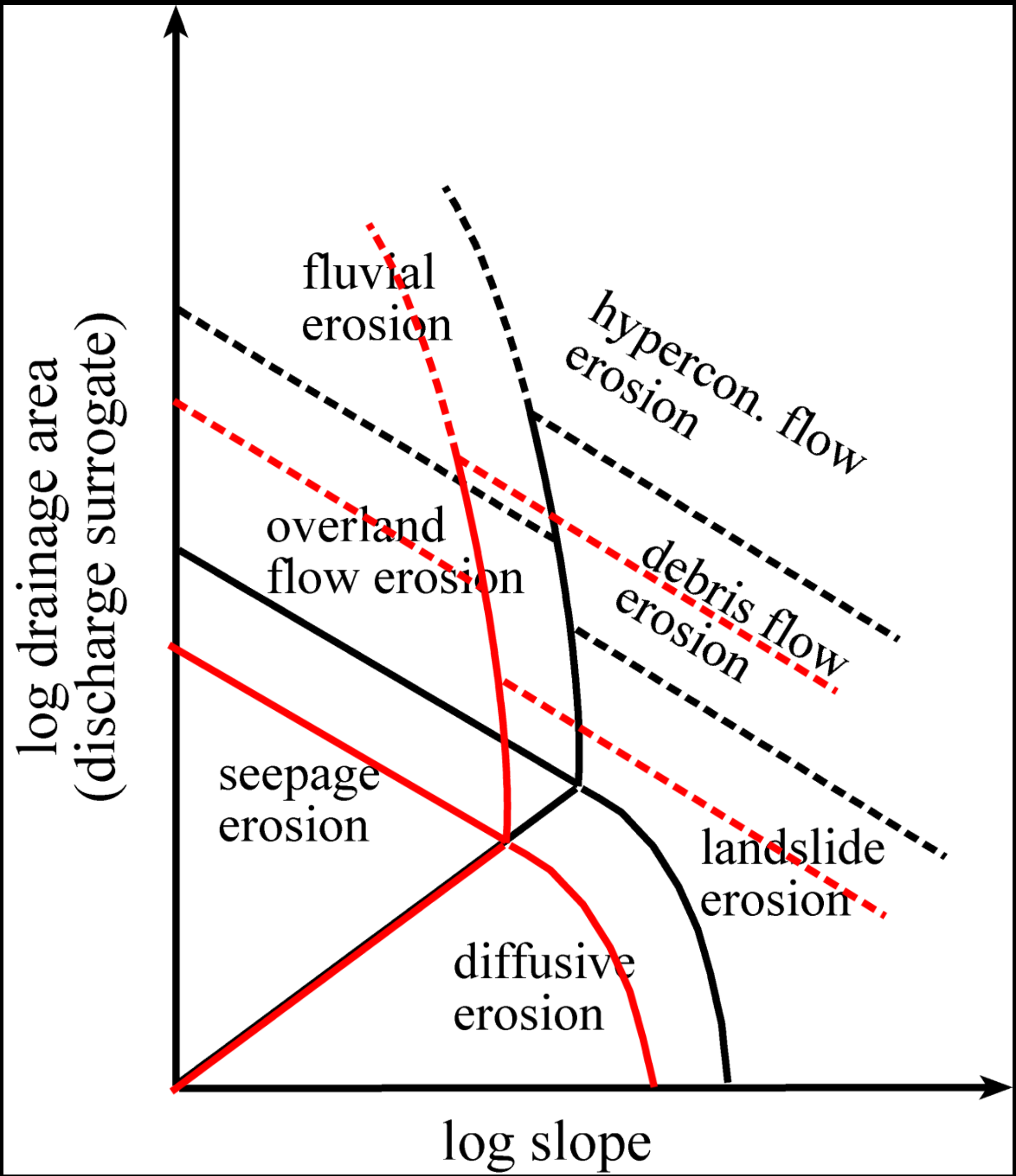
*shallow landsliding*




Dietrich & Montgomery (1998)

Figure 10.

# *Process Domains & Fire*



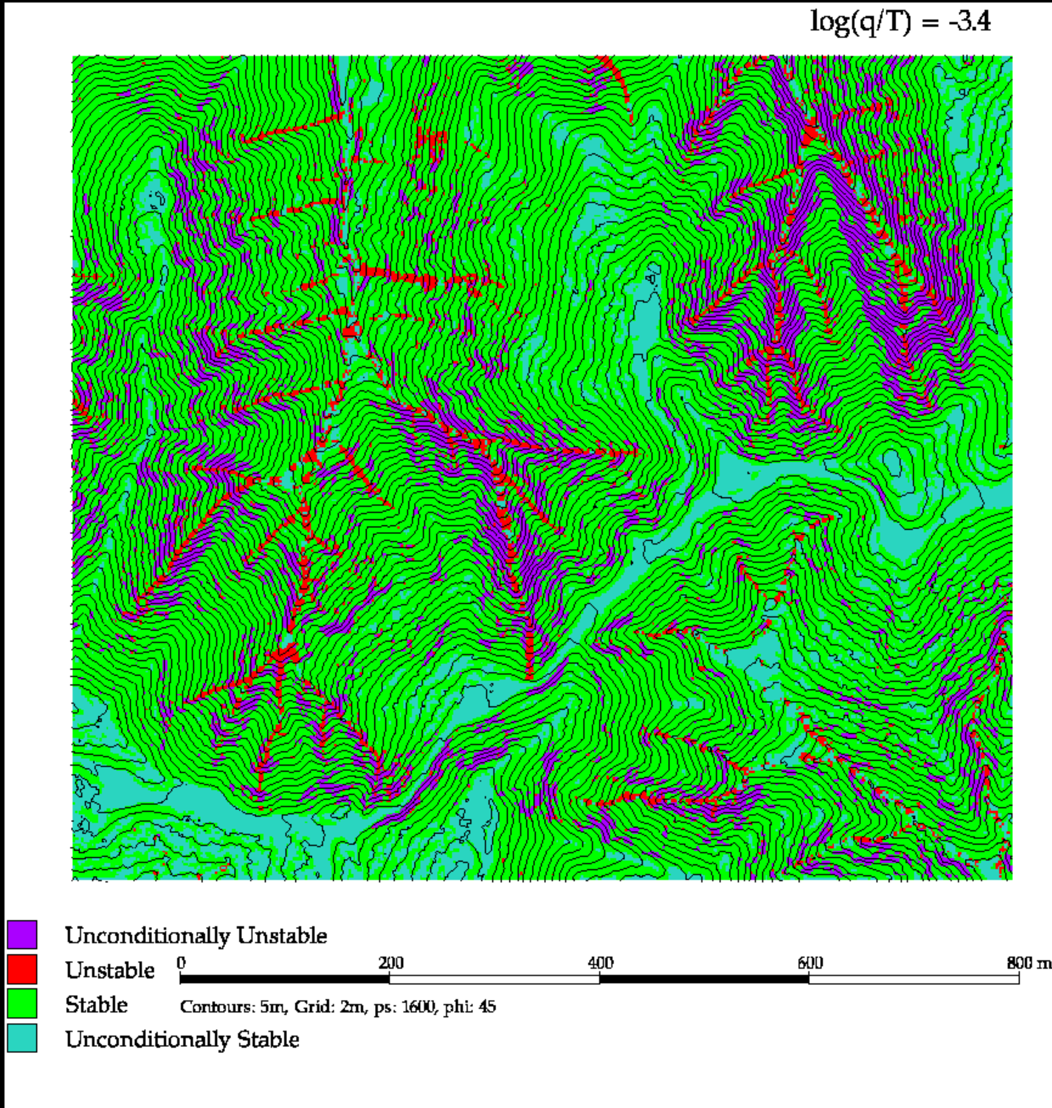

*Consequences of fire:*

- more efficient runoff (greater flow for given drainage area)
- decreased soil/sediment resistance to erosion
- threshold for erosion (critical drainage area–slope combination) decreases
- Result: potential changes in the location, spatial extent and type of erosional processes

(modified from Montgomery & Dietrich 1994)

Altered hydrology (q) or sediment characteristics (T) changes the potential spatial extent of shallow landsliding

- NetMap [*Benda et al.*]
- USGS [*Cannon et al.*]

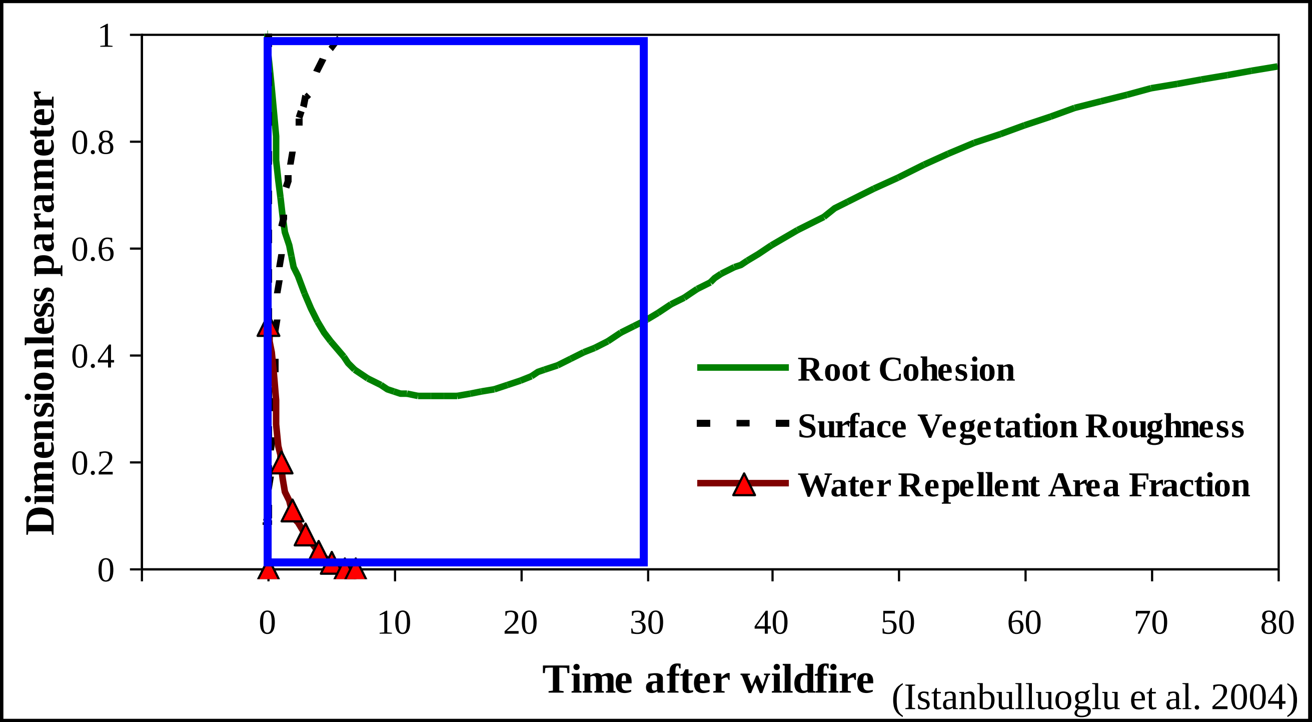



Dietrich & Montgomery (1998) Figure 10.

# *Postfire Erosion*

- Depends on the interaction of 5 factors
  - topography (slope)
  - drainage area (cumulative discharge)
  - soil/sediment characteristics (geologic history, bioturbation)
  - weather (type, magnitude, timing of precip.)
  - fire characteristics (spatial extent, severity, time since fire)

# *Temporal changes*




window of vulnerability

*Multiple events & prolonged period of disturbance*

- burned basins can produce multiple disturbances over years to decades following fire

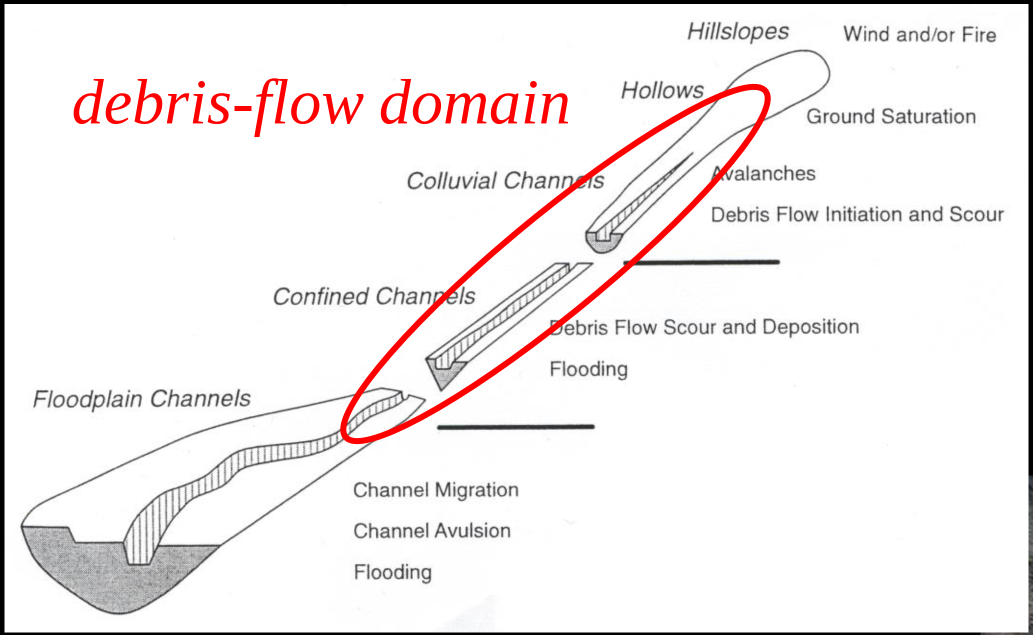
*Why does disturbance persist?*

- much of the initial hillslope erosion is moved into temporary storage elements along valley floors that provide longer-term sediment supply during subsequent floods

# *Outline*

- Overview of fire effects, and the types & causes of post-fire erosion
- Geomorphic process domains & styles of wood input
- Effects of fire on channel morphology & aquatic habitat

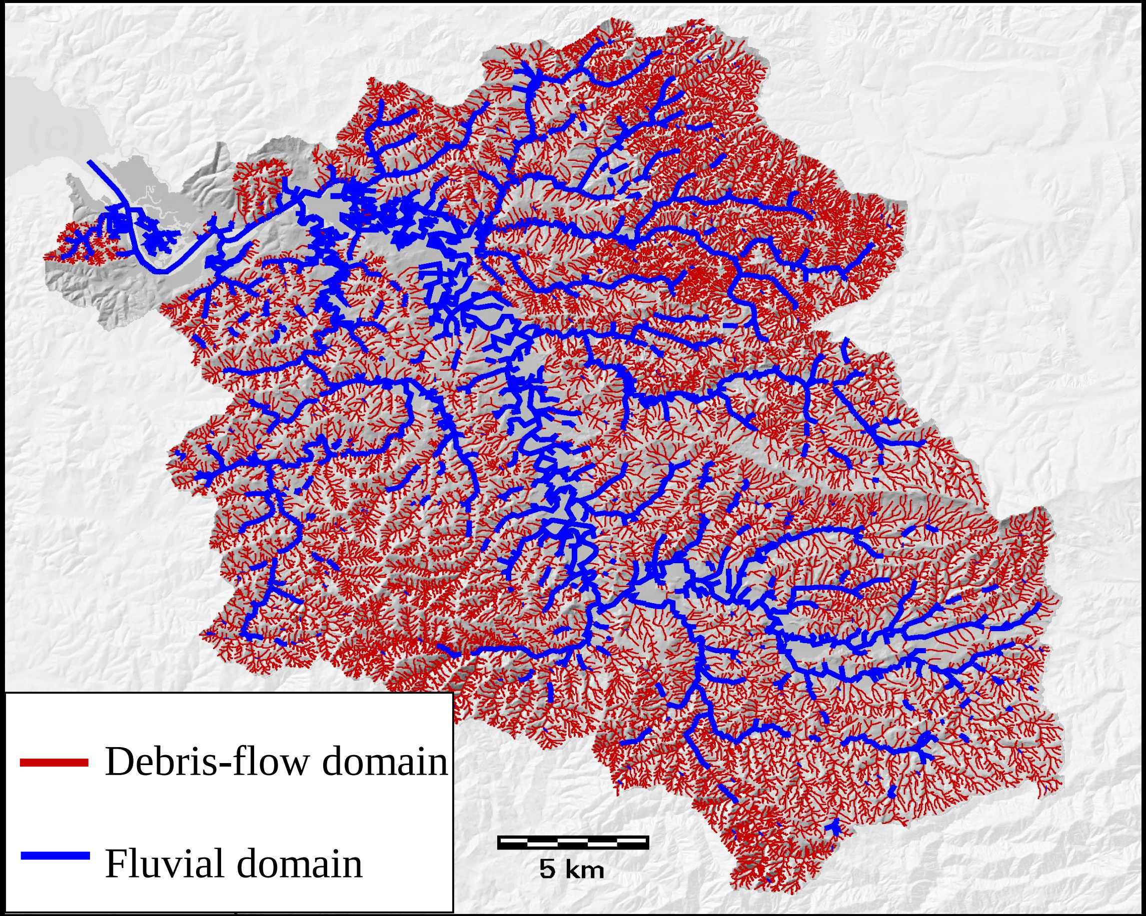
# *Spatial distribution of geomorphic process domains*




[*Montgomery*, 1999]

# *Why do we care about the debris-flow domain?*

- It typically comprises 80-90% of the stream length in mountain basins [*Stock and Dietrich*, 2003; *Buffington et al.*, 2004]

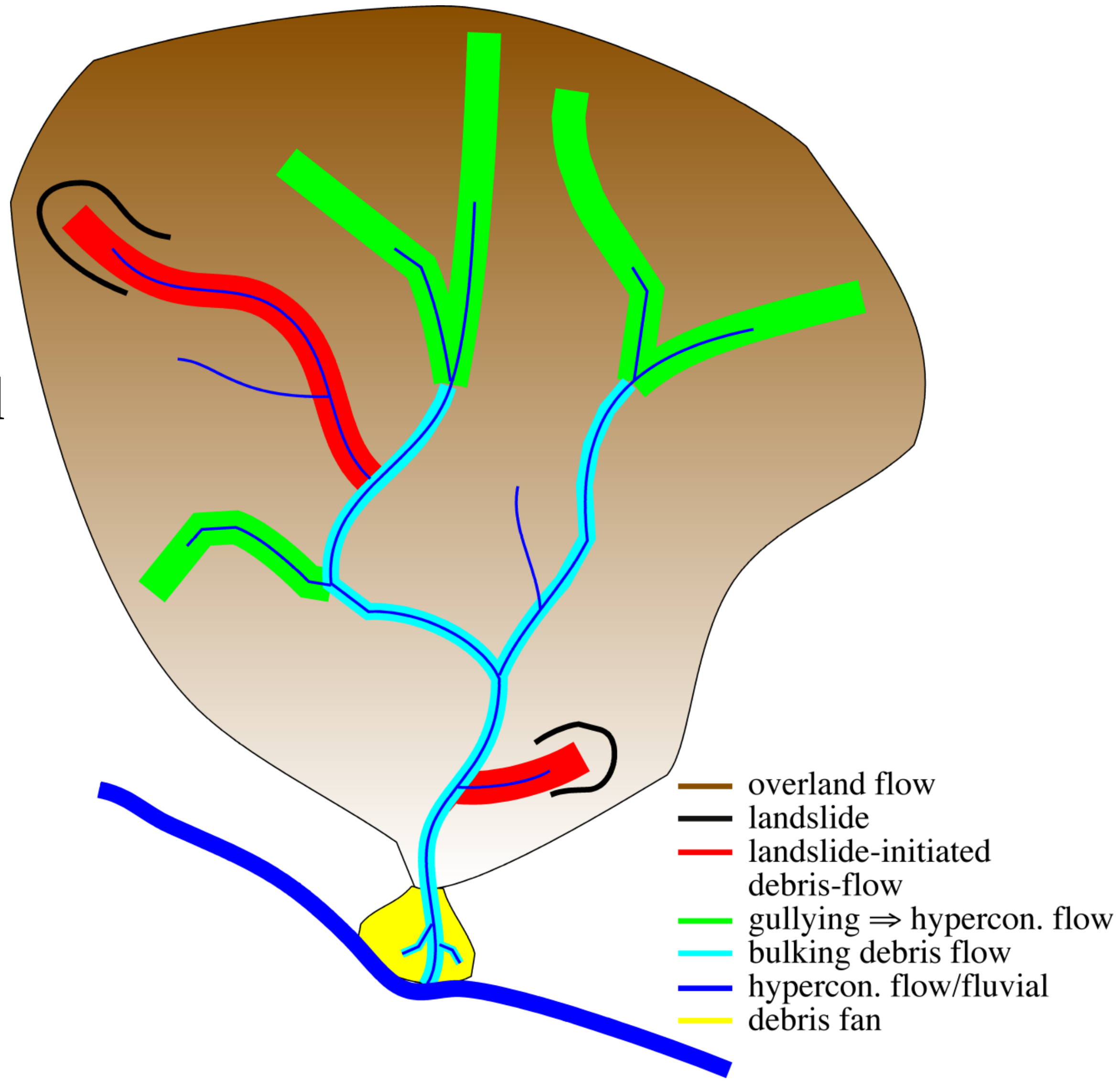


# *Why do we care about the debris-flow domain?*

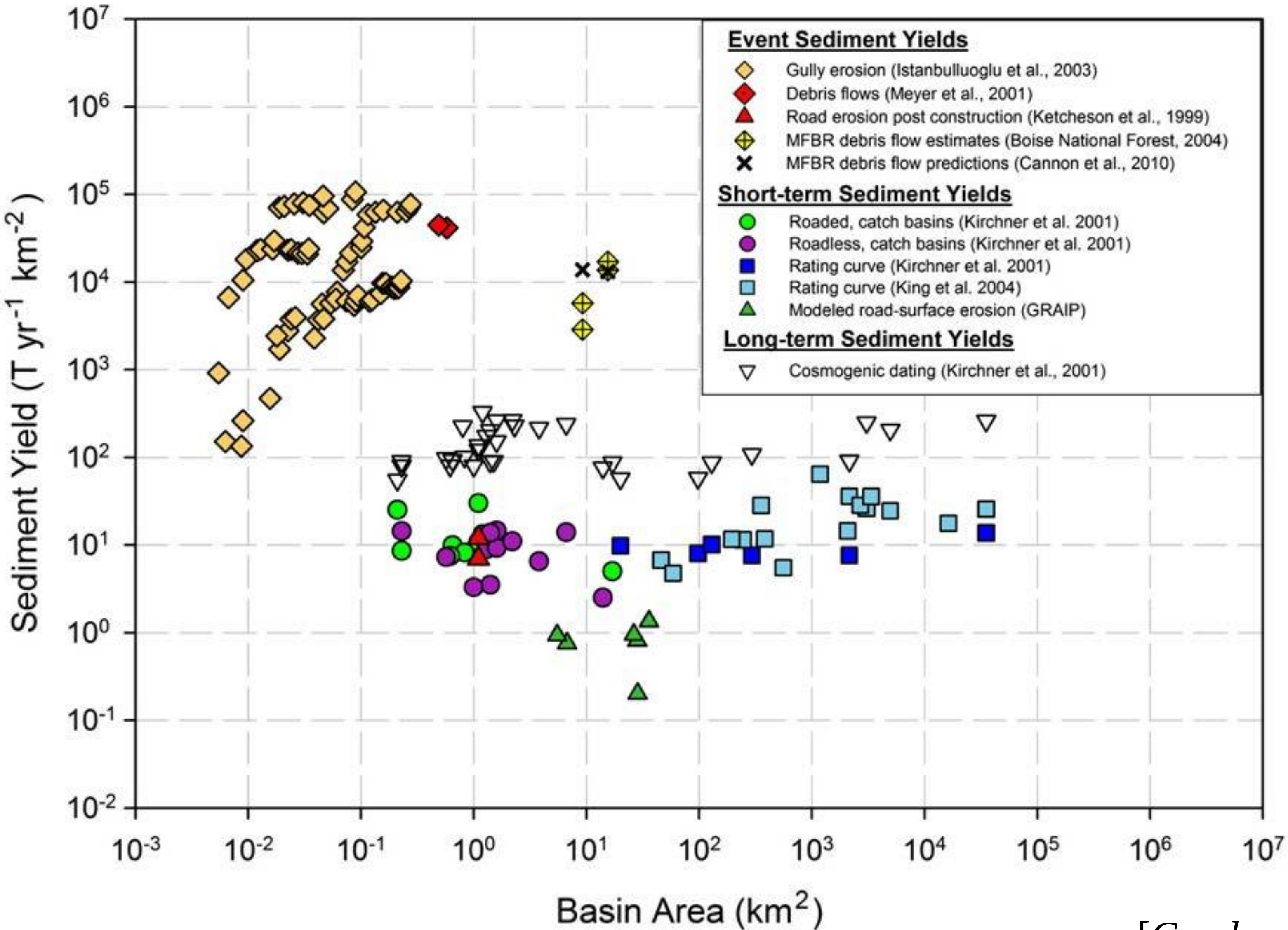
- Debris flows are the primary mechanism for delivery of sediment and wood after fires.

# *Debris-flow routing*

- steep, confined channels, coupled to hillslopes
- debris/hyperconcentrated flows can traverse entire network to the mainstem confluence

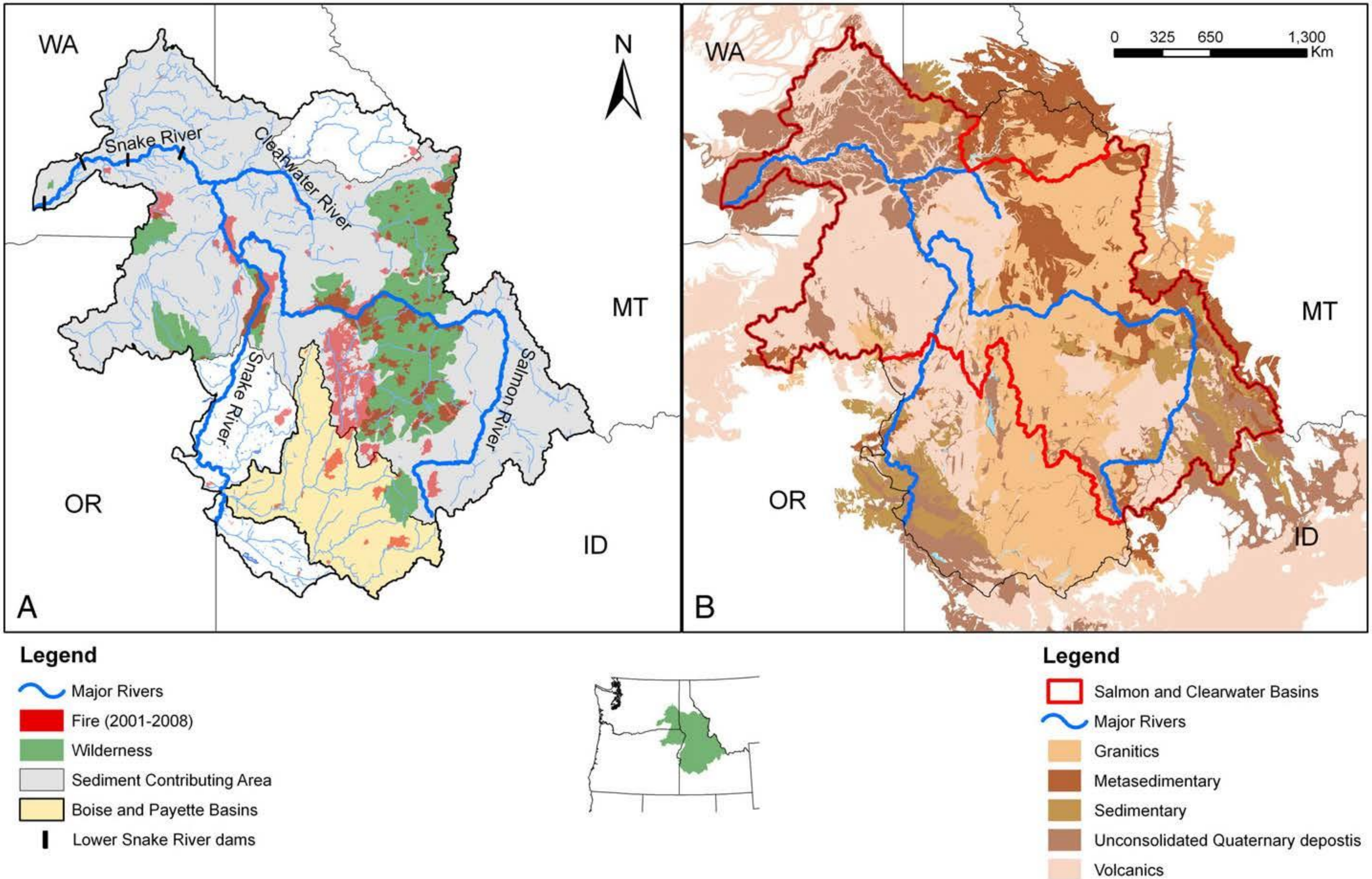


# *Sediment yield in central Idaho*

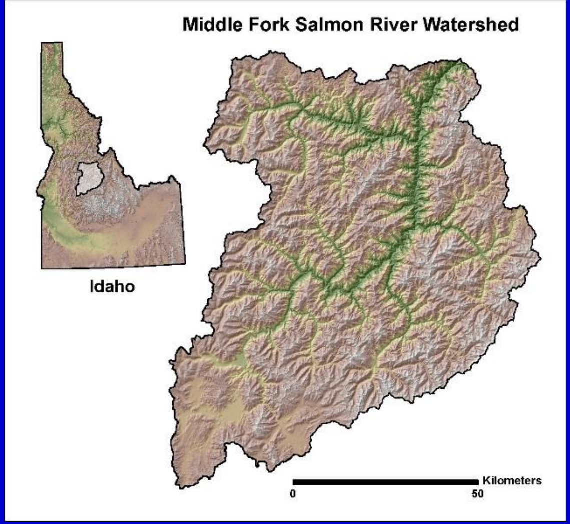



[*Goode et al.*, 2012]

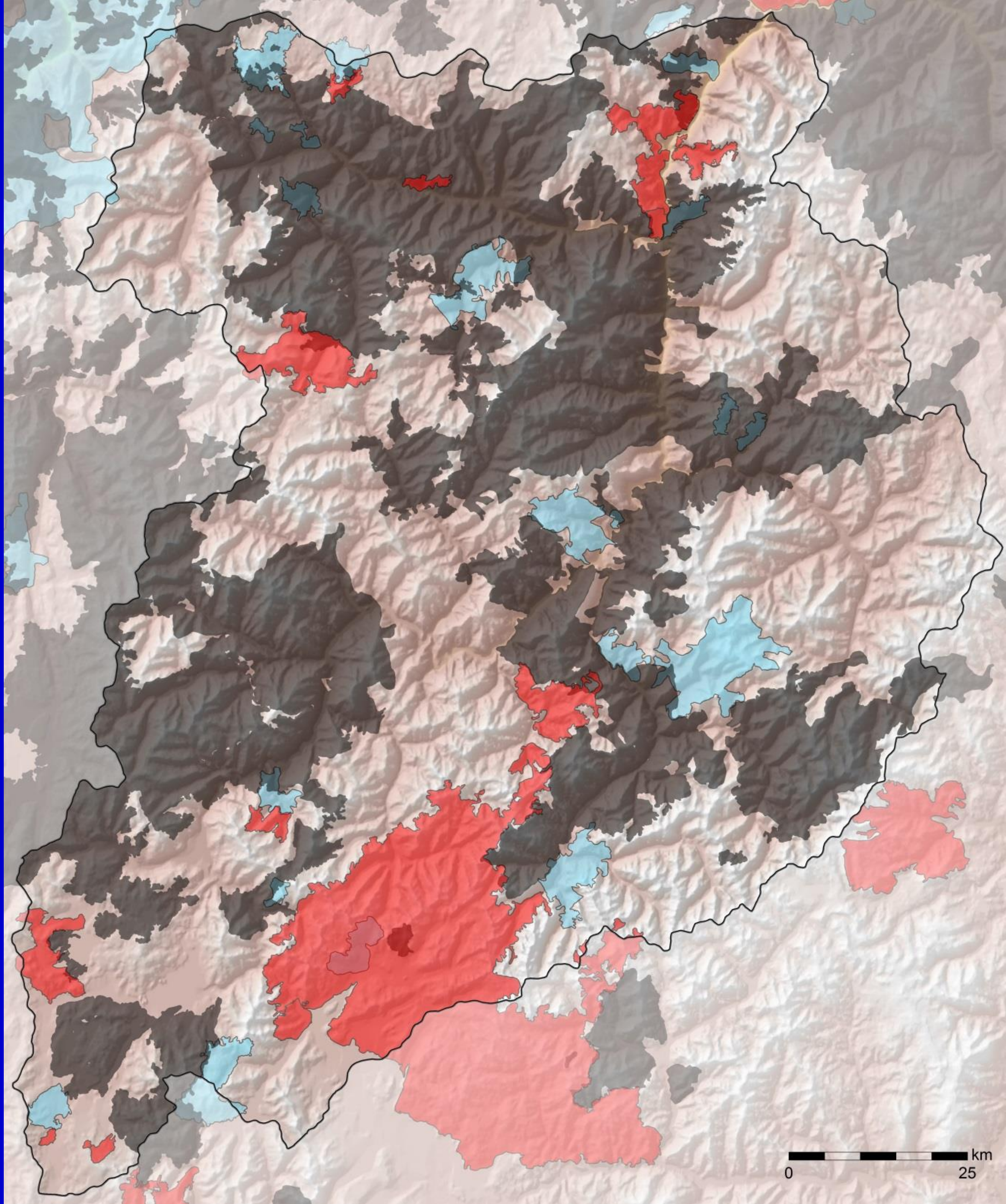
***Expect high sediment yields in next few decades due to recent fires***




**Lower Snake Basin: > 20% burned in last decade.**




# Middle Fork Salmon Fire Perimeters Cumulative 1990-2013




**52% of the basin burned**

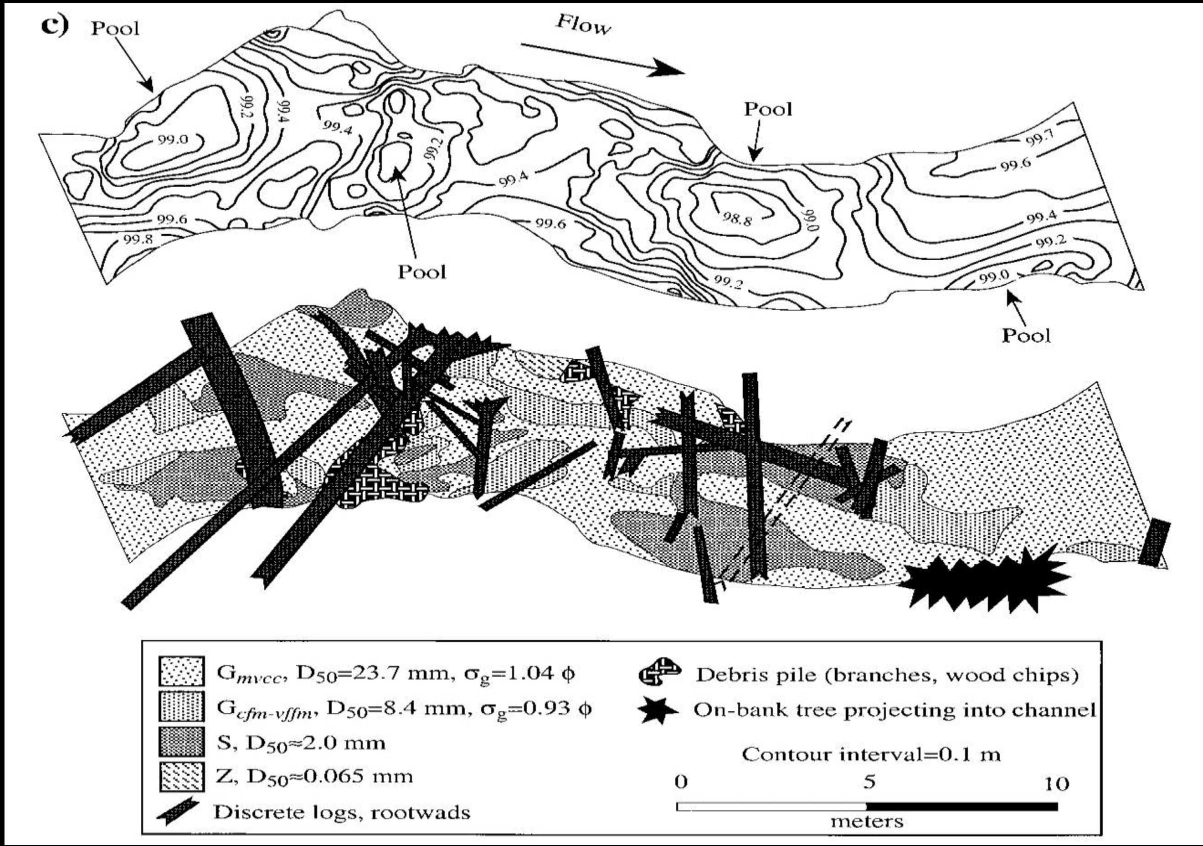
# *Post-fire wood input*

- Toppling of fire-damaged trees
- Debris-flow entrainment and routing
- Snow avalanches

# *Wood Inputs*

Increase complexity:

- Topographic variation (pool scour, bar deposition)
- Flow variation (depth, velocity, area)
- Grain size variation (hydraulic sorting into patches)
- Hyporheic exchange



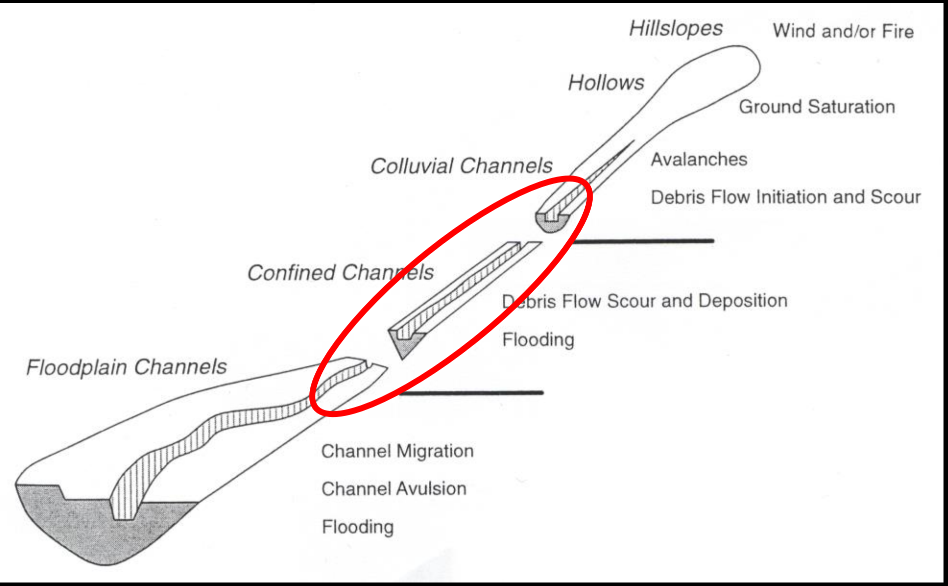
# *Outline*

Effects of fire on channel morphology and aquatic habitat

- In headwater rivers that experience debris flows (steep confined rivers)
- In headwater rivers buffered from debris flows (moderate-gradient unconfined valleys)
- In mainstem rivers that receive debris-flow slugs (major tributary confluences)

# *Headwater rivers in the debris-flow zone*

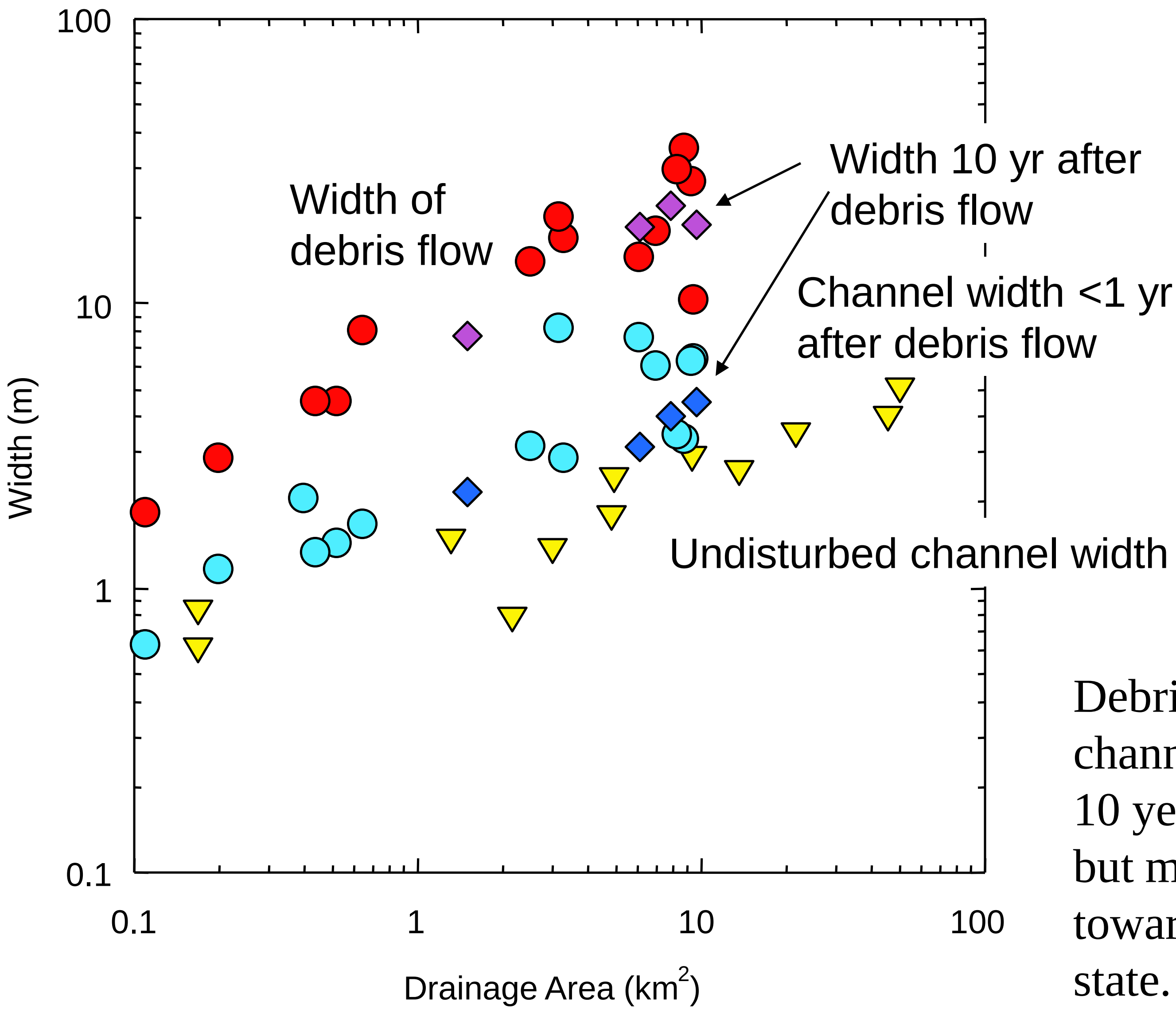
- How do fires and debris flows affect
  - Channel morphology
  - Stream temperature




# *Methods*

- Channel width & reach type
- Treatments:
  - Recent post-fire debris flow (< 1 yr.)
  - Older post-fire debris flow (10 yr.)
  - Undisturbed (over historical record)
- Space for time


debris-flow width
channel width



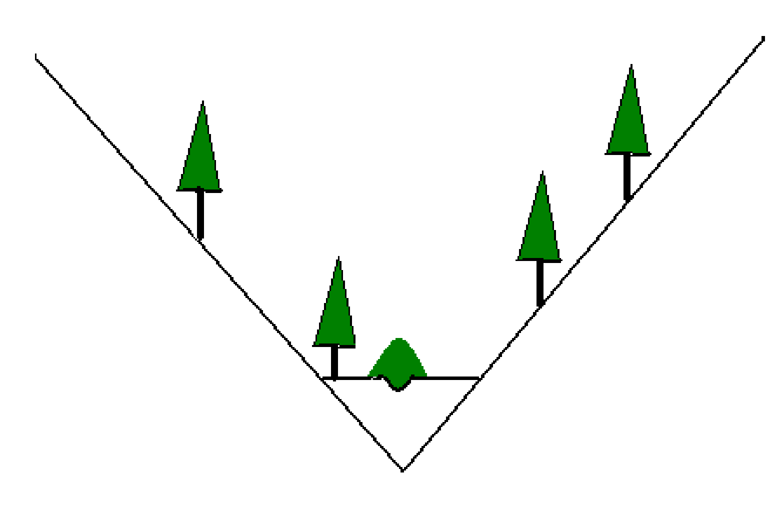

Debris-flow impacted channels are wider up to 10 years after disturbance, but may narrow with time toward the undisturbed state.

# *Headwater rivers in the debris-flow zone*

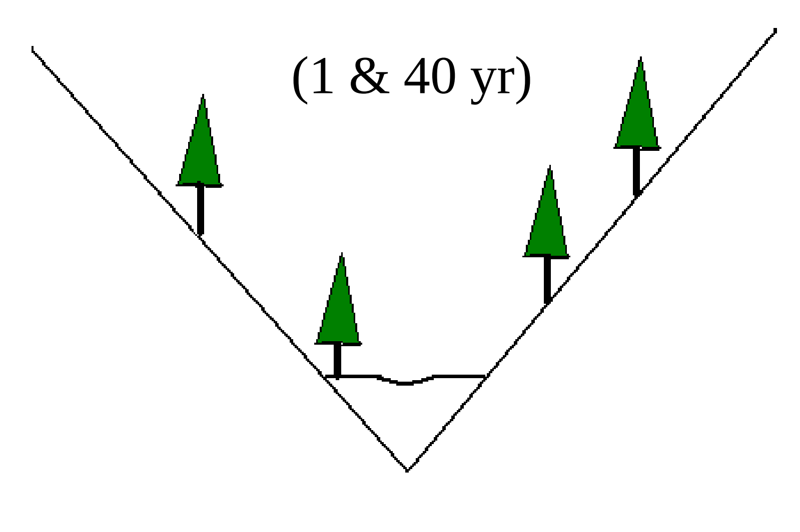
- Channel geometry
- Stream temperature
  - How do fires and debris flows affect streamside vegetation, shading, and water temperature over short time scales (1-50 years)?
  - How quickly does vegetation and stream temperature recover following channel disturbance?

# *Disturbance type & hypothesized vegetation (degree of stream shading)*

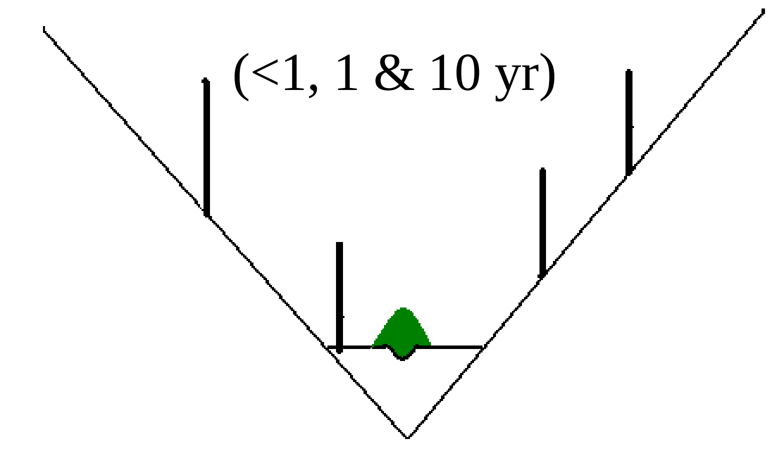
**No Recent Disturbance**



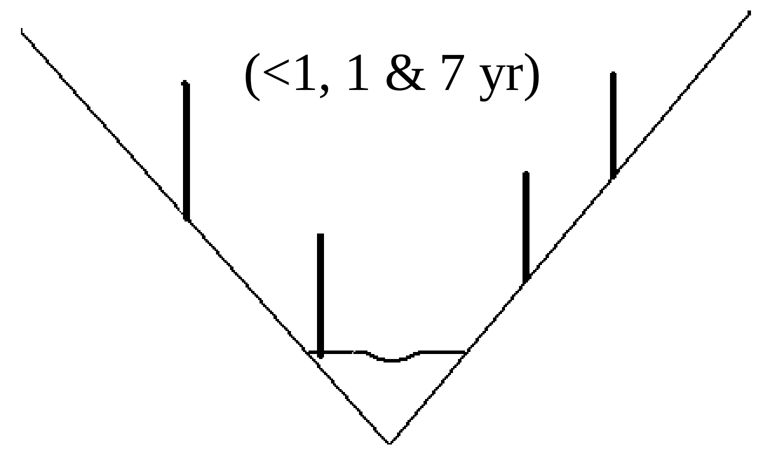
**Debris Flow Only**




**Fire Only**




**Fire & Debris Flow**




Undisturbed

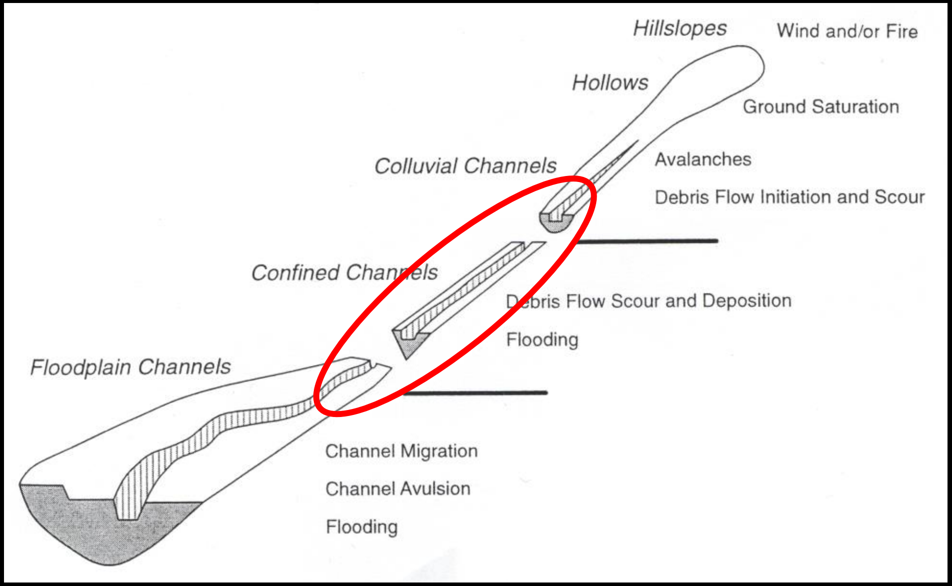

Debris-flow only


Fire only


Fire & debris flow

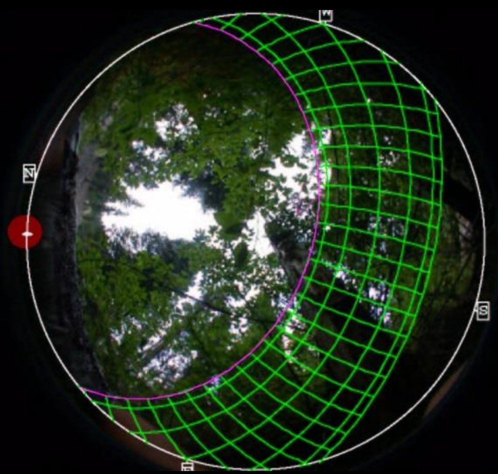
# *Study design & measurements*

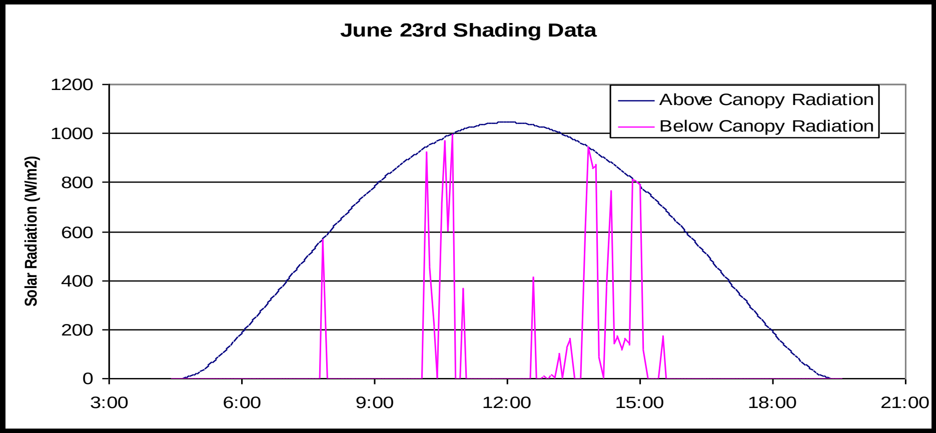
- 4 treatments (undisturbed, debris-flow only, fire only, fire & debris flow)
- 32 streams in the Boise National Forest, southern Idaho Batholith
- Water temperature recorded during summer months
- Sampled vegetation every 20 m over reach lengths of 300-500 m:
  - Took hemispherical photos to estimate solar radiation
  - Counted woody stems within 1 m of channel
- Space for time substitution



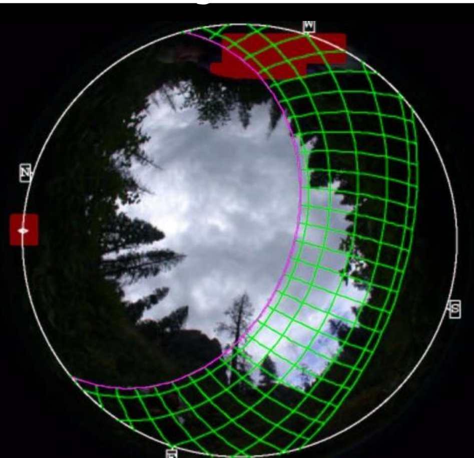
# *Hemispherical photography*

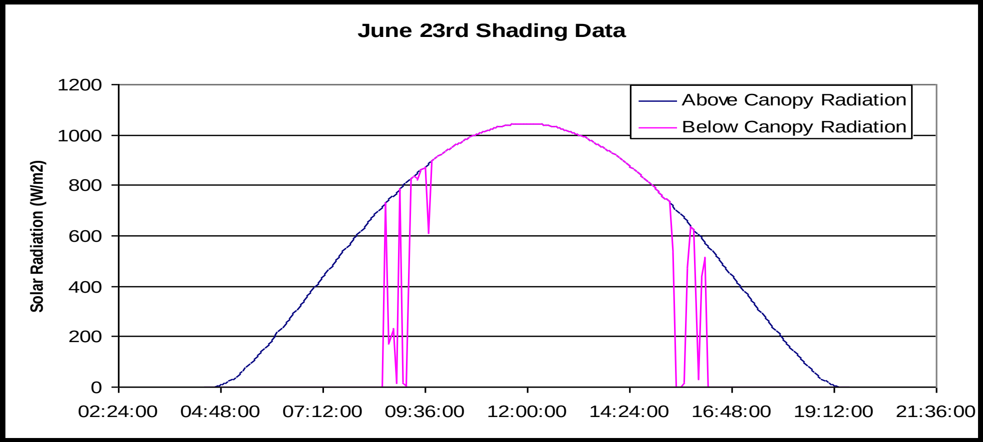
## Shaded Site

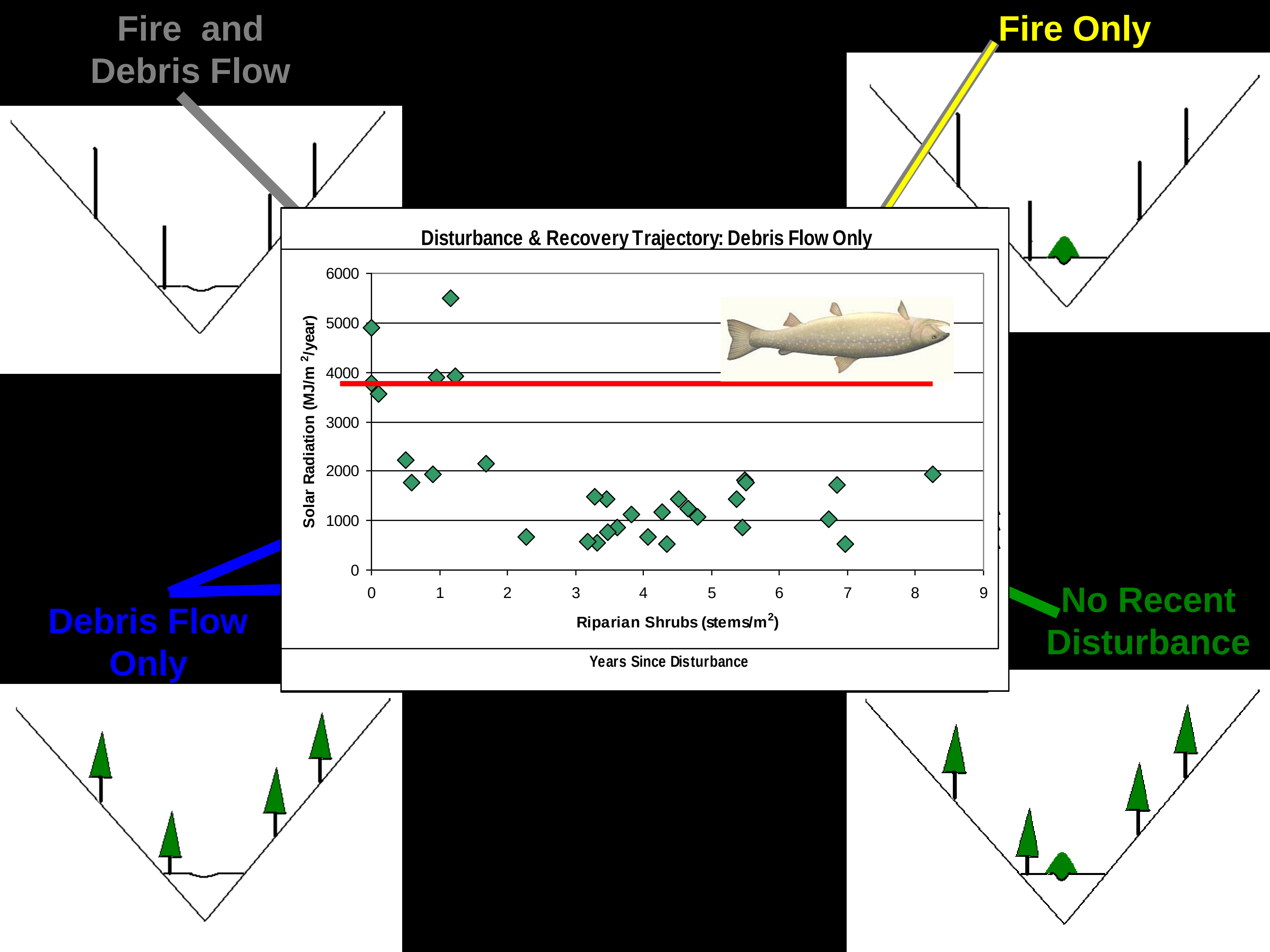





## Poorly Shaded Site





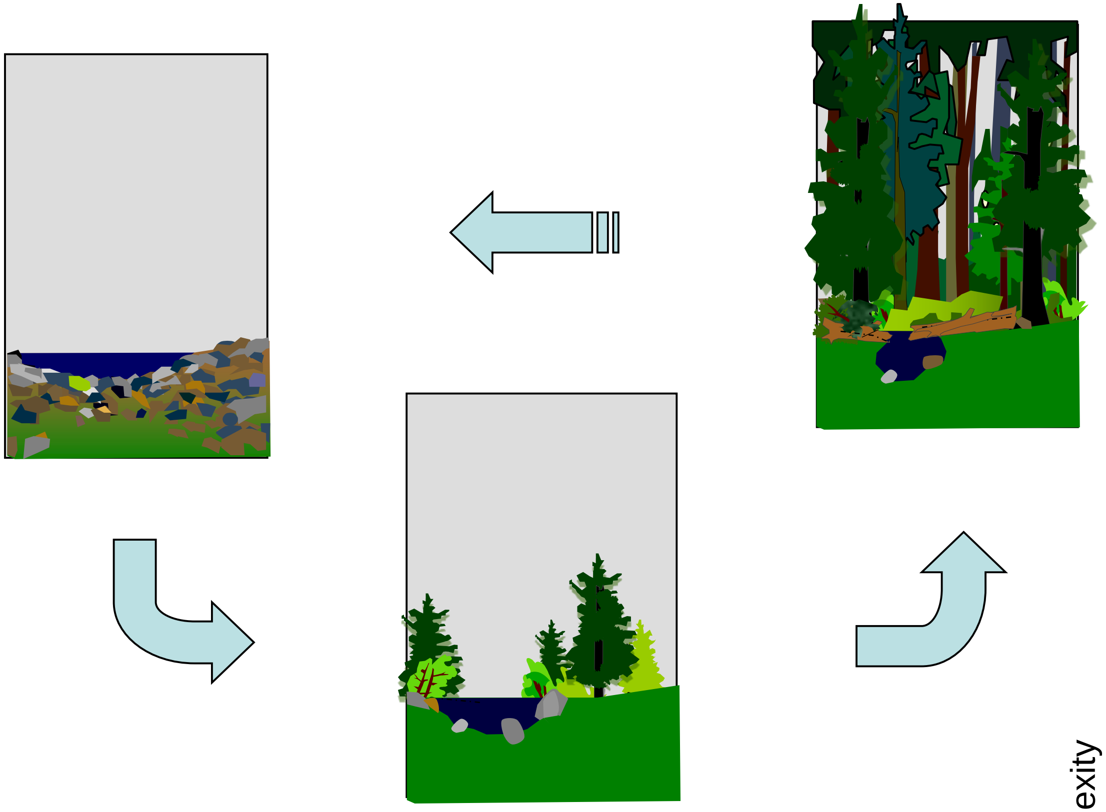


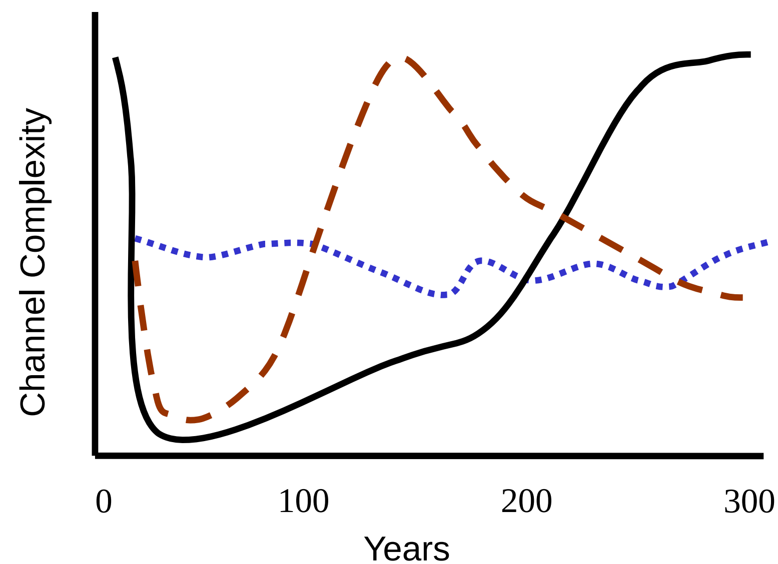
Fire and Debris Flow
Fire Only
Disturbance & Recovery Trajectory: Debris Flow Only
6000
5000
4000
3000
2000
1000
0
0 1 2 3 4 5 6 7 8 9
Solar Radiation (MJ/m 2/year)
Riparian Shrubs (stems/m2)
Years Since Disturbance
Debris Flow Only
No Recent Disturbance

# *Headwater rivers buffered from debris flows*

- How does fire affect channel morphology & aquatic habitat over longer time scales (10’s-100’s of years) in channels decoupled from direct debris-flow inputs?

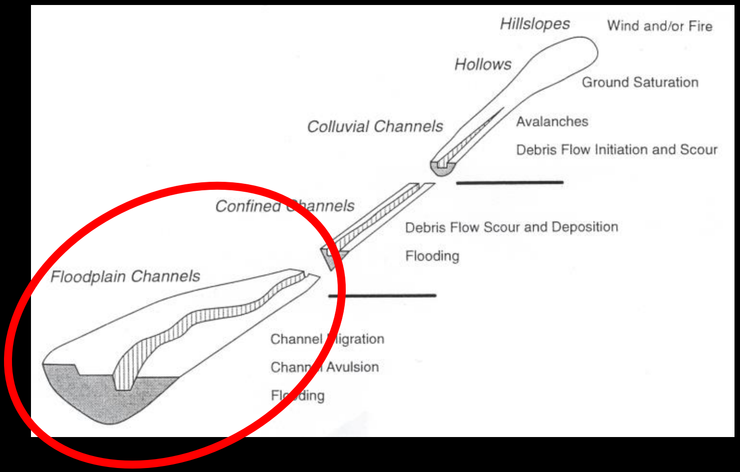
# *Channel Succession*





# *Study design*

- 3 treatments (15-20, 90-130, > 150 years since fire)
- 19 streams in the Idaho Batholith
- Controlled for elevation, drainage area, valley slope, geology, land use
- Moderate slope (2-4%), unconfined floodplain channels
  - Decoupled from direct hillslope inputs and debris-flow passage
  - Focus on post-fire changes in basin hydrology, sediment supply, and proximal riparian characteristics
- Space for time
- Fish-bearing




# *Measurements*

- Channel morphology (channel geometry, pool characteristics, grain size)
- Riparian canopy (tree density, basal area per unit area)
- Large woody debris (amount, location, function, size)

# *Results*

- None of the 14 morphologic characteristics varied between treatments ($\alpha = 0.10$)
- 2 out of 27 wood characteristics varied: number of pieces above bankfull, number of non-functional pieces ($\alpha = 0.10$)…largely the same pieces of wood in both cases
  - Differences in wood characteristics had little effect on channel morphology & associated aquatic habitat

# *Conclusion*

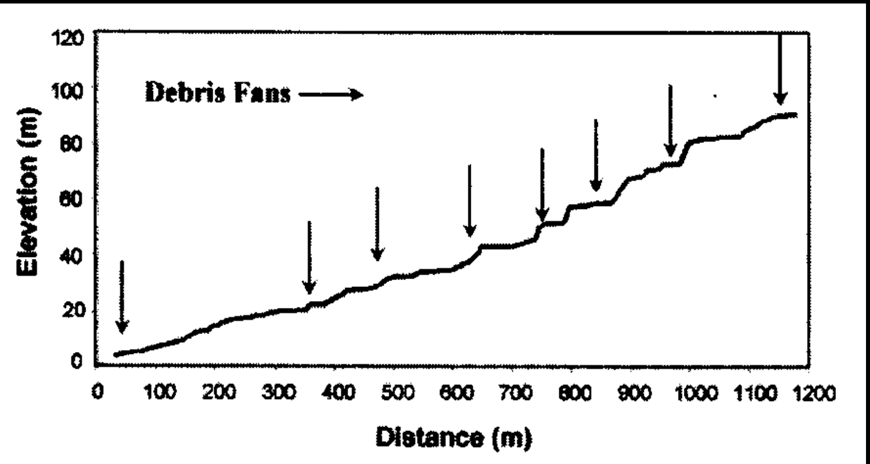
- The lack of morphologic variability between age classes of channels implies that wildfire disturbance does not have a long-term effect on channels of this stream type, suggesting that moderate-gradient, unconfined channels act as relatively stable, potentially productive, refugia for aquatic organisms.

# *Mainstem rivers receiving post-fire debris-flow slugs*

- How do sediment pulses affect channel morphology and aquatic habitat?

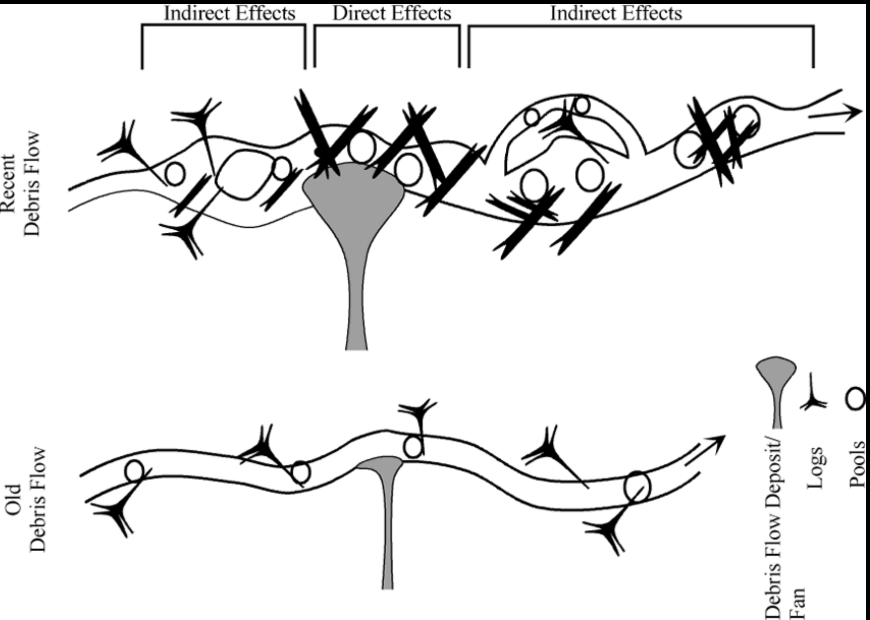
# *Debris Fans Locally Alter:*

## Channel Slope

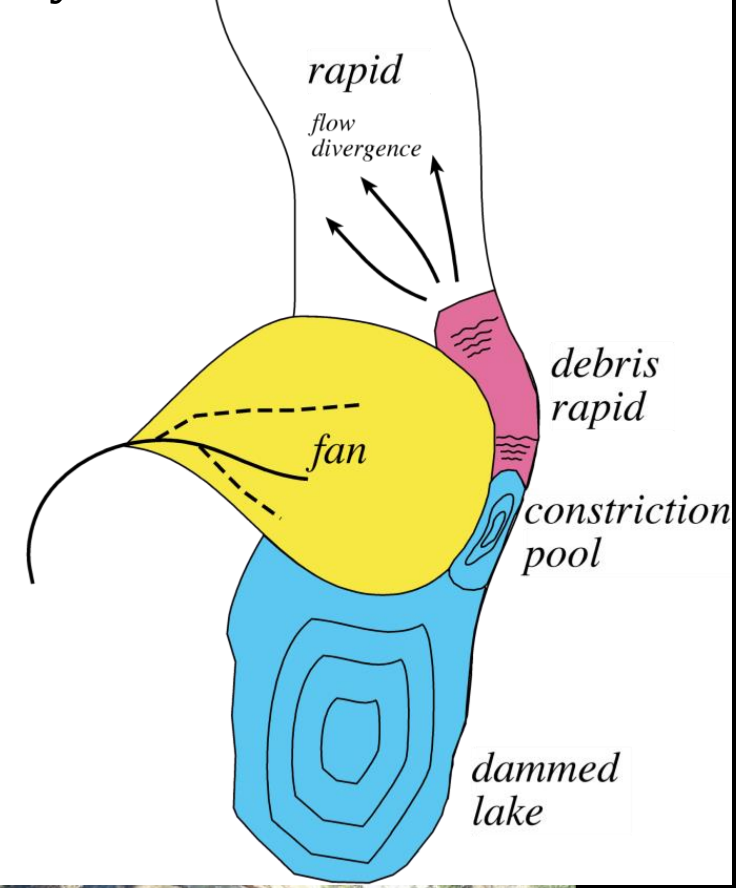



[*Benda et al.* 2003]

## Channel Width & Complexity

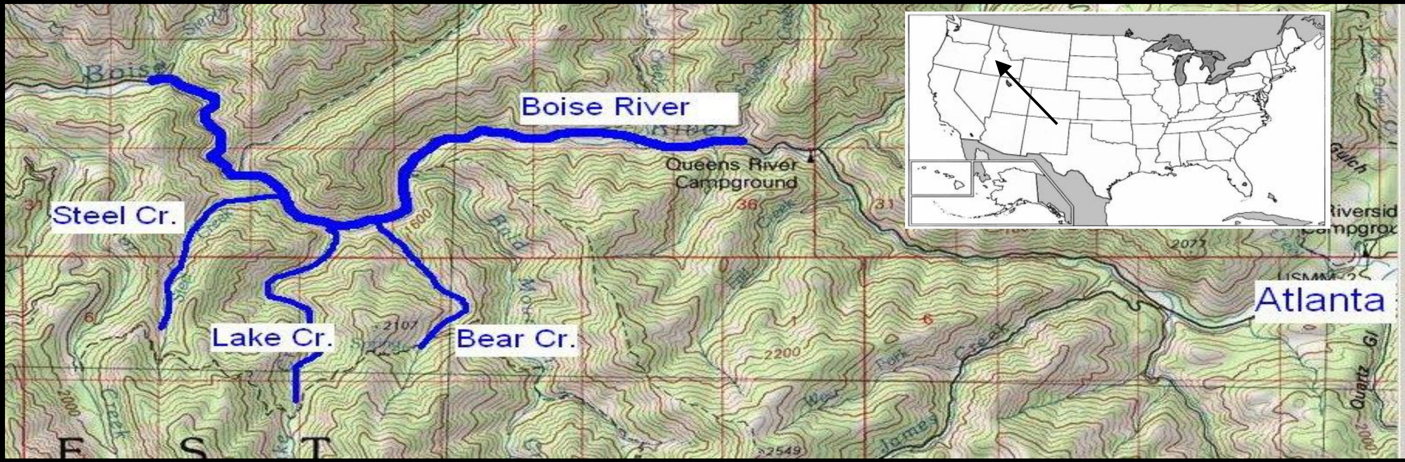



## Hydraulics & channel units



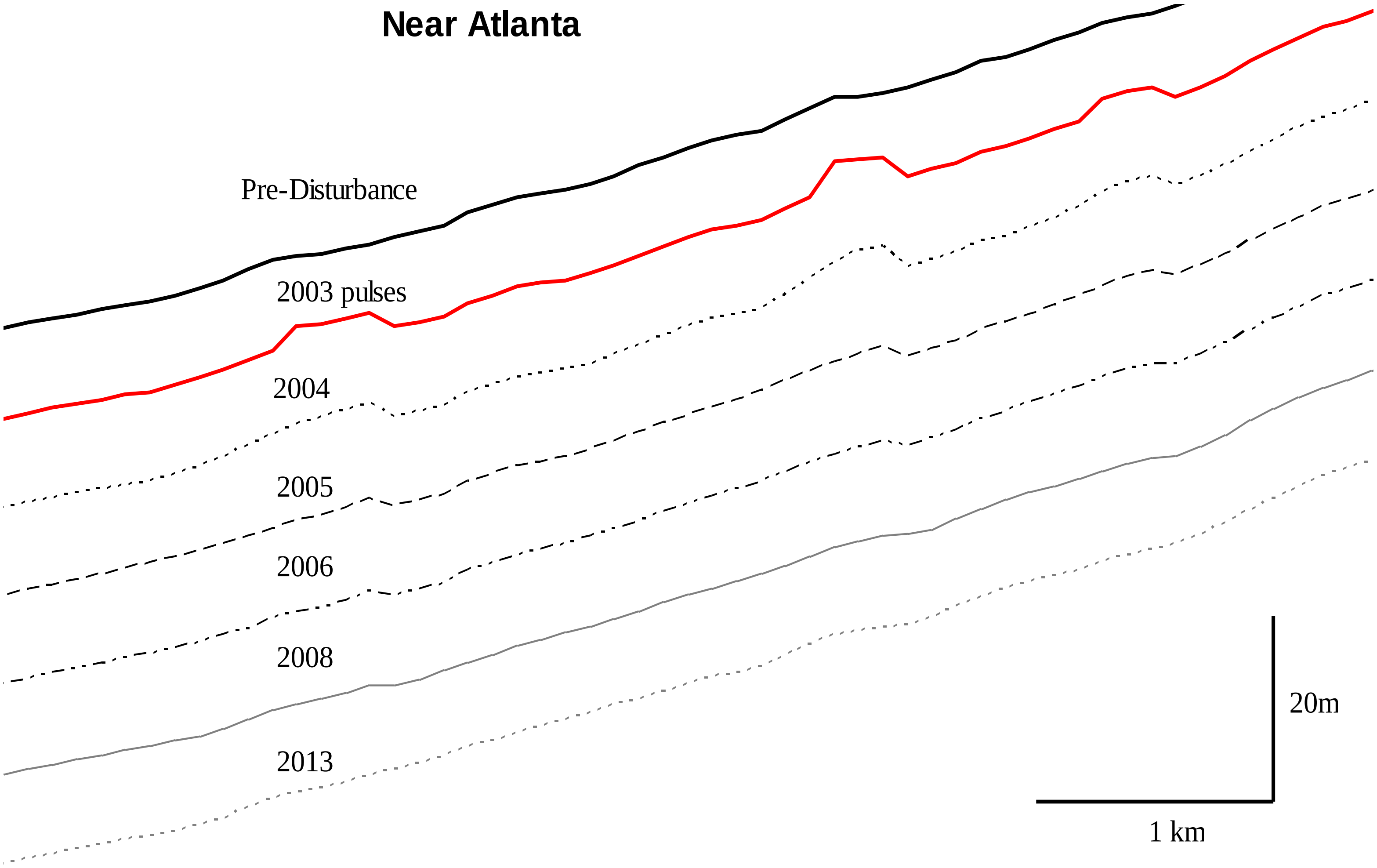

- But debris flows cause distal effects as the sediment wave propagates downstream

# *Field and numerical studies*

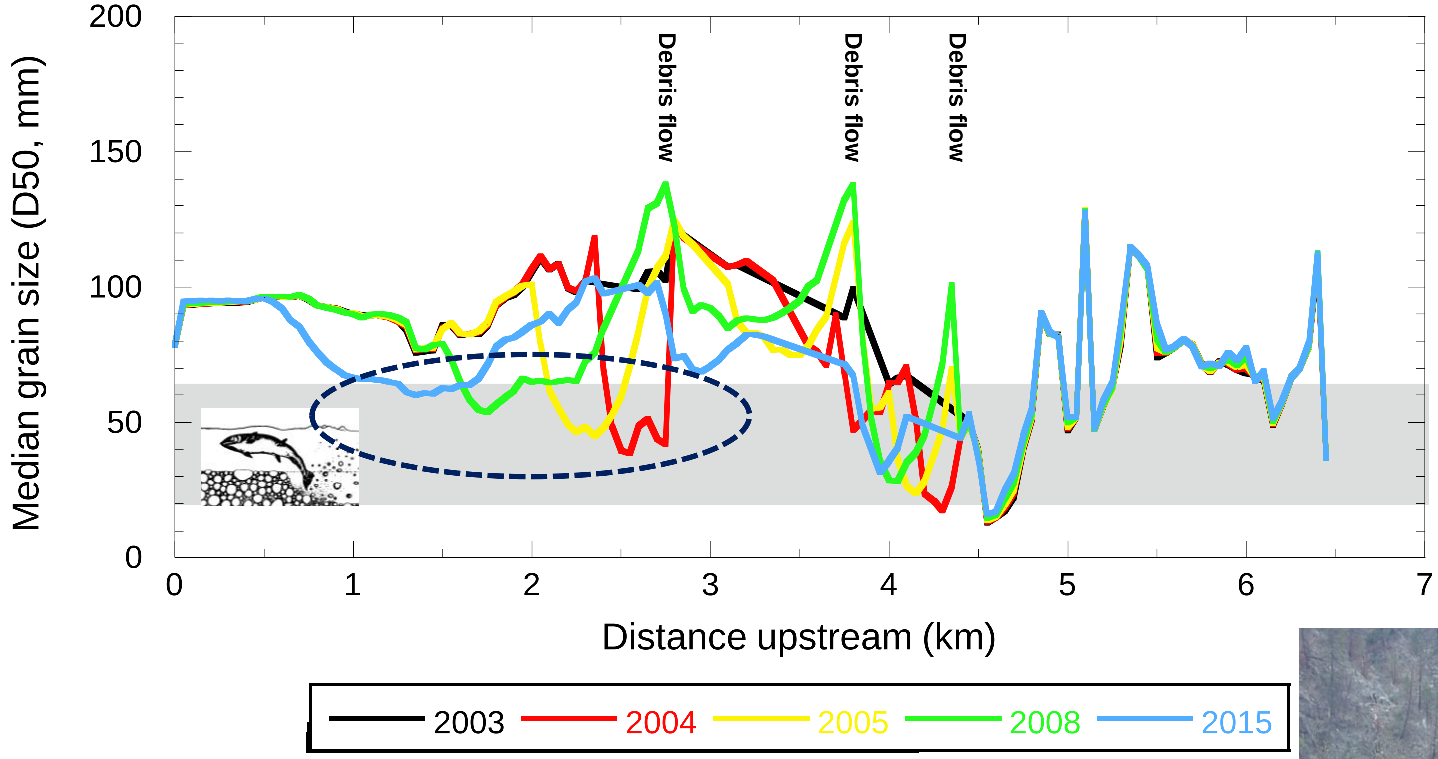



- 3 post-fire debris flows in neighboring basins
- Repeat topographic surveys of debris fans and mainstem river
- Numerical model of fan evolution and network sediment routing (*Cui*, 2005)

## Predicted Longitudinal Profile, Middle Fork Boise River Near Atlanta

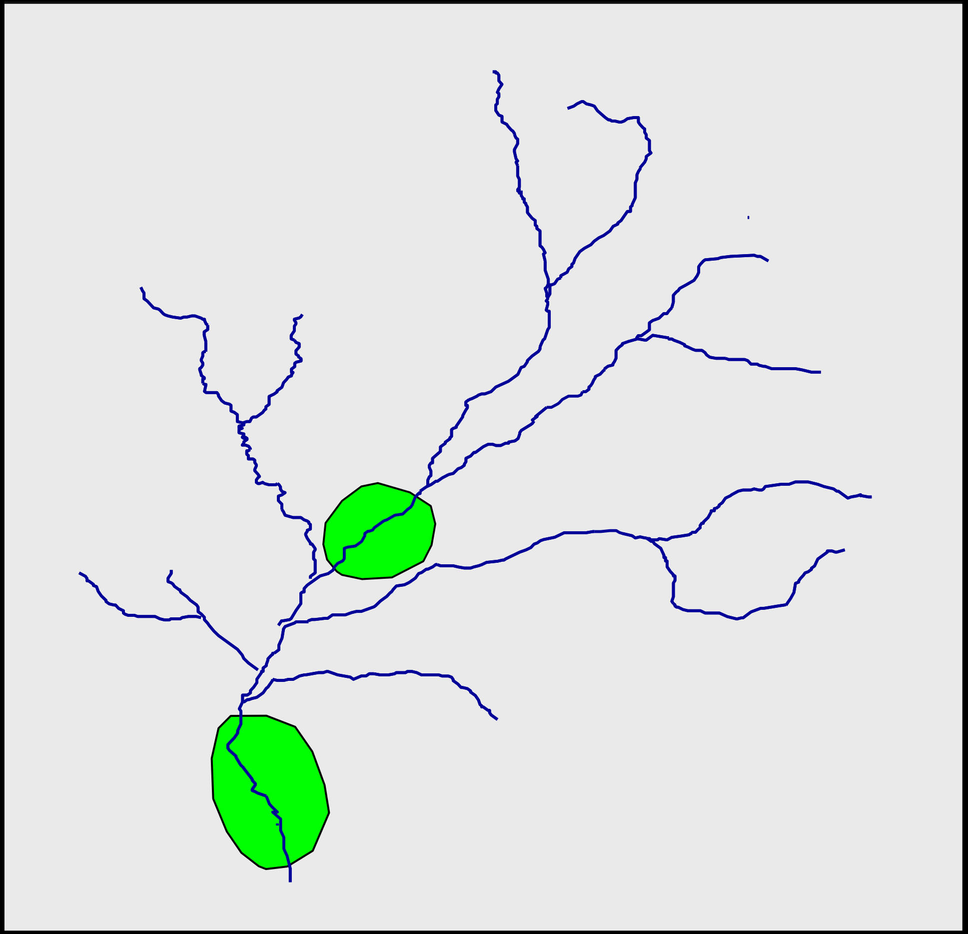



Bed profile predicted to recover to pre-disturbance conditions within 10 years in this steep (1.4%), confined river.

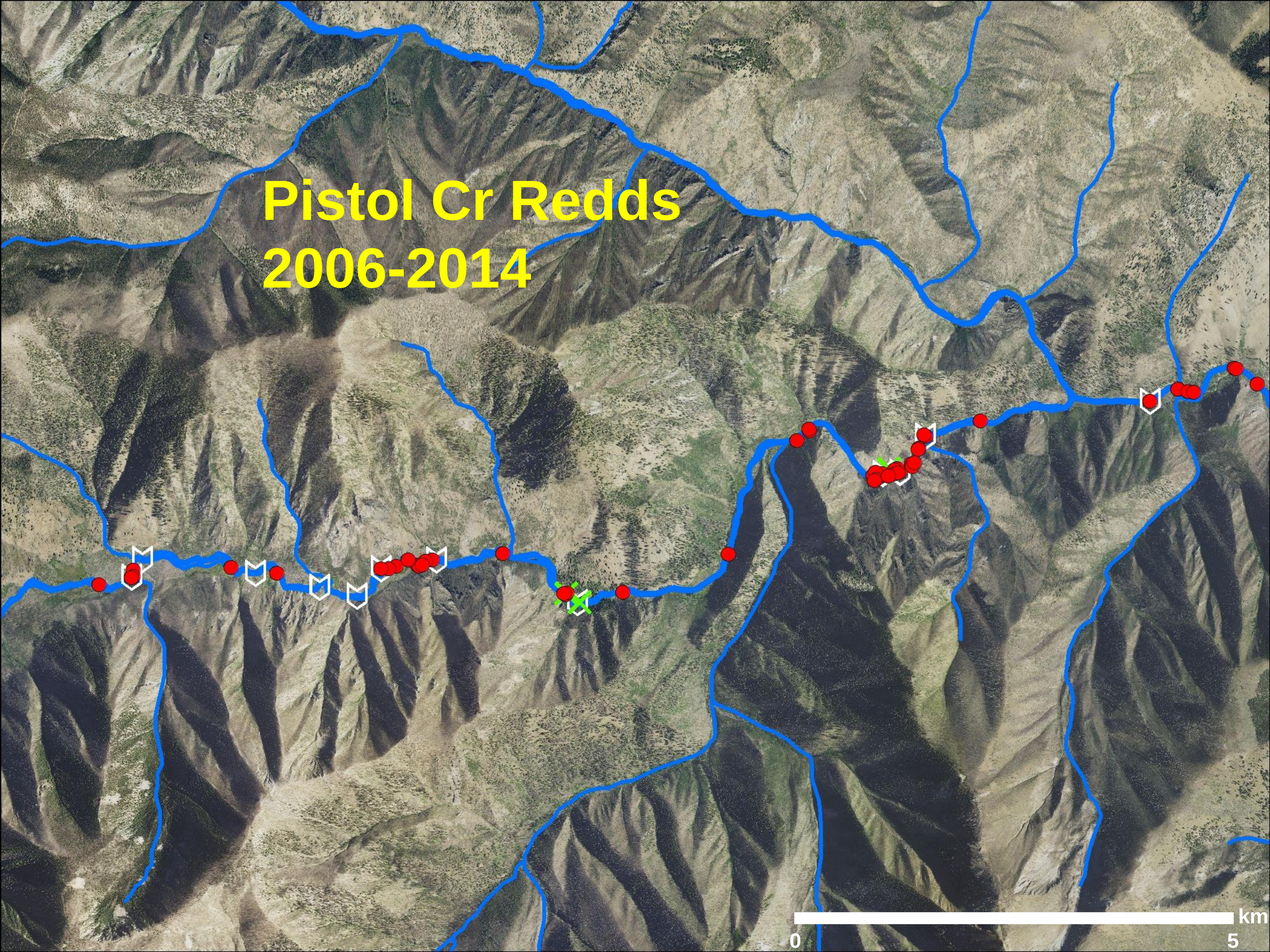


Median grain size (D50, mm)
200
150
100
50
0
0
1
2
3
4
5
6
7
Distance upstream (km)
Debris flow
Debris flow
Debris flow
2003
2004
2005
2008
2015


# *Dynamic (transient) responses*




Manu Esteve 2000


Pistol Cr Redds
2006-2014
km
0
5


Spawning on New Gravels in Fan
(no gravel 1979-2005)
2007 Redds
2005 Fan

# *Take-home messages*

- Location matters
  - Risk & type of post-fire disturbance depends on location in the channel network & associated process domain.
- Pros & cons to fire
  - Fires cause damage, but they also have important ecological benefits; aquatic organisms have evolved with these landscape disturbances and show adaptation to them.