Effects of Wildfires on Runoff and Erosion

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- Sergio Alegre (visiting Ph.D. student, 2010).

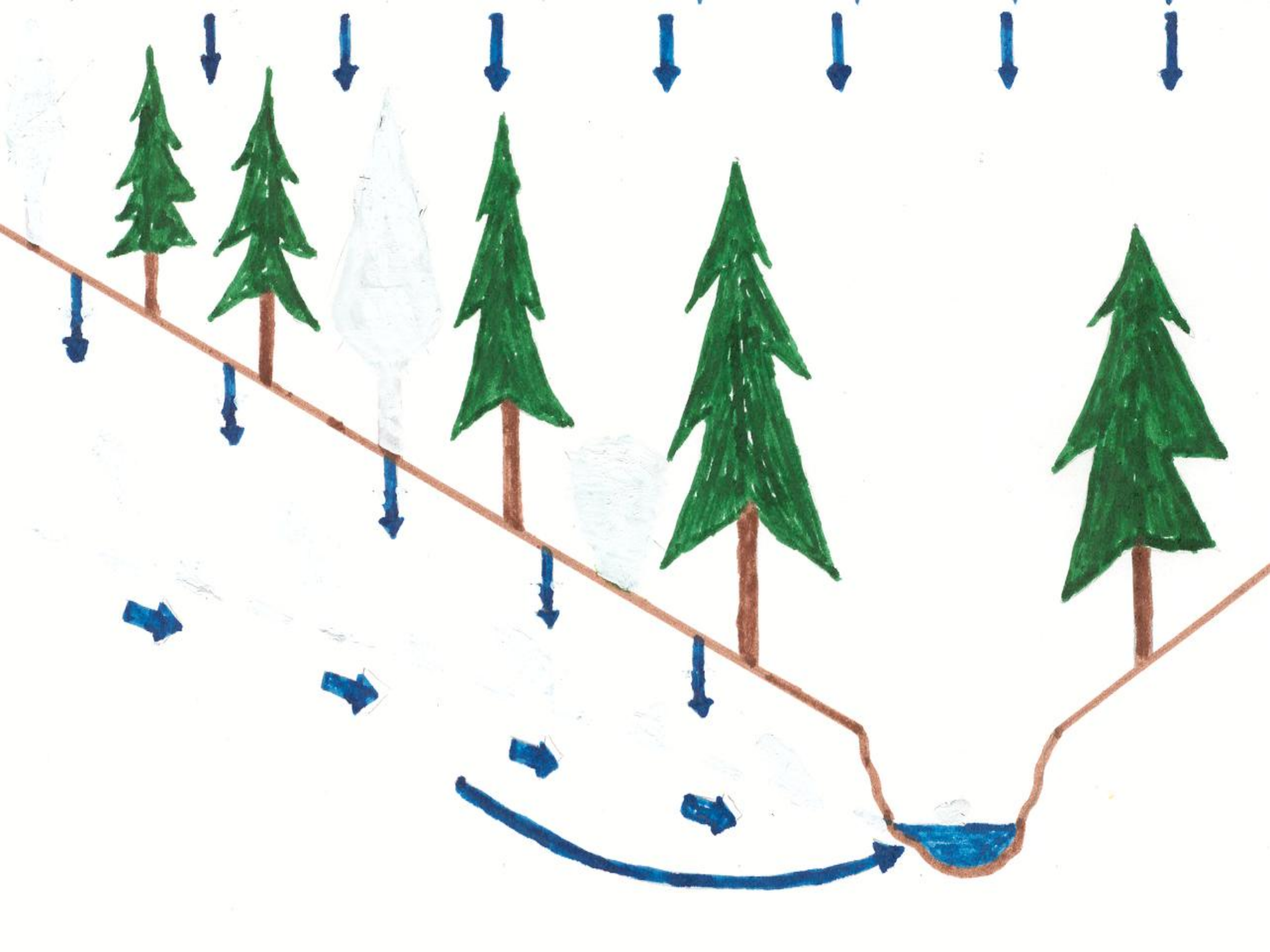
Why the concern about wildfires?

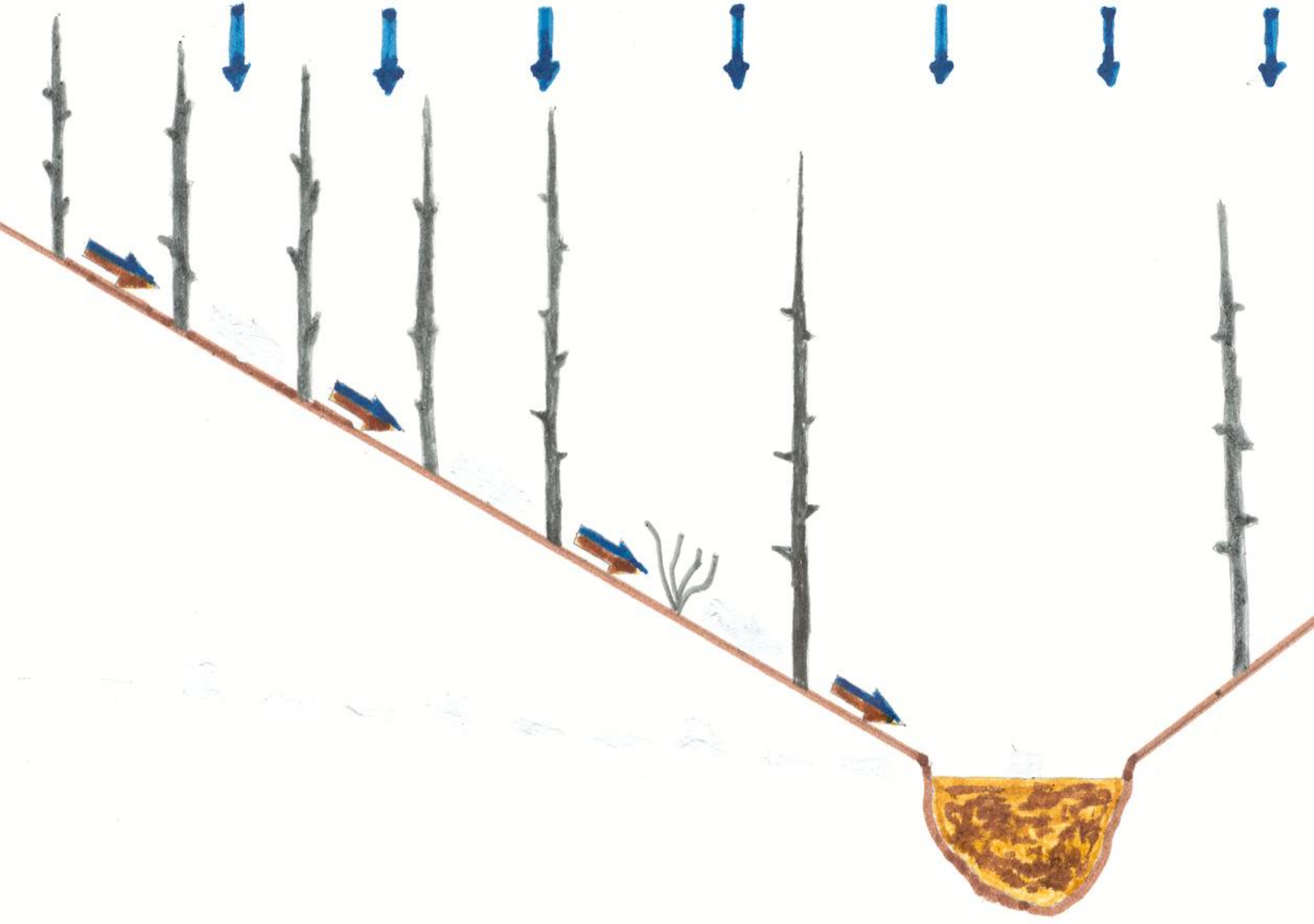
Hayman Fire, Colorado: August 2004

Channel incision from a 20 mm/hr rain event after the Cerro Grande Fire near Los Alamos, NM

Photo by John Moody, USGS


Alluvial fan from Saloon Gulch extending into
the South Platte River, Summer 2004
(2 years after burning!)





Objectives

1. Provide a process-based understanding of the effects of wild and prescribed fires on soils, runoff, and erosion;

2. Evaluate the relative importance of different controlling factors on post-fire erosion rates;

3. Determine the rate of recovery to pre-fire conditions;

4. Discuss how post-fire processes and recovery vary with increasing scale, and put the effects of wildfire in a broader context.

Post-fire Effects Vary with Burn Severity

1) **High severity:** complete consumption of organic horizon and alteration of the structure or color of the underlying mineral soil; loss of aggregates (“pulverization”):

2) **Moderate severity:** consumption of litter layer but no visible alteration of the surface of the mineral soil;

3) **Low severity:** only partial consumption of the surface litter.

Severity is **not** equal to intensity (heat loss per unit width per unit time), but severity and intensity often assumed to be closely correlated;

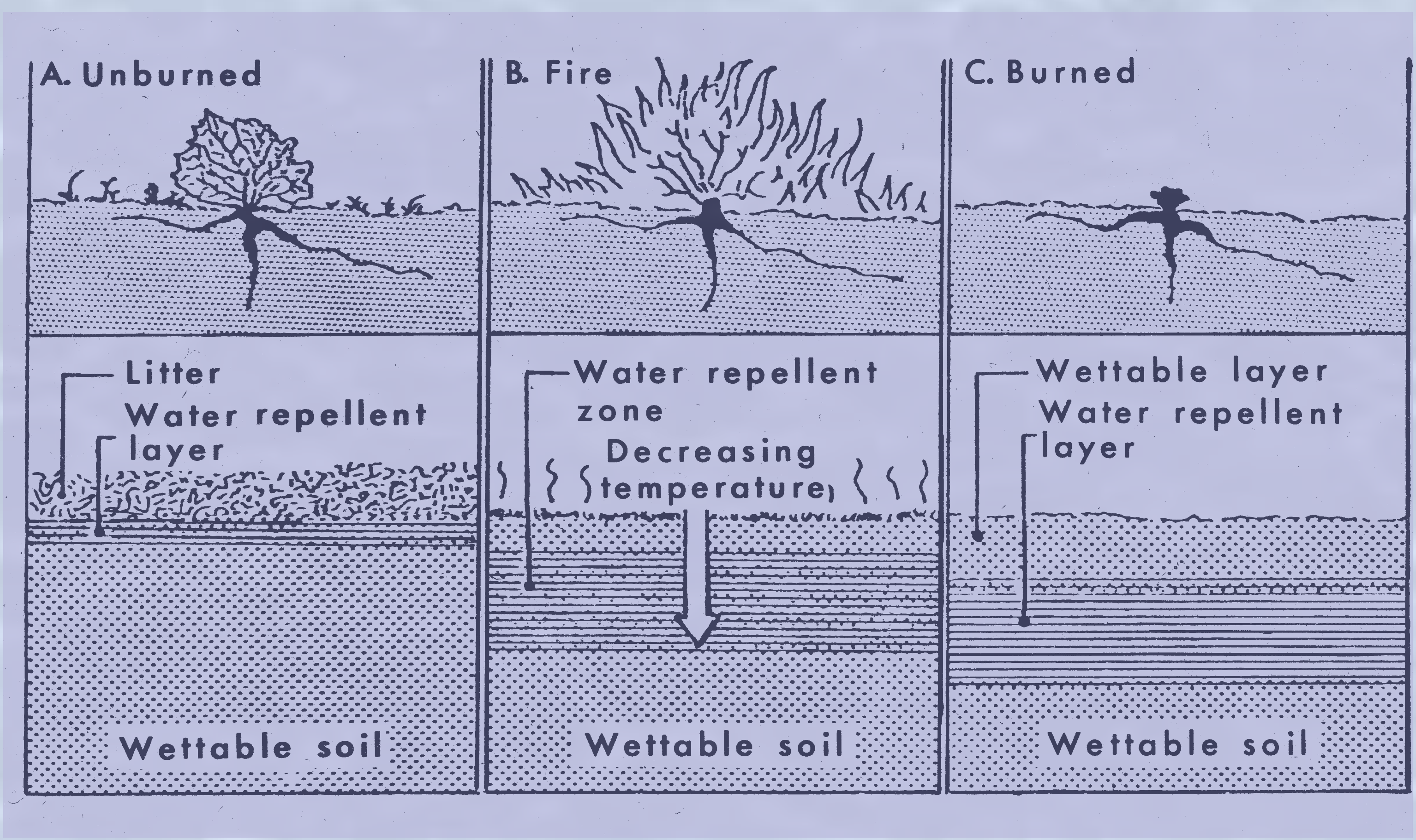
Why the sharp increase in runoff and erosion after some high-severity wildfires?

1. Loss of canopy decreases interception and evapotranspiration, increasing runoff;
2. Loss of litter decreases interception and exposes soil to raindrop impacts (increased erodibility) and sealing;
3. Loss of soil organic matter disaggregates or pulverizes the soil, and this increases soil erodibility;
4. Increase in soil water repellency can decrease infiltration and increase surface runoff;
5. Loss of litter decreases surface roughness and increases runoff velocities, increasing erosion;

Effects are synergistic, but which is most important?

Soil Water Repellency

Fire-induced soil water repellency



(DeBano, 1981)

Methods of Analysis

Water drop penetration time (WDPT):

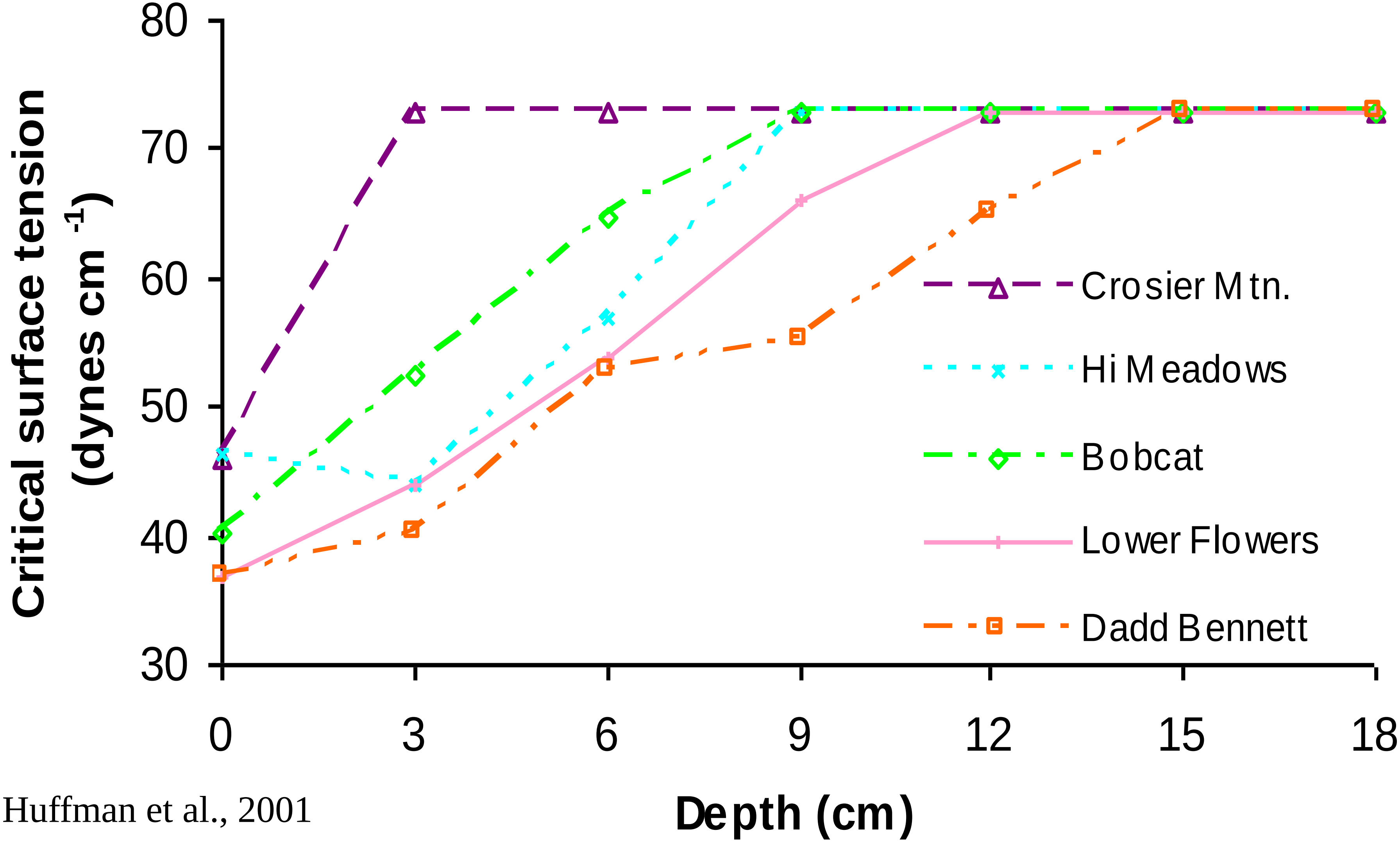
- Apply drops at different depths, beginning at mineral soil surface;
- Indefinite waiting time;
- Assesses persistence of soil water repellency.

Critical surface tension test (CST):

- Apply 5 drops of de-ionized water;
- If 4 of 5 drops are not absorbed within 5 seconds, test solutions with progressively higher ethanol concentrations (increasing ethanol concentrations decrease surface tension);
- Critical surface tension (CST) is the tension of the first solution that is readily absorbed into the soil ("strength").

Critical surface tension in wild and prescribed fires: High-severity sites

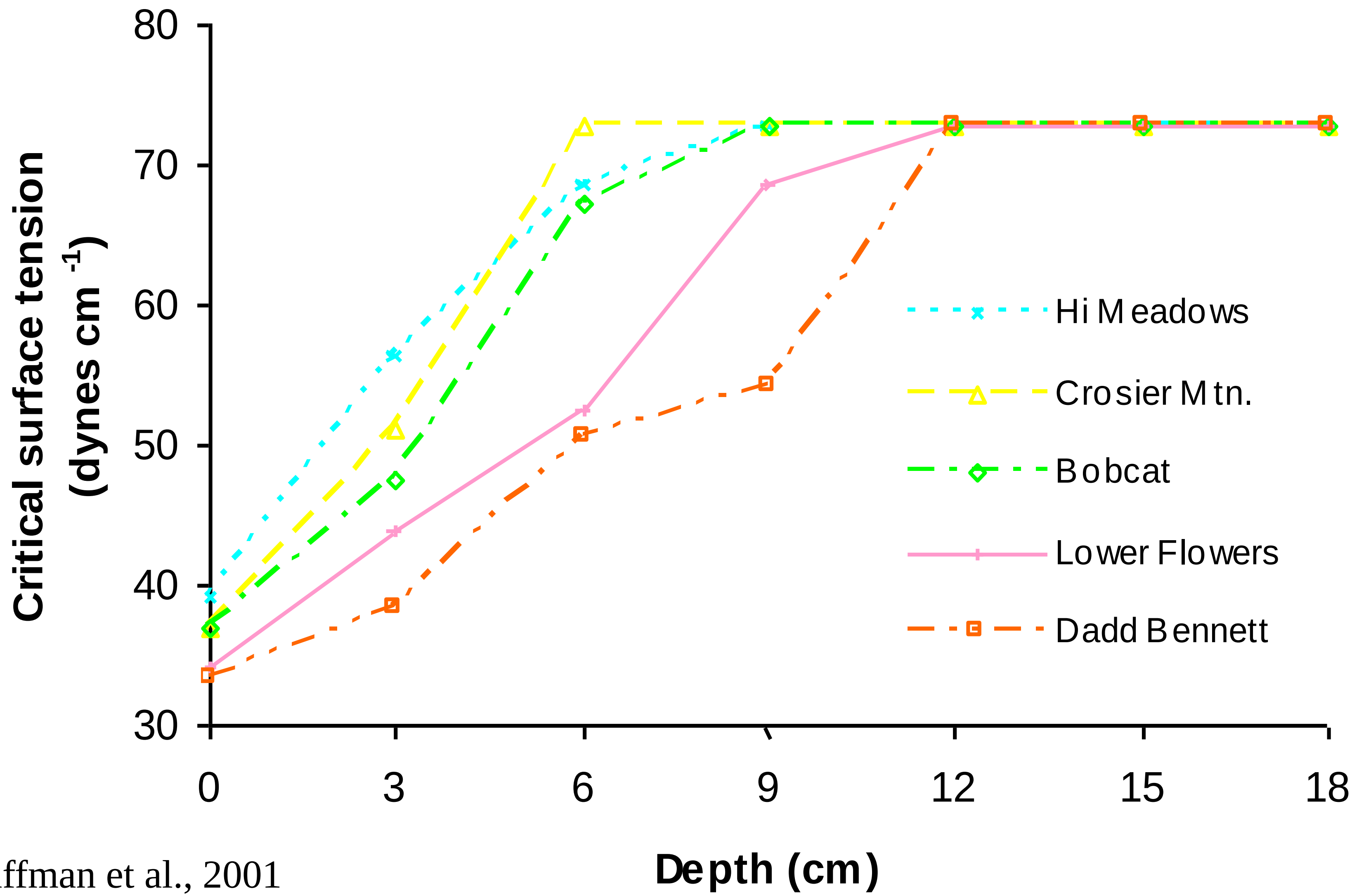
(bottom two sites are prescribed fires)



Huffman et al., 2001

Critical surface tension in wild and prescribed fires: Moderate-severity sites

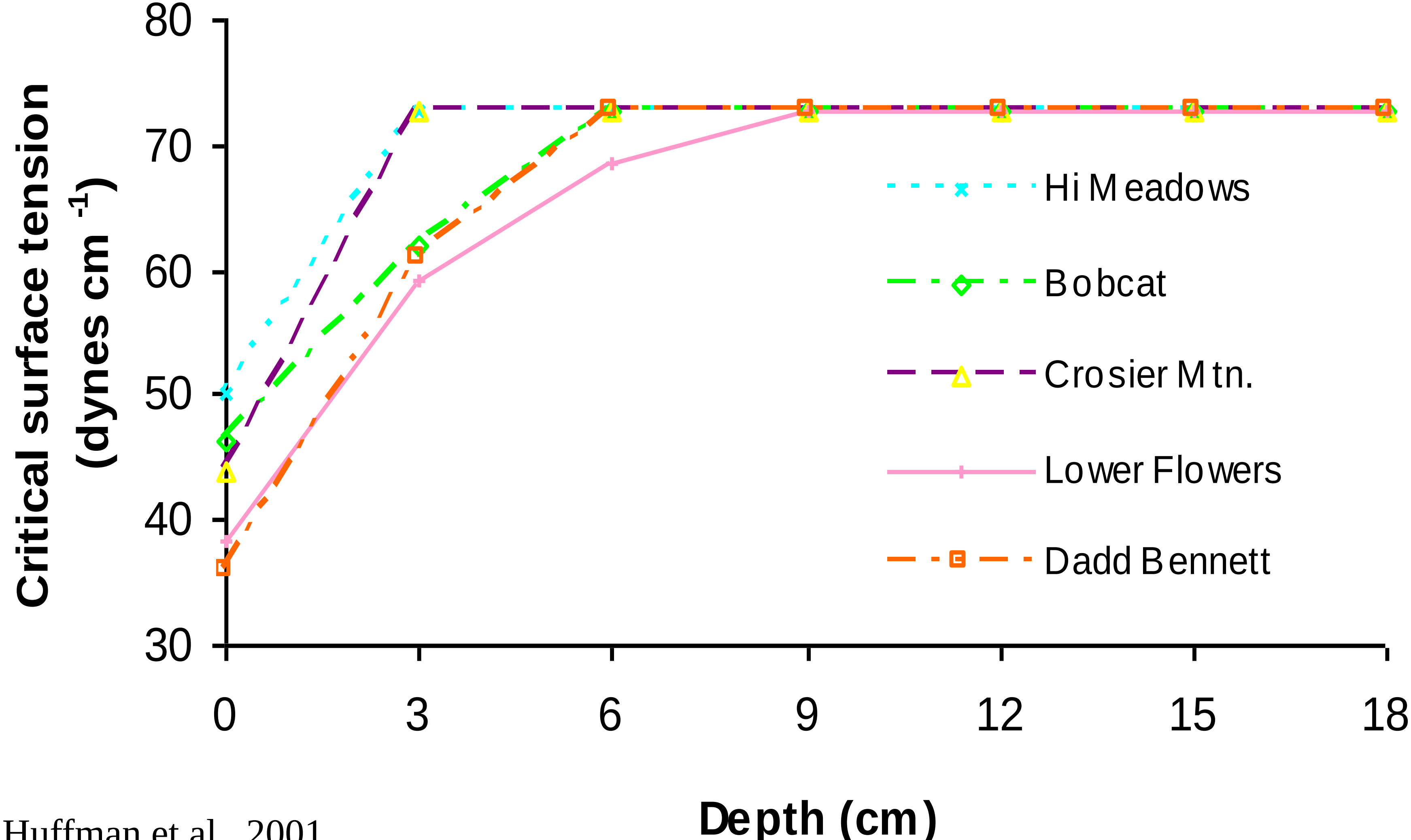
(bottom two sites are prescribed fires)



Huffman et al., 2001

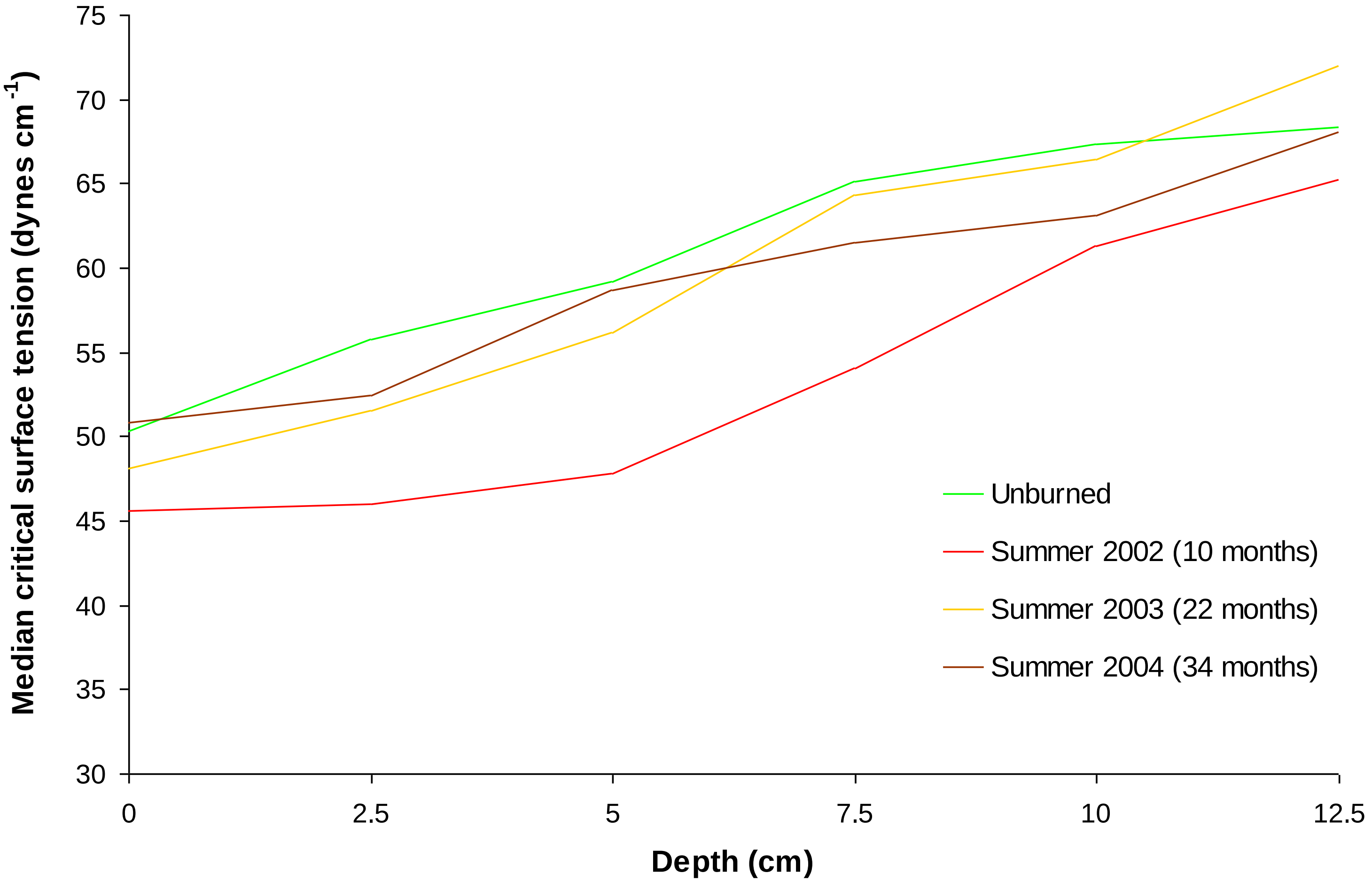
Critical surface tension in wild and prescribed fires: Low severity sites

(bottom two sites are prescribed fires)



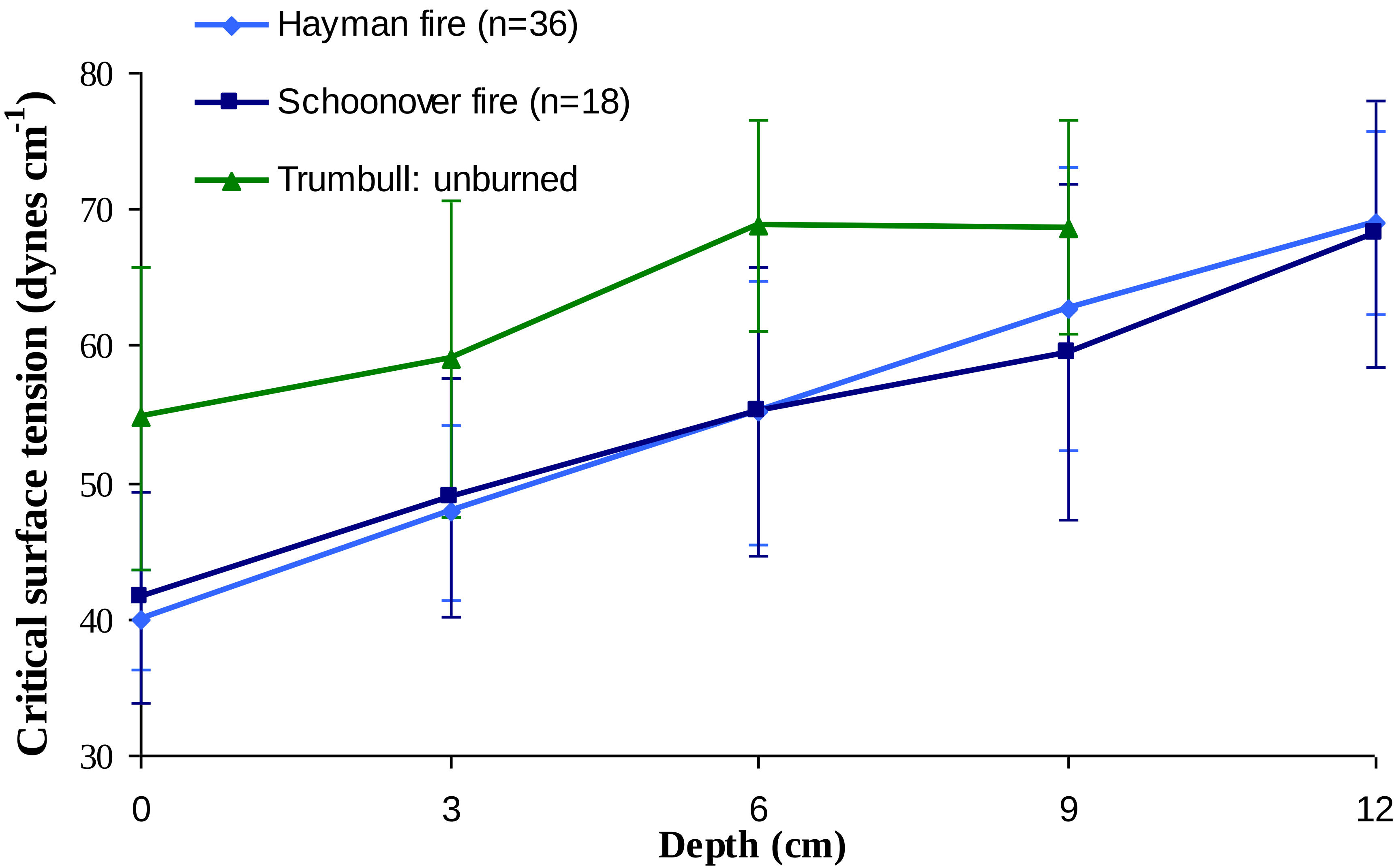
Huffman et al., 2001

Median soil water repellency over time, Star Fire, Tahoe National Forest



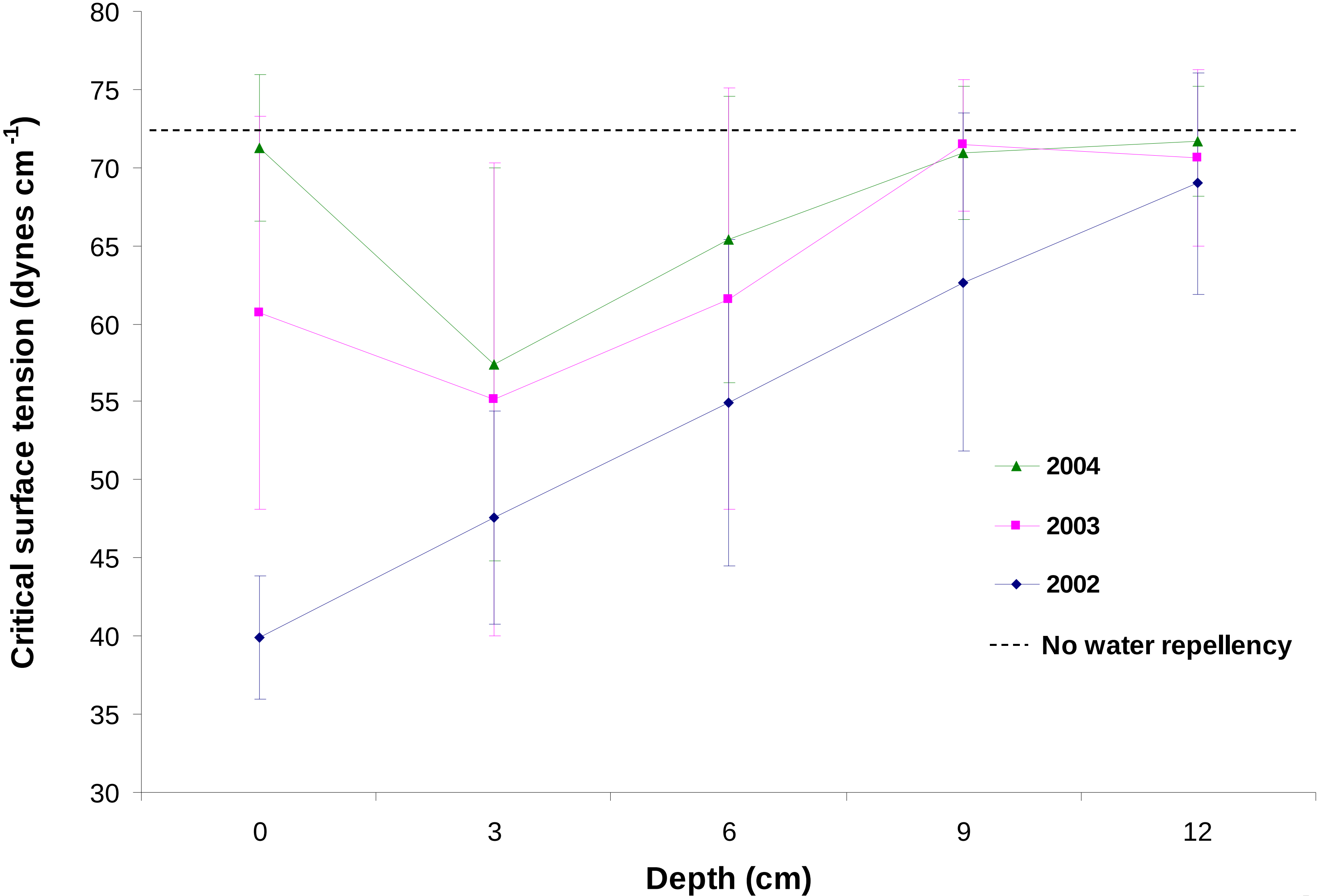
E. Chase, M.S.. thesis, Colorado State Univ., 2006

Mean soil water repellency by depth: Unburned vs. burned sites, summer 2002



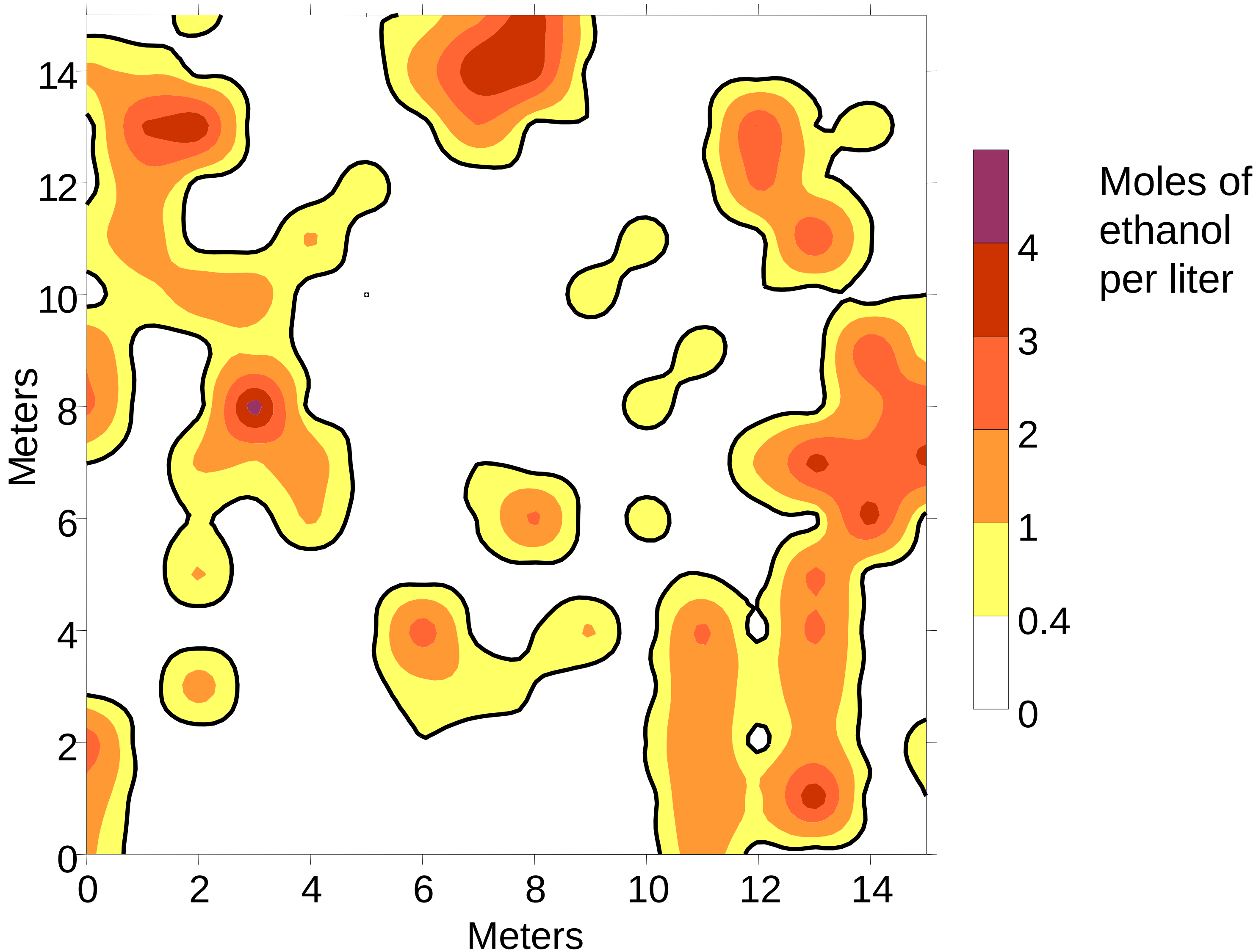
D. Rough, 2007

Soil water repellency from 2002-2004: Upper Saloon Gulch, Hayman fire



D. Rough, 2007

Spatial variability in soil water repellency: Plot H1, high severity, Hayman fire



Woods et al. 2007, *Geomorphology*

Summary: Soil Water Repellency

- Soils in unburned areas usually water repellent;
- Fire-induced water repellency is usually shallow (maximum of 9 cm);
- May be stronger in prescribed fires due to higher fuel loadings and slower rate of fire spread;
- Very high spatial variability;
- Relatively rapid recovery (≤ 2 years);
- Not present under wet conditions (~10-35 percent soil moisture), depending on fire severity;
- CST faster and more consistent than WDPT.

Supporting Data

Three papers on my web site (type “Lee MacDonald” into google):

1. Huffman, E.L., L.H. MacDonald, and J.D. Stednick, 2001. “Strength and persistence of fire induced soil hydrophobicity under ponderosa and lodgepole pine, Colorado Front Range”, *Hydro. Proc. 15: 2877-2892.*

2. MacDonald, L.H., and E.L. Huffman, 2004. “Persistence and soil moisture thresholds”, *Soil Sci. Soc. Am. J.* 68: 1729-1724;

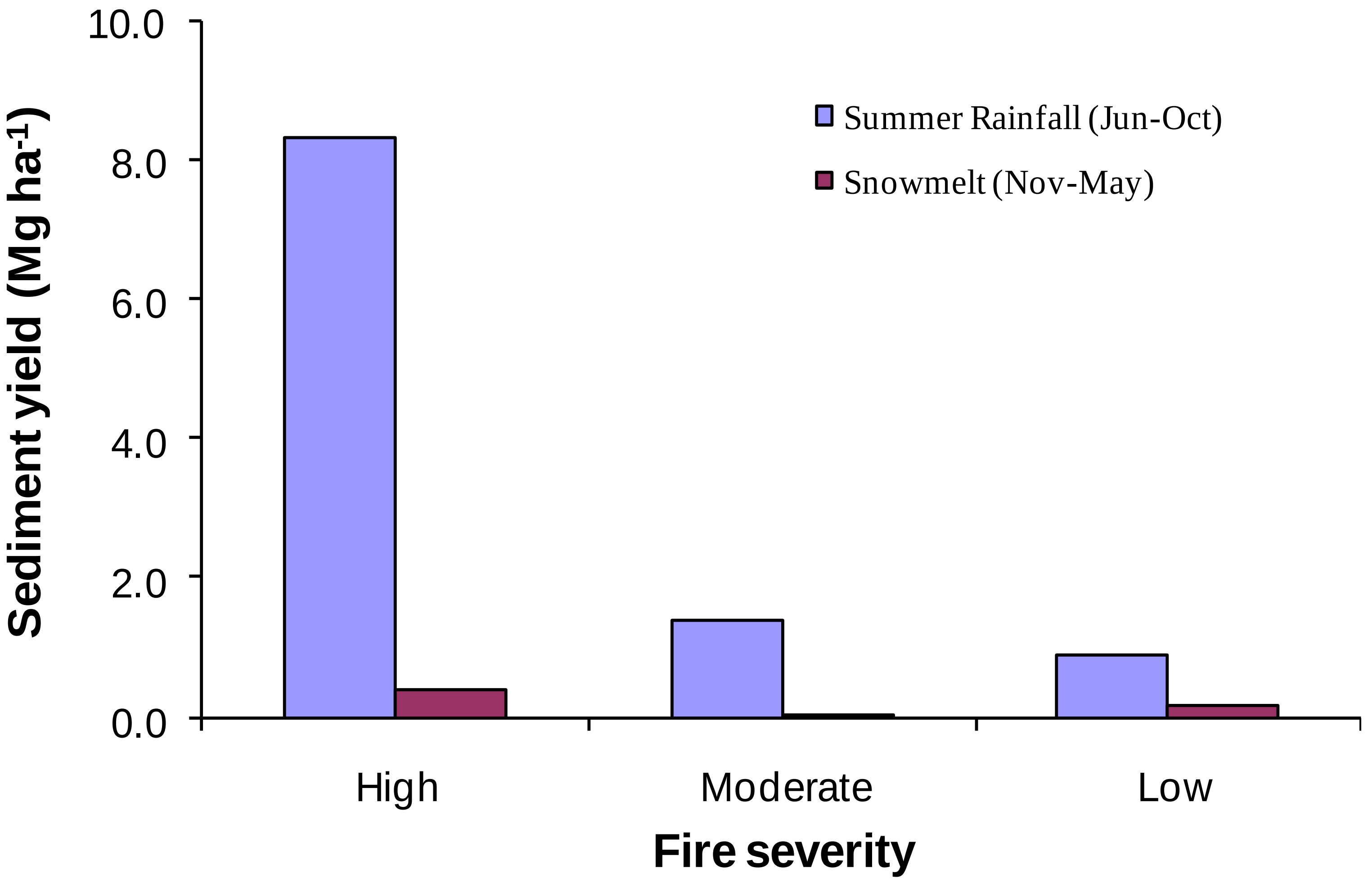
3. Doerr, S.H., R.H. Shakesby, and L.H. MacDonald, 2009. “Soil water repellency: a key factor in post-fire erosion?” In *Restoration Strategies after Forest Fires*, edited by A. Cerda and P.R. Robichaud, Science Publishers, Inc., Enfield, NH.


Sediment Production at the
Hillslope Scale
9. 7. 2002

Total plot years of data by treatment

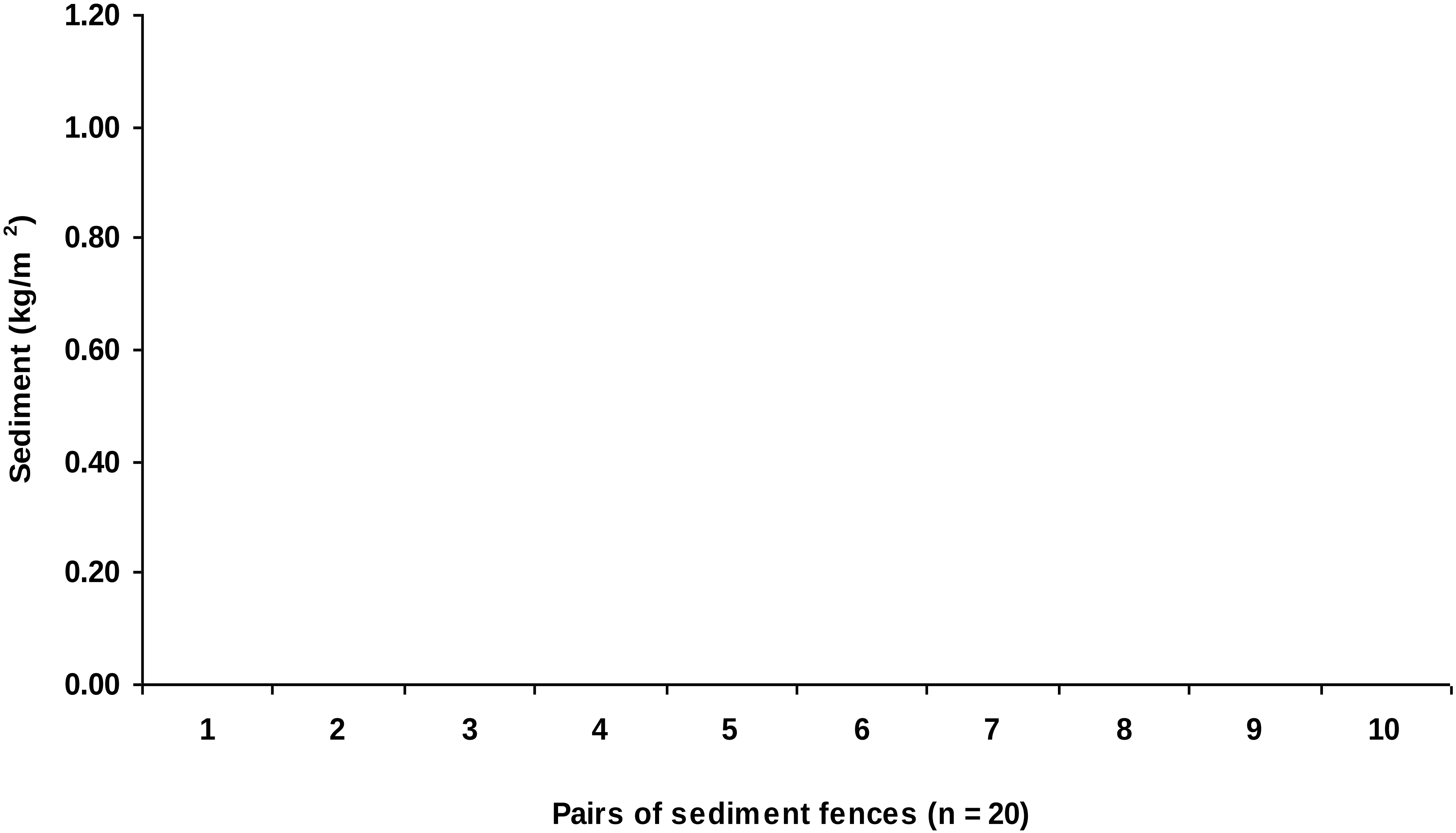
Untreated	
High severity	319
Moderate severity	55
Low severity	34
Treated (all high severity)	
Seeding and scarification with seeding	36
Straw mulch and straw mulch with seeding	60
Contour-felled logs	44
Ground-applied hydromulch	20
Aerially-applied hydromulch	20
Polyacrylamide	12
Total	**600**

Sediment yields by fire severity and season: First two years after burning (Colorado)

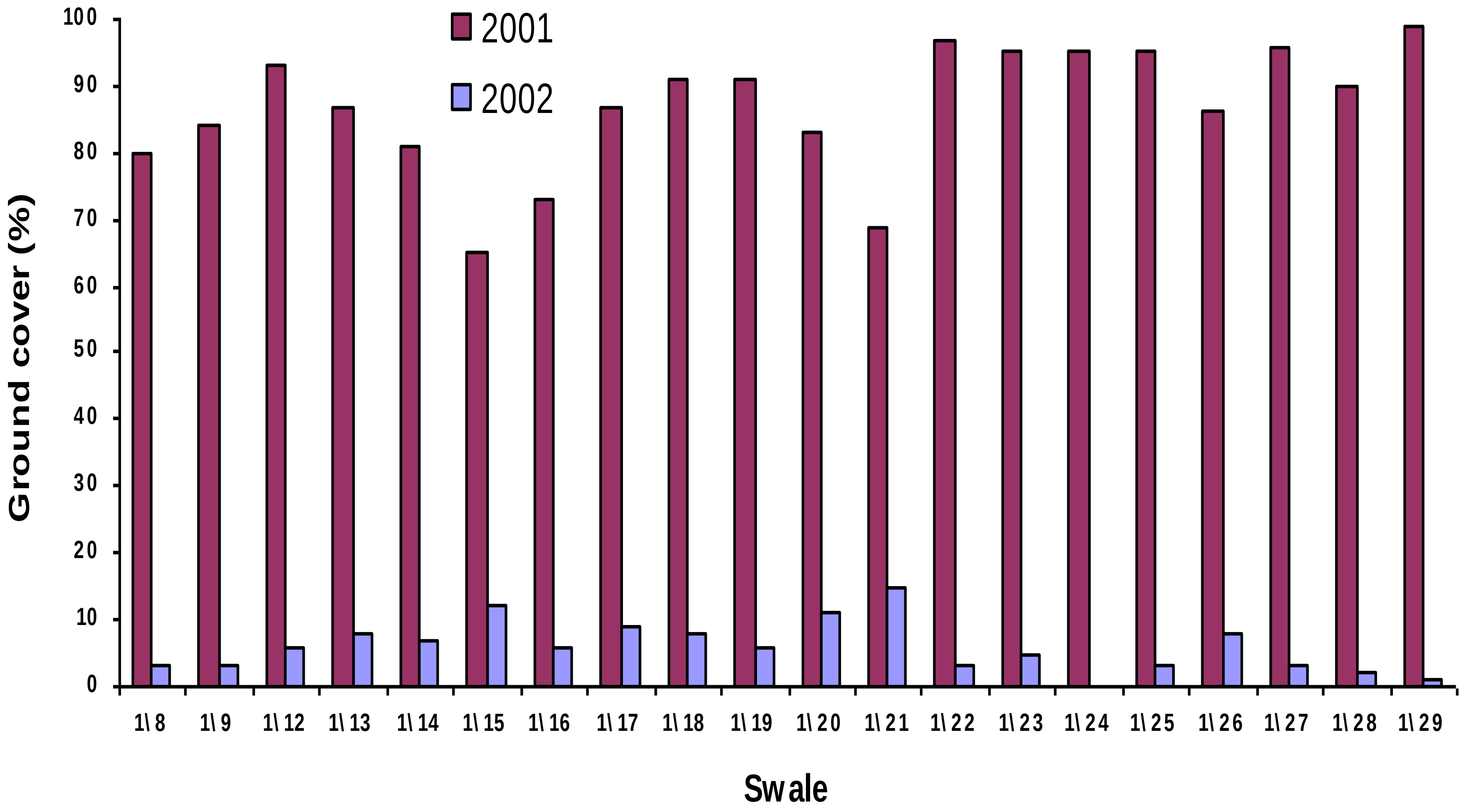


Role of surface cover, recovery over time, and rainfall intensity

Sediment production: Summer 2001 (before Hayman fire)

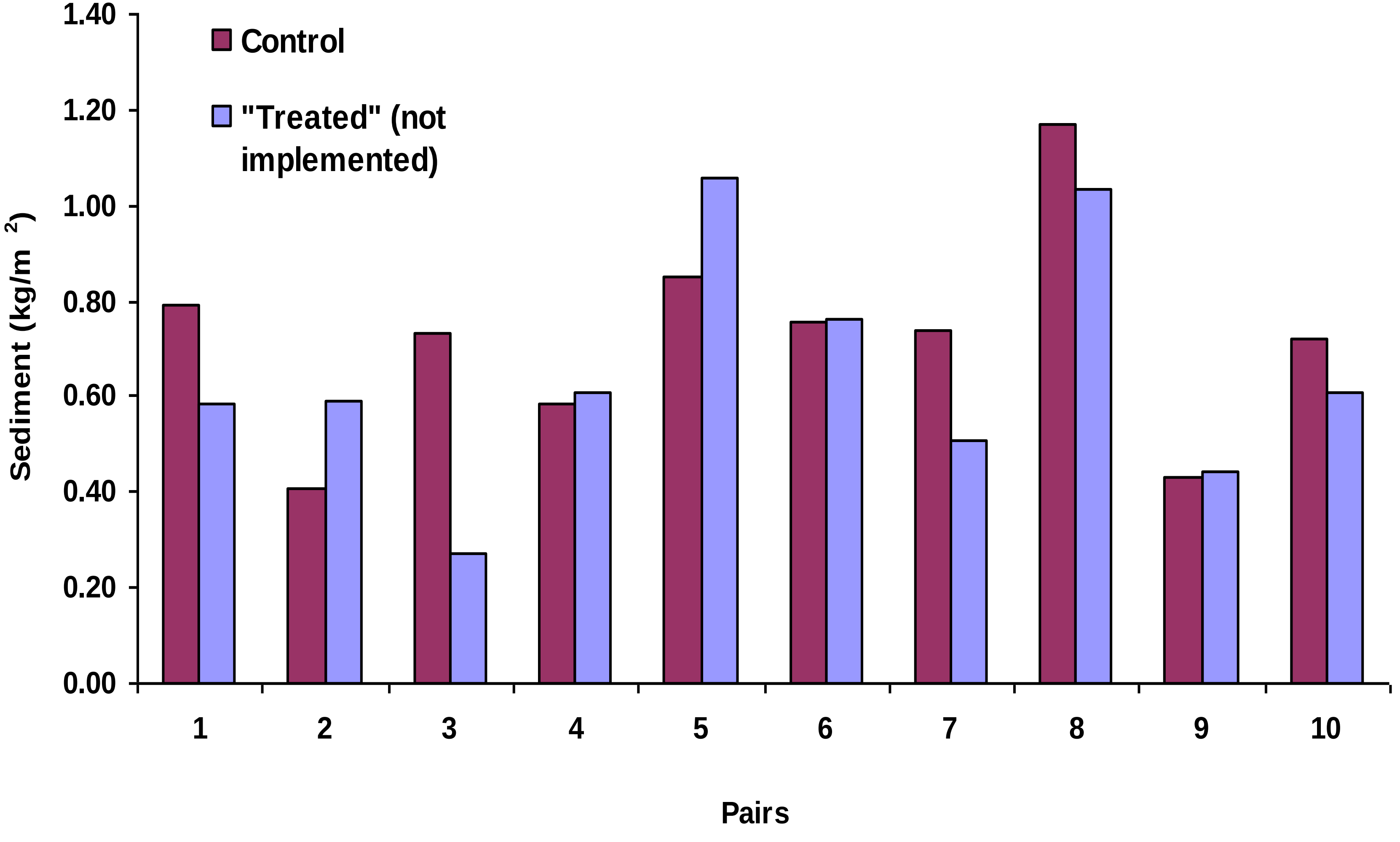


Mean percent ground cover in Upper Saloon Gulch in 2001 (prior to burning) and 2002 (after the Hayman fire)



Sediment from 11 mm of precipitation in 45 minutes on 21 July 2002

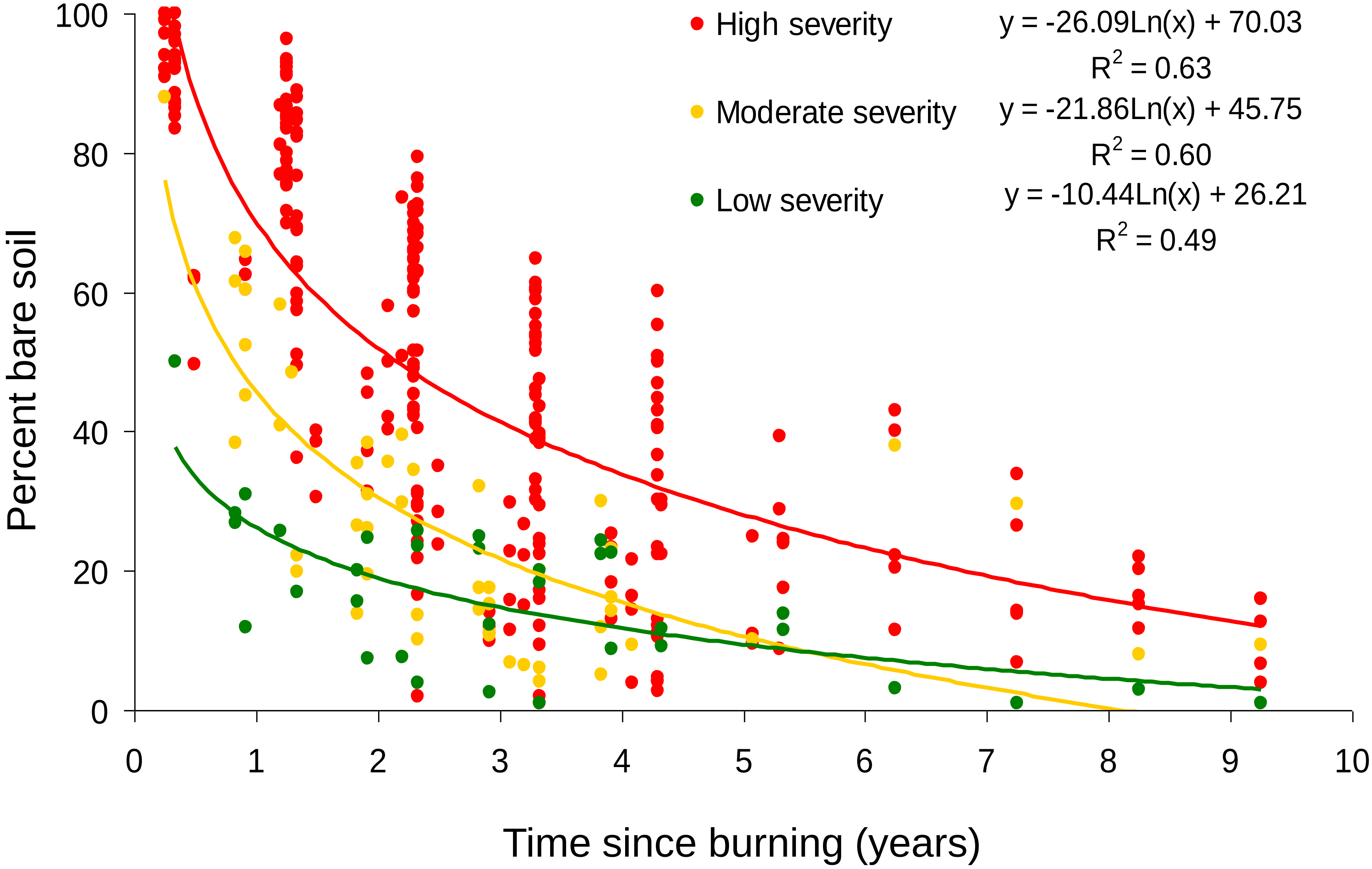
Sediment production after Hayman fire: 21 July 2002 storm (11 mm in 45 minutes)



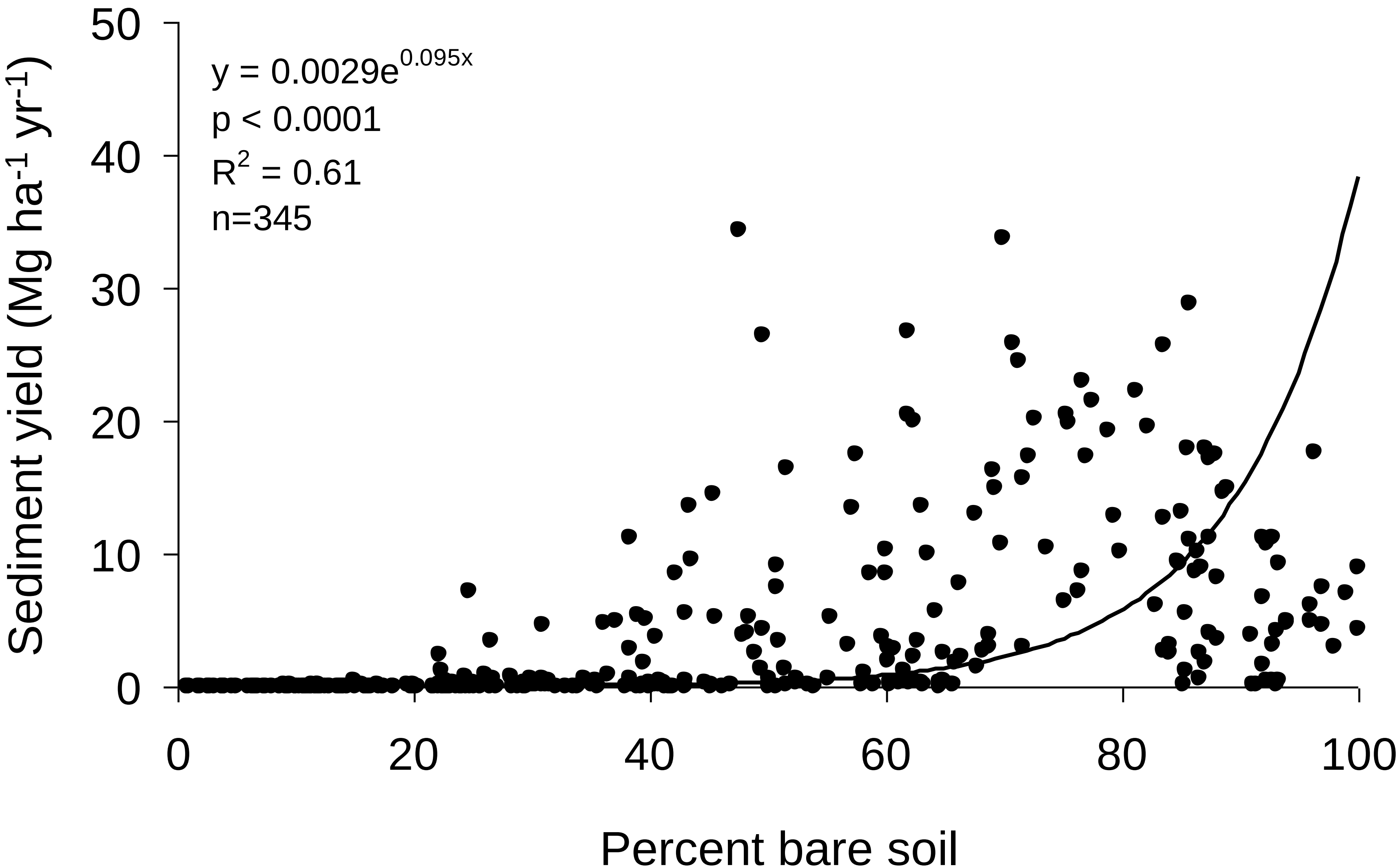
Vegetation recovery over time

Bobcat fire, sediment fence #9

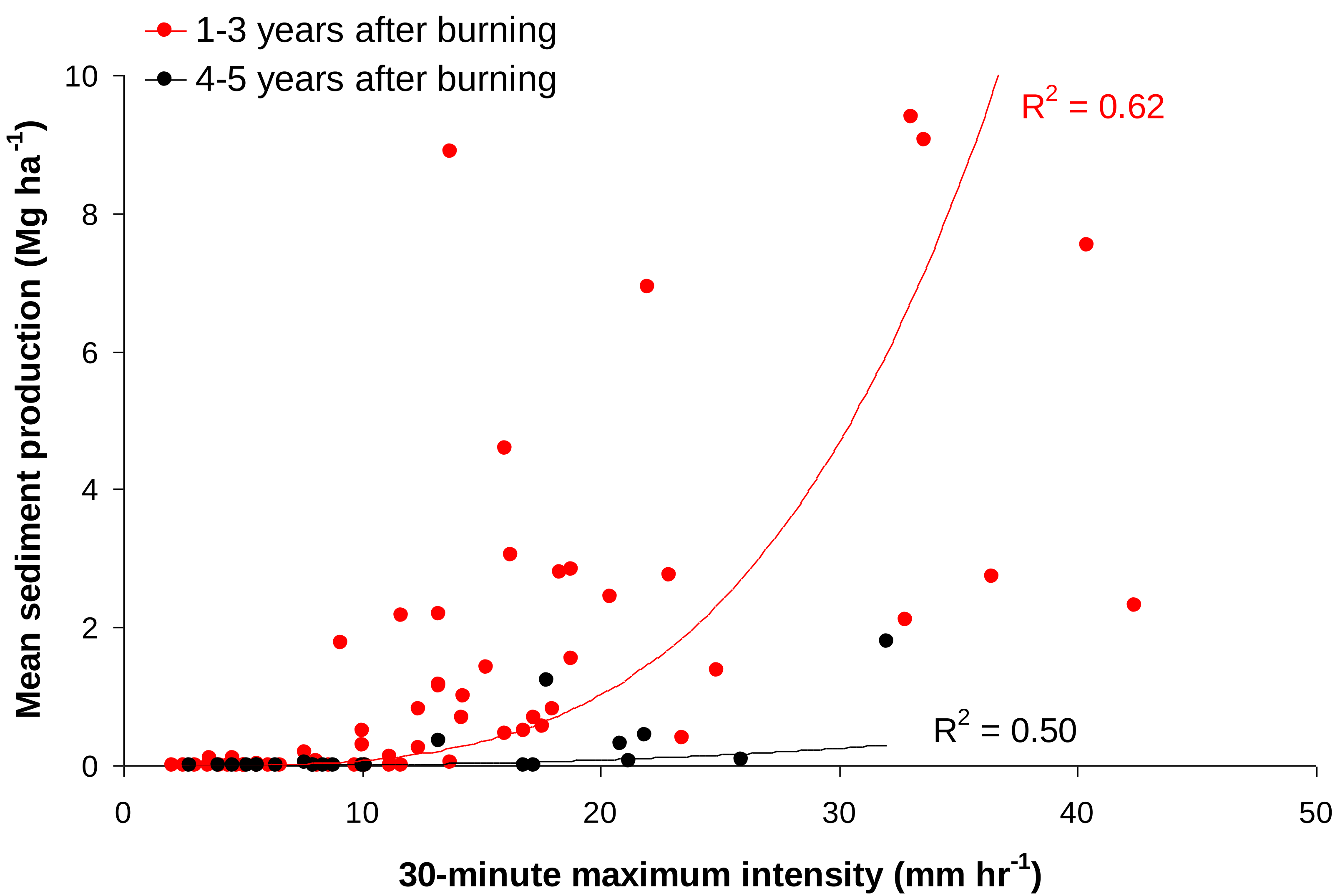
Percent bare soil vs. time since burning



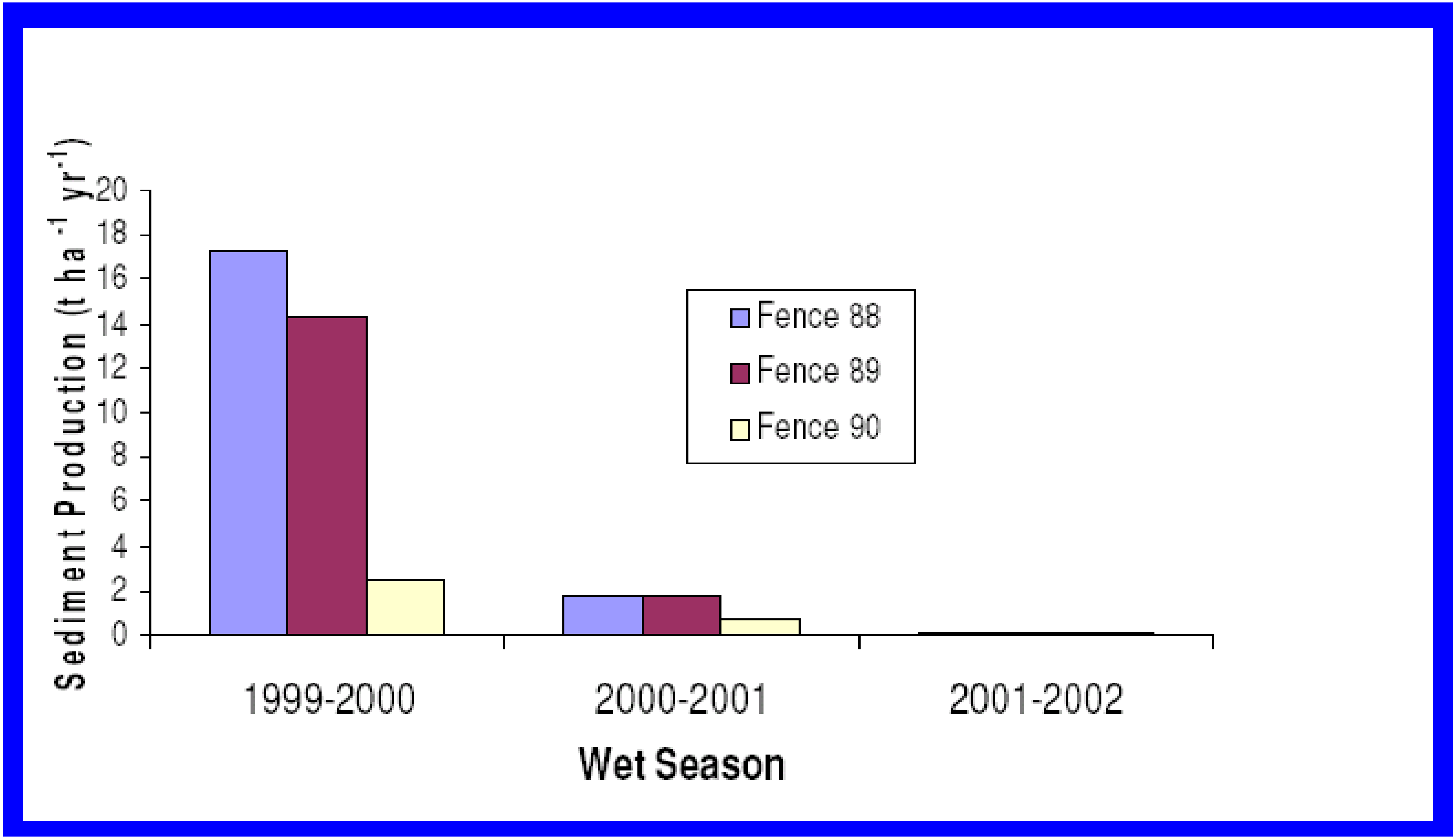
Sediment yield vs. percent bare soil



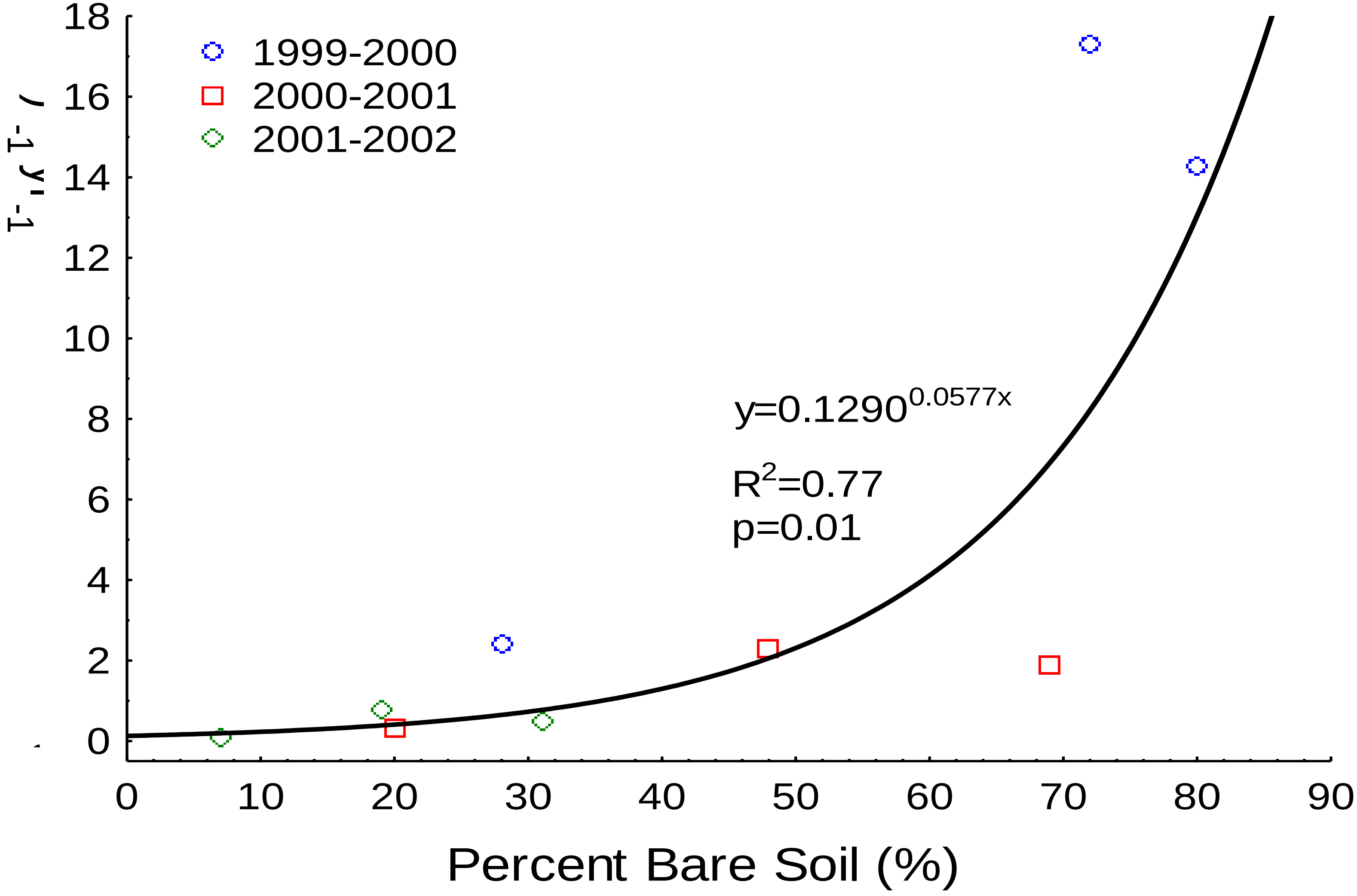
Event-based sediment production vs. I_{30}: High-severity wildfires



Sediment production over time: Pendola fire, Eldorado N.F.



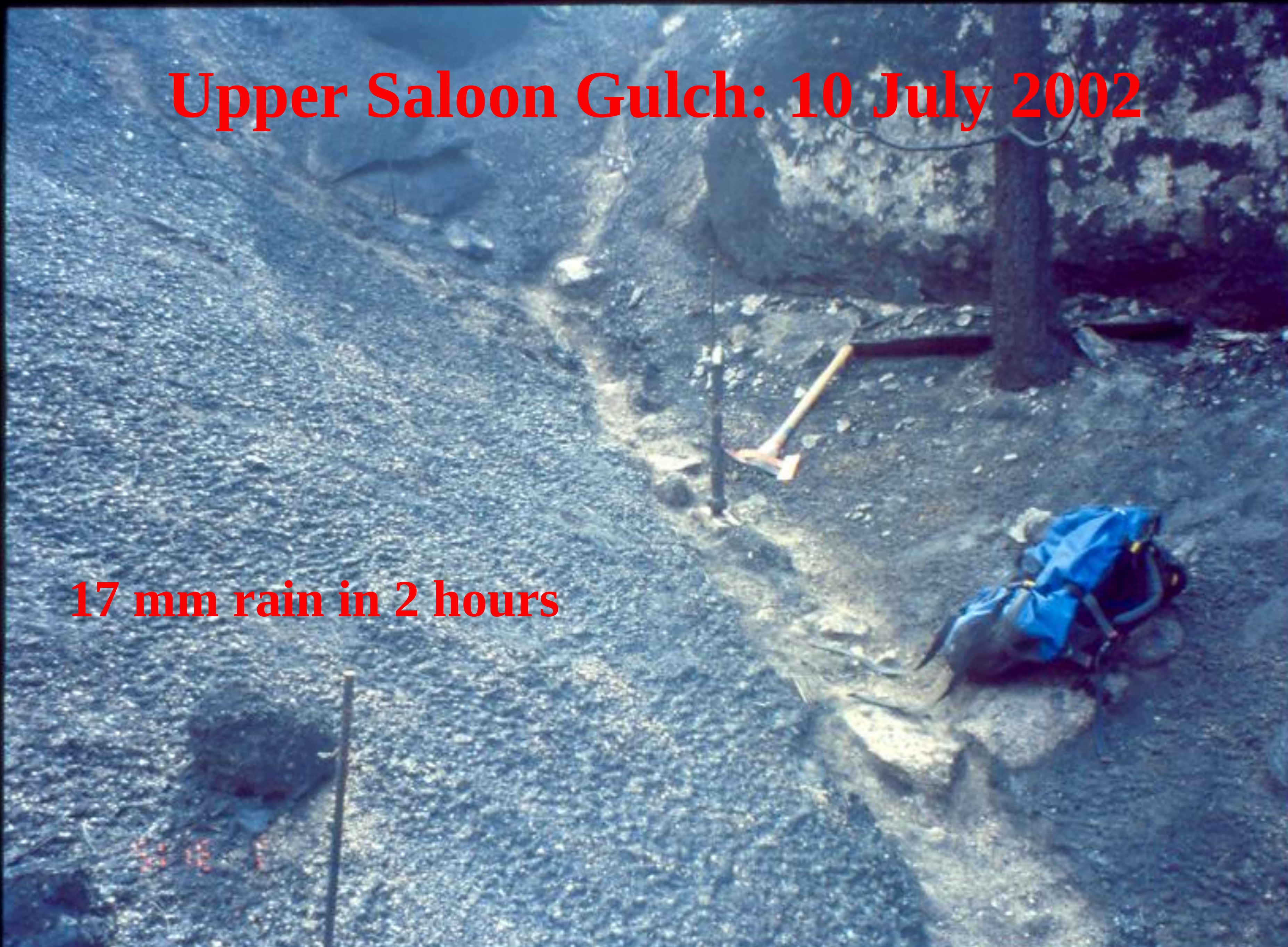
Post-fire erosion vs. percent bare soil: Pendola fire, Eldorado N.F.



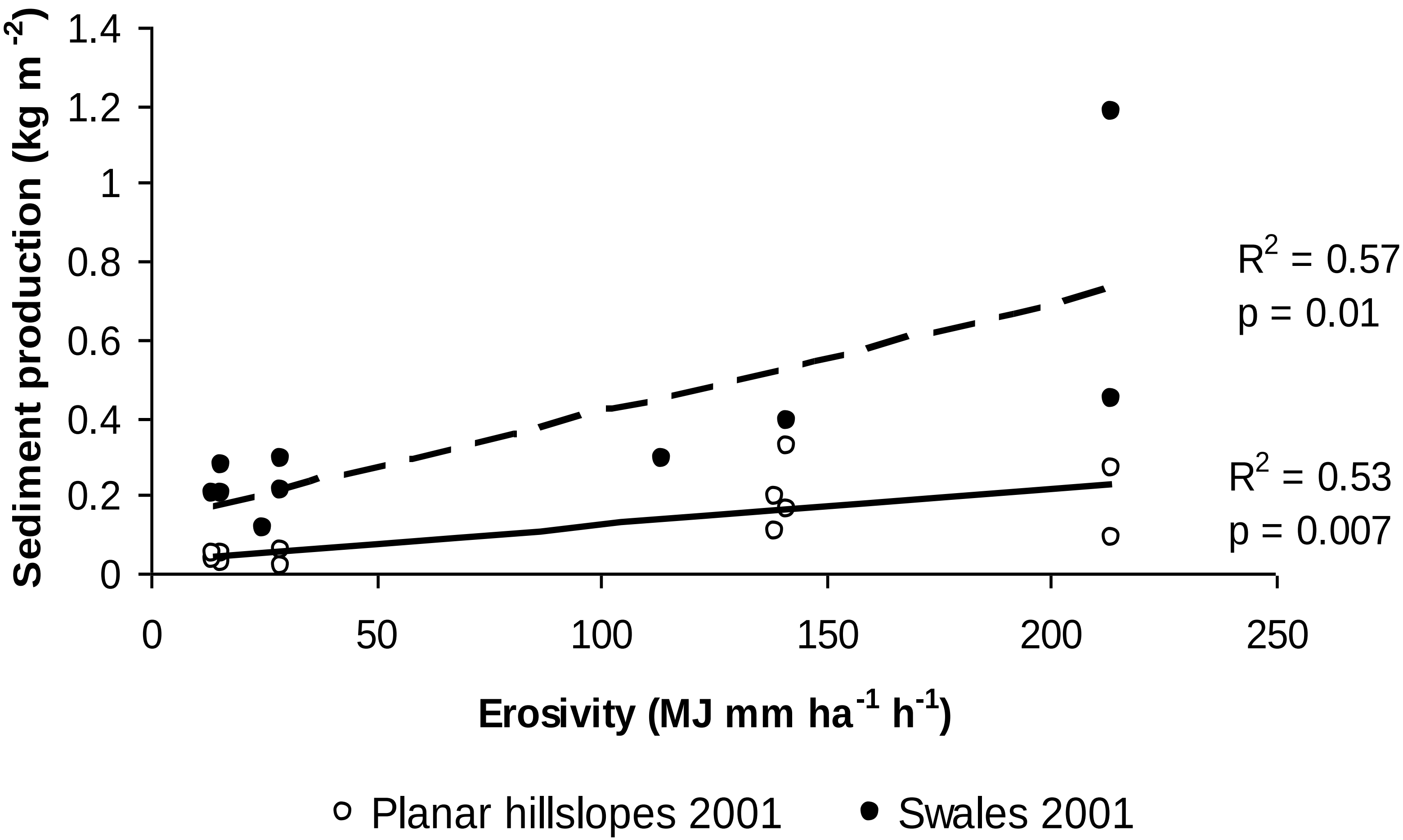
Is all this sediment coming from:

(a) rainsplash and sheetwash on the hillslopes; or

(b) rill, gully, and channel erosion?

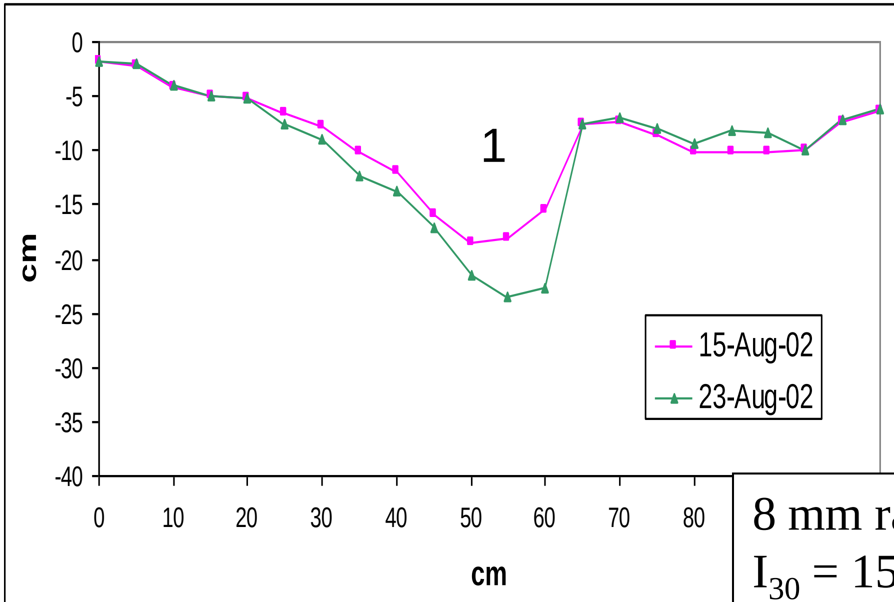

Upper Saloon Gulch: 10 July 2002
17 mm rain in 2 hours

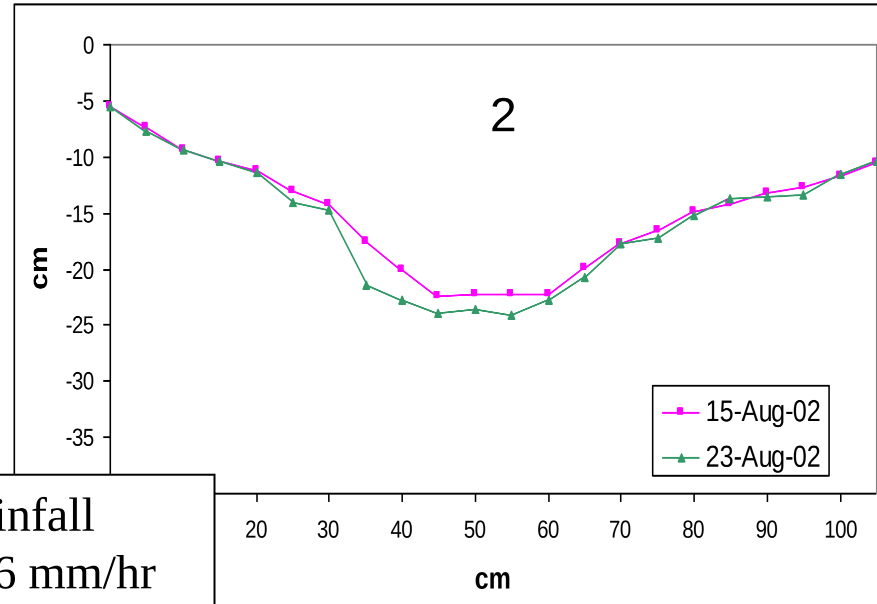
Sediment yields from swales vs. planar hillslopes in 2001: Bobcat fire



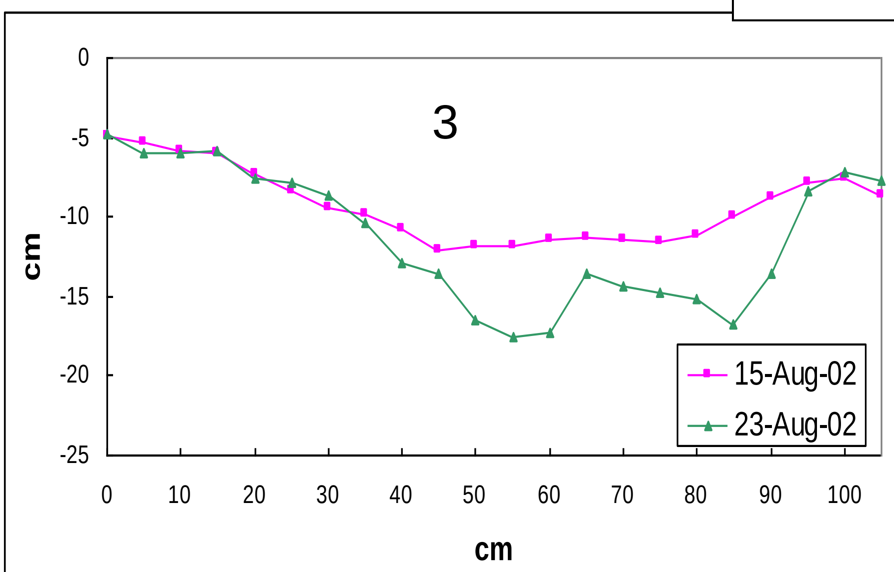
Measuring rill erosion, Hayman fire

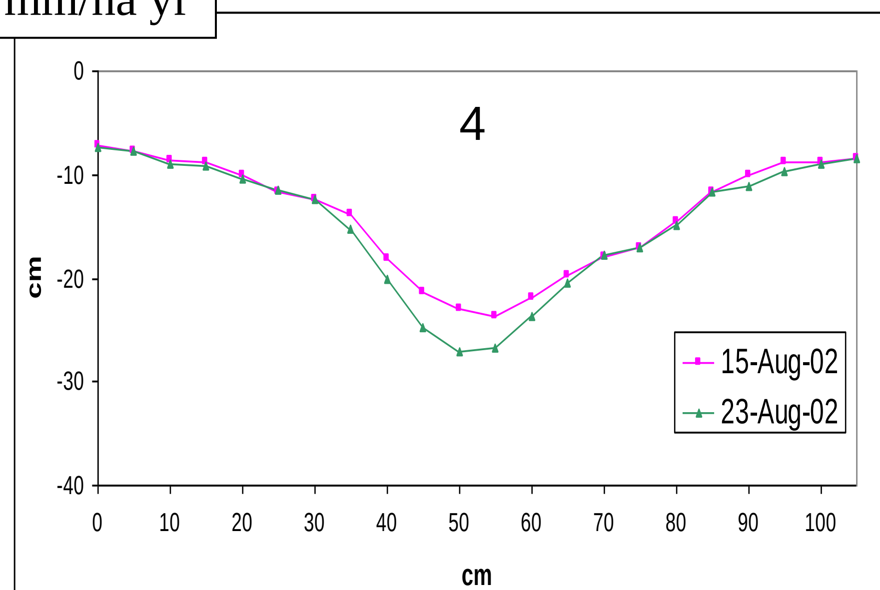
Rill erosion in Swale 4: Storm on 21 August 2003



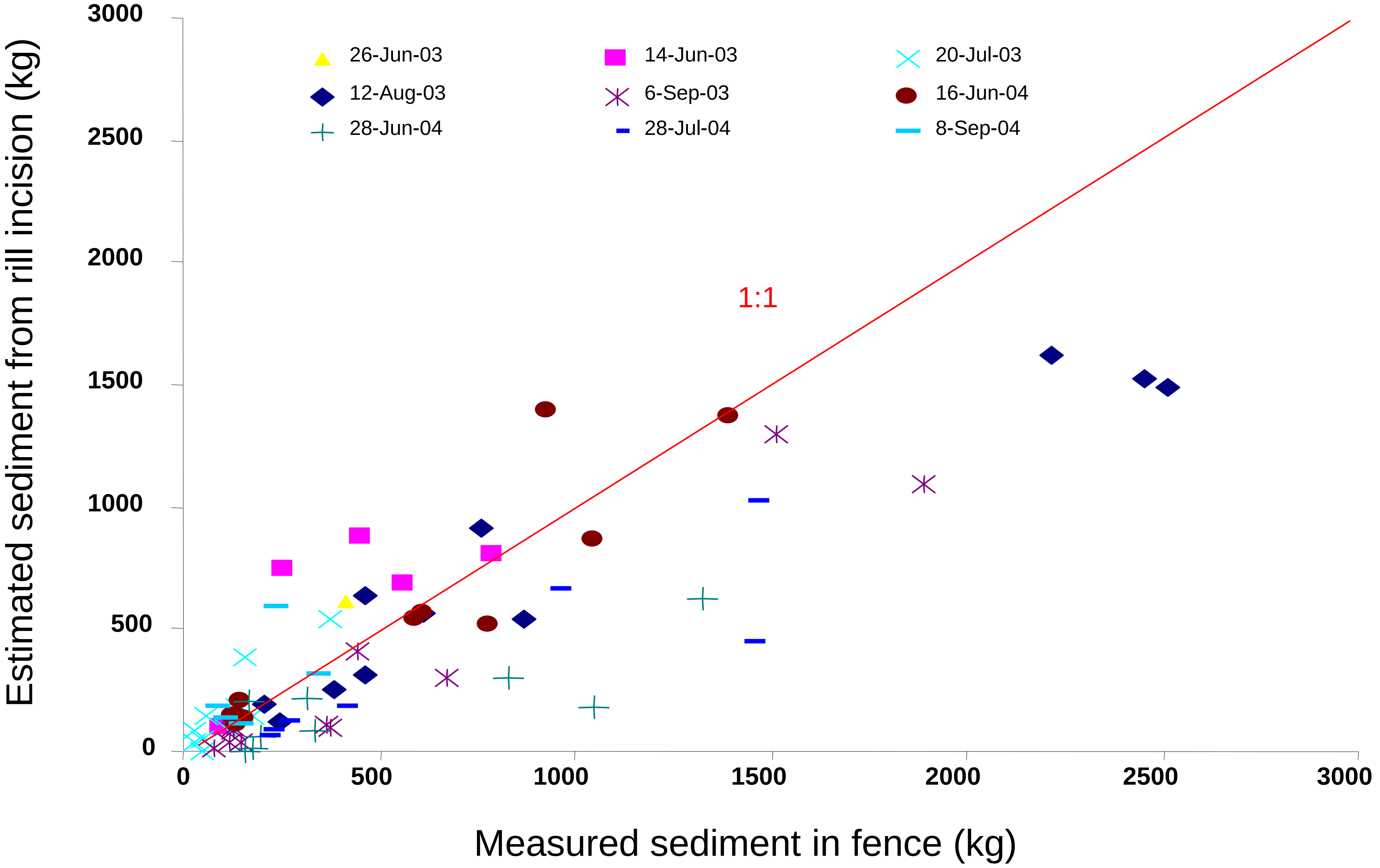


8 mm rainfall
I_{30} = 15.6 mm/hr
27.4 MJ mm/ha yr





Estimated sediment from rill erosion vs. measured sediment: Hayman wildfire



Inferred sources of runoff and erosion

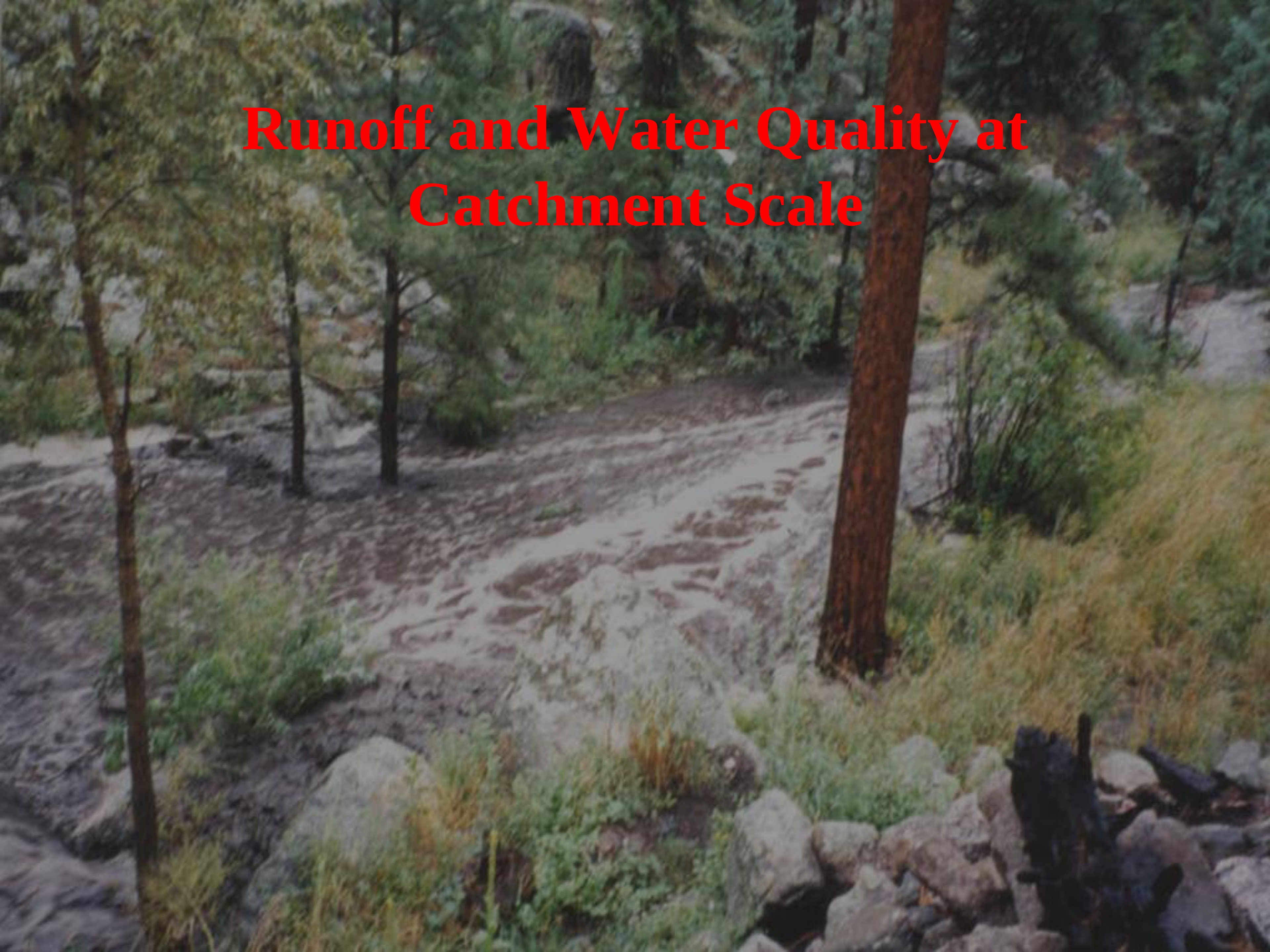
- About 80% of the sediment is coming from rilling on the hillslopes;
- These and other data indicate that the post-fire runoff is coming from the hillslopes, but most of the post-fire sediment is coming from incision due to concentrated flows (rill, gully, and channel erosion);

- See also Moody and Martin, 2001; 2009.

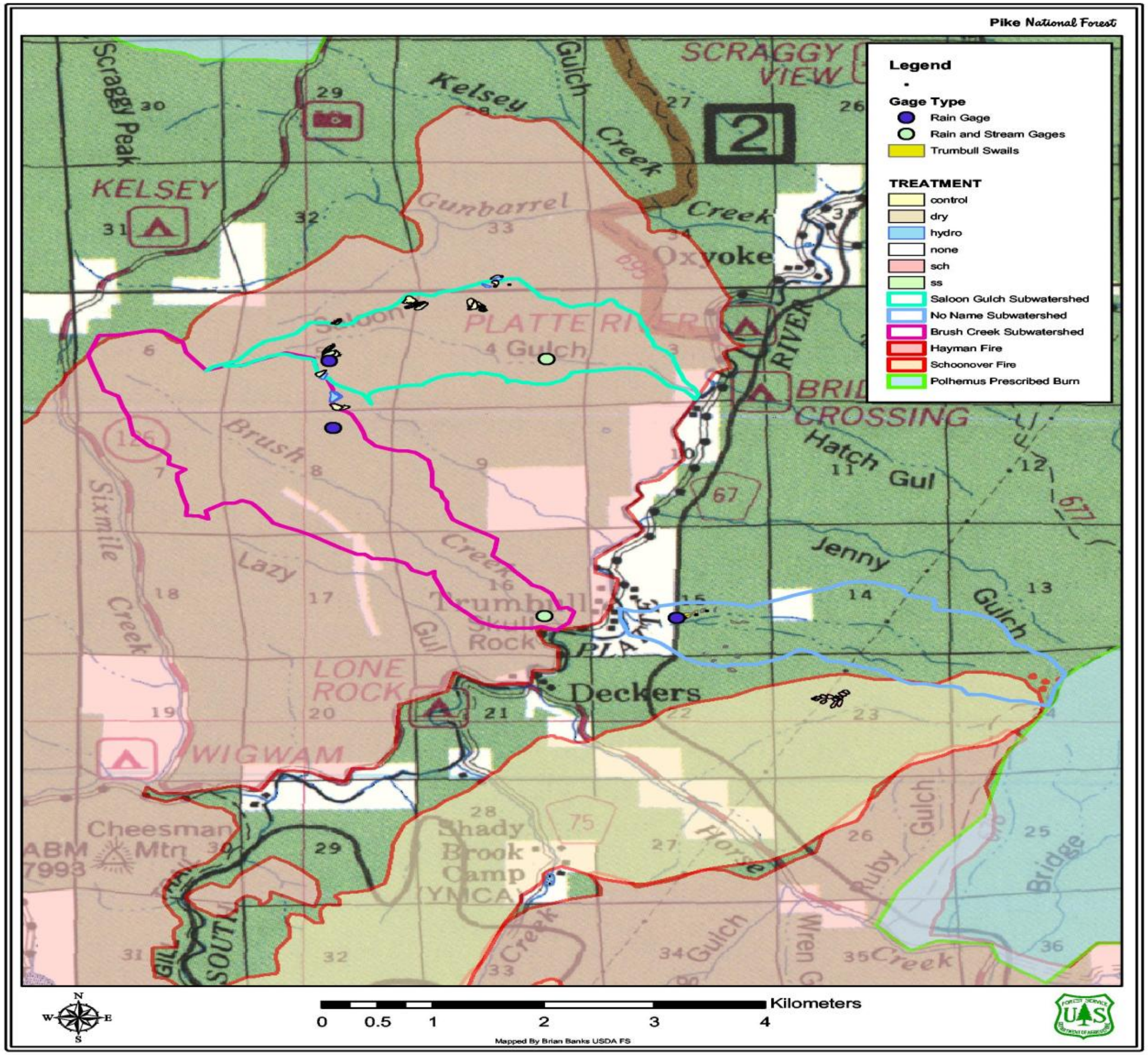
Controls on Post-fire Erosion

- Erosion rates most strongly related to percent bare soil, which is primarily a function of fire severity and time since burning;
- For a given percent cover and slope, rainfall intensity is the dominant control, and erosion increases non-linearly with rainfall intensity or erosivity;
- Soil water repellency can help reduce infiltration after burning, but the rapid decay and spatial variability suggests it is not the dominant control;
- Soil type is generally a third-order control, after cover and rainfall intensity;
- Rainfall simulations and other work suggest that post-fire soil sealing is limiting infiltration (*SSSAJ*, 2009).

Runoff and Water Quality at Catchment Scale



Saloon Gulch and Brush Creek: A Paired Watershed Study to Investigate the Effects of Thinning



Stream reaches: Summer 2001

Saloon Gulch

Brush Creek

Saloon Gulch flume before Hayman fire

Saloon Gulch flume after first post-fire rainstorm

Saloon Gulch flume cleaned out after first post-fire rainstorm

Saloon Gulch flume after second post-fire rainstorm

Lower Brush Creek: Upstream of flume

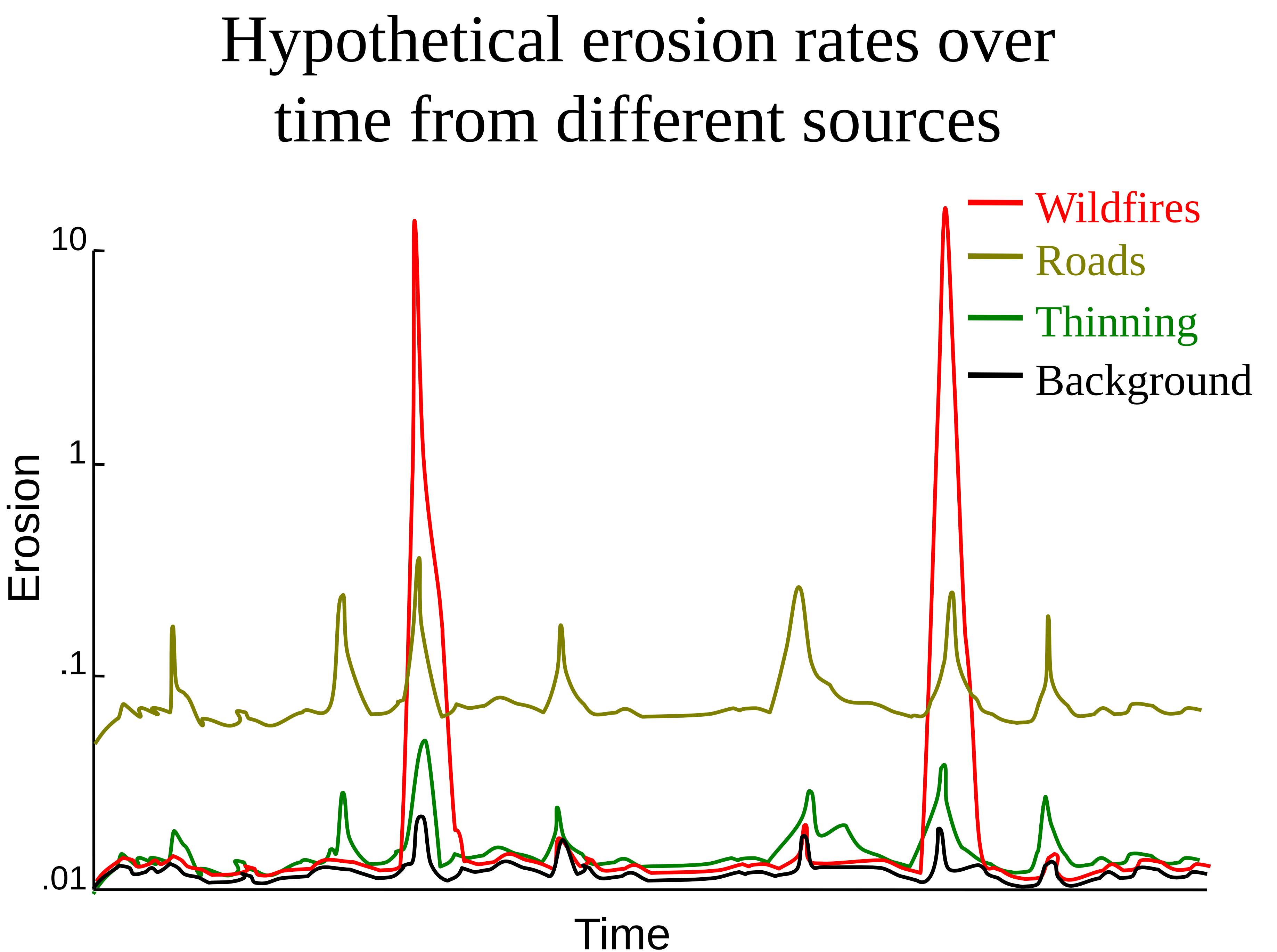
Since runoff rates decline within 2-4 years after burning, how long will it take to transport the excess sediment out of this channel?

Bobcat fire, 8 years later: How long until this becomes a forest again?

Hayman fire, 7 years later: How long until this becomes a forest again?

Hayman fire, seven years later: How long until this stops eroding and degrading water quality?

Buffalo Creek fire, 2009
(13 years after burning)


Hypothetical erosion rates over time from different sources
Wildfires
Roads
Thinning
Background
10
1
.1
.01
Erosion
Time

Conclusions: Part 2

- High-severity fires can dramatically increase runoff and erosion rates in headwater areas;
- Large sediment deposits in lower-gradient channels can result in long-term degradation of aquatic habitat;
- For more information, see my web site (type "Lee MacDonald" into google).


Questions?