Post-fire Recovery and Restoration: Soils, Runoff and Erosion

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Objectives

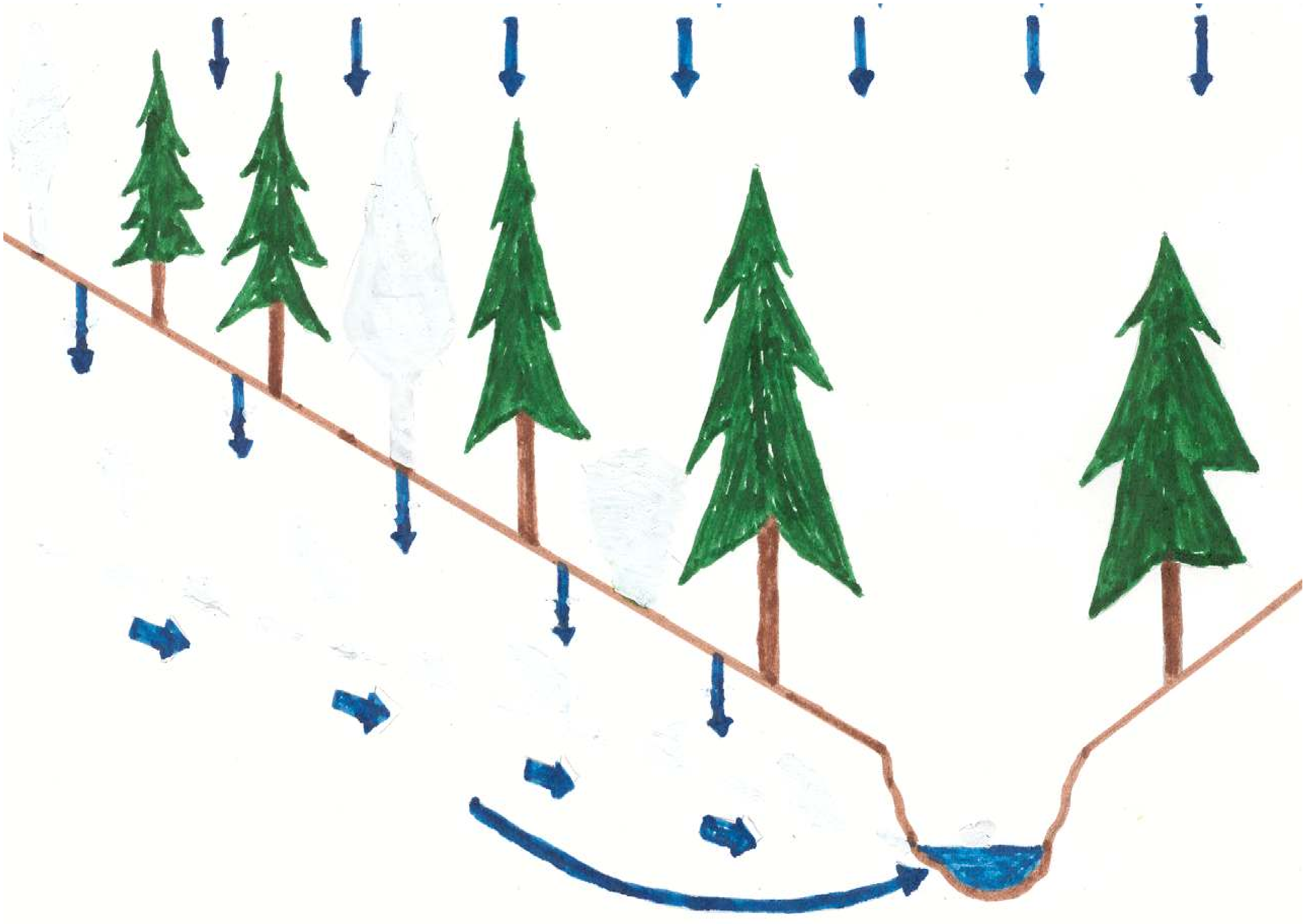
1. Provide a process-based summary of how fires in the Colorado Front Range affect soils, runoff, and erosion:

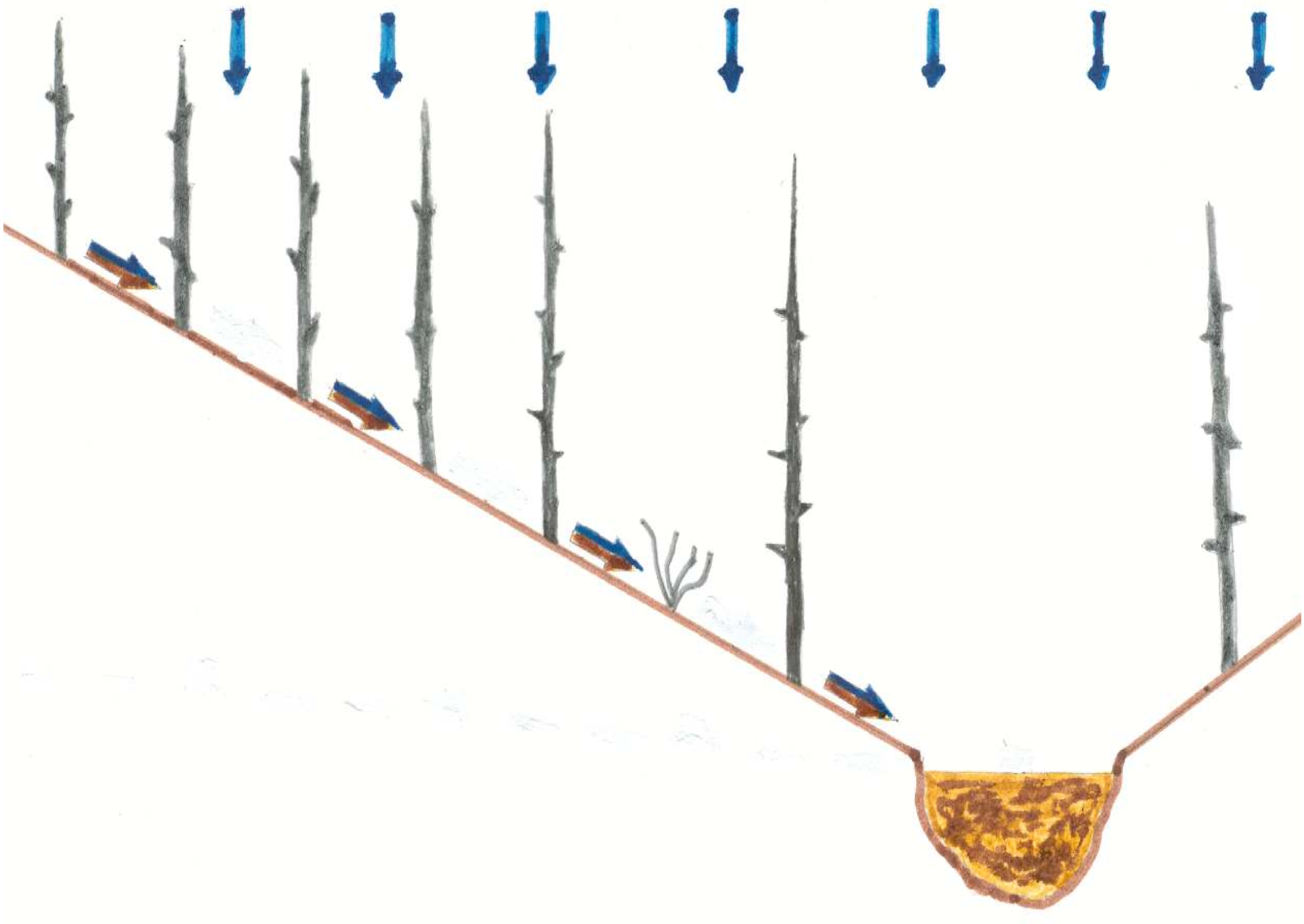
   At different spatial scales;

   Recovery over time;

2. Present data and observations from the High Park fire;

3. Use this knowledge and understanding to predict future recovery and potential for rehabilitation.

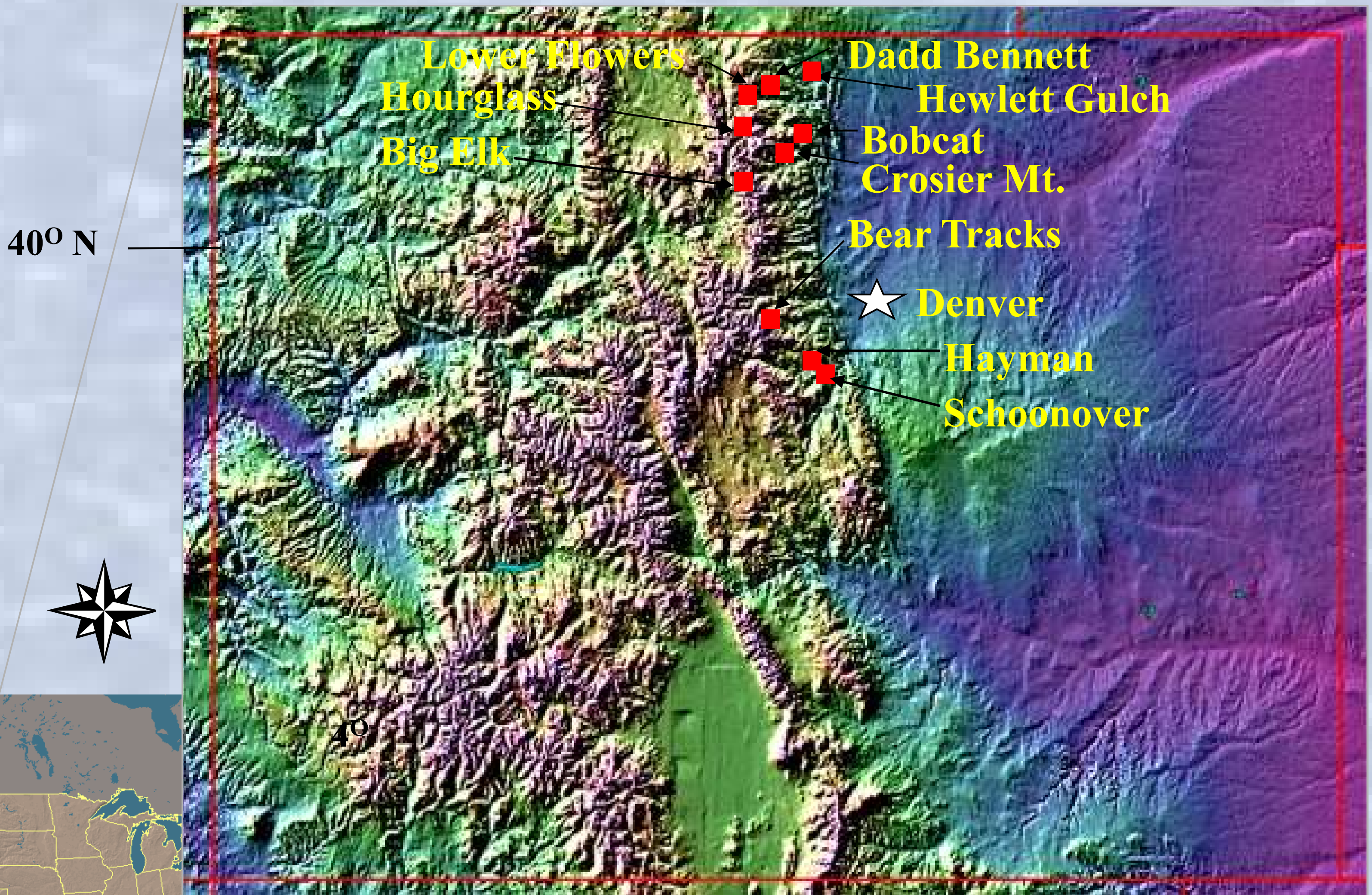


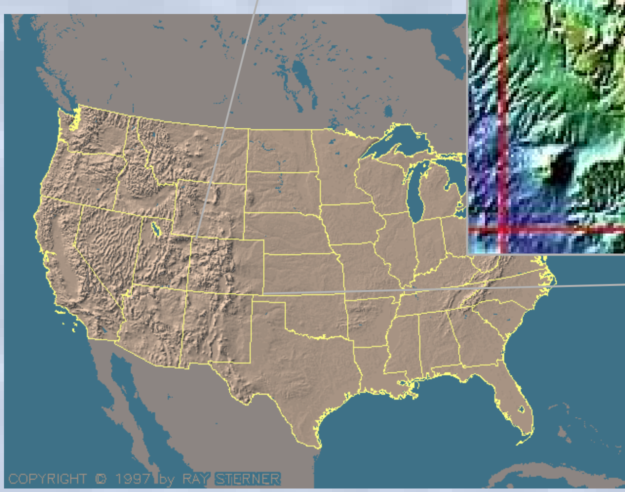


Post-fire Hydrology

- Loss of vegetative canopy and surface cover;
- Shift in runoff processes from sub-surface stormflow to infiltration-excess (Horton) overland flow;
- LARGE increases in peak flows and erosion rates;
- Downstream sedimentation;
- Degradation in water quality (turbidity, suspended sediment, nitrate, manganese, dissolved organic carbon), and aquatic habitat.

What are the primary causes of post-fire runoff and erosion, and what can we do to reduce them?





Study sites in the Colorado Front Range

Contributors

- Tedd Huffman (M.S., 2002);
- Juan Benavides-Solorio (Ph.D., 2003);
- Joe Wagenbrenner (M.S., 2003);
- Matt Kunze (M.S., 2003);
- Zamir Libohova (M.S., 2004);
- Jay Pietraszek (M.S., 2006);
- Daniella Rough (M.S., 2007);
- Duncan Eccleston (M.S., 2008);
- Keelin Schaffrath (M.S., 2009);
- Ethan Brown (M.S., 2009);
- Darren Hughes (M.S., 2010?);
- Dr. John Stednick;
- Isaac Larsen (Research assistant, 2004-2007);
- Sergio Alegre (Visiting Ph.D. student, 2010).

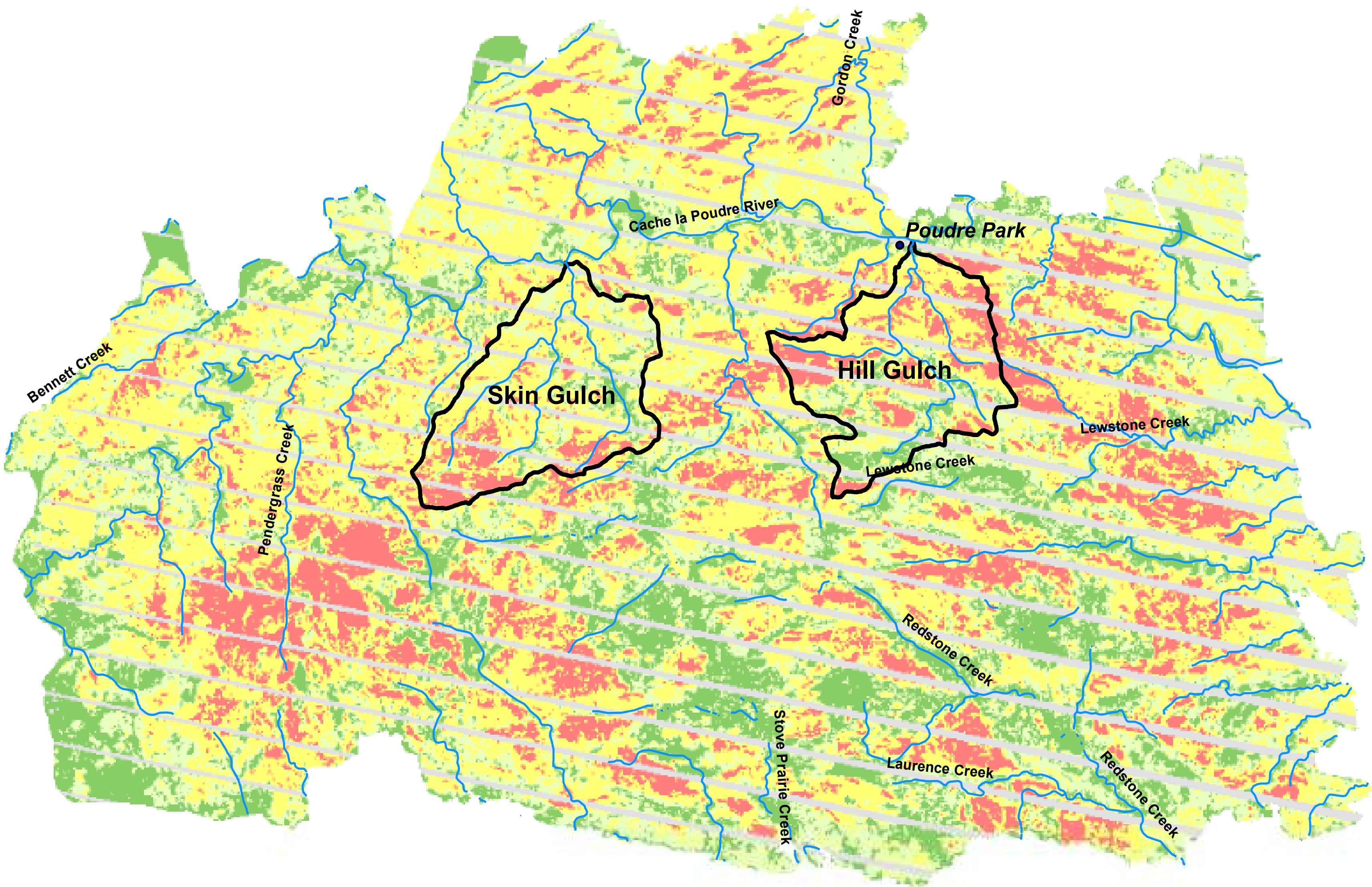
More students to do the hard work: Sarah Schmeer (Watershed) and Dan Brogran (Civil Engineering)

Thanks to private landowners who allow access!

Key Observations about the High Park Fire

- Relatively small area burned at high severity;

Fire severity map (CSU version)



Key Observations about the High Park Fire

- This patchiness relatively typical;
- Amount and distribution of burn severity has important implications for runoff, erosion, and delivery to the Poudre River;

Key Observations about the High Park Fire

- Burned relatively long and late, as only contained on 1 July;
- First major storm occurred on 6 July, so little opportunity to collect baseline (pre-storm) data;
- Relatively wet July led to lots of runoff and erosion;
- Second largest fire in Colorado history, plus proximity to CSU, led to an interdisciplinary research proposal;

RAPID Grant from NSF

- Detailed imagery and topography of the burned area;
- Physical science component:
  - Sediment fences to measure hillslope-scale sediment production;
  - Channel cross-sections and longitudinal profiles to track incision and deposition;
  - Use measured sediment production rates and detailed imagery to predict watershed-scale sediment production;
  - Use channel data to roughly estimate the proportion of sediment being delivered to the Cache la Poudre River;
- Now have about 20 sediment fences and 8 rain gages installed, but relatively dry August!

Hillslope component

Newly-installed sediment fence to measure sediment production

Later that afternoon in a rainstorm . . .

600 kg of sediment from 0.75 inches of rain!

At Hill Gulch in a storm . . .

And downstream at Highway 14…

Using high water marks to estimate peak flows

Threat of yet another flood!

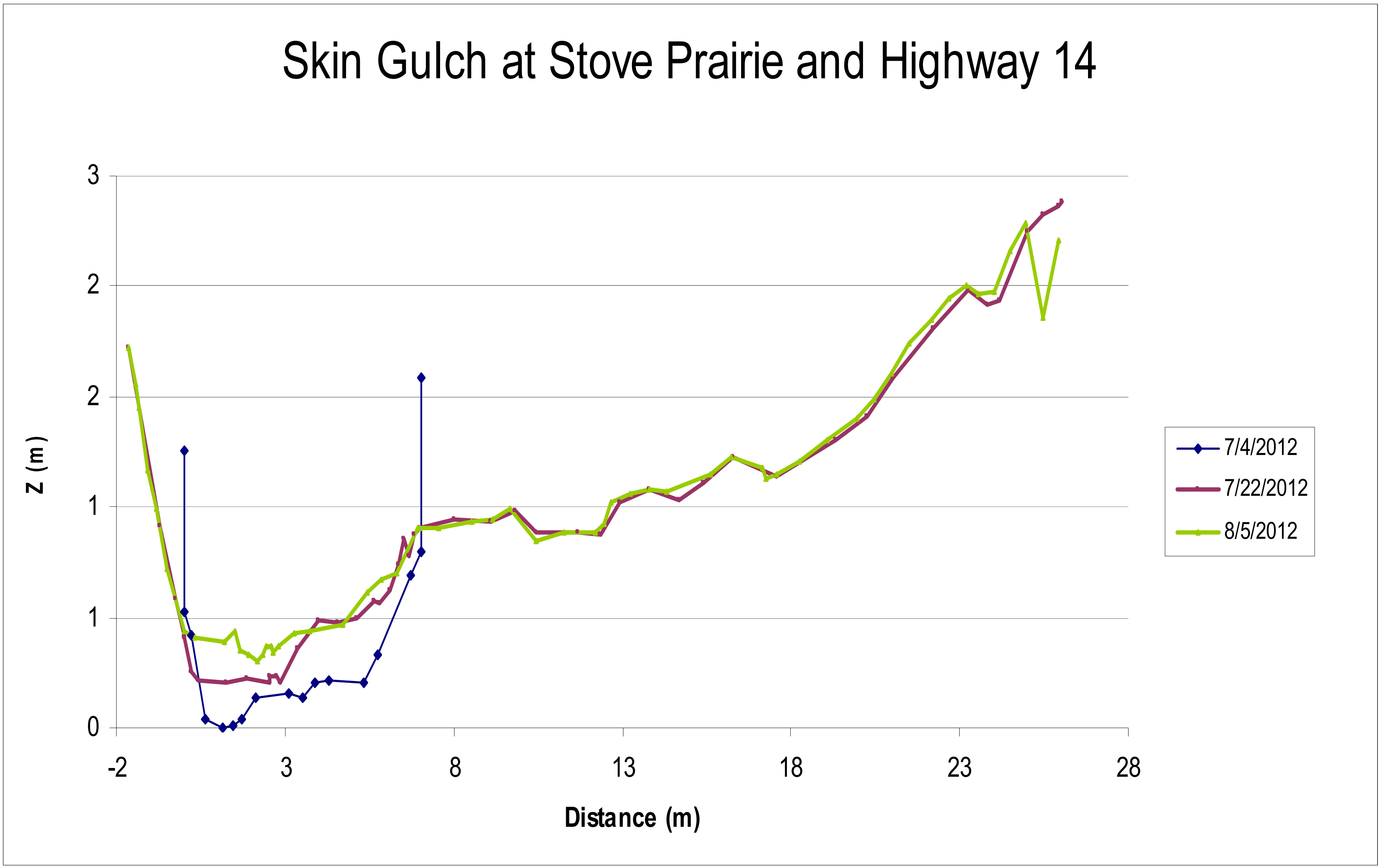
At Skin Gulch, a 7-ft culvert no longer big enough ….

Flow across Highway 14 and into the Poudre…

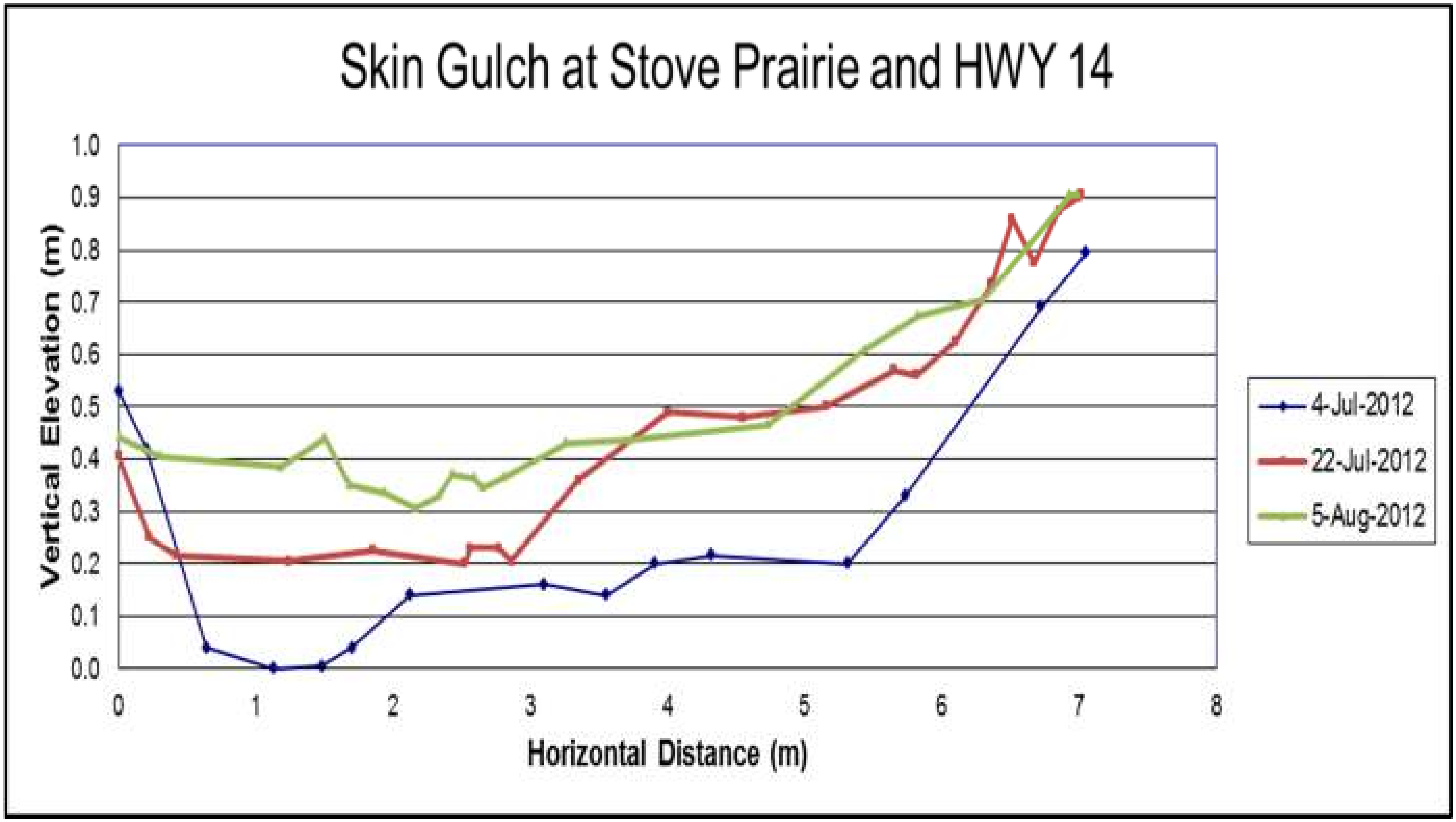
- Cross-section at Skin Gulch, pre-flood

Accumulation of woody debris and sediment, Skin Gulch cross-section

Cross-section 100 m upstream over time



Channel cross-section change



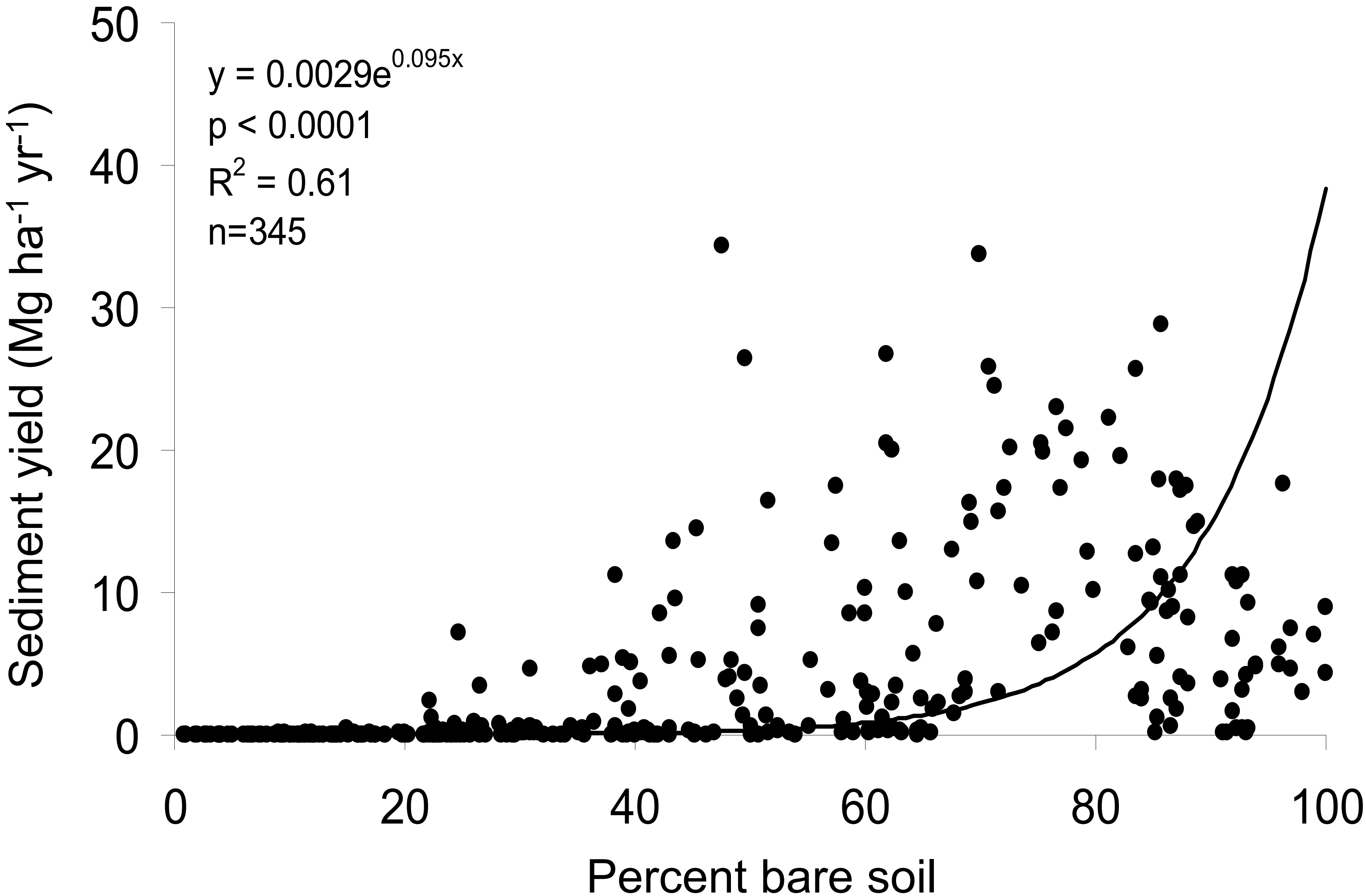
Key Observations about the High Park Fire

- Very large increase in peak flows;
- Undersized culverts at risk, particularly on private roads;
- Large amounts of sediment deposited in main channels;
- Believe that most of the sediment is NOT reaching the Poudre River;
- Ash and fine sediment deposited in the Poudre River, primarily along channel margins;

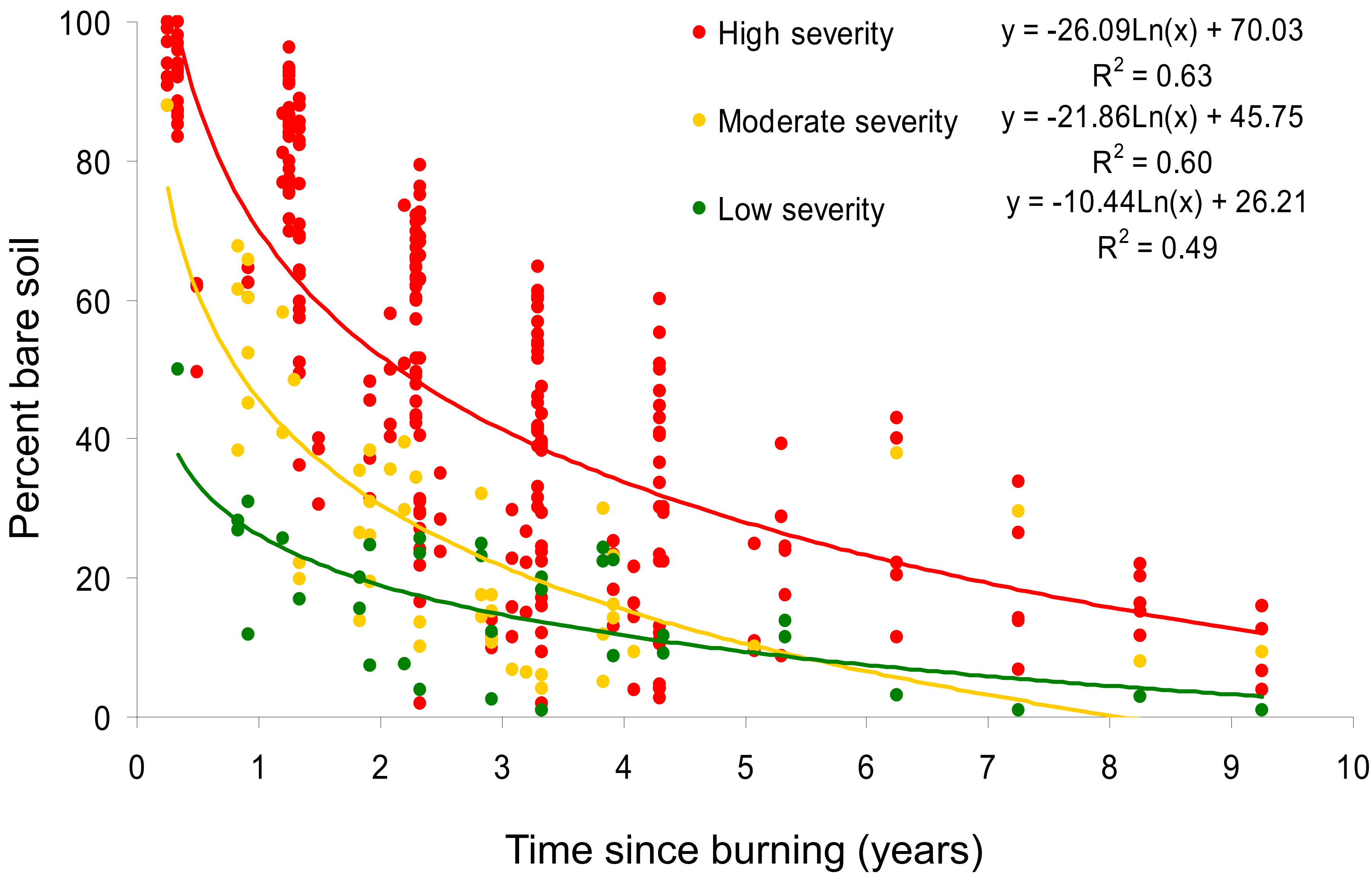
Implications

- Relatively low amounts of high severity and a wet July has led to rapid regrowth;
  - Riparian areas;
  - Shrublands;
  - Most sites burned at moderate severity;

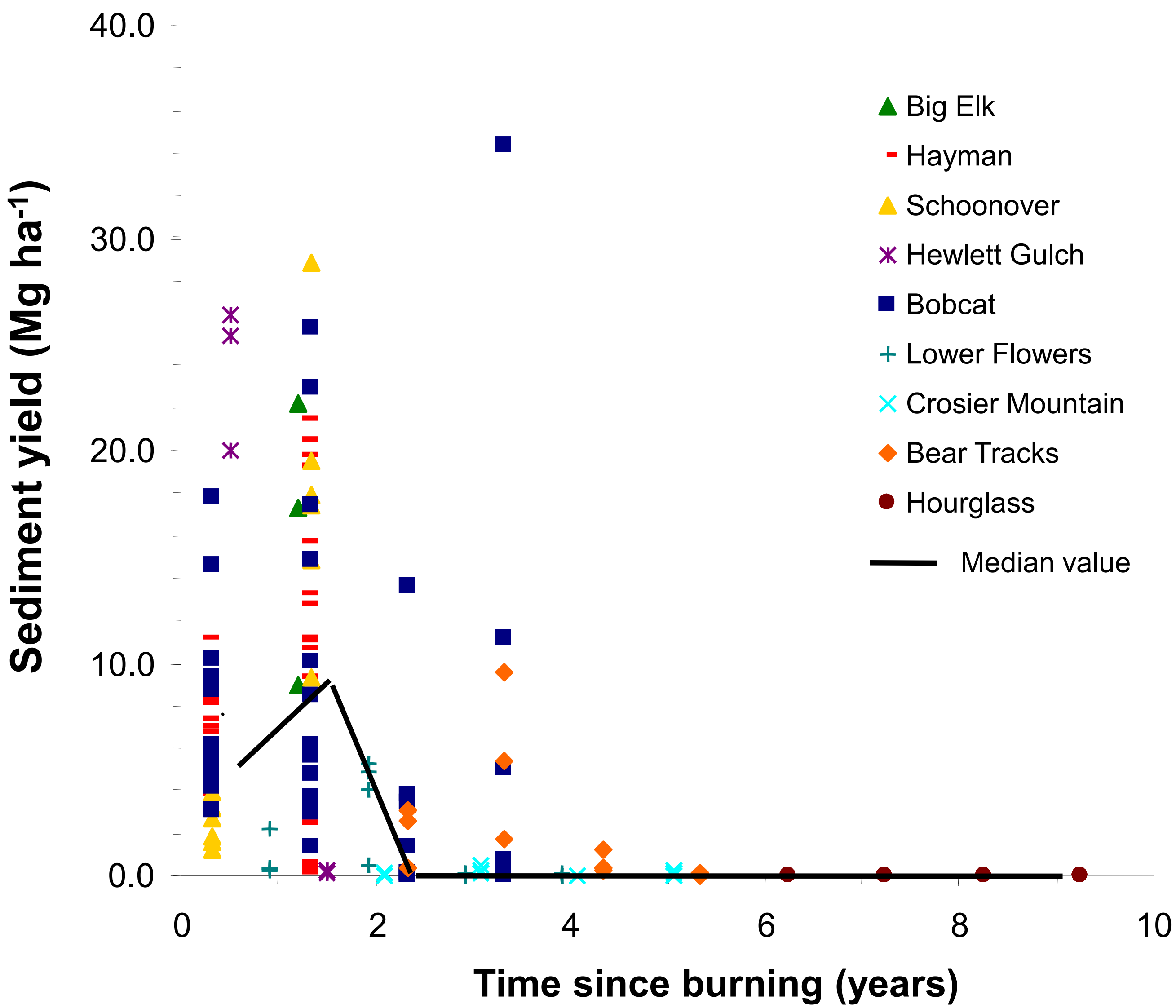
Sediment yield vs. percent bare soil



Percent bare soil vs. time since burning



Annual sediment yields vs. time since burning: High severity sites



Hierarchy of controls on post-fire runoff and erosion

- Percent ground cover;
- Rainfall intensity (8-10 mm/hr sufficient to generate surface runoff and erosion);
- Soil:
  - Moisture;
  - Water repellency;
  - Soil type.

Predictions: Now to summer 2013

- Relatively rapid regrowth in shrublands and areas burned at moderate severity;
- Nearly at the end of the summer thunderstorm season, so probably will not see flooding like we saw in July (whew!);
- Fall rains and winter-spring snowmelt should?

Predictions

- Fall rains and winter-spring snowmelt should:
  - Not cause any significant hillslope erosion;
  - May cause some continuing channel incision in areas that have large sediment deposits, but most of this will still not reach the Poudre River;
  - Mobilize much of the ash and fine sediment that is currently stored along the channel margins in the Poudre River and transport it further downstream;

Predictions: Summer 2013?

- Most of the ash and readily available fine sediment has already washed off the slopes and been delivered to the Poudre River, so next summer the water will not be nearly as black;
- Hillslope erosion rates, given similar rainfall events, will be much less due to the reduction in percent bare soil;
- Tributary channels will continue to incise and slowly stabilize;

Recovery: What to do?

- Selective mulching can help in summer 2013:
  - Focus on high severity areas that still have relatively little regrowth;
  - Even less of the sediment generated from the hillslopes and channels will reach the Poudre River;
  - Focus on those tributaries that burned at high severity in their lower sections;
- Poudre River should slowly clean itself;

Recovery: What to do?

- Consider planting trees in the areas where natural seeding is unlikely;
  - Litter is arguably the most important source of ground cover, particularly in poorer sites that cannot support a dense ground cover;
- Big problem with invasive species in some areas;

Good cover, but all leafy spurge (Hill Gulch)

Recovery: What to do?

- If we get an extreme storm event, all these predictions go out the window!
  - In Hill Gulch, the 1976 Big Thompson storm has had a larger effect on the channels than the High Park fire.

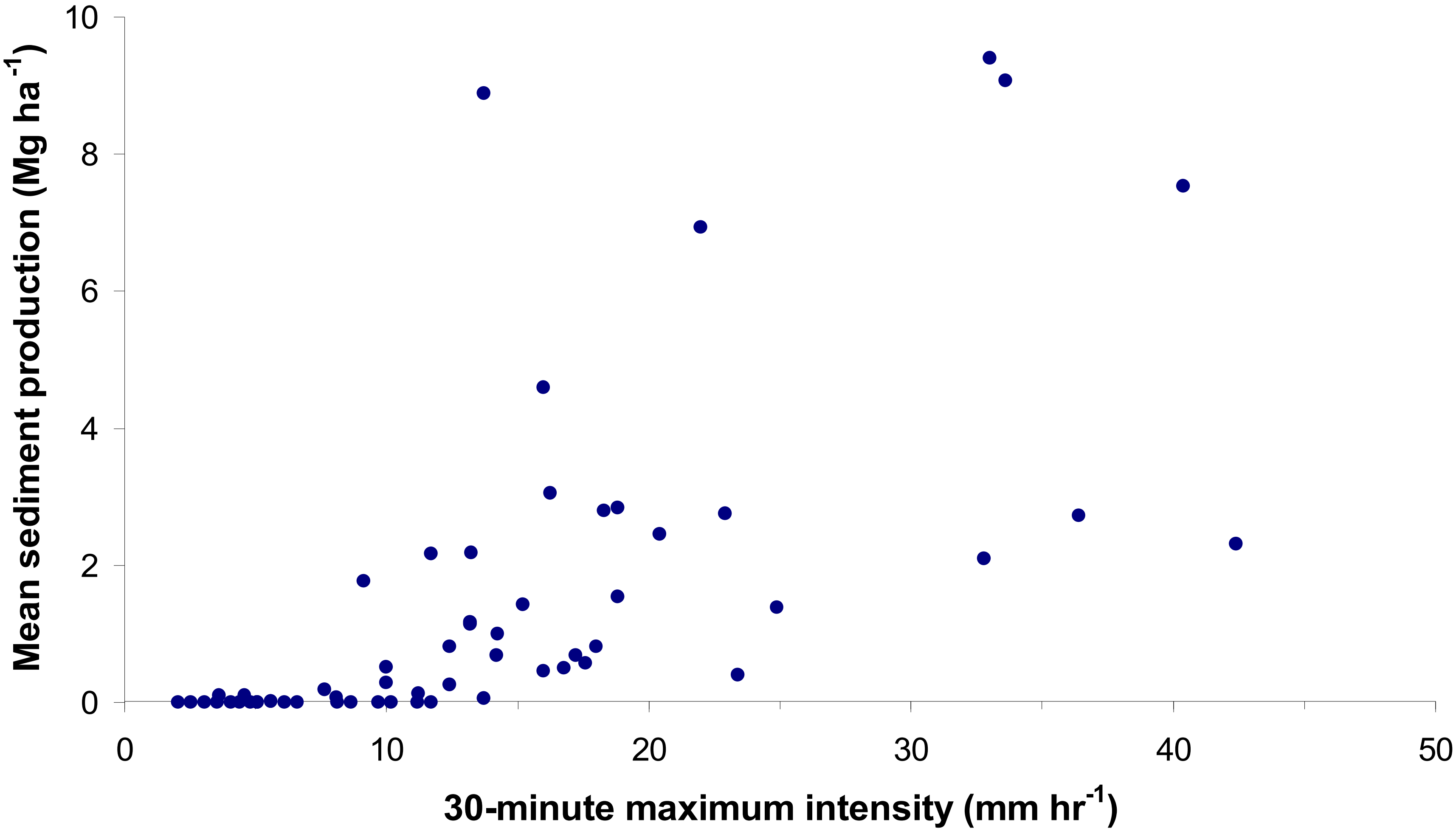
More information

- Type Lee MacDonald into google, and look at the publications on my web site;
- 2008 *Stream Notes* provides a nice readable summary;

Predictions

- Relatively rapid regrowth in shrublands and areas burned at moderate severity;
- Winter rains and snowmelt will:
  - Not cause any significant hillslope erosion;

Sediment vs. I_{30}: Recently burned, high severity wildfires



Predictions

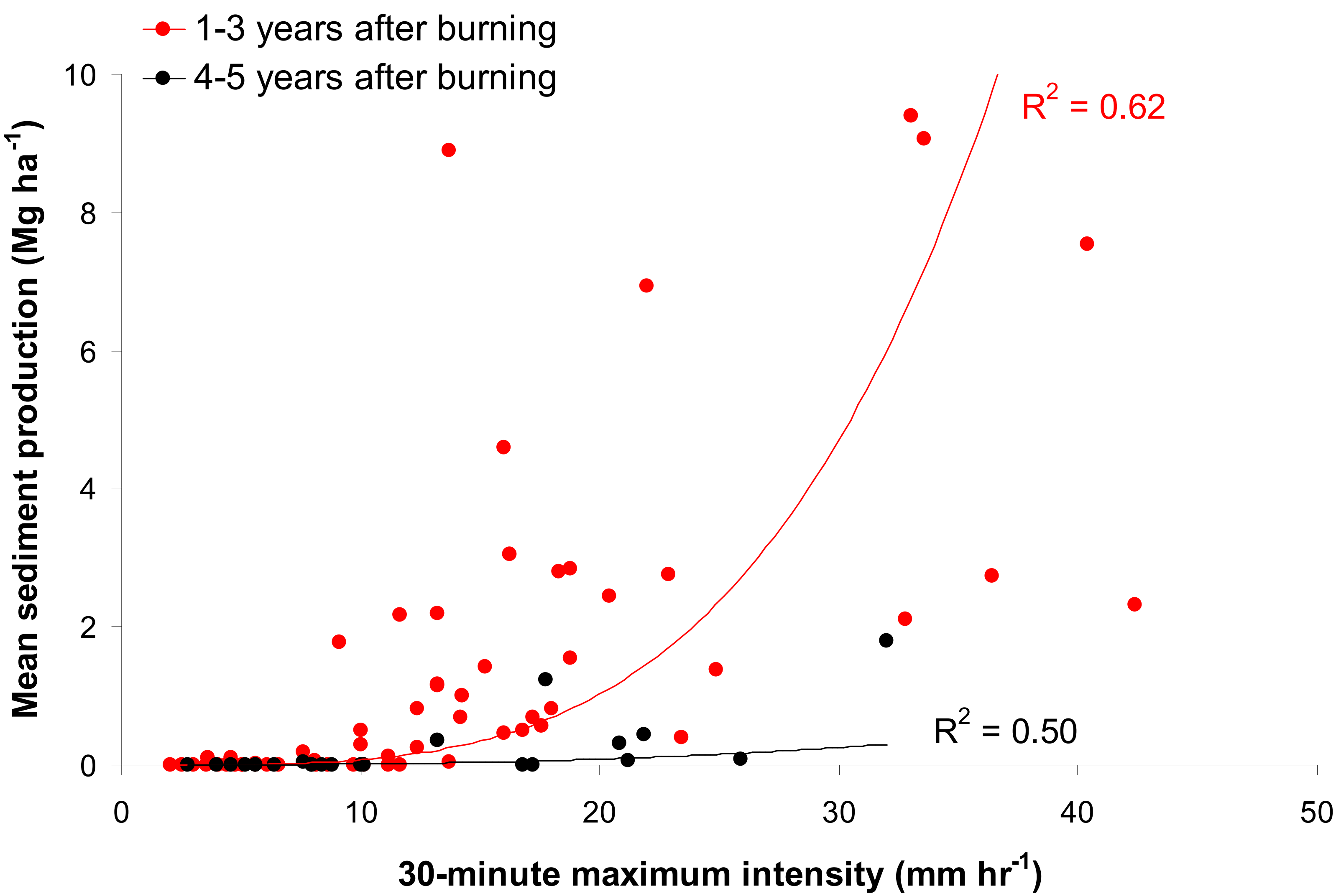
- Relatively rapid regrowth in shrublands and areas burned at moderate severity;
- Winter rains and snowmelt will:
  - Not cause any significant hillslope erosion;
  - ;
- Why is this important?

Collecting Data at Different Spatial Scales

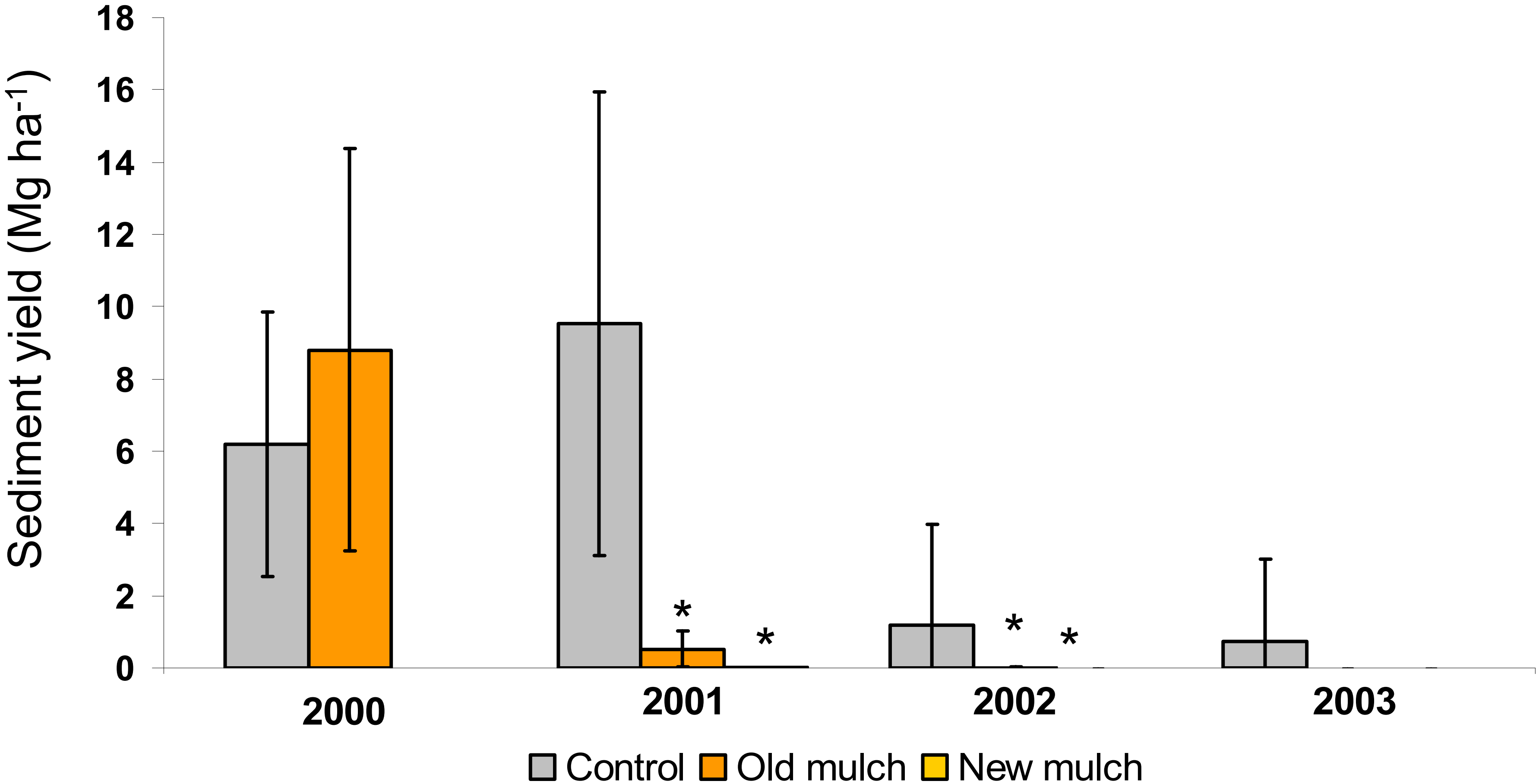
- Point scale: soil water repellency;
- Small plot scale (1 m^2):
  - Runoff and sediment yields from rainfall simulations;
- Hillslope scale (0.01 to 1 ha):
  - Sediment production from planar hillslopes and swales (zero-order catchments) using sediment fences;
  - Using replicated hillslopes (swales) to compare different rehabilitation methods against untreated controls;
- Small catchment scale (0.04 to 6 km^2):
  - Measuring runoff, suspended sediment yields, water quality, and channel morphology.

Our cover data

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

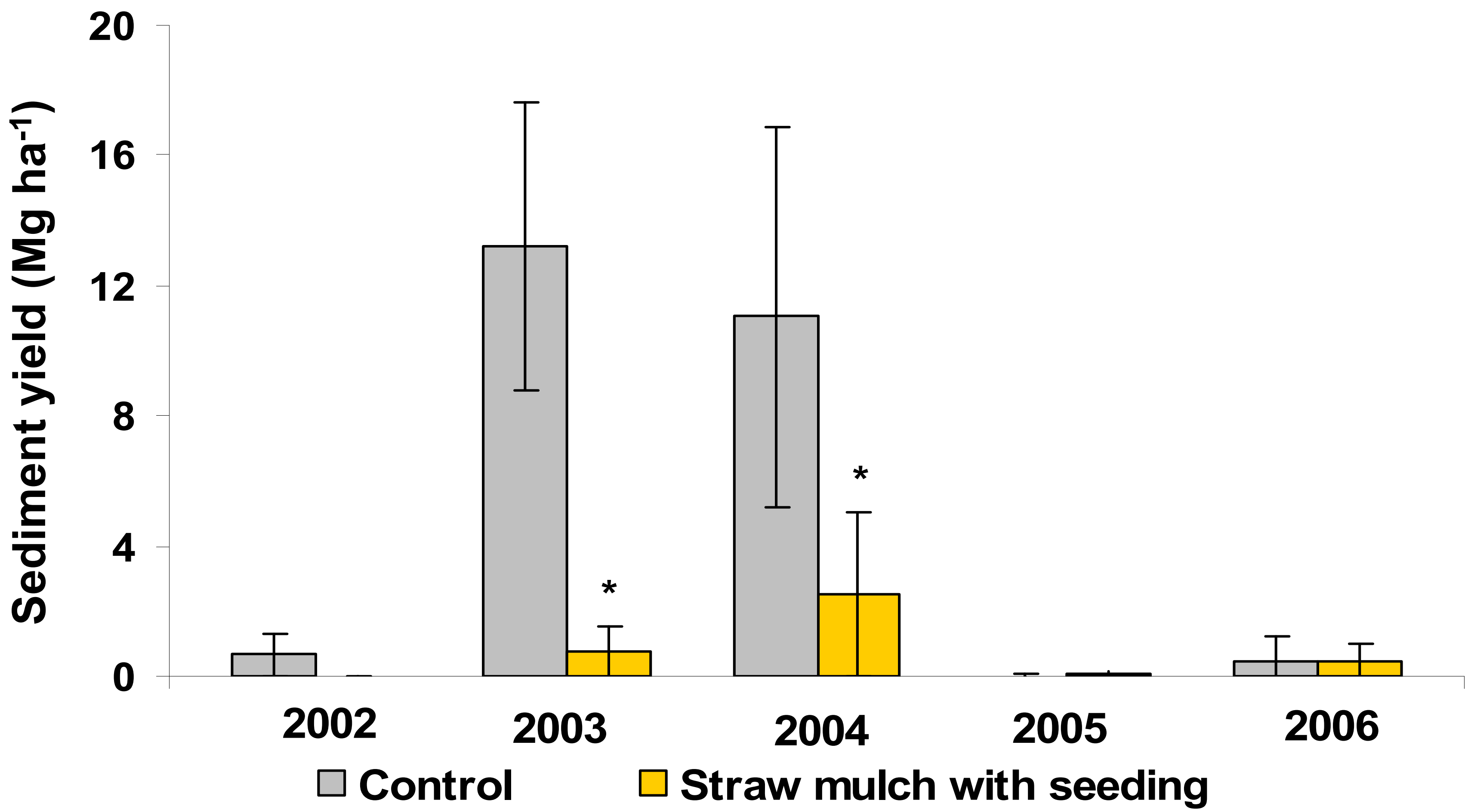


Mean sediment yields on control and mulched plots: Bobcat fire, 2000-2003



* = Significant treatment effect (p<0.05)

Sediment yields for controls and straw mulch with seeding: Hayman fire, 2002-2006



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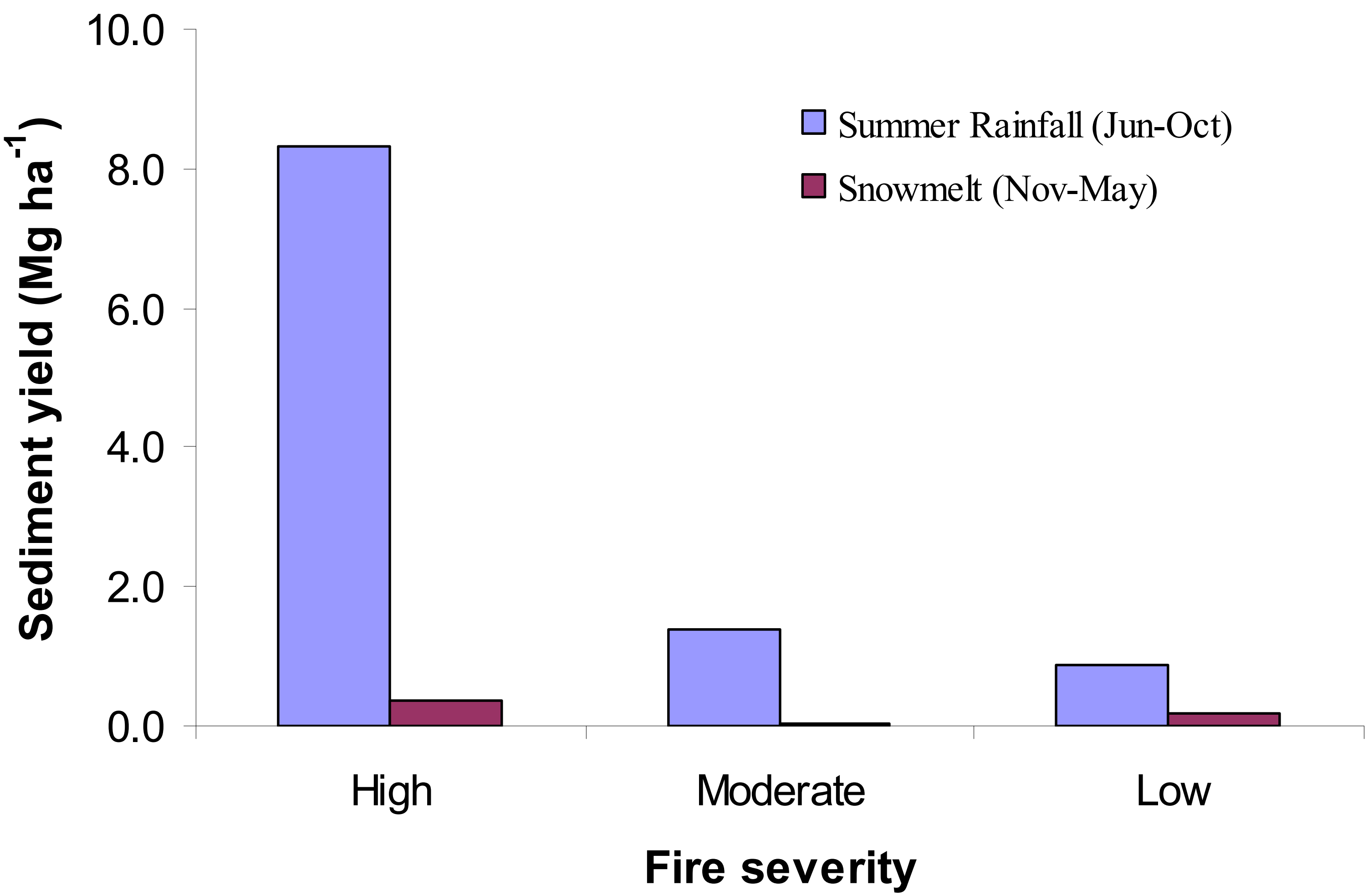
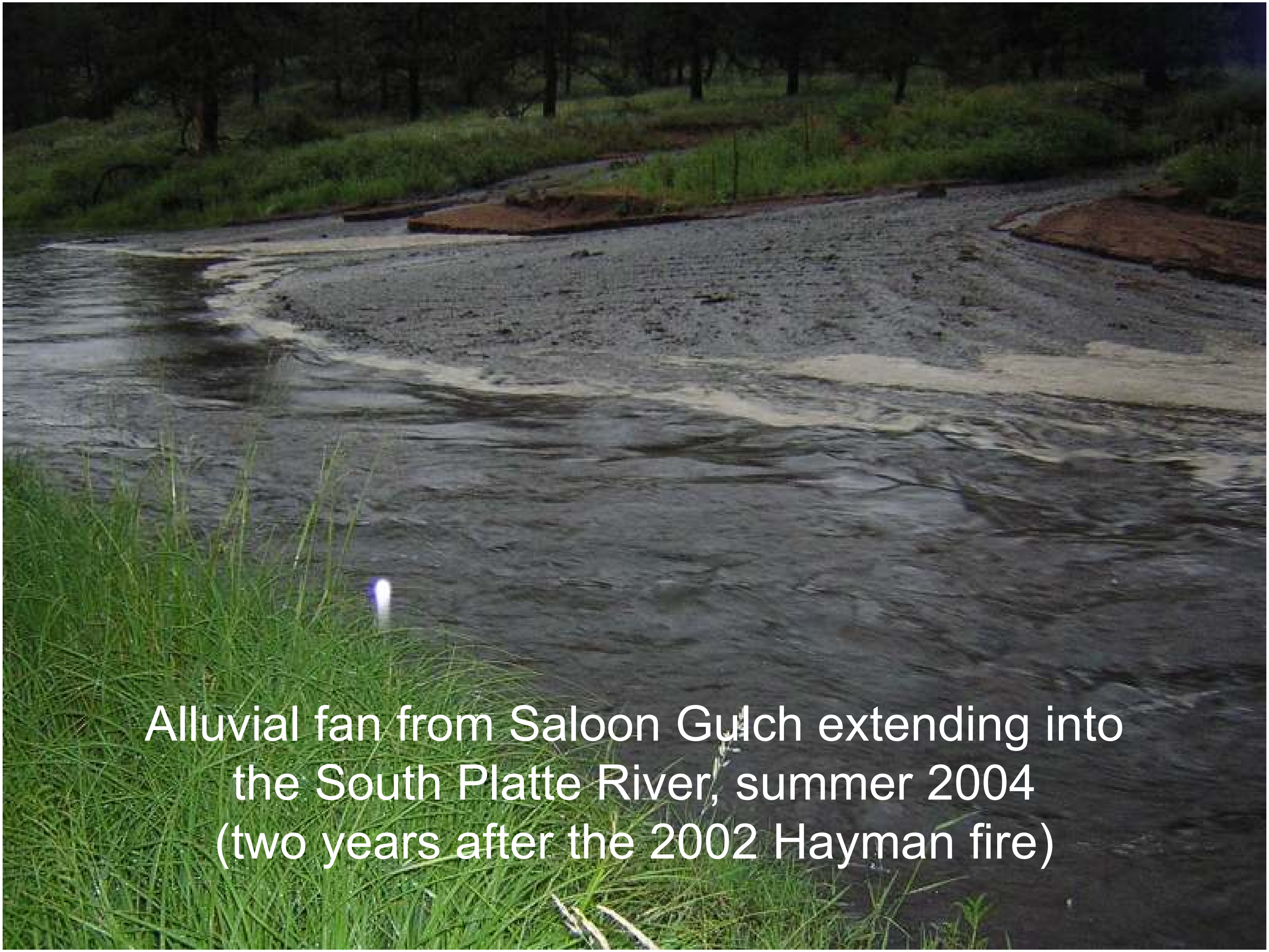
Sediment yields by fire severity and season: First two years after burning

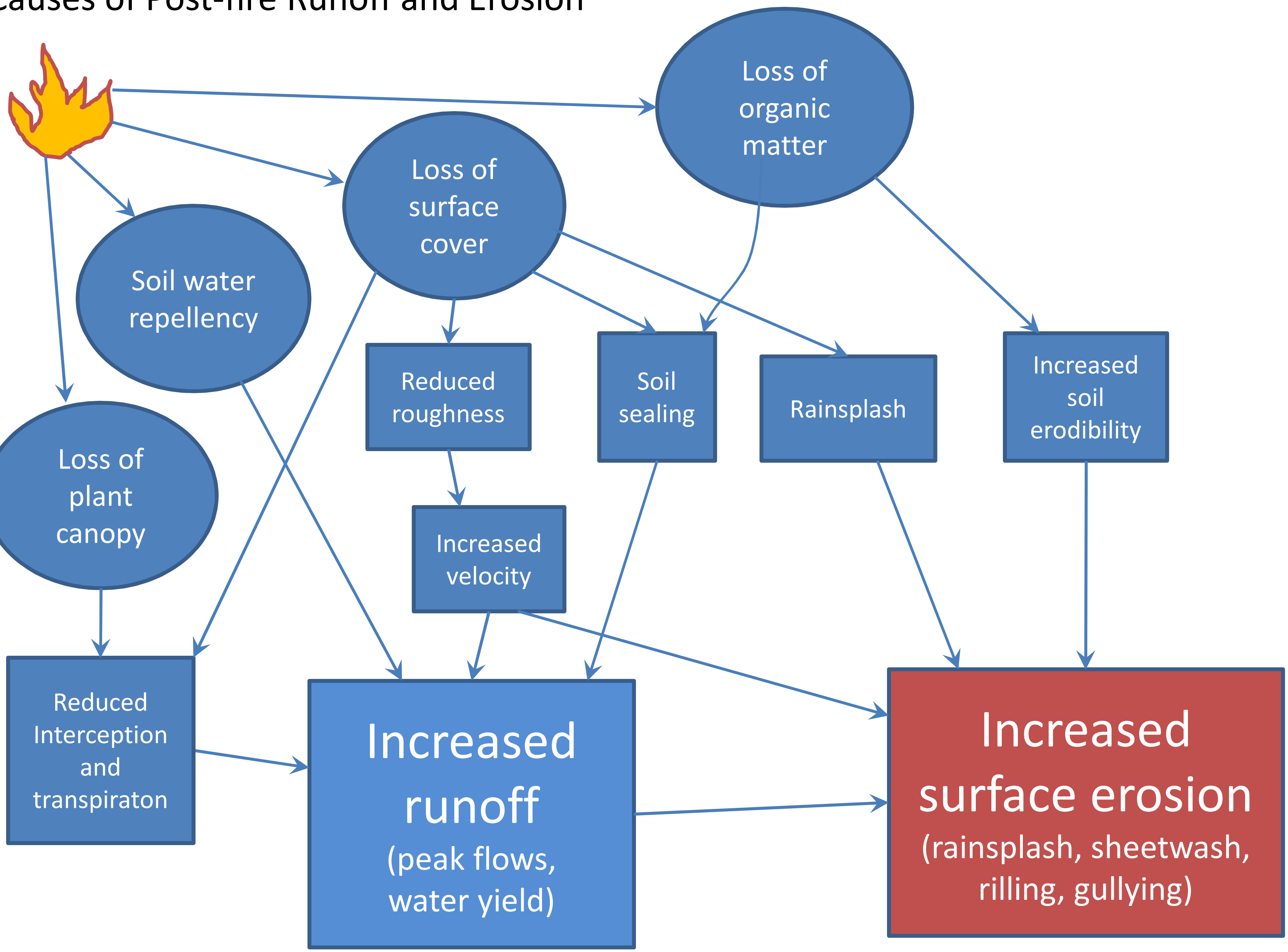


Hayman Fire, Colorado: August 2004

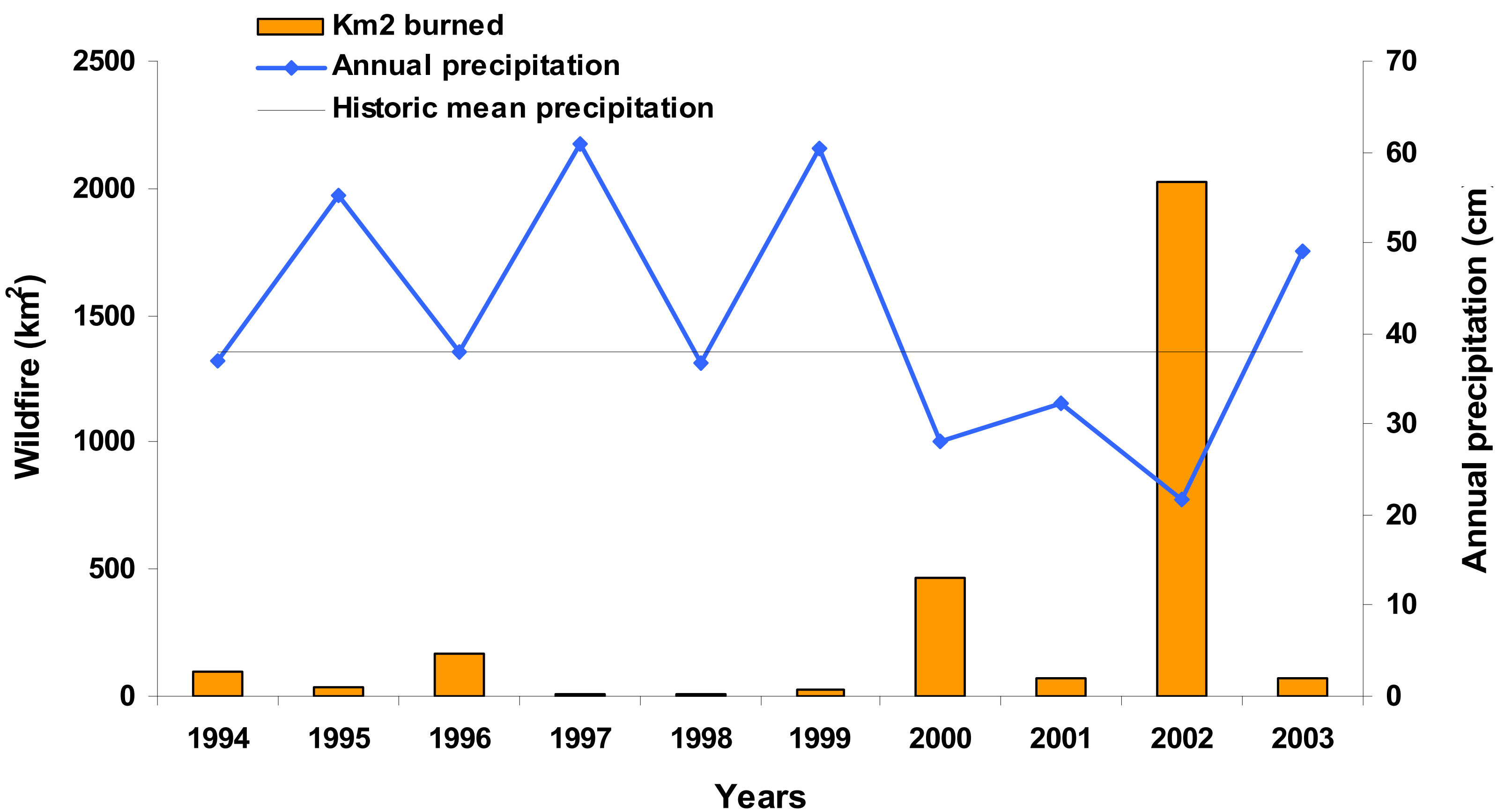


Alluvial fan from Saloon Gulch extending into the South Platte River, summer 2004 (two years after the 2002 Hayman fire)

Causes of Post-fire Runoff and Erosion



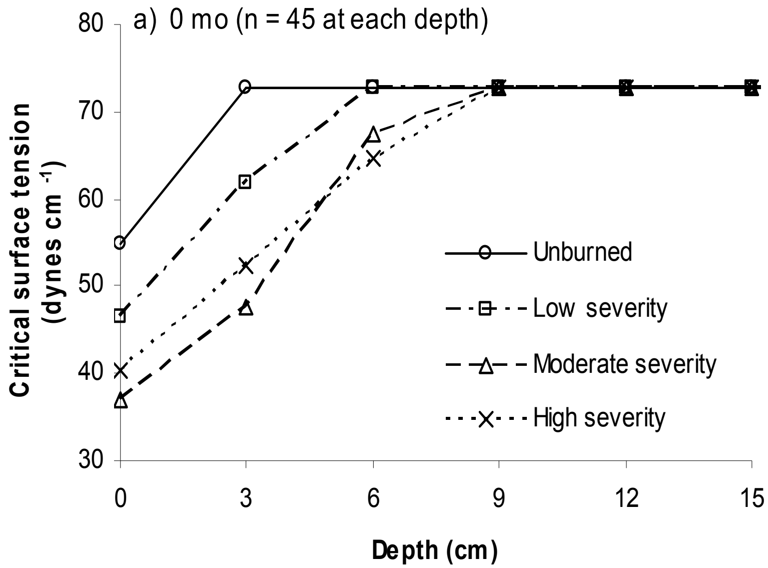
Area Burned and Precipitation, 1994-2003

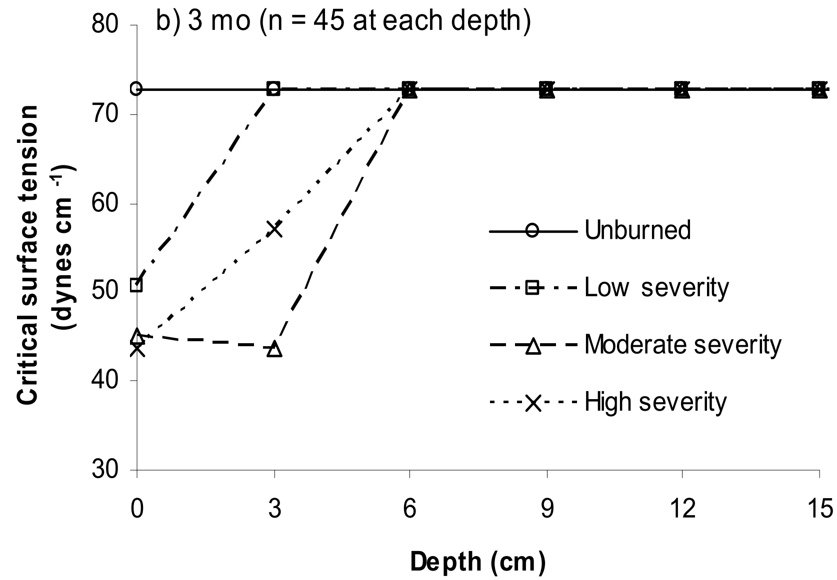


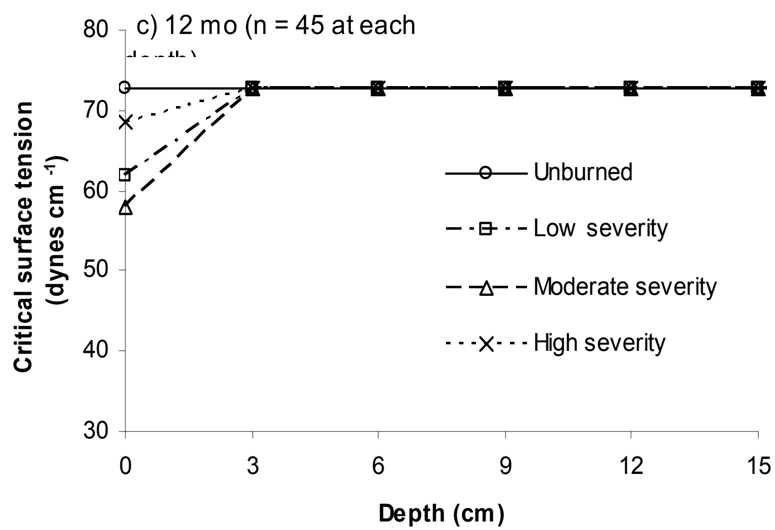
Climate change can greatly affect the amount and severity of future wildfires!

Soil Water Repellency

Soil water repellency over time: Bobcat fire

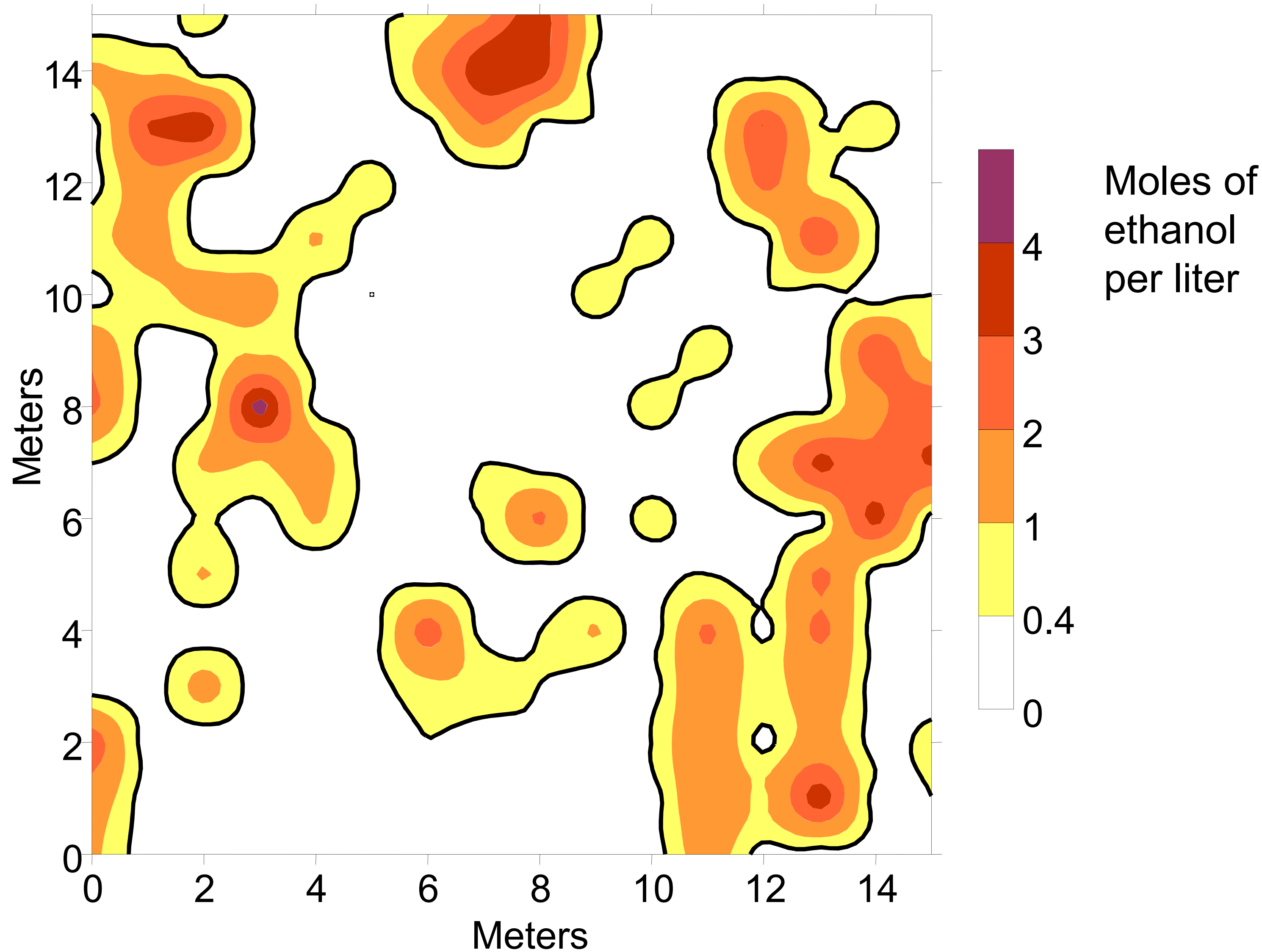






MacDonald and Huffman, 2004

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



Woods et al. 2007, *Geomorphology*

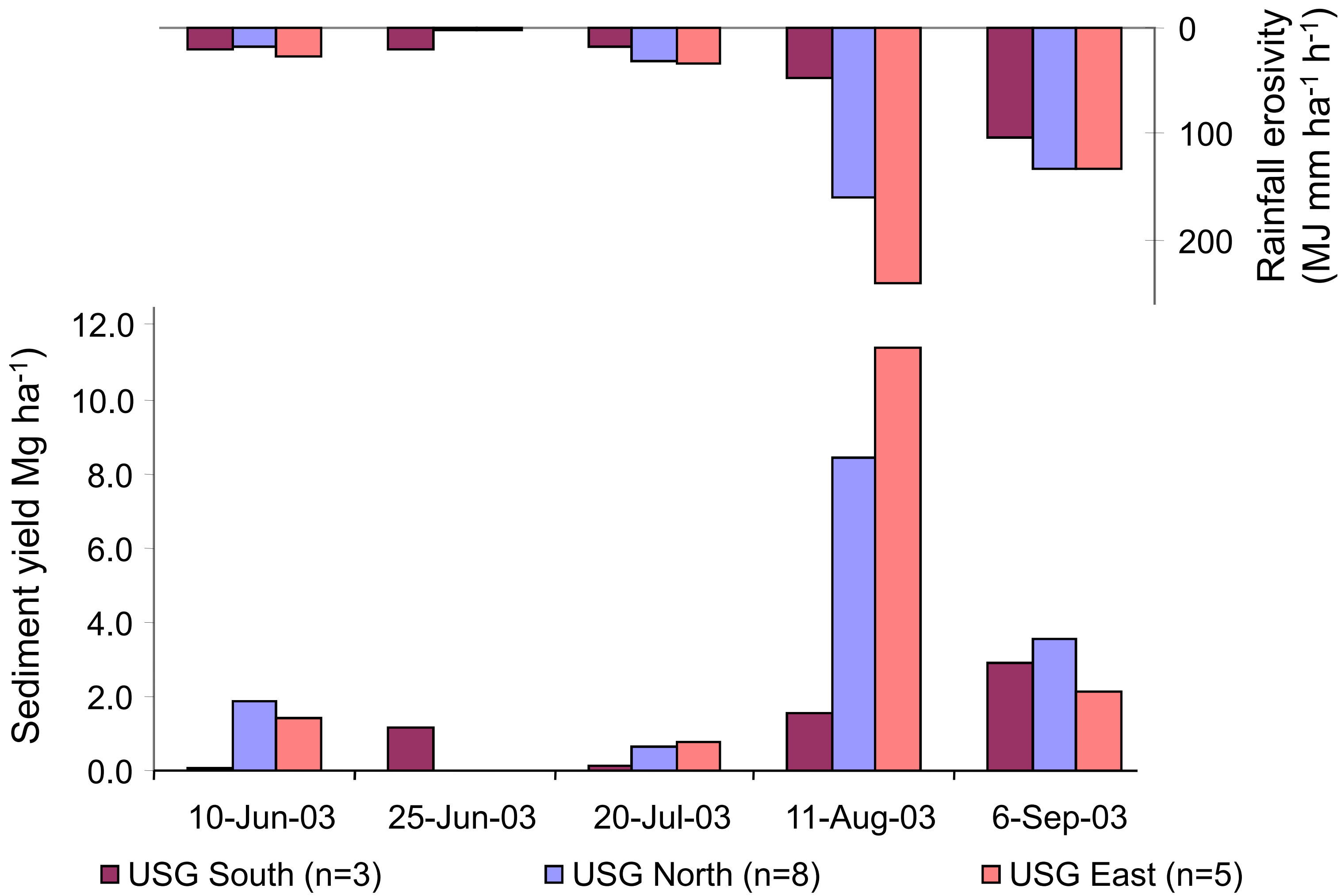
Summary: Soil Water Repellency

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

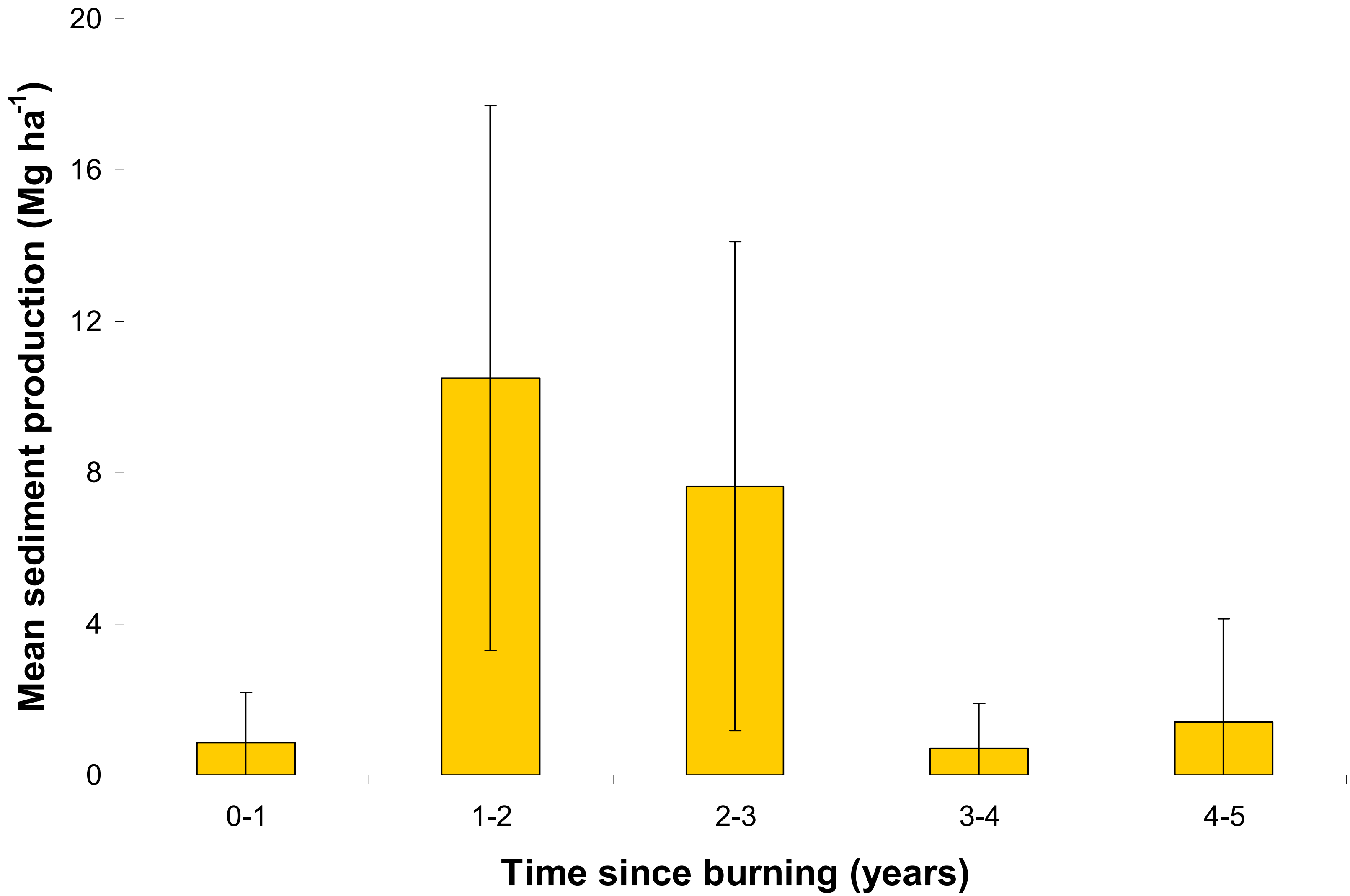
Vegetation recovery over time

Bobcat fire, sediment fence #9

Rainfall erosivity versus mean sediment yields: Five storms on three areas, Hayman fire, 2003

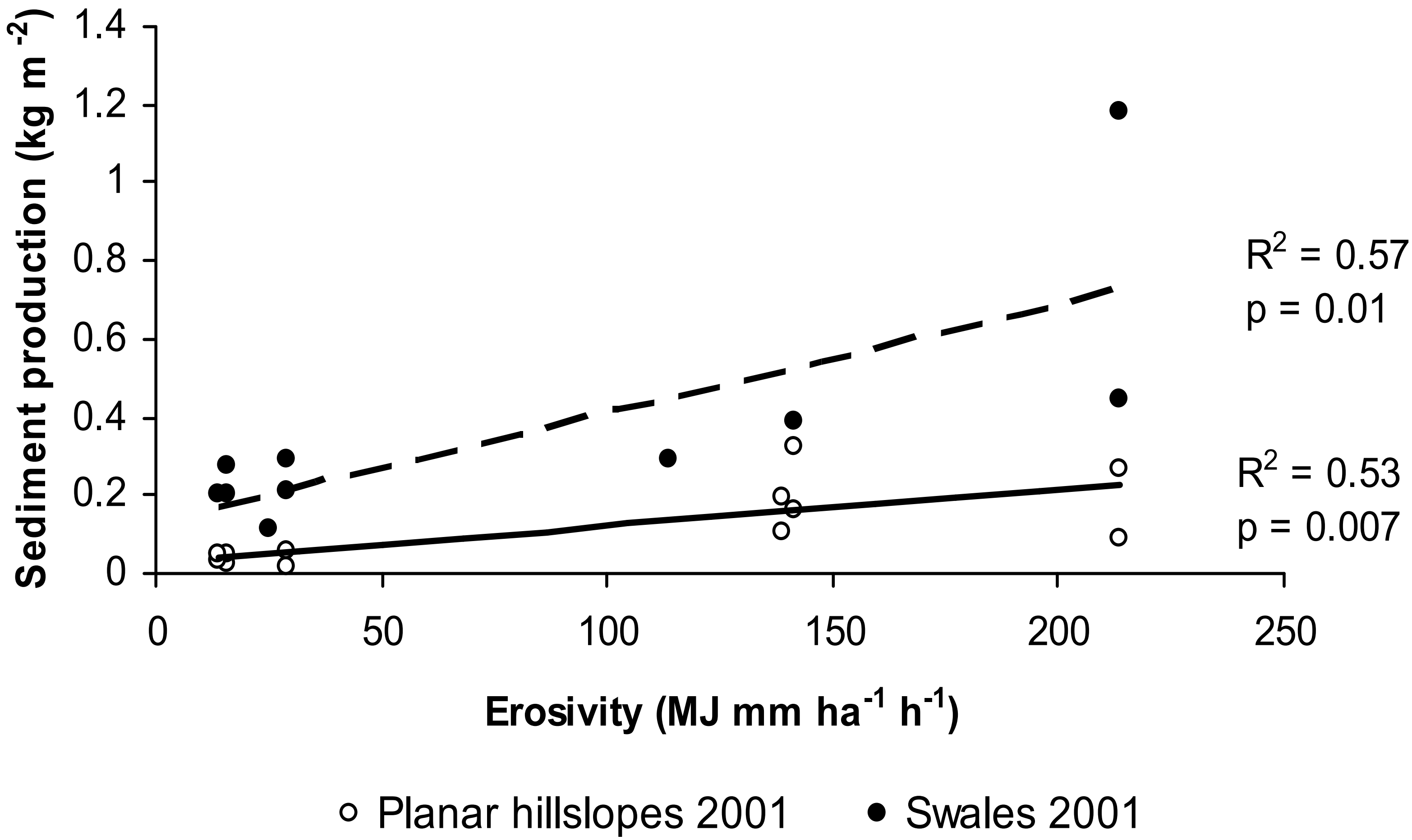


Slower recovery on high-severity sites, Hayman-Schoonover wildfires




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

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

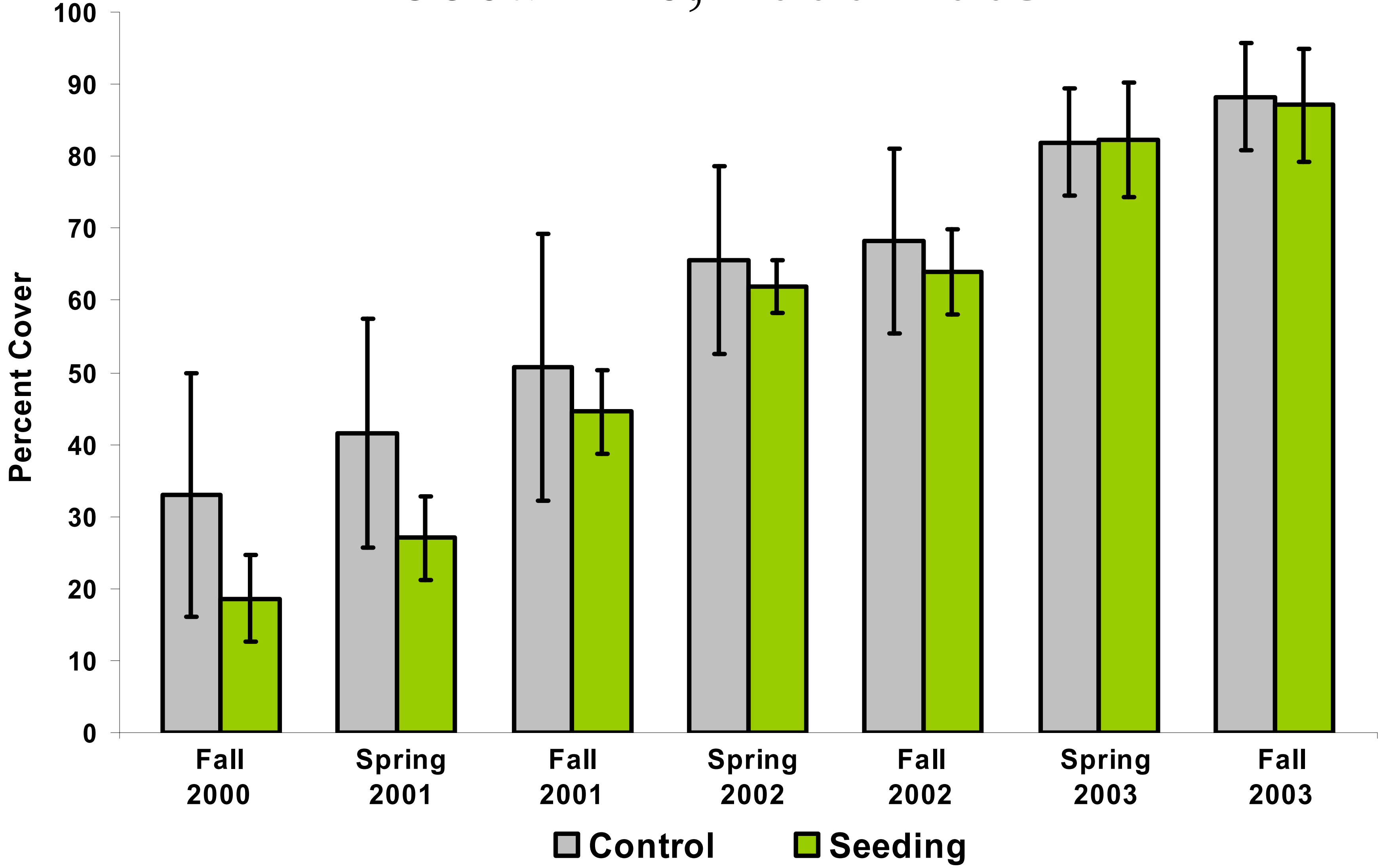


Treatments after the Hayman fire: 2002

1. Scarifying and seeding;
2. Straw mulching with seed;
3. Hydromulching
   - Ground based;
   - Aerial;
4. Polyacrylamide (soil binding agent).

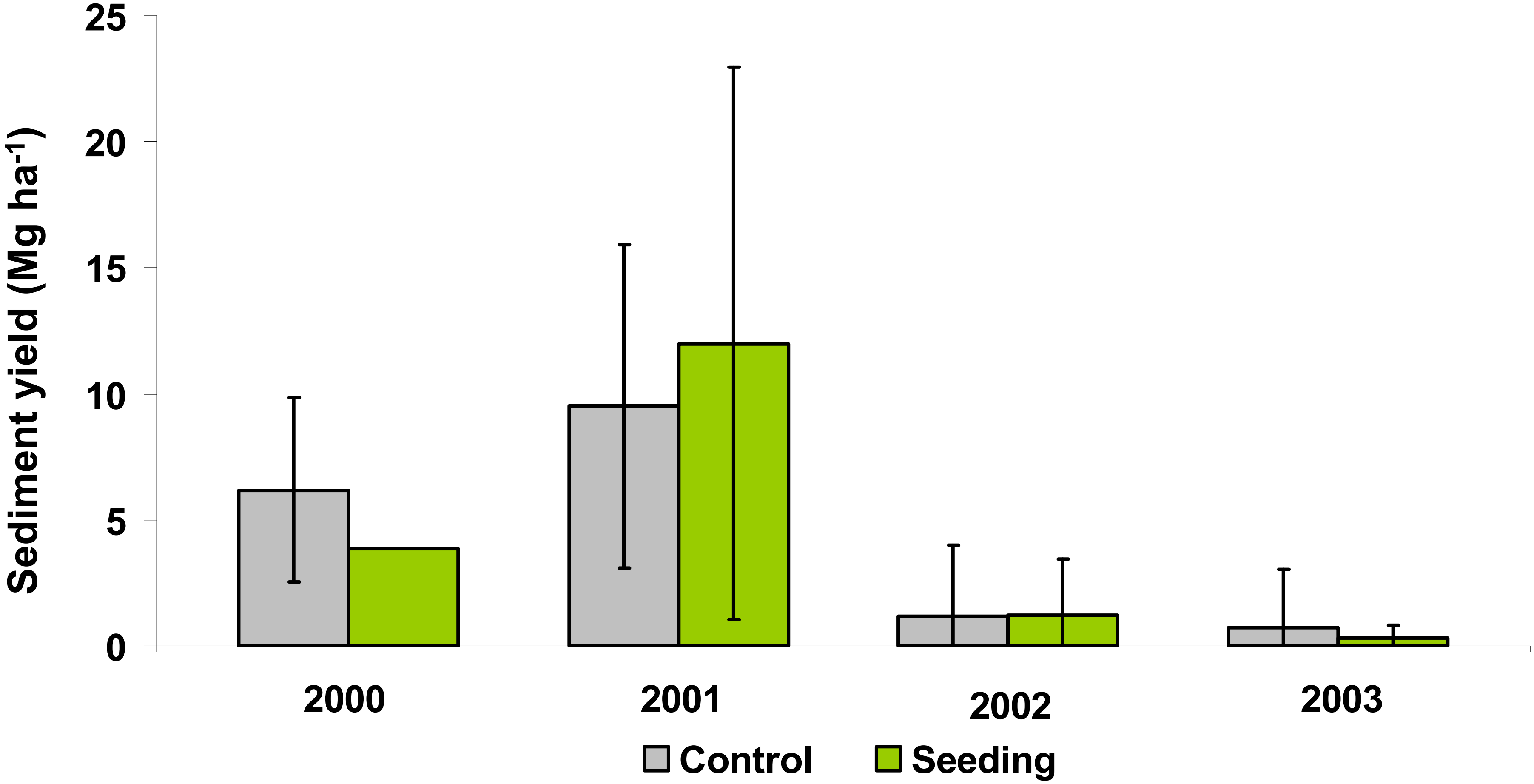

Seeding

Percent surface cover for controls and seeding: Bobcat fire, 2000-2003



No significant treatment effect

Sediment yields for controls and seeding: Bobcat fire, 2000-2003

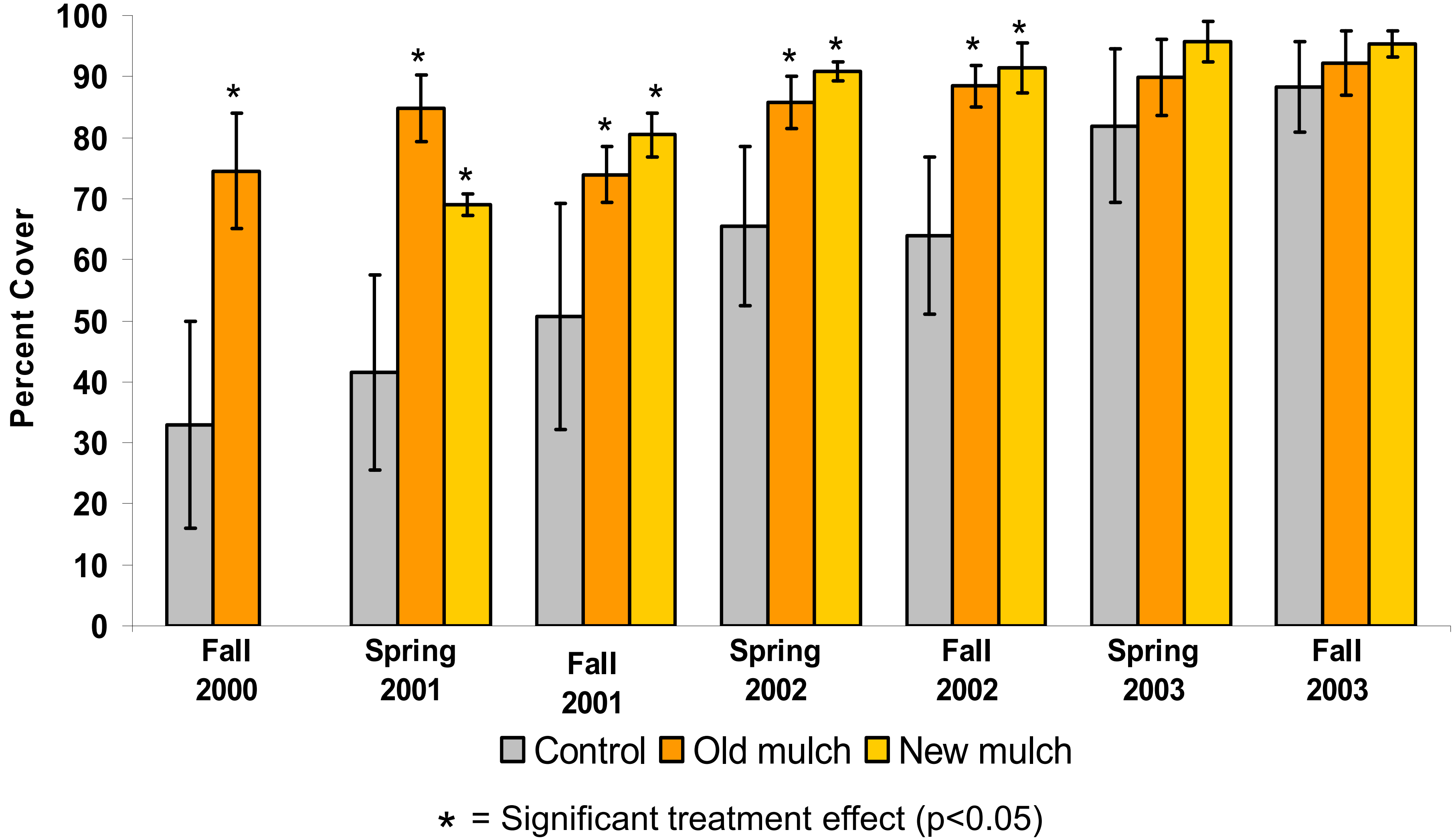


No significant treatment effect

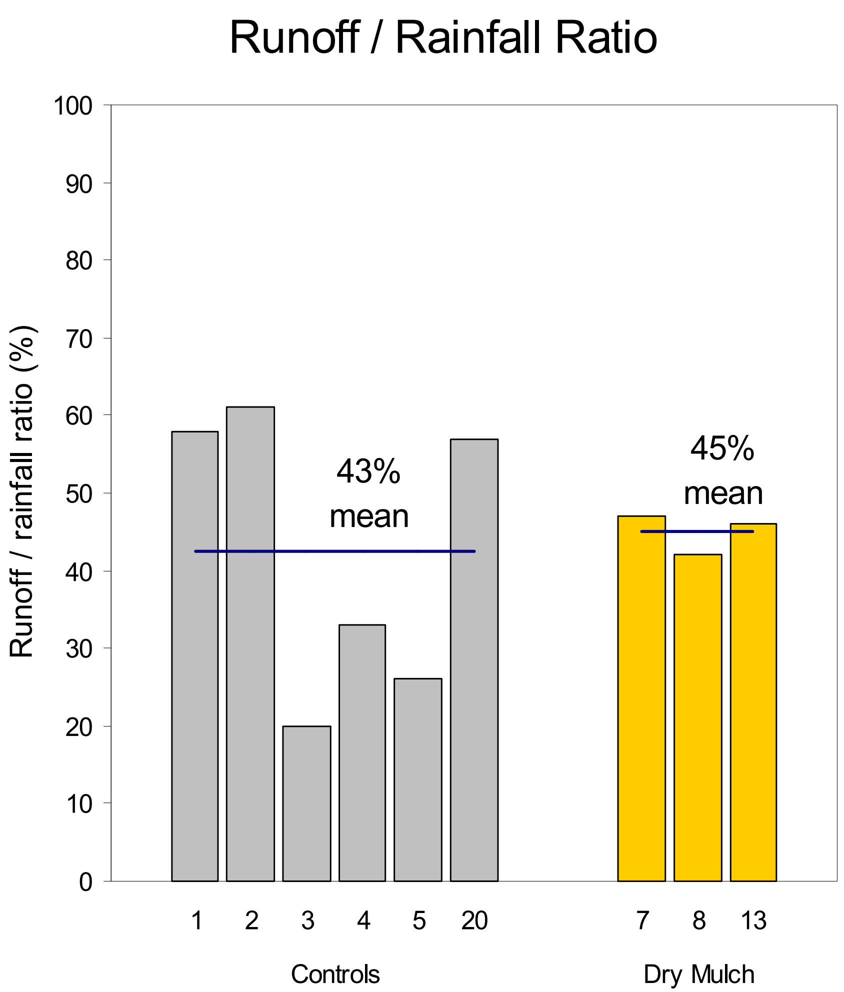

Mulching

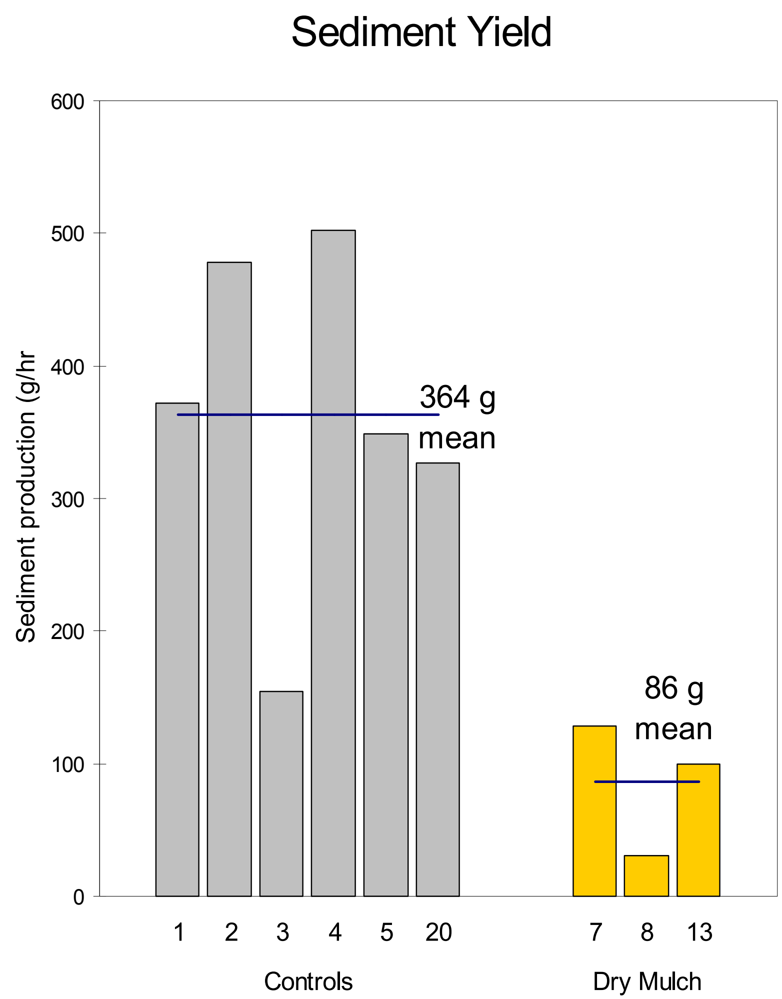
Video Clip: Mulching

Percent surface cover on control and mulched plots: Bobcat fire, 2000-2003

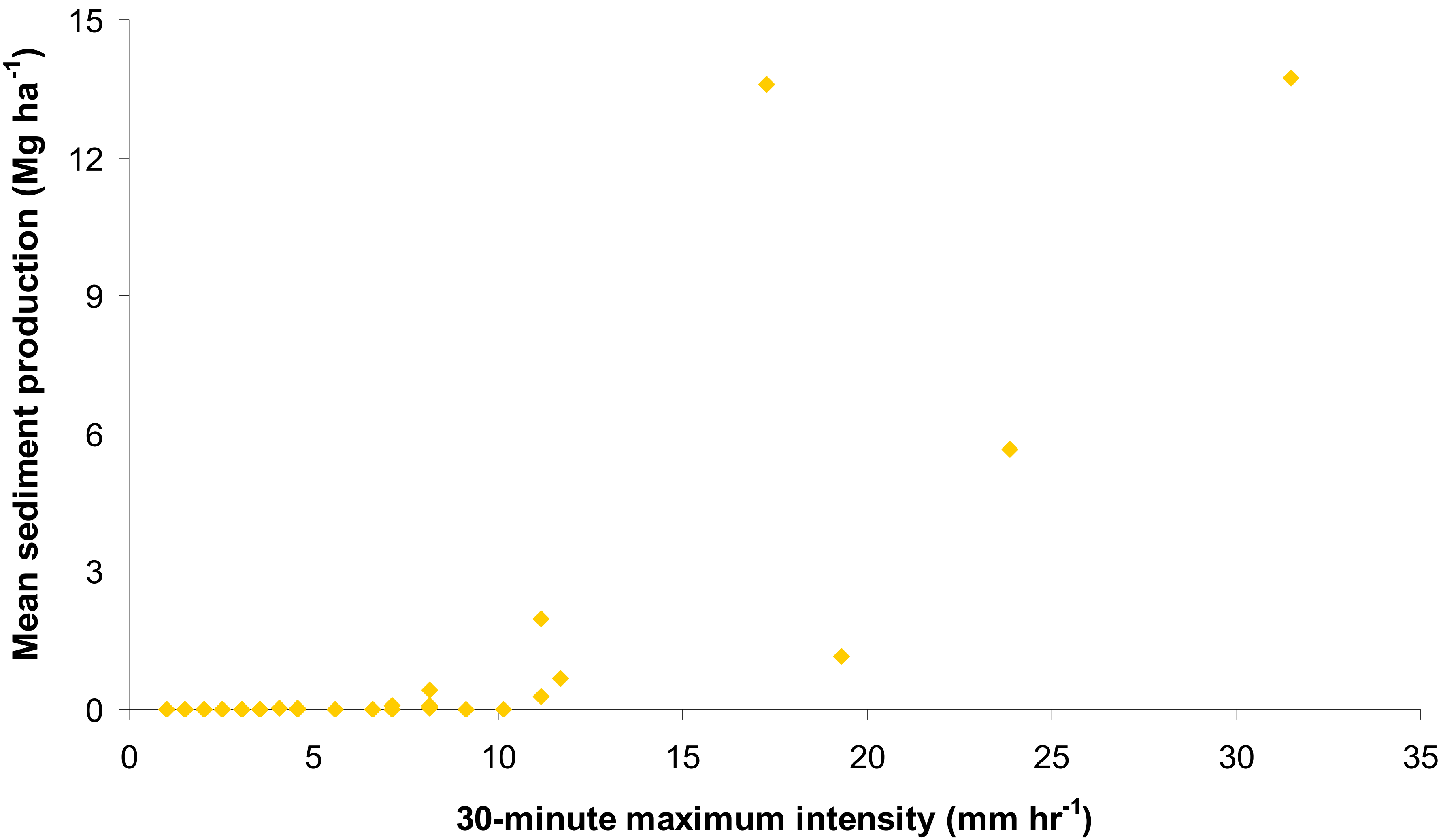


Runoff and sediment yields from rainfall simulations on control and straw mulch plots: Hayman fire, 2003

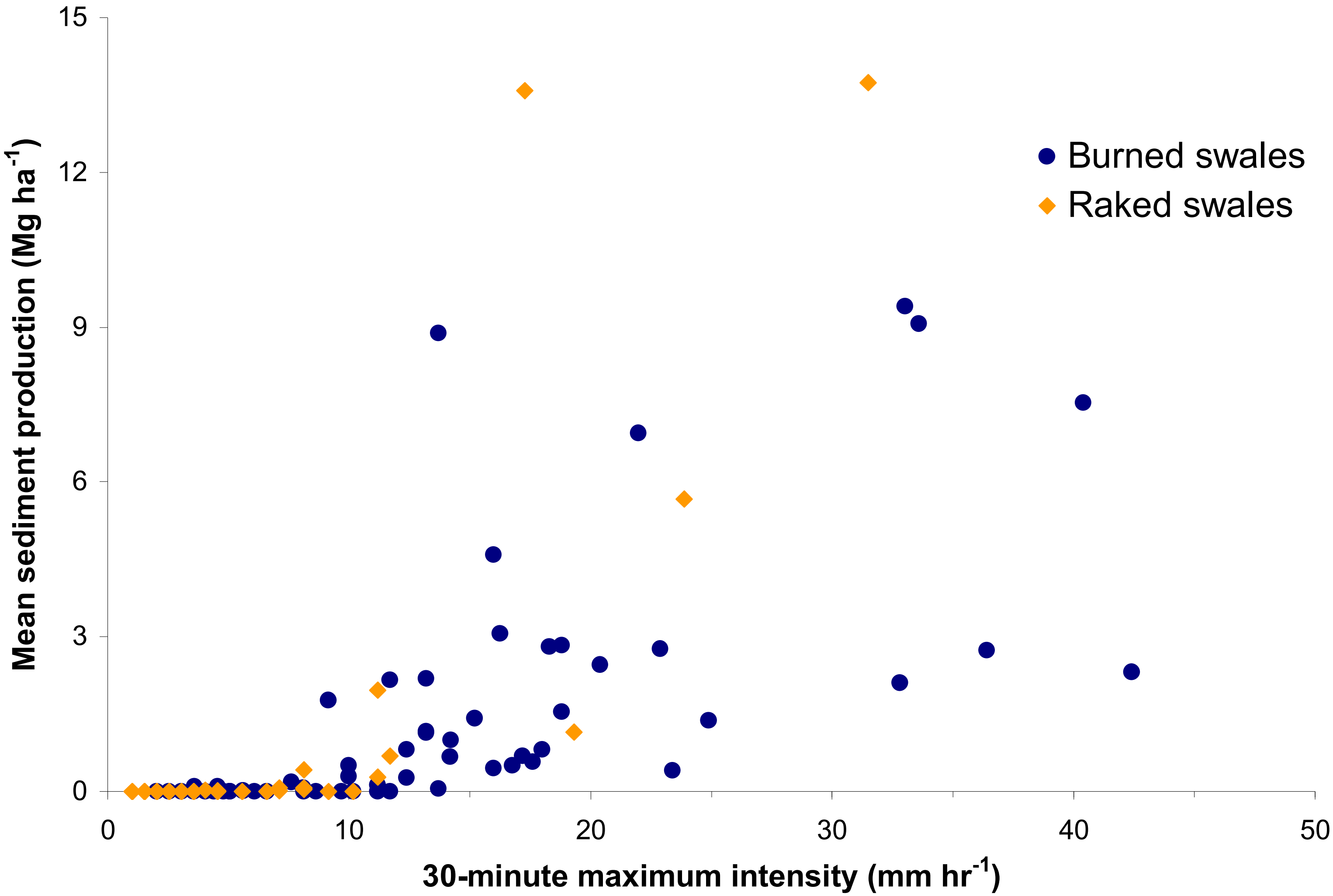




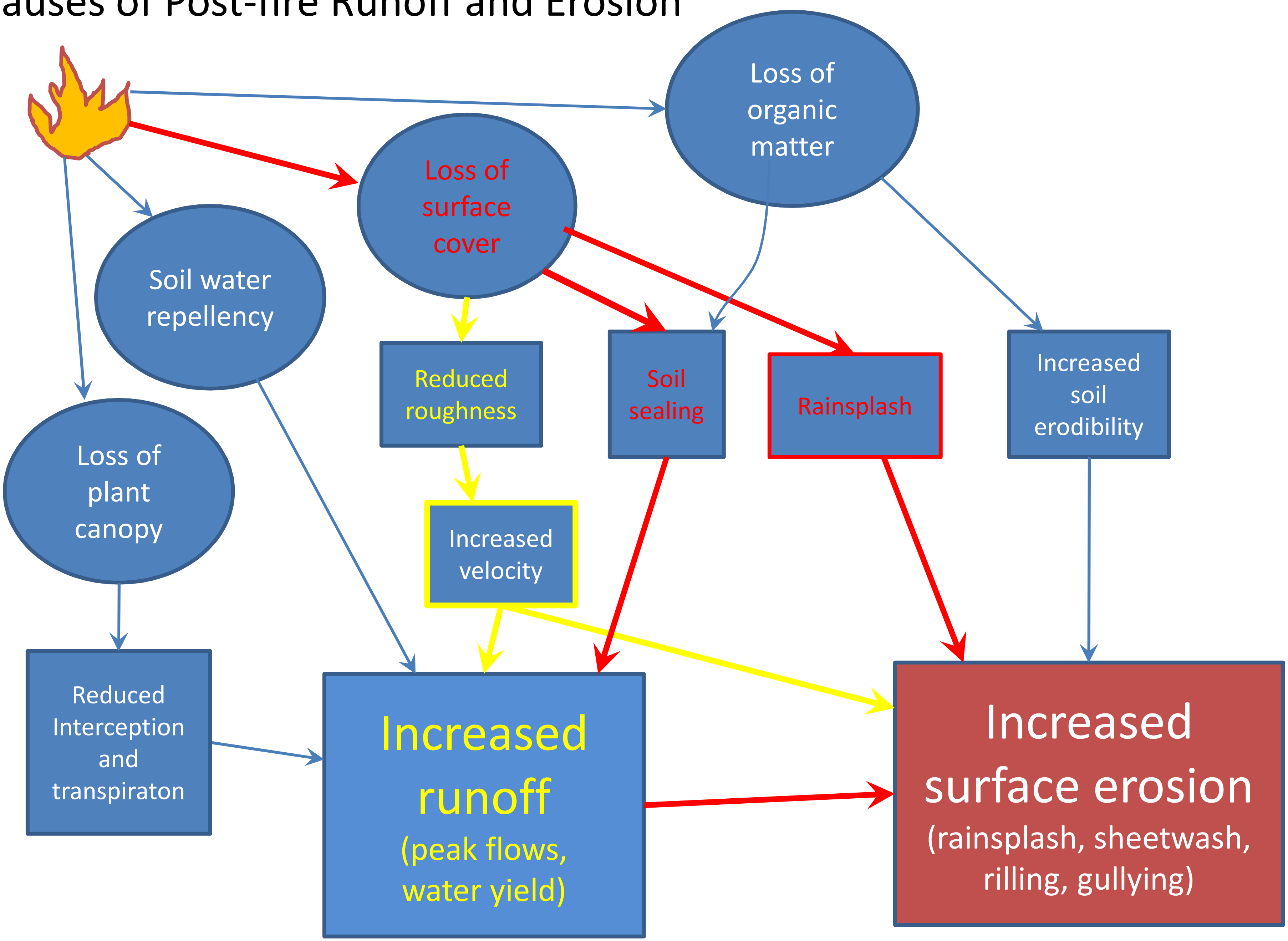
Intensity threshold: Raked swales



Event-based sediment production vs. I_{30}: Burned and raked swales



Causes of Post-fire Runoff and Erosion



Lessons for Future Studies

- High variability between sites necessitates replication;
- Replication at plot and hillslope scale feasible, while replication at the catchment scale is costly and sites are difficult to find and replicate;
- One can never have too many rain gages, as the variability in rainfall can easily confound the results;
- Detailed site measurements are needed to interpret and explain the results (how do you understand the processes if you only measure the outputs?);
- Few studies are lucky enough to capture the largest storm events that may be of most interest, so the effects of these events have the greatest uncertainty.

Conclusions (1)

- High-severity wildfires increase runoff and sediment production rates by several orders of magnitude;
- Sediment production rates from high-severity sites are nearly an order of magnitude higher than sites burned at moderate or low severity;
- Sediment production rates are highest in the first two summers after burning, and rapidly decline to near-background levels except in sites with exceptionally coarse soils with poor growing conditions;

Conclusions (2)

- Percent ground cover is the most important control on post-fire erosion rates;
- Rainfall erosivity, topographic convergence, and soil texture are secondary controls on post-fire erosion;
- Rill erosion in convergent areas is the dominant erosion process rather than sheetwash on hillslopes;
- Soil water repellency is too short-lived to account for the observed increases in sediment production;
- We believe that soil sealing on bare soil is the primary cause of high post-fire runoff and erosion rates;

Conclusions (3)

- Erosion prediction models are not very accurate for individual sites, but can provide a first-order estimate of average sediment yields;
- Seeding and scarification do not increase ground cover or reduce erosion rates. Mulching is the most effective post-fire rehabilitation technique because it immediately provides ground cover and prevents soil sealing, but does not increase regrowth rates;
- Large amounts of sediment are deposited in downstream areas, and downstream channels are likely to take decades or even centuries to recover to pre-fire conditions.

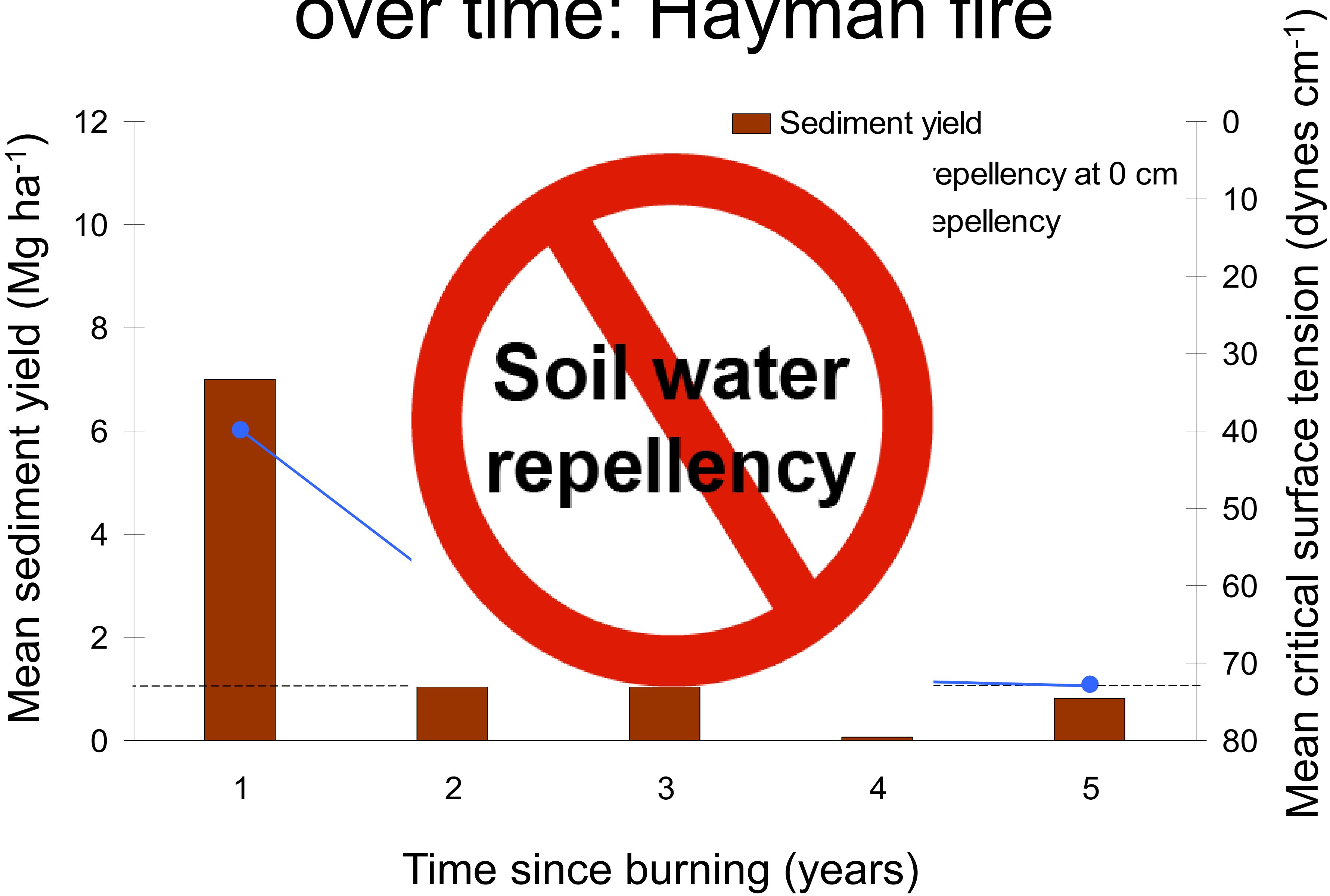
Even more information . . . .

- Numerous papers on my web site

(type “Lee MacDonald, Colorado” into google).


Questions?

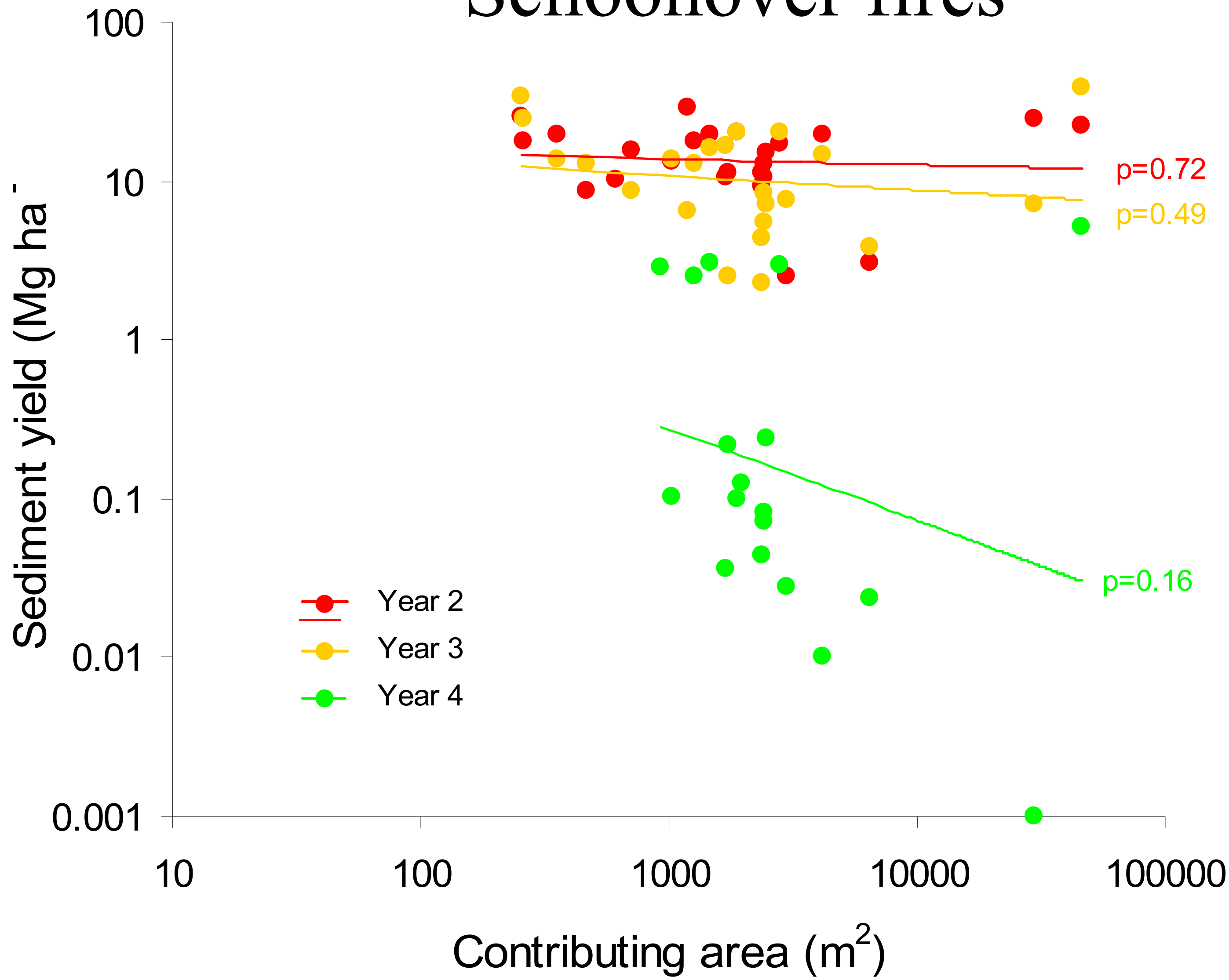
Soil water repellency and sediment yields over time: Hayman fire



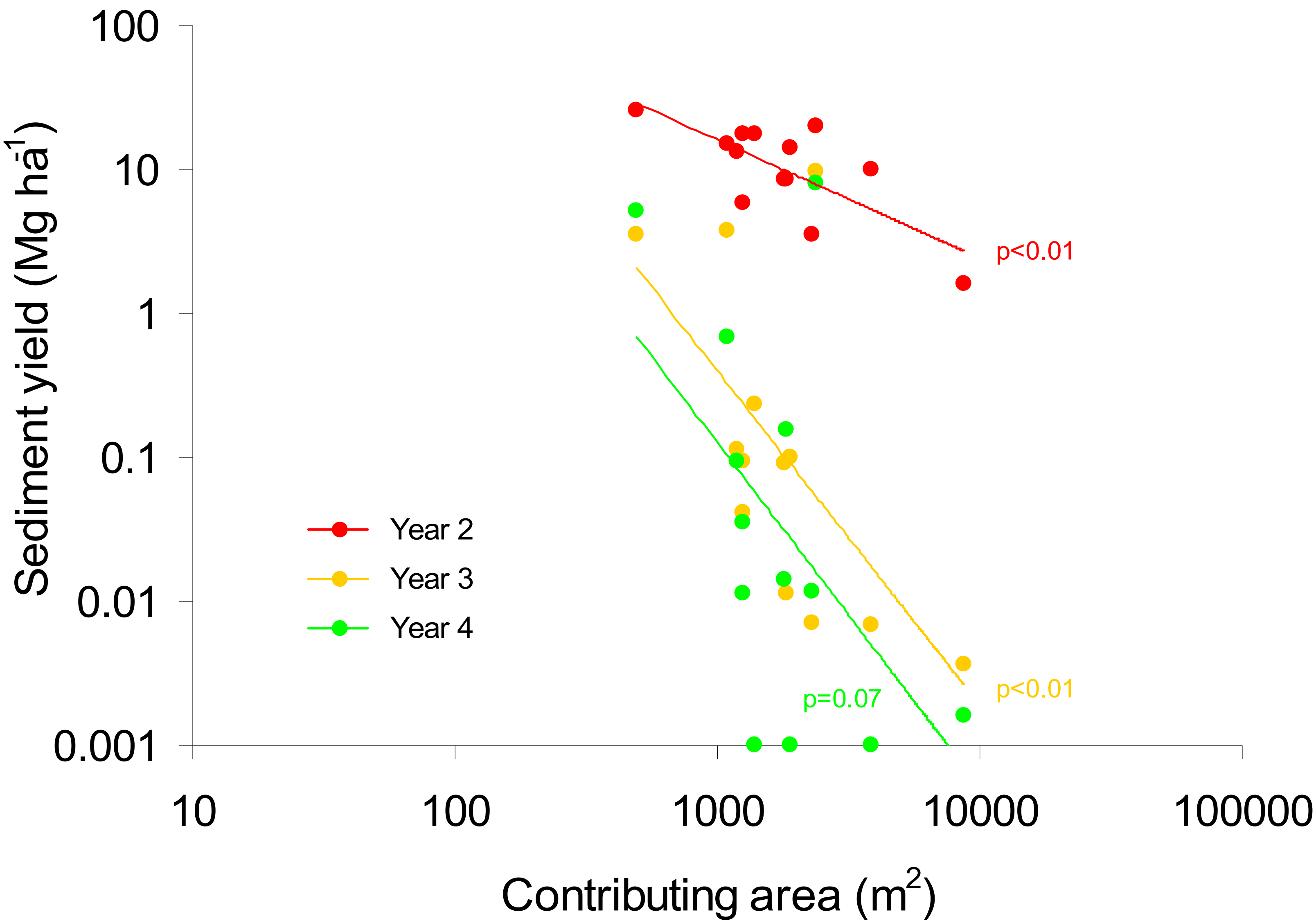
Scale effects:

How do post-fire sediment yields vary with contributing area?

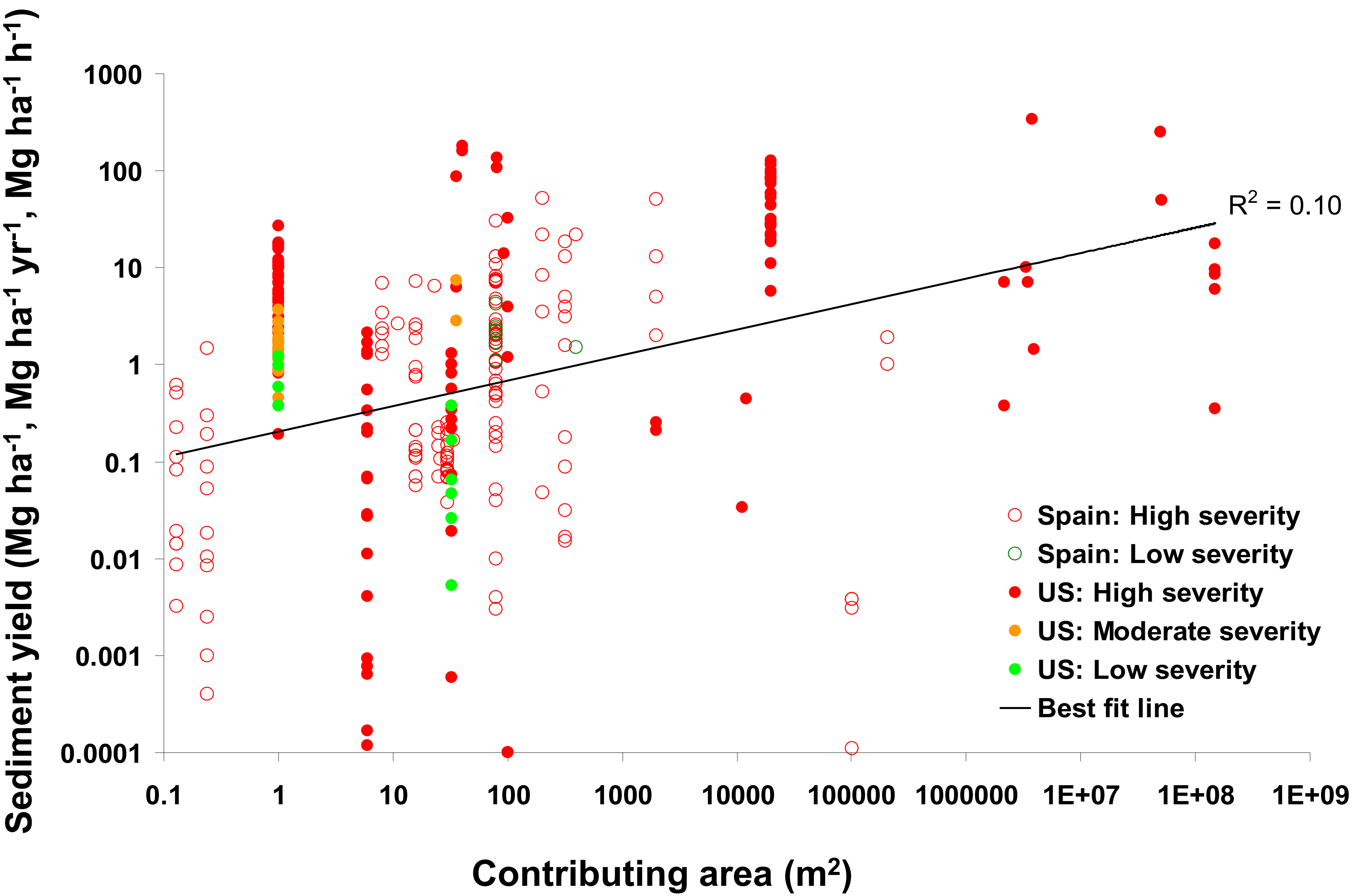
Sediment yield versus contributing area for convergent hillslopes and watersheds: Hayman and Schoonover fires



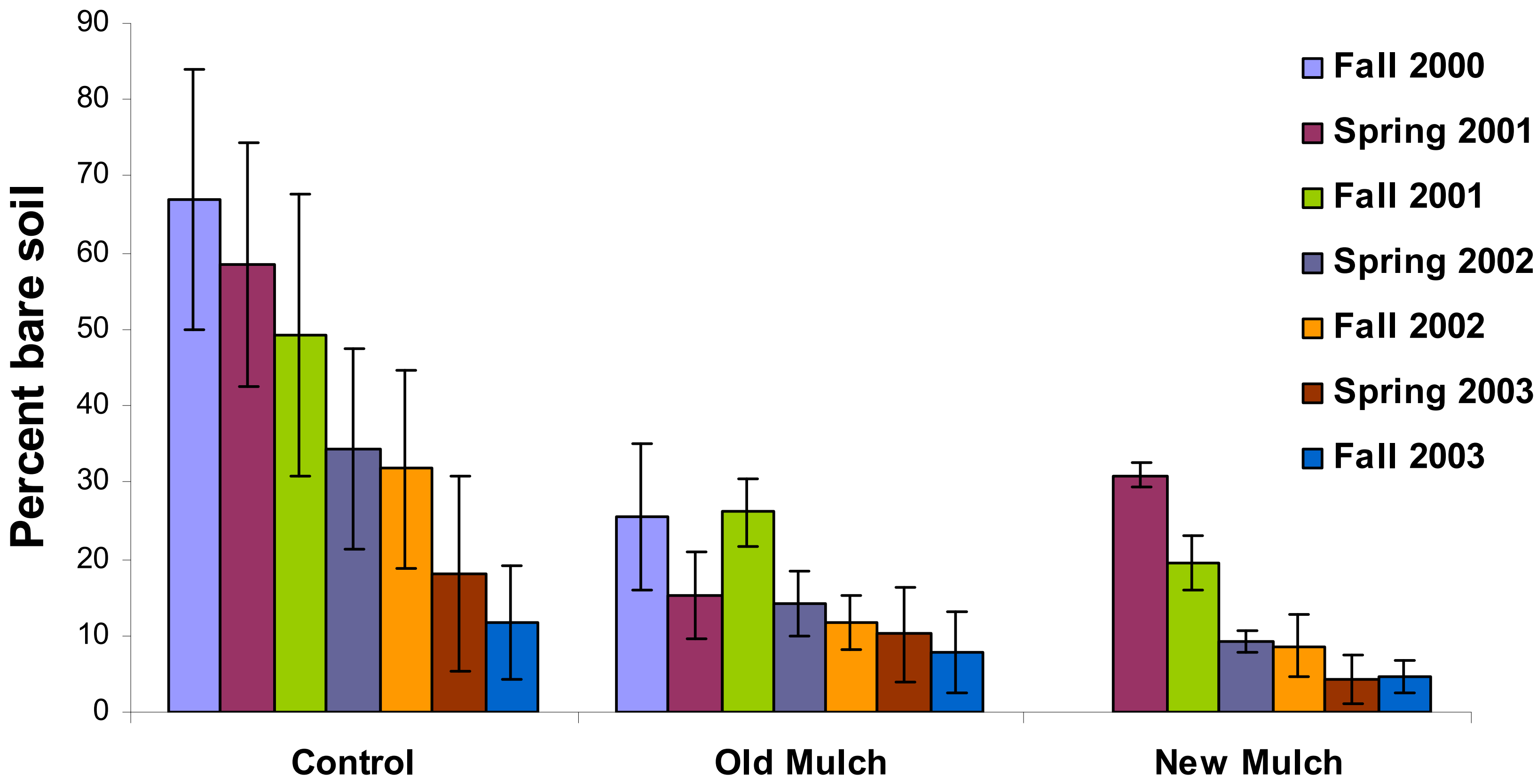
Sediment yield versus contributing area for convergent hillslopes: Bobcat fire



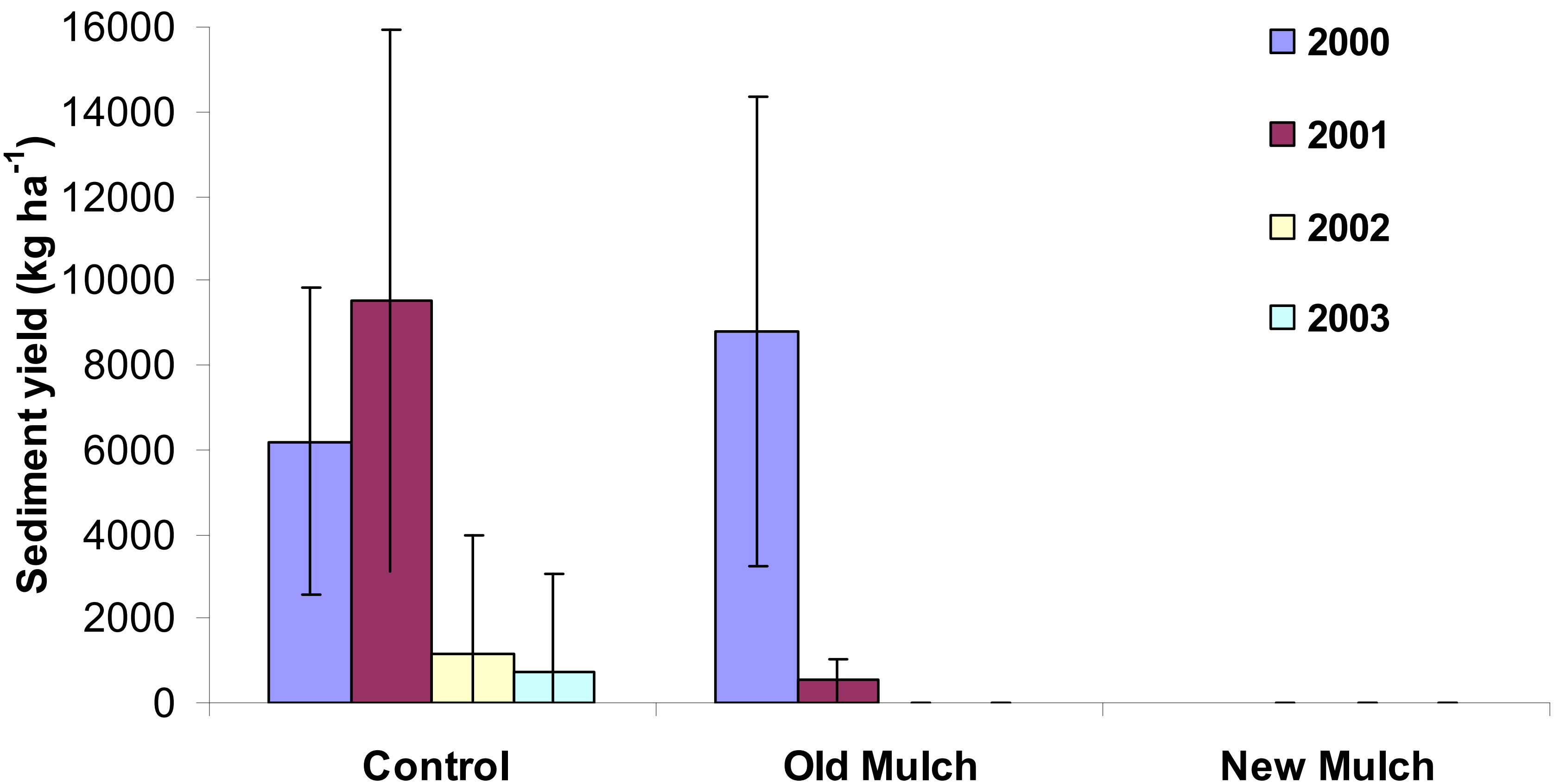
Contributing area versus sediment yield



Percent bare soil on control and mulched plots: Bobcat fire, 2000-2003

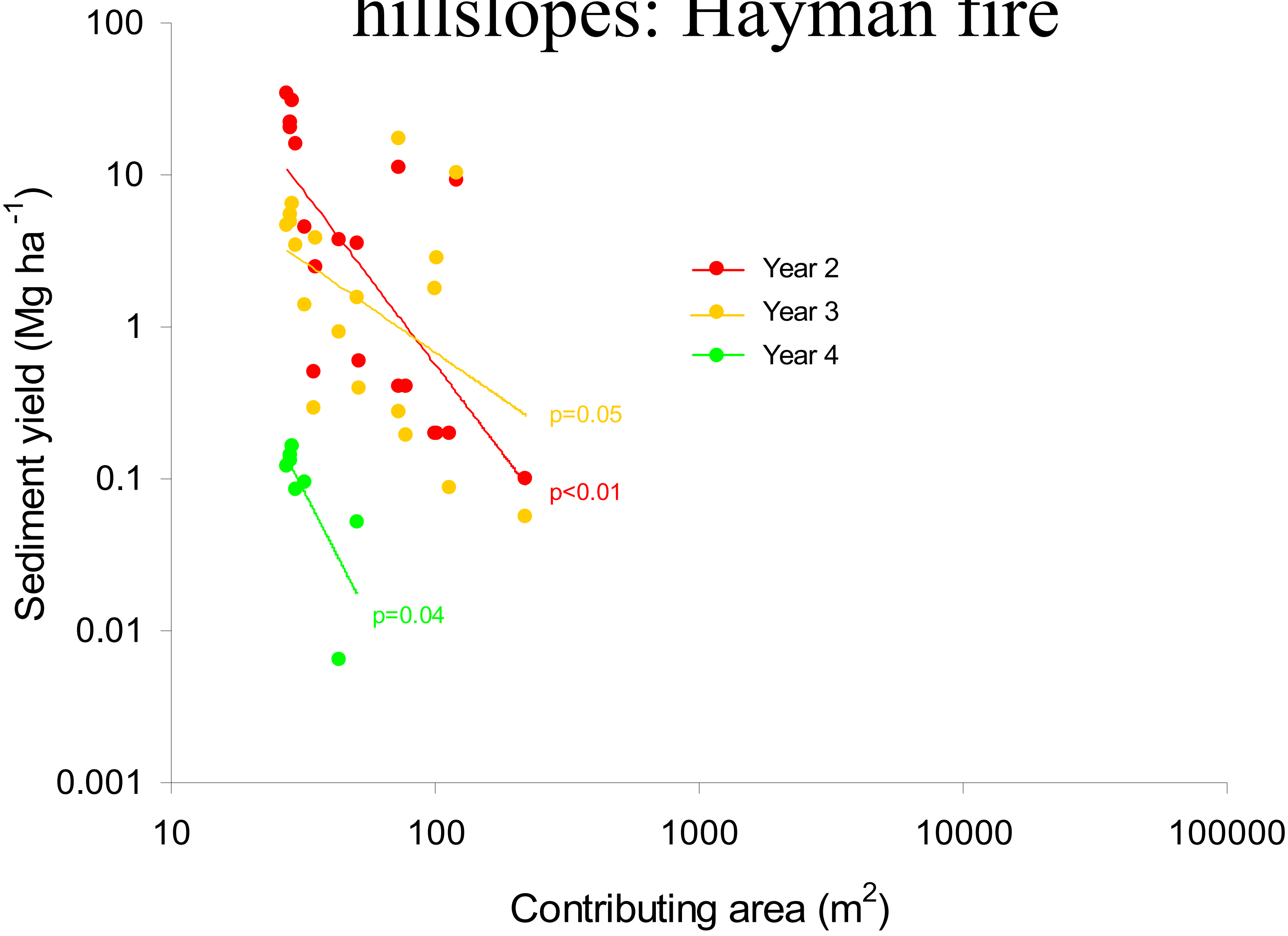


Mean sediment yields on control and mulched plots: Bobcat fire, 2000-2003

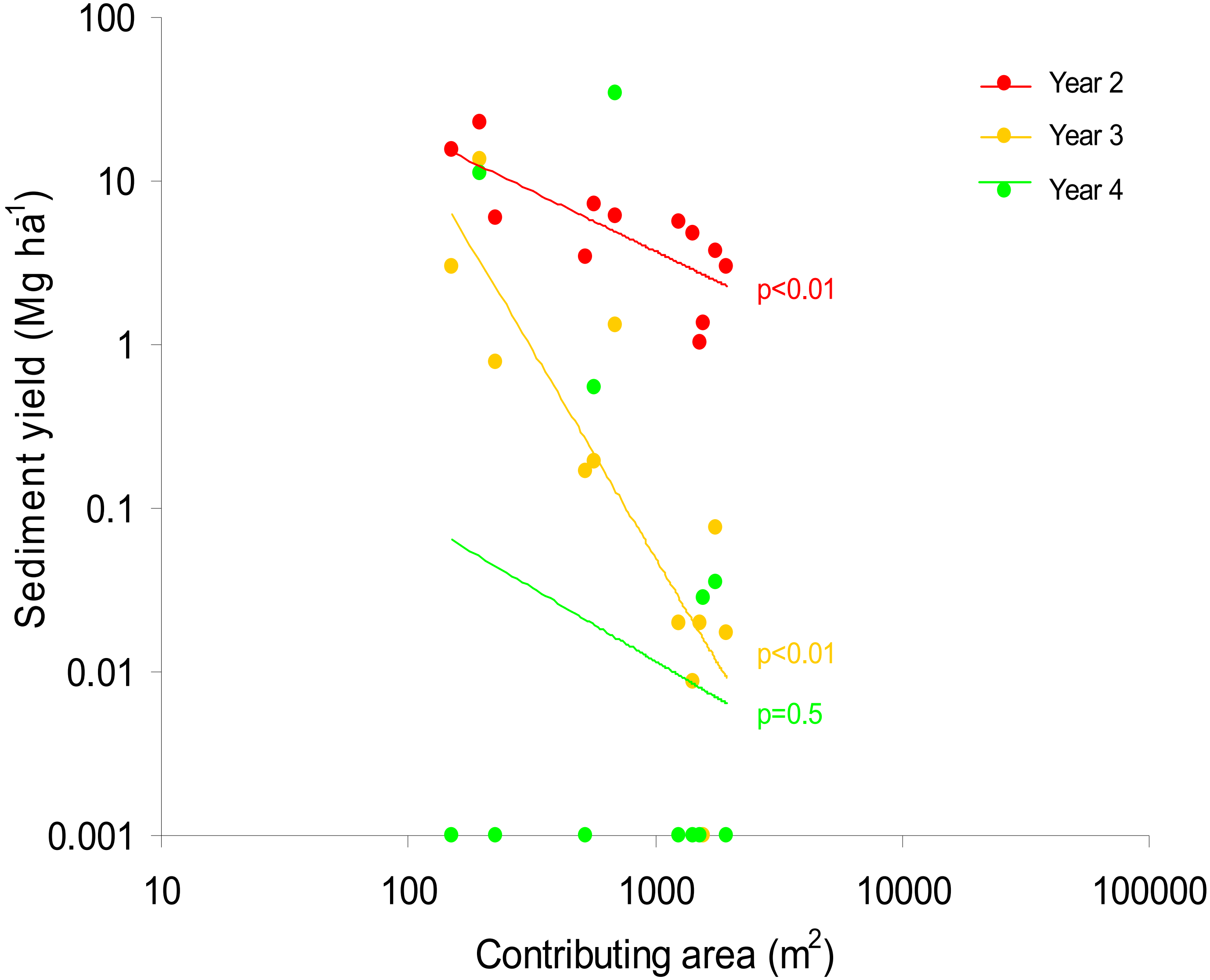


Questions?

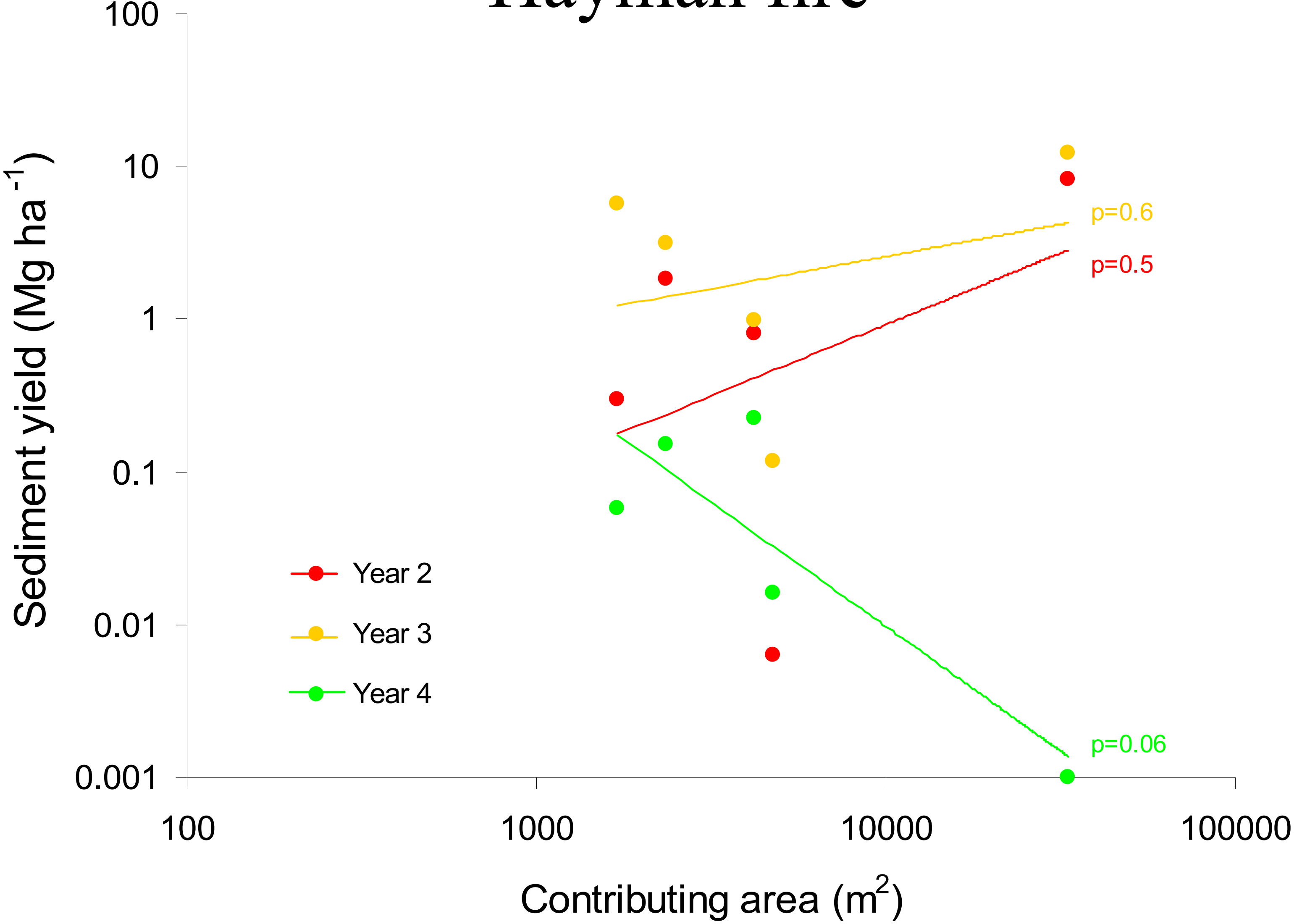
Sediment yield versus contributing area for planar hillslopes: Hayman fire



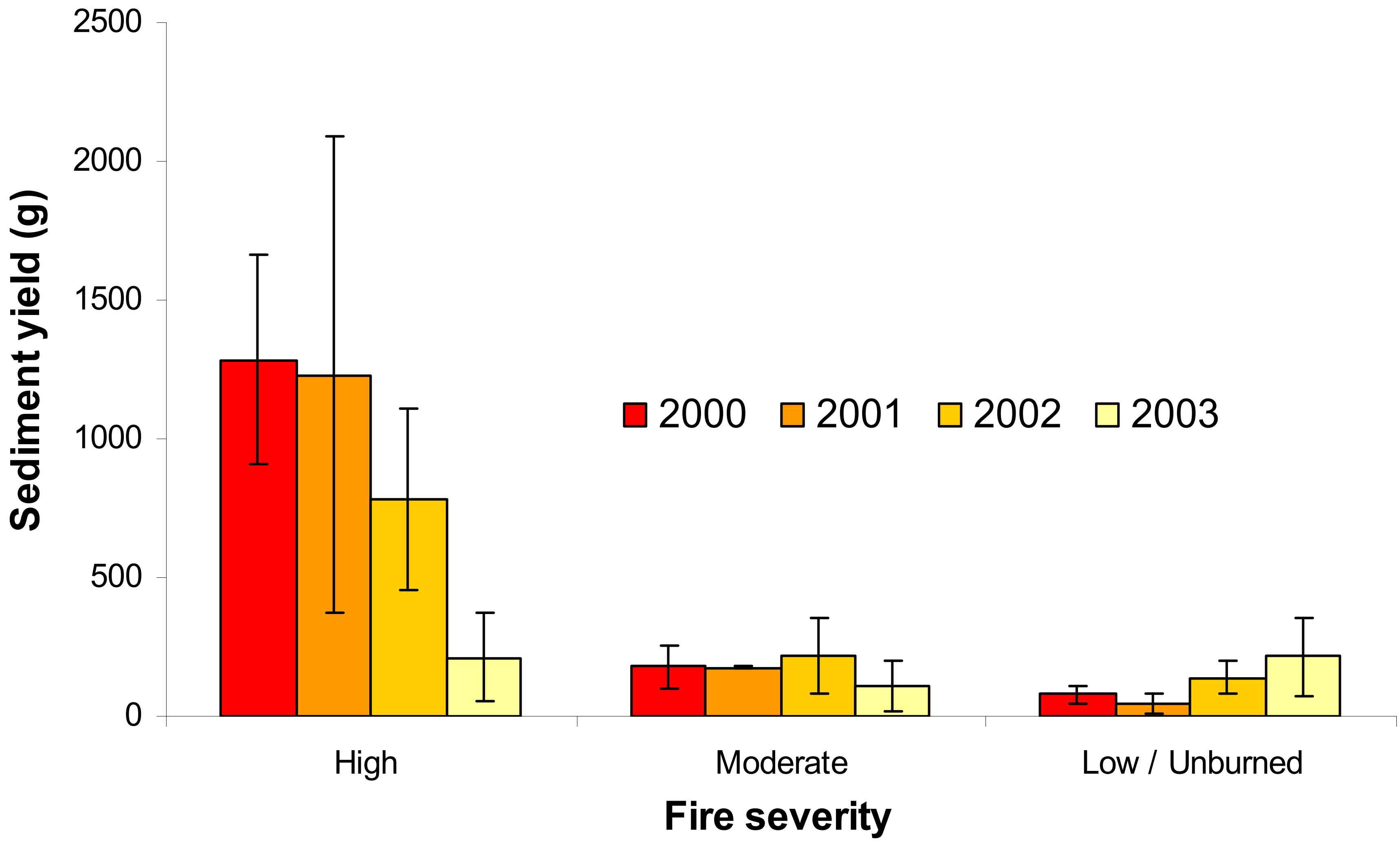
Sediment yield versus contributing area for planar hillslopes: Bobcat fire



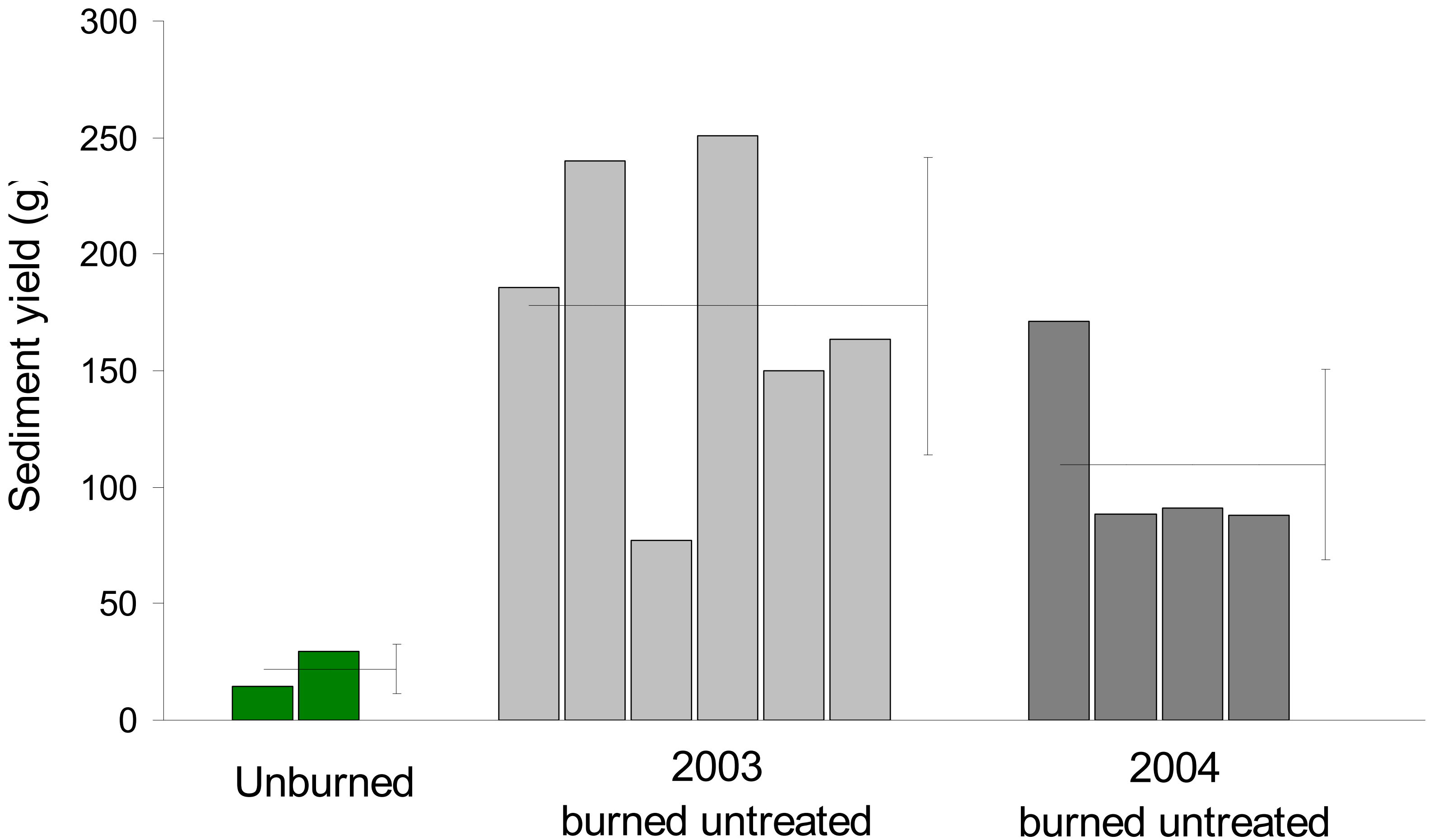
Sediment yield versus contributing area for mulched convergent hillslopes and watersheds: Hayman fire



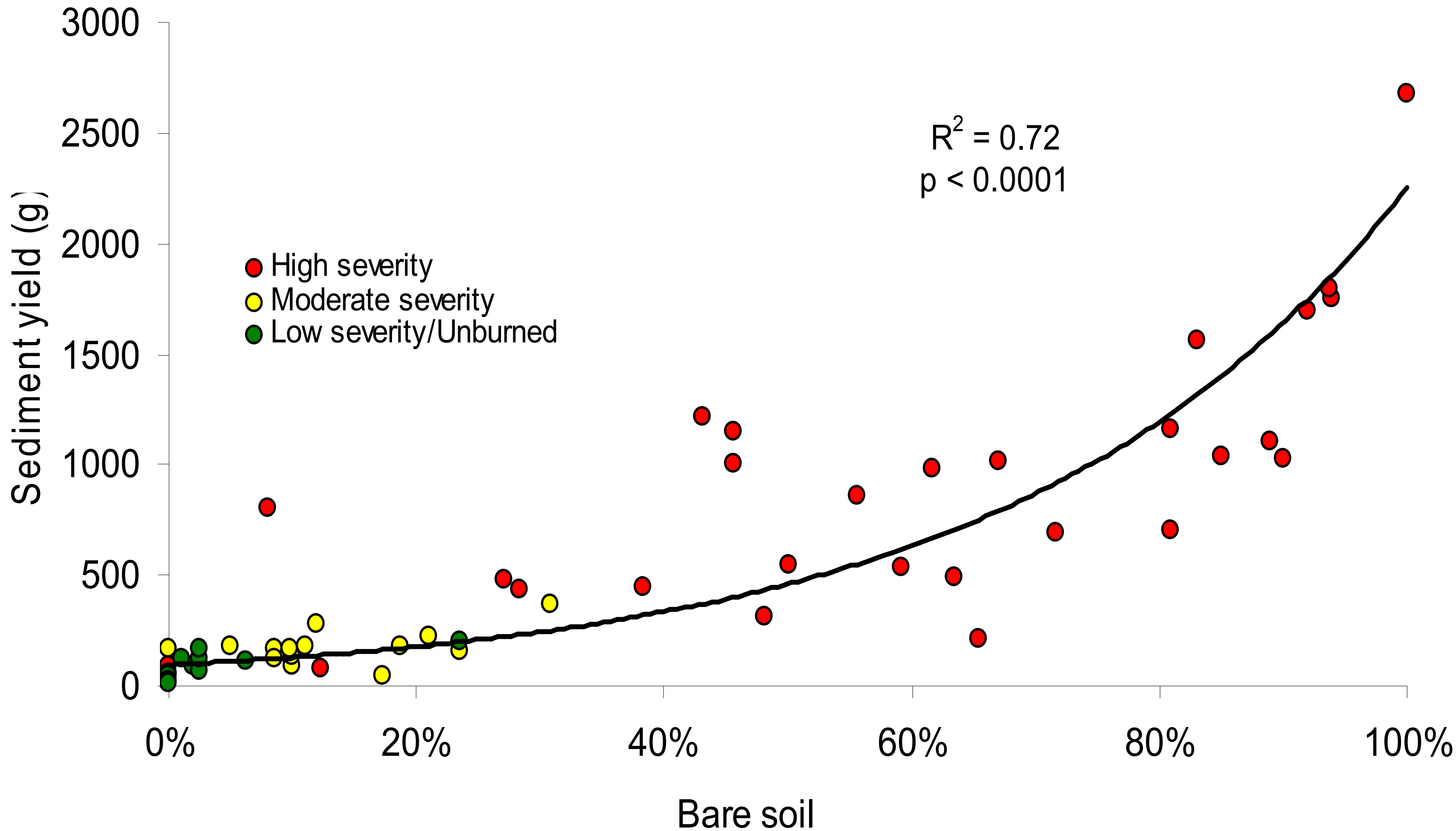
Mean sediment production by fire severity and year: Bobcat Fire 2000-03



Sediment yields from unburned plots and burned untreated plots, Hayman fire

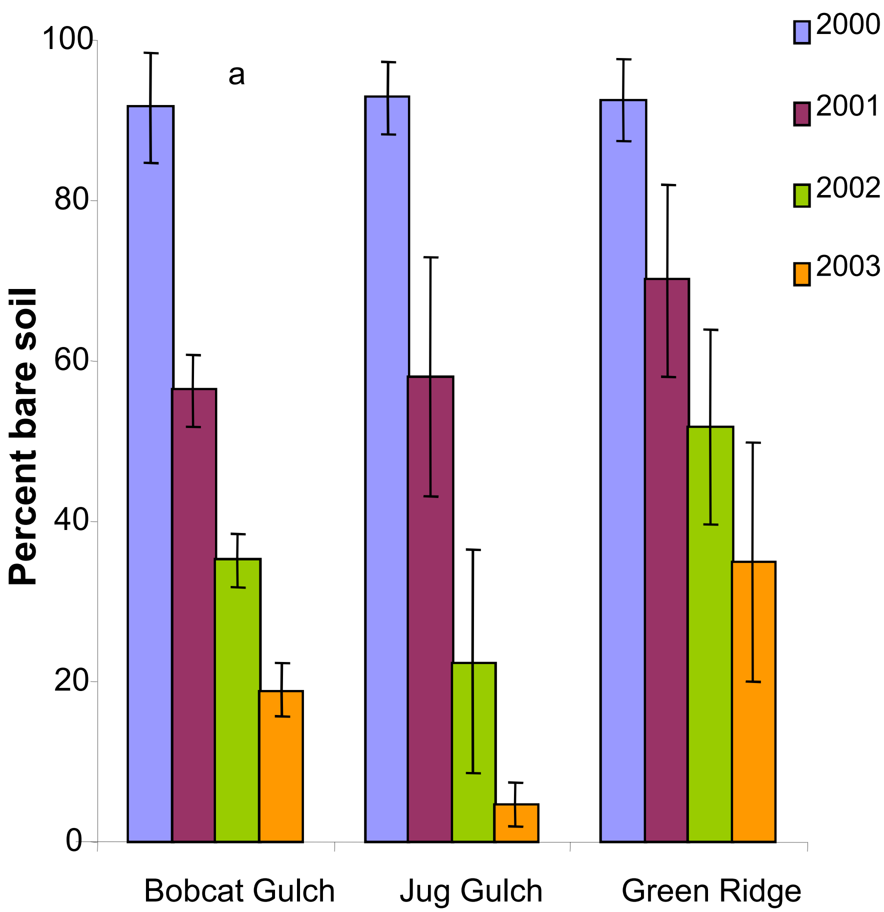


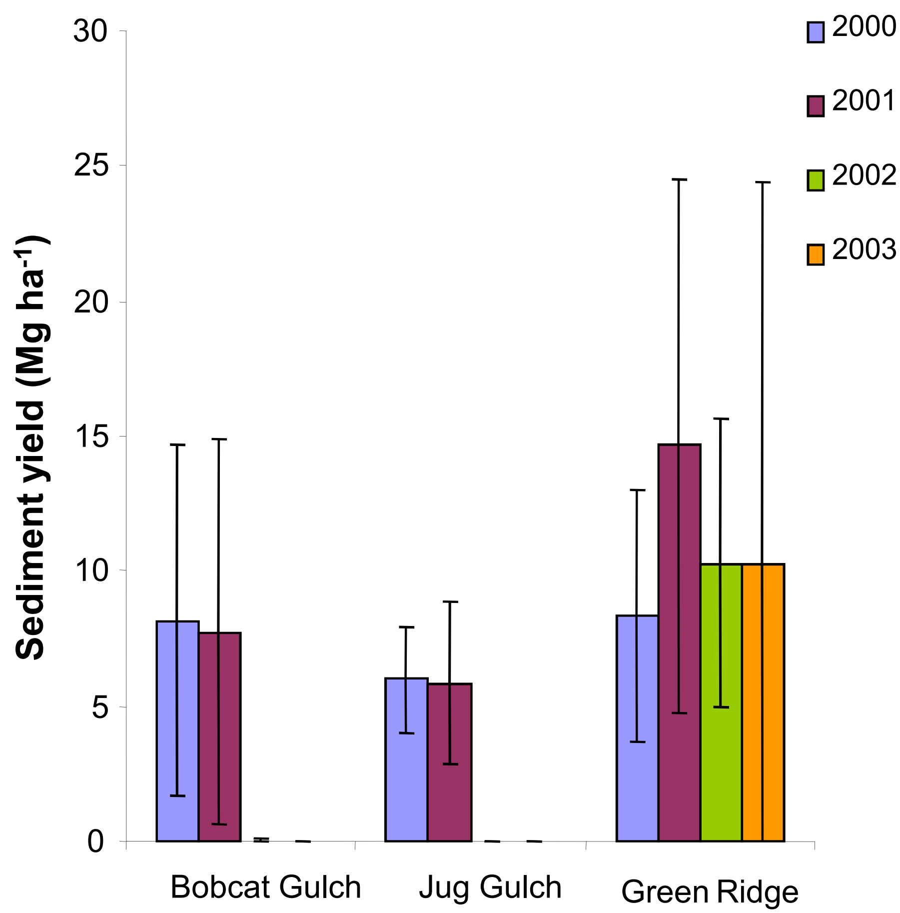
Sediment yield vs. percent bare soil for rainfall simulations, Bobcat Fire



Percent bare soil and sediment yields for three areas in the Bobcat Fire

(all high severity; bars indicate one standard deviation)





Hydrology of Unburned Forests

- Typically coarser-textured soils (loam, or sandy loam);
- Generally good ground cover (usually ≥ 80%);
- Storm runoff generated primarily by subsurface stormflow;
- Low peak flows from all but highest-magnitude storm events;
- Very low mean erosion rates (<0.1 t ha^{-1} yr^{-1});
- Clean, high quality water.

Cross-section slightly upstream