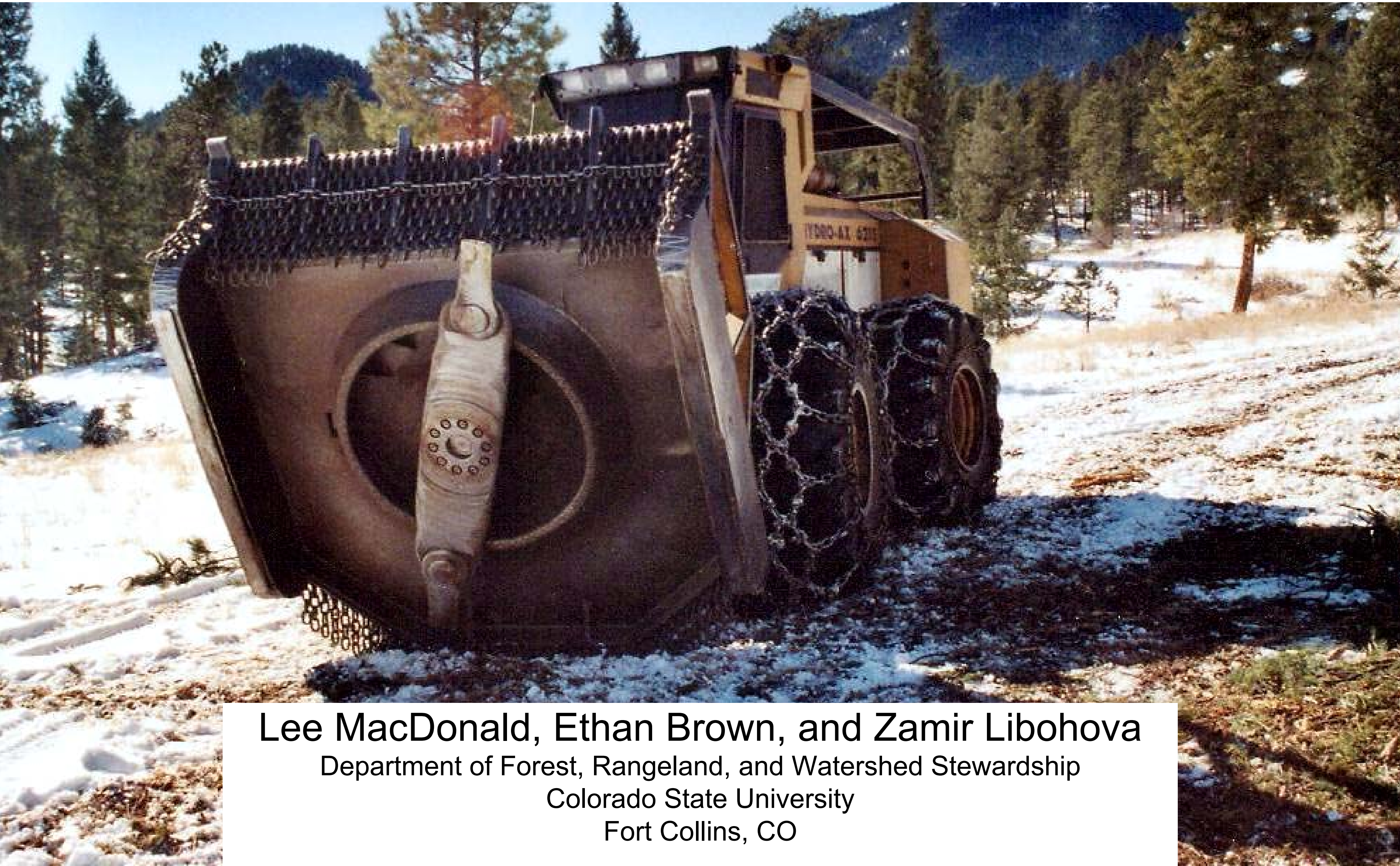
Effects of Forest Restoration and Roads: A Case Study from Colorado



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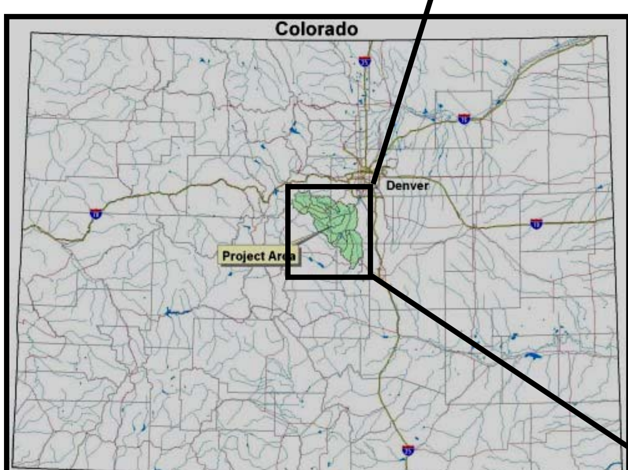
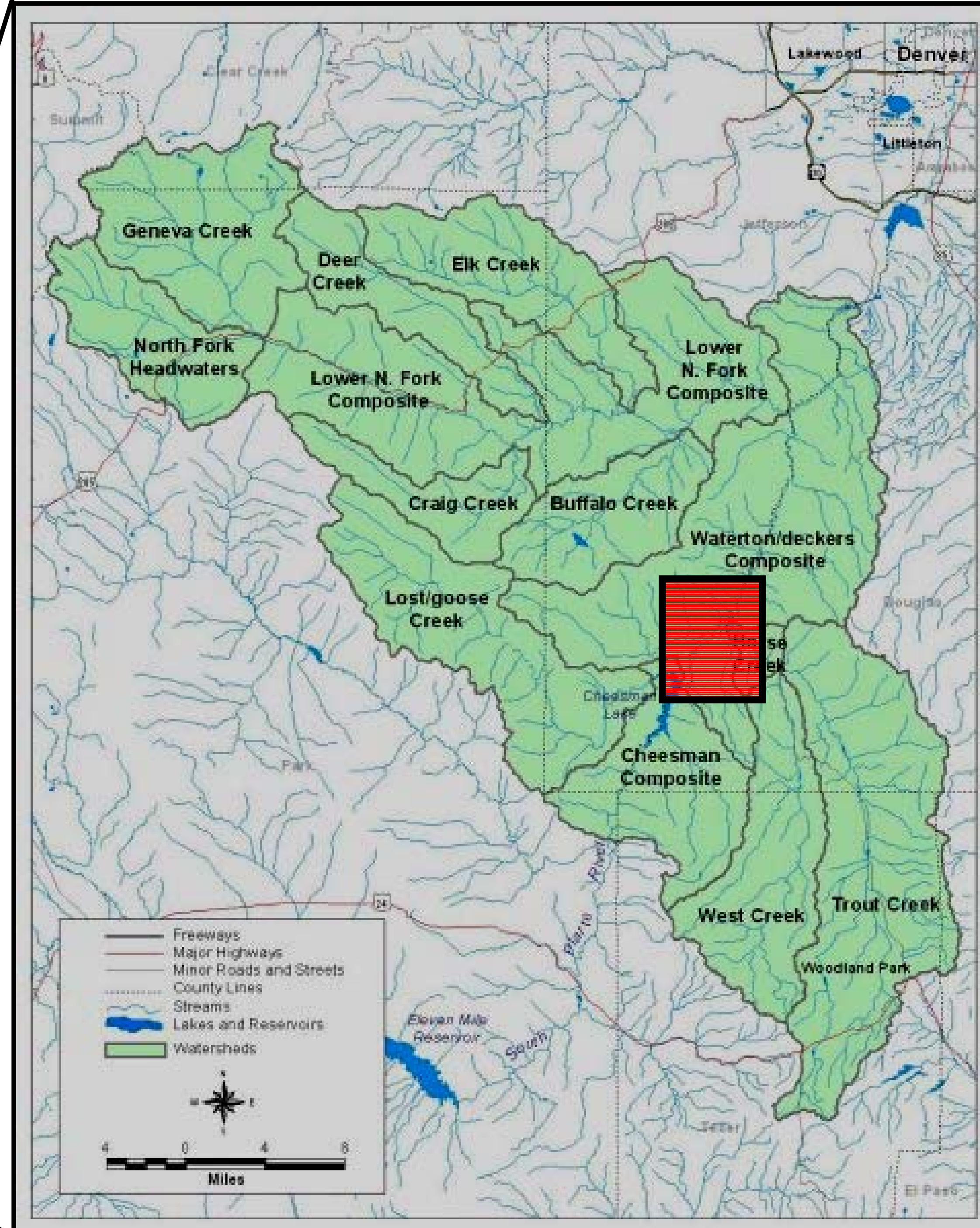
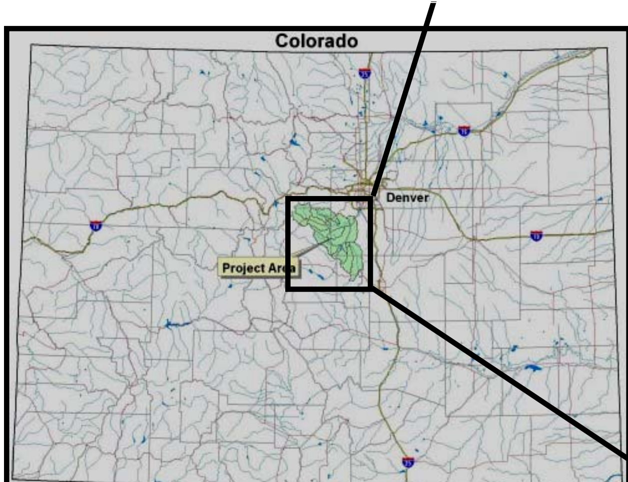
- Upper South Platte Watershed supplies 70% of Denver’s water, and is at high risk for wildfire

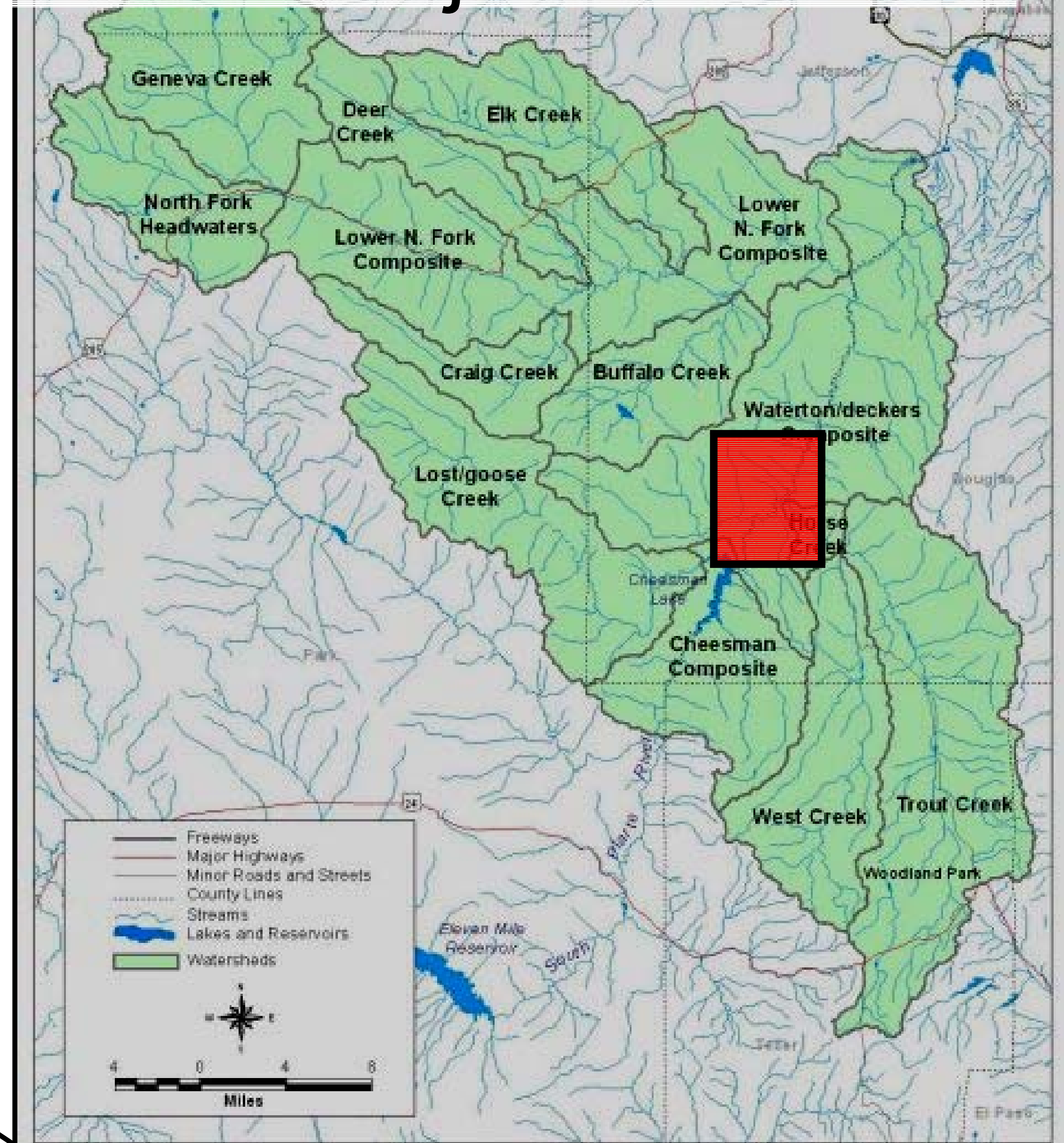




Upper South Platte Protection and Restoration Project

Following the 1996 Buffalo Creek and 2000 Hi-Meadows fires, forest thinning was proposed to reduce fire risk in the Upper South Platte River Basin.

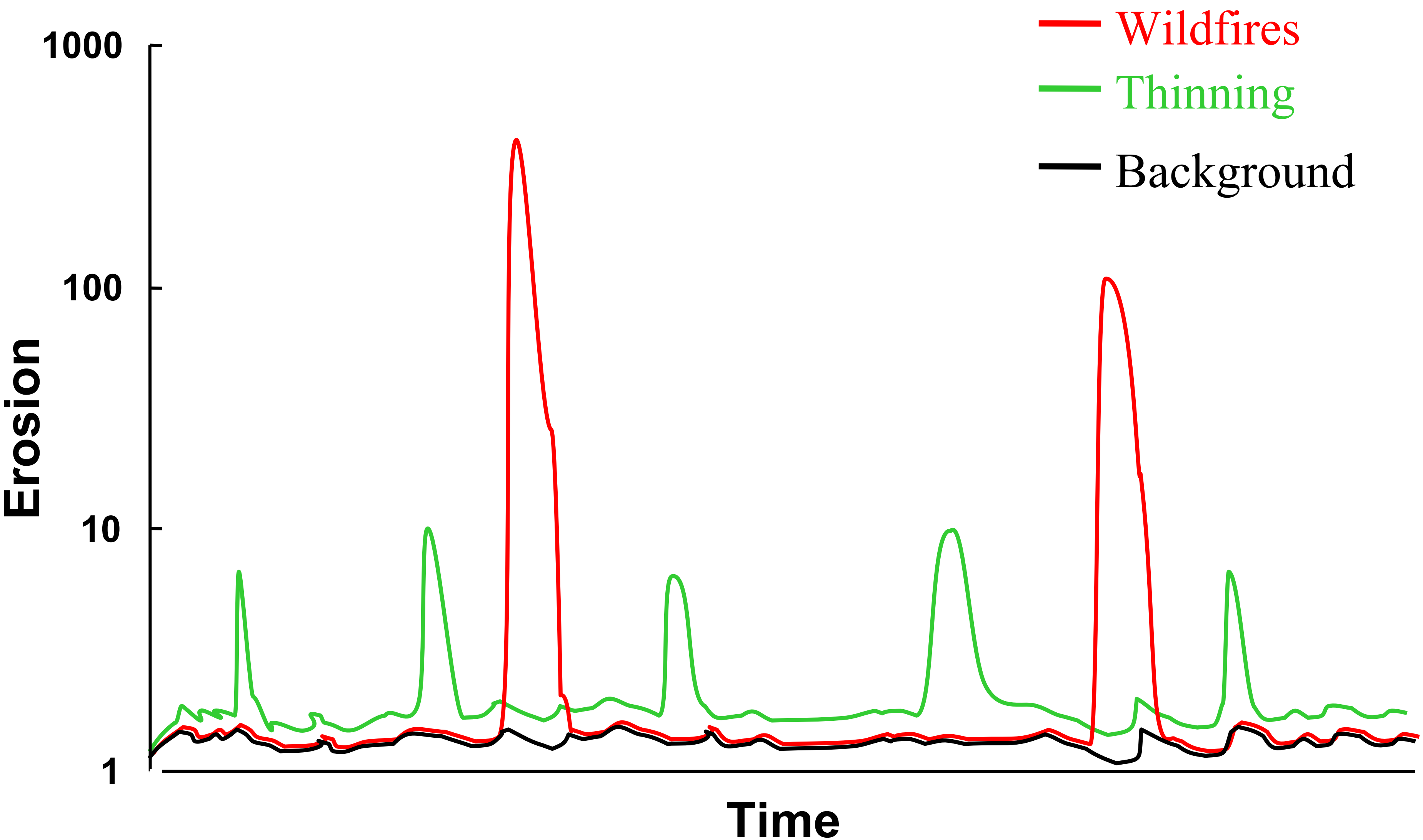




Thinning in the Upper South Platte Watershed

- Thinning being done by USFS on nearly 5,000 ha;
- Specific guidelines include:
  - No treatment of slopes over 30%;
  - Retain largest trees and those over 150 years old;
  - Lop and scatter slash.
- Treatments began in 2002;
- Some private lands also being treated (e.g., Denver Water Board).

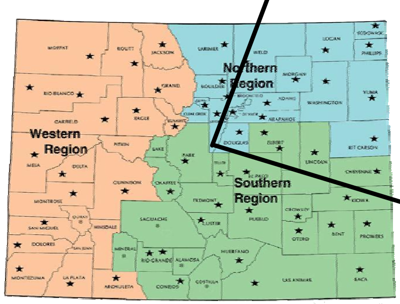
Hypothetical erosion rates: wildfires vs. thinning vs. background

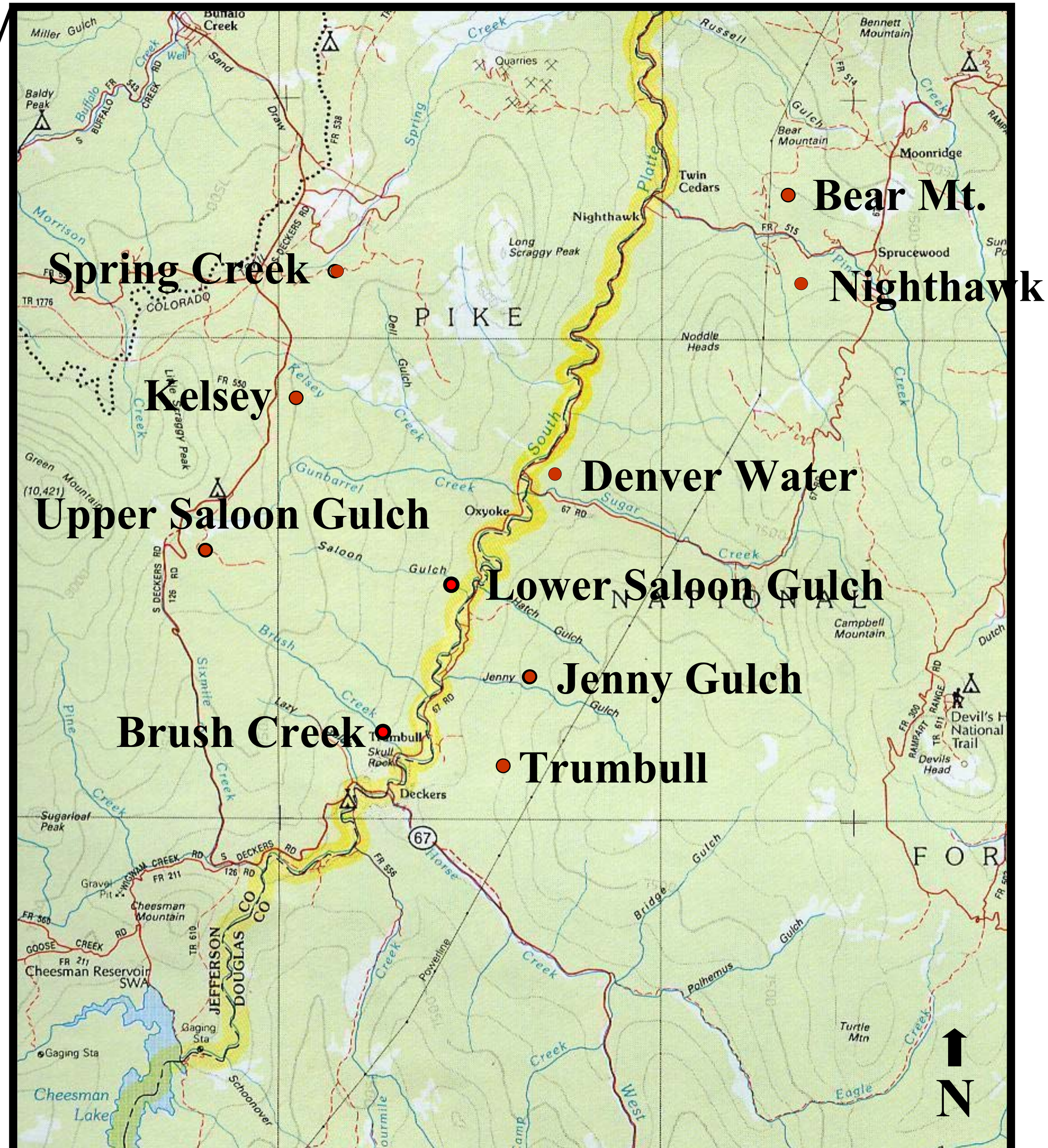


Objectives

1. Monitor sediment production rates from forested hillslopes, thinned hillslopes, and unpaved forest roads;
2. Relate sediment production rates to site characteristics and precipitation;
3. Determine effects of thinning on soil moisture;
4. Monitor the effects of thinning on runoff in two small watersheds;
5. Monitor changes in water quality and channel morphology in four small watersheds.

Location of study areas





Project Design: Hillslope Scale

- 20 paired swales: one thinned and one control;
- Sediment fences used to measure erosion;
- Precipitation recorded with tipping bucket rain gauges;
- Measure swale characteristics (e.g., contributing area, slope, percent cover);
- Test relationships between rainfall, road or swale characteristics, and measured erosion rates.

Pair of swales: Trumbull

Objectives: Roads

- Quantify road erosion rates;
- Develop a quantitative understanding of processes controlling road erosion;
- Assess connectivity of roads to streams;
- Compare sediment production and delivery from roads to other land use activities.

Number of Sites by Year

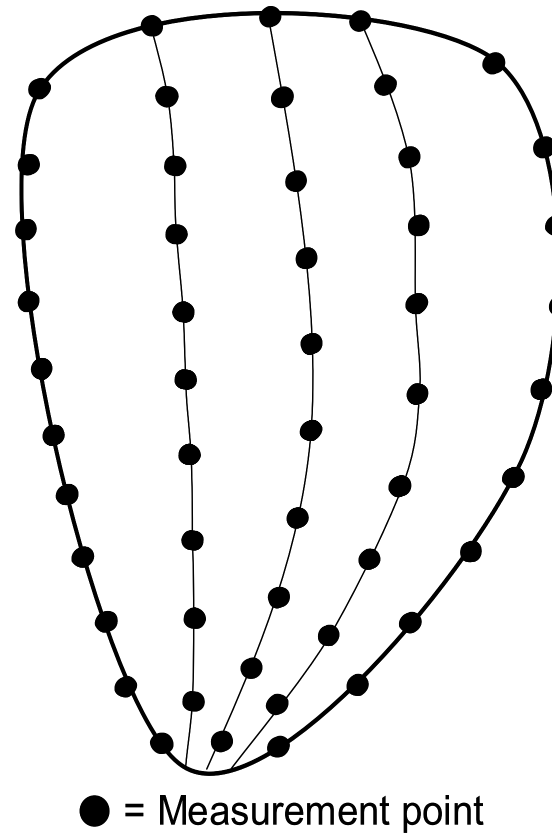
Year	Control swales	Treated swales	Burned swales	Road segments
2001	40	0	0	14
2002	13	5	20	21
2003	34	8	20	26
2004	20	20	20	22

Summary of sites and treatments by study area

Study area	Swale pairs	Road fences	Installed	Burned	Thinned
Upper Saloon Gulch	10	3	2001	Yes	No
Trumbull	8	8	2001	No	2002
Spring Creek	1	12	2001	No	2004
Bear Mountain	5	0	2003	No	2004
Denver water	3	0	2003	No	2003
Kelsey	4	2	2003	No	2004
Nighthawk	0	3	2003	No	2004
Jenny Gulch	6	0	2004	No	2004

Methods: Soil moisture

- Soil moisture at 0-5 cm was measured on:
  - 3 pairs of swales in Bear Mountain (wet site);
  - 2 pairs of swales in Jenny Gulch (dry site);
  - 50 points in each swale.
- Using time domain reflectometry (TDR).



TRIME-FM time domain reflectometery probe

Litter Removal

- Lawn rakes used to remove litter;
- Litter was weighed and sampled for moisture content;
- Ground cover was measured after raking.

Effects of Thinning on Nitrogen

- Determine if thinning alters the amount of available nitrogen;
- Using resin bags to assess the availability of nitrogen just below the mineral soil surface in thinned and control swales in summer and winter, respectively;
- Use longer-term fertilization experiment to determine whether nitrogen is limiting tree growth in the Upper South Platte.

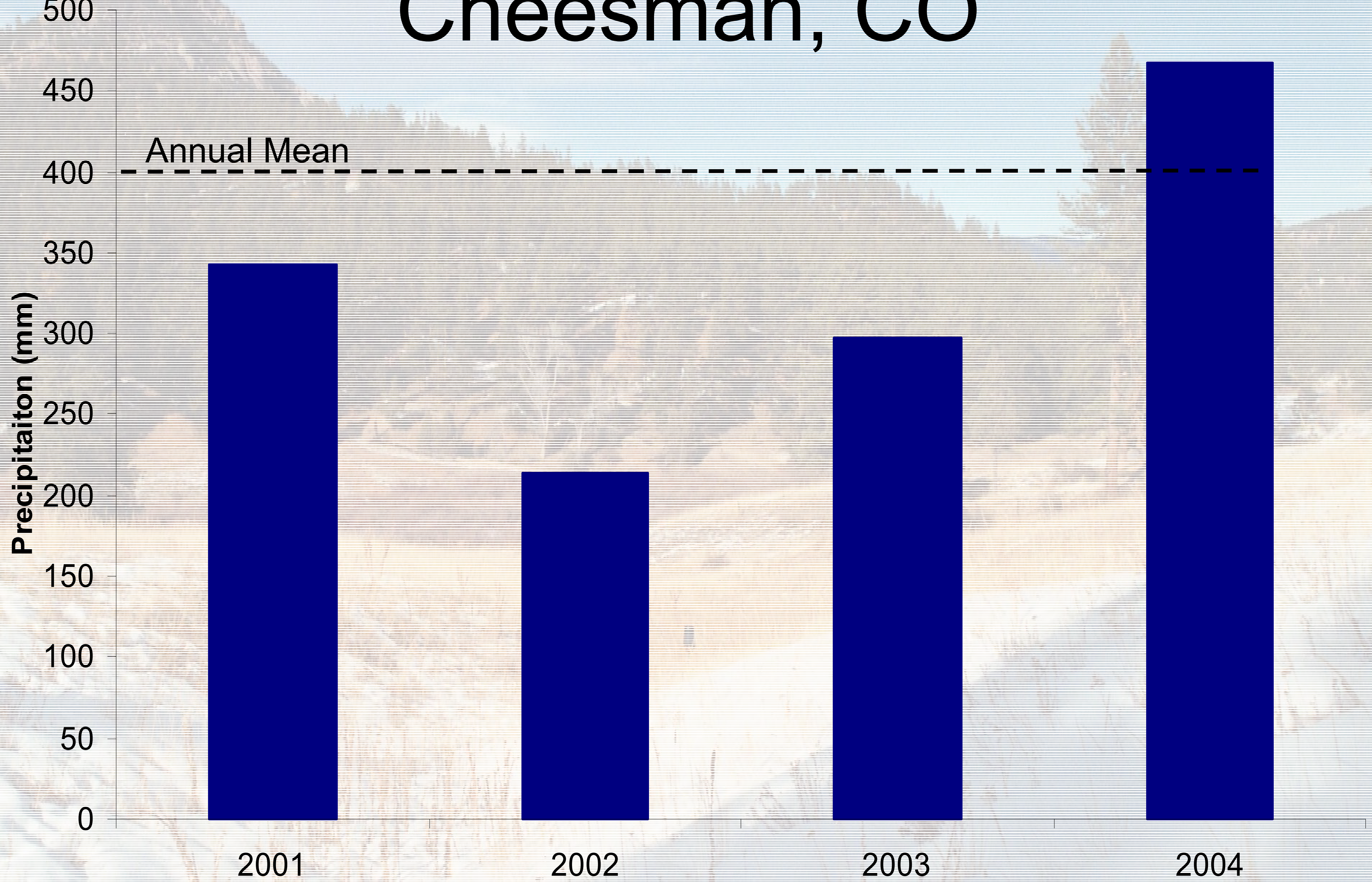
Ion exchange resin bags

Ion exchanging resin

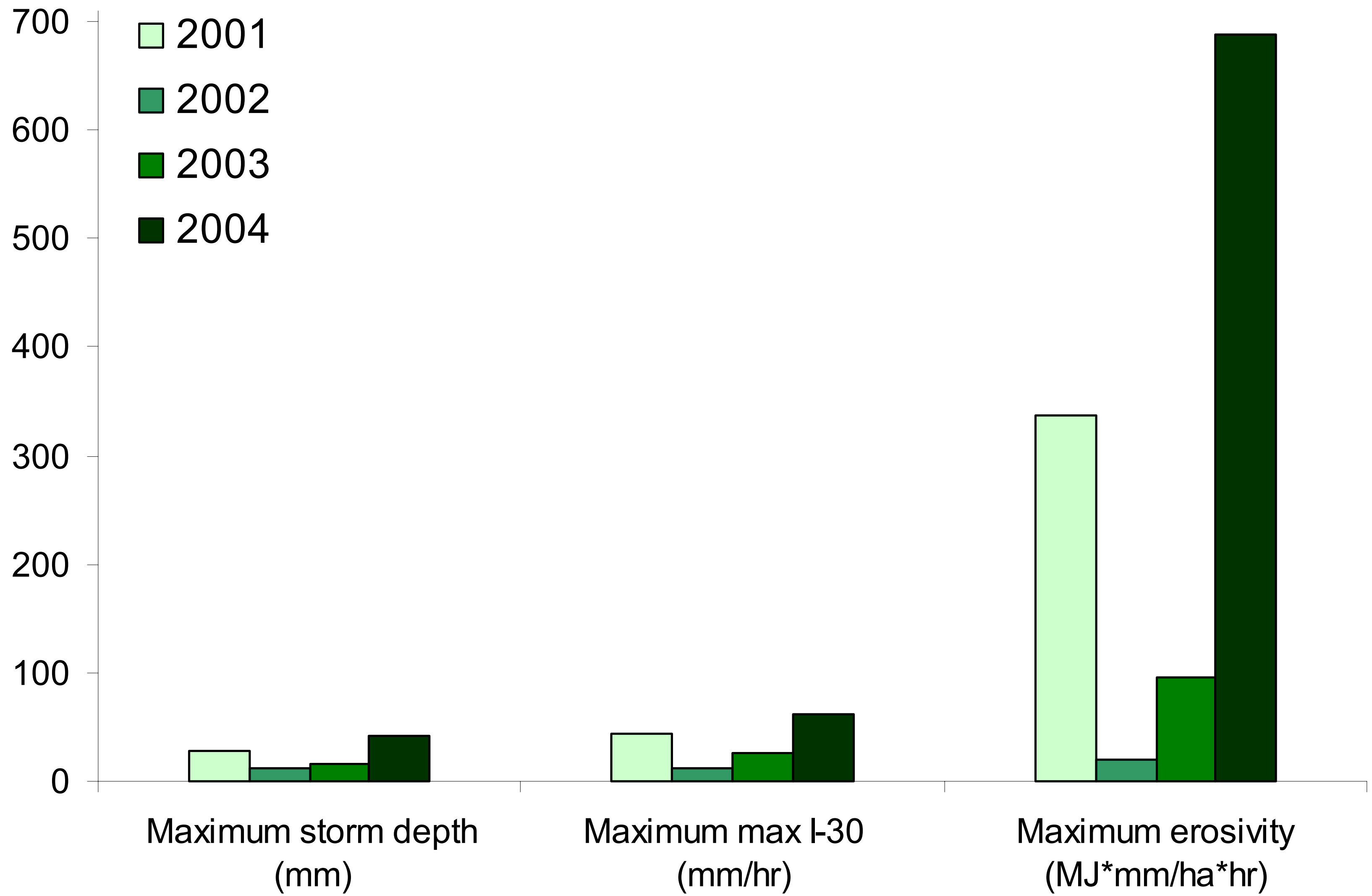
http://gocctech.com/default2/resin.jpg

Nylon stocking material

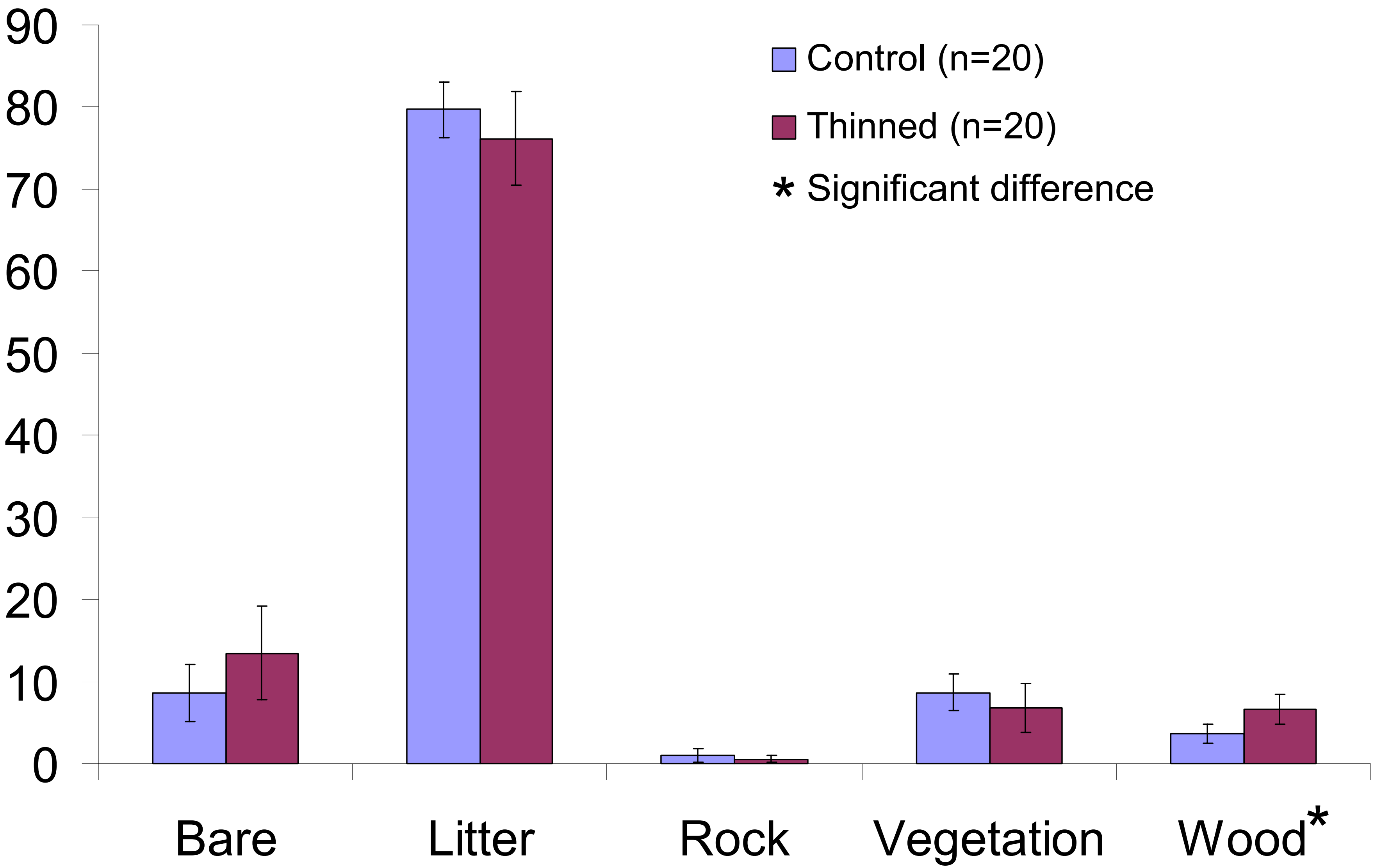
Annual precipitation 2001-2004: Cheesman, CO



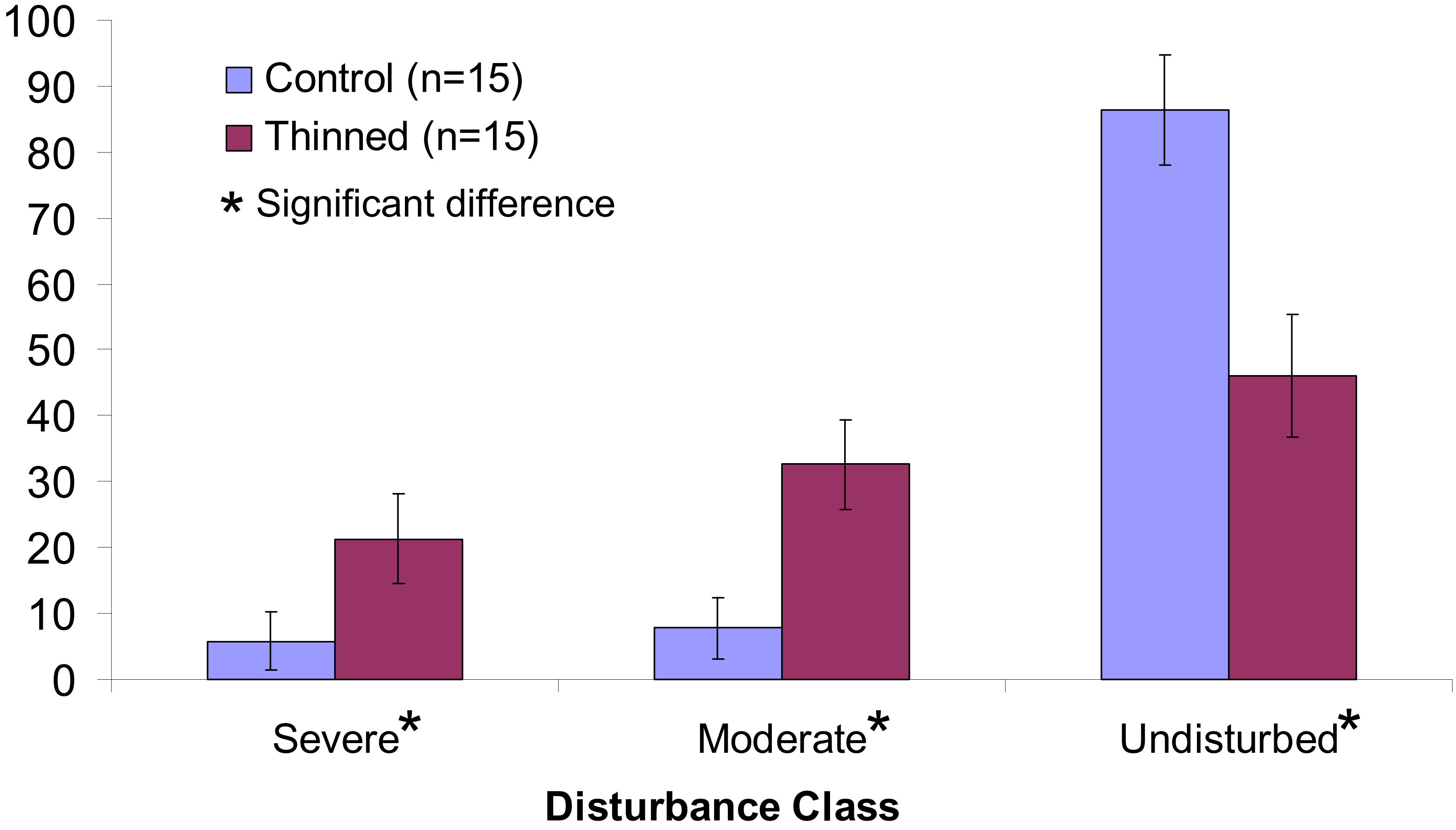
Annual maximum storm depth, I_{30}, and erosivity: 2001-2004



Ground cover in thinned and control swales: first year after thinning



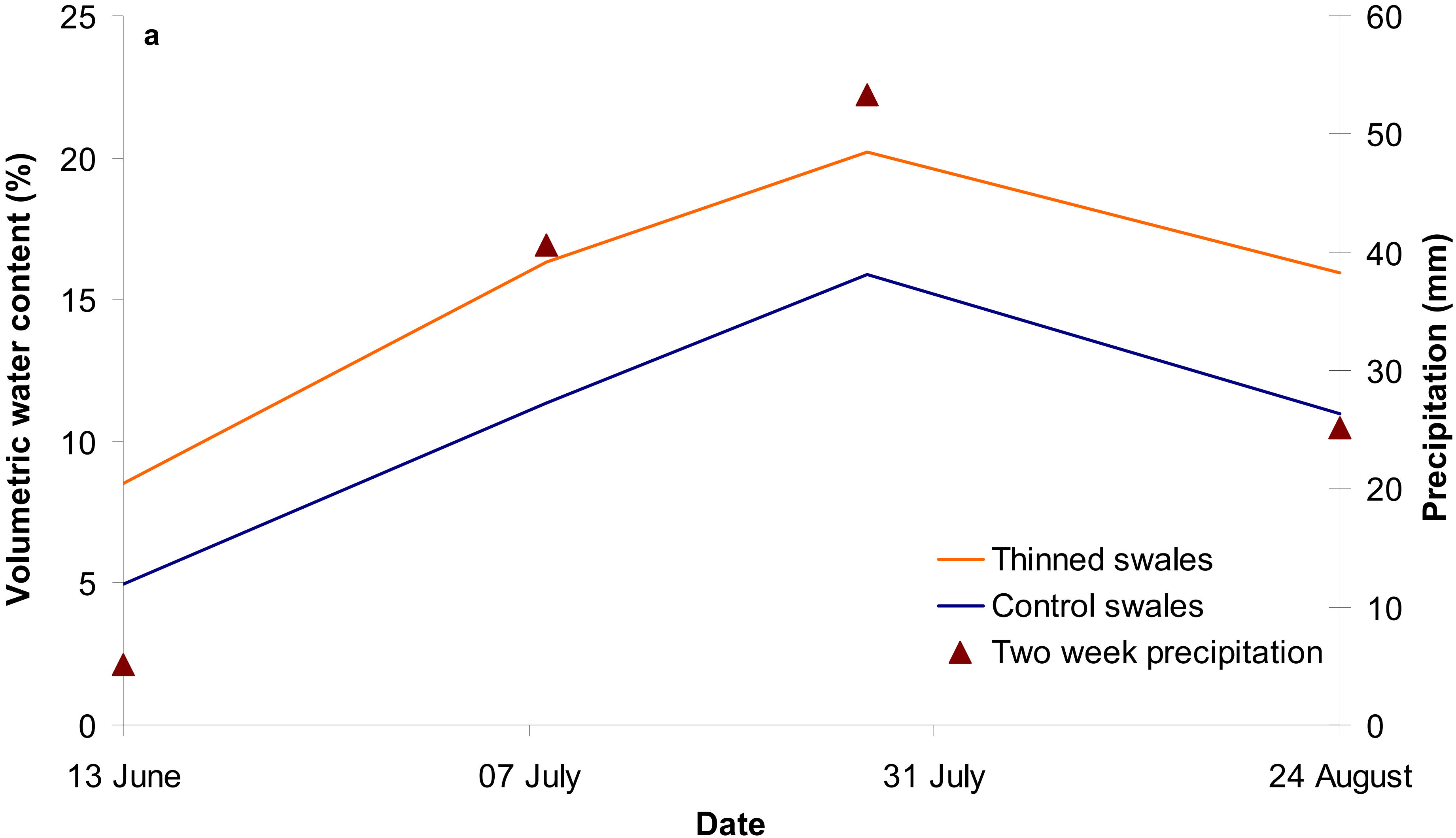
Percent disturbance in thinned and control swales: First year after thinning



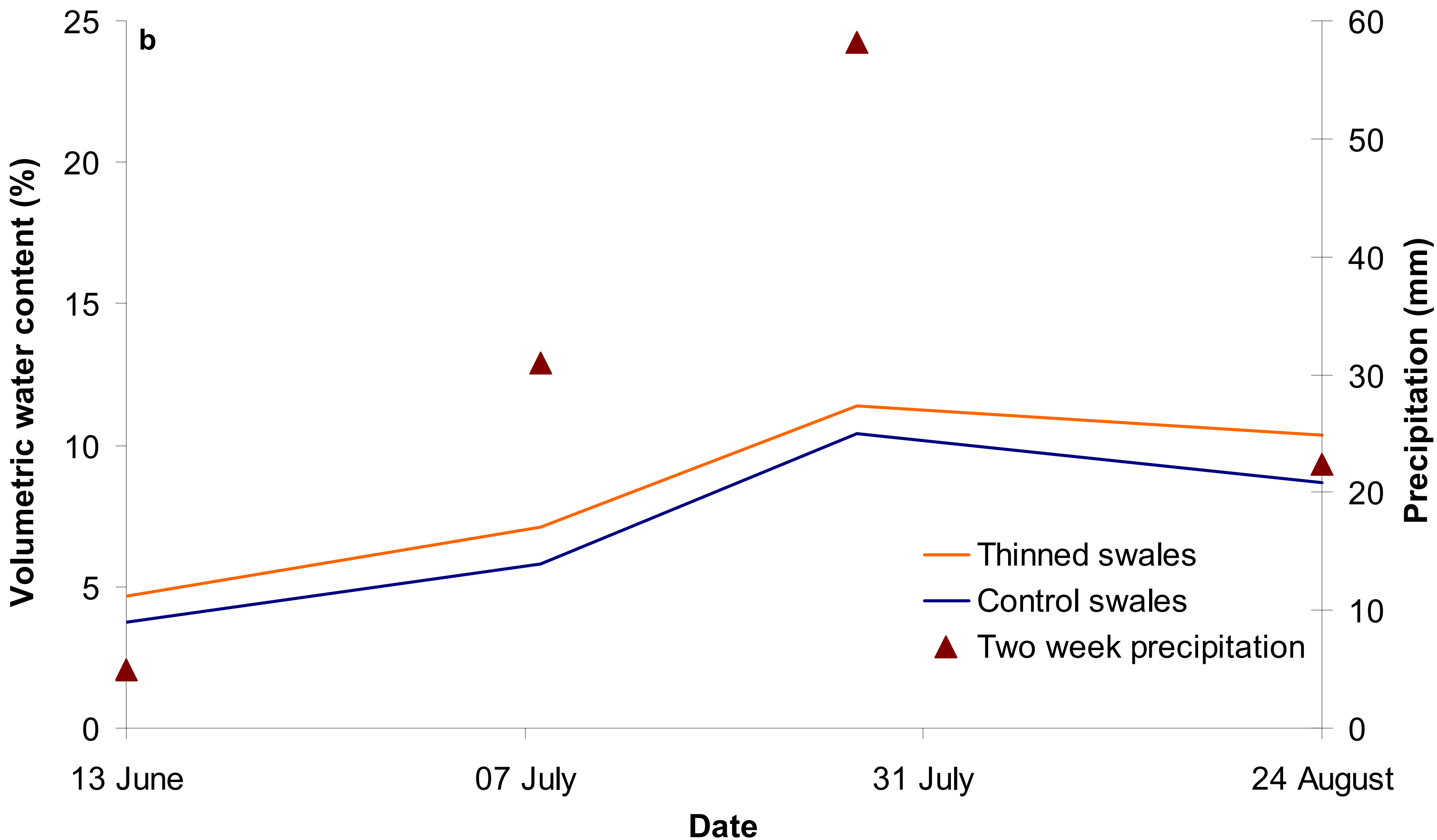
Effects of thinning on trees

- Mean number of trees reduced from 650 to 200 trees ha^{-1} ($p<0.0001$);
- Mean DBH increased from 18 to 28 cm ($p<0.0001$).

Effects of thinning on soil moisture: Bear Mountain (wet site)



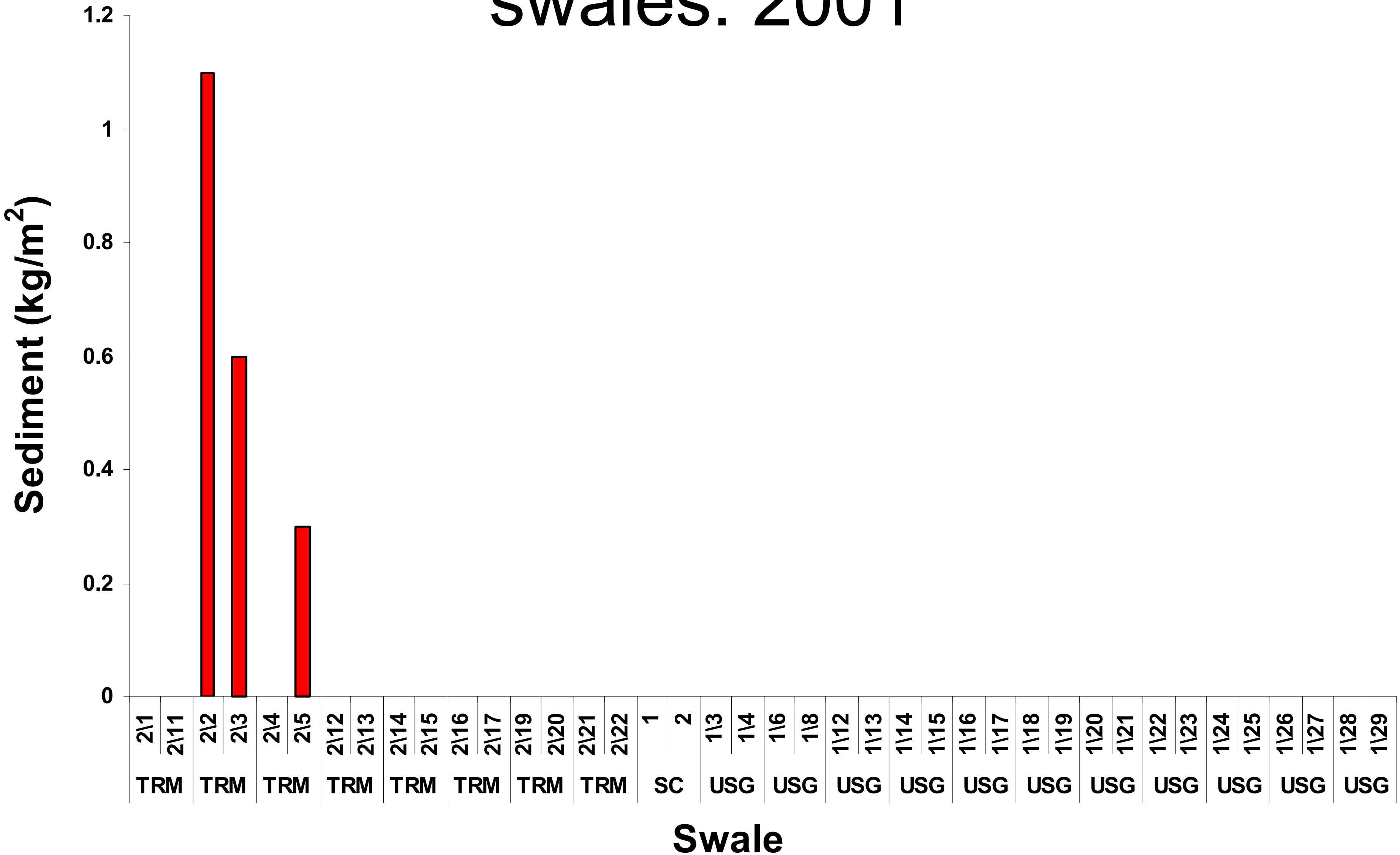
Effects of thinning on soil moisture: Jenny Gulch (dry site)



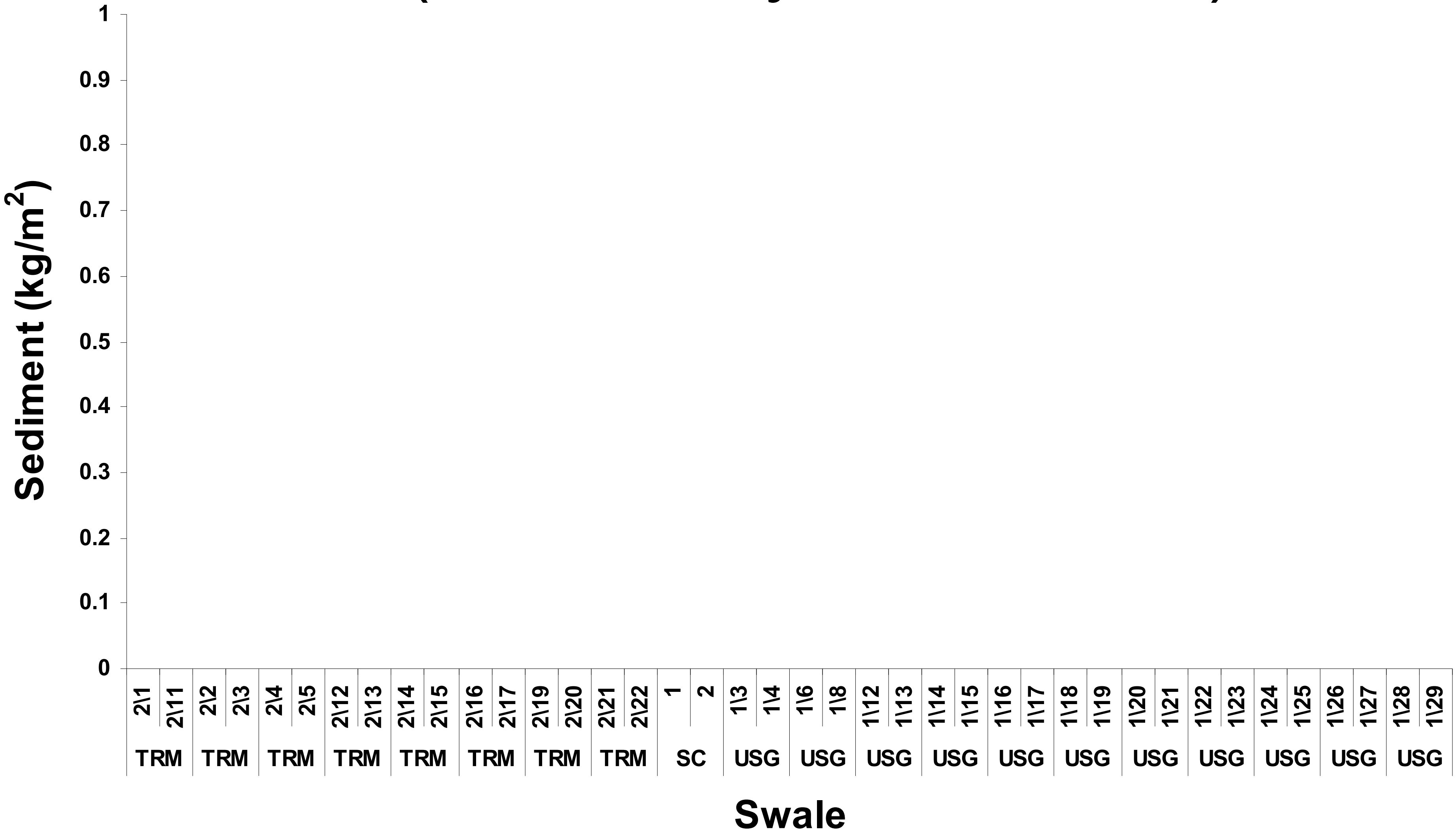
Results: Soil Moisture

- Soil moisture significantly affected by:
  - Measurement date ($p<0.0001$);
  - Measurement site ($p=0.028$);
  - Treatment ($p=0.043$);
  - Interaction between measurement site and date ($p<0.0001$);
  - Interaction between treatment and date ($p=0.038$).

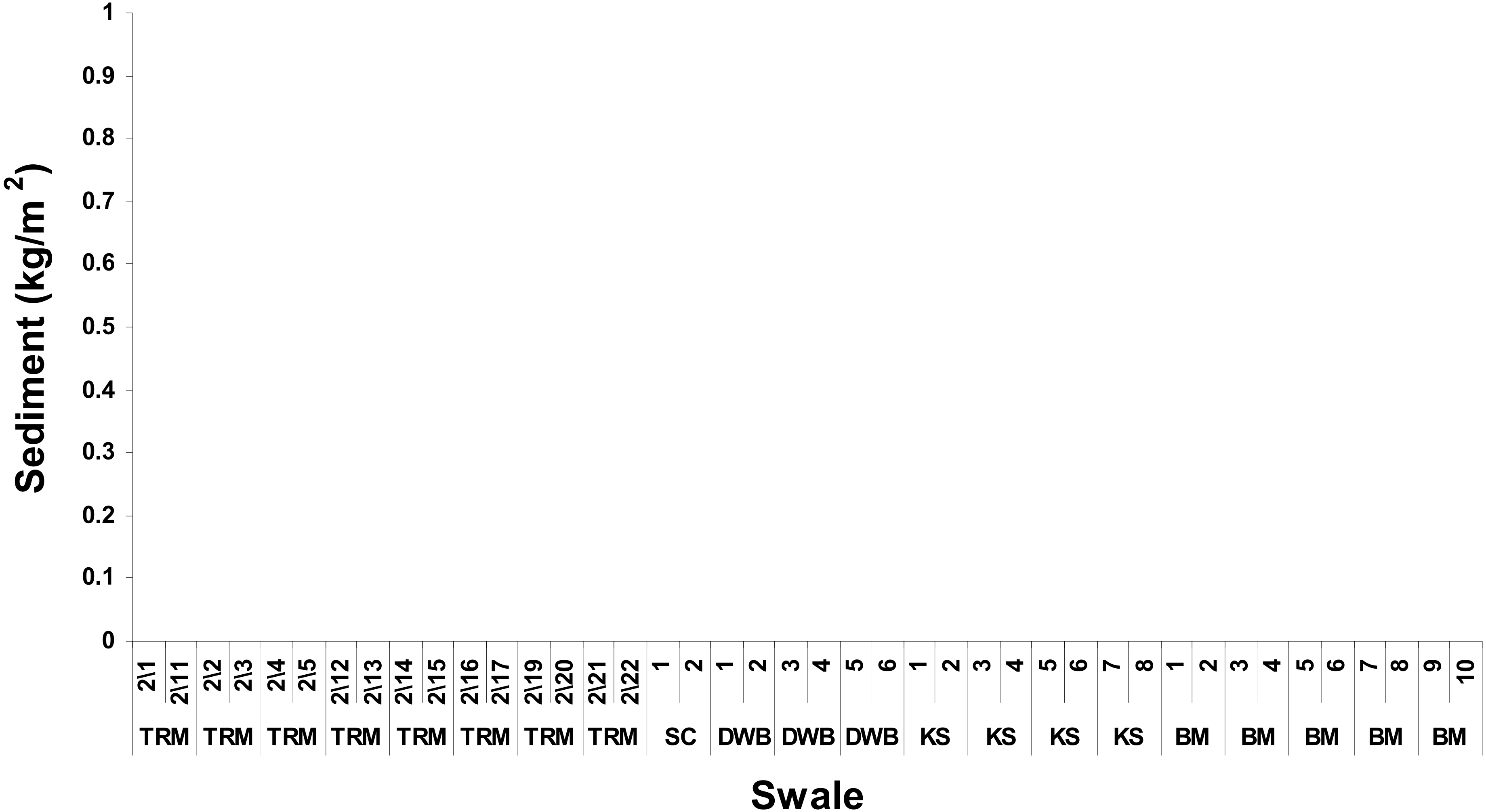
Sediment production rates from swales: 2001



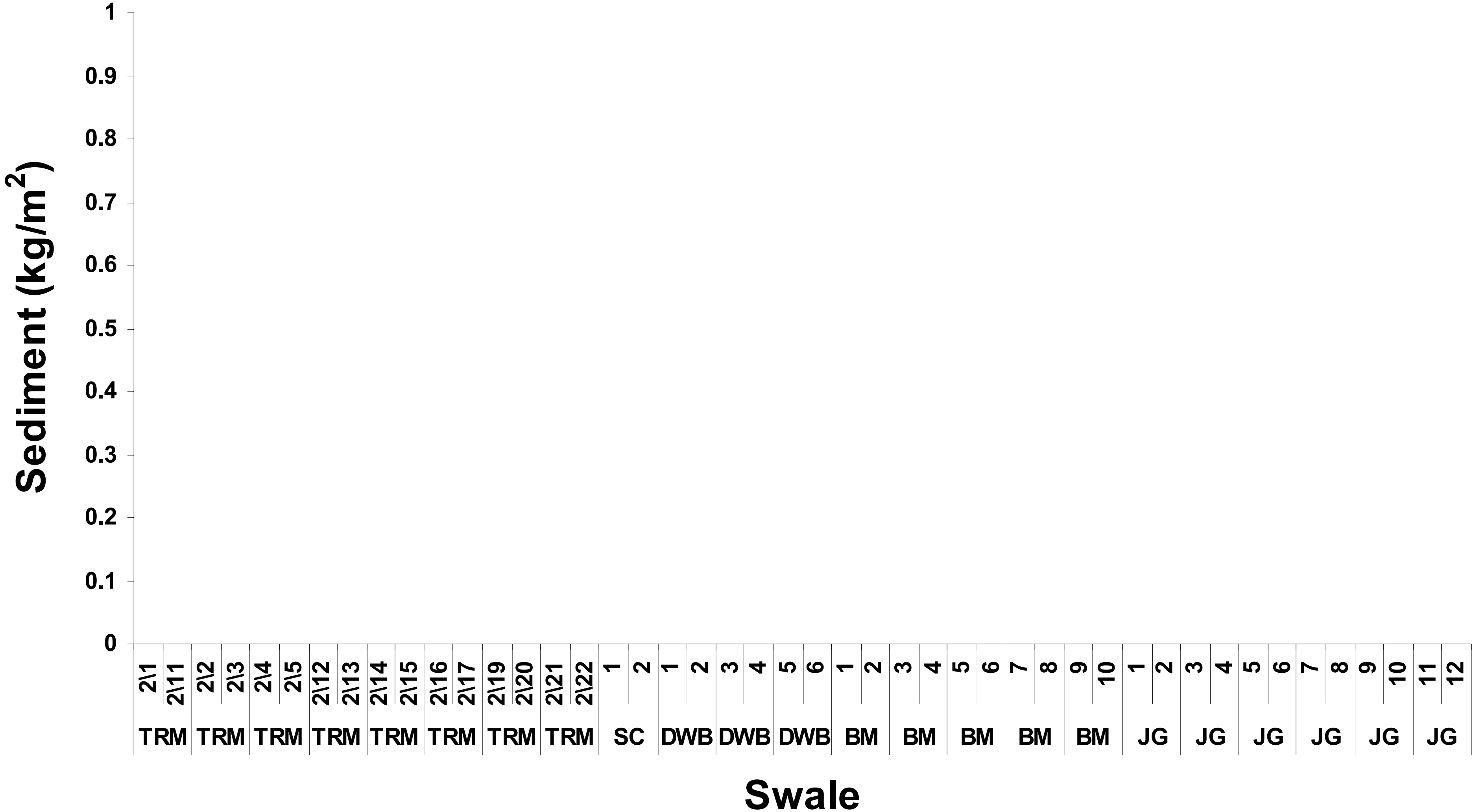
Sediment production rates from swales: 2002 (before Hayman wildfire)



Sediment production rates from thinned and control swales: 2003



Sediment production rates from thinned and control swales: 2004

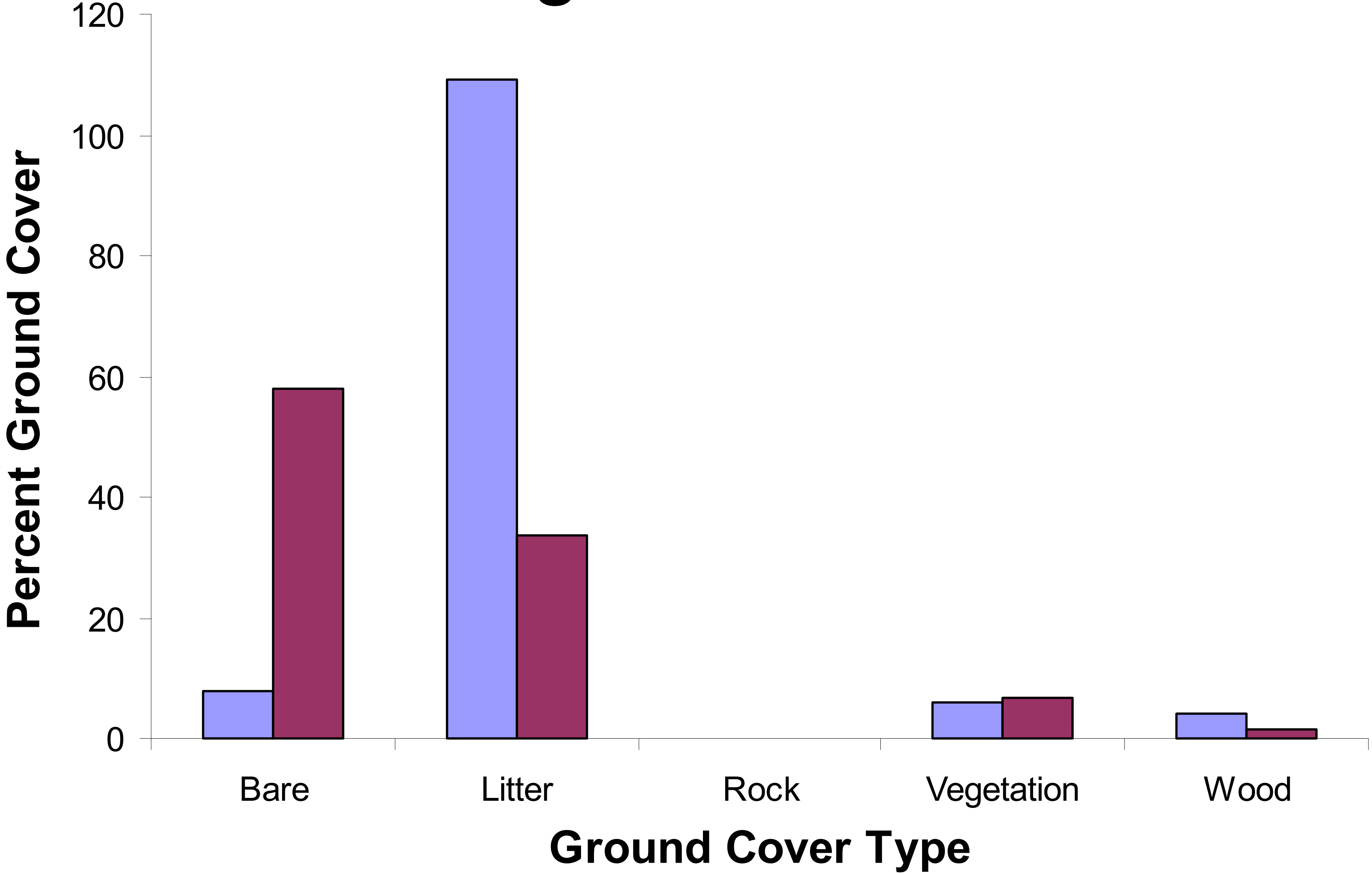


Results: Sediment Production

- In 2001 only 3 of 40 unthinned swales produced sediment;
  - Mean sediment yield from those 3 swales was 0.7 kg m^{-2};
  - Mean sediment yield from 20 swales at Trumbull was 0.1 kg m^{-2};
  - Rain gauge not yet installed.
- None of the thinned or control swales produced sediment in 2002, 2003, or 2004 (control=107 plot-years: thinned=33 plot-years);
- Largest storm to date is 42 mm in 60 minutes, and this occurred on the steepest swales (20-50° slopes);
- Visual observations of erosion from some skid-like trails in 2003, but only one sediment fence has been installed.

Comparison of raked and control swales

Ground cover prior to and after raking: swale 2-12



Litter Manipulation: Results

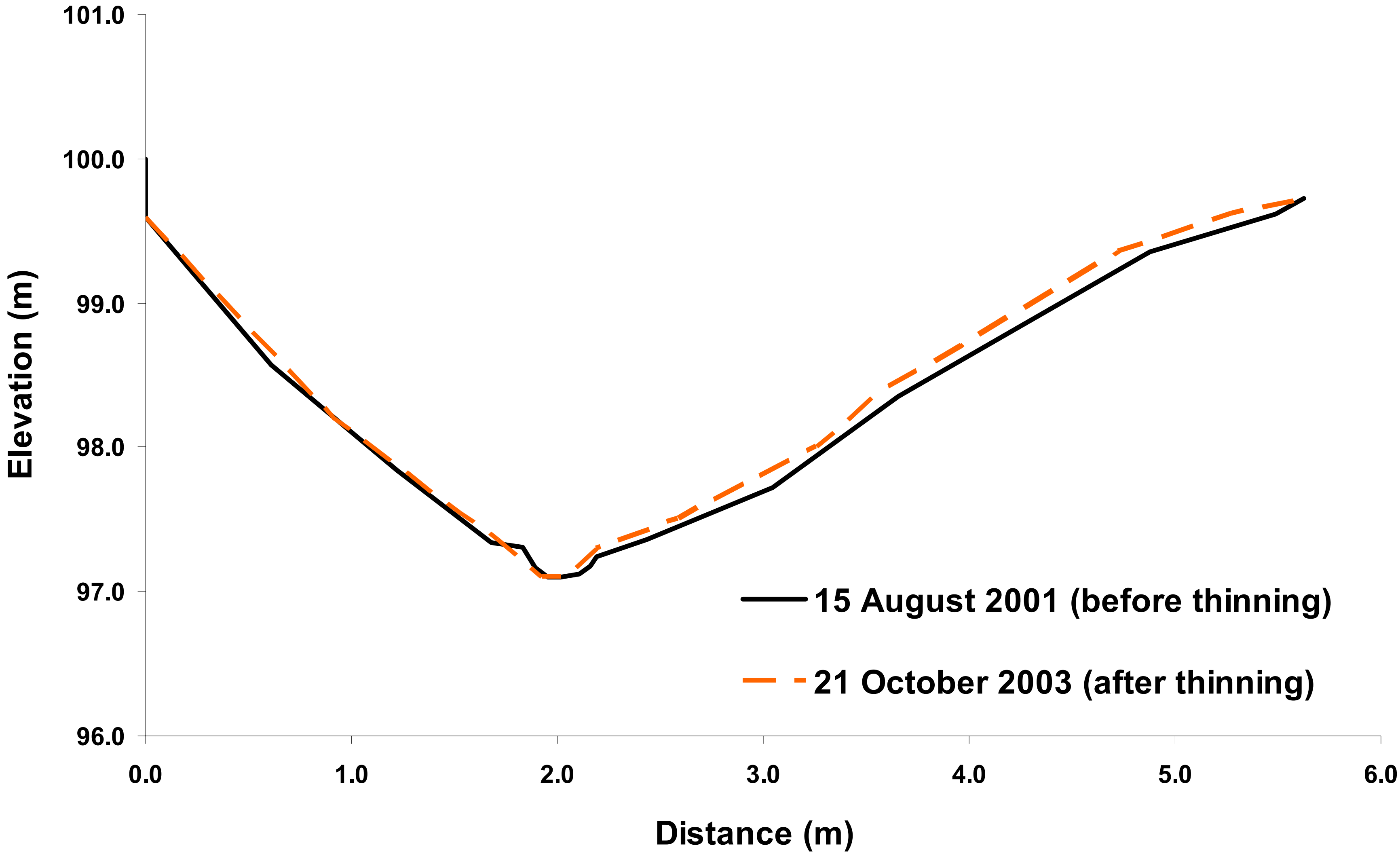
- Mean mass of litter is 2 kg m^{-2}, but this included some mineral soil;
- Increased percent bare soil from less than 10% to nearly 60%;
- Largest storm after raking was only 12 mm with a maximum I_{30} of 10 mm hr^{-1};
- No erosion in 2003 due to low rainfall intensities, but substantial erosion in 2004.


Watershed Scale

Methods: Watershed Scale

- Monitor runoff in Saloon Gulch (“treated”) and Brush Creek (“control”) with H-flumes;
- Annually monitor channel characteristics on streams draining Trumbull, Saloon Gulch, and Spring Creek;
- Periodically monitor discharge and water quality on Trumbull, Saloon Gulch, Spring Creek, and Brush Creek.

Effects of thinning at the watershed scale: channel cross-section at No Name Creek



Results: Nitrogen

- Summer 2004 resin bags have been analyzed;
- Thinning appears to decrease available nitrogen, depending on amount of thinning that has occurred;
- Winter resin bags ready to be removed;
- Decrease in nitrogen may be a function of the amount of carbon made available by thinning.

Roads are needed for thinning

Literature suggests that unpaved roads are often the dominant source of sediment in forested watersheds.

Objectives: Roads

- Quantify road erosion rates;
- Develop a quantitative understanding of processes controlling road erosion;
- Assess connectivity of roads to streams;
- Compare sediment production and delivery from roads to other land use activities.

Methods: Road segment scale

- Sediment production measured with sediment fences at road drainage outlets;
- Measure segment slope, active area, cover, surface particle-size distribution (repeating as necessary);
- Estimate or measure traffic, time since grading, surface type (e.g., native surface vs. rocked);
- Storm rainfall, intensity, and erosivity;
- 27 to 65 road segments monitored in CA for 1-3 years, yielding 139 plot-years of data (efforts now focussing on the Sierra and Lassen National Forests);
- 14-26 road segments monitored for 1-4 years in CO, yielding 80 plot-years of data.

Methods: Road Connectivity

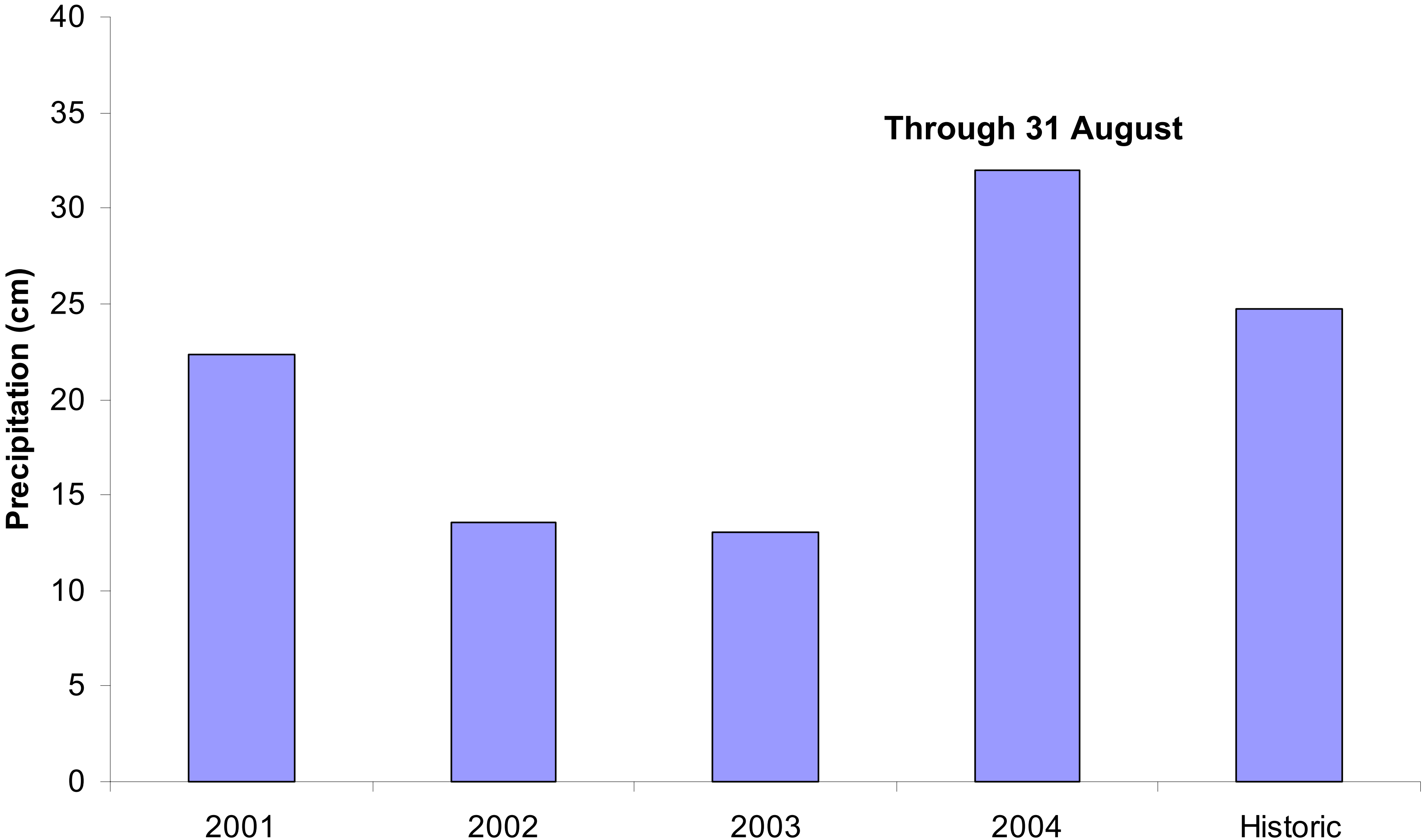
- Divide roads into segments based on drainage divides or distinct drainage locations;
- Measure key road segment characteristics (e.g., slope, width, length, drainage type, cutslope characteristics, hillslope position);
- Assess presence and length of sediment plumes or rills at each drainage location;
- Classify each segment by connectivity class;
- Assessed 20 km (285 segments) in California;
- Assessed 17.5 km (257 segments) in Colorado.

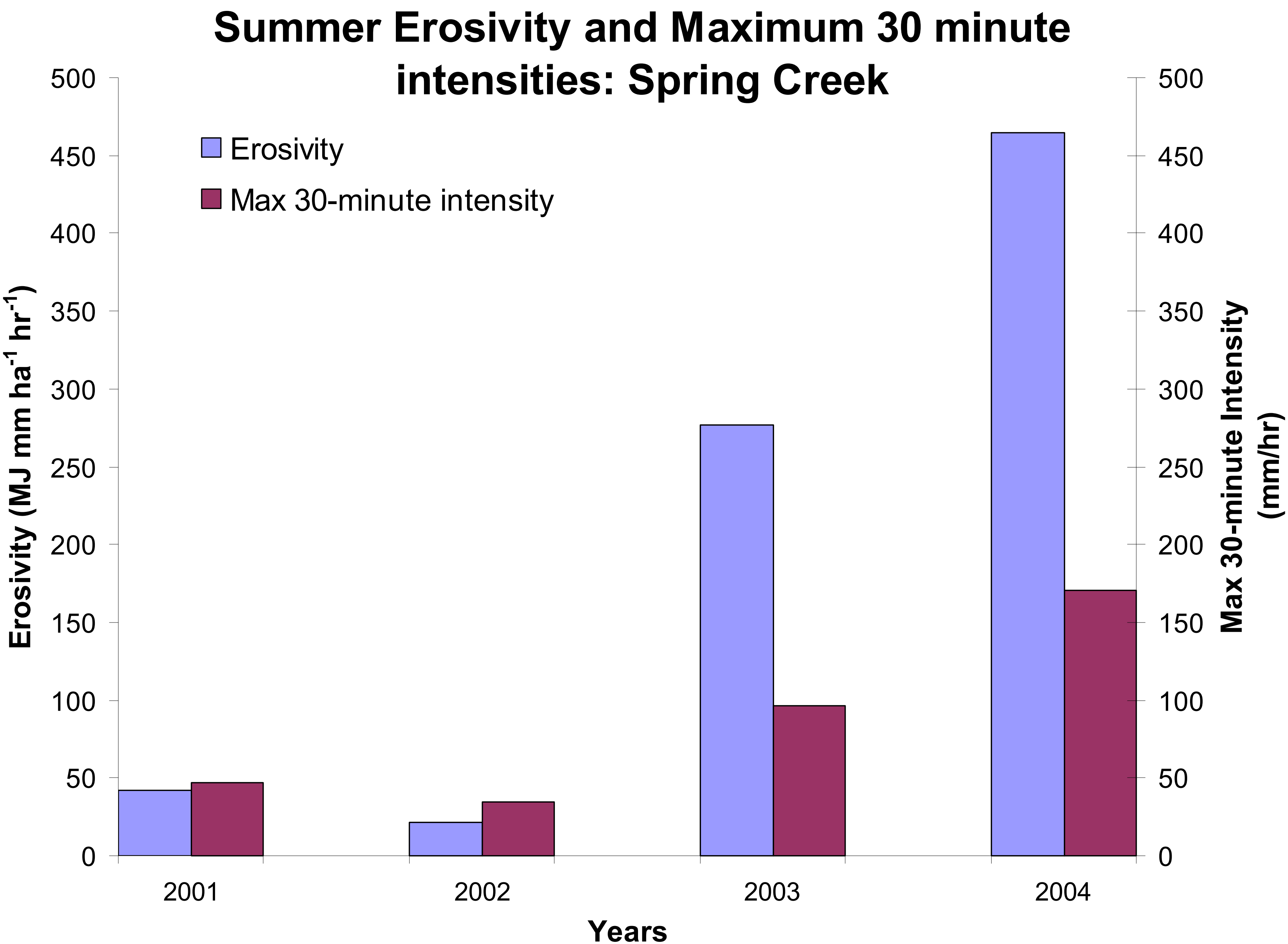
Road Sediment Fence

Number of Road Segments by Year

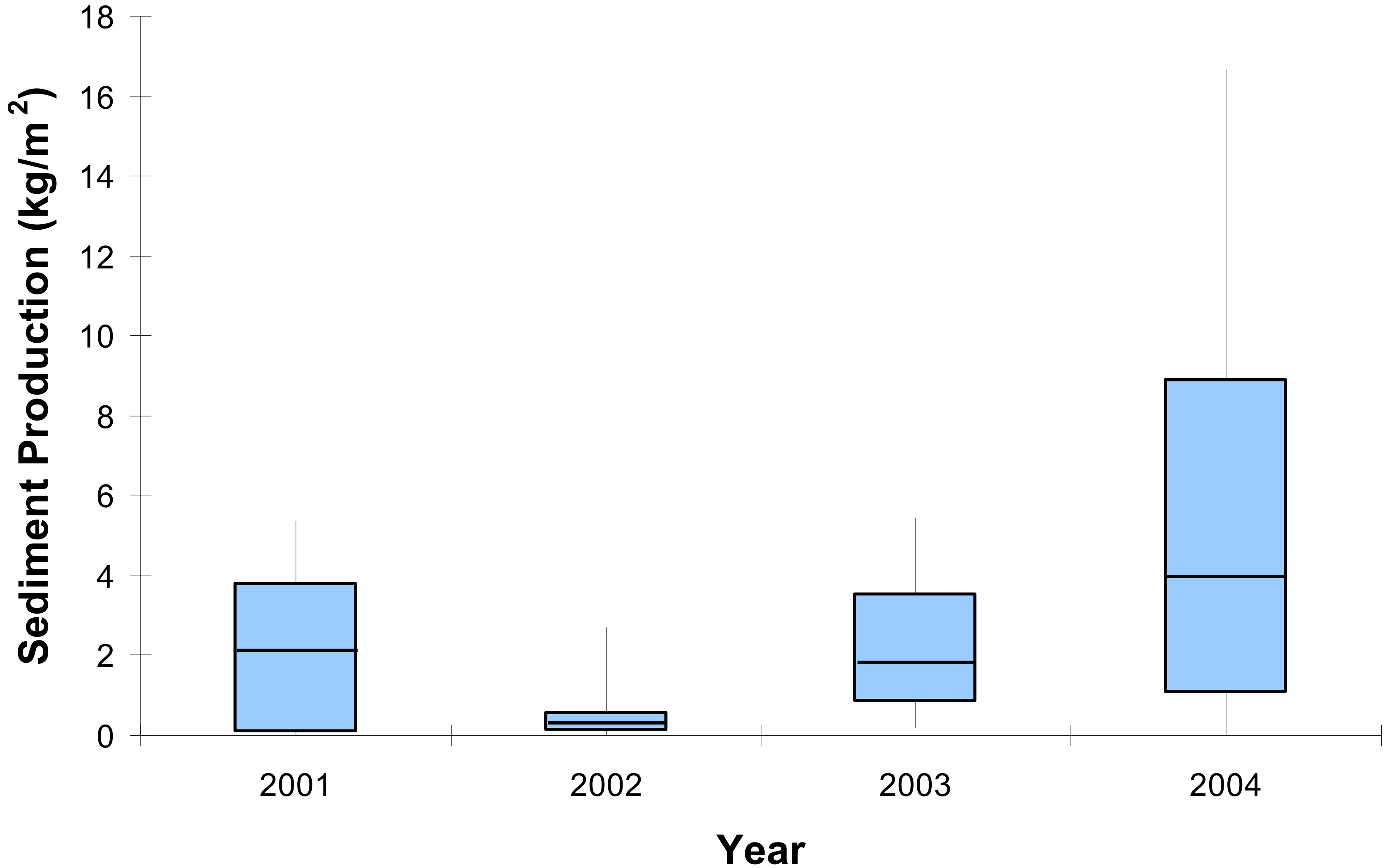
Year	Control swales	Treated swales	Burned swales	**Road segments**
2001	40	0	0	**14**
2002	13	5	10	**21**
2003	34	8	10	**26**
2004	20	20	10	**22**

Cheesman Reservoir
Precipitation from 1 May to 30 September

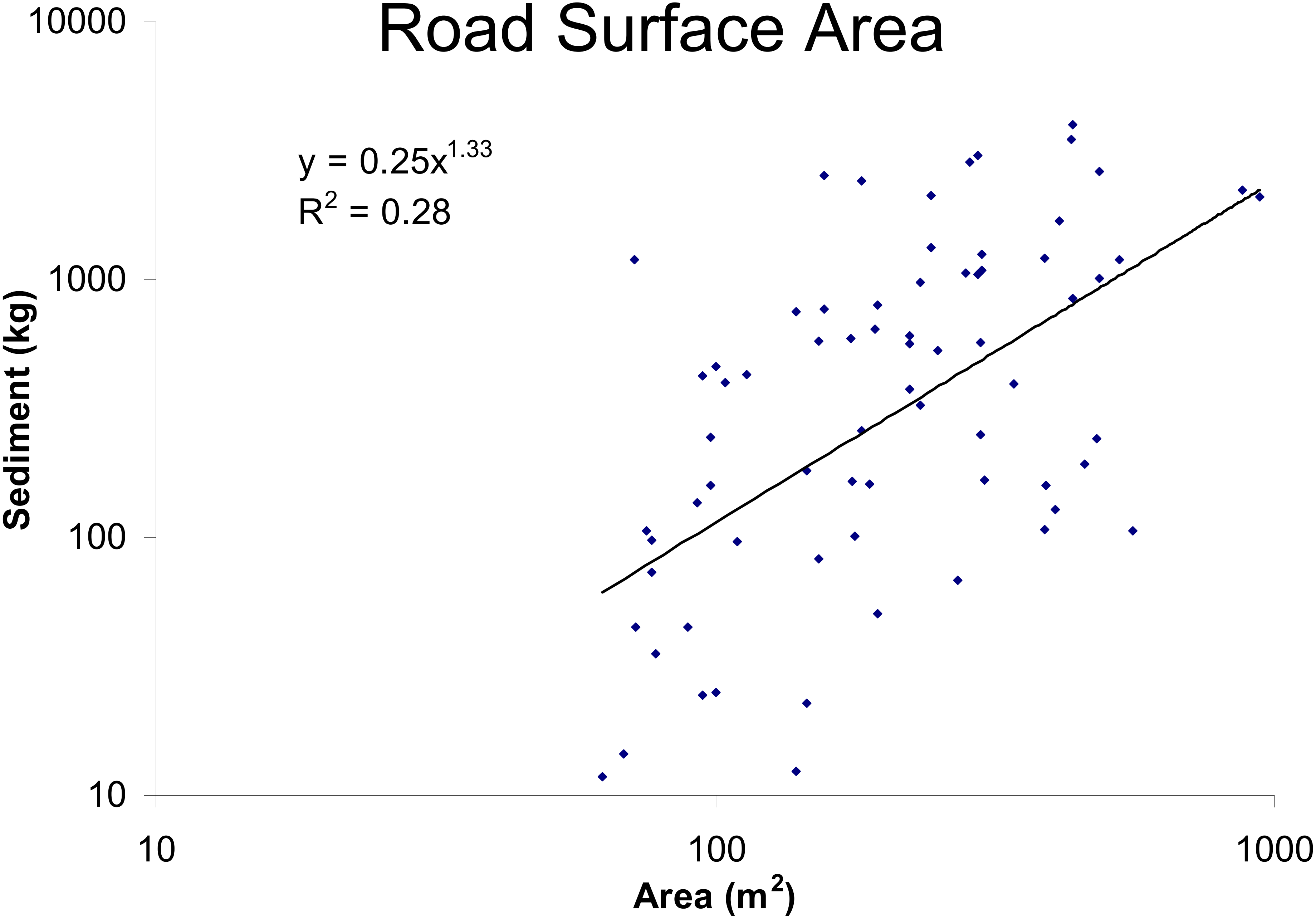


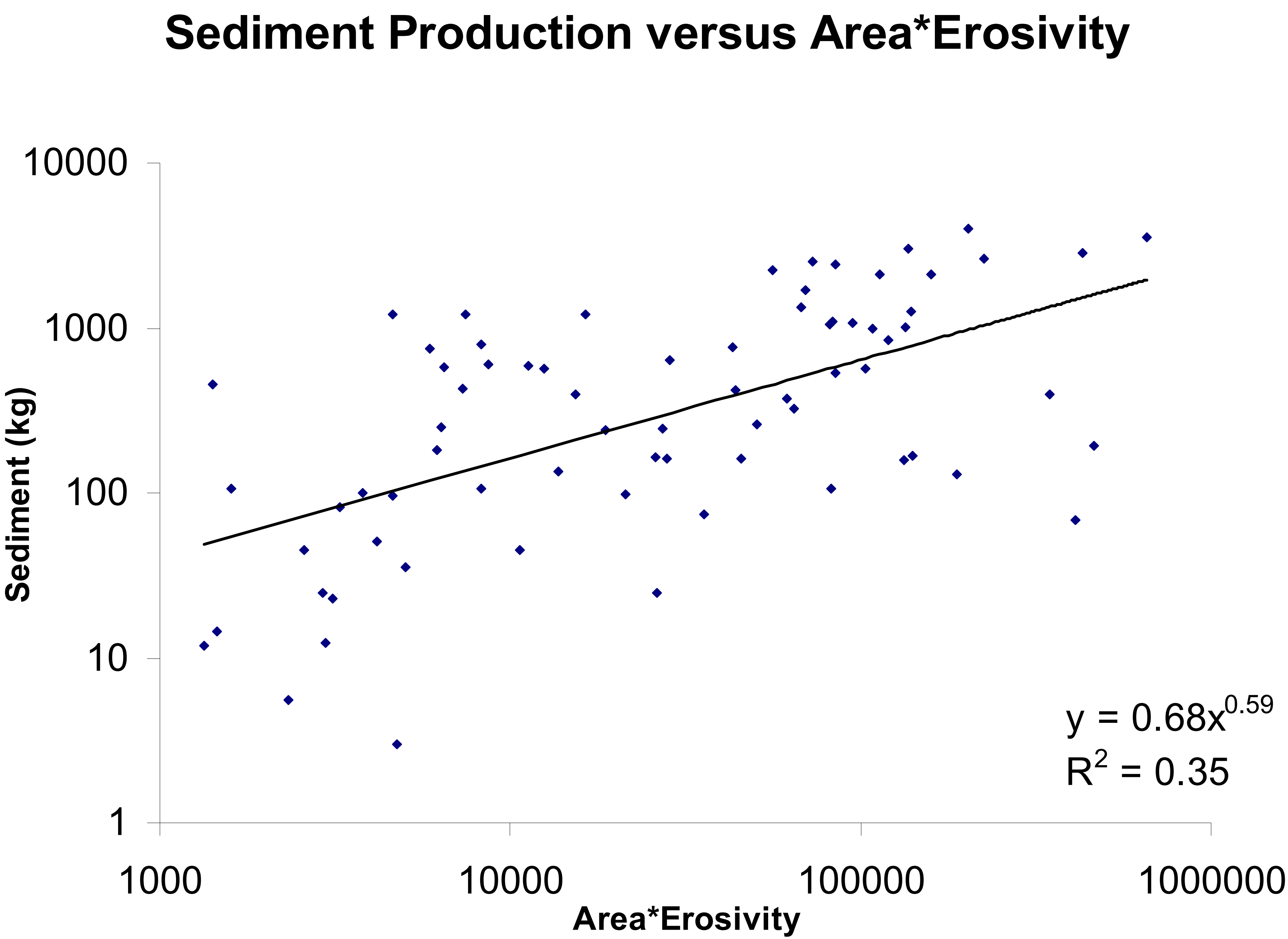

Summer Erosivity and Maximum 30 minute intensities: Spring Creek
Erosivity
Max 30-minute intensity
Erosivity (MJ mm ha-1 hr-1)
Max 30-minute Intensity (mm/hr)
0
50
100
150
200
250
300
350
400
450
500
2001
2002
2003
2004
Years

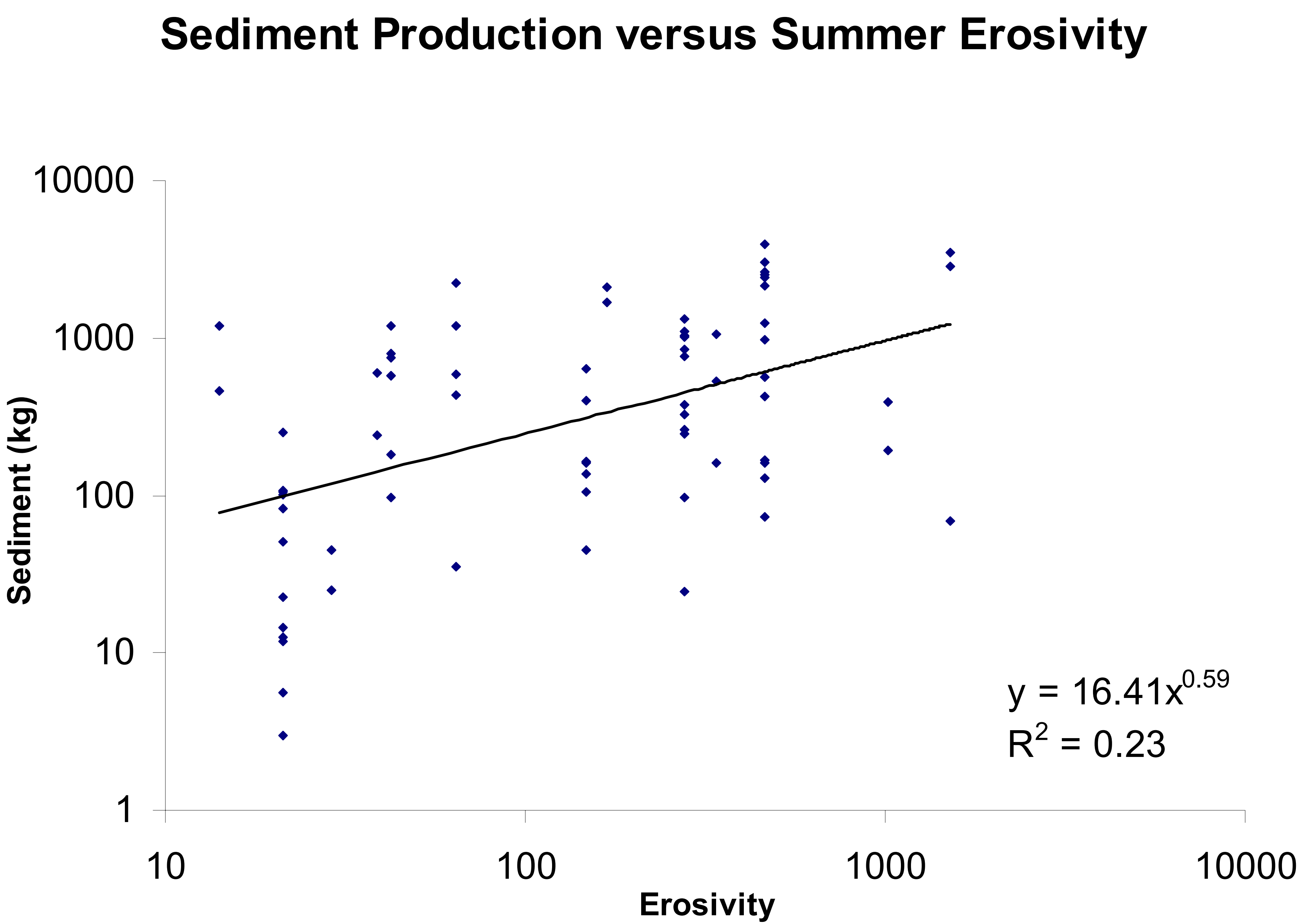
Annual Road Sediment Production, CO



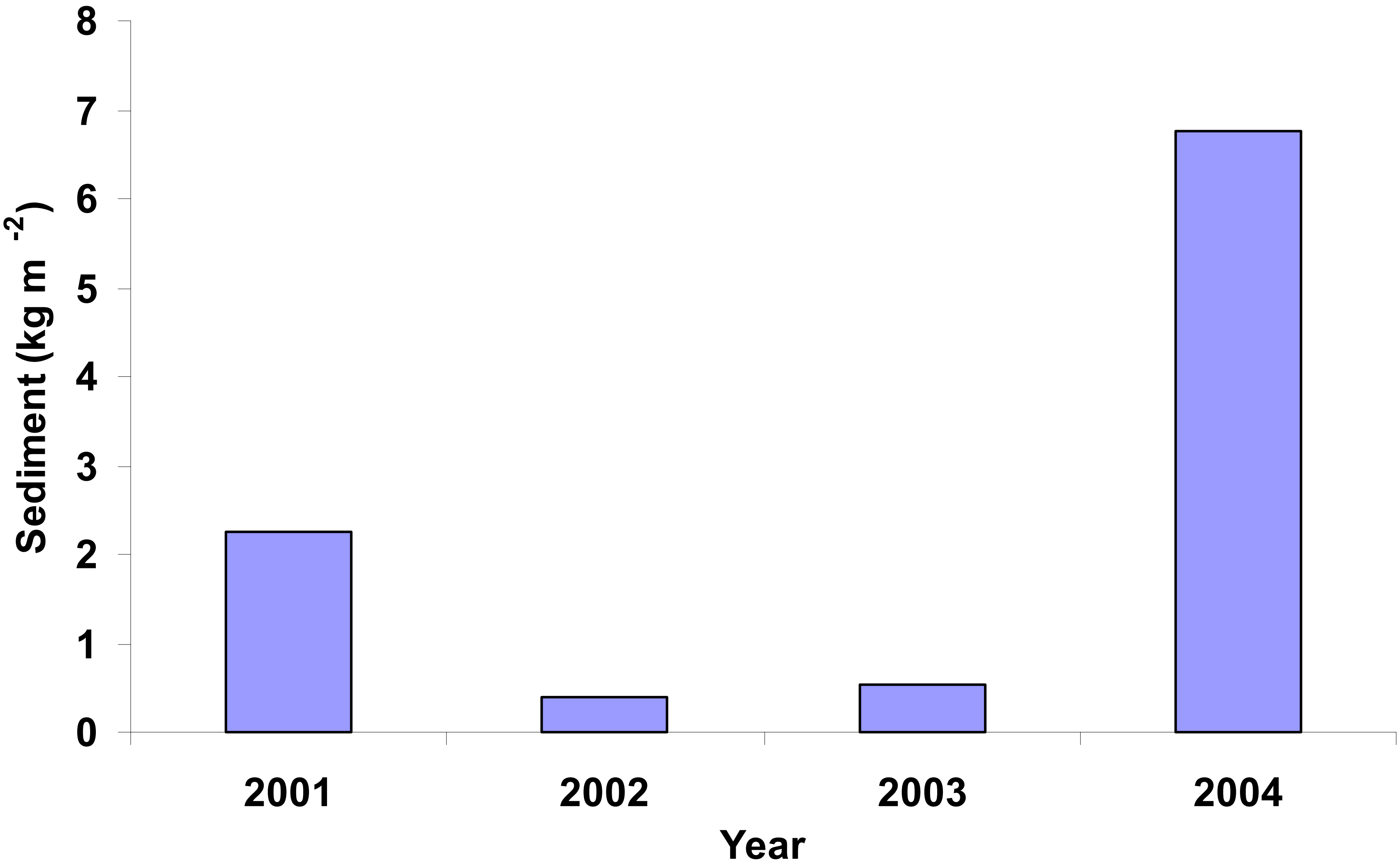
Sediment Production versus Road Surface Area



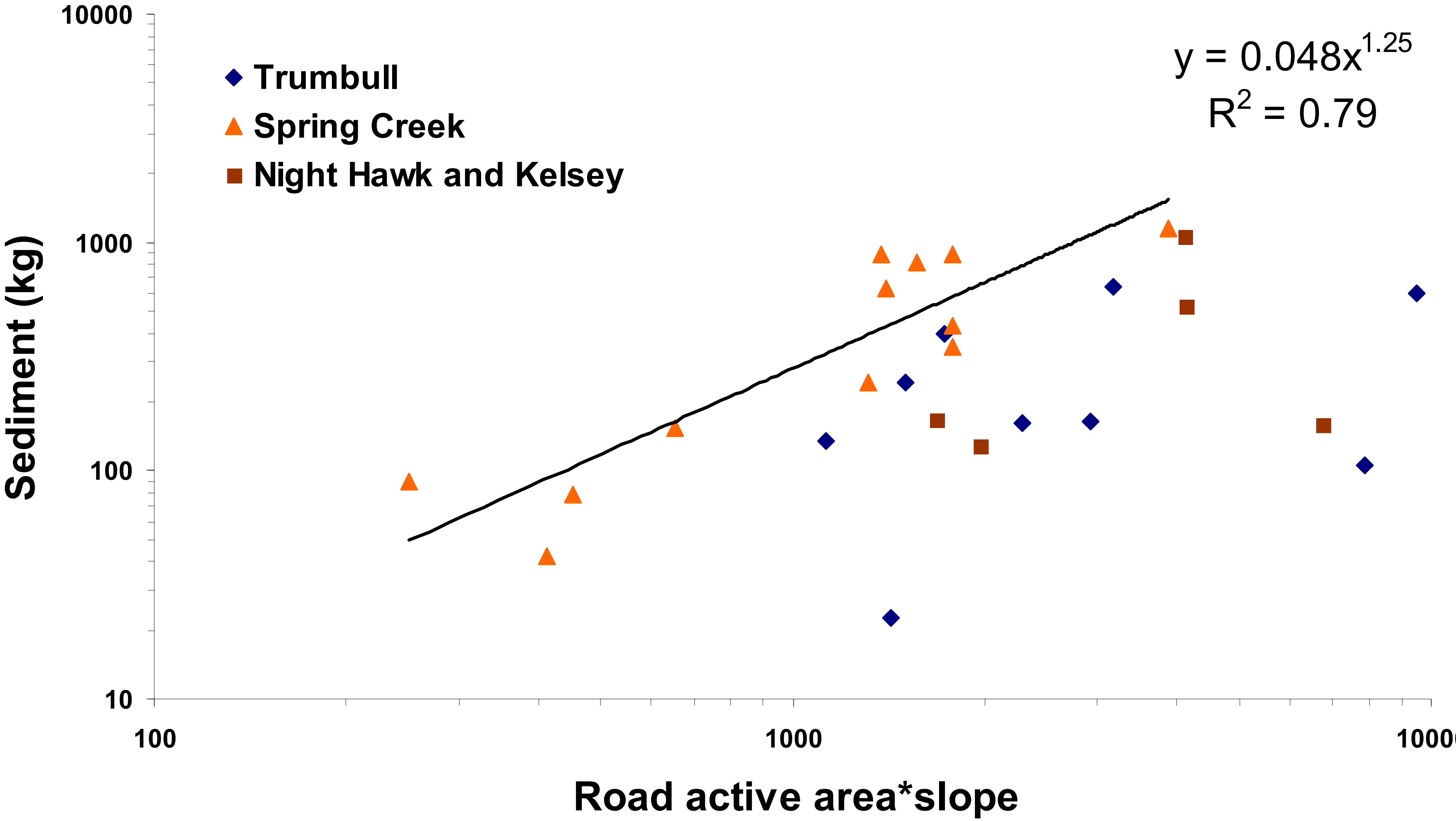

Sediment Production versus Area*Erosivity
10000
1000
100
10
1
Sediment (kg)
1000
10000
100000
1000000
Area*Erosivity
y = 0.68x^0.59
R^2 = 0.35

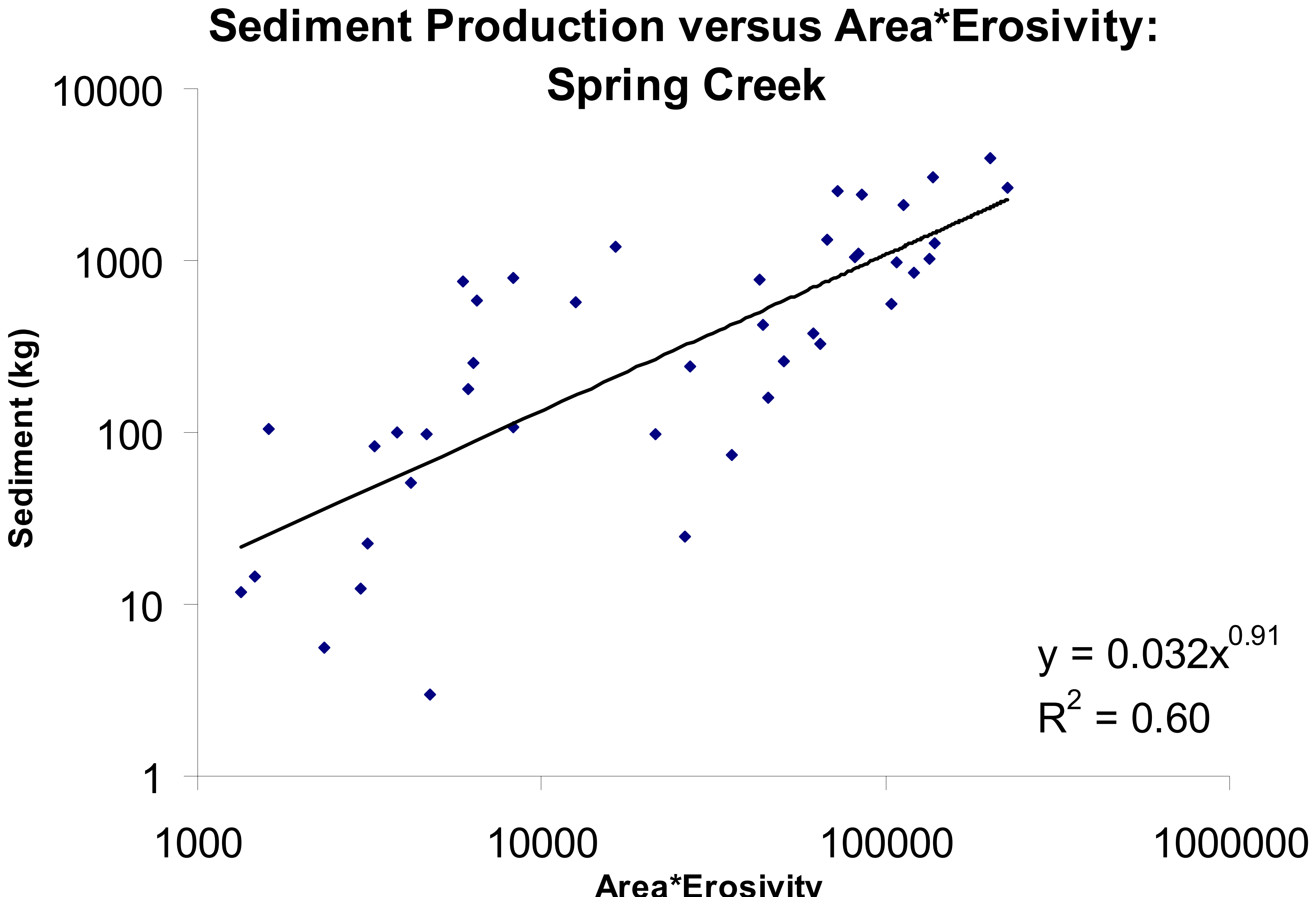

Sediment Production versus Summer Erosivity
Sediment (kg)
10000
1000
100
10
1
10
100
1000
10000
Erosivity
y = 16.41x^0.59
R^2 = 0.23

Mean sediment production from road segments: Spring Creek 2001-2004



Annual sediment yield vs. road segment area*slope





Sediment Production versus Area*Erosivity:
Spring Creek
10000
1000
100
10
1
1000
10000
100000
1000000
Sediment (kg)
Area*Erosivity
y = 0.032x^0.91
R^2 = 0.60

Univariate Analysis: Annual Sediment Production

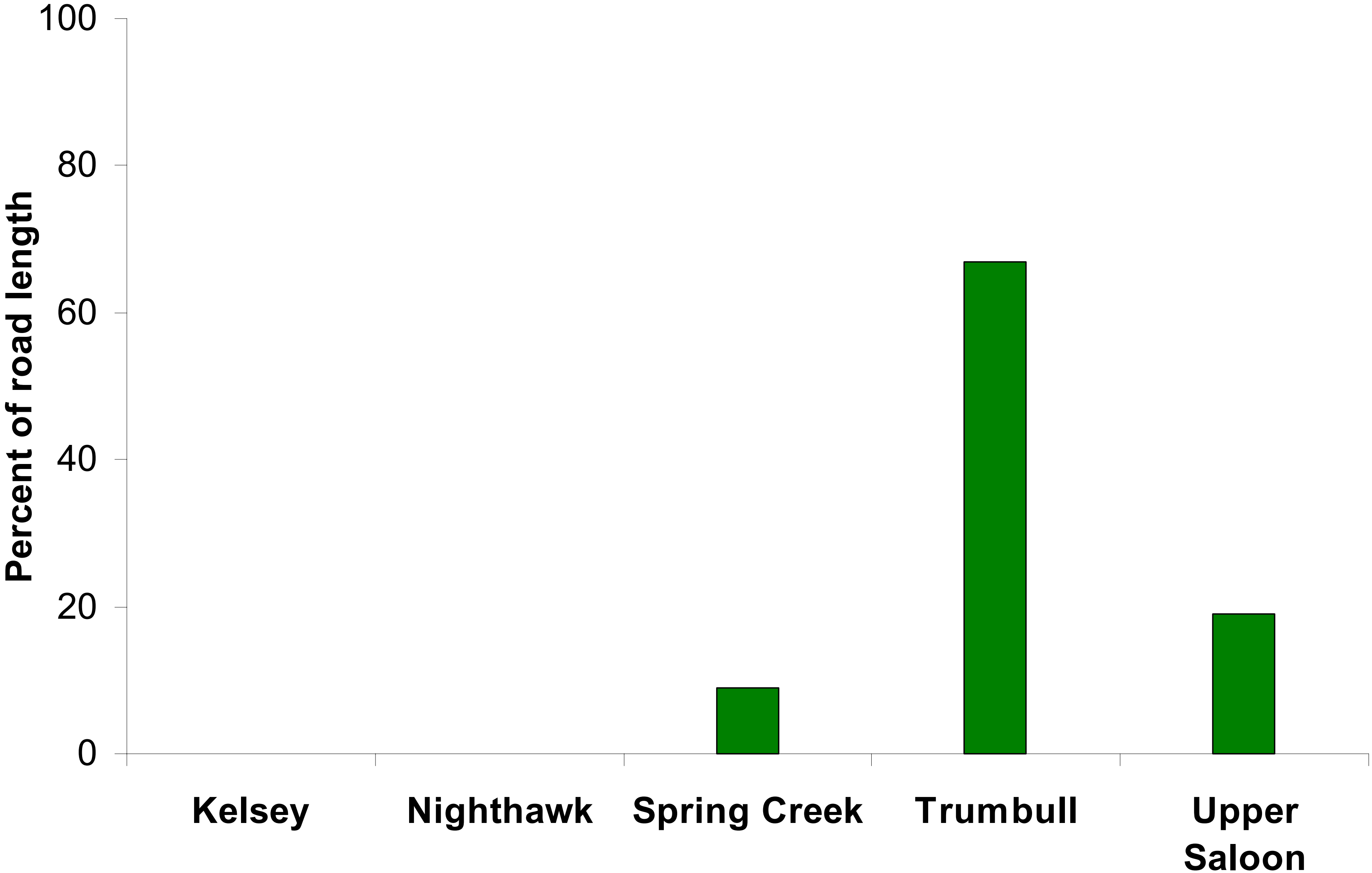
Variable	R2	P-value
Area	0.28	<0.001
Rainfall erosivity	0.23	0.003
Slope	0.20	0.02
Site	<0.01	0.63
Percent bare soil	<0.01	0.67

Does sediment production matter if it doesn't reach the stream network?

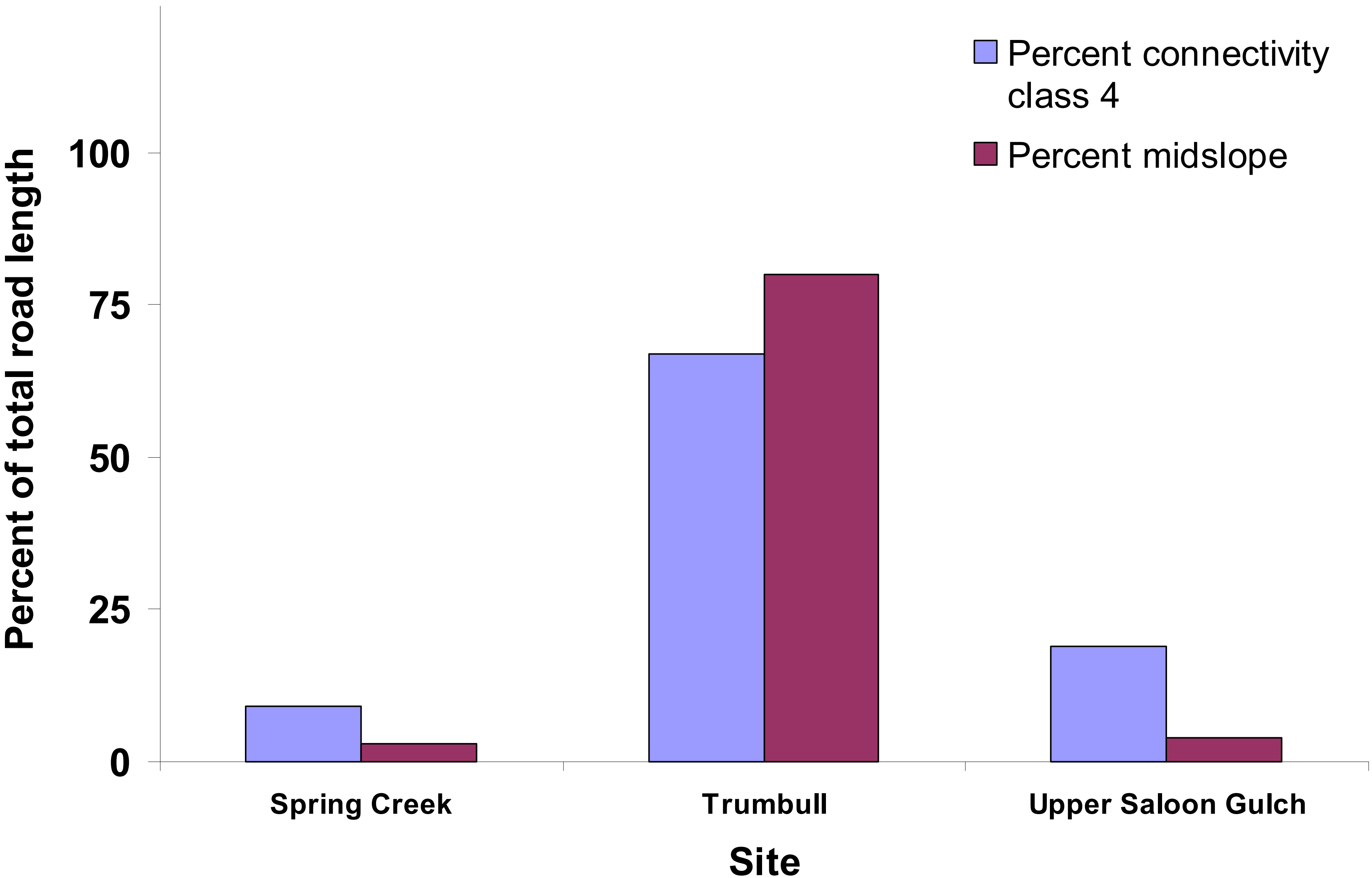
Methods: Connectivity Classes

- Class 1 = No sign of concentrated flow below the drainage outlet;
- Class 2 = Concentrated flow present but extends for less than 20 m;
- Class 3 = Concentrated flow for more than 20 m but stops more than 10 m from channel;
- Class 4 = Continuous rill or sediment plume to a stream channel.

Percent of roads in connectivity class 4 by study area, Colorado



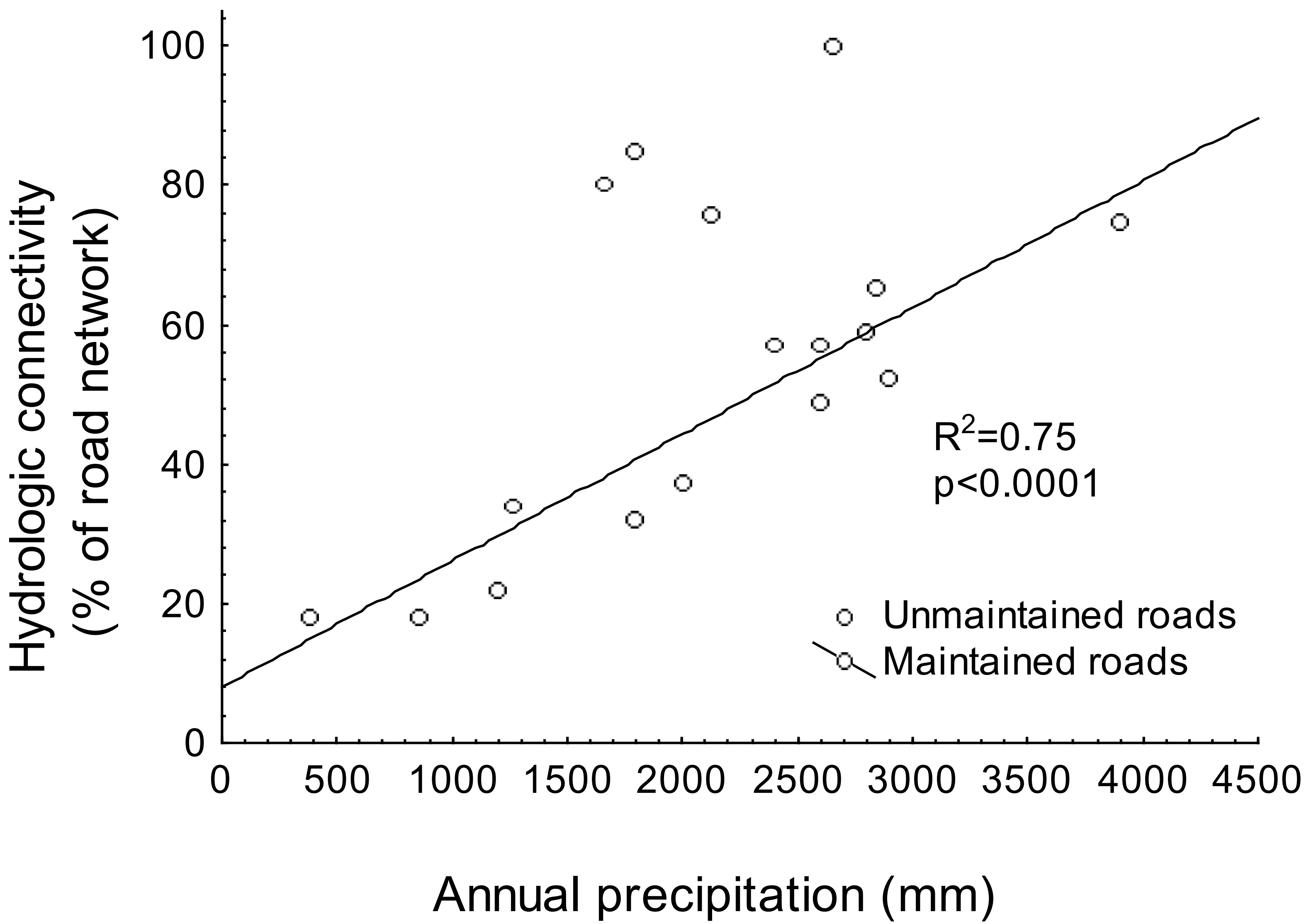
Connectivity and road location, Colorado



Controls on sediment plume length, rill length, and rill volume

	Sediment plume length (m)	**Rill length (m)**	**Rill volume (m^3)**
Segment characteristics	**R^2 (p-value)**	**R^2 (p-value)**	**R^2 (p-value)**
Active area*slope	0.54 (<0.0001)	0.43 (0.01)	0.31 (0.001)
Road surface area (m^2)	0.23 (<0.0001)	0.38 (0.0003)	0.12 (0.06)
Road length (m)	0.20 (0.0001)	0.32 (0.001)	0.08 (0.12)
Segment slope (%)	0.08 (0.02)	0.02 (0.42)	0.07 (0.15)
Percent cover	0.18 (0.19)	0.41 (0.08)	-
Downslope gradient (%)	0.01 (0.42)	0.03 (0.34)	0.01 (0.51)

Percent Connectivity vs. Mean Annual Precipitation



Conclusions: Effects of Thinning

- Thinning:
  - Increases wood cover;
  - disturbs the mineral soil and litter;
  - decreases tree density;
  - increases mean diameter at breast height;
  - and increases soil moisture at 0-5 cm.
- No erosion has been recorded from the thinned swales;
- Absence of surface runoff and erosion at the hillslope scale implies no changes at the watershed scale.

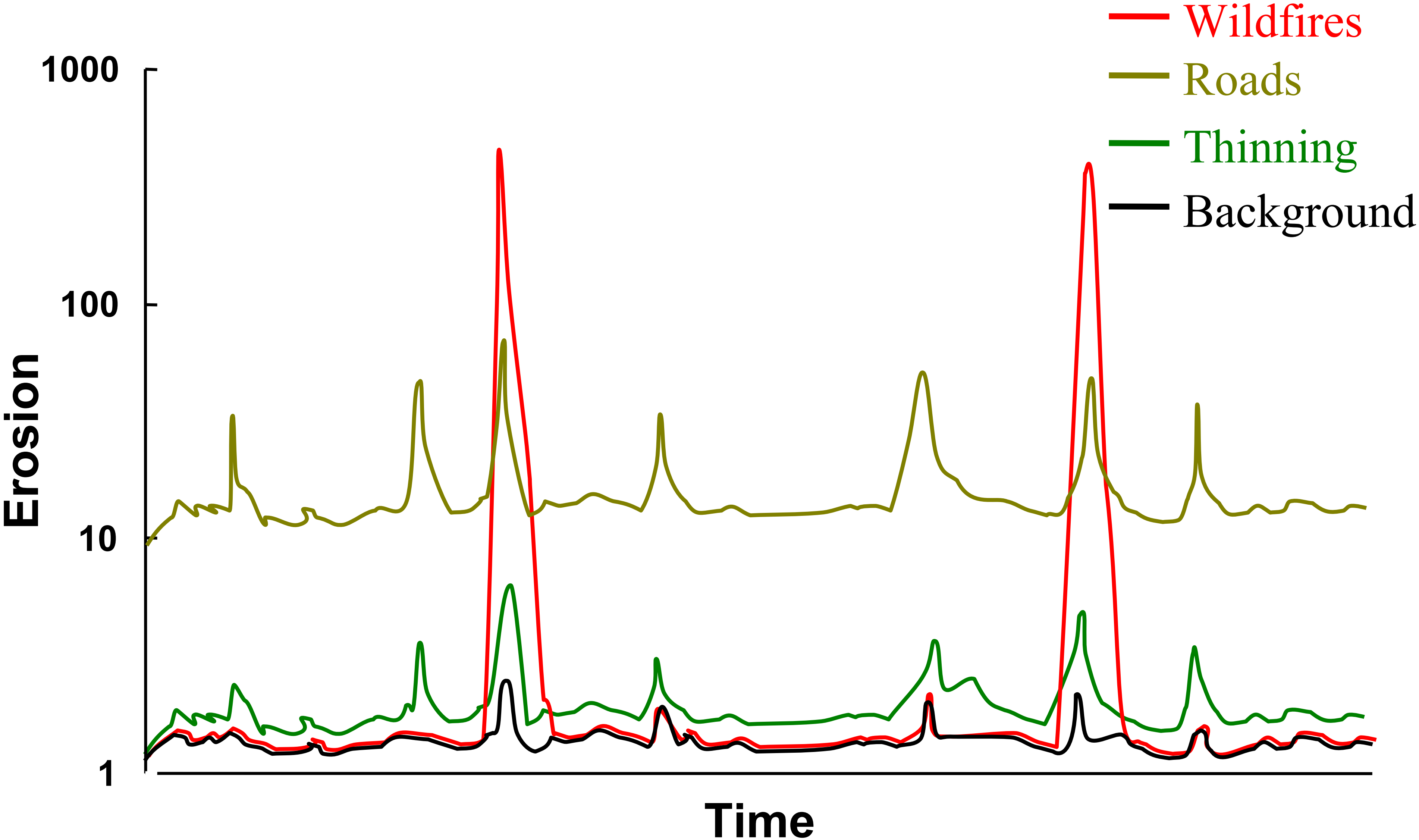
Conclusions: Roads

- In the absence of high-severity wildfires, unpaved roads are the primary sediment source;
- Segment area*slope is the best predictor of sediment production;
- Most roads are not connected to the channels;
- Sediment is unlikely to reach the stream network unless the road segment is in a midslope or valley bottom location.

Conclusions: Wildfire

- Wildfires increase runoff and erosion rates by several orders of magnitude;
- Wildfires can greatly alter channel morphology and water quality;
- Wildfires have a much greater effect on erosion and water quality than mechanical thinning.

Hypothetical erosion rates: wildfires vs. thinning vs. roads vs. background



Questions?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