Water, Earth, and Fire: Runoff, Erosion and Landslides after Wildfire in Southern British Columbia

Peter Jordan

B.C. Forest Service, Nelson, BC

Research Seminar Series, 15 March 2011

Photo: Don Dobson

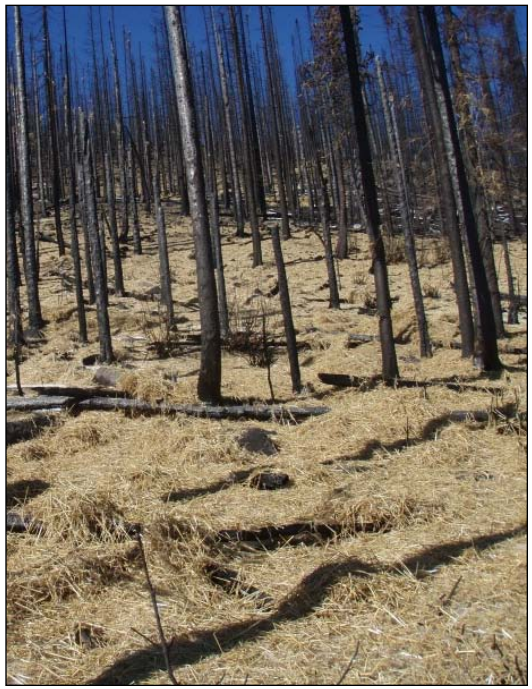
Introduction and Background:

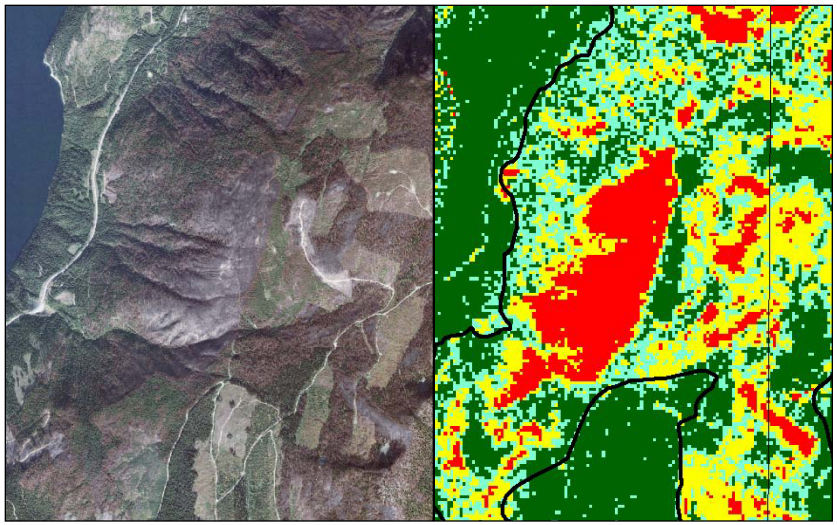
What is the problem, and why are we studying it?

- Following the extreme fire season of 2003, several damaging debris flow and flood events occurred in southern BC.
- Southern Interior Forest Region research and engineering staff developed a procedure to assess post-wildfire risks, and a research program to study the causes of such events.
- Although common elsewhere, large post-wildfire events had not been previously reported in Canada. **Why?**
  - lower rainfall intensities are typical in more northern latitudes
  - relatively moist, cool climate – high soil moisture (usually), thick forest floors
  - low population density – events may have occurred but not been documented

Outline

1. Landslide and flood events after wildfire
2. The 2007 fires in southeastern BC – risks and mitigation
3. Research project objectives and methods
4. Erosion at the plot scale – silt fence measurements and effects of treatments
5. Runoff and erosion at the plot scale – rainfall simulation experiments
6. Runoff at the small watershed scale
7. Runoff and sediment yield at the large watershed scale
8. Conclusions

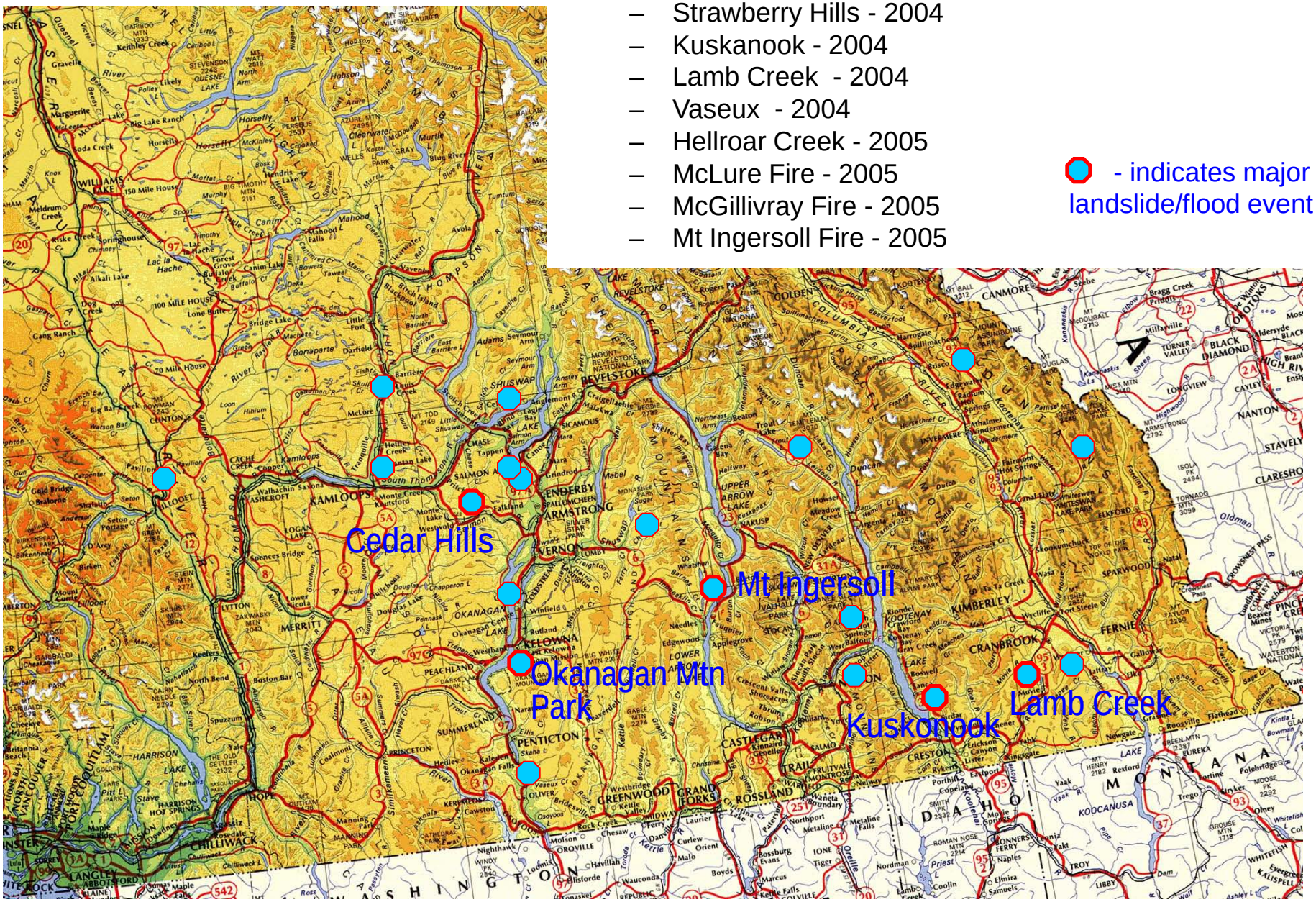




Landslide / erosion / flood events following 2003 fires

- Okanagan Mtn. Park Fire - 2003
- Cedar Hills - 2004
- Strawberry Hills - 2004
- Kuskanook - 2004
- Lamb Creek - 2004
- Vaseux - 2004
- Hellroar Creek - 2005
- McLure Fire - 2005
- McGillivray Fire - 2005
- Mt Ingersoll Fire - 2005

- indicates major landslide/flood event



Events following the 2003 wildfires

Kelowna: Erosion event in October 2003 following the Okanagan Mountain Park fire

Photo: Don Dobson

Cedar Hills fire: Erosion, debris floods, and debris flow in June 2004 Photos: Bill Grainger

Lamb Creek fire: Large debris flood and several small landslides in August 2004

Kuskonook fire: two debris flows in August 2004

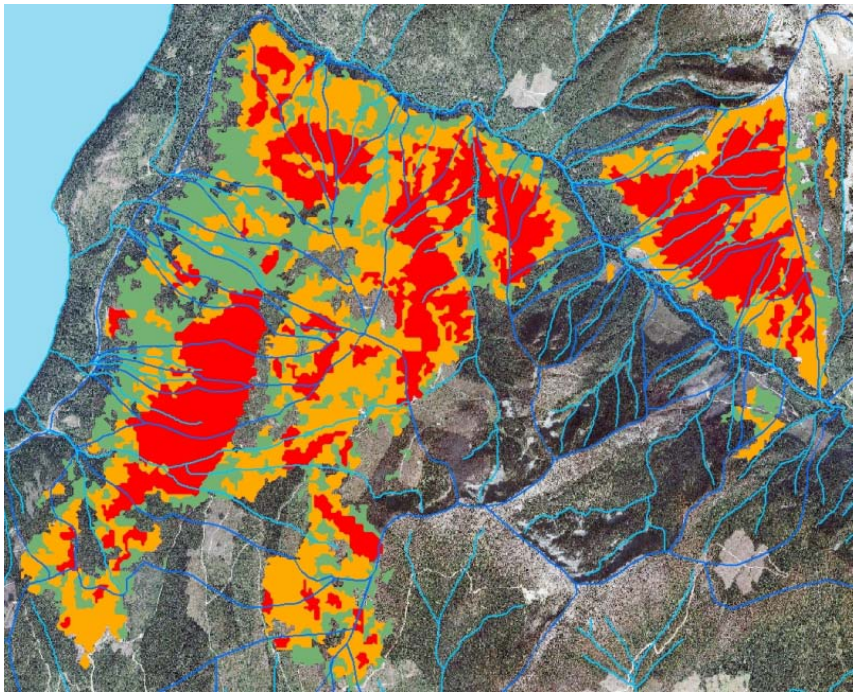
Ingersoll fire: 15 debris flows and debris avalanches during a rainstorm in October 2005

Causes of the post-2003-wildfire events:

- extensive water repellency was noted in the burned areas
- unusually high soil burn severity may have been due to extreme drought conditions in 2003
- all the events, except Ingersoll, occurred during short, very high-intensity, rainstorms

The 2007 fires – Risk Analysis

Springer Fire (N50372), near Slocan



– Quickbird satellite image Sept 2007
– BARC (Burned Area Reflectance Classification) mapping from Landsat imagery

The purposes of the risk analysis procedure are to:
– identify and map hazards
– analyze risks to public safety and infrastructure
– warn affected parties (through PEP and local government)
– identify mitigation opportunities

Field work to assess soil burn severity and identify hazards

2007 Springer Fire Risk Analysis

Because of the high risks identified in this fire, the Forest District and the Southeast Fire Centre decided to apply mitigation treatments: aerial straw mulching, and further deactivation of old roads and trails. MOT upgraded culverts and built a catch basin on the highway, and conducted snow avalanche hazard assessments.

Mitigation options: three general categories

- Road engineering treatments – improvements to road drainage (e.g. culverts, cross-ditches)
- Protective structures – dikes, berms, check-dams etc.
- Broadcast treatments such as straw mulching

Cross-ditch, Springer fire

Berms to protect houses, Terrace Mtn fire, 2009

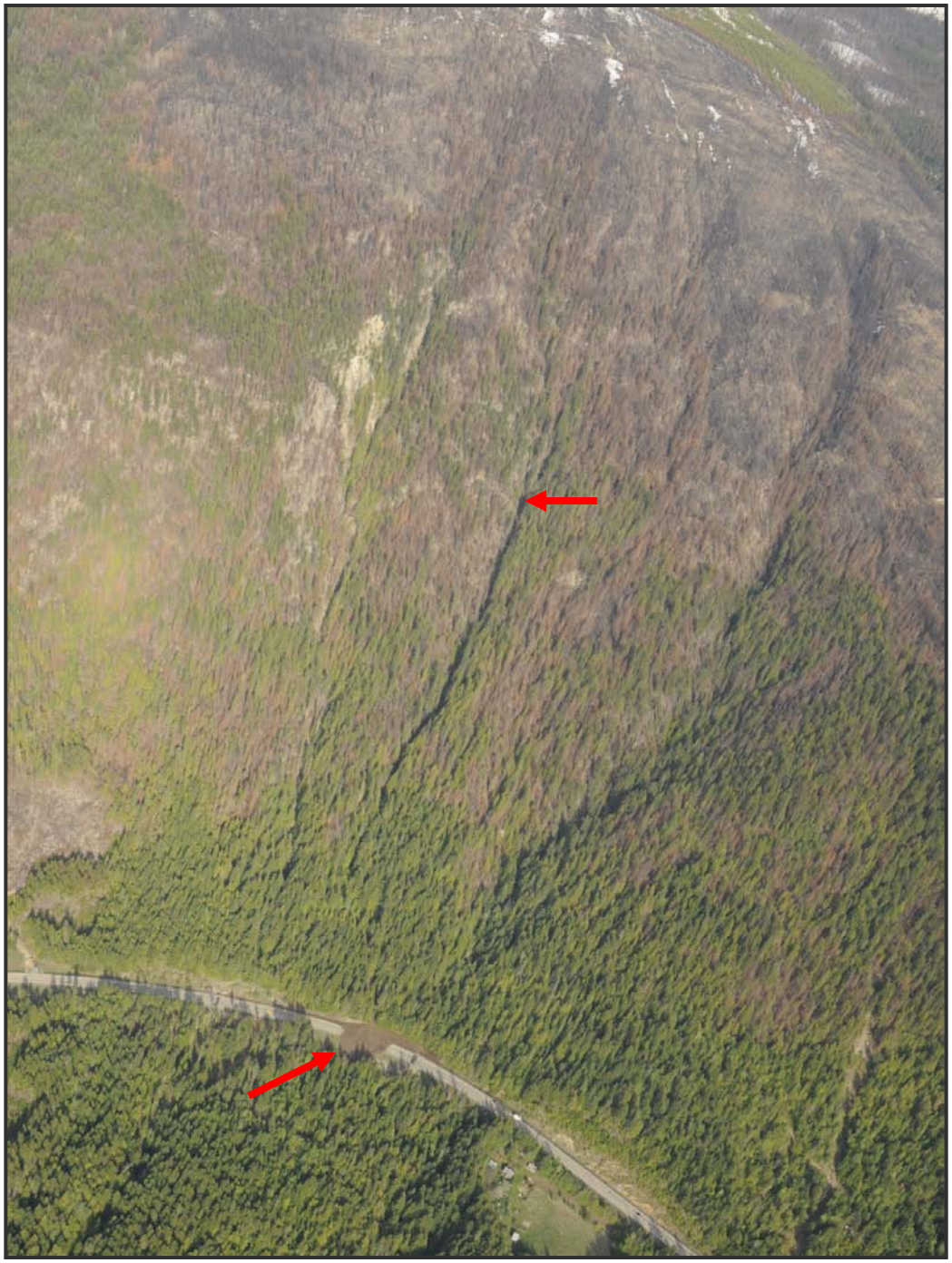
Photos: Tim Smith

Aerial straw mulching, Springer fire, 2007

Spreading straw mulch by hand, Terrace Mtn fire, 2009

Events following the 2007 fires

- Springer fire: Debris flow in May 2008, 5000 m^3
- Initiated in the channel; most sediment came from channel incision
- A smaller debris flow in the same channel occurred in May 2010



Springer fire debris flows :

- four large debris flows (1000 m^3 +), several small debris flows, in a remote area of the fire
- summer/fall rain (< 2 yr events)
- steep gullied mountainside, subject to debris flows before the fire (about 20 y return period)

Quickbird image,
Springer fire, Sept 2007

Research objectives:

A research project to investigate post-wildfire runoff, erosion, and mass wasting processes received three years of FIA-FSP funding beginning in 2007.

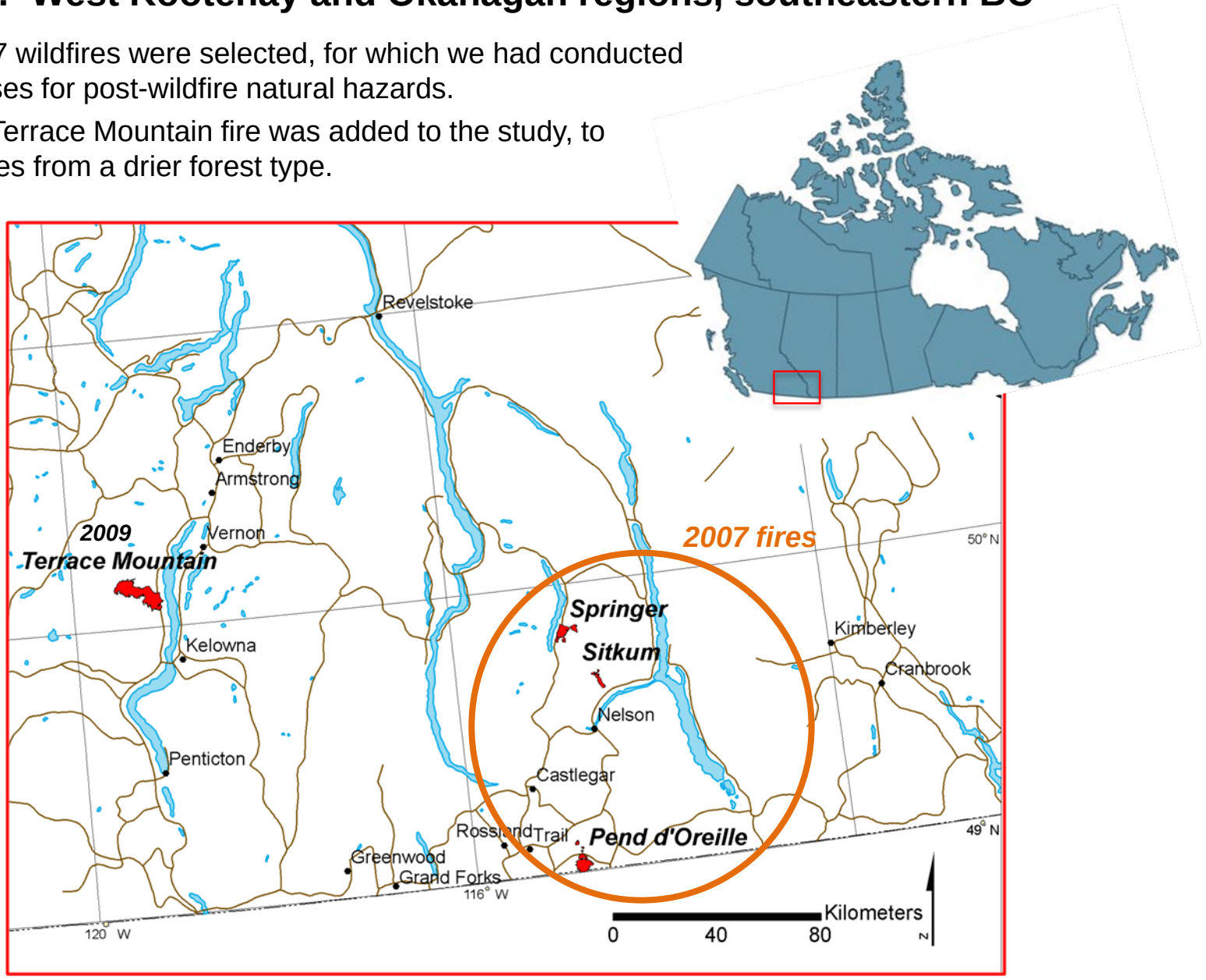
The study addressed the following questions:

- What burn severity and extent is necessary to generate substantial overland flow?
- What are the roles of water repellent soils, loss of forest floor, and other factors such as plugging of soil pores?
- What are the best ways to measure and map post-fire soil hydrologic changes?
- What is the influence of pre-fire weather and soil moisture on soil burn severity?
- What rainfall intensities are necessary to produce overland flow and trigger mass movement events?
- How can site-scale processes (overland flow, soil erosion) be extended to catchment-scale responses (stream discharge, sediment yield)?
- How long does hydrologic recovery take after fire?

Study team: Peter Jordan, Ashley Covert, Amy O'Neill, Mike Curran (Southern Interior Forest Region, Nelson)

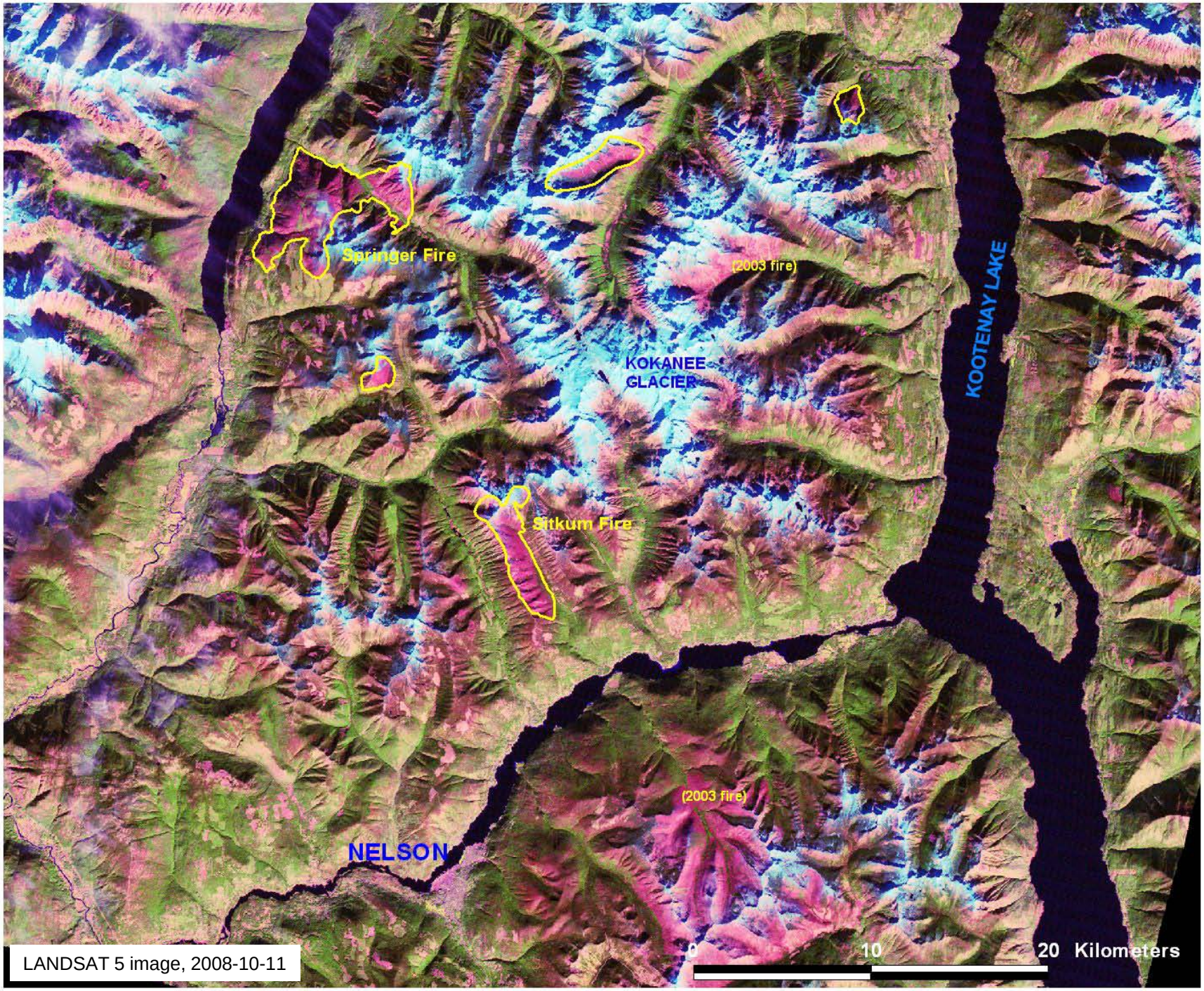
Location: West Kootenay and Okanagan regions, southeastern BC

- Three 2007 wildfires were selected, for which we had conducted risk analyses for post-wildfire natural hazards.
- The 2009 Terrace Mountain fire was added to the study, to include sites from a drier forest type.



Research sites: data for plots and installations in each fire

SITE AND CHARACTERISTICS	Pend d'Oreille	Springer	Sitkum	Terrace Mountain
Year of fire	2007	2007	2007	2009
BEC zones	ICHdw1, ICHmw2	ICHmw2, ESSFwc1	ESSFwc4	IDFmw1
Elevation	1145-1330	1465-1560	1600-1800	1000-1100
Aspect	SW	SW	NE	W
Bedrock geology	Fine-textured sedimentary	Granitic	Granitic	Volcanic, granitic
Mean annual precip.	880	970	1290	400

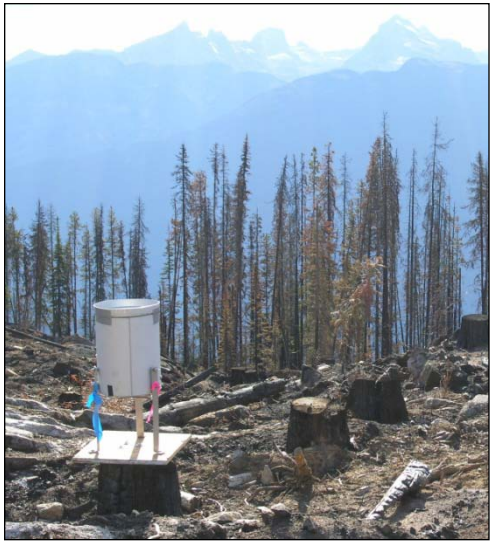


LANDSAT 5 image, 2008-10-11

Methods:

- Plot-scale – Silt fence erosion plots, to measure erosion at sites of different burn severity, and of different treatments (all fires)
- Plot-scale – Rainfall simulation experiments, to measure erosion and runoff at high rainfall intensity (Springer, Pend d'Oreille, Terrace Mountain)
- Catchment-scale – Streamflow weirs and sediment sampling, to compare burned/unburned and treated/untreated watersheds (Sitkum only)
- Landslide events – investigated as they occurred

- Soil and weather –
  Soil moisture recording stations, water repellency transects, rain gauges



Measurement Units for Erosion and Sediment Yield:

Tonnes per hectare – T/ha or Mg/ha [Mg = megagrams]

1 mm removal of surface soil ≈ 10 Mg/ha

Erosion = removal of soil material from the surface
Sediment yield = the amount of eroded material collected in a trap, or carried by streamflow

For comparison:

- typical logging road erosion per year is 10 to 100 Mg/ha
  ... or averaged over the logged/roaded landscape, 0.1 to 1 Mg/ha
- typical annual suspended sediment yield for small forested watersheds in the West Kootenays is about 10 Mg/km^2 or 0.1 Mg/ha
- U.S. studies on post-wildfire erosion:
  1 to 100 Mg/ha in the first year is common (lots of variability); in the order of 10 Mg/ha is typical

Summary:
- erosion over a wide area of >1 Mg/ha is probably significant
- >10 Mg/ha may be of concern for sediment input to streams, or for water quality

Kuskonook Creek headwaters,
August 2004

Plot-scale erosion – silt fence sediment traps

- Originally installed to measure effectiveness of mulching treatments
- 4 m x 15 m plots (approximately)
- 40 silt fences on the 4 fires
- Measure erosion under naturally-occurring rainfall and snowmelt conditions
- In 2008 and 2009, they were measured after spring runoff, and after every major rainfall event (and once or twice in 2010)
- There were no significant high-intensity rainstorms during the study

Springer fire: different soil burn severities

Sitkum fire:
Aerial straw mulching, treatment and control

September 2009

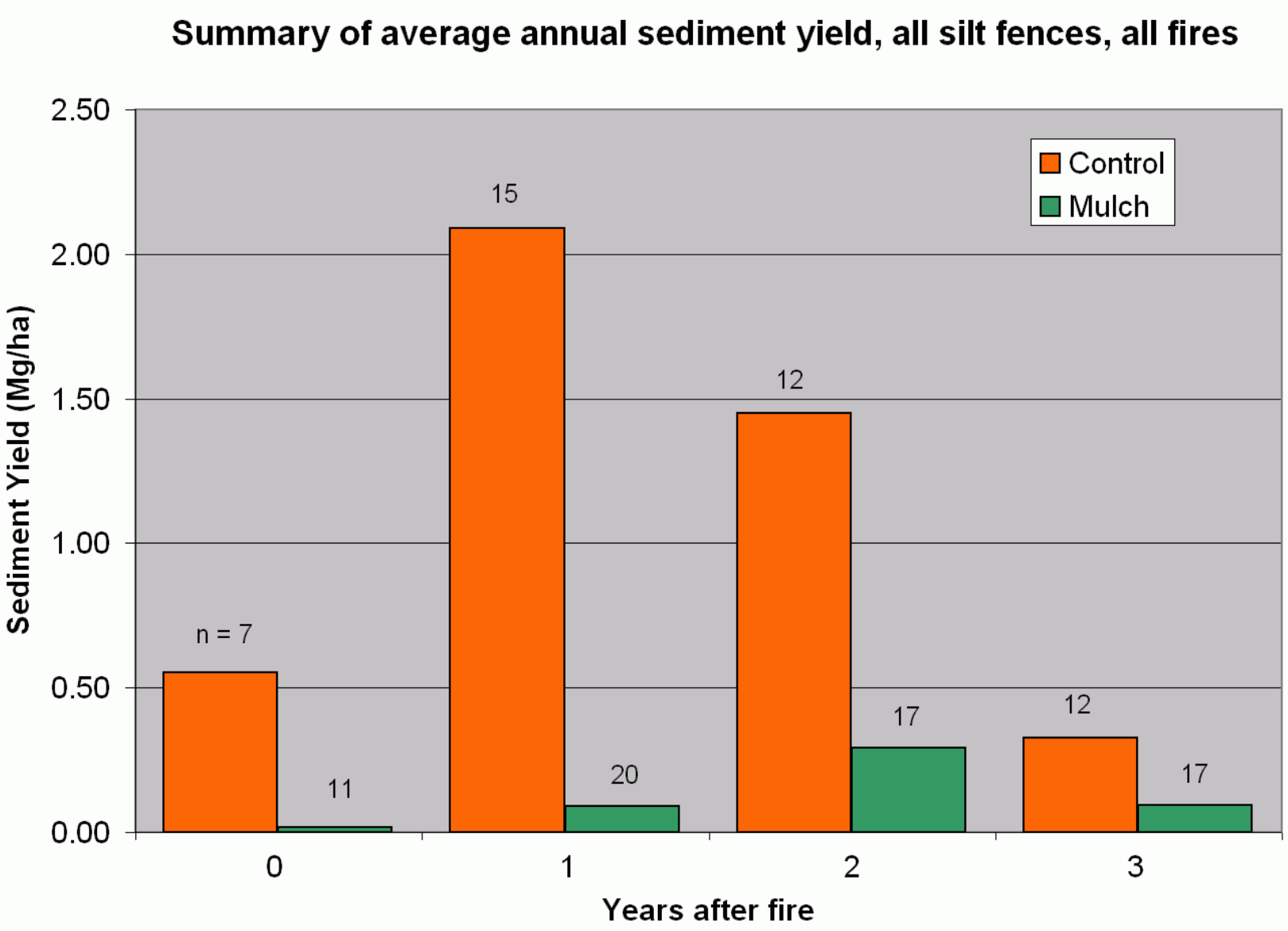
August 2010

Terrace Mountain: High-severity site, silt fences to test mulch spread by hand

All silt fences - Mean annual sediment yield (Mg/ha) [or Tonnes/hectare]

Fire	Treatment	N	Years after fire 0	1	2	3
Springer (2007)	Control	6	0.44	4.15	0.69	0.22
	Mulch	11	0.0	0.10	0.05	0.06
Sitkum (2007)	Control	2		0.58	6.36	1.28
	Mulch	2		0.02	2.20	0.49
Pend d'Oreille (2007)	Control	4		1.08	0.14	0
	Mulch	4		0.10	0.01	0
Terrace Mtn (2009)	Control	3	0.70	0.32		
	Mulch	3	0.06	0.09		

Note: All data reported here are for high soil burn severity sites.


Summary of average annual sediment yield, all silt fences, all fires
Sediment Yield (Mg/ha)
2.50
2.00
1.50
1.00
0.50
0.00
Control
Mulch
n = 7
11
15
20
12
17
12
17
0
1
2
3
Years after fire

Plot-scale erosion – rainfall simulation experiments

- Measure erosion and runoff from a simulated rainfall of approximately 70 mm/h for 20 minutes, equivalent to a 100 year return period event for this area
- over 80 runs on Springer, Pend d'Oreille, and Terrace Mountain sites
- Designed to measure erosion and runoff on 1 m^2 plots at sites of differing burn condition (high & moderate soil burn severity, unburned)
- At Terrace Mountain, they were also used to test mulching treatments

Springer – Rainfall simulation experiments on four different surface conditions
  – number indicates number of replicates each year; repeated in 2008 and 2009
  – moderate burn sites have natural mulch from needle fall

High

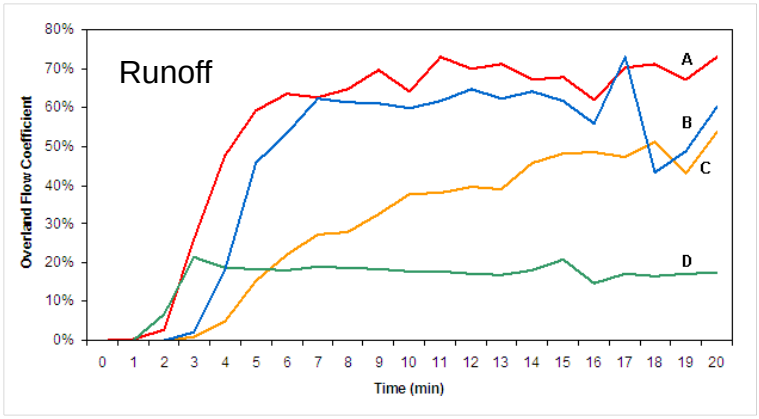
Unburned

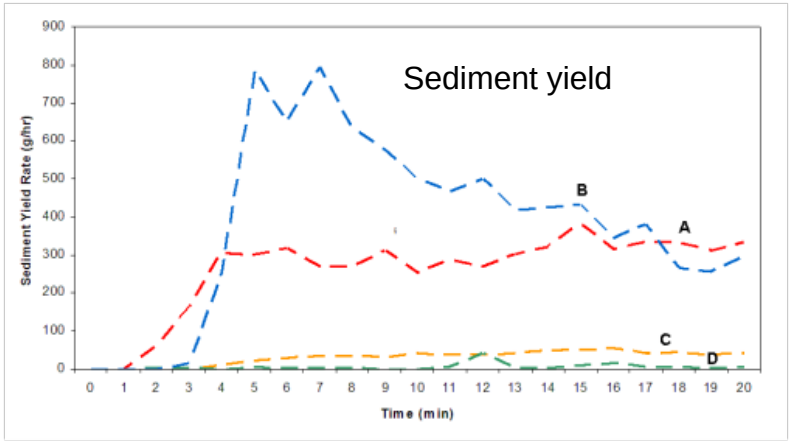
Moderate

Unburned - FF Removed

Rainfall simulator operation

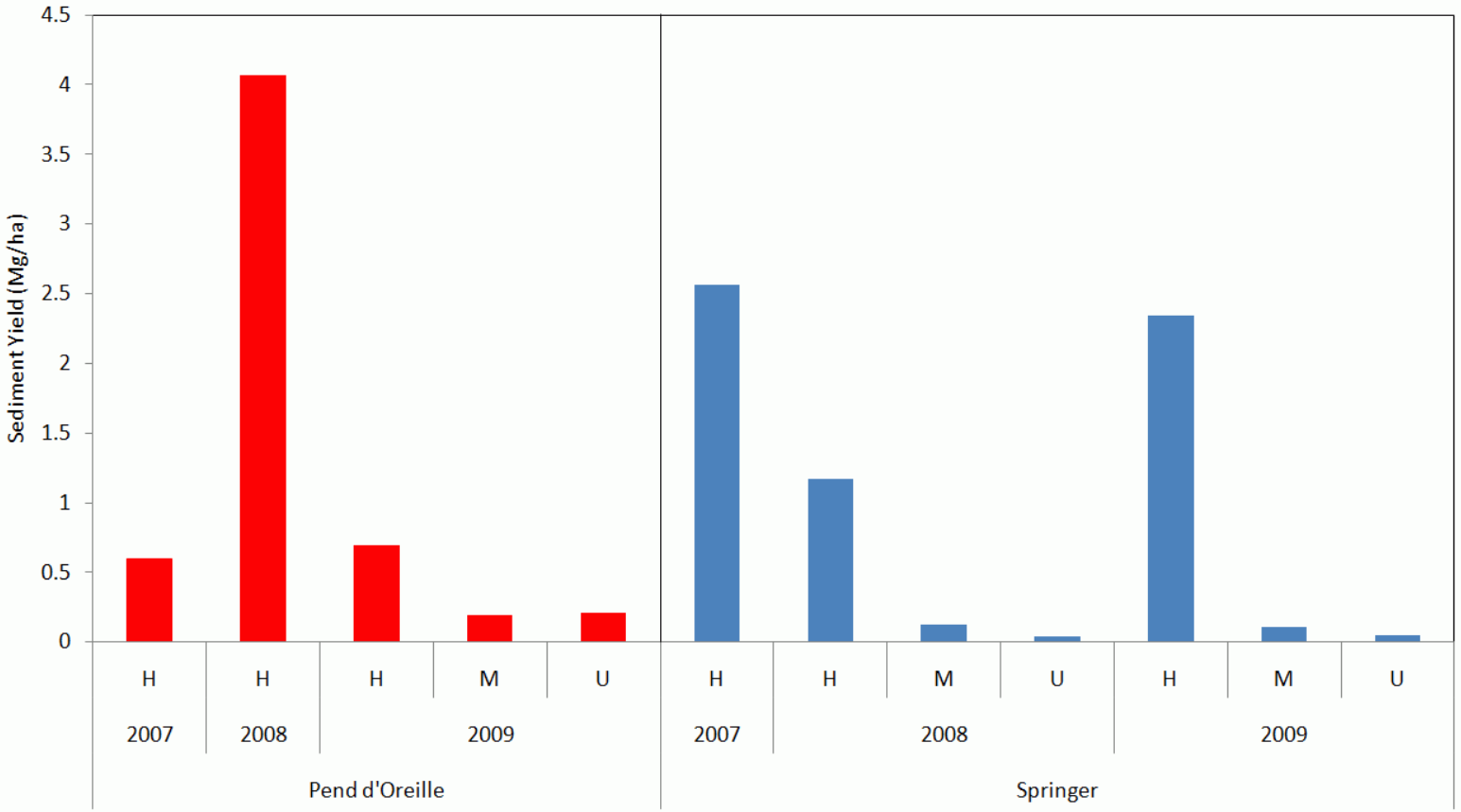
- Since high-intensity rainfalls are unlikely to occur naturally, these experiments simulate runoff and erosion that might occur in a 100-year, short-duration, rainstorm.
- After a calibration to measure the exact rainfall rate, the simulator is run for 20 minutes.
- For 30 seconds every minute, water and sediment are collected in bottles.
- The samples are analyzed in the lab.
- Runoff and sediment yield over the measurement interval are measured.
- Overland flow ratio, infiltration rate, and total sediment yield can be calculated.

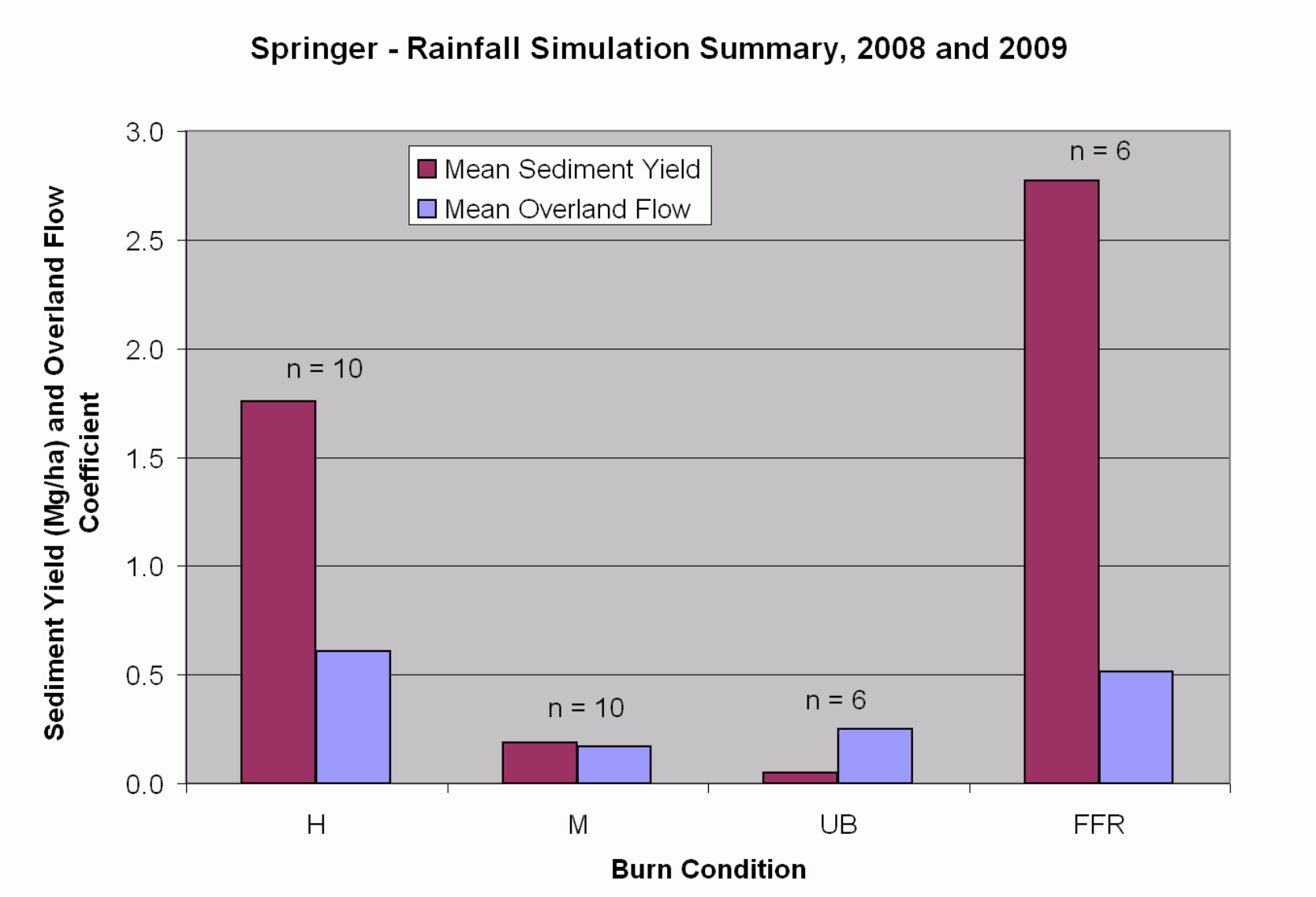




A High severity
B Unburned FF removed
C Moderate severity
D Unburned

RAINFALL SIMULATION RESULTS –
Sediment yield for each experimental unit, mean for all replications





High soil burn severity

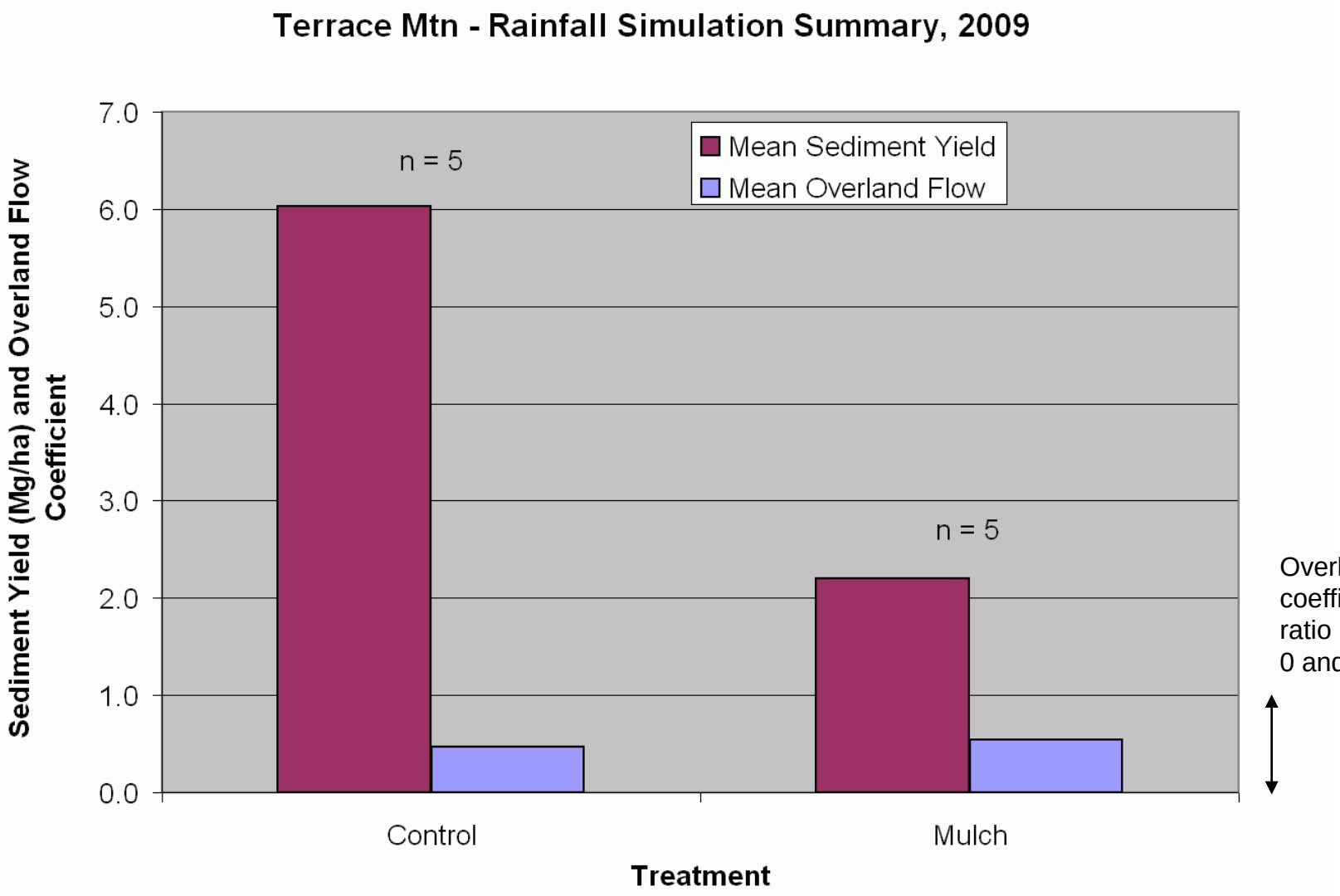
Moderate soil burn severity; needle-fall mulch

Unburned

Unburned, forest floor removed

We know from the silt fence measurements that mulch greatly reduces sediment yield (under low-intensity, naturally-occurring, rainfall).

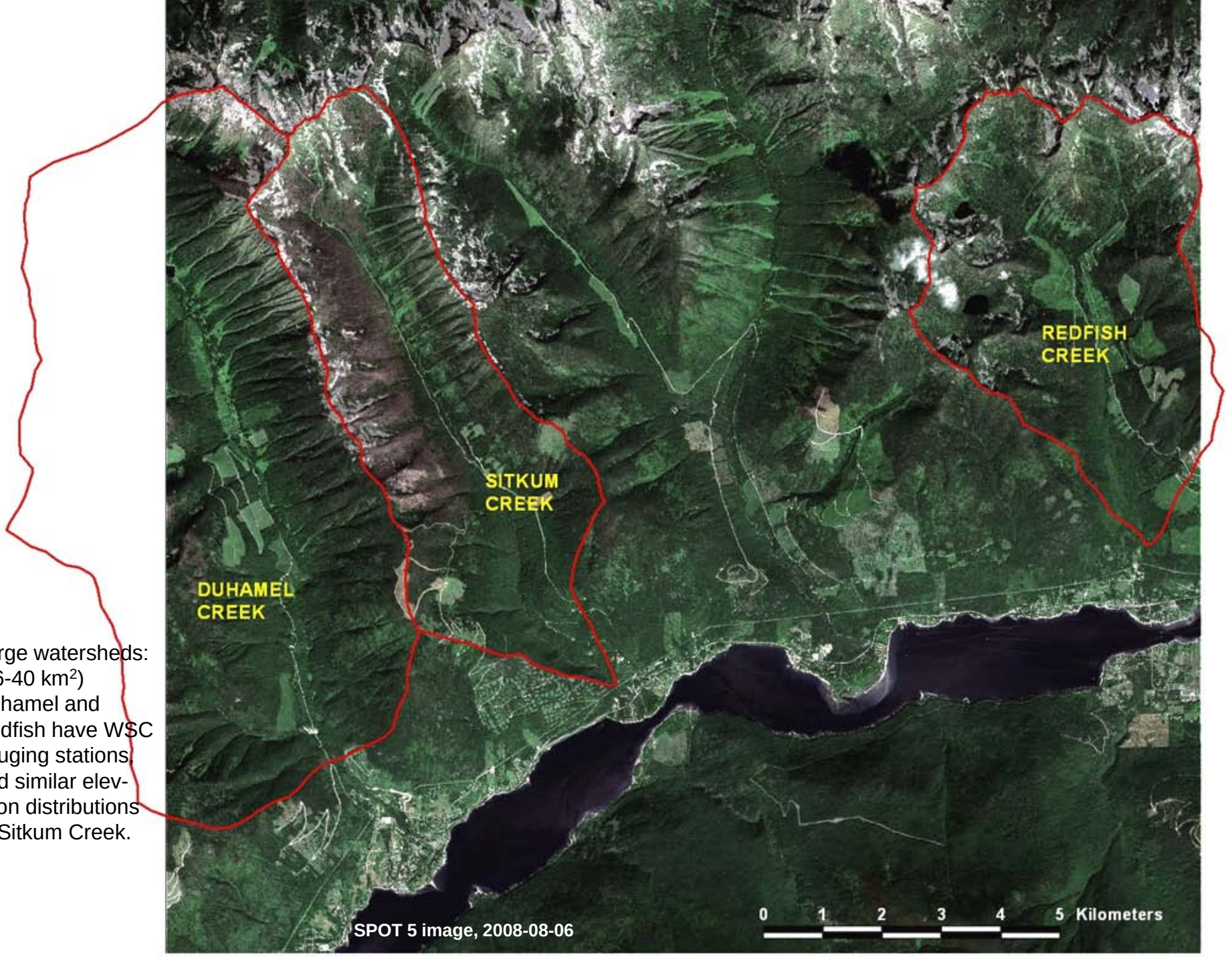
Does mulch reduce overland flow?



Overland flow coefficient is a ratio between 0 and 1

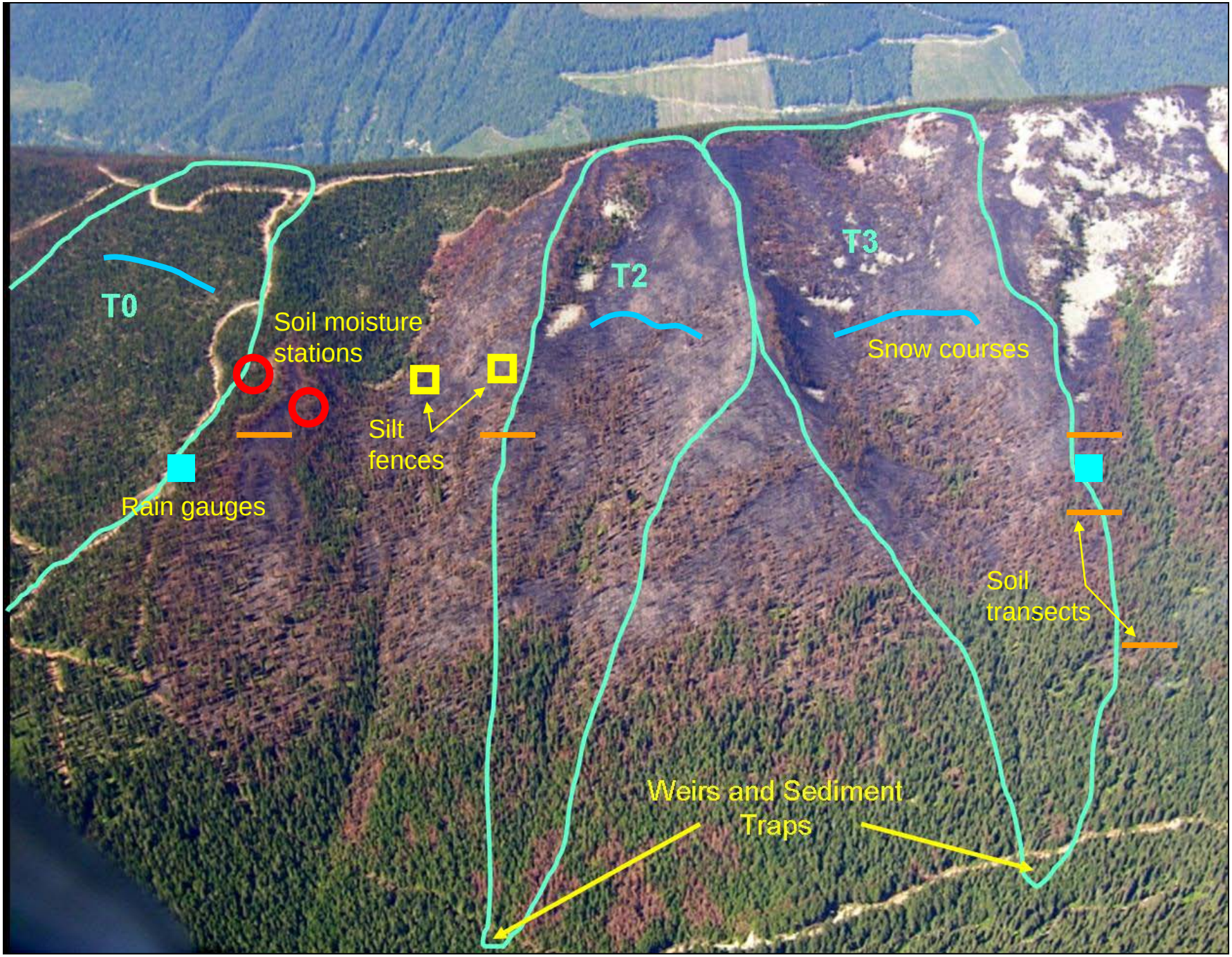
Study area for catchment-scale measurements – Sitkum Fire, July-August 2007

- Elevation – 1500 to 2100 m
- Mean precipitation – ~1300 mm, mostly snow
- Snow-free season averages 4 to 5 months
- Soils – sandy loam, stony, derived from glacial till and granitic rocks
- Forests – mostly spruce, subalpine fir



Large watersheds: (26-40 km^2) Duhamel and Redfish have WSC gauging stations, and similar elevation distributions to Sitkum Creek.

T3
T2
T0
Small catchments:
Sitkum Creek tributaries
0
1
2 Kilometers


T0
T2
T3
Soil moisture stations
Silt fences
Rain gauges
Snow courses
Soil transects
Weirs and Sediment Traps

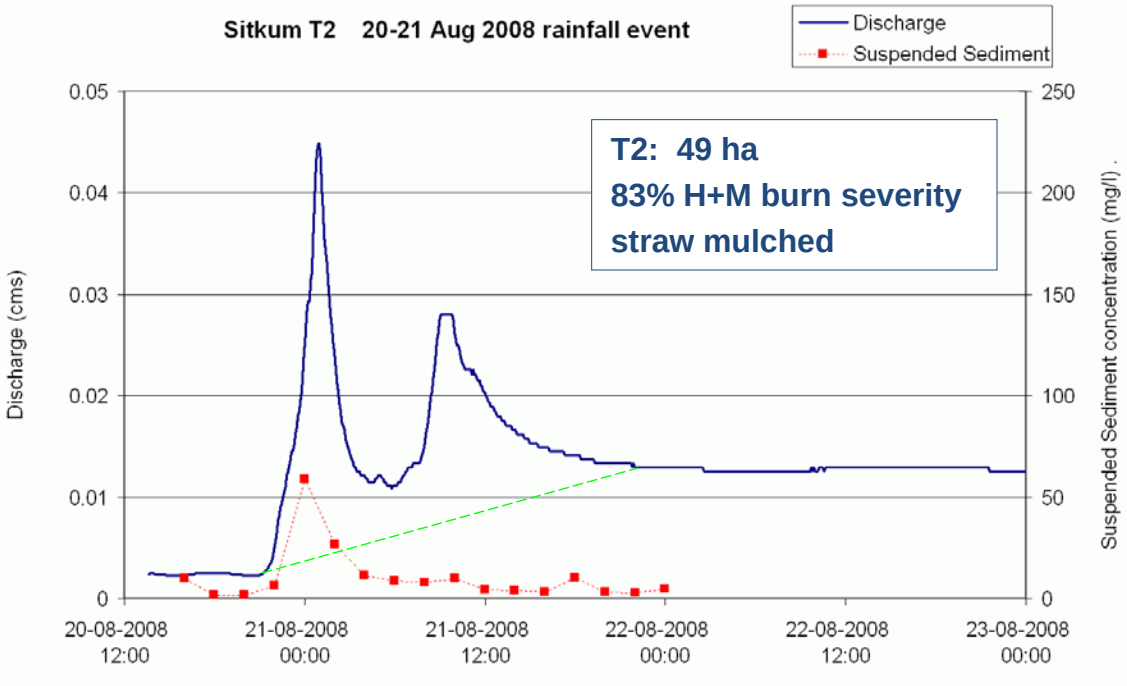
Instrumentation on each stream:

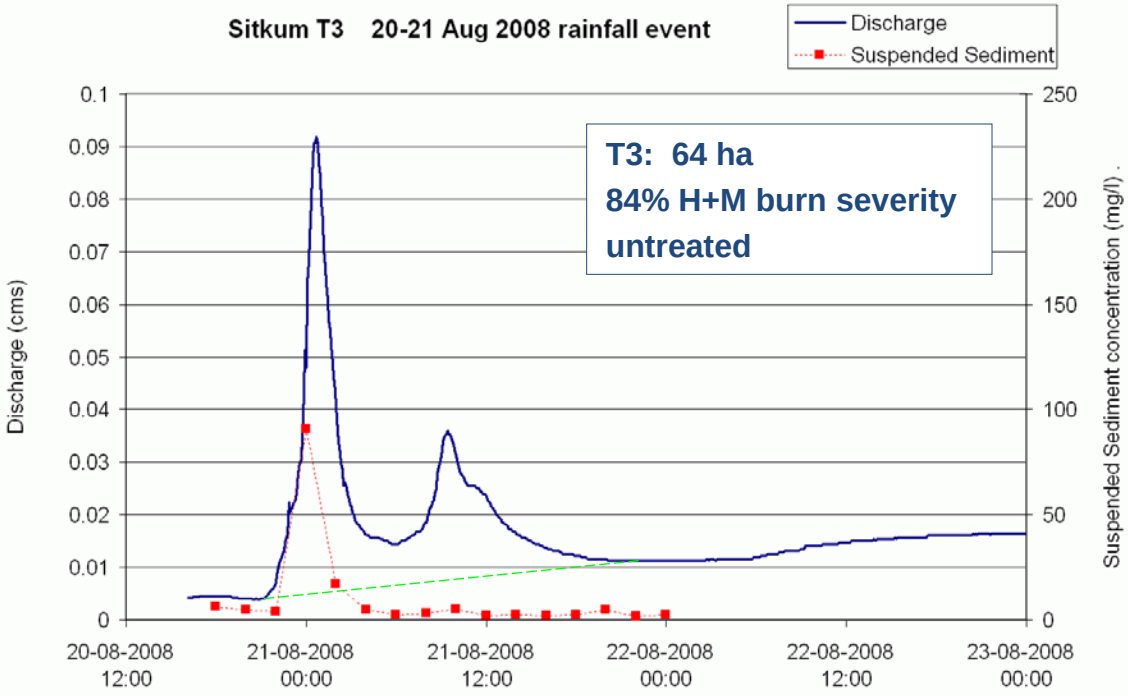
- V-notch weir, design capacity of 0.4 m^3/s
- Water level recorder (Odyssey in 2008-09, pressure transducer & CR10 in 2010)
- ISCO pump sampler, normally programmed to take daily samples, but can be programmed for any interval
- Operated May – October each year

- A log sediment trap was built above each weir, to catch coarse sediment – emptied as necessary.
- These streams are potentially subject to debris flows, so the installation could be destroyed.

Sitkum T3 weir at peak flow

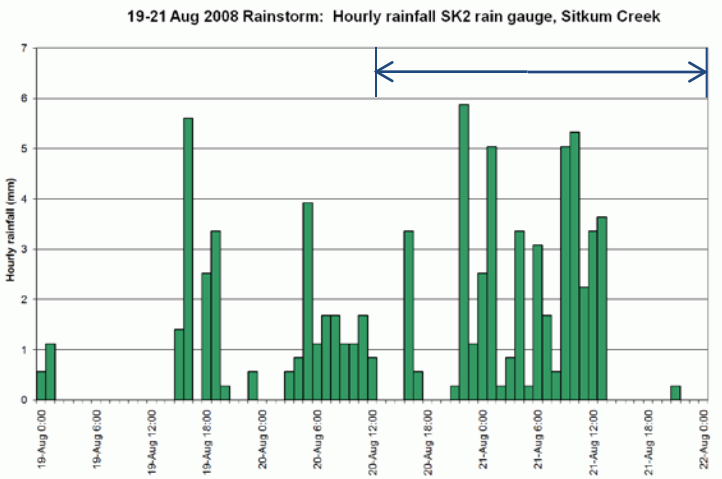
Stream gauging station on lower Sitkum Creek – staff gauge, pressure transducer & data logger, pump sampler

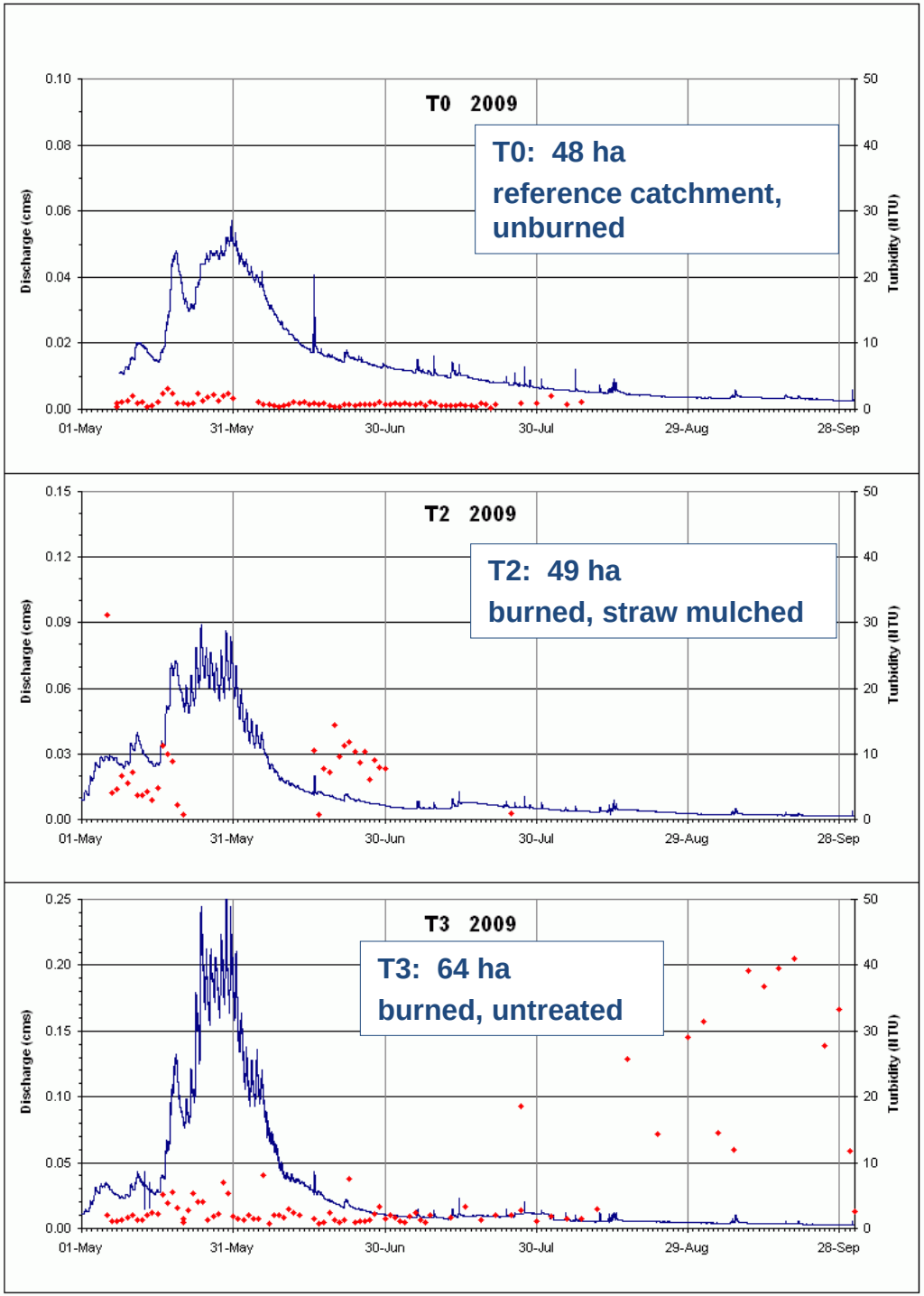




Results – Catchment scale

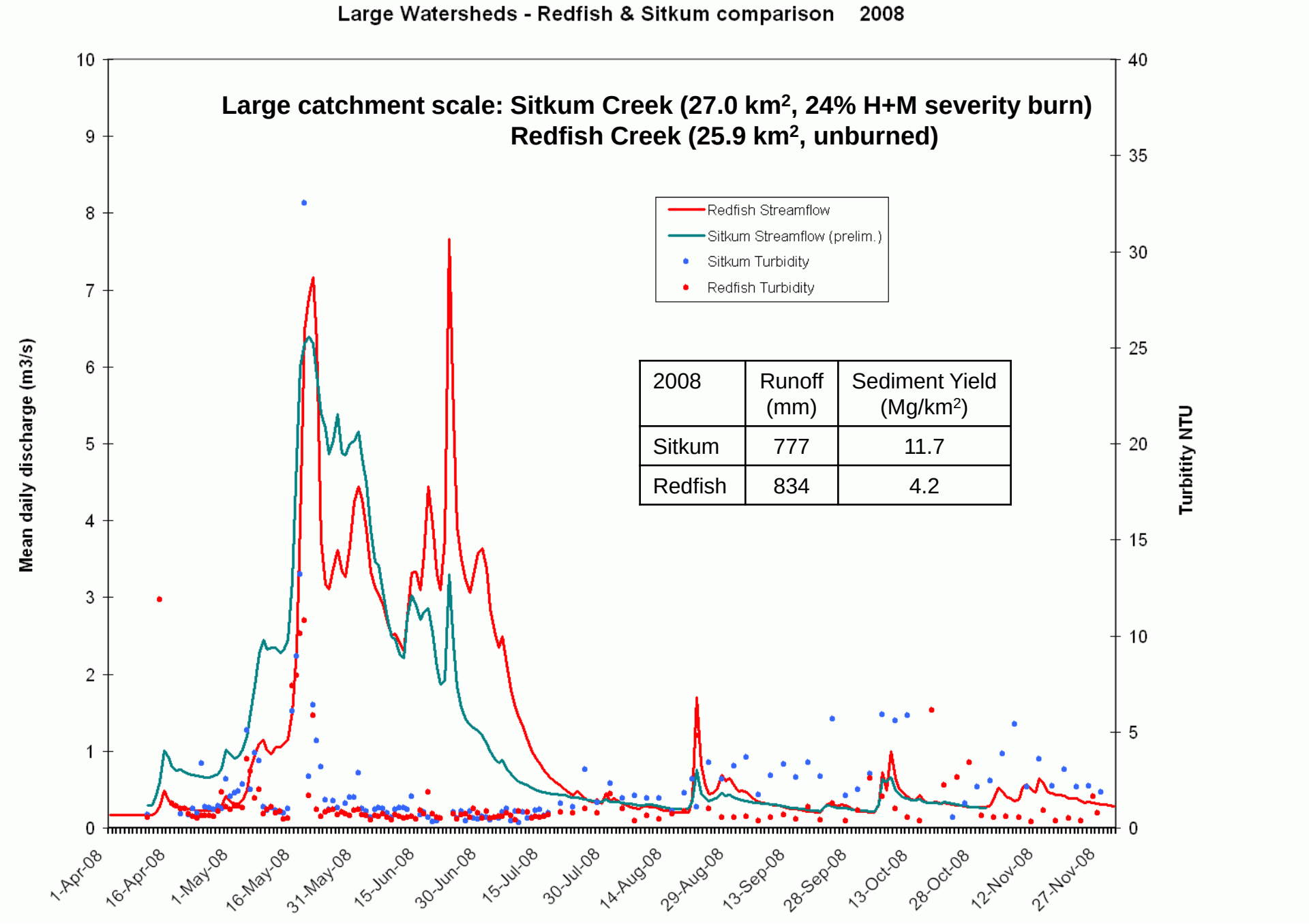
- only one significant rainstorm in 2 ½ seasons of measurement
- 75 mm rain in 3 days; most of it on the third day
- 24 hour rain was a 5-year return period event; shorter rainfall intensities were < 2 year return period
- storm runoff was 2 mm (average), less than 3% of rainfall
- sediment yield:
  T2 0.5 kg/ha = 0.0005 Mg/ha
  T3 0.8 kg/ha = 0.0008 Mg/ha
- these yields are 1000 to 10,000 times less than the site-scale silt fence plots
- effect of mulch was minimal – slightly lower sediment yield and less rapid runoff response





Catchment scale results for 2009, annual basis

- There were no significant rainstorms in the summer of 2009.
- T0 (unburned) – less diurnal variation during snowmelt; slower recession after snowmelt.
- T2 and T3 – more rapid snowmelt, higher total water yield.
- T2 and T3 have significantly higher turbidity (a measure of suspended sediment) than T0.
- Local factors confound interpretation of sediment results –organic material (eroded forest floor) in T2, logging in T3 catchment.
- Caution must be applied in drawing conclusions – there are no pre-fire data, and there may be unknown differences in pre-fire hydrologic response between the catchments.


Large Watersheds - Redfish & Sitkum comparison 2008
Large catchment scale: Sitkum Creek (27.0 km², 24% H+M severity burn)
Redfish Creek (25.9 km², unburned)
Redfish Streamflow
Sitkum Streamflow (prelim.)
Sitkum Turbidity
Redfish Turbidity
2008 | Runoff (mm) | Sediment Yield (Mg/km²)
Sitkum | 777 | 11.7
Redfish | 834 | 4.2
Mean daily discharge (m3/s)
Turbitity NTU
0
1
2
3
4
5
6
7
8
9
10
0
5
10
15
20
25
30
35
40
1-Apr-08
16-Apr-08
1-May-08
16-May-08
31-May-08
15-Jun-08
30-Jun-08
15-Jul-08
30-Jul-08
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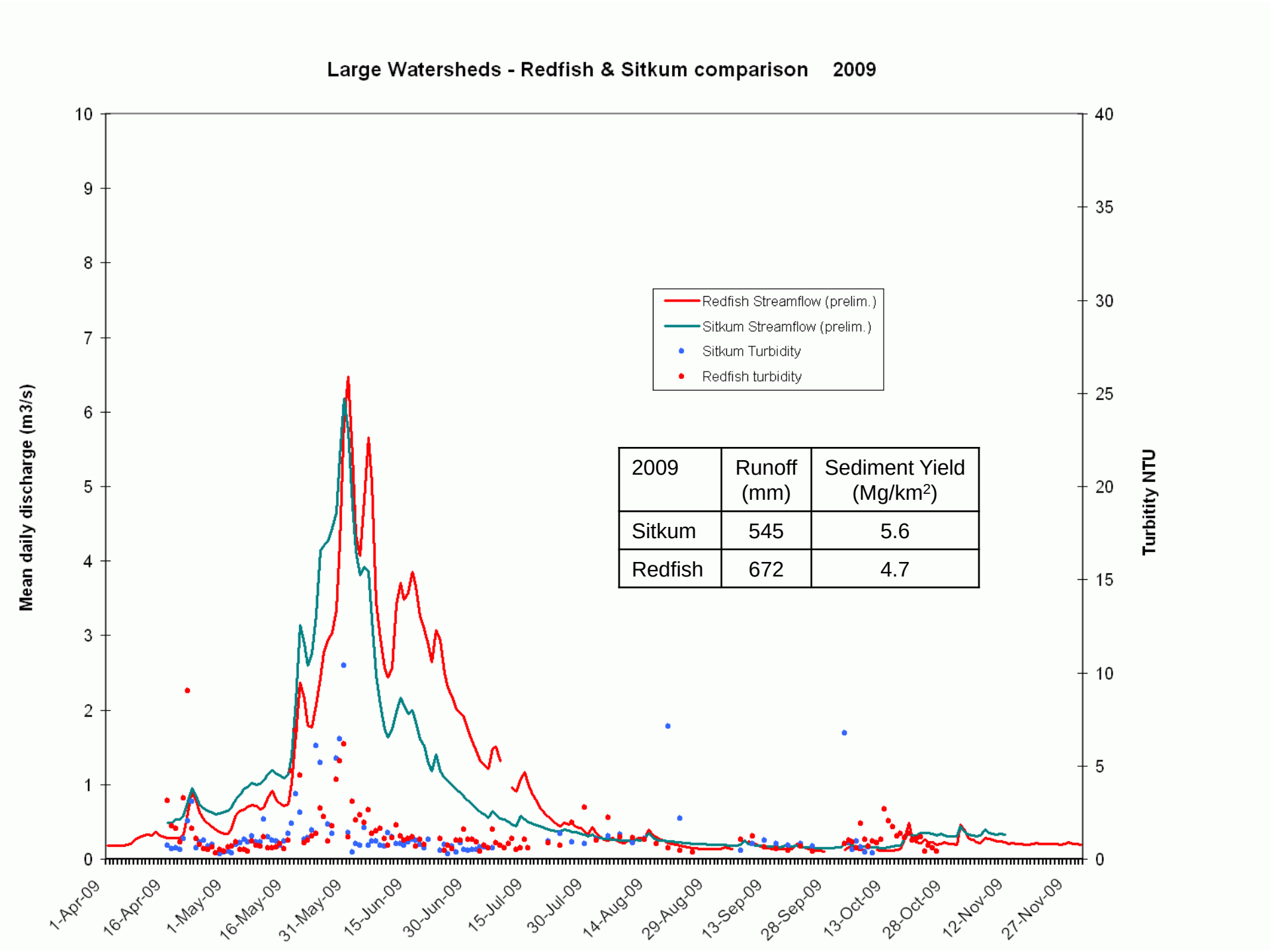
12-Nov-08
27-Nov-08


Large Watersheds - Redfish & Sitkum comparison 2009
Mean daily discharge (m3/s)
Turbitity NTU
Redfish Streamflow (prelim.)
Sitkum Streamflow (prelim.)
Sitkum Turbidity
Redfish turbidity
2009 | Runoff (mm) | Sediment Yield (Mg/km2)
Sitkum | 545 | 5.6
Redfish | 672 | 4.7
1-Apr-09
16-Apr-09
1-May-09
16-May-09
31-May-09
15-Jun-09
30-Jun-09
15-Jul-09
30-Jul-09
14-Aug-09
29-Aug-09
13-Sep-09
28-Sep-09
13-Oct-09
28-Oct-09
12-Nov-09
27-Nov-09

Catchment scale sediment yields are several orders of magnitude (10^2 to 10^4) lower than plot scale sediment yields. **Why?**

1. Many areas of apparently high soil burn severity have features which allow infiltration.

Root holes

Rocky areas

Rotten logs

We tend to not select these areas for our plot-scale experiments.

2. Intermediate storage – Most eroded sediment moves only a short distance downslope before being caught behind an obstruction, or by gentle slopes.

Sitkum Creek – U-shaped bowls have gently-sloping land between steep slopes and the channel, where sediment is deposited. Unburned riparian vegetation may also trap sediment.

Roads and logging trails may catch sediment, and allow infiltration in ditches – however, they also can cause drainage diversion and concentration. (Springer fire)

3. Scaling – Plots are 1 to 15 m long, typical hillslopes are much longer.

How infiltration capacity and erosion resistance develop on severely burned sites:

mushrooms
Sitkum fire,
year 3

Terrace Mtn,
year 1

A crust of fungus and moss forms at many sites
– mycelia and fine roots provide pathways for water
– moss absorbs raindrop impact

Infiltration and sediment transport at small scales, Sitkum T2 & T3 catchments:

– considerable erosion on dry, high-elevation sites, 3 years after the fire

– sediment is deposited on low-slope micro-sites, and behind obstructions

– wetter sites have dense vegetation, which traps sediment

Sitkum Creek sediment sources:

Salvage logging in 2009 – cutblock ground disturbance, recontoured forwarding trail, haul road

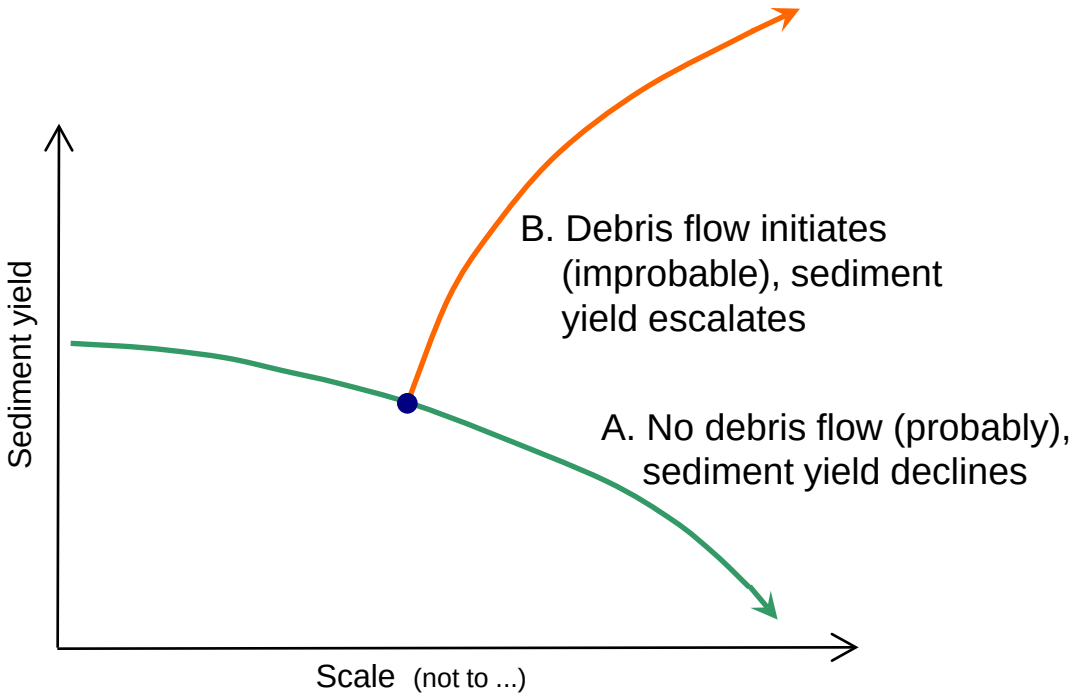
Conclusions:

- Shallow erosion takes place in areas of high soil burn severity, especially steep slopes, dry sites, and south aspects.
- Most sediment is carried only a short distance downslope, and deposited on gentler slopes or behind obstructions.
- Revegetation, and moss & fungal growth – reduce erosion, trap sediment, and provide infiltration pathways. Revegetation is fastest on moist sites, lower slope positions, and lower elevations.
- Erosion rates in this study were low (especially compared to some US studies) – but there were no high-intensity rainstorms during the study.
- Typical erosion rates across the landscape are low, and sediment delivery to streams is also low. (Watershed-scale sediment yields in this study were extremely low, and salvage logging was responsible for more sediment than was erosion from burned areas.)
- Mulching significantly reduces the amount of post-wildfire soil erosion. However, it is probably less effective at reducing overland flow.
- Water repellency was less extensive and continuous than in the 2003 fires. Water repellency may be less important than other factors (loss of forest floor, pore sealing) in generating overland flow.
- At some locations, landslides and channel erosion can occur – at these sites, sediment yield can be extremely high (in addition to the risks these events present to public safety and infrastructure).
- Post-wildfire landslides have occurred in 3 seasons (spring, summer, fall) due to snowmelt, high-intensity thunderstorms, and low-intensity frontal rain.
- Debris flows are the most common type of post-wildfire landslide – they usually originate in channels, and are usually caused by increased runoff (not by soil erosion and sediment bulking).

Typical post-wildfire sediment yields (very approximate, order of magnitude; applicable to this study area only)

(Caution: only 3 years of record; no unusually large or intense rainstorms have occurred)

- Source area (selected small plots, high soil burn severity): **1 Mg/ha**
- Catchment scale (no large-scale mass movement): **0.001 – 0.01 Mg/ha**
- Debris flows in small catchments: **100 Mg/ha**
  (most sediment comes from channel incision, not from burned area)



Debris flows: likelihood of occurrence (= hazard)

- logging and roads – increased 5-10 X
- post-wildfire – increased 10-100 times (if susceptible terrain exists and soil burn severity is high)

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the end

for publications on this project, go to:
ftp://ftp.for.gov.bc.ca/RSI/external/!publish/Wildfire_Risk_Analysis/Publications

thank you ....