Cameron Peak and East Troublesome Fires: What can we expect and why?

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Where I’ve worked on fires

40° N

California

Montana

Colorado Front Range

Plus Spain and Portugal
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  • Megan Sears and Eric Clark, CSU graduate students.
Outline

• Overview of fire effects on runoff and erosion;
• Summary data on the Cameron Peak and East Troublesome fires;
• Likely effects from snowmelt, especially in the higher elevation snow zones;
• Likely effects from summer convective storms;
• Fire effects on roads, trails, and ditches;
• Treatment priorities.
Basic processes: Infiltration rates after high and moderate severity fires typically <10 mm/hr
Post-fire headward channel extension

Large reduction in surface roughness
Huge increase in hillslope-stream connectivity!
Hillslope-scale sediment production rates increase by several orders of magnitude.

July 2012: just 18 mm of rain in Skin Gulch and 600 kg!

Overtopped sediment fence in Hill Gulch
Ash and coarser sediment may not travel together

Coarse sediment and ash captured in the first storm after the 2002 Hayman fire
Downstream effects

Bottom of Hill Gulch
Summer 2012

Ash and sediment-laden water at the diversion for the Monroe Tunnel
Extreme erosion and deposition in Skin Gulch one week after the High Park Fire
Deposition of ash and fine sediment at Picnic Rock, Cache la Poudre River
Alluvial fan from Saloon Gulch extending into the South Platte River, summer 2004 (two years after the 2002 Hayman fire)
Fire severity classes

Soil burn severity ≠ vegetation burn severity;
Can simplify into two classes for very rough first-year predictions:

• **High and moderate soil burn severity:** litter layer completely consumed and much of vegetation is killed, resulting in high runoff and erosion rates;

• **Low severity and unburned:** substantial amounts of ground cover and live vegetation, so minimal changes in runoff and erosion.
Percent bare soil vs. time since burning

- **High severity**
  - Formula: \( y = -26.09\ln(x) + 70.03 \)
  - \( R^2 = 0.63 \)

- **Moderate severity**
  - Formula: \( y = -21.86\ln(x) + 45.75 \)
  - \( R^2 = 0.60 \)

- **Low severity**
  - Formula: \( y = -10.44\ln(x) + 26.21 \)
  - \( R^2 = 0.49 \)
Sediment yield vs. percent bare soil

\[ y = 0.0029e^{0.095x} \]

\[ p < 0.0001 \]

\[ R^2 = 0.61 \]

\[ n = 345 \]
Annual sediment yields vs. time since burning: High severity sites

![Graph showing sediment yield vs. time since burning for high severity sites.](image-url)
Key controls on post-fire runoff and erosion

• Rainfall (or snowmelt) intensity and percent bare soil;
  - Key processes in the Colorado Front Range are rainsplash to detach soil particles, and overland flow to transport them and cause rilling and gullying;

• Slope, soil type, soil water repellency, soil rock content, and other factors generally play a secondary role.
Cameron Peak Fire: Burn severity
East Troublesome Fire: Burn severity

[Map showing burn severity with legend: High, Moderate, Low, Unburned/Very low]
### Percent area by burn severity class

<table>
<thead>
<tr>
<th>Fire</th>
<th>High</th>
<th>Moderate</th>
<th>Low</th>
<th>Unburned/very low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cameron Peak</td>
<td>5.8</td>
<td>30.6</td>
<td>43.7</td>
<td>19.9</td>
</tr>
<tr>
<td>East Troublesome</td>
<td>3.9</td>
<td>47.9</td>
<td>38.6</td>
<td>9.6</td>
</tr>
</tbody>
</table>

* Considerable uncertainty as snow cover limited post-fire LANDSAT data and field verification
Area in burn perimeter by elevation zone: Cameron Peak fire
Area in burn perimeter by elevation zone:
East Troublesome fire

![Histogram with Area in Burn Perimeter by Elevation Zone for East Troublesome Fire]

- 92% of the area is within the burn perimeter.

Axes:
- Y-axis: Acres within burn perimeter
- X-axis: Elevation (feet)
What changes in water quality and erosion can we expect, especially in the higher elevation zones?

Little Beaver Creek

Photo by E. Wohl
1. What will happen to the ash?

• Much of the ash has already been dispersed;
• Fire was immediately followed by snowfall;
• Snow and snowmelt will compact the ash and help incorporate it into the soil;

  Much less of the ash will be readily available for transport by wind or overland flow;

Little or no increase in turbidities to date.
2. Effects of the fire on snowpack, snowmelt, and size and duration of peak flows

- Increase in the snowpack due to less interception and less sublimation;
- Earlier and faster melt;

> Substantial increase in the size and duration of peak flows, possible headward extension of the channel network, and some bed and bank erosion.
Expected effects of the changes in snowmelt

1. Minimal hillslope erosion due to limited amounts of overland flow;

2. Some dirty water in the spring, but relatively low amounts of ash and sediment compared to Buffalo Creek, Hayman, and High Park due to less overland flow and dilution by unburned and low severity areas.

3. Can use Disturbed WEPP/QWEPP to predict the mass on a spatially-explicit basis.
What about the summer thunderstorms?
3a. Effects of summer thunderstorms

- At higher elevations (e.g., >~8500 ft) rainfall intensities are substantially lower than at lower elevations:
Maximum 1-hour rainfall rates by year for four SNOTEL sites

Rainfall (mm)

Water year

Copeland Lake: 2621 m (8599 ft)
Black Mountain: 2719 m (8921 ft)
Hourglass Lake: 2859 m (9380 ft)
Joe Wright: 3085 m (10121 ft)
3a. Effects of summer thunderstorms

• Burned areas will have had 9 months of regrowth and consolidation of the soils and ash;
• Higher rock contents at higher elevations lower soil erodibility;
• Very little area burned at high severity;
• No data on post-fire runoff and erosion from spruce-fir forests, but after the 2002 Mt. Zirkel fire complex the primary sediment sources were in-channel erosion;
• I would expect low hillslope erosion rates in the persistent snow zone, and low-to-moderate erosion in the 8500-10,000 foot zone.
3b. Effects of summer thunderstorms: Low and mid-elevations

- Lower sensitivity in these two fires than after “normal” June fires when high-intensity rainstorms occur just after burning;
- Relatively low risk due to small proportion of burned areas at lower elevations, and limited areas burned at high severity;
- Water users should be prepared for periodic high suspended sediment loads, but the upstream location of these fires will allow for greater dilution than after the High Park fire;
- Effects will depend on what large storms occur where.
Roads, trails, and fire lines

- Unpaved roads have very low infiltration rates so they generate more runoff and unit area erosion than wildfires!

Higher erosion due to increased hillslope runoff after burning.

Sosa-Perez and MacDonald, 2016
After a fire, nearly all of the roads in areas burned at high and moderate severity are connected to a stream!

Sosa-Perez and MacDonald, *ESPL*, 2016
Debris flows

- Debris flows can and do occur in the areas covered by the Cameron Peak and East Troublesome fires, but I’ve seen very few in Colorado, especially post-fire;

- USGS model tends to overpredict their likelihood, and hyperconcentrated flows are often inaccurately considered to be debris flows;

- Predicted debris flow volumes are highly inaccurate and typically orders of magnitude too large;

- Definitely a concern, but in my opinion more on a geologic than management time scale.

D. Coe, Cal-Fire, pers. comm.
Potential post-fire treatments

• Hillslope treatments to reduce runoff and erosion are not cost-effective, especially at larger scales;
  - How do we know where a large storm will occur?
• Road (and possibly trail treatments) are the most cost-effective:
  - Install larger culverts or low water crossings;
  - More frequent drainage.

Gannon et al., 2019
P. Robichaud, USFS
My big concern:
Post-fire conversion of lower elevation areas to grass/shrubland

Hayman fire, about seven years after burning

Climate change will only make it harder for trees to regrow, and is increasing area burned!
Conclusions

• We are likely to see a substantial increase in snowmelt peak flows, and these will cause channel erosion, delivering some ash and sediment into the streams and rivers;

• Hillslope erosion most likely to occur at mid- and lower elevations from thunderstorms in the first summer after burning; lower risk than other Front Range fires due to lower burn severity, limited area at lower elevations, and regrowth;

• Treatment efforts should focus on roads and trails;

• Restoration efforts should be focused on planting ponderosa pine trees in lower elevation areas where there is no seed source within about 200 m;

• I am cautiously optimistic, but Nature calls the shots!
Questions?

For publications type “Lee MacDonald, Colorado” into google
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Sediment and wood inputs to Ralph Price Reservoir following the September 2013 long-duration flood

Pre-flood

Post-flood

Rathburn et al., *Geology*, 2017
Area in burn perimeter by vegetation type

- Ponderosa pine: 20,000 acres
- Mixed-conifer: 20,000 acres
- Lodgepole pine: 90,000 acres
- Spruce-fir: 35,000 acres
- Aspen: 5,000 acres
- Riparian: 5,000 acres
- Other: 15,000 acres
Causes of Post-fire Runoff and Erosion

- Soil water repellency
- Loss of surface cover
- Loss of organic matter
- Reduced roughness
- Soil sealing
- Increased velocity
- Rainsplash
- Increased soil erodibility
- Loss of plant canopy
- Reduced interception and transpiration
- Increased runoff (peak flows, water yield)

Increased surface erosion (rainsplash, sheetwash, rilling, gullyling)
Maximum 1-hour snowmelt rates by year for four SNOTEL sites

- **Copeland Lake**: 2621 m (8599 ft)
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Ground cover changes in Lower Hill Gulch: August 2012 – September 2013

Over 13 months live vegetation increased from <5% to 27%
Bare soil decreased from 70% to 41%
Regrowth is critical for reducing hillslope runoff and erosion, hillslope-stream connectivity, and downstream sediment transport.

Lower Hill Gulch
Same channel after the September 2013 flood:
1 m of thalweg incision, 20 m² increase in channel area,
much of the fine sediment washed away
Effects of large floods:
Hill Gulch after the 1976 Big Thompson flood

Would this have looked any different if there had been a fire beforehand?
Effects of High Park fire and 2013 flood: Lower Hill

July 2013

22 Sept. 2013

September 2016
1996 Buffalo Creek fire and the following 100-year storm contributed <10 years of sediment above the background rate, while the much larger Hayman fire contributed very little.

Dredged 230,000 yd³ $20 million!
Sediment and wood inputs to Ralph Price Reservoir following the September 2013 long-duration flood

Pre-flood

Post-flood

Rathburn et al., *Geology*, 2017
Effects of a large flood vs. fires: Example 2

- In the St. Vrain watershed the September 2013 storm caused more than 100 years of watershed-scale erosion (Rathburn et al., Geology, 2017);
- About 60% of this or 300,000 m$^3$ was transported down to Price Reservoir, with about 100,000 m$^3$ being delivered into the reservoir from 2013-15;
- 2013 flood transported more sediment down to Price Reservoir than the total sediment inputs into Strontia Springs Reservoir following both the Buffalo Creek and Hayman fires.
Why are fires not so important at larger scales as compared to floods?

1. Fires are a mix of burn severities
   Typically about half of a burned area is either unburned or burned at low severity;

2. Summer thunderstorms drive most post-fire erosion in the Rocky Mountains, but these typically cover only a small area;

3. Fires mostly occur in headwater areas, so they rarely burn an entire watershed;

4. Duration of post-fire increases in runoff and erosion typically persist for only about 2-3 years;
   - Areas with poor soils and drier climates take longer.
Fires and floods: a longer-term context

- Post-fire deposition into Strontia Springs Reservoir added no more than a decade or so of sediment inputs under unburned conditions;

- Long-term denudation rates in the Colorado Front Range are around 0.05 mm/yr;
  - Post-fire erosion typically about 20-40 Mg/ha, or about 1 mm;
  - Moderate and high severity fires would have to occur about every 20 years to account for the long-term denudation rate;

- Fires cannot be the dominant cause of long-term erosion, at least in the Rocky Mountains;

- No time, but the same arguments apply to the Sierra Nevada and the Cascades.
1996 Buffalo Creek Fire:
Still almost no ponderosa pine!
Starting dates of fires in Colorado
>1,000 acres by week: 1992-2015

plot by Russ Schumacher/Colorado Climate Center
data source: USDA Fire Program Analysis fire-occurrence database
Spring 2013: Snowmelt and low-intensity rains caused minimal hillslope erosion, but incised into and eroded some of the deposited sediment.

Skin Gulch during spring snowmelt (11 months after burning)
Fires are a mix of green, brown, and black
Sediment and wood inputs to Ralph Price Reservoir following the September 2013 long-duration flood

Pre-flood

Post-flood

Rathburn et al., *Geology*, 2017
Effects of a large flood vs. fires: Example 2

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Why are fires not so important at larger scales as compared to floods?

• The floods that deliver most of the sediment to downstream dams and reservoirs are typically caused by a large amount of rain over a large area (e.g., entire watershed), causing higher and longer peak flows, so much more erosion and sediment transport, especially in the larger valley bottoms;

• High Park fire had very little geomorphic effect on the Cache la Poudre River, while the 2013 flood caused much larger geomorphic changes, especially in larger watersheds;

• More debris flows from the 2013 flood than we’ve observed after fires outside of Southern California.
High flows resulting from a 30-minute rainfall intensity of 19 mm per hour one year after the Buffalo Creek wildfire

Photo by John Moody, USGS
Wind and surface runoff very good at removing straw mulch!

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

* = Significant treatment effect (p<0.05)
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

* = Significant treatment effect (p<0.05)
Huge expansion of channel network resulting in very high connectivity, but channels rapidly disappear with regrowth, reducing hillslope connectivity (Wohl and Scott, in review)
Lower Brush Creek: Upstream of flume
Post-fire deposition in Saloon Gulch: Flow now subsurface, leading to high persistence
Reservoir sedimentation:
A huge concern AND persistent

• 1996 Buffalo Creek and 2002 Hayman fires caused about 1 million m$^3$ of deposition into Strontia Springs Reservoir;

• Converts to only about 20 years of sediment inputs;

• Denver Water spent $30$ million on dredging, but only removed about 25% of this amount;

• Water utilities are initiating and supporting forest thinning efforts to reduce fire risk, but this is probably not economic given the costs and low probabilities of burning.
Fire severity classes

• Need to distinguish between vegetation fire severity and soil burn severity;

• **High severity**: vegetation completely killed, litter layer completely consumed, and surface soil altered by consumption of soil organic matter and fine roots (“soil disaggregation”);

• **Moderate severity**: nearly all vegetation killed but some burned and unburned needles may be left on trees and fall to the forest flow; litter layer completely consumed but mineral soil unaltered;

• **Low severity**: larger trees not killed, litter layer not completely consumed, and burning very patchy.
Area in burn perimeter by snow zone

- Intermittent snow zone (31%)
- Transitional snow zone (49%)
- Persistent snow zone (20%)

Elevation (feet) vs. Acres within burn perimeter graph.
Cache la Poudre boundary above Canyon Mouth

Cameron Peak

High Park