Wildfire-Induced Flooding and Erosion Potential Modeling: Examples from Colorado, 2012 & 2013

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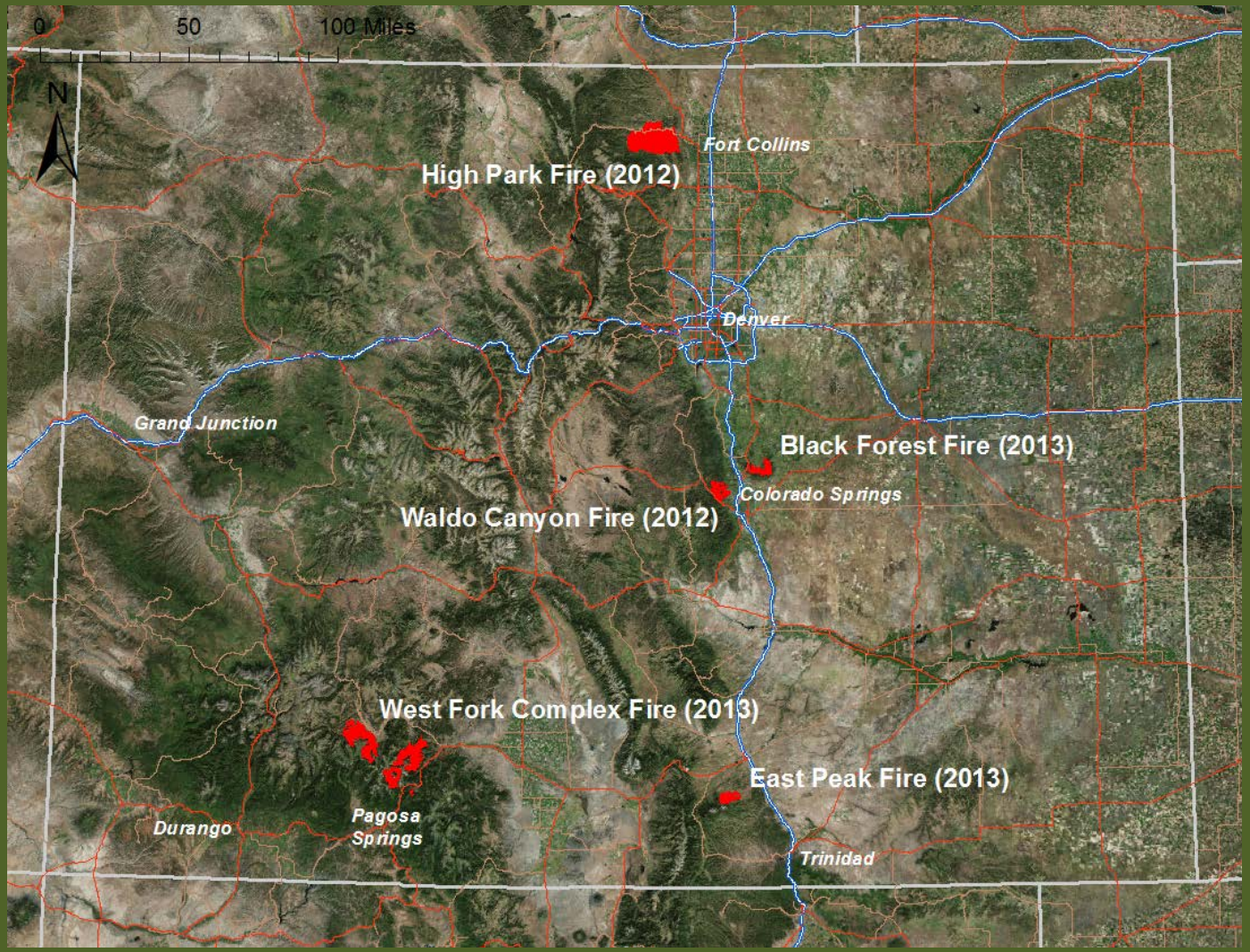
Presentation Overview

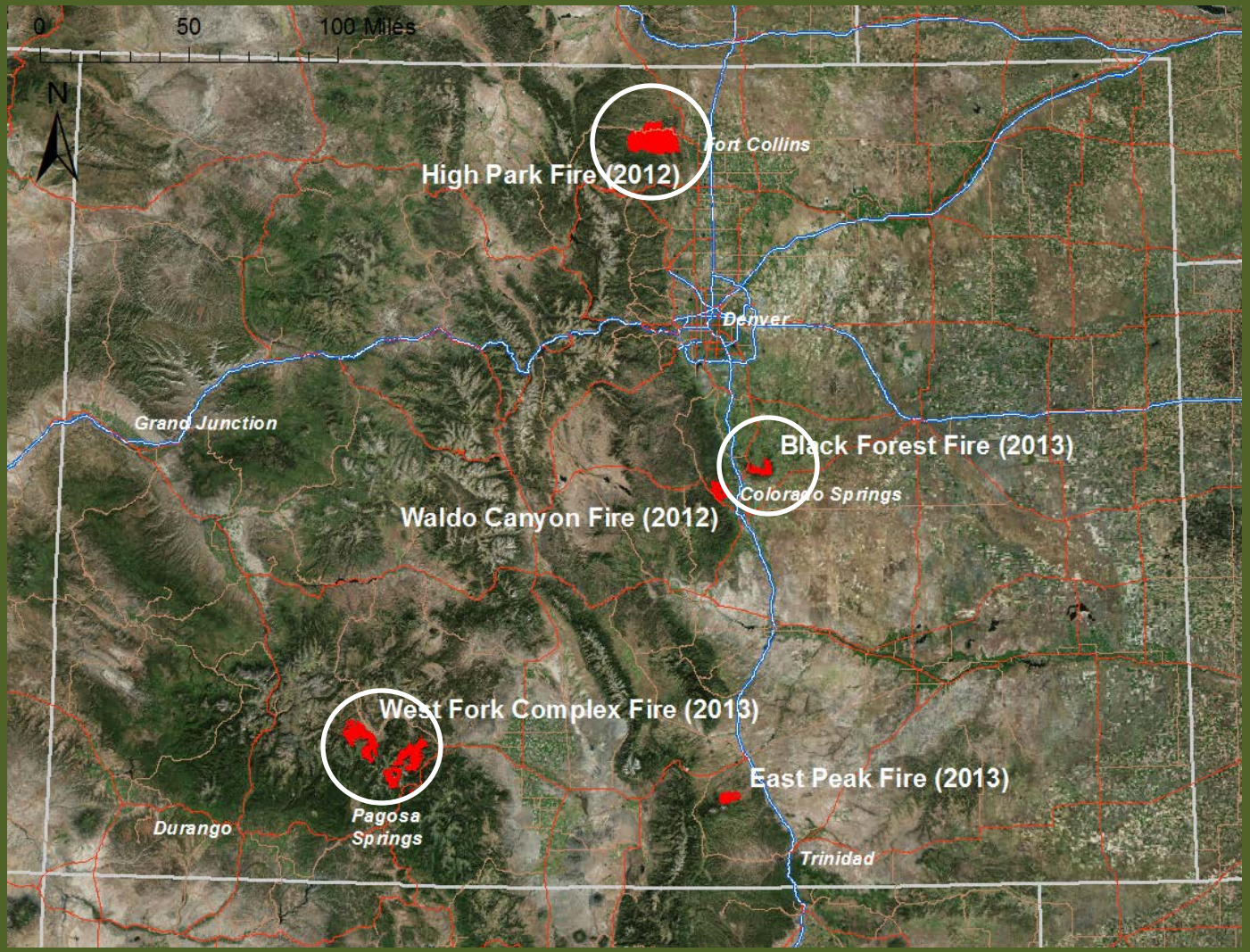
- Overview of some of the most substantial Colorado wildfires of 2012 and 2013.
- Overview of flood responses and fundamental processes
- Modeling results, products, and limitations
- Qualitative review of modeling results in comparison to observed runoff events

Sheldon Lake at City Park, Fort Collins, 6/9/2012

Most Substantial Colorado Wildfires: 2012 & ‘13



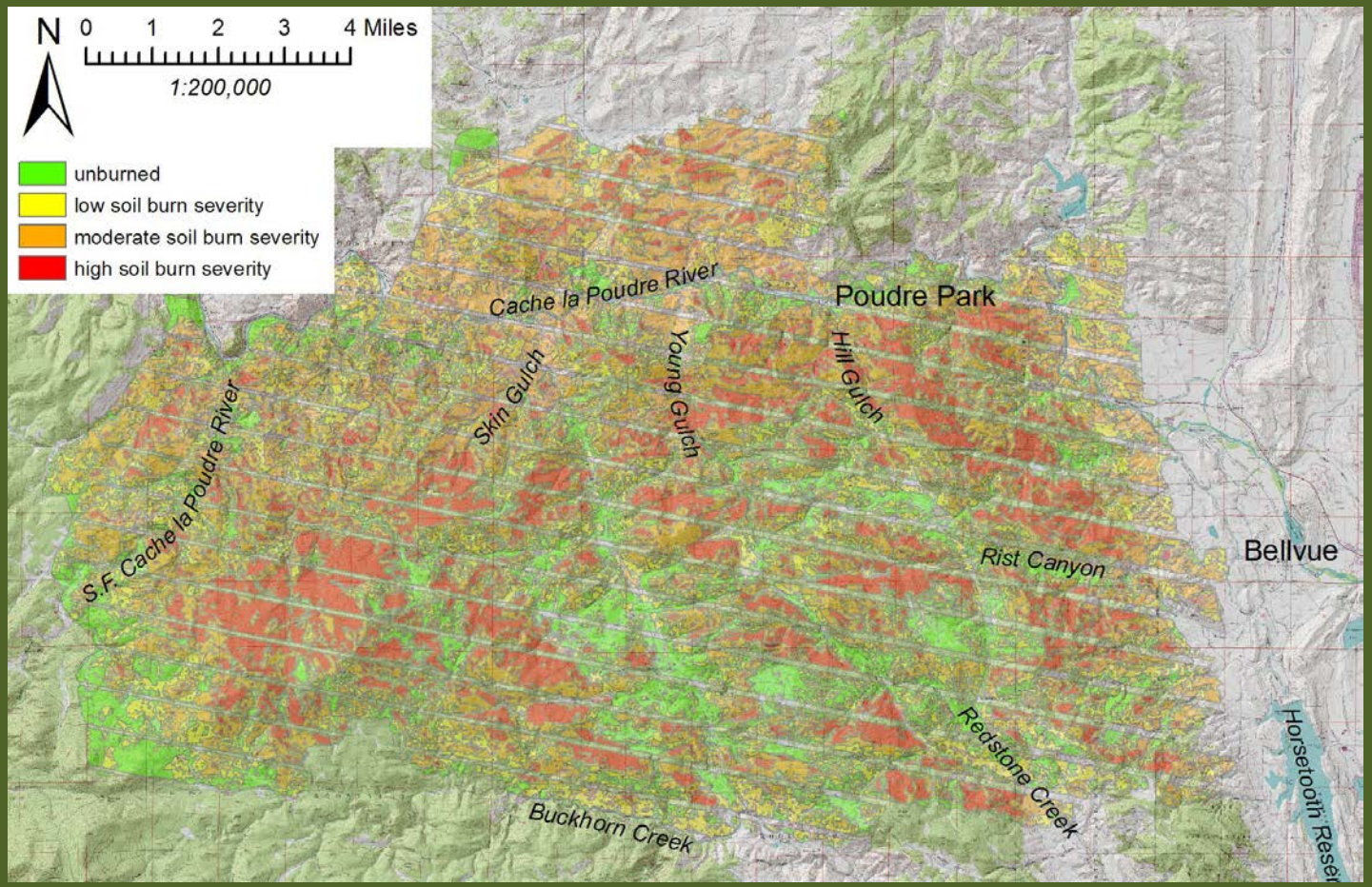
Focus of Analyses



High Park Wildfire (2012)

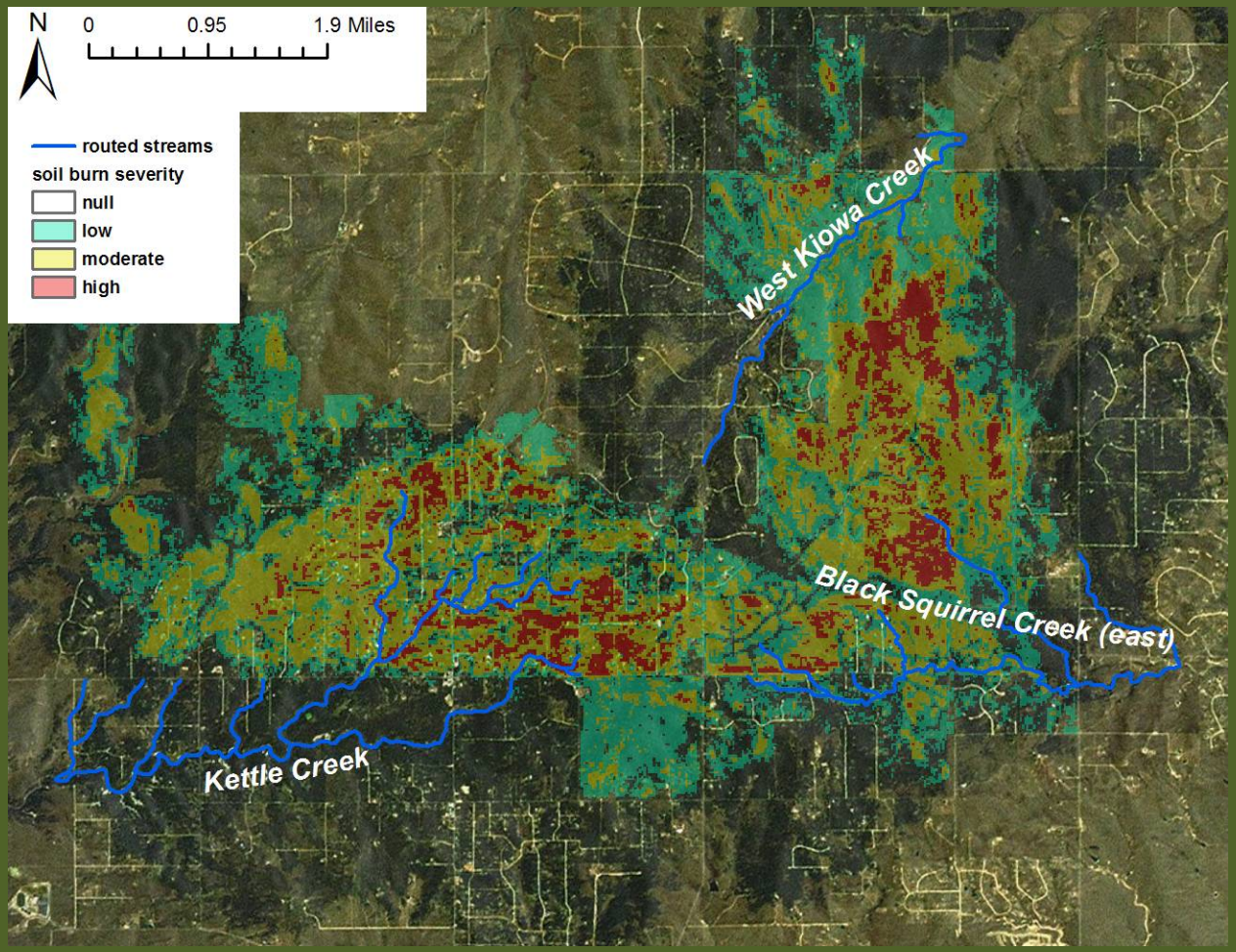
- Second-largest wildfire in state history (at the time)
- 87,000 acres
- Roughly 50% on private lands

derived from Landsat 7



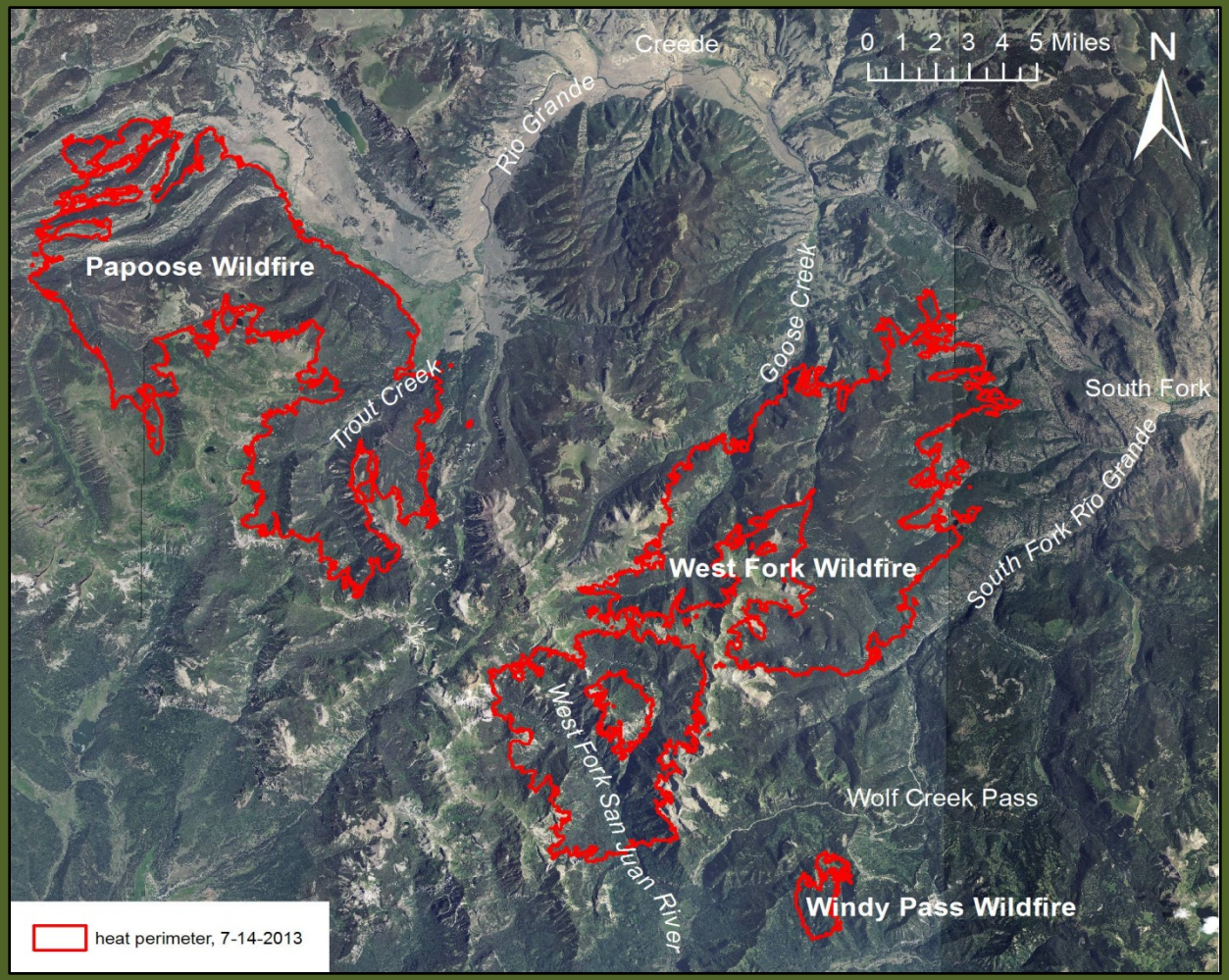
Black Forest Wildfire (2013)

- Most property destruction in Colorado history
- 14,300 acres
- no federally-managed lands
- no BAER



West Fork Complex Wildfire (2013)

- Second-largest wildfire in Colorado History
- 109,000 acres



Floods Occur Immediately after the Wildfires

- Fire season tends to substantially reduce intensity in early to mid July, with “monsoon” rains in Colorado.
- With these rains come floods from the freshly-burned landscapes
- These floods are sediment and ash-laden
- Debris flows can also be common

High Park Fire, Rist Creek
7/6/2012

Floods Occur Immediately after the Wildfires

High Park Fire, Falls Gulch, 6/27/2012

Falls Gulch confluence with Cache la Poudre River 6/27/2012

- First flush of ash after fire.
- Substantial negative impacts on water quality and municipal water supply.

Floods Occur Immediately after the Wildfires

- First flush of ash after fire
- Substantial negative impacts on water quality and municipal water supply (& beer!)

Hill Gulch, 7/6/2012

High Park Fire, Cache la Poudre River, 7/6/2012

Scientific Background of Wildfire Hydrology

Denver Post

- Substantially increased runoff and sediment production result from:
  - Loss of vegetation interception
  - Loss of ground litter & cover
  - Loss of surface roughness
  - Hydrophobicity

- Hydrophobicity: Fire-induced vaporization and condensation of organic compounds, creating a waxy layer
  - Greatly reduces infiltration
  - Sandy soils -- more hydrophobicity

Scientific Background of Wildfire Hydrology

High soil burn severity ground surface.

- Dramatic changes in surface condition can result in:
  - Shift in rainfall response from infiltration-dominated processes to surface-runoff dominated processes (Hortonian Overland Flow)
- Undisturbed forests: Saturation-excess overland flow (variable source area) is likely dominant
  - This shift in process is a fundamental problem for Wildfire Hydrology

Scientific Background of Wildfire Hydrology

Moderate & high soil burn severity watershed

- Example: Runoff response from a burned Swiss catchment resulted in
  - 10-year rainfall event causes 100- to 200-year runoff
  - Conedera et al. (2003)
- Spatial scale is important:
  - Greater runoff enhancement can be expected from smaller catchments
  - Post-fire runoff is oftentimes overestimated from larger watersheds

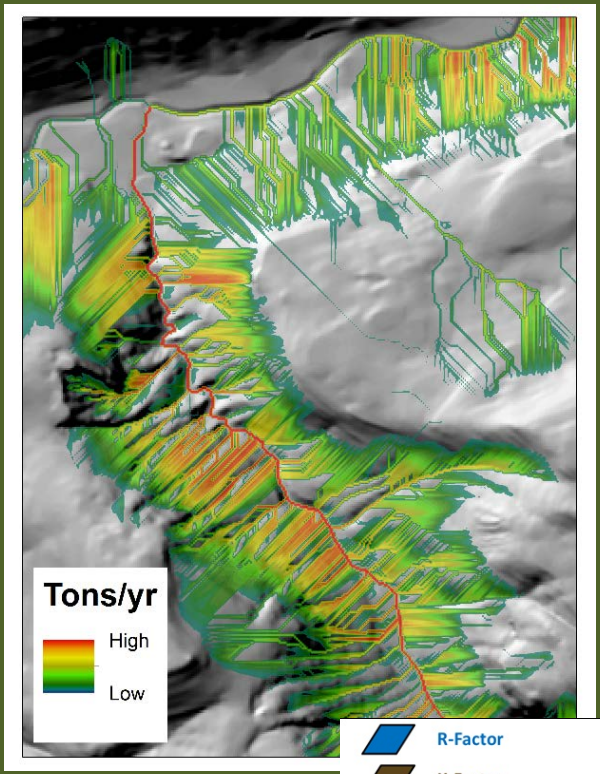
Analyses Performed

High Park Fire, NASA image

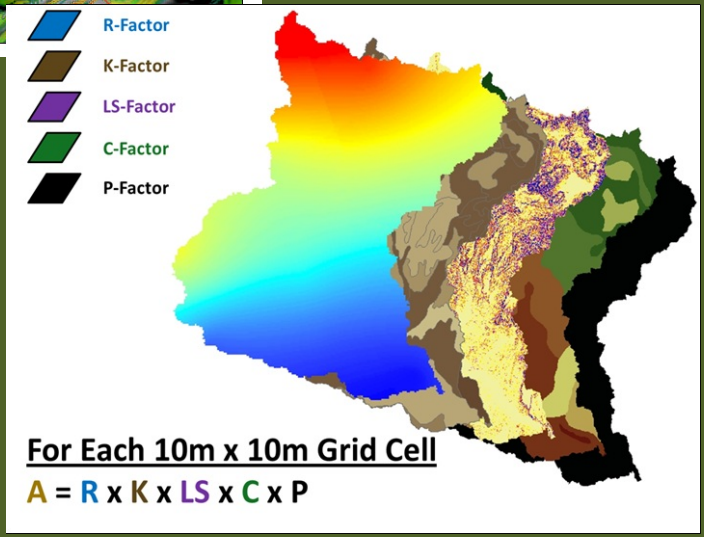
- Objective: Provide local officials and first responders with estimates at primary points of concern (at values at risk) downstream of wildfire areas
- For each of these wildfires, the following analyses were performed, for pre- and post-fire conditions
  - Curve Number (CN) based runoff estimates
  - Revised Universal Soil Loss Equation (RUSLE) estimates

Methods

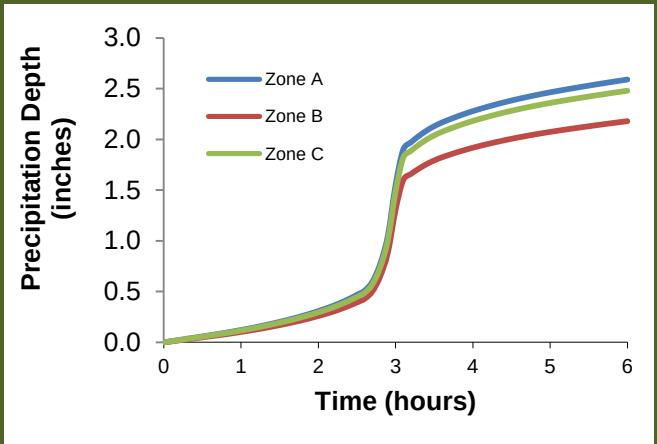
- CN: semi-distributed model, with limited size catchments and stream routing
- RUSLE: GIS modeling, with stream routing and deposition/sediment reduction
- Refer to:
  - SEDHYD-2015 proceedings paper
  - Individual project reports

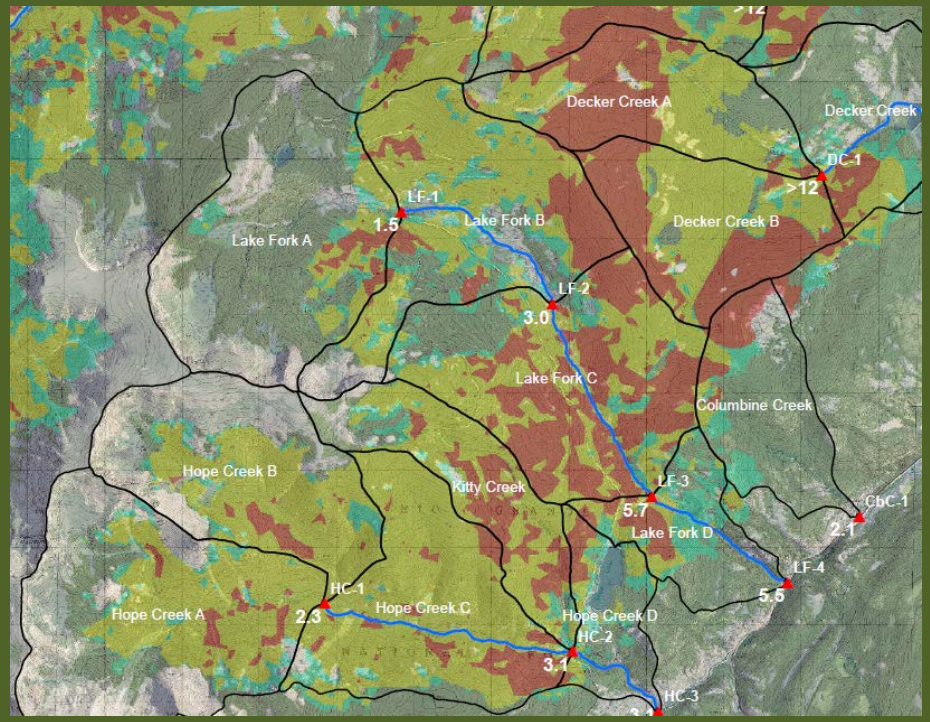


RUSLE modeling



CN modeling



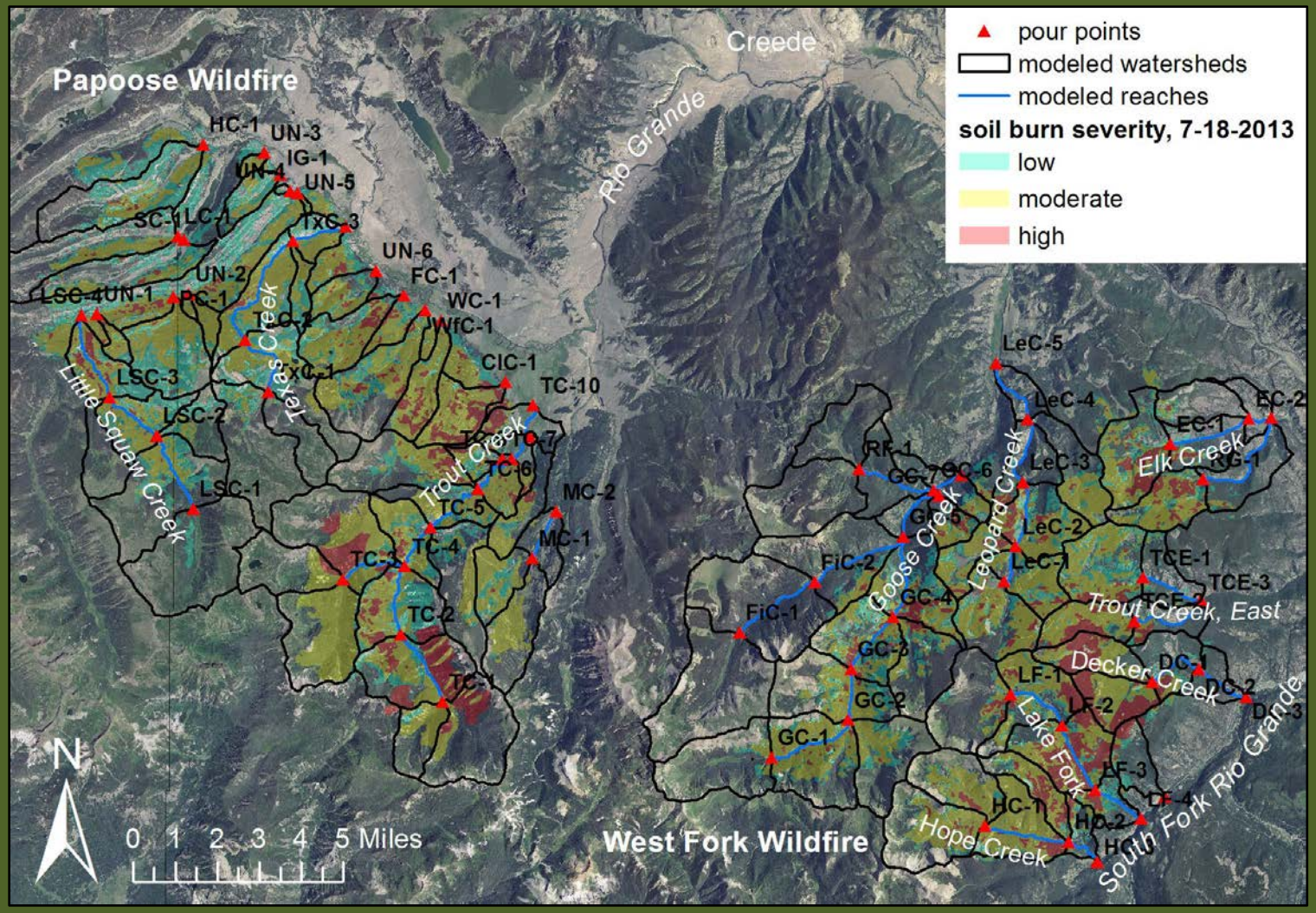


South Fork Rio Grande, West Fork Complex Fire

Results

- Provided estimates of expected increase in peak flow and sediment from wildfire areas, at pour points
  - High Park Fire: 96
  - Black Forest Fire: 52
  - West Fork Complex: 70
- Results communicated using post/pre fire response ratios
  - ratio of 3.1 = 3.1 times the pre-flood runoff expected given the same rainfall

Example Results: West Fork Complex Fire



- Blue lines indicate modeled stream reaches
- Catchments usually less than 2000 acres in size, with a maximum size of 3900 acres.

Example Results: West Fork Complex Fire

West Fork Complex Fire Area Estimated Flood Magnification
South Fork Rio Grande **12/12/2013**

USDA NRCS
United States Department of Agriculture
Natural Resources Conservation Service

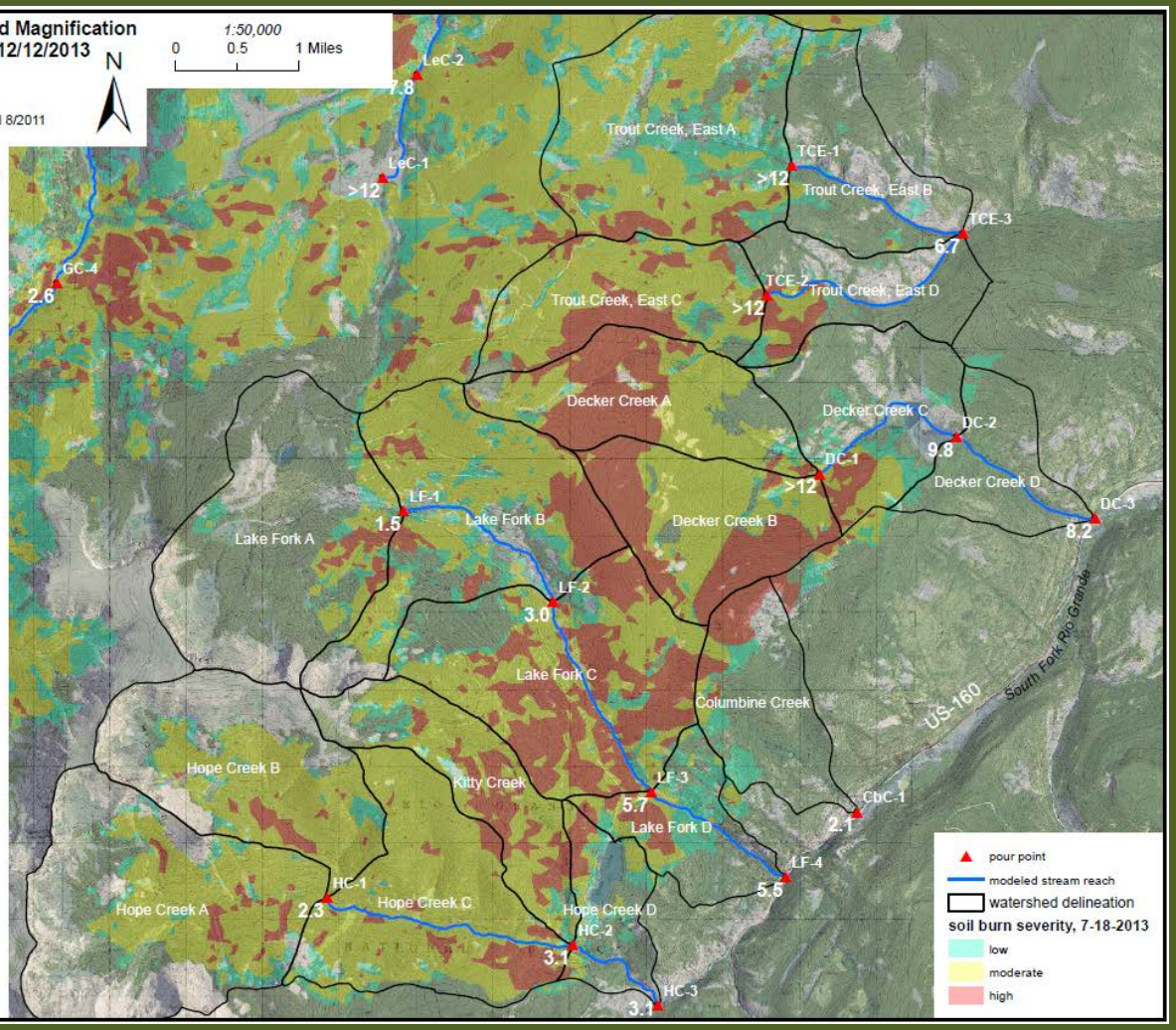
aerial imagery collected 8/2011

Peak flow predictions and flood magnification ratios are provided for the 6-hour, 25-year rain event. The magnification ratios (larger bold, white numbers) are computed as (post fire peak flow) / (pre fire peak flow). Predicted peak flows are also provided in the table below.

Methods:
* Post and pre fire flows predicted using the NRCS Curve Number (CN) methodology, using a 6-hour rainfall event over the entire stream catchment.
* Simulation modeled in HEC-HMS (3.5).
* CN development accounted for hydrologic soil group, vegetation type and soil burn severity.
* Streamflow routing performed using Muskingum-Cunge methodology.
* Sediment bulking factor included in seperate prediction values, using a simple multiplication factor that is dependent upon the catchment percent moderate and high soil burn severity.
* Aerial precipitation reduction factors applied for catchements > 11 mi^2.

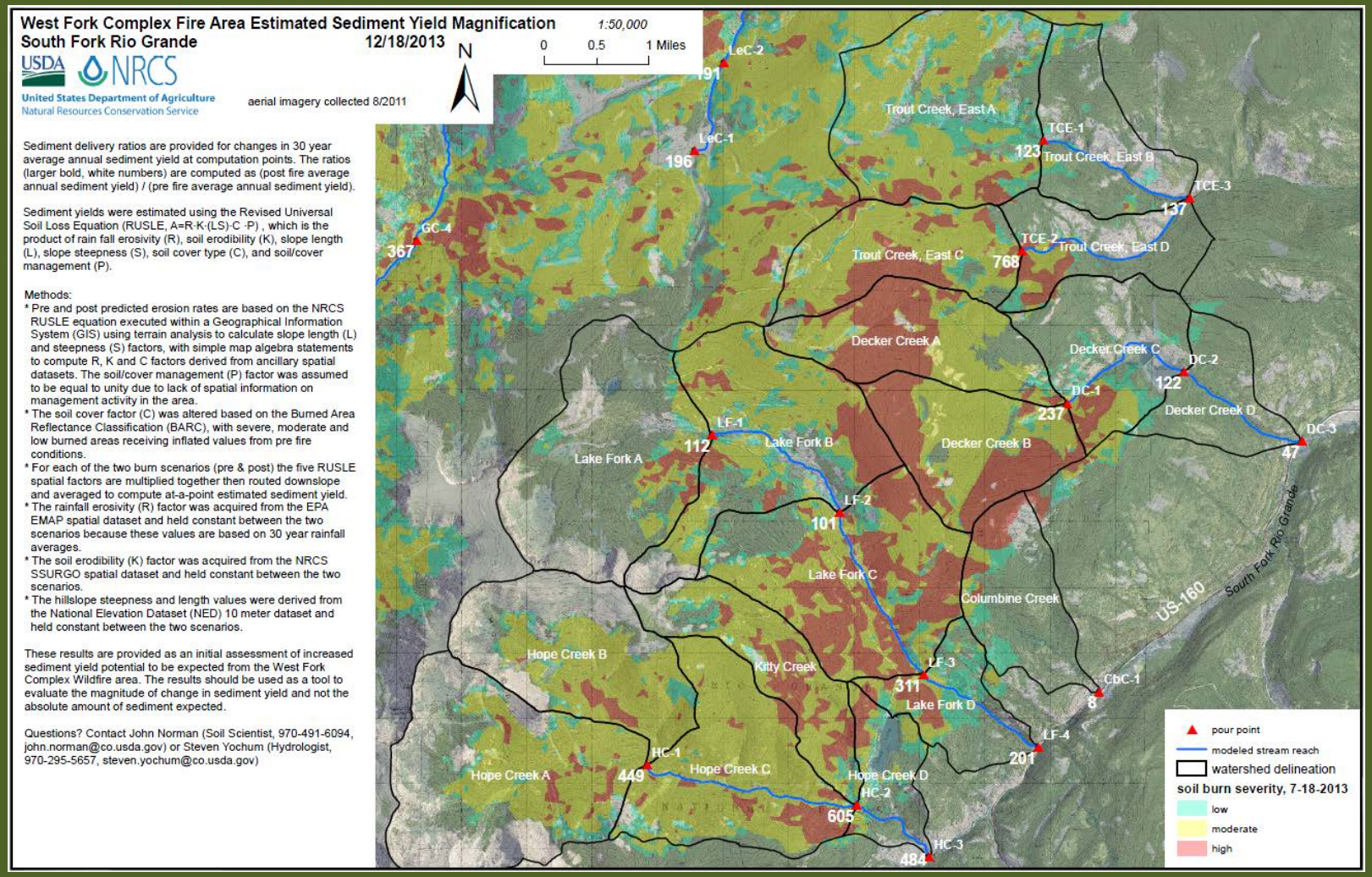
Questions? Contact Steven Yochum, NRCS Hydrologist (970-295-5657, steven.yochum@co.usda.gov)

Pour Point	Drainage Area (mi^2)	25-Year Rain Event Predicted Flow (cfs) Pre Fire	Post Fire	Bulking	Post/Pre Peak Flow
HC-A	3.58	370	780	850	**2.1**
HC-B	2.51	270	670	840	**2.5**
HC-1	6.09	630	1400	1800	**2.3**
KC	1.53	100	650	820	**6.3**
HC-2	10.20	860	2700	3300	**3.1**
HC-3	11.04	910	2800	3500	**3.1**
LF-1	3.34	140	210	210	**1.5**
LF-2	6.27	170	510	630	**3.0**
LF-3	9.50	240	1400	1700	**5.7**
LF-4	10.59	270	1500	1800	**5**
CbC-1	1.42	94	200	220	**2**
DC-A	1.90	44	610	760	**>12**
DC-B	1.85	77	1000	1200	**>12**
DC-1	3.75	110	1500	1900	**>12**
DC-2	5.56	170	1600	2100	**10**
DC-3	6.63	210	1700	2200	**8.2**
TCE-1	3.28	47	610	760	**>12**
TCE-2	1.79	26	510	640	**>12**
TCE-3	8.06	200	1300	1700	**6.7**



- 10-year rainfall causes 50- to 100-year floods
- 25-year rainfall yields up to 8 to 12 times the pre-fire runoff

Example Results: West Fork Complex Fire

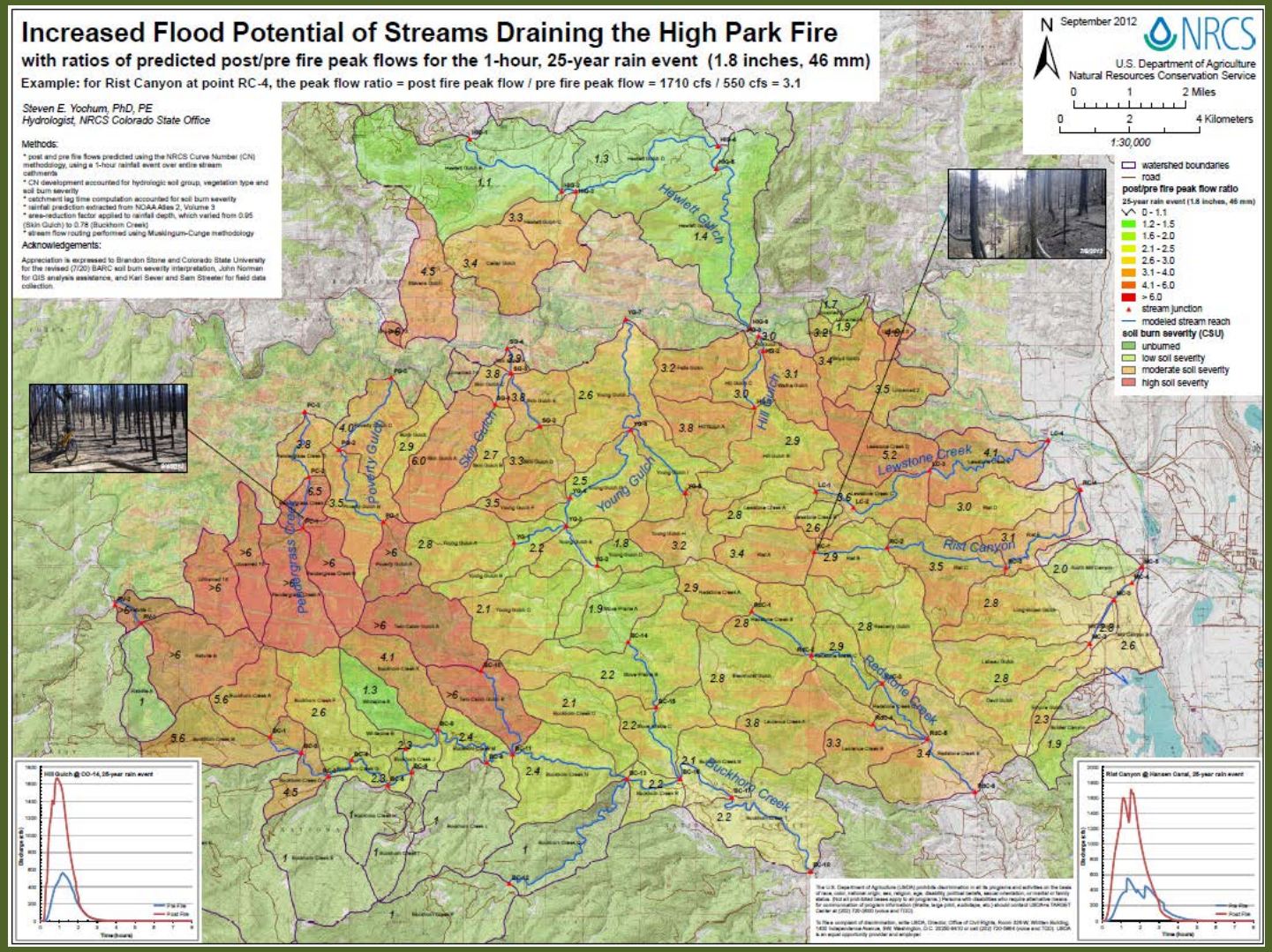


- Sediment rates 130-times greater than pre-fire, overall
- A number of locations have sediment ratios >200

Limitations

- Results are most appropriately used in a relative manner, comparing runoff and sediment liberation potential between catchments
  - Comparing the catchments and the values at risk can inform an educated ranking of priorities for treatment and mitigation
- The results are approximate, with the runoff estimates potentially questionable for such applications as:
  - Design flows for culvert replacements (though better than having NO design flows…)
- Uncertainty in results need to be effectively communicated with decision makers

Example Results: High Park Fire



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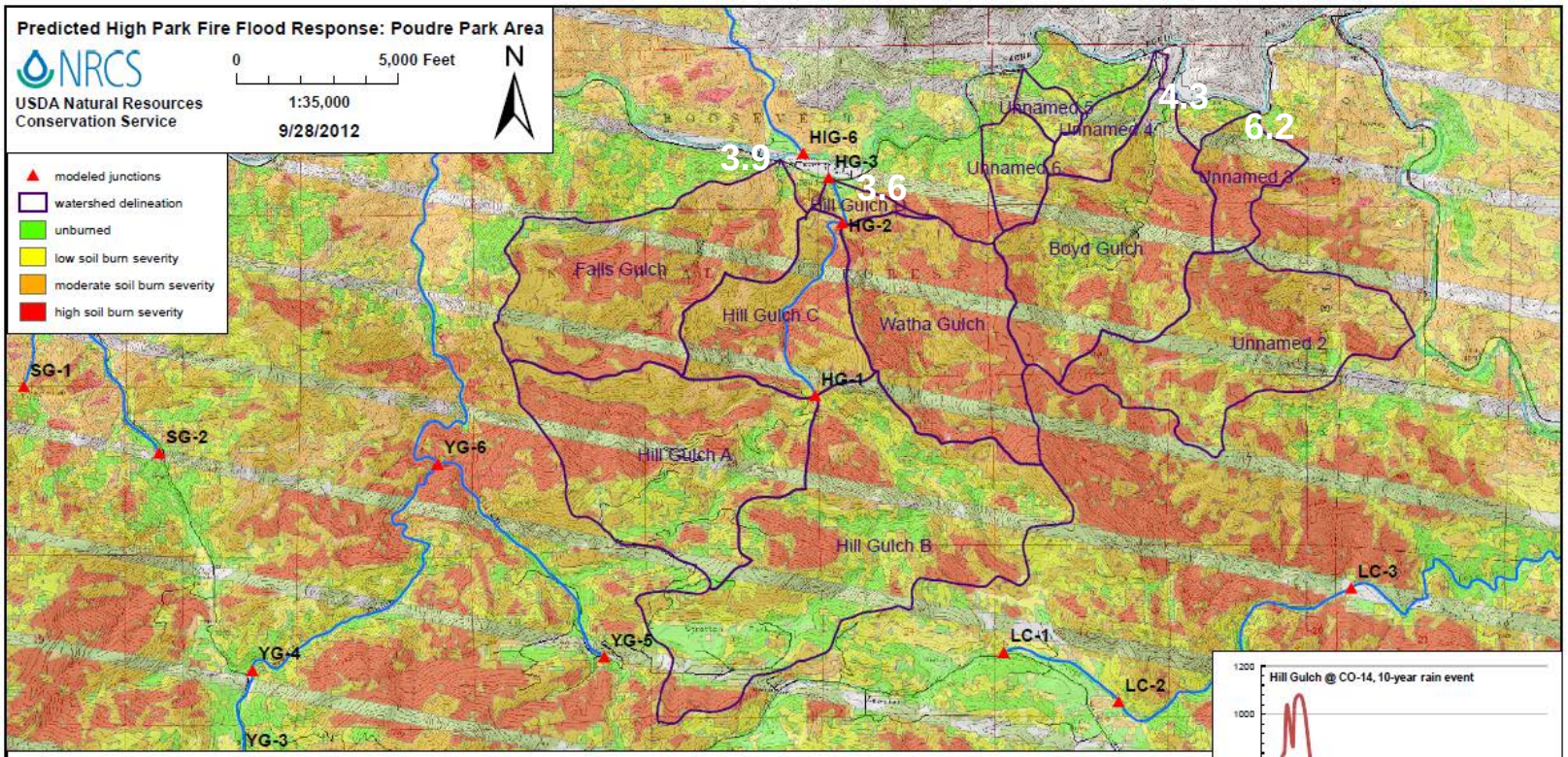
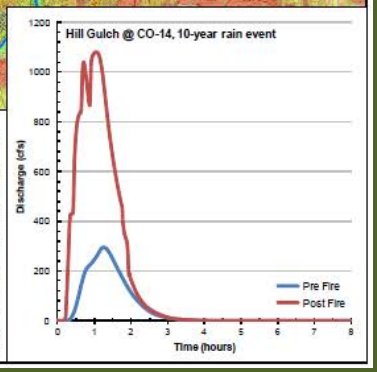
Example Results: High Park Fire



Junction or Catchment	Drainage Area (mi²)	2-Year Rain Event (0.8 inches) Predicted Flow (cfs) Pre Fire	Post Fire	Post/Pre Peak Flow	Sed. Bulking Flow (cfs)	10-Year Rain Event (1.5 inches) Predicted Flow (cfs) Pre Fire	Post Fire	Post/Pre Peak Flow	Sed. Bulking Flow (cfs)	25-Year Rain Event (1.8 inches) Predicted Flow (cfs) Pre Fire	Post Fire	Post/Pre Peak Flow	Sed. Bulking Flow (cfs)	50-Year Rain Event (2.2 inches) Predicted Flow (cfs) Pre Fire	Post Fire	Post/Pre Peak Flow	Sed. Bulking Flow (cfs)	100-Year Rain Event (2.4 inches) Predicted Flow (cfs) Pre Fire	Post Fire	Post/Pre Peak Flow	Sed. Bulking Flow (cfs)
Falls Gulch	1.33	6.3	120	20	160	140	550	3.9	680	240	770	3.2	960	390	1100	2.8	1400	480	1300	2.6	1600
Hill Gulch A	1.41	0	59	n/a	74	78	390	5.0	490	150	580	3.8	720	280	880	3.1	1100	360	1000	2.9	1300
Hill Gulch B	2.20	0	34	n/a	37	89	330	3.7	360	180	520	2.9	570	350	820	2.4	900	440	990	2.3	1100
HG-1	3.61	0	88	n/a	110	160	630	4.0	790	320	980	3.1	1200	600	1500	2.5	1900	760	1800	2.4	2300
Watha Gulch	1.12	12	150	12	180	150	580	3.7	720	260	810	3.1	1000	430	1100	2.7	1400	520	1300	2.6	1700
HG-2	5.45	12	200	17	250	290	1100	3.6	1300	560	1700	3.0	2100	990	2600	2.6	3200	1300	3000	2.4	3800
HG-3	5.53	12	200	17	250	300	1100	3.6	1400	560	1700	3.0	2100	990	2600	2.6	3200	1300	3100	2.4	3800
Boyd Gulch	1.22	0.30	76	253	95	97	420	4.3	520	180	610	3.4	760	310	900	2.9	1100	390	1100	2.7	1300
Unnamed 2	1.17	0	63	n/a	79	82	360	4.3	440	150	520	3.5	650	270	770	2.9	960	330	900	2.7	1100
Unnamed 3	0.28	0	28	n/a	35	21	130	6.2	160	42	200	4.6	240	81	290	3.6	360	100	350	3.4	430
Unnamed 4	0.20	0.40	5.8	15	6.4	21	48	2.3	53	38	74	1.9	81	67	120	1.7	130	83	140	1.7	150
Unnamed 5	0.089	0	1.2	n/a	1.3	7.9	17	2.2	19	16	27	1.7	30	29	43	1.5	47	36	51	1.4	56
Unnamed 6	0.21	0	6.2	n/a	6.8	12	55	4.6	61	26	82	3.2	90	52	130	2.5	140	67	160	2.4	170



- 10-year rainfall causes 50- to 100-year floods
- 25-year rainfall yields up to 5 to 10 times the pre-fire runoff

Reasonableness of Results: High Park Wildfire

Upper Pendergrass Creek area (9/4/2012)

Upper Rist Canyon (7/9/2012)

- Quantitative studies are being performed, though first monsoon season runoff events (immediately after fire) typically missed
  - These first events were often the most significant
- The focus of this presentation will be qualitative.

Reasonableness of Results: High Park Wildfire

9/9/2013

- Most dramatic responses observed from small catchments (< ~1.5 mi^2) with direct access to values at risk
  - Example: steep sloped mountainside immediately above a state highway
- These drainages had little flow previously observed

Reasonableness of Results: High Park Wildfire

- Small catchments with direct access to values at risk…
  - More of these should have been modeled.

Viewing upstream, 7/29/2013

Viewing downstream, 7/29/2013

Reasonableness of Results: High Park Wildfire

- Small catchments with direct access to values at risk…
  - >>1000 cfs from 1.3 mi^2 catchment

Falls Gulch, 7/29/2013

Reasonableness of Results: High Park Wildfire

- Small catchments with direct access to values at risk…
  - More of these should have been modeled.

Whale Rock Road, 7/29/2013

Rist Canyon, 7/29/2013

Reasonableness of Results: High Park Wildfire

- Medium size catchments (~2 to ~6 mi^2) also experienced flooding
  - Modeling for these catchments appear to be reasonable

9/9/2013

Alluvial fan deposit that partially dammed and was later mobilized by the Cache la Poudre River

Hill Gulch, 7/8/2012

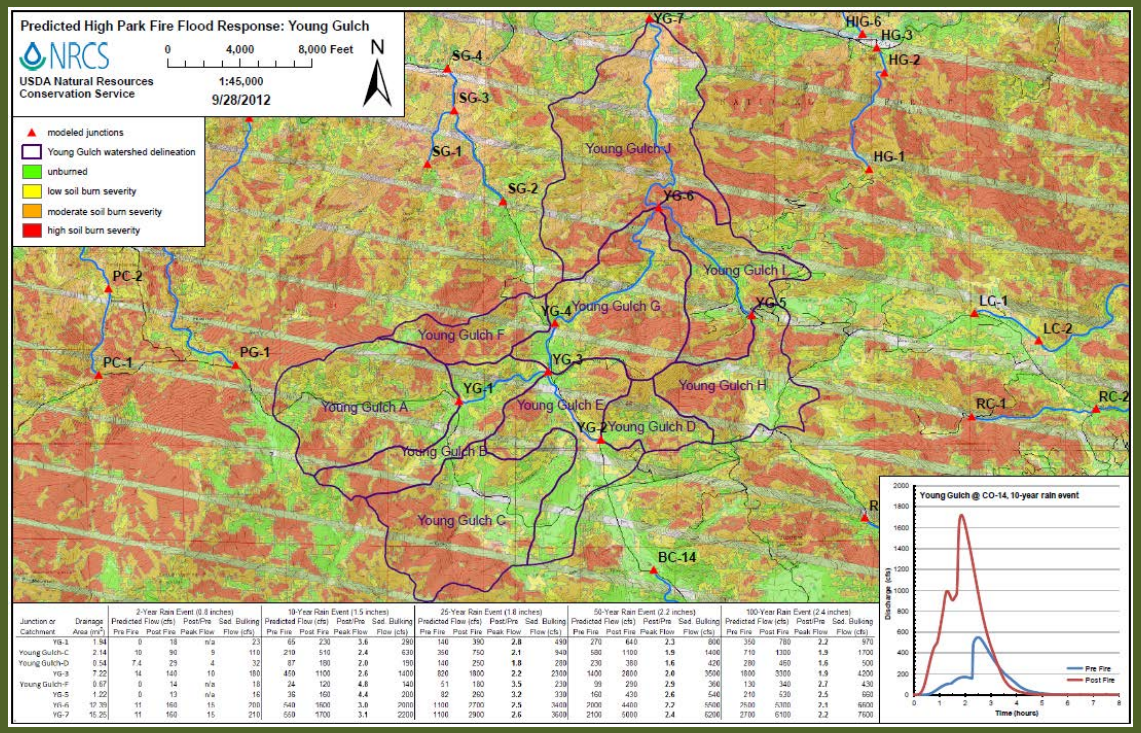
Reasonableness of Results: High Park Wildfire

- Medium size catchments (~2 to ~6 mi^2) also experienced flooding
  - Modeling for these catchments appear to be reasonable

Skin Gulch, 7/29/2013

Reasonableness of Results: High Park Wildfire

- Flood events not typically observed in larger-sized watersheds (> ~8 mi^2)
  - More typical rain events tend to impact smaller areas
- Exception: 2013 Front Range Flood
- Modeling substantially overestimated flows in these watersheds
- More research is needed



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YG-1	1.94	0	18	n/a	23	65	230	3.6	290	140	390	2.8	490	270	640	2.3	800	350	780	2.2	970
Young Gulch-C	2.14	10	90	9	110	210	510	2.4	630	390	750	2.1	940	580	1100	1.9	1400	710	1300	1.9	1700
Young Gulch-D	0.54	7.4	25	4	32	87	180	2.0	190	140	250	1.8	280	230	380	1.6	420	280	450	1.6	500
YG-3	7.22	14	140	10	180	450	1100	2.6	1400	820	1800	2.2	2300	1400	2600	2.0	3500	1800	3300	1.9	4200
Young Gulch-F	0.67	0	14	n/a	18	24	120	4.8	140	51	180	3.5	230	99	260	2.9	300	130	340	2.7	430
YG-5	1.22	0	13	n/a	16	36	160	4.4	200	82	260	3.2	330	160	430	2.6	540	210	530	2.5	660
YG-6	17.39	11	160	15	200	540	1600	3.0	2000	1100	2700	2.5	3400	2000	4400	2.2	5500	2600	6300	2.1	6600
YG-7	18.25	11	160	15	210	560	1700	3.1	2200	1100	2900	2.6	3600	2100	5000	2.4	6200	2700	6100	2.2	7500

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Questions?