Impact of Wildfires on Water Quality and Treatment

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Wildfires

Wildfires

Wildfires

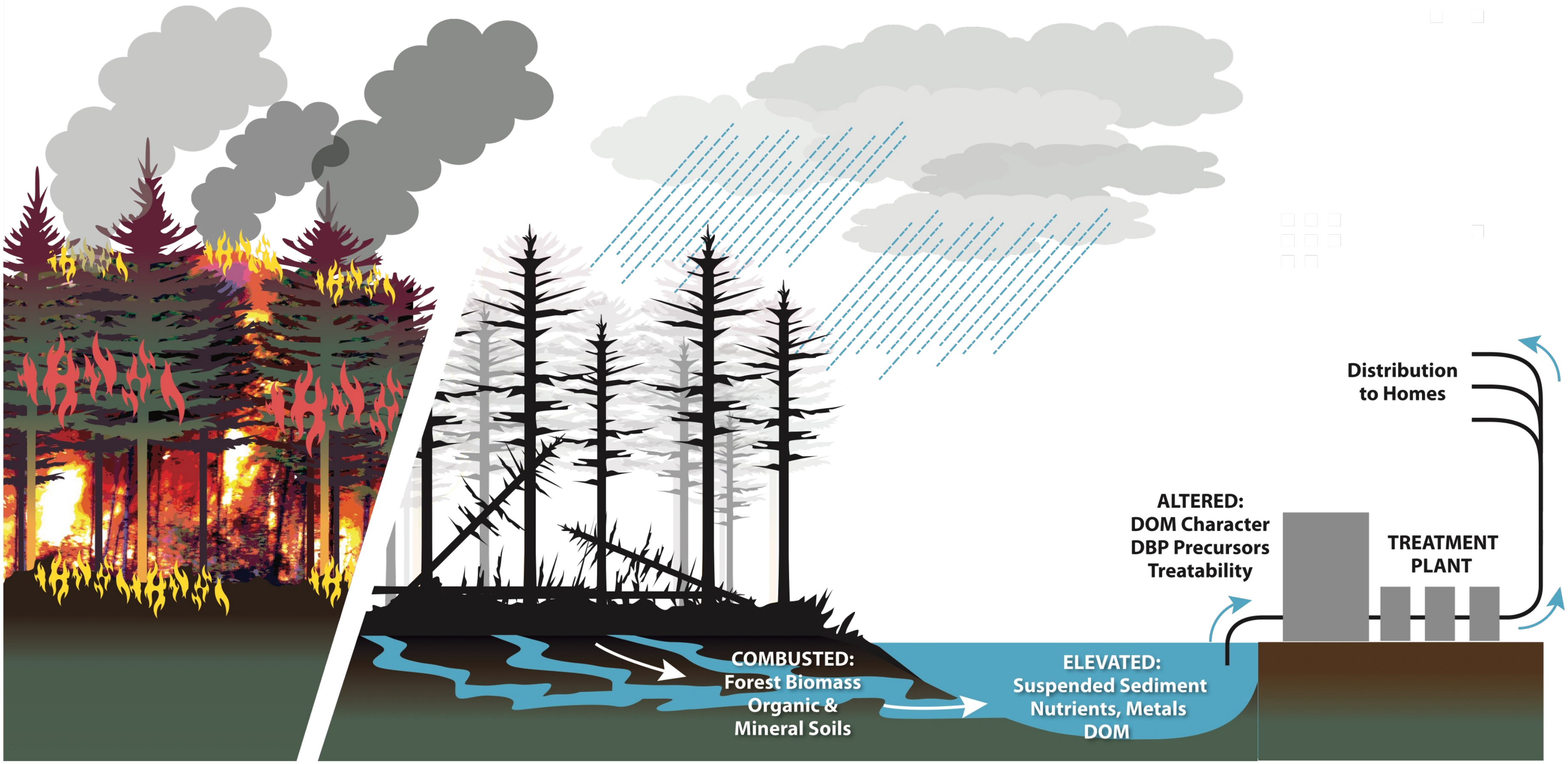
- Approximately two thirds of municipalities in the US rely on water from forested watersheds
- Wildfires can abruptly and adversely impact watersheds which generally provide high quality source water
- The effects of wildfires on a watershed are complex and long lasting

Changes in Water Quality

- Effects include:
  - Enhanced mobilization of nutrients and metals
  - Increases in turbidity
  - Changes in concentration and reactivity of dissolved organic matter
  - Algae growth and associated issues

- Responses from water treatment perspective
  - Modification of treatment steps
  - Potential upgrades to system
  - Increase monitoring

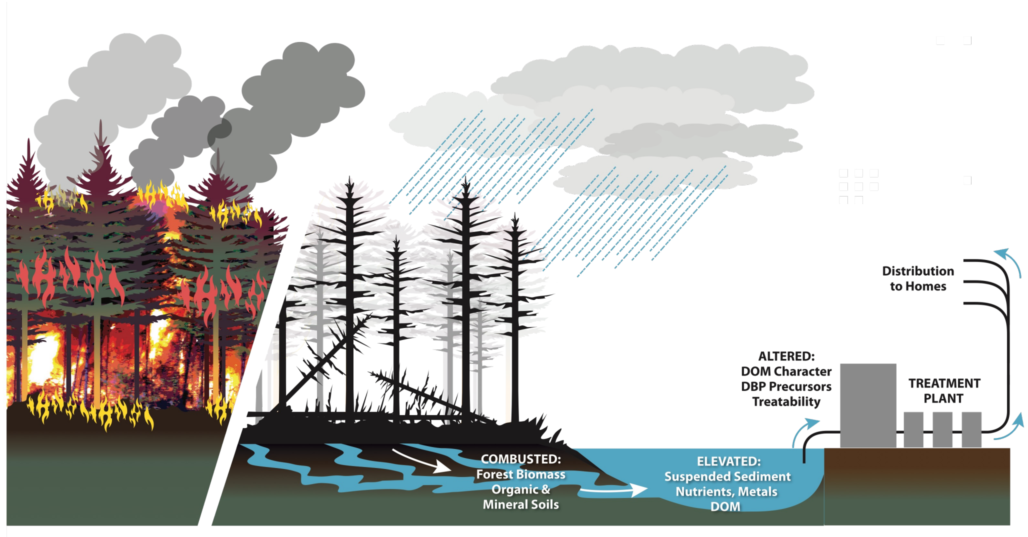
Wildfires



Hohner et al., 2019

Outline

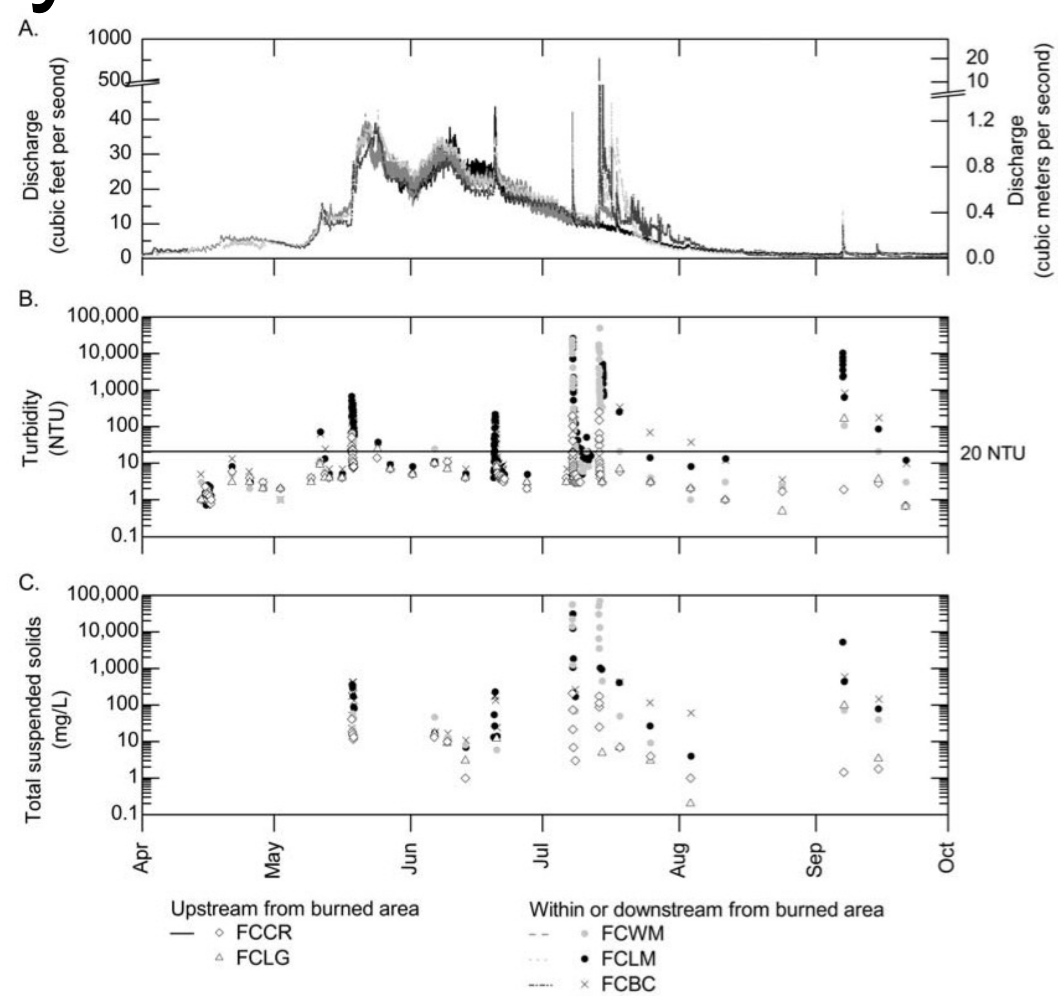
- Turbidity/sediments
- Nutrients
- DOM
- DBP
- Treatment impacts
- New issues related to contamination



Turbidity/sediments

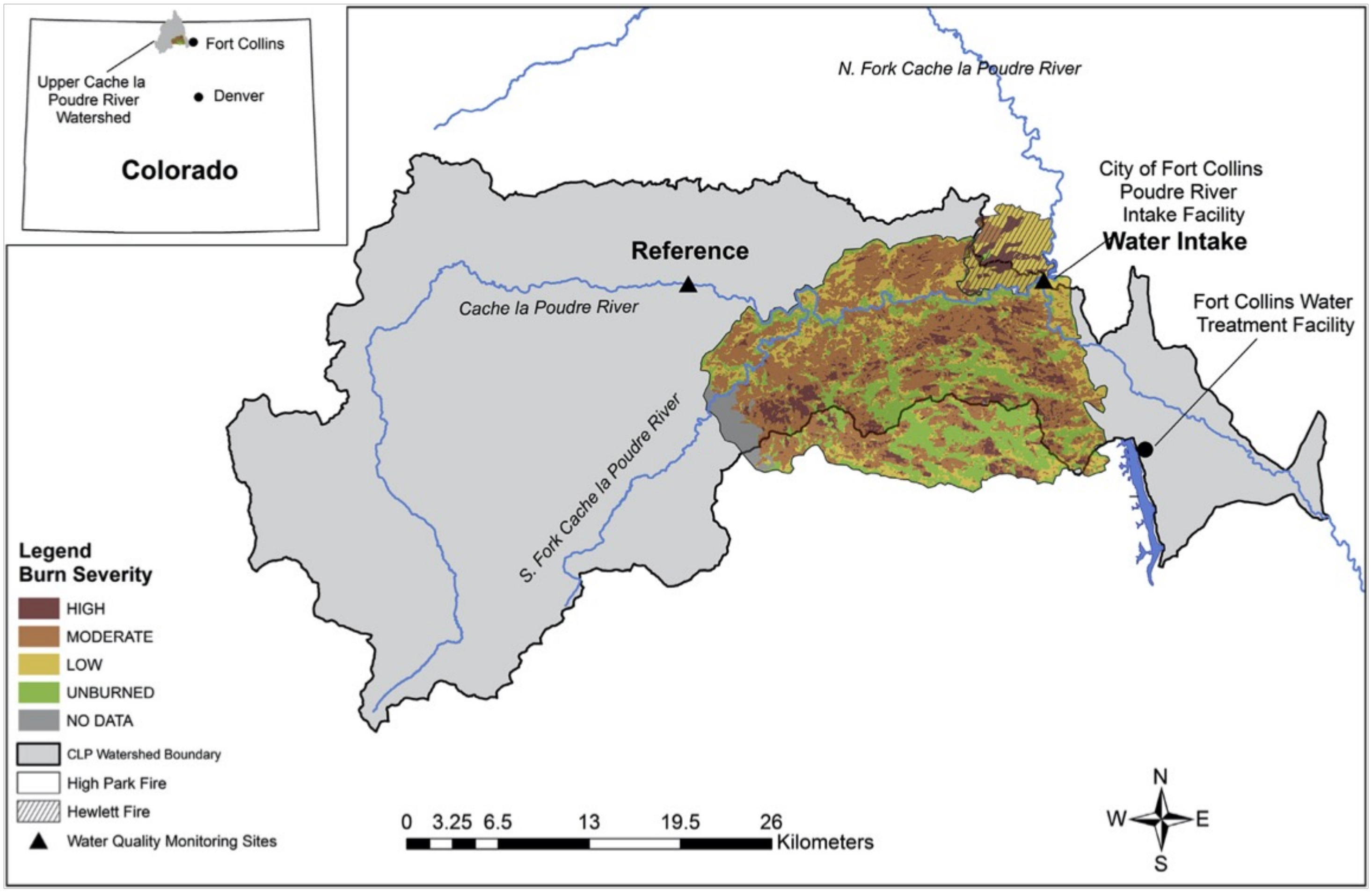
- Changes to slope vegetation result in enhanced sediment mobilization, resulting in potential for high turbidity events
- High turbidity events are triggered by rain events
- Potential impacts to infrastructure

Turbidity



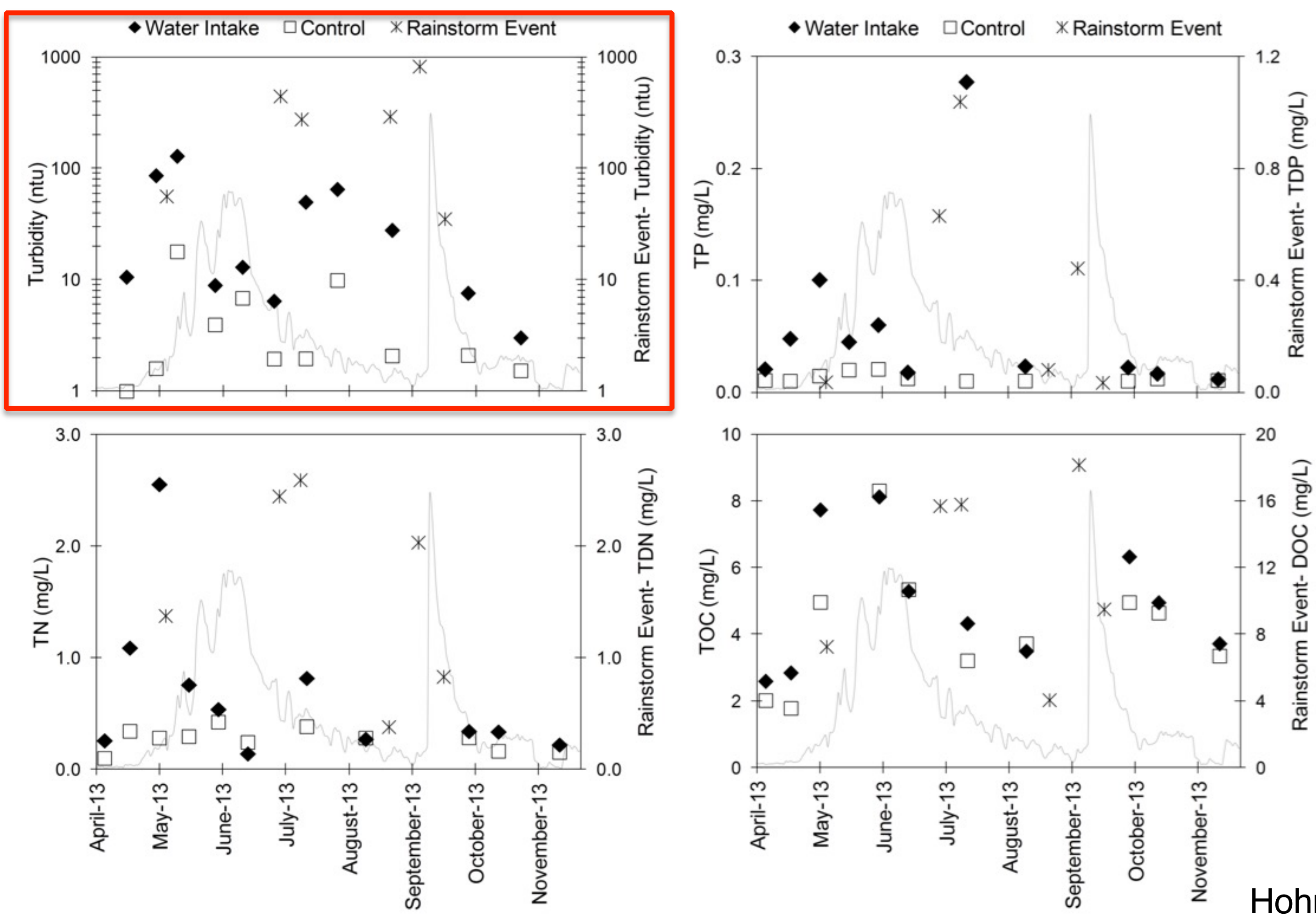
Murphy et al., 2012

Case Study: High Park Fire, 2012



Hohner et al., 2016

Turbidity



Hohner et al., 2016

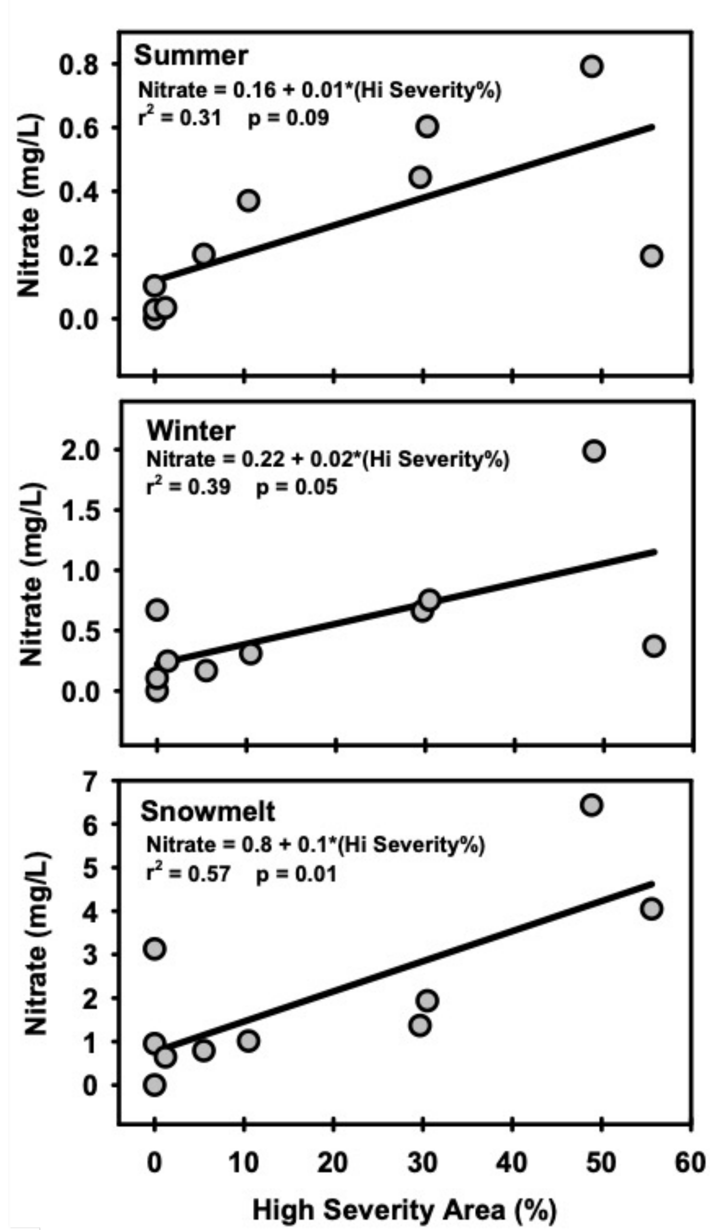
Turbidity

- Turbidity values after wildfires can be quite high, creating challenges for utilities
- Turbidity values can spike as a function of localized rain events
- Consider adding early warning systems, sedimentation basins

Hohner et al., 2016

Nutrients Exports

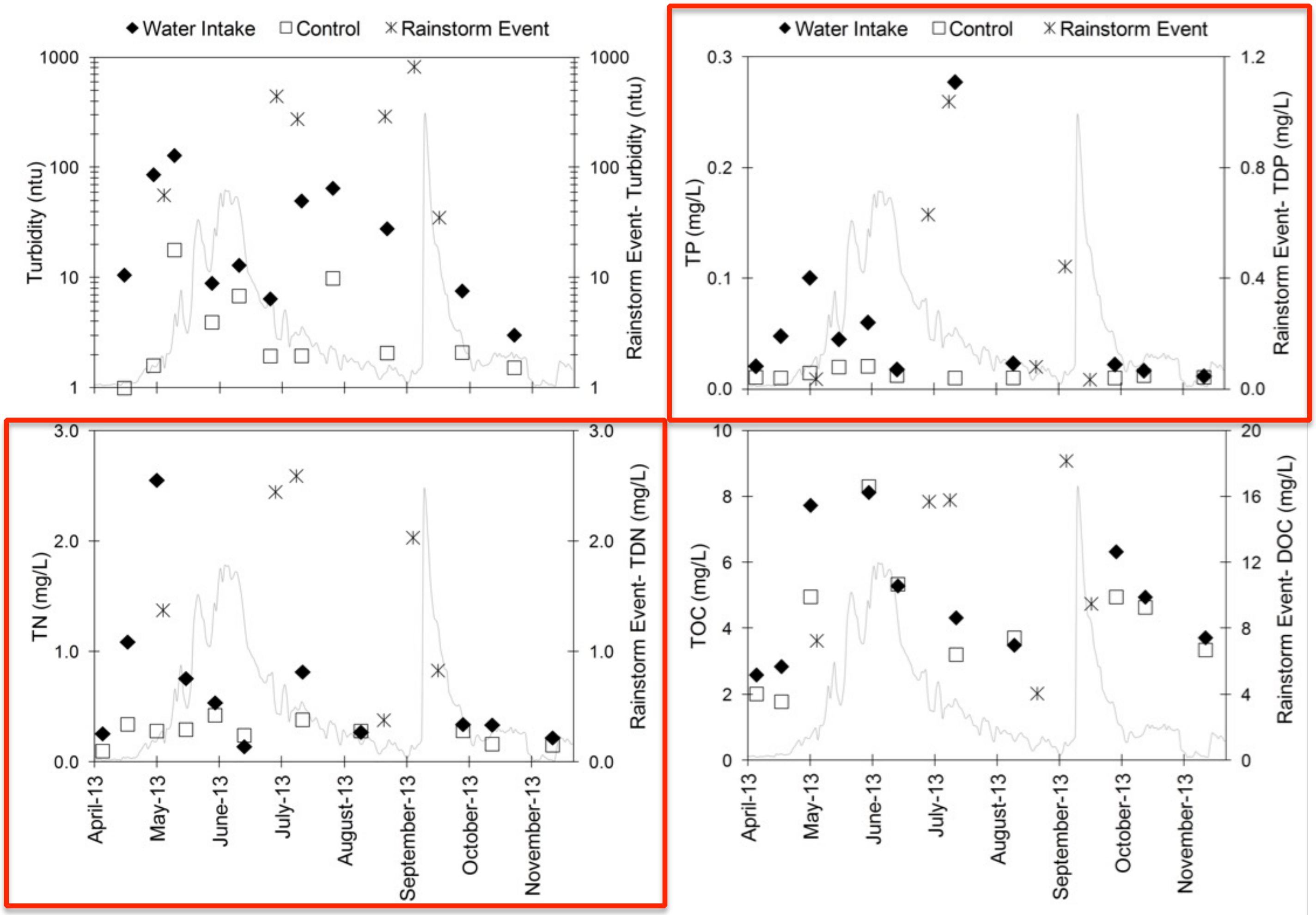
- It is well documented that nutrients exports can increase after a wildfire
- Impacts can be long lasting and related to severity



Rhoads et at., 2006

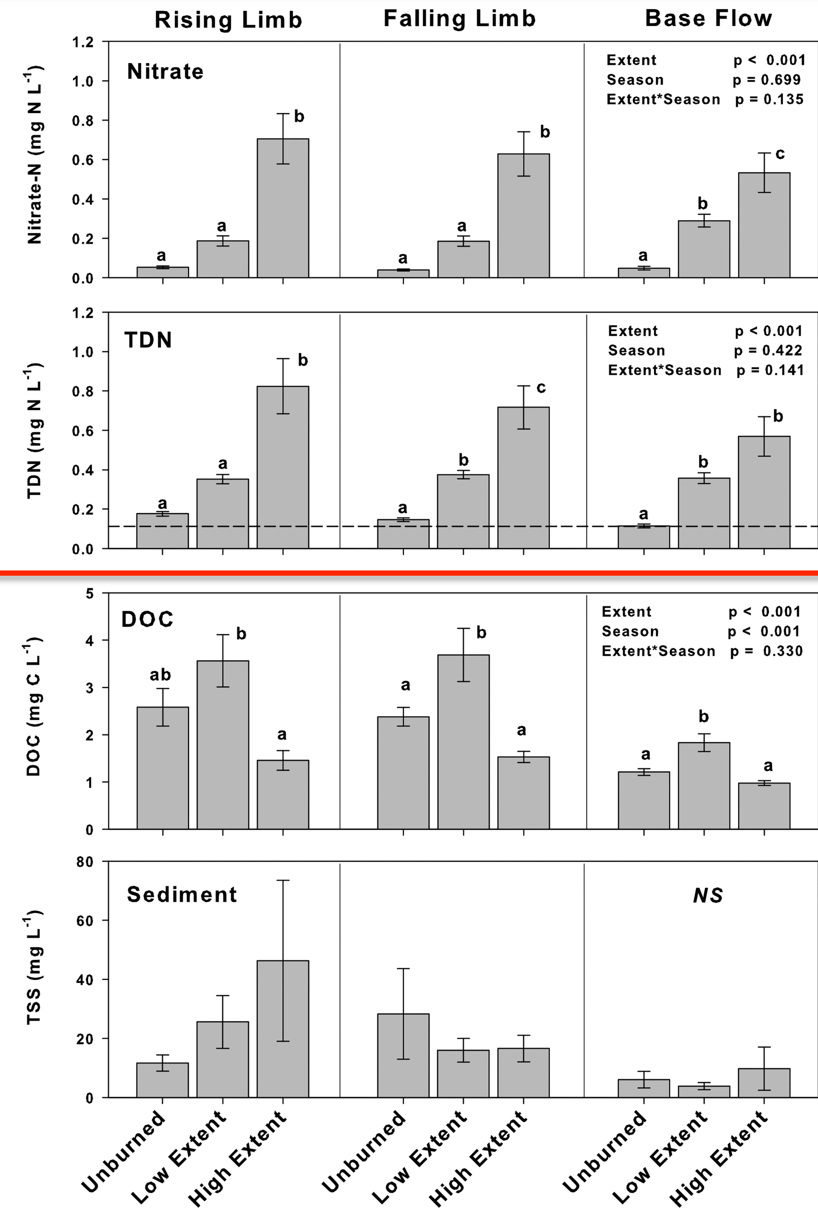
Hohner et al., 2016

Nutrients Exports



Nutrients Exports

- Enhanced mobilization of nutrients can result in eutrophication

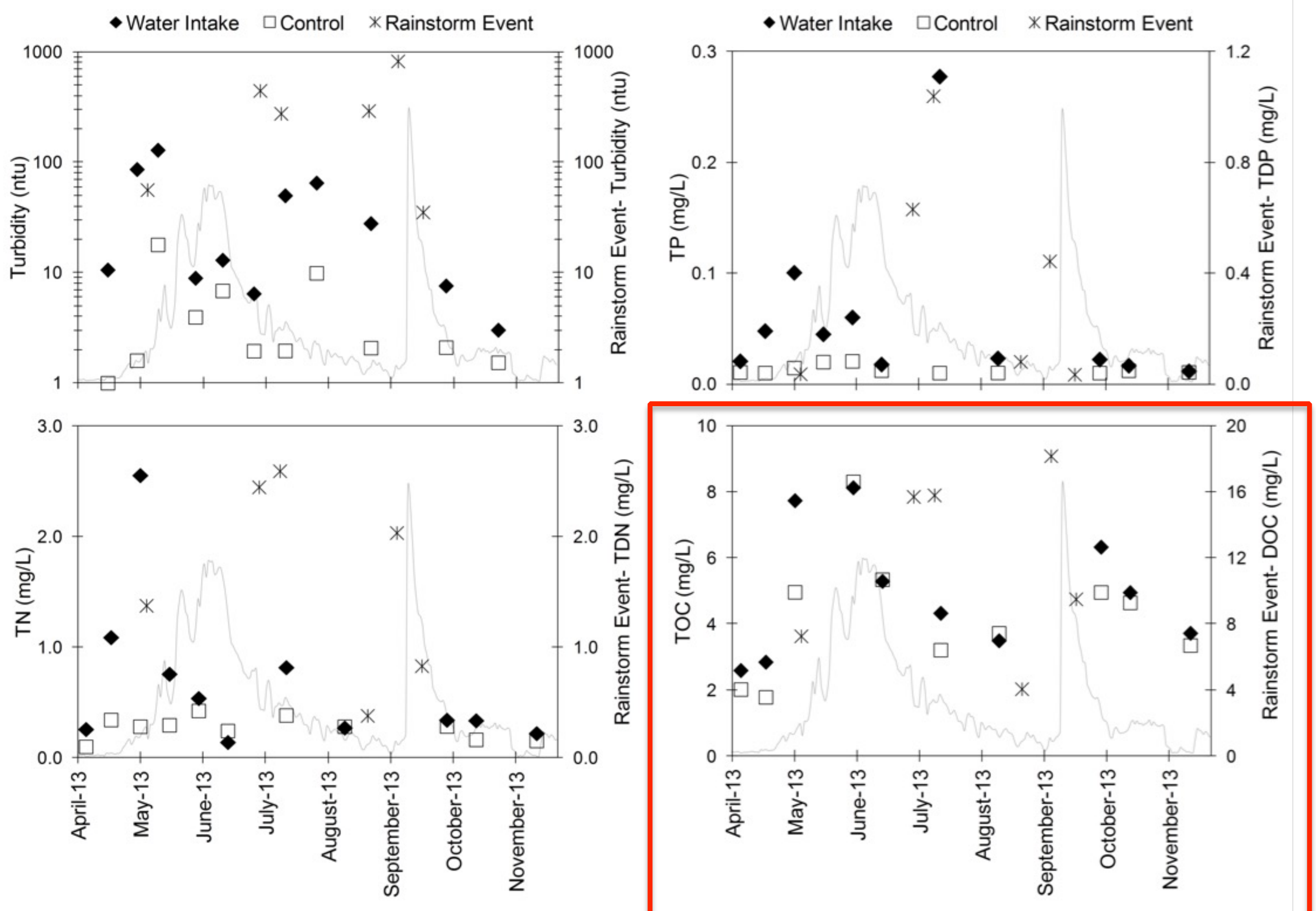


Rhoades et al., 2018

Dissolved Organic Carbon

- DOC is a complex mixture of organic compounds found in surface waters
- DOC impacts different aspects of treatment process
- DOC dynamics in watersheds after wildfire are complex

Dissolved Organic Carbon

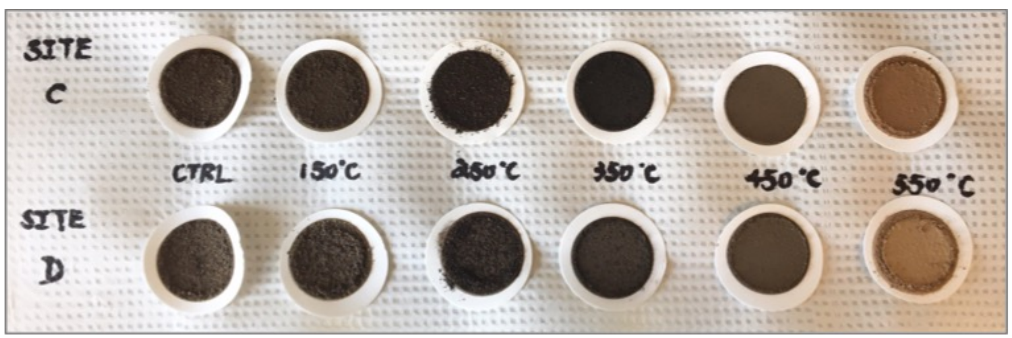


Dissolved Organic Carbon

- DOC mobilization does show a distinct temperature profile
- Previous work done on soils (mineral layer) indicate that the mobilization of DOC resembles a gaussian distribution
  - For litter (organic layer), the effects of temperature are more complex

Laboratory Simulation

- Soil sampling
  - Boulder county
- Processed samples
  - Drying at 100 ºC
  - Homogenization
  - Heating for 2 hours at given temperature
  - Leached into laboratory water and filtered



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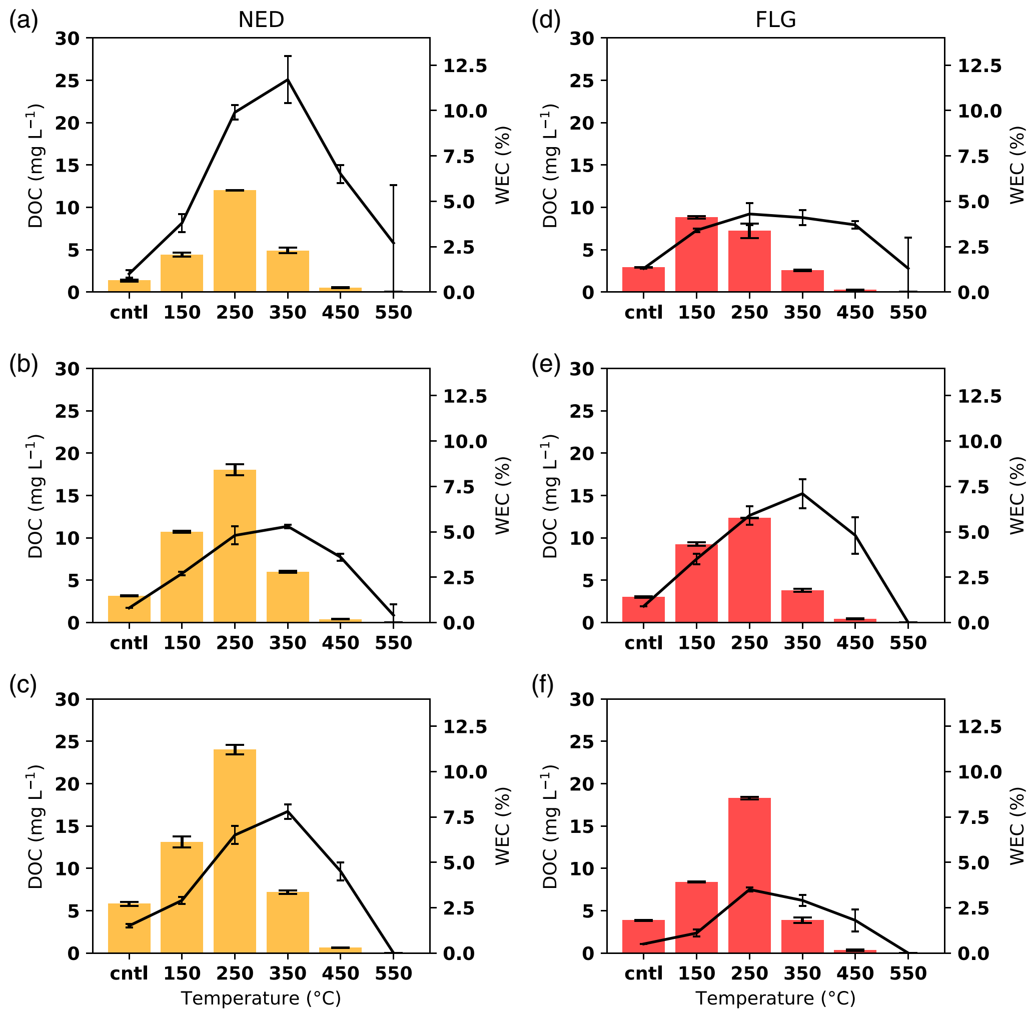
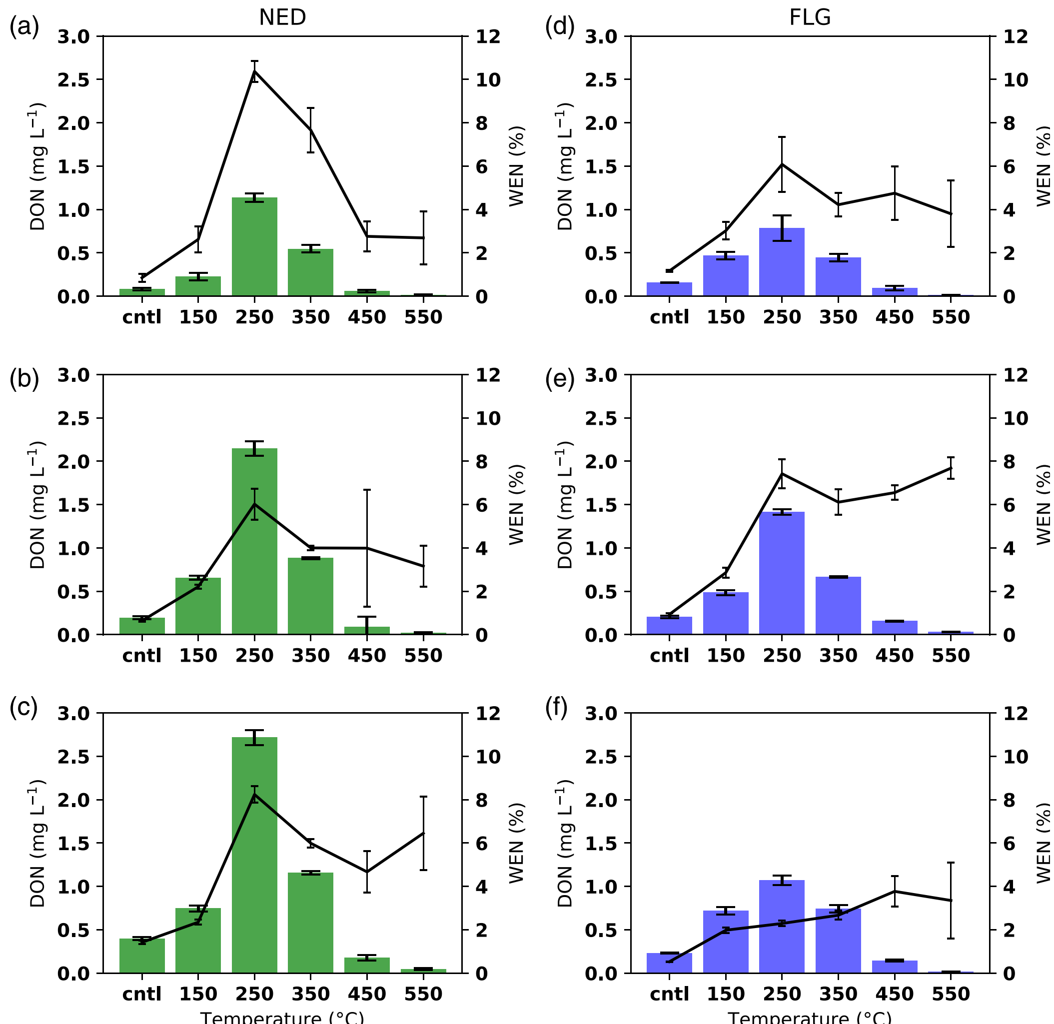
DOC Mobilization



Wilkerson and Rosario-Ortiz, 2021

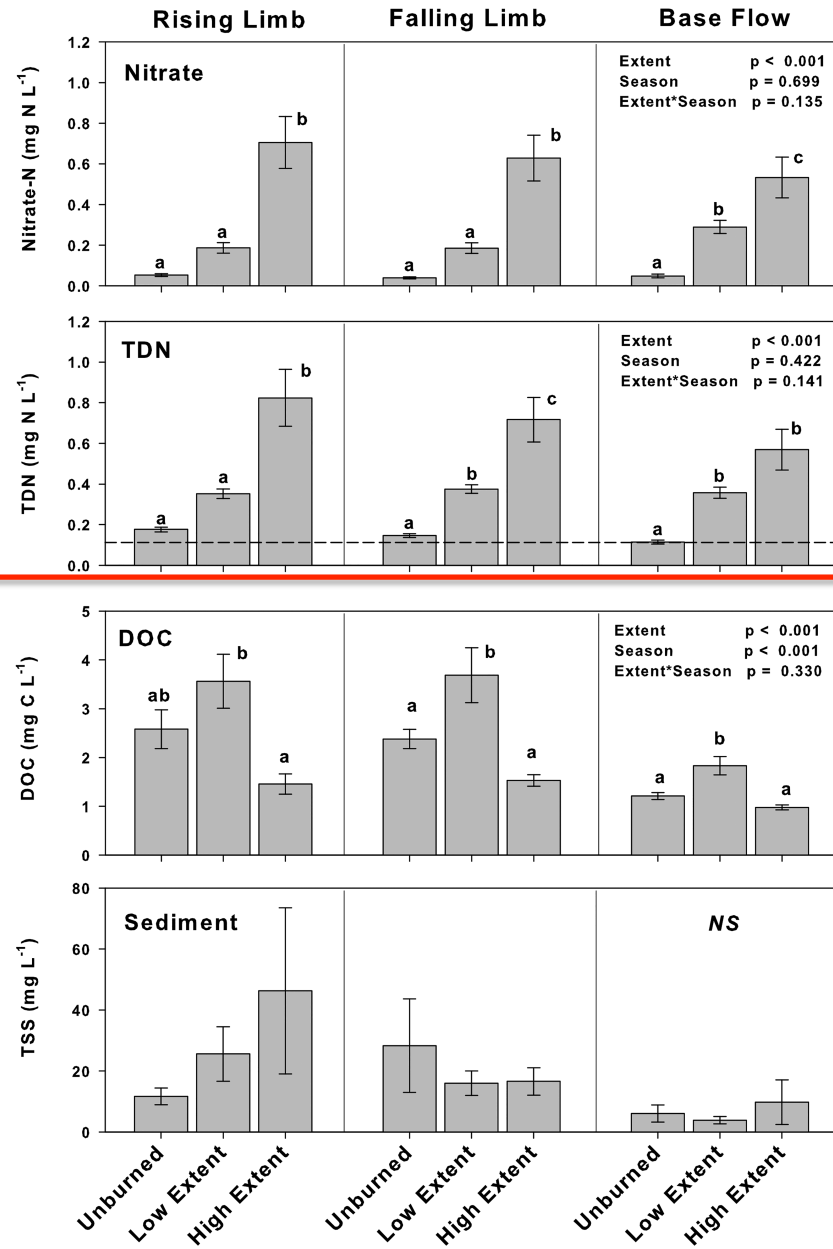
DON Mobilization



Wilkerson and Rosario-Ortiz, 2021

DOC Mobilization

- DOC mobilization trends have been observed numerous times in lab and field experiments



Rhoades et al., 2018

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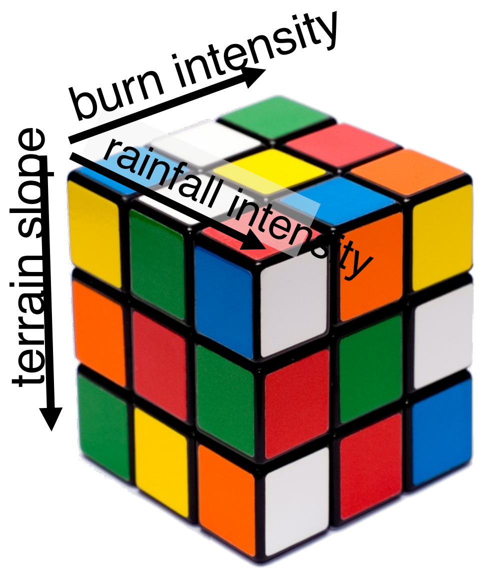
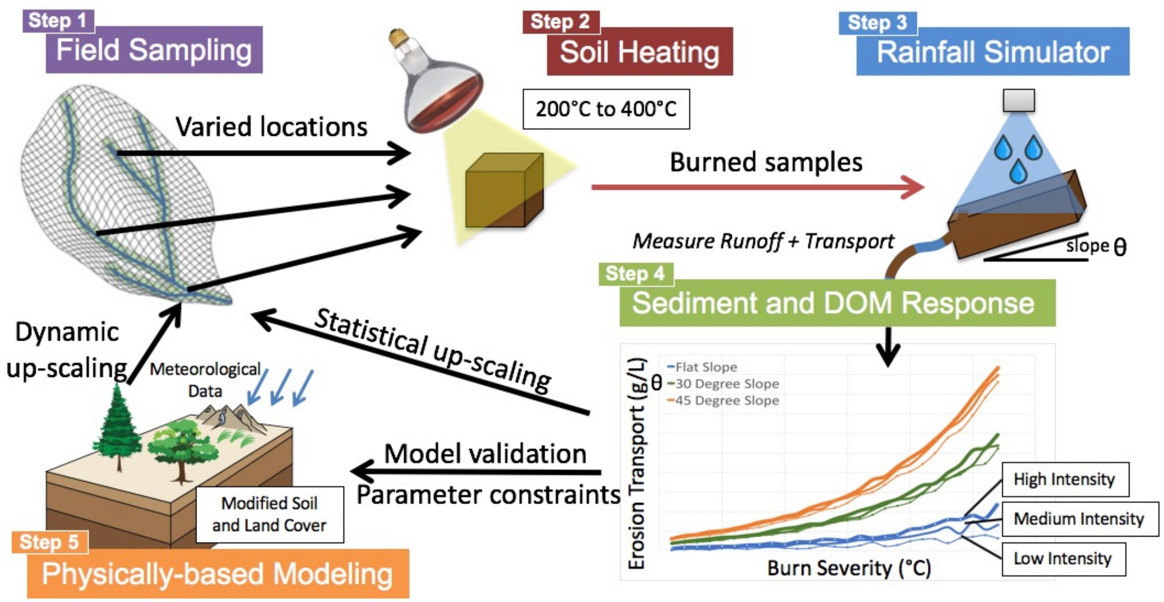
Modeling of DOC

- Analyzing sedimentation and water quality response in a 3D matrix of controls



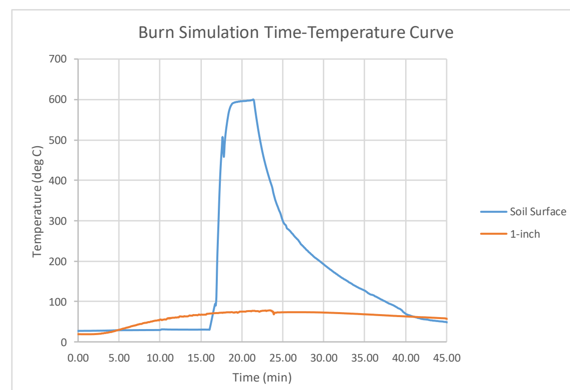


Brucker et al., In Prep

Modeling of DOC

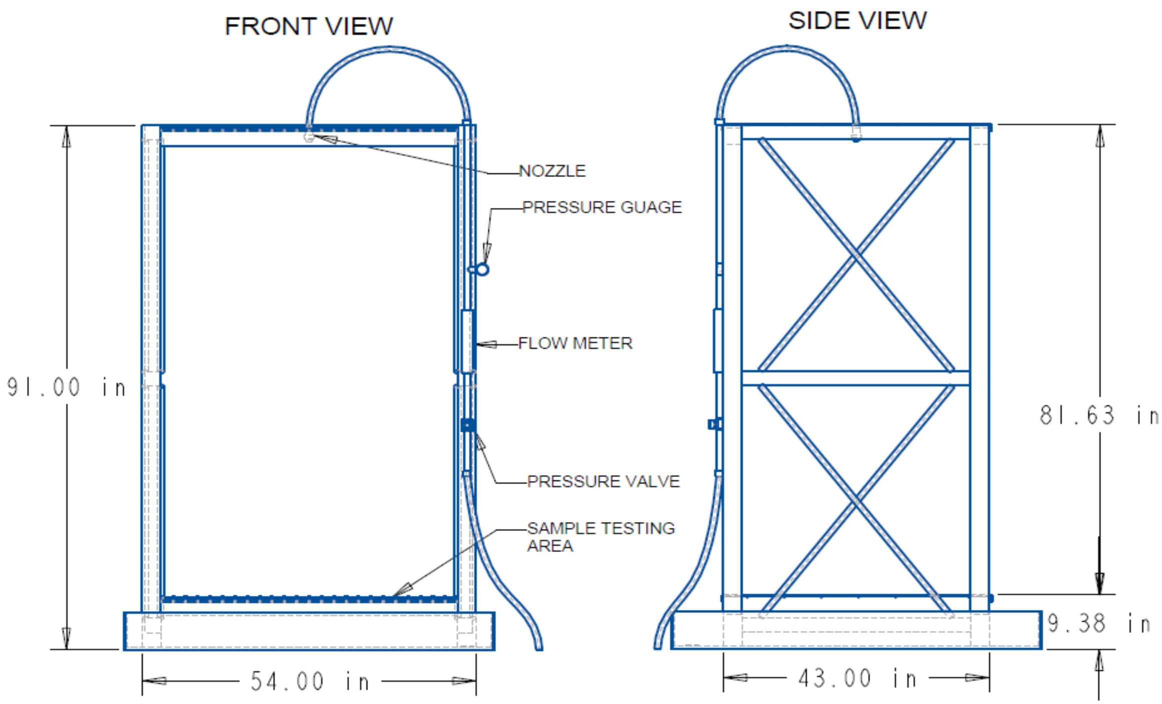
- Study location: the Cache la Poudre Basin near Fort Collins, CO
- Soil samples collected with intact soil structure in steel containers

Wildfire Simulation

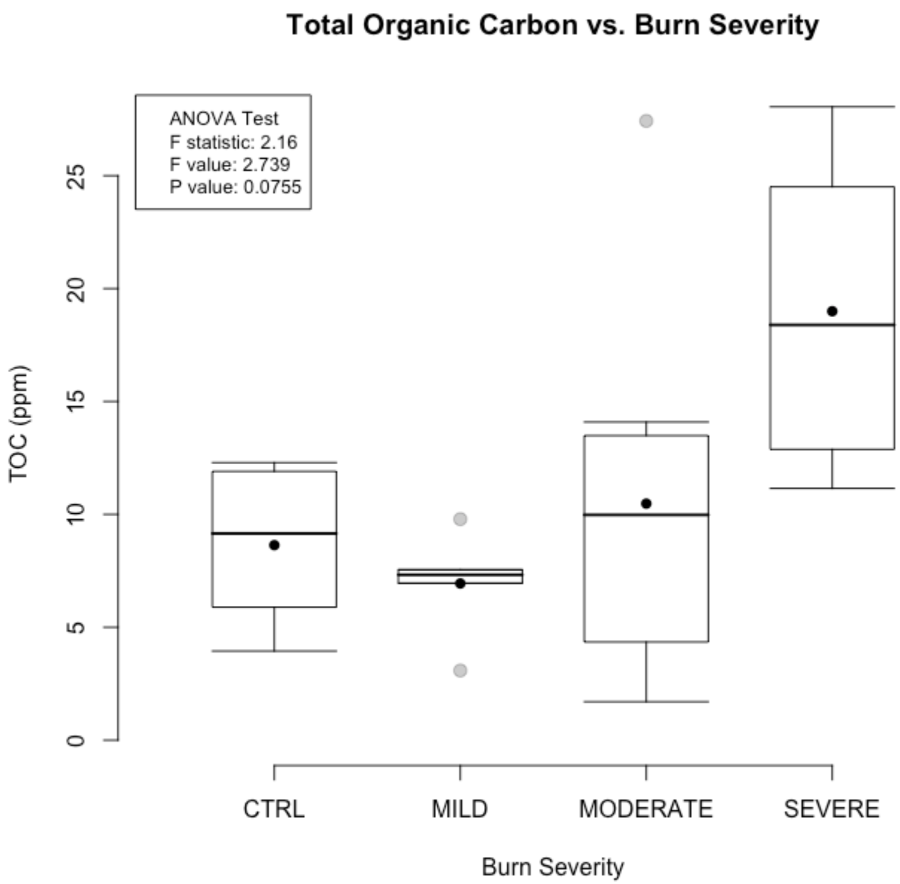


Rainfall Simulation

- Created variable-intensity rainfall simulator, closely approximating natural rainfall kinetic energy, droplet size, and distribution



DOC Mobilization

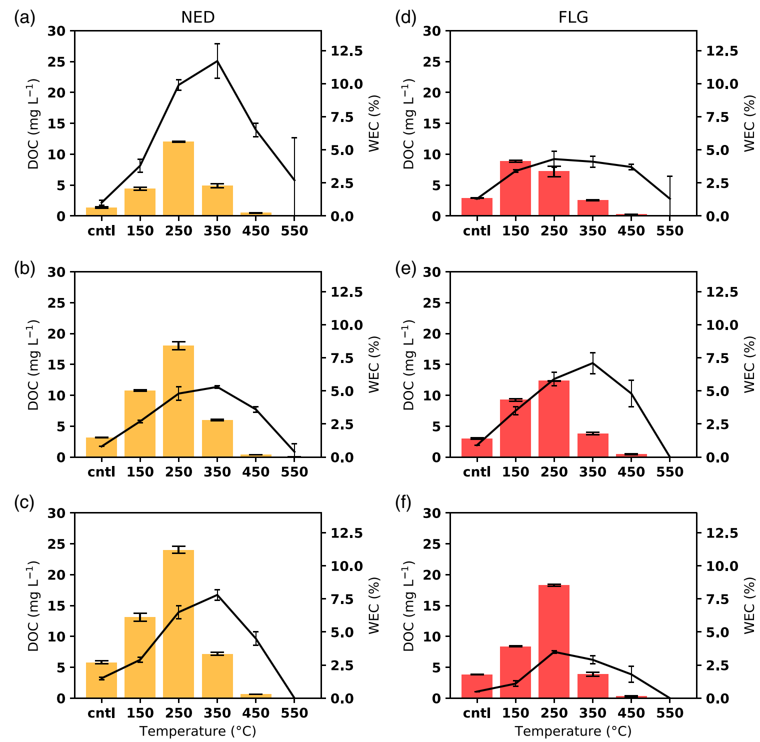


Simulation confirms lab and field work

Will expand to look at sediments

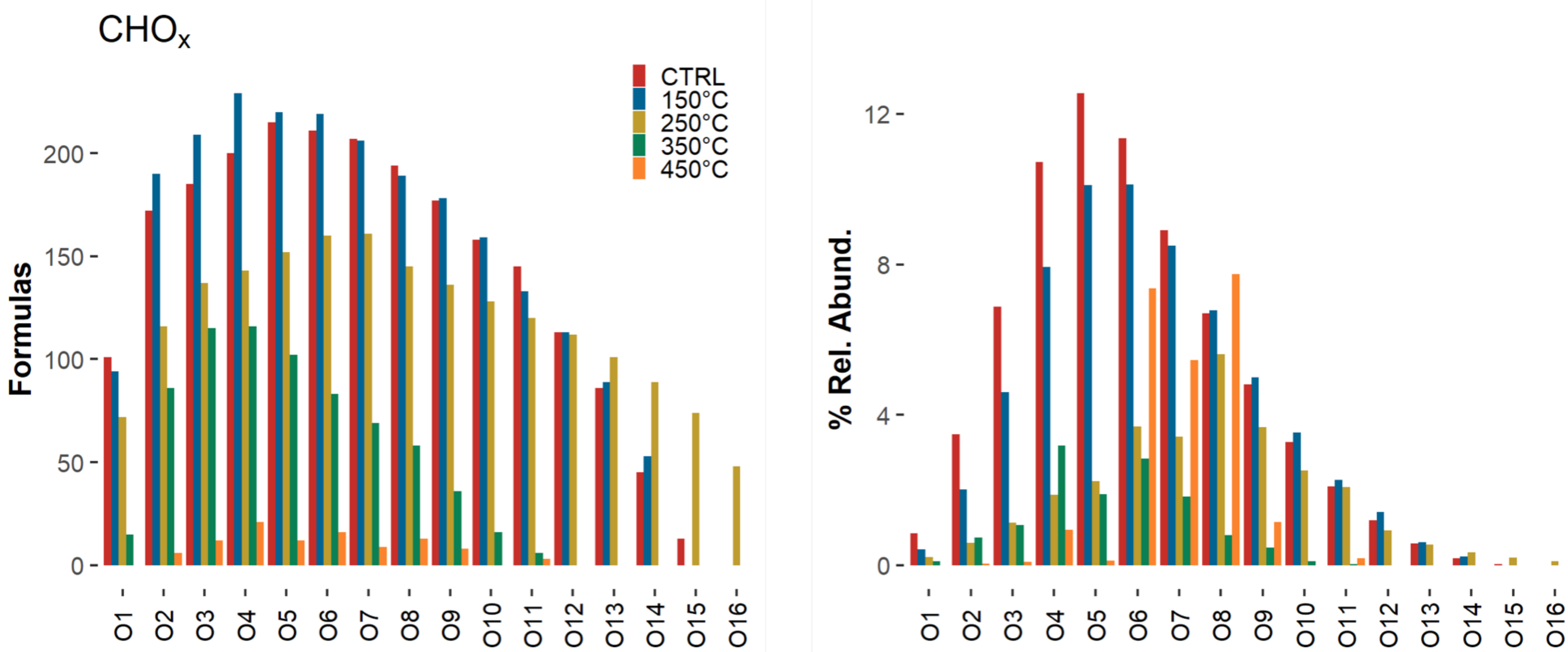
DOC Mobilization

- Enhanced mobilization of DOC at some temperatures
- How different is this DOC?
- We have performed enhanced analytical work to understand DOC mobilization
  - Using NMR and MS



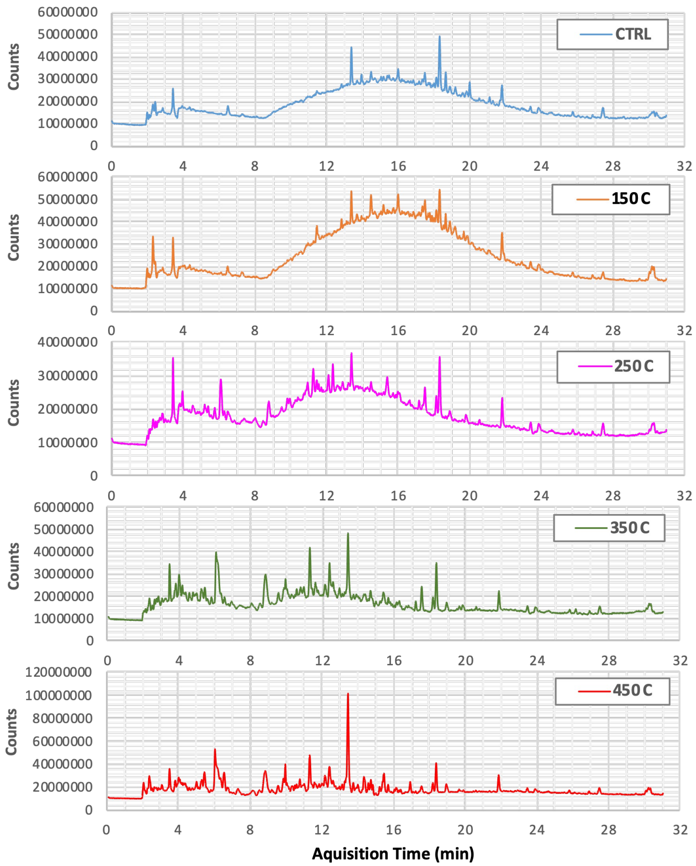
Wilkerson and Rosario-Ortiz, 2021

DOC Mobilization

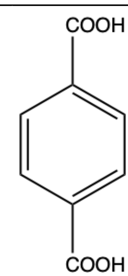


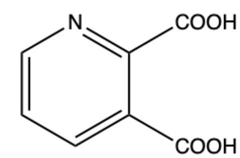
CHO Class Abundance Comprised of Few Formulas at High Intensities (BPCAs)

DOM Mobilization



	Benzene Polycarboxylic Acids BPCAs	Isomers	Detected	Pyridine Polycarboxylic Acids PPCAs	Isomers	Detected
2-COOH	B2CAs	1,2-B2CA	● (green)	P2CAs	2,3-P2CA	● (red)
					2,4-P2CA	● (red)
		1,4-B2CA	● (green)		2,5-P2CA	● (red)
					2,6-P2CA	● (red)
		1,3-B2CA	● (green)		3,4-P2CA	● (red)
					3,5-P2CA	● (green)
3-COOH	B3CAs	1,2,4-B3CA	● (green)	P3CAs	2,3,4-P3CA	● (green)
					2,3,5-P3CA	● (green)
		1,2,3-B3CA	● (green)		2,3,6-P3CA	● (green)
					3,4,5-P3CA	● (green)
		1,3,5-B3CA	● (green)		2,4,5-P3CA	● (green)
					2,4,6-P3CA	● (green)
4-COOH	B4CAs	1,2,4,5-B4CA	● (green)	P4CAs	2,3,5,6-P4CA	● (red)
		1,2,3,4-B4CA	● (green)		2,3,4,5-P4CA	● (red)
		1,3,4,5-B4CA	● (green)		2,3,4,6-P4CA	● (red)
5-COOH	B5CA		● (red)	P5CA		● (red)
6-COOH	B6CA		● (red)	/		

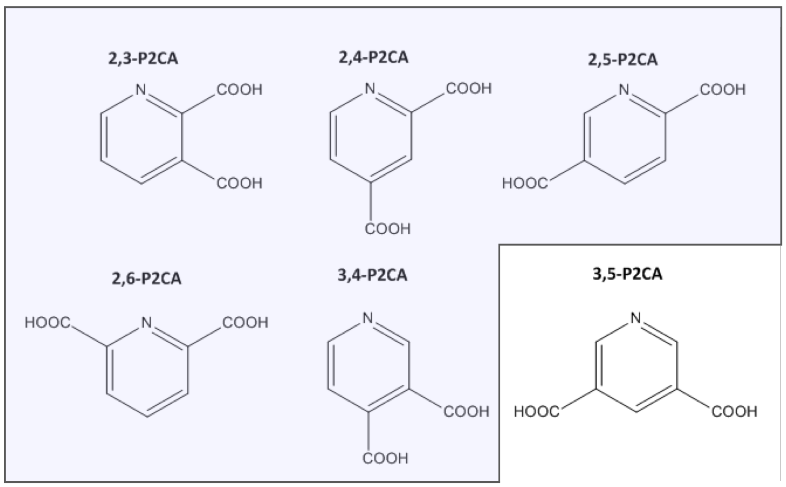




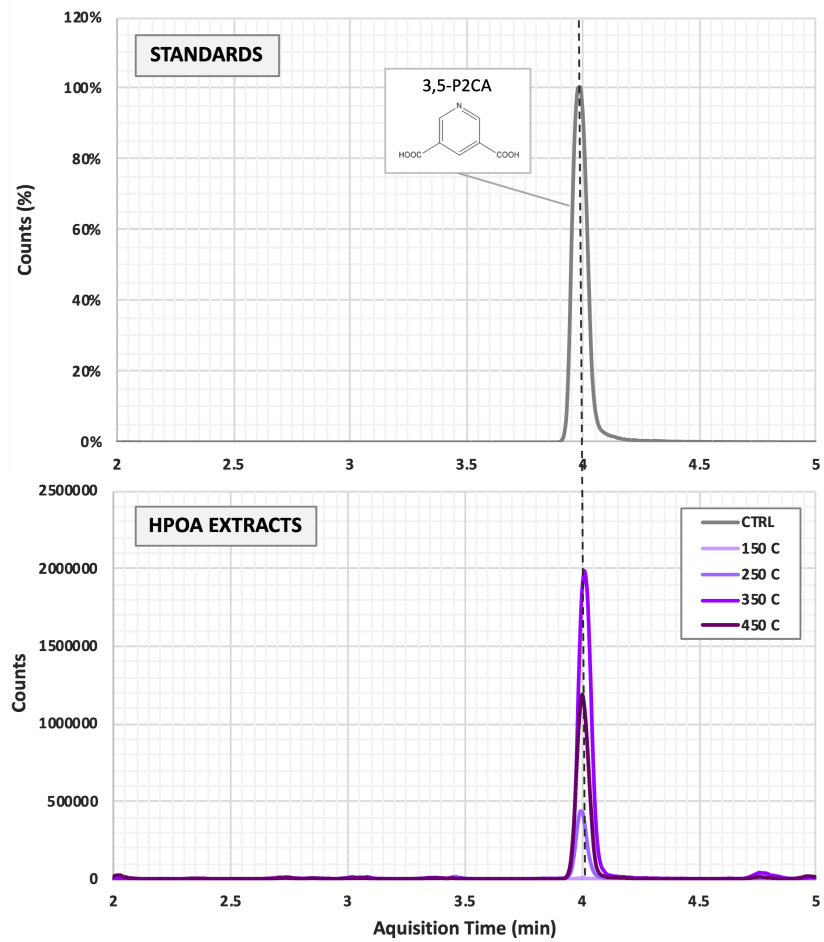
Thurman et al., 2020

DOM Mobilization

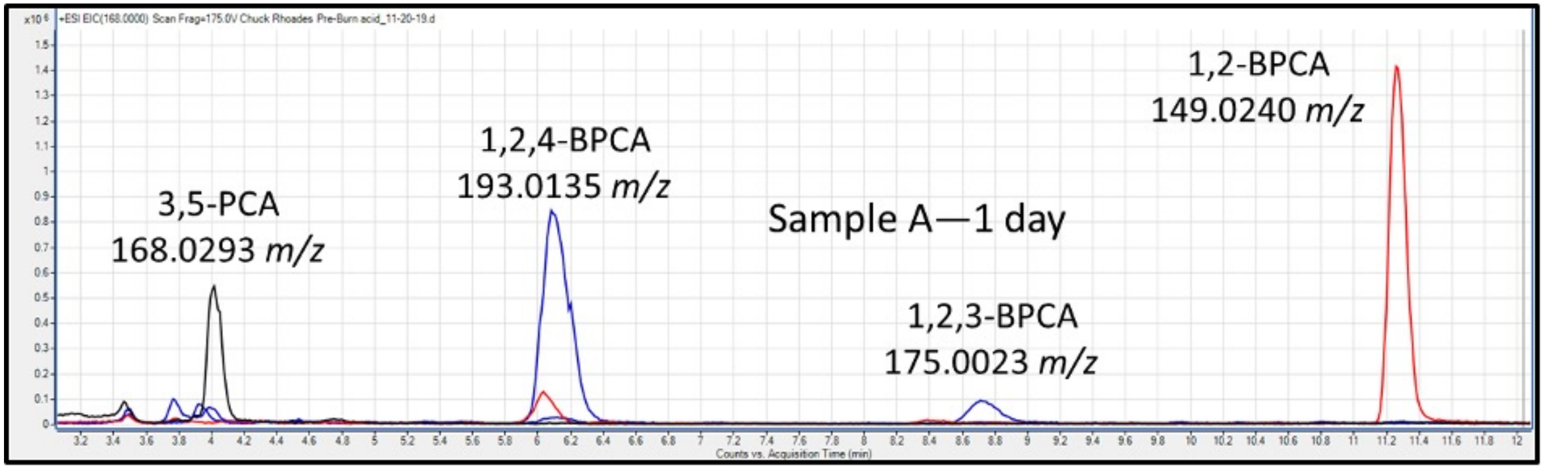
Pyridine Dicarboxylic Acids (P2CAs)					
	Retention Time (min)	Ions	Accurate Mass	Measured Mass	Accuracy (ppm)
		$[MH-HCOOH]^+$	122.0237	122.0236	0.82
3,5-P2CA	3.990	$[M+H]^+$	168.0291	168.0292	0.60
		$[M+Na]^+$	205.9761	205.9759	0.97

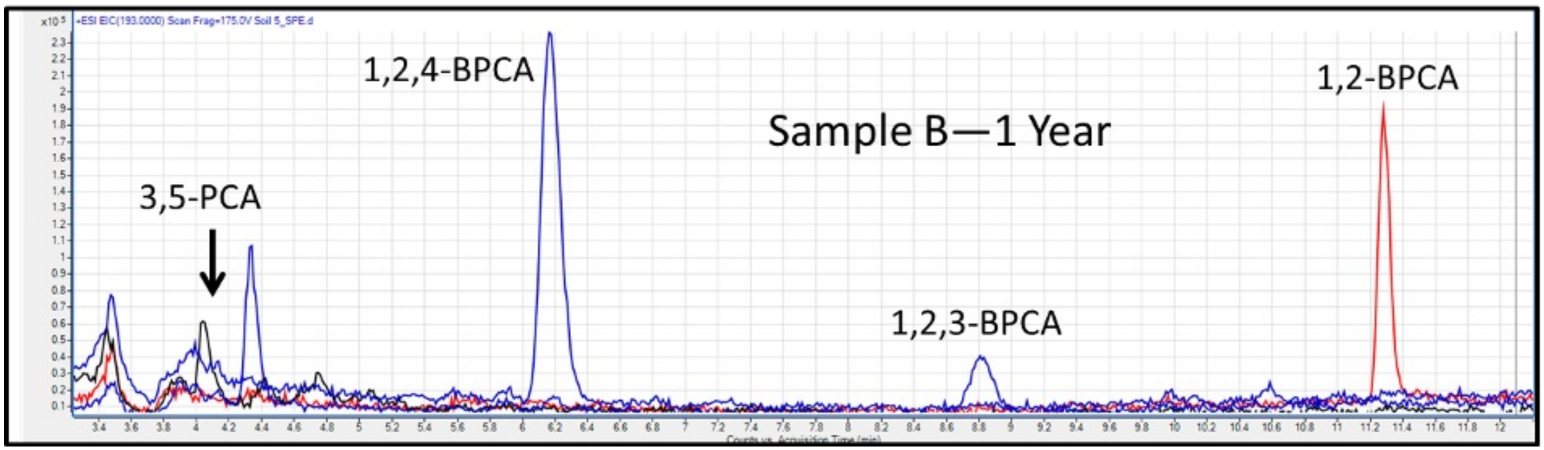


Other 5 isomers not detected

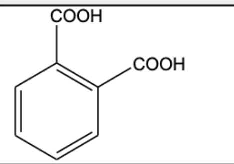
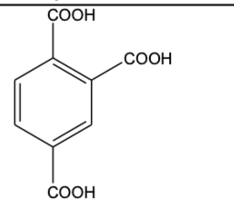
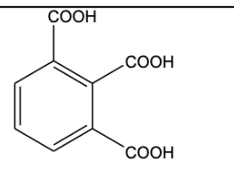
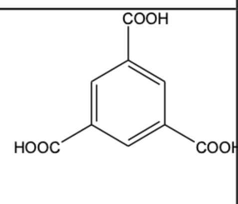
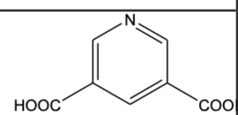


Field Data

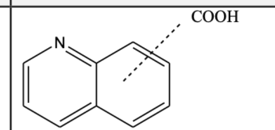
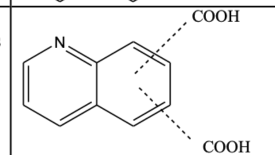
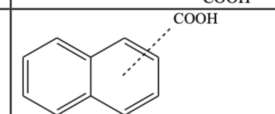
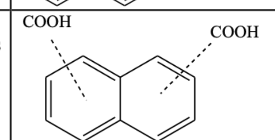
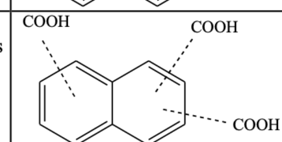
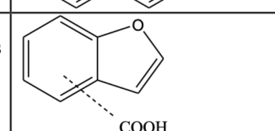
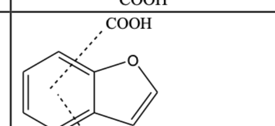

3,5-PCA
168.0293 m/z
1,2,4-BPCA
193.0135 m/z
Sample A—1 day
1,2,3-BPCA
175.0023 m/z
1,2-BPCA
149.0240 m/z


1,2,4-BPCA
Sample B—1 Year
1,2-BPCA
3,5-PCA
1,2,3-BPCA

Compounds detected in ash leachates and water samples. Retention time, chemical structure, observed ions, and their corresponding accurate mass are shown. Black is in positive ion mode and red is in negative ion mode.

Compound	Ret. time (min)	Chemical Structure	+Ion/-Ion	Calculated Ac Mass of m/z
1,2-BPCA (phthalic acid)	11.3		$[M-H+2Na]^+$ $[M+Na]^+$ $[MH-H_2O]^+$ $[M-H]^-$ $[M-H-CO_2]^-$ $[M-H-2\ CO_2]^-$	210.9978 189.0158 149.0233 165.0193 121.0295 77.0397
1,2,4-BPCA	6.1		$[M-H+Ca]^+$ $[M+Na]^+$ $[MH-H_2O]^+$ $[MH-2H_2O]^+$ $[MH-HCOOH]^+$ $[M-H]^-$ $[M-H-CO_2]^-$ $[M-H-2CO_2]^-$	248.9709 233.0057 193.0131 175.0026 165.0182 209.0092 165.0193 121.0295
1,2,3-BPCA	8.8		$[M-H+2Na]^+$ $[M+Na]^+$ $[MH-H_2O]^+$ $[MH-2H_2O]^+$ $[M-H]^-$ $[M-H-CO_2]^-$ $[M-H-2CO_2]^-$	254.9876 233.0057 193.0131 175.0026 209.0092 165.0193 121.0295
1,3,5-BPCA	9.9		$[M-H+2Na]^+$ $[M-H+Ca]^+$ $[M+Na]^+$ $[M+H]^+$ $[MH-H_2O]^+$ $[M-H]^-$ $[M-H-CO_2]^-$ $[M-H-2CO_2]^-$	254.9876 248.9709 233.0057 211.0237 193.0131 209.0092 165.0193 121.0295
3,5-PCA	3.9		$[M+H]^+$ $[MH-H_2O]^+$ $[MH-HCOOH]^+$ $[M-H]^-$ $[M-H-CO_2]^-$ $[M-H-2CO_2]^-$	168.0291 150.0186 122.0237 166.0146 122.0248 78.0349

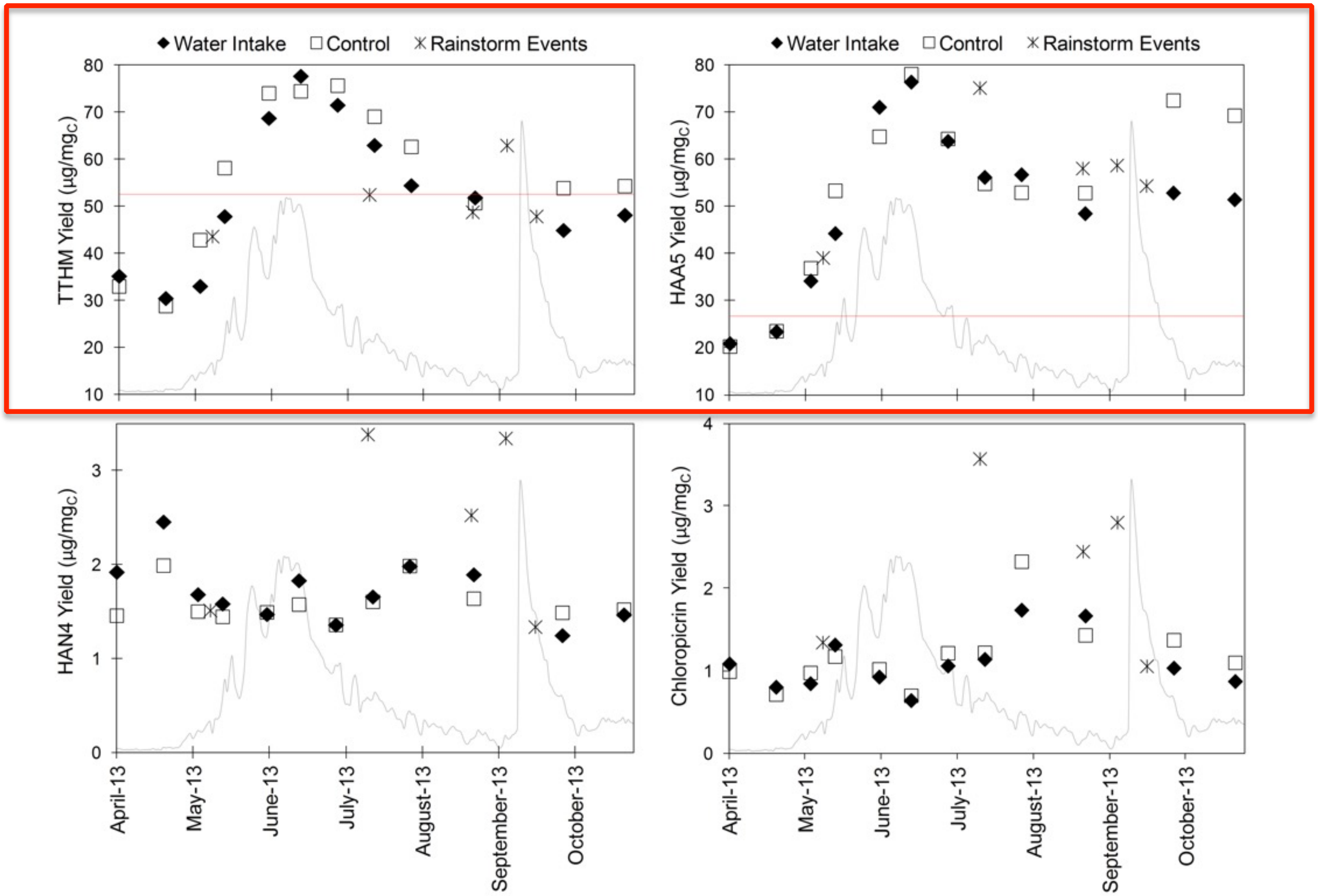
Putative identifications of compounds found in ash leachates and water samples. The chemical structures, observed ions, and their corresponding accurate masses are shown. Black is in positive ion mode and red is in negative ion mode.

Compound	Chemical Structure	+Ion/-Ion	Calculated A Mass of m/
Quinoline monocarboxylic acids		$[MH]^+$ $[MH-CO_2]^+$ $[MH-HCOOH]^+$ $[MH-\ CO_2-CH2=CH]$	174.0550 130.0651 128.0495 103.0539
Quinoline dicarboxylic acids		$[MH]^+$ $[MH-CO_2]^+$ $[MH-HCOOH]^+$	218.0448 174.0550 128.0495
Naphthoic acid		$[M-H]^-$ $[M-H-CO_2]^-$	171.0452 127.0553
Naphthalene dicarboxylic acids		$[M-H]^-$ $[M-H-CO_2]^-$ $[M-H-2CO_2]^-$	215.0350 171.0452 127.0553
Naphthalene tricarboxylic acids		$[M-H]^-$ $[M-H-CO_2]^-$ $[M-H-2CO_2]^-$ $[M-H-3CO_2]^-$	259.0248 215.0350 171.0452 127.0553
Benzofuran monocarboxylates		$[M-H]^-$ $[M-H-CO_2]^-$	161.0244 117.0346
Benzofuran dicarboxylates		$[M-H]^-$ $[M-H-CO_2]^-$ $[M-H-2CO_2]^-$	205.0142 161.0244 117.0346

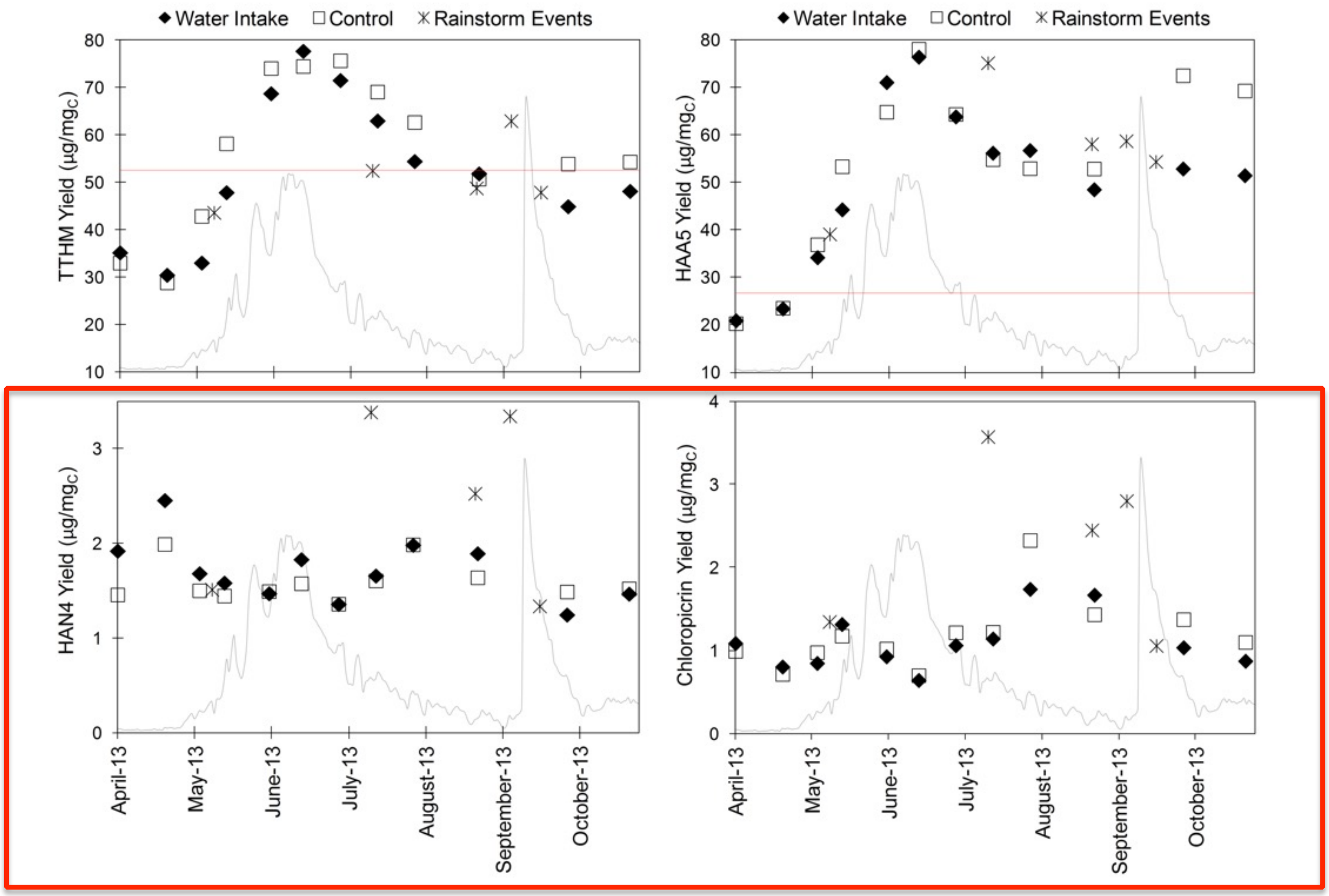
DBPs

- The impact on DBP formation is also complex, showing different temperature dependencies based on temperature

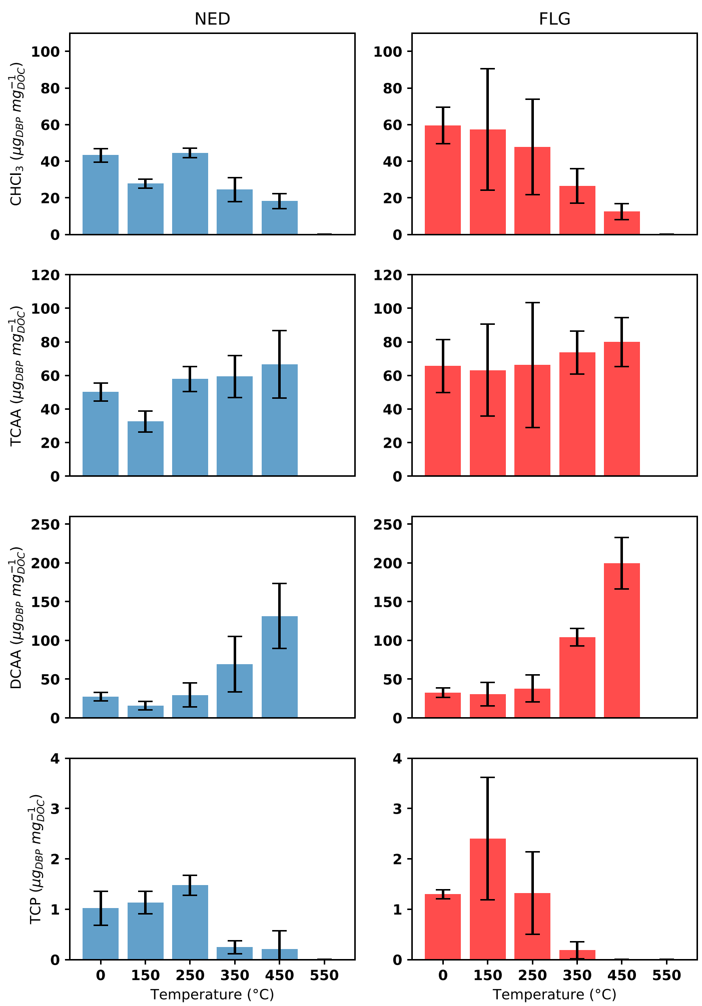
DBP Formation-Field Data

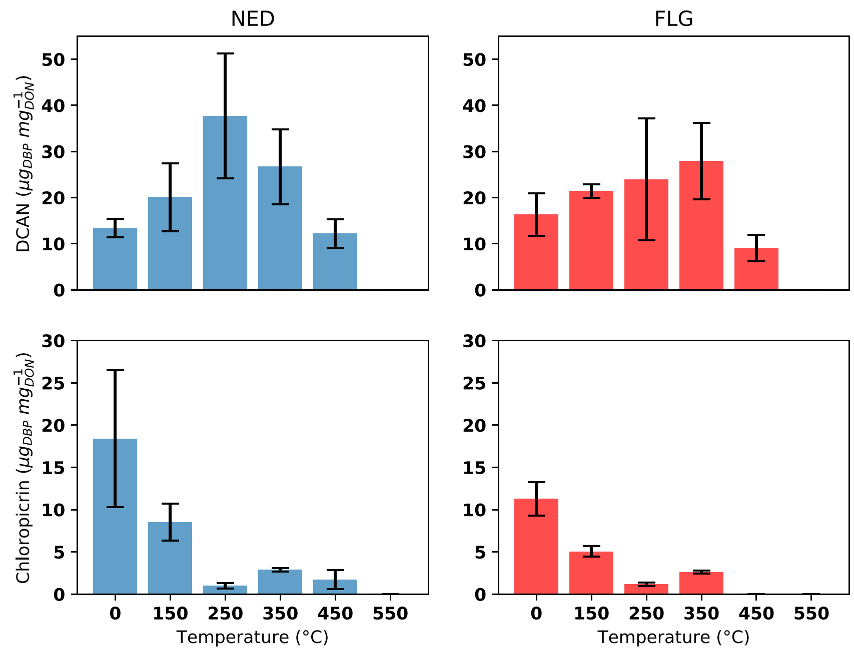


DBP Formation-Field Data



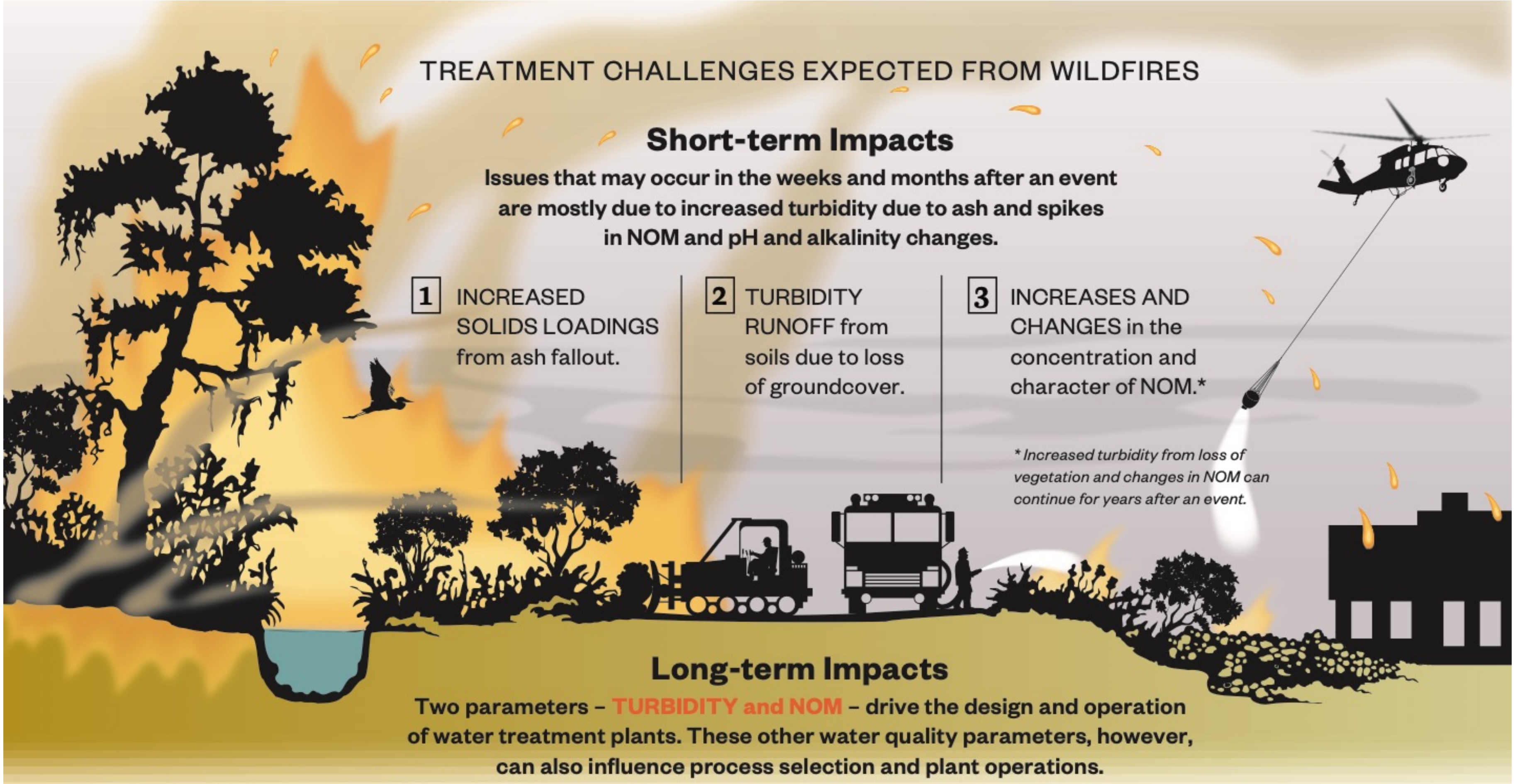
Results for DBP Mobilization





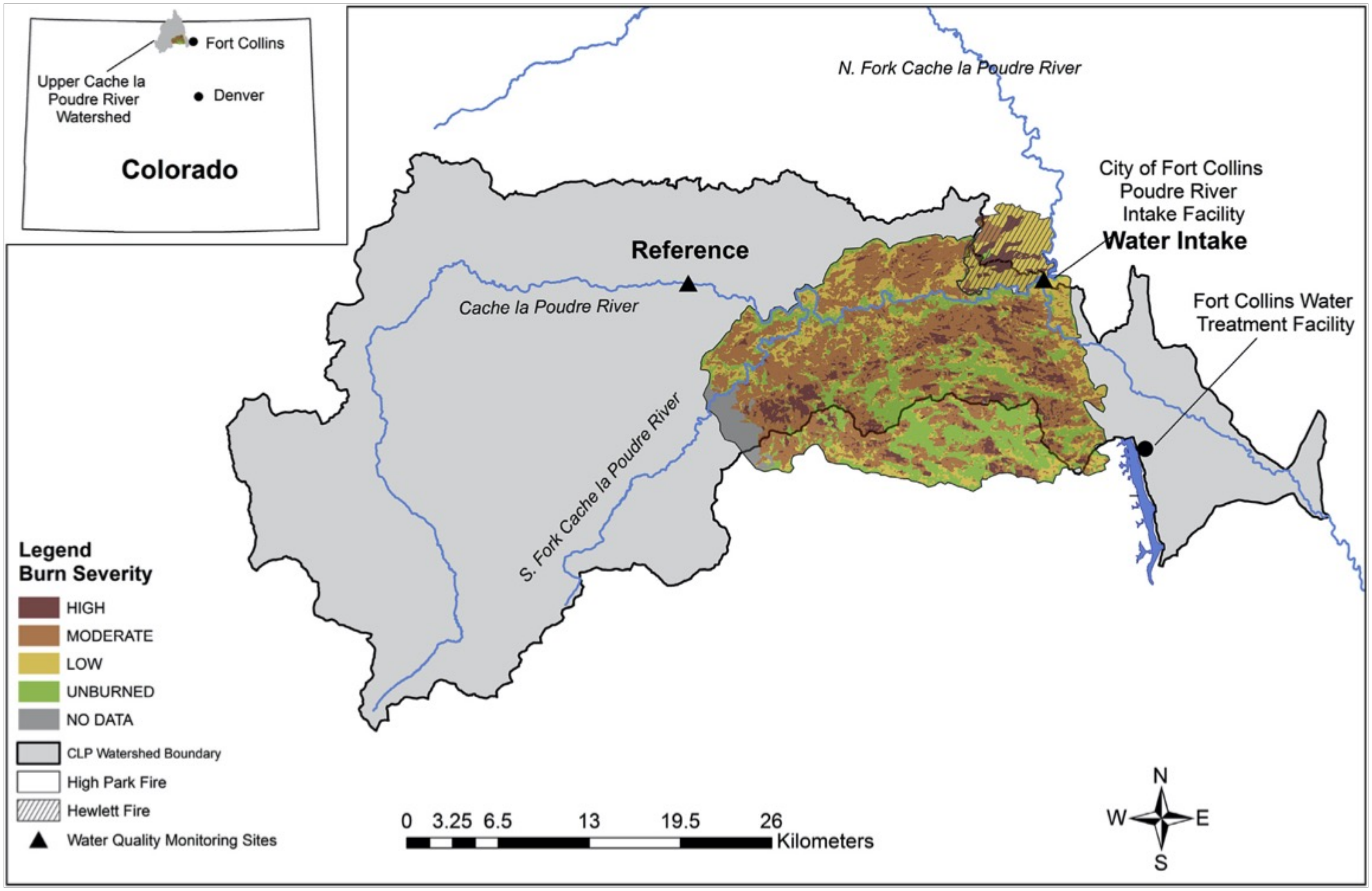
Wilkerson and Rosario-Ortiz, 2021

Impact of Wildfire on Water Treatment



Becker, et al., JAWWA 2018

Case Study: High Park Fire, 2012

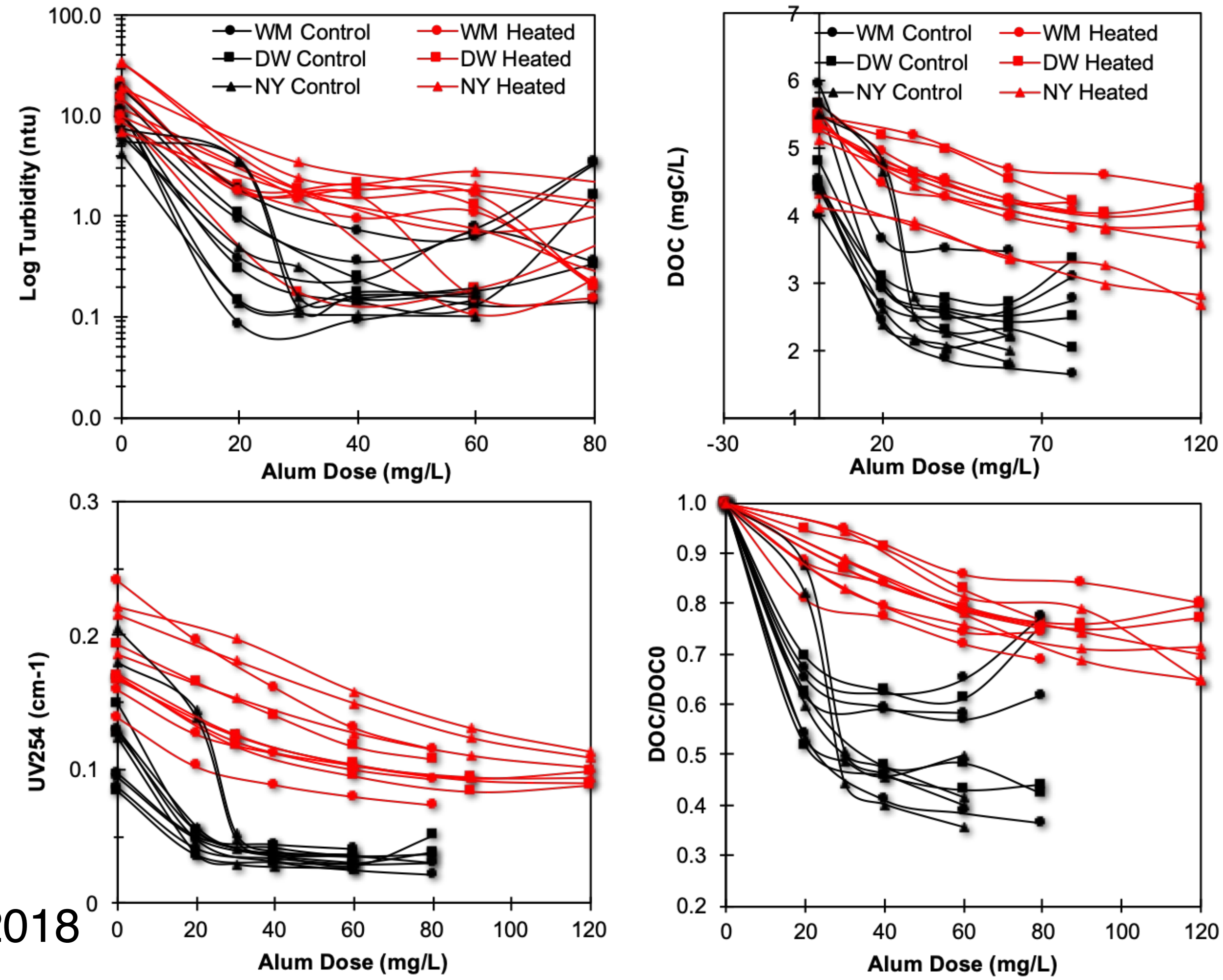


Hohner et al., 2016

Water Treatment

Treatment Parameter		Water Intake	Control	Delta (intake-control)
Alum Dose (mg/L)	Mean	44	34	9.6
	Median	45	28	7.5
Treated Water DOC (mg_C/L)	Mean	1.6	1.4	0.2
	Median	1.4	1.3	0.2
Treated Water UV_{254} (cm^{-1})	Mean	0.032	0.027	0.005
	Median	0.024	0.023	0.004

Performance of coagulation



Hohner, et al., 2018

Issues with Contamination

NY Times, October 2, 2020

Issues with Contamination

NY Times, October 2, 2020

Issues with Contamination

Chemical	Exposure and public notification limits				Tubbs Fire (21 months post-fire)		Camp Fire (8 months post-fire)				
	Long-term limits		Short-term limits		City of Santa Rosa		PID		SWR CB in PID	DOWC (three systems)[a]	
	US[b]	California[c]	HA[d]	NL[e]	*n*	Max	*n*	Max	*n* = 1	*n*	Max
Benzene	5	1	200, 26[i]	—	8,387	40,000	1,699[f]	923	>2,217	200[g] *40/20/140*	530 *8.1/5.3/530*
Dichloromethane	5	200	10,000	—	6,254	41	NA[h]	28	—	NA	—
Naphthalene	—	100	500	17	661	6,800	NA	278	693	NA	—
Styrene	100	100	20,000	—	6,227	460	NA	6,800	378	NA	—
Tert-Butyl alcohol	—	—	—	12	339	29	NA	600	—	NA	—
Toluene	1,000	—	20,000	—	8,387	1,130	NA	1,400	676	NA	—
Vinyl chloride	2	—	3,000	—	6,227	16	NA	0.8	—	NA	—

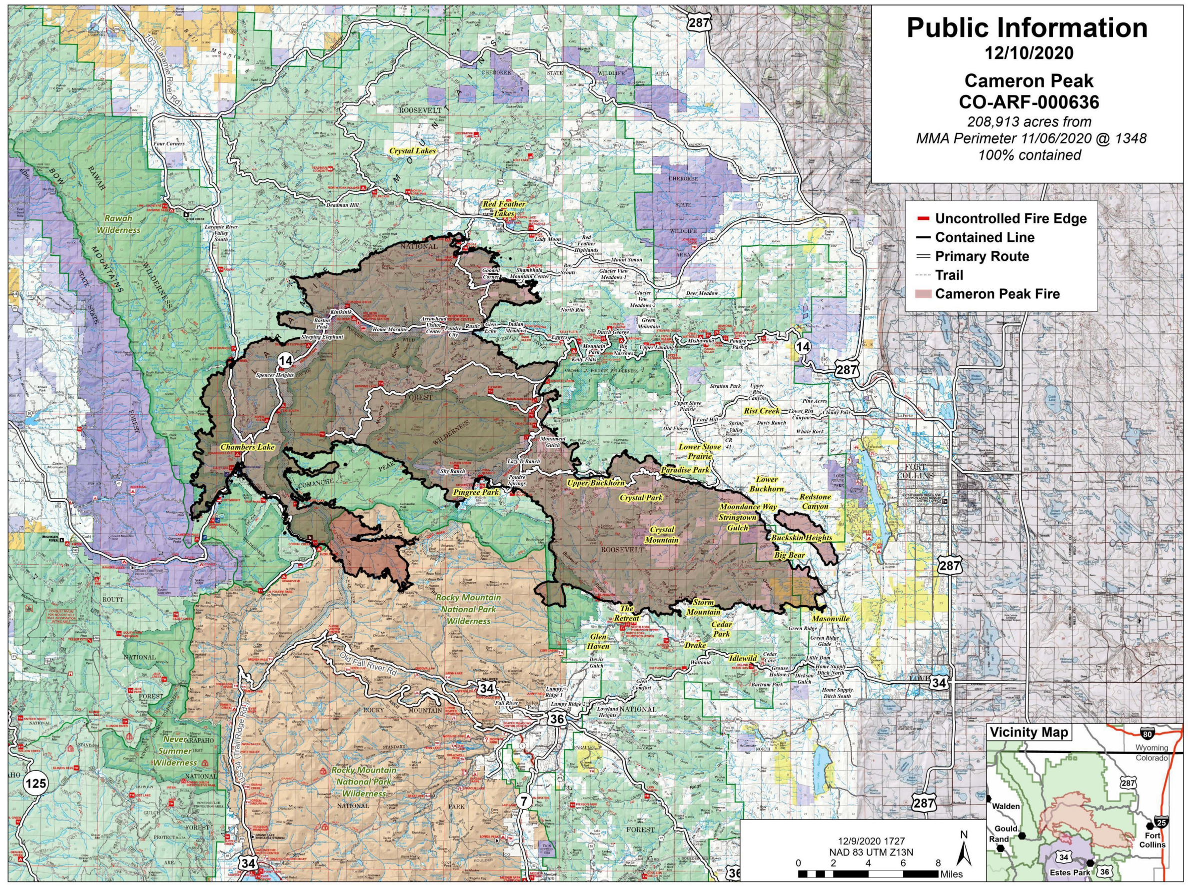
Proctor, et al., AWWA Water Science, 2020

Issues with Contamination

What about sources within the watershed?

Issues with Contamination

- Collected samples from Cameron Peak fire
- Developed methods for 12 compounds
- Analyzed several samples collected from the watershed



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Issues with Contamination

Compound	Pingree Blackwater 7-1-21	Blak 5-18-21	Shep 5-18-21	Pono 5-18-21	FCW Blackwater No Date	Chuck's Ditch 6-25-21
3,5-PCA	2.0	<0.025	<0.025	<0.025	<0.025	<0.025
1,2,4-BPCA	174	0.20	0.33	<0.025	1.01	1.24
1,2,3-BPCA	67	<0.15	0.06	<0.15	0.17	0.23
1,3,5-BPCA	20	<0.15	<0.15	<0.15	<0.15	<0.15
1,2-BPCA	43	<0.25	<0.25	<0.25	<0.25	<0.25
1,4-BPCA	13	<0.50	<0.50	<0.50	<0.50	<0.50
1,3-BPCA	28	<0.50	<0.50	<0.50	<0.50	<0.50
3-Methyphthalic Acid	2.3	<0.20	<0.20	<0.20	<0.20	<0.20
1,4-Naphthalene Dicarboxylic Acid	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
2,6--Naphthalene Dicarboxylic Acid	0.38	<0.05	<0.05	<0.05	<0.05	<0.05
4,4'-Biphenyl Dicarboxylic Acid	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
2,2'-Biphenyl Dicarboxylic Acid	0.22	<0.05	<0.05	<0.05	<0.05	<0.05

Summary

- Wildfires impact water quality and treatment
  - Enhanced nutrient and DOC mobilization
  - Changes in DBP formation
  - Enhanced treatment costs

- Additional work is still needed to continue to improve our understanding of the complex effects of wildfires on water quality and treatment

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