EPA

Free Monthly Webinar Series

Challenges and Treatment Solutions for Small Drinking Water Systems

Hosted by EPA's Office of Research and Development (ORD) and Office of Water (OW)

Schedule & Recordings: epa.gov/water-research/small-systems-monthly-webinar-series

Wildfires and Resulting Impacts to Water Bodies Used as Drinking Water Sources

September 29, 2020

A certificate of attendance will be provided for this webinar

Webinar Slides: Located under "Handouts" in the right navigation bar on your screen.

To Ask a Question: Type in the "Questions" box located in right navigation bar on your screen.

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50 EPA at

Progress for a Stronger Future

EPA turns 50 this year! Join us in our year-long anniversary celebration. epa.gov/50

Certificates of Attendance

Requirements:

1. You must be registered or be in a room with someone who is.

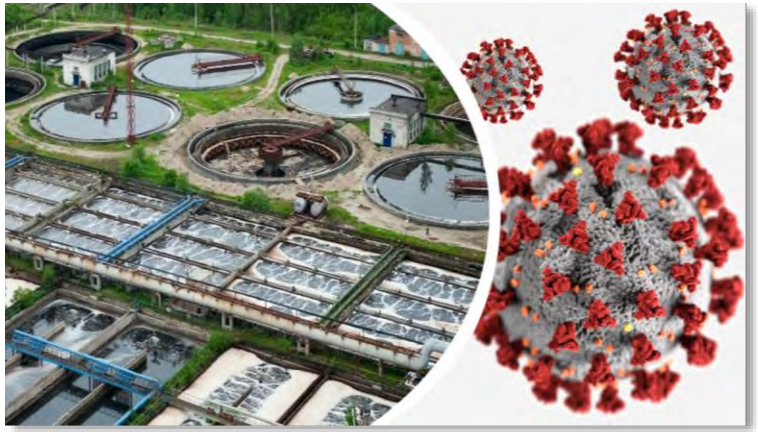
2. You must **attend** the live webinar **for 60 minutes.**

3. If in a room with others, the **names of people not logged in must be provided by the person who is logged in**. Type additional names in the "Questions" box or send names to webcastinfo@cadmusgroup.com.

Note

Acceptance of certificates is contingent on organization requirements—EPA cannot guarantee acceptance. Closed-captioned recordings of the webinars are provided below for later viewing and as a training resource; certificates cannot be provided for viewing webinar recordings.

Upcoming EPA Webinars



Water Research Webinar Series

September 30: *SARS CoV-2 in Wastewater Monitoring: Linking Research and Application to Meet Immediate Needs*

Registration and Additional Information

Tools and Resources Webinar Series

October 21: *Lead Action Plan Research Update*

Registration and Additional Information

Solicitation Research Questions

National Priorities: Systems-Based Strategies to Improve the Nation's Ability to Plan And Respond to Water Scarcity and Drought

Additional Information

- How does drought affect water quality and availability?
- How do drought related events, such as surface runoff and wildfire, change water quality and availability?
- How can water quality changes driven by drought, such as changes in timing and intensity of spring snowmelt and runoff, affect water quality?
- What adaptive management strategies and innovative, cost-effective technologies protect against drought impacts?
- How can management strategies and technologies be demonstrated in communities to facilitate adoption?

EPA

Awarded Institutions

Clemson University

Forest Fuel Reduction Techniques as Effective Watershed Management Practices Against Wildfire: Drinking Water Quality Aspects

Tanju Karanfil and Alex Chow Additional Information

Water Research Foundation

An integrated modeling and decision framework to evaluate adaptation strategies for sustainable drinking water utility management under drought and climate change

Kenan Ozekin, Joseph Kasprzyk, Scott Summers, Fernando Rosario- Ortiz, Balaji Rajagopalan, and Benjamin Livens Additional Information

Water Quality After a Wildfire

Watershed Factors

- Vegetation
- Fire Intensity
- Topography
- Hydrologic factors

Potential Impacts from Wildfires

- Increased flooding
- Ecosystem harm
- Greater rates of erosion
- Water quality impacts: nutrients and sediment

Source: https://ca.water.usgs.gov/wildfires/wildfires-water-quality.html

Wildfire Impacts on Drinking Water Quality

Alex Chow, Ph.D

achow@clemson.edu

Dr. Chow is a professor of biogeochemistry in the Department of Forestry and Environmental Conservation, with a joint appointment in the Department of Environmental Engineering and Earth Science at Clemson University. His research focuses on watershed perturbation, such as wildfire, flooding, and land use changes on exports of dissolved organic matter and DBP precursors. Dr. Chow holds a Ph.D. in hydrologic science from University of California, Davis.

Tanju Karanfil, Ph.D.

tkaranf@clemson.edu

Dr. Karanfil is a professor of Environmental Engineering in the Department of Environmental Engineering and Earth Science and is also a vice president of research at Clemson University. His research focuses on drinking water quality, including DBPs, water treatability, and other emerging contaminants. Dr. Karanfil holds a Ph.D. in environmental engineering from University of Michigan.

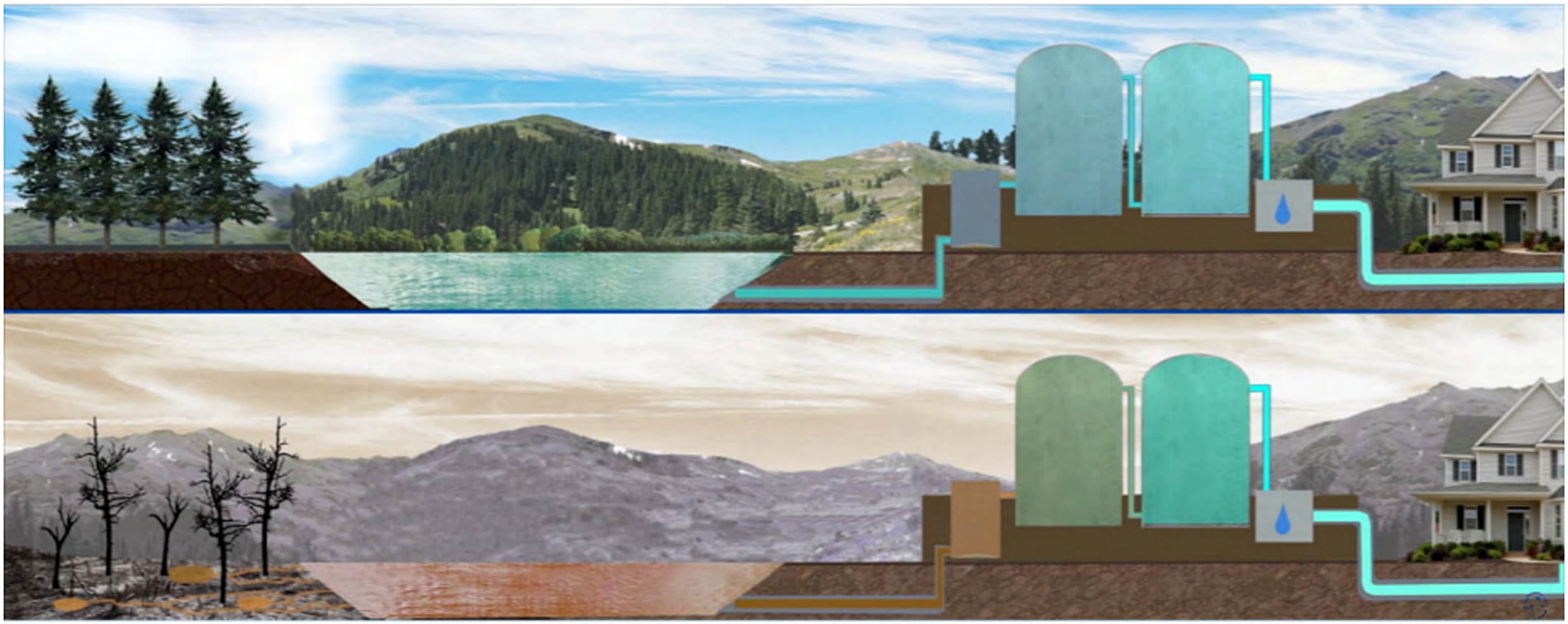
EPA
Small Systems
Webinar Series

Wildfire Impacts on Drinking Water Quality

Low-Severity Prescribed Fire and High-Severity Wildfire

Tanju Karanfil & Alex Chow

Sept. 29, 2020



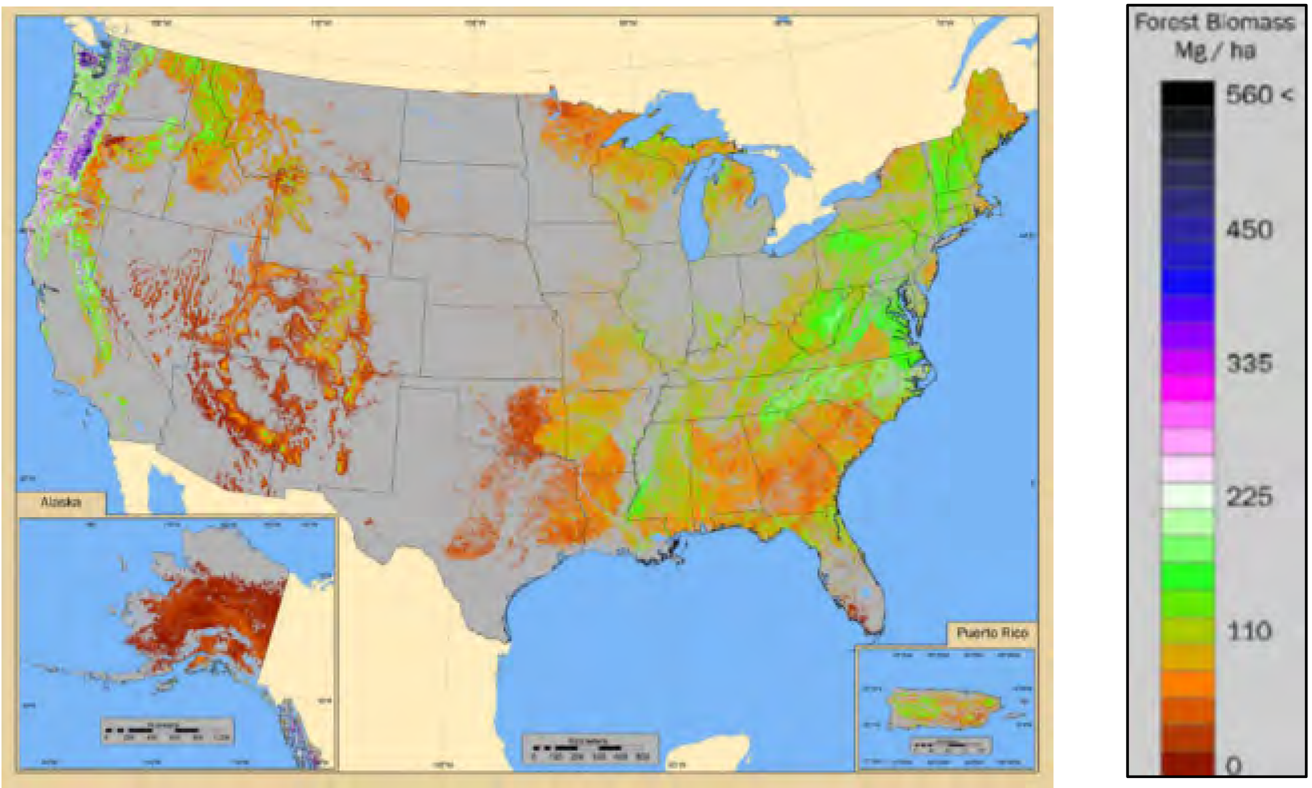
CLEMSON UNIVERSITY

Clemson University
Biogeochemistry & Environmental Quality

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Forest Land ⟷ Source Waters

Forest land comprises 766 million acres, or 33% of the total land area of the United States

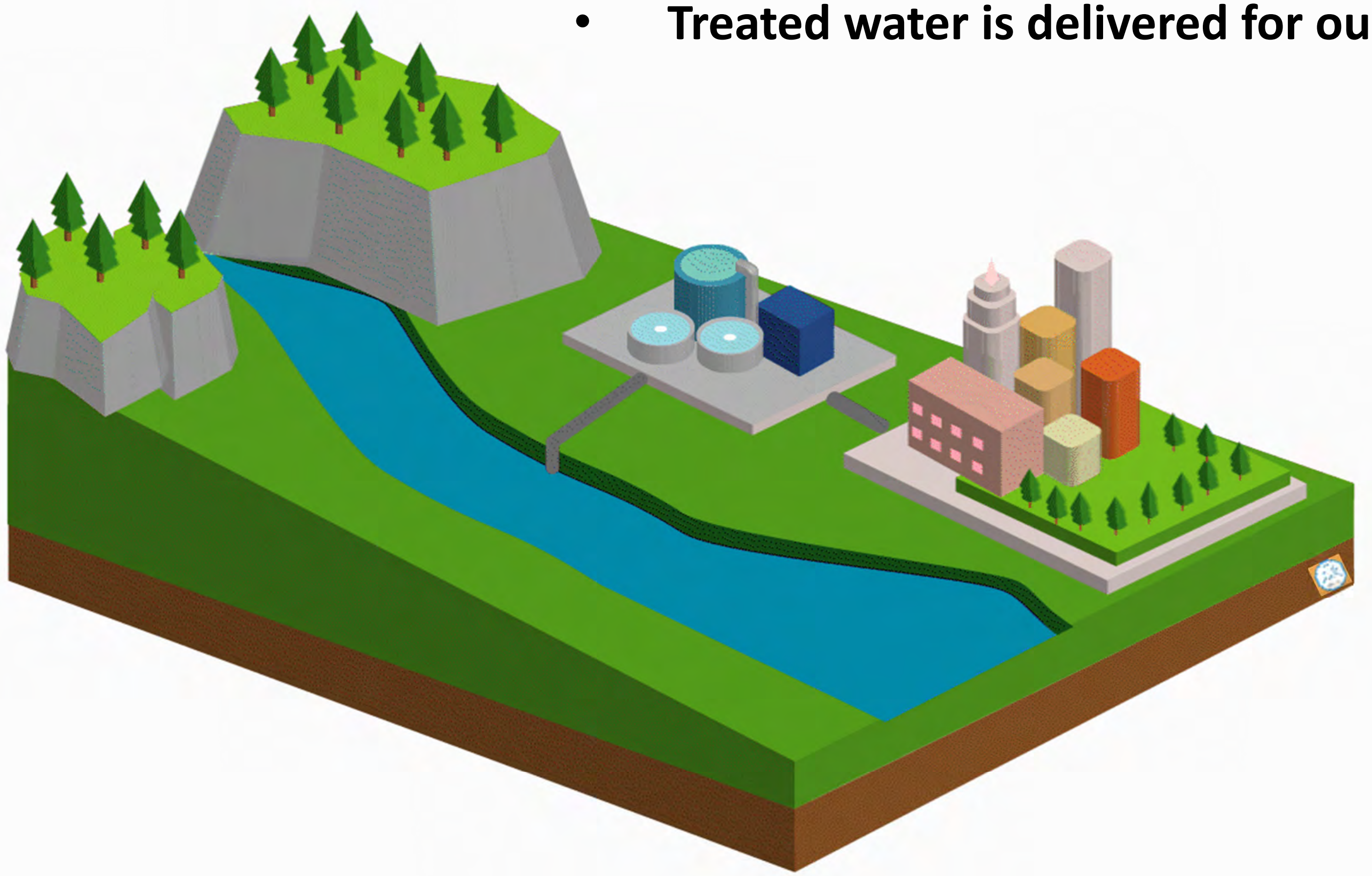


About 53% of the water supply in the US is surrounded by forest land

Sources: Blackard et al. 2008. Remote Sensing of Environment 112(4): 1658-1677 / US Forest Resource Facts and Historical Trends, 2012

From Headwater to Household Tap Continuum

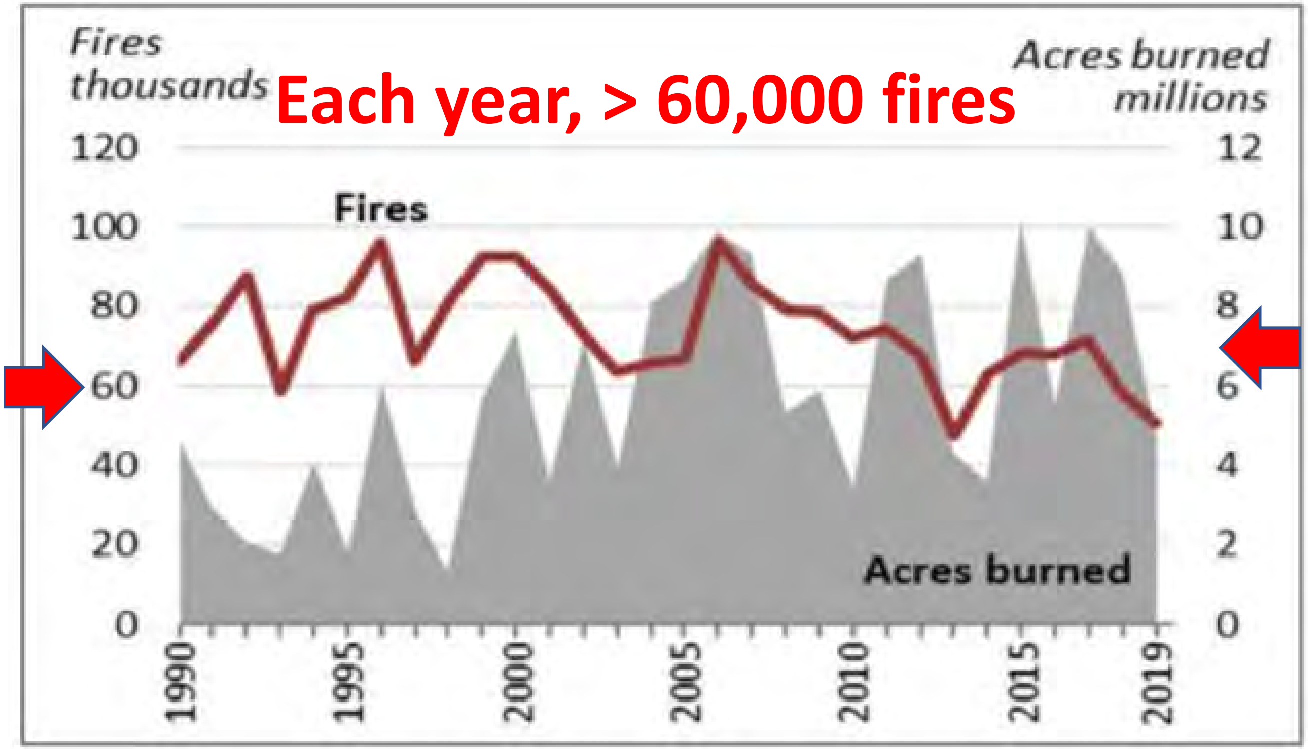
- Water is drained from forested watershed
- It is source water for downstream utilities
- Treated water is delivered for our use



- Wildfire consumes biomass and generates ash
- Post-fire rainstorms flush ash to surface water
- It is a challenge to treat ash loaded water

Wildfire Statistics

Annual Wildfires and Acres Burned (1990 – 2019)



County Fire near Lake Berryessa

Angora Fire near Lake Tahoe

An average of 7 million acres burned each year

As of September 1, 2020, nearly 40,000 wildfires have burned over 4 million acres this year

Source: Congressional Research Service IF 10244 / National Interagency Fire Center (NIFC)

Detritus in Forested Watersheds

- Forest detritus is an ignition source of forest fire.
- Forest detritus is a major terrestrial source of dissolved organic matter (DOM) in source water.
- DOM is a precursor of carcinogenic disinfection byproducts (DBPs) during drinking water treatment.

Forest Litter

Fuel

&

Sources of NOM

Prescribed Fire as a Fuel Reduction Technique

Hypothesis

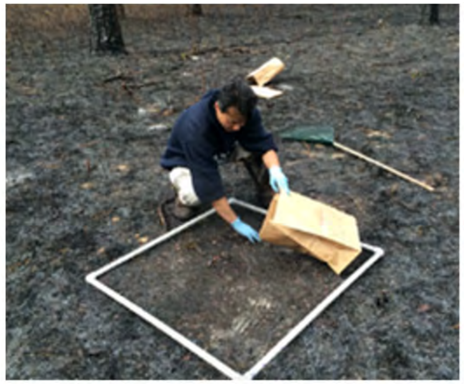
Reduce		Reduce		Reduce
Mass of litter & duff per unit area	→	**DOM Exports from Watersheds**	→	**DBP Precursor in Source Water**

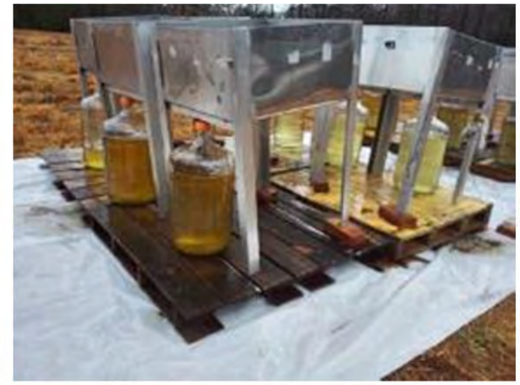
Low-severity Prescribed Fire on Water Quality and Formation of Disinfection Byproducts

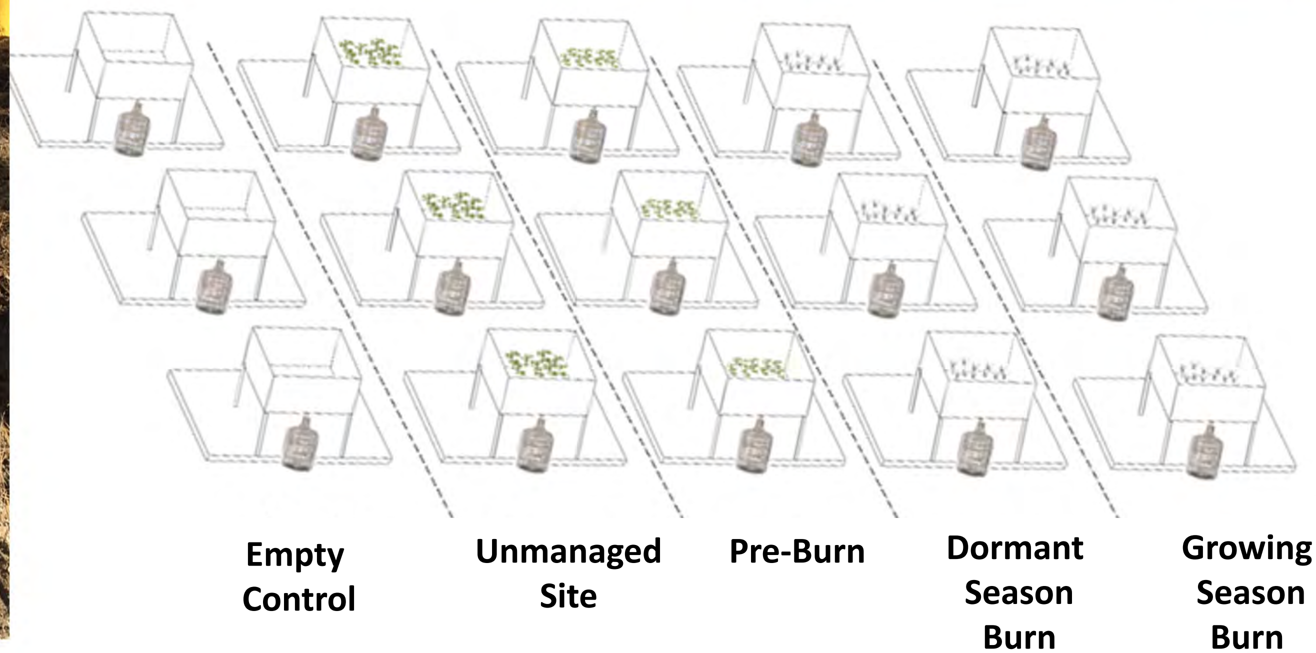
- ❑ **Treatability of Prescribed Fire Derived DOM**
- ❑ **Dynamics of DBP Precursors in Post-Fire Runoffs**
- ❑ **Long-term Effects of Prescribed Fire Practice**

Treatability of Prescribed Fire Derived DOM

Controlled Field Study – 1 Year Water Leaching Experiment







Treatability of Prescribed Fire Derived DOM

Results – Box Model on the Yields of DBPs and Treatability

Samples	Forest floor: W_{woody} / $W_{detritus}$ (Mg/ha)	Leachate water quality: Cumulative DOC export (g)	Leachate water quality: DOC Concentration (mg/L)	Leachate water quality: THM FP (µg/L)	Leachate water quality: HAA FP (µg/L)	Treatability: DOC (Alum / Ferric removals, %)	Treatability: THM FP (Alum / Ferric removals, %)	Treatability: HAA FP (Alum / Ferric removals, %)
Unmanaged	7.6 ±4.2 / 36.7 ±4.6	~16.9	41.4 ±15.8	4299 ±2080	4191 ±2113	52 ±7 / 56 ±11	69 ±3 / 70 ±7	79 ±3 / 78 ±9
Managed pre-burnt (2-3 years)	8.0 ±4.6 / 8.9 ±1.0	~8.94	23.7 ±10.3	2519 ±1537	2428 ±1468	52 ±4 / 57 ±6	69 ±7 / 70 ±10	79 ±6 / 81 ±11
After dormant season burn	6.1 ±2.0 / 2.0 ±0.5	~8.49	22.5 ±9.1	2168 ±1044	2297 ±1209	48 ±9 / 51 ±11	68 ±9 / 72 ±11	77 ±7 / 78 ±10
After growing season burn	5.9 ±1.0 / 5.1 ±1.1	~8.21	23.6 ±9.4	2092 ±965	2273 ±1197	42 ±14 / 49 ±13	67 ±7 / 67 ±10	75 ±13 / 77 ±10

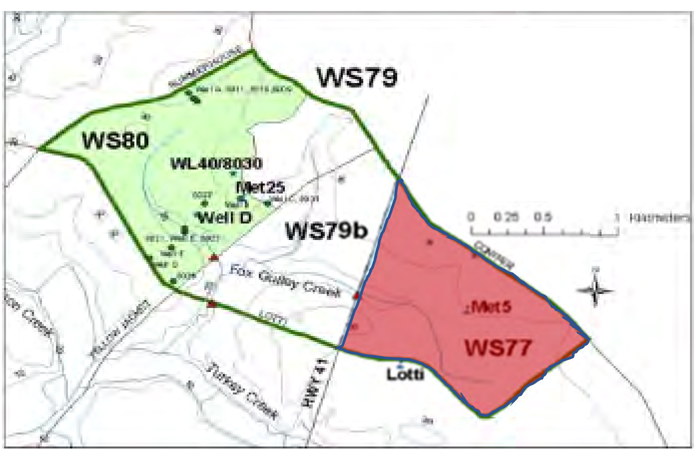
Dynamics of DBP Precursors in Post-Fire Runoffs

Watershed-scale Investigations

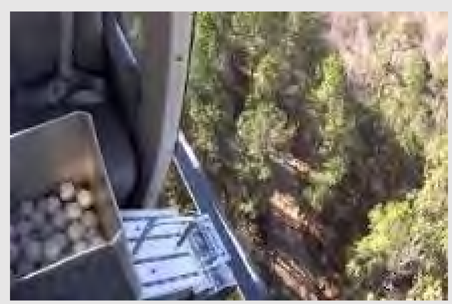
Study Sites:

Francis Marion
National Forest

US Forest Service
Santee Experimental Forest

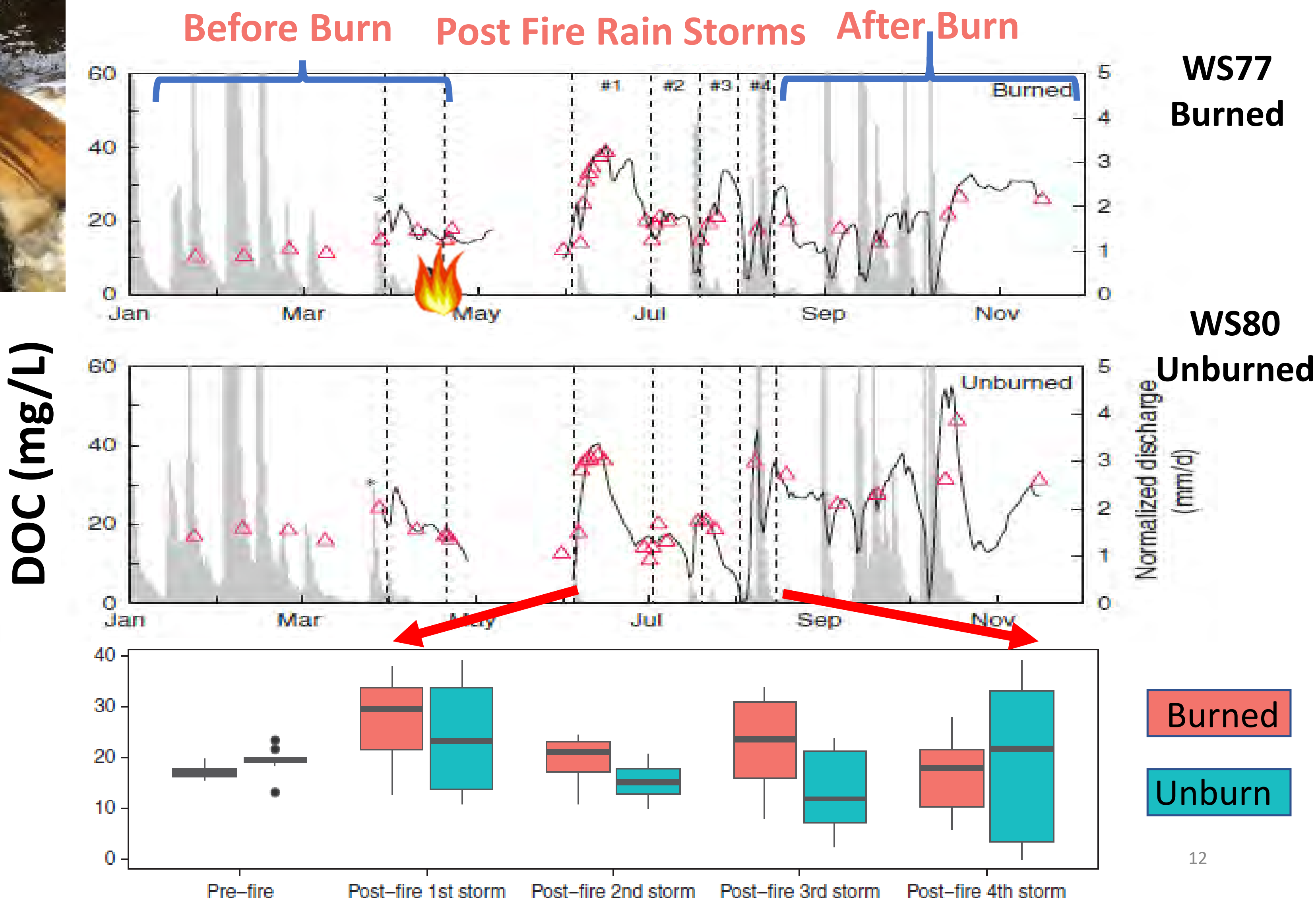


- A paired watershed – 160 ha each
- 1st order stream
- Control vs Prescribed burn
- Operation since 1960s
- Burn every 2-4 years



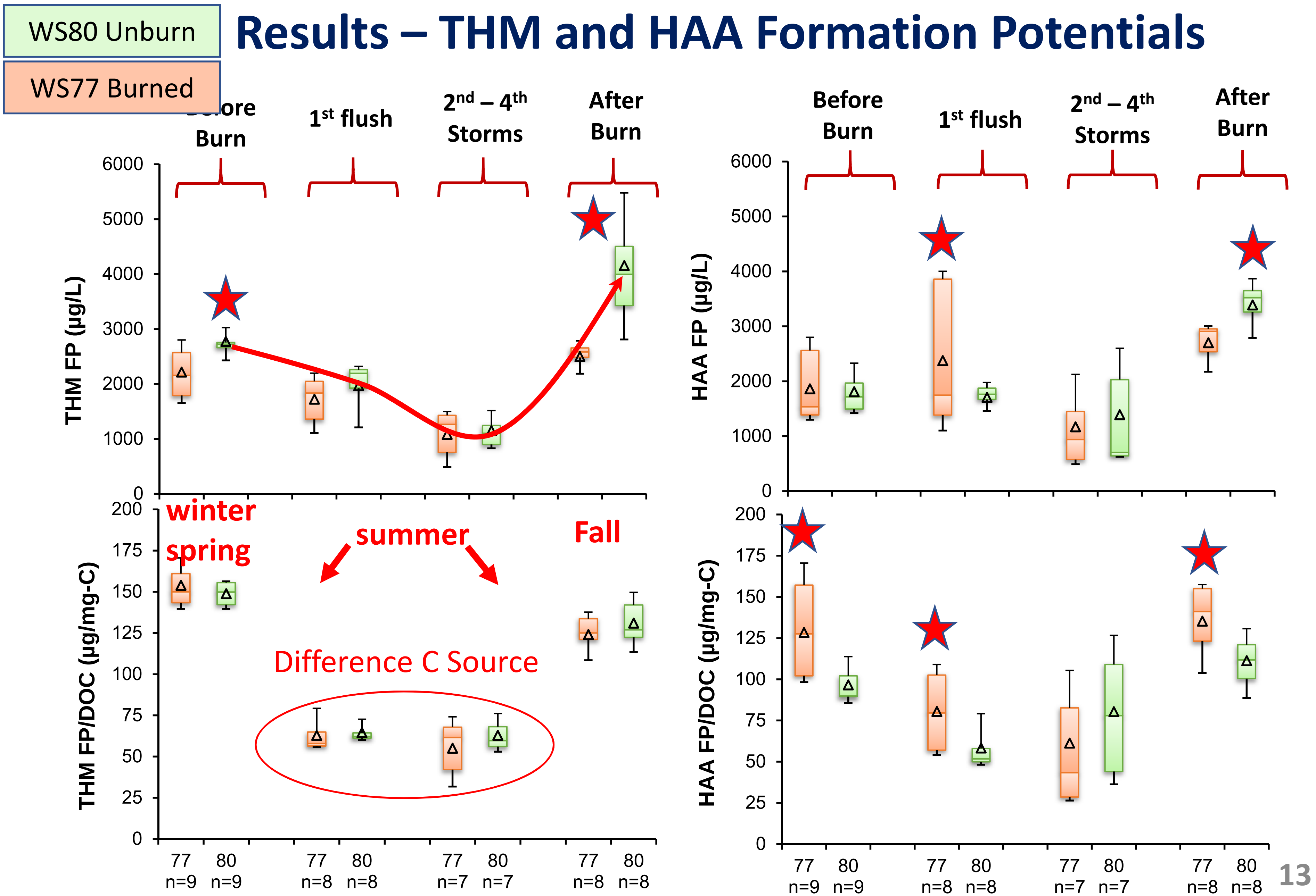
Dynamics of DBP Precursors in Post-Fire Runoffs

Results – DOC Concentrations



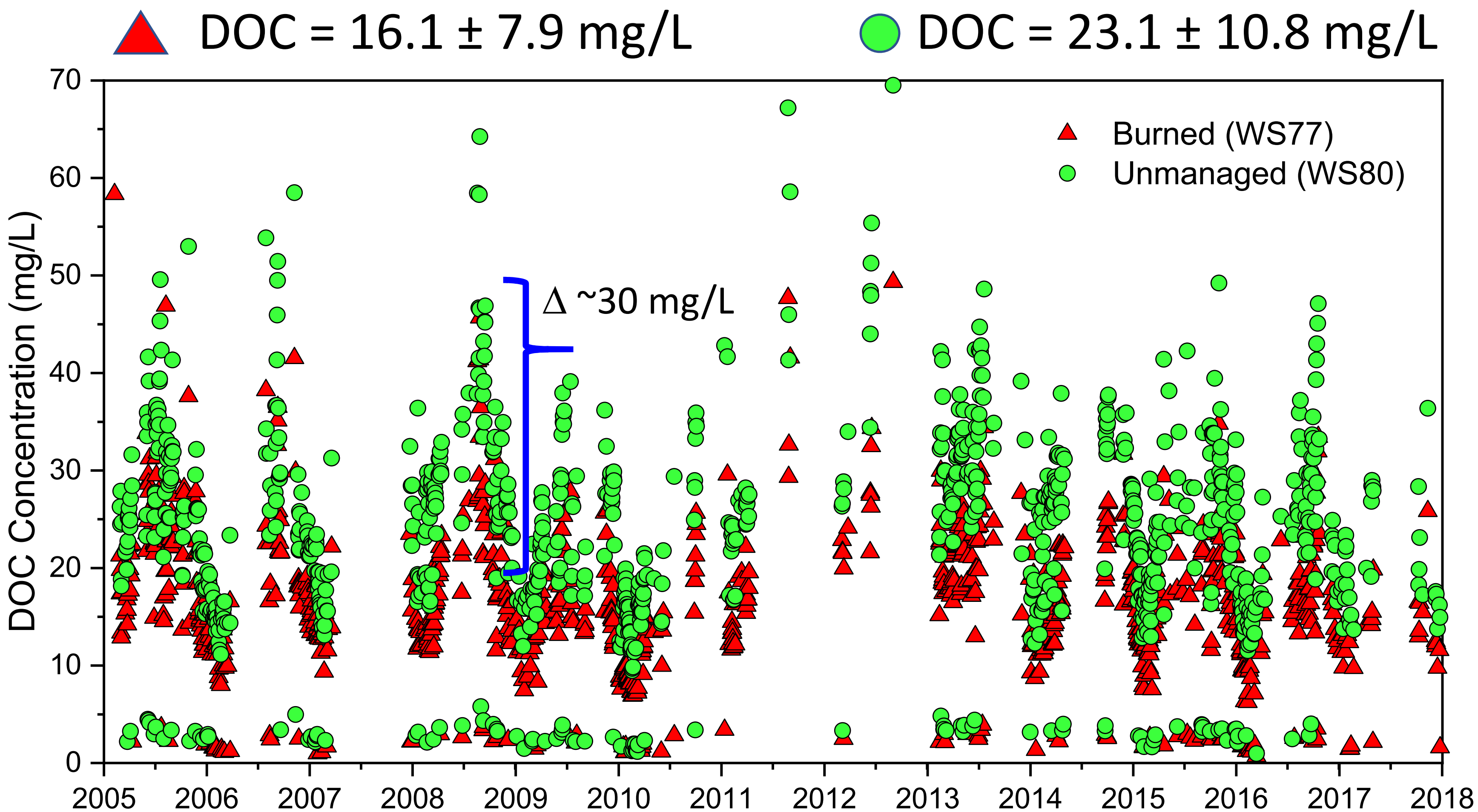
Dynamics of DBP Precursors in Post-Fire Runoffs

Results – THM and HAA Formation Potentials



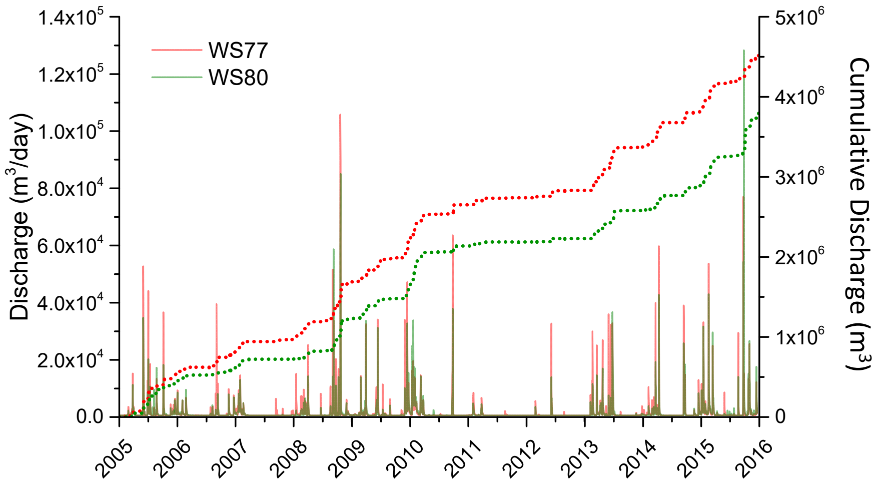
Long-Term Effects of Prescribed Fire Practice

Results – DOC Concentration



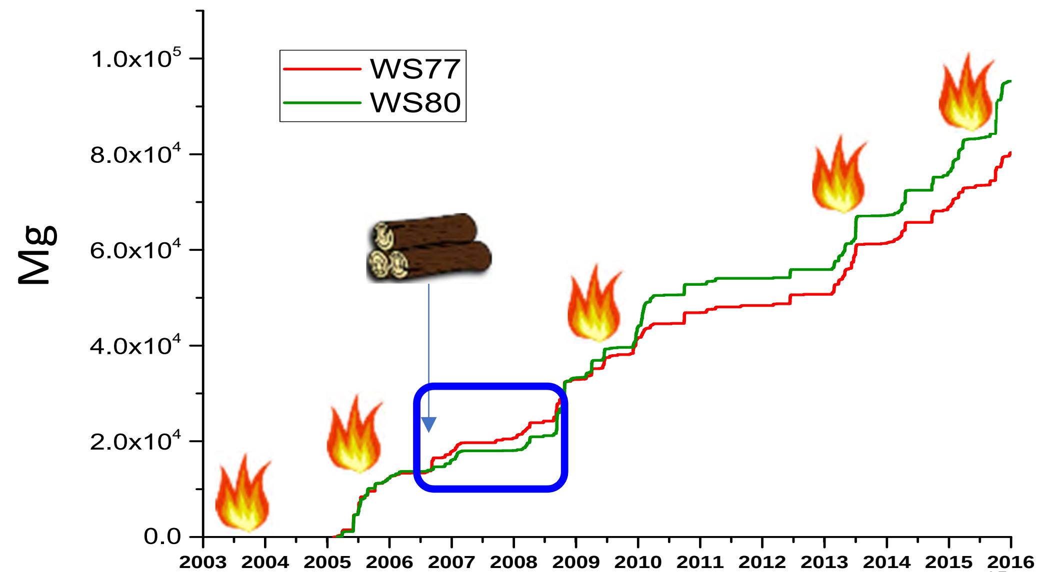
Long-Term Effects of Prescribed Fire Practice

Results – Water and DOC fluxes



Prescribed Burn WS77		Unmanaged WS80
$[DOC]_{77}$	<	$[DOC]_{80}$
$[Discharge]_{77}$	>	$[Discharge]_{80}$
$[DOC\ Load]_{77}$	<	$[DOC\ Load]_{80}$

DOC Load
= [DOC] x [Discharge]



Long-Term Effects of Prescribed Fire Practice

Results – Yields of DBP Precursors

Reduce		Reduce		Reduce
Mass of litter & duff per unit area	→	DOM Exports from Watersheds	→	DBP Precursor in Source Water

Watershed	Forest Floor	Surface Water Quality	DBPs
Managed *(Watershed 77)*	12.3 ± 1.1 Mg/ha *Litter Mass*	21.94 ± 1.8 *DOC (mg/L)* ↓	2143 ± 136 *THM-FP (µg/L)* ↓
	5.8 ± 1.6 Mg/ha *Duff Mass* ↓	0.9 ± 0.08 *TDN (mg/L)*	43.0 ± 4.2 *HAN-FP (µg/L)* ↓
Unmanaged *(Watershed 80)*	12.5 ± 0.7 Mg/ha *Litter Mass*	24.95 ± 2.6 *DOC (mg/L)*	2667 ± 192 *THM-FP (µg/L)*
	10.5 ± 1.4 Mg/ha *Duff Mass*	1.0 ± 0.1 *TDN (mg/L)*	66.5 ± 6.0 *HAN-FP (µg/L)*

* one year average

Pile Fire in UC Berkeley Sagehen Creek Field Station

Benefits of Low-severity Prescribed Fire on Water Quality Formation of Disinfection Byproducts

❑ Treatability of Prescribed Fire Derived DOM

- Greater DOC and DBP formation from unburned forest substrates
- No difference was observed in alum / ferric removal efficiency

Uzun et al. 2020. Water Research 187, 116385

❑ Dynamics of DBP Precursors in Post Fire Runoffs

- Slightly higher DOC but only in first few post-fire runoffs
- No different in yield of THM but higher HAA yield was observed

Olivares et al. 2019. International Journal of Wildland Fire 28, 761-768

❑ Long-term Effects on DBP

- Prescribed fire increases water yield of the watershed
- Prescribed fire lowers DOC and DBP precursors in source water

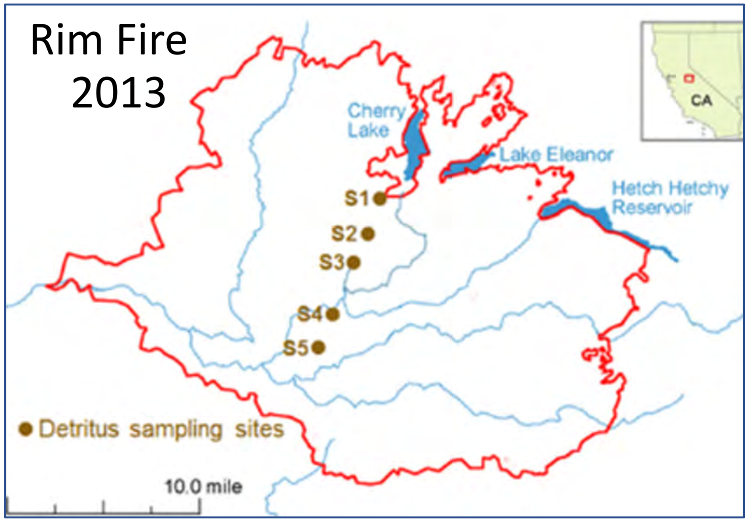
Majidzadeh et al. 2019. International Journal of Wildland Fire 28, 804-813

High-Severity Wildfire on Water Quality and Formation of Disinfection Byproducts

- ❑ Treatability of Wildfire-Derived DOM
- ❑ Dynamics of DBP Precursors in Post-fire Runoffs
- ❑ Wildfire at a Previously Burnt Site

Treatability of Wildfire-Derived DOM

Laboratory Study - Water Leaching Experiments



ponderosa pine
white fir

black ash
white ash

Filtered with 0.45 μm

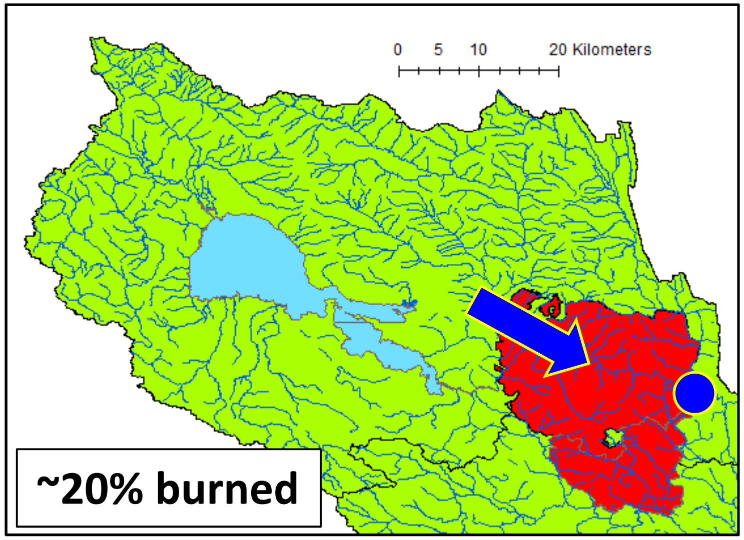
	Treatments	Fir	Pine	B1	W1	B2	W2
DOC	*DOC (mg/g-material)*						
	Raw	41.1	40.3	3.05	5.79	0.45	0.15
	Treated	23.3	23.1	2.04	3.95	0.36	0.13
	Removal (%) [a]	43.3	42.6	33.3	31.8	20.0	14.4
DON	*DON (mg/g-material)*						
	Raw	1.18	0.98	0.25	0.47	0.26	0.18
	Treated	0.35	0.50	0.17	0.36	0.25	0.17
	Removal (%)	70.6	49.2	31.5	23.5	1.83	1.91
SUVA	*$SUVA_{254}$ (L/mg-m)*						
	Raw	3.61	3.28	3.73	4.36	5.24	3.48
	Treated	1.28	1.33	2.89	3.45	4.39	2.99
	Removal (%)	64.5	59.6	22.5	20.8	16.2	14.2

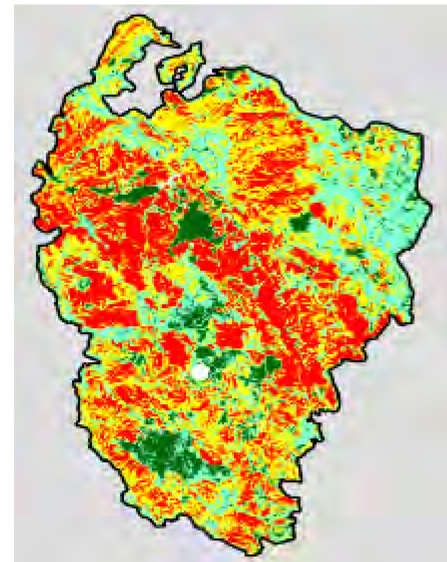
Dynamics of DBP Precursors in Post-fire Runoffs

Field Investigation – California Wildfire

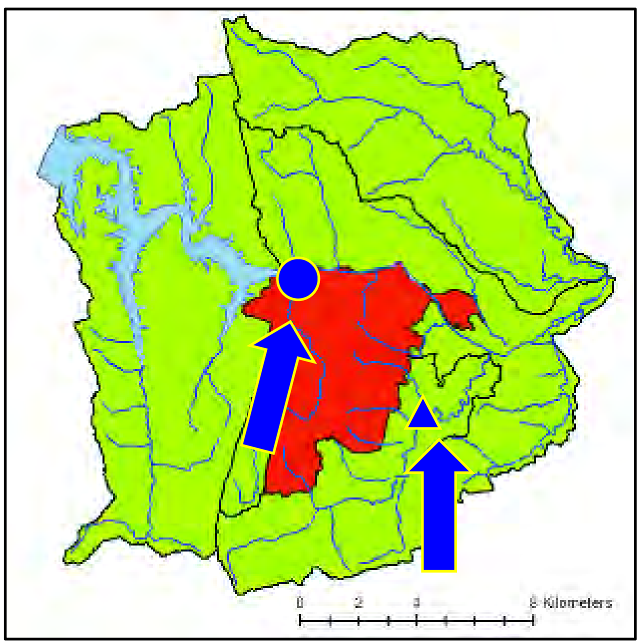
2015

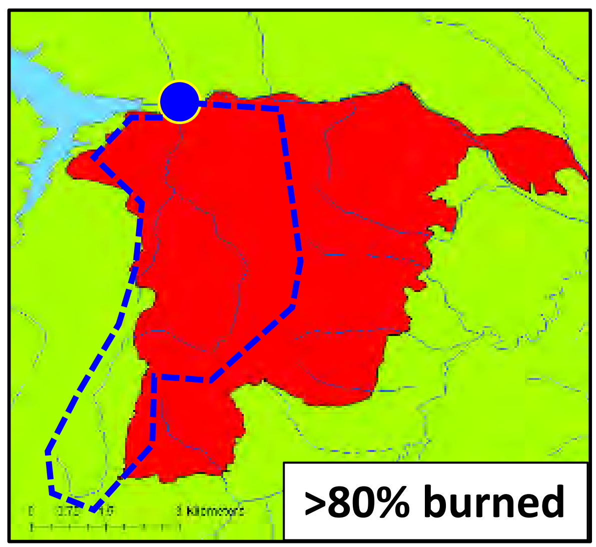
Rocky Fire
383 km^2
(Aug 2015)



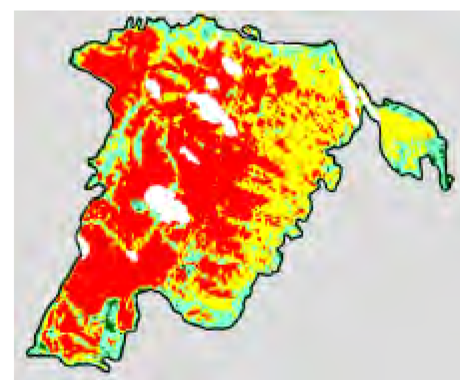


Wragg Fire
33 km^2
(July 2015)





Burn Severity
Unburned to Low
Low
Moderate
High

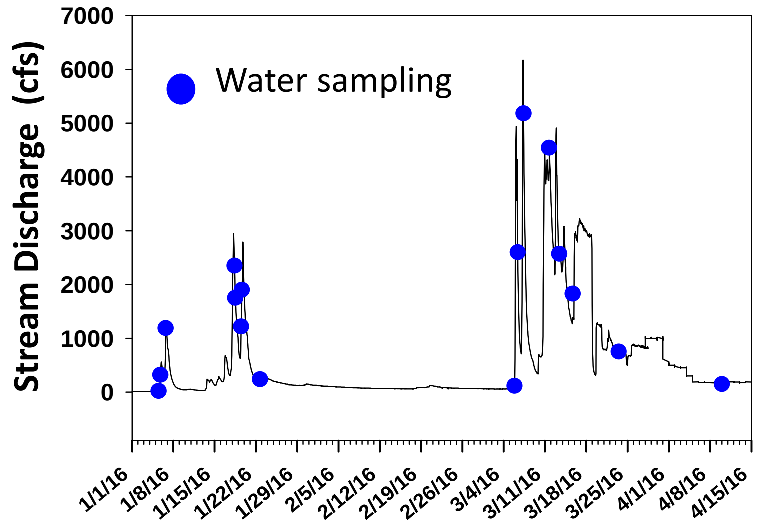


Dynamics of DBP Precursors in Post-fire Runoffs

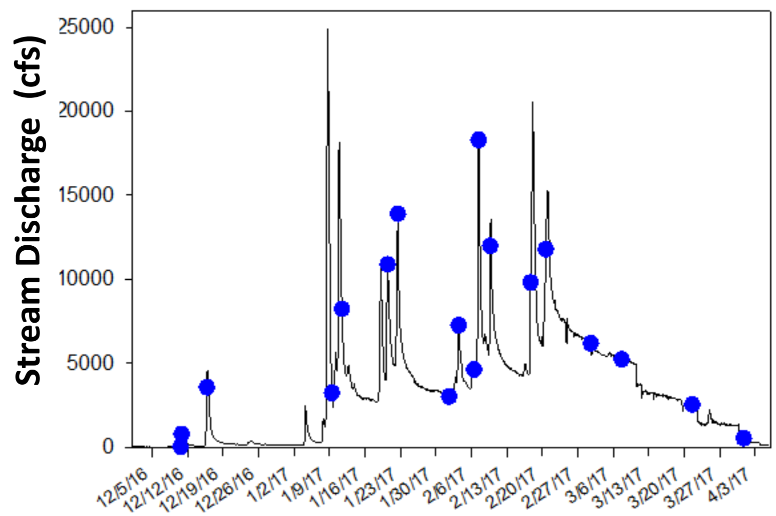
Field Investigation – Post Fire Runoffs

Burned in July/August 2015
First flush in January 2016

2015-2016 Water Year



2016-2017 Water Year

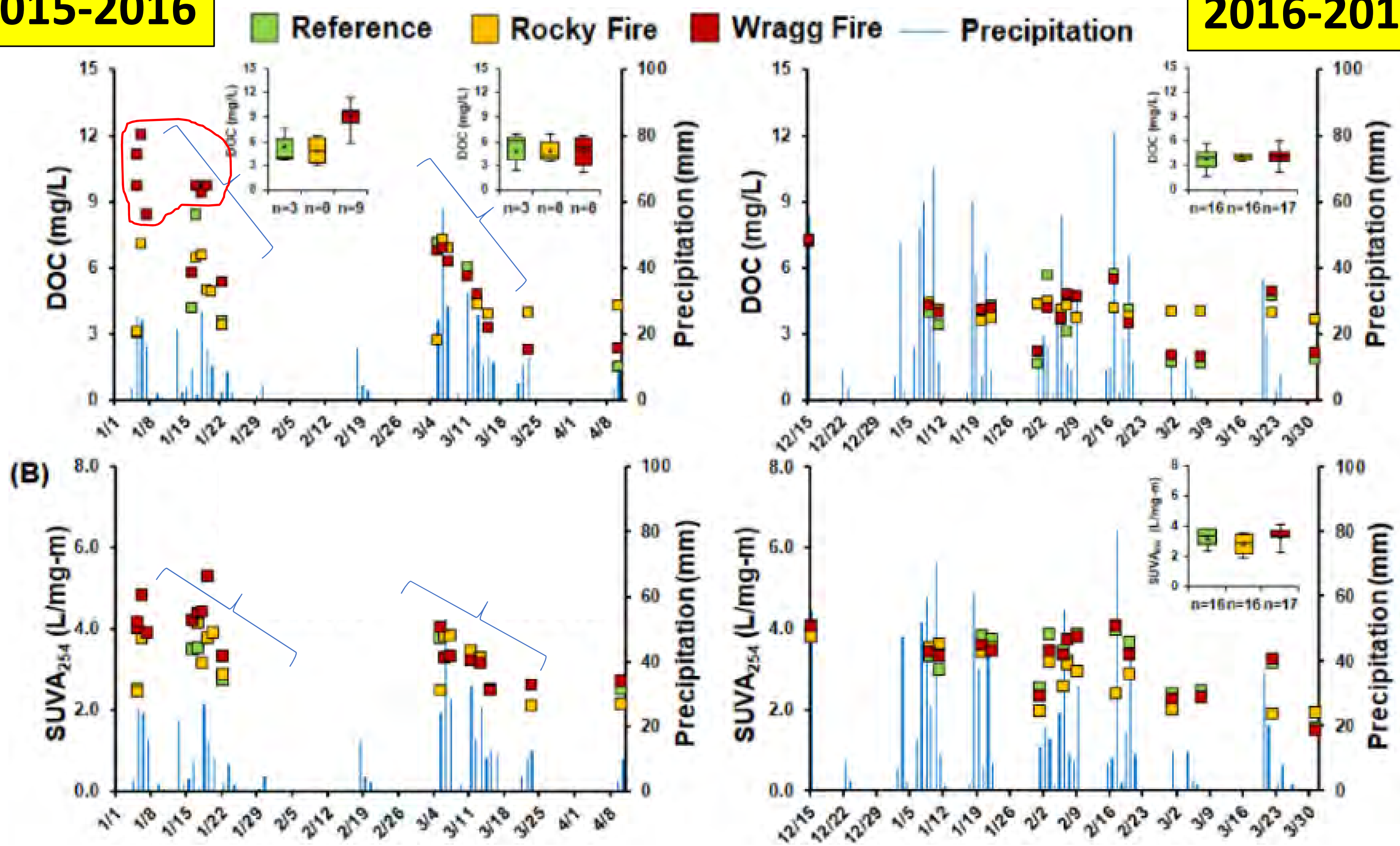


Dynamics of DBP Precursors in Post-fire Runoffs

Results – DOC Concentration and SUVA

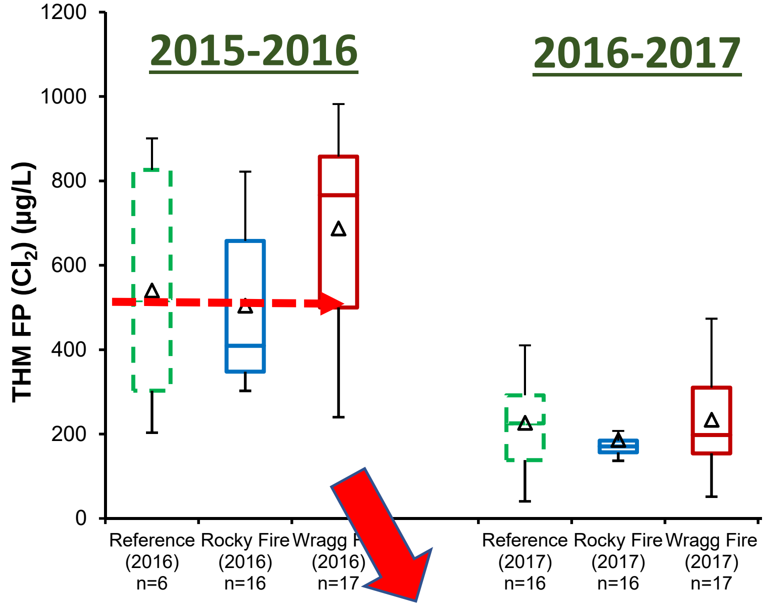
2015-2016

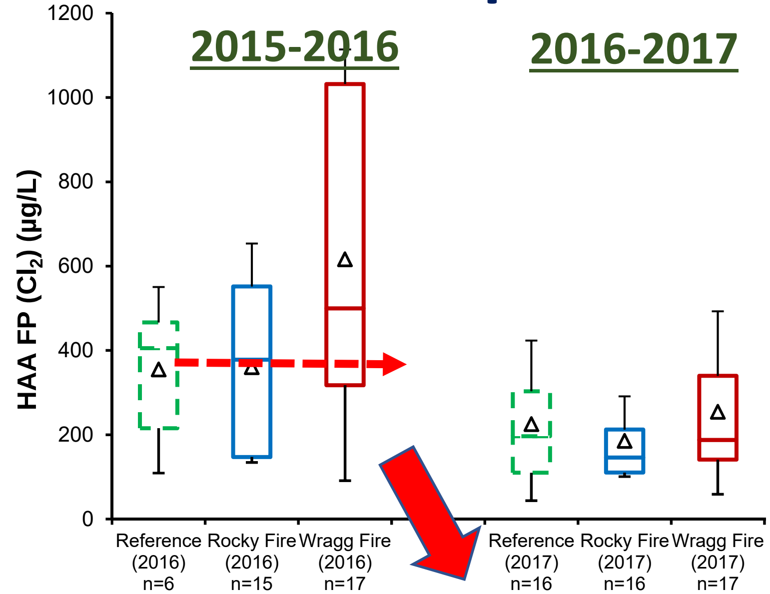
2016-2017

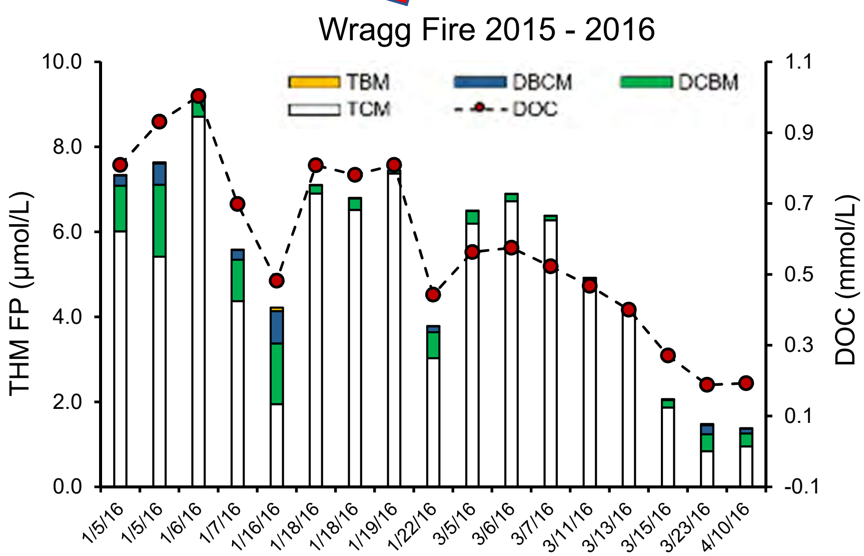


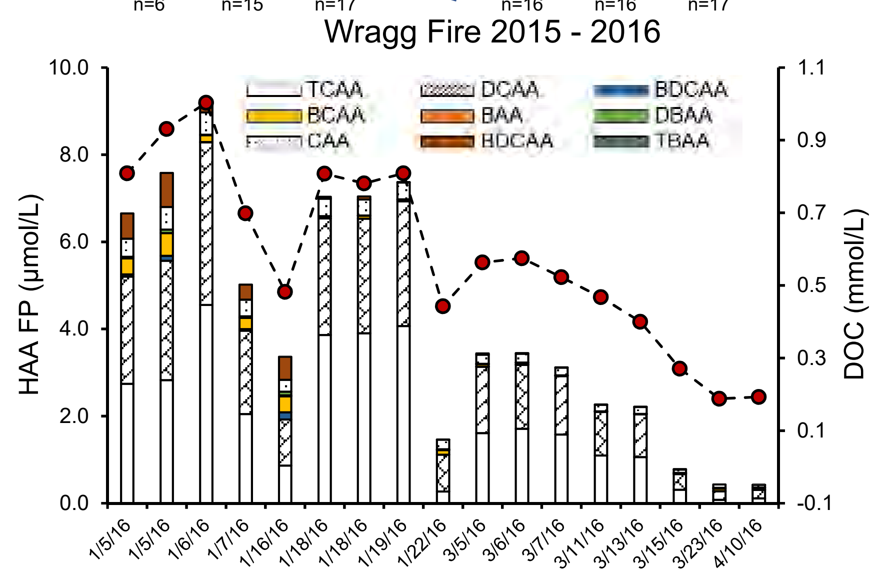
Dynamics of DBP Precursors in Post-fire Runoffs

Results – DBP Formation Potential & Speciation





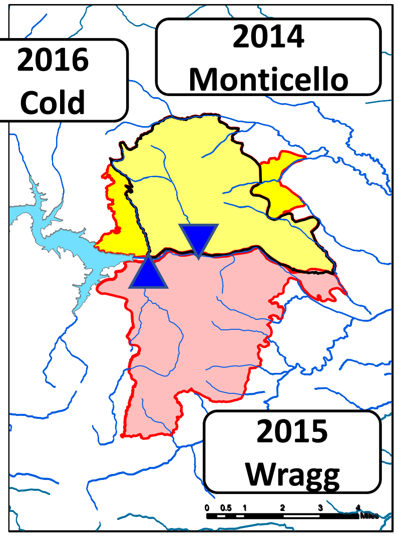




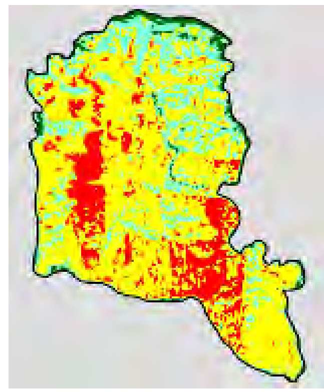
Br (µg/L) 440 690 117 368 695 73 104 21 189 59 26 10 12 10 49 93 153

440 690 117 368 695 73 104 21 189 59 26 10 12 10 49 93 153

Wildfire in a Previously Burnt Site

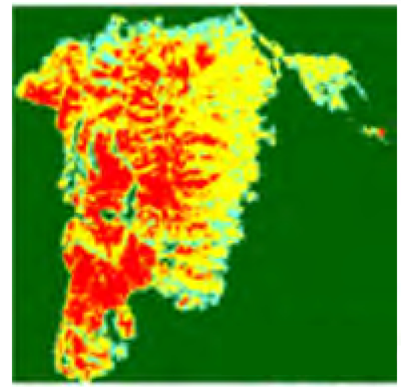


2014



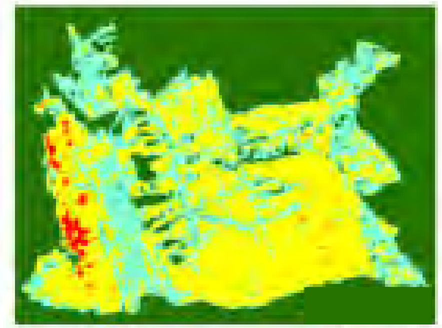
Monticello Fire

2015

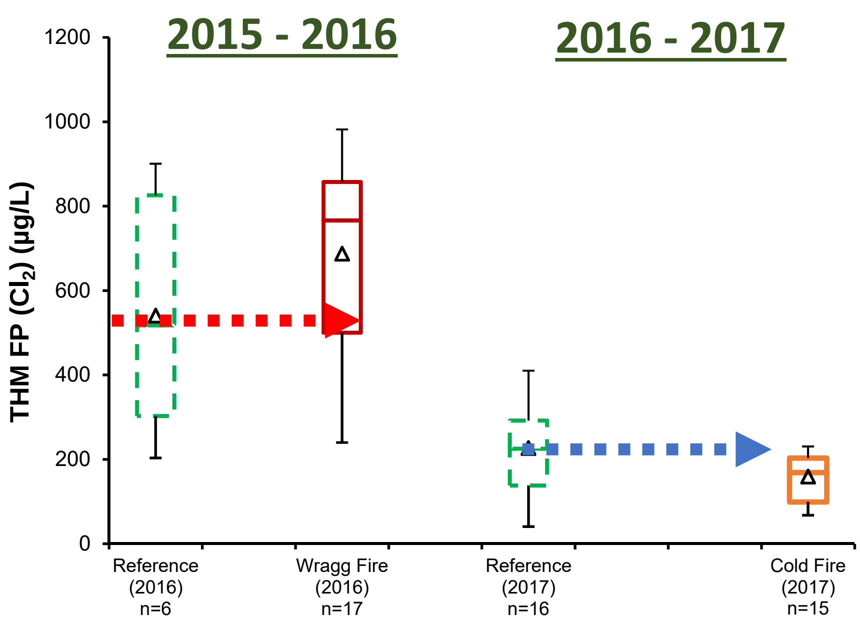


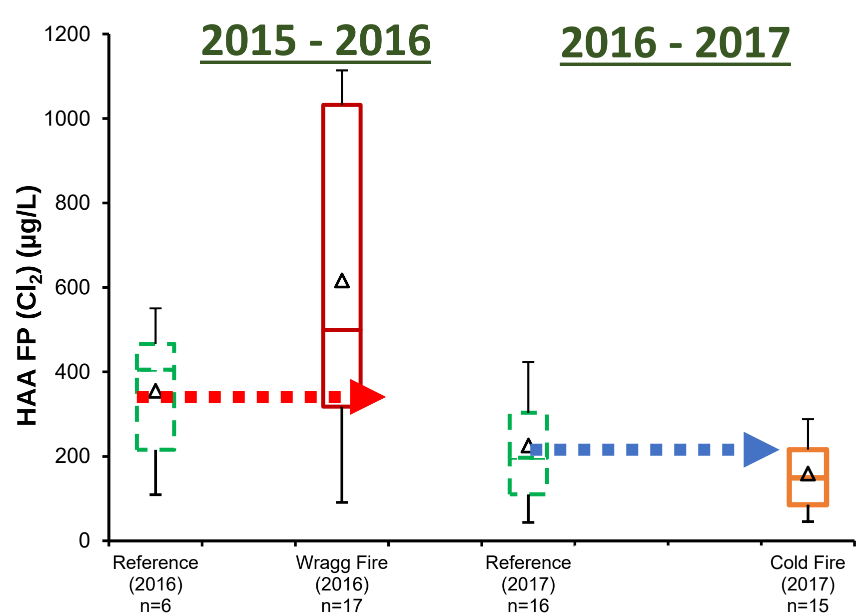
Wragg Fire

2016



Cold Fire





Impacts of High-severity Wildfires on Water Quality & Formation of Disinfection Byproducts

❑ Treatability of Wildfire-Derived DOM

- In the areas we investigated, DOM was more reactive in forming THM and HAA after wildfire
- DOM had low alum removal efficiency

Chen et al. 2020. Water Research 184, 116111

❑ Dynamics of DBP Precursors in Post-Fire Runoffs

- Increases of DOC and DBP formation in first few post-fire runoffs
- Increases of brominated DBPs in first few post-fire runoffs

Uzun et al. 2020. Water Research 181, 115891

❑ Wildfire at a Pre-Burnt Site

- No difference in DOC and DBP formation to non-burn reference

List of Our Publications Related to Wildfire

1. Uzun H, Zheng WB, Olivares CI, Erdem CU, Coates A, and Karanfil T, and Chow AT (2020) Effect of prescribed fires on the export of dissolved organic matter, precursors of disinfection by-products, and water treatability. Accepted by *Water Research* 187: 116385.
2. Chen H, Uzun H, Chow AT, and Karanfil T (2020) Low water treatability efficiency of wildfire-induced dissolved organic matter and disinfection by-product precursors. *Water Research* 184, 116111.
3. Uzun H, Dahlgren RA, Olivares CI, Erdem CU, Karanfil T, and Chow AT (2020) Two-years of post-wildfire impacts on dissolved organic matter, nitrogen, and precursors of disinfection by-products in California stream waters. *Water Research* 181: 115891.
4. Chow AT, Tsai KP, Fegel TS, Pierson DN, and Rhoades CC (2019) Lasting effects of wildfire on disinfection byproduct formation in forest catchments. *Journal of Environmental Quality* 48: 1826-1834.
5. Olivares C, Zhang WB, Uzun H, Cargi E, Majidzadeh H, Trettin C, Karanfil T, and Chow AT (2019) High temporal resolution optical in-situ sensors capture dissolved organic carbon dynamics after wildland fire in blackwater forest ecosystems. *International Journal of Wildland Fire* (Special Issue – Forests, Flames and Faucets: Influence of Wildfire on Water Quality and Watershed Processes) 28: 761-768.
6. Majidzadeh H, Chen H, Coates TA, Tsai KP, Olivares C, Trettin C, Uzun H, Karanfil T, and Chow AT (2019) Periodic prescribed fire is an effective watershed management strategy to reduce organic matter export and disinfection byproduct precursors in source water. *International Journal of Wildland Fire* (Special Issue – Forests, Flames and Faucets: Influence of Wildfire on Water Quality and Watershed Processes) 28: 804-813 & 822.
7. Tsai KP, Uzun H, Chen H, Karanfil T, and Chow AT (2019) Control wildfire-induced Microcystis aeruginosa blooms by copper sulfate: Tradeoffs between reducing algal organic matter and promoting disinfection byproduct formation. *Water Research* 158: 227-236.
8. Abney T, Kuhn T, Chow AT, Hockaday W, Fogel M, Berhe A (2019) Pyrogenic carbon erosion after the Rim Fire, Yosemite National Park: role of fire severity and slope on erosional transport of PyC. *Journal of Geophysical Research - Biogeosciences:* 2018JG004787.
9. Chen H, Chow AT, Li XW, Ni HG, Dahlgren RA, Zeng H, and Wang JJ (2018) Wildfire burn intensity affects the quantity and speciation of PAH in soils. *ACS Space and Earth Chemistry 2:* 1262-1270, [Cover story of the issue].
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List of Our Publications Related to Wildfire

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16. Tsai KP and Chow AT. (2016) Growing algae alter spectroscopic characteristics and chlorine reactivity of dissolved organic matter from thermally-altered forest litters. *Environmental Science & Technology* 50(15): 7991-8000.
17. Wang JJ, Dahlgren RA, Ersan M[&], Karanfil T, Chow AT (2016) Temporal variations of disinfection byproduct precursors in wildfire detritus. *Water Research* 99: 66-73.
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21. Tsai KP, Rogers MF, **Chow AT**, and Diaz F (2015) Forest fire alters dissolved organic matter and disinfection byproduct precursors exports from forested watersheds - Part II: A controlled field study. *In,* Disinfection Byproducts in Drinking Water - Occurrence, Formation, Health Effects, and Control. Karanfil et al. Eds., American Chemical Society Symposium Book, Chapter 16, pp. 293-306, Washington DC, USA.

Outreach Products

YouTube video:

1) Wildfire Impact on Drinking Water Quality: Link - https://www.youtube.com/watch?v=XoEuteiGDGk
2) Prescribed Fire Improves Drinking Water Quality: https://youtu.be/v_BOrtPl8z0

Acknowledgement

National Priorities: Systems-Based Strategies to Improve The Nation's Ability to Plan And Respond to Water Scarcity and Drought Due to Climate Change

Fuel Reduction Techniques as Effective Forested Watershed Management Practices against Wildfire:
Drinking Water Quality Aspects (USEPA Grant Number: R835864)

Co-Investigators

University of California, Davis: Professor Randy Dahlgren
US Forest Service: Dr. Carl Trettin
South Carolina Department of Natural Resources: Mr. Jamie Dozier
Environmental Molecular Science Laboratory (PNNL): Dr. Errol Robinson
Dr. Sarah Burton

Presentation 2

Decision Support for Drinking Water Utilities Impacted by Wildfire

Joseph Kasprzyk, Ph.D.

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Dr. Kasprzyk is an associate professor in the Civil, Environmental, and Architectural Engineering Department at the University of Colorado Boulder. His research focuses on multi-objective decision making and model diagnostics for engineering problems in the areas of water resources planning and management, environmental engineering applications, and advancing methodological contributions to decision making and optimization under uncertainty. Dr. Kasprzyk holds a Ph.D. in civil engineering from Penn State University.

Fernando Rosario-Ortiz, Ph.D.

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Dr. Rosario-Ortiz is a professor of environmental engineering and the director of the Environmental Engineering Program at the University of Colorado Boulder. His research centers around environmental chemical processes and implications of forest fires on water quality and treatment. Dr. Rosario-Ortiz holds a D.Env. in environmental science and engineering from UCLA.

Decision Support for Drinking Water Utilities Impacted by Wildfire

Investigators: Kenan Ozekin[1]; Balaji Rajagopalan[2,3], Joseph Kasprzyk[2], Ben Livneh[2,3], Fernando Rosario-Ortiz[2], R Scott Summers[2]

1: The Water Research Foundation

2: Civil, Env., Arch. Engineering, University of Colorado Boulder

3: Cooperative Institute for Research in Environmental Sciences

Presented By: Joseph Kasprzyk and Fernando Rosario-Ortiz

University of Colorado Boulder

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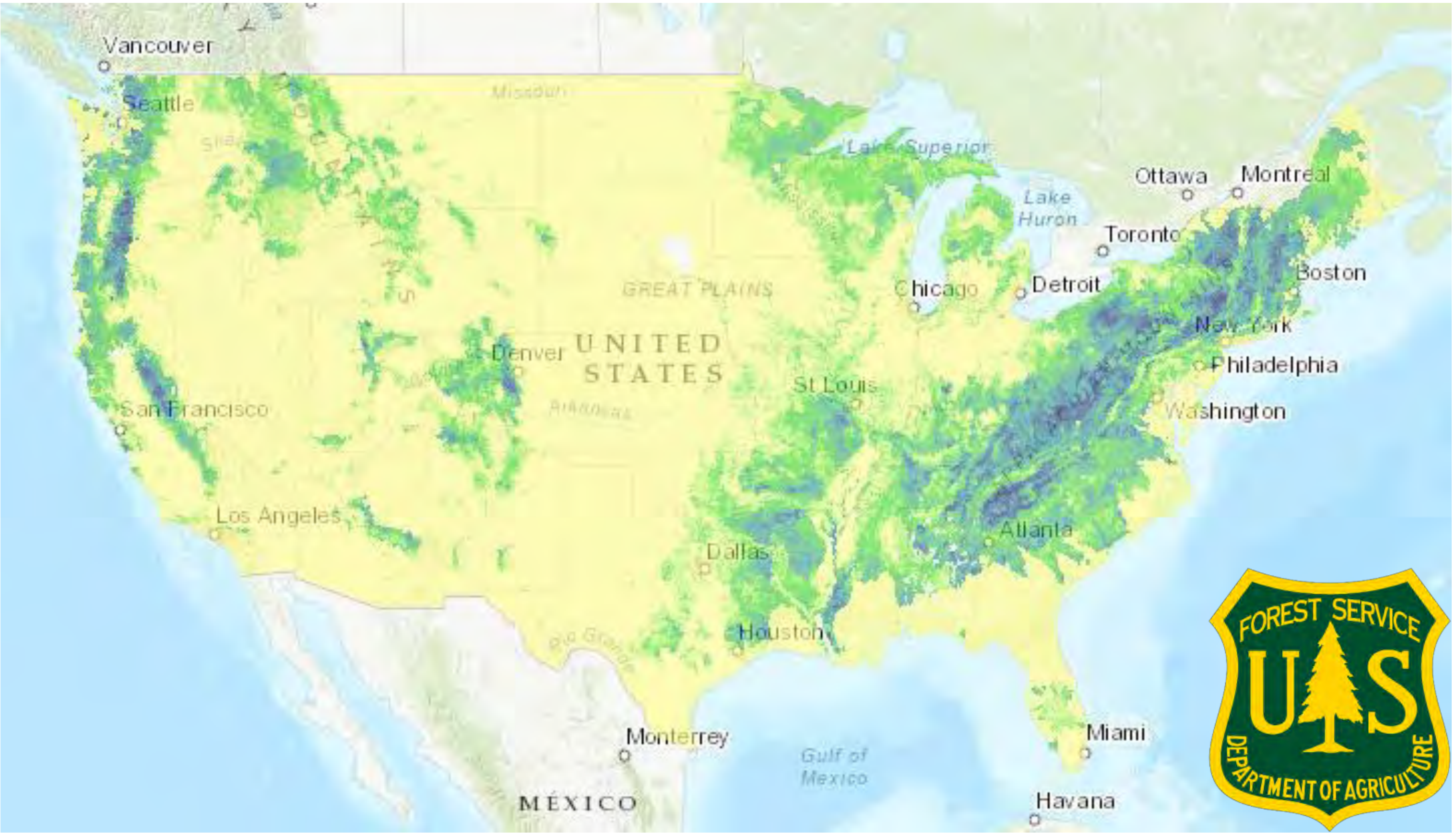
Major US cities are dependent on surface drinking water which originate from forested catchments.



Index of forest importance to surface drinking water

National Extent

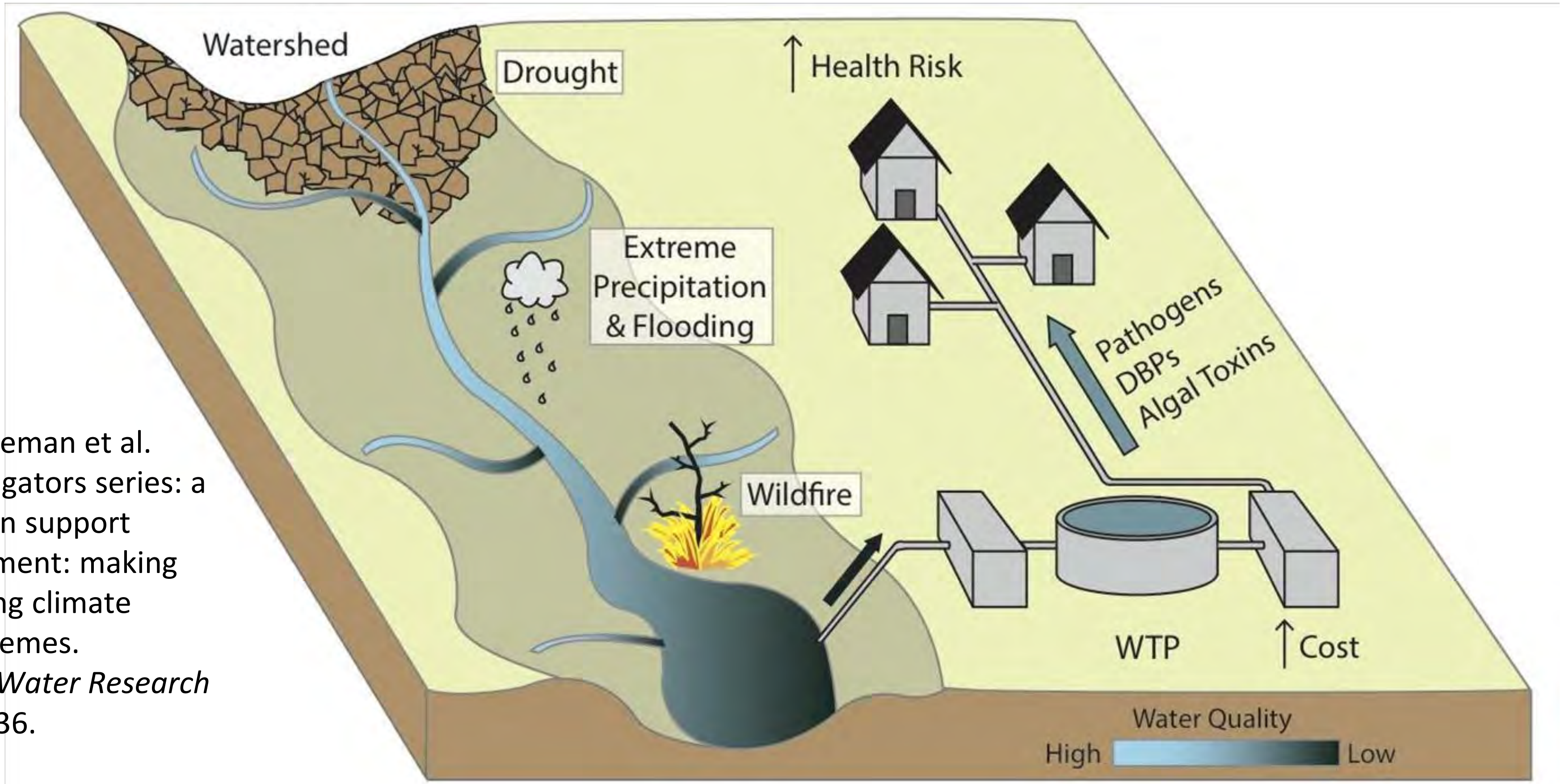
- 0 - 10
- 11 - 20
- 21 - 30
- 31 - 40
- 41 - 50
- 51 - 60
- 61 - 70
- 71 - 80
- 81 - 90
- 91 - 100

What does this mean for our water supply?

[Bladon et al. 2012]

- Wildfires can release…
  - Sediments
  - Nutrients
  - Heavy metals
- Water quality degradation (taste, odor, color)
- Decrease life-span of reservoirs

Our research **integrates** source watersheds, water quality, and water treatment plants.



Project publication: Raseman et al. (2017). Emerging investigators series: a critical review of decision support systems for water treatment: making the case for incorporating climate change and climate extremes. *Environmental Science: Water Research & Technology*, *3*(1), 18–36.

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Fort Collins is a mid-sized city, serving 133,000 people between its two drinking water sources.

Cache la Poudre River

[visitftcollins.com]

Horsetooth Reservoir

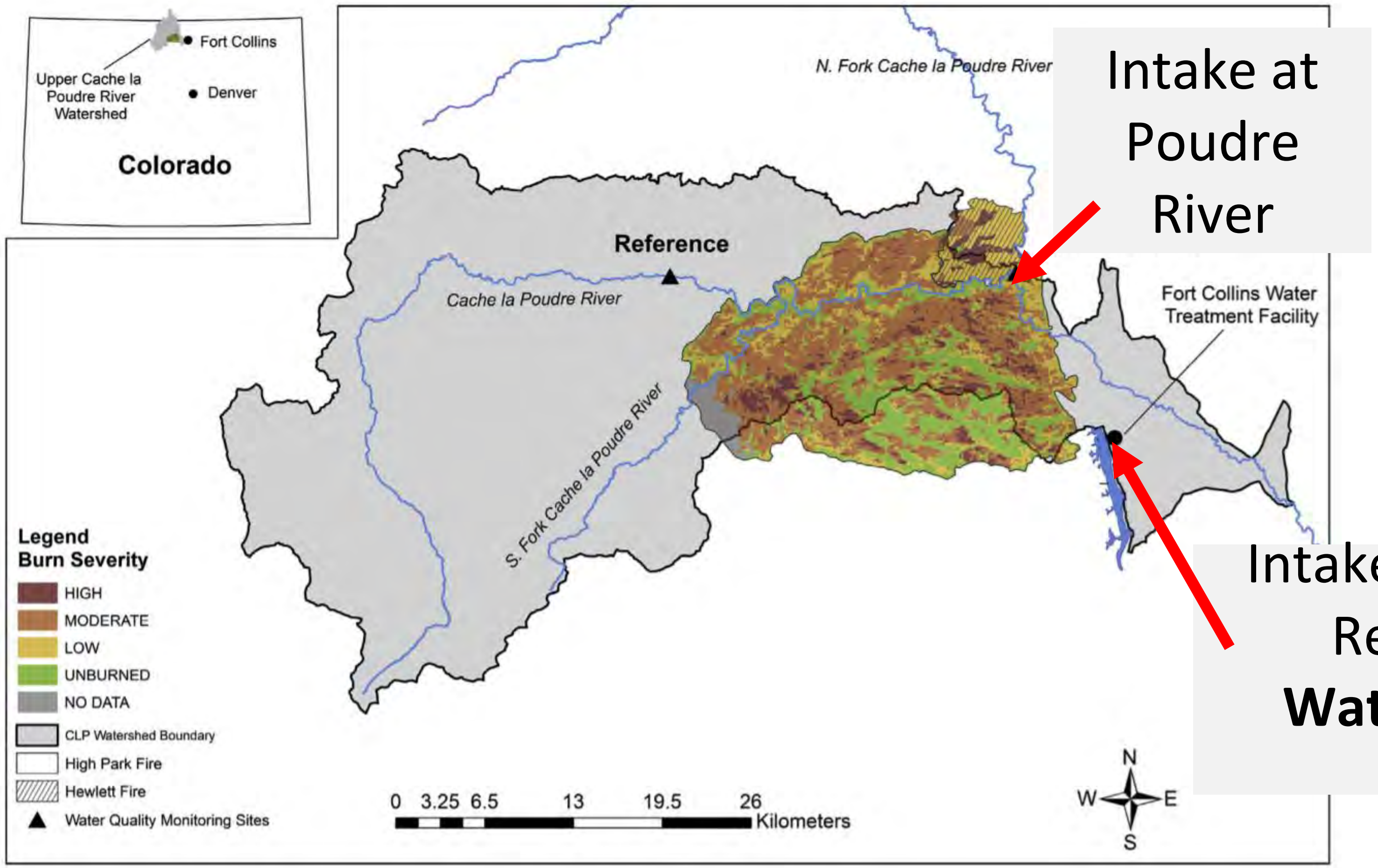
[Northern Water]

In 2012, the High Park fire burned 90,000 acres just west of Fort Collins—the 3rd largest wildfire in state history.

[City of Fort Collins]

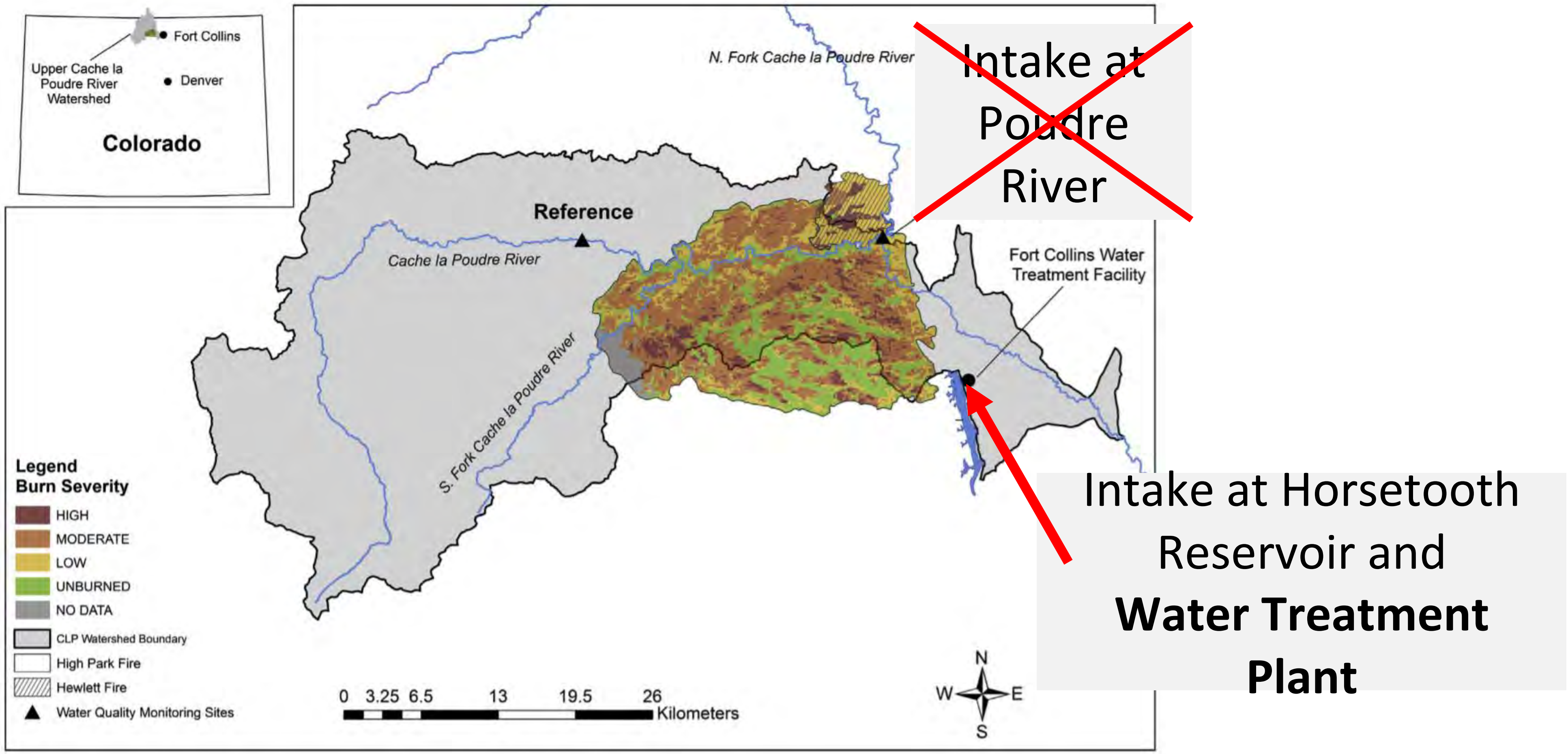
[NASA]

The Poudre watershed was burned, compromising water quality in Poudre River.



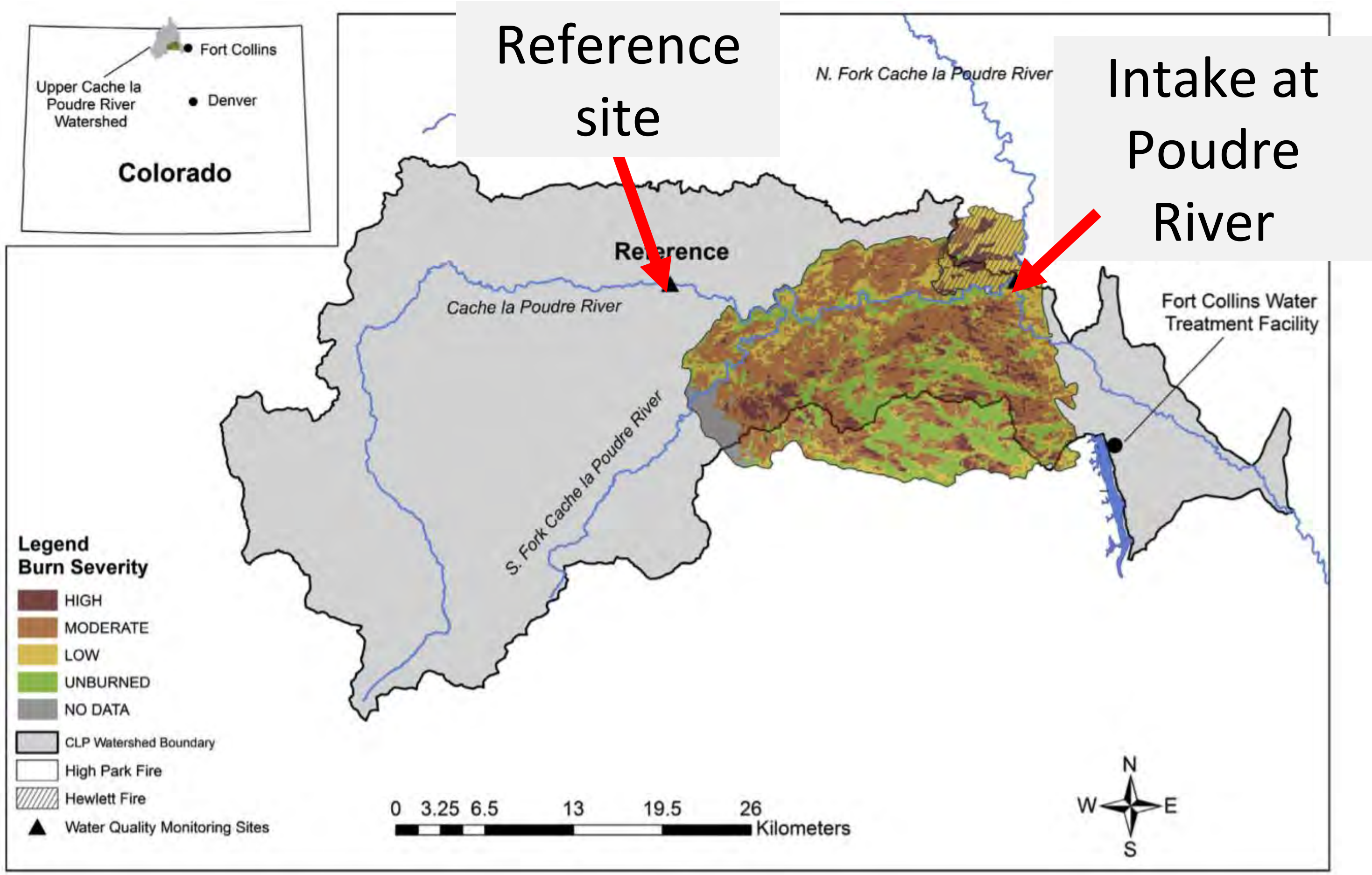
[Hohner et al. 2016]

Due to elevated levels of turbidity, the city closed the intake to Poudre River for nearly 100 days.



Meanwhile, back at the universities…

By comparing water quality at a reference (unburned) site and the intake, researchers could isolate impact of fire.



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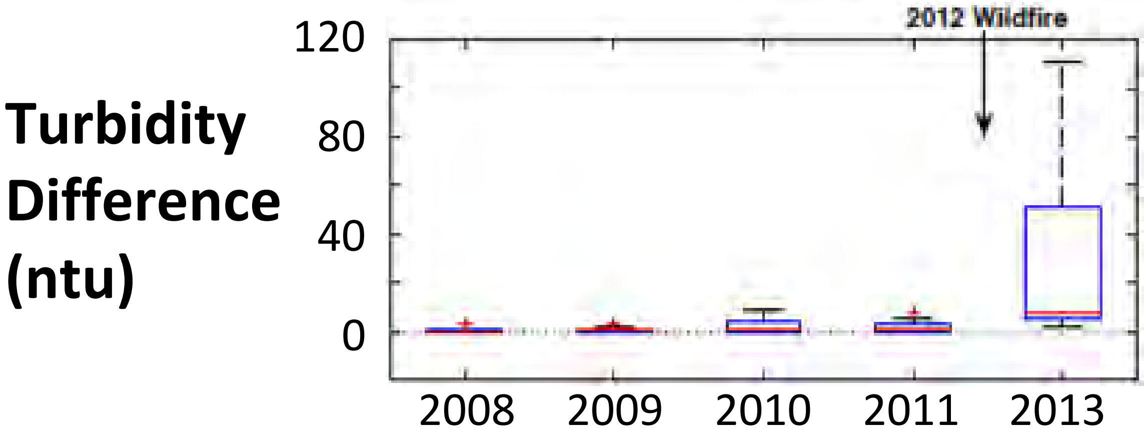
To compare water quality at the two sites, a pairwise difference was calculated.

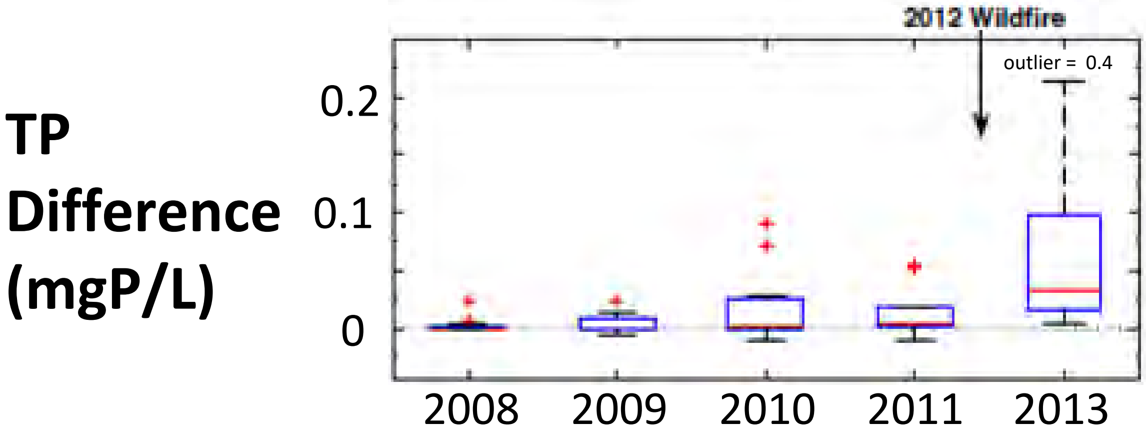
Burned site: 2.1 ntu

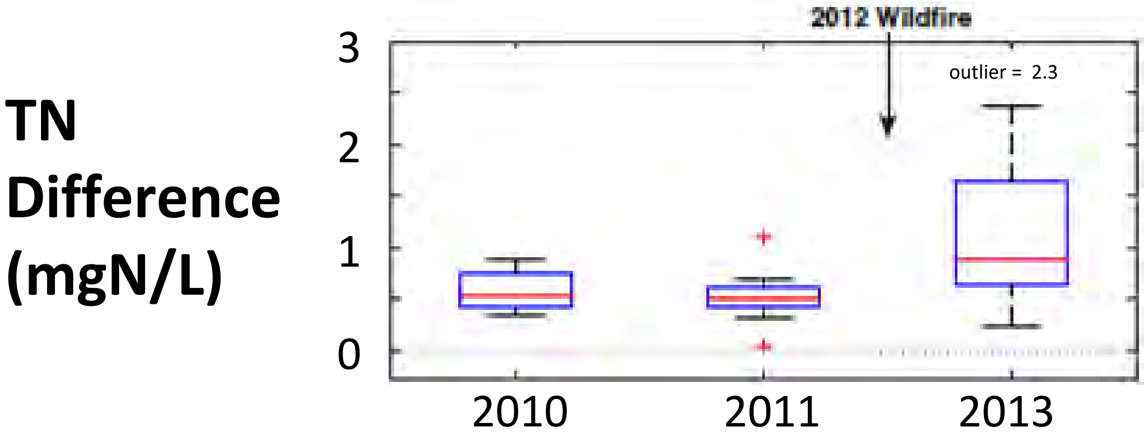
Reference site: 1.0 ntu

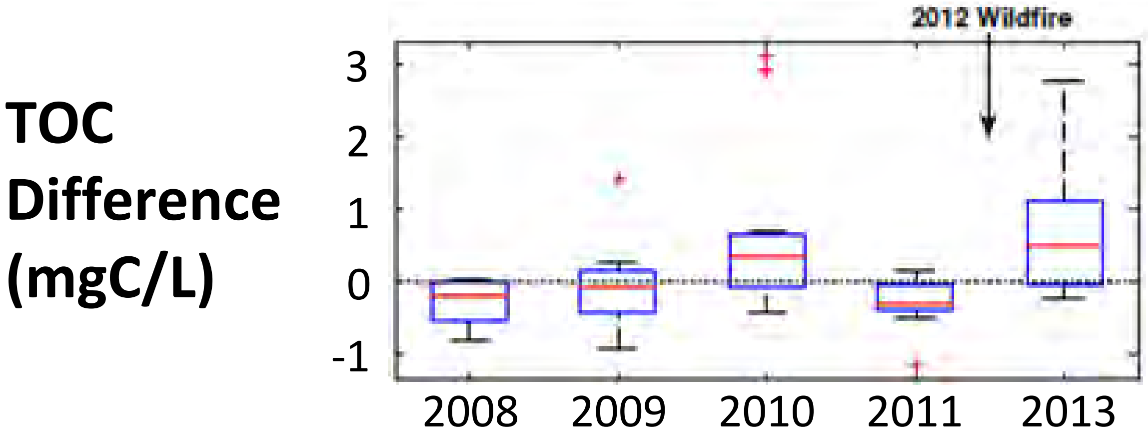
Pairwise difference: 2.1 – 1.0 = **1.1 ntu**

Found significant differences in turbidity, nutrients, and organic carbon between the two sites and increased variability.



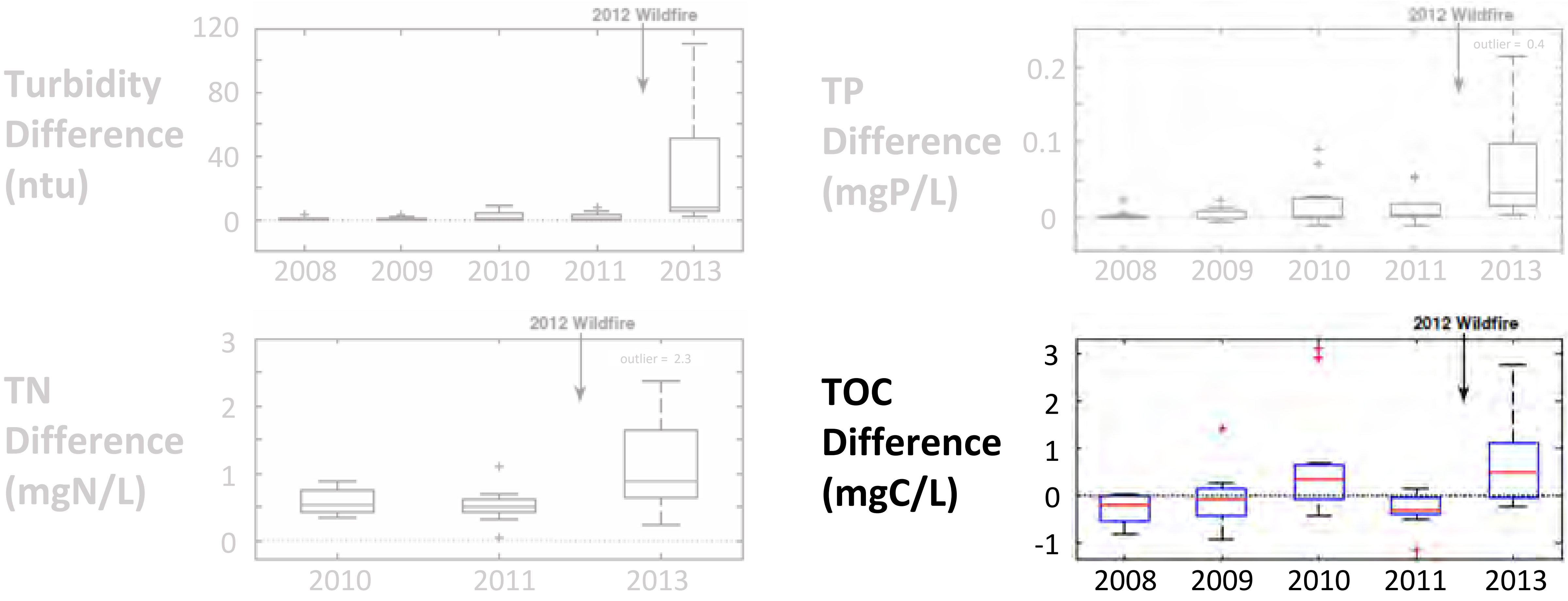






[Hohner et al. 2016]

Found significant differences in turbidity, nutrients, and organic carbon between the two sites and increased variability.



[Hohner et al. 2016]

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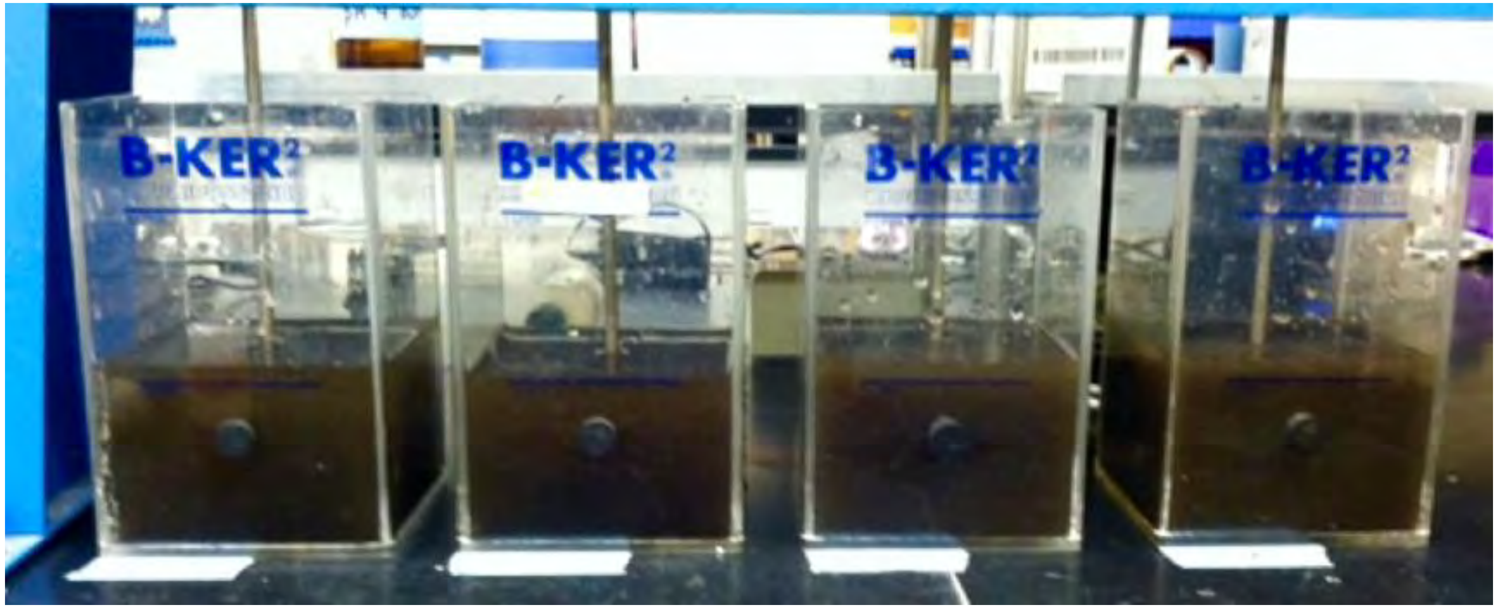
Treatability experiments, including DBP formation potential and jar tests, revealed that most samples could be treated but had:

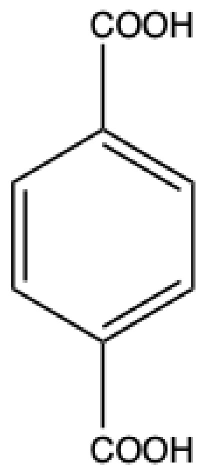
- High costs due to **increased coagulant doses**
- **High levels of DBPs** (disinfection byproducts)

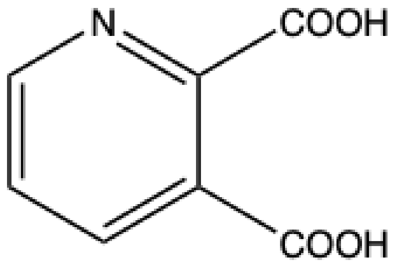


[Hohner et al. 2016]

More recently, we have evaluated the presence of other organic compounds:

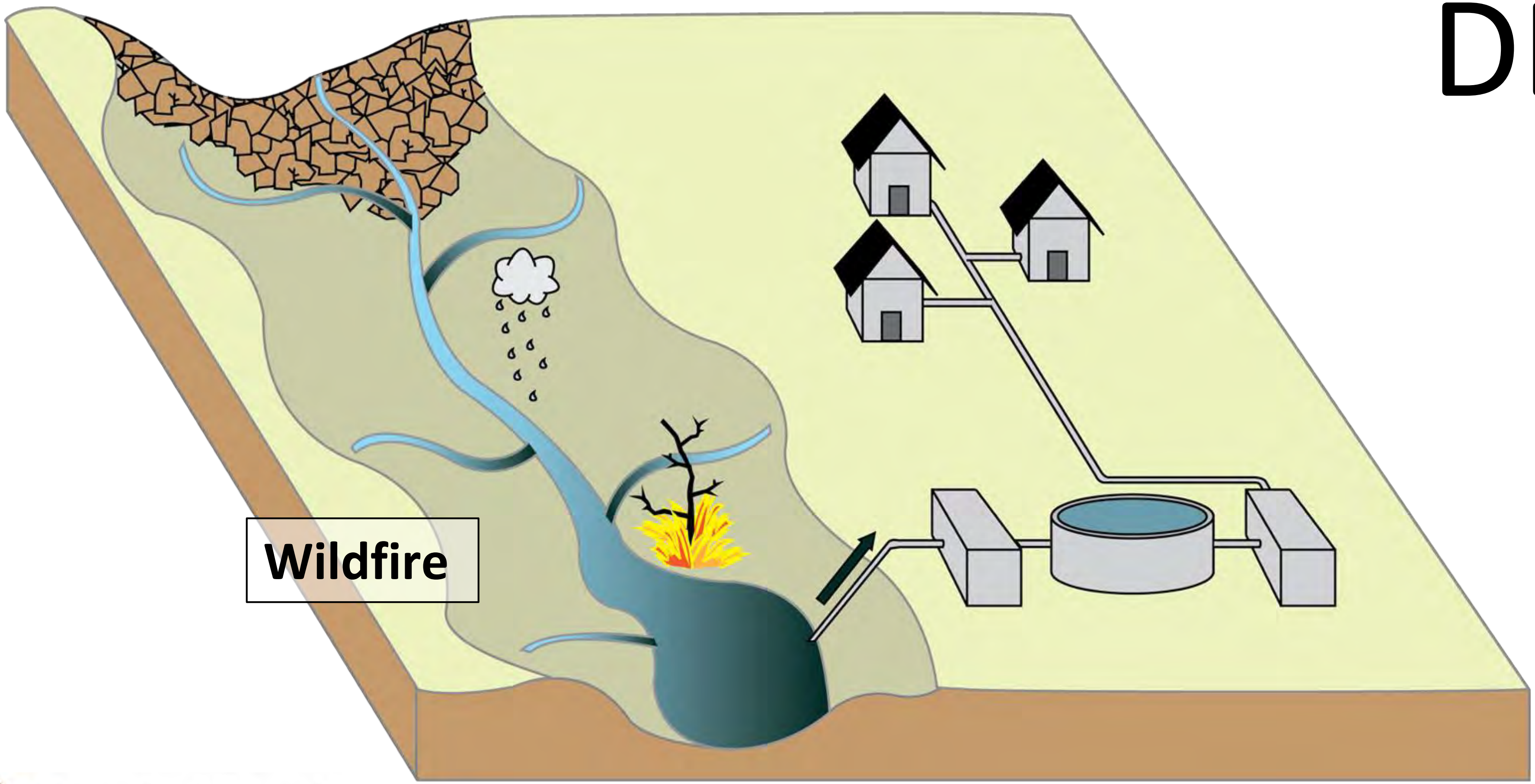
- Benzoic acid-derivatives, pyridines, etc.
- Compounds found in simulated samples and also in the field





Thurman et al (2020). Molecular Identification of Water-Extractable Organic Carbon from Thermally Heated Soils: C-13 NMR and Accurate Mass Analyses Find Benzene and Pyridine Carboxylic Acids. *Environmental Science and Technology,* 54, 5, 2994-3001

Simulation can be used to test management strategies for impacted water quality scenarios.



DBPs?

Cost?

Raseman et al (2020). Multi-objective optimization of water treatment operations for disinfection byproduct control. *Environmental Science: Water Research and Technology,* 6, 702-714

Operational policies, such as chemical dosing strategies, can impact performance.

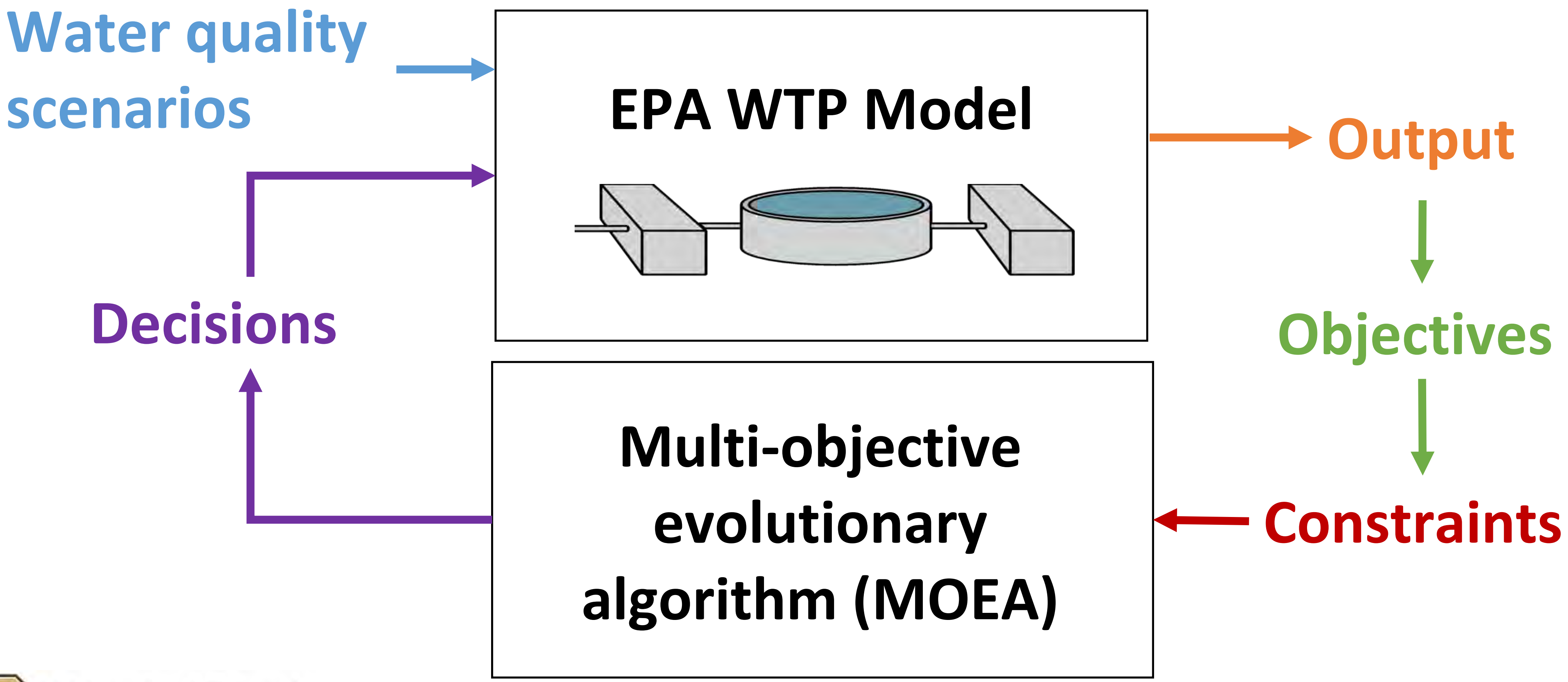
- Raw water quality
- Treatment train
- Distribution system
- Chemical doses **(decisions)**

EPA WTP Model

Input **Output**

- Finished water quality
- DBPs
- Chemicals used

Our decision support system (DSS) tests thousands of operating policies to find the top performers.



Step 1: The MOEA suggests operating policies which are input into the model.

Water quality scenarios

EPA WTP Model

Output

Objectives

Constraints

Decisions

Operating Policies

- Alkalinity setpoint
- pH setpoint

Multi-objective evolutionary algorithm (MOEA)

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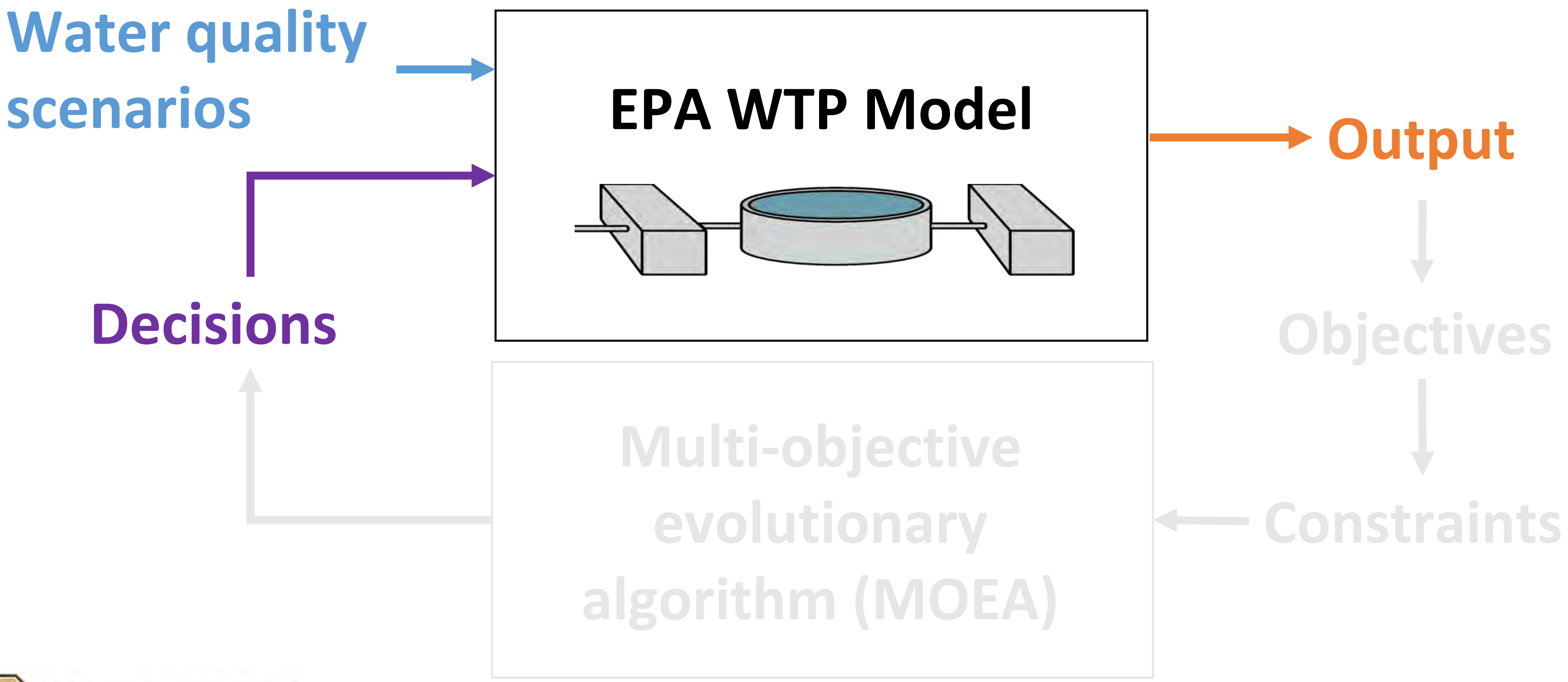
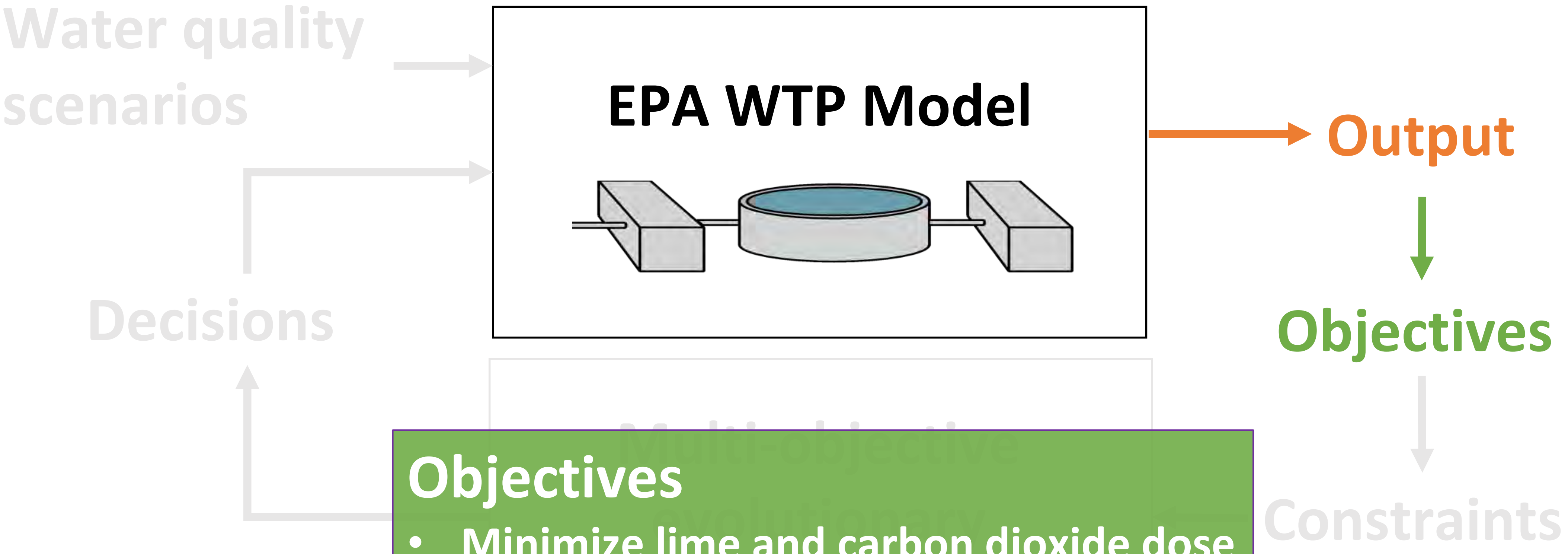
Step 2: The WTP model tests the operating policy on a number of water quality scenarios.



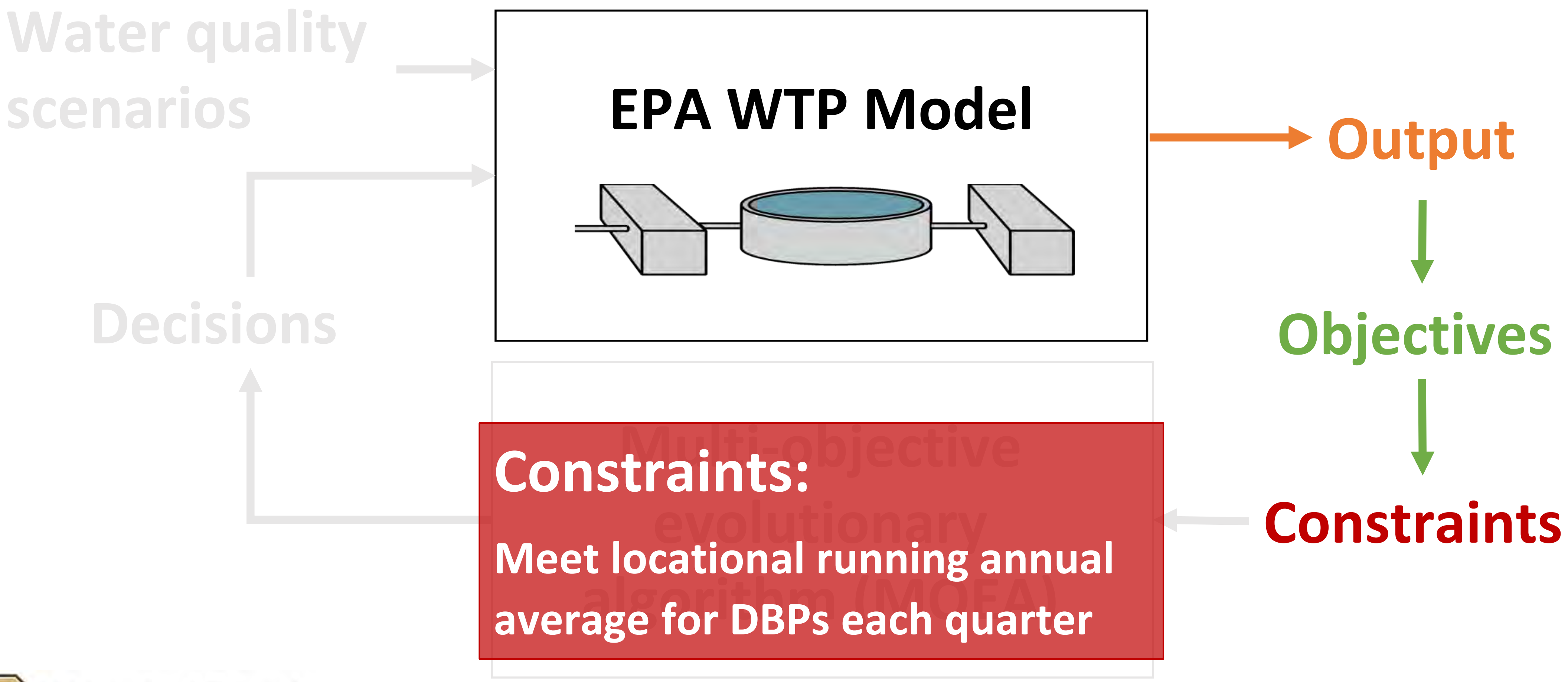
Step 3: Model outputs are translated into objectives (measures of performance).



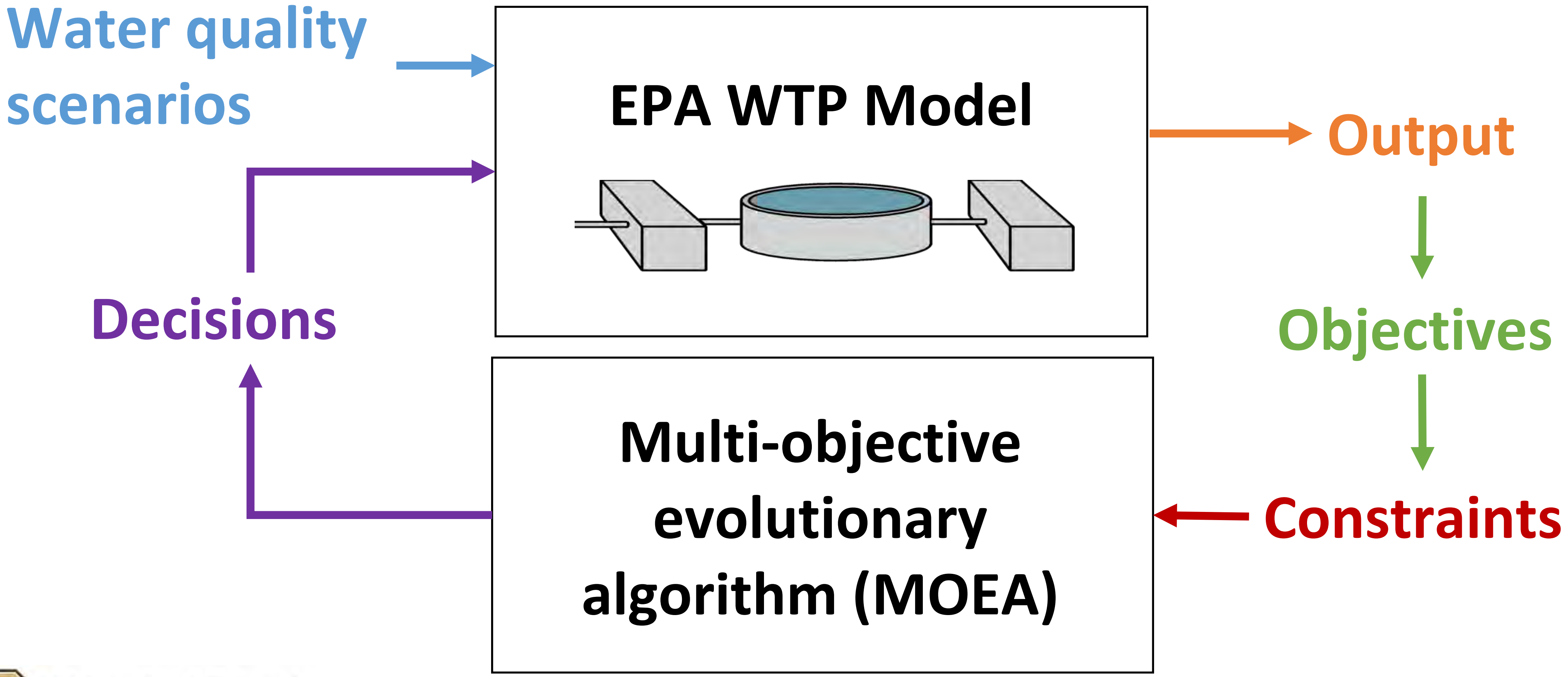
Objectives

- Minimize lime and carbon dioxide dose
- Minimize solids production
- Minimize DBP > MCL in any quarter

Step 4: Operations which do not meet constraints (restrictions on performance) are filtered out.

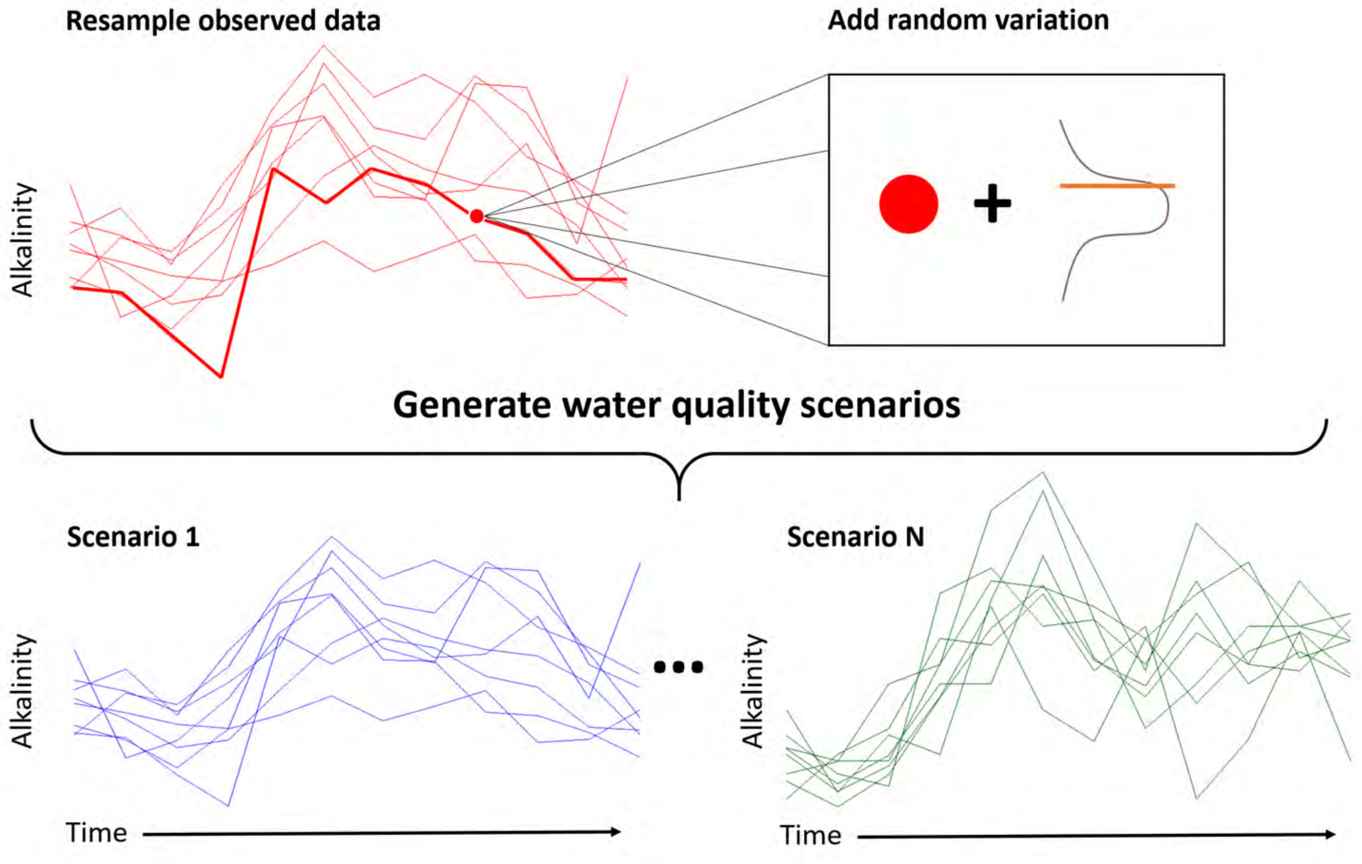


Step 5: The process repeats and the MOEA mimics evolution to identify the best operating policies.



Modified *k*-Nearest Neighbor algorithm

- Want to capture important statistics of observed data
  - **Median** and **variance**
  - **Seasonality**
  - **Autocorrelation** (i.e., persistence)
  - **Joint correlation** among water quality variables
- Generate values beyond the observed record



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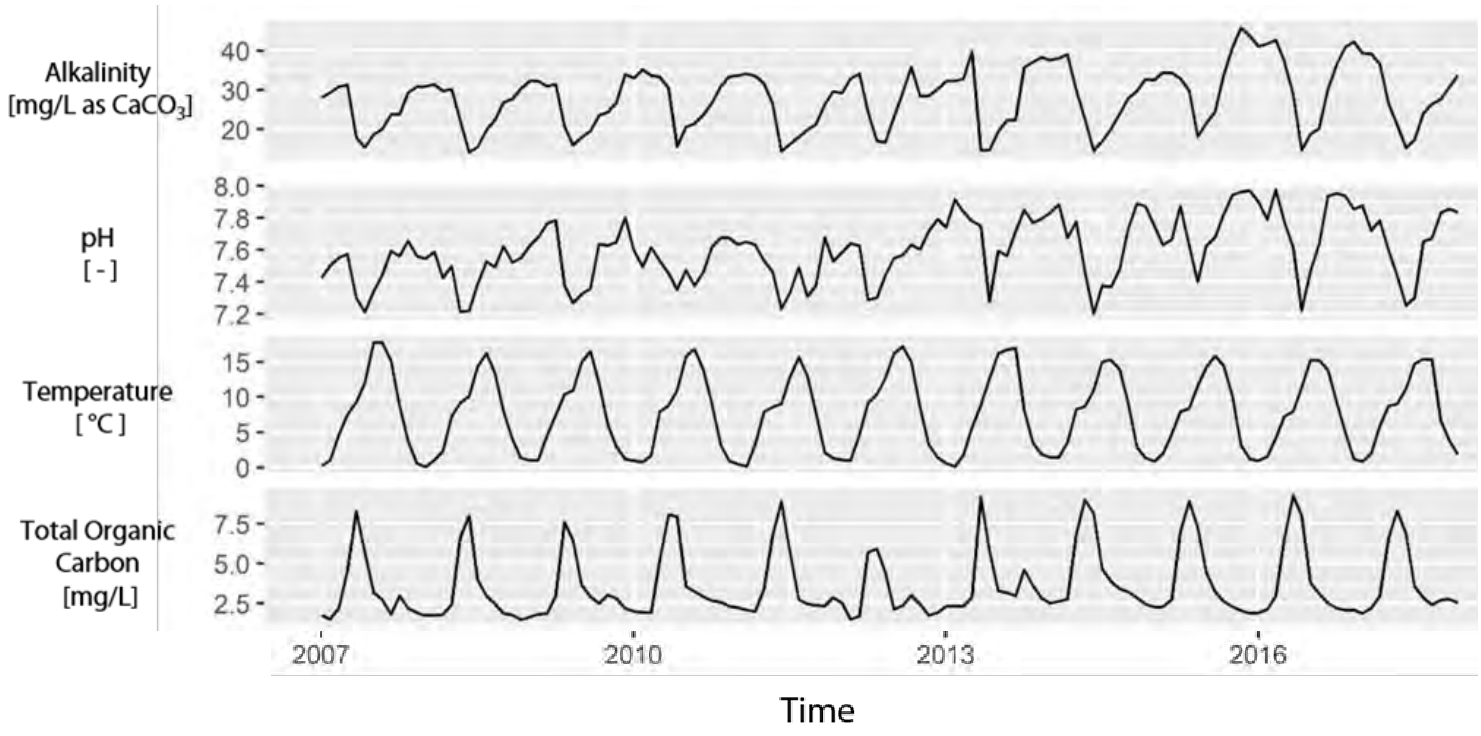
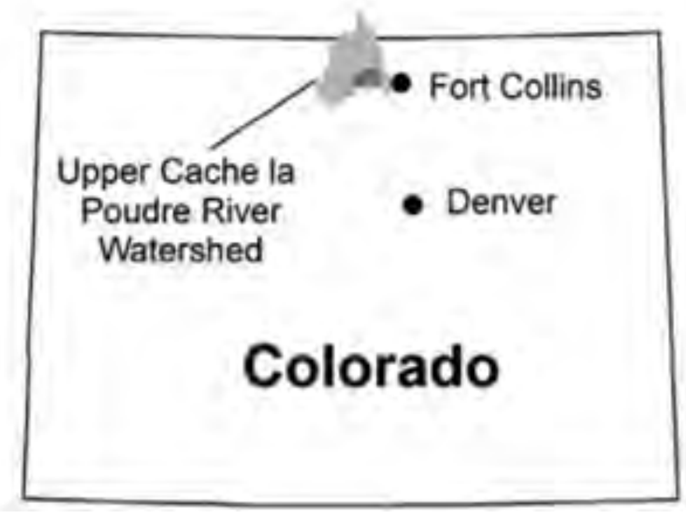
Using Cache la Poudre River data, created 2,500 realizations using a monthly simulation of four water quality parameters.





[Hohner et al. 2016]

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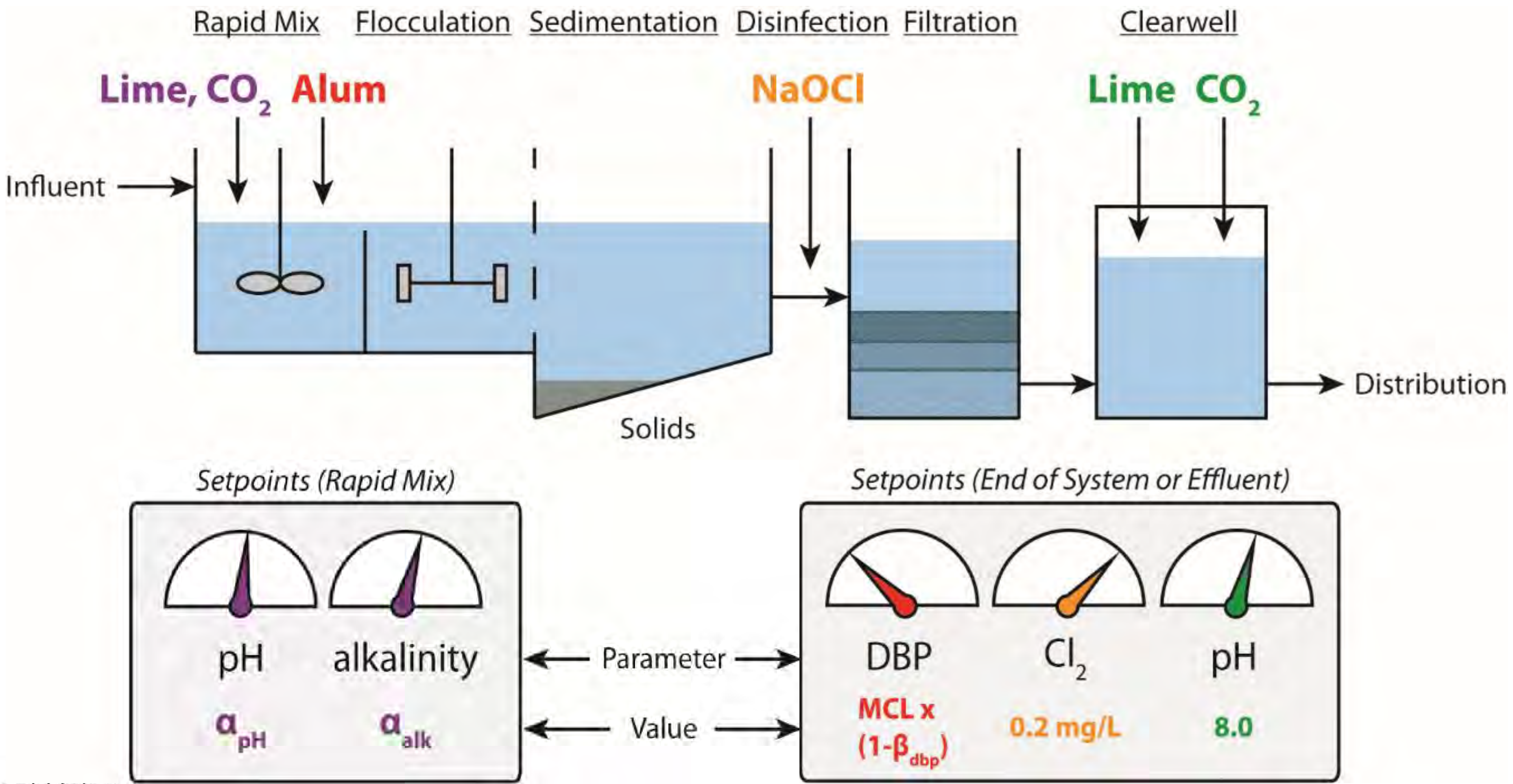
Decision variables: water quality setpoints, quarterly



Constraints: drinking water regulations

Constraint	USEPA Regulation
Locational running annual average disinfection byproducts concentration must not exceed the maximum contaminant level	Stage 1 and 2 Disinfectants and Disinfection Byproducts Rules
Total organic carbon percent removal must be achieved	Stage 1 and 2 Disinfectants and Disinfection Byproducts Rules
Contact time ratio for disinfection must be at least one	Long Term 2 Enhanced Surface Water Treatment Rule

$$c_{mcl} \geq \frac{\gamma_{t-3} + \gamma_{t-2} + \gamma_{t-1} + \gamma_t}{4}$$

where, γ_t refers to the DBP concentration of the current quarter being simulated

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We developed Parasol, an interactive visualization library, to alleviate these issues.

- High-quality, shareable **web applications**
- Parasol apps can be used in **environmental management and beyond**
- **Interactivity will be an essential** aspect of visualization with the rise of big(ger) datasets


ELSEVIER

Environmental Modelling & Software

Volume 116, June 2019, Pages 153-163

Parasol: an open source, interactive parallel coordinates library for multi-objective decision making

William J. Raseman [a], Joshuah Jacobson [b], Joseph R. Kasprzyk [a]

University of Colorado Boulder

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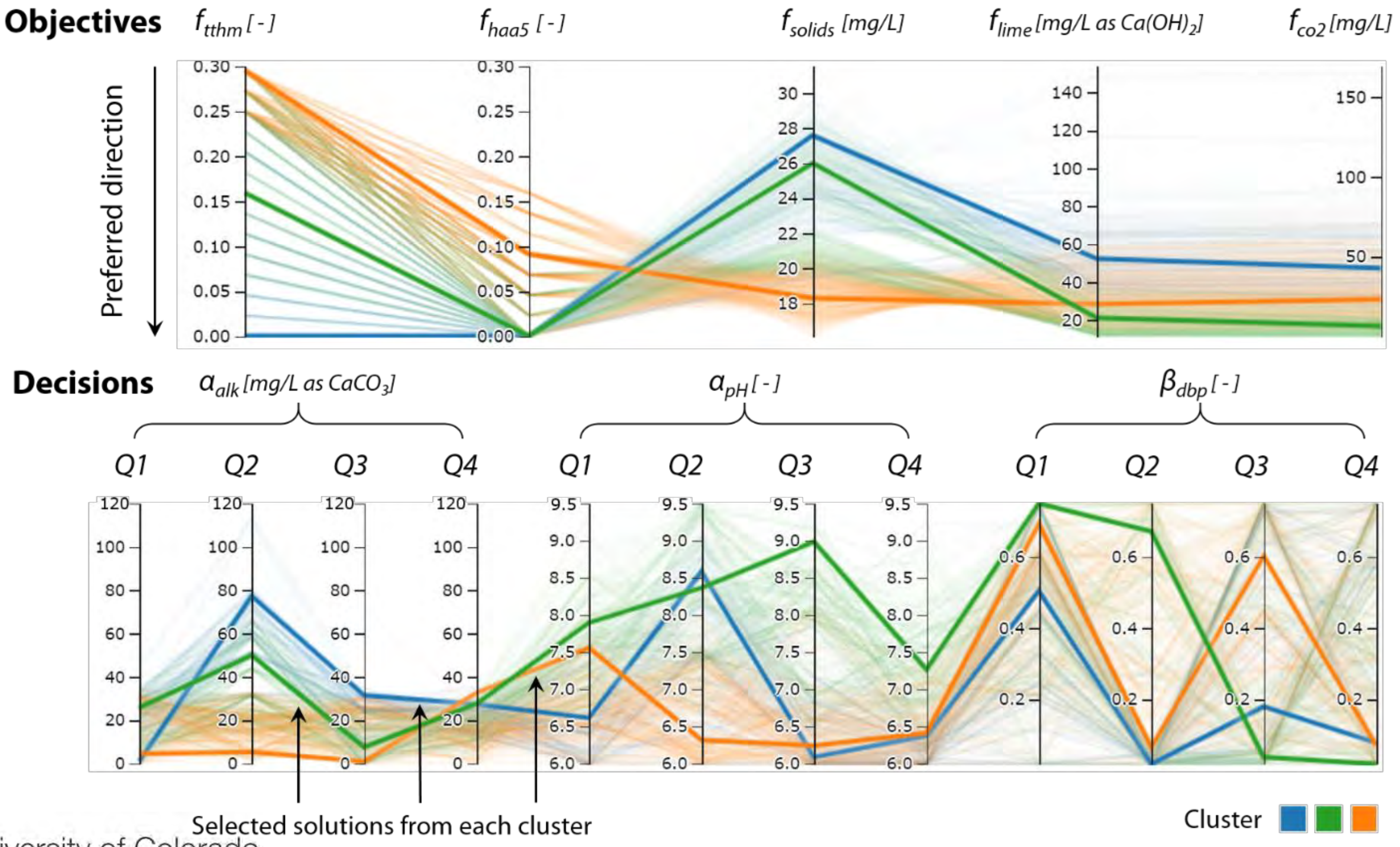
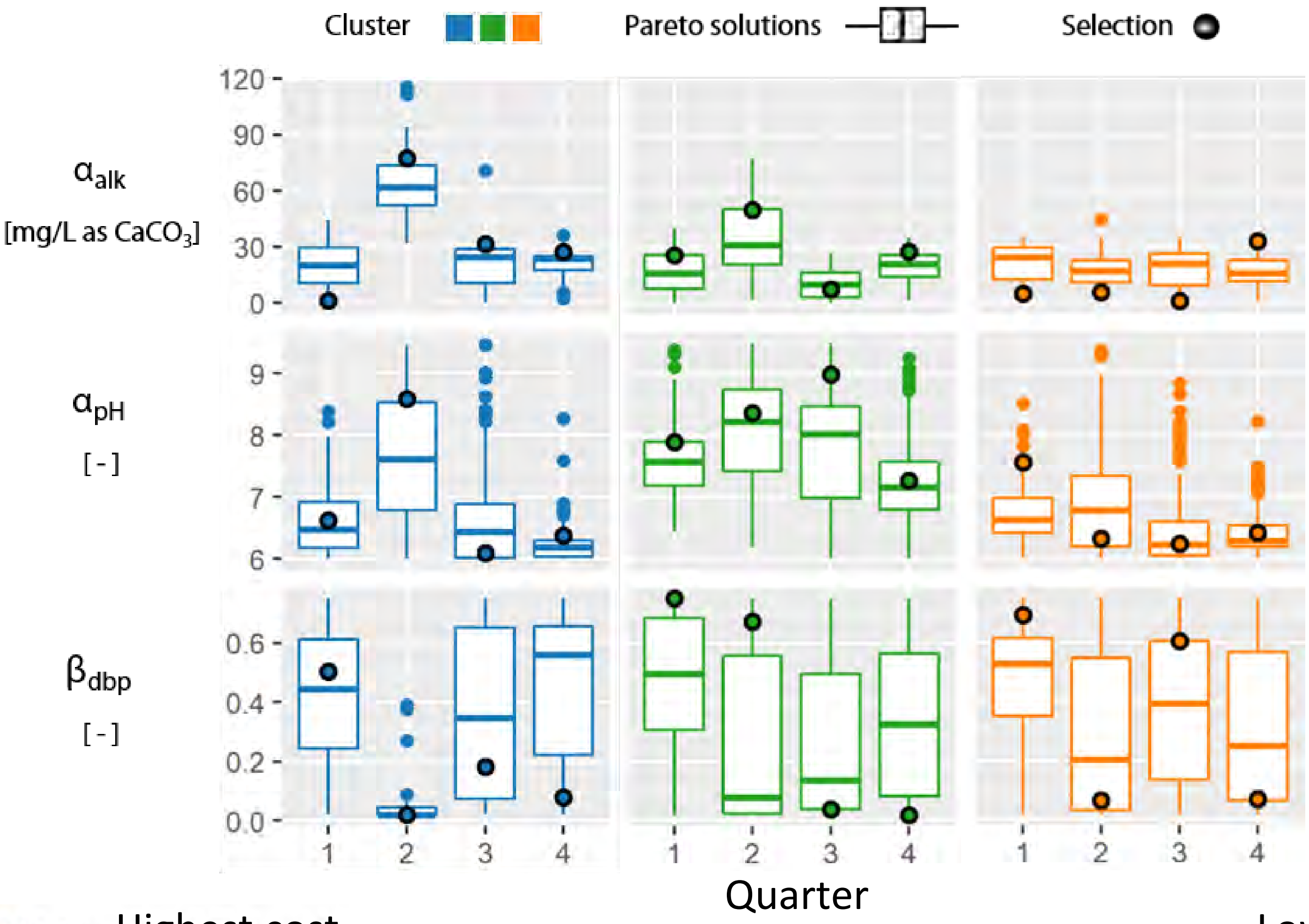
We visualize MOEA-generated solutions using linked, parallel coordinates plots.



Interactive example:

https://wraseman.github.io/parasol/demo/water-treatment.html

k-means clustering reveals distinct operating choices.



Highest cost
Lowest risk

Lowest cost
Highest risk

- **Blue cluster**
  - Strongly seasonal decisions
  - Alkalinity and pH mimic TOC profile
  - Least elevated DBP risk
- **Green cluster**
  - Intermediate risk
  - High pH setpoints
- **Orange cluster**
  - Little to no pH and alkalinity adjustment
  - Highest risk, lowest cost

We acknowledge the gracious support of EPA Office of Research and Development National Priorities Grant Program (Cooperative Agreement No. R835865) and The Water Research Foundation (Project 4636)

Title: An Integrated Modeling and Decision Framework to Evaluate Adaptation Strategies for Sustainable Drinking Water Utility Management under Drought and Climate Change

Investigators: Kenan Ozekin[1]; Balaji Rajagopalan[2,3], Joseph Kasprzyk[2], Ben Livneh[2,3], Fernando Rosario-Ortiz[2], R Scott Summers[2]

1: The Water Research Foundation

2: Civil, Env., Arch. Engineering, University of Colorado Boulder

3: Cooperative Institute for Research in Environmental Sciences

Researchers: Ariel Retuta, Amanda Hohner, Billy Raseman, Josh Jacobsen

Presented By: Joseph Kasprzyk and Fernando Rosario-Ortiz

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