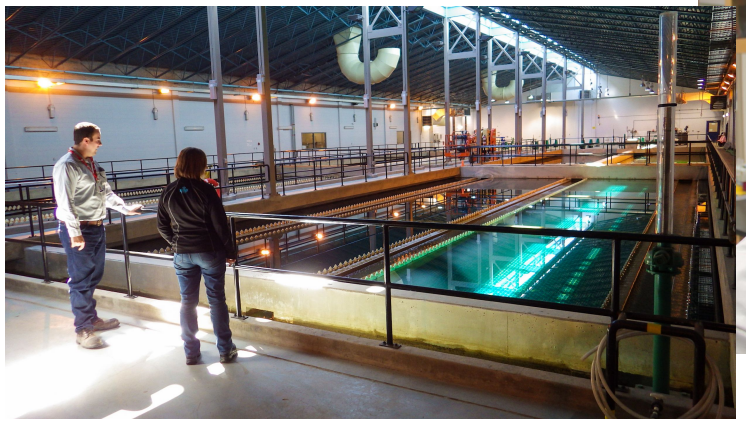
Groundwater Supplies are Also Vulnerable to Climate Change-Exacerbated Landscape Disturbance: Evidence & Strategies for Ensuring Treatment Resilience

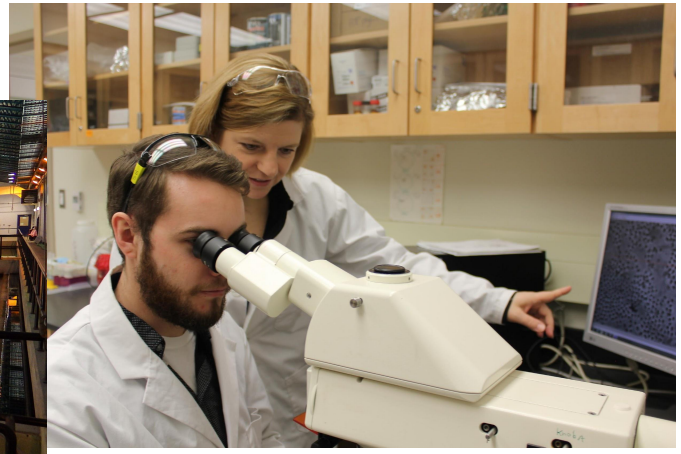
Monica B. Emelko, Omar Chowdhury, Xiaohui Sun,
Allie Kennington, Phillip J. Schmidt, Uldis Silins, Micheal Stone

UNIVERSITY OF WATERLOO
WATER Science, Technology & Policy Group

NWWC
Niagara Falls, ON
November 13, 2023

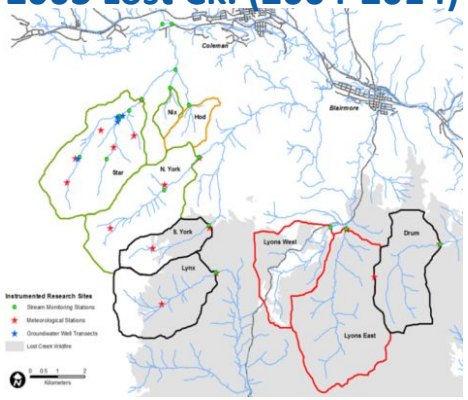
A little about me



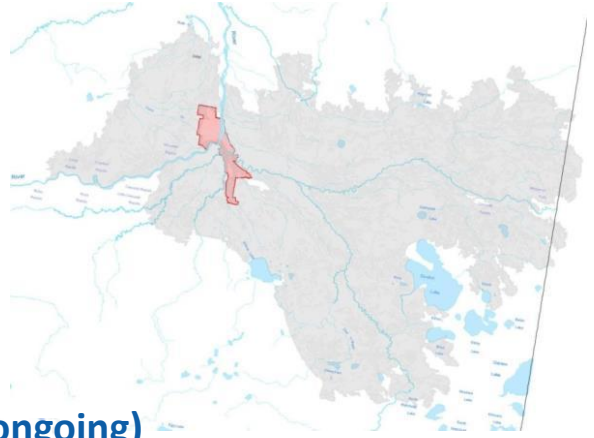


Southern Rockies Watershed Project

2003 Lost Ck. (2004-2014)



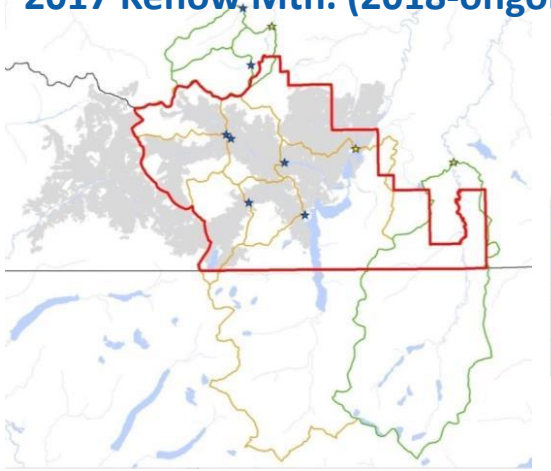
2016 Horse R. (2016-ongoing)



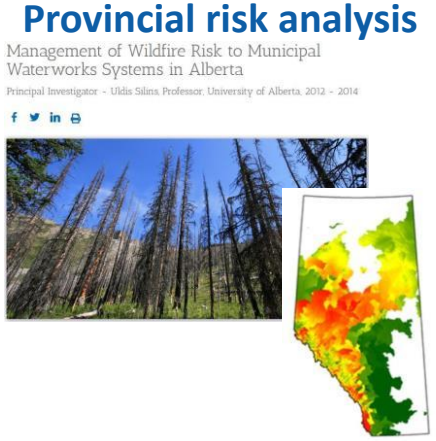
2012
Milk River

2014
Spreading Creek

2017 Kenow Mtn. (2018-ongoing)



Provincial risk analysis



2017
Elephant Hill, Thuja Ck.
Little Fort Complex (B.C.)

Climate change-exacerbated Landscape Disturbance Effects on Water

- Warming climate
  □□
  more landscape disturbance
- Affects water quantity *and* quality
- Drinking water security is significantly threatened in many regions globally
- Wildfire can be especially “hard” on water
- IPCC 2022 □ emphasizes that compound disturbances exacerbate impacts on water


(CBC, 2022)


(Global News, 2018)


(Darryl Dyck/The Canadian Press, 2021)


(BBC, 2021)

Disturbance: Immediate- & Shorter-term Concerns for Water Providers

- Loss of power and SCADA
- Loss of pressure
- Staff unable to get to work
- Boil water orders for systems that cannot be operated or lost pressure
- Excess draw for fire fighting
- Loss of pump or treatment plant throughput
- Failure of upstream pollution control facilities
- Debris flows
- Contamination of distributed water

Photo by Richard Hinrichs of the State Water Resources Control Board.

Less about treatment More about emergency response

Wildfire can be especially “hard” on water…

Wildfire impacts on water quality and treatability

WATER RESEARCH 45 (2011) 461–472

Available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/watres

Implications of land disturbance on drinking water treatability in a changing climate: Demonstrating the need for "source water supply and protection" strategies

Monica B. Emelko [a,*], *Uldis Silins* [b], *Kevin D. Bladon* [c], *Micheal Stone* [d]

[a] *Civil and Environmental Engineering, University of Waterloo, Waterloo, Ontario, Canada N2L 3G*
[b] *Renewable Resources, University of Alberta, Edmonton, Alberta, Canada T6G 2H1*
[c] *Natural Resource Sciences, Thompson Rivers University, Kamloops, British Columbia, Canada V2*
[d] *Geography, University of Waterloo, Waterloo, Ontario, Canada N2L 3G1*

Table 3 – Water quality parameters impacted by wildfire and their potential implications to drinking water treatability (modified from Emelko et al., 2008).

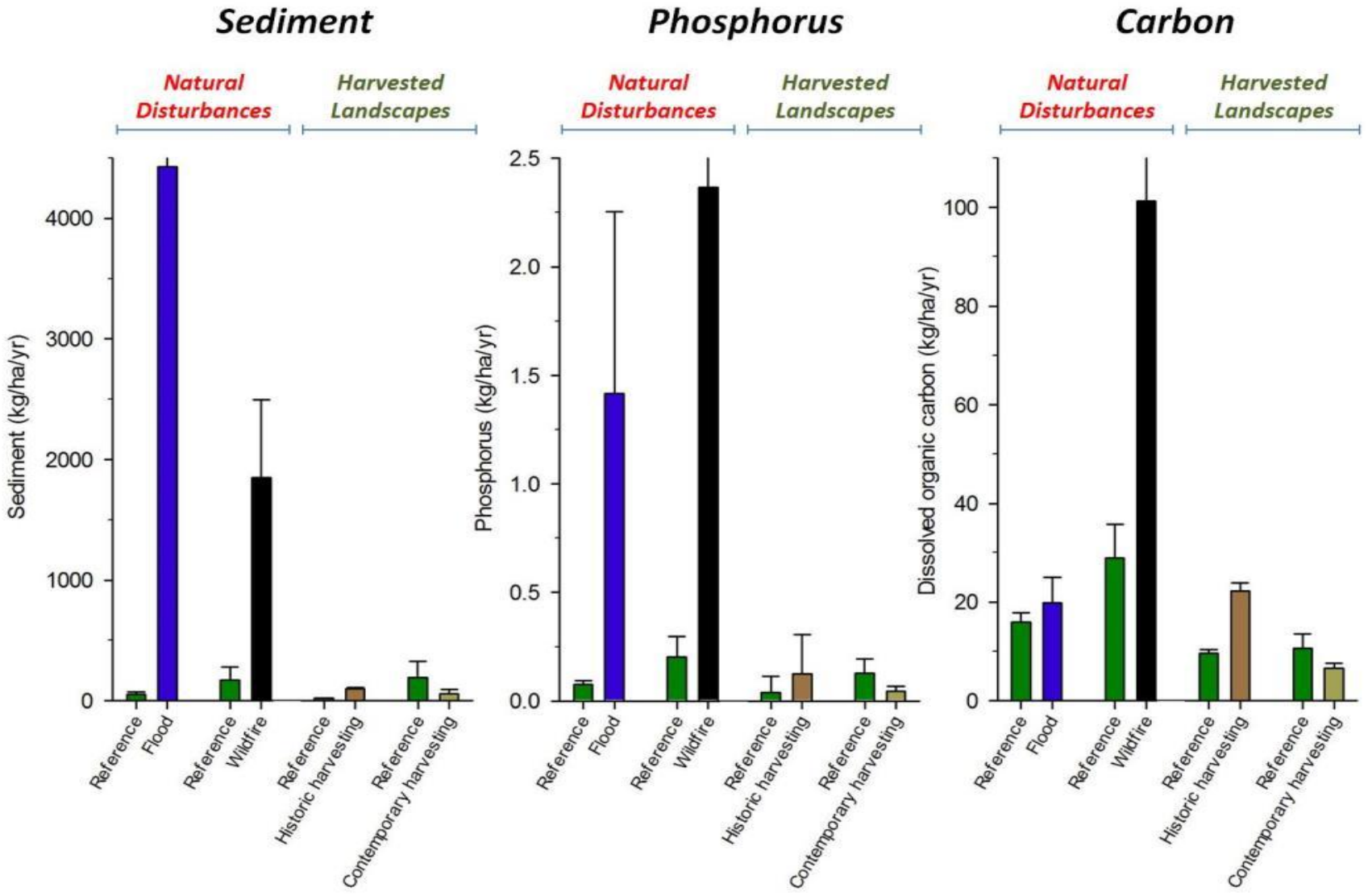
Impact on Treatment	Parameter					
	Turbidity	TP	DON and TKN	Hg	DOC	Chl.-*a*
Need for solids removal (C/F/S)	✓	✓			✓	✓
↑ Coagulant demand	✓				✓	✓
↑ Sludge production	✓				✓	✓
↑ Oxidant demand	✓		✓		✓	✓
↑ DBPs	✓		✓		✓	✓
↑ Fluence required for UV			✓		✓	✓
↑ microcystins		✓				✓
↑ Taste and odor concerns			✓		✓	✓
Compliance concerns	✓		✓	✓	✓	✓
↑ Operating costs	✓	✓	✓	✓	✓	✓

Wildfire impacts on water quality that drive treatment design

Impact on Treatment	Parameter			
	Turbidity	TP	DON and TKN	DOC
Need for solids removal (C/F/S)	✓	✓		✓
↑ Coagulant demand	✓			✓
↑ Sludge production	✓			✓
↑ Oxidant demand	✓		✓	✓
↑ DBPs	✓		✓	✓
↑ Fluence required for UV			✓	✓
↑ microcystins		✓		
↑ Taste and odor concerns			✓	✓
Compliance concerns	✓		✓	✓
↑ Operating costs	✓	✓	✓	✓

(Abbreviated from Emelko et al., 2011)

Disturbance Effects on Water Quality: Fires, Floods, Forestry



Silins et al. (2024)

Algae-associated threats are increasing: Continental-scale evidence

Environmental Science & Technology

ACS Editors' Choice

Article

pubs.acs.org/est

Continental-Scale Increase in Lake and Stream Phosphorus: Are Oligotrophic Systems Disappearing in the United States?

John L. Stoddard,*[,†] John Van Sickle,[†,‡] Alan T. Herlihy,[§] Janice Brahney,[∥] Steven Paulsen,[†] David V. Peck,[†] Richard Mitchell,[⊥] and Amina I. Pollard[⊥]

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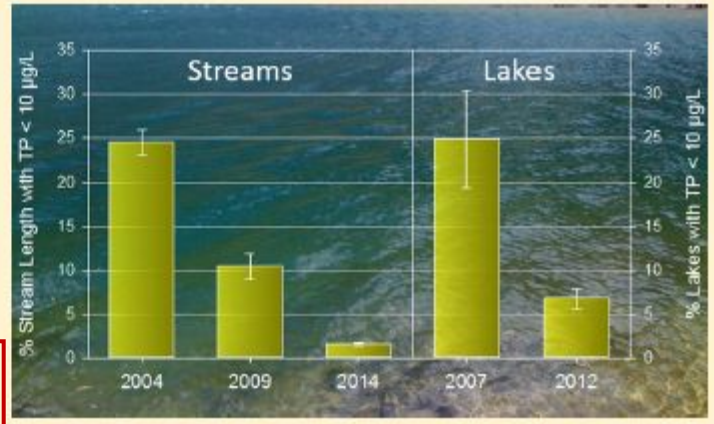
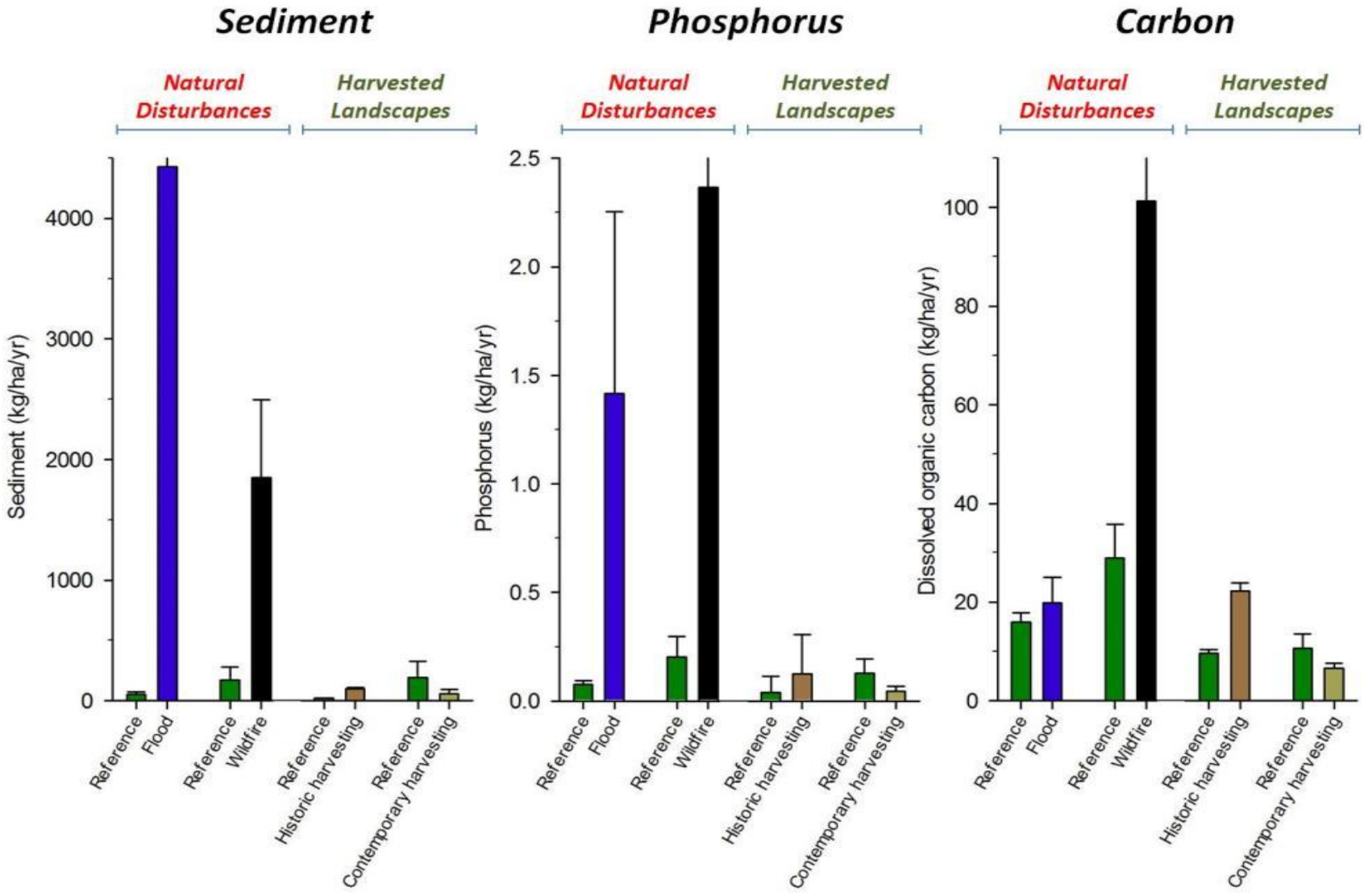
Supporting Information

ABSTRACT: We describe continental-scale increases in lake and stream total phosphorus (TP) concentrations, identified through periodic probability surveys of thousands of water bodies in the conterminous U.S. The increases, observed over the period 2000–2014 were most notable in sites in relatively undisturbed catchments and where TP was initially low (e.g., less than 10 $\mu g\ L^{-1}$). Nationally, the percentage of stream length in the U.S. with TP $\leq$ 10 $\mu g\ L^{-1}$ decreased from 24.5 to 10.4 to 1.6% from 2004 to 2009 to 2014; the percentage of lakes with TP $\leq$ 10 $\mu g\ L^{-1}$ decreased from 24.9 to 6.7% between 2007 and 2012. Increasing TP concentrations appear to be ubiquitous, but their presence in undeveloped catchments suggests that they cannot be entirely attributed to either point or common non-point sources of TP.



Disturbance Effects on Water Quality: Fires, Floods, Forestry



Silins et al. (2024)

Resilience to wildfire is resilience to most natural landscape disturbance!

Source Water Quality Impacts

	Extreme Heat/Cold	Wildfire	Extreme Precipitation	Earthquake	Drought	Intense Storms
Increased turbidity	✓	✓	✓	✓	✓	✓
Changing NOM characteristics	✓	✓	✓		✓	✓
Increased inorganics (metals, bromide)	✓	✓	✓		✓	✓
Changing background water quality (pH, alkalinity, hardness)	✓	✓		✓	✓	
Increased TOC	✓	✓	✓			✓
Increased color		✓	✓		✓	✓
Objectionable taste and odor	✓	✓	✓		✓	
Increased nutrients (nitrogen, phosphorus)		✓	✓			✓
Anthropogenic (chemical release, stormwater overflow, road salt)	✓	✓	✓	✓		✓

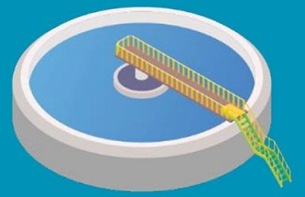
Treatability Impacts

Conventional / biological treatment
- Increased treatment chemical demand
- Reduced UFRV

Membrane treatment
- Decreased recovery
- Increased fouling

GAC/ion exchange
- Premature breakthrough
- Additional GAC consumption
- Resin fouling

Disinfection/oxidation
- Increased oxidant demand
- Increased disinfectant demand
- Inability to meet CT



Distribution System

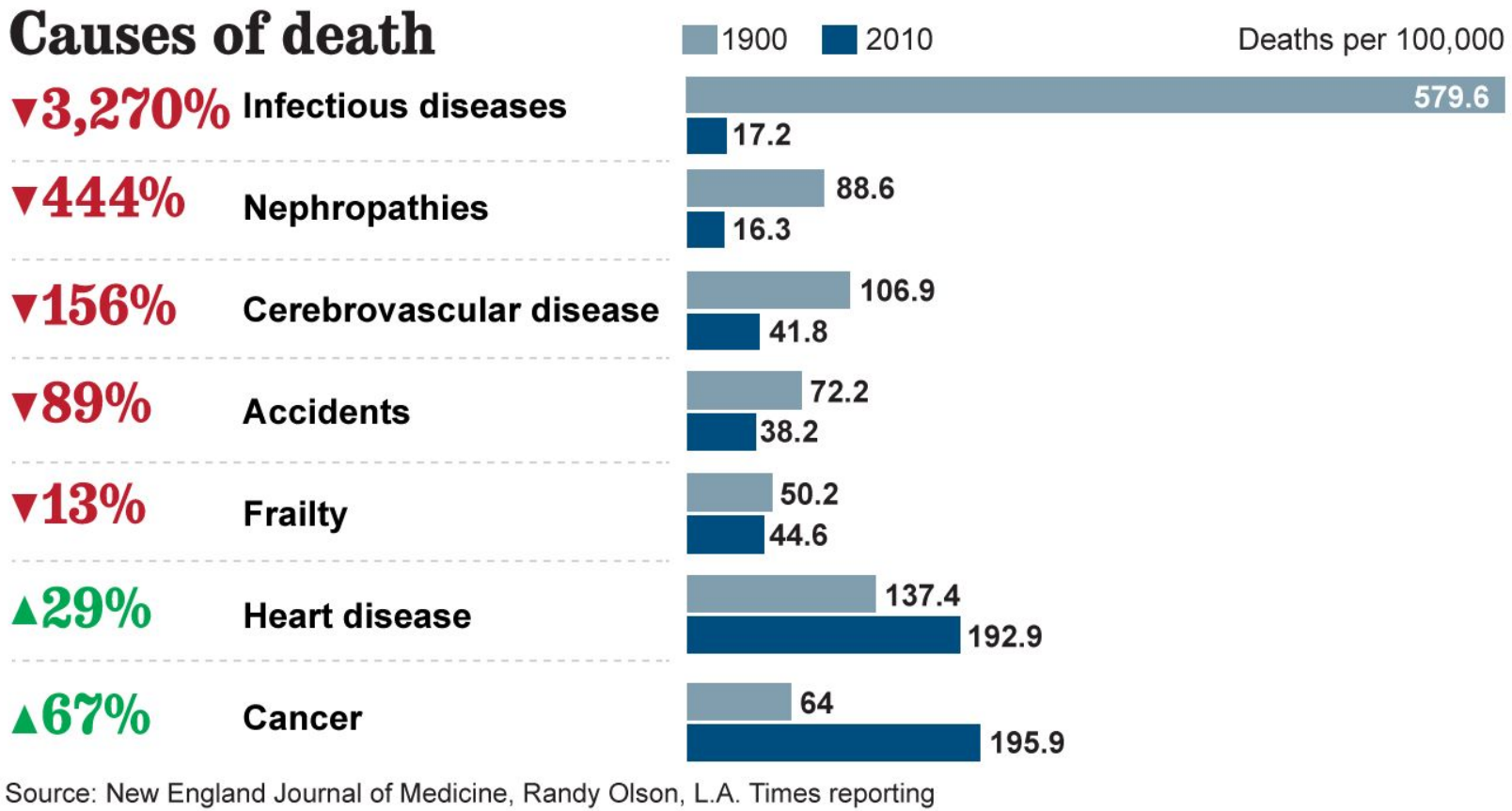
Destabilization of pipe scale/biofilm
- Color
- Taste
- Turbidity
- Adsorbed metal release

- Increased DBP levels
- Increased Pb/Cu corrosivity
- Increased CSMR

Residual disinfectant stability
- Increased demand
- Loss of residual
- Reduced chloramine stability; nitrification

https://doi.org/10.1002/awwa.1925

Water treatment is about public health protection

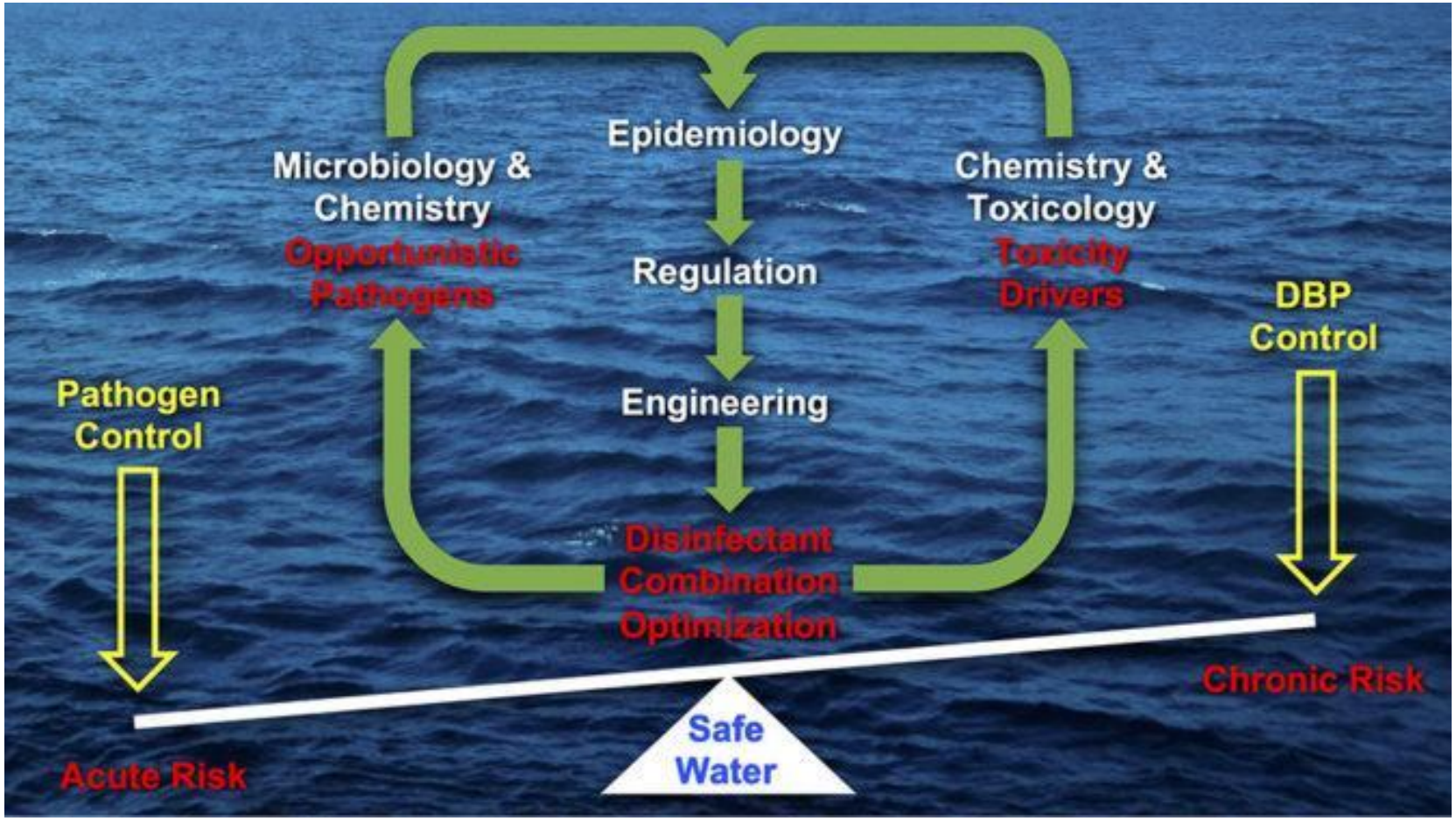


Source: New England Journal of Medicine, Randy Olson, L.A. Times reporting

Cartoon by Zim (1919) Source: Cutler & Miller (2004)

ALL water supplies require some level of treatment

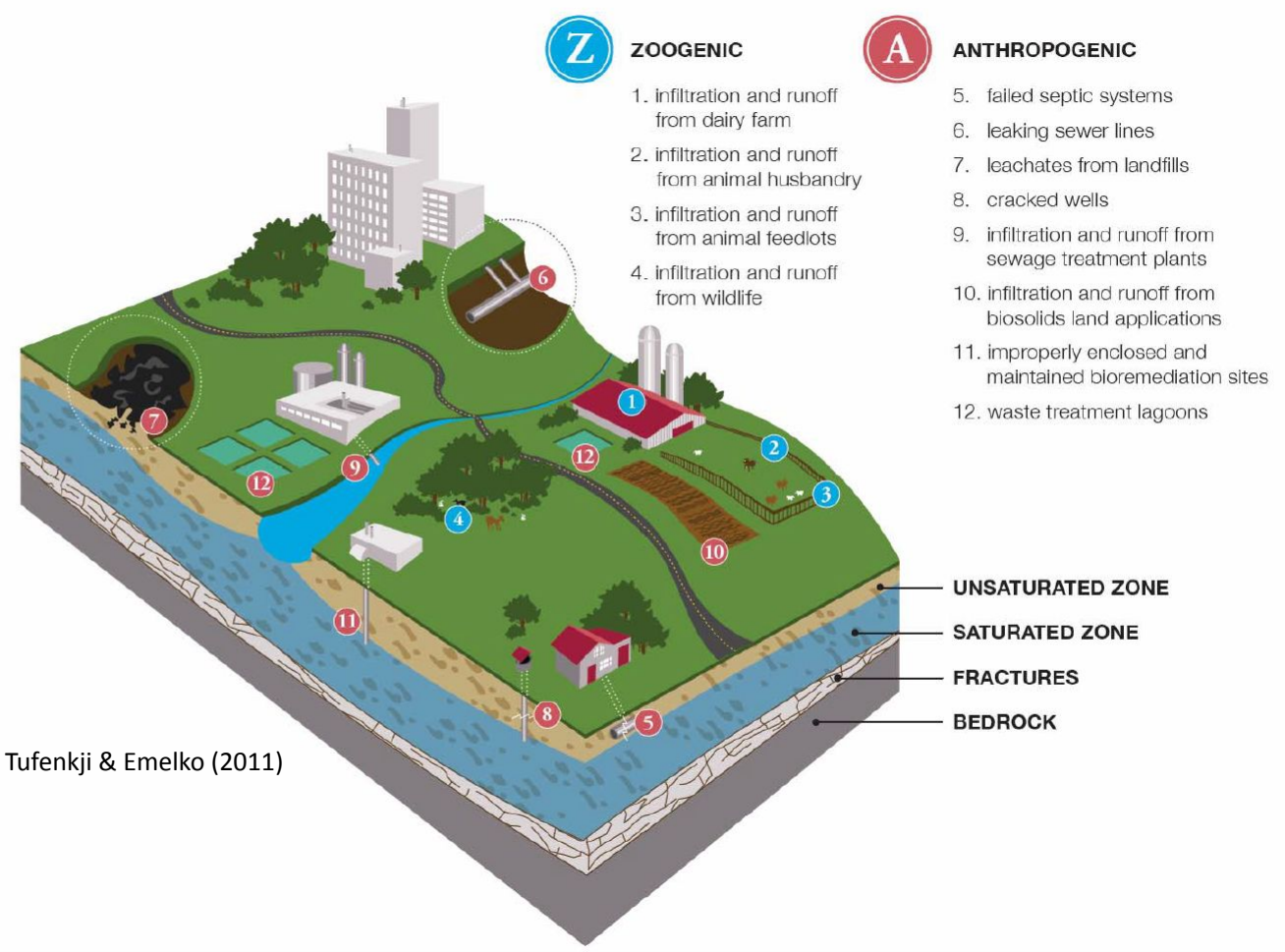
Drinking Water Treatment: Always a Balancing Act



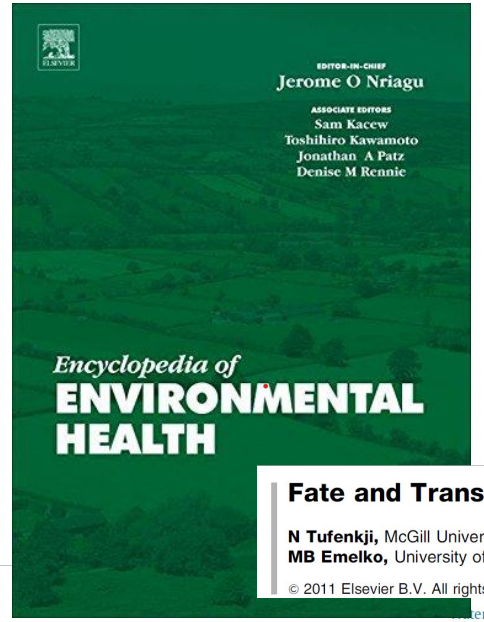
ACUTE RISK IS ALWAYS THE TOP PRIORITY

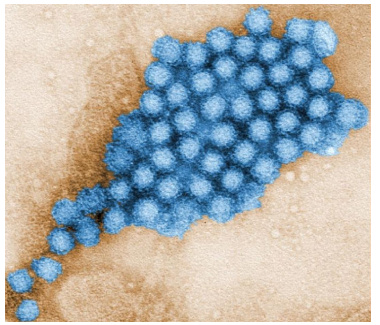
Li & Mitch (2017) *ES&T*

ALL water supplies require some treatment – Disinfection is a minimum



Tufenkji & Emelko (2011)





CDC/Charles D. Humphrey, PhD.
Public Health Image Library (PHIL)

Fate and Transport of Microbial Contaminants in Groundwater

N Tufenkji, McGill University, Quebec, QC, Canada
MB Emelko, University of Waterloo, Ontario, ON, Canada

Water Research 157 (2019) 356–364

Contents lists available at ScienceDirect

Water Research

journal homepage: www.elsevier.com/locate/watres

Confirming the need for virus disinfection in municipal subsurface drinking water supplies

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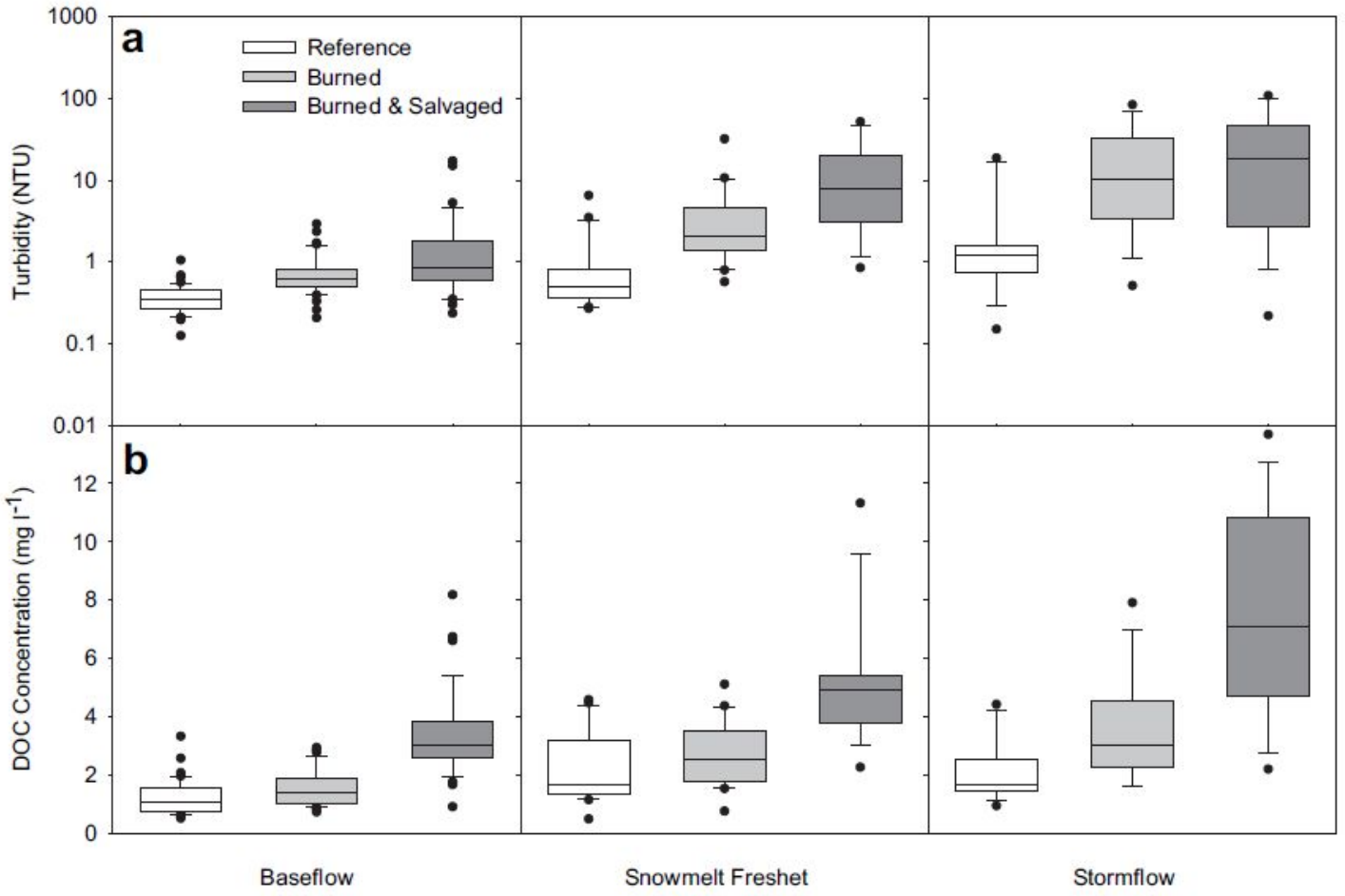
[b] Agricultural Research Service, U.S. Department of Agriculture, Marshfield, WI, 54449, United States

WATER QUALITY DRIVER:

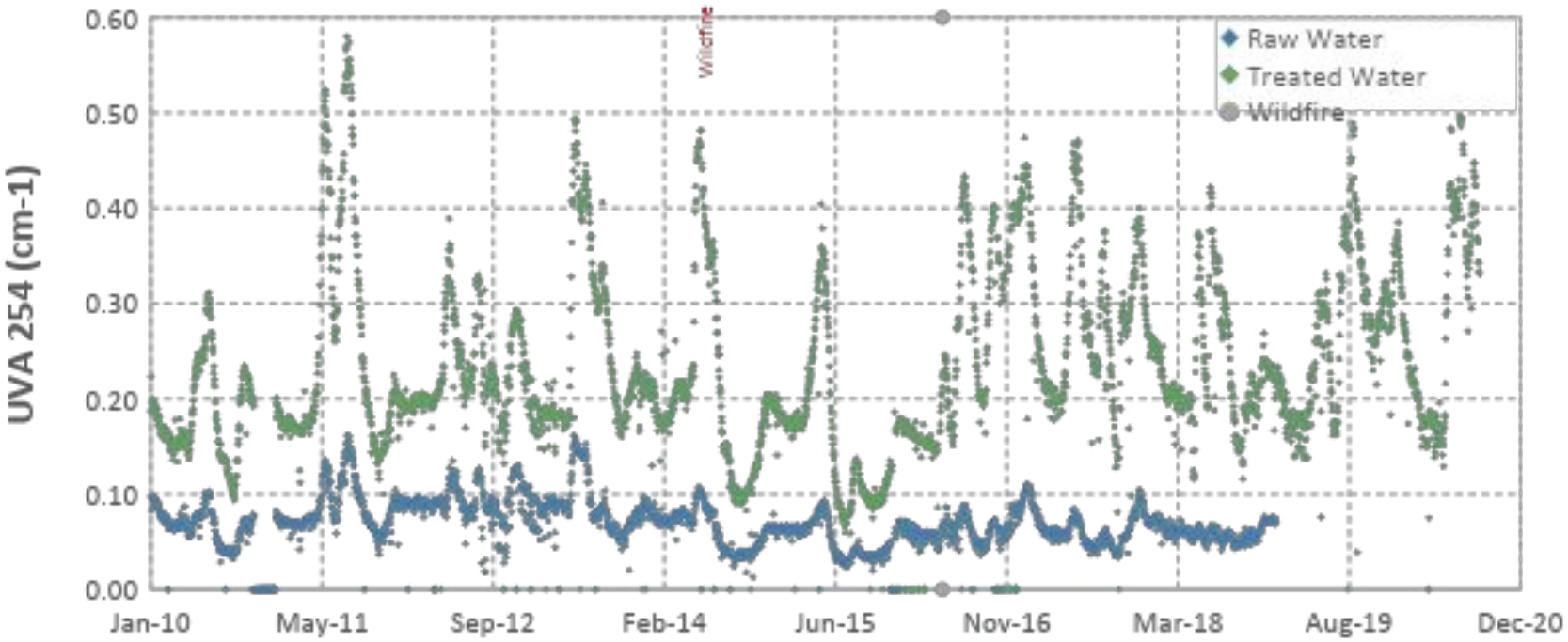
- **PATHOGENS**
  (bacteria, viruses & protozoa)

Key Water Quality Drivers of Treatment after the Lost Creek Wildfire

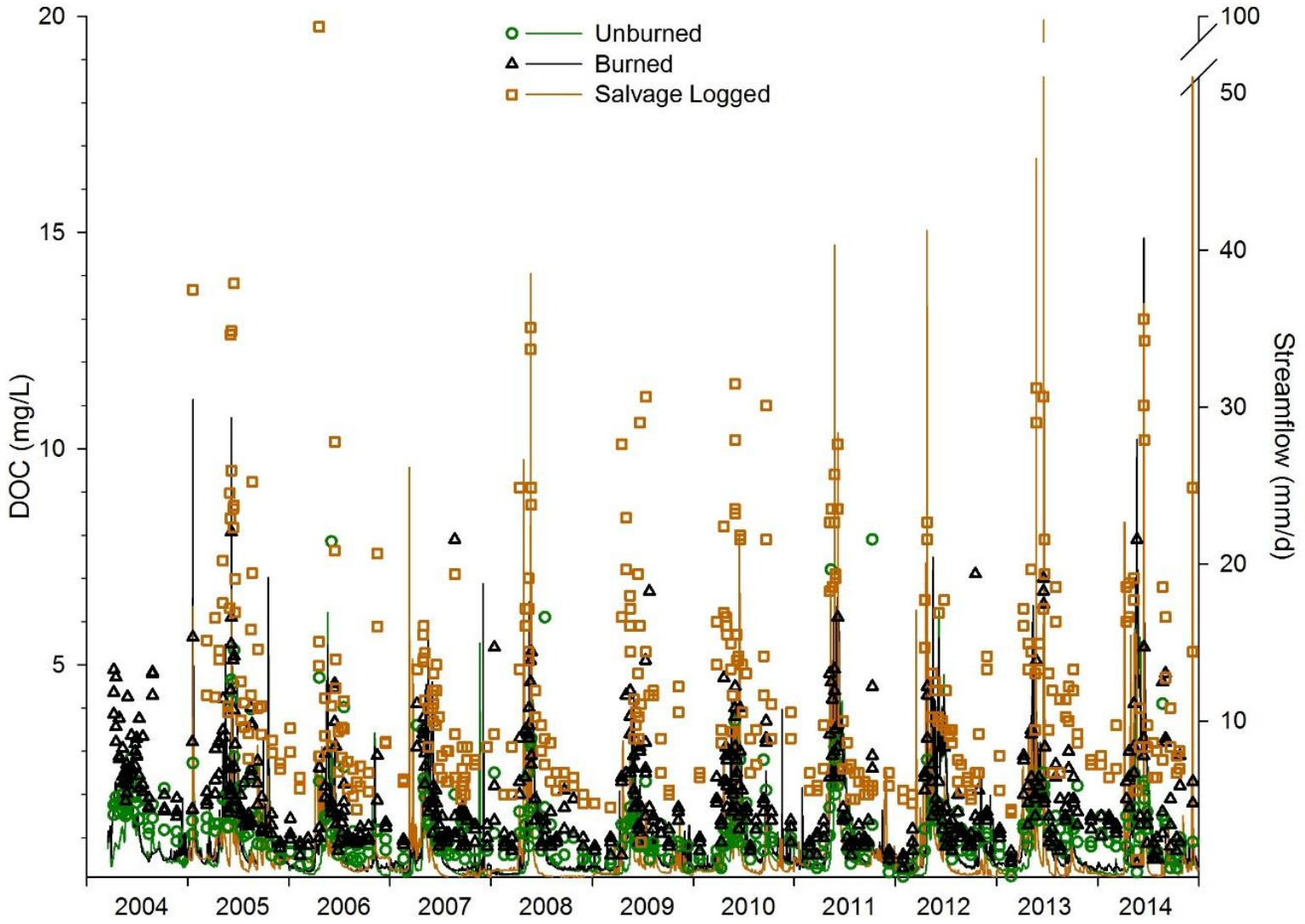


Emelko et al. (2011)

UV_{254} remains a key indicator of shifts in organic carbon (Fort McMurray, Canada)

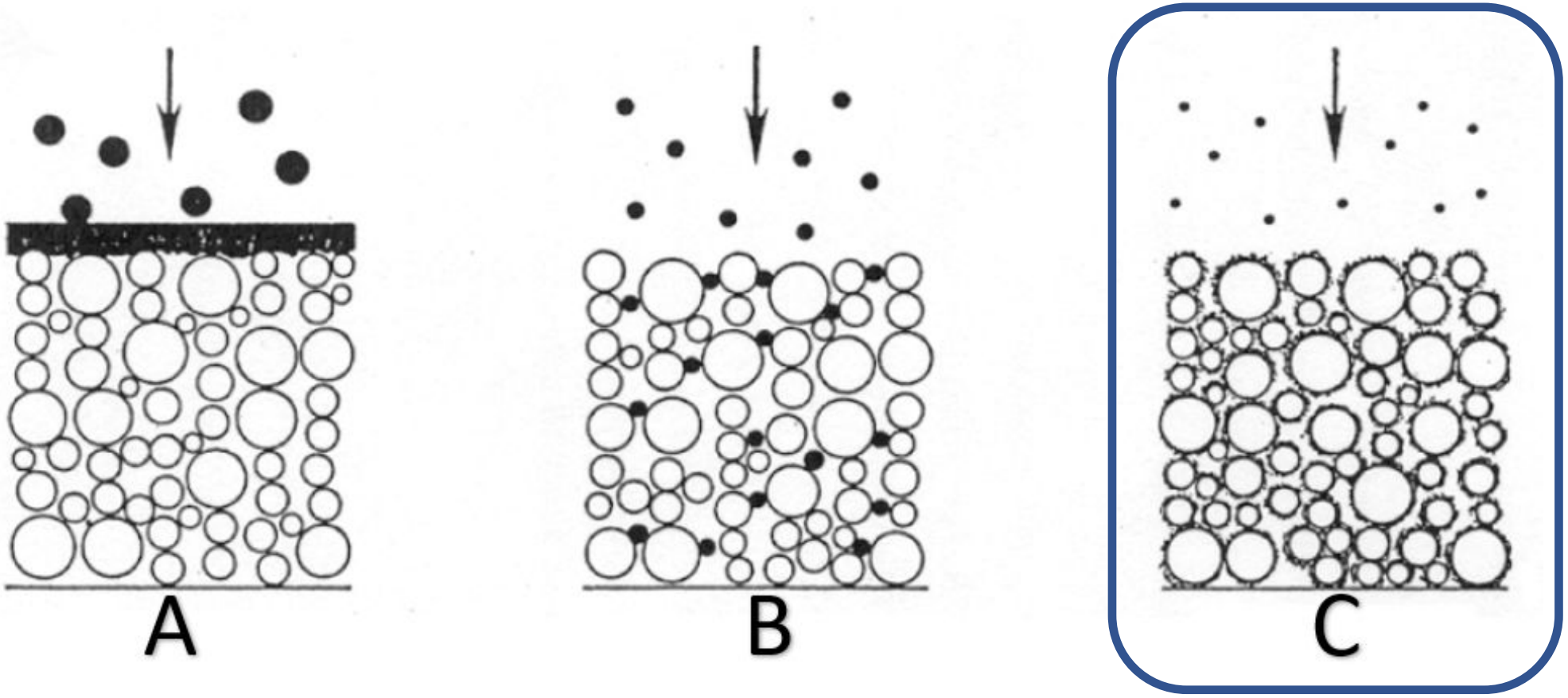


…sometimes for a decade or longer (2003 Lost Creek Wildfire, Alberta, Canada)

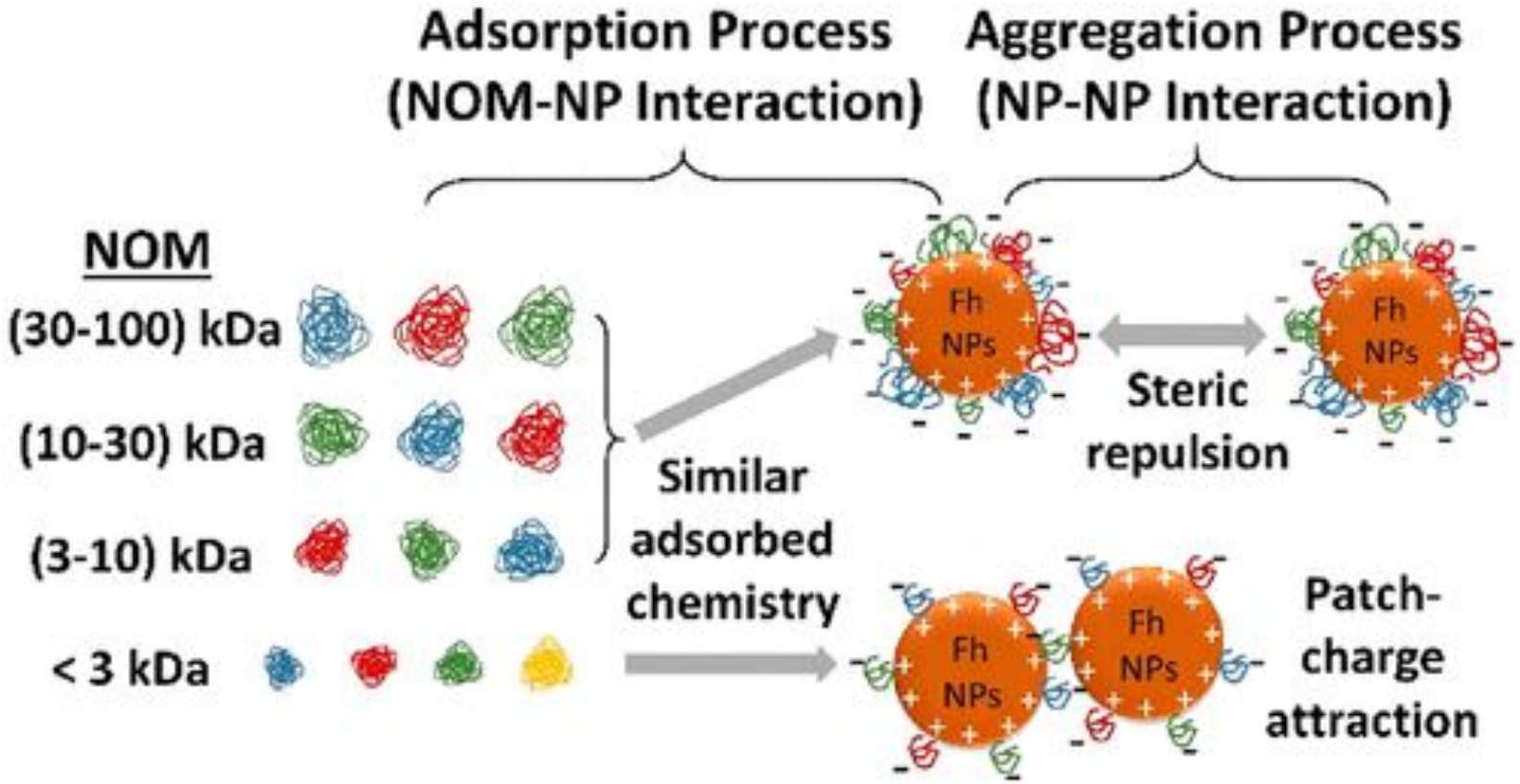


What does this mean for "groundwater"?

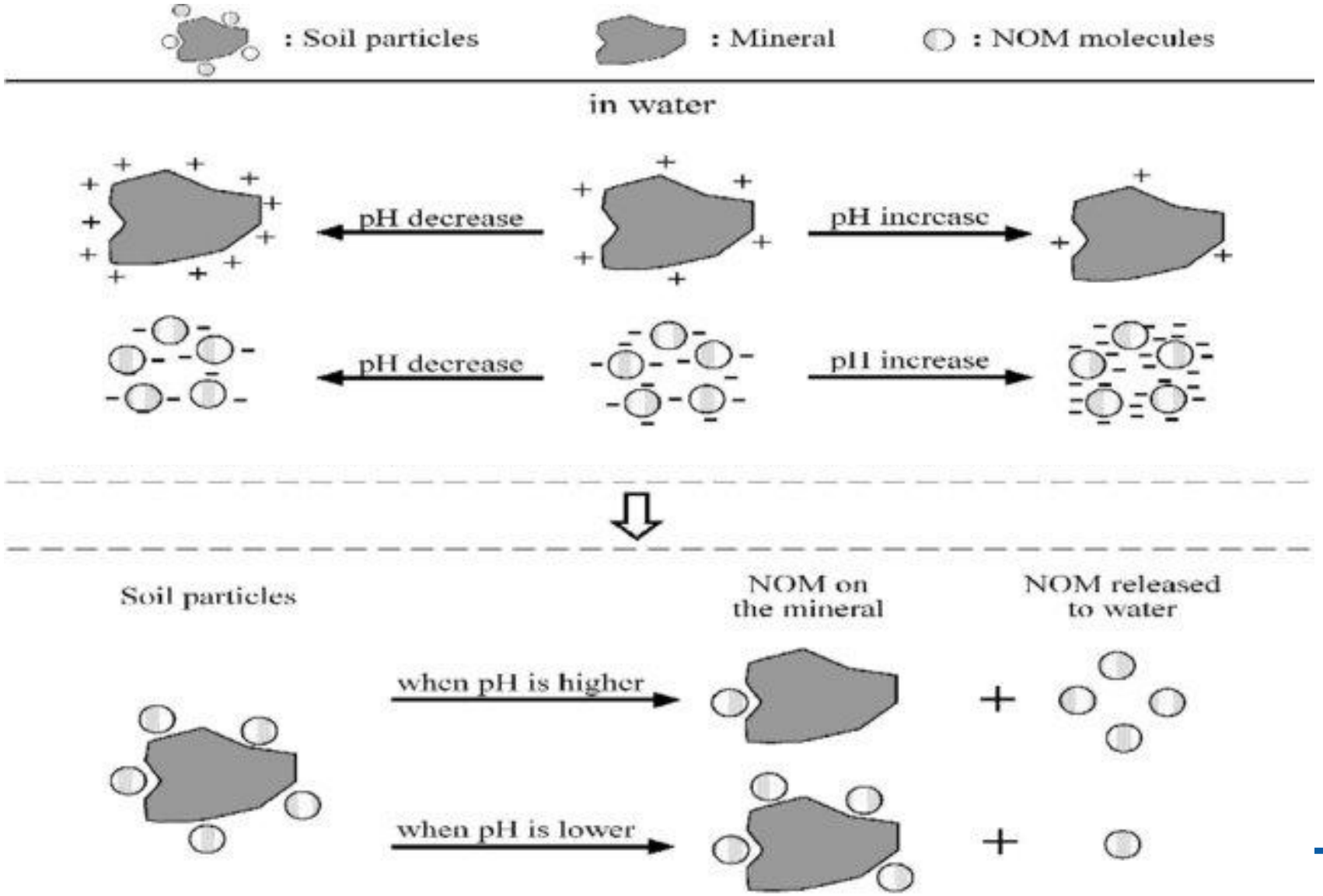
Physico-chemical filtration is <u>not</u> a size exclusion process



NOM drives particle charge in natural waters…



Particle charge is also affected by other system characteristics (e.g., pH)



Evaluation of Shifts in Post-fire Water Quality – Column Tests

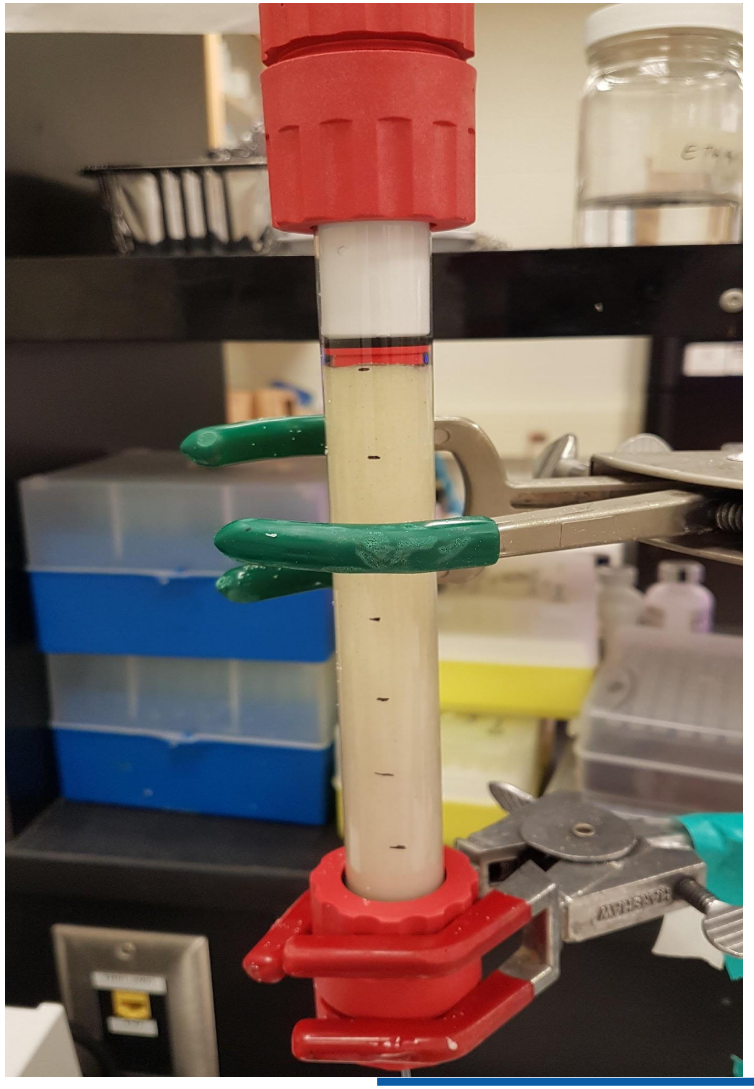
- Column diameter = 1.6 cm
- Media depth = 15 cm
- Silica sand: ES = 0.35 mm, UC = 1.69

- Hydraulic loading rate = 1.2 m/h
- Experiment duration ~75 minutes
- Background solution :

2017 Kenow Wildfire watersheds

or

wildfire ash + background



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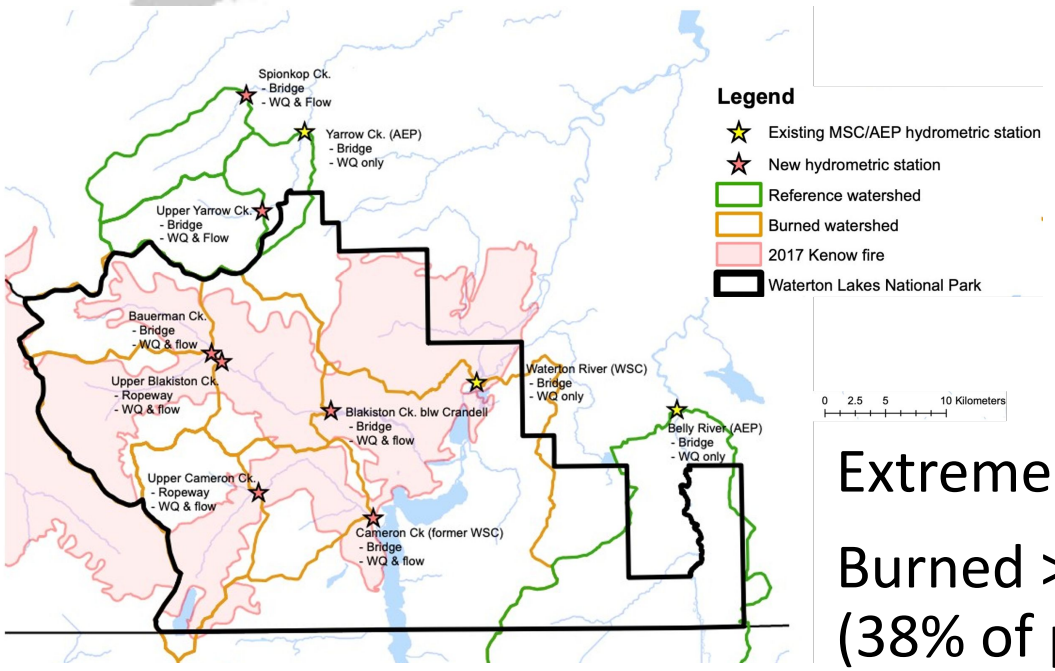
wildfire ash + background

2017 Kenow Wildfire

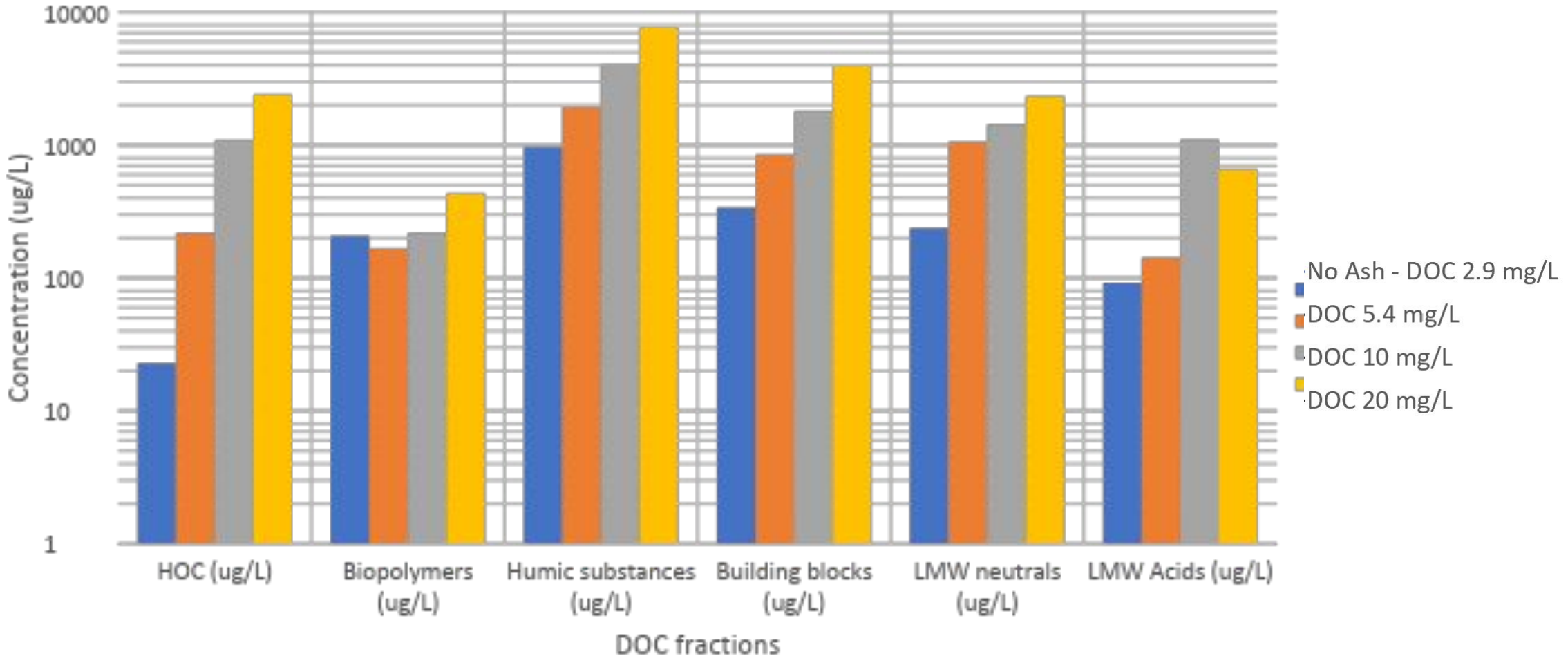

Photo: Parks Canada



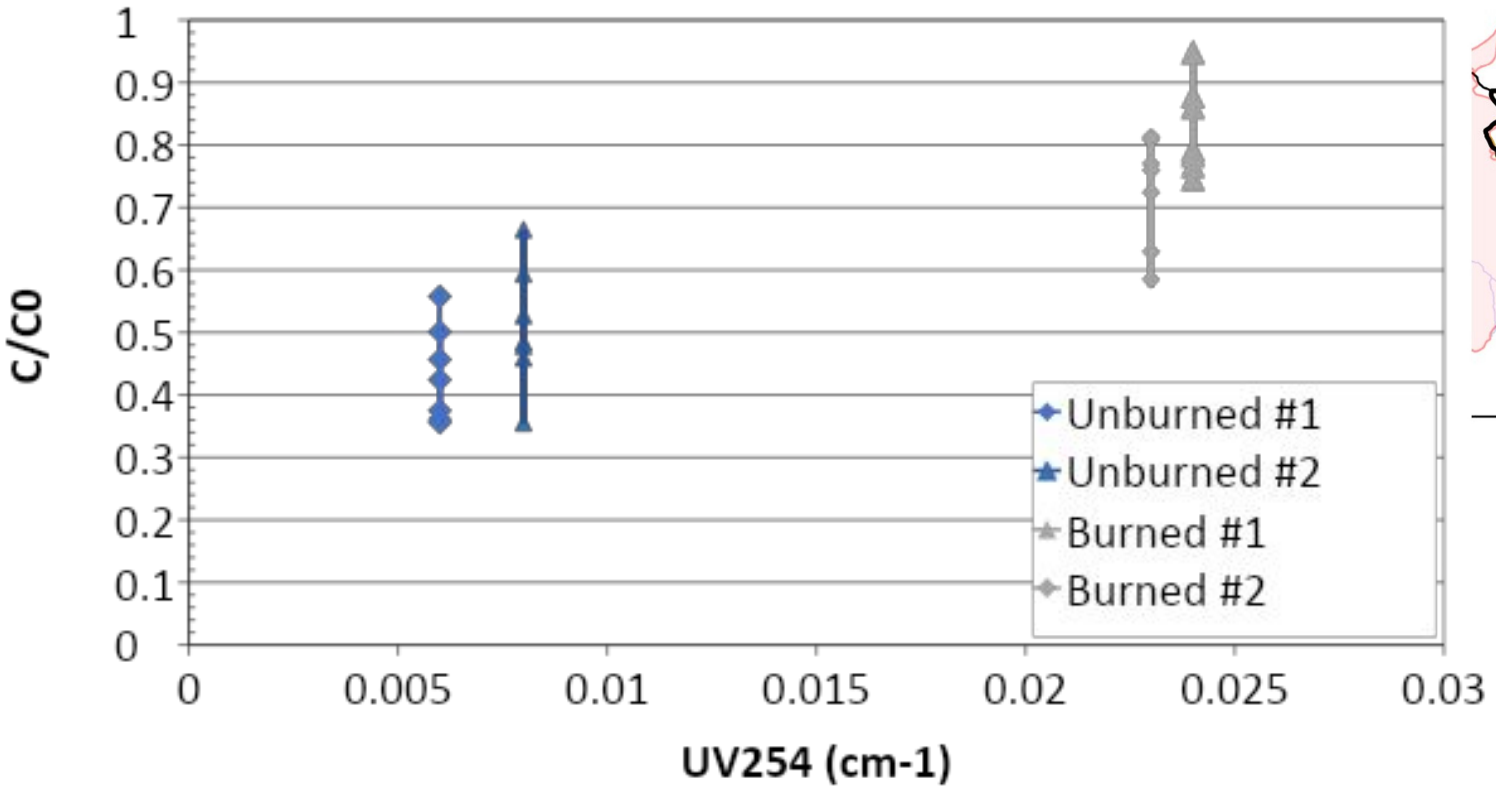
Extremely severe

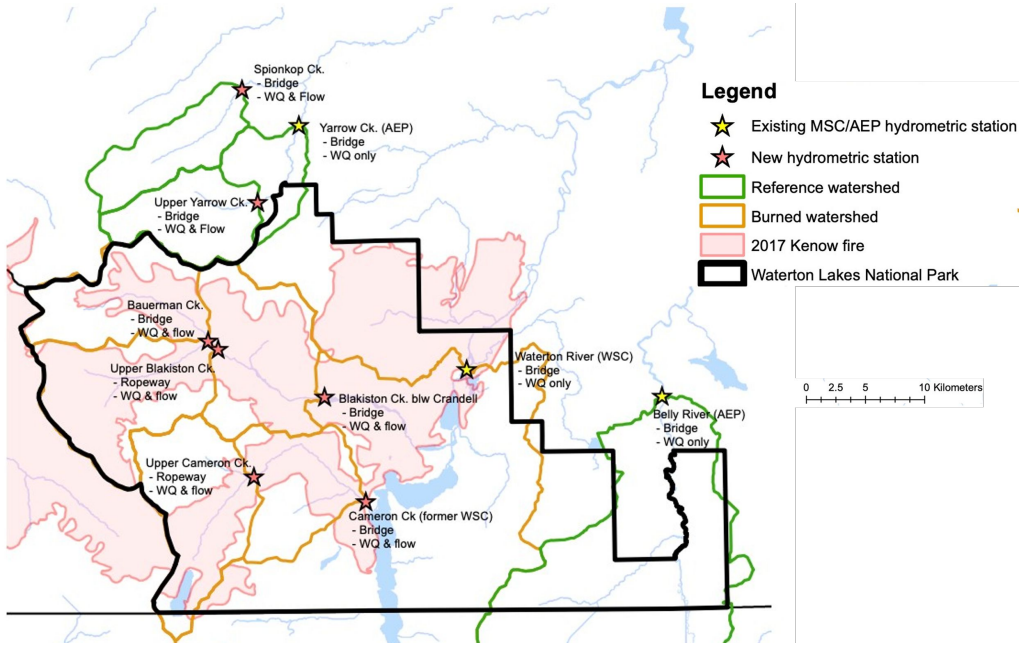
Burned >35,000 ha
(38% of park surface area)

DOC Fractionation – Wildfire Ash-Impacted Water



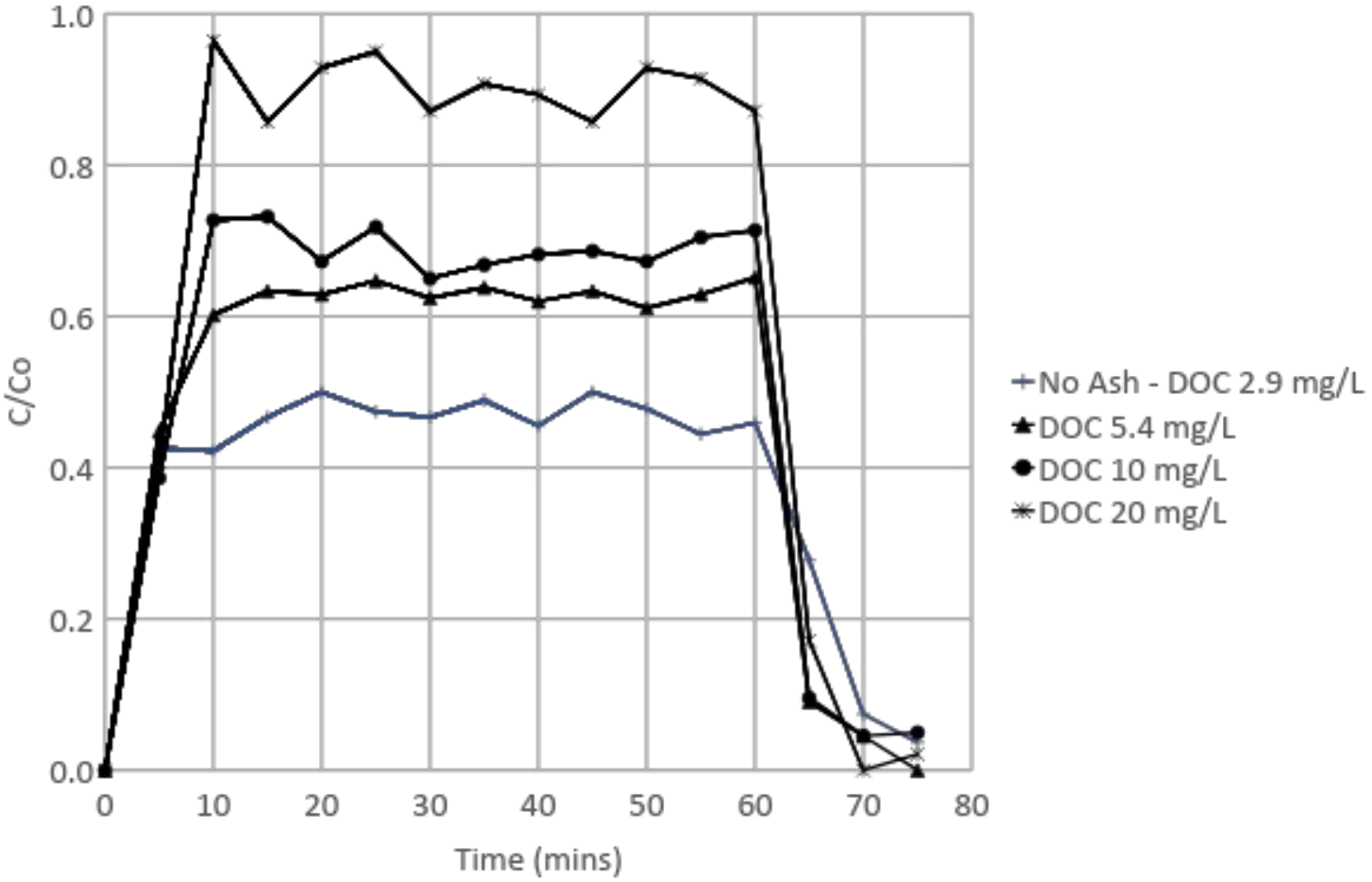
Wildfire Impacts on *E. coli* Transport

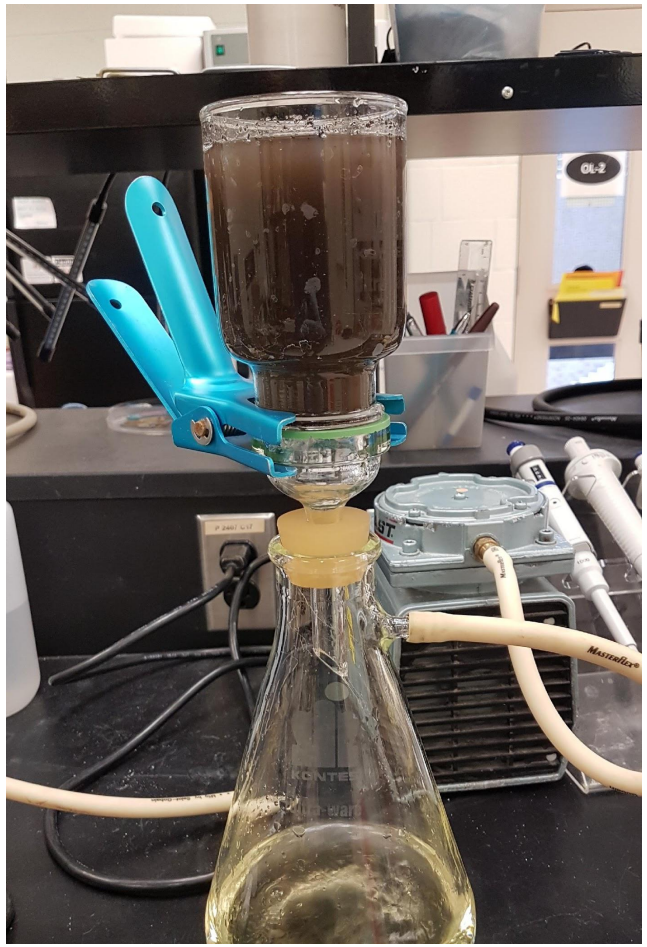




DOC 1.1, 1.9 mg/L 2.3, 2.4 mg/L

Wildfire Impacts on *C. parvum* Transport (wildfire ash-impacted water)





Triplicate experiments

Climate-change-exacerbated disturbance threats to groundwater supplies?

- Post-disturbance shifts in DOC concentration/character may impact pathogen transport in the subsurface
- Potential for increased transport (in some cases)
- Competition for deposition sites?
- Increases/shifts in alkalinity/pH/ionic strength should also be considered
- Similar implications to colloid- and nanoparticle-associated contaminants
- More work on this topic is needed!

Thank you

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www.waterstp.ca