Wildfire Threats to Water Quality & Treatability

Monica B. Emelko, PhD, FCAE, PEng
Canada Research Chair in Water Science, Technology & Policy

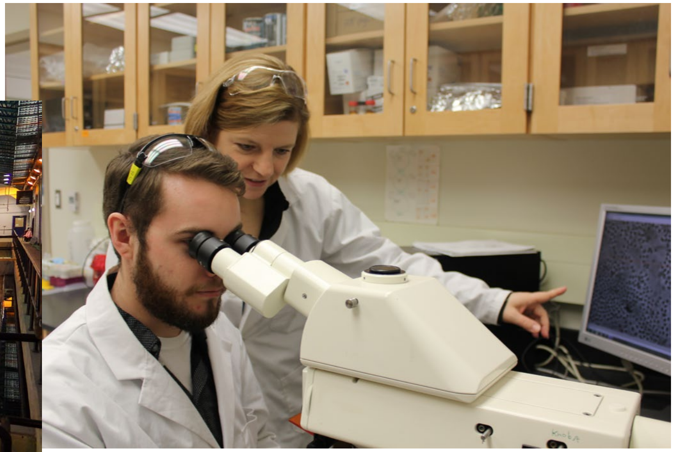
Water & Wastewater Workshop

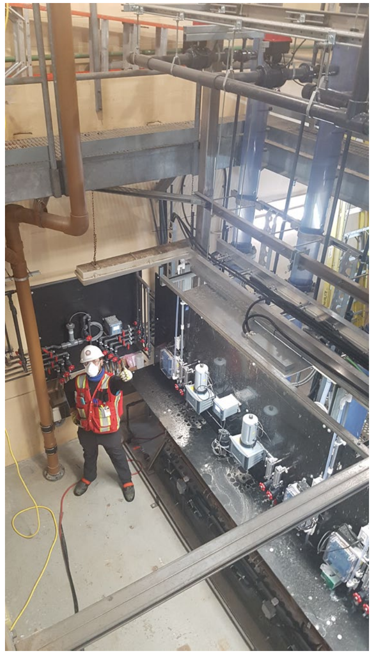
Newfoundland Labrador

March 26, 2024

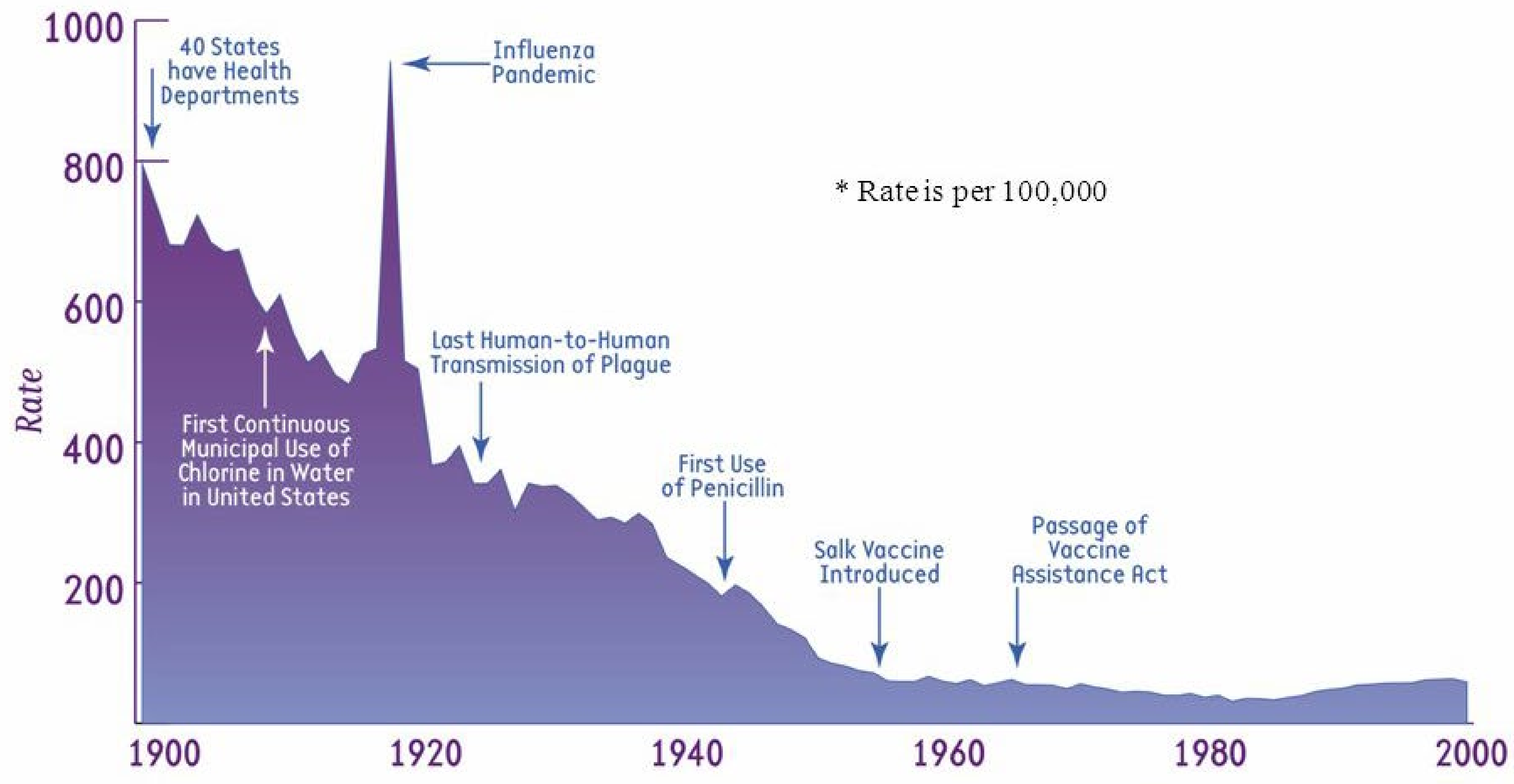
UNIVERSITY OF WATERLOO
WATER Science, Technology & Policy Group
forWater

A little about me



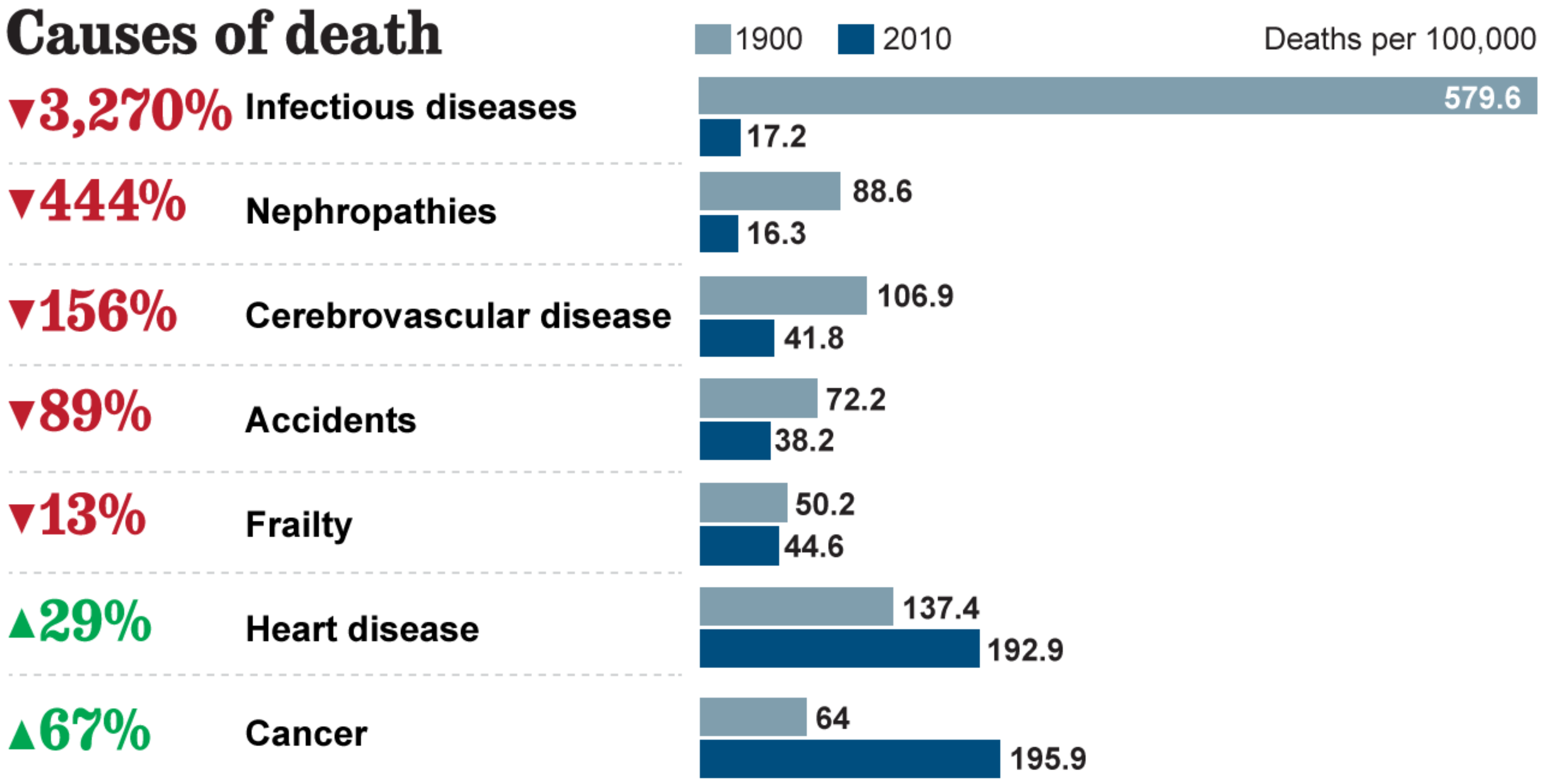


U.S. infectious disease crude death rate, 1900-2000

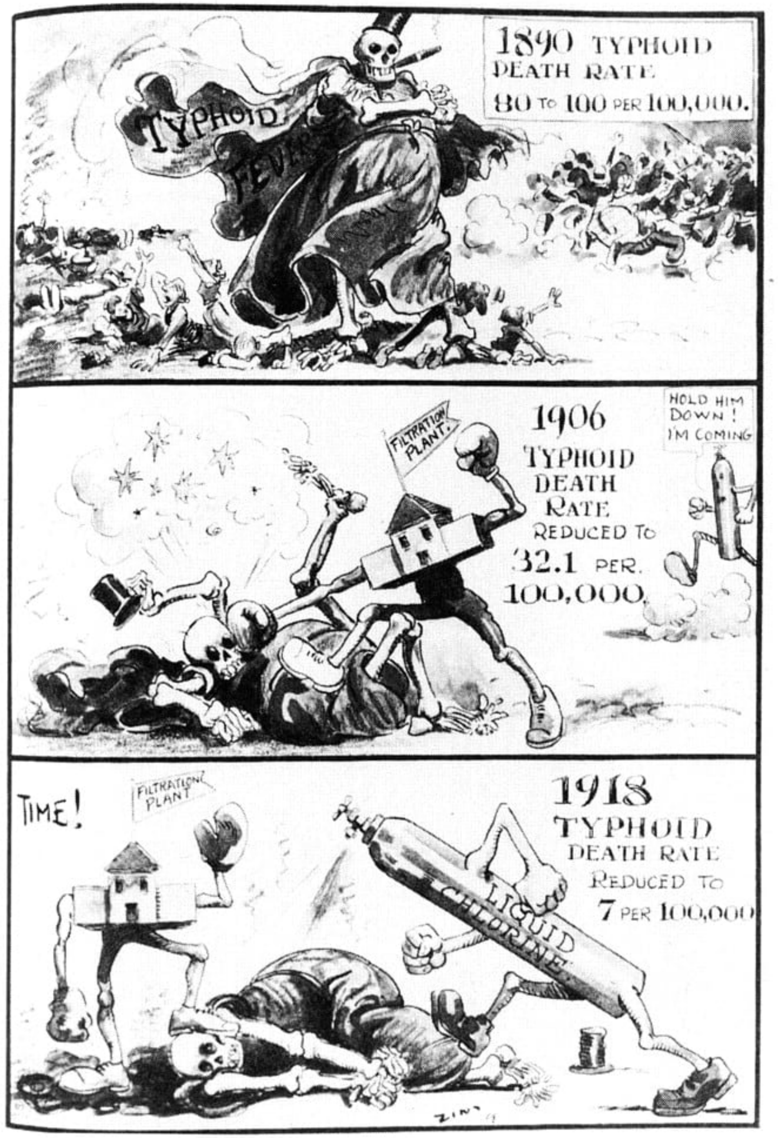


MMWR, CDC, 1999

Water treatment is about public health protection



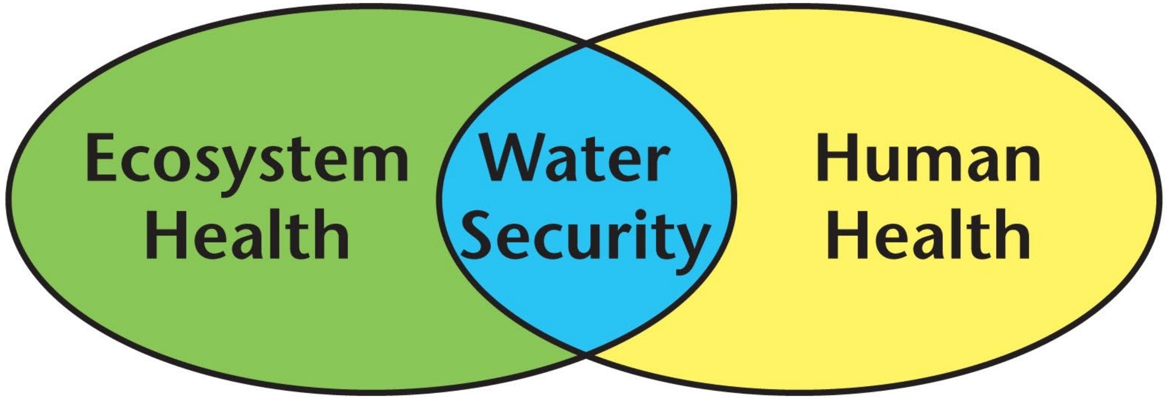
Source: New England Journal of Medicine, Randy Olson, L.A. Times reporting



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

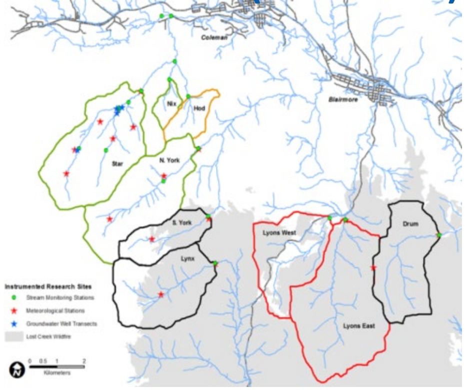
<u>ALL</u> water supplies require some level of treatment

Drinking Water, "Water Security" & the Importance of "Treatability"

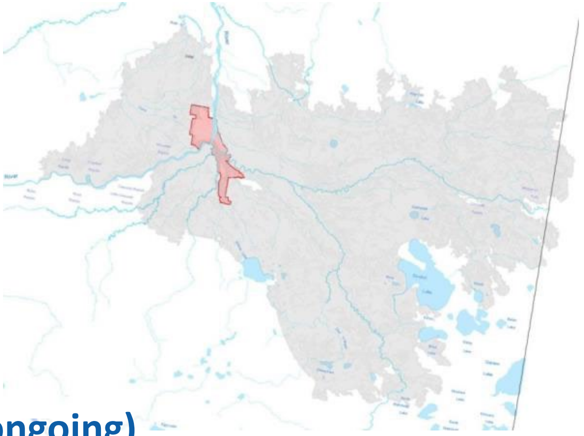


Southern Rockies Watershed Project

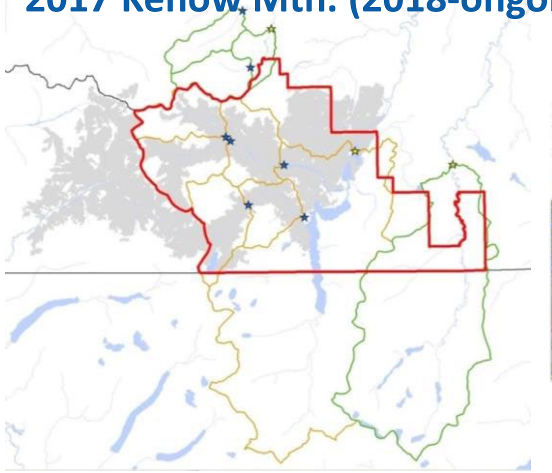
2003 Lost Ck. (2004-2014)



2016 Horse R. (2016-ongoing)



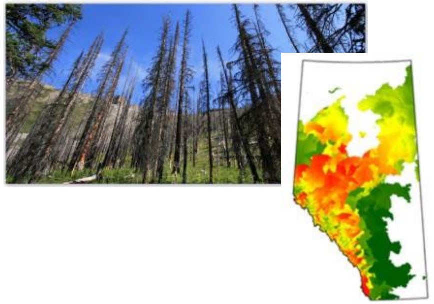
2017 Kenow Mtn. (2018-ongoing)



Provincial risk analysis

Management of Wildfire Risk to Municipal Waterworks Systems in Alberta

Principal Investigator - Uldis Silins, Professor, University of Alberta, 2012 - 2014



2012
Milk River

2014
Spreading Creek

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

Key Water Quality Drivers of Drinking Water Treatment

WATER RESEARCH 45 (2011) 461–472

ELSEVIER

Available at www.sciencedirect.com

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

WATER RESEARCH

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 3G1
[b] Renewable Resources, University of Alberta, Edmonton, Alberta, Canada T6G 2H1
[c] Natural Resource Sciences, Thompson Rivers University, Kamloops, British Columbia, Canada V2C 5N3
[d] Geography, University of Waterloo, Waterloo, Ontario, Canada N2L 3G1

Almost all "typical" target compounds can be readily treated by currently available processes/technologies.

Drinking water treatability must be considered.

Process	Turbidity	Color	TOC
Conventional	high >20 NTU	high >20 c.u.	high >4 mg/L
Direct/Inline Filtration	low ≤15 NTU	moderate to low ≤20 c.u.	low <4 mg/L
Microfiltration	low ≤10 NTU	moderate to low ≤10 c.u.	low <4 mg/L

Emelko et al. (2011)

The Importance of Treatability


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[c] Natural Resource Sciences, Thompson Rivers University, Kamloops, British Columbia, Canada V2C 5N3
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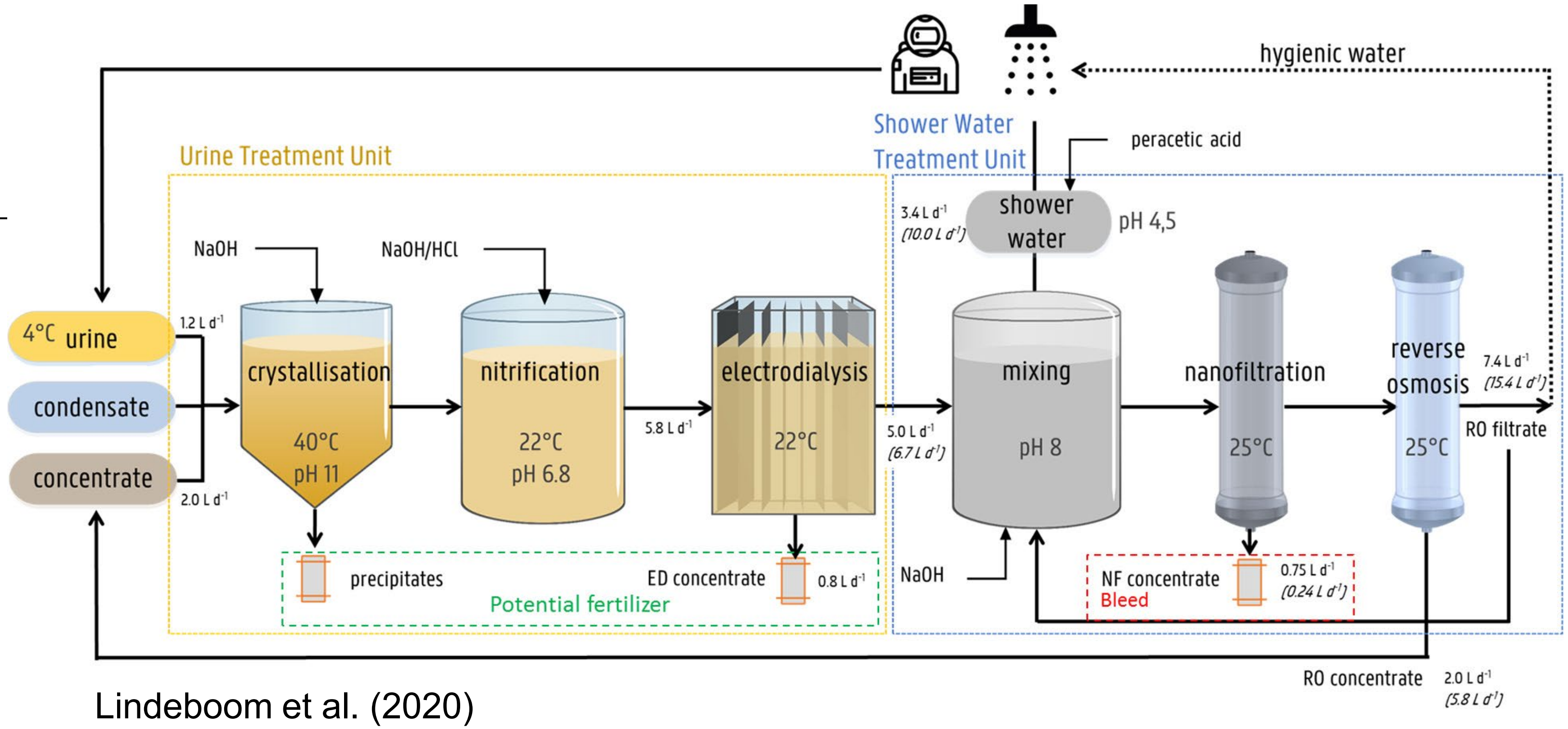
Drinking water treatability must be considered.

We can treat water, even in space.



Lindeboom et al. (2020)

Key Water Quality Drivers of Drinking Water Treatment

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Emelko et al. (2011)

Almost all "typical" target compounds can be readily treated by currently available processes/technologies.

How <u>resilient</u> are systems to water quality fluctuations?

Wildfire Threats to
Source Water Quality & Treatability

Forests: Critical Sources of Drinking Water

Pepacton Reservoir, Downsville, NY

Sydney, Australia

Lake Paijane, Helsinki, Finland

Lake Miygase, Tokyo, Japan

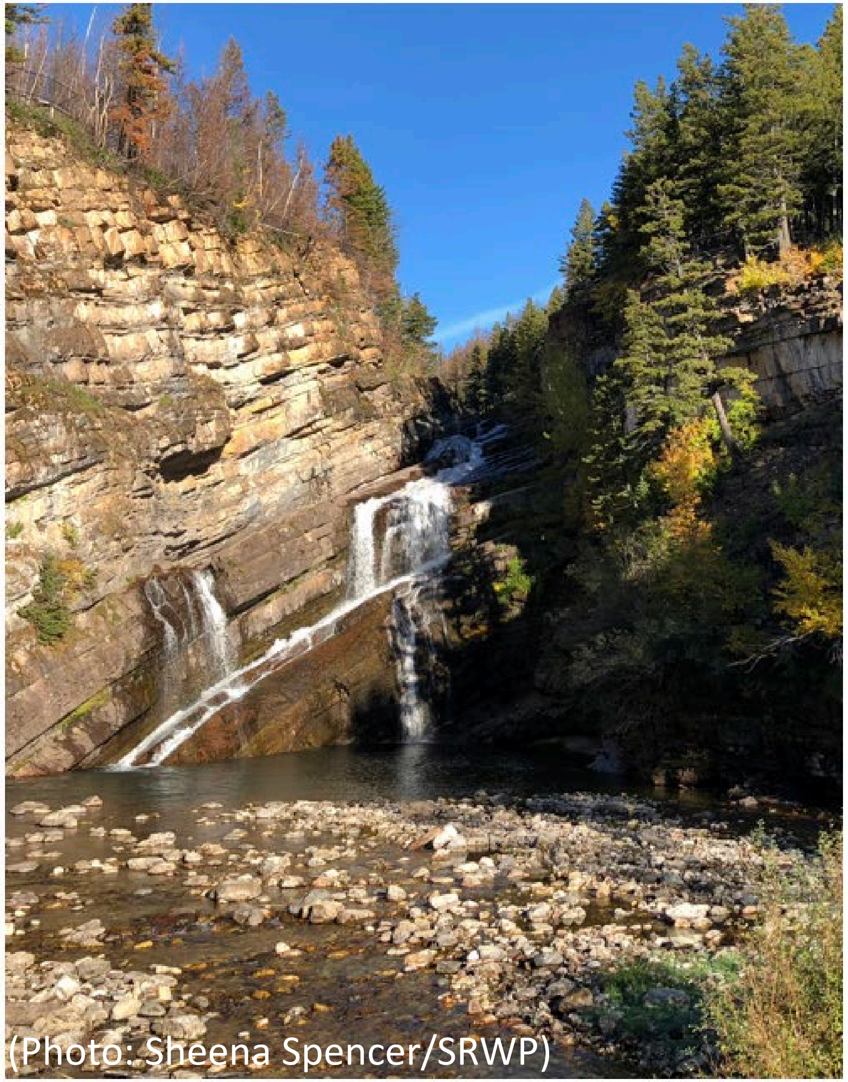
Guandú Watershed,
Rio de Janeiro, Brazil

Bow River Basin, Calgary, Canada

Landscape Disturbances in a Warmer World

Landscape Disturbances in a Warmer World – Adaptation?

Wildfire impacts on water?


(Photo: Sheena Spencer/SRWP)


(Photo: Kaleigh Watson/Parks Canada)

Wildfire can be especially "hard" on water…

Wildfire can be especially "hard" on water…

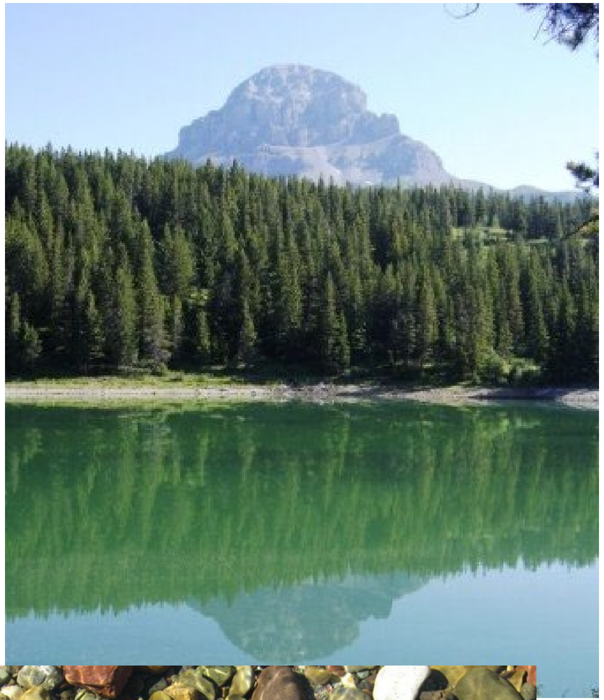
Firefighters move on to flood control

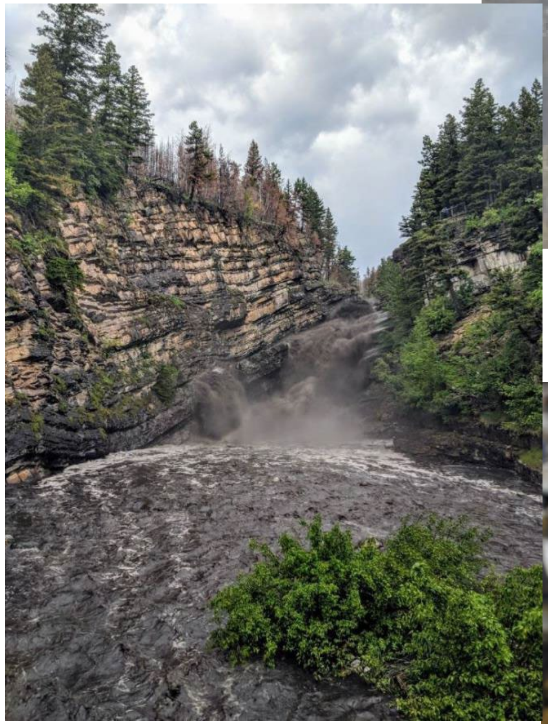
Steven G. Smith/Tribune

Thomas Tenorio (left) applies a bandage to the blistered hands of James Calabaza in the scorched woodlands west of Los Alamos. The two firefighters from Santo Domingo Pueblo have gone from fighting fire to flood-control efforts, raking the ash-laden forest floor to allow rainwater to seep into the ground rather than to run off.

Water quality deterioration can be expected after severe fire…

Before…

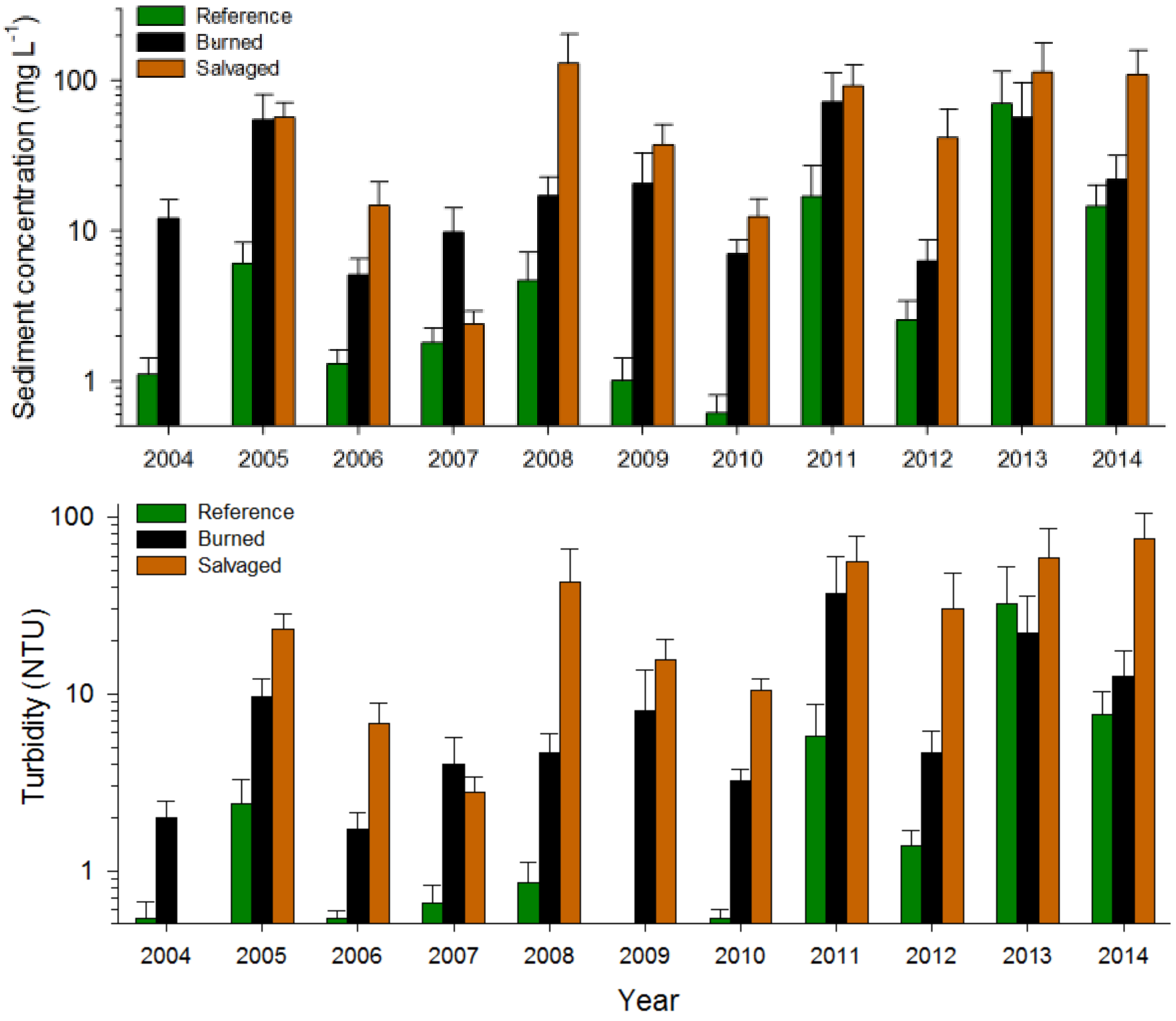




Impact?
How big?
How long?

….After

Sediment and Turbidity after Wildfire: A Legacy of Impacts



Silins et al. (2019)

Water quality: Impact of Erosion, Fine sediment & Biostabilization

undisturbed riverbed

post-disturbance fine sediment

+

post-disturbance nutrients + biofilm

riverbed biostabilization

Physical Sediment Characteristics

	Consolidation Period [day]	Critical Shear Stress for for Erosion (T_c) [Pa]	Erosion Depth @ T_c [mm]
Castle River	2	0.105	0.013
UNBURNED	7	0.141	0.008
	14	**0.165**	**0.014**
Lynx Creek	2	0.120	0.336
BURNED	7	0.230	0.426
	14	**0.310**	**1.540**

Stone et al. (2011) Water Research

- **Increased risk of taste & odor events**
- **More variable source water quality**
- **Better control over coagulation required!**

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WATER RESEARCH

The effect of bed age and shear stress on the particle morphology of eroded cohesive river sediment in an annular flume

Micheal Stone[a,*], Bommanna G. Krishnappan[b], Monica B. Emelko[c]

[a]School of Planning and Department of Geography, University of Waterloo, Waterloo, Ontario, Canada N2L 3G1
[b]Aquatic Ecosystems Impacts Research Division, National Water Research Institute, Burlington, Ontario, Canada L7R 4A6
[c]Department of Civil and Environmental Engineering, University of Waterloo, Waterloo, ON, Canada N2L 3G1

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ScienceDirect
journal homepage: www.elsevier.com/locate/watres
WATER RESEARCH

Biostabilization and erodibility of cohesive sediment deposits in wildfire-affected streams

M. Stone[a,*], M.B. Emelko[b], I.G. Droppo[c], U. Silins[d]

[a]Department of Geography and Environmental Management, University of Waterloo, Waterloo, Ontario, Canada N2L3G1
[b]Department of Civil and Environmental Engineering, University of Waterloo, Waterloo, Ontario, Canada N2L3G1
[c]National Water Research Institute, Environment Canada, Burlington, Ontario, Canada L7R4A6
[d]Department of Renewable Resources, University of Alberta, Alberta, Canada T6G2H1

Science of the Total Environment 473–474 (2014) 642–650
Contents lists available at ScienceDirect
Science of the Total Environment
journal homepage: www.elsevier.com/locate/scitotenv

The use of composite fingerprints to quantify sediment sources in a wildfire impacted landscape, Alberta, Canada

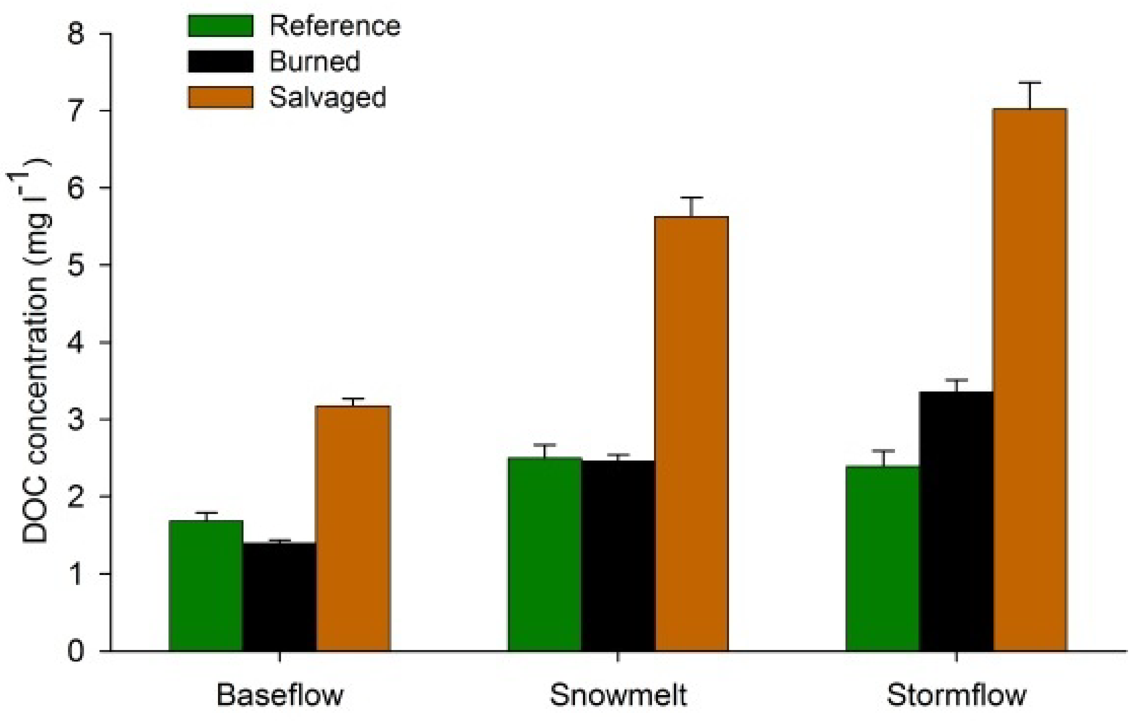
M. Stone[a], A.L. Collins[b,e,*], U. Silins[c], M.B. Emelko[d], Y.S. Zhang[e]

Global Change Biology
Global Change Biology (2016) 22, 1168–1184, doi: 10.1111/gcb.13073

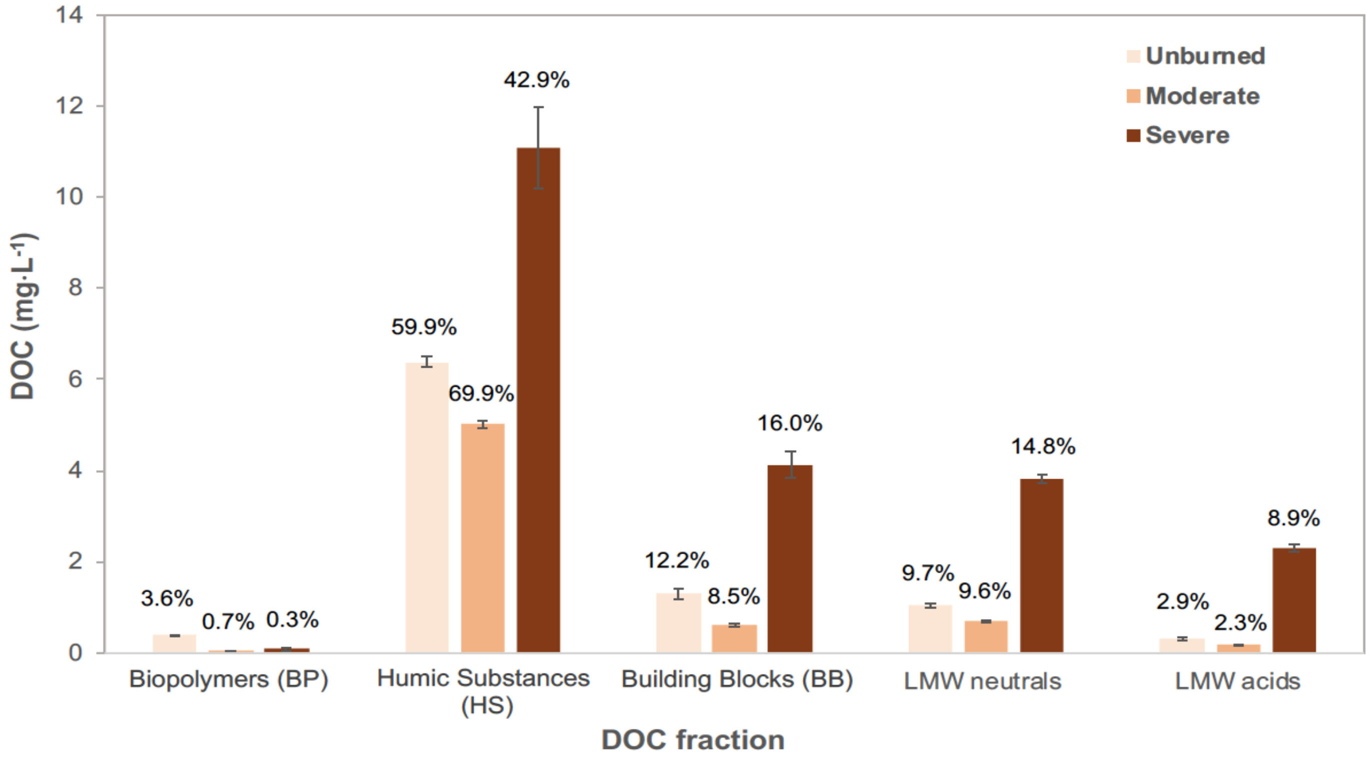
Sediment-phosphorus dynamics can shift aquatic ecology and cause downstream legacy effects after wildfire in large river systems

MONICA B. EMELKO[1], MICHEAL STONE[2], ULDIS SILINS[3], DON ALLIN[2], ADRIAN L. COLLINS[4], CHRIS H. S. WILLIAMS[3], AMANDA M. MARTENS[3] and KEVIN D. BLADON[5]

Wildfire-ash Associated Shifts in Dissolved Organic Carbon Character

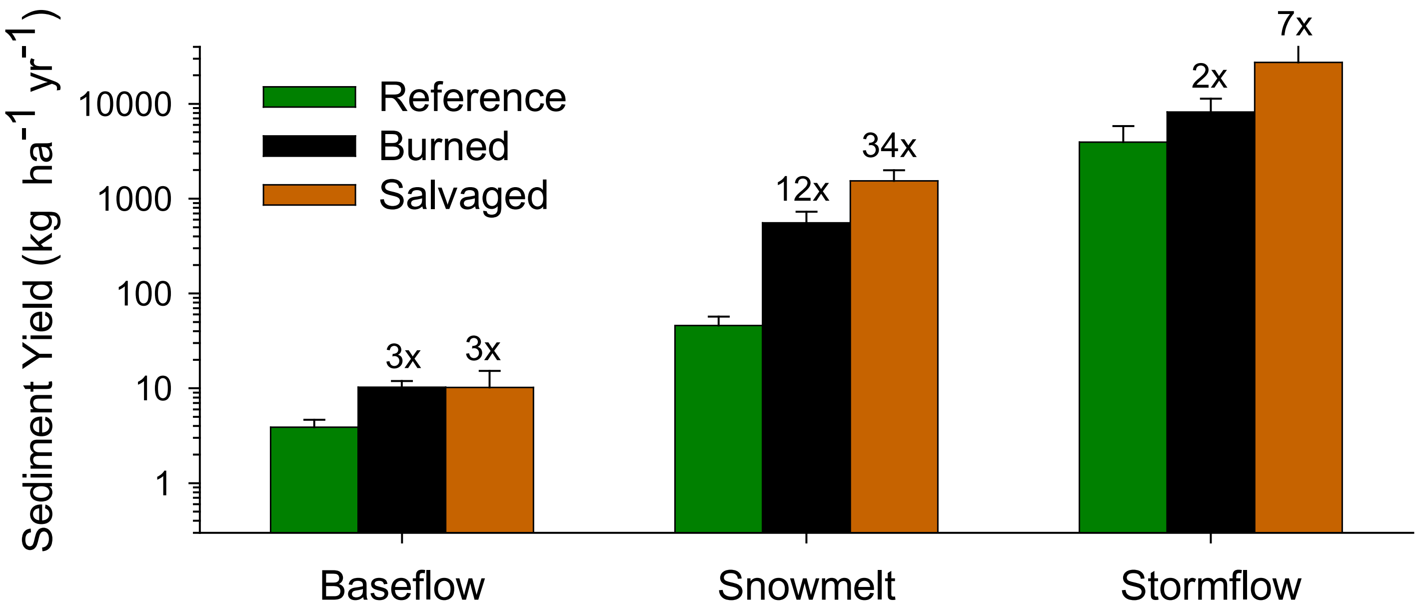


Emelko et al. (2011)



Skwaruk et al. (2020)

Sediment and turbidity after wildfire: Event sampling is important!



Emelko et al. (2011)

Sediment-associated Contaminant (e.g., Metals) Increases after Wildfire

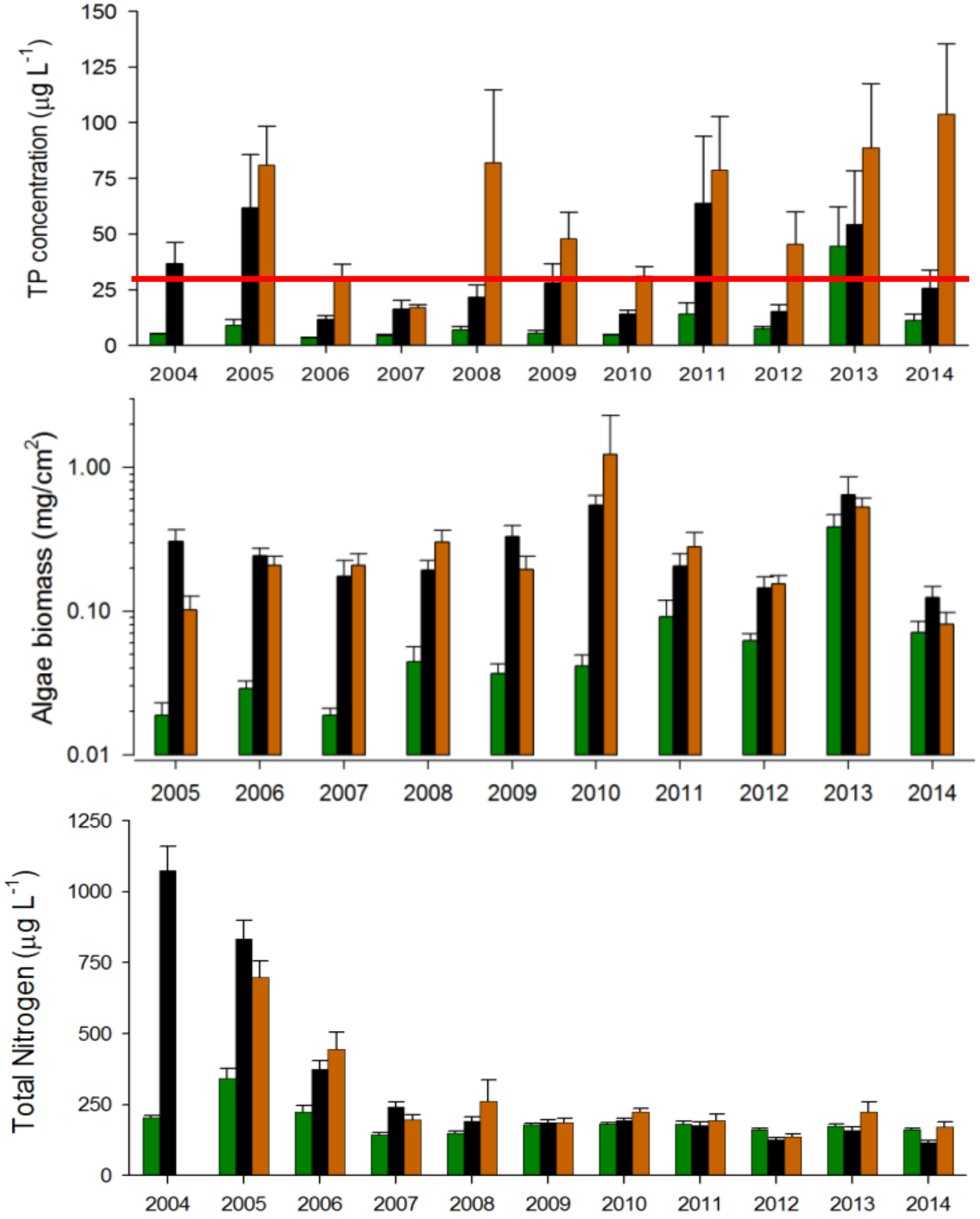
Table 7: Post-fire metal concentrations in streams in north-eastern Victoria after the 2003 bushfires and following intense summer storm events

Author	Location	Location description	Metal	Pre-event concentration (mg L^{-1})	Storm event concentration (mg L^{-1})
Leak et al. (2003)[a]	Buckland River, NE Victoria	30 km downstream of a cluster of debris flows	Iron	Not available	740
			Arsenic		0.28
			Chromium		0.92
			Lead		0.98
North East Water (2003)	Ovens River, NE Victoria	Upstream of water quality impacts from debris flow	Iron	0.64	30
			Copper	0.001	0.032
			Zinc	<0.002	0.1
			Chromium	0.001	0.04
			Arsenic	0.003	0.012
			Lead	0.001	0.033

[a] These concentrations should not be considered event maximums given that the sample was collected on the receding limb of the hydrograph at 1.5 $m^3 s^{-1}$, compared to the peak flow of 68 $m^3 s^{-1}$ that occurred less than 12 hours earlier.

Smith, H *et al*. Desktop review – Impacts of bushfires on water quality, DSEWPC, March 2011

Phosphorus, Algae, and Nitrogen after Wildfire



Silins et al. (2014)

Wildfire impacts on water quality that drive treatment design & operation

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)

Key Water Quality Drivers of Drinking Water Treatment

Process	Turbidity	Color	TOC
Conventional	high >20 NTU	high >20 c.u.	high >4 mg/L
Direct/Inline Filtration	low ≤15 NTU	moderate to low ≤20 c.u.	low <4 mg/L
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Emelko et al. (2011)

Almost all "typical" target compounds can be readily treated by currently available processes/technologies.

How resilient are systems to water quality fluctuations?

TREATABILITY (infrastructure AND operations) must be a consideration!

Planning for & Responding to Wildfire Threats to Water Quality & Treatability

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Canada Research Chair in Water Science, Technology & Policy

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Wildfire: Immediate- and 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.

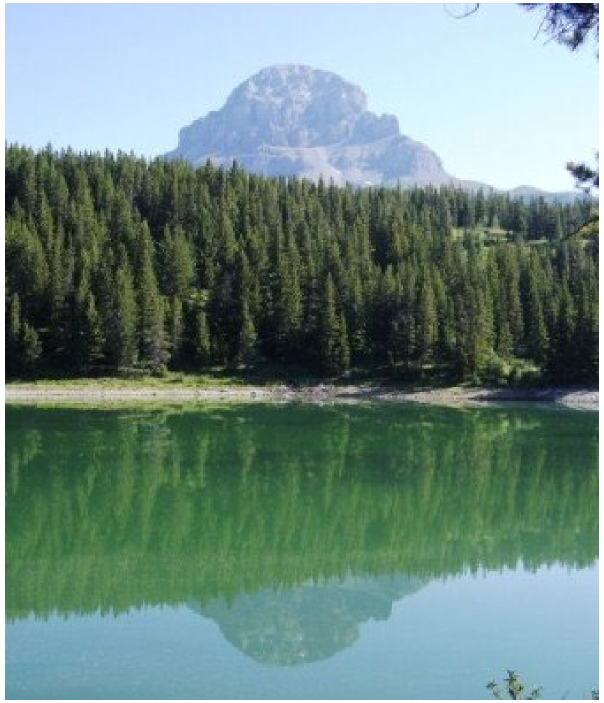
Less about treatment → More about emergency response

Wildfire impacts on water quality that drive treatment design & operation

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	✓	✓	✓	✓

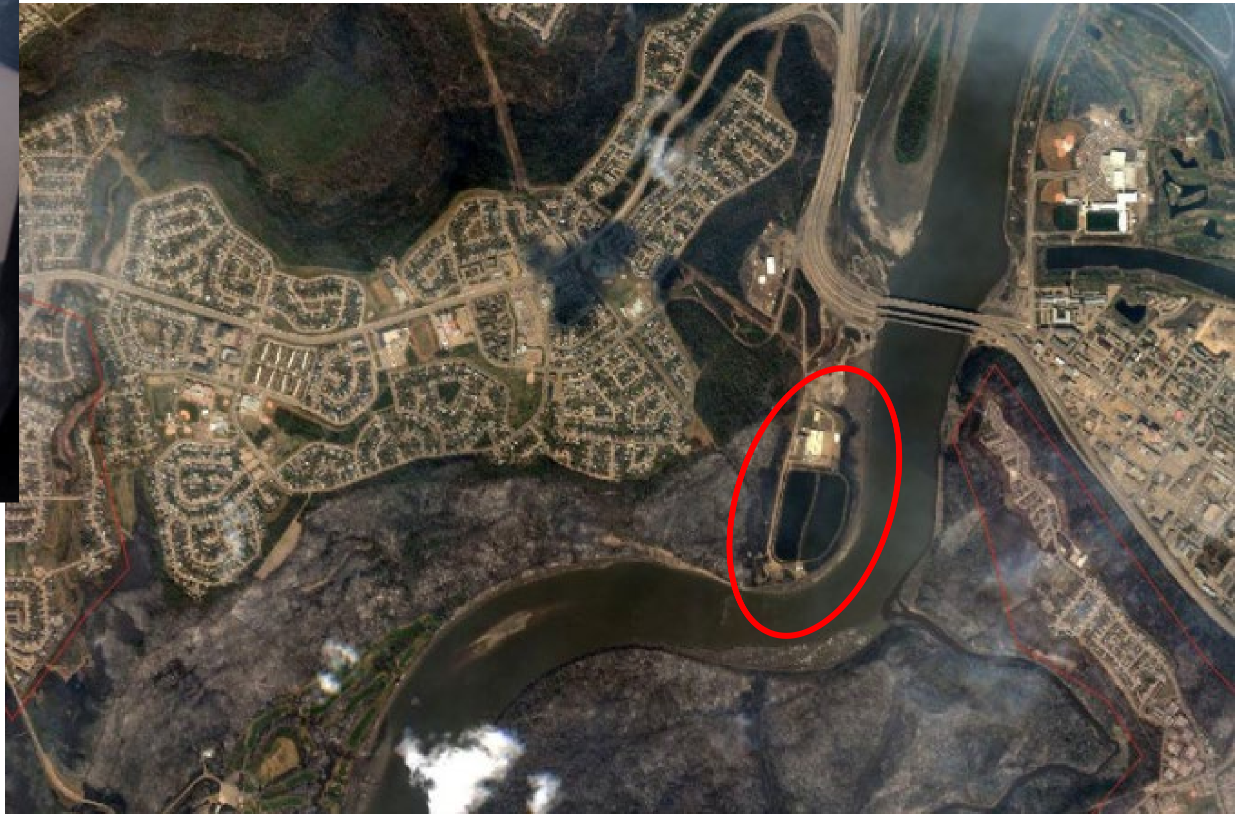
(Abbreviated from Emelko et al., 2011)

High quality systems have the most to lose…



…but impacts can be observed in all systems!

2016 Horse Rive wildfire: Impacts to water treatment and security?



Watershed- vs plant-scale impacts: Importance of local hydrology

Water Research 183 (2020) 116071

Contents lists available at ScienceDirect

Water Research

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ELSEVIER

Severe western Canadian wildfire affects water quality even at large basin scales

Craig A. Emmerton [a, b, *], Colin A. Cooke [a, c, **], Sarah Hustins [a], Uldis Silins [d], Monica B. Emelko [e], Ted Lewis [f], Mary K. Kruk [a], Nadine Taube [a], Dongnan Zhu [a], Brian Jackson [a], Michael Stone [g], Jason G. Kerr [a], John F. Orwin [a]

[a] Alberta Environment and Parks, Edmonton/Calgary, Alberta, Canada
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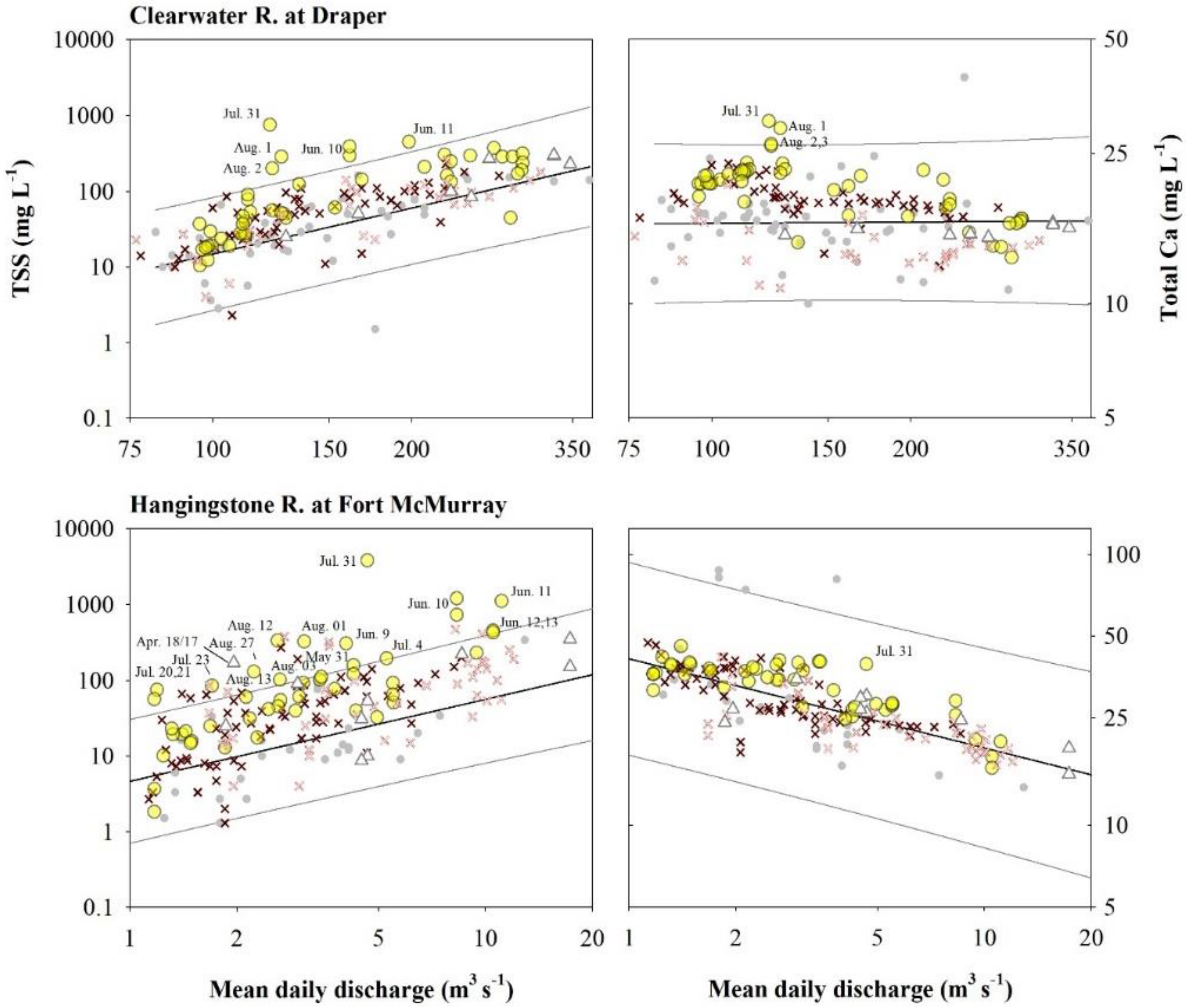
Emmerton et al. (2020)

Watershed- vs plant-scale impacts: Importance of local hydrology



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[g] Department of Geography and Environmental Management, University of Waterloo, Waterloo, Ontario, Canada

Emmerton et al. (2020)

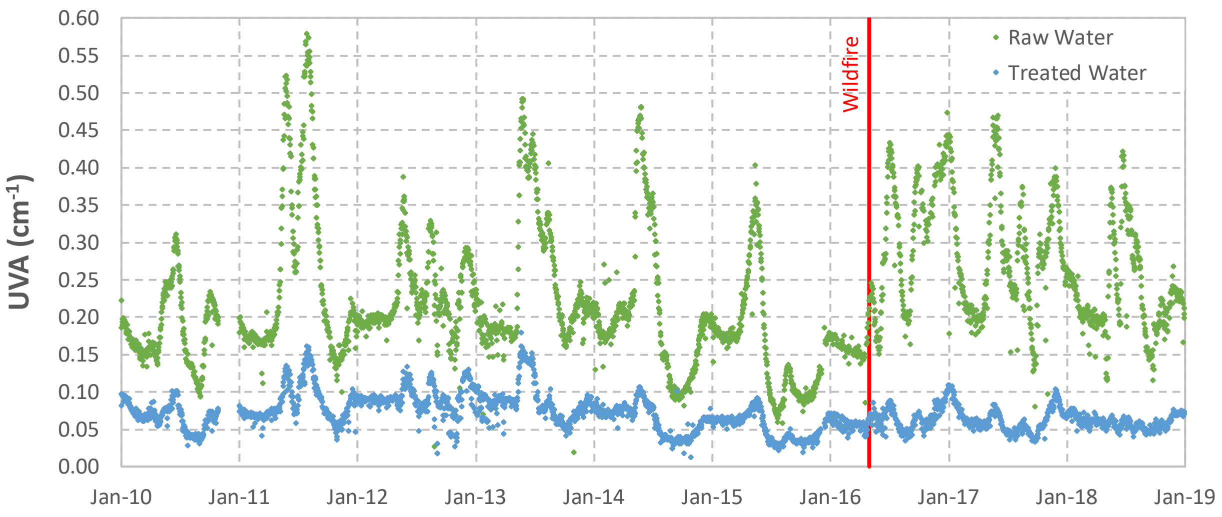
Horse River Wildfire Effects on Water Treatment

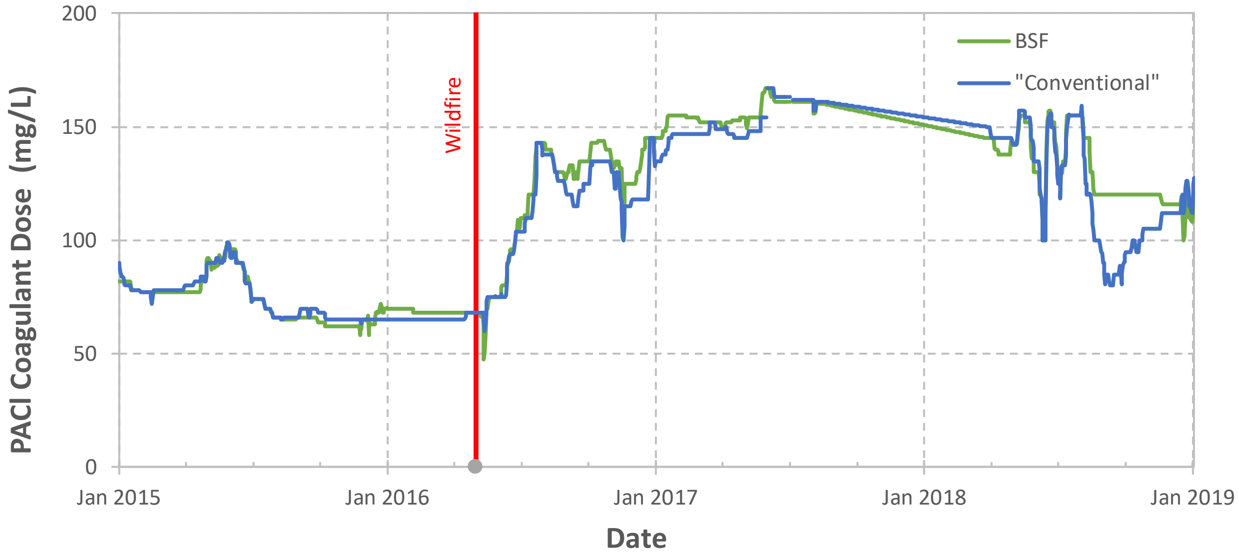
- Upstream local hydrology affects water quality entering Fort McMurray WTP
- Water quality change very difficult to anticipate

Little Fisheries Creek
Upstream of FMM WTP

Fire Effects on Raw Water Quality & Chemical Coagulant Dosing

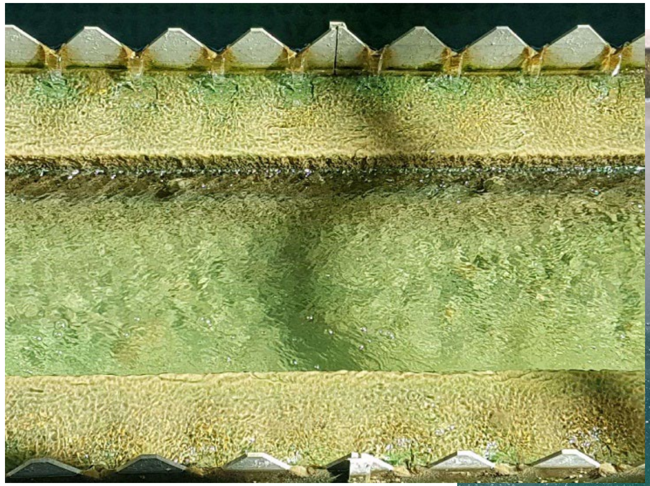
- Increased, more variable UVA_{254} – increased coagulant demand, tougher to get dose right!
- Microbial community in ponds also affects DOC character, coagulant demand & DBP precursors
- Maintained excellent quality of treated water….
- **…50% increase in chemical coagulant costs alone** (+ distribution system maintenance implications)

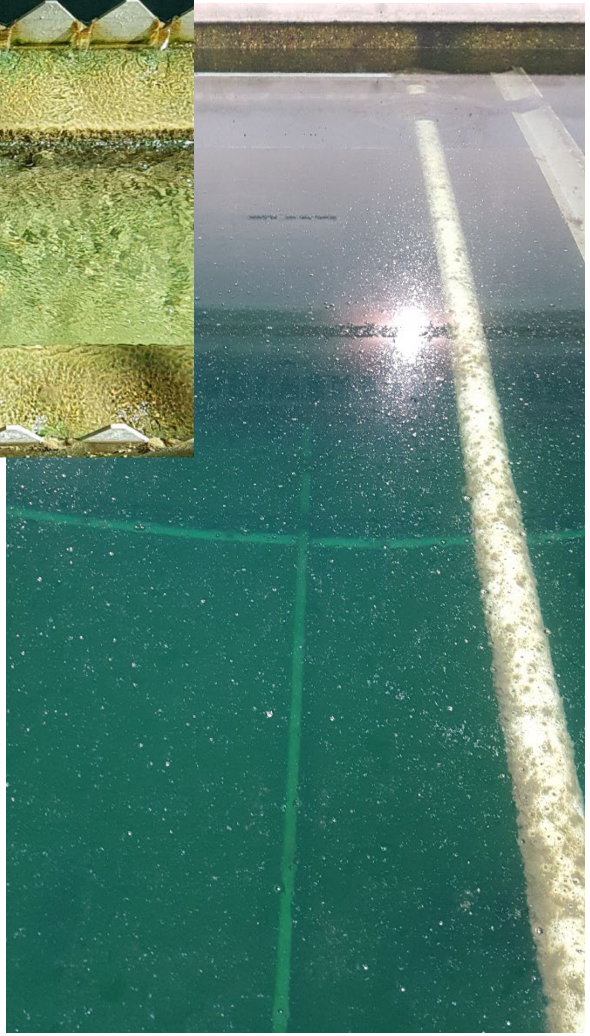


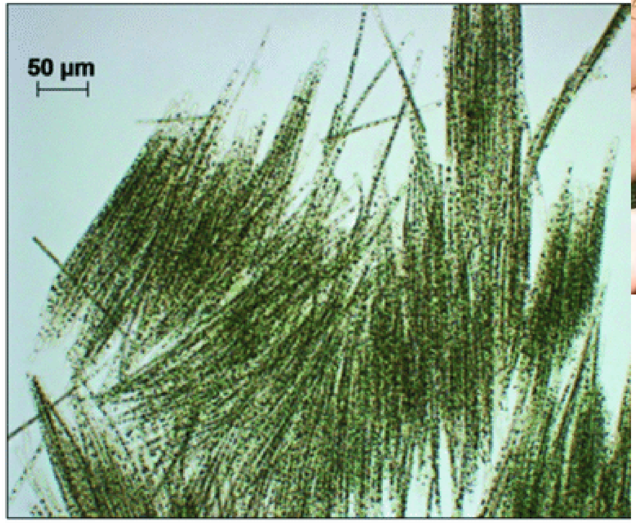


WATER STP

Fine Sediment-associated Phosphorus (P) and Algae Blooms







...every year!

Piloting Program: Raw Water Pond Assessments

- Clearly evolving biological system within the raw water ponds

2016 – 2023 Observations Overview

2016-2020:

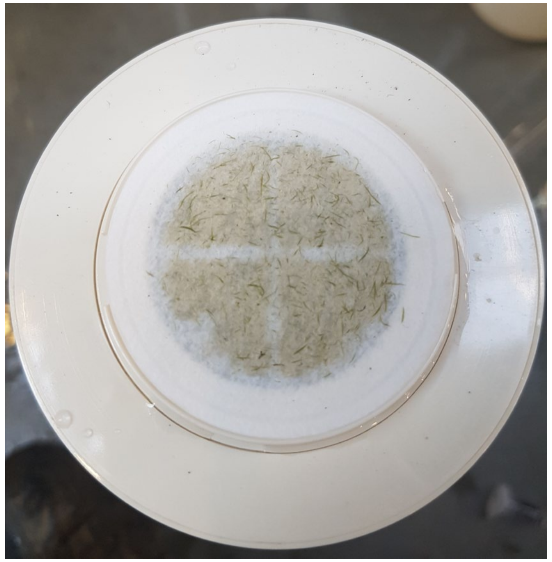
- DOC leads to increased coagulant demand and potential distributions system impacts
- Sediment-associated bioavailable P promotes algae growth
- Toxin formation is a significant concern = **RISK**

2021/23:

- DOC remains a persistent issue
- Increased bioavailable P in raw water pond sediments = **RISK**
- Algae blooms every year since 2016 wildfire
- Increased algal diversity & more alignment with known toxin formers = **INCREASED RISK**
- Capacity to produce microcystin (regulated toxin) = **INCREASED RISK**
- Fort McMurray WTP: does not have the technology to treat all toxins

2023:

- **Microcystin & geosmin detected in raw water during algal blooms NO TOXIN MEASURED IN TREATED WATER**



Algae blooms – Risk Management

- Ozone is the most effective oxidant for potential algal toxins
- Microcystin only regulated cyanobacterial toxin (MAC of 0.0015 mg/L)
- Other toxins not yet regulated here, but will likely be in the future
- Combination of ozone and free chlorine addresses all toxins….?

Cost?! $25+ million

Intra-cellular toxin?

Oxidant	Microcystins	Microcystin-LA	Cylindro-spermopsin	Anatoxin A	Saxitoxins	MIB and geosmin
Free Chlorine	pH Dependent		pH Dependent	Slow/No Oxidation		
Permanganate						?
Ozone			pH Dependent	pH Dependent		
Monochloramine	Slow/No Oxidation					?

Wildfire Threats to Forested Drinking Water Supplies

Workshop Overview

October 3, 2023 Workshop

The Water Research Foundation

forWater

Goal: Provide a state-of-the-science assessment of knowledge and practice on the characterization of wildfire impacts on water supplies, treatment, and distribution.
Strategies for proactive and reactive watershed management were also discussed.

October 3, 2023 Workshop

The workshop was structured to address three key questions:

1. What is the newest understanding of wildfire threats to water supply and treatment?
2. What water management options are available to mitigate wildfire threats to water supply and treatment?
3. What forest management options are available to mitigate wildfire threats to water supply and treatment?

Established International Consensus

- Wildfire threats to water supplies are recognized and increasing globally. Fires differ in size and intensity, and the severity of impact can vary spatially and temporally, depending on wildfire size, intensity and severity; physical, biological, and chemical attributes of the landscape; and hydroclimatic conditions before and after the fire.

- Vegetation is reduced or absent after severe wildfire. In some cases, more precipitation reaches the land surface, soils can become hydrophobic, and there can be reduced infiltration and increased surface runoff, leading to increased erosion. In some areas, intense rainfall can trigger fast-moving debris flows that can strip vegetation, block drainage ways, damage structures, reduce raw/untreated water reservoir storage capacity, and endanger human life.

- When surface water quality is impacted by wildfire, it is typically more variable with increased peak values. In rivers and streams, these changes are typically episodic and observed at higher discharge conditions. Changes in water quality can include increases in turbidity/suspended solids and fine sediment-associated contaminants including metals, organics (e.g., PAHs, dioxins, furans), and nutrients (phosphorus, nitrogen, and micronutrients). Dissolved ammonium and nitrate can also increase. Dissolved organic carbon (DOC) is frequently elevated and more aromatic after wildfire, thereby leading to increased coagulant demand and disinfection by-product formation potential and potentially the associated need for increased removal prior to disinfection. In some areas, releases of phosphorus from sediments to the water column have been observed and have promoted primary productivity, including the proliferation of algae that can produce toxins of human health concern and microorganisms associated with the production of taste and odor compounds.

Established International Consensus

- When fire occurs on the built environment, infrastructure can serve as a secondary source of contaminants via adsorption and desorption processes. These typically persistent organic contaminants can be released to both source (i.e., via runoff) and treated water supplies; for example, VOC/SVOC contamination of isolated water supplies in buried distribution networks.

- Collectively, the potential water quality impacts of wildfire underscore that wildfire may challenge drinking water treatment plants beyond their operational capabilities, possibly resulting in increased costs, service disruptions, or outages. As well, they may further result in the release of contaminants to the distribution system. Thus, water treatment resilience that reflects the collective importance of source water protection, treatment, and distribution barriers should be prioritized.

- Wildfire impacts on water quality and treatability can range from none to long lasting and/or severe, and may be immediate or delayed (e.g., years). In some regions they can last for decades or longer. As well, some contaminants can be transported over long downstream distances. Wildfire effects on water quality and treatability are often most evident in the first several years after wildfire.

- Severe wildfire on a relatively small percentage of watershed area (e.g., < 10%) can have a significant impact on untreated/raw water quality and treatability, even at large basin scales and in systems with already deteriorated source water quality.

Recent Advancements

You don’t have to have a wildfire to be impacted by it…

Australian wildfires caused unprecedented ocean algae blooms

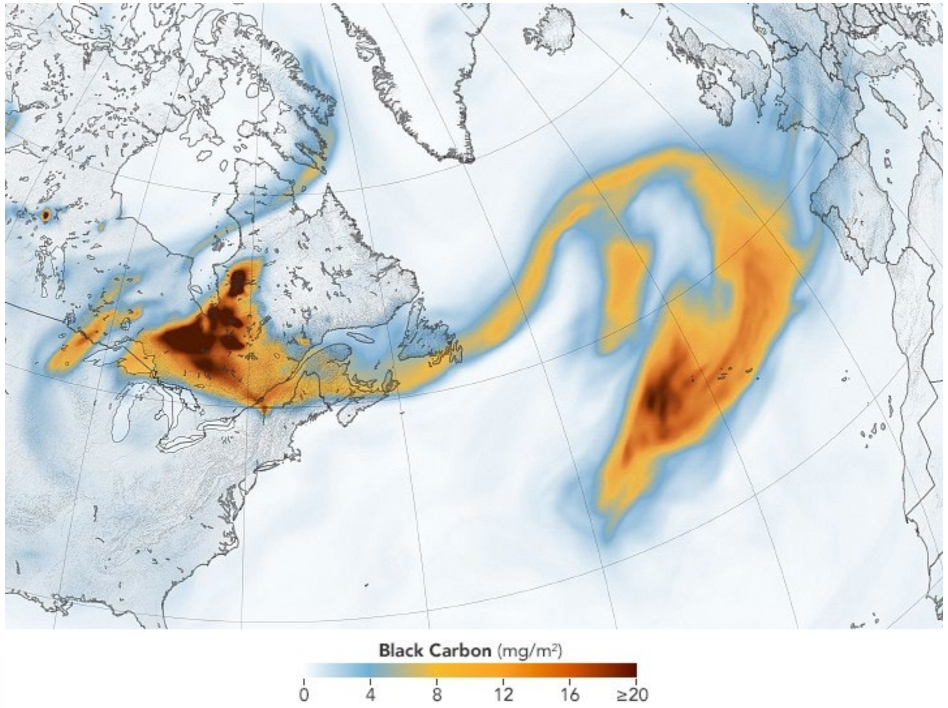
The 2019-20 burns emitted twice as much CO_2 than previously thought and seeded the ocean thousands of kilometers away with nutrients

by ***Emily Harwitz***

September 15, 2021 | A version of this story appeared in **Volume 99, Issue 34**

Credit: NASA/USGS/Landsat/Lauren Dauphin

Thick plumes of smoke billow away from one of the 2019-2020 Australian wildfires, spewing CO_2 and mineral-laden aereosols into the atmosphere.



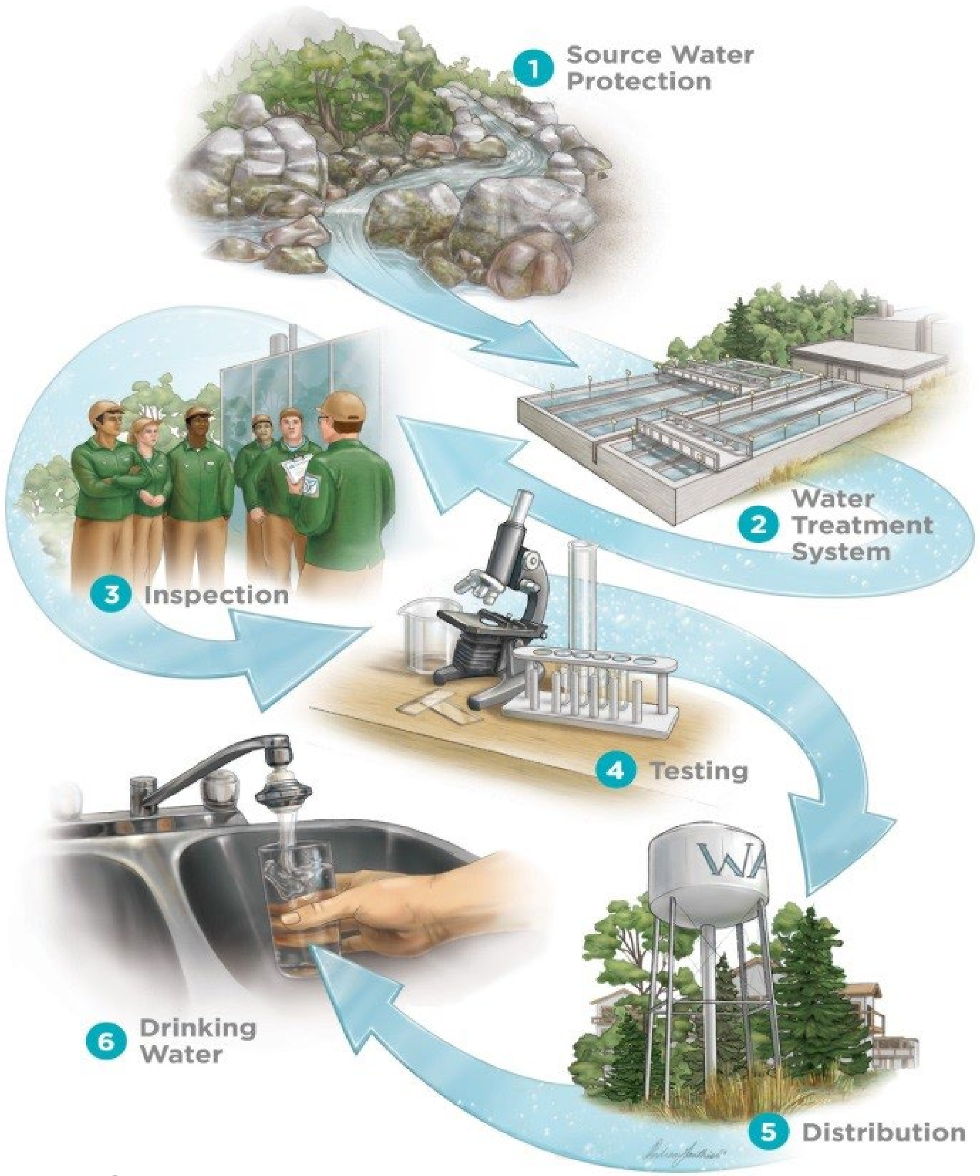
Fire in the Built Environment

Who is responsible for evaluating distribution system/premise plumbing contamination?

Wildfire threats to drinking water: Risk management strategies & needs

Framework

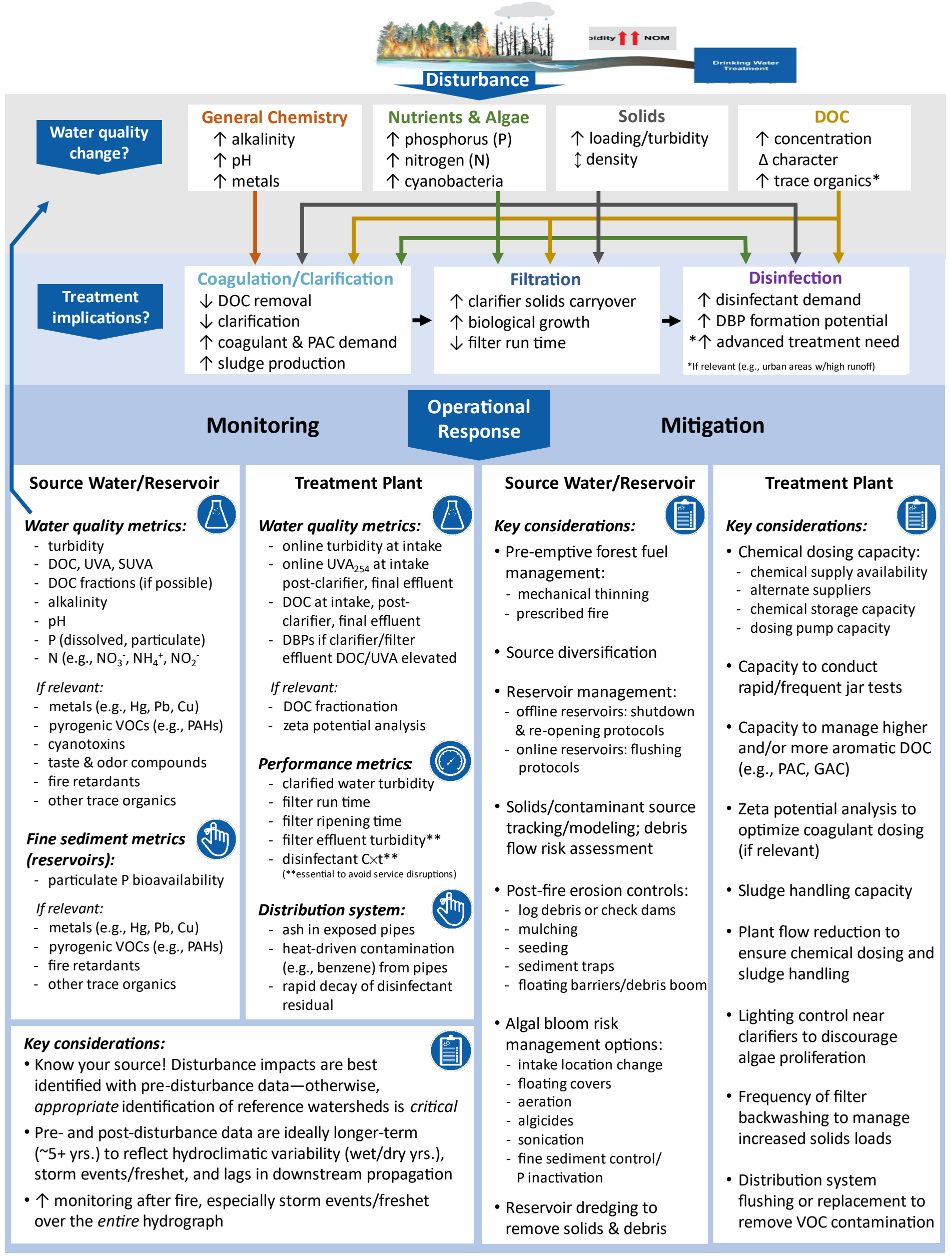
Multi-barrier Approach to Safe Drinking Water



Source: Conservation Ontario

- How do we know if things are changing if we don't monitor?
- Guidance for watershed monitoring is lacking and needed.
- What should we be looking for to ensure treatment resilience?

A framework for identifying risk management strategies and needs



Skwaruk et al. (in review)

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)	✓	✓	✓	✓		✓

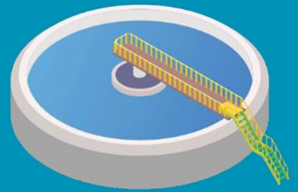
Treatability Impacts

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

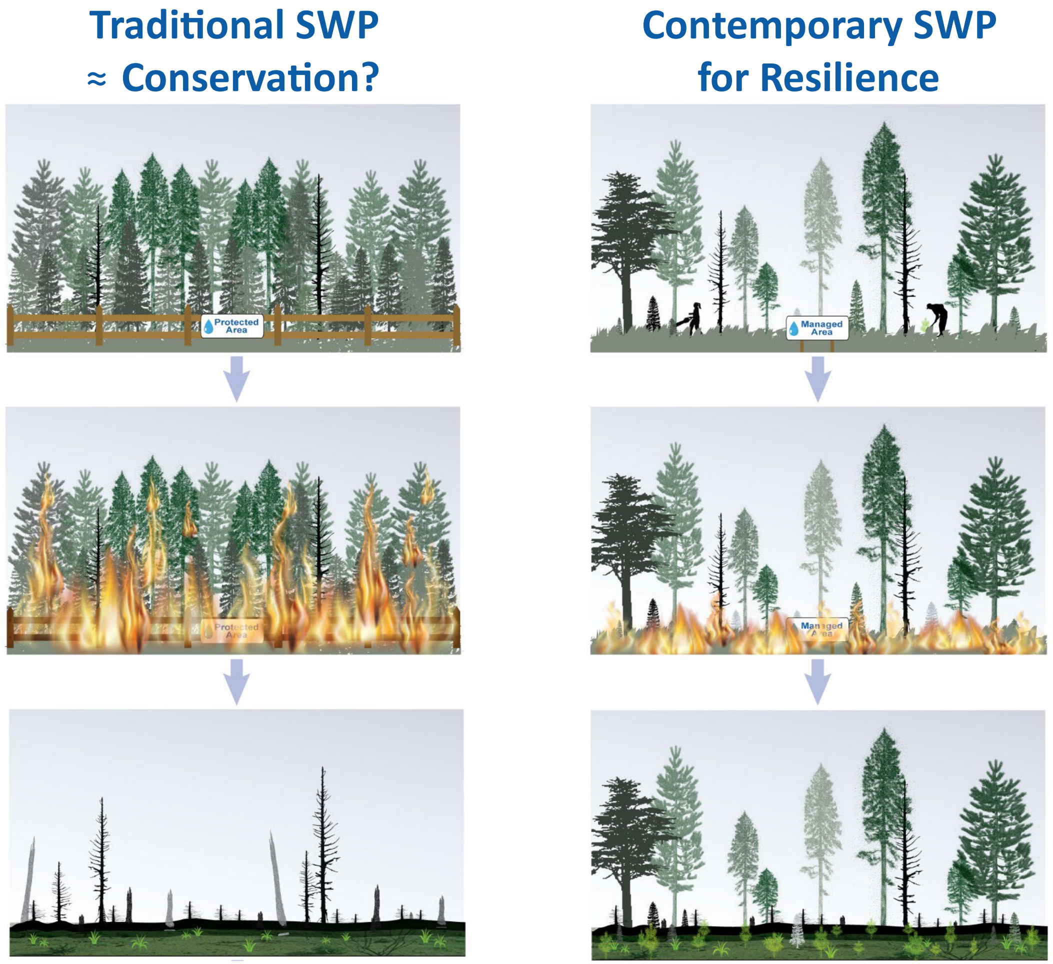
https://doi.org/10.1002/awwa.1925

*for*Water Network Information

We regularly offer hold webinars and partner workshops. Please contact us if you’re interested in participating!

mbemelko@uwaterloo.ca

*for*Water: Advancing Resilience in Source Water Protection & Treatment

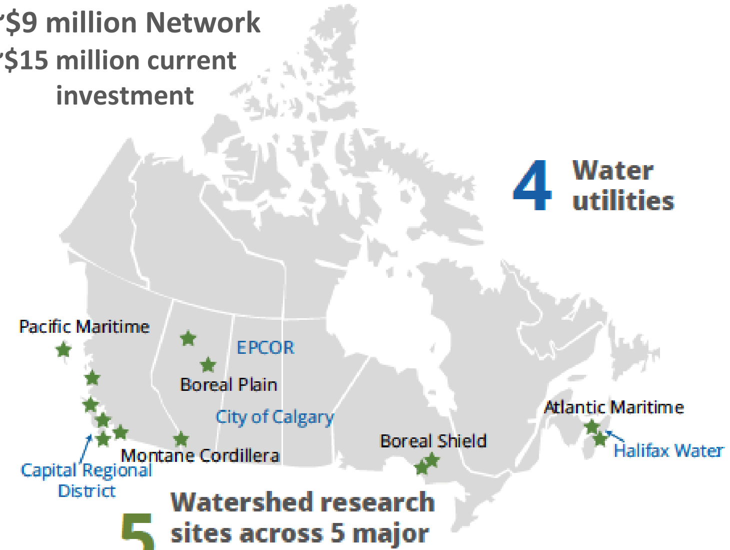


Climate change adaptation:
Leveraging and integrating “green” & “grey” infrastructure & techno-ecological nature-based solutions

Co-developing Research & Accelerating Actionability

*for*Water Network Research

>$60M prior investment
~$9 million Network
~$15 million current investment



4 Water utilities

5 Watershed research sites across 5 major forested ecozones

"The forWater Network is breaking new ground in addressing the ever-increasing need to protect drinking water from increasing wildfires, floods, and hurricanes. We're working towards providing safe drinking water across Canada."

MONICA EMELKO
PRINCIPAL INVESTIGATOR OF THE *for*WATER NETWORK

3

*for*Water Network Impact

101 Research presentations sharing findings

$9M Additional funds secured (CFI & prov. matching)

18 Young professional training sessions

91% Increase in Twitter followers

18 Undergraduate lab support semesters

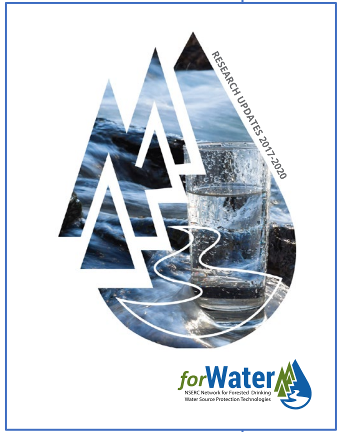
33 Graduated students

Alumni from the Network find work with government, water utilities, research groups in their field!

"Not only is it vital to all biological functions on earth, water links abiotic and biotic, connects the earth to the atmosphere, and creates a dynamic fluid continuum between ecosystems. Water connects our world; it must be respected, protected and managed equitably and sustainably."

HANNAH MCSORLEY
UNIVERSITY OF BRITISH COLUMBIA
*for*WATER NETWORK GRADUATE & ALUMNI

4



The *for*Water Strategic Network is contributing critical new knowledge and technologies needed to ensure safe drinking water in a world affected by climate change.

Researchers work with industry and government partners to seek out innovative solutions and build resilient, adaptive communities.

Midway through the Network's timeline we are sharing preliminary research findings which start to paint the picture for future water treatability and source water protection to ensuring safe drinking water for large and small communities across Canada.

Interdisciplinary research spanning

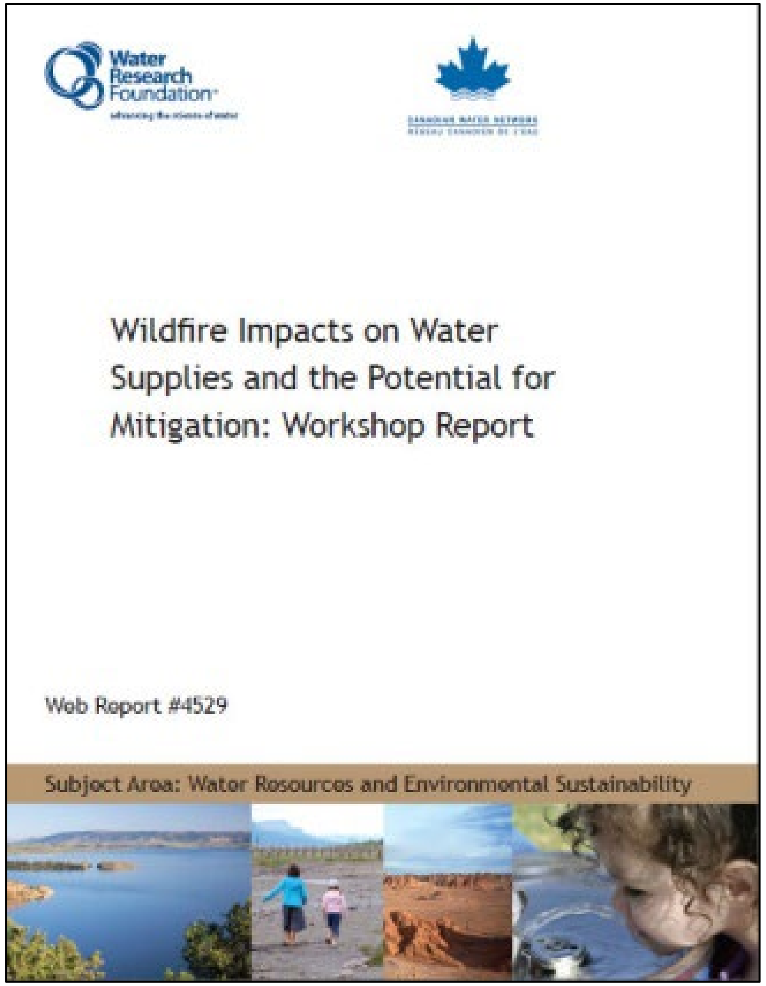
- **7** Staff
- **23** Researchers
- **43** Young professional Master's and PhD students
- **45** Industry partners

9 Collaborative Universities

4 Research Themes

2

Adaptation: Both Green (SWP) & Grey (In-plant) Infrastructure are Needed



Mitigation of the impacts of wildfire on drinking water supplies requires a three-pronged approach that includes:

1) Assessment of wildfire risks based on the potential to impact the desired values for protection, which includes drinking water supplies as a consideration

2) Strategic forest management for the protection of source water supplies, specifically drinking water treatability

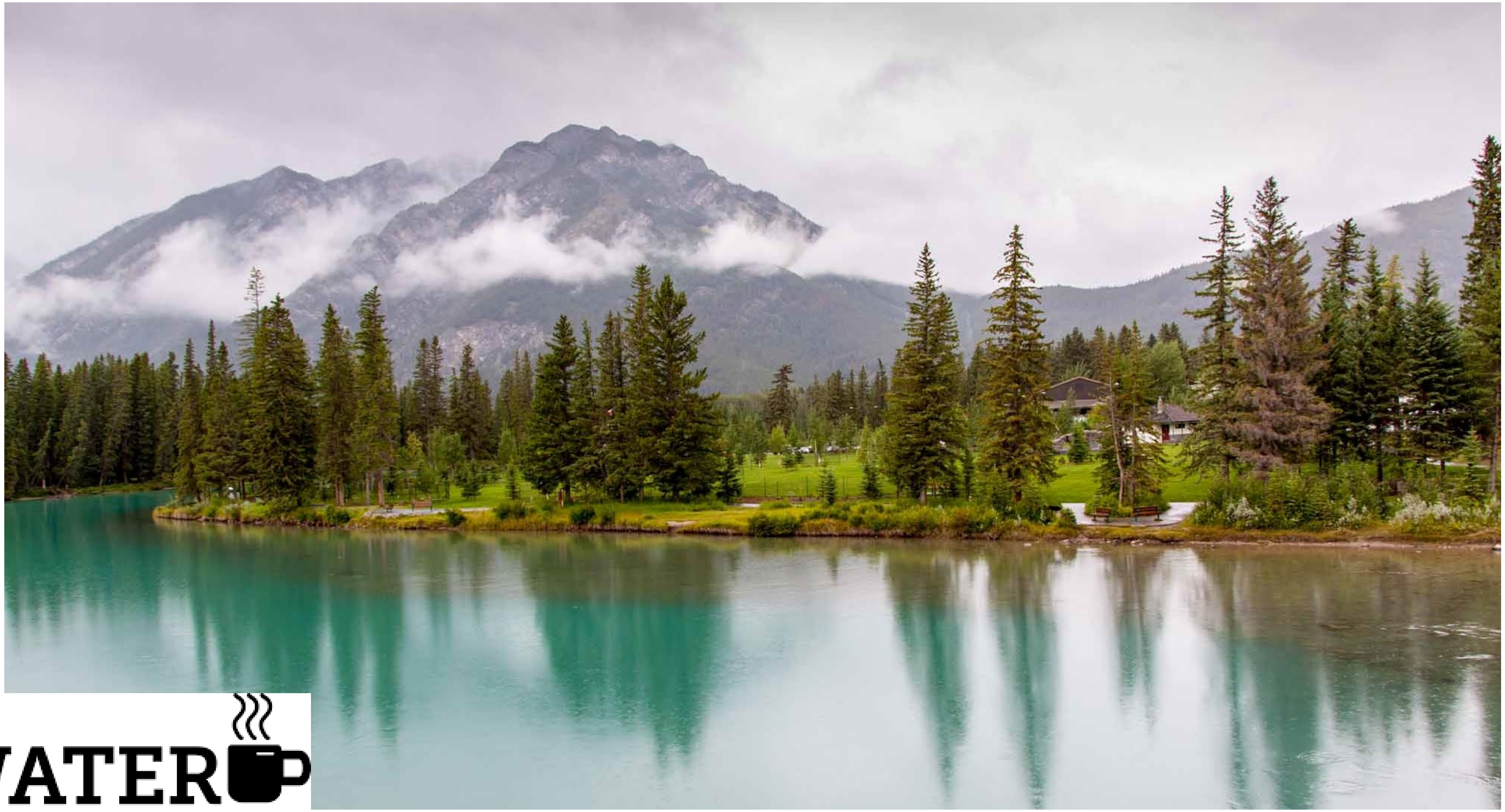
3) Drinking water supplier preparedness (i.e., enhancements to infrastructure)

Emelko & Sham (2014)

Partnerships are critical!

Alberta
ALBERTA INNOVATES
BALSILLIE SCHOOL OF INTERNATIONAL AFFAIRS
BC Centre for Disease Control
Canadian Water Network
CANFOR
Calgary
City of Guelph
cost EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY
CRD Making a difference...together
DALHOUSIE UNIVERSITY
eawag aquatic research
Environment Canada
EPCOR
ERG
Halifax Water
Health Canada Santé Canada
McMaster University
National Collaborating Centre for Environmental Health / Centre de collaboration nationale en santé environnementale
Natural Resources Canada / Ressources naturelles Canada
NOVA SCOTIA
NSERC CRSNG
Ontario
Public Health Agency of Canada / Agence de la santé publique du Canada
Region of Waterloo
Regional Municipality of Wood Buffalo
ROTHAMSTED RESEARCH
SFU SIMON FRASER UNIVERSITY
Southern Rockies Watershed Project
Spray Lake Sawmills
TU WIEN TECHNISCHE UNIVERSITÄT WIEN Vienna | Austria
TORONTO
TRENT UNIVERSITY
UNIVERSITY OF ALBERTA
UBC THE UNIVERSITY OF BRITISH COLUMBIA
UNIVERSITY OF CALGARY
uOttawa
VANCOUVER ISLAND UNIVERSITY
UNICAMP
VEOLIA
the water INSTITUTE University of Waterloo
THE Water Research FOUNDATION
West Fraser
Weyerhaeuser
CANADIAN PHYCOLOGICAL CULTURE CENTRE
forWater

Thank you!



NO WATER NO COFFEE®

American Water Works Association

Let’s connect!

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www.waterstp.ca