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PI:	Hohner, Amanda Assistant Professor, Washington State University email:ahohner@wsu.edu phone:5093359834
Co-PI(s):	Boll, Jan Professor, Washington State University email:j.boll@wsu.edu phone:509-335-4767

Abstract

Fire-prone forested watersheds generally provide high quality water for downstream communities. Climate change influences are tied to the marked increase in wildfire activity in Washington State, western North America, and other regions globally. Wildfires can influence both water quantity and quality, and water providers must confront the challenge of adapting to a dramatically altered watershed and disrupted water supply. Currently, there is a lack of post-fire source water quality and treatability information available for Washington State water purveyors facing recent unprecedented wildfire seasons. Such information is essential to support decision-making and effective management of post-fire threats to drinking water quality.

Our goal is to quantify and characterize the water quality and treatment concerns following the 2017 wildfire season in Washington. The Norse Peak wildfire recently burned the eastern slope of the Central Washington Cascade Mountains, including 22,625 hectares of the Naches River watershed. The City of Yakima depends on the Naches River for their primary source of drinking water. Our approach is to partner with the City of Yakima Water/Irrigation Division to explore raw source water quality at the Naches River water intake, pre- and post-fire. The watershed is characterized by steep slopes vulnerable to soil erosion, which will likely be enhanced following the fire. Spring runoff and flooding can cause high particle levels (i.e., turbidity), which the current Naches water treatment plant cannot effectively process. Post-fire runoff may also contain elevated natural organic matter (NOM) levels, which can react with chlorine to form toxic disinfection byproducts (DBPs). Water treatment plants must reduce NOM to meet DBP regulations under the Safe Drinking Water Act. The effects of the Norse Peak fire will likely heighten existing pressures on Yakima’s water system, including particle removal, solids processing, and DBP formation.

We will leverage existing historical monitoring data to characterize pre-fire water quality for the water intake. In addition, we will conduct a field-based sampling campaign of the Naches River intake during the 2018 snowmelt and runoff season to supplement existing monitoring frequency, and expand analytical measurements through more advanced analyses. Samples will be characterized for post-fire changes in turbidity, nutrients (N, P), NOM quantity and quality, and DBP precursors. Additionally, a bench-scale treatability study will be used to address process performance (i.e., conventional coagulation, direct filtration) challenges and finished water quality implications (i.e., DBP levels). Our work has the potential to engage stakeholders and researchers in hydrology, ecology, forestry, water quality, and engineering. We will provide Washington communities with a knowledge base and recommendations founded on science to prepare for degraded source water quality following a wildfire.

The project will provide partial support for one MS graduate student and will serve as a chapter in the student's thesis, which will be submitted to a peer reviewed journal, such as Water Research. The graduate student will present project findings at the 2019 American Water Works Association Pacific Northwest Section conference. This project supports the mentoring of an early career researcher by a senior faculty, and serves to kick-start the PI's future research strategy.

Washington wildfires disrupt water quality: Are drinking water systems resilient to climate change?

1. Washington State Water Problem

Fire-prone forested watersheds generally provide high quality water for downstream communities, naturally filtering, storing, and conveying water. The Cascade Mountain Range encompasses watersheds serving as water supplies for population centers in western Washington and small and mid-size communities on the eastern slope. The USDA program, *Forests to Faucets,* highlights the importance of the Cascades as surface drinking water supplies[1] (Figure 1). Extreme weather events such as wildfire can influence both water *quantity* and water *quality*. Water providers, who rely on vulnerable forests, must confront the challenge of adapting to a dramatically altered watershed and disrupted water supply. Currently, there is a lack of post-fire source water quality and treatability information available for Washington State water purveyors. Such information is essential to support decision-making and effective management of post-fire threats to drinking water quality.

The Pacific Northwest (PNW) was overwhelmed by wildfires in 2017. Eastern and western Washington were engulfed in smoke, while Oregon and British Columbia also faced unprecedented wildfire seasons. Over 93,0000 hectares in the Okanogan-Wenatchee National Forest were burned[2]. Beginning in 2000, the annual area burned in the Cascade Mountains has increased substantially [3]. Climate change influences are tied to the marked increase in wildfire activity in Washington State [3], western North America, and other regions globally [4-6]. Higher temperatures, extensive droughts, and earlier snowmelt coupled with abundant fuel loads have resulted in more severe, larger wildfires, and extended fire seasons [6]. Once the wildfire is contained and the smoke has passed, the challenge is not over- communities are faced with the aftermath of a burned watershed. In 2017 forested watersheds serving as surface water supplies for the communities of Tacoma (Saw Mill Creek Fire), Cle Elum (Jolly Mountain Fire), Yakima (Norse Peak Fire), and Portland (Eagle Creek Fire-Oregon) were burned [2]. The impacts of wildfires on potable water quality and process performance for PNW water treatment plants (WTPs) remain unknown, lacking any direct evaluation for the region.

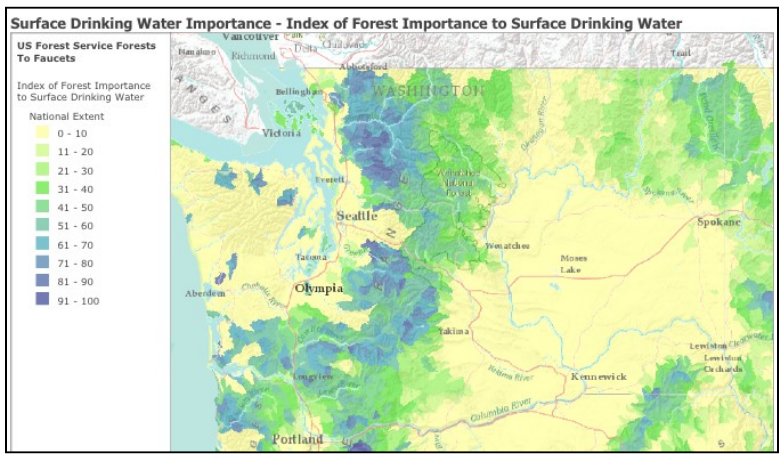

Figure 1. Index of Forest Importance to Surface Drinking Water in Washington State. Source: US Forest Service Forests to Faucets [1]

Wildfires can consume vegetation, char soils, and alter hydrologic processes. Increased streamflows and flooding events frequently occur after wildfire due to decreased vegetative cover, lower infiltration rates, and hydrophobic soils [7,8]. Accelerated soil erosion processes may result in destructive landslides, debris flows, and increased sediment loads to nearby waters. Post-fire water quality impacts include elevated particle levels, organic matter, nutrients (N, P), and metals from increased erosion and transport of burned materials to downstream drainages [9]. High particle levels, measured as turbidity, commonly present the greatest risk to water supply infrastructure (e.g., clogged pipelines). Elevated turbidity can challenge water treatment coagulation processes, and can strain filters and solids removal processes. Further, increased levels of natural organic matter (NOM) can degrade finished water quality. Terrestrial NOM is derived from decaying leaves and soil organics, and is typically quantified as total organic carbon (TOC). NOM poses a concern to water utilities because it reacts with chlorine to form *carcinogenic disinfection byproducts* (DBPs), an unintended consequence of providing safe drinking water [10]. A main goal of treatment is to reduce the TOC concentration, the primary precursor for DBP formation. Stricter regulations coupled with climate change effects have heighted pressures on WTPs to meet DBP maximum contaminant levels (MCLs). **We propose to investigate post-fire source water quality changes to turbidity and NOM, and to evaluate treatment challenges for coagulation and DBP formation. Our aim is to provide guidance for Washington water utilities to enable resilient water supply systems that meet consumer water demands and EPA regulations.**

2. Nature, Scope, and Objectives

Our work serves to address the SWWRC priority research area: "*climate change effects on water supply, demand, and quality*". Our long-term goal is to enable informed planning for post-fire resiliency of Washington's water systems in a changing climate. Our specific goal for this proposed work is to quantify and characterize the water quality and treatment concerns following the 2017 wildfire season in Washington. We will provide Washington communities with a knowledge base to prepare for degraded source water quality following a wildfire. Three objectives support our research goals as follow:

1. ***Evaluate disruptions to source water quality following a Washington State wildfire.***

2. ***Address post-fire challenges to water treatment processes performance and the implications for finished water quality.***

3. ***Communicate findings and deliver recommendations to stakeholders.***

Our approach is to partner with the City of Yakima Water/Irrigation Division (referred to as "Yakima" hereinafter) to explore raw source water quality at the Naches River water intake, pre- and post-fire. We communicated with Yakima regarding the proposed research, and have planned a site visit for November 2017 to tour their watershed and treatment facility, and further discuss collaborative research goals. The PI (Hohner) is a junior faculty member with expertise in source water quality and drinking water treatment and the co-PI (Boll) is a senior faculty member with expertise in watershed hydrology and water quality. Together the disciplines of the PIs will serve to bridge natural and engineered systems, from watersheds to distribution systems. Our proposed project is *timely* and poses a situational *opportunity* to expand the current understanding of challenges facing Washington drinking water systems in the aftermath of wildfires. Due to the range of post-fire environmental concerns, our work has the potential to engage stakeholders and researchers in hydrology, ecology, forestry, water quality, and engineering.

3. Study Area: *Norse Peak fire and the Naches River water supply*

The Norse Peak wildfire recently burned the eastern slope of the Central Washington Cascade Mountains. The fire was ignited on August 11th, 2017 and the estimated containment date was

November 1st [2]. The wildfire burned 22,625 hectares, approximately 10-15% of the hydrologic drainage for Yakima's water supply, including upstream areas near the Naches River[11] (Figure 2). Yakima depends on the Naches River for their primary source of drinking water, serving nearly 94,000 consumers. In addition, four groundwater wells supplement surface water supplies during dry summer months when precipitation is the lowest and domestic and irrigation water demands are highest. Climate change and population growth have created new challenges for the region to meet water demands, sustain healthy ecosystems, and maintain water quality.

The raw water intake is located ~6 miles west of Yakima along the Naches River, and water travels ~3500 ft downgradient to the WTP through a pipeline. The Naches WTP is a direct filtration facility, meaning water is filtered immediately following coagulation, without a period of sedimentation for solids separation. Direct filtration is permitted by the EPA for water systems that treat generally high quality water, with <u>low turbidity</u> (<15 NTU). However, in recent years the Yakima WTP has experienced periods of elevated turbidity, attributed to runoff and soil erosion from land-use in the watershed and climate change effects[12]. When the Naches River water quality is compromised due to high turbidity levels (e.g., > 50 NTU), the intake is shut down and the water goes through an emergency bypass system. Under these circumstances Yakima relies solely on groundwater wells for water production, straining aquifer levels. However, in the summer months during peak water demands, the WTP <u>does not</u> always have the option to bypass highly turbid water.

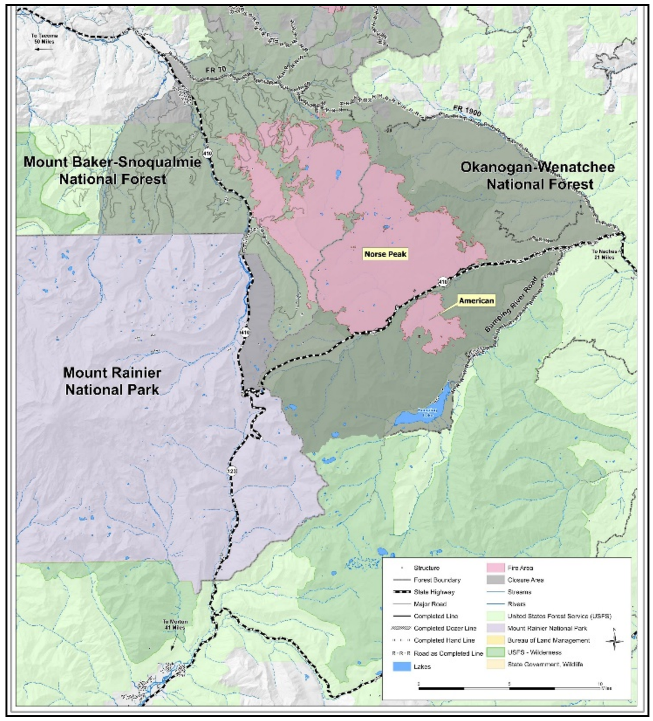

Figure 2. Norse Peak fire burn area in the Naches River watershed. The City of Yakima water intake is located along the Naches River ~ 6 miles west of Yakima [2].

Discussions with Yakima indicated the watershed recently experienced several storm events with turbidity exceeding <u>1000 NTU</u> at the raw water intake[11]. The watershed is characterized by steep slopes vulnerable to soil erosion, which will likely be enhanced following the Norse Peak fire. An analysis of Yakima's water system identified <u>*wildfire as a Tier 1 threat to their surface water supply*</u> from an increase in turbidity[12]. Seasonal spring runoff and flooding can cause high turbidity levels for the Naches River WTP, which the current system cannot effectively process, interrupting their primary water source. The effects of the Norse Peak fire will likely heighten these existing pressures on Yakima's water system.

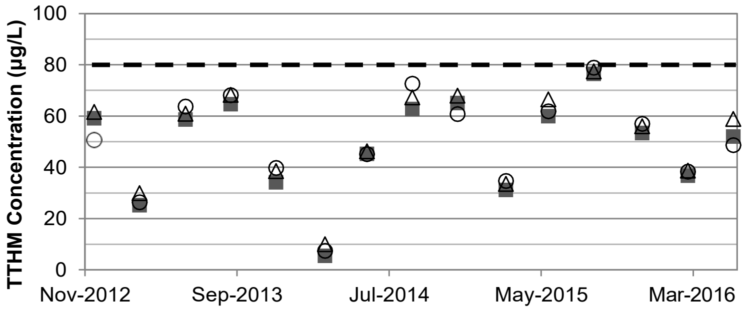

Figure 3. DBP concentrations for Yakima's finished water samples. TTHM = total trihalomethanes- the sum of four organic DBPs regulated by the EPA. Source: Kuhns, 2017.

To enhance the regional groundwater sources and increase water system reliability, Yakima has developed an Aquifer Storage and Recovery (ASR) program[12]. Naches River water is treated to drinking water standards and injected into the ground through two wells. Under Washington State regulation, DBP concentrations of injected water must be less than 50% of the drinking water MCLs to protect groundwater supplies, a significantly more stringent regulation. Post-fire runoff may contain higher concentrations of DBP precursors[13,14]. In recent years several samples were near the 80 µg/L regulation for total trihalomethanes (TTHMs) (Figure 3), and would not have met the 40 µg/L requirement for ASR injection. Therefore, Yakima must carefully manage post-fire runoff and optimize treatment operations to ensure DBP MCLs and ASR DBP regulations are met.

4. Project Tasks, Methods and Procedures

We will leverage existing data available from Yakima, US Bureau of Reclamation, and Washington Department of Ecology. In addition, we will conduct a field-based sampling campaign of the Naches River intake and characterize post-fire changes in turbidity, TOC levels, and NOM quality. A bench-scale treatability study will be used to address process performance challenges and finished water quality implications (i.e., DBP levels). The burned Naches watershed presents a unique environmental experiment to explore. To date, minimal research has addressed post-fire drinking water quality effects[13,15,16]. Our proposed tasks are detailed below.

Task 1. Evaluate pre-fire source water quality data for the Naches River water intake

We will gather existing pre-fire, streamflow, precipitation, turbidity, TOC, and nutrient (N, P) data to understand the pre-fire seasonal and temporal watershed trends. The Naches River watershed is within the Washington State Water Resources Area 38 monitored by Ecology. Importantly, the City of Yakima has continuously monitored turbidity at their intake since 2004, and TOC, nutrients, and DBPs quarterly. We will examine the historical data using non-parametric statistical analyses. A comprehensive understanding of the characteristics of pre-fire Naches River hydrology, water quality, and overall watershed health is critical to subsequent tasks, which serve to address post-fire water quality changes. We will apply data from the USBR stream gauge located near the town of Naches to better understand hydrologically driven changes in water quality concentrations. For instance, *do the greatest spikes in turbidity correspond with snowmelt, rainstorms, or rain-on-snow events? What is the variability for influent TOC concentration?* Investigating water quality changes following wildfire is complex due to the range of influences and interrelated factors that affect water quality responses. The availability of substantial pre-fire data is rare, and poses an opportunity to better interpret post-fire effects.

Task 2. Quantify and characterize post-fire changes in Naches River water quality during the 2018 runoff season

We will expand sampling following the Norse Peak fire to supplement Yakima's existing monitoring program. Specifically, we will increase sampling frequency and incorporate more advanced analytical methods to better characterize post-fire spikes in turbidity, TOC, nutrients, and other parameters of high importance to treatment that are not routinely monitored (Table 1). Based on the location of the wildfire, snowmelt runoff from the burned areas will likely lead to enhanced erosion. We will sample the intake bi-weekly beginning April 1st and continuing through July 2018 to capture snowmelt runoff. Monthly sampling will occur from August - October 2018 during baseflow conditions, when water quality changes are generally less variable. Rainstorms in the Naches River watershed are most common in the late fall and early winter months. We have communicated with Yakima to ensure sampling and analysis of runoff from rainstorms is captured, within a reasonable scope.

We will analyze all samples for turbidity, total suspended solids, nutrients, TOC, ultraviolet absorbance (UVA), metals (Fe, Mn), bromide, pH, and alkalinity following standard methods[17] (Table 1). We will characterize DBP precursors through advanced DOM analytical methods including organic nitrogen quantification, and optical properties such as UVA and spectral slopes which provide insight to the DBP reactivity of NOM. Chlorination of the raw water samples provides a characterization of the DBP precursors prior to treatment. Chlorination tests will follow uniform formation conditions methods representative of an average WTP [18]. DBP species analyzed will include regulated TTHMs and five haloacetic acids (HAA5), plus four unregulated HAAs. The unregulated, yet more toxic nitrogenous DBPs[19] including haloacetonitriles and chloropicrin will also be analyzed (Table 1). QA/QC measures will be followed, including sampling and analytical duplicates (~10%). A total of 12 samples will be collected, plus post-rainstorm samples as appropriate.

Table 1. Water quality parameters and DBPs for analysis of post-fire Naches River samples collected from Yakima's water intake.

Water Quality Parameter	Analytical Method/Instrument
Turbidity	HACH 2100N Turbidimeter
Total Suspended Solids (TSS)	Standard Method 2540-D
pH	Standard Method 4500-H
Conductivity	Standard Method 2510-B
Alkalinity	Standard Method 2320-B
Bromide	Standard Method 4110
Iron and Manganese	Perkin Elmer NexION 350XX
Total Phosphorus, Nitrate, Nitrite, Ammonia	Seal Analytical AQ400
Total Organic Carbon, Total Nitrogen	Shimadzu TOC-N V analyzer
Ultraviolet Absorbance (UVA)	Perkin-Elmer Lambda 365
Total Trihalomethanes (TTHMs)	EPA Method 551.1
Haloacetic Acids (HAAs)	EPA Method 552.2
Haloacetonitriles (HANs)	EPA Method 551.1
Chloropicrin	EPA Method 551.1

Task 3. Address post-fire challenges to treatment process performance for Yakima's water treatment system and explore alternative treatment options

High turbidity can strain conventional coagulation processes by creating an increased coagulant demand. Furthermore, soils eroded from burned landscapes may be of an altered character compared to unburned materials. For instance, ash is less dense and can result in a lower particle settling velocity [20]. For a direct filtration WTP, like Yakima's, high turbidity levels can strain filter media, and decrease filter run-times due to the need for more frequent backwashing. The Yakima WTP is a relatively small system with fewer resources and less flexibility for coping with extreme changes in turbidity or spikes in TOC. Exploring alternate treatment process scenarios will provide Yakima, and other small direct filtration WTPs, with a knowledge base for future decision-making. Currently minimal post-fire treatability information is available, and for Washington WTPs such research has yet to be explored.

Samples collected for Task 2 will be evaluated with bench-scale treatability tests to explore and optimize treatment conditions and advance the current understanding of post-fire effects on process performance (Table 2). Two coagulants will be evaluated and compared: aluminum chlorohydrate (ACH) and ferric chloride, which is more effective for NOM removal than ACH. Yakima currently applies ACH which can effectively remove particles, but generally does not provide significant NOM removal. Jar test experiments will be conducted with ACH and ferric chloride at a range of doses to develop dose-response curves. Further, for both coagulants, two different treatment conditions will be used: direct filtration (coagulation/filtration) and conventional treatment (coagulation/ flocculation/ sedimentation/ filtration). Optimal coagulant doses will be selected from dose-response curves based on turbidity and TOC removal. Samples treated at the optimal doses will be chlorinated following the conditions used in Task 2. Chlorinated samples will be analyzed for DBP formation, DBP precursors reactivity (DBP concentration normalized by TOC concentration), speciation, and nitrogenous DBP formation and reactivity. DBP precursor removal from the various treatment conditions will be determined using the raw water DBP formation data from Task 2 and finished water DBP concentrations from Task 3, to assess the efficacy of the various treatment scenarios for DBP precursor reduction.

Table 2. Treatment scenarios for evaluation of post-fire runoff.

Treatment Conditions	
Direct Filtration	ACH
	Ferric Chloride
Conventional Treatment	ACH
	Ferric Chloride

Chlorination and Treated Water Quality Analysis →

pH
Turbidity
UVA
TOC
DBPs

Task 4. Develop a summary report and presentation detailing findings and recommendations.
The summary report and guidance document will be tailored to a broad audience including water utilities, regulatory agencies, and forest/fire managers to engage stakeholders from a multi-disciplinary audience. The report will convey the key findings from our work and will include recommendations to aid stakeholders and decision makers as they prepare for, or respond to, wildfire. A presentation of key findings and recommendations will be given at a Yakima Valley Fire Adapted Communities meeting to DNR, Forest Service, NOAA and other interested stakeholders. Through active engagement with the WSU Extension offices in Yakima, Kittitas,

and Ferry Counties we will seek out opportunities to communicate our research to fire-prone communities as part of the land-grant mission of WSU.

Project Timeline

The project timeline is shown in Table 3. Task 1 can begin immediately and will be ongoing throughout the project as more data are gathered and the graduate student begins analysis. Tasks 2 and 3 will begin with the first spring sampling event and will continue through Fall 2018. The project timeline is extended beyond the SWRRC end date to ensure adequate time for dissemination of our findings. Funding from the PI's start-up will support such efforts.

Table 3. Project timeline of proposed tasks.

Spring 2018	Summer 2018	Fall 2018	Winter 2018	Spring 2019	Summer 2019
Task 1					
Task 2					
Task 3					
				Report, Presentations, & Publications	

Facilities and Equipment

Sample analyses and experiments will be conducted in the Water Environmental Research Laboratory (WERL) in WSU's Environmental Technology Building. The samples will be collected by Yakima personnel and shipped to WSU labs, and/or the graduate student will commute to Yakima and collect samples, as appropriate. Instrumentation for general water quality measurements (pH, alkalinity, etc.) is available in the WERL. A Perkin-Elmer Lamba 365 spectrophotometer will be used for UV absorbance measurements. A Perkin Elmer NexION 350XX inductively-coupled plasma mass spectrometer will be used for metals analysis. Samples for DBP analysis will be performed with an Agilent Gas Chromatograph. A Seal Analytical AQ 400 will be used for nutrient analyses. A Shimadzu TOC-N analyzer will be used for TOC and TN measurements through the Department of Biological Systems Engineering Analytical Chemistry Service Center.

5. Expected Results and Benefits

Our study will expand the current data driven knowledge of post-fire changes in water quality parameters of high importance to water providers. Findings will enable Washington communities in fire-prone areas, to consider the benefits of increasing monitoring efforts at additional upstream locations (e.g., early warning systems for turbidity), and expanding water quality parameters routinely monitored (e.g., UVA). Small, rural communities are often located in fire-prone regions, and lack the resources and personnel for research, extensive monitoring, advanced treatment, and system upgrades. Treatability studies will contribute data and tools such as the efficacy of various processes and conditions for turbidity and TOC removal, and DBP reduction. Treatability data can be used to provide recommendations regarding optimal coagulant doses and alternative coagulants for removing TOC and meeting regulations. The potential benefits of conventional treatment vs. direct filtration will be explored to allow utilities to consider expansion of treatment processes. Lastly, results will contribute an advanced characterization of NOM and potential challenges meeting DBP MCLs and DBP ASR requirements following a wildfire. Collectively, the contributions from our work will identify vulnerabilities for direct filtration WTPs and develop suggested solutions to achieve more resilient water systems by managing post-fire risks.

Spin-up for future work

Results from this work will kick-start the PI's long-term research goals and future funding strategy by providing preliminary field and laboratory data for external grant proposals on climatic and anthropogenic disturbances to drinking water supplies. Specific topics planned for follow-up include: 1) a fundamental characterization of post-fire particle properties (colloidal fraction, adsorptive properties, mineral content, density, size) and influences on coagulation processes; 2) Post-fire organic nitrogen levels and the control of nitrogenous DBP precursors. Further, the PI will pursue opportunities to work with Cle Elum, Portland, Tacoma, and other fire-affected water providers. The PI plans to leverage utility and stakeholder connections to submit proposals to the Water Research Foundation (WRF) which requires support from water utilities. Recently, NSF has incorporated WRF funding opportunity collaborations into the Chemical, Bioengineering, Environmental and Transport Systems program, an avenue the PI plans to submit future research proposals through in collaboration with utilities facing water quality disturbances.

Interdisciplinary collaborations

The nature of our proposed work is broad with potential for a range of collaborations with forest service, soil scientists, air quality researchers, hydrologists, environmental scientists, among others. Future collaborations with hydrologists to use or develop physically based models for TOC and turbidity following a wildfire will be pursued. The data from this project would support a proposal for model testing and development. Joint research projects with the USFS to investigate approaches to mitigate post-fire erosion and protect source water quality of burned watersheds would serve to bridge efforts of water utilities and forest managers and would create a preventative approach rather than a treatment approach to coping with post-fire runoff. The PIs will pursue research on this topic through the Joint Fire Science Program and USDA funding opportunities.

6. Related Research

Previous research shows post-fire watershed responses depend on local conditions, including *watershed* specific (e.g., hydrologic regime, soil type, land use) and *wildfire* specific (e.g, burn area) factors, resulting in a wide range of observations and warranting the need for case-study based research to address post-fire knowledge gaps. Previous research has primarily been conducted by the forestry, ecology, and hydrology communities, which speculate on potential implications for drinking water, but lack a direct evaluation of treatability and finished water quality [9]. Very few studies have investigated the impacts of wildfire on drinking water, with no published work for the PNW to our knowledge.

Within the drinking water community, the first documentation of post-fire effects were anecdotal experiences of WTPs, lacking a scientific research investigation [21]. Emelko et al. (2013) showed an increase in nutrients and turbidity following a Canadian wildfire and performed jar tests[15]. Their samples, however, were not collected until five years after the fire, and the most significant impacts may not have been captured. Nonetheless the authors provided insight to potential increased solids handling issues for WTPs. This study focused on source water protection strategies and did not thoroughly investigate water treatment processes, but rather *qualitatively* discusses potential implications for water providers. Their work was not in collaboration with a water utility, rather they sampled a burned watershed that was not as a direct water supply.

Research conducted by Wang et al. investigated NOM and DBP precursors leached using ash from a California fire [14,22,23]. They have also conducted laboratory heating experiments to generate charred material and characterize changes to DBP precursors. These studies did not include a post-fire field-based study, and focused on fundamental changes in terrestrial sources of NOM from heating. In contrast, we apply a field-based approach to capture post-fire effects.

The PI and collaborators have published several studies investigating treatment challenges following a Colorado wildfire [13,16]. Our work focused on conventional coagulation with aluminum sulfate. The proposed study builds on those experiences by exploring ACH and ferric chloride coagulants, and direct filtration. In Colorado, the post-fire water quality response was driven by intense convective summer rainstorms, whereas the rainfall patterns and hydrology in Washington are expected to differ, possibly resulting in different patterns for post-fire water quality spikes. The PI has conducted sediment leaching experiments [24] and controlled laboratory heating studies [25] to understand the character of DOM leached from soils and is aware of ongoing research by her former advisor, Rosario-Ortiz[26], which differs from our proposed field-based observational study.

7. Training Potential and Contribution to SWWRC Mission

The project will fund one MS graduate student in Environmental Engineering with Summer and Fall 2018 support, detailed in the budget. The PI will provide supplementary funding for one summer undergraduate student from her start-up for additional student exposure to the water field. The students will gain skills and knowledge on field-sampling, treatability tests, advanced analytical methods, instrument operation, and data analysis. The graduate student will present project findings at the *2019 American Water Works Association Pacific Northwest Section* conference which draws an audience from utilities, regulatory agencies, and academia. The results will serve as a chapter in the student's thesis, which will also be submitted to a peer reviewed journal. Additionally, this project supports the mentoring of an early career researcher (PI-Hohner) by a senior faculty (Co-PI Boll), and presents an opportunity for their first collaboration.

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