Executive Summary

Wildfire Impacts on Drinking Water Treatment Process Performance: Development of Evaluation Protocols and Management Practices (project 4590)

Key Findings

- Post-fire water quality was simulated by heating soil and litter samples in a furnace. Following heating, the samples were leached in low-carbon tap water and the character of the dissolved organic matter was assessed. Bench-scale treatment tests were performed to evaluate the treatability of the leachates.
- Soil and litter released different quantities and qualities of dissolved constituents following heating. In general, low temperatures resulted in enhanced mobilization of carbon from soils, and lower for litter. At higher temperatures, both soils and litter released less carbon.
- The leachates consistently exhibited an overall poor response to coagulation and, even at high coagulant doses, often marginal dissolved organic carbon removal was achieved. Utilities should plan for higher coagulant doses, and the subsequent solids handling implications on downstream processes. Coagulant doses will likely be case specific depending on the wildfire- and watershed-specific factors, and post-fire flow events.

Background

The frequency and intensity of wildfires has increased in recent decades, and this trend is expected to continue in the near future, especially in areas where climate change is predicted to result in warmer, drier conditions. In particular, the western United States has observed an increase in the frequency, duration, and amount of burned area from wildfires. Extreme droughts, higher temperatures, earlier snowmelt, and changes in precipitation patterns can all contribute to the likelihood of wildfires. Other factors influencing wildfire occurrence include land use changes, such as livestock grazing and fire suppression. Consequently, wildfires are of increasing concern, and their resulting impacts on the environment must be further investigated.

As wildfire frequency increases, the potential effects on forested watersheds, which commonly serve as high-quality drinking water sources for many communities, become a concern. Drinking water utilities that rely on these water sources are considering the potential impacts of wildfires in their watersheds. These impacts include water quantity and availability, source water quality, and the ability to effectively treat and provide the high-quality water that the public demands. Currently, there are a limited number of reported case studies where post-wildfire water quality and treatability were monitored at drinking water utilities. Therefore, there is a need to better understand the effects of wildfires on source water quality and treatability, while also considering the effects on treatment plant operations and costs.

Objectives

The overarching objective of this project was to expand the knowledge base regarding the effects of wildfire on drinking water quality, treatment, plant performance, and operations. In order to meet this objective, this project focused on three main aspects. First, in order to evaluate the effects of a wildfire on a particular treatment operation, an approach to simulate the effects of a wildfire on water quality was developed. Second, simulated post-fire runoff was treated using mostly conventional processes. Lastly, an evaluation of the best treatment practices to deal with wildfire-impacted source waters was conducted. An additional objective of this project was to extend the post-fire water quality monitoring at a water intake in a burned watershed.

This project included the collaboration and support from the following utilities:

- Denver Water (DW)
- City of Westminster, CO (WM)
- City of Northglenn, CO
- City of Thornton, CO
- San Francisco Public Utilities Commission (SFPUC)
- New York City Department of Environmental Protection (NYCDEP)
- Truckee Meadows Water Authority
- Metropolitan Water District of Southern California

Approach

To complete this project, the team first collected surface soil and litter samples from watersheds serving four water utilities (DW, WM, SFPUC, NYCDEP). The samples were collected from multiple sites in the different source watersheds for the utilities. The samples were transported to the University of Colorado Boulder (CU Boulder) for processing. At CU Boulder, the samples were air dried and heated at a temperature of 225ºC for two hours in a muffle furnace. This temperature was selected as the amount of dissolved organic carbon (DOC) released into solution was greatest compared to other temperatures (350ºC and 500ºC). Therefore, for this study, heating soils and litter materials at 225ºC represents worst-case scenario conditions for disinfection byproduct (DBP) precursors.

After the samples were heated, they were leached into water, followed by an evaluation of the water quality and treatability by coagulation. Unheated (control) soil/litter leachates were also characterized and evaluated with bench-scale treatment studies and compared to the heated leachates.

Results/Conclusions

Soil and litter samples released different quantities and qualities of dissolved constituents following heating. Litter tended to release more dissolved organic matter (DOM) following heating compared to soil. The release of anions and cations was altered following heating. Anion release into solution showed strong heating dependence, but was not consistent among the measured species. Sulfate concentrations demonstrated the most consistent behavior, increasing with heating of each material, especially litter, which was shown to release nearly ten times more sulfate than soil following heating. Nitrate concentrations generally decreased following heating of both litter and soil. Phosphate release was not constant among the soils, but phosphate release from litter increased after heating at 225°C. Iron and manganese showed similar trends and demonstrated greater release after heating.

Generally, the trends observed for the four utilities were consistent and aid in understanding the effects of heating on water soluble compounds, raw water quality, and the associated treatment challenges. Marginal increases in pH and alkalinity were observed for the heated samples, which may be attributed to the denaturing of organic acids upon heating, with residual alkaline components remaining. An observed decrease in the quantity of DOC leached per gram of material for the heated leachates is consistent with other work indicating partial combustion of soluble organic carbon compounds at 225°C. Alternatively, organic nitrogen has been shown to volatilize at higher temperatures, supporting the observed enrichment of dissolved organic nitrogen (DON) relative to DOC following heating. SFPUC leachates did not follow the same trend as the other utilities, and the DOC leached per gram of soil increased after heating. Only soils were leached for the SFPUC samples (litter samples were not available), and perhaps different organic precursor materials of soils and litter may help explain the difference. Clear and measurable alterations to the soluble DOM character was indicated by increased specific UV absorbance at 254 nm ($SUVA_{254}$). Iron concentrations of the heated leachates were low (< 0.005 mg/L) and did not significantly interfere with absorbance measurements. Consistently higher $SUVA_{254}$ for the heated samples indicates enhanced aromaticity of soluble compounds upon heating, supported by previous soil organic matter studies.

For raw water (not coagulated) carbonaceous DBP (C-DBP) yields, the changes following heating at 225°C varied for total trihalomethane (TTHM) and haloacetic acid (HAA) precursors, but C- DBP yields were often lower following heating. However, this trend was not consistent for all samples. Bromide concentrations were low (< 0.003 mg/L), and primarily chlorinated DBP species were formed. It should be noted that the similar or lower TTHM and HAA precursor reactivity of the heated leachates compared to the control (unheated) samples may not be representative of the precursor load a water treatment facility might receive in its influent supply post-wildfire. Enhanced erosion of terrestrial DOM following a wildfire can significantly increase DOC levels and DBP formation, as observed in field-based studies. Haloacetonitrile (HAN) precursor reactivity of the raw waters also varied following heating. Alternatively, the chloropicrin precursor reactivity was generally higher for the heated leachates, which may be associated with the enrichment of DON relative to DOC, or elevated inorganic nitrogen levels. While the DOC:DON ratio decreased upon heating, and chloropicrin formation and precursor reactivity per unit of carbon increased, HAN4 precursors did not appear consistently altered by heating at 225°C. Previous studies have associated elevated HAN4 reactivity with wildfire.

Following heating of soil and litter, the leachates consistently exhibited an overall poor response to coagulation and, even at high coagulant doses (e.g., > 80 mg/L alum), often marginal DOC removal was achieved (e.g., <30%). The treatability findings are consistent with the results from a field-based post-fire watershed monitoring study when rainstorms transported substantial sediments and debris downstream to a water intake. The adverse effect of heating on the treatability of the leachates might be explained by a lower molecular weight DOM composition. Despite the higher $SUVA_{254}$, a change in DOM quality, such as a shift towards lower molecular weight compounds, may have adversely affected coagulation treatment, resulting in elevated settled water turbidity levels and minimal DOC removal. Further, finished water quality was negatively influenced, including the exceedance of DBP maximum contaminant levels (MCLs) and high chloropicrin concentrations. Heat-induced changes to particle size and characteristics were not explored in this study, but may have negatively affected coagulation processes, possibly due to the presence of finer materials. Following treatment, most heated leachates exceeded DBP MCLs, whereas all control samples were below MCLs. Treated water nitrogenous DBP formation was also higher for the heated leachates, specifically chloropicrin. While findings suggest an altered DOM character, utilities may also experience an increase in influent DOC concentrations coupled with higher, or even extreme, sediment loads, resulting in compounding effects on water treatment.

Lastly, recommendations were made regarding the design and operation of treatment systems for utilities under the threat of wildfire. The following recommendations are presented with the assumption that sufficient space is available.

- Pre-sedimentation basin
  - May be required/useful if raw water turbidity exceeds 100 NTU for long periods (i.e., days or weeks)

- Include the ability to bypass under normal conditions or potential addition of an oxidant
- Coagulation
  - Ensure chemical storage and feed pumps can deliver the higher chemical doses that may be needed after a wildfire
  - Consider polymer feed facilities that may be needed to treat waters with ash content
  - Develop operational protocols and install equipment such as streaming current monitors or zeta potential analyzers to help determine optimum coagulant dosages
- Flocculation
  - Install a means of removing silty solids that may settle out in flocculation tanks under high turbidity conditions
- Sedimentation
  - Use large conventional sedimentation basins if possible to handle large amounts of solids; if not practical, consider the use of lamella plate settlers
  - Ensure solids can be easily removed from basins via mechanical sludge removal equipment
  - If in an area where it is not likely that high turbidity will reach the intake, and there is concern that algal blooms could occur, consider dissolved air flotation (e.g., where ash or soil-related turbidity from a watershed after a fire is likely to settle out in an upstream reservoir, but nutrients could be transported to downstream reservoirs)
- Filtration
  - Consider the use of deep bed dual-media filters with larger media that can store more solids than conventional filters
  - Consider granular activated carbon (GAC) in place of anthracite to help with taste and odor
  - Provide enough backwash water and waste backwash storage so multiple filters can be backwashed at once
- Membranes
  - Membrane-based treatment systems should not be used if the raw water will be subject to the impact of firefighting foams that could foul membranes
- Disinfection
  - Higher levels of NOM may lead to DBP compliance issues
  - Attention should be given to maximizing removal of NOM or relying on the use of alternative disinfectants including UV and ozone
- Advanced treatment
  - Smoky taste and odor could occur after a fire
  - Nutrient release from wildfires could result in long-term eutrophication and increased algal growth in downstream reservoirs leading to algal toxins and taste and odor issues
  - The installation of powdered activated carbon or post filter GAC contactors should be considered to handle these events
  - The installation of ozone/biofiltration should also be considered when possible

Applications/Recommendations

It is recommended that utilities under the threat of wildfires consider the treatment implications of this perturbation in their watersheds. The results from this study indicate that higher coagulant doses will likely be required, with implications for operations and residual handling. If extreme post-fire erosion conditions occur, coagulation alone may not be effective for meeting turbidity and TOC removal requirements. Expanding water storage capacity and diversifying water sources is also recommended to handle worst-case scenario runoff conditions. In addition, a robust water quality monitoring plan is needed to ascertain the specific effects following wildfire and to rapidly and effectively adjust and respond to water quality changes. Utilities should have the capacity to conduct simple treatment evaluation tests in-house to address site-specific effects of post-fire runoff on treatment operations.

Related WRF Research

Project Title	Research Focus
An Integrated Modeling and Decision Framework to Evaluate Adaptation Strategies for Sustainable Drinking Water Utility Management Under Drought and Climate Change (project 4636)	This project will develop an integrated framework to assess water quality and availability impacts under a suite of climate and natural hazards in the supply watershed, along with evaluation of decision options.
Effects of Wildfire on Drinking Water Utilities and Best Practices for Wildfire Risk Reduction and Mitigation (project 4482)	This project conducted a wildfire readiness and response workshop that disseminated relevant information, and facilitated the sharing of knowledge and experience among water utilities that have been affected by wildfire or are preparing to manage water resources in anticipation of wildfire. Issues discussed during the workshop and highlighted in the report include: evaluating the potential for wildfire in specific source water protection areas; understanding the impacts of wildfire on water quality; identifying and characterizing strategies for preventing, mitigating, or minimizing wildfire impacts; assessing implications of land disturbance on water quality and drinking water treatability; determining the mechanisms and timeframes for watersheds to recover from wildfires; understanding challenges faced by drinking water utilities after wildfires, and solutions that have been effective; improving awareness of the impacts of fire-fighting techniques on source water quality; assessing strategies for managing and protecting water quality with proven restoration and management practices; and providing case studies of intermunicipal cooperation and management strategies.
Impact of Wildfires on Source Water Quality and Implications for Water Treatment and Finished Water Quality (project 4524)	This study will evaluate the impact of forest fires on water quality and subsequent treatment, with a focus on dissolved organic matter properties. A range of water treatment technologies, from conventional coagulation to activated carbon adsorption, will be assessed.
Utility Guidance for Mitigating Catastrophic Vegetation Change in Watersheds (project 4009)	This project helps utilities assess the risks they face with respect to large-scale watershed vegetation change. It provides specific information on the changes in water quality and quantity that can occur after different events. Information on potential management strategies to reduce the risk of large-scale vegetation change or mitigate the impacts of these changes is included. In addition, a series of case studies to document utilities' experiences was developed.

Related WRF Research	
Project Title	**Research Focus**
Wildfire Impacts on Water Supplies and Potential for Mitigation: Workshop Report (project 4529)	Thirty leading scientists and practitioners from Canada, the United States, and abroad met in September 2013 to discuss what leading-edge science exists to explain trends in wildfire occurrence and risks, the impacts of wildfires on water supply and treatment, and the evidence supporting the effectiveness of forest and water management techniques to mitigate the impacts of wildfires on drinking water supplies and treatment. The workshop report captures the high-level messages that emerged through the workshop, and the relative state of the confidence in current abilities to address the questions considered.

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