



Wildfire Impacts on Water Supplies and the Potential for Mitigation: Workshop Report

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Established in 2001 and headquartered in Waterloo, Ontario, Canadian Water Network (CWN) is a non-profit corporation driving Canada's progress on core water management challenges. CWN enables Canada to address the big picture and challenge traditional thinking surrounding water. This leads to the development of robust solutions that address multiple needs and are appropriate to regional realities.

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The <u>Secure Source Waters Consortium</u> seeks to better integrate the needs of water managers within watersheds with those managing related aspects of down stream water sources accessed for a variety of uses to improve benefits for all.

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About the Water Research Foundation

The Water Research Foundation (WRF) is a member-supported, international, 501(c)3 nonprofit organization that sponsors research that enables water utilities, public health agencies, and other professionals to provide safe and affordable drinking water to consumers.

WRF's mission is to advance the science of water to improve the quality of life. To achieve this mission, WRF sponsors studies on all aspects of drinking water, including resources, treatment, and distribution. Nearly 1,000 water utilities, consulting firms, and manufacturers in North America and abroad contribute subscription payments to support WRF's work. Additional funding comes from collaborative partnerships with other national and international organizations and the U.S. federal government, allowing for resources to be leveraged, expertise to be shared, and broad-based knowledge to be developed and disseminated.

From its headquarters in Denver, Colorado, WRF's staff directs and supports the efforts of more than 800 volunteers who serve on the board of trustees and various committees. These volunteers represent many facets of the water industry, and contribute their expertise to select and monitor research studies that benefit the entire drinking water community.

Research results are disseminated through a number of channels, including reports, the Website, Webcasts, workshops, and periodicals.

WRF serves as a cooperative program providing subscribers the opportunity to pool their resources and build upon each other's expertise. By applying WRF research findings, subscribers can save substantial costs and stay on the leading edge of drinking water science and technology. Since its inception, WRF has supplied the water community with more than \$460 million in applied research value.

More information about WRF and how to become a subscriber is available at <u>www.WaterRF.org</u>.

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EXECUTIVE SUMMARY

Forested regions account for a substantial proportion of the water supplying the population of North America. In Alberta, the majority of water supplies originate on the forested eastern slopes of the Rocky Mountains—the headwaters to hundreds of communities in Alberta and the Prairie provinces. When wildfires occur in remote forested watersheds, their potential impacts on water supplies, water quality, and stream health can extend far downstream and persist for many years. The effects of wildfires pose risks to water supplies, potentially compromising the ability of water systems to deliver safe drinking water to the public.

Although studies to date have explored aspects of the relationship of wildfires to water quality, a comprehensive assessment of the potential impacts of wildfires on drinking water utilities has not been conducted. Research to identify the key threats posed by wildfires to water supply and treatment; forest and water management options to mitigate wildfire risks to water supply and treatment; and the relative impacts and efficacy of forest and water management options in mitigating wildfire risks to water supply and treatment is still in its infancy.

At the request of Alberta Environment and Sustainable Resource Development (ESRD), and in partnership with the Water Research Foundation (WRF), Canadian Water Network (CWN) convened a two-day experts' workshop in Kananaskis, Alberta, to assess the state of knowledge with respect to wildfires, water supplies, and the potential for mitigation of the impacts of wildfire on the provision of safe drinking water. From September 18 to 19, 2013, thirty leading scientists and practitioners from Canada, the United States, and abroad discussed 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 following report captures the high-level messages that emerged through the workshop discussions and the relative state of the confidence in current abilities to address the questions considered. These key messages are relevant for decision-makers and practitioners in the fields of water supply and treatment, land and natural resource management, public health, risk management, and emergency preparedness, with a common interest in determining the most appropriate steps to mitigate the impacts of wildfire on the provision of safe drinking water. The workshop was scoped with Alberta's needs as central to the design, yet the experts discussed the best available knowledge based on their own experiences in other forested locations. Hence, the outcomes of this workshop are equally relevant to many areas in the U.S. and other country conditions.

Key messages shared at the workshop:

- Wildfires in forested regions are associated with negative impacts on drinking water source quality.
- In some regions where forest and climatic conditions are prone to wildfire, forests in which wildfire has been historically suppressed are associated with significantly increased wildfire risk.

- After wildfire, the timing and magnitude of precipitation events (rainstorm or snowmelt) are key factors driving changes in water quality, making effects more variable and difficult to predict.
- The short-term broadly ranging fluctuations in water quality that may often be anticipated after severe wildfire can constitute a major challenge for drinking water treatment, because source water quality often exceeds existing treatment and/or operational capacities.
- Drinking water source quality can be negatively impacted for variable durations after wildfire (short-term impacts lasting months to years, or long-term impacts lasting years to decades), necessitating additional and costly treatment capacity (infrastructure and/or operational) beyond that required prior to wildfire.
- Water treatment plants and processes are not always designed to treat the range of changes in the character and/or magnitude of source water quality parameters (e.g., peak values of turbidity, dissolved organic carbon, nutrients, or heavy metals) after wildfire, and some of these fluctuations may render existing treatment capacity inadequate.
- Historical fire suppression has led to a buildup of fuel in some parts of North America, including some areas of Alberta. Furthermore, historical suppression measures in some regions of the province are associated with forest conditions that can make future wildfires more extensive and severe.
- Forest management and water treatment strategies that can reduce wildfire risks to water supply and treatment exist.
- 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 fuel management for the protection of source water supplies
 - 3) Drinking water supplier preparedness (i.e., enhancements to infrastructure)

CHAPTER 1. BACKGROUND AND INTRODUCTION

Forests provide numerous important functions for the natural environment, society, and economy; among these, they contribute a significant proportion of the freshwater that is accessible for human use. Forests are a critical component of the global water cycle and regulate surface and groundwater flows. Most healthy forests also contribute to water purification by helping to prevent impurities from entering streams, lakes, and groundwater, which is an important ecosystem function that benefits drinking water supplies. Maintaining these functions while managing forests and surrounding lands for other uses remains a challenge. This challenge is particularly relevant to the development of adaptation strategies for drinking water supply and treatment in response to climate change, which increasingly reinforces the strategic, global importance of sustainable and integrated forest and water management.

It is widely recognized that wildfire is a natural component of healthy forest ecosystems, resulting in positive ecological changes. However, the international scientific community has noted significant changes in the frequency of large, uncontrollable fires (mega-fires) have increased across the world; including Canada and the United States. Discussions among experts at the workshop confirmed that among the potential impacts to public and environmental health, the relevance of increasing mega-fires to ensuring the safety of drinking water supplies is a key In some areas, including Alberta, wildfires have occurred in forests historically concern. resistant to wildfire. In certain regions, these changes in wildfire regime have occurred because decades of forest management focused on fire suppression,¹ or because preservation of wilderness increased available fuel loads in forests. Climate change has also resulted in warmer temperatures, less moisture, longer fire seasons, and drier fuels (as well as other changes in forest condition such as pest infestation). These combined factors lead to the availability of drier, more flammable fuels. In Canada and the United States, the total annual area of forests burned by wildfires has significantly increased over the last 30 years. This trend is forecasted to continue as a result of climate change.

Members of the scientific community, water treatment practitioners, and forest management practitioners recognize that wildfires can have catastrophic impacts on drinking water source quality, aquatic ecosystem health, and water providers' ability to deliver safe, clean drinking water to communities. Wildfires can cause shifts in physical, chemical, and biological landscape processes that result in increased inputs of sediments, nutrients, and heavy metals to aquatic ecosystems. While some environments may recover relatively quickly after wildfire (i.e., after a few years), in some situations the impacts of wildfire on water may persist for several decades or longer and also may extend far downstream of burned areas, resulting in long-term issues for drinking-water supplies.

The integration of forest and water management practices to address collective concerns related to wildfires, water quality, and drinking water treatment is a relatively new area of practice and research. Understanding the inter-relationships between watershed, wildfire, and water treatment processes requires an interdisciplinary approach, involving forestry science, water quality science, fire science, hydrology, hydrogeology, geomorphology, resource economics, water treatment engineering, watershed management, and other areas of expertise.

¹ It was noted by one workshop expert that there are areas in the U.S. where the significance or dominance of fire suppression or exclusion are unclear because of the many factors that contribute to wildfire risk.

CHAPTER 2. EXPERT WORKSHOP DESIGN

At the request of Alberta Environment and Sustainable Resource Development (ESRD), and in partnership with the Water Research Foundation (WRF), Canadian Water Network (CWN) convened a two-day experts' workshop in Kananaskis, Alberta, to assess the state of knowledge on wildfires, water supplies, and the potential for mitigation of the impacts of wildfire on the provision of safe drinking water.

From September 18th to 19th, 2013, thirty leading scientists and practitioners from Canada, the United States, and abroad discussed what leading-edge science exists to explain trends in wildfire occurrence and risks, the known impacts of wildfires on water supply and treatment, and the evidence supporting the effectiveness of certain forest and water management techniques for mitigating the impacts of wildfires on drinking water supplies and treatment capacity (see Appendix C for a list of workshop participants).

Experts who participated included researchers and practitioners from academia, government, and non-profit groups who were identified with the assistance of an Advisory Panel (Appendix B). The co-chairs were Monica B. Emelko, Ph.D., Associate Professor, Department of Civil and Environmental Engineering, University of Waterloo, and Chi Ho Sham, Ph.D., Senior Vice-President, Environmental Science and Policy Division of The Cadmus Group, Inc. The workshop was facilitated by Douglas Thompson, a Senior Mediator of the Consensus Building Institute.

Expert panelists were asked to comment on a number of statements related to wildfire and water that were grouped within three general themes expressed as the following questions:

- 1. What are the key threats posed by wildfires to water supply and treatment?
- 2. What forest and water management (e.g., treatment) options (if any) are available to mitigate wildfire risks to water supply and treatment?
- 3. What are the relative impacts/efficacies of forest and water management (e.g., treatment) options in mitigating wildfire risks to water supply and treatment?

Prior to the workshop, the Advisory Panel developed a list of eleven statements within the three general themes outlined above that were designed to elicit views and frame the facilitated discussion among the invited experts. These statements are denoted below as 3.1.a through 3.3.c and were distributed to the group in advance of the workshop. The extent of consensus reached by the experts for each of these statements during the workshop was reported and recorded, as well as knowledge gaps and divergent views.

The 2013 WRF report entitled, "*Effects of Wildfire on Drinking Water Utilities and Best Practices for Wildfire Risk Reduction and Mitigation*"² was also provided to participants prior to the workshop. This report complements several of the issues discussed by the experts. Specifically, the WRF report presents: current information on the impacts from wildfires on drinking water utilities, lessons learned, and recommendations for future research derived from the WRF "Wildfire Readiness and Response Workshop" held in Denver, Colorado in April 4-5, 2013. The 2013 CWN-WRF workshop was designed to build on the findings of this report.

² Water Research Foundation, "Effects of Wildfire on Drinking Water Utilities and Best Practices for Wildfire Risk Reduction and Mitigation,"2013. Available at: <u>http://www.waterrf.org/PublicReportLibrary/4482.pdf</u>

CHAPTER 3. WORKSHOP DISCUSSION OUTCOMES: STATEMENTS FOR GROUP EXPLORATION

3.1. What are the key threats posed by wildfires to water supply and treatment?

To address this question, invited experts first discussed changes in wildfire regime over the available period of record in North America and globally, as well as projected future scenarios. Discussions then shifted to the range of potential impacts of wildfire on water, which includes potential changes in water quality, water quantity, and the timing of water availability, which refers to the point in time at which water is available to water systems. For example, snowmelt-dependent water supplies are vulnerable to shifts in the timing of spring/summer snowmelt, which may result in earlier replenishment of reservoirs and subsequent lack of adequate supply in the summer months.

3.1. a Wildfire size, frequency, and in some areas severity, have increased in recent decades.

The workshop discussions indicated *strong consensus among the experts* that wildfire size has increased in recent decades and that there is *some evidence to suggest* that the severity of wildfires is also increasing in many regions globally. These trends are highly evident in western forests where fires are common and they have been documented in the scientific literature for Canada, the United States, and Australia, among others. Within North America, these changes have been most evident in western parts of the continent. The experts noted that it is impossible to prevent wildfires from occurring, and impossible and unsustainable to attempt total suppression of wildfires.

While there was a *strong degree of consensus* that wildfire frequency has generally increased in recent decades, the experts agreed that size and severity are the more relevant metrics with which to evaluate wildfire impacts on water. Experience has repeatedly demonstrated that small and/or low severity fires may have minor, if any, detectable effects on water, whereas large, severe wildfires may have significant or catastrophic impacts on water.

3.1. b The current wildfire regime (size, severity, and frequency) is likely to continue or increase in many areas in the future.

The workshop discussions indicated strong consensus among experts that the current wildfire regime (size, frequency, and in some cases severity) is likely to continue or increase in the future. The experts noted that many location-specific factors influence the potential occurrence and associated impacts of potentially catastrophic wildfires and that some relevant factors, such as forest composition, are shifting as a result of climate change. Regardless, wildfire activity is expected to increase in many parts of the world. These expectations are attributed to a number of factors: increased fuel loads and connectivity, and climate change-associated factors that include longer fire seasons, increased ignitions (including increased lightning strikes and human activity), and more severe fire danger conditions resulting primarily from an increase in the frequency and severity of drought.

3.1. c Wildfires can impact the quality, quantity, and timing of availability of downstream water supplies.

The workshop discussions indicated *strong consensus among experts* that wildfires can impact the quality, quantity, and timing of availability of downstream water supplies. These potential impacts have been documented extensively in the scientific literature for Canada, the United States, and Australia, among others.

The experts noted that sufficiently large and/or severe wildfires can cause shifts in physical, chemical, and biological landscape processes that result in increased outputs of sediments (i.e., turbidity), nutrients (e.g., dissolved organic carbon, phosphorus, and nitrogen), and heavy metals to downslope and downstream environments. Specific changes in water quality over time due to wildfire are dependent on site-specific characteristics of the wildfire, landscape conditions, and hydroclimatic conditions such as watershed area, soil type, geology, slope, and the interaction between hydrologic conditions and meteorological fluxes (see Figure 1).

In general, the effects of wildfire on water quality are most pronounced during precipitation events in the months or year(s) following fire, when erosion rates are likely to be at their highest due to loss of vegetation and forest canopy, particularly if forest soils are at or near saturated conditions, or if those surfaces are hydrophobic. In the years after wildfire, hillslopes with little or no vegetation are vulnerable to overland flow and channelization (e.g., rills and gullies) during precipitation events of high magnitude and duration. This movement of earth leads to erosion and the mobilization of ash, sediment and other materials into receiving waters, which would then be transported downstream in rapid flow environment conditions (e.g., flash floods). In addition, mass wasting processes (e.g., debris flows, bank failure, rock falls, etc.) can be enhanced after wildfire, promoting downslope transfer of materials that may obstruct channels and reduce reservoir capacity. Post-fire increased nutrient levels in receiving streams, if persistent, may result in shifts in ecosystem abundance and diversity; possibly altering "baseline" water quality. The degree to which water quality in an area recovers after wildfire, and the speed with which that occurs, will regulate the duration of water treatment challenges faced by downstream water providers.



The experts also noted that water quantity and timing of availability after wildfire will depend on wildfire size and severity as well as regional hydrology. Overall, *there was agreement* that the impacts of wildfire on water quantity and timing of availability are less well understood than those on water quality. Total annual water yields generally increase in areas affected by wildfire due to decreased evapotranspiration associated with reduced vegetation, and forest canopy, which alter the volume and changes in the timing of snowmelt (e.g., more exposure of snow pack to direct sunlight due to lack of shade).

3.1. d Wildfire impacts on water can affect drinking water treatment.

The workshop discussions indicated *strong consensus among experts* that wildfire impacts on water can affect drinking water treatment process. Impacts can range from essentially none to catastrophic impacts. It is only recently (i.e., during the last decade) that coordinated discussions of wildfire impacts on drinking water treatment has begun. These impacts have been documented predominantly at meetings of professional and research organizations such as American Water Works Association (AWWA) and WRF. Description has also begun to appear in the scientific literature. The experts noted that wildfire impacts on drinking water treatment are dependent on how water quality, quantity, and availability are impacted by fire; the proximity of the treatment plant intake to the burned region (including influence of unburned source regions); available treatment infrastructure and operational capacity; and treatment plant preparedness.

Most drinking water treatment plants with surface water supplies utilize several physicochemical processes to produce safe drinking water. Conventional treatment typically includes coagulation, flocculation, clarification, granular media filtration, and disinfection. Conventional treatment of surface water sources may be modified to exclude some of these processes (e.g., direct or inline filtration) or replace them (e.g., solids contact units or ballasted sand flocculation, membranes, etc.). Regardless of the exact treatment process configuration, drinking water treatment process design is driven by current and anticipated untreated, "raw" water quality. Raw water turbidity, dissolved organic carbon (DOC) concentration, and colour are critical water quality parameters that guide general drinking water process selection and design. As these aspects of source water quality may be significantly impacted by wildfire, drinking water treatment can also be impacted by wildfire.

3.2 What forest and water management (e.g., treatment) options (if any) are available to mitigate wildfire risks to water supply and treatment?

To address this question, the experts discussed forest management strategies, their efficacy, and their potential impacts on downstream water supplies and drinking water treatment.

3.2. a Fuel management strategies can limit the size and severity of future wildfires.

The workshop discussions indicated a *strong degree of consensus among experts* that fuel management strategies can limit the size and severity of future wildfires. Evidence for this consensus was founded on computer models that simulate fire ignition and growth (based on observed patterns of vegetation, weather, and topography) and limited experience, rather than empirical data and extensive experience.

3.2. b Wildfire impacts on downstream water supplies can be mitigated using fuel management strategies.

The workshop discussions indicated a *strong degree of consensus among experts* that wildfire impacts on downstream water supplies can be mitigated using fuel management strategies. The expectation among the workshop experts is that a reduction in the size and severity of wildfires will also reduce the risks to water supplies. The group underscored that the use of fuel management strategies to mitigate wildfire impacts on downstream water supplies has not been formally evaluated; particularly, within the context of avoided impacts on water (including ecosystem health) and drinking water treatment. This hypothesis is currently being evaluated by field-based research.

3.2. c Post-fire landscape mitigation strategies can limit wildfire impacts on water supplies and treatment.

The workshop discussions indicated a *strong degree of consensus among experts* that post-fire landscape mitigation strategies (such as post-fire assessment and monitoring, emergency stabilization, restoration and rehabilitation) can limit wildfire impacts on water quality and treatment. [Note: The basis for this consensus was founded on post-fire effects mitigation and site rehabilitation practices in North America. An example is the extensive experience of Burned Area Emergency Response (BAER) treatment outcomes in the U.S. and British Columbia (other examples are noted in Appendix A). The goal of the BAER program is

to identify and mitigate imminent post-wildfire threats to human life and safety, property, and critical natural and cultural resources. The BAER program is widely recognized for its value in post-fire response, with significant success in reducing erosion and flooding and to protect watershed values. BAER has evolved since its inception in the 1970s, and is now implemented on all U.S. national forests as well as other Federal lands, on Crown lands in British Columbia, and in Spain, Mexico, Portugal, Italy, Greece, and France.³]

3.2. d Water providers can mitigate the impacts of wildfire on water treatment through preparedness and response strategies.

The workshop discussions indicated *consensus among experts* that water providers can mitigate some impacts of wildfire on water treatment through preparedness and response strategies. The experts underscored that the ability to mitigate the impacts of wildfire on water treatment will depend on the extent of wildfire impacts on source water quality, the proximity of the treatment plant or water intake to the burned region (including influence of unburned source regions), availability of (access to?) un-impacted water supplies, treatment infrastructure that is in place and available, and treatment plant operational capacity (Figure 1).

Rapid changes in raw water quality pose the most difficult treatment scenarios for water providers in that they require 1) robust infrastructure with resilience to a wide range of raw water quality conditions, 2) continuous raw water quality data to enable the appropriate response, and 3) highly trained operators who are capable of rapidly optimizing treatment process performance as raw water quality changes. Operator training and availability may be particularly challenging for small drinking water systems, which comprise the majority of drinking water systems in many jurisdictions, including Alberta. As well, treatment infrastructure may employ a variety of methods and technologies with varying degrees of resilience to the extreme fluctuations that are common following a wildfire event. The costs associated with designing a water treatment system to handle water quality conditions outside a 'normal' range of conditions, such as those for infrequent disturbances, is often very high. Thus, the availability of specific treatment infrastructure may mitigate the impacts of wildfire in some cases or may be insufficient in others. Although infrastructure capable of treating post-fire water quality may exist, its implementation may not be feasible based on time, financial and/or capacity constraints for some communities.

In contrast, extreme post-fire events such as catastrophic debris flows (e.g., the Buffalo Creek wildfire that impacted the City of Denver's Strontia Springs Reservoir in Colorado) likely cannot be reasonably mitigated through water provider preparedness nor response. One expert underscored that although wildfires can have documented catastrophic impacts on drinking water treatment, not *all* wildfires are so severe or their impacts so far-reaching that the associated changes in water quality will pose significant challenges to drinking water treatment.

3.3 What are the relative impacts/efficacy of forest and water management (e.g., treatment) options in mitigating wildfire risks to water supply and treatment?

To address this question, the experts discussed known and available approaches for evaluating forest and water provider management strategies in mitigating wildfire risks to water supply and treatment. Several experts underscored that many of the ecosystem services provided

³ Information supported by workshop participant, Pete Robichaud, Research Engineer, United States Department of Agriculture Forest Service Forest Service.

by healthy forests have not been monetized, and therefore the economic contributions of healthy, intact forested ecosystems are often under-valued when making land use decisions. Source Water Protection planning connects land management decisions with water impacts. Accordingly, the experts discussed key science needed to enable decision-makers to evaluate the trade-offs between various land management approaches that are focused on managing wildfire risk and their impacts on source waters.

3.3. a The impact of land management strategies in mitigating the impacts of wildfire on water supplies (quality, quantity, and timing of availability) can be evaluated.

The workshop discussions demonstrated *strong expert consensus* that the impacts of land management strategies in mitigating the impacts of wildfire on water supplies can be evaluated. Evidence for this consensus was founded on post-fire effects mitigation and site rehabilitation practices in North America (e.g., extensive experience of BAER treatment outcomes in the U.S., and some in Canada) such as those described in 3.2 of this report and a very large body of research documenting impacts of wildfire on water supplies. There is evidence to demonstrate the efficacy of certain specific land management measures in protecting water quality (as identified in Table 1); however, comparative analysis is needed to make this useful for decision makers. The experts also noted that the impacts of many land management strategies (e.g., contemporary harvesting practices, including forest thinning, stand type conversion, etc.) in mitigating the impacts of wildfire on water supplies have not been evaluated.

3.3. b The impacts of land management strategies in mitigating the impacts of wildfire on water treatment can be evaluated.

The workshop experts were *unable to conclude that expert consensus is possible* to evaluate land management strategies in mitigating the impacts of wildfire on water treatment. The experts underscored that there is a need for interdisciplinary discussion of avoided impacts of wildfire on water supply and treatment because of land management. They were unaware of any existing evaluations or frameworks for evaluating the efficacy of land management strategies in mitigating impacts of wildfire on water treatment. The experts noted that this workshop is an important first step in gathering the available information and highlighting knowledge gaps.

3.3. c The efficacy of water provider preparedness and response strategies in mitigating impacts of wildfire on water treatment can be evaluated.

The workshop experts were *unable to conclude that expert consensus is possible* on evaluating the efficacy of water provider preparedness and response strategies in mitigating impacts of wildfire on water treatment. The expert panel underscored that interdisciplinary discussion of avoided impacts of wildfire on water supply and treatment with regard to water provider preparedness and response has just begun. They were unaware of any existing evaluations or frameworks for evaluating the efficacy of water provider preparedness and response strategies in mitigating impacts of wildfire on water treatment. The experts noted that this workshop is an important first step in gathering the available information and identifying the most relevant knowledge gaps.

CHAPTER 4. CONCLUSIONS

Research and experience indicate that wildfire can have potentially catastrophic impacts on drinking water source quality and treatability. In regions, such as Alberta, where forest and climatic conditions are already conducive to wildfire, these risks are likely to increase due to climate change; however effective and efficient forest management can minimize these risks. There is a clear need to integrate wildfire and watershed management to protect drinking water sources in areas that may experience greater likelihood of severe wildfire and have potentially vulnerable and susceptible drinking water supplies.

The workshop discussions highlighted a strong expectation that management options to mitigate the severity and extent of wildfires have the potential to reduce wildfire risks to water supply and treatment, although further study is required to evaluate these options and their relative efficacy.

Expert knowledge and tools exist to assess forest and watershed conditions, as well as drinking water treatment capacity, to determine the vulnerability of water supply and treatment systems to wildfire impacts and the probability of such impacts occurring. There is anecdotal and scientific evidence to support many of the techniques used in forest and water management for the purpose of mitigating impacts of wildfire on the provision of safe drinking water. However, further study in Alberta and elsewhere would improve knowledge on the effectiveness, costs and benefits of such techniques.

Fire management decisions are conducted in consideration of risks based on the following criteria: 1) human life; 2) communities, 3) watershed and sensitive soils, 4) natural resources, 5) infrastructure of significance); however, some techniques may achieve common objectives. Improved efforts to evaluate these benefits through integrated planning are warranted.

CHAPTER 5. OPPORTUNITIES

5.1 Actions Related to Fire Suppression

There are many technical challenges for treatment plants to adequately address drinking water treatment challenges following wildfires. Hence, protection of public health for areas reliant on surface water supplies in forested watersheds will require:

- 1. Development of strategic forest management plans focused on prioritizing and protecting key drinking water supplies, and
- 2. Ensuring preparedness of drinking water providers.

5.2 Source-Water Protection Actions Within Forested Watersheds to Manage Wildfire Risk Should Include:

- 1. Actions designed to reduce the impact (extent and severity) of wildfires (e.g., management of fuel loads and break-up of continuity of fuels using prescribed fires, harvesting, management of forest vegetation composition, etc.); particularly in key drinking water source watersheds, and
- 2. Actions that mitigate the impacts of wildfires on water quality and treatments to prevent burned materials from entering water supply systems, such as those included as part of the BAER program (e.g., treatments to limit erosion such as mulching, sediment traps, riparian treatments, log deflectors/tree racks, floating booms, etc.).

5.3 Water Utility Wildfire Preparedness That Includes the Development of a Drinking Water Response Plan Should:

Emergency response plans should be considered by water utilities, especially those identified as at high risk of threat from wildfires.

- 1. Identify any potential alternate sources of water,
- 2. To the extent possible, anticipate the range of potential impacts of wildfire on water quality (including the potential for long term sediment production, storage and downstream transport),
- 3. Identify any additional drinking water treatment infrastructure and/or analytical capacity for water quality evaluation (including raw water monitoring) that may enable improved treatment process performance optimization,
- 4. Develop treatment plant technological and operational response options (including focused operator training), and,
- 5. Include a knowledge mobilization strategy to ensure that local stakeholders and those affected by wildfire effects on water supplies understand the risks and actions that may be required in the event of a wildfire, and the implicit costs associated with water utility preparedness.

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APPENDIX A: OPTIONS TO MITIGATE WILDFIRE THREATS TO WATER SUPPLY AND TREATMENT

Management technique	Intended outcome	Considerations	Factors affecting the efficacy	Evidence/case study	Implications for water supplies
Fire and forest n	nanagement options				
Pre-fire					
Predictive tools for modeling fire behaviour (i.e., hazard assessment)	Wildfire preparedness; enabling the assessment of fire manage-ment options	Uncertainty of risk, in-house capacity of agencies to conduct modeling, and data availability	Decision makers' confidence in output The effectiveness of modeling tools are dependent on the quality and accuracy of input data (e.g., fuel, weather and topography).	U.S. Geological Survey, Alberta Prometheus Burn-P3 CanFIRE; Crown Fire Initiation Spread models have been used to provide spatial and temporal assessments of fire behaviour potential (see references).	Fire landscape models and fire behavior models to model fire on the landscape and model fire severity can be incorporated into water supply vulnerability analysis.
Predictive tools for modeling runoff erosion and sediment	Source water protection preparedness; modeling to evaluate erosion protection options	The appropriate spatial scale must be considered. In-put data and output- data resolution; data availability. Must be able to identify the flow route of fire-affected water from burned area to downstream water intake or diversion to understand dilution effects and chemical transformations Very dependent on the timing, frequency and magnitude of post-fire storm events relative to groundcover recovery	The drivers affecting post-fire response, e.g., intense rainfall vs. snowmelt (cannot model snowmelt) Erosion profiles can change suddenly, so there is limited confidence in the results of erosion models. Decision-maker confidence in the output to evaluate tradeoffs	IC-Water or RAVAR-Water, Samuels et al. CanFIRE has been used to predict fuel consumption but not runoff erosion and sediment flow. Sydney, Australia catchments post-1994 and 2002 fires; Melbourne, Australia catchments in recent years	Allows water providers to assess vulnerability and plan post-fire responses Fire severity will impact fuel consumption, which in turn impacts ash loads and soil (slope) stability, which is difficult to predict.
Un-even aged stand forest management	Uneven-aged management may be an objective for many reasons such as aesthetics, regeneration of shade-tolerant species, health, soil, habitat; but also fire protection	Uneven-aged forest management is generally considered to be more difficult than even-aged management. Cost and difficulty of harvesting increases.	Uneven-aged systems tend to favor the regeneration and development of shade- tolerant species.	British Columbia	Reduced fire behavior generally equates to reduced intensity, severity and impacts.

Management	Intended outcome	Considerations	Factors affecting the	Evidence/case study	Implications for
technique	Intended outcome	Consider ations	efficacy	L'huchec/ease study	water supplies
Fire and forest n	nanagement options		U U		
Pre-fire					
Fuel management (i.e., thinning)	Thinning reduces the total crown fuel load, and crown bulk density; hence, reduction in wildfire risks.	Tree species (e.g., conifer forests require substantial thinning), public perceptions and NIMBYism, landscape scarring caused by equipment can increase erosion potential. Less effective under extreme fire weather and fire behavior. Predictive models can be used to determine the best thinning options and the impacts on sediment loads.	Vegetation type, topography, and land maintenance Surface fuel loads are not reduced (and can be increased if thinning is not combined with surface fuel treatment). The Canadian Forest Fire Danger Rating System (CFFDRS) for fire behavior prediction does not allow for changing the fuel types (i.e. fuel types are fixed). CanFIRE provides some greater flexibility.	Cochrane et al., 2012 Fulé et al.;2012 Safford et al., 2009; Pete Robichaud (forthcoming); (Van Wagner 1977); Crown Fire Initiation Spread models	Reduced fire behavior generally equates to reduced intensity, severity and impacts. Increased solar radiation and wind may increase surface fuel drying and thus reduce impacts on water providers.
Fuel management (i.e., prescribed burns)	Reduces service fuel fire intensity and spread	Frequency of prescribed burns, areal extent, season (window of opportunity), public acceptance, and impacts to air quality. Prescribed burns are more suitable in some vegetative conditions than others.	The timing and period available for prescribed burning will determine fire behavior and subsequent fire effects. Large burn units can be partitioned and burned as units to control the impacts on air and water, and minimize escapes. Normally used in areas to protect populations, hence efficacy for water supplies is determined by location of the burn relative to the intake. Need to coordinate with water utility so that they may be prepared in case of erosion.	Warm Lake, Idaho; Kootenay River; Pete Robichaud and Bill Elliot - Joint Fire Science Program.	Predictive models can be used to determine the best thinning options and the impacts on sediment loads. It is assumed that the impacts from prescribed burns on water quality are more manageable than from wildfires (via size of burn, intensity, severity, location, and preparedness).
Fuel management (i.e., thinning and burning underbrush)	Reduces fuel and ladder fuels; reduces fire intensity and spread	Public perceptions and aversion to smoke More suitable in some vegetative conditions than others	Vegetation type Topography	Arkle et al., 2012 Battle and Golladay, 2003	Higher severity fires result in greater runoff and erosion and thus greater impacts on water providers.

Management technique	Intended outcome	Considerations	Factors affecting the efficacy	Evidence/case study	Implications for water supplies
Fire and forest man	nagement option	S			
Post-fire					
Prohibition or enforcement of best manage-ment practices in salvage logging in high risk areas of the watershed (i.e., headwaters)	The aim is to reduce the increased erosion that is associated with salvage logging.	Post-fire environments are more sensitive, so logging practices need to be "better" than best. Lumber may already allocated to timber companies through binding agreements.	Ability to enforce measures Disturbance from salvage logging can be mapped with satellite imagery.	BAER teams (U.S. and British Columbia) have been successful in identifying and mitigating impacts from wildfires. Robichaud and MacDonald, 2014 Yambulla catchment study in New South Wale, Australia showed large effects of salvage logging on sediment loads when compared with wildfire in the absence of salvage harvesting.	Avoided sediment transfer to water sources. The incremental impact of improper salvage logging on water quality is 18-20 fold increase in sediment.
Hillslope treatment (e.g., hydro mulching using wood, straw, green, and seeding)	Reduces erosion	Cost; areal extent. Bio-mats (matted mulch) can become dislodged and turn into debris.	Shown to be effective in small to medium rainfall events. Effectiveness determined by slope.	Cumulative impacts of the failure of these measures and subsequent sedimentation are becoming an increasing concern. Robichaud et al, 2000 Robichaud and Ashmund, 2012.	Reduced erosion and sedimentation for water quality. Enhances vegetation re- growth; it can also reduce fire behavior potential.
Contour felling (i.e. cutting dead, burned trees such that they fall perpendicular to the main direction of the slope)	To reduce erosion and increase infiltration	Wildlife habitat value of the dead trees; Felling in a burned area is dangerous due to a significant risk that trees may drop branches.	This is a short-term solution. Severity of precipitation events and slope determine the efficacy.	United States Department of Agriculture (USDA), Montana	When unanchored, logs may be washed downstream causing damage to drainage improvements or blockage of natural channels resulting in increased erosion.

Management technique	Intended outcome	Considerations	Factors affecting the efficacy	Evidence/case study	Implications for water supplies
Fire and forest ma	nagement option	S			
Post-fire					
Forest restoration/ assisted rehabilitation	Altering vegetative trajectories, bioremedi- ation, species conversion (e.g., using fast growing species to expedite recovery)	Resources/cost	Ecosite specific	Evidence from BAER teams in U.S. and British Columbia, Canada	Reduced erosion and runoff. The implications for water management can be significant, particularly if a precipitation event occurs after the wildfire.

Management	Intended	Considerations	Factors affecting the	Evidence/case	Implications for water supplies
Water management	ontions		cificacy	Study	water supplies
Pre-fire					
Knowledge mobilization (i.e., social marketing to educate public about source water protection issues)	Improved awareness of the link between land impacts and water availability; preparedness	Difficult to determine the effectiveness of these measures	The "tools" that could be used may be restricted by the legal and institutional structures in place in Alberta. Heavily dependent upon land tenure as some measures will suit public forest while others can be used in the context of freehold or leasehold title.	FireSmart in Alberta. Schindler, et al 2009. Santa Fe and Denver, Colorado, U.S. Valuation of watershed services and the use of Payments for Watershed Services (PWS) is a growing area of social and economic research in natural resource management.	Improved awareness of the limitations of utilities in the event of a fire can aid in the implementation of emergency measures.
Emergency response plan	Preparednes s and education of the water treatment plant/system operator	Cost of developing the plan; willingness to pay will be influenced by understanding of risk (e.g., low probability but high consequence). Need to coordinate with land managers, educate public. Need monitoring and early warning systems to alert water providers to take actions such as closing water intakes. An operator users' guide post-fire treatment is needed.	Costs for implementing the plan can be at the front end or the back end (i.e. fuel treatment vs. restoration). Requires additional knowledge mobilization efforts for public education and engagement.	U.S. Environmental Protection Agency and U.S. Department of Agriculture Farm Service Agency, Colorado Source Water Protection Plans Colorado Department of Health and Environment, 2012	Provides an assessment of multiple vulnerabilities
Incorporating source water protection costs into water bills	Cost recovery for other necessary measures	Regulations may be a limiting factor; determining an appropriate pricing scheme.	Effective communication to support changes.	Denver	Enables water suppliers more management and treatment options if people pay for some of the hidden costs associated with water delivery.

Management	Intended	Considerations	Factors affecting the	Evidence/case	Implications for		
technique	outcome		efficacy	study	water supplies		
Water management options							
Pre-fire	1	Γ	1	Γ	1		
Quantitative risk assessment and mapping risks for watershed protection	Assessing vulnerability to wildfire to be strategic in developing preparedness measures and determining priority areas	Fire and forest managers are managing for a suite of priorities, of which water is just one. Needs to be communicated with public, politicians, stakeholders. Vulnerability includes degree of sensitivity and degree of adaptive capacity.		Calkin et al, USDA 2007	Preparedness; opportunity to prioritize mitigation measures or emergency response planning based on vulnerability. Combined with sediment models to determine impacts on water.		
Advanced physicochemical pre-treatment capacity (e.g., ballasted sand flocculation)	Mitigation of wildfire impacts through treatment	Must be designed, transported a priori	Severity and nature of wildfire impacts	M.B. Emelko, experiences in Calgary and elsewhere	Potential to maintain water quality; addressing certain issues related to sediment and nutrient transport		
Check dams, off stream reservoir	Decreases the slope of a channel, directing water, reducing stream velocity.	Limited evidence of the capacity to address water quality issues	Land-specific; severity of rainfall events.	Some documented success. International Rivers conference in Africa and Germany, Los Angeles, U.S. county after the 2009 Station Fire.	Temporary blockade for sediment		

Management	Intended	Considerations	Factors affecting the	Evidence/case	Implications for		
technique	outcome		efficacy	study	water supplies		
Water management options							
Post-fire							
Alternate water	Buys time	Not available to all	The capacity of the	Portland, secondary	Redundancy and		
sources (when	for treatment	providers, notably if	alternate water	groundwater source	resiliency in the		
available)	alteration.	the system is small	source; readiness of	Page 31 in GTR-	system		
	Temporarily	and/or remote.	operator	240, RMRS			
	avoid			publication			
	treating	Greater connectivity		Robichaud, et al.,			
	affected	of a water source		2010			
	water	leads to greater the					
	source,	vulnerability of those					
	maintain	systems if the source					
	water	is affected.					
	supplies.						
Monitor source	Under-	Water purveyor needs		M.B. Emelko,	Preparedness;		
water quality	standing	to determine what		experience in	better		
(upstream)	changing	their baseline desired		Calgary and other	understanding of		
	source water	water quality is. Not		parts of Alberta,	baseline water		
	quality	all water plant		Canada;	quality		
	conditions to	managers have the		commenting on	requirements;		
	make	capacity to do this.		experiences of Fort	better		
	adjustments.			Collins, CO	understanding of		
					post-fire water		
	Determining				quality		
	'tipping				implications and		
	points' with				treatment		
	respect to				requirements		
	water						
	quality,						
	sediment.						

APPENDIX B: WILDFIRES AND WATER ADVISORY PANEL

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APPENDIX D: AGENDA



State of the Science Workshop Wildfires Impacts on Water Supplies and Potential for Mitigation September 17, 18 & 19, 2013 1 Centennial Drive Kananaskis Village, Alberta

AGENDA

Septembe	r 17, 2013	
7:00 p.m.	Welcome reception and dinner	Dawson/Stewart
		Room
7:10 p.m.	Welcome, introductions, and description of workshop objecti	ves

September	r 18, 2013	
(optional) 7:00 a.m.	20-minute outdoor hike	Meet front lobby
8:00 a.m.	Buffet breakfast	Rockies Room
9:00 a.m.	Introduction to the workshop	Bronze Room
9:10 a.m.	Theme 1 introductory presentation	
9:20 a.m.	 Theme 1: What are the key threats posed by wildfires to water supply and treatment? What does the current science support regarding the trends in wildfire severity, the significance of wildfires as a component of threats to water quality, quantity and timing of availa bility? What is known a bout the implications of wildfires for drinking water and (potable) supplies of water? 	
10:30 a.m.	A.M. break	Convention Foyer
÷	Theme 1: Synthesis session on key risks to water supplies from wildfires	2
12:00 p.m.	Buffet lunch	Rockies Room
1:00 p.m.	Theme 2 introductory presentation	Bronze Room





1:10 p.m.	 Theme 2: What forest and water management (e.g., treatment) options are available to mitigate wildfire risks to water supply and treatment? What is known (clearly demonstrated) and projected (conjecture) about the ability of forest management options to mitigate wildfire risks to source waters? What is known (clearly demonstrated) and projected about the ability of water management options to mitigate wildfire risks to source waters? What is known (clearly demonstrated) and projected about the ability of water management options to mitigate wildfire risks to drinking water? What evidence exists about the efficacy of these options? 	
2:30 p.m.	P.M. break	Convention Foyer
3:00 p.m.	Theme 2: Synthesis session on forest and water management (e.g., treatment) options that are available to mitigate wildfire risks to water supply and treatment	Bronze Room
6:00 p.m.	Reception and buffet dinner	Seasons Restaurant

September 19, 2013			
(optional) 7:00 a.m.	20-minute outdoor hike	Meet front lobby	
8:00 a.m.	Buffet breakfast	Rockies Room	
9:00 a.m.	Theme 3 introductory presentation	Bronze Room	
9:10 a.m.	 Theme 3: What are the relative impacts/efficacy of forest and water management options (e.g., treatment) in mitigating wildfire risks to water supply and treatment? What is known (e.g., clearly demonstrated) and projected (conjecture) about the ability of those options to mitigate wildfire risks to source waters? How are the impacts of forest and water management to mitigate wildfire risks measured? 		
10:30 a.m.	A.M. break	Convention Foyer	
11:00 a.m.	Theme 3: Synthesis session on the relative impacts/efficacy of forest and water management (e.g., treatment) options in mitigating wildfire risks to water supply and treatment What are the advantages and disadvantages of these options?		
12:00 p.m.	Buffet lunch	Rockies Room	
1:00 p.m.	Continue Theme 3 discussion	Bronze Room	





2:30 p.m.	P.M. break	Convention Foyer
, 3:00 p.m.	Overall synthesis: Review, discussion and synthesis on key wildfire risks, management options to mitigate those risks and the degree to which expectations for various options can (or could) be supported by the science	Bronze Room
3:45 p.m.	Discussion about next steps Closing remarks	
4:00 p.m.	Meeting adjourn	