NATURAL RESOURCES

The Forest Resiliency Burning Pilot Project

December 2018

WASHINGTON STATE DEPT OF
NATURAL RESOURCES
HILARY S. FRANZ
COMMISSIONER OF PUBLIC LANDS

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Report to the Legislature

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Prepared by
Washington State Department
of Natural Resources and
Washington Prescribed Fire Council

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Executive Summary

More than 100 years of fire suppression and land management practices have severely degraded Eastern Washington's fire-adapted dry forests. Without the regular, low-intensity fires that created their open stand structure and resiliency, tree density has increased and brush and dead fuels have accumulated in the understory. The impact of these changes in combination with longer fire seasons have contributed to back-to-back record-breaking wildfire years, millions spent in firefighting resources and recovery, danger to our communities, and millions of acres of severely burned forest.

Forest resiliency burning, also called prescribed fire or controlled burning, returns fire as an essential ecological process to these forests and is an effective tool for reducing fuels and associated risk of severe fires. Forest experts have identified 2.7 million acres of Central and Eastern Washington forests in need of restoration (Haugo et al. 2015). The agency's 20-year Forest Health Strategic Plan addresses the need to increase the pace and scale of forest restoration treatments, which includes the use of prescribed fire.

Successful implementation of prescribed fire in dry forest ecosystems faces a number of challenges, primarily unfavorable weather conditions, smoke management regulations, and some public opposition.

Recognizing these challenges, the urgent need for large-scale forest restoration, and the usefulness and benefits of prescribed fire, the Legislature passed Engrossed Substitute House Bill (ESHB) 2928. It instituted the Forest Resiliency Burning Pilot Project to "ensure restrictions on outdoor burning for air quality reasons do not impede measures necessary to ensure forest resiliency to catastrophic fires."

This report, as requested by the Legislature, presents the results of the Forest Resiliency Burning Pilot Project. The goal of the pilot project was to assess the benefits of prescribed fire and the impacts on ambient air quality and develop recommendations for continuing or expanding its use.

ESHB 2928 directed the Washington Department of Natural Resources (DNR) to design and implement the pilot project in coordination with three Washington forest collaboratives and the Washington Prescribed Fire Council. These partners convened to design a monitoring system, identify burn projects, develop communication and outreach materials, and carry out the pilot project.

Forest Resiliency Burning Pilot Project

Collaborators identified 15 burn projects totaling 8,329 acres along the east slopes of the Washington Cascades and the Selkirk Mountains of northeast Washington. Two burn projects were on lands managed by the Washington Department of Fish & Wildlife, 10 were in the Okanogan-Wenatchee National Forest, and three were in the Colville National Forest.

ESHB 2928 mandated that pilot burn projects receive 24-hour smoke management approval instead of approval on the morning of the planned burn. DNR tested this process, making internal assessments on the success of a 24-hour approval process for protecting air quality.

A network of nine temporary and four permanent air quality monitors was used in communities around burn projects to monitor air quality and smoke from prescribed burning activities. Study sites were established at 14 of the pilot burn projects to assess the before-and-after fuel load, as well as tree damage. Data was analyzed to predict tree mortality and to test widely used fuel-modeling software.

Pilot partners engaged in a statewide and targeted local outreach campaign during the fall and spring prescribed burn windows. An Outreach Work Group was convened to create materials, ensure consistent messaging, and coordinate efforts.

Pilot Project Results

Between the fall of 2016 and the spring of 2017, 3,017 acres were treated with prescribed fire at 13 of the burn projects. Weather in the fall and spring limited burning opportunities. Livestock grazing conflicts and operational challenges, such as a lack of resources needed to safely ignite prescribed fires, meant two of the pilot sites could not be burned.

Smoke from prescribed fire activities had limited impacts to air quality in communities and generally fell within acceptable ranges as established by federal regulations. This was true of all locations except one, where prescribed burning operations on a project not associated with the pilot combined with topographical challenges, which resulted in several days of smoke impacts, including two days where air quality levels likely exceeded 24-hour average standards to a level deemed "unhealthy for sensitive groups." Final determination of an exceedance of air quality standards could not be made because the monitors on site were not federal reference monitors. Only monitors calibrated to federal standards can be used to determine the presence or absence of an exceedance of federal air quality thresholds, but none were available for the pilot project. There was no significant difference in air quality and smoke impacts between using a 24-hour burn approval process versus the current policy of day-of burn approval. DNR's internal analysis of its smoke approval process found that, during the more stable fall burning window, 24-hour advance predictions held better than in the more historically unsettled spring season. That said, burning and assessment opportunities were limited by very early fall rains and our long, wet spring.

It is also important to note that 2016 was a very low-intensity fire season, so there was less smoke in the air than usual. Less smoke in the air during fire season may have resulted in greater public acceptance of prescribed fire during the shoulder seasons. Further, higher relative humidity in the fall of 2016 suggests that there was greater instability in the upper atmosphere, leading to better smoke transport. Combined with the variable weather influences and small sample size, it is difficult to draw decisive conclusions from the pilot on air quality impacts.

Fuel inventory and tree damage assessments found that pilot prescribed burning activities reduced surface fuel loads across burned sites, while limiting damage to large-diameter trees, meeting burn objectives and contributing to the restoration of historically dry forests. Data were limited for both the air quality and fuels monitoring by the aforementioned short burn seasons. More information would provide higher-quality results.

Pilot partners successfully engaged communities regionally and locally through coordinated social media, posters and mailers, field trips, *Living in the Era of Megafires* presentations, interactive online maps, a dedicated website, and much more. While there was no formal study on smoke complaints due to time and resource constraints, anecdotal evidence from local organizations suggests that complaints and inquiries into smoke from prescribed burning activities declined over the duration of the pilot.

Recommendations

The recommendations provided in this report identify possible solutions to smoke management and air quality challenges, and share the common goals of restoring forest health to severely degraded ecosystems, improving community safety, restoring habitat, and protecting natural resources. A wide suite of options must be considered through a continued collaborative process.

The recommendations in this report are broken down into the following areas:

- State prescribed fire capacity:
    - Trained and qualified personnel.
    - Funding and state agency prescribed fire program support.
    - Cross-boundary prescribed fire support.
    - Burn decision support.
- Improving existing fire-related policies:
    - Smoke policies.
    - Fire safety burn bans.
- Improving communications, outreach, and collaboration.
- Increasing forest products infrastructure.
- Improving smoke monitoring.

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Washington Department of Natural Resources

Washington Prescribed Fire Council

North Central Washington Forest Health Collaborative

Tapash Sustainable Forest Collaborative

Northeast Washington Forestry Coalition

U.S. Forest Service, Okanogan-Wenatchee National Forest

U.S. Forest Service, Colville National Forest

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Chumstick Wildfire Stewardship Coalition

Cascadia Conservation District

Okanogan Conservation District

Methow Conservancy

Chelan County Fire District #3

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Table of Contents

Introduction

In spring 2016, the Washington State Legislature passed Engrossed Substitute House Bill (ESHB) 2928, otherwise known as the Forest Resiliency Burning Pilot Project (hereinafter referred to as the pilot). This bill recognized the forest health issue contributing to catastrophic wildfire and directed the Washington State Department of Natural Resources (DNR) to assess the benefits and impacts of forest resiliency burning as a tool for forest health and restoration and community protection. The pilot engaged forest collaboratives, federal and state land management agencies, state regulatory agencies, U.S. Forest Service research, University of Washington, and other organizations in monitoring and evaluation of the benefits and impacts of forest resiliency burning on air quality; developing and implementing outreach and education to communities; and providing recommendations for continuing and expanding forest resiliency burning.

This report summarizes the pilot project implementation, results, and outcomes, and presents recommendations for continuing and expanding forest resiliency burning developed through this pilot.

Forest Health

Centuries of land management practices and fire suppression has altered Central and Eastern Washington forests and have been further impacted by climate change. While forest type, composition, and diversity vary considerably, these regions are dominated by ponderosa pine and mixed-conifer dry forests. Historically, these dry forests grew in tandem with regular, low-intensity fires burning through the forest floor and understory. The frequent return of fire to these forests reduced fuels and created conditions that kept fire intensities low, with a landscape dominated by open canopies and older, fire-resistant trees.

Now these same forests are overly dense. Their structure and composition have been dramatically altered with higher tree density and a dense build-up of understory brush and vegetation, making them more susceptible to insects, disease, high-intensity fires, and other stressors. When paired with hot, dry summers, and especially in conjunction with drought conditions, these forests are at an increased risk to burn more intensely, resulting in a higher risk to public safety and higher tree mortality.

Land managers, researchers, and policy makers have recognized these changes within Washington's forests, the impact of these changes on our forests and communities, and the challenges inherent in the scope and scale of the problem. Recent studies have shown that 2.7 million acres of Central and Eastern Washington forests are at risk and in need of active restoration (Haugo et al. 2015) . The agency's 20-Year Forest Health Strategic Plan addresses the need to increase the pace and scale of forest restoration treatments to address conditions leading to unhealthy forests and contributing to uncharacteristically large wildfires.

Forest resiliency burning, also known as prescribed fire or controlled burning, is a tool used to meet different types of ecological and land management objectives, including reducing wildfire fuels, enhancing forest restoration, increasing food for wildlife, and creating and maintaining habitat. In prescribed burning, fire is used by land managers and fire professionals within well-defined boundaries with a set of procedures and pre-developed prescriptions, also known as a burn plan. In Washington state, prescribed fire is used by federal, state, tribal, and private land management agencies and organizations in fire-adapted ecosystems, including forests, oak woodlands, wetlands, and prairies. Prescribed fire is an effective tool, and has been shown to reduce the severity of wildfires.

The implementation of prescribed fire follows generally accepted principles and guidelines, established through the National Wildfire Coordinating Group. Prescribed fire practitioners, land managers, and other experts identify goals and objectives for the use of fire on the landscape and outline a plan for its use. They identify the prescription – the set of weather and fuel conditions needed to do the burn in a way that meets objectives and manages risks; they identify how many resources they need and the type of equipment is necessary to complete the job effectively and safely; and they establish communication systems and detailed emergency and contingency plans.

Prescribed Fire Risk

Prescribed fire carries risks that must be addressed before implementation can occur. These risks include smoke impacts from burn operations and potential for fire to escape the burn area. Prescribed burn practitioners make plans to address these risks. They practice best management practices for addressing smoke impacts, communicate when and where a burn is happening so those sensitive to smoke can make arrangements to avoid it, and have contingency plans to shut down burning early if impacts are occurring. While fire escapes (burning outside defined burn plan boundaries) are rare, and over 99% of prescribed burns occur without issue, practitioners establish contingency and communication plans before a burn to ensure swift response to any escape incident.

Challenges to Prescribed Fire Implementation

There are significant barriers to implementation of prescribed fire. In Washington, these barriers can include community opposition, political and legal constraints, a lack of capacity, and operational challenges such as weather and topography.

The public may oppose prescribed fire for many reasons, including smoke and health impacts, fear of escaping fire, aversion to risk, perceived impacts to wildlife and forests, and perceived loss of timber value. Agencies may lack funding, technical expertise or capacity for prescribed fire programs, limiting their ability to implement projects. Having trained and qualified personnel is essential, and the skills and qualifications necessary to implement prescribed fire safely and effectively take years of experience. Several federal and state laws regulate prescribed fire, including those related to air quality, water quality, and endangered species. Policies and laws set up to protect the public from exceedances of state and federal air quality standards or the public health impacts of particulate matter exposure can further restrict prescribed burning.

Together, these barriers may seriously inhibit the use of prescribed fire at a scale and in a manner that meaningfully contributes to forest restoration goals. Addressing these barriers and finding solutions is necessary if prescribed fire is to be used more often in forest restoration.

Air Quality and Smoke Policies

The Environmental Protection Agency (EPA) administers the Clean Air Act and sets National Ambient Air Quality Standards (NAAQS) to protect human health. The Washington State Department of Ecology (DOE) and regional clean air agencies have the task of implementing the goals set by EPA on a local level by regulating air quality in Washington, including most types of outdoor burning. However, the Washington Clean Air Act directs DNR to administer and regulate smoke from silvicultural burning on forested federal lands, as well as state and private lands. The DNR Smoke Management Plan outlines the roles, responsibilities, policies, and standards that govern silvicultural burning.

These laws and policies help protect the public from air quality impacts, including smoke. Smoke can inhibit visibility and can cause serious health problems, especially for sensitive populations like the very old, the very young, and those with respiratory or cardiopulmonary problems.

In an effort to protect communities from smoke impacts, these policies can restrict implementation of prescribed fire.

Burn Projects

Due to the short timeline of the pilot and the necessity of implementation-ready projects, only the Okanogan-Wenatchee National Forest, Colville National Forest, and Washington Department of Fish & Wildlife (WDFW) were able to engage in the pilot with eligible burn projects.

The early onset of winter weather in 2016 resulted in a shorter burn season, which left some pilot funds unspent. These funds were used in spring 2017 for air quality, smoke monitoring, and fuels assessments, but not for the implementation of burning itself.

Partners identified 15 burn projects totaling 8,329 acres.

Eligibility Criteria and Identification

The forest collaboratives were responsible for identifying the pilot burn projects. DNR worked with the Tapash Sustainable Forest Collaborative, Northeast Washington Forest Collaborative, Okanogan-Wenatchee National Forest, Colville National Forest, and WDFW to identify and prioritize potential burn projects.

As part of the legislative requirements, DNR established eligibility criteria that each proposed burn project had to meet to participate in the pilot:

- Select a location in one of the following Central or Eastern Washington counties: Klickitat, Yakima, Kittitas, Chelan, Okanogan, Ferry, Stevens, or Pend Oreille.
- Forestland must be the predominant fuel type burned (at least 50% of the project area). Other acceptable fuel types included grass, shrubs, and trees blown down in windstorms.
- Implement at least 250 acres of forest resiliency burning.
- Receive recommendation by the appropriate forest health collaborative.
- Obtain all necessary regulatory and environmental permits.
- Complete a prescribed fire plan that contains all elements as described in the National Wildfire Coordinating Group publication PMS 484 *Interagency Prescribed Fire Planning and Implementation Procedures Guide*, and submit a copy of the plan to DNR.

The WDFW burn projects submitted by the Tapash Sustainable Forest Collaborative and the Northeast Washington Forest Collaborative were both under 250 acres (although each burn project is part of much larger landscape projects). Despite their size, these projects were included because they were identified as priorities by their respective forest collaboratives and because including WDFW provided additional variety in land ownership. Partners were unable to identify a private lands parcel available to participate in the pilot.

Partners recognized that the rapid timeline set by ESHB 2928 – that is, the bill was passed at the end of March and burning had to be completed by the end of the year – restricted the amount of eligible burn projects, and limited the ability of other agencies to participate in the pilot. Other agencies were approached by the forest collaboratives, but they did not have burn projects that were ready in the fall of 2016. Further, the work required to develop and initiate the Pilot to meet the parameters of ESHB 2928 took three months, closing off the spring 2016 burn season.

Burn Projects

The forest collaboratives identified 15 Pilot burn projects. Of those, 10 were in the Okanogan-Wenatchee National Forest, three were in the Colville National Forest, and two were on WDFW lands.

ESHB 2928 stated that no burn implementation could be funded past December 31, 2016, although other activities would qualify for funding. The limited fall season left burn implementation funds unspent, so in the spring of 2017, six of the original 15 burn projects were selected to receive monitoring support. Those burn names of those burn projects were: Canteen, Oak Creek, Twenty Five Mile, Upper Rendezvous, Eight Mile Bottom, and Sherman Creek. Because of a higher than normal snowpack, WDFW could not ignite Oak Creek and monitoring was shifted to the Goat burn project with agreement from the Tapash Sustainable Forest Collaborative and other pilot partners.

Many of the other burn projects from fall 2016 were burned in the spring 2017 season per agency directive, but were not included in pilot monitoring. Monitoring was not conducted on all of the burn blocs within the pilot projects, so not all ignitions associated with a pilot project are included in this assessment. As such, they did not receive additional air quality monitors or post-burn fuels inventory and tree damage assessments.

Project Description

Fuels

The composition of trees and fuels varied between burn projects. Projects were located within dry conifer forests, predominantly ponderosa pine or Douglas-fir, often mixed with western larch. Other less fire-tolerant species such as lodgepole pine and grand fir were occasionally present. Understory fuels included tree seedlings and saplings, needles, twigs, leaves, grass, shrubs, unburned timber harvest slash, partially decomposed vegetation, and dead or downed wood. The density of forests with trees taller than 4.5 feet varied between burn projects, from 32 trees per acre at Sherman Creek to 1,359 trees per acre at Upper Rendezvous. The high-density stands are due to large numbers of small-diameter trees growing among few mid- to large-diameter trees, while stands with low density were often composed of only mid- to large-diameter trees. Steepness of the burn areas ranged from flat to 30-degree slopes that faced all compass directions. More information on the composition of fuels can be found in Appendix A (fuel report).

Acreage

Proposed burn projects ranged from 80 acres to over 1,000 acres, although many of the larger acreage projects were to be burned in smaller units over multiple days. U.S. Forest Service (USFS) burn projects are often part of landscape scale project areas encompassing large watersheds. Overall, 8,329 acres of forest resiliency burning over fifteen projects were planned across south central, north central, and northeast Washington. Approximately 4,473 acres were planned across six burn projects for the spring of 2017 (Table 1).

Table 1: Prescribed Burn Projects Identified by Forest Collaboratives for Inclusion in Pilot

Project Name	*Agency*	*USFS District*	*Location*	*Acres*
Tapash Sustainable Forest Collaborative				
Orion	Okanogan-Wenatchee NF	Cle Elum	5 miles N of Liberty	400
Liberty	Okanogan-Wenatchee NF	Cle Elum	In proximity to Liberty	115
Canteen*	Okanogan-Wenatchee NF	Naches	4 miles N of Nile	600
Angel	Okanogan-Wenatchee NF	Naches	5 miles W of Nile	600
Oak Creek	WDFW	NA	Oak Creek Wildlife Area, 14 miles west of Naches	80
North Central Washington Forest Collaborative				
Chumstick	Okanogan-Wenatchee NF	Wenatchee River	7 miles N of Leavenworth	400
Natapoc	Okanogan-Wenatchee NF	Wenatchee River	In proximity to Plain and Lake Wenatchee	800
Twenty Five Mile*	Okanogan-Wenatchee NF	Chelan	9 miles NW of Manson	600
Upper Rendezvous*	Okanogan-Wenatchee NF	Methow Valley	8 miles NW of Winthrop	936
Goat*	Okanogan-Wenatchee NF	Methow Valley	10 miles NW of Winthrop	1,070
Eight Mile Bottom*	Okanogan-Wenatchee NF	Methow Valley	11 miles NNW of Winthrop	479
Northeast Washington Forestry Coalition				
Little Vulcan	Colville NF	Republic	4 miles NW of Curlew	872
Paradise 90	Colville NF	Three Rivers	16 miles ESE of Republic and 15 miles WSW Kettle Falls	804
Hanlon	Colville NF	Newport	9 miles SE of Ione	493
Sherman Creek*	WDFW	NA	Sherman Creek Wildlife Area, 5 miles W of Kettle Falls	80

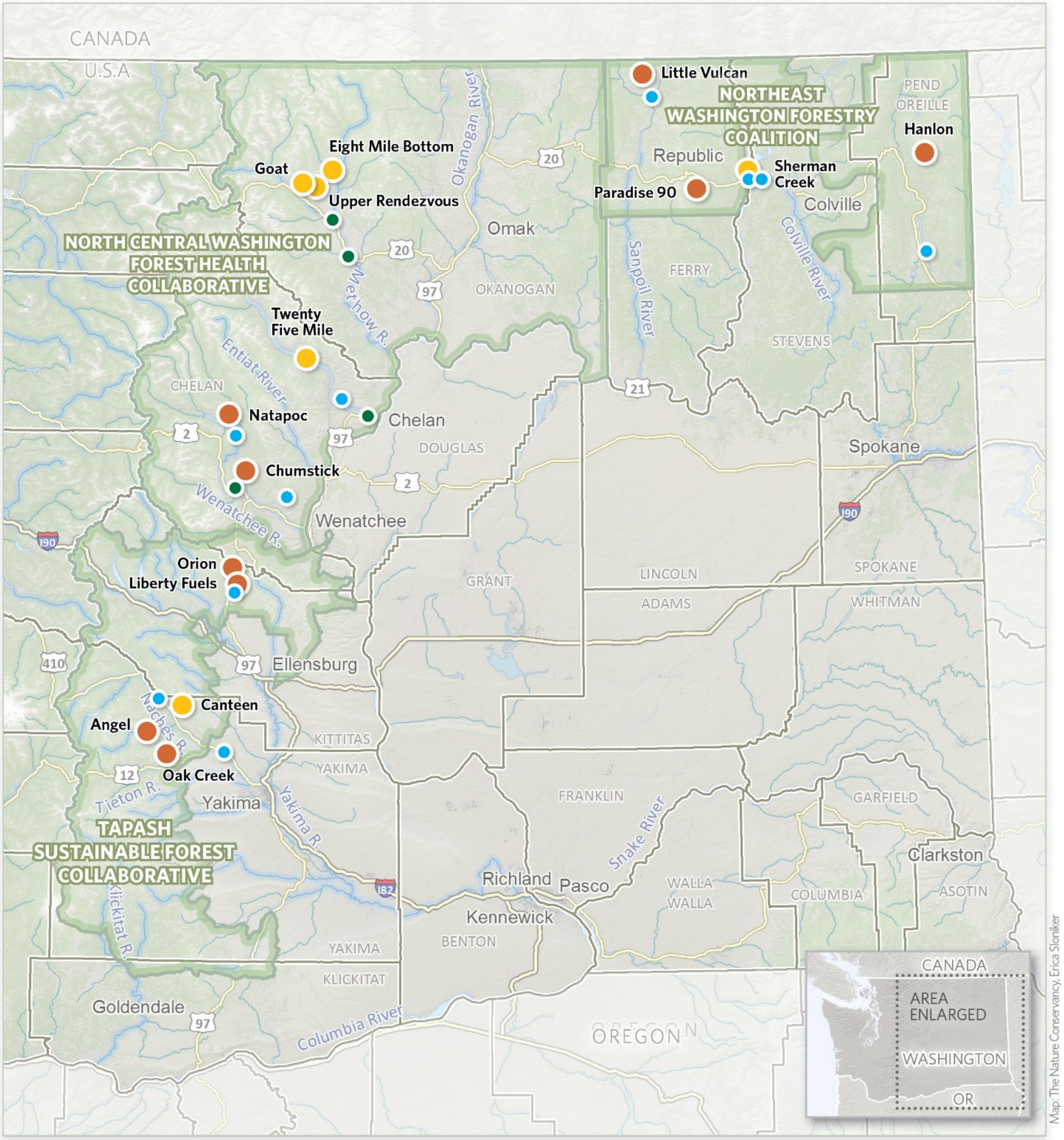
*Spring 2017 burn projects

Surrounding Areas

Burn project areas (see map on Page 8) were often surrounded by similar forested landscapes. There are instances of infrastructure, cultural sites, or private lands and houses within or in proximity to project boundaries. Many USFS burns were done near established campsites, and many more had dispersed campsites in proximity or within the project areas themselves. For example, the Twenty Five Mile burn project identified homestead units and other camps within the project boundaries.

Burn projects varied in distance to population centers. For example, the Liberty burn project is adjacent to the town of Liberty, while the Hanlon burn project, in sparsely populated northeast Washington, is 9 miles southeast of Lone, the nearest town. Likewise, the Chumstick and Natapoc burn projects are both near the communities of Leavenworth, Plain, and Lake Wenatchee. Projects were selected so that the impacts on communities could be tested.

Forest Resiliency Burning Pilot (ESHB 2928)



MAP LEGEND

Forest Health Collaborative Boundary

Forest Cover

Forest Resiliency Burning Pilot Projects

Fall Burn Site

Spring & Fall Burn Site

Air Quality Monitoring Site

Permanent

Temporary

Burn Objectives for Pilot Sites

Prescribed burning is used to complete various land management and operational objectives depending on landowner goals and priorities, landscape characteristics and uses, and location of nearby communities. There are several themes shared by burn project objectives:

- Forest health restoration:
  - Reduce the susceptibility of forest stands to insects, disease, and other stressors.
  - Maintain or encourage fire-resilient, complex forests, including large-diameter trees.
- Fuels reduction:
  - Reduce the likelihood of forest stands spreading large fires and contributing to uncharacteristically large wildfires.
- Wildlife habitat improvement:
  - Restore and maintain desirable forest structures.
  - Promote growth of forage plants for game species, such as deer and elk.
- Wildland-Urban Interface:
  - Reduce risk of wildfire from spreading into residential areas and communities.

Additional objectives included providing a sustainable supply of commercially valuable timber, improving scenic and recreational qualities of forest stands, and maintaining habitat for certain species, such as the northern spotted owl at the Angel and Twenty Five Mile burns, and the lynx at the Little Vulcan burn.

Burn Accomplishments

Fall 2016

During the fall 2016 burn season, 10 out of the 15 burn projects had some amount of burning accomplished. Overall, 2,297 acres were burned in the fall over 12 days starting September 14 and ending October 6. Due to wetter-than-normal fall weather, burning ended early, but two of the burn projects, Hanlon and Paradise 90, completed their entire proposed acreage.

The DNR Daily Smoke Management Approvals website portal[1] was used to track burn requests, approvals, and burning. There were 45 separate requests for burn approvals associated with the pilot project. Of those, 39 were approved for burning and two were rescinded before DNR could approve or deny them, because of local concerns with air quality or fire danger.

[1] https://fortress.wa.gov/dnr/protection/burnrequests

Of the 45 requests for approval, 26 were for day-of-ignition, and 19 were for 24-hour advanced approval.

Spring 2017

During the spring 2017 burn window, five of the 15 burn projects had some amount of burning accomplished. Overall, 720 acres were burned in the spring over eight days, starting on April 28 and ending on June 13. For the pilot, the DNR Daily Smoke Management Approvals website portal recorded 31 smoke management requests, seven of which were for 24-hour approval. Of the seven 24-hour requests, six were approved by DNR section staff, and all were ignited. Of the remainder, 24 requests were submitted, 18 approved, and 13 burned. The spring burn window was very narrow because a wetter than-normal winter delayed the opening of the season.

Table 2: Summary of Acres Burned During the Pilot Program

Project Name	*Agency*	*USFS District*	*Location*	*Acres Planned*	*2016 Acres*	*2017 Acres*
Tapash Sustainable Forest Collaborative						
Orion	Okanogan-Wenatchee forest	Cle Elum	5 miles north of Liberty	400	253	
Liberty	Okanogan-Wenatchee forest	Cle Elum	In proximity to Liberty	115	40	
Canteen*	Okanogan-Wenatchee forest	Naches	4 miles north of Nile	600	0	5
Angel	Okanogan-Wenatchee forest	Naches	5 miles west of Nile	600	115	
Oak Creek	WDFW		Oak Creek Wildlife Area, 14 miles west of Naches	80	0	
North Central Washington Forest Collaborative						
Chumstick	Okanogan-Wenatchee forest	Wenatchee River	7 miles north of Leavenworth	400	71	

Natapoc	Okanogan-Wenatchee forest	Wenatchee River	In proximity to Plain and Lake Wenatchee	800	126	
Twenty Five Mile*	Okanogan-Wenatchee forest	Chelan	9 miles northwest of Manson	600	156	170
Upper Rendezvous*	Okanogan-Wenatchee forest	Methow Valley	8 miles northwest of Winthrop	936	95	53
Goat*	Okanogan-Wenatchee forest	Methow Valley	10 miles northwest of Winthrop	1,070	123	162
Eight Mile Bottom*	Okanogan-Wenatchee forest	Methow Valley	11 miles northwest of Winthrop	479	0	0

Northeast Washington Forestry Coalition

Little Vulcan	Colville forest	Republic	4 miles northwest of Curlew	872	0	
Paradise 90	Colville forest	Three Rivers	16 miles southeast of Republic, 15 miles southwest of Kettle Falls	804	825	
Hanlon	Colville forest	Newport	9 miles southeast of Ione	493	493	
Sherman Creek*	WDFW		Sherman Creek Wildlife Area, 5 miles west of Kettle Falls	80	0	330

* Spring 2017 burn projects

TOTAL	**8,328**	**2297**	**720**

Limitations to Burning

Discussions with burn managers over the winter included statements from fire staff at the Okanogan-Wenatchee National Forest that the USFS had modified its burn program to ensure a higher chance of success in its smoke management requests to DNR. It behooves requestors to understand DNR's process and relevant state and federal statutes and policies so their requests are more likely to be successful. Fire staff understands the parameters of the current policies and approval process and are frequently aware when they will not get approval. They have also planned burn projects that are smaller in acreage and emissions to increase the likelihood of approval and reduce associated planning and resources.

There is a desire among some burners, and pressure from stakeholders, to increase the amount of prescribed burning and sizes of burn projects. Issues arise when attempting larger burns within the current system. Approving burns the day before ignition would give agencies wishing to increase their burned acreage time to assemble crews and plan projects. With those changes to the current policies and systems of smoke approval, such as 24-hour approval, the USFS and others could complete larger acreage burns because they would have, for example, more planning time to secure additional resources and capacity.

Photo by © John Marshall

Air Quality and Smoke Monitoring

USFS's Pacific Wildland Fire Sciences Lab established an air quality and smoke monitoring protocol to assess the impacts of smoke from prescribed burning on air quality and communities and to test new smoke approval processes. The AirFire Research Team at the lab led air quality and smoke monitoring for the pilot, in coordination with DNR, independent contractors, and with support from DOE.

The specific objective of the air quality and smoke monitoring was to compare 24-hour advance approval of burn projects to the current morning-of-burn approval policy, and to assess if this extra advance time increased the likelihood of air quality impacts.

The following provides a summary of the "Smoke and Air Quality Monitoring Data Report in Support of the Washington State Department of Natural Resources 2016 Forest Resiliency Burning Pilot Project."[2]

Study Design

The Pacific Wildland Fire Sciences Lab and partners deployed nine temporary air monitors and used four existing air quality monitors in fall 2016, and deployed five temporary monitors and used four existing monitors in spring 2017 in communities that were most likely to be impacted by smoke from burn projects. Each pilot burn project had at least one air quality monitor located in a nearby community. Because of the proximity of several of the burn projects, some air quality monitors were designated for up to three different burn projects.

Burn records were compiled from the DNR Daily Smoke Management Approval website, which records burn requests, information about the burn including location and size, whether a burn received smoke management approval, and the acres and tons of fuel that were burned.

To identify as many smoke sources as possible, all prescribed burns and hotspots detected by thermal satellite imagery were recorded in a 32-kilometer radius from each monitor. Satellite hotspots are detected through multiple satellites and reported to the National Oceanic and Atmospheric Administration Hazard Mapping System.

Not all potential smoke sources were able to be identified as part of the air quality monitoring effort, including wildfires, small prescribed burns (burns under 100 tons do not require a permit and are not recorded in the DNR database), tribal burning, field burning, backyard burning, and home wood heating.

[2] See Appendix B for full report.

Quantifying air quality conditions

The current air quality standards for PM2.5, or fine particulate matter, are of most concern to forest resiliency burning and smoke produced from these activities. Under the EPA, the current NAAQS standard for PM2.5 is set at 35 µg/m^3 (micrograms per cubic meter of air) over 24 hours. However, smoke can affect visibility, health, or cause concern from the public in shorter time periods than 24-hours, so 1-hour averages were considered in this analysis as well, even though it holds no regulatory significance.

The national Air Quality Index (AQI) was developed by the EPA as a tool to inform the public of health risks and protective actions to take when air quality becomes impaired.

The AQI for PM2.5 is a strong indicator of whether smoke is causing impaired air quality; "Good" and "Moderate" on the AQI scale fall within the acceptable 24-hour NAAQS (35 µg/$m^{3)}$ standard. Categories of "Unhealthy for Sensitive Groups" and worse indicate the 24-hour NAAQS are likely to have been exceeded.

Table 3: National Air Quality Index Health Concerns and Actions for Fine Particulate Matter*

Levels of Health Concern	PM2.5 24-hr avg. (μg/m^3)	Air Quality Index (AQI)	Recommended Action
Good	0-12	0-50	Air quality is considered satisfactory, and air pollution poses little or no risk.
Moderate	12.1-35.4	51-100	Air quality is acceptable however there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	35.5-55.4	101-150	Members of sensitive groups may experience health effects and should take steps to reduce their exposure. The general public is not likely to be affected.
Unhealthy	55.5-150.4	151-200	Everyone may begin to experience health effects and should take steps to reduce exposure by cutting back on outdoor exertion, by changing either time or intensity of exertion, or both. Members of sensitive groups may experience more serious health effects.
Very Unhealthy	150.5-250.4	201-300	Health warnings of emergency conditions. The entire population is more likely to be affected. Everyone should stay indoors and avoid prolonged or heavy outdoor exertion.
Hazardous	>250.5	301-500	Health alert: everyone may experience more serious health effects. Everyone should avoid all outdoor activity. People at greater risk may want to evacuate to a clean air shelter, if one is available or leave the area, and if it is safe to do so. This is especially important if they are having symptoms or smoke levels are expected to remain high. Symptoms such as chest pain or tightness, palpitations, shortness of breath, or unusual fatigue may indicate a serious problem. People with these symptoms should contact their doctor.

Data Sources: EPA/AirNow

Results

In the fall of 2016, four of the pilot burn projects used 24-hour approval over 10 burn days, including Orion, Twenty Five Mile, Paradise 90, and Hanlon. In the spring of 2017, just two of the pilot burn projects used 24-hour approval on two burn days: Twenty Five Mile and Sherman Creek. Some of the pilot burn projects that were eligible to use 24-hour approval did not use the advance approval process. In many cases, for reasons specific to the burner and the burn location, they opted instead to fall back to morning-of-ignition approval.

Fall 2016 Air Quality Monitoring

Overall, one location was impacted by PM2.5 levels that met “Unhealthy for Sensitive Groups” AQI over a 24-hour period, and several locations met “Moderate” air quality over a 24-hour period.

Table 4: Fall 2016 Air Quality Impacts from Pilot Burn Project

Monitor Location	Nearby Pilot Burns	Air Quality Impacts	Likely Source of Impact	24-Hour Approval Requested?
Manson	Twenty Five Mile	No significant impacts		Yes
Chelan	Twenty Five Mile	No significant impacts		Yes
Plain	Chumstick**, Natapoc**	Unhealthy for Sensitive Groups on two days; Moderate for seven days	The Natapoc burn, the non-pilot Fishloop burn, and other possible burn projects.	Yes, but not during the timeframe of cited air quality impacts.
Leavenworth	Chumstick**, Natapoc**	Moderate for two days	The non-pilot Fishloop burn and other non-pilot burns in the area.	Yes
Liberty	Liberty, Orion	Moderate for one day	Orion	No for Liberty, yes for Orion
Pinecliff*	Angel, Canteen, Oak Creek	No significant impacts		Yes for Angel, no for Canteen and Oak Creek
Naches*	Angel, Canteen, Oak Creek	No significant impacts		Yes for Angel, no for Canteen and Oak Creek
Twisp	Goat, Upper Rendezvous, Eight Mile Bottom	No significant impacts		Yes for Upper Rendezvous, no for Goat or Eight Mile
Winthrop	Goat, Upper Rendezvous, Eight Mile Bottom	No significant impacts		Yes for Upper Rendezvous, no for Goat or Eight Mile
Kettle Falls	Paradise 90, Sherman Creek	Moderate one day	Other burns, possibly the non-pilot Rickey Point burn	Yes for Paradise 90, no ignitions for Sherman Creek
Sherman Creek Fish Hatchery	Paradise 90, Sherman Creek	Moderate one day	Paradise 90	Yes for Paradise 90, no ignitions for Sherman Creek
Kalispel Tribal Center	Hanlon	Moderate one day	The Hanlon burn and others, non-pilot burns	Yes

*The Rock Creek wildfire contributed to one day of "Moderate" air quality during fall 2016. ** The Chumstick and Natapoc burns did not request 24-hour approval during the period of impacts.

The town of Plain experienced a greater amount of prescribed fire and smoke impacts than any other community adjacent to a pilot burn. Air quality likely exceeded the 24-hour standard for PM2.5 on two separate days and levels reached the moderate air quality category on seven days. Leavenworth, the second most impacted location, had two days of moderate 24-hour air quality. In addition to the

Chumstick and Natapoc pilot projects, there were several non-pilot burns close to both Plain and Leavenworth, including the Fishloop burn. The Chumstick burn project, between Plain and Leavenworth, did not cause impacts to either location. Burners did not request 24-hour advanced approval for the Chumstick and Natapoc burns in this instance.

In Plain, elevated smoke concentrations occurred mostly at night and in the early morning hours. According to the Pacific Wildland Fire Sciences Lab, "Plain is in a small mountain valley and it is likely nighttime wind patterns would bring smoke from the higher elevation to the north down the valley."

The monitoring locations of Liberty, Kettle Falls, Sherman Creek Fish Hatchery, and Kalispel Tribal Center all were impacted by prescribed burning in fall 2016. None of the smoke impacts were from pilot burns. Of the pilot burns in the area, only a few requested 24-hour approval.

For other locations near the pilot project, prescribed burning did not significantly impact air quality. Pinecliff and Naches were both impacted by smoke from the Rock Creek wildfire. Other locations recorded elevated concentrations of PM2.5 that could not be attributed to a single source.

Spring 2017 Air Quality Monitoring

None of the spring 2017 burns impacted air quality in exceedance of NAAQS standards over a 24-hour period. Only one pilot burn—Sherman Creek— had "Moderate" air quality over a 24-hour period, while the rest of the locations saw no significant impacts from prescribed fire activity.

Two pilot burn projects requested 24-hour approval in the spring of 2017. Twenty-Five Mile, outside of Manson and Chelan, requested 24-hour approval on a single day, and ignited several other burns with day-of-ignition approval. None of these burns had significant impacts on Manson or Chelan. Sherman Creek, outside of Kettle Falls, requested 24-hour approval on several days, and some burns were conducted without 24-hour approval. None of these burns had significant impacts on Kettle Falls, although there were two days of moderate air quality recorded at the Sherman Creek Fish Hatchery.

Several pilot burns were also conducted around Twisp and Winthrop in North Central Washington and around Pinecliff and Naches in South Central Washington. None of these burns utilized 24-hour advance approval, although they were eligible to request that approval. Neither of these areas saw significant impacts from those burns. Naches and Pinecliff saw elevated moderate 24-hour air quality levels, but these are from an unknown source and not related to prescribed burn activities as no activity was recorded in the area at that time.

Table 5: Spring 2017 Air Quality Impacts From Pilot Burn Project

Monitor Location	Nearby Pilot Burns	Air Quality Impacts	Likely Source of Impact
Manson	Twenty Five Mile*	No significant impacts	
Chelan	Twenty Five Mile*	No significant impacts	
Pinecliff	Canteen	No significant impacts	
Naches	Canteen	No significant impacts	
Twisp	Goat, Upper Rendezvous, Eight Mile Bottom	No significant impacts	
Winthrop	Goat, Upper Rendezvous, Eight Mile Bottom	No significant impacts	
Kettle Falls	Sherman Creek*	No significant impacts	
Sherman Creek Fish Hatchery	Sherman Creek*	Moderate two days	Sherman Creek (Bisbee sub-unit)

* Requested 24-hour advanced approval

Conclusions

For fall 2016 and spring 2017 burn projects, there was no significant difference between the current, standard day of approval burns and the 24-hour advance approval burns. In addition, while there were several locations where air quality edged into the "Moderate" AQI for one or two days, these levels are below the NAAQS limit. There were several locations where there was no measured air quality impact from prescribed burning at all.

> *"Burning conducted by the Pilot burn project seems to have been successful with burning either resulting in minimal impact to air quality or impacts on-par with non-pilot burns."*[3]

Plain, the only location that was significantly impacted by smoke from prescribed burning and where 24-hour approval was not used for nearby pilot burns, is a location with significant topographical and meteorological challenges to good smoke dispersion and could benefit from additional study. Overall, this study found that more data is needed to make definite conclusions:

[3] O'Neill, Susan, et al, *Smoke and Air Quality Monitoring Data Report in Support of the Washington State Department of Natural Resources 2016 Forest Resiliency Burning Pilot Project*

"As a final note, these data are far too limited to draw definite conclusions and many other factors come into play such as location (proximity of the burn to populations), multiple burns on the same day (which burn caused the impacts?), wind patterns (valley inversions, drainage flows, day/night patterns, etc.) presence of other sources, and quantity of fuel consumed both during the day of ignition and whether any smoldering fuels continue to put smoke into the atmosphere for days afterward."[4]

Photo by © John Marshall

[4] O'Neill, Susan, et al, *Smoke and Air Quality Monitoring Data Report in Support of the Washington State Department of Natural Resources 2016 Forest Resiliency Burning Pilot Project*

Smoke Management Process

DNR administers the Smoke Management Plan[5] that regulates silvicultural burning, including forest resiliency burning, on federal, state, and private lands. Land managers that fall under these regulations must receive smoke management approval to burn. Burns of less than 100 tons of material are not required to receive approval, though they may still be restricted if there is a fire safety burn ban and they are on DNR-protected lands, or if burning is suspended because of poor air quality conditions. Currently, DNR reviews requests and either approves or denies them on the morning of the requested burn.

For the pilot project, ESHB 2928 states that DNR "must approve burns at least twenty-four hours prior to ignition of the fire." Agencies implementing burn projects through the pilot had the opportunity to request 24-hour approval versus the usual morning of burn approval process.

To test the 24-hour approval process over normal operations, DNR staff made two different approval decisions. As per ESHB 2928, when land managers requested 24-hour approval for pilot burn projects, DNR staff made a smoke decision the morning before ignition day. This was the decision that land managers moved forward with.

Additionally, DNR staff conducted a second, day-of analysis on the morning of the burn to determine if staff would have made the same decision as they did 24-hours prior. This was not a binding decision; land managers were still free to move forward with their original approval. However, if approval was given 24-hours prior and subsequent morning-of analysis indicated that conditions had changed to the point that approval would not have been given, DNR staff contacted burners to discuss smoke impact mitigation options.

Over the fall of 2016 and spring of 2017, 24-hour burn approval was requested 73 times. DNR staff gave approval 61 times. Of these times, there were two situations in which conditions had changed so substantially between the 24-hour time period and the day of the burn that DNR staff would have not made the same decision.

[5] http://file.dnr.wa.gov/publications/rp_burn_smptoc.pdf

Fuel Load Inventory

The Fire and Environmental Research Applications Team[6] (FERA) and the School of Environmental and Forest Sciences at the University of Washington (UW) conducted pre- and post-burn fuel and tree damage assessments to assess the reduction in fuels obtained by prescribed burning activities, and to predict the amount of tree mortality that would occur from these burns.

FERA and UW established a protocol and study design and conducted fuel and tree assessments on 14 of the pilot burn projects. Post-burn inventories and tree mortality predictions were conducted on seven study sites that burned during the duration of the pilot project.

The following provides a summary of the "Pre- and Post-Burn Fuel Characterization and Tree Mortality Assessment for the Forest Resiliency Burning Pilot."[7]

To evaluate the benefits of forest resiliency burning and the impacts on ambient air quality, it was necessary to analyze fuels burned, fuel consumption, and how those fuels might contribute to smoke. FERA and UW conducted a pre- and post-burn fuel characterization and tree mortality assessments on pilot burn projects. This provided an opportunity to assess, 1) whether prescribed fire was reducing fuels in the burn projects, 2) what composition of fuels were contributing to smoke, 3) amount and characterization of predicted tree mortality, and 4) whether fuel modeling programs used by burning agencies and smoke regulators are accurate.

> *"Quantifying fuel loading is essential for estimating fuel consumption, predicting smoke emissions, and assessing potential fire behavior and effects from prescribed burning. Measuring the amount of fuel consumed following a burn also gives managers better insight into how well burn objectives are being met and the efficacy of these forest fuel reduction treatments."* [7]

FERA and UW characterized pre-burn forest fuels assessments at 14 pilot burn project study sites, and evaluated post-burn fuel consumption, quantified post-burn tree damage, and predicted tree mortality at seven study sites where burning occurred. Five of the study sites were burned in the fall of 2016 and two were burned in the spring of 2017.

In addition to fuel load and tree damage assessments, FERA and UW evaluated Consume, a software program used to predict fuel consumption and emissions.

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[6] FERA is part of the USFS, PNW Research Station located at Pacific Wildland Fire Sciences Lab
[7] See Appendix C for full report.

Study Design

Study sites were established in 14 of the 15 Pilot burn projects; one project site (Liberty) was not inventoried due to time constraints. At each study site, 20 plots were established inside, and approximately 200 feet from, the burn project boundaries using a consistent plot layout and design.

Results

Five sites were burned in the fall of 2016, and two sites were burned in the spring of 2017. Post-burn data from Hanlon (fall 2016) was dropped from the data set because that unit was burned under moist conditions and the forested area where plots were located did not burn.

Fuel Load

Fuel loads varied across study sites from 14.9 to 52.9 tons per acre. Fuel consumption also varied across burned study sites, with consumption ranging from 62 to 86% of fuels for fall 2016 burns to 12 to 22% for spring 2017 burns. For sites burned in the fall of 2016, duff fuels (partially decomposed plant matter) comprised the largest proportion of fuels across fuel-bed categories and were the largest proportion of fuels consumed (30 to 67% of fuels consumed). However, other fuel-bed categories such as litter (pine needles and leaves) and fine woody fuels consumed a higher percentage of their original, pre-burn fuel loads than duff did.

Tree Damage

Predicted tree mortality ranged from 26 to 74% reduction in stand density. However, it is estimated that only 7 to 23% of the tree basal area (the total space all trees take up on the ground over a certain area) would be lost due to tree mortality, because mortality is concentrated in smaller diameter trees. Importantly, the FERA and UW report states:

> *"Considering that tree damage was most pronounced in the smaller diameter trees and that predicted mortality was expected to minimally reduce stand basal area, these burns appear to have been successful in reducing forest fuels while limited impacts to the overstory. Maintaining older-fire resistant trees while opening canopy structure, reducing forest fuels and vertical fuel continuity (removing smaller trees and shrubs to limit 'ladder fuels'), increasing average tree diameters, and elevating crown base heights are common restoration goals with these types of restoration/fuels treatments."*[8]

[8] See Appendix C for full report.

Key Findings

Data suggests that the pilot burns reduced forest fuels with limited impacts to the overstory. Burns reduced fuels among all categories on burned sites, including significant amounts of duff, which likely contributed the most to smoke. Modeled tree mortality predictions suggest higher mortality in small diameter understory trees and low mortality in mature trees, which is in line with land manager objectives and forest restoration goals.

Results suggest that forest resiliency burning can meet forest restoration and land management objectives for fire-dependent forests under ideal conditions. It is important to note that the data gathered are far too limited to draw significant conclusions, and more study is needed to understand how fuel moisture levels influence consumption and smoke generation, when burners and regulators can expect ideal conditions to emerge for restoration and forest health objectives to be met, and how to take advantage of the best burn days in the fall and spring burn windows.

Photo by Ben Hartmann

Outreach and Communication

From the start of the pilot project, prescribed burning agencies and practitioners identified public understanding of the rationale for prescribed fire as a priority, specifically addressing why prescribed fire is used by land management agencies. Project partners engaged in outreach and education efforts during the pilot project, focusing on the why, when, and where of prescribed fire. Local outreach was coordinated through the forest collaboratives, while the Washington Prescribed Fire Council (WPFC) coordinated statewide outreach and an outreach workgroup to coordinate efforts among all project partners, produce outreach materials, and create consistent messaging.

Outreach conducted under the pilot project included field trips, community meetings, the *Living in the Era of Megafires* presentation, informational mailers and posters, an interactive online burn map, and coordinated social media. It also convened partners and stakeholders to address challenges related to implementing forest resiliency burning.

The objectives of the outreach and communication portion of the pilot project were to:

- Increase public understanding of prescribed fire and forest restoration objectives.
- Fully inform the public of when and where planned burns were occurring.
- Engage in outreach and communication efforts within local communities.
- Develop coordinated prescribed fire outreach strategies and communication materials.

There were several components to the outreach and communication portion of the pilot project, specifically:

- Community outreach and educational activities.
- Partner coordination.
- Prescribed fire and smoke communication guide.
- Smoke inquiry and complaint tracking.

Public Understanding

Research has shown that around three-quarters of the public supports forest restoration treatments, including prescribed fire and mechanical thinning, and that they have a sophisticated understanding of forest health and the risks of fire within their local communities.[9] However, support for prescribed fire is not absolute; support is directly linked to perception of risk and consequences, which can be quite variable. While some of the public does support the full use of prescribed fire for forest restoration or fuels and risk reduction treatments, others support it on a more limited scale, implemented away from communities. They may have concerns about specific outcomes, including health and visibility impacts from smoke, the risk of fire escape, impacts to wildlife, impacts to forest aesthetics and value, and tree mortality and loss of timber.

Smoke from prescribed burn operations may affect communities, reduce visibility, and affect human health, especially for those with respiratory issues. Although the research states that a majority of the public supports prescribed burning, and that smoke is not a significant barrier for most of the public, a third of households do find smoke to be a health concern.

Acceptance of prescribed fire as a management practice, as well as acceptance of smoke from burning, is primarily driven by the public's understanding of the benefits of prescribed burning, as well as their level of trust in the agency implementing the management practice. The research indicates that focusing on increasing knowledge of prescribed burning, building community trust in burning agencies, and addressing smoke will be key to public support.

Outreach and Communication Partners

The forest collaboratives and their local members and partners led and engaged in outreach in coordination with their local burning agencies. These organizations and other pilot project partners engaged in the Outreach Work Group.

Outreach and Communication Methods

Pilot partners initiated outreach across multiple communication medium and information sources. Messaging was concentrated on how and why prescribed fire is used, when and where prescribed burning was taking place, and addressing public concerns. There were several messaging themes; forest health and wildfire risk reduction were the dominant messages used, but messaging also included how prescribed burn practitioners plan and conduct prescribed burning operations safely and the steps taken by burners and regulators to mitigate smoke impacts.

To reach as many audiences as possible while creating opportunities for deeper engagement, partners used many strategies throughout the fall and spring. Strategies varied depending on community needs and concerns, primary communication pathways, geographic scope, strengths, and capacity. No one

[9] For more see Sarah M. McCaffrey and Christine S. Olsen, "Research perspectives on the public and fire management: a synthesis of current social science on eight essential questions." Gen. Tech. Rep. NRS-104 (2012).

strategy was employed across all agencies and organizations that were engaged in Pilot outreach, but all were used at some point, including:

- Community assessments.
- Social media.
- Phone and email alerts.
- Online resources.
- Traditional media.
- Signage.
- Community events.
- Public service announcements.
- Media stories.
- Additional partner engagement.

Community Assessment

Understanding community needs and communication methods is essential for effective outreach. The North Central Washington Forest Collaborative developed a community needs assessment, and, with the Tapash Sustainable Forest Collaborative, conducted pre-burn interviews with stakeholders and local community members to determine their outreach needs, potential project partners, public perception, barriers, and concerns. These assessments helped frame pilot project outreach strategies and determine organizational needs and capacity.

Social Media

Partners used social media to communicate with as many individuals as possible and to spread information quickly on when and where prescribed burning was occurring. Both Facebook and Twitter were used by pilot partners. It is difficult to ascertain the reach and impact of all the pilot project social media efforts, but the Okanogan-Wenatchee National Forest alone had an average of 5,654 views on their pilot project related Facebook posts in the fall of 2016.

Phone and Email Alerts

Phone calls, texts, and email notifications can move information about burns quickly and directly to individuals. The Okanogan-Wenatchee National Forest has a text news and alert system, and they included daily prescribed fire updates starting in the fall of 2016. Ranger districts also engage in pre-burn notifications as part of their burn plans, including direct phone calls and emails. The Chumstick Wildfire Stewardship Coalition worked with Chelan County Emergency Management to send weekly prescribed fire notifications by text or email to approximately 2,100 individuals in the fall of 2016.

Online Resources

Partners developed a pilot project website (http://putfiretowork.org) as an online hub of information on ESHB 2928, prescribed fire, the pilot burn projects, and partners.

The Okanogan-Wenatchee National Forest's Wenatchee River Ranger District created an online interactive burn map that showed the locations of prescribed burns happening in the fall of 2016. USFS shared this map widely online and through a QR barcode on a mailer and flyer that was distributed to the communities of Plain, Lake Wenatchee, and Leavenworth. There were 1,779 views of the map during the active burn window.

The success of this map led to the development of an Okanogan-Wenatchee forest-wide map for the spring of 2017 that showed prescribed burns planned across the entire forest.

Traditional Media

Traditional sources of outreach used in the pilot project included flyers, posters, mailers, radio, and newsletters. Several partners used posters in high-use community areas to provide information about local prescribed burning operations to community members, tourists, and other members of the public. The North Central Washington Forest Collaborative created several versions of postcard mailers to reach out to approximately 8,000 residents across North Central Washington with information about local events.

Signage

USFS provides signage along roads to alert traffic during burn operations and after for lingering smoke. For the pilot project, the Northeast Washington Forestry Coalition provided an electronic reader board to alert drivers of possible smoke on Highway 20 and Highway 395 in the fall of 2016.

Community Events

Events such as community meetings and field trips created opportunities for direct engagement and outreach between community members, fire managers, and other stakeholders. Field trips also offered a chance for the public to see restoration actions onsite pre- and post-burn and to engage in in-depth discussions about prescribed fire. Outreach partners conducted field trips with the public and policymakers at the local, state, and federal level throughout North Central Washington.

The Northeast Washington Forestry Coalition worked with a local fire district for the Paradise 90 burn. The fire district staged a new fire truck at a prominent junction where smoke would be visible, where both fire truck and smoke drew attention. The public stopping by learned about the new fire truck as well as the burn.

Pilot project partners also leveraged other events for further educational opportunities within their communities that were not directly affiliated with the pilot project, such as the salmon festival in Leavenworth and county fairs in Northeast Washington.

Living in the Era of Megafires

Showings of the multi-media presentation *Living in the Era of Megafires*, hosted by Dr. Paul Hessburg of the USFS Pacific Northwest Research Station, were held in communities across the entire pilot project area, including Yakima, Cle Elum, Leavenworth, Chelan, Omak, Nespelem, and Spokane. Organizers used different strategies to add local context to the presentation, such as hosting a panel or an open house with local organizations, experts, and stakeholders to engage and answer questions from the audience.

Public Service Announcements

The Outreach Work Group created four public service announcements to spread messaging across social media and television. The Outreach Work Group developed the PSAs collaboratively, addressing forest health, community values, prescribed fire smoke, and safety.

Media stories

The forest collaboratives, participating agencies, and other partners received coverage in various media several times throughout the pilot project, including a story in the Yakima Herald-Republic[10] that was picked up nationally by The Associated Press, and several articles in The Seattle Times.

Additional Partner Engagement

In addition to community outreach and engagement, pilot project partners engaged with each other and with other organizations and agencies, from the local to statewide and federal levels. Some of these opportunities were initiated by the pilot project, such as local stakeholder meetings and additional coordination efforts between local agencies. Others were opportunities to engage with existing collaboratives and networks involved with the pilot project, such as forest collaborative meetings and briefings with the Washington State Fire Adapted Communities Learning Network, the National Fire Adapted Communities Learning Network, and National Fire Protection Association's Firewise USA® program, among others.

[10] https://www.yakimaherald.com/news/local/when-it-comes-to-protecting-washington-state-forests-fire-can/article_e08e0d8e-8087-11e6-bb03-3ff6af3073f2.html

Prescribed Fire and Smoke Communication Guide

Prescribed fire and smoke communication is a challenge across the United States. Recognizing that there are examples of successful outreach and communication strategies being employed, the "Engaging Communities in Prescribed Fire and Smoke Best Management Practices Guide"[11] collected case studies and resources in Washington and other Western states as a guide to assist prescribed fire practitioners, community organizers, burning and regulatory agencies, and others engaged with prescribed fire. This resource will support prescribed fire and smoke communication in Washington state post-pilot, and can assist others across the country.

Smoke Inquiry and Complaint Tracking

Smoke is the most visible sign of prescribed burning operations and is a source of direct public impact. Likewise, the most observable expression of public concern about prescribed fire is direct public contact, including phone calls to local, regional, and state agencies. Calls can be either complaints or inquiries about burning or smoke. Smoke complaint calls indicate a health or quality-of-life impact to a member of the public, whether that be a health impact, visibility impact, or general concern. Inquiry calls are from members of the public who are curious, looking for more information about the source of the smoke or other issue.

Burners do have communication plans designed to notify the public through emails, phone calls, and press releases, but it is not possible to notify everyone, and a burner's capacity to communicate and engage on larger scales can be limited.

As part of the pilot project, the Chumstick Wildfire Stewardship Coalition engaged their partners in a study of complaint and inquiry tracking around the Leavenworth and Plain areas. This quick study over a relatively limited area revealed a complex, largely uncoordinated system. Currently, complaint or inquiry calls come to the burning agency (in this case the USFS), or to DNR as the smoke management regulatory agency, Ecology, local fire districts, 911, or local chambers of commerce. There is no central location for inquiries or complaint calls. This results in an incomplete understanding of the nature of calls. Calls can add an additional burden to the responding organization, and in the case of local fire districts, the impact may be significant because they must respond physically, regardless of the source.

Anecdotal reports suggest that complaints or inquiries about prescribed fire operations where fewer during the two burn seasons under the pilot project versus previous seasons, and that may be attributable to the increased outreach.

[11] See Appendix D for full report.

Agency Coordination

Although not directly a proposed component of the outreach and communication portion of the pilot project, there was an increase in inter-organization communication and collaboration created through this process. Inter-organization communication and coordination around prescribed fire messaging and information can build trust and support relationships between agencies, increasing the spread of information, and ultimately reaching more of the public.

For example, the Northeast Washington Forestry Coalition, the Colville National Forest, and local fire districts worked closely to ensure information flow and successful outreach. Engaging the fire districts was essential. By bringing them in on outreach and empowering them with information, they became partners. From the forestry coalition's report:

> *"The power of informing local fire district personnel cannot be understated. These people interact throughout the community and are often the 'go-to' sources for information. When they are fully informed, they are real ambassadors for the project. Knowledge increases their confidence and rightfully deserved status in the community. The pilot created stronger, now self-sustaining relationships."*

Results

Efforts taken during the pilot project unquestionably connected more people with prescribed fire outreach than if there had been no pilot project. More than 8,000 households received educational postcard mailers. The Okanogan-Wenatchee National Forest alone had an average of 5,654 views on their daily Facebook posts, the pilot project website had over 1,200 visits and will continue to be a resource in the future, and *Era of Megafires* was shown to well over 600 people. These metrics are the tip of the iceberg. During the pilot project, prescribed fire was a visible presence in Washington.

At the same time, complaints were limited across the project area, according to anecdotal reports from project partners. There was a smoke intrusion into one community, and there were calls associated with that impact, but otherwise calls were generally dispersed, often inquiring about smoke rather than complaining, and adequately responded to by participating agencies. That said, the system of processing and responding to complaints and inquiries about prescribed fire operations is limited and uncoordinated.

From the beginning of the development of the pilot project, partners recognized that effective outreach and communication could generate community understanding and support for burning and is essential to increasing the pace and scale of restoration. Research shows that the public supports prescribed burning when they understand the ecological benefits and trust burning agencies. Outreach efforts under the pilot project successfully addressed both of these messages, and supported them by using local partners, not burning agencies alone.

Perhaps as important as community outreach, this work connected local agencies and organizations, building trust and strengthening partnerships between them. The resulting coordinated communication and understanding between agencies will continue to pay dividends.

Given current limitations in funding and capacity, most local organizations are not normally capable of sustaining the amount of outreach that was conducted during the Pilot Project. However, this limitation was recognized, and efforts were focused toward creating durable and reusable outreach materials such as mailers, posters, brochures, PSAs, and more that can be used beyond this project.

Overall, the outreach and communication portion of the pilot project successfully addressed stated objectives.

Cheryl Barth Photography

Forest Resiliency Burning Recommendations

Altogether, the recommendations presented in this report are focused on improving forest health, reducing risks to communities, protecting natural resources, restoring wildlife habitat, and finding solutions to smoke and air quality issues.

The recommendations are broken down into the following areas:

- State prescribed fire capacity:
    - Trained and qualified personnel.
    - Funding and state agency prescribed fire program support.
    - Cross-boundary prescribed fire support.
    - Burn decision support.
- Improving existing fire-related policies:
    - Smoke policies.
    - Fire safety burn bans.
- Improving communications, outreach, and collaboration.
- Increasing forest products infrastructure.
- Improving smoke monitoring.

State Prescribed Fire Capacity

Trained and Qualified Personnel

Context: Trained and qualified prescribed fire personnel are essential to effective and safe use of prescribed fire as a tool for addressing forest health issues, reducing fuels, and protecting communities.

Issue: There is a shortage of training opportunities for existing prescribed fire practitioners and for wildland and structural firefighters to increase qualifications and expertise in using prescribed fire, including National Wildfire Coordinating Group position task books related to prescribed fire.

Expected Results: The following recommendations aim to increase the number of qualified and trained prescribed fire personnel across the state to conduct burning, and increase wildland fire coordination, training, and preparedness.

Recommendations	Convening Party	Actions or Response
Facilitate statewide interagency prescribed fire training program to accelerate large landscape restoration, increase training opportunities, and accelerate prescribed fire qualifications and expertise. As an example: organize and support prescribed fire training exchanges known as TREX.	Washington Prescribed Fire Council (WPFC), The Nature Conservancy (TNC), DNR working closely with WDFW, federal, tribal, and local partners.	DNR is hiring a prescribed fire program manager to develop a prescribed fire program within the agency; the agency is providing financial support and participation with in-state TREX.
Increase coordination and awareness of existing training opportunities between local, state, federal, tribal, and private land managers and fire practitioners at the regional level across the state.	WPFC, DNR	DNR's prescribed fire program manager will aid in addressing and facilitation.
Establish a Burn Manager Certification Program. This program would include training on all relevant aspects of prescribed fire in Washington, and ideally would provide liability protection to prescribed burn managers who become certified and follow the requirements of the program.	DNR	Passage of HB 2733 authorizes implementation of this recommendation and DNR is currently working on development and implementation.

Funding and State Agency Prescribed Fire Program Support

Context: Adequately funded prescribed fire and forest management programs are necessary to address the scope and scale of the forest health restoration and community risk reduction needs in Washington. Effective state prescribed fire programs in the Southeast United States and across the West make larger investments in programs that implement prescribed fire to meet their goals.

Issue: Washington state agencies do not have sufficient funding, capacity, or sufficiently trained personnel to implement prescribed fire on state lands commensurate with the scale of need in Washington.

Expected Results: The following recommendations aim to increase the pace and scale of forest treatments on state lands to achieve forest health and community-risk-reduction goals as well as meet cross-boundary ownership objectives.

Recommendations	Convening Party	Actions or Response
Review state agency prescribed burn programs and fund development of DNR and WDFW prescribed fire programs.	DNR, WPFC, Legislature	To Be Determined (TBD)
Fund expansion of DNR and WDFW prescribed fire participation with USFS.	Legislature	TBD

Cross-Boundary Prescribed Fire Support

Context: Wildland fires, insects, diseases, and post-fire flooding within our forests and rangelands do not heed jurisdictional boundaries.

Issue: To be most effective, forest health and fuel reduction treatments need to be addressed at a cross-boundary landscape scale as identified in the 20-Year Forest Health Strategic Plan (20-year strategy). Participation of agencies across and between boundaries are essential to increasing capacity, efficiencies, training opportunities, and increasing pace and scale of forest restoration and is currently taking place under the 20-year strategy.

Expected Results: The following recommendations aim to accomplish a more efficient and effective use of interagency (local and regional) fire personnel and equipment to meet forest health and community risk reduction goals, and decreased barriers to implementing cross-boundary forest resiliency burning.

Recommendations	Convening Party	Actions or Response
Develop interagency Master Participating Agreement between state, federal, tribal, nonprofits, and other groups within the state to share resources, facilitate training opportunities, and allow participation in prescribed burning in Washington.	WPFC, state and federal partners	TBD
Change state policy to allow direct payment to all fire personnel.	Legislature	TBD
Use Good Neighbor Authority and other authorities granted in the Farm Bill, Cooperative Forestry, and Cooperative Wildfire Management Acts to increase acres treated with prescribed burning.	DNR, USFS, WDFW	TBD

Provide continued funding for landscape evaluations and quantitative risk assessments to identify high priority restoration areas across ownership boundaries.	Legislature	TBD
Emphasize and build partnerships across all public and private sectors to obtain prescribed burning goals.	DNR, WPFC, other landowners and stakeholders	TBD

Improving Existing Fire-Related Policies

Smoke Policies

Context: Washington state and its agencies have adopted laws and policies to regulate forest resiliency burning and associated risks and impacts to ambient air quality for the greater public good. Federal laws and policies also direct state laws and policies.

Issue: Some policies that are intended to protect air quality and safe implementation of prescribed burning can unintentionally and unnecessarily limit burn windows to the extent that treatment is ineffective or cannot occur.

Expected Results: The following recommendations aim to increase opportunities to conduct safe and effective forest resiliency burning.

Note: *DNR has yet to sign onto several of the following recommendations, since they are elements of the state's Smoke Management Plan, which is the subject of ongoing review and revision. This should not be construed as disagreement with the recommendations made below. DNR, advised by a diverse group of stakeholders, is seriously considering adopting many of them.*

Recommendations	Convening Party	Actions or Response
Lift ban on weekend burning after Labor Day, particularly outside of Class 1 airsheds.	DNR will propose changes, DOE and EPA approval needed	Will be proposed in Smoke Management Plan update.
Continue 24-hour burn decision (vs. 8am morning of). Twenty-four-hour burn decisions contribute to significantly more efficient mobilization of resources, saves money, improves trust and relationships between regulators and implementers, and contributes to improved planning prior to ignition.	DNR will propose changes, DOE and EPA approval needed	A change to the day of decision will be proposed in Smoke Management Plan update.
Increase tonnage amount for burning without a permit.	DNR, USFS	Further analysis needed by DNR.

Continue approval of single- or multi-day burn permits if the burning is unlikely to significantly contribute to an exceedance of air quality standards by RCW 70.94.	DNR	Continuing
Continued engagement of diverse group of federal, state, and private prescribed practitioners and air regulators in revision of the DNR Smoke Management Plan.	DNR	Continuing
Consider alternate source of funding rather than tonnage to incentivize certain types of forest resiliency burning.	Legislature	TBD

Fire Safety Burn Bans

Context: DNR uses fire safety burn bans as a tool to reduce human-caused wildfires when wildfire risk is high. When a DNR burn ban is in place, it prohibits outdoor fires on all state, county, city, and private land under DNR fire protection. This burn ban is different from "air quality burn bans" that are put in place by air regulators when air quality conditions are deteriorating.

Issue: Fire safety burn bans issued on lands under DNR fire protection has at times been interpreted as a blanket burn ban on outdoor burning when there is elevated risk of wildfire in some parts of the state. Firefighting resource availability, weather, and burning conditions differ from region to region and from day to day during fire safety burn bans. The blanket fire safety burn ban is clear, easy to communicate, and has been effective in reducing accidental unwanted ignitions by the public. However, it inhibits prescribed burning by state and private crews that have considerably different expertise and resources to evaluate local fire risk and manage fire. Professional fire managers have developed burn plans with fire protection contingences based on local fuel and weather conditions and need a clear, consistent and efficient process to request the ability to conduct prescribed burning during a declared fire safety burn ban.

Expected Results: The following recommendations aim to increase opportunities to burn safely and effectively to meet the state's forest health and community wildfire risk reduction goals. Some individuals or communities may not make the distinction between an individual using fire during a fire safety burn ban, and a professional prescribed burning crew with contingent fire protection resources on hand.

Recommendations	Convening Party	Actions or Response
Update DNR internal policies on the Commissioner Order Burn Ban Regions so fire safety burn bans apply to general risk categories (campfires, fire pits, etc.) but exclude prescribed burns conducted by trained and qualified burn practitioners with a burn plan.	DNR	The Commissioner Order Burn Ban provides an exception process for prescribed fire.
Update DNR internal policies so prescribed fire can be allowed within the existing regional approach, and allow for regional and local differences.	DNR	Internal policies allow regions to set burn restrictions and allow for prescribed fire when other burning is prohibited.
Develop communications materials for land managers and prescribed burners that convey why prescribed burners may be allowed to burn during a fire safety burn ban.	DNR, WPFC	TBD

Improving Communications and Collaboration

Communication and Outreach

Context: Pilot results indicate that communication and outreach is essential to gaining community support and trust to use prescribed fire as a tool to meet forest management and community wildfire risk reduction goals. Communities living in fire prone landscapes have a varying understanding of why and when forest resiliency burning is occurring. There are varying degrees of understanding of who has what responsibility and role when living in a community that is prone to burning. Conflicts are more likely if community members are not engaged in dialogue nor understand the reason for burning, or do not have timely notification of where and when burning will occur.

Issues: Three main challenges exist:

- Inconsistent and uncoordinated prescribed fire outreach and communication efforts within and between agencies and organizations across local, regional, and statewide scales.
- Different agencies and organizations conducting outreach are perceived differently in communities and vary in ability and capacity to engage and receive feedback by community members. Often, the messenger matters.
- It is confusing for members of public to know where to look or whom to call to find out information about fire and smoke (wildfire, prescribed, outdoor burning) or make an inquiry or complaint about smoke given the number of

local, state and federal entities involved. Furthermore, information provided can vary greatly and can lead to further misunderstanding and frustration of members of public.

Expected Results: The following recommendations aim to reduce the amount of complaints and increase support to implement prescribed burning to meet management goals. Specifically, they would:

- Increase capacity and effectiveness to communicate, reach the broader constituency, and provide requested information on prescribed burning.
- Identify local outreach needs and opportunities.
- Ensure consistent and common messaging.
- Increase coordination between stakeholders.
- Increase trust between communities and entities using prescribed fire and those managing air quality.
- Accelerate lessons learned.
- Build trust through collaboration and partnerships.

Recommendations	**Convening Party**	**Actions or Response**
In addition to providing information on where and when prescribed fire will occur, provide information on why. Outreach must be consistent in ways that address the needs of local communities, as well as regionally and statewide.	WPFC, USFS, WDFW, DNR	TBD
Support and fund forest collaboratives and local organizations to develop forest resiliency burning outreach communications and engage community members working with local, state, and federal agencies, as successfully demonstrated during the pilot.	Legislature	TBD
Continue to support and fund state agencies to work with pilot partners on effective outreach and communication efforts, as successfully demonstrated during pilot.	Legislature	TBD
Convene an interagency/entity task force to create a streamlined process for public to find out information about prescribed fire and smoke: the when, where, and why.	DNR	TBD
Development of statewide interagency web based prescribed burn map based on updates from burn permits or other sources.	DNR	DNR will explore opportunity and cost of this type of resource.

Support the dispersal of lessons learned, communication resources, and materials from the pilot to beyond pilot partners. Use pilot website “putfiretowork.org” as state clearinghouse.	WPFC, DNR	TBD

Collaboration

Context: Multiple federal, state, local, tribal, private, and nonprofit landowners engage in burning across Washington state, such as prescribed, industrial, and agricultural landowners, as well as home heating. These uses are regulated by local, state, and federal agencies to reduce potential impacts to human health, property, and visibility.

Issue: Limited communication between burners and regulators decreases trust and has impeded successful outcomes. Without regular communication (phone, in person, field time), issues and regulatory challenges likely won’t be addressed effectively; areas of improvement will not be realized, decreasing opportunities to conduct burning while managing emissions.

Expected Results: The following recommendations aim to maintain partnerships between burners and regulators, and increased and maintain interagency prescribed fire coordination, communication, and relationships that expedite resolutions as issues arise.

Recommendations	Convening Party	Actions or Response
Host bi-annual, and potentially regional, prescribed burn coordination and lessons-learned meetings.	DNR, WPFC	TBD
Support and fund forest collaboratives to convene regional stakeholders.	DNR, Legislature	2018 legislative session funded DNR investments in forest collaboratives to aid their capacity for outreach and other activities; DNR is seeking additional funding as part of the 2019-21 capital budget request.
Work with other smoke stakeholders and regulators to identify areas where coordination will improve prescribed burning outcomes.	DNR, DOE, regional clean air agencies, WPFC, Burners	TBD

Increasing Forest Products Infrastructure

Context: Commercial and non-commercial thinning can be used as a way to reduce fuels and establish historical stand structure and density in Central and Eastern Washington forests. Thinning and prescribed fire, used in conjunction as forest management tools, can most effectively reduce fuels and the risks of severe fires.

Issue: A shortage of forest products-related infrastructure in some regions limits the capacity of communities to support and implement prescribed burning as part of forest restoration.

Expected Results: The following recommendations aim to increase the pace and viability of restoration thinning to increase acres available for safe and effective forest resiliency burning.

Recommendations	Convening Party	Actions or Response
Develop strategy for targeted state support for increased infrastructure.	DNR	DNR is seeking 2019-21 operating funding to implement recommendation.
Support community-based collaboration for forest restoration.	DNR	DNR is seeking 2019-21 operating funding to support and facilitate efforts.
Support prescribed fire restoration education that underscores the benefits of proactive forest management rather than reactive management.	DNR, WFPC, WDFW	Commissioner of Public Lands Hilary Franz and DNR communications staff provide messaging through media outlets including social media. Partners such as USFS and WDFW also support efforts through media releases.

Improving Smoke Approval and Monitoring

Burn Decision Support

Context: Burn decisions concerning air quality are currently made by qualified DNR regulatory staff using best available information and modeling for all forest resiliency burning.

Issue: DNR staff has limited capacity and resources to engage with local burners and to integrate localized knowledge of geography and conditions into burn decisions.

Discrepancies between burn decisions and on the ground conditions have caused confusion among burners and affect burning and air quality outcomes.

Expected Results: The following recommendations aim to improve communication between burners and regulators, maximizing opportunities to burn safely and effectively while reducing the potential for air quality impacts on communities.

Recommendations	Convening Party	Actions or Response
Support staff needs at DNR to improve on-ground and local communication with prescribed fire practitioners.	Legislature	TBD
Support staff needs at DNR to improve interagency coordination and communication with burners, and to make improvements to the Smoke Management Approval process.	Legislature	TBD
Base a regulatory DNR staff position at least seasonally in Central and Eastern Washington.	DNR	TBD

Smoke Monitoring

Context: Air quality monitors are used to track ambient air quality impacts from smoke over time. There are several permanent air quality monitors in some at-risk locations across Central and Eastern Washington, but most communities do not have one. During the pilot, in addition to using permanent monitors, portable air quality monitors were deployed near burn projects to monitor ambient air quality, and to assess differences between forecasted smoke and actual smoke created by burning.

Issue: The exact source of smoke impact may not always be clear, even with air quality monitors in place. There may be several sources of smoke, including multiple prescribed burns or other sources, that make identification difficult. While the air quality monitoring network successfully tracked air quality impacts from burning during the pilot project within a short timeline, more data and study could provide better conclusions, assist in tracking smoke intrusions, and better inform the smoke approval process.

Expected Results: The following recommendations aim to improve smoke forecasting, as well as coordination and understanding of smoke sources and ways to reduce air quality impacts.

Recommendations	Convening Party	Actions or/Response
Coordinate across the region and between regulators and burners to identify smoke sources.	DNR, DOE, clean air agencies	TBD
Establish mobile air quality monitors to allow for flexibility in monitoring, and to increase the understanding of smoke and smoke impacts.	DNR, DOE, USFS	TBD

Future Work

Future work could include:

- Smoke modeling to evaluate the utility of smoke forecasting systems to aid the burn approval decision process and support the assessment of impacts from simultaneous multiple burns.
- A meteorological analysis could identify typical wind patterns in areas with complex terrain. This could also aid in the burn approval decision process; Plain especially may benefit from an analysis such as this.
- An analysis of additional smoke sources that impact air quality, such as in Liberty and Curlew, could give insights into whether wood stove smoke effects PM2.5 readings.

Appendix A

Table A1 – Unit photos, fuel loadings, measured and modeled consumption.

ANGEL

(Okanogan-Wenatchee National Forest)

PRE-BURN

POST-BURN

Fuel Load and Consumption

	Pre-Fire Load	Post-Fire Load	Measured Consumption	Measured Consumption	Consume 2.1 Consumption	Consume 4.2 Consumption
Fuelbed Category	*tons acre^{-1}*			*%*	*tons acre^{-1}*	
1 h	0.38	0.07	0.31	82	0.38	0.38
10 h	1.09	0.25	0.84	77	0.95	0.94
100 h	1.47	0.23	1.24	84	1.24	1.15
1000 h S	2.62	0.49	2.13	81	0.72	1.44
1000 h R	4.85	0.08	4.77	98	1.02	3.08
litter	2.47	0.46	2.01	81	1.68	2.47
duff	11.07	4.36	6.71	61	5.51	3.73
herb	0.06	0.01	0.05	83	0.06	0.06
shrub	0.13	0.05	0.08	62	0.09	0.09
Total	**24.14**	**6.00**	**18.14**	**75**	**11.64**	**13.34**

Overstory Characteristics, Tree Damage, and Predicted Mortality

Diameter Class	Tree Density	Tree Basal Area	Measured Crown Volume Scorched	Measured Bole Char Height	FOFEM Predicted Mortality	FOFEM Predicted Mortality
	trees acre^{-1}	*ft^2 ac^{-1}*	*%*	*ft*	*% trees acre^{-1}*	*% basal area*
0-2	315	1.5	68	N/C	95	N/C
> 2	251	106.1	56	N/C	22	N/C
All	566	107.6	59	4.6	75	23

N/C = Not calculated

CHUMSTICK
(Okanogan-Wenatchee National Forest)

NO PRE-BURN PHOTO

POST-BURN

Fuel Load and Consumption

	Pre-Fire Load	Post-Fire Load	Measured Consumption	Measured Consumption	Consume 2.1 Consumption	Consume 4.2 Consumption
Fuelbed Category	*tons acre^{-1}*			*%*	*tons acre^{-1}*	
1 h	0.12	0.01	0.11	92	0.12	0.12
10 h	1.28	0.12	1.16	91	1.13	1.11
100 h	2.71	0.17	2.54	94	2.36	2.13
1000 h S	2.46	0.12	2.34	95	1.01	1.77
1000 h R	0.10	0.00	0.10	100	0.02	0.09
litter	4.24	0.71	3.53	83	3.15	4.24
duff	5.33	1.18	4.15	78	2.46	2.27
herb	0.03	0.01	0.02	67	0.03	0.03
shrub	0.04	0.02	0.02	50	0.03	0.03
Total	**16.31**	**2.34**	**13.97**	**86**	**10.31**	**11.79**

Overstory Characteristics, Tree Damage, and Predicted Mortality

Diameter Class	Tree Density	Tree Basal Area	Measured Crown Volume Scorched	Measured Bole Char Height	FOFEM Predicted Mortality	FOFEM Predicted Mortality
	trees acre^{-1}	*ft^2 ac^{-1}*	*%*	*ft*	*% trees acre^{-1}*	*% basal area*
0-2	75	0.4	92	N/C	97	N/C
> 2	118	94.2	44	N/C	27	N/C
All	193	94.6	54	5.1	65	16

N/C = Not calculated

ORION
(Okanogan-Wenatchee National Forest)

PRE-BURN

POST-BURN

Fuel Load and Consumption

	Pre-Fire Load	Post-Fire Load	Measured Consumption	Measured Consumption	Consume 2.1 Consumption	Consume 4.2 Consumption
Fuelbed Category	*tons acre^{-1}*			*%*	*tons acre^{-1}-*	
1 h	0.01	0.01	0.00	0	0.01	0.01
10 h	0.53	0.31	0.22	42	0.44	0.46
100 h	0.84	0.37	0.47	56	0.68	0.66
1000 h S	0.70	0.18	0.52	74	0.23	0.43
1000 h R	0.82	0.34	0.48	59	0.17	0.65
litter	2.53	0.42	2.11	83	1.72	2.53
duff	9.26	3.77	5.49	59	4.36	2.95
herb	0.14	0.03	0.11	79	0.14	0.13
shrub	0.07	0.00	0.07	100	0.05	0.05
Total	**14.90**	**5.43**	**9.47**	**64**	**7.78**	**7.87**

Overstory Characteristics, Tree Damage, and Predicted Mortality

Diameter Class	Tree Density	Tree Basal Area	Measured Crown Volume Scorched	Measured Bole Char Height	FOFEM Predicted Mortality	FOFEM Predicted Mortality
	trees acre^{-1}	*ft^2 ac^{-1}*	*%*	*ft*	*% trees acre^{-1}*	*% basal area*
0-2	109	0.4	51	N/C	100	N/C
> 2	50	87.7	26	N/C	7	N/C
All	159	88.1	42	2.7	74	7

N/C = Not calculated

PARADISE 90
(Colville National Forest)

PRE-BURN

POST-BURN

Fuel Load and Consumption

	Pre-Fire Load	**Post-Fire Load**	**Measured Consumption**	**Measured Consumption**	**Consume 2.1 Consumption**	**Consume 4.2 Consumption**
Fuelbed Category	*tons acre^{-1}*			*%*	*tons acre^{-1}*	
1 h	0.26	0.07	0.19	73	0.26	0.26
10 h	1.49	0.41	1.08	72	1.32	1.29
100 h	1.64	0.71	0.93	57	1.34	1.29
1000 h S	7.97	3.67	4.30	54	1.88	2.36
1000 h R	2.76	0.76	2.00	72	0.52	1.28
litter	1.57	0.64	0.93	59	0.93	1.57
duff	29.71	10.74	18.97	64	15.66	7.21
herb	0.05	0.03	0.02	40	0.05	0.05
shrub	0.38	0.35	0.03	8	0.27	0.25
Total	**45.83**	**17.38**	**28.45**	**62**	**22.22**	**15.56**

Overstory Characteristics, Tree Damage, and Predicted Mortality

Diameter Class	**Tree Density**	**Tree Basal Area**	**Measured Crown Volume Scorched**	**Measured Bole Char Height**	**FOFEM Predicted Mortality**	**FOFEM Predicted Mortality**
	trees acre^{-1}	*ft^2 ac^{-1}*	*%*	*ft*	*% trees acre^{-1}*	*% basal area*
0-2	137	0.5	18	N/C	39	N/C
> 2	125	98.6	8	N/C	10	N/C
All	262	99.1	8	1.6	26	9

N/C = Not calculated

25 MILE
(Okanogan-Wenatchee National Forest)

PRE BURN

POST BURN

Fuel Load and Consumption

	Pre-Fire Load	Post-Fire Load	Measured Consumption	Measured Consumption	Consume 2.1 Consumption	Consume 4.2 Consumption
Fuelbed Category	*tons acre^{-1}*			*%*	*tons acre^{-1}*	
1 h	0.07	0.03	0.04	56	0.07	0.07
10 h	0.77	0.28	0.49	64	0.66	0.67
100 h	1.28	0.55	0.72	57	0.85	1.03
1000 h S	6.07	5.6	0.47	8	0.72	0.71
1000 h R	3.24	2.75	0.49	15	0.29	0.73
litter	3.93	2.33	1.6	41	2.43	2.68
duff	7.11	6.15	0.97	14	1.31	0.00
herb	0.16	0.04	0.12	75	0.16	0.15
shrub	0.12	0.1	0.02	18	0.08	0.08
Total	**22.75**	**17.83**	**4.92**	**22**	**6.57**	**6.12**

Overstory Characteristics, Tree Damage, and Predicted Mortality

Diameter Class	Tree Density	Tree Basal Area	Measured Crown Volume Scorched	Measured Bole Char Height	FOFEM Predicted Mortality	FOFEM Predicted Mortality
	trees acre^{-1}	*ft^{2} ac^{-1}*	*%*	*ft*	*% trees acre^{-1}*	*% basal area*
0-2	86	0.1	100	N/C	84	N/C
> 2	81	116.6	22	N/C	10	N/C
All	167	116.7	36	3.4	49	9

N/C = Not calculated

Sherman Creek
(Sherman Creek Wildlife Area)

PRE BURN

POST BURN

Fuel Load and Consumption

	Pre-Fire Load	Post-Fire Load	Measured Consumption	Measured Consumption	Consume 2.1 Consumption	Consume 4.2 Consumption
Fuelbed Category	*tons acre^{-1}*			*%*	*tons acre^{-1}*	
1 h	0.03	0.02	0.01	29	0.03	0.03
10 h	0.89	0.79	0.11	12	0.78	0.78
100 h	1.79	1.49	0.30	17	0.99	1.45
1000 h S	4.58	4.58	0.00	0	0.09	0.08
1000 h R	1.75	1.32	0.43	25	0.02	0.07
litter	2.04	0.48	1.55	76	0.68	0.71
duff	13.90	13.43	0.48	3	1.29	0.00
herb	0.27	0.12	0.14	54	0.27	0.25
shrub	0.08	0.03	0.05	62	0.06	0.05
Total	**25.33**	**22.26**	**3.07**	**12**	**4.21**	**3.42**

Overstory Characteristics, Tree Damage, and Predicted Mortality

Diameter Class	Tree Density	Tree Basal Area	Measured Crown Volume Scorched	Measured Bole Char Height	FOFEM Predicted Mortality	FOFEM Predicted Mortality
	trees acre^{-1}	*ft^2 ac^{-1}*	*%*	*ft*	*% trees acre^{-1}*	*% basal area*
0-2	1	0	40	N/C	N/A	N/C
> 2	31	47.3	1	N/C	0	N/C
All	32	47.3	1	1.1	0	6

N/C = Not calculated

Hanlon
(Colville National Forest)

PRE-BURN

Fuel Load and Consumption

	Pre-Fire Load	Post-Fire Load	Measured Consumption	Measured Consumption
Fuelbed Category	*tons acre^{-1}*			*%*
1 h	0.42	-	-	-
10 h	1.27	-	-	-
100 h	1.14	-	-	-
1000 h S	1.02	-	-	-
1000 h R	2.56	-	-	-
litter	1.81	-	-	-
duff	14.27	-	-	-
herb	0.01	-	-	-
shrub	0.31	-	-	-
Total	**22.81**	**-**	**-**	**-**

Overstory Characteristics, Tree Damage, and Predicted Mortality

Diameter Class	Tree Density	Tree Basal Area	Measured Crown Volume Scorched	Measured Bole Char Height	FOFEM Predicted Mortality	FOFEM Predicted Mortality
	trees acre^{-1}	*ft^2 ac^{-1}*	*%*	*ft*	*% trees acre^{-1}*	*% basal area*
0-2	21	0.1	-	-	-	-
> 2	187	91.4	-	-	-	-
All	208	91.5	-	-	-	-

8 MILE
(Okanogan-Wenatchee National Forest)

PRE BURN

Fuel Load and Consumption

	Pre-Fire Load	Post-Fire Load	Measured Consumption	Measured Consumption
Fuelbed Category	*tons acre^{-1}*			*%*
1 h	0.19	-	-	-
10 h	1.18	-	-	-
100 h	1.79	-	-	-
1000 h S	4.80	-	-	-
1000 h R	3.87	-	-	-
litter	2.65	-	-	-
duff	15.13	-	-	-
herb	0.07	-	-	-
shrub	0.51	-	-	-
Total	**30.19**	**-**	**-**	**-**

Overstory Characteristics, Tree Damage, and Predicted Mortality

Diameter Class	Tree Density	Tree Basal Area	Measured Crown Volume Scorched	Measured Bole Char Height	FOFEM Predicted Mortality	FOFEM Predicted Mortality
	trees acre^{-1}	*ft^2 ac^{-1}*	*%*	*ft*	*% trees acre^{-1}*	*% basal area*
0-2	1	0	-	-	-	-
> 2	37	71.6	-	-	-	-
All	38	71.6	-	-	-	-

CANTEEN
(Okanogan-Wenatchee National Forest)

PRE BURN

Fuel Load and Consumption

	Pre-Fire Load	Post-Fire Load	Measured Consumption	Measured Consumption
Fuelbed Category	*tons acre^{-1}*			*%*
1 h	0.54	-	-	-
10 h	2.63	-	-	-
100 h	4.17	-	-	-
1000 h S	4.56	-	-	-
1000 h R	8.68	-	-	-
litter	1.14	-	-	-
duff	25.28	-	-	-
herb	0.22	-	-	-
shrub	0.08	-	-	-
Total	**47.30**	**-**	**-**	**-**

Overstory Characteristics, Tree Damage, and Predicted Mortality

Diameter Class	Tree Density	Tree Basal Area	Measured Crown Volume Scorched	Measured Bole Char Height	FOFEM Predicted Mortality	FOFEM Predicted Mortality
	trees acre^{-1}	*ft^2 ac^{-1}*	*%*	*ft*	*% trees acre^{-1}*	*% basal area*
0-2	91	0.4	-	-	-	-
> 2	48	30.2	-	-	-	-
All	139	30.6	-	-	-	-

GOAT
(Okanogan-Wenatchee National Forest)

PRE BURN

Fuel Load and Consumption

	Pre-Fire Load	Post-Fire Load	Measured Consumption	Measured Consumption
Fuelbed Category	*tons acre^{-1}*			*%*
1 h	0.18	-	-	-
10 h	1.11	-	-	-
100 h	1.60	-	-	-
1000 h S	3.42	-	-	-
1000 h R	2.46	-	-	-
litter	2.65	-	-	-
duff	17.88	-	-	-
herb	0.10	-	-	-
shrub	0.00	-	-	-
Total	**29.40**	**-**	**-**	**-**

Overstory Characteristics, Tree Damage, and Predicted Mortality

Diameter Class	Tree Density	Tree Basal Area	Measured Crown Volume Scorched	Measured Bole Char Height	FOFEM Predicted Mortality	FOFEM Predicted Mortality
	trees acre^{-1}	*ft^2 ac^{-1}*	*%*	*ft*	*% trees acre^{-1}*	*% basal area*
0-2	475	2.5	-	-	-	-
> 2	91	85.7	-	-	-	-
All	566	88.2	-	-	-	-

NATAPOC
(Okanogan-Wenatchee National Forest)

PRE BURN

Fuel Load and Consumption

	Pre-Fire Load	Post-Fire Load	Measured Consumption	Measured Consumption
Fuelbed Category	*tons acre^{-1}*			*%*
1 h	1.46	-	-	-
10 h	4.34	-	-	-
100 h	6.06	-	-	-
1000 h S	13.10	-	-	-
1000 h R	10.28	-	-	-
litter	2.15	-	-	-
duff	14.27 [a]	-	-	-
herb	0.17	-	-	-
shrub	0.44	-	-	-
Total	**52.27**	**-**	**-**	**-**

[a] Duff load assumed to be similar to Hanlon for modeling

Overstory Characteristics, Tree Damage, and Predicted Mortality

Diameter Class	Tree Density	Tree Basal Area	Measured Crown Volume Scorched	Measured Bole Char Height	FOFEM Predicted Mortality	FOFEM Predicted Mortality
	trees acre^{-1}	*ft^2 ac^{-1}*	*%*	*ft*	*% trees acre^{-1}*	*% basal area*
0-2	127	0.4	-	-	-	-
> 2	37	63.7	-	-	-	-
All	164	64.1	-	-	-	-

OAK CREEK
(Oak Creek Wildlife Area)

PRE BURN

Fuel Load and Consumption

	Pre-Fire Load	Post-Fire Load	Measured Consumption	Measured Consumption
Fuelbed Category	*tons acre^{-1}*			*%*
1 h	0.42	-	-	-
10 h	1.03	-	-	-
100 h	1.50	-	-	-
1000 h S	10.03	-	-	-
1000 h R	7.89	-	-	-
litter	1.21	-	-	-
duff	19.55	-	-	-
herb	0.11	-	-	-
shrub	0.02	-	-	-
Total	**41.76**	**-**	**-**	**-**

Overstory Characteristics, Tree Damage, and Predicted Mortality

Diameter Class	Tree Density	Tree Basal Area	Measured Crown Volume Scorched	Measured Bole Char Height	FOFEM Predicted Mortality	FOFEM Predicted Mortality
	trees acre^{-1}	*ft^2 ac^{-1}*	*%*	*ft*	*% trees acre^{-1}*	*% basal area*
0-2	298	1.4	-	-	-	-
> 2	192	87.9	-	-	-	-
All	490	89.3	-	-	-	-

UR-1
(Okanogan-Wenatchee National Forest)

PRE BURN

Fuel Load and Consumption

	Pre-Fire Load	Post-Fire Load	Measured Consumption	Measured Consumption
Fuelbed Category	*tons acre^{-1}*			*%*
1 h	0.15	-	-	-
10 h	0.76	-	-	-
100 h	1.87	-	-	-
1000 h S	2.04	-	-	-
1000 h R	6.70	-	-	-
litter	2.21	-	-	-
duff	26.45	-	-	-
herb	0.02	-	-	-
shrub	0.07	-	-	-
Total	**40.27**	**-**	**-**	**-**

Overstory Characteristics, Tree Damage, and Predicted Mortality

Diameter Class	Tree Density	Tree Basal Area	Measured Crown Volume Scorched	Measured Bole Char Height	FOFEM Predicted Mortality	FOFEM Predicted Mortality
	trees acre^{-1}	*ft^2 ac^{-1}*	*%*	*ft*	*% trees acre^{-1}*	*% basal area*
0-2	1264	7.3	-	-	-	-
> 2	95	85.4	-	-	-	-
All	1359	92.7	-	-	-	-

Vulcan
(Colville National Forest)

PRE BURN

Fuel Load and Consumption

	Pre-Fire Load	Post-Fire Load	Measured Consumption	Measured Consumption
Fuelbed Category	*tons acre^{-1}*			*%*
1 h	0.34	-	-	-
10 h	1.61	-	-	-
100 h	2.93	-	-	-
1000 h S	3.85	-	-	-
1000 h R	6.10	-	-	-
litter	1.71	-	-	-
duff	29.71[a]	-	-	-
herb	0.05	-	-	-
shrub	0.36	-	-	-
Total	**46.66**	**-**	**-**	**-**

[a] Duff load assumed to be similar to Paradise 90 for modeling

Overstory Characteristics, Tree Damage, and Predicted Mortality

Diameter Class	Tree Density	Tree Basal Area	Measured Crown Volume Scorched	Measured Bole Char Height	FOFEM Predicted Mortality	FOFEM Predicted Mortality
	trees acre^{-1}	*ft^2 ac^{-1}*	*%*	*ft*	*% trees acre^{-1}*	*% basal area*
0-2	16	0	-	-	-	-
> 2	135	97.9	-	-	-	-
All	151	97.9	-	-	-	-

Appendix B

Table B1 – Results of Consume version 2.1 and 4.2 model outputs for all Forest Resiliency Burning Pilot project units under Fall 2016 and Spring 2017 fuel moisture scenarios.

ANGEL		*Fall 2016 Moisture Conditions*		*Spring 2017 Moisture Conditions*	
Category	**Pre-Fire Load (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**
1 h	0.38	0.38	0.38	0.38	0.38
10 h	1.09	0.95	0.94	0.95	0.94
100 h	1.47	1.19	1.03	0.80	1.15
1000 h S	2.62	0.66	1.28	0.11	0.12
1000 h R	4.85	0.92	2.83	0.14	0.54
litter	2.47	1.62	2.47	1.13	1.10
duff	11.07	5.15	2.79	1.59	0.00
herb	0.06	0.06	0.06	0.06	0.06
shrub	0.13	0.09	0.09	0.09	0.09
Total	**24.14**	**11.02**	**11.87**	**5.25**	**4.38**

CHUMSTICK		*Fall 2016 Moisture Conditions*		*Spring 2017 Moisture Conditions*	
Category	**Pre-Fire Load (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**
1 h	0.12	0.12	0.12	0.12	0.12
10 h	1.28	1.13	1.11	1.13	1.11
100 h	2.71	2.27	2.13	1.88	2.13
1000 h S	2.46	0.85	1.57	0.14	0.14
1000 h R	0.10	0.02	0.09	0.00	0.01
litter	4.24	2.99	4.24	2.34	1.89
duff	5.33	1.84	1.34	0.00	0.00
herb	0.03	0.03	0.03	0.03	0.03
shrub	0.04	0.03	0.03	0.03	0.03
Total	**16.31**	**9.28**	**10.66**	**5.67**	**5.46**

ORION		*Fall 2016 Moisture Conditions*		*Spring 2017 Moisture Conditions*	
Category	**Pre-Fire Load (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**
1 h	0.01	0.01	0.01	0.01	0.01
10 h	0.53	0.44	0.46	0.44	0.46
100 h	0.84	0.65	0.66	0.25	0.66
1000 h S	0.70	0.21	0.38	0.03	0.03
1000 h R	0.82	0.16	0.61	0.02	0.08
litter	2.53	1.67	2.53	1.17	1.13
duff	9.26	4.12	2.34	0.83	0.00
herb	0.14	0.14	0.13	0.14	0.13
shrub	0.07	0.05	0.05	0.05	0.05
Total	**14.90**	**7.45**	**7.17**	**2.94**	**2.55**

PARADISE 90		*Fall 2016 Moisture Conditions*		*Spring 2017 Moisture Conditions*	
Category	**Pre-Fire Load (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**
1 h	0.26	0.26	0.26	0.26	0.26
10 h	1.49	1.32	1.29	1.32	1.29
100 h	1.64	1.34	1.29	0.95	1.29
1000 h S	7.97	1.89	3.80	0.30	0.34
1000 h R	2.76	0.53	1.73	0.08	0.31
litter	1.57	0.93	1.57	0.52	0.70
duff	29.71	15.57	7.49	9.35	0.00
herb	0.05	0.05	0.05	0.05	0.05
shrub	0.38	0.27	0.25	0.27	0.25
Total	**45.83**	**22.16**	**17.73**	**13.10**	**4.49**

HANLON		*Fall 2016 Moisture Conditions*		*Spring 2017 Moisture Conditions*	
Category	**Pre-Fire Load (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**
1 h	0.42	0.42	0.42	0.42	0.42
10 h	1.27	1.12	1.10	1.12	1.10
100 h	1.14	0.91	0.89	0.51	0.89
1000 h S	1.02	0.39	0.73	0.06	0.06
1000 h R	2.56	0.49	1.57	0.08	0.28
litter	1.81	1.11	1.81	0.68	0.81
duff	14.27	6.94	3.60	2.90	0.00
herb	0.01	0.01	0.01	0.01	0.01
shrub	0.31	0.22	0.21	0.22	0.21
Total	**22.81**	**11.61**	**10.33**	**6.00**	**3.78**

25 MILE		*Fall 2016 Moisture Conditions*		*Spring 2017 Moisture Conditions*	
Category	**Pre-Fire Load (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**
1 h	0.07	0.07	0.07	0.07	0.07
10 h	0.77	0.66	0.67	0.66	0.67
100 h	1.28	1.05	1.03	0.66	1.03
1000 h S	6.07	1.45	2.79	0.23	0.26
1000 h R	3.24	0.59	1.82	0.09	0.35
litter	3.93	2.76	3.93	2.14	1.54
duff	7.11	2.87	0.43	0.00	0.00
herb	0.16	0.16	0.15	0.16	0.15
shrub	0.12	0.08	0.08	0.08	0.08
Total	**22.75**	**9.69**	**10.97**	**4.09**	**4.08**

8 MILE		*Fall 2016 Moisture Conditions*		*Spring 2017 Moisture Conditions*	
Category	**Pre-Fire Load (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**
1 h	0.19	0.19	0.19	0.19	0.19
10 h	1.18	1.03	1.02	1.03	1.02
100 h	1.79	1.47	1.40	1.08	1.40
1000 h S	4.80	1.18	2.32	0.20	0.21
1000 h R	3.87	0.74	2.52	0.21	0.48
litter	2.65	1.76	2.65	1.26	1.18
duff	15.13	7.43	3.82	3.25	0.00
herb	0.07	0.07	0.06	0.07	0.06
shrub	0.51	0.36	0.34	0.36	0.34
Total	**30.19**	**14.23**	**14.32**	**7.65**	**4.88**

CANTEEN		*Fall 2016 Moisture Conditions*		*Spring 2017 Moisture Conditions*	
Category	**Pre-Fire Load (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**
1 h	0.54	0.54	0.54	0.54	0.54
10 h	2.63	2.36	2.27	2.36	2.27
100 h	4.17	3.54	3.27	3.15	3.27
1000 h S	4.56	1.36	2.53	0.22	0.23
1000 h R	8.68	1.65	5.40	0.26	1.31
litter	1.14	0.60	1.14	0.29	0.51
duff	25.28	13.22	6.38	7.49	0.00
herb	0.22	0.22	0.20	0.22	0.20
shrub	0.08	0.06	0.05	0.06	0.05
Total	**47.30**	**23.55**	**21.78**	**14.59**	**8.38**

GOAT		*Fall 2016 Moisture Conditions*		*Spring 2017 Moisture Conditions*	
Category	**Pre-Fire Load (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**
1 h	0.18	0.18	0.18	0.18	0.18
10 h	1.11	0.97	0.96	0.97	0.96
100 h	1.60	1.31	1.26	0.91	1.26
1000 h S	3.42	0.95	1.84	0.15	0.16
1000 h R	2.46	0.47	1.50	0.07	0.27
litter	2.65	1.76	2.65	1.26	1.18
duff	17.88	9.01	4.51	4.41	0.00
herb	0.10	0.10	0.09	0.10	0.09
shrub	0.00	0.00	0.00	0.00	0.00
Total	**29.40**	**14.75**	**12.99**	**8.05**	**4.10**

NATAPOC		*Fall 2016 Moisture Conditions*		*Spring 2017 Moisture Conditions*	
Category	**Pre-Fire Load (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**
1 h	1.46	1.46	1.46	1.46	1.46
10 h	4.34	3.93	3.75	3.93	3.75
100 h	6.06	5.18	4.75	4.79	4.75
1000 h S	13.10	4.52	8.40	0.73	0.72
1000 h R	10.28	1.96	7.25	0.30	2.05
litter	2.15	1.38	2.15	0.93	0.96
duff	14.27 [a]	6.94	3.60	2.90	0.00
herb	0.17	0.17	0.16	0.17	0.16
shrub	0.44	0.31	0.29	0.31	0.29
Total	**52.27**	**25.85**	**31.81**	**15.52**	**14.14**

[a] Duff load assumed to be similar to Hanlon for modeling consumption.

OAK CREEK		*Fall 2016 Moisture Conditions*		*Spring 2017 Moisture Conditions*	
Category	**Pre-Fire Load (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**
1 h	0.42	0.42	0.42	0.42	0.42
10 h	1.03	0.90	0.89	0.90	0.89
100 h	1.50	1.22	1.18	0.83	1.18
1000 h S	10.03	2.31	4.40	0.36	0.42
1000 h R	7.89	1.50	5.07	0.23	0.97
litter	1.21	0.65	1.21	0.30	0.54
duff	19.55	9.98	4.93	5.12	0.00
herb	0.11	0.11	0.10	0.11	0.10
shrub	0.02	0.01	0.01	0.01	0.01
Total	**41.76**	**17.10**	**18.21**	**8.28**	**4.53**

SHERMAN CREEK		*Fall 2016 Moisture Conditions*		*Spring 2017 Moisture Conditions*	
Category	**Pre-Fire Load (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**
1 h	0.03	0.03	0.03	0.03	0.03
10 h	0.89	0.78	0.78	0.78	0.78
100 h	1.79	1.52	1.45	1.13	1.45
1000 h S	4.58	1.42	2.63	0.23	0.23
1000 h R	1.75	0.34	1.37	0.05	0.22
litter	2.04	1.30	2.04	0.85	1.21
duff	13.90	6.74	5.40	2.75	0.00
herb	0.27	0.27	0.25	0.27	0.25
shrub	0.08	0.06	0.05	0.06	0.05
Total	**25.33**	**12.46**	**14.00**	**6.15**	**4.22**

UR-1		*Fall 2016 Moisture Conditions*		*Spring 2017 Moisture Conditions*	
Category	**Pre-Fire Load (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**
1 h	0.15	0.15	0.15	0.15	0.15
10 h	0.76	0.65	0.66	0.65	0.66
100 h	1.87	1.54	1.47	1.15	1.47
1000 h S	2.04	0.70	1.31	0.12	0.11
1000 h R	6.70	1.28	3.52	0.20	0.83
litter	2.21	1.44	2.21	0.97	0.99
duff	26.45	13.91	6.67	7.99	0.00
herb	0.02	0.02	0.02	0.02	0.02
shrub	0.07	0.05	0.05	0.05	0.05
Total	**40.27**	**19.74**	**16.06**	**11.30**	**4.28**

VULCAN		*Fall 2016 Moisture Conditions*		*Spring 2017 Moisture Conditions*	
Category	**Pre-Fire Load (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**	**Consume 2.1 Consumption (tons acre^{-1})**	**Consume 4.2 Consumption (tons acre^{-1})**
1 h	0.34	0.34	0.34	0.34	0.34
10 h	1.61	1.43	1.39	1.43	1.39
100 h	2.93	2.46	2.30	2.07	2.30
1000 h S	3.85	1.32	2.45	0.22	0.21
1000 h R	6.10	1.16	4.34	0.18	1.01
litter	1.71	1.04	1.71	0.62	0.76
duff	29.71[a]	15.74	7.49	9.35	0.00
herb	0.05	0.05	0.05	0.05	0.05
shrub	0.36	0.25	0.24	0.25	0.24
Total	**46.66**	**23.79**	**20.31**	**14.51**	**6.30**

[a] Duff load assumed to be similar to Paradise 90 for modeling consumption.

Appendix C

Table C1 – Sampling and processing procedures for dry-weight biomass and fuel moisture

Fuel Type	Samples per site	Maximum time before ignition (hrs)	Oven Temperature (°F)	Duration (hours)	Sampled in standing fuel plots
Grass	10	1	158	48	Yes
Forbs	--	--	158	48	Yes
Shrubs	10	6	158	48	Yes
1-h	10	1	158	48	No
10-h	10	6	158	48	No
100-h	10	24	212	48	No
1000-h	20	24	212	48	No
Litter	10	1	158	48	No
Duff	10	24	212	48	No

Table C2 – Sampling plot radii (meters) for trees and shrubs by unit.

Unit	Seedlings, Saplings & Shrub counts	Shrubs (Ht > 4.5')	Trees (<3" DBH)	Trees (Ht > 4.5')	Trees (>24" DBH)	Overstory plots	Notes
25 Mile	2	3	3	10	15	10	
8 Mile Bottom	2	2	20	20	20	10	
Angel	2	2	3	10	15	10	
Canteen	2	2	12	12	12	20	
Chumstick	2	2	10	10	10	10	
Goat	2	2	4	15	15	10	
Hanlon	2	2	6	6	10	10	
Natapoc	2	3	3	15	15	10	
OakCreek	2	2	4	4	7	20	
Orion 2	2	2	15	15	15	10	
Paradise 90	2	2	7	7	10	10	
Sherman Creek	2	2	20	20	20	10	
UR-1	2	2	4*	10	10	10	<1" DBH = 3m
Vulcan	2	4	4	9	9	10	

Appendix B

Smoke and Air Quality Monitoring Data Report in Support of the Washington State Department of Natural Resources 2016-17 Forest Resiliency Burning Pilot Project

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1. INTRODUCTION

Washington Department of Natural Resource (DNR) and the U.S. Forest Service, Pacific Wildland Fire Sciences Lab, collaborated to implement an air quality monitoring study designed to respond in part to the requirements of Engrossed Substitute House Bill (ESHB) 2928 passed by the Washington State Legislature during the 2016 regular session. ESHB 2928 instructed DNR to conduct a forest resiliency burning pilot project to monitor and evaluate the benefits of forest resiliency burning and the impacts on ambient air quality. Specifically they provided funding to (http://www.putfiretowork.org/):

- Safely complete controlled burns in priority areas
- Give 24 hour advance notice of burn approval to fire managers to encourage safe and successful completion of planned burns, and make it easier to complete multi-day burns
- Fully inform the public of planned burns, their purpose and projected effects
- Monitor how much smoke was forecasted and ultimately created by Pilot controlled burning and make recommendations for updating the DNR Smoke Management Plan
- Analyze and monitor fuel reductions and conditions of the forest stands before and after controlled burning
- Track outcomes and make recommendations for Pilot controlled burning to achieve more resilient forest conditions and reduce wildfire risks to communities in Washington

This report summarizes results of the ambient air quality monitoring portion of the pilot project and where available provides analysis of whether giving 24-hr advance notice of burn approvals to fire managers (instead of day-of-burn approval) had any noticeable impacts to air quality.

2. METHODS

2.1 Air Quality Monitoring Network

Fifteen potential pilot burn areas were identified on the Okanogan-Wenatchee National Forest (10 pilot units), the Colville National Forest (3 pilot units), and on lands managed by the Washington Department of Fish and Wildlife (2 pilot units) (Figure 1). Expert opinion from the fire managers about possible smoke movement from these pilot burns was used to identify locations for air quality monitoring. State air quality monitoring instruments were already in place at some of the at-risk locations but many locations were not represented. Nine temporary, portable monitors were deployed to locations throughout the state to detect air quality impacts from prescribed burning during the fall 2016 period of the pilot study and five were deployed during the spring of 2017.

Choosing an exact location for one of the temporary monitoring instruments depended on several factors 1) monitors needed to be in an area thought to be at risk from smoke impacts from a pilot burn, 2) monitors would ideally be placed near towns or other populated areas where people were likely to be affected by smoke, 3) access to electrical power, and 4) a clear view of the sky to allow data transfer via satellite modem. Figure 2 shows the locations of both the permanent (4) and temporary (9) monitors used in this study, in addition to the pilot burns from Figure 1. Table 1 lists details about the monitors including information on whether the monitor was permanent or temporary, what kind of monitor was used, and the nearest planned pilot burn. Figure 3 shows an example of one of the 9 temporary monitors deployed.

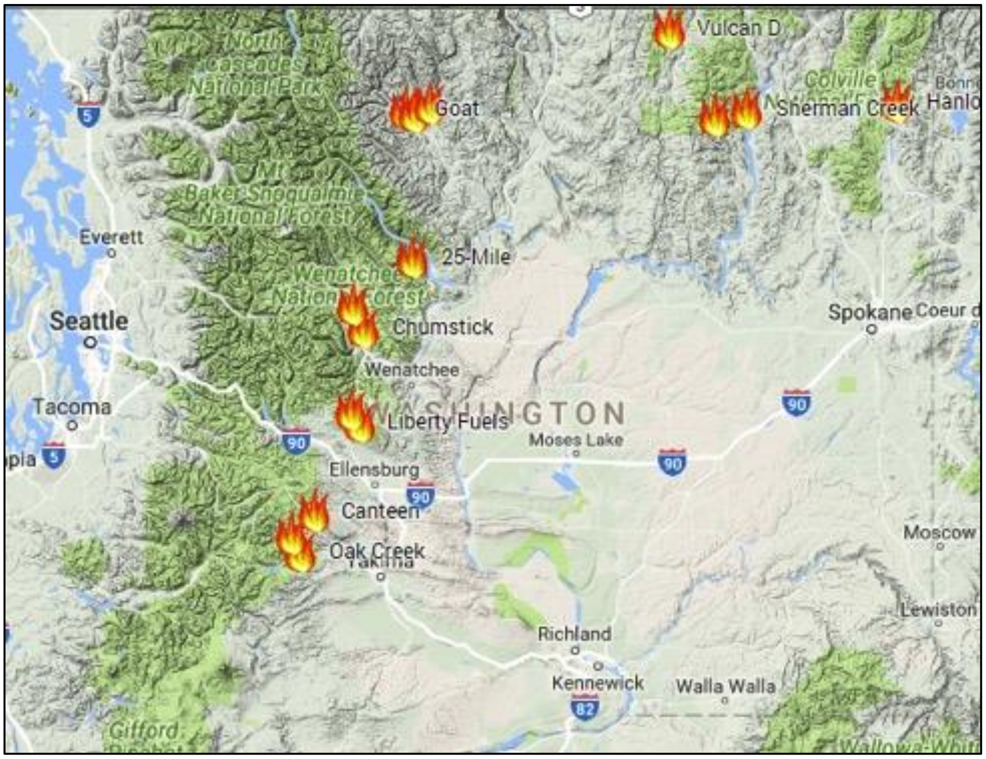


Figure 1: Location of the 15 proposed pilot burn units.

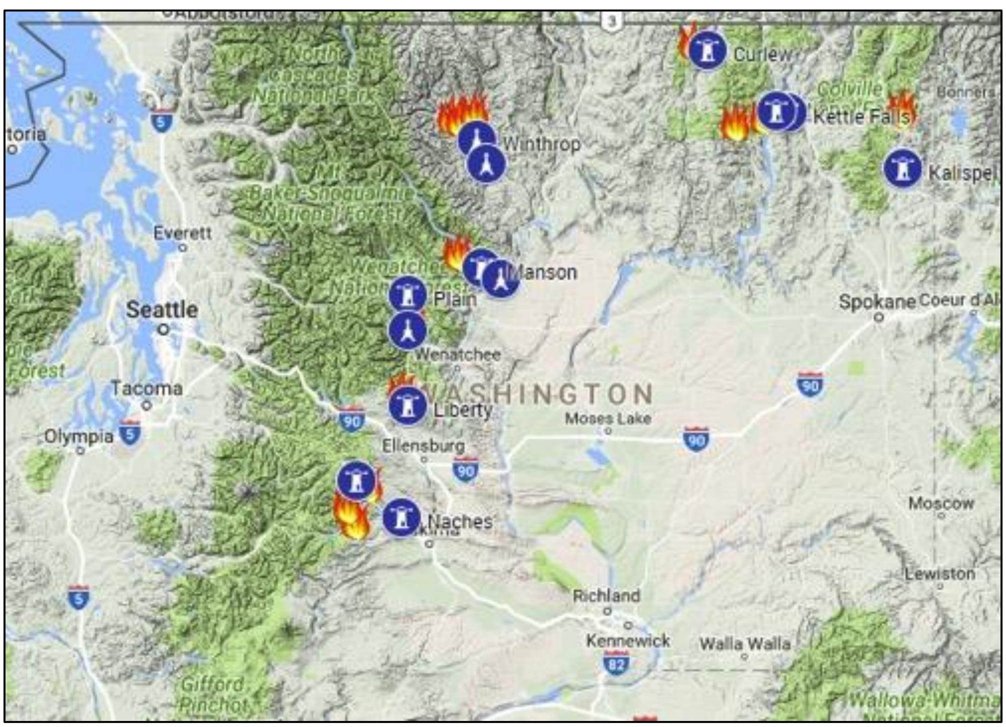


Figure 2. Locations of air quality monitors and 15 proposed pilot burns. The monitors at Leavenworth, Chelan, Twisp, and Winthrop are permanent (the narrow figure in the blue icons), others were installed for the study (the wide figure in the blue icons).

Table 1. Air quality monitors used for the 2928 Pilot burns, including location, name of nearest pilot burn units, and type of particulate monitor. "Neph" refers to Radiance Research M903 nephelometer, and EBAM and E-Sampler refer to the Met-One instruments. Nine temporary monitors were deployed in fall 2016 and five temporary monitors were deployed in spring 2017.

Air Quality Monitors	Location & Year	Nearby pilot burns	Latitude, Longitude	Monitor Type
Permanent	Winthrop	Goat, Eight Mile Bottom, Upper Rendezvous	48.48, -120.19	Neph
	Twisp	Goat, Eight Mile Bottom, Upper Rendezvous	48.36, -120.12	Neph
	Chelan	25 Mile	47.84, -120.02	Neph
	Leavenworth	Natapoc, Chumstick	47.60, -120.66	Neph
Temporary	Manson (2016,2017)	25 Mile	47.89, -120.15	EBAM
	Plain (2016)	Natapoc, Chumstick	47.77, -120.66	EBAM
	Liberty (2016)	Orion, Liberty Fuels	47.25, -120.67	EBAM
	Naches (2016, 2017)	Canteen, Angel, Oak Creek	46.73, -120.71	E-Sampler
	Pinecliff (2016, 2017)	Canteen, Angel, Oak Creek	46.90, -121.02	E-Sampler
	Curlew (2016)	Vulcan D	48.88, -118.61	EBAM
	Hatchery (2016, 2017)	Paradise 90, Sherman Creek	48.61, -118.13	EBAM
	Kettle Falls (2016, 2017)	Paradise 90, Sherman Creek	48.60, -118.06	E-Sampler
	Kalispel Tribal Center (2016)	Hanlon	48.34, -117.27	E-Sampler


Figure 3. Example of one of the E-Samplers deployed as part of the Pilot Burn Project. This unit was deployed at the Volunteer Fire Department in Plain, WA.

2.2 Prescribed Burn and Satellite Hotspot Information

The overall goal of the air quality monitoring portion of the pilot burn study was to test whether the 24-hour advance approval of prescribed burns increased the likelihood of air quality impacts. To do this other potential sources of air pollution that could impact a monitor need to be considered (not just the Pilot burns). Therefore, all prescribed burning events needed to be part of the analysis including those that received the standard day-of-burn approval. Other sources of air quality degradation could be present at the sites but were not identified as part of this study. They include sources such as wildfires, prescribed burning of <100 tons (does not need a permit so is not in the DNR database), tribal burning (which operates under Environmental Protection Agency authority), field burning, backyard burning, home wood heating, and any anthropogenic sources that may impact the more urbanized locations.

The DNR smoke management permitting webpage (https://fortress.wa.gov/dnr/protection/burnrequests/) was used to gather prescribed burn records for all pilot and non-pilot burning during the period of the study. Records of prescribed burns which received smoke management approval between Sept 1 and October 15, 2016 or April 1 thru June 23, 2017; reported accomplishments (i.e. were actually burned); and were located in the vicinity of the pilot burn study area were compiled. The DNR webpage was the source for date-of-burn, latitude/longitude of burn, and whether the burn received smoke management approval. DNR is known to rely on an older method of calculating fuel consumed that is especially suspect for modeling fuel consumption on the forests of the eastside of the Cascades. For this reason, reported fuel consumed from prescribed burning was retrieved from a federal burn-reporting database as information reported by Forest Service fire managers was believed to be more reliable and consistent. DNR reported consumption values were used for Washington Department of Fish and Wildlife burns. Appendix A provides a list of all the prescribed burning activity analyzed in this report.

In the future, it would be valuable to compare estimates of fuel consumed from both of the DNR estimates and FS estimates to the results of the companion study which measured fuel loading and consumption on many of the burns proposed for the pilot study (See the companion USDA Forest Service Pacific Wildland Fire Sciences Laboratory Report *Pre- and Post-Burn Fuel Characterization and Tree Mortality Assessment for the Forest Resiliency Burning Pilot*).

Satellites can detect "hotspots" on the ground which can be an alternative source of basic information about burning that does not show up in the prescribed fire database. Several different satellites detect "hotspots" which are reported in the National Oceanic and Atmospheric Administration (NOAA) Hazard Mapping System (HMS) product. Many factors affect how successful the satellites are at detecting fires, including the size of the fire and cloudiness. The geographic location of each hotspot was matched to GIS-mapped fuel types so a rough fire size and fuel consumed could be estimated. In some cases these hotspots are very likely the prescribed burns that are already in the database, in other cases it is likely they are the other unquantified categories of fires described previously.

2.3 Quantifying Air Quality Conditions

The Environmental Protection Agency (EPA) sets air quality standards for the purpose of protecting human health. PM2.5 is the primary regulated pollutant of concern when considering smoke from fires. The national ambient air quality standard (NAAQS) for fine particulate matter (PM2.5) is 35 $\mu g/m^3$ averaged over 24-hours. The EPA has also developed a simple index that can be used when communicating air quality conditions with the public (Table 2). The air quality index (AQI) color codes air quality conditions in one of 6 health-based categories depending on the level of PM2.5 concentration. It is important to note that these categories are based on 24-hour averages. People can often be concerned about smoke or feel health effects from smoke in a much shorter time period than 24-hours. For this reason tracking both 24-hour averages measured at the monitoring network but also short term 1-hour averages was important. One hour average PM2.5 does not have any official regulatory significance but it can indicate when the public may be affected or concerned by smoke concentrations. Wildland fire smoke can cause dramatic, short-term changes in $PM_{2.5}$ concentration however, the AQI for particle pollution is a 24-hour average to reflect EPA's national ambient air quality standards and the science on PM exposures and health. One other point to note is that none of the instruments used in this study (permanent or temporary monitors) are considered adequate for official EPA tracking of NAAQS.

Table 2. The national air quality index (AQI) links air quality conditions to health concern categories.

Levels of Health Concern	**AQI Values**	**PM2.5 24-hr ave. ($\mu g/m^3$)**
Good	0-50	0-12
Moderate	51-100	12.1-35.4
Unhealthy for Sensitive Groups (USG)	101-150	35.5-55.4
Unhealthy	151-200	55.5-150.4
Very Unhealthy	201-300	150.5-250.4
Hazardous	301-500	>250.5

3. RESULTS

Five of the pilot burns used the 24-hr prior approval process in this study for a total of 10 burn days in the fall of 2016 and 7 burn days in the spring of 2017. They were Orion Unit 2 (3 burn days, fall 2016), 25 Mile (2 burn days fall 2016, 1 burn day spring 2017), Paradise 90 (4 burn days, fall 2016), Sherman Creek (6 burn days, spring 2017) and Hanlon (1 burn day, fall 2016). Details about the burn locations, the date and ignition time they were burned, and tons of fuel consumed are given in tables 3 and 4 for fall 2016 and tables 5 and 6 for spring 2017.

Figure 4 shows an overview of all of the prescribed fires that were included in the fall 2016 analysis with the 24-hour advance approval pilot burns displayed with a darker fire icon. Figure 5 shows the prescribed fires included in the analysis for spring 2017. Satellite detected hotspots throughout the region are also shown (triangles) and the air quality PM2.5 monitoring sites (blue circles). This Results section presents the data and analysis for each of the monitoring sites, with sites in close proximity grouped together. Each section has maps centered on the monitor and showing all the prescribed burns and satellite hot spots in a 32-km radius. Time series of the 1-hr and 24-hr average PM2.5 concentrations with the prescribed burns and satellite hot spots are also given. Finally, a table summarizing all the fire activity (prescribed burns and satellite hot spots) with the day-of and day-after 24-hr PM2.5 concentrations and maximum 1-hr concentrations are provided for each monitoring location.

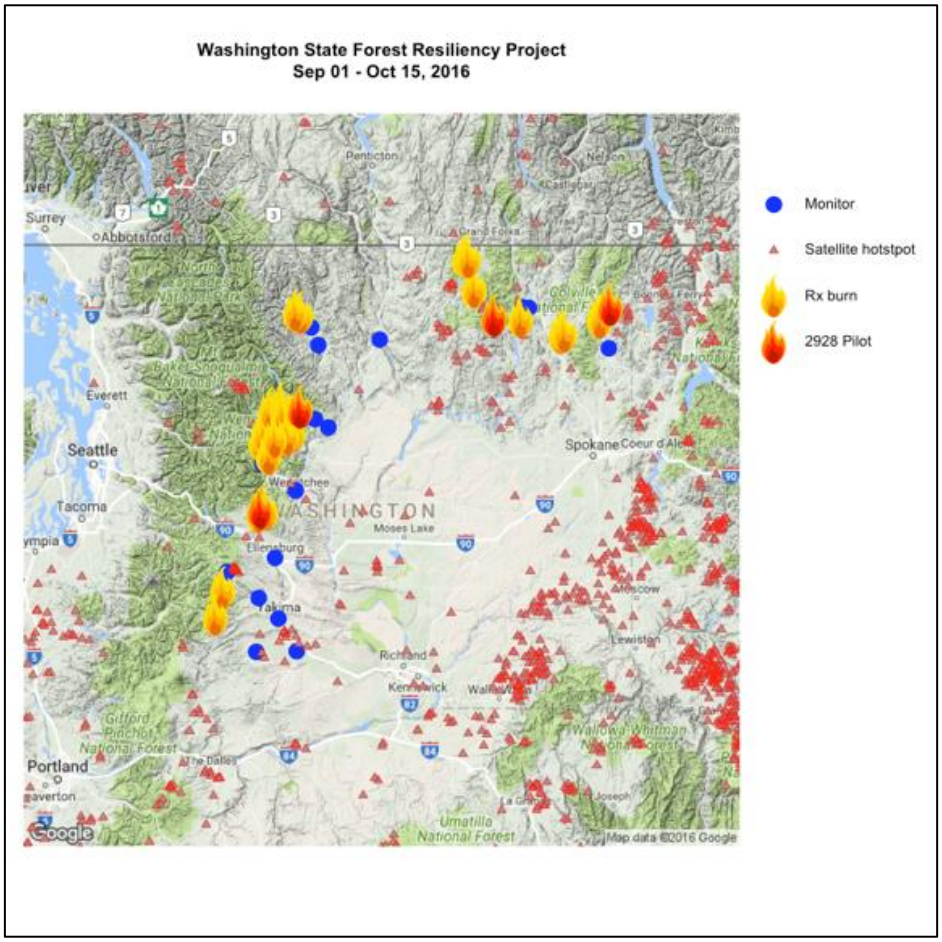


Figure 4: Map of reported prescribed fires, 2928 Pilot prescribed fires using 24-hour advanced approval, permanent and temporary air quality monitors (blue circles), and satellite detected hot spots for fall of 2016.

Table 3. Locations of the pilot burns accomplished using 24-hour advance approval during the fall of 2016.

Unit Name	Region	Land Owner	Nearest AQ monitor	Latitude	Longitude
Paradise 90	Colville NF	Three Rivers	Kettle Falls & Fish Hatchery	48.56	-118.40
Orion Unit 2	Wenatchee NF	Cle Elum	Liberty	47.32	-120.69
Hanlon HF Hand	Colville NF	Sullivan Lake	Kalispel Tribal Center	48.62	-117.26
25 Mile UB 2016	Wenatchee NF	Chelan	Manson	47.97	-120.2991

Table 4. Pilot burn accomplishments using 24-hour advance approval in fall of 2016.

Date	Ignition Time (PDT)	Unit	Proposed Tons	Accomplished Tons
9/14/16	11:00	Paradise 90	2400	1600
9/14/16	11:30	Orion Unit 2	1518	40
9/15/16	11:00	Paradise 90	960	480
9/21/16	9:30	Orion Unit 2	640	480
9/22/16	10:00	Orion Unit 2	680	624
9/26/16	15:00	Hanlon HF Hand	600	90
9/27/16	11:00	Paradise 90	7200	645
9/28/16	10:00	Paradise 90	7200	3627
9/28/16	10:30	25 Mile UB 2016	502	220
9/29/16	10:30	25 Mile UB 2016	502	290

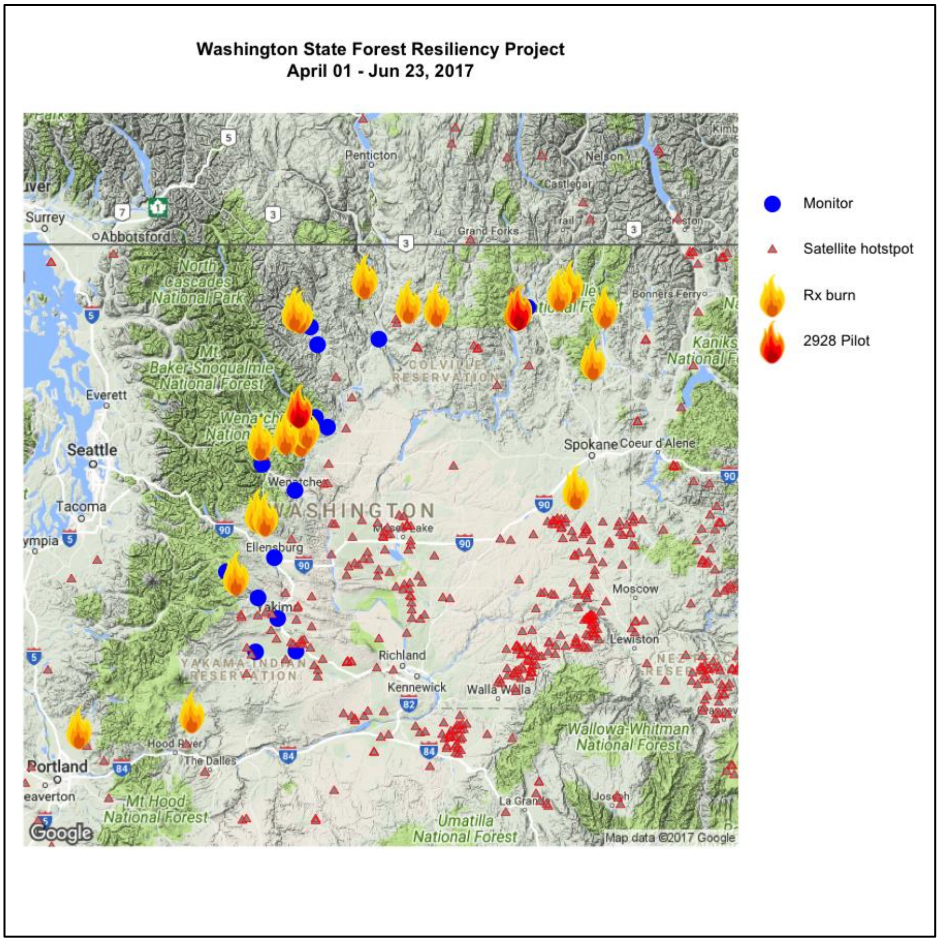


Figure 5: Map of reported prescribed fires, 2928 Pilot prescribed fires using 24-hour advanced approval, permanent and temporary air quality monitors (blue circles), and satellite detected hot spots for spring of 2017.

Table 5. Locations of the pilot burns accomplished using 24-hour advance approval during the spring of 2017.

Unit Name	Region	Land Owner	Nearest AQ monitor	Latitude	Longitude
25 Mile UB 2016	Wenatchee NF	Chelan	Manson	47.97	-120.2991
Rail	NE Region	WDFW	Kettle Falls & Fish Hatchery	48.59	-118.16
Bridge/Hatch/Trail	NE Region	WDFW	Kettle Falls & Fish Hatchery	48.597	-118.14
Bisbee	NE Region	WDFW	Kettle Falls & Fish Hatchery	48.604	-118.141

Table 6. Pilot burn accomplishments using 24-hour advance approval in spring of 2017.

Date	Ignition Time (PDT)	Unit	Proposed Tons	Accomplished Tons
5/8/2017		25 Mile 2017	797	245
5/9/2017		Rail	300	480
5/30/2017		Bridge/Hatch/Trail	300	129
6/1/2017		Bridge/Hatch/Trail	240	204
6/6/2017		Bisbee	360	180
6/12/2017		Bisbee	354	115
6/13/2017		Bisbee	364	91

Manson and Chelan

The small town of Manson, WA, approximately 12-km upriver from Chelan, WA was identified for placement of a temporary monitor because of the expected fire activity from the 25 Mile Pilot burn in the Wenatchee National Forest. A permanent monitor is also located in Chelan, WA.

All 24-hr average PM2.5 concentrations were within the good air quality category for these two sites during the pilot burning project. Manson and Chelan had a mix of Pilot and non-Pilot burns and there was no obvious difference in air quality impacts between Pilot and non-Pilot burns.

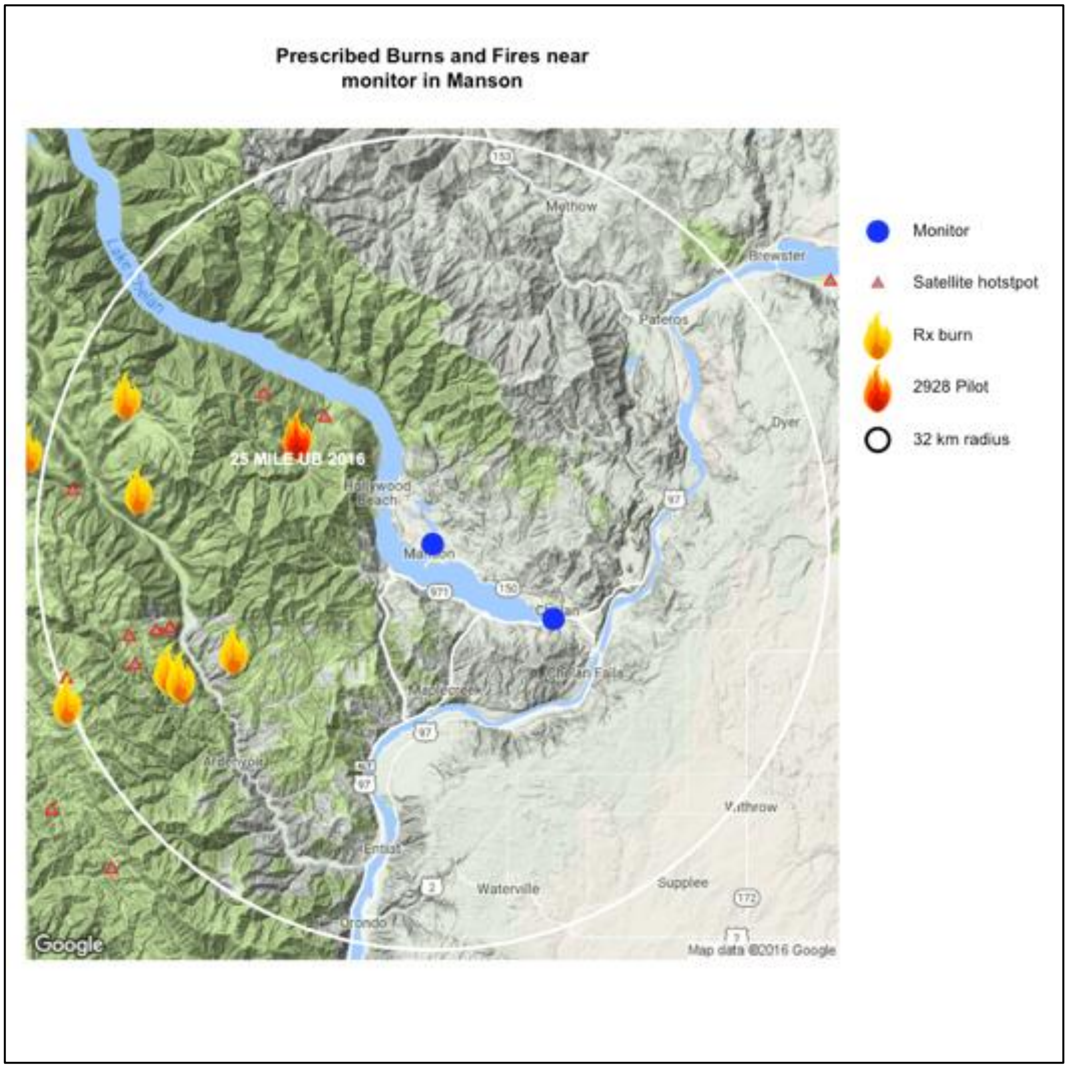


Figure 6: Location of prescribed fires and hotspots detected by satellite in the vicinity of the temporary monitor placed in Manson, WA in fall of 2016. One day of burning on the 25 Mile pilot burn was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.

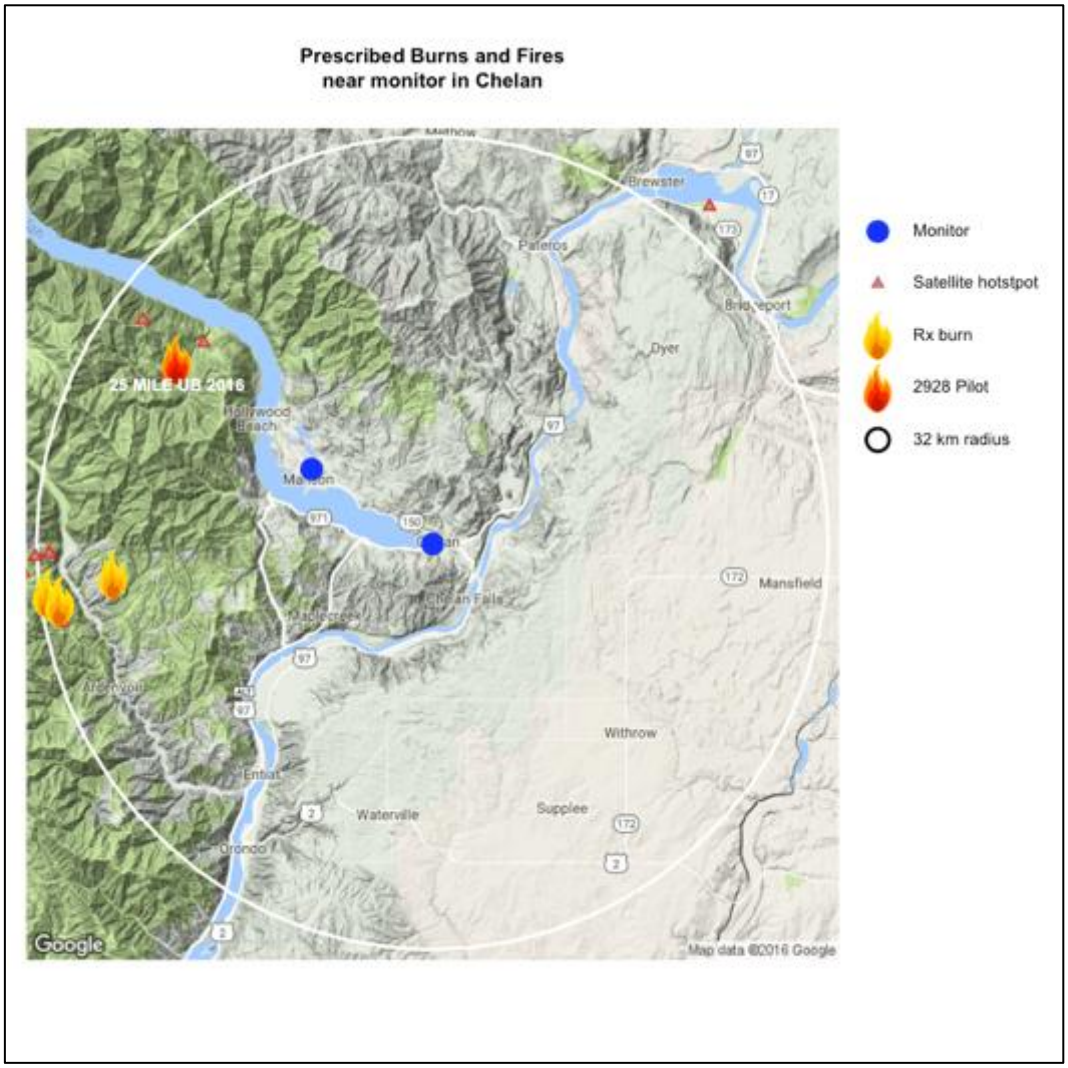


Figure 7: Location of prescribed fires and hotspots detected by satellite in the vicinity of the permanent monitor in Chelan, WA in fall of 2016. One day of burning on the 25 Mile pilot burn was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.

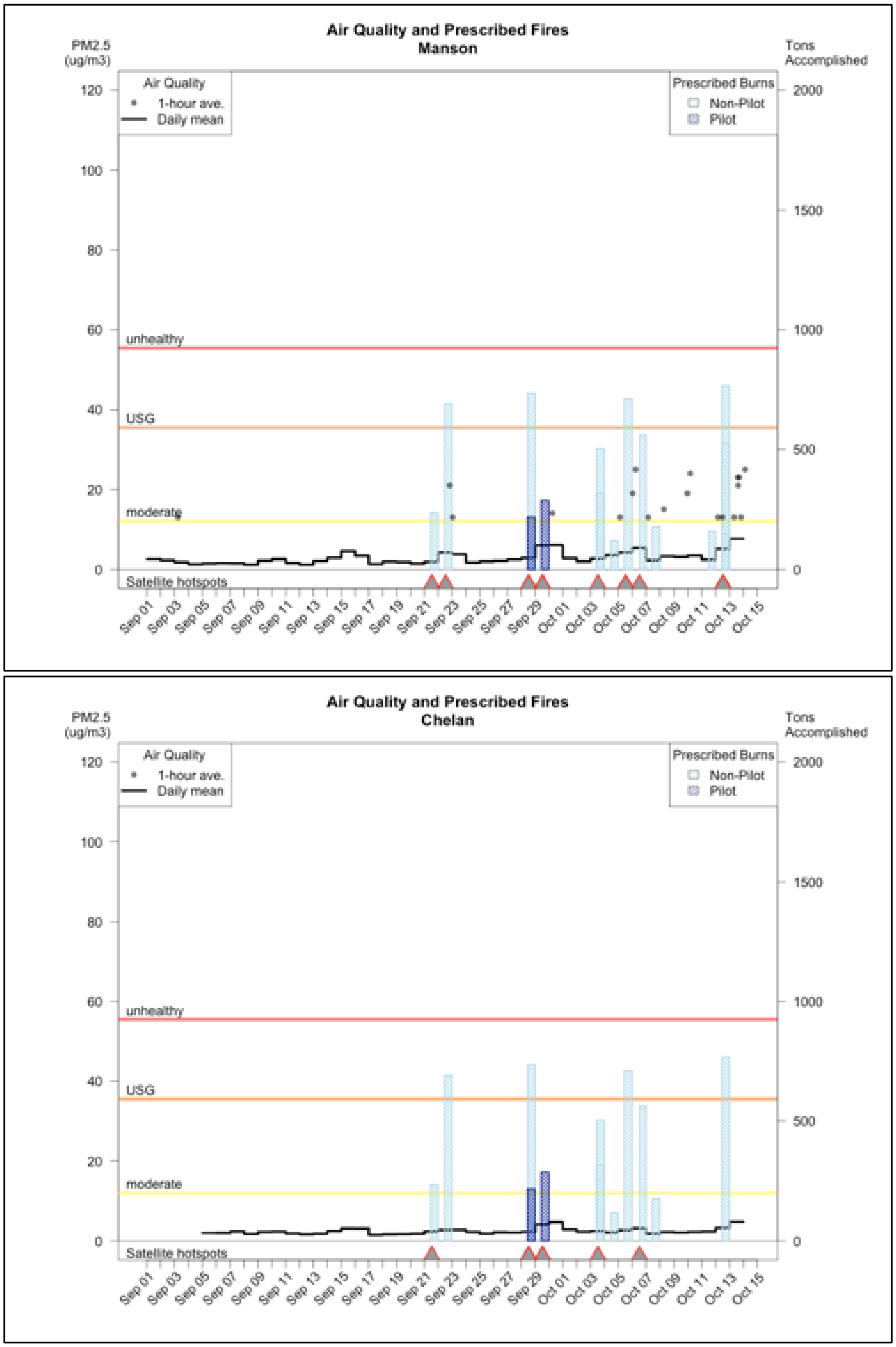


Figure 8: Air quality, tons consumed by prescribed burning, and satellite-detected hotspots by date in the vicinity of Manson and Chelan, WA during the fall of 2016. Daily mean PM2.5 values can be compared to colored horizontal lines to see how air quality measurements compare to national Air Quality Index health thresholds. (One-hour average measurements (dots) below 12.1μg/m^3 were not plotted to reduce clutter on the graph.)

Table 7: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of the monitor at Manson in fall of 2016.

Manson Date (2016)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 μg/m^3 (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 μg/m^3 (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
21-Sep	LOWER TYEE FALL 2016	240	22.8	SW	2	8	1400	4	21	2000
21-Sep	satellite	28	22.8	SW						
22-Sep	LOWER TYEE FALL 2016	700	22.8	SW	4	21	2000	4	13	0100
22-Sep	satellite	112	25.4	SW						
28-Sep	25 MILE UB 2016*	220	13.8	W	3	8	2300	6	12	0200
28-Sep	LOWER TYEE FALL 2016	744	22.8	SW						
28-Sep	satellite	253	17.9	W						
28-Sep	satellite	28	22.2	SW						
29-Sep	25 MILE UB 2016*	290	13.8	W	6	12	0200	6	14	0600
29-Sep	satellite	253	13.9	W						
29-Sep	satellite	28	22.2	SW						
3-Oct	25 MILE UB 2016	510	13.8	W	3	7	0300	4	11	1200
3-Oct	LOWER TYEE FALL 2016	320	22.8	SW						
3-Oct	satellite	506	13.2	NW						
4-Oct	LOWER TYEE FALL 2016	120	22.8	SW	4	11	1200	4	13	0300
5-Oct	TYEE PILES 2016	720	23.4	SW	4	13	0300	5	25	0600
5-Oct	satellite	506	25.8	SW						
5-Oct	satellite	506	24.6	SW						
6-Oct	NORTH FORK POTATO FALL 2016	568	18	SW	5	25	0600	2	13	0400
6-Oct	satellite	28	23.5	SW						
7-Oct	TYEE PILES 2016	180	23.4	SW	2	13	0400	3	15	0700
11-Oct	SHADY PASS 2016	160	27.3	W	2	12	1100	5	13	0400
12-Oct	ENTIAT RIDGE REHAB 2015	534	31.9	SW	5	13	0400	8	23	1400
12-Oct	FROG ROCK MACHINE	150	24	W						
12-Oct	LOWER TYEE FALL 2016	776	22.8	SW						
12-Oct	satellite	28	23.3	SW						
12-Oct	satellite	1651	29.2	W						
12-Oct	satellite	251	31.4	SW						

*24-Hr Advance approval pilot burn.

Table 8: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of the monitor at Chelan in the fall of 2016.

Chelan Date (2016)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
21-Sep	satellite	28	30.6	SW	2	3	1900	3	5	2000
21-Sep	LOWER TYEE FALL 2016	240	30.4	SW						
22-Sep	LOWER TYEE FALL 2016	700	30.4	SW	3	5	2000	3	5	100
28-Sep	satellite	253	29.2	W	2	3	2300	4	6	2200
28-Sep	satellite	28	30.9	SW						
28-Sep	25 MILE UB 2016*	220	25.2	W						
28-Sep	LOWER TYEE FALL 2016	744	30.4	SW						
29-Sep	satellite	253	25.3	W	4	6	2200	5	6	0000
29-Sep	satellite	28	30.9	SW						
29-Sep	25 MILE UB 2016*	290	25.2	W						
3-Oct	satellite	506	24.3	W	3	3	0600	2	3	2300
3-Oct	LOWER TYEE FALL 2016	320	30.4	SW						
3-Oct	25 MILE UB 2016	510	25.2	W						
4-Oct	LOWER TYEE FALL 2016	120	30.4	SW	2	3	2300	3	4	1200
5-Oct	TYEE PILES 2016	720	31.3	SW	3	4	1200	3	4	1200
6-Oct	satellite	28	30.5	SW	3	4	1200	2	2	0400
6-Oct	NORTH FORK POTATO FALL 2016	568	25.9	SW						
7-Oct	TYEE PILES 2016	180	31.3	SW	2	2	0400	2	3	1400
12-Oct	LOWER TYEE FALL 2016	776	30.4	SW	3	4	2200	5	9	1700

*24-Hr Advance approval pilot burn.

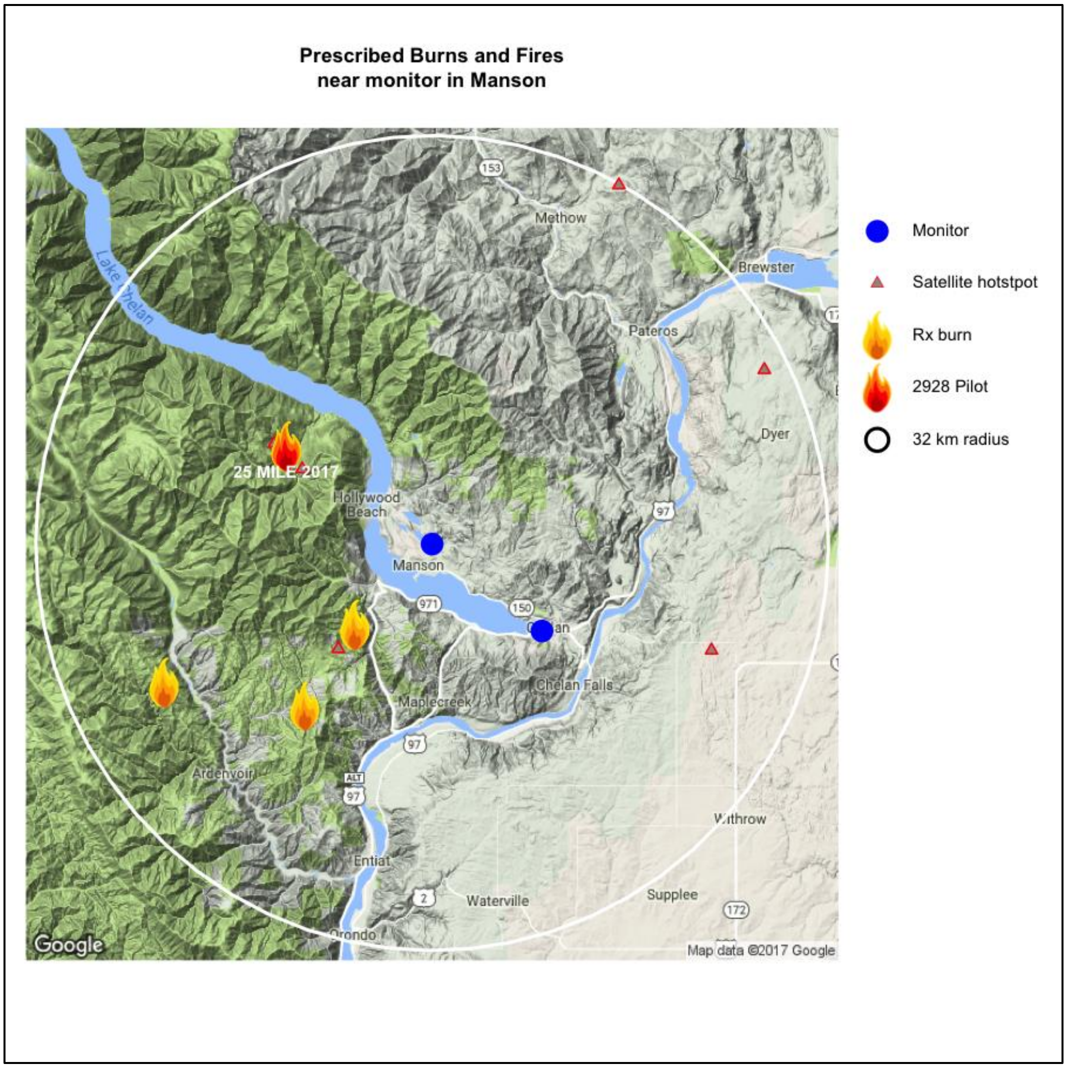


Figure 9: Location of prescribed fires and hotspots detected by satellite in the vicinity of the temporary monitor placed in Manson, WA in spring of 2017. One day of burning on the 25 Mile pilot burn was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.

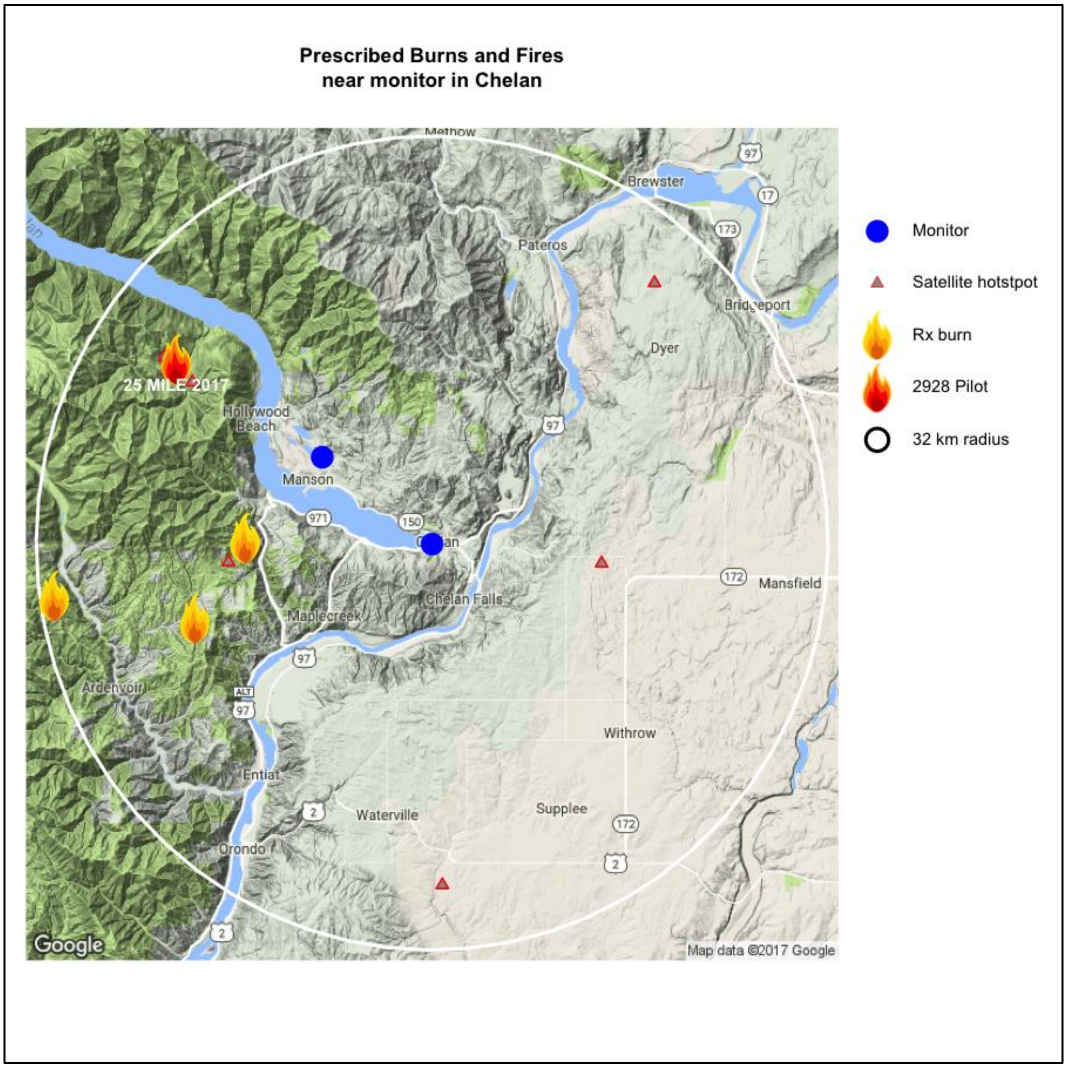
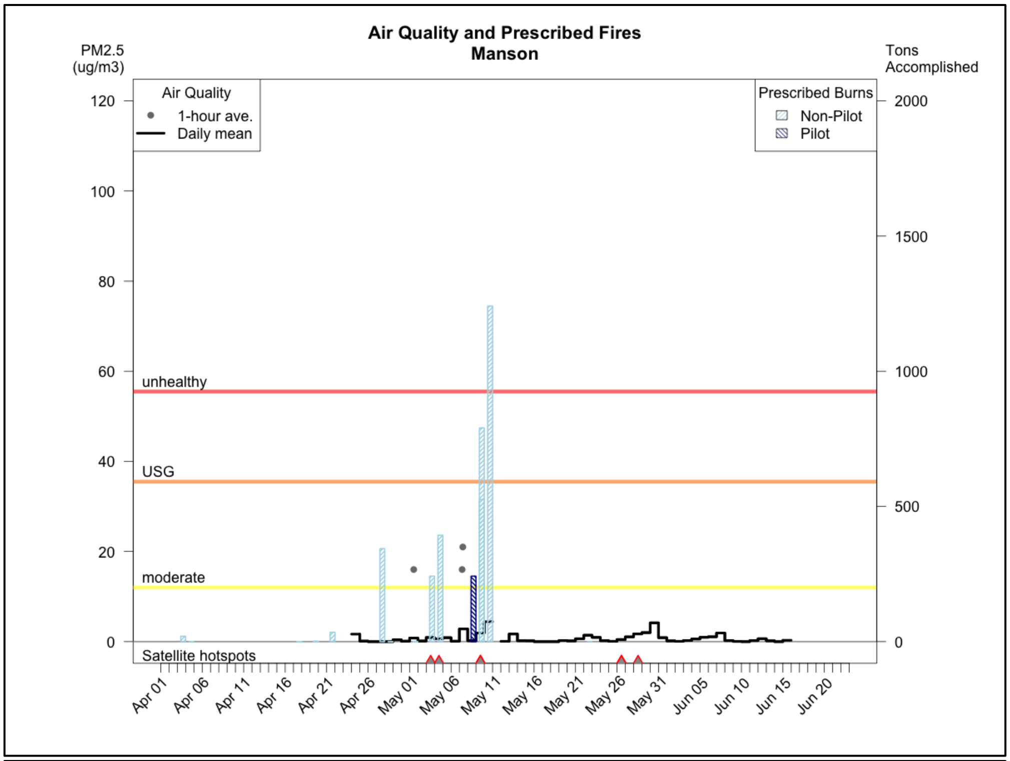


Figure 10: Location of prescribed fires and hotspots detected by satellite in the vicinity of the permanent monitor in Chelan, WA in spring of 2017. One day of burning on the 25 Mile pilot burn was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.



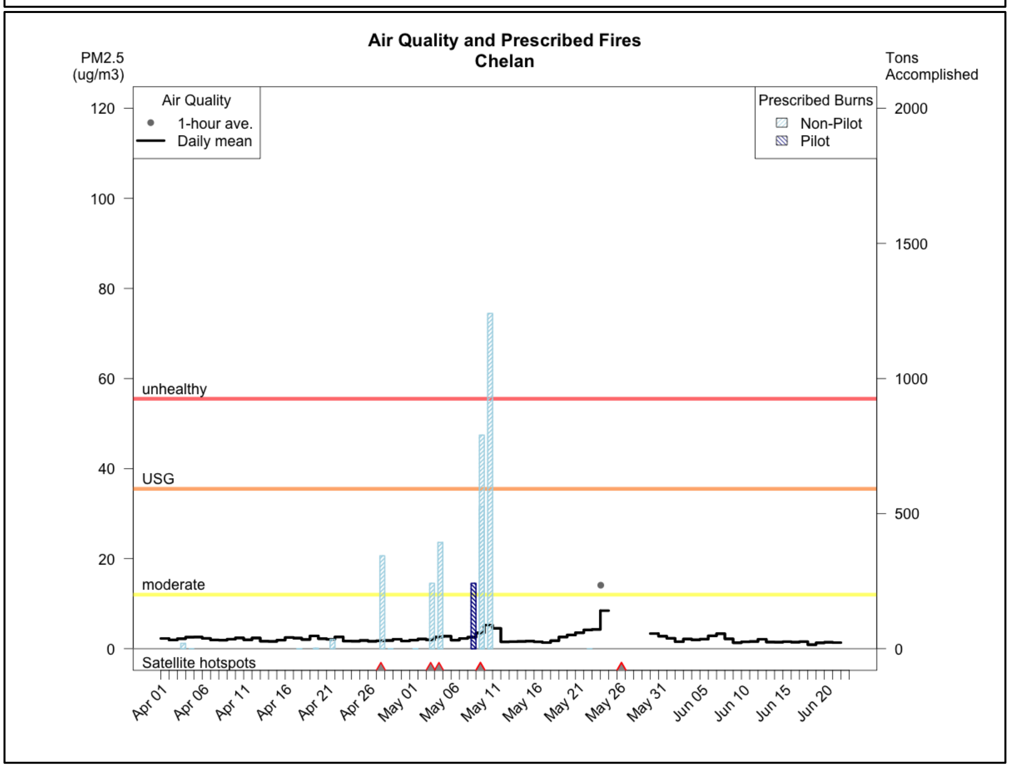


Figure 11: Air quality, tons consumed by prescribed burning, and satellite-detected hotspots by date in the vicinity of Manson and Chelan, WA during the spring of 2017. Daily mean PM2.5 values can be compared to colored horizontal lines to see how air quality measurements compare to national Air Quality Index health thresholds. (One-hour average measurements (dots) below 12.1μ/m^3 were not plotted to reduce clutter on the graph.)

Table 9: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of the monitor at Manson in spring of 2017.

Manson Date (2017)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
3-Apr	2017 BISPING-PALMICH	20	16.3	S	NA	NA	NA	NA	NA	NA
19-Apr	FOREST JOHNSON 2017	2	8.9	S	NA	NA	NA	NA	NA	NA
21-Apr	25 MILE 2017	35	14	W	NA	NA	NA	NA	NA	NA
27-Apr	FOREST JOHNSON 2017	348	8.9	S	0	0	0000	0	0	0000
3-May	satellite	758	12	W	0.9	2	0300	0.6	2	2100
3-May	25 MILE 2017	245	14	W						
4-May	satellite	84	11.2	S	0.6	2	2100	0.9	3	0800
4-May	FOREST JOHNSON 2017	398	8.9	S						
8-May	25 MILE 2017*	245	14	W	0.2	1	0700	1.9	7	2300
9-May	satellite	506	14.9	W	1.9	7	2300	4.4	12	2100
9-May	satellite	279	24.4	SW						
9-May	25 MILE 2017	532	14	W						
9-May	LOWER TYEE 2017	800	24.2	SW						
10-May	LOWER TYEE 2017	1256	24.2	SW	4.4	12	2100	NA	NA	NA
26-May	satellite	553	30	NE	0.5	5	2100	1.1	4	1300
26-May	satellite	641	24	E						
28-May	satellite	1099	31.9	N	1.7	6	1200	2	8	2100

*24-Hr Advance approval pilot burn.

Table 10: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of the monitor at Chelan in the spring of 2017.

Chelan Date (2017)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn PM2.5 μ/m³ (24hr)	Day of Burn Max PM2.5 (1-hr)	Day of Burn Time of Max 1-hr PDT	Day after Burn PM2.5 μ/m³ (24hr)	Day after Burn Max PM2.5 (1-hr)	Day after Burn Time of Max 1-hr PDT
3-Apr	2017 BISPING-PALMICH	20	20	SW	2.2	4	2100	2.6	3.9	1900
19-Apr	FOREST JOHNSON 2017	2	15.1	W	2.8	4.7	1400	2.2	3	1000
21-Apr	25 MILE 2017	35	25.2	W	2.1	3	2200	2.6	3.5	0200
27-Apr	satellite	553	26.9	SE	1.8	3.6	1400	1.8	1.9	0100
27-Apr	FOREST JOHNSON 2017	348	15.1	W						
3-May	satellite	758	23.1	W	2	2.3	2300	2.6	5.3	2300
3-May	25 MILE 2017	245	25.2	W						
4-May	satellite	84	16.5	SW	2.6	5.3	2300	2.8	4.8	0000
4-May	FOREST JOHNSON 2017	398	15.1	W						
8-May	25 MILE 2017*	245	25.2	W	2.6	2.8	1900	3.5	10.1	2300
9-May	satellite	506	26.1	W	3.5	10.1	2300	5.2	9.3	0000
9-May	satellite	279	30.8	SW						
9-May	25 MILE 2017	532	25.2	W						
9-May	LOWER TYEE 2017	800	30.7	SW						
10-May	LOWER TYEE 2017	1256	30.7	SW	5.2	9.3	0000	4.5	8.8	1000
26-May	satellite	553	27.2	N	Na	NA	NA	Na	NA	NA
26-May	satellite	641	13.7	E						

*24-Hr Advance approval pilot burn.

Plain and Leavenworth

The small town of Plain, WA was identified for placement of a temporary monitor during Fall of 2016 because of the expected fire activity in the Wenatchee National Forest and anecdotal accounts of smoke impacts in the area. A permanent monitor was already located in Leavenworth, WA, 22.5 km down-valley to the south of Plain. Plain experienced the greatest amount of prescribed fire activity with 10 prescribed fire projects within 32 km, many with multiple day burns. Many of the same prescribed fires were within 32 km of Leavenworth as well. None of the burns were 2928 pilot burns.

Air quality impacts were in the USG AQI category (> 38 $\mu g/m^3$) on two days at Plain. Seven days experienced 24-hr concentrations in the Moderate AQI category (> 12 $\mu g/m^3$). This location had the highest smoke impacts of all the monitoring sites. Conversely, Leavenworth only experienced two days of 24-hr average PM2.5 concentrations in the Moderate AQI category. Three prescribed fire units are most likely responsible for smoke into Plain; Fishloop, Natapoc, and possibly Entiat Ridge Rehab 2015.

Fishloop is located 4-km north of Plain and it was ignited on 4 separate days. It is most likely responsible for the USG occurrences. Furthermore, periods of elevated PM2.5 concentrations would continue during the night and early morning hours for several days after the prescribed fire was completed. Afternoons were generally clear. For example, during the Sep 28 – Oct 4 period smoke would clear during the day, then concentrations would be elevated overnight and into the early morning hours. Plain is in a small mountain valley and it is likely nighttime wind patterns would bring smoke from the higher elevation to the north down the valley. It is unknown at this point whether smoldering fuels were present in the unit to contribute to the nighttime smoke concentrations. The fourth and final Fishloop burn (on 9/28/2016) was probably responsible for the Moderate AQI category conditions in Leavenworth the following day.

Natapoc is located 1.4-km southwest of Plain and was ignited on three consecutive days (9/20-22/2016). It brought some smoke into Plain but not to the degree that Fishloop did even with similar tonnage and being closer to town. Daily average PM2.5 concentrations remained in the Good AQI category and peak 1-hr PM2.5 concentrations occurred late afternoon into the early evening (e.g. 83 $\mu g/m^3$ at 1800 PDT) and in one case into the evening (night of 9/22/2016). Natapoc did not impact Leavenworth.

Chumstick is located12-km southeast of Plain and 6 km north of Leavenworth. Interestingly enough it did not cause impacts of note to either town.

On October 13 both Plain and Leavenworth experienced a Moderate AQI category day. It is difficult to ascertain whether Entiat Ridge Rehab 2015 was responsible or if it was a combined effect from several burns further away (17-29 km) to the northeast.

The Orion Unit 2 pilot burn was approximately 32 km to the south of Leavenworth. This burn did not impact Leavenworth.

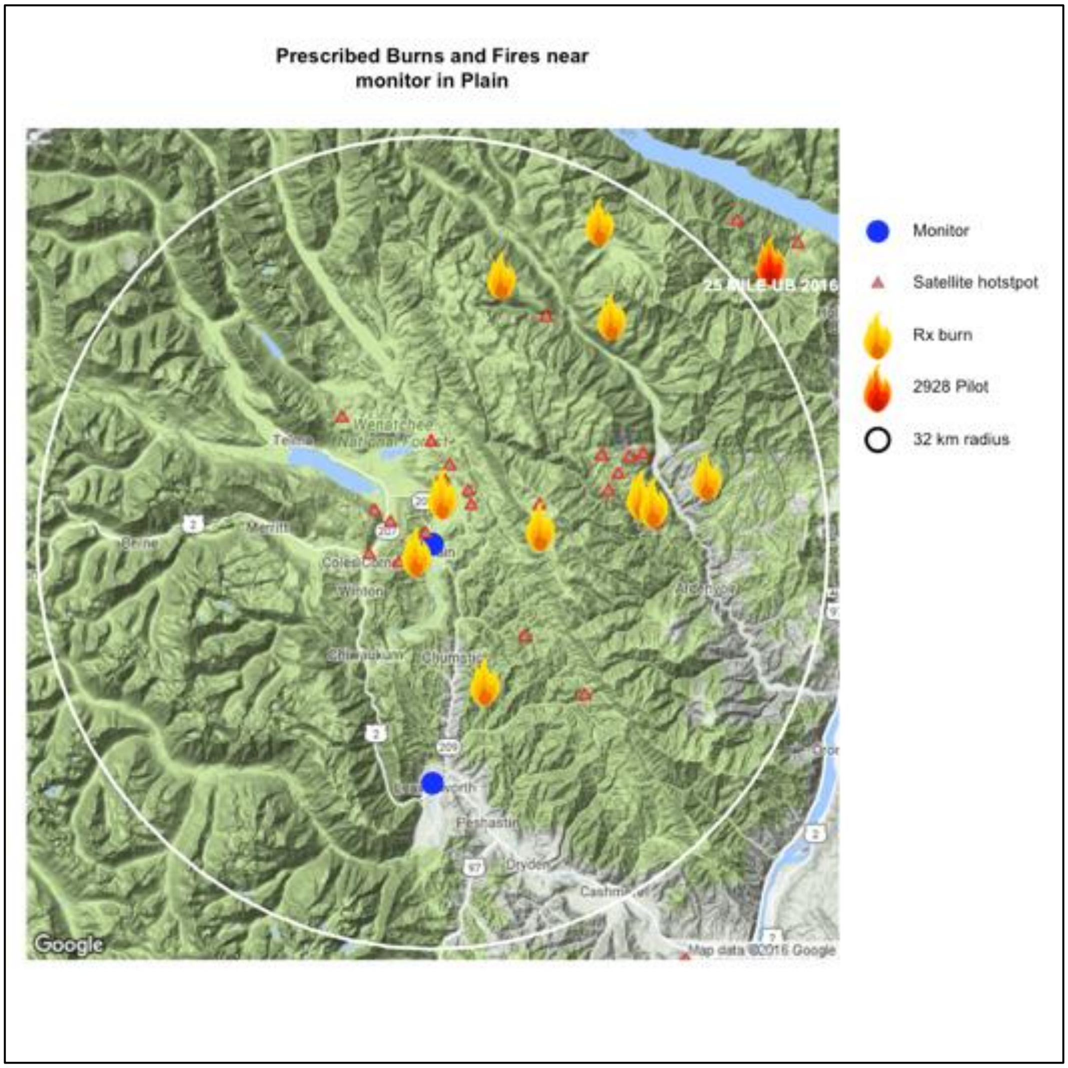


Figure 12: Location of prescribed fires and hotspots detected by satellite in the vicinity of the temporary monitor placed in Plain, WA in fall of 2016. No prescribed burning in the vicinity was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.

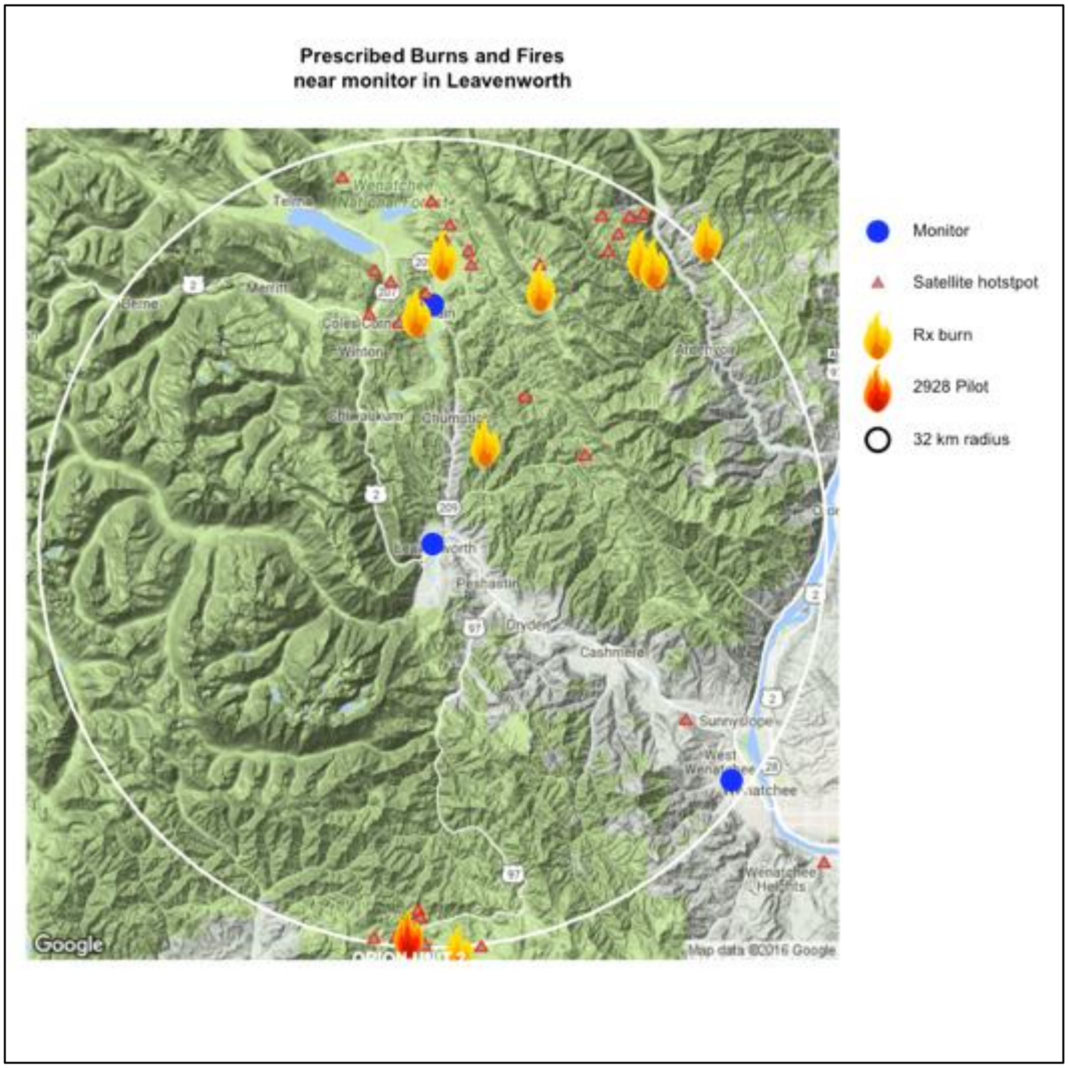


Figure 13: Location of prescribed fires and hotspots detected by satellite in the vicinity of the permanent monitor in Leavenworth, WA in fall of 2016. Two days of burning on the Orion Unit 2 pilot burn was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.

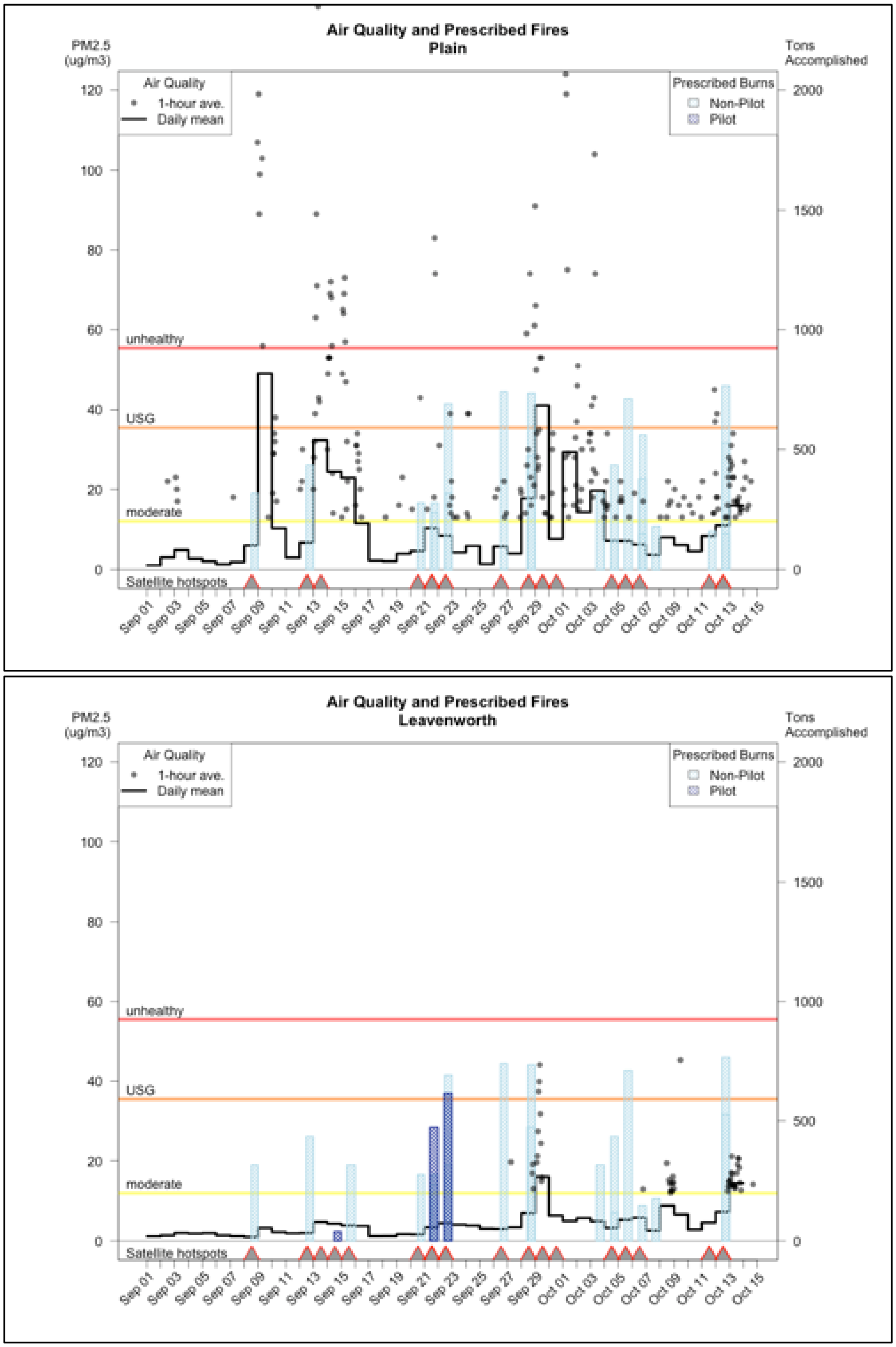


Figure 14: Air quality, tons consumed by prescribed burning, and satellite-detected hotspots by date in the vicinity of Plain and Leavenworth, WA during the fall of 2016. Daily mean PM2.5 values can be compared to colored horizontal lines to see how air quality measurements compare to national Air Quality Index health thresholds. (One-hour average measurements (dots) below 12.1μg/m^3 were not plotted to reduce clutter on the graph.)

Table 11: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of the monitor at Plain, fall 2016.

Plain Date (2016)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
9/8	FISHLOOP UNDERBURNS	320	4.0	N	6	107	2300	49	185	0500
9/8	satellite	253	6.3	N						
9/12	FISHLOOP UNDERBURNS	440	4.0	N	7	30	0500	32	158	0700
9/12	satellite	506	5.0	N						
9/12	satellite	253	8.0	N						
9/13	satellite	253	8.0	N	32	158	0700	24	72	0600
9/20	NATAPOC	280	1.4	SW	5	43	1700	10	83	1800
9/20	satellite	4232	5.2	W						
9/21	LOWER TYEE FALL 2016	240	18.1	NE	10	83	1800	8	39	2100
9/21	NATAPOC	280	1.4	SW						
9/21	satellite	4232	1.0	NW						
9/21	satellite	846	3.1	SW						
9/21	satellite	28	18.0	E						
9/22	LOWER TYEE FALL 2016	700	18.1	NE	8	39	2100	4	18	0000
9/22	NATAPOC	320	1.4	SW						
9/22	satellite	112	15.3	NE						
9/22	satellite	846	5.3	NW						
9/26	FISHLOOP UNDERBURNS	750	4.0	N	6	22	1800	4	20	2300
9/26	satellite	846	12.3	NW						
9/28	FISHLOOP UNDERBURNS	480	4.0	N	18	74	1500	41	277	1000
9/28	LOWER TYEE FALL 2016	NA	18.1	NE						
9/28	satellite	28	18.4	NE						
9/28	satellite	253	4.8	N						
9/29	satellite	28	18.4	NE	41	277	1000	8	34	0700
9/29	satellite	253	4.3	NE						
9/30	satellite	846	5.0	NE	8	34	0700	29	146	0700
10/3	LOWER TYEE FALL 2016	NA	18.1	NE	20	104	0700	7	34	0500
10/4	CHUMSTICK UNDERBURNS	440	11.6	SE	7	34	0500	7	22	0400
10/4	LOWER TYEE FALL 2016	NA	18.1	NE						
10/4	satellite	846	10.4	SE						
10/5	TYEE PILES 2016	720	17.3	NE	7	22	0400	6	19	0400

10/5	satellite	253	14.8	E						
10/5	satellite	253	16.0	E						
10/6	CHUMSTICK UNDERBURNS	150	11.6	SE	6	19	0400	4	12	0600
10/6	NORTH FORK POTATO FALL 2016	568	22.8	NE						
10/6	TOMMY MAD	382	21.9	N						
10/6	satellite	28	18.1	E						
10/7	TYEE PILES 2016	180	17.3	NE	4	12	0600	8	22	1400
10/11	SHADY PASS 2016	160	28.7	N	8	45	2200	11	39	0200
10/11	satellite	1693	3.8	NW						
10/12	ENTIAT RIDGE REHAB 2015	534	8.8	NE	11	39	0200	16	34	0600
10/12	FROG ROCK MACHINE	150	23.0	N						
10/12	LOWER TYEE FALL 2016	776	18.1	NE						
10/12	satellite	28	17.3	NE						
10/12	satellite	1651	20.0	NE						
10/12	satellite	1011	17.2	SE						
10/12	satellite	251	9.2	E						

Table 12: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of the monitor at Leavenworth, fall 2016.

Leavenworth Date (2016)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn PM2.5 µg/m³ (24hr)	Day of Burn Max PM2.5 (1-hr)	Day of Burn Time of Max 1-hr PDT	Day after Burn PM2.5 µg/m³ (24hr)	Day after Burn Max PM2.5 (1-hr)	Day after Burn Time of Max 1-hr PDT
8-Sep	satellite	253	25.1	N	1	2	2100	3	9	0800
8-Sep	FISHLOOP UNDERBURNS	320	22.8	N						
12-Sep	satellite	758	23.8	N	2	5	0700	5	11	0700
12-Sep	satellite	758	26.9	NW						
12-Sep	FISHLOOP UNDERBURNS	440	22.8	N						
13-Sep	satellite	253	26.9	NW	5	11	0700	4	8	1200
14-Sep	satellite	846	29.7	S	4	8	1200	4	6	1400
14-Sep	ORION UNIT 2*	40	30.9	S						
15-Sep	satellite	846	29.7	S	4	6	1400	4	7	1300
15-Sep	ORION UNIT 2	320	30.9	S						
20-Sep	satellite	4232	18.7	NW	2	2	0800	3	7	2300
20-Sep	NATAPOC	280	18.3	NW						
21-Sep	satellite	5079	19.7	NW	3	7	2300	5	8	0800
21-Sep	satellite	5079	17.6	NW						
21-Sep	satellite	5079	29.1	S						
21-Sep	satellite	5079	31.9	S						
21-Sep	satellite	28	28.7	N						
21-Sep	ORION UNIT 2*	480	30.9	S						
21-Sep	LOWER TYEE FALL 2016	240	28.5	N						
21-Sep	NATAPOC	280	18.3	NW						
22-Sep	satellite	112	29.2	N	5	8	0800	4	6	2300
22-Sep	satellite	2539	31.4	S						
22-Sep	satellite	846	22.0	NW						
22-Sep	ORION UNIT 2*	624	30.9	S						
22-Sep	LOWER TYEE FALL 2016	700	28.5	N						
22-Sep	NATAPOC	320	18.3	NW						
26-Sep	satellite	846	29.7	NW	3	9	1000	3	20	0600
26-Sep	FISHLOOP UNDERBURNS	750	22.8	N						
28-Sep	satellite	28	31.0	N	7	19	2000	16	44	0800
28-Sep	satellite	253	23.7	N						
28-Sep	FISHLOOP UNDERBURNS	480	22.8	N						
28-Sep	LOWER TYEE FALL 2016	744	28.5	N						
29-Sep	satellite	28	31.0	N	16	44	0800	6	8	1900

29-Sep	satellite	253	22.1	N						
30-Sep	satellite	846	23.2	N	6	8	1900	5	8	0800
3-Oct	LOWER TYEE FALL 2016	320	28.5	N	5	6	2000	3	6	0600
4-Oct	satellite	846	13.8	N	3	6	0600	5	12	0600
4-Oct	satellite	4232	31.7	S						
4-Oct	LOWER TYEE FALL 2016	120	28.5	N						
4-Oct	CHUMSTICK UNDERBURNS	440	9.1	N						
5-Oct	satellite	506	27.1	N	5	12	0600	6	13	1900
5-Oct	satellite	506	28.6	N						
5-Oct	TYEE PILES 2016	720	28.4	N						
6-Oct	satellite	28	27.3	N	6	13	1900	3	8	1100
6-Oct	CHUMSTICK UNDERBURNS	150	9.1	N						
7-Oct	TYEE PILES 2016	180	28.4	N	3	8	1100	9	19	1200
11-Oct	satellite	66	24.9	E	5	12	2200	7	15	2300
11-Oct	satellite	1693	20.9	NW						
12-Oct	satellite	28	30.2	N	7	15	2300	15	21	0400
12-Oct	satellite	1011	14.1	NE						
12-Oct	satellite	251	23.6	N						
12-Oct	LOWER TYEE FALL 2016	776	28.5	N						
12-Oct	ENTIAT RIDGE REHAB 2015	534	22.1	N						

*24-Hr Advance approval pilot burn.

Liberty

The tiny town of Liberty, WA was identified for placement of a temporary air quality monitor in fall of 2016 due to the proximity of a proposed 2928 pilot burn “Orion Unit 2” in the Wenatchee National Forest. Orion Unit 2 was burned on 4 occasions, with three of those occasions taking advantage of the 24-hr approval window. Two additional prescribed fires were accomplished on 2 different days in the area of the Liberty monitor using the standard DNR approval process.

The 24-hr average PM2.5 concentrations generally stayed in the Good AQI category (below 12 $\mu g/m^3$) with the exception of one day after the Orion Unit 2 burn on 9/22/2016, when the 24-hr average PM2.5 concentration went to a Moderate AQI 16 $\mu g/m^3$ on 9/23/2016. This burn used the 24-hr approval process. The maximum 1-hr PM2.5 concentration was 92 $\mu g/m^3$ at 9 AM PDT on 9/23/2016. This burn had the second highest tonnage consumed and like all the other prescribed burns was less than 8-km from town.

This site appears to be influenced by sources other than prescribed burning because 1-hr PM2.5 concentrations often ranged up to 30 $\mu g/m^3$ independent of any burning activities, and typical 24-hr PM2.5 concentrations ranged between 5-10 $\mu g/m^3$. In summary, some impact from prescribed burning activity was noticeable at this site, but only once resulting in anything other than good air quality.

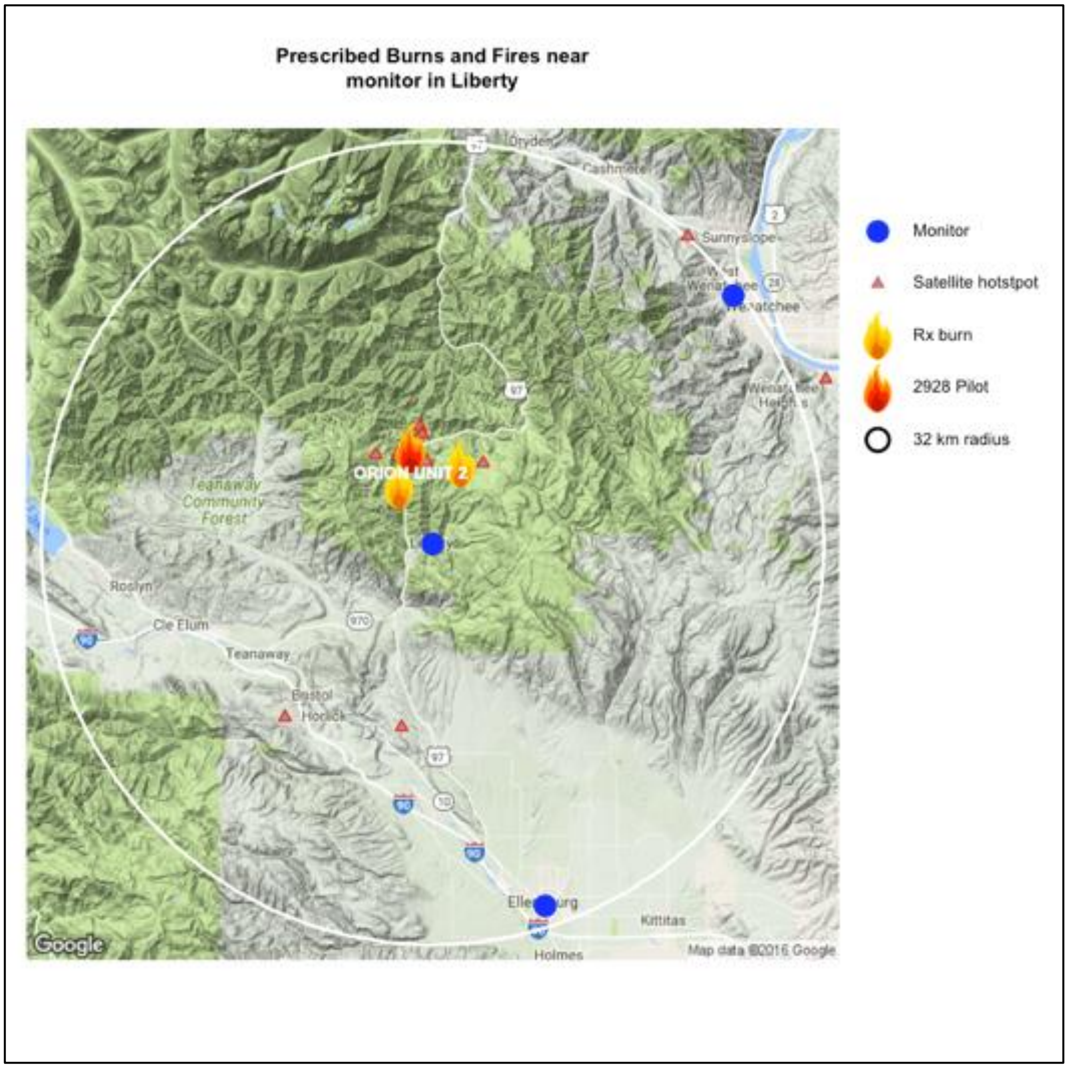


Figure 14: Location of prescribed fires and hotspots detected by satellite in the vicinity of the temporary monitor placed in Liberty, WA in fall of 2016. Two days of burning on the Orion Unit 2 pilot burn was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.

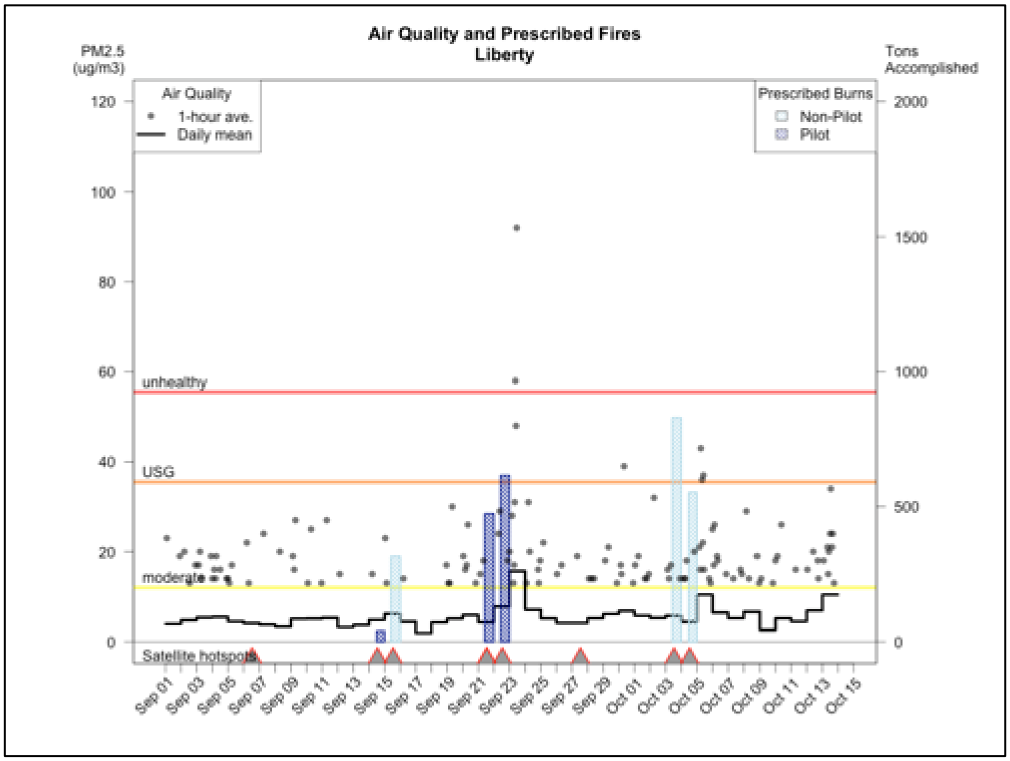


Figure 15: Air quality, tons consumed by prescribed burning, and satellite-detected hotspots by date in the vicinity of Liberty, WA during the fall of 2016. Daily mean PM2.5 values can be compared to colored horizontal lines to see how air quality measurements compare to national Air Quality Index health thresholds. (One-hour average measurements (dots) below 12.1μg/m^3 were not plotted to reduce clutter on the graph.)

Table 13: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of the monitor at Liberty in fall of 2016.

Liberty Date (2016)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
6-Sep	satellite	364	14.8	S	4	22	0500	3.8	24.0	0600
14-Sep	satellite	846	8.8	NW	5	15	0500	6.2	23.0	0100
14-Sep	ORION UNIT 2*	40	7.8	NW						
15-Sep	Satellite	846	8.8	NW	6	23	0100	4.5	14.0	0500
15-Sep	ORION UNIT 2	320	7.8	NW						
21-Sep	satellite	5079	9.4	NW	4	18	0800	7.8	29.0	0900
21-Sep	satellite	5079	6.6	NW						
21-Sep	ORION UNIT 2*	480	7.8	NW						
22-Sep	satellite	2539	7.7	NW	8	29	0900	15.7	92.0	1100
22-Sep	ORION UNIT 2*	624	7.8	NW						
27-Sep	satellite	187	18.3	S	4	19	0800	5.2	14.0	0200
3-Oct	satellite	846	7.6	N	6	17	0800	4.4	20.0	2000
3-Oct	LIBERTY FUELS UNITS 52-56	840	6.8	N						
4-Oct	satellite	4232	8.5	NW	4	20	2000	10.4	43.0	0600
4-Oct	ORION SBA UNIT 8	560	5.5	NW						

*24-Hr Advance approval pilot burn.

Pinecliff and Naches

The narrow canyon northwest of Naches, WA was identified for a placement of a temporary air quality monitor because of the expected fire activity in the Wenatchee National Forest and anecdotal accounts of smoke impacts in the area. The monitor was located at Pinecliff, WA at a USDA Forest Service site. The Angel Underburn and Canteen were the only prescribed fires within a 32 km radius of Pinecliff and Naches in 2016 and 2017 respectively and they were not Pilot Burns. The Angel Underburn was burned on two days (9/15/2016 and 9/28/2016) and Canteen was burned on 5/25/2017 and neither caused air quality impacts to either Pinecliff or Naches.

In fall 2016, the 24-hr average PM2.5 concentrations were all in the Good AQI category (below 12 $\mu g/m^3$) for both sites with the exception of one day in the Moderate AQI category in Naches on 9/14/2016. Unknown fire activity occurred from 9/10-16/2016 on the ridge less than 10 km east of Pinecliff and 25-30 km northwest of Naches. This unknown fire activity is likely the cause of the peak 1-hr average PM2.5 concentrations that ranged up to 60 $\mu g/m^3$ during this time period. It is interesting to note that higher concentrations were measured at Naches rather than at Pinecliff.

In spring 2017, the 24-hr average PM2.5 concentrations were all in the Good AQI category (below 12 $\mu g/m^3$) for both sites with the exception of 3 days in the Moderate AQI category at Pinecliff 6/21-23/2017. These elevated concentrations are probably not due to fire activity because there were not any satellite hot spot detections or reported burn activity.

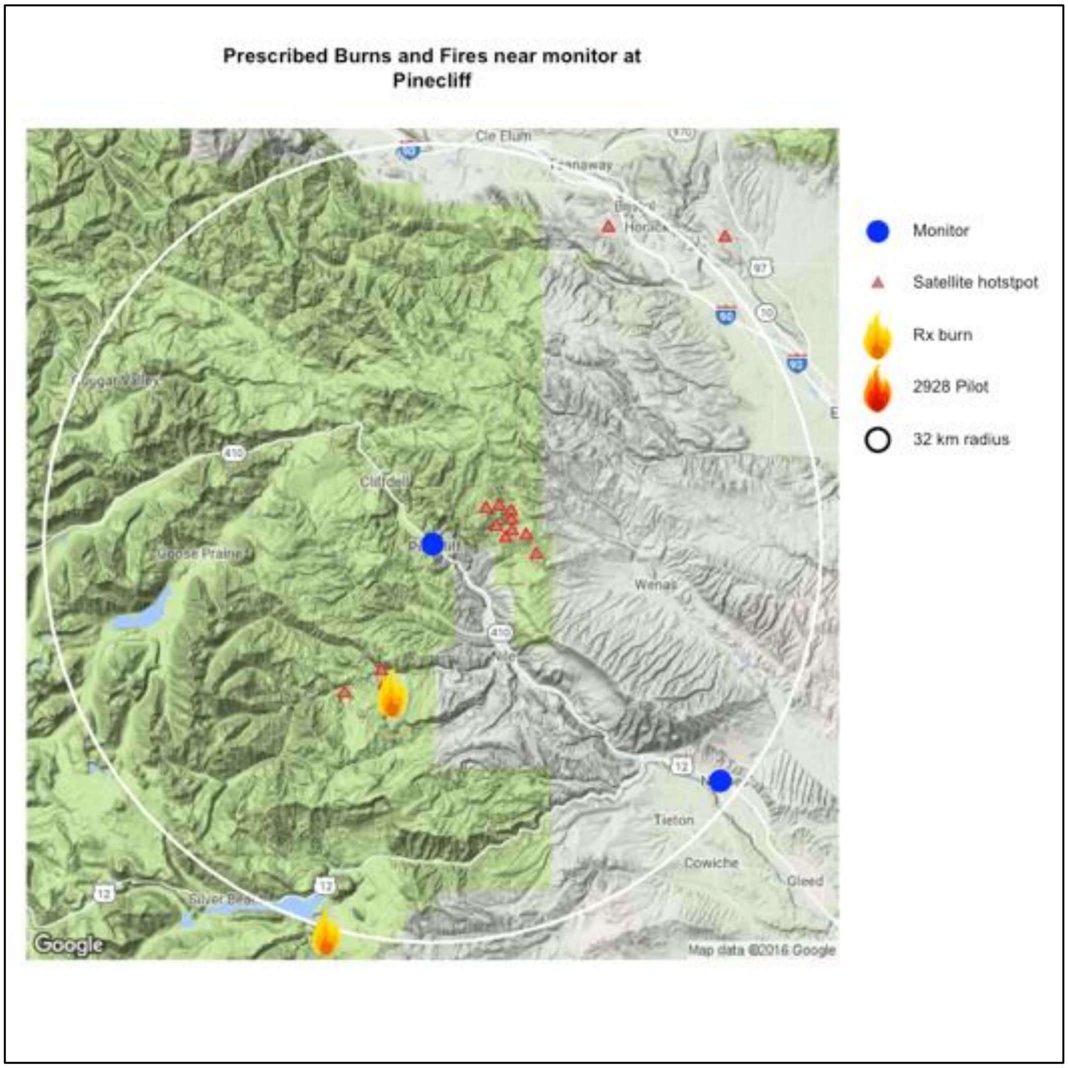


Figure 16: Location of prescribed fires and hotspots detected by satellite in the vicinity of the temporary monitor placed in Pinecliff, WA in fall of 2016. No prescribed burning in the vicinity was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.

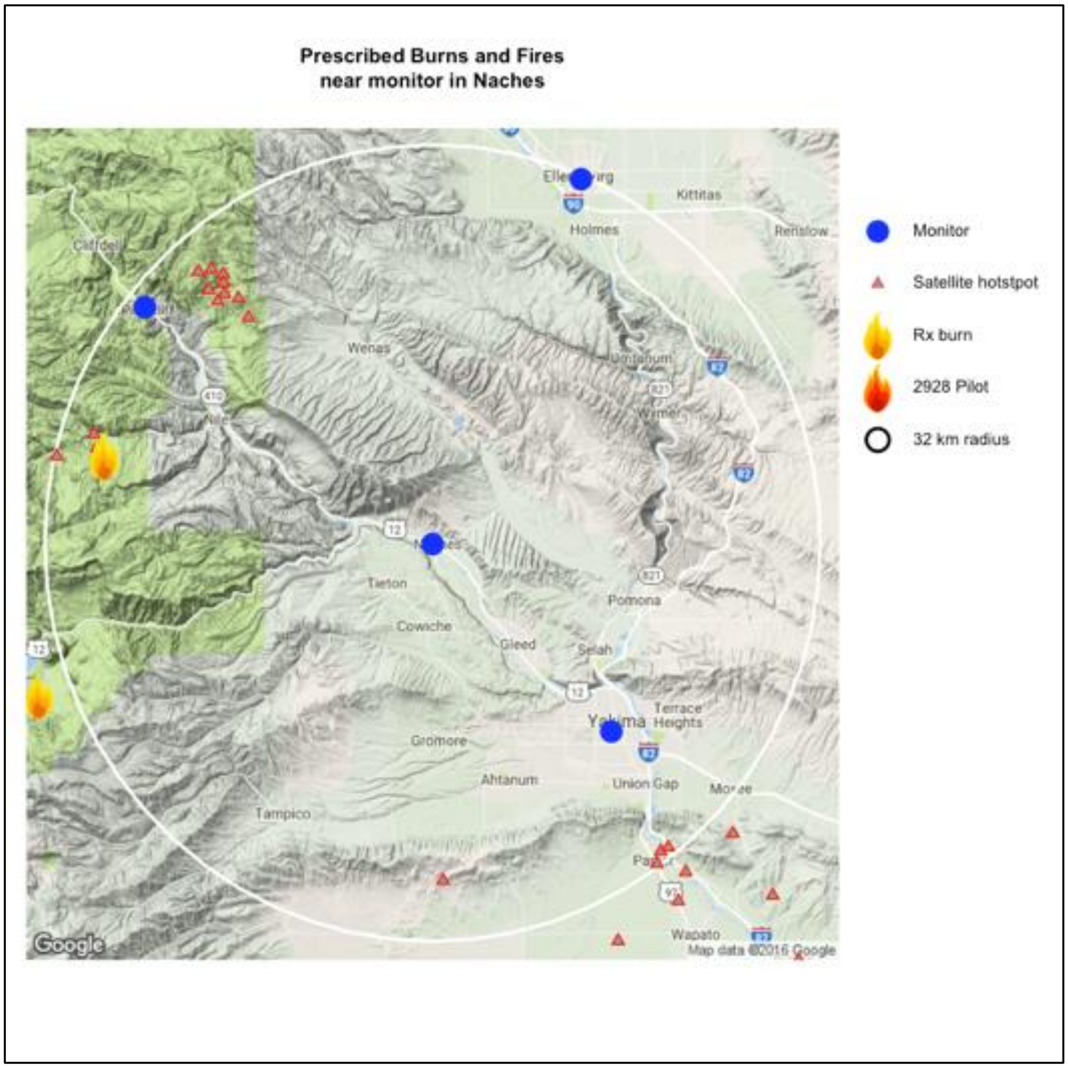
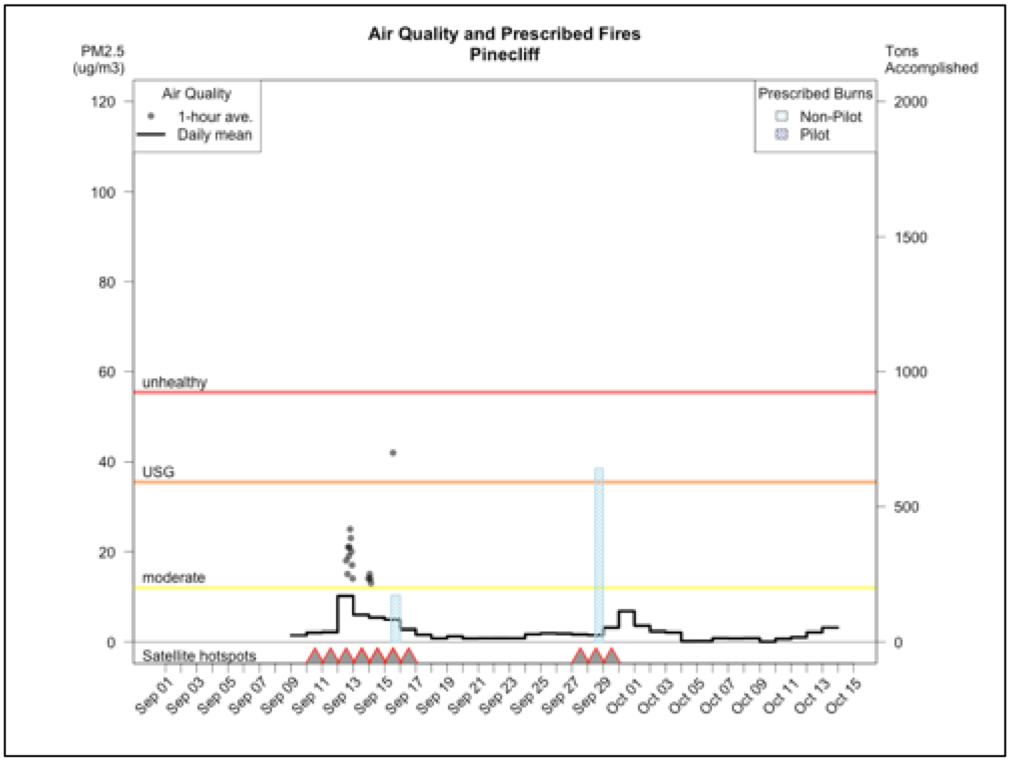


Figure 17: Location of prescribed fires and hotspots detected by satellite in the vicinity of the temporary monitor placed in Naches, WA in fall of 2016. No prescribed burning in the vicinity was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.



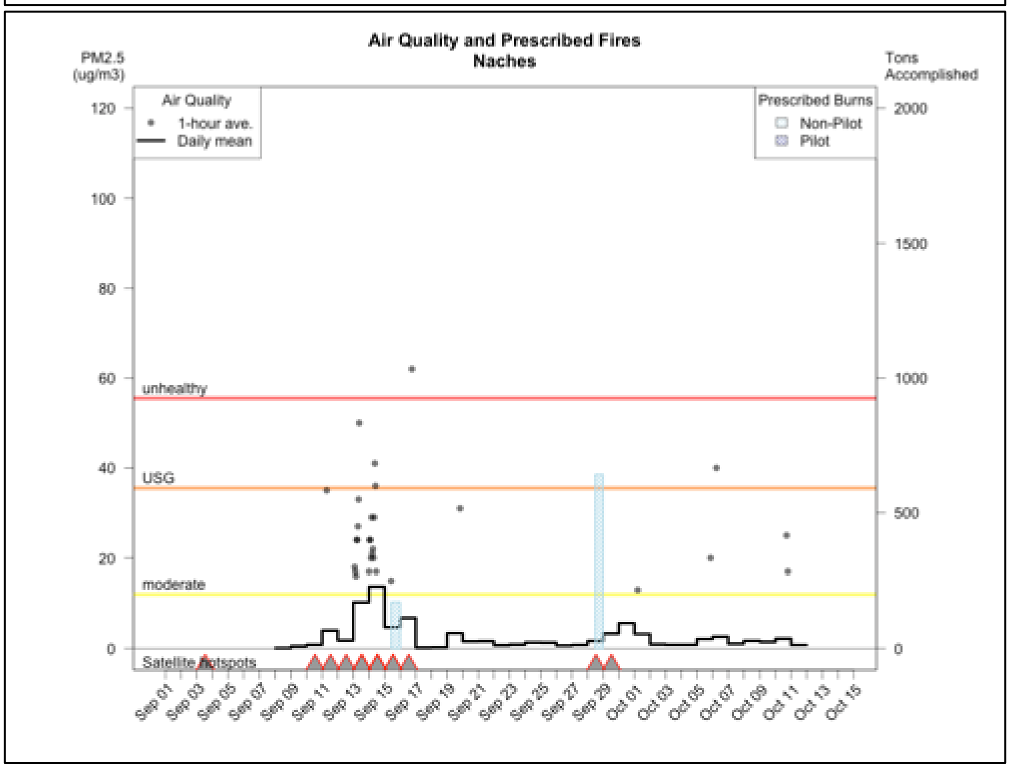


Figure 18: Air quality, tons consumed by prescribed burning, and satellite-detected hotspots by date in the vicinity of Pinecliff and Naches, WA during the fall of 2016. Daily mean PM2.5 values can be compared to colored horizontal lines to see how air quality measurements compare to national Air Quality Index health thresholds. (One-hour average measurements (dots) below 12.1μg/m^3 were not plotted to reduce clutter on the graph.)

Table 14: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of the monitor at Pinecliff in fall of 2016.

Pinecliff Date (2016)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
10-Sep	satellite	11004	6.0	NE	2	5	0000	2.2	4	2000
11-Sep	satellite	4550	5.4	NE	2	4	2000	10.1	25	1900
12-Sep	satellite	6772	6.6	NE	10	25	1900	5.9	14	2300
13-Sep	satellite	3033	8.5	E	6	14	2300	5.3	15	0100
13-Sep	satellite	3033	6.7	NE						
14-Sep	satellite	758	7.7	NE	5	15	0100	4.9	42	1300
14-Sep	satellite	2539	5.2	NE						
15-Sep	ANGEL UNDERBURN 2016	174	12.4	S	5	42	1300	2.7	7	0700
15-Sep	satellite	1517	7.0	NE						
15-Sep	satellite	846	12.0	S						
16-Sep	satellite	253	6.3	NE	3	7	0700	1.6	4	0000
27-Sep	satellite	187	29.1	N	2	3	0000	1.5	3	2100
28-Sep	ANGEL UNDERBURN 2016	650	12.4	S	2	3	2100	3.1	6	2300
28-Sep	satellite	846	14.0	S						
29-Sep	satellite	846	11.0	S	3	6	2300	6.8	12	0300

Table 15: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of the monitor at Naches in fall of 2016.

Chelan Date (2016)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
3-Sep	satellite	321	27.1	SE	NA	NA	NA	NA	NA	NA
10-Sep	satellite	11004	26.3	NW	1	3	2300	4	35	0700
11-Sep	satellite	4550	27.5	NW	4	35	0700	2	8	2000
12-Sep	satellite	6772	26.4	NW	2	8	2000	10	50	0900
13-Sep	satellite	4973	31.1	SE	10	50	0900	14	41	0900
13-Sep	satellite	3033	23.6	NW						
13-Sep	satellite	3033	27.1	NW						
14-Sep	satellite	1658	31.2	SE	14	41	0900	5	15	1000
14-Sep	satellite	1658	31.7	SE						
14-Sep	satellite	758	25.4	NW						
14-Sep	satellite	2539	29.1	NW						
15-Sep	satellite	1517	27.6	NW	5	15	1000	7	62	1800
15-Sep	satellite	846	28.7	W						
15-Sep	ANGEL UNDERBURN 2016	174	27.9	W						
16-Sep	satellite	253	28.6	NW	7	62	1800	0	1	0600
28-Sep	satellite	846	31.7	W	2	5	2200	3	8	0800
28-Sep	ANGEL UNDERBURN 2016	650	27.9	W						
29-Sep	satellite	846	29.2	W	3	8	0800	6	9	0700

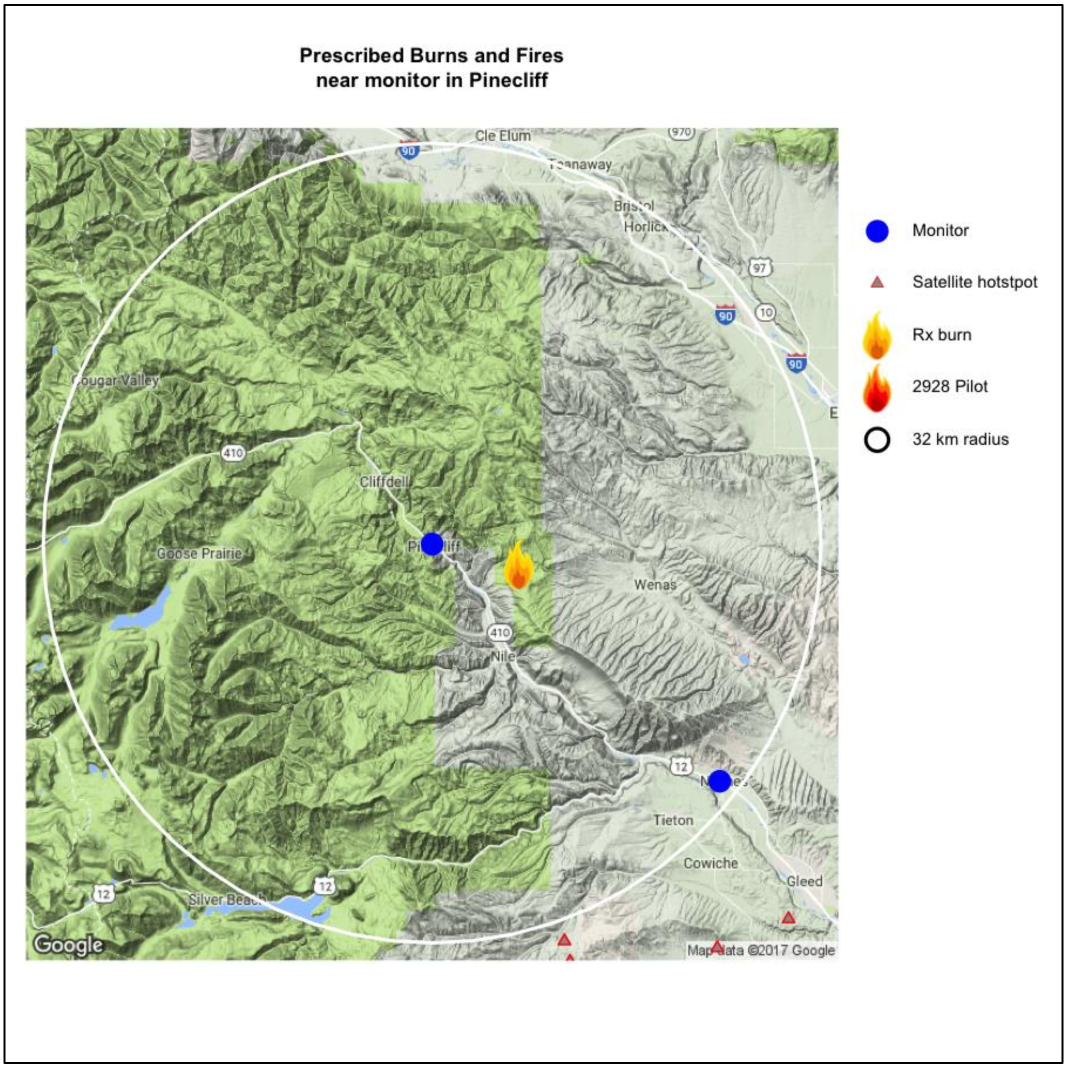


Figure 16: Location of prescribed fires and hotspots detected by satellite in the vicinity of the temporary monitor placed in Pinecliff, WA in spring of 2017. No prescribed burning in the vicinity was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.

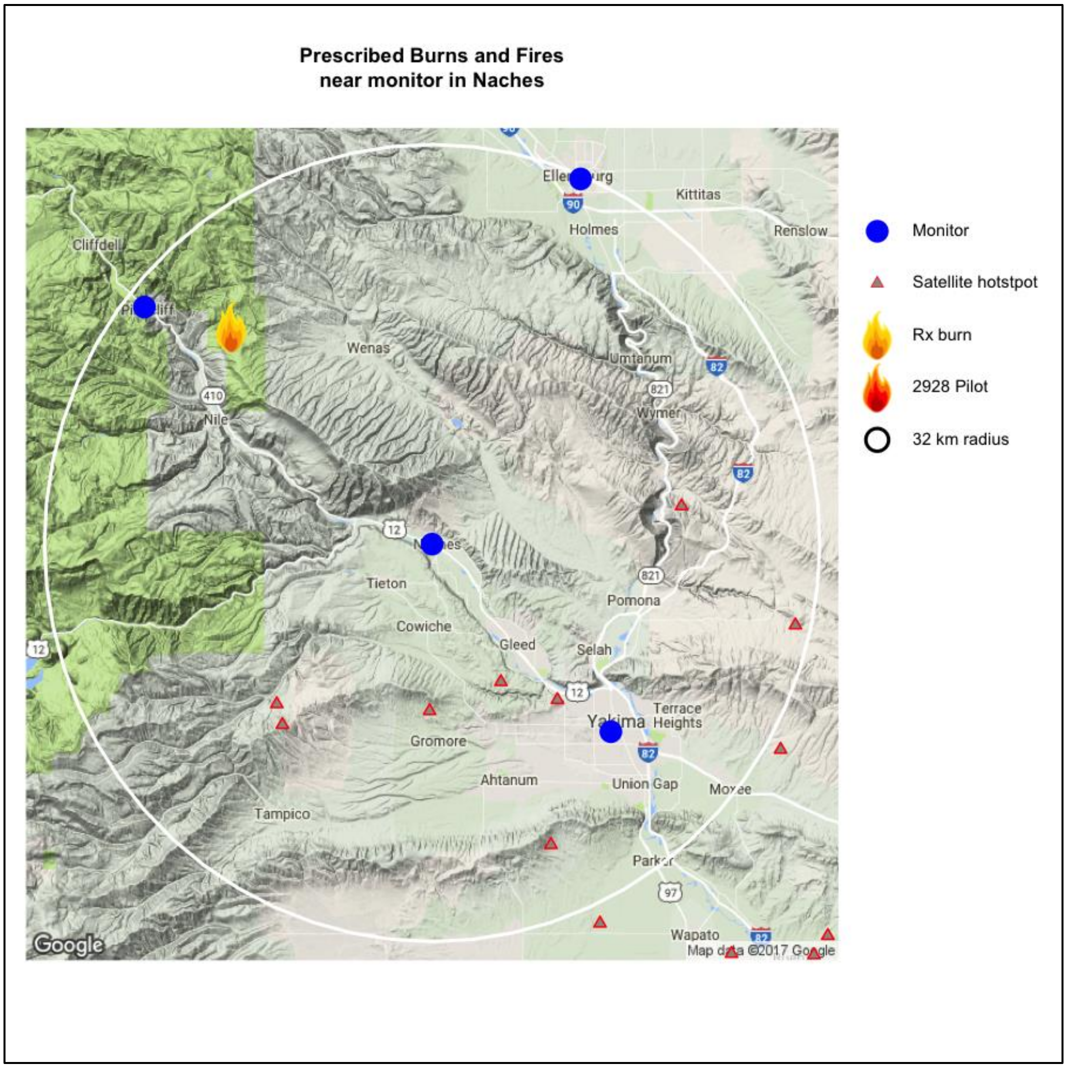


Figure 17: Location of prescribed fires and hotspots detected by satellite in the vicinity of the temporary monitor placed in Naches, WA in spring of 2017. No prescribed burning in the vicinity was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.

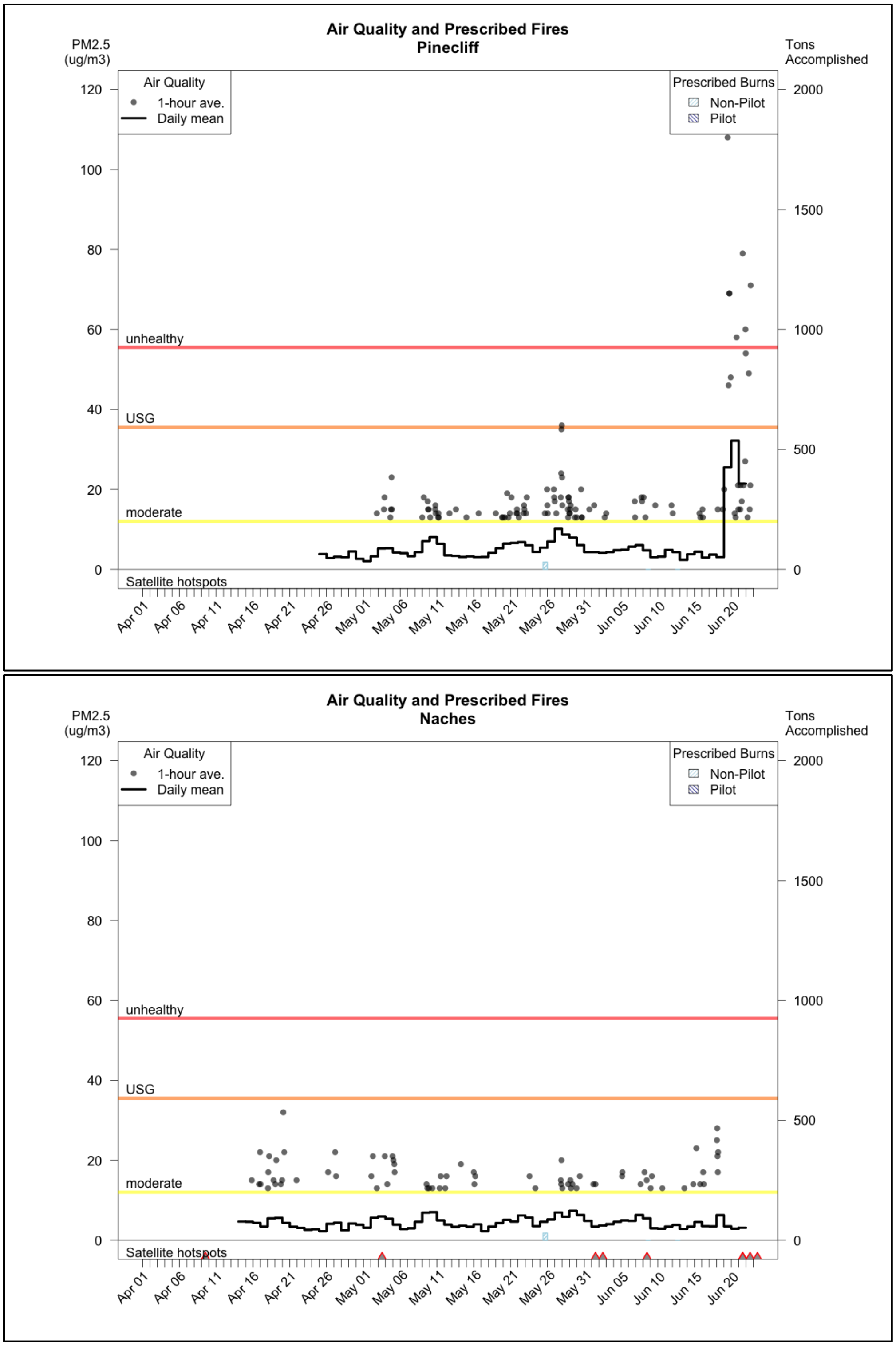


Figure 18: Air quality, tons consumed by prescribed burning, and satellite-detected hotspots by date in the vicinity of Pinecliff and Naches, WA during the spring of 2017. Daily mean PM2.5 values can be compared to colored horizontal lines to see how air quality measurements compare to national Air Quality Index health thresholds. (One-hour average measurements (dots) below 12.1μg/m^3 were not plotted to reduce clutter on the graph.)

Table 14: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of the monitor at Pinecliff during spring of 2017.

Pinecliff Date (2017)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
25-May	CANTEEN UB2017	30	7.3	E	5.4	20	2300	7	20	2100

Table 15: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of the monitor at Naches during spring of 2017.

Naches Date (2017)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 µ/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 µ/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
9-Apr	satellite	20	26.1	SE	NaN	NA	NA	NaN	NA	NA
3-May	satellite	131	20.7	NE	5.9	21	2200	5.3	21	2300
25-May	CANTEEN UB2017	30	24	NW	4.6	12	2000	5.2	12	2100
1-Jun	satellite	561	12.4	SE	3.4	14	0600	3.7	9	0900
2-Jun	satellite	561	16.2	SE	3.7	9	0900	4	9	0200
8-Jun	satellite	561	13.4	S	5.5	17	0500	3	16	0500
21-Jun	satellite	413	18.1	SW	3.1	12	1200	NA	11	0600
21-Jun	satellite	413	19.1	S						
22-Jun	satellite	1926	30.6	E	NA	11	0600	NA	NA	NA
23-Jun	satellite	373	30.6	E	NA	NA	NA	NA	NA	NA

Twisp and Winthrop

Permanent air quality monitors are located in Twisp and Winthrop, WA. These two towns are approximately 12 km apart within the Methow valley. Two non-Pilot prescribed fires, 2016 Upper Rendezvous and 2016 Goat, were conducted about 30 km north of Twisp and 18 km north of Winthrop in both 2016 and 2017. They did not cause air quality impacts to either town.

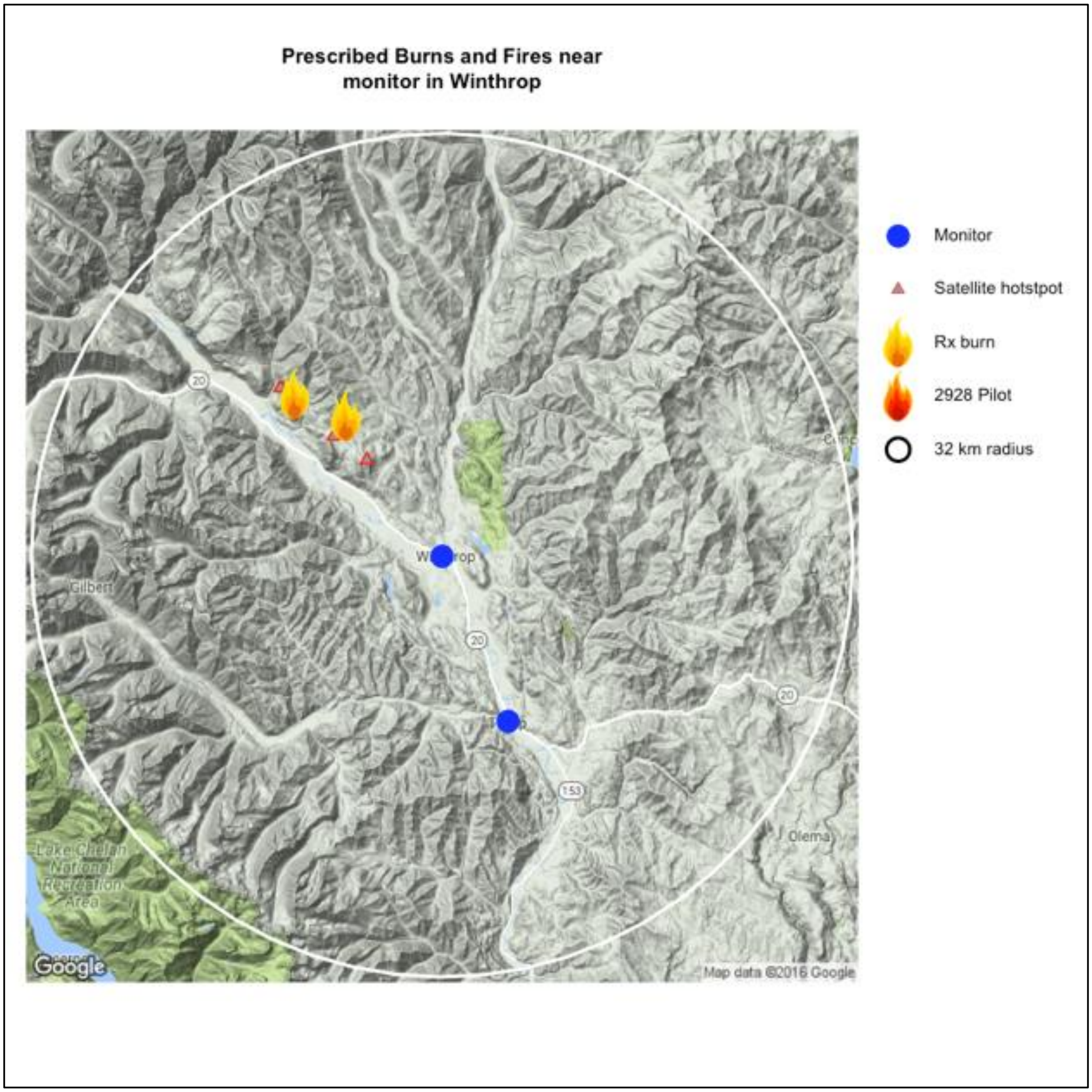


Figure 19: Location of prescribed fires and hotspots detected by satellite in the vicinity of the permanent monitor in Winthrop, WA in fall of 2016. No prescribed burning in the vicinity was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.

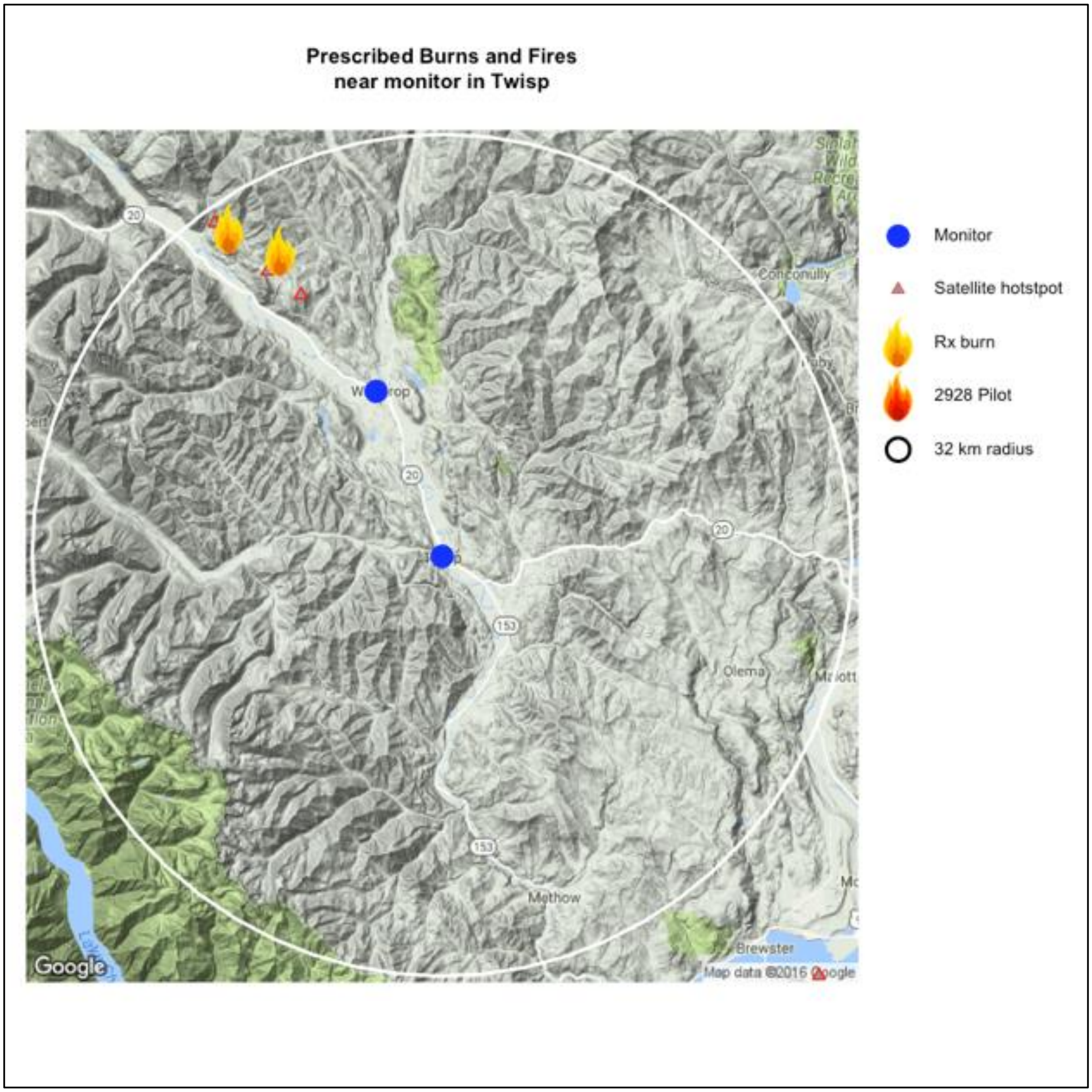
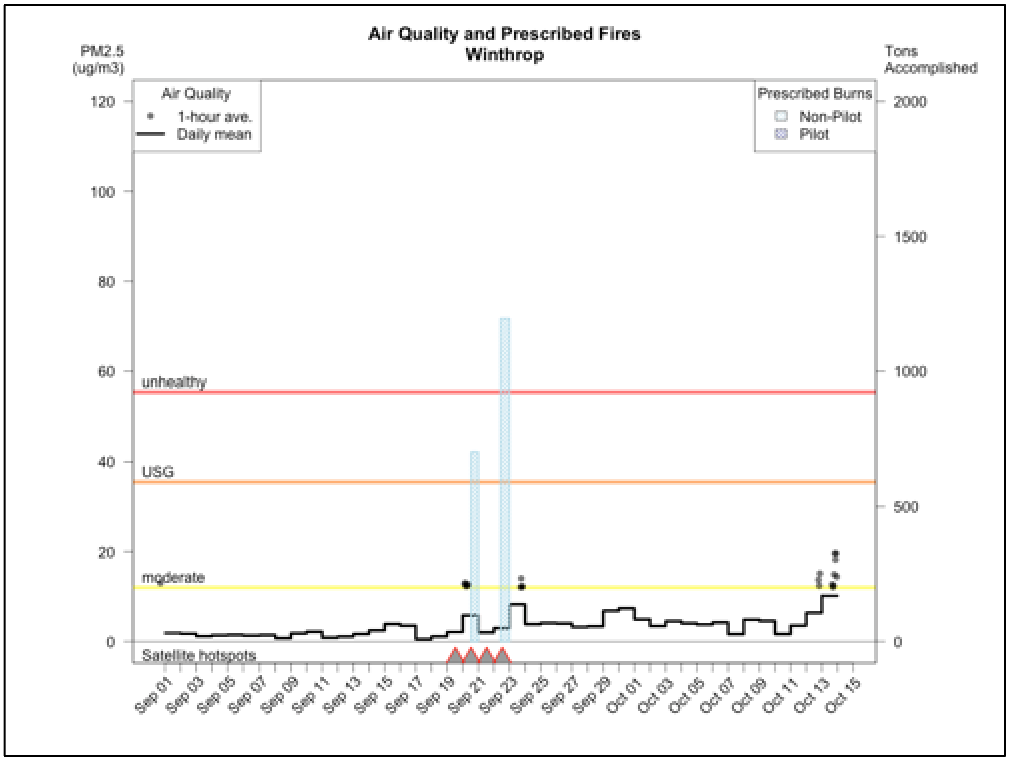


Figure 20: Location of prescribed fires and hotspots detected by satellite in the vicinity of the permanent monitor in Twisp, WA in the fall of 2016. No prescribed burning in the vicinity was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.



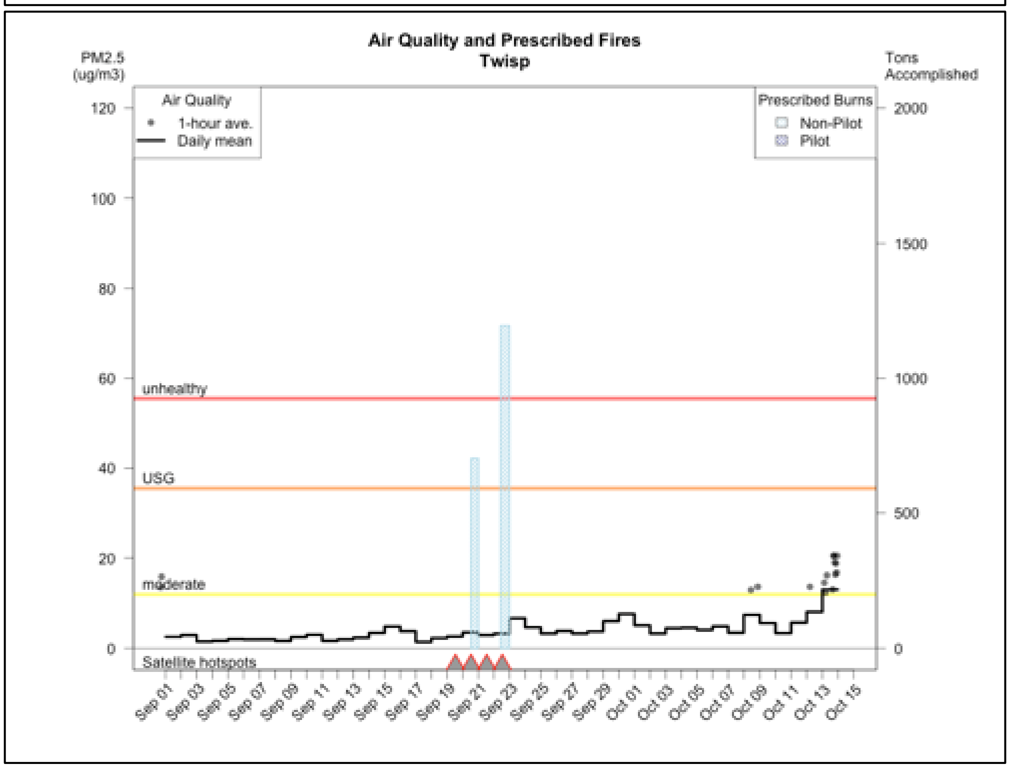


Figure 21: Air quality, tons consumed by prescribed burning, and satellite-detected hotspots by date in the vicinity of Winthrop and Twisp, WA during the fall of 2016. Daily mean PM2.5 values can be compared to colored horizontal lines to see how air quality measurements compare to national Air Quality Index health thresholds. (One-hour average measurements (dots) below 12.1μ/m^3 were not plotted to reduce clutter on the graph.)

Table 16: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of the monitor at Winthrop in fall of 2016.

Winthrop Date (2016)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 μg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 μg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
19-Sep	satellite	506	11.9	NW	2	4	0700	6	13	0400
20-Sep	satellite	1011	12.4	NW	6	13	0400	2	3	2200
20-Sep	2016 UPPER RENDEZVOUS 1	712	13.0	NW						
21-Sep	satellite	254	9.4	NW	2	3	2200	3	6	1600
22-Sep	satellite	1264	17.9	NW	3	6	1600	8	14	1800
22-Sep	2016 GOAT	1210	16.8	NW						

Table 17: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of the monitor at Twisp in fall of 2016.

Twisp Date (2016)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 μg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 μg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
19-Sep	satellite	506	25.2	NW	3	4	0700	4	7	2100
20-Sep	satellite	1011	25.5	NW	4	7	2100	3	4	0000
20-Sep	2016 UPPER RENDEZVOUS 1	712	26.4	NW						
21-Sep	satellite	254	22.7	NW	3	4	0000	3	5	2100
22-Sep	satellite	1264	30.9	NW	3	5	2100	7	11	1000
22-Sep	2016 GOAT	1210	29.9	NW						

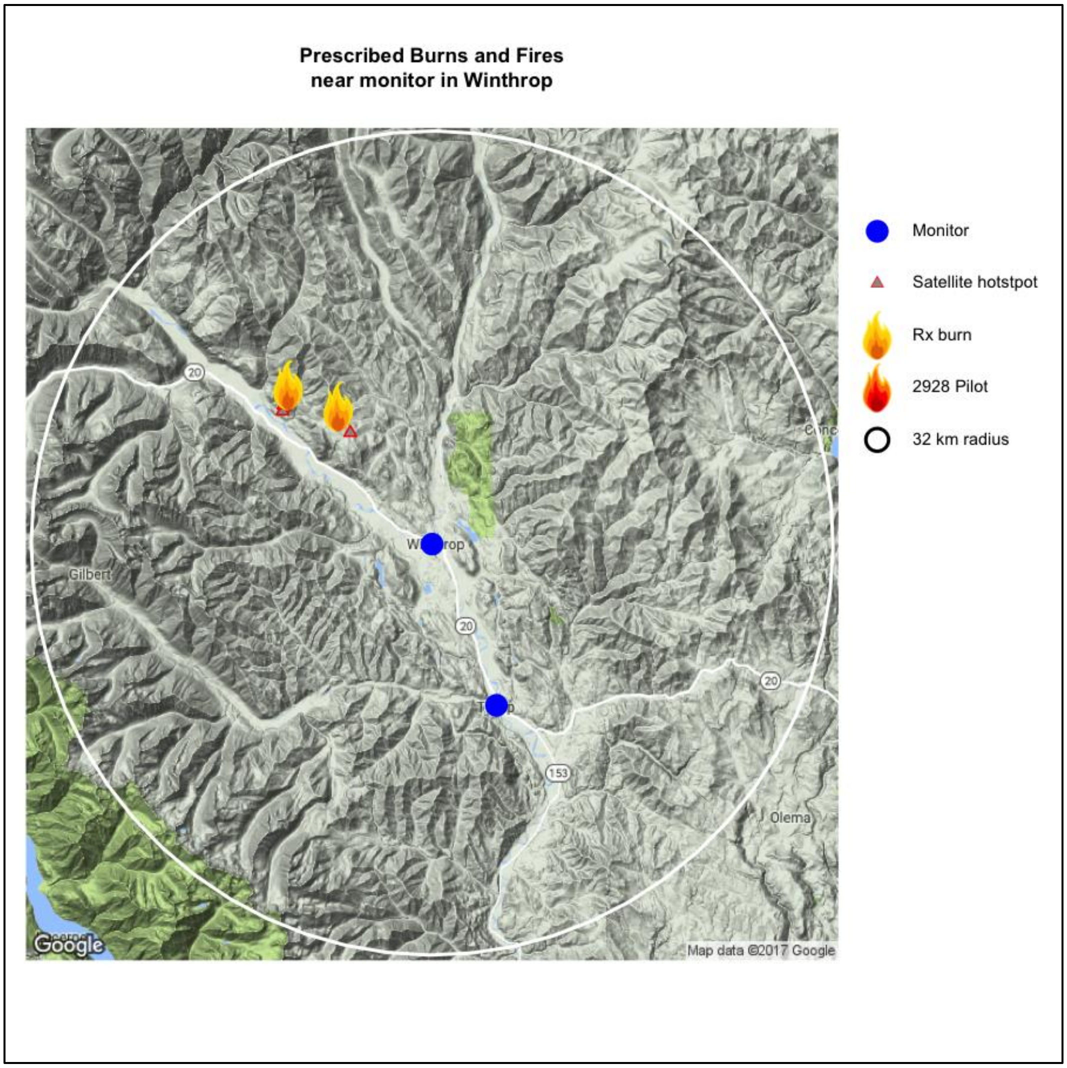


Figure 22: Location of prescribed fires and hotspots detected by satellite in the vicinity of the permanent monitor in Winthrop, WA in spring of 2017. No prescribed burning in the vicinity was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.

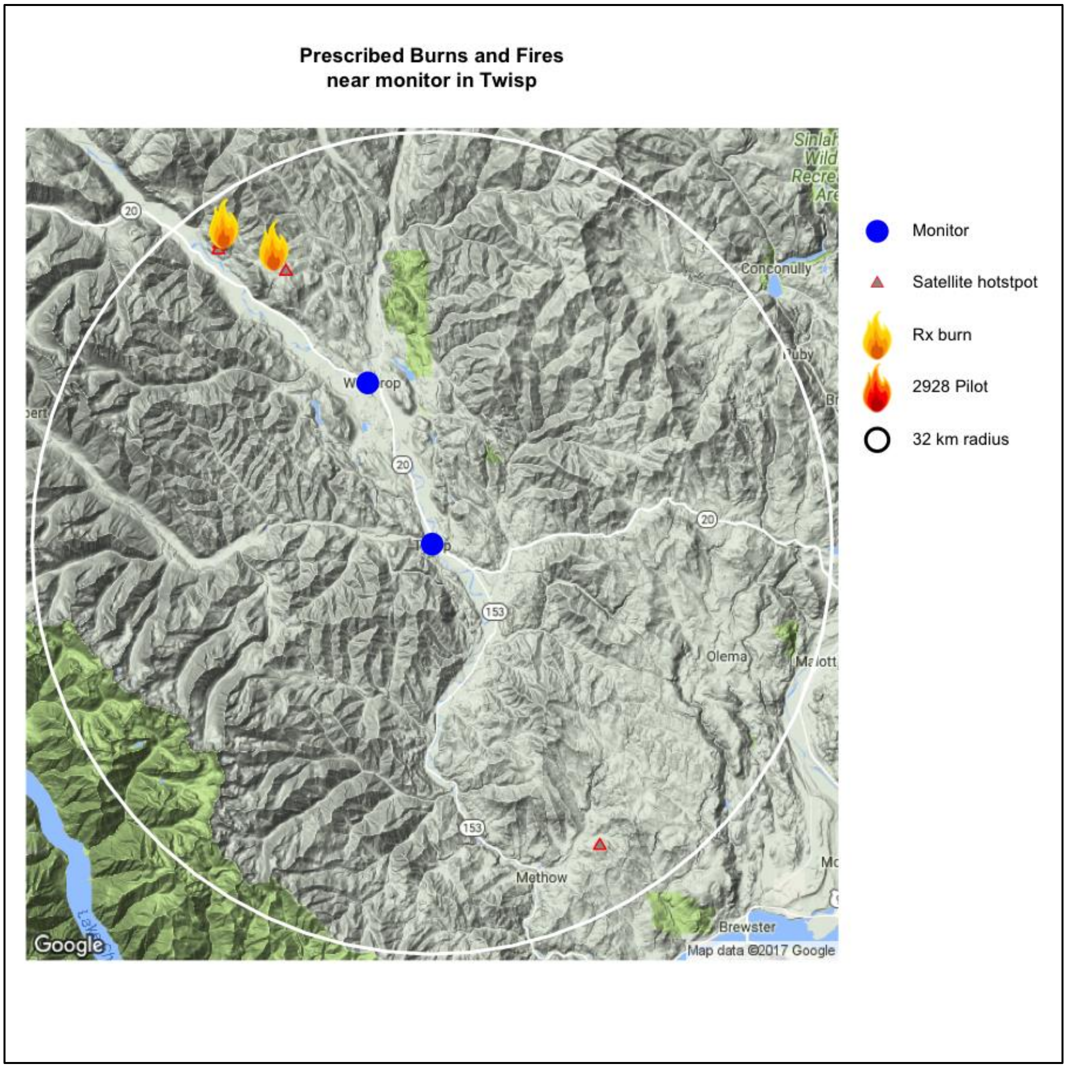
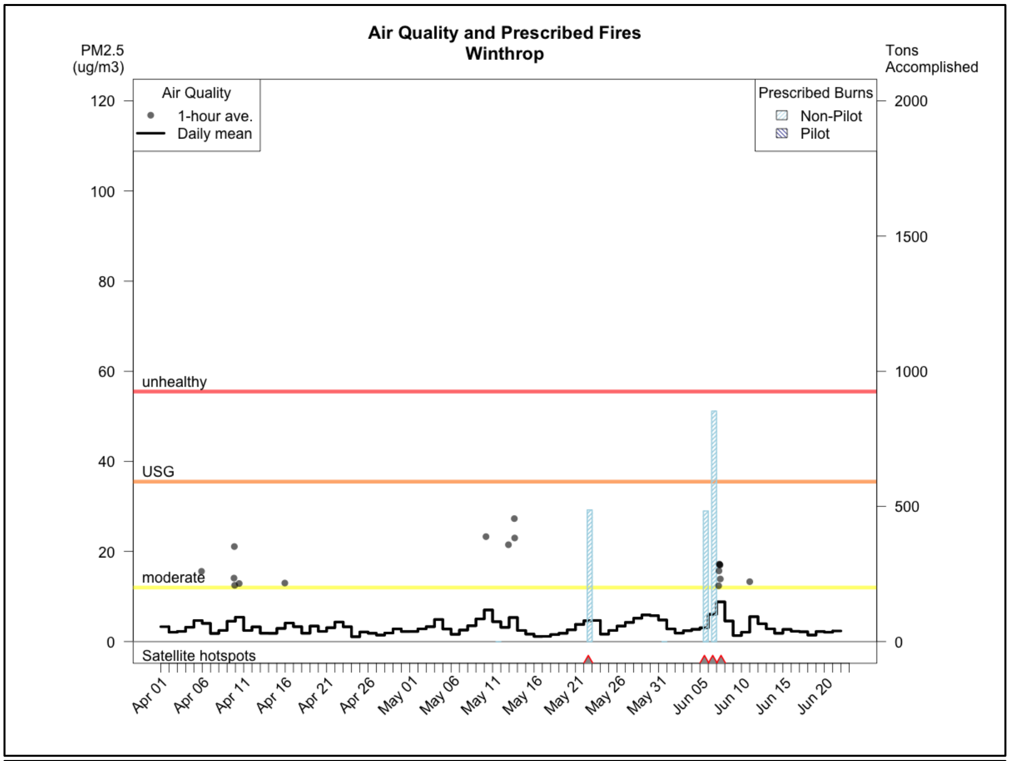


Figure 23: Location of prescribed fires and hotspots detected by satellite in the vicinity of the permanent monitor in Twisp, WA in spring of 2017. No prescribed burning in the vicinity was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.



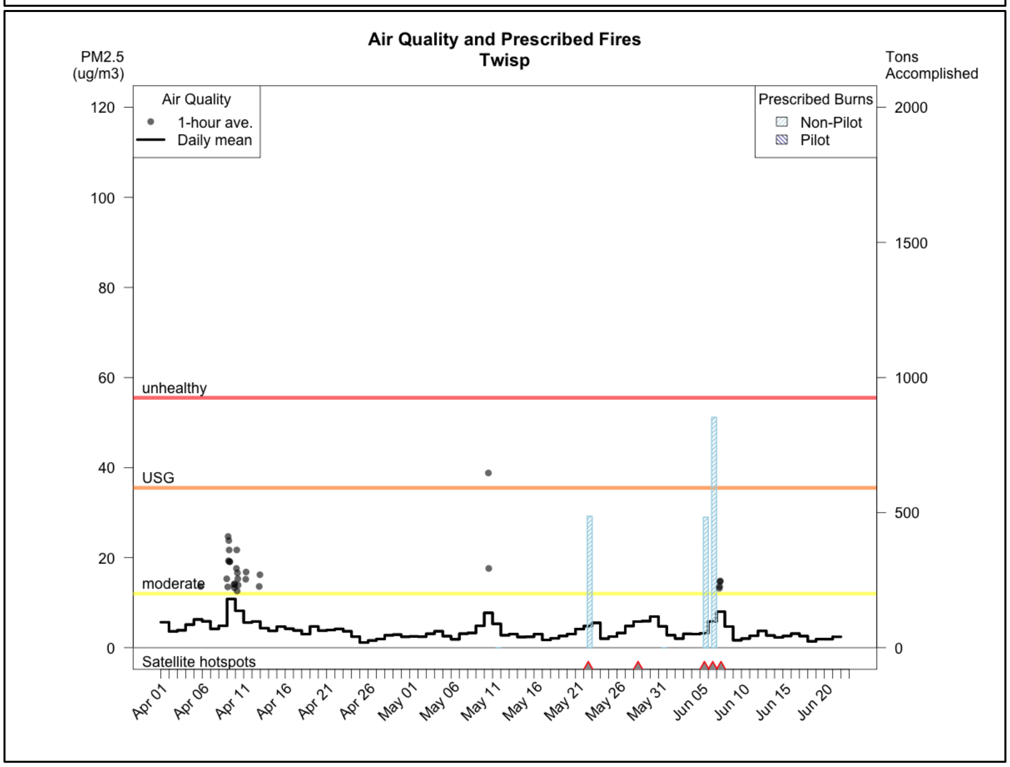


Figure 24: Air quality, tons consumed by prescribed burning, and satellite-detected hotspots by date in the vicinity of Winthrop and Twisp, WA during the spring of 2017. Daily mean PM2.5 values can be compared to colored horizontal lines to see how air quality measurements compare to national Air Quality Index health thresholds. (One-hour average measurements (dots) below 12.1μg/m^3 were not plotted to reduce clutter on the graph.)

Table 18: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of the monitor at Winthrop in spring of 2017.

Winthrop Date (2017)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
22-May	satellite	506	15.7	W	4.6	7.1	2200	4.7	7.1	0500
22-May	2017 GOAT	493	16.8	NW						
5-Jun	satellite	3630	10.8	NW	3.1	6.8	2300	6.1	11.5	0500
5-Jun	2017 UPPER RENDEZVOUS 1	489	13	NW						
6-Jun	satellite	10889	16.2	NW	6.1	11.5	0500	8.8	17.2	0800
6-Jun	2017 GOAT	863	16.8	NW						
7-Jun	satellite	907	16	W	8.8	17.2	0800	4.6	8.9	0700

Table 19: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of the monitor at Twisp in spring of 2017.

Twisp Date (2017)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
22-May	satellite	506	28.5	NW	4.8	5.8	1400	5.5	8.9	0900
22-May	2017 GOAT	493	29.9	NW						
28-May	satellite	1099	27.1	SE	5.8	8.1	0600	5.9	8.8	0600
5-Jun	satellite	3630	24.2	NW	3.2	4.7	2200	5.8	9.9	0800
5-Jun	2017 UPPER RENDEZVOUS 1	489	26.4	NW						
6-Jun	satellite	10889	29.3	NW	5.8	9.9	0800	8	14.8	1100
6-Jun	2017 GOAT	863	29.9	NW						
7-Jun	satellite	907	28.8	NW	8	14.8	1100	4.7	10.9	0600

Curlew

The tiny town of Curlew, WA was identified for placement of a temporary air quality monitor in fall of 2016 due to the proximity of a proposed 2928 pilot burn "Vulcan D" on Forest Service managed lands. Vulcan D was not burned in the fall of 2016 due to grazing conflicts although the Colville National Forest hopes to burn Vulcan D in the spring of 2017. Six prescribed fire ignitions in 3 different treatment units were accomplished on 5 different days in the area of the Curlew monitor using the standard DNR approval process.

Prescribed burns in the vicinity of Curlew during the fall 2016 time period of the study were mostly small although burning in the Vulcan 49 unit on 9/28/2016 consumed 956 tons and was just 7.3 km W-NW of the Curlew monitor. Twenty-four hour average PM2.5 concentrations stayed well below the Moderate AQI threshold (12.1 $\mu g/m^3$) and maximum 1-hour values never exceeded 35 $\mu g/m^3$. One hour values do appear elevated at times but no direct link to prescribed burning in the area is obvious. Maximum 1-hour values seem to increase later in the time period of the monitoring which may point to a home heating cause. In summary, air quality in Curlew was not significantly impacted by prescribed burning during the time period of the pilot study.

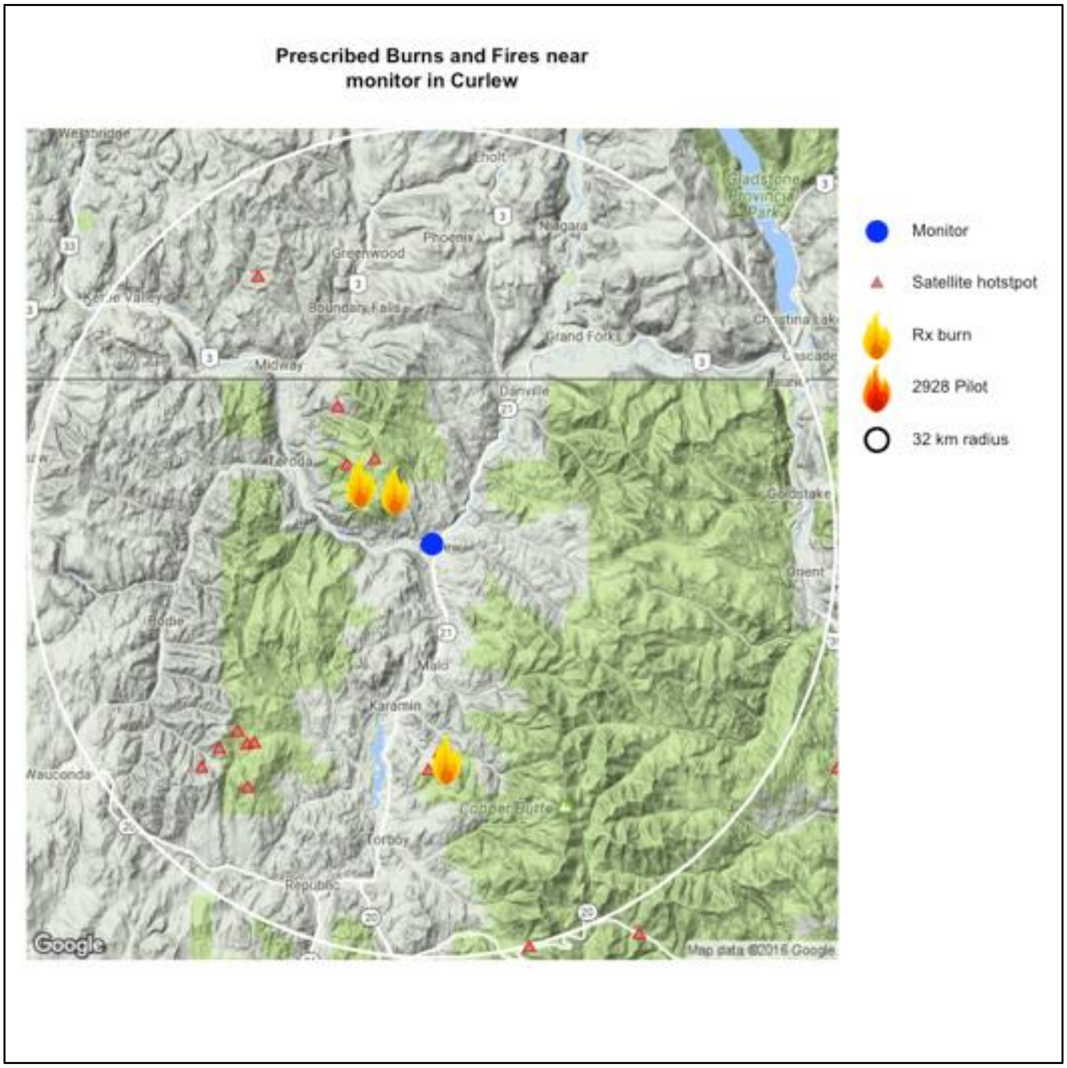


Figure 25: Location of prescribed fires and hotspots detected by satellite in the vicinity of the temporary monitor placed in Curlew, WA in fall of 2016. No prescribed burning in the vicinity was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.

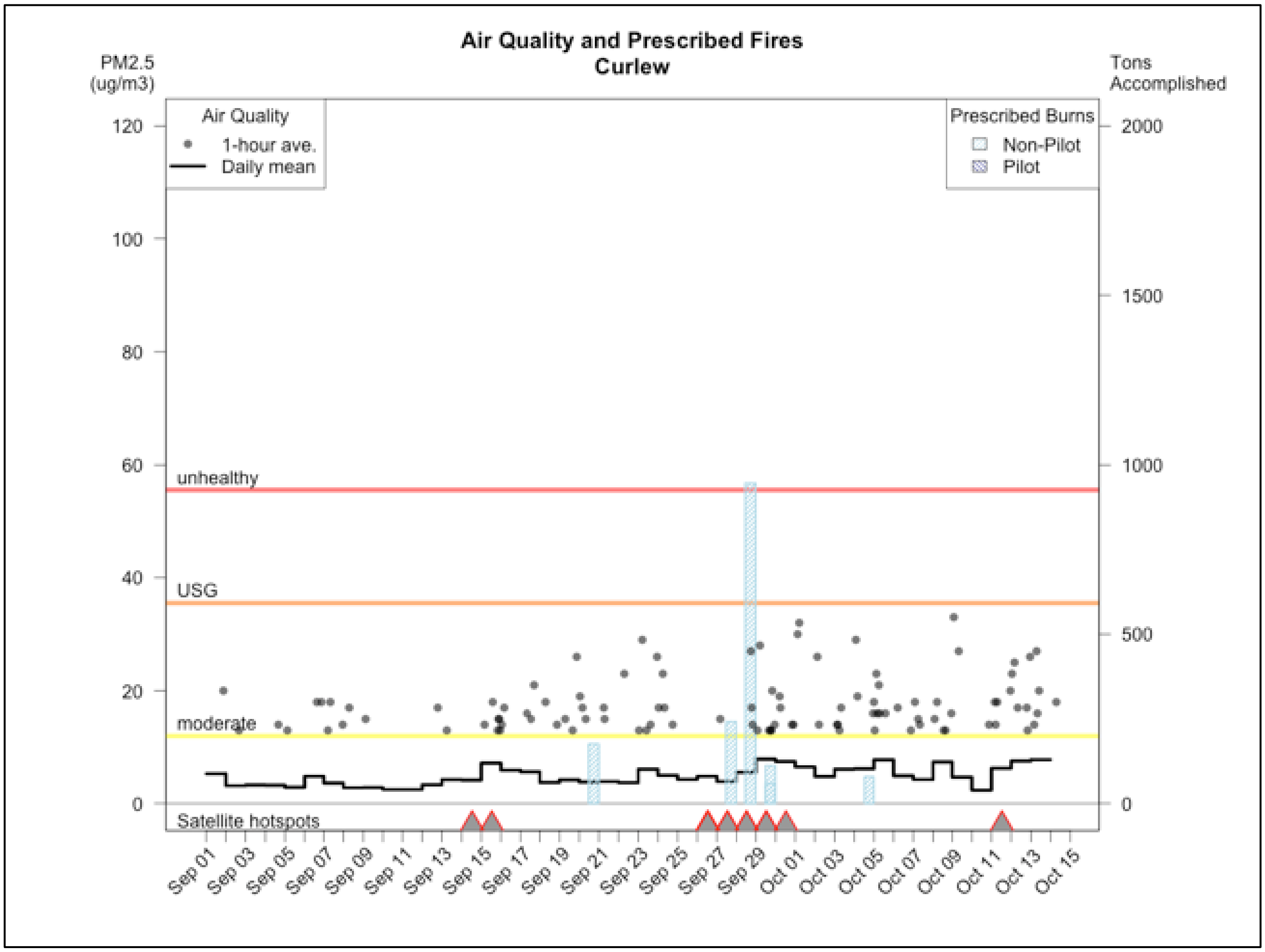


Figure 26: Air quality, tons consumed by prescribed burning, and satellite-detected hotspots by date in the vicinity of Curlew, WA during the fall of 2016. Daily mean PM2.5 values can be compared to colored horizontal lines to see how air quality measurements compare to national Air Quality Index health thresholds. (One-hour average measurements (dots) below 12.1μg/m^3 were not plotted to reduce clutter on the graph.)

Table 20: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of Curlew, WA in fall of 2016. (None of the prescribed fires near this location were burned using 24-hour advance approval.)

Curlew Date (2016)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
14-Sep	satellite	506	21	S	4	10	1800	7	18	1400
15-Sep	satellite	253	21	S	7	18	1400	6	17	0400
20-Sep	MEL 130145149	179	17	SE	4	19	0100	4	17	0600
26-Sep	satellite	2275	24	S	5	12	0300	4	15	0400
26-Sep	satellite	2275	21	SW						
26-Sep	satellite	2275	23	SW						
26-Sep	satellite	2275	25	SW						
27-Sep	satellite	1011	17	SE	4	15	0400	6	27	1800
27-Sep	satellite	1011	18	S						
27-Sep	MEL 130145149	245	17	SE						
28-Sep	satellite	253	17	SE	6	27	1800	8	28	0500
28-Sep	satellite	253	9	W						
28-Sep	VULCAN 49	956	7	W						
29-Sep	satellite	253	16	SE	8	28	0500	8	19	0500
29-Sep	satellite	253	8	NW						
29-Sep	MEL 130145149	61	17	SE						
29-Sep	VULCAN 49	114	7	W						
30-Sep	satellite	86	13	NW	8	19	0500	7	32	0500
4-Oct	VULCAN 212269	81	5	NW	6	29	0200	8	23	0300
11-Oct	satellite	NA	25	NW	6	20	2300	8	26	2300

Kettle Falls and Sherman Creek Fish Hatchery

The small town of Kettle Falls and the nearby Sherman Creek Fish Hatchery were identified for placement of temporary air quality monitors in fall 2016 and spring 2017 to detect possible smoke impacts from proposed 2928 pilot burns.

Fall 2016

In fall 2016 there were two proposed 2928 pilot burns: Paradise 90, and Sherman Creek. Burning with 24-hour approval notification under the conditions of the pilot was accomplished on 4 different days in the Paradise 90 unit. A total of 6,352 tons of material was consumed in the Paradise 90 unit with an impressive single day accomplishment of 3,627 tons on 9/28/2016. No burning was accomplished in the Sherman Creek unit in 2016.

Very little in the way of air quality impacts were measured at Kettle Falls with the exception of a fairly short term spike in measured PM2.5 on 10/4/2016. This may have been from the prescribed fire Rickey Point which was ignited on that day. Twenty four hour average concentrations bumped up to Moderate AQI category due to the short term elevation of PM2.5. None of the 4 days of burning on the Paradise 90 pilot burn, appear to have significantly impacted Kettle Falls with smoke. There is evidence of a bit of smoke entering Kettle Falls on September 14-16, 2016 but the 1-hour stayed below 20 $\mu g/m^3$.

Paradise 90 burning looks to have sent some smoke into the area of the Sherman Creek Fish Hatchery monitor around September 29 – 30, 2016. The last ignition of Paradise 90 took place on September 28, 2016 but it's not uncommon for fuels to smolder for a day or two after ignition. Smoldering combustion can be problematic for air quality since the smoke says close to the ground and doesn't disperse as easily. The 24-hour average PM2.5 concentration indicates that air quality was in the Moderate AQI category for 1 day.

Overall, fall 2016 burning on the Paradise 90 pilot burn seems to have been quite successful with four days of burning on the unit resulting in minimal impact to air quality.

Spring 2017

In spring 2017 burning with 24-hour approval notification under the conditions of the pilot was accomplished on 6 different days in the Sherman Creek pilot burn in three sub-units: Bridge Hatch Trail, Rail and Bisbee. An additional 5 days of burning not using the 24-hr advance notice was also conducted for a total of 11 burns in spring 2017 in the Sherman Creek unit.

Air quality remained in the good category during spring 2017 at Kettle Falls.

Two days in the Moderate AQI category occurred at the Fish Hatchery. They are both attributable to the Bisbee sub-unit burns just 0.6 km from the monitor. Bisbee was burned on three consecutive days (June 5, 6, and 7, 2017). The second day (June 6) used the 24-hr advance notice. The two moderate days are most likely attributable to the June 6 and 7, 2017 Bisbee burns, when smoke impacts occurred the mornings after those burns (June 7 and June 8 respectively). After the June 6 Bisbee pilot burn, a maximum 1-hr average PM2.5 concentration of 204 μg/m^3 occurred at 0100 PDT on June 7 giving a June 7 24-hr PM2.5 average of 31 μg/m^3. After the non-pilot Bisbee burn on June 7, a maximum 1-hr average PM2.5 concentration of 75 μg/m^3 occurred at 0500 PDT on June 8 giving a June 8 24-hr average concentration of 14.5 μg/m^3. Thus a mixture of pilot and non-pilot burning both yielded Moderate AQI category impacts at the Sherman Creek Fish Hatchery.

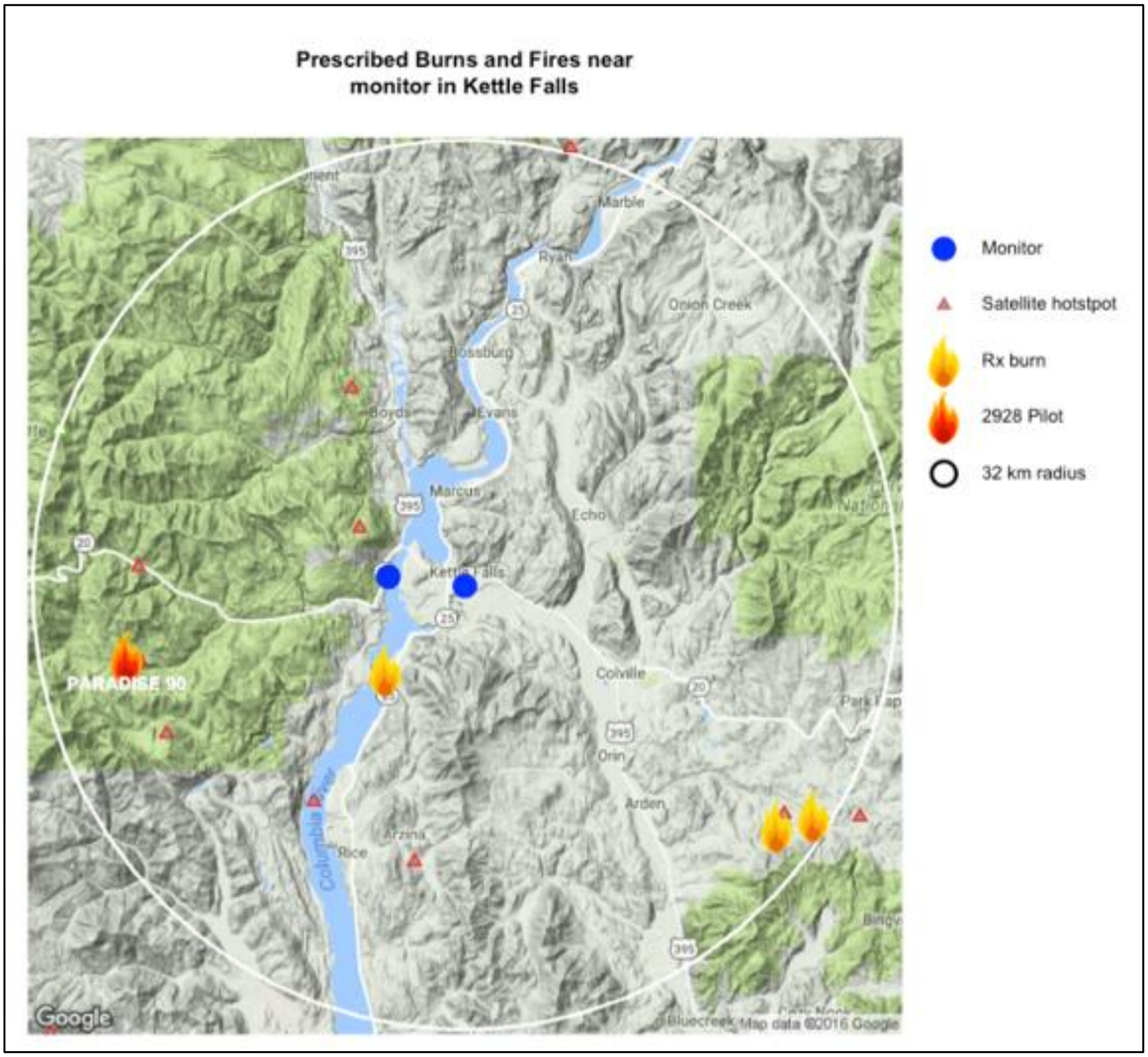


Figure 27: Location of prescribed fires and hotspots detected by satellite in the vicinity of the temporary monitors placed in Kettle Falls in fall of 2016. Four days of burning on the Paradise 90 pilot burn was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.

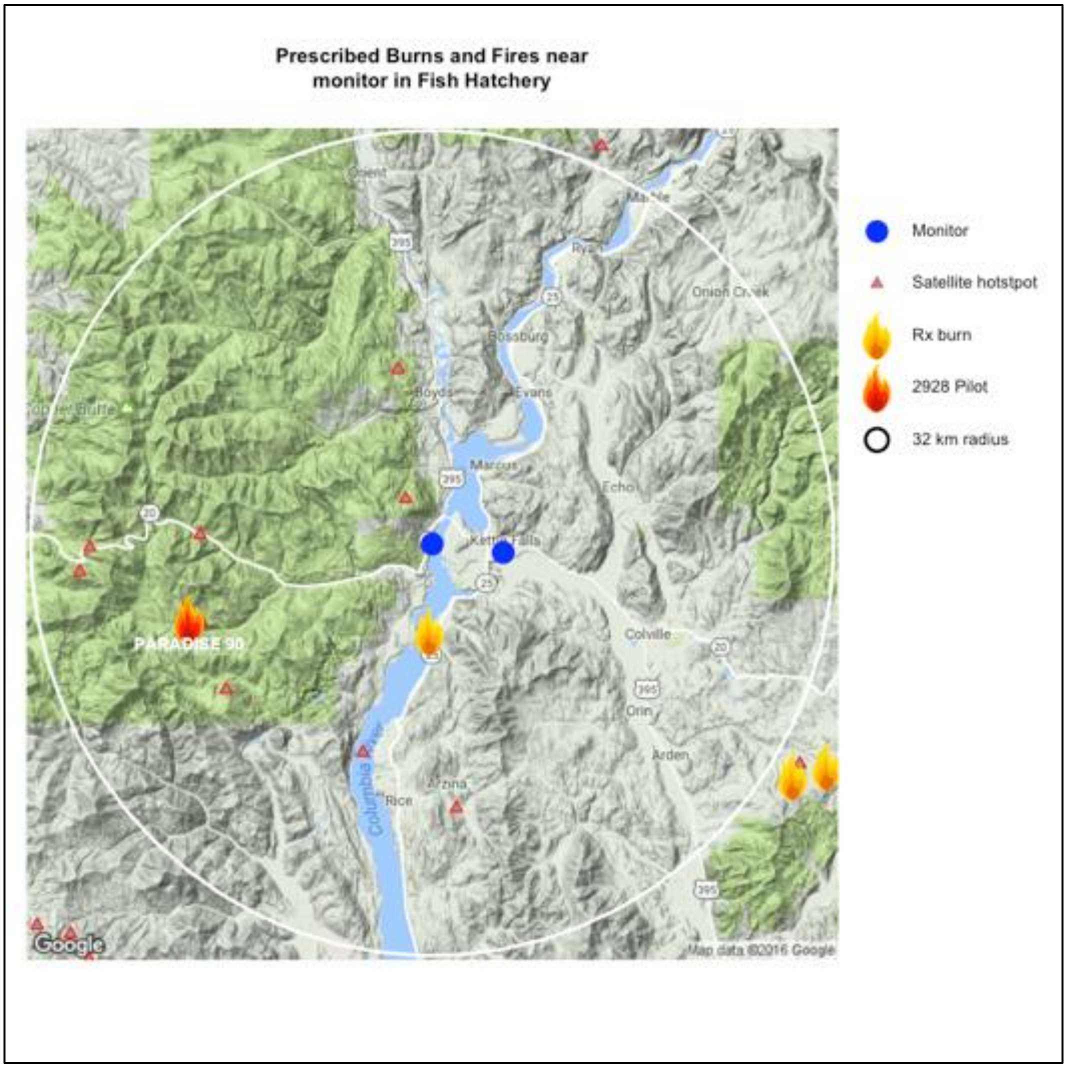
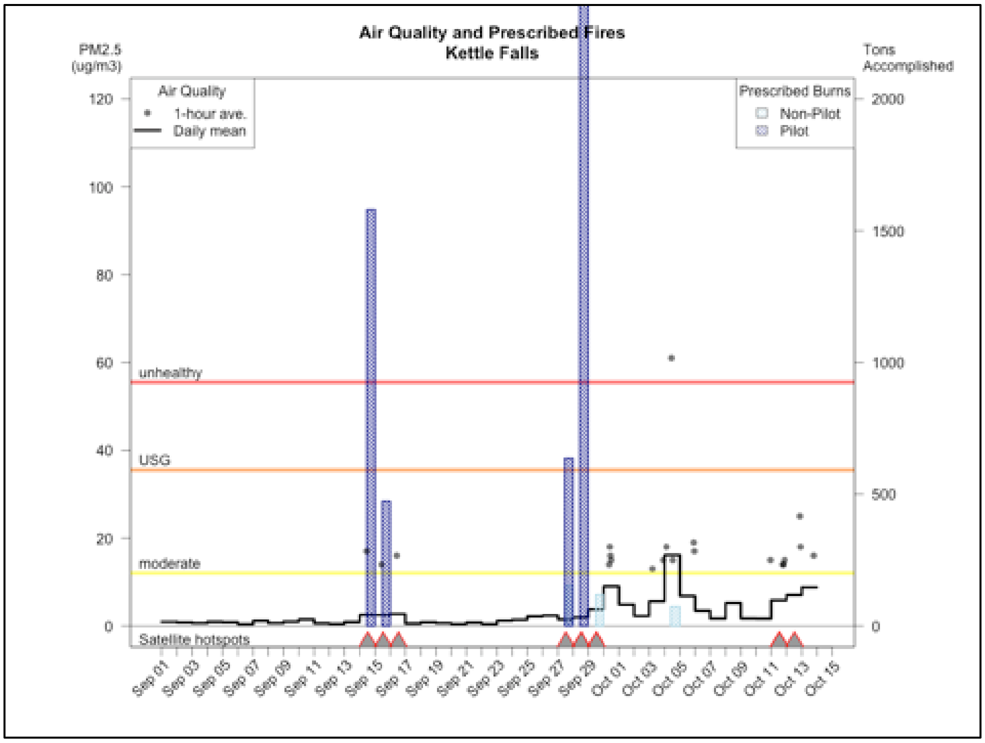


Figure 28: Location of prescribed fires and hotspots detected by satellite in the vicinity of the temporary monitor placed at the Sherman Creek Fish Hatchery in fall of 2016. Four days of burning on the Paradise 90 pilot burn was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.



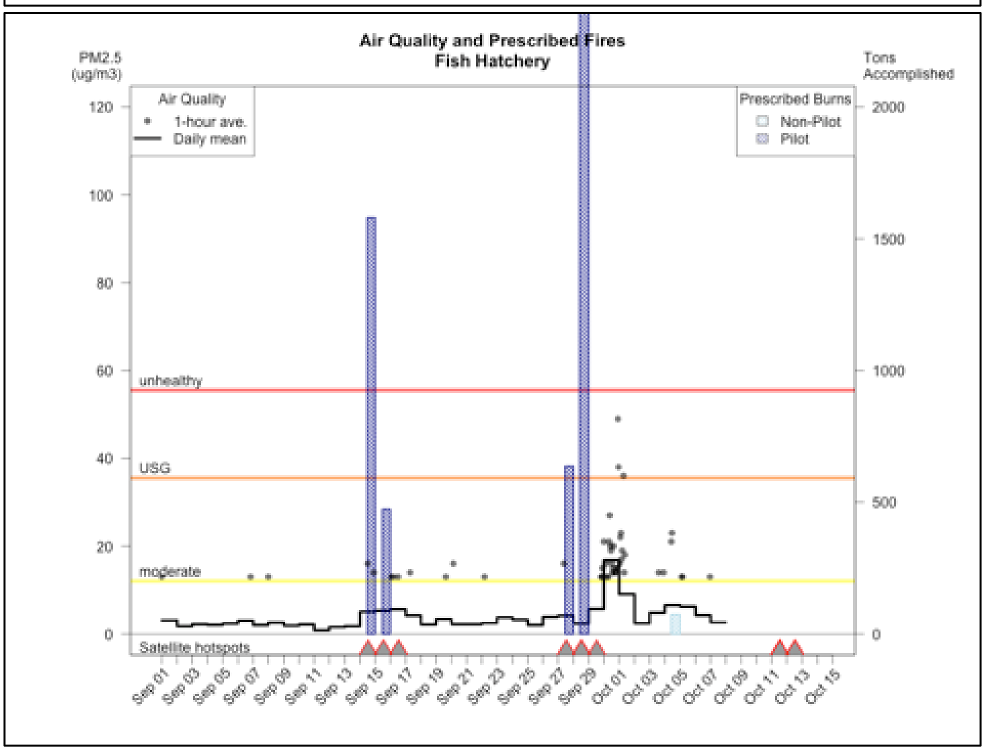


Figure 29: Air quality, tons consumed by prescribed burning, and satellite-detected hotspots by date in the vicinity of Kettle Falls and Fish Hatchery monitors during the fall of 2016. Daily mean PM2.5 values can be compared to colored horizontal lines to see how air quality measurements compare to national Air Quality Index health thresholds. (One-hour average measurements (dots) below 12.1µg/m^3 were not plotted to reduce clutter on the graph.)

Table 21: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of Kettle Falls, WA in fall of 2016.

Kettle Falls Date (2016)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
14-Sep	satellite	506	25.7	SW	3	17	1100	3	14	1000
14-Sep	PARADISE 90*	1600	25.5	SW						
15-Sep	satellite	253	25.7	SW	3	14	1000	3	16	1000
15-Sep	PARADISE 90*	480	25.5	SW						
16-Sep	satellite	253	24.1	W	3	16	1000	1	6	1500
27-Sep	satellite	506	24.6	SW	2	4	0500	2	9	1800
27-Sep	PARADISE 90*	645	25.5	SW						
27-Sep	LOG BARN MEADOW	156	28.8	E						
28-Sep	satellite	574	19.1	S	2	9	1800	4	8	1800
28-Sep	satellite	253	24.5	SW						
28-Sep	PARADISE 90*	3627	25.5	SW						
29-Sep	satellite	253	28.7	E	4	8	1800	9	18	1000
29-Sep	satellite	253	24.6	SW						
29-Sep	CHRISTIANSEN	120	30.6	E						
4-Oct	RICKEY POINT	75	8.5	S	16	152	1200	7	19	2200
11-Oct	satellite	253	20.2	S	6	15	2100	7	25	2100
11-Oct	satellite	253	8.8	W						
12-Oct	satellite	253	16.4	NW	7	25	2100	9	16	1900

*24-Hr Advance approval pilot burn.

Table 22: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of the monitor at the Sherman Creek fish hatchery in fall of 2016.

Hatchery Date (2016)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
14-Sep	satellite	506	20.4	SW	5	16	1200	5	11	0200
14-Sep	PARADISE 90*	1600	20.2	SW						
15-Sep	satellite	253	20.4	SW	5	11	0200	6	13	0100
15-Sep	PARADISE 90*	480	20.2	SW						
16-Sep	satellite	253	18.5	W	6	13	0100	4	14	0700
27-Sep	satellite	506	19.3	SW	4	16	0900	2	8	1500
27-Sep	PARADISE 90*	645	20.2	SW						
28-Sep	satellite	574	17.1	S	2	8	1500	6	15	2200
28-Sep	satellite	253	19.9	SW						
28-Sep	PARADISE 90*	3627	20.2	SW						
29-Sep	satellite	253	19.3	SW	6	15	2200	17	49	2200
4-Oct	RICKEY POINT	75	6.8	S	7	23	1100	6	13	0200
11-Oct	satellite	253	20.6	SE						
11-Oct	satellite	253	4.1	NW						
11-Oct	satellite	758	27.2	SW						
12-Oct	satellite	253	13.8	NW						
12-Oct	satellite	253	28.1	SW						

*24-Hr Advance approval pilot burn.

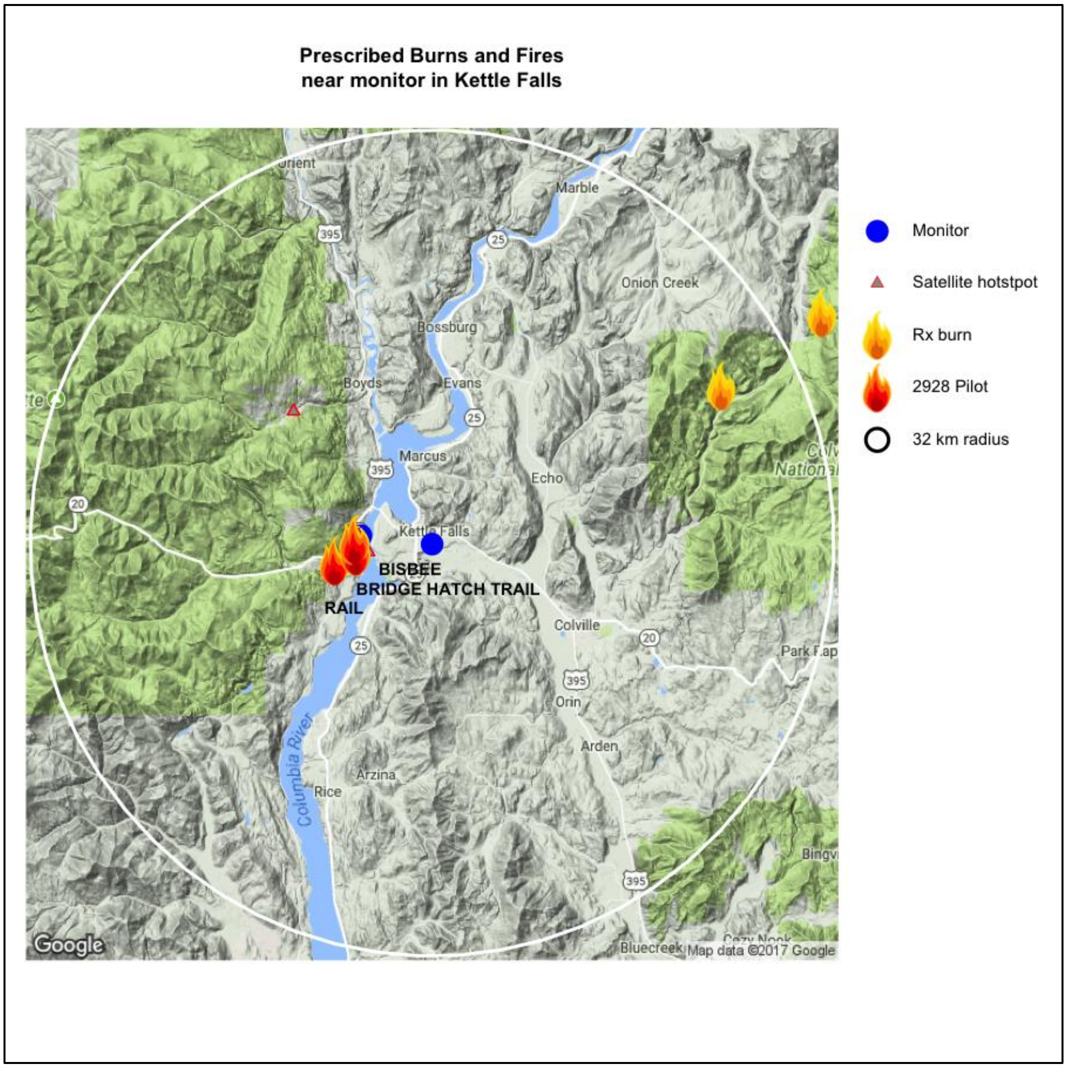


Figure 27: Location of prescribed fires and hotspots detected by satellite in the vicinity of the temporary monitors placed in Kettle Falls in spring of 2017. Six days of burning on units collectively called Sherman Creek (Bisbee, Bridge/Hatch/Trail, and Rail) was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.

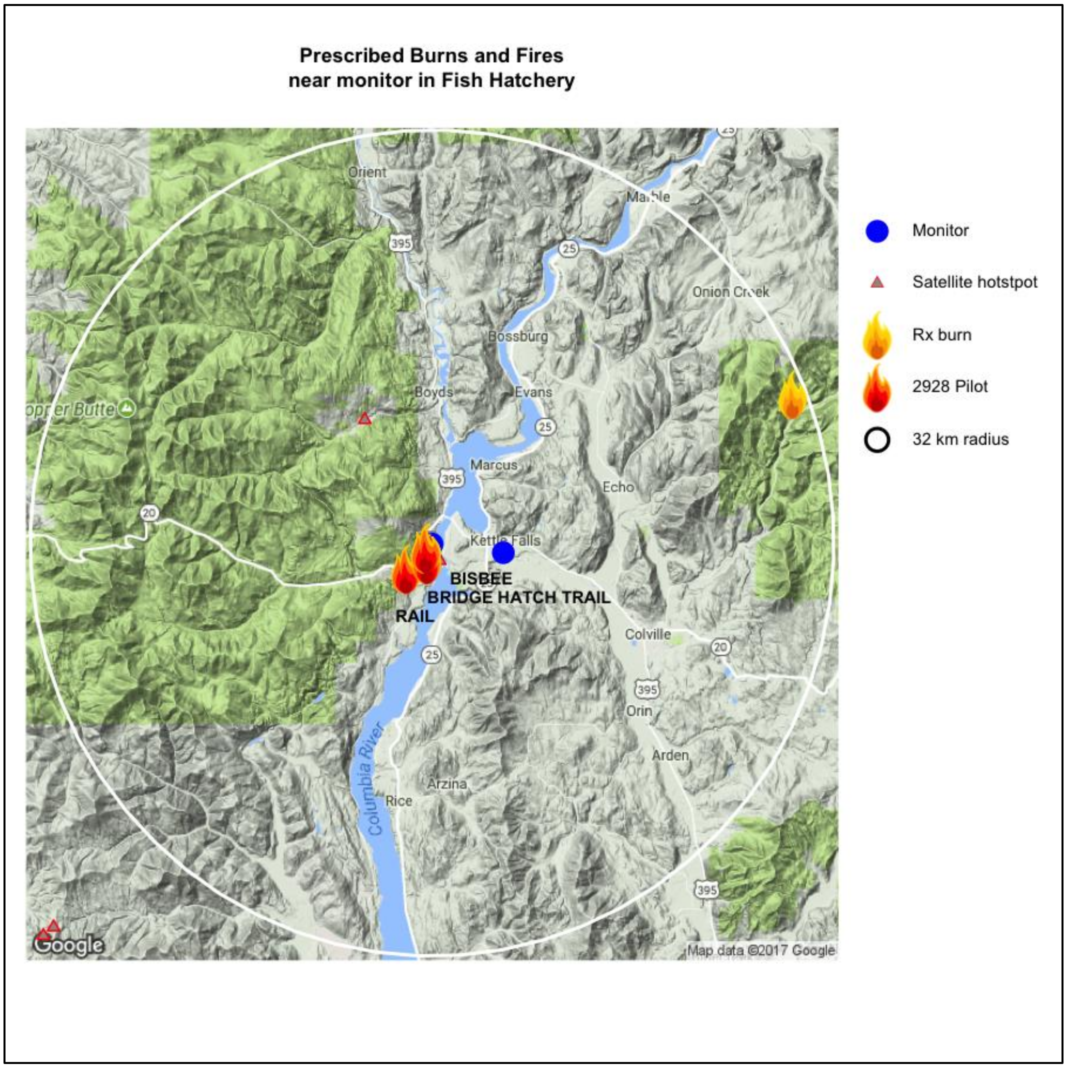
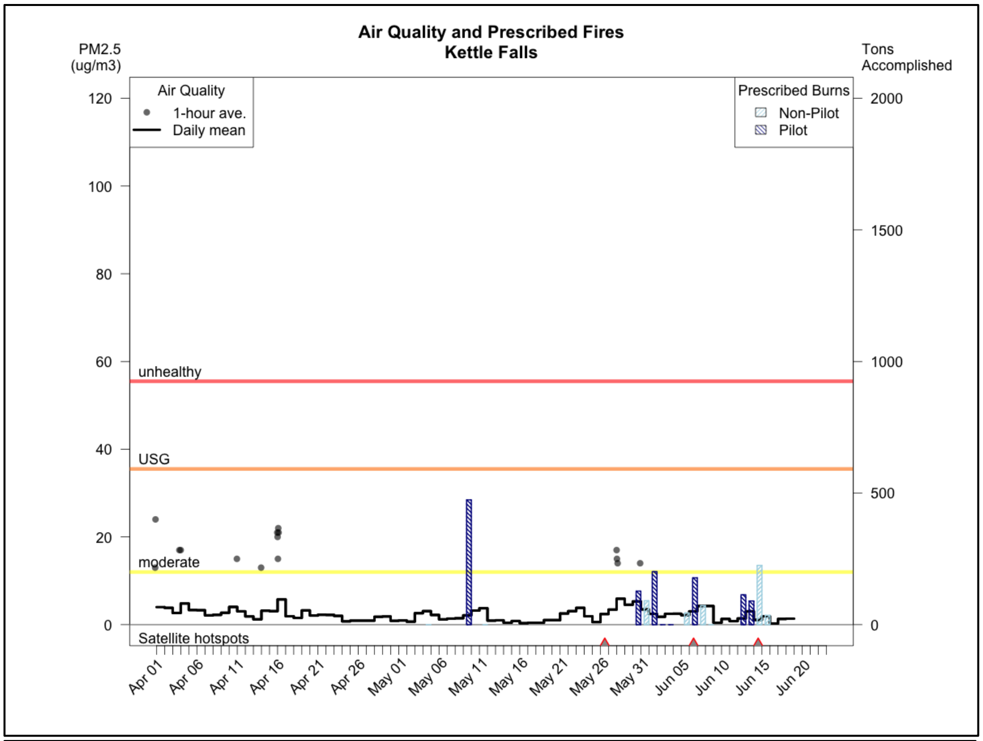


Figure 28: Location of prescribed fires and hotspots detected by satellite in the vicinity of the temporary monitor placed at the Sherman Creek Fish Hatchery in spring of 2017. Six days of burning on units collectively called Sherman Creek (Bisbee, Bridge/Hatch/Trail, and Rail) was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.



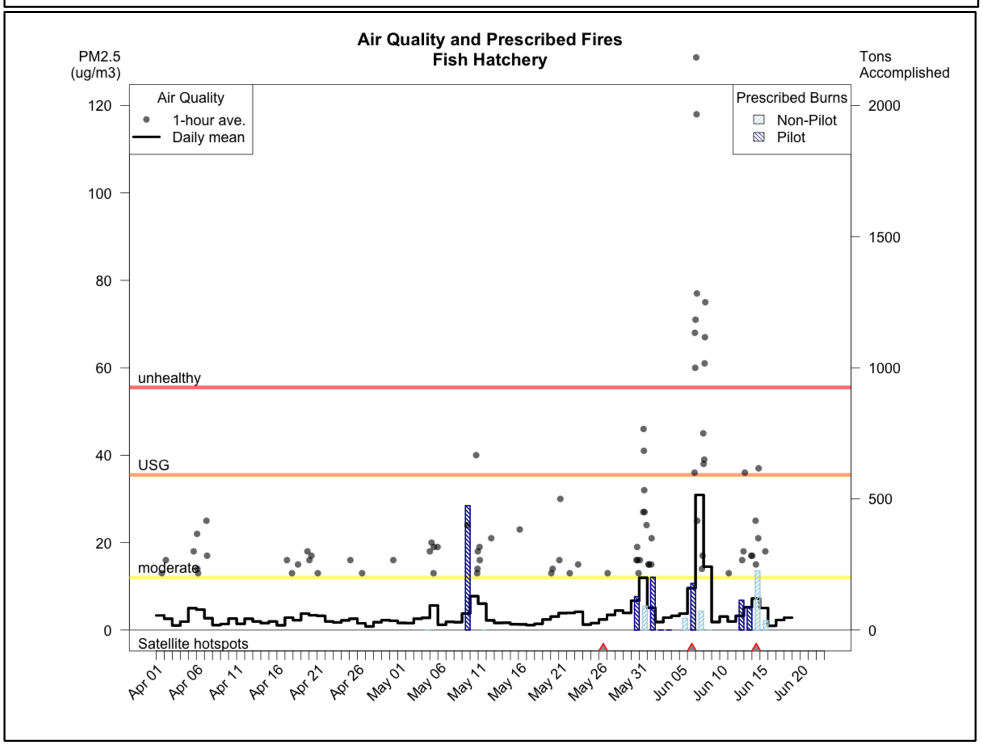


Figure 29: Air quality, tons consumed by prescribed burning, and satellite-detected hotspots by date in the vicinity of Kettle Falls and Fish Hatchery monitors during the spring of 2017. Daily mean PM2.5 values can be compared to colored horizontal lines to see how air quality measurements compare to national Air Quality Index health thresholds. (One-hour average measurements (dots) below 12.1µg/m^3 were not plotted to reduce clutter on the graph.)

Table 23: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of Kettle Falls, WA in spring of 2017.

Kettle Falls Date (2017)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 µg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
9-May	RAIL*	480	7.8	SW	2.1	5	2000	3.2	6	2100
26-May	satellite	253	15	W	2.4	10	2000	3.4	8	2300
30-May	BRIDGE HATCH TRAIL*	129	6.1	SW	5.3	14	2200	3.5	6	0700
31-May	BRIDGE HATCH TRAIL	92	6.1	SW	3.5	6	0700	2.5	9	1400
1-Jun	BRIDGE HATCH TRAIL*	204	6.1	SW	2.5	9	1400	1.8	8	1600
5-Jun	BISBEE	45	6.2	W	2.2	5	2200	3	6	2300
6-Jun	satellite	2722	6.3	W	3	6	2300	4.2	7	0800
6-Jun	BISBEE*	180	6.2	W						
7-Jun	BISBEE	73	6.2	W	4.2	7	0800	4.2	11	0900
12-Jun	BISBEE*	115	6.2	W	1.4	3	2100	3	5	1400
13-Jun	BISBEE**	91	6.2	W	3	5	1400	1.1	2	0100
14-Jun	satellite	64	5.1	SW	1.1	2	0100	1.9	4	0900
14-Jun	BISBEE	228	6.2	W						
15-Jun	BISBEE	36	6.2	W	1.9	4	0900	0.3	2	2300

*24-Hr Advance approval pilot burn.
**Request for 24-hr approval was denied although burning of <100 tons could proceed.

Table 24: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of the monitor at the Sherman Creek fish hatchery in spring of 2017.

Fish Hatchery Date (2017)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 μg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 μg/m³ (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
9-May	RAIL*	480	2.8	SW	3.8	24	1600	7.8	40	1800
26-May	satellite	253	11	NW	2.4	8	1900	3.5	13	0200
30-May	BRIDGE HATCH TRAIL*	129	1.2	S	6.7	19	1800	12	46	1300
31-May	BRIDGE HATCH TRAIL	92	1.2	S	12	46	1300	5.1	21	1300
1-Jun	BRIDGE HATCH TRAIL*	204	1.2	S	5.1	21	1300	1.8	9	0300
5-Jun	BISBEE	45	0.6	SW	3.8	11	0300	9.6	68	2200
6-Jun	satellite	2722	0.7	NW	9.6	68	2200	30.9	204	0100
6-Jun	BISBEE*	180	0.6	SW						
7-Jun	BISBEE	73	0.6	SW	30.9	204	0100	14.5	75	0500
12-Jun	BISBEE*	115	0.6	SW	3.2	18	2300	5.2	36	0300
13-Jun	BISBEE**	91	0.6	SW	5.2	36	0300	7.2	37	2000
14-Jun	satellite	64	1.4	SE	7.2	37	2000	5	18	1600
14-Jun	BISBEE	228	0.6	SW						
15-Jun	BISBEE	36	0.6	SW	5	18	1600	1	5	1600

*24-Hr Advance approval pilot burn.

**Request for 24-hr approval was denied although burning of <100 tons could proceed.

Kalispel Tribal Center

A temporary monitor was placed at the Kalispel Tribal Center near Cusick and Usk, WA in the fall of 2016 to monitor for air quality impacts from the Forest Service Hanlon pilot burn. One day of burning on the Hanlon unit was accomplished under terms of the pilot and a second day of burning on Hanlon used the standard DNR approval process. The first burn day (pilot) accomplished just 90 tons. The second burn day (non-pilot) was more significant and accomplished 1250 tons.

September 26, 2016, the day Hanlon was burned under terms of the pilot, shows no evidence of smoke at the monitor. On September 28, 39, and 30, 2016 a fairly significant amount of tons were consumed on 2 prescribed fires permitted using the standard DNR procedure: Hanlon, Blue Ruby West, and Misery. It appears some smoke from this burning found its way to the Kalispel Tribal Center monitor resulting in modestly elevated 1-hour concentrations and 1 day where the 24-hour AQI was Moderate.

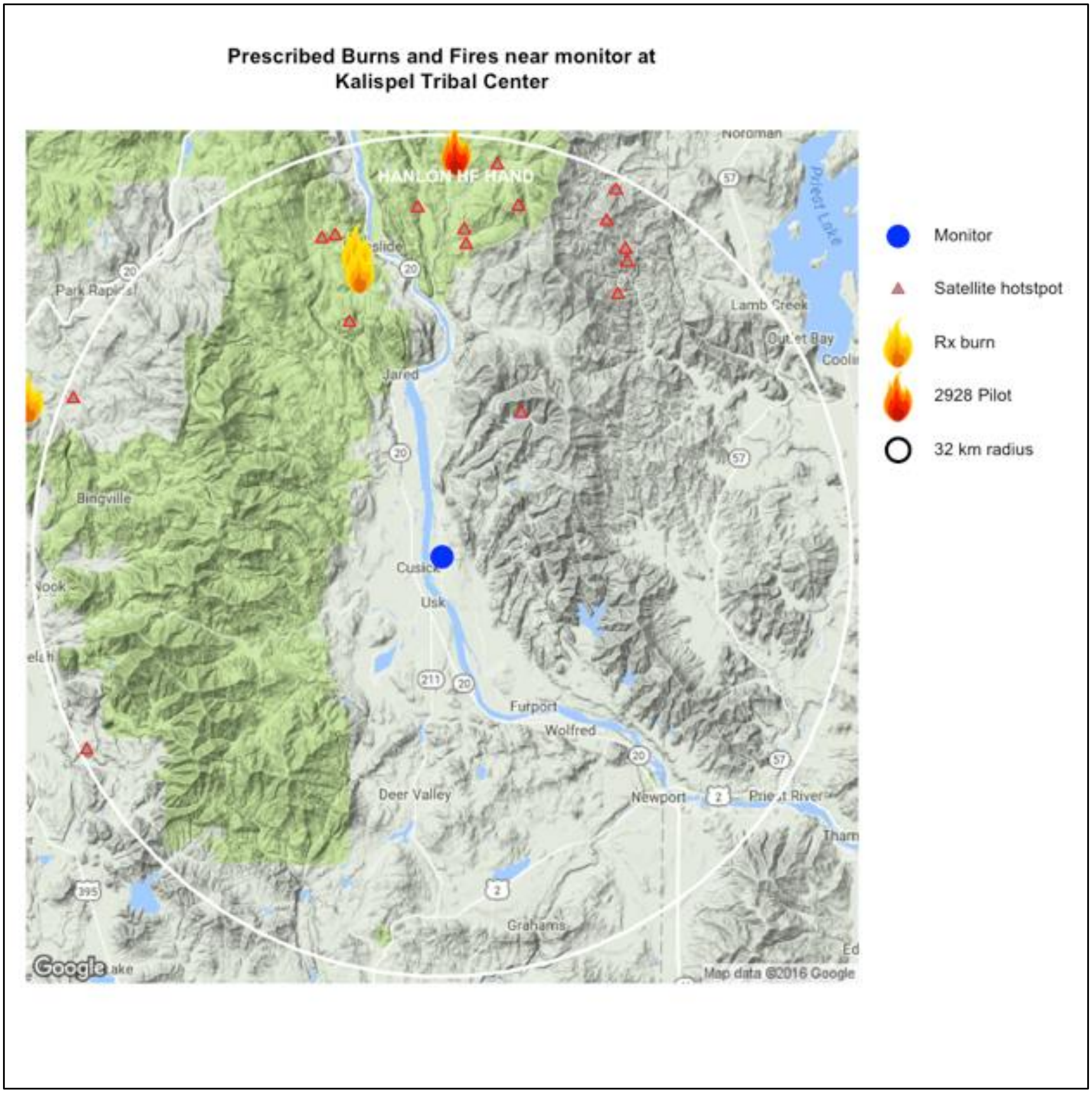


Figure 30: Location of prescribed fires and hotspots detected by satellite in the vicinity of the temporary monitor placed at the Kalispel Tribal Center in fall of 2016. One day of burning on the Hanlon pilot burn was accomplished using the 24-hour pre-approval process allowed by the 2928 pilot study.

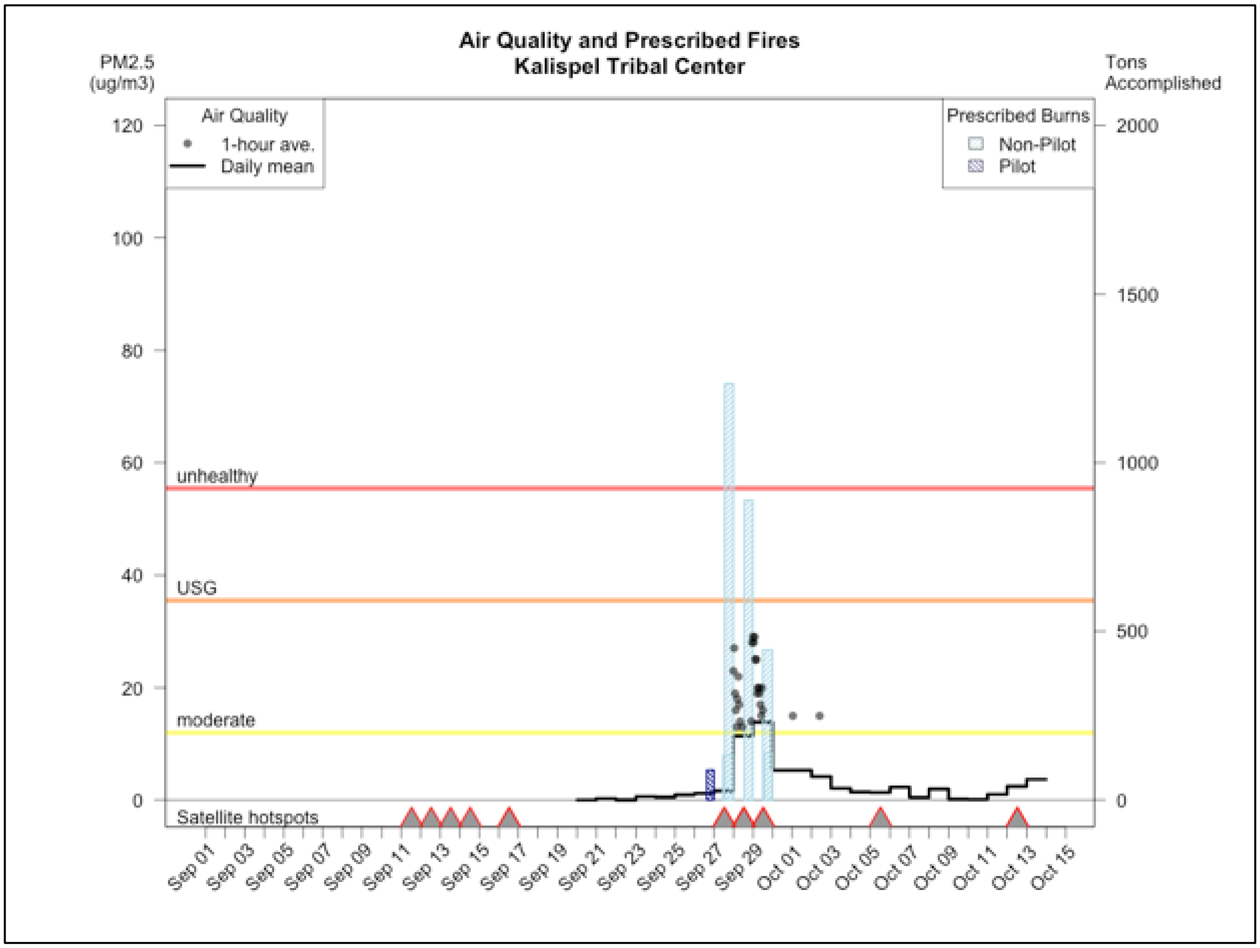


Figure 31: Air quality, tons consumed by prescribed burning, and satellite-detected hotspots by date in the vicinity of the Kalispel Tribal Center during the fall of 2016. Daily mean PM2.5 values can be compared to colored horizontal lines to determine the amount of impact to air quality in comparison to national Air Quality Index health thresholds. Equipment difficulties at this location resulted in missing data early in the study window. (One-hour average measurements (dots) below 12.1μg/m^3 were not plotted to reduce clutter on the graph.)

Table 25: Prescribed fires, satellite detected hotspots, and air quality by date in the vicinity of the Kalispel Tribal Center near Cusick, WA, fall 2016. PM2.5 concentrations in units of µg/m³.

Kalispel Date (2016)	Prescribed Burn or Satellite Hotspot	Tons Burned	Distance from Monitor (km)	Direction from Monitor	Day of Burn			Day after Burn		
					PM2.5 (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT	PM2.5 (24hr)	Max PM2.5 (1-hr)	Time of Max 1-hr PDT
11-Sep	satellite	253	28.5	N						
12-Sep	satellite	846	30.9	N						
13-Sep	satellite	846	27.4	N						
14-Sep	satellite	95	31.4	SW						
16-Sep	satellite	846	26.6	N						
16-Sep	satellite	846	24.8	N						
26-Sep	HANLON HF HAND*	90	30.9	N	1	3	1100	2	7	2300
27-Sep	satellite	846	27.2	N	2	7	2300	11	28	2300
27-Sep	satellite	1693	23.7	N						
27-Sep	BLUE RUBY WEST AERIAL RX HF	135	24.2	NW						
27-Sep	HANLON HF AERIAL	1250	30.9	N						
28-Sep	satellite	253	12.5	N	11	28	2300	14	29	0000
28-Sep	satellite	253	26.5	NW						
28-Sep	satellite	846	25.7	NW						
28-Sep	BLUE RUBY WEST AERIAL RX HF	900	24.2	NW						
29-Sep	satellite	253	19.2	NW	14	29	0000	5	8	1300
29-Sep	satellite	253	25.9	NW						
29-Sep	BLUE RUBY WEST HAND RX HF	450	24.2	NW						
29-Sep	MISERY 54 62	141	22.8	NW						
5-Oct	satellite	846	24.1	N	1	4	1000	2	5	0900
12-Oct	satellite	846	30	N	2	6	2100	4	6	1100
12-Oct	satellite	253	31.1	W						

*24-Hr Advance approval pilot burn.

SUMMARY AND CONCLUSIONS

Four Pilot burns were conducted over 10 burning days during the fall of 2016 and two pilot burns were conducted over 7 burning days during the spring of 2017. A total of 55 individual fires were accomplished in the fall of 2016 and 25 individual fires were accomplished in the spring of 2017 (see Appendix A). Overall, for the cases analyzed here, there was not an appreciable difference between the standard day-of approval burns and the 24-hr approval burns. Burning conducted by the pilot burn project seems to have been successful with burning either resulting in minimal impact to air quality or impacts on-par with non-pilot burns.

- 16 days with air quality in the Moderate AQI category.
  - Thirteen days were from non-pilot burns
  - Three days were from pilot burns, two of which may have been due to longer term smoldering of fuels (Paradise 90 and Sherman Creek at the Sherman Creek Fish Hatchery monitor).
- 2 days with air quality in the unhealthy for sensitive groups AQI category. This was due to non-pilot burns at Plain, WA
- In the spring of 2017 there were three days in the Moderate AQI category at Pinecliff but no burning was reported or detected by satellites in the area. Therefore, the air quality impacts were probably due to another source.

Specifically:

- The Orion Unit 2 pilot burn 8-km northwest of Liberty, WA burned on 3 different days. One day resulted in a Moderate AQI category day with a 24-hr PM2.5 concentration of 16 $\mu g/m^3$. This site appears to be impacted by other sources because 1-hr PM2.5 concentrations > 12 $\mu g/m^3$ often occurred independent of burning.
- The 25 Mile pilot burn NW of Manson and Chelan burned on 2 different days and did not cause air quality impacts. If anything, greater air quality impacts occurred with the non-Pilot burns at this site.
- The Paradise 90 pilot burn west of Sherman Creek Fish Hatchery (20-km) and Kettle Falls (25-km) burned on 4 days with an impressive total of 6,352 tons of fuel consumed. Smoldering fuels are possibly responsible for the Moderate AQI category day at the Fish Hatchery two days after ignition on 9/29/2016. Fish Hatchery had the most nearby 24-hr approval burns and the impacts were minor or on-par with other non-pilot burns.
- None of the 4 days of burning on the Paradise 90 pilot burn appear to have significantly impacted Kettle Falls with smoke.
- The Sherman Creek pilot burn burned on 11 individual days in 2017, six of which used the 24-hr advance notice. Two days of Moderate AQI category impacts occurred at the Sherman Creek Fish Hatchery monitor; one due to an advance notice pilot burn and one due to a non-advance notice burn. In both cases, impacts occurred the next morning probably due to overnight smoldering of fuels. This burn was only 0.6 km from the Sherman Creek Fish Hatchery monitor. Smoke impacts did not occur in Kettle Falls, about 6-km away from these burns.

- The Hanlon pilot burn 31-km north of the Kalispel Tribal Center burned on one day with minimal consumption (90 tons) and did not cause any air quality impacts. Non-pilot prescribed burns in the following days impacted the site resulting in modestly elevated 1-hr concentrations and one day in the Moderate AQI category.

Plain, WA experienced the greatest amount of prescribed fire activity and had the highest smoke impacts with 7 days of moderate air quality and two days of USG. None of the prescribed burns at this location were pilot burns. Often at this site PM2.5 concentrations would be elevated during the nighttime and early morning hours, then clear during the day. This pattern would persist sometimes for several days after the prescribed burn was originally ignited. The combination of smoldering fuels and nighttime valley drainage flows could be responsible for this pattern.

As a final note, these data are far too limited to draw definite conclusions and many other factors come into play such as location (proximity of the burn to populations), multiple burns on the same day (which burn caused the impacts?), wind patterns (valley inversions, drainage flows, day/night patterns, etc.), presence of other sources, and quantity of fuels consumed both during the day of ignition and whether any smoldering fuels continue to put smoke into the atmosphere for days afterward.

FUTURE WORK

Future work could include smoke modeling to evaluate the utility of smoke forecasting systems in helping with the go/no-go decisions and assessing impacts from multiple burns in an area on a given day. This work should include the fuel consumption information measured by the FERA team in their companion study *Pre- and Post-Burn Fuel Characterization and Tree Mortality Assessment for the Forest Resiliency Burning Pilot*.

A meteorological analysis could identify typical wind patterns (valley inversions, drainage flows, day/night patterns, etc.) in these areas of complex terrain, which can also aid in go/no-go decision-making. This could be especially helpful to an area such as Plain, WA where there was lots of burning and lots of impacts – is there ever a good time to burn near Plain?

Finally, two of the sites in particular, Liberty and Curlew, appear to have other sources of PM2.5 impacting air quality. Analyzing the measured temperature data to look for correlations with low temperatures and elevated nighttime PM2.5 concentrations could give insights into whether wood stove smoke could be a source of PM2.5 at a location.

Appendix A1: Data for all prescribed fires in 2016 used in the analysis. Burns that could be considered for 24-hour advance approval as part of the pilot study are indicated in the final column. “True” means advance approval was utilized.

--- From DNR Smoke Management Permitting Webpage ---								From FS Fire Portal Reporting Database			
Date	Region	Land Owner	Unit	Latitude	Longitude	Proposed Acres	Proposed Tons	Acres Burned	Accomplished Tons	Ignition time	Pilot 24-Hr Advance
9/8/2016	WENATCHEE NF	WENATCHEE RIVER	FISHLOOP UNDERBURNS	47.8038	-120.654	0	960	40	320	1230	
9/12/2016	WENATCHEE NF	WENATCHEE RIVER	FISHLOOP UNDERBURNS	47.8038	-120.654	80	640	55	440	1130	
9/14/2016	COLVILLE NF	THREE RIVERS	PARADISE 90	48.55556	-118.397	150	2400	100	1600	1100	TRUE
9/14/2016	WENATCHEE NF	CLE ELUM	ORION UNIT 2	47.3217	-120.69	183	1518	5	40	1130	TRUE
9/15/2016	COLVILLE NF	THREE RIVERS	PARADISE 90	48.55556	-118.397	60	960	30	480	1100	TRUE
9/15/2016	WENATCHEE NF	CLE ELUM	ORION UNIT 2	47.3217	-120.69	120	960	40	320	930	FALSE
9/15/2016	WENATCHEE NF	NACHES	ANGEL UNDERBURN 2016	46.7945	-121.06	58	232	58	174	1000	FALSE
9/20/2016	COLVILLE NF	REPUBLIC	MEL 130145149	48.7359	-118.593	50	525	13	179	1130	
9/20/2016	WENATCHEE NF	WENATCHEE RIVER	NATAPOC	47.7631	-120.682	50	500	35	280	1200	FALSE
9/20/2016	OKANOGAN NF	METHOW VALLEY	2016 UPPER RENDEZVOUS 1	48.573	-120.292	64	896	50	712	1235	FALSE
9/21/2016	WENATCHEE NF	ENTIAT	LOWER TYEE FALL 2016	47.798	-120.426	30	240	30	240	1100	
9/21/2016	WENATCHEE NF	CLE ELUM	ORION UNIT 2	47.3217	-120.69	80	640	60	480	930	TRUE
9/21/2016	WENATCHEE NF	WENATCHEE RIVER	NATAPOC	47.7631	-120.682	35	280	35	280	1200	FALSE
9/22/2016	WENATCHEE NF	ENTIAT	LOWER TYEE FALL 2016	47.798	-120.426	146	1168	53	700	1100	
9/22/2016	WENATCHEE NF	CLE ELUM	ORION UNIT 2	47.3217	-120.69	85	680	78	624	1000	TRUE

9/22/2016	WENATCHEE NF	WENATCHEE RIVER	NATAPOC	47.7631	-120.682	40	320	40	320	1200	FALSE
9/22/2016	OKANOGAN NF	METHOW VALLEY	2016 GOAT	48.588	-120.346	117	2106	85	1210	1000	FALSE
9/26/2016	WENATCHEE NF	WENATCHEE RIVER	FISHLOOP UNDERBURNS	47.8038	-120.654	125	750	125	750	1200	
9/26/2016	COLVILLE NF	SULLIVAN LAKE	HANLON HF HAND	48.62139	-117.257	100	600	15	90	1500	TRUE
9/27/2016	COLVILLE NF	REPUBLIC	MEL 130145149	48.7359	-118.593	50	525	30	245	1100	
9/27/2016	US FISH AND	LITTLE PEND OREILLE NWR	LOG BARN MEADOW	48.4457	-117.745	52	111	52	156	1230	
9/27/2016	COLVILLE NF	THREE RIVERS	PARADISE 90	48.55556	-118.397	450	7200	80	645	1100	TRUE
9/27/2016	COLVILLE NF	SULLIVAN LAKE	BLUE RUBY WEST AERIAL RX HF	48.55335	-117.362	200	1800	15	135	1100	
9/27/2016	COLVILLE NF	SULLIVAN LAKE	HANLON HF AERIAL	48.62139	-117.257	350	1925	250	1250	1300	FALSE
9/28/2016	WENATCHEE NF	ENTIAT	LOWER TYEE FALL 2016	47.798	-120.426	110	880	93	744	1100	
9/28/2016	COLVILLE NF	REPUBLIC	VULCAN 49	48.9278	-118.686	112	1848	75	956	1050	
9/28/2016	COLVILLE NF	THREE RIVERS	PARADISE 90	48.55556	-118.397	450	7200	450	3627	1000	TRUE
9/28/2016	WENATCHEE NF	CHELAN	25 MILE UB 2016	47.9691	-120.299	70	502	30	220	1030	TRUE
9/28/2016	WENATCHEE NF	NACHES	ANGEL UNDERBURN 2016	46.7945	-121.06	57	684	57	650	1130	FALSE
9/28/2016	WENATCHEE NF	WENATCHEE RIVER	FISHLOOP UNDERBURNS	47.8038	-120.654	60	480	60	480	1000	
9/28/2016	COLVILLE NF	SULLIVAN LAKE	BLUE RUBY WEST AERIAL RX HF	48.55335	-117.362	200	1800	100	900	1300	
9/29/2016	US FISH AND	LITTLE PEND OREILLE NWR	CHRISTIANSEN	48.4524	-117.708	50	140	40	120	1130	
9/29/2016	COLVILLE NF	REPUBLIC	MEL 130145149	48.7359	-118.593	10	110	7	61	1130	
9/29/2016	COLVILLE NF	REPUBLIC	VULCAN 49	48.9278	-118.686	12	204	9	114	1145	
9/29/2016	WENATCHEE NF	CHELAN	25 MILE UB 2016	47.9691	-120.299	70	502	40	290	1030	TRUE
9/29/2016	COLVILLE NF	SULLIVAN LAKE	BLUE RUBY WEST HAND RX HF	48.55335	-117.362	100	600	50	450	1200	
9/29/2016	COLVILLE NF	NEWPORT	MISERY 54 62	48.54101	-117.359	30	150	30	141	1400	

10/3/2016	WENATCHEE NF	ENTIAT	LOWER TYEE FALL 2016	47.798	-120.426	40	320	40	320	1000	
10/3/2016	WENATCHEE NF	CLE ELUM	LIBERTY FUELS UNITS 52-56	47.3108	-120.636	82	1722	40	840	1000	FALSE
10/3/2016	WENATCHEE NF	CHELAN	25 MILE UB 2016	47.9691	-120.299	80	575	70	510	1030	FALSE
10/4/2016	WENATCHEE NF	ENTIAT	LOWER TYEE FALL 2016	47.798	-120.426	110	880	15	120	1100	
10/4/2016	COLVILLE NF	REPUBLIC	VULCAN 212269	48.9229	-118.649	27	486	6	81	1230	
10/4/2016	NTL PARK SVC	LAKE ROOSEVELT NATIONAL RECREATION AREA	RICKEY POINT	48.54667	-118.137	22	319	6	75	945	
10/4/2016	WENATCHEE NF	CLE ELUM	ORION SBA UNIT 8	47.2956	-120.703	70	581	70	560	1100	FALSE
10/4/2016	WENATCHEE NF	WENATCHEE RIVER	CHUMSTICK UNDERBURNS	47.6712	-120.608	55	440	55	440	1100	FALSE
10/5/2016	WENATCHEE NF	ENTIAT	TYEE PILES 2016	47.804	-120.439	146	847	120	720	1000	
10/6/2016	WENATCHEE NF	ENTIAT	NORTH FORK POTATO FALL 2016	47.817	-120.368	71	426	65	568	1230	
10/6/2016	WENATCHEE NF	ENTIAT	TOMMY MAD	47.959	-120.59	72	382	43	382	1100	
10/6/2016	WENATCHEE NF	WENATCHEE RIVER	CHUMSTICK UNDERBURNS	47.6712	-120.608	55	550	15	150	1100	FALSE
10/7/2016	WENATCHEE NF	ENTIAT	TYEE PILES 2016	47.804	-120.439	50	299	30	180	1100	
10/11/2016	WENATCHEE NF	ENTIAT	SHADY PASS 2016	47.997	-120.484	20	160	20	160	1200	
10/12/2016	WENATCHEE NF	ENTIAT	FROG ROCK MACHINE	47.93	-120.471	6	311	6	150	1100	
10/12/2016	WENATCHEE NF	ENTIAT	LOWER TYEE FALL 2016	47.798	-120.426	97	776	97	776	1030	
10/12/2016	WENATCHEE NF	NACHES	LOST SPENCER 2016	46.6217	-121.131	90	270	20	60	900	
10/12/2016	WENATCHEE NF	ENTIAT	ENTIAT RIDGE REHAB 2015	47.781	-120.548	56	534	56	534	1100	

Appendix A2*: Data for all prescribed fires in 2017 used in the analysis. Burns that could be considered for 24-hour advance approval as part of the pilot study are indicated in the final column. “True” means advance approval was utilized.

- - - From DNR Smoke Management Permitting Webpage - - -										
Date	Region	Land Owner	Unit	Latitude	Longitude	Proposed Acres	Proposed Tons	Acres Burned	Tons Burned	Pilot 24-Hr Advance
4/3/2017	WENATCHEE NF	ENTIAT	2017 BISPING-PALMICH	47.786	-120.279	30	101	5	20	FALSE
4/19/2017	WENATCHEE NF	ENTIAT	FOREST JOHNSON 2017	47.843	-120.225	104	350	1	2	FALSE
4/21/2017	WENATCHEE NF	CHELAN	25 MILE 2017	47.9691	-120.2991	100	720	5	35	FALSE
4/27/2017	WENATCHEE NF	ENTIAT	FOREST JOHNSON 2017	47.843	-120.225	104	348	104	348	FALSE
5/3/2017	WENATCHEE NF	CHELAN	25 MILE 2017	47.9691	-120.2991	100	720	35	245	FALSE
5/4/2017	WENATCHEE NF	ENTIAT	FOREST JOHNSON 2017	47.843	-120.225	118	398	118	398	FALSE
5/8/2017	WENATCHEE NF	CHELAN	25 MILE 2017	47.9691	-120.2991	111	797	35	245	TRUE
5/9/2017	WENATCHEE NF	CHELAN	25 MILE 2017	47.9691	-120.2991	76	532	76	532	FALSE
5/9/2017	WENATCHEE NF	ENTIAT	LOWER TYEE 2017	47.802	-120.431	75	628	75	800	FALSE
5/9/2017	NE REGION	SHERMAN CREEK WILDLIFE AREA	RAIL	48.58994	-118.1625	50	300	80	480	TRUE
5/10/2017	WENATCHEE NF	ENTIAT	LOWER TYEE 2017	47.802	-120.431	150	1256	125	1256	FALSE
5/22/2017	OKANOGAN NF	METHOW VALLEY	2017 GOAT	48.588	-120.346	53	938	40	493	FALSE
5/25/2017	WENATCHEE NF	NACHES	CANTEEN UB2017	46.8869	-120.9223	35	210	5	30	FALSE

5/30/2017	NE REGION	WDFW - SHERMAN CREEK WILDLIFE AREA	BRIDGE HATCH TRAIL	48.597	-118.14	65	300	28	129	TRUE
5/31/2017	NE REGION	WDFW - SHERMAN CREEK WILDLIFE AREA	BRIDGE HATCH TRAIL	48.597	-118.14	65	300	20	92	FALSE
6/1/2017	NE REGION	WDFW - SHERMAN CREEK WILDLIFE AREA	BRIDGE HATCH TRAIL	48.597	-118.14	20	240	17	204	TRUE
6/5/2017	OKANOGAN NF	METHOW VALLEY	2017 UPPER RENDEZVOUS 1	48.573	-120.292	53	938	40	489	FALSE
6/5/2017	NE REGION	WDFW	BISBEE	48.60438	-118.141	40	360	5	45	FALSE
6/6/2017	OKANOGAN NF	METHOW VALLEY	2017 GOAT	48.588	-120.346	109	1254	70	863	FALSE
6/6/2017	NE REGION	WDFW	BISBEE	48.60438	-118.1401	40	360	20	180	TRUE
6/7/2017	NE REGION	WDFW	BISBEE	48.60438	-118.1401	60	400	11	73	FALSE
6/12/2017	NE REGION	WDFW	BISBEE	48.60438	-118.1401	40	354	13	115	TRUE
6/13/2017	NE REGION	WDFW	BISBEE	48.60438	-118.1401	40	364	10	91	TRUE
6/14/2017	NE REGION	WDFW	BISBEE	48.60438	-118.1401	40	364	25	228	FALSE
6/15/2017	NE REGION	WDFW	BISBEE	48.60438	-118.1401	40	364	4	36	FALSE

*Note that these data are what is known to the best of our knowledge as-of 6/23/2017 from working with personnel at the Washington State DNR and pilot project participating land managers.

Appendix C

Pre- and post-burn fuel characterization and tree mortality assessment for the Forest Resiliency Burning Pilot

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July 31, 2017

Forest Resiliency Burning Pilot project (HSB 2928 – 2015-2016).

Abstract

As part of the Forest Resiliency Burning Pilot project conducted by the Washington Department of Natural Resources, the Fire and Environmental Research Application team (FERA) at the Pacific Wildland Fire Sciences Laboratory (PWFSL), and the School of Environmental and Forest Sciences, University of Washington (UW) characterized pre-fire forest fuels across 14 pilot burn units. Burn units were located on lands managed by the U.S. Forest Service and Washington State Department of Fish and Wildlife. We evaluated post-burn fuel consumption at four sites that were prescribed burned in fall of 2016, and at two sites that were prescribed burned in spring of 2017 and evaluated the Consume (v. 2.1 and 4.2) fuel consumption and emissions prediction software. The FERA and UW team also quantified post-burn tree damage and predicted tree mortality using the First Order Fire Effects Model (v. 6.3.1; FOFEM). Fuel loading, including shrubs, herbaceous vegetation, downed wood, litter, and duff, ranged from 14.90 to 52.27 tons acre^{-1} across the study sites. Consumption of fuels was generally moderate to high for fall-burned sites, ranging from 62-86% of total surface fuels, and low in the spring-burned sites, ranging from 12-22%. Both Consume v 2.1 and Consume 4.2 predictions were less than measured consumption in fall-burned sites and greater than measured consumption in spring-burned sites. Consume v. 2.1 predictions had lower accuracy than newer Consume v. 4.2, which is part of the Fire and Fuel Tools (FFT), in five of the six sites where post-fire data was analyzed. Consume v. 4.2 predicted consumption with greater accuracy than Consume v. 2.1 for coarse downed woody fuel strata, but was less accurate for the duff stratum. Measured fuel consumption indicated that the duff layer, decomposing organic matter on the forest floor that typically smolders during fires, comprised a significant proportion of the fuel consumed in the fall-burned sites, but was not a major component of consumed fuels for spring-burned sites. Consume predictions reflected observed trends regarding the relative contribution of duff to consumption, but reductions of duff consumption were the most underestimated of all fuel strata. For the fall-burned sites, measures of tree damage including crown scorch and bole char were light to moderate. Predicted tree mortality was 26 to 74%, with a 7-23% reduction in basal area. Tree damage in the two spring-burned sites was generally light. Predicted tree mortality was 0 and 49%, with a 0 and 6% reduction of basal area. Predicted percent of stems killed was higher than predicted basal area reductions because most mortality was forecast to occur in small-diameter (0-2 inches at DBH) trees.

Introduction

The Washington Department of Natural Resources was tasked by the state's legislature to conduct the Forest Resiliency Burning pilot project during the fall of 2016 to monitor and evaluate the benefits of forest resiliency burning impacts on ambient air quality. The project was later extended to include the spring 2017 prescribed burning season for selected project units that were not burned in the fall. The Fire and Environmental Research Applications team (FERA) at the Pacific Wildland Fire Sciences Laboratory (PWFSL) in collaboration with the School of Environmental and Forest Sciences, University of Washington (UW) participated in this project and was part of a larger monitoring protocol. The FERA and UW team characterized pre- and post-fire forest fuels (shrubs, herbaceous vegetation, downed wood, litter, and duff), measured fuel consumption by fuelbed strata, and assessed post-fire tree damage and predicted tree mortality using tree characteristics and post-fire damage assessments. Data from this study were also used to evaluate the internal fuel consumption models within the Consume v. 2.1 program (Ottmar et al. 2000) used in the State of Washington's Smoke Management Program and the most recent Consume v. 4.2, embedded within the new Fuel and Fire Tools (FFT) software (Prichard et al. 2016).

The specific objectives were to:

- Characterize pre- and post-fire fuels and quantify consumption for each fuelbed stratum across the study sites. Document environmental conditions (including fuel moisture content) for each fuelbed stratum on the day of each burn. Ensure that all measurements are compatible with the input requirements of Consume versions 2.1 and 4.2 for model evaluation.
- Provide an initial assessment of the predictive capability of Consume v. 2.1 and Consume v. 4.2 using the pre-burn inventory data and burn-day environmental conditions.
- Assess pre-fire overstory characteristics and post-fire tree damage on the burn sites and predict tree mortality from post-fire tree damage estimates using FOFEM (First Order Fire Effects Model).

A companion study entitled "Smoke and Air Quality Monitoring Data Report in Support of the Washington State Department of Natural Resources 2016 Forest Resiliency Burning Pilot Project" reports results for the ambient air quality monitoring portion of the pilot project. The report also provides analysis of the effect of 24-hr advance notice of burn approvals to fire managers (instead of day-of-burn approval) on impacts to air quality.

Materials and Methods

Study Area

The study area encompasses dry conifer forests on state and federal lands in eastern Washington (Figs. 1 and 2) including Klickitat, Yakima, Chelan, Okanogan, Ferry, Stevens and Pend Oreille counties. Study sites are located along the eastern slopes of the Cascade Mountains (Eastern Cascades Slopes and Foothills, and North Cascades ecoregions) and northeastern Washington (Northern Rockies ecoregion).

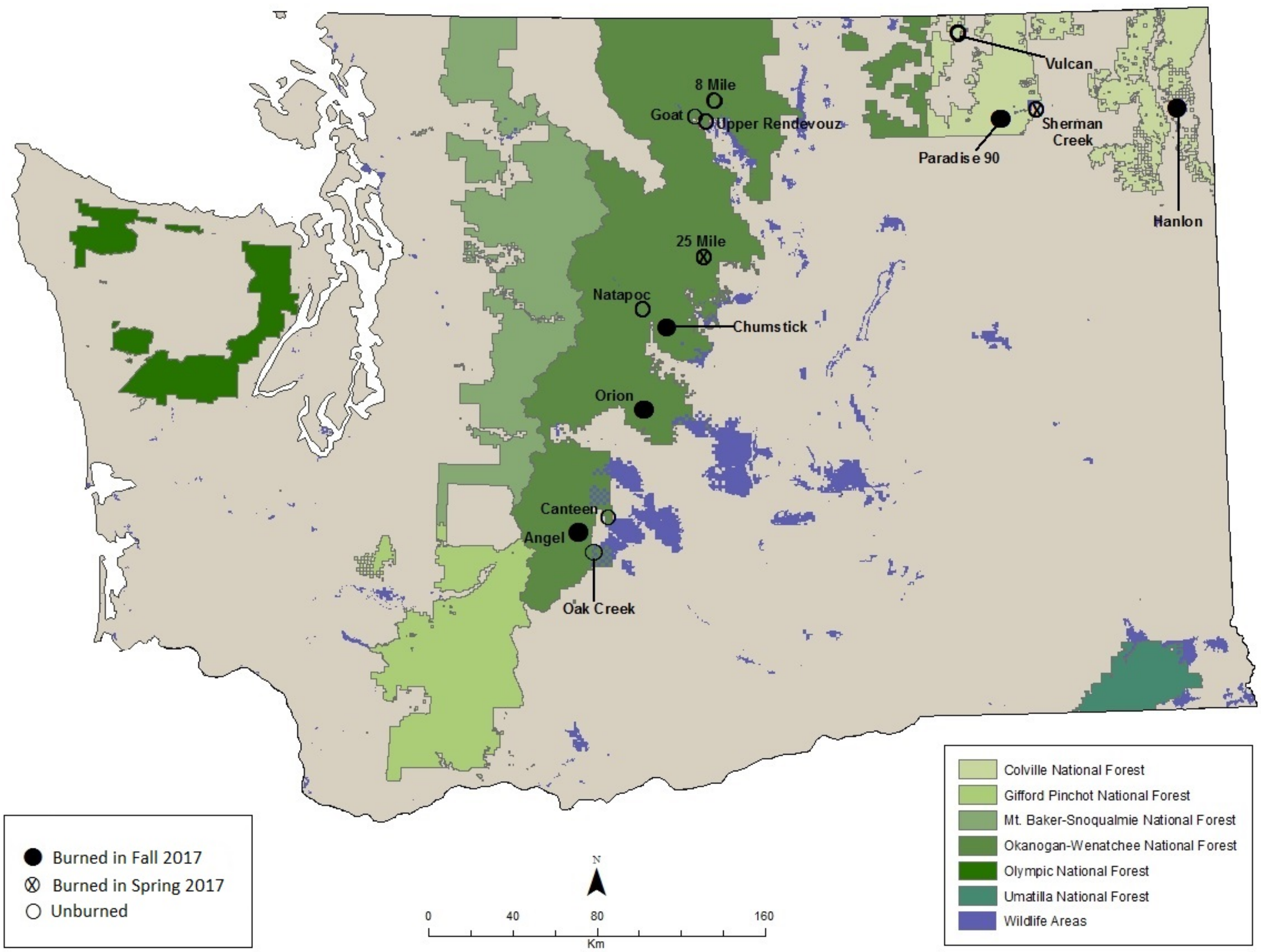

Figure 1 – Location of Forest Resiliency Burning Pilot project prescribed burn treatment locations in Washington State where fuel consumption and tree damage from prescribed burning was assessed.

Climate along the eastern slopes of the Cascade Mountains contains elements of marine and continental climates. Average minimum and maximum monthly temperatures are 15-25°F and 25-35°F, respectively in January and 45-50°F and 70-85°F, respectively in July. There is a large decrease in

Figure 2 – Typical ponderosa pine/Douglas-fir forests inventoried for the Forest Resiliency Burning Pilot project.

precipitation with distance east from the crest of the Cascade Mountains. For example, average annual precipitation at Stampede Pass (elev. 3958 ft) is 92 inches and 22 inches in Cle Elum (elev. 1920 ft), 20 miles to the east. Northeastern Washington has a continental climate. Average minimum and maximum monthly temperatures are 10-20°F and 25-35°F, respectively in January and 45-50°F and 85-90°F, respectively in July. There is less variation in precipitation across the geographic area and the annual average ranges from of 17 inches in Spokane to 28 inches near the border of British Columbia and Idaho. Soils vary across sites and include: Inceptisols (n = 9), Alfisols (n = 2) and Mollisols (n = 3) (Washington Dept. of Nat. Res., Soil Conservation Service et al., 1980). Average slopes among sites ranged from 0˚ to 30˚ and most site aspects were south-facing (n = 8), as opposed to north-facing (n = 5) or flat (n =1). Plots were located in dry coniferous forests characterized by an overstory where ponderosa pine (*Pinus ponderosa* Douglas ex P. Lawson & C. Lawson) was either dominant or co-dominant with Douglas-fir (*Pseudotsuga menziessii* (Mirb.) Franco) or western larch (*Larix occidentalis* Nutt.), a midstory that is either open or contains areas of dense regeneration of overstory species and less fire tolerant species including grand fir (*Abies grandis* (Douglas ex D. Don) Lindl.) and lodgepole pine (*Pinus contorta* Douglas ex Loudon), and an understory of shrubs and herbs including oceanspray (*Holodiscus discolor* (Pursh) Maxi,.), snowberry (*Symphoricarpos albus* (L.) S.F. Blake), birch-leaved spirea (*Spiraea betulifolia* Pall.), bearberry (*Arctostaphylos uva-ursi* (L.) Spreng.), pinegrass (*Calamagrostis rubescens* Buckley), lupine (*Lupinus* L.), and arrowleaf balsamroot (*Balsamorhiza sagittata* (Pursh) Nutt.).

Study Design

Plots were established in 14 prescribed burn units that were part of the Forest Resiliency Burning Pilot project (HSB 2928 – 2015-2016). Plot layout and measurements were designed to assess fuel consumption and overstory mortality following prescribed fire in dry coniferous forest types (Fig. 3).

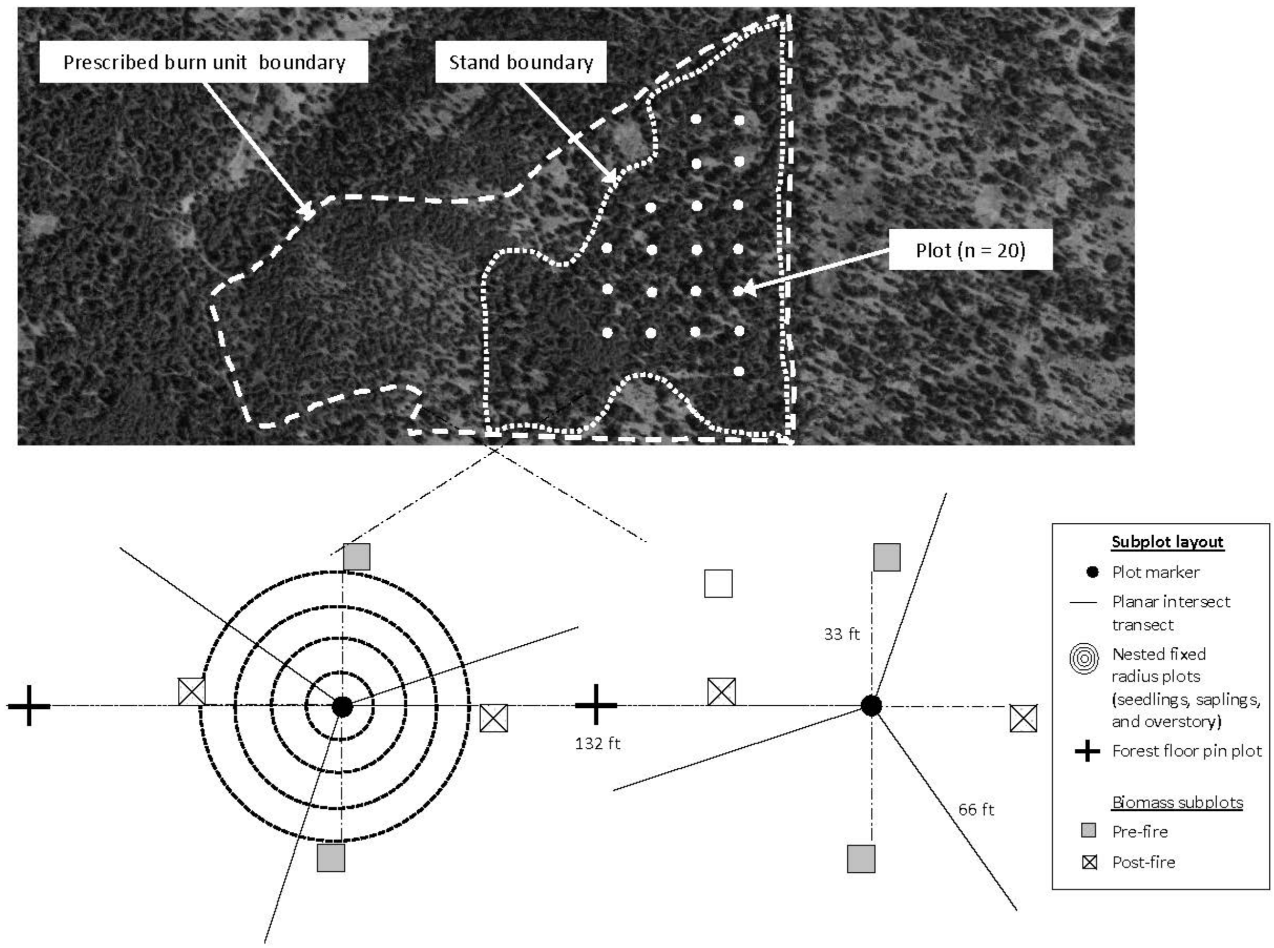

Figure 3 – Plot layout and design.

As such, the plots only describe fuels for a given stand within each prescribed burn unit and may not be representative of the entire unit, especially if multiple fuel types are present. All burn units were operational prescribed burning projects where the management objectives were to reduce surface fuels and minimize mortality to fire-resistant overstory species such as ponderosa pine and Douglas-fir. Sampling for this project was conducted from August to October, 2016, and again from April to June, 2017. The dates that sites were burned are listed in table 3. Of the fourteen sites, seven remain unburned

(Table 1). One site (Hanlon) burned under wet conditions and was removed from the post-burn data set because fire spread within the plots was negligible. Pre-burn fuel inventory is reported for this site. Day-of-burn fuel moisture and surface weather conditions were measured at each of the burned sites. We measured post-fire surface fuels and overstory damage within 2-5 weeks following a burn.

Table 1 – Fourteen study sites across the state of Washington selected for burning as part of the Forest Resiliency Burning Pilot project.

Unit	Location	Agency[a]	Elevation (ft)	Slope (°)	Aspect	Forest Type
25 Mile	Okanogan-Wenatchee NF	USFS	3774	20-25	S-SE	Ponderosa pine
8 Mile	Okanogan-Wenatchee NF	USFS	2848	<5	S	Ponderosa pine
Angel	Okanogan-Wenatchee NF	USFS	3274	15-25	NW	Ponderosa pine
Canteen	Okanogan-Wenatchee NF	USFS	4150	5-20	NE	Ponderosa pine
Chumstick	Okanogan-Wenatchee NF	USFS	2401	25-35	SE-SW	Ponderosa pine
Goat	Okanogan-Wenatchee NF	USFS	2955	20	S-SE	Douglas-fir
Hanlon	Colville NF	USFS	3023	5-20	SE-SW	Douglas-fir
Natapoc	Okanogan-Wenatchee NF	USFS	2878	15-25	N-NW	Douglas-fir
Oak Creek	Oak Creek Wildlife Area	DFW	4240	5-30	NE	Douglas-fir
Orion	Okanogan-Wenatchee NF	USFS	3120	5	S-SE	Ponderosa pine
Paradise 90	Colville NF	USFS	3360	30	S	Ponderosa pine
Sherman Creek	Sherman Creek Wildlife Area	DFW	1601	0	Flat	Ponderosa pine
UR-1	Okanogan-Wenatchee NF	USFS	3718	<5	NE	Ponderosa pine
Vulcan	Colville NF	USFS	4312	5-30	NE	Western larch

[a]USFS: U.S. Forest Service; DFW: Washington State Dept. of Fish and Wildlife

At each site, 20 plots spaced two chains (132 ft) apart were systematically installed along a grid that conformed to dry coniferous forest stand boundaries. Stands were defined by areas of vegetation with similar tree species and age distribution, and disturbance history limited to low severity such as surface fire or thinning treatments. Plots were limited to a single stand type to reduce the influence of confounding variables within and among prescribed burn units. To avoid effects from holding operations along the fire line, plot boundaries were at least three chains (198 ft) from the prescribed burn unit boundary or roads within the unit. Plot centers were marked with a five-foot steel conduit and sub-plot locations for measures of each fuel stratum (Fig. 4) were marked with one-foot metal markers. Coordinate readings were recorded at each plot center with GPS units (GPSmap 64s, Garmin International, Inc., Olathe, KS) using the waypoint average function.

Forest Floor

Loading and consumption of the forest floor was assessed by applying known bulk density values to average pre- and post-fire depth of the litter and duff layers measured at each site. At each plot, forest floor type and depth was measured at 8 locations spaced at 20-inch intervals along two 160 inch intersecting lines whose endpoints face in cardinal directions (Fig. 5). At each forest floor measurement location six-inch steel nails were inserted through the litter and duff layers into the mineral soil and positioned so that the head of the nail marked the top of the pre-fire litter layer (Beaufait et al. 1977). Where the forest floor exceeded six inches, 14-inch welding electrodes were used instead of steel nails. During pre-fire sampling, litter depth was measured as the distance from the head of the nail to the litter-duff boundary and litter and duff type were recorded. During post-fire sampling the distance from the head of the nail to the surface of the remaining unburned surface material and mineral soil was recorded. Together, data from the sampling episodes was used to calculate the litter and duff profile and consumption of each layer. Reductions in litter and duff depth were calculated as the average depth reduction of all of the measurement points that burned, multiplied by the proportion of the overall area that burned (Prichard et al. 2014).

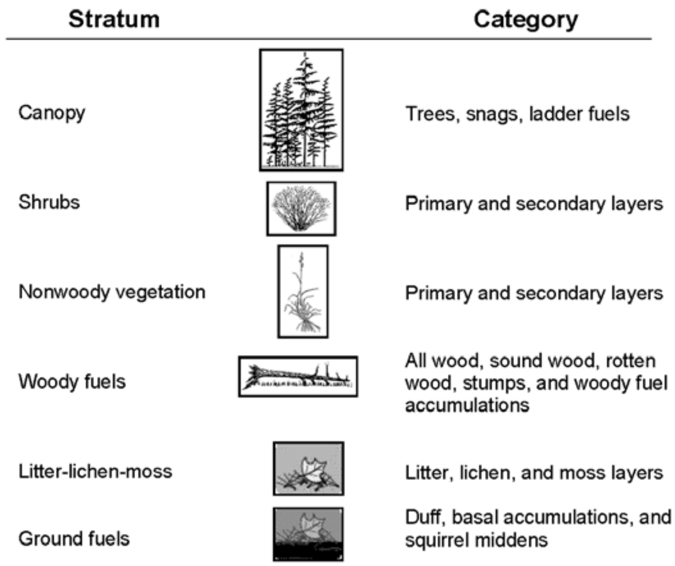

Figure 4 – Forest fuel strata and the categories of fuel that typify them.

Data from the forest floor measurement locations described above can only be used to calculate litter and duff loading when pre- and post-fire measurements are collected. We collected surrogate forest floor profile measurements in the event that sites were not burned. These measurements were collected at four surrogate locations in each forest floor plot (Fig. 5) during spring 2017 to ensure that we could characterize the forest floor in the event sites were not burned.

For the two sites (Vulcan and Natapoc) that were not burned, and were not re-sampled in spring 2017, duff depths could not be assessed since forest floor fuels were not destructively sampled. For modeling purposes (see *Evaluation of the Consume v. 2.1 and Consume v. 4.2 Model for Fuel Consumption*

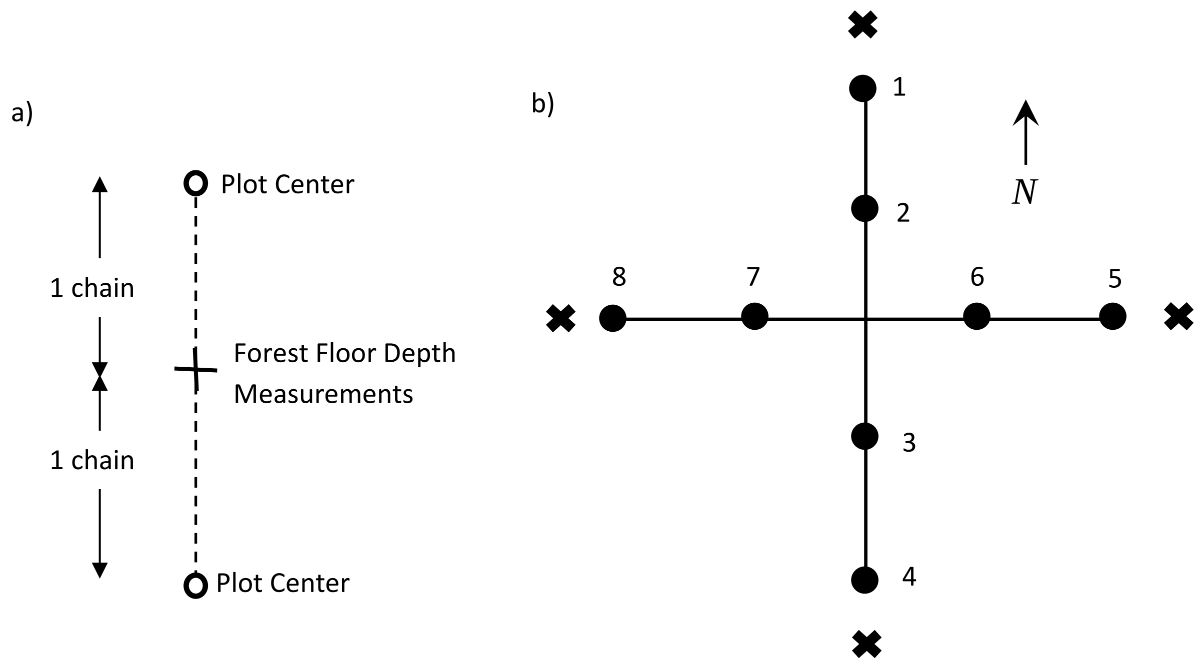

Figure 5 – Forest floor depth measurement layout. a) shows location of forest floor depth plots relative to plot centers and b) shows locations of the eight depth measurements per plot. Six-inch nails are spaced 20 inches apart on two intersecting 160 inch lines. Sequential numbers follow North to South and East to West. "X" markslocations of surrogate pits where both litter and duff depths are measured pre-fire.

Predictions below) we used duff load values from sites with similar litter depths and type (see Appendix A for details). All forest floor depth values were measured to the nearest millimeter.

Downed Woody Fuels

Loading of downed wood was measured before and after treatment burns along planar intersect transects (Brown 1974). Three one-chain (66 ft) transects originated from each plot center at 120˚ spacing using a single randomly determined azimuth. Small-diameter, 1-h (< ¼ inch) and 10-h (¼-1 inch), timelag fuel classes were recorded along the last six and ten feet of each transect, respectively (Fig. 6). Larger-diameter, 100-h (1-3 inches) and 1000-h (> 3 inches), timelag fuels were recorded along the entire 66 ft transect length. Transect endpoints were marked with one-foot metal rods so they could be located and re-measured during post-fire sampling. The 1-h, 10-h, and 100-h timelag fuels were tallied along their respective transect lengths and fuel loadings calculated according to Brown (1974). Differences between pre- and post-burn woody fuel loads were calculated as consumption within each respective timelag class. The following data were collected for each of the larger diameter 1000-h timelag fuel: species, level of decay, and diameter at location of intersection with the transect. The 1000-h timelag fuel diameters were measured to the nearest tenth of a foot. Downed woody fuels were not counted if the centerline of the fuel particle fell below the surface of the forest floor.

Figure 6 – Conducting woody fuels inventory.

Shrub and Herbaceous Vegetation

Destructive pre- and post-fire biomass sampling plots were used to assess fuel loading of standing surface vegetation. At each plot, four one-meter square sub-plots were located ½ chain (33 ft) from the plot center at 90° intervals. Two opposite facing sub-plots were sampled prior to the prescribed burn treatment and the other two were sampled after the treatment. At sites where standing surface fuel cover was homogenous, the number of sub-plots was reduced to one pre- and post-fire sub-plot per plot. Within each sub-plot, all live and dead standing plant biomass that was part of the surface fuel stratum (i.e., grasses, forbs and shrubs less than 4.5 ft tall) and rooted within the sampling area was clipped at ground level and separated by vegetation type. Differences between pre- and post-burn biomass, on a dry-weight basis (see Dry Weight Procedures below), were calculated and used as consumption values for shrubs and herbaceous (forbs and grasses) fuel strata separately.

Fuel Moisture

Fuel moisture samples from each fuel strata were collected from each burn unit on the day in which they were burned. Samples were taken within a time frame such that fuel moisture would not change between the time of sampling and ignition. For each fuel strata except 1000-h timelag fuels, we collected 10 samples from within a ½ chain (33 ft) radius of odd-numbered plots. For 1000-h timelag fuels we collected 20 samples from fuel particles that were representative of the distribution of sizes, species, and decay class from marked locations within one chain (66 ft) of the plot center. Samples were representative of the distribution of each fuel strata within the sample area. Moisture samples were placed in 12 x 12 inch four-millimeter thick, re-sealable plastic bags. To determine wet mass, samples were weighed the day of collection on a portable electronic balance to the nearest 0.1g. Fuel samples were oven-dried (see Dry Weight Procedures below) and fuel moisture calculated on a gravimetric basis (water weight / oven-dry fuel weight).

Dry Weight Procedures

To determine dry weight of clipped standing surface fuels and fuel moisture samples, samples were transported to the Pacific Wildland Fire Sciences Laboratory in Seattle, WA and oven dried to a constant mass (see Appendix A Table C1 for details) and weighed with an electronic balance to the nearest 0.1g.

Tree Damage Assessment

We sampled 966 trees at six burned sites to compare observed and predicted mortality (Fig. 8). The First Order Fire Effects Model (FOFEM v. 6.3.1; Lutes 2016) was used to predict post-fire tree mortality and results are presented in this report. We do not report tree mortality because to do so, field observations must be conducted no earlier than spring 2018, as tree mortality typically does not occur for 1-3 years following fire. At each site, trees were sampled in 10 nested fixed-radius plots. Trees were categorized into six diameter classes and sampling radius was adjusted on a site by site basis for each category based on density (see Appendix C, Table C2 for details). Metal tags with unique identification numbers were affixed to each tree within nested circular plots so trees can be re-measured over time. Measured pre-fire characteristics included: species, diameter at breast height (DBH), canopy base height, height to live crown, and total height. Trees were re-measured within five weeks of prescribed burn treatments. Post-fire measurements included maximum height of crown scorch, percentage of the crown volume scorched, minimum and maximum bole char, and tree severity index (US Department of the Interior National Park Service 2003). Tree height measurements were

Figure 8 – Forest Resiliency Burning Pilot project prescribed burns in a-b) fall, 2016 at the Angel unit and c-d) spring, 2017 at the 25 Mile unit.

measured to the nearest foot, except for bole char which was measured to the nearest tenth of a foot. Percentage of crown volume scorched was measured to the nearest 5%.

The FOFEM v. 6.3.1 computer program was used to predict the number of overstory trees killed by the prescribed burn units and the corresponding reduction in basal area. FOFEM is widely used by land managers in the western US to evaluate fuel treatment effectiveness. The mortality model used in this program was developed by Ryan and Reinhardt (1988) and updated several years later (Ryan & Amman 1994). The mortality model is a logistic regression model that uses bark thickness and scorch height to predict fire-related tree mortality occurring within three years of a fire. To predict mortality, trees were binned into two-inch diameter classes by species that spanned the range of sampled diameters (0-40 inches). For each diameter class we calculated the necessary FOFEM inputs including trees per acre (TPA), diameter at Breast Height (DBH), tree height, and crown ratio. The tree data grid in FOFEM was populated with overstory data collected from overstory plots at each site. The average scorch height observed in each prescribed burn unit was also indicated during FOFEM modeling. FOFEM model outputs are reported and include predicted percent reduction in TPA and basal area.

Evaluation of the Consume v. 2.1 and Consume v. 4.2 Model for Fuel Consumption Predictions

We used pre-burn fuel inventory data along with day-of-burn weather and fuel moisture parameters to predict fuel consumption at each site burned. We compared predicted values from Consume v. 2.1 (Ottmar et al. 2000) and Consume v. 4.2 (Prichard et al. 2016) with field-quantified consumption values, within each unit, for all fuelbed strata (herbaceous (grass and forbs), shrubs, dead surface woody fuels (fine and coarse), litter, and duff.

We used differences in fuel moisture we encountered between sampling in fall and spring to identify differences in the two Consume versions. To do this we compared predicted fuel consumption for all 14 sites using both Consume versions 2.1 and 4.2 for average fuel moisture values measured at burned sites during the fall, 2016 and spring, 2017 sampling periods.

The process diagram describes the work completed for this study (Fig. 10).

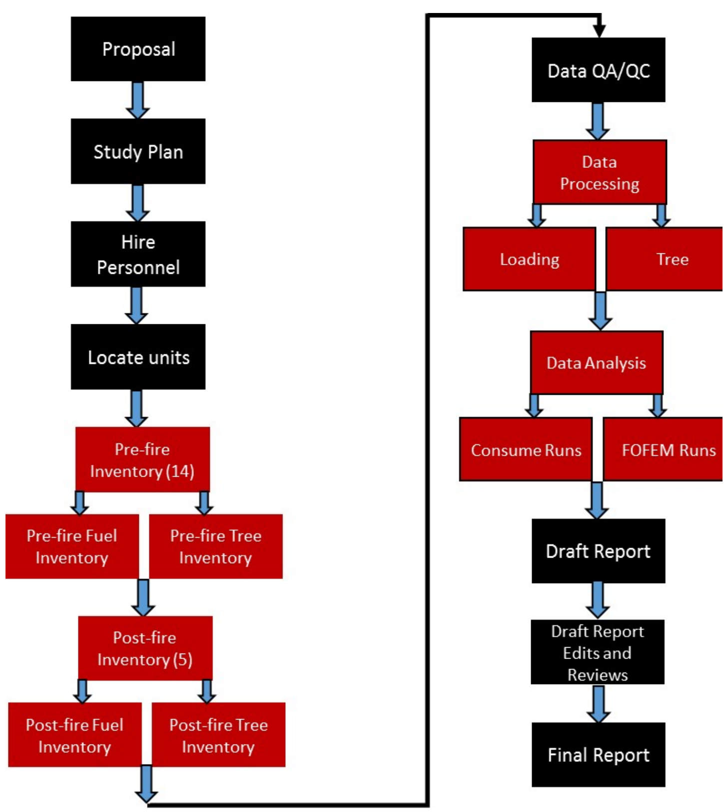

Figure 10 – Process diagram of work performed in this study as part of the Forest Resiliency Burning Pilot project (HSB 2928 – 2015-2016).

Results

Pre-Burn Fuel Loading--All Sites

Fuel and overstory characteristics were quantified for 14 sites proposed for prescribed burning and fuel loading ranged widely (Table 2) with Orion having the least amount of fuel (14.90 tons acre^{-1}) and Natapoc containing the most (52.27 tons acre^{-1}). Duff biomass accounted for the largest percentage of surface fuel loading. The average across all sites (except Vulcan and Natapoc where duff loading was not measured) was 47% and ranged from 31 to 66% of total fuel loading. Herbaceous vegetation and shrubs were the lowest contributors to total surface fuel loading; both comprised less than 1% of total loading (see Appendix A for detailed fuel loading by each stratum).

Table 2 – Total fuel loading, measured consumption and predicted consumption across 14 sites assessed in the study. Measured consumption is only included for the six sites that were burned.

	Fuel Loading		**Measured Consumption**		**Predicted Consumption**	
	Pre-Fire	**Post-Fire**			**Consume 2.1**	**Consume 4.2**
Unit	*tons acre^{-1}*		*tons acre^{-1}*	*% of load*	*tons acre^{-1}*	
Angel	24.14	6.00	18.14	75	11.64	13.34
Chumstick	16.31	2.34	13.97	86	10.31	11.79
Orion	14.90	5.43	9.47	64	7.78	7.87
Paradise 90	45.83	17.38	28.45	62	22.22	15.56
25 Mile	22.75	17.83	4.92	22	6.57	6.12
Sherman Creek	25.33	22.26	3.07	12	4.21	3.42
8 Mile	30.19	-	-	-	-	-
Canteen	47.30	-	-	-	-	-
Goat	29.40	-	-	-	-	-
Hanlon	22.81	-	-	-	-	-
Natapoc	52.27*	-	-	-	-	-
Oak Creek	41.76	-	-	-	-	-
UR-1	40.27	-	-	-	-	-
Vulcan	46.66*	-	-	-	-	-

*Duff loading was imputed from average duff load values from the two sites with the litter loading that was closest to site.

Fuel Loading and Consumption-- Burned Sites

Total surface fuel loading was light to moderate for sites that were burned and are representative of natural dry coniferous forests in the northwest that have been managed with a combination of silviculture and prescribed fire (Table 2). Orion, in Okanogan-Wenatchee National Forest, contained the least amount of surface fuel loading (14.90 tons acre-1) while Paradise 90, in the Colville National Forest, contained the highest loading (45.84 tons acre^{-1}; Natapoc is excluded because duff loading was imputed). Percent consumption of surface fuels was moderately high across sites burned in the fall and ranged from a low of 62% at Paradise 90 to 86% at Chumstick (Table 2). Spring-burned sites had considerably lower percent fuel consumption even though pre-fire surface fuel loading was similar to fall-burned sites. Percent consumption was 12% at Sherman Creek and 22% at 25 Mile. Fine dead fuel moistures was similar between fall and spring-burned sites (Table 3), with 8-13% moisture in litter and 9-13% in 1-h woody fuels. For live vegetation, the duff layer, and coarse downed woody fuels, fuel moisture was higher in sites burned in the spring versus fall. For instance, 1000-h downed woody fuel moisture was 26-55% in fall-burned sites and 80-127% in spring-burned sites. Likewise, duff was 8-28% in fall-burned sites and 70-138% in those burned in spring. A similar trend occurred with live fuels. Grass fuel moisture was 33-61% for fall-burned sites and 110-126% in spring-burned sites, while shrub fuel moisture was 81-122% at sites burned in the fall and 130-180% at sites burned in spring. Weather conditions were mild on the days in which sites were burned (Table 3). Temperatures ranged from 55-71 °F and relative humidity was between 38 and 51%. Winds were relatively light and ranged from 0 to 6 mph. Onsite day-of-burn weather observation data was not available for Angel or Hanlon.

Table 3 – Fuel moisture content and weather parameters immediately prior to ignition and proportion of each unit burned.

	Burn	**Fuel Moisture (%)**								**Weather**			**Area**
	Date	**Litter**	**Duff**	**Grass**	**Shrub**	**1h**	**10h**	**100h**	**1000h**	**Temp**	**RH**	**Wind**	**Burned**
Unit		----------------------------------%------------------------------------								°F	%	mph	%
Angel[a]	9/27/16	12	18	49	81	13	16	14	28	-	-	-	74
Chumstick	10/4/16	8	8	33	122	9	9	13	26	55	51	2-4	80
Orion	9/22/16	10	20	61	88	11	14	12	28	65	38	0	82
Paradise 90	9/28/16	13	28	34	98	16	19	20	55	64	43	0-1	63
Hanlon[b]													
Avg. Fall[c]	na	11	27	44	97	12	15	17	35	-	-	-	
25 Mile	5/9/17	12	70	126	130	12	13	31	80	65	44	4-6	74
Sherman Ck.	5/9/17	12	138	110	180	10	32	101	127	71	38	0-2	51
Avg. Spring[c]	na	12	109	118	155	11	23	66	104	-	-	-	

[a]Burn day weather observation data were not available for this report for this unit. [b]This unit is excluded from fall average values. [c]Average moisture values from these burns were used for modeling consumption across all sites for the Fall 2016 and Spring 2017 fuel moisture scenarios. [c]This unit is excluded from average values used for the Fall 2016 fuel moisture scenario because fuel moisture values were above the moisture of extinction around plots.

Evaluation of the Consume v. 2.1 and Consume v. 4.2 Model for Fuel Consumption Predictions

In general, Consume v. 4.2 more accurately predicted consumption than Consume v 2.1 for all fall and spring-burned sites. Both versions of Consume underestimated total surface fuel consumption for fall-burned sites and overestimated consumption for spring-burned sites. The difference in accuracy between Consume versions 2.1 and 4.2 was not large; percent deviation from total measured consumption averaged 29% for Consume v. 2.1 and 23% for Consume v. 4.2

For fall-burned sites (n = 4), Consume v. 2.1 predictions of surface fuel consumption were less than measured values by 18 to 36% and for spring-burned sites (n =2) Consume v. 2.1 predictions were greater than measured values by 34 and 37% (Table 2). The updated Consume v. 4.2 better predicted consumption in the burned sites compared to Consume v. 2.1 with one exception: Paradise 90. At these sites the Consume v. 4.2 prediction was 45% less than measured consumption while the Consume v. 2.1 prediction was only 22% less (Appendix A). The reason for Consume v. 4.2's lower performance at this particular site has to do with duff. The algorithm for calculating duff in Consume v. 2.1 produced more accurate predictions of consumption than the algorithm in Consume v. 4.2 (18% versus 44% deviation from measured consumption). Paradise 90 had considerably more duff than any other burned site and the results from the Consume v. 2.1 duff algorithm outweighed consumption predictions for other fuel strata. For fall-burned sites, Consume v. 4.2 predictions of surface fuel consumption were less than measured values by 16 to 45% and for spring-burned sites Consume v. 4.2 predictions were greater than measured values by 11 and 24% (Table 2).

The Consume v. 2.1 and 4.2 predictions using average fuel moisture conditions for the Fall 2016 and Spring 2017 sampling periods show large differences in predicted surface fuel consumption across all 14 sites (Table 4). For the Fall 2016 fuel moisture scenario, Consume v. 2.1 predicted 41 to 57% of surface fuels would be consumed and Consume v. 4.2 predicted 39 to 65% consumption. By comparison, predicted consumption for the Spring 2017 fuel moisture scenario was 18 to 35% and 10 to 33% of surface fuels for Consume v. 2.1 and 4.2, respectively. For Consume v. 2.1, the majority of predicted consumption in the Spring 2017 scenario was in the duff layer (47%). Predicted consumption within each fuel strata for Consume v. 4.2 was different than v. 2.1 (Appendix B). Consumption was evenly distributed across litter (19%), 10-h (23%), and 100-h (32%) downed woody fuels, and predicted consumption in the duff layer was 0% of total consumption (i.e. no duff was predicted to consume in spring-burned sites). The majority of consumption in the Fall 2016 scenario was also predicted to occur in the duff layer. However, Consume v. 2.1 predicted that a larger percentage of the duff (54%) would be consumed relative to Consume v. 4.2 (28%) which more evenly distributed consumption across the duff, litter (15%), 100-h (11%), and 1000-h (14%) downed woody fuels.

Table 4 - Total modeled consumption (tons acre^{-1}) for all burn sites given average fall and spring fuel moisture conditions.

	Fall Moisture Conditions		*Spring Moisture Conditions*	
Unit	**Consume 2.1 Consumption** *(tons acre^{-1})*	**Consume 4.2 Consumption** *(tons acre^{-1})*	**Consume 2.1 Consumption** *(tons acre^{-1})*	**Consume 4.2 Consumption** *(tons acre^{-1})*
Angel	11.02	11.87	5.25	4.38
Chumstick	9.28	10.66	5.67	5.46
Orion	7.45	7.17	2.94	2.55
Paradise 90	22.16	17.73	13.10	4.49
Hanlon	11.61	10.33	6.00	3.78
25 Mile	9.69	10.97	4.09	4.08
8 Mile	14.23	14.32	7.65	4.88
Canteen	23.55	21.78	14.59	8.38
Goat	14.75	12.99	8.05	4.10
Natapoc	25.85	31.81	15.52	14.14
Oak Creek	17.10	18.21	8.28	4.53
Sherman Creek	12.46	14.00	6.15	4.22
UR-1	19.74	16.06	11.30	4.28
Vulcan	23.79	20.31	14.51	6.30

Stand Characteristics and Tree Damage Assessment

Measured basal area and TPA for stems greater than 2 inches in diameter was variable among sites because of differences in stand age structure, management techniques, and site productivity (Table 5). The lowest basal area was measured at Canteen (30.2 ft^2 ac^{-1}) and Sherman Creek (47.3 ft^2 ac^{-1}) where recent logging operations created an open stand with widely scattered mature trees. The highest basal area was measured at Angel (106.1 ft^2 ac^{-1}) and 25 Mile (116.6 ft^2 ac^{-1}) where plots were located in natural untreated stands and medium-diameter trees (12-22 inches in diameter) were abundant. The sites with the lowest TPA were Sherman Creek (31 trees acre^{-1}) and, 8 Mile and Natapoc (both 37 trees acre^{-1}). As with Sherman Creek and Canteen, the open nature of stands measured at 8 Mile and Natapoc are visible in site photos (Appendix A).

Sites with the highest TPA are Angel (251 trees acre^{-1}) and Oak Creek (192 trees acre^{-1}). Plots at both these sites were located in untreated natural stands. Basal area of small diameter stems (0-2 inches in diameter) contributed little in the way of total basal area. Density of these stems varied widely from 1-1264 and was highest in stands with pockets of dense regeneration such as Angel and UR-1. At the six burned sites, measures of overstory damage indicated light to moderate fire effects on the overstory (Table 6). For example, Angel and Chumstick were the two sites with the greatest measures of measured crown volume scorched for stems greater than 2 inches in diameter with 56% and 44%, respectively. Chumstick had the highest average crown scorch height (30 ft) and bole char (5.1 ft), and

Table 5 – Overstory characteristics for all stems greater than 4.5 ft. tall.

	Tree Density			**Tree Basal Area**		
Diameter class	**0-2 in.**	**2-40 in.**	**All**	**0-2 in.**	**2-40 in.**	**All**
Unit		*trees acre^{-1}*			*feet^2 acre^{-1}*	
Angel	315	251	566	1.5	106.1	107.6
Chumstick	75	118	193	0.4	94.2	94.6
Paradise 90	137	125	262	0.5	98.6	99.1
Orion	109	50	159	0.4	87.7	88.1
25 Mile	86	81	167	0.1	116.6	116.7
8 Mile	1	37	38	0	71.6	71.6
Canteen	91	48	139	0.4	30.2	30.6
Goat	475	91	566	2.5	85.7	88.2
Hanlon	21	187	208	0.1	91.4	91.5
Natapoc	127	37	164	0.4	63.7	64.1
Oak Creek	298	192	490	1.4	87.9	89.3
Sherman Creek	1	31	32	0	47.3	47.3
UR-1	1264	95	1359	7.3	85.4	92.7
Vulcan	16	135	151	0	97.9	97.9

Angel had the second highest average crown scorch height (21 ft) and bole char (4.6 ft). Overstory damage was lowest at Sherman Creek where crown volume scorched was 1%. FOFEM mortality predictions are based on scorch height and bark thickness where bark thickness is a product of tree diameter and species. Predicted mortality at Angel (74%) was higher than Chumstick (65%) despite a

Table 6 – Tree damage and predicted mortality for stems greater than 4.5 ft. tall in burned sites.

	Measured Crown Volume Scorched			**Measured Crown Scorch Height**	**Measured Bole Char Height**	**FOFEM Predicted Mortality**				**FOFEM Predicted Mortality**
Diameter class	**0-2 in.**	**2-40 in.**	**All**	**All**	**All**	**0-2 in.**	**2-8 in.**	**8-40 in.**	**All**	**All**
Unit		*%*		*feet*			*% trees acre^{-1}*			*% basal area*
Angel	68	56	59	21	4.6	95	29	10	75	23
Chumstick	92	44	54	30	5.1	97	45	12	65	16
Paradise 90	18	8	8	6	1.6	39	10	9	26	9
Orion	51	26	42	13	2.7	100	14	5	74	7
25 Mile	100	22	36	24	3.4	84	27	3	49	9
Sherman Creek	40	1	1	0	1.1	NA	0	0	0	6

lower scorch height. This was probably because the density of 0-2 inch diameter trees, which are most susceptible to fire-caused mortality, was highest at Angel (422 trees acre^{-1} compared to 104 trees acre^{-1} at Chumstick)

Discussion

Quantifying fuel loading is essential for estimating fuel consumption, predicting smoke emissions, and assessing potential fire behavior and effects from prescribed burning. Measuring the amount of fuel consumed following a burn also gives managers better insight into how well burn objectives are being met and the efficacy of these fuel reduction treatments.

In this study, six of the fourteen sites that were evaluated for pre-burn fuel loading were successfully burned. Pre-burn fuel loading varied across all fourteen sites, including those sites that were burned. Fuel consumption at fall-burned sites was greater than 60% of the total surface fuel loading and prescribed burning substantially reduced forest fuel biomass. Fuel consumption at spring-burned sites was less than fall-burned sites due to high fuel moisture of duff and coarse downed woody fuels. At these sites consumption was less than 25% of the total surface fuel loading and was relegated to fine fuels. Total forest fuel biomass consumed (tons ac^{-1}) was generally associated with pre-burn fuel loading for fall-burned sites but not at spring-burned sites where fuel moisture seemed to be the limiting factor. Our results show that conditions during the fall are likely to result in both sufficient fuel consumption and limited ecological damage (e.g. overstory mortality). This combination is key to using prescribed fire for both fuels reduction and for ecological benefits. Conditions for burning during the spring are likely to result in ecological benefits (e.g. nutrient cycling, wildlife forage), but only limited reduction in hazardous fuels. Our results highlight the capacity of fuel moistures to strongly affect consumption. Yet, we recommend caution regarding the inference of seasonal effects on consumption. While fall is preceded by dry and warm weather relative to spring, climate conditions vary from year-to-year and spatially across the study area. Multi-year data is necessary to establish seasonal differences in fuel consumption during prescribed fires. Monitoring consumption as part of a prescribed burning program will help to guide managers in assessing local conditions that are favorable for successful burning and to determine whether prescribed burn conditions are resulting in successful reductions in forest fuels.

Forest floor duff comprised a significant proportion of the fuel loading in the sites burned in this study. Duff was the largest individual source for fuel consumption during the fall burning season, but little to no duff consumed during the spring where consumption was restricted to fine fuels. Finer fuels tend to burn under flaming combustion, but forest floor duff smolders. It may be important for managers to consider duff combustion when burning to reduce forest fuel loading and to consider the impacts of smoldering combustion (e.g. long smoldering durations and smoke emissions). And while fine fuels react more readily to environmental conditions, duff moisture is slower to change. Similar to large-diameter woody fuels, duff is more readily consumed following prolonged drying conditions (e.g. fall). Fall burns in this study resulted in significant duff reductions. Large-diameter woody fuels (1000-h) were rare in most sites and thus contributed less to total fuel consumption. Given that duff slowly accumulates on the forest floor, as a result of decomposition of fallen litter, sites with longer fire-free intervals may have substantial duff accumulations. Duff may also act as an important vector for fire spread near the base of trees, where consumption of duff and the resultant soil heating may increase tree injury and overstory mortality. The use of frequent burning as an ecological and fuels management tool in these fire-dependent ecosystems, however, constrains duff and coarse downed woody fuel accumulation. A better understanding of duff combustion and conditions in which favorable, but not excessive, duff consumption occurs is critical for the improvement of predictive consumption modeling, and may aid the ability of managers to meet objectives with the use of prescribed fire.

Predicted consumption from the Consume v. 2.1 model ranged from 41 to 57% of total fuels across all fourteen sites with the Fall 2016 fuel moisture scenario and 18 to 35% under the Spring 2017 fuel moisture scenario. Predicted consumption from the newer Consume v. 4.2 was more variable for the Fall 2016 and Spring 2017 fuel moisture scenarios, ranging from 39 to 65%; and 10 to 33%, respectively. Consumption was underestimated using Consume v. 2.1 by 18 to 36% in the four fall-burned sites and overestimated by 34 and 37% in the two spring-burned sites. Consume v. 4.2 performed better at predicting coarse downed woody fuel consumption, although it was less accurate at predicting the amount of duff consumed. As duff represented a significant proportion of both modeled and actual fuel consumption, imprecision in total fuel consumption predictions may primarily be a result of the modeling performance in the duff stratum. While predictions of fine fuel consumption seem to be reasonable, a next step to improving fuel consumption predictions should focus on modeling consumption of these dense forest floor fuels that burn under smoldering conditions. This will provide improved duff consumption prediction for inputs into smoke modeling systems that will enhance predictions of potential low buoyant smoldering smoke air quality impacts.

The fall-burned sites generally resulted in moderate crown scorch and low to moderate bole char to the overstory while these measures were low for spring-burned sites. As a result of overstory conditions across these sites and quantified tree damage, it is estimated that 0 to 74% of stand density, but only 0 to

23% of basal area would be lost due to anticipated post-burn tree death; with predicted mortality concentrated in smaller diameter (0-2 inches) trees. Differences in tree damage and predicted mortality across the burned sites are likely attributed to variation in fire behavior, but also in stand structure. For example, bole char height (1.6 ft) and area burned (63%), were lowest at Paradise 90. This is indicative of lower fire intensity because these measures respond to fire independently of stand structure whereas crown volume scorched can vary due to changes in fire intensity or the position of the canopy relative to the surface. The greatest predicted loss of both stand density and basal area occurred in the Angel unit, which had high measures of bole char and crown volume scorched and high density of small-diameter trees. Considering that tree damage was most pronounced in the smaller diameter trees and that predicted mortality was expected to minimally reduce stand basal area, these burns appear to have been successful in reducing forest fuels while limiting impacts to the overstory. Maintaining older fire-resistant trees while opening canopy structure, reducing forest fuels and vertical fuel continuity (removing smaller trees and shrubs to limit 'ladder fuels'), increasing average tree diameters, and elevating crown base heights are common restoration goals with these types of restoration/fuels treatments (Agee and Skinner 2005). While denser stands may result in greater impacts to the overstory when burned, using fire as a 'thinning' tool in these sites may enhance meeting restoration targets in fire-dependent forests. Understanding the conditions in which small-diameter trees may be killed using prescribed fire, but where impacts to mature trees are limited may be key using prescribed fire as a restoration and fuels reduction tool. Further evaluation of actual mortality in these burned sites would increase our knowledge as to how these forests were impacted by these burning treatments.

Key Findings

- Pre-fire surface fuel loading varied across all 14 sites and ranged from 14.9 to 52.3 ton acre^{-1}). The duff fuel bed category contributed from 33 to 65% of the total surface loading.

- Seven of the 14 sites inventoried were burned, however plots did not ignite at one unit because of wet conditions and it was removed from the post-fire data set. Of the six sites that burned well, consumption ranged from 3.1 to 28.5 tons acre^{-1}. Duff consumption contributed substantially to the total fuel consumed in fall-burned sites and ranged from 4.2 to 19.0 tons acre^{-1} (30 to 67% of total fuel consumed). Consumption was much lower in the spring-burned sites (less than 1 ton acre^{-1}) and only contributed 15.6 and 19.7% to total fuel consumption.

- Both versions of Consume under-predicted fuel consumption in the fall-burned sites and over-predicted fuel consumption in the spring-burned sites. In the fall, Consume v. 2.1 under-predicted total fuel consumption by 18% to 36% while the Consume v. 4.2 under-predicted total fuel consumption by 16 to 45%. In the spring, Consume v. 2.1 over-predicted total fuel consumption by 34% and 37% while the Consume v. 4.2 under-predicted total fuel consumption by 11 and 24%.

- Consume v. 4.2 performed better at predicting coarse downed woody fuel than Consume v. 2.1; both models underestimated duff consumption.

- Fire related damage and FOFEM predictions suggest higher percent mortality in small diameter understory trees and low mortality in mature trees indicating prescribed burns were successful in reducing forest fuels with limited impacts to the overstory.

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Literature Cited

Beaufait, W.R., Hardy, C.E., Fisher, W.C. 1977. Broadcast burning in larch-fir clearcuts: the Miller Creek-Newman Ridge study. Res. Pap. INT-175, US Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. 73 p.

Brown, J.K. 1974. Handbook for inventorying downed woody material. Gen. Tech. Rep. INT-16. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 24 p.

Ottmar, R.D., Anderson, G.K., DeHerrera, P.J., Reinhardt, T.E. 2000**.** Consume User's Guide, Version 2.1. USDA Forest Service Pacific Northwest Research Station, Fire and Environmental Research Applications Group, Seattle, WA, USA.

Ottmar, R. D., Sandberg, D. V., Riccardi, C. L., Prichard, S. J. 2007. An overview of the Fuel Characteristic Classification System-Quantifying, classifying, and creating fuelbeds for resource planning This article is one of a selection of papers published in the Special Forum on the Fuel Characteristic Classification System. Canadian Journal of Forest Research, 37(12), 2383-2393.

Prichard, S.J., E.C. Karau, R.D. Ottmar, M.C. Kennedy, J.B. Cronan, C.S. Wright, and R.E. Keane. 2014. "Evaluation of the CONSUME and FOFEM fuel consumption models in pine and mixed hardwood forests of the eastern United States." Canadian Journal of Forest Research: 44(7): 784-795.

Prichard, S.J., Ottmar, R.D., Swedin, K., Eagle, P. 2016. Fuel and Fire Tools. http://www.fs.fed.us/pnw/fera/fft/ (accessed 12/12/2016)

Reinhardt, E.D., Keane, R.E., Brown, J.K. 1997. First Order Fire Effects Model: FOFEM 4.0, user's guide. USDA Forest Service General Technical Report INT-GTR-344.

Ryan, K.C. and E.D. Reinhardt. 1988. Predicting postfire mortality of seven western conifers. Canadian Journal of Forest Research. 18(10), 1291-1297.

Ryan, K.C. and G.D. Amman. 1994. Interactions between fire-injured trees and insects in the greater Yellowstone area. In: D.G. Despain, ed. Plants and their environments: proceedings of the first biennial scientific conference on the Greater Yellowstone ecosystem, 16–17 September 1991, Yellowstone National Park, Wyoming. Technical report NPS/ NRYELL/NRTR. U.S. Department of the Interior, National Park Service, Natural Resources Publication Office, Denver, CO: 259-271

U.S. Depart. of the Interior, National Park Service. 2003. Fire monitoring handbook. Fire Management Program Center, National Interagency Fire Center, Boise, Idaho.

Washington Dept. of Natural Resources, Soil Conservation Service; U.S. Dept. of Agriculture, Forest Service; Washington State University. 1980. Washington SOILS [map]. "Private Forest Land Grading System". http://geography.wa.gov/data-products-services/data/data-catalog (accessed December 7, 2016).

Washington State HSB 2928 – 2015-2016. Effective date: March 31, 2016. Ensuring that restrictions on outdoor burning for air quality reasons do not impede measures necessary to ensure forest resiliency to catastrophic fires

Appendix D

Engaging Communities in Prescribed Fire and Smoke

Best Management Practices Guide

Prepared for:
Washington Field Office of The Nature Conservancy
Washington Resource Conservation and Development Council

Prepared by:

Wildfire Planning International

March 2017

Report Information:

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Table of Contents

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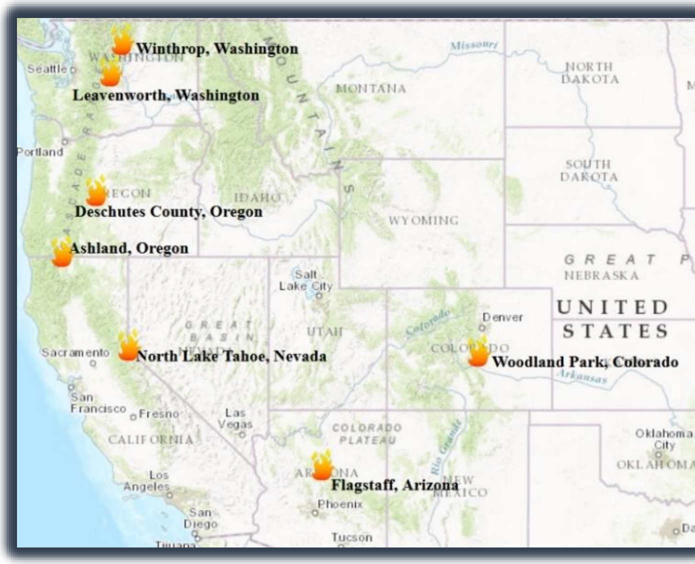
Prescribed Fire and Smoke Messaging Guide

The Prescribed Fire and Smoke Messaging Guide is designed with the local community practitioner in mind. This guide provides information on effective communication strategies compiled from seven case studies in the western United States. Each case study highlights a variety of outreach tools to implement **before, during, and after** a prescribed fire event.



Research from seven case studies was gathered to provide best management practices for practitioners seeking to implement prescribed fire and smoke management outreach.

While each case study provides unique ideas for community outreach tools, several themes are summarized to provide general guidance to practitioners, including:

- **Collaborate and dedicate resources.** Designing and implementing a successful prescribed fire and smoke management program requires a coordinated multi-stakeholder approach and dedicated staff to administer the program.

- **Make early investments – they will pay off.** Building trust is a fundamental requirement for community outreach efforts. Successful programs include meaningful and strategic opportunities to discuss information with residents and address their concerns – well in advance of a prescribed fire. While upfront work can be more time and/or resource intensive, this approach pays dividends later.

- **Develop a robust toolkit.** Preparing materials, information and resources to have before, during and after a prescribed fire helps target different audiences and their concerns or questions. In addition, forming messages for various levels of prescribed fire education will allow for a progression of knowledge on the subject.

- **Get people in the field!** Creating opportunities for residents, media, elected officials and other community members to witness prescribed fire and its effects is an exciting and effective way to communicate its ecological benefits. It also generates participant enthusiasm for the process.

- **Keep the messages going.** Integrating prescribed fire messaging into ongoing, year-round activities – such as other wildfire outreach events or community meetings – promotes a higher level of community awareness and a greater degree of acceptance.

Community Case Studies

Seven in-depth case studies were conducted throughout the western United States to showcase a variety of tools and approaches used for prescribed fire and smoke management programs. Each case study was conducted by a phone interview with a primary program contact having firsthand knowledge and direct involvement in their prescribed fire and smoke management activities. Case study research identified:

- Unique local strategies and messages;
- Resources needed to perform specific outreach tasks (if information was available);
- A delineation of activities based on their occurrence before, during, or after a prescribed fire event, and any ongoing activities.

The Community Tools Matrix (below) captures specific tools discussed during research interviews, which are highlighted in each case study within this report. *Note: this matrix is not necessarily representative of all tools implemented by each community. Tool names also reflect those used by interviewees to capture accuracy of each conversation.*

Community Tools Matrix

	Ashland, Oregon	Deschutes County, Oregon	Flagstaff, Arizona	Leavenworth, Washington	North Lake Tahoe, Nevada	Winthrop, Washington	Woodland Park, Colorado
Agency Coordination	X	X	X	X	X	X	X
Classroom Presentations			X		X		
Commercials		X					
Community Events			X	X	X	X	X
Community Needs Assessment				X			
Complaint Tracking				X		X	X
Door to Door Outreach			X	X			
Emergency Radio Station	X						
Field Tour	X	X	X	X			X
Highway Notification	X						X
Information Hotline						X	
Informational Flyers		X	X	X	X	X	X
Informational Video	X						
Interpretive Kiosks	X		X				
Interviews-Media Event						X	X
Posters		X				X	
Pre-Burn Announcements		X					
Prescribed Fire Map				X	X		
Press Release			X	X	X	X	X
Professional Marketing Plan		X					
Public Information Officers	X						
Public Meetings		X		X		X	
Public Service Announcements		X					
Reverse 911 System	X						
Smoke Monitoring Station	X						
Smoke Sensitive List Notification/Direct Notification	X		X	X	X	X	
Social Media	X	X		X	X	X	X
Web Banners		X					
Webpage	X	X	X	X	X		X

Case Study 1: Ashland, Oregon

Ashland Forest Resiliency Stewardship Project

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Forest Division Chief
Ashland Forest Resiliency Stewardship Project
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Overview

The Ashland Forest Resiliency Stewardship Project provides an example of a well-rounded forest resiliency plan that successfully incorporates prescribed fire activities. The City is situated in a valley prone to smoke inversions – with a population of 20,000 but a significant seasonal influx of tourists during the summer months, the timing of prescribed fire activity can be tricky. However, the Stewardship Project has been able to find creative and consistent ways to educate local residents and visitors on the role of prescribed fire and potential smoke effects.

Initial implementation steps focused on thinning vegetation in overgrown forests and communicating the need for prescribed fire. The Stewardship Project distributed information on proper forestry techniques throughout the community. When forests were ready for pile and broadcast burning, operations were kept small, allowing the community to assimilate to controlled fire and smoke. A grant from the PERFACT program (a cooperative agreement between The Nature Conservancy, USDA Forest Service and agencies of the Department of the Interior) provides funding for some of the following outreach activities.

Table 1.1: Community Outreach Activities in Ashland, OR

Implementation Timeframe: Before the Burn		
Activity	**Target Audience**	**Purpose and Description**
Ensure Agency Coordination	**Local Residents**	To ensure a cohesive message is delivered to residents: • A meeting facilitated by the Ashland Forest Resiliency Stewardship Project was conducted with the major community stakeholders (hospitals, tourism board, Chamber of Commerce, etc.) to develop messages for Ashland residents and analyze the most effective communication tactics. • Stakeholders meet every week to analyze media and outreach topics.

Build Interpretive Kiosks	**General Public**	To increase public awareness on fire's natural role prior to prescribed fire within the community, stakeholders: • Built and placed interpretive signs on a popular local hiking trail – seven years later this trail was within the first prescribed burn area. • Signs highlighted fire's historical and natural role, and why prescribed fire is needed to restore the forest to its natural state.
Maintain Smoke Sensitive List Notification	**Smoke Sensitive Individuals**	Two days before ignitions, emails are sent to a smoke sensitive list, which identifies information on: • The prescribed burn location and planned events. • How to mitigate the impacts of smoke. • The ability of controlled burns to lower wildfire risk in the summer time.

Implementation Timeframe: During the Burn

Activity	Target Audience	Purpose and Description
Utilize the Fire Department Radio Station	**General Public**	The Stewardship Project's partnership with the City's Fire Department enables use of the emergency radio station during prescribed burns. This reduces calls to dispatch and is at no additional cost to the Stewardship Project activities.
Post Highway Notifications	**Affected Residents/ General Public**	To inform anyone who could be impacted by smoke: • Signs are posted on highways and local roads during the burn. • Messages provide the phone number for the emergency radio station.
Stage Public Information Officers	**General Public**	Public Information Officers (PIOs) are staged in town and near the burn site to have conversations on the use of prescribed fire and the current operation.
Utilize Reverse 911 System	**Affected Residents**	If a major smoke incident occurs, the Reverse 911 system is capable of pinpointing areas where smoke may affect residents.

Provide Field Tours	**Elected Officials, Media, Interested Parties**	During a recent successful burn, a group of city council members, weather service members, and a photographer were taken through a burn site to show: • Fire effects. • Operations that take place on the fire line.
Implementation Timeframe: After the Burn/ Ongoing Activities		
Activity	**Target Audience**	**Purpose and Description**
Utilize Smoke Monitoring Station	**General Public**	A permanent smoke monitoring station within city limits is primarily for wildfire use, but is checked during a prescribed fire for timely and accurate information about potential smoke hazards in the area.
Create and Manage Social Media Sites	**General Public**	A Facebook page allows stakeholders to message prescribed fire updates quickly and efficiently: • Messages include location and size of prescribed burns. • Posts also highlight prescribed fire benefits, such as a healthy watershed and clean drinking water. • One to two hours a week are dedicated to maintaining posts and tracking outreach through site analytics. • Funds are designated for Facebook sponsorship of certain posts. "A really good Facebook post might get a couple thousand views, a professionally done post can reach 30,000 people." (Chris Chambers, Ashland Forest Resiliency Stewardship Project).
Provide Informational Videos	**General Public**	The Ashland Forest Resiliency Stewardship Project website provides professionally made informational videos on the use of prescribed fire in the community, highlighting: • Descriptions of all operations conducted and evaluations of the forest restoration work. • A cohesive message from the Mayor, Fire Chief, and the Chamber of Commerce communicating the benefits of prescribed fire. The video cost was substantial, requiring "a couple hundred hours of staff time and $1,000 a minute to produce" (Chris Chambers, Ashland Forest Resiliency Stewardship Project).

Case Study 2: Deschutes County, Oregon

Project Wildfire

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Overview

Project Wildfire is the coordinating entity for prescribed fire communication within Deschutes County, OR. This organization has put an emphasis on both community outreach to its rapidly growing 157,000 residents and coalition building with stakeholders. With a grant from the Fire Adapted Communities (FAC) Learning Network, Project Wildfire hired a professional marketing campaign to assist in community outreach activities focused on prescribed fire. The campaign created a unified message of prescribed fire benefits, increased public awareness on prescribed fire and smoke impacts, and enhanced relationships with local media.

Table 1.2: Community Outreach Activities in Deschutes County, OR

Implementation Timeframe: Before the Burn		
Activity	**Target Audience**	**Purpose and Description**
Conduct Professional Marketing Plan	**General Public**	A professional marketing company funded through the FAC Learning Network utilized: • Handouts in downtown areas. • Public service announcements. • Web banners with a landing page describing the benefits of prescribed fire. • A 30 second Prescription to Burn commercial. Project wildfire received discounted rates from media outlets as a non-profit organization. The creation of the commercial cost $250. The commercial aired 32 times for $1,000. The web banners cost $850 for 100,000 impressions.
Utilize Posters	**Affected Residents**	Directly before a prescribed burn, communities predicted to be affected will be notified via posters around the burn area.

Distribute Press Release	**General Public**	Public service announcements through news outlets in the community are posted prior to ignitions. Information includes: • Location of the burn. • Expected duration of the burn. • Ecological, defensible space, and smoke control benefits of prescribed fire.
Implementation Timeframe: During the Burn		
Activity	**Target Audience**	**Purpose and Description**
Conduct Field Tours	**General Public / Interested Parties**	Recently, tours were given by The Nature Conservancy during an active prescribed fire on a a 400-acre tree farm slated for development: • The prescribed fire was close to development and drew a significant amount of public attention. • Enough resources were committed to the fire enabled several experienced fire personnel to explain the operations to concerned citizens.
Implementation Timeframe: After the Burn/ Ongoing Activities		
Activity	**Target Audience**	**Purpose and Description**
Facilitate Public Meetings	**General Public/ Interested Parties**	Meetings take place only when something goes wrong such as a smoke inversion or an escaped burn. • Project wildfire and the management agency in charge will conduct the meeting. • This tactic was used during an escaped prescribed burn in 2009.
Manage Social Media	**General Public**	Social Media sites are heavily used by Project Wildfire. Messages are used for: • Plans to initiate a burn. • Location and activity of the fire. • Pictures and videos of fire activity and smoke to keep the community updated on the fire's progression. • Notification of completion. • Site analytics are used to track the numbers and segments of population reached.

		Other government agencies, such as the local tourism board, will repost these messages. This is the most economical avenue for practitioners to reach the public. "Spending a small amount of money ($50) for the social media outlet to sponsor a post can reach a much larger population." (Alison Green, Project Wildfire)
Manage Webpage	**General Public**	Project wildfire's main webpage has a complete section on the importance of using prescribed fire to mitigate "mega fires" and the uncontrollable smoke that comes with it.
Conduct Field Tours	**General Public / Interested Parties**	Post fire burn tours have also been implemented to educate the public: • Five tours were conducted with approximately 20 attendees each. • Interpretive resources were available through other local organizations, resulting in 10-15 hours of planning to make the first tour successful. Alison Green, program manager for Project Wildfire, shared, "After the first tour was complete, the following tours were much easier to implement."

Project Communication Examples

Project Wildfire added 4 new photos.
October 5, 2015
Like Page

The prescribed burn last Thursday was a shining example of partnerships making the difference. The burn would not have been as successful without key participation from the Sisters Ranger District, Prineville BLM, Central Oregon Rappellers, Prineville Hotshots,Redmond Hotshots, Oregon Department of Forestry, Sisters Camp Sherman Fire, Black Butte Ranch Fire, Warm Springs BIA, and GFP.

Implementing a prescribed burn with all these partners illustrates how productive these relationships are in providing valuable training opportunities, as well as allowing us to further our mission in managing the landscape.

Project Wildfire Facebook post highlighting the local partnerships during a burn. Source: Project Wildfire

Case Study 3: Flagstaff, Arizona

Flagstaff Fire Department

Name of Contact: Paul Summerfelt
Fire Management Officer
Flagstaff Fire Department
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PSummerfelt@flagstaffaz.gov
www.flagstaff.az.gov

Overview

Flagstaff, Arizona has a population of 65,000 permanent residents and a substantial Northern Arizona University student population. A prescribed fire program was initiated in 1996, and many subsequent fire mitigation efforts, including the implementation of their Wildland Urban Interface Code and the Flagstaff Watershed Protection Project, are linked to the roots of this program.

The Flagstaff Fire Department attributes much of its ongoing prescribed fire program success to being the most trusted government agency in the area, conducting short duration burns close to homes, and utilizing university research to complement prescribed fire and smoke messaging. The following outreach strategies were developed by the Flagstaff Fire Department with contributions from the Greater Flagstaff Forest Partnership.

Table 1.3: Community Outreach Activities in Flagstaff, AZ

Implementation Timeframe: Before the Burn		
Activity	**Target Audience**	**Purpose and Description**
Facilitate Agency Coordination	**General Public**	Prescribed fire communications are largely isolated to individual jurisdictions: • The Flagstaff Fire Department will send a mass email to all 650 city employees notifying them of prescribed burning in other jurisdictions. • This distributes information quickly, supplementing outreach done by the burning agency. • This strategy is the most economical outreach practice before a burn.
Perform Classroom Presentations	**Flagstaff Students**	Several class rooms in the Flagstaff Area have begun to teach fire ecology and the Fire Department presents to those classes when invited.

Community Events Coordination	**General Public**	While planning for a prescribed fire, the department will check to see if there are major events being held outside to ensure the burn is not scheduled during that time.
Distribute Press Releases	**General Public**	Prior to a burn, the fire department will generate a press release for newspaper, radio and social media sites. This information includes: • Where the burn is located. • When it is planned. • What fire and smoke effects to expect. • A message enforcing why they are burning.
Distribute Informational Flyers	**General Public**	Flyers with contact information and tips on avoiding smoke are distributed throughout the community.
Maintain Smoke Sensitive List Notification	**Smoke Sensitive Individuals**	Major community institutions, such as schools and hospitals, as well as individuals on the smoke sensitivity list will be directly notified by phone to allow them time to take precautions.
Implementation Timeframe: During the Burn		
Activity	**Target Audience**	**Purpose and Description**
Conduct Door-to-Door Outreach	**Affected Residents**	The Fire Department has conducted burns immediately adjacent to homes. Before ignitions: • Three firefighters dedicate a half-day going door to door during and after the burn to explain the conditions and actions taken. • While resource-intensive, it is the most effective outreach. "This can be viewed as an investment into the relationship with the community, mending any backlash from the community that is affected negatively would cost much more money and time. During a [recently] scheduled burn, a homeowner was sensitive to smoke and could not leave the premises due to recent surgery. Burning operations were suspended until the individual could take proper precautions. This action has paid dividends in the community and that individual has become a champion of the prescribed fire program". (Paul Summerfelt, Flagstaff Fire Department)

Adjust Duration of Fires	**General Public**	Prescribed fires are designed to be of short duration (two days). Smaller burns and a shorter duration of smoke is more tolerable within the community.
Field Tour/ Public Familiarity	**General Public**	Most of the prescribed burns done are within municipal boundaries, allowing the community to see the effect of prescribed burning first hand and on a regular basis.
Implementation Timeframe: After the Burn/ Ongoing Activities		
Activity	**Target Audience**	**Purpose and Description**
Coordinate Messaging	**General Public**	Key messages focus on defensible space and protection of the community while providing for the best practices of fire ecology: • Smoke aversion and the controlled timing of smoke in the community is a message used within the community, but is not the main message used by the Fire Department.
Build Interpretive Kiosks	**General Public**	In conjunction with the Greater Flagstaff Forest Partnership: • Two interpretive kiosks have been built in County parks where prescribed fires have taken place. • One sign includes a covered area and places to sit and the other is a smaller sign. • The larger Kiosk was $15,000 to build and the smaller $3,000.
Maintain Webpage	**General Public**	The Flagstaff Fire Department's Wildfire Management Page contains several prescribed fire documents: • The document titled "It Works," highlights wildfires that were successfully suppressed due to previously implemented prescribed fires. • Post event economic reports of detrimental fires, such as the Shultz fire promote the need for a prescribed fire program. • The *Flagstaff Interface Treatment Prescription* and Fighting Fire with Fire document describe the burning process. • The Greater Flagstaff Forest Partnership also communicates within the community and provides educational information on their website http://gffp.org/.

Project Communication Examples


Contact Information

The following agencies routinely manage Rx fire within our area and can be contacted for additional information.

U.S. Forest Service– Supervisor's Office
Coconino National Forest
928-527-3600
www.fs.fed.us/r3/coconino/fire

Arizona State Lands Department-
Fire Management – Flagstaff
928-774-1425
www.azstatefire.org

Arizona Department of Environmental Quality – ADEQ
www.azdeq.gov/environ/air/smoke

Flagstaff Fire Department
928-213-2500
www.flagstaff.az.gov/wildlandfire

Your Local Contact Information:

Personal Mitigation

People sensitive to smoke include those with chronic lung or heart diseases, young children, pregnant women and the elderly. When smoke is present those who are sensitive are advised to:

- Stay inside and keep windows and doors closed.
- Use the recycle or recirculation mode on the air conditioner in your home or car.
- Some room air cleaners, such as HEPA filters, can help reduce smoke indoors.
- Avoid physical exertion. Keep children from playing outdoors during smoky periods.
- Asthmatics should follow their asthma management plan.

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A Partnership of Emergency Services In the Greater Flagstaff Area

Prescribed Fire and Smoke

Personal Smoke Mitigation Flyer used by the Flagstaff Fire Department. Source: Flagstaff Fire Department

Case Study 4: Leavenworth, Washington

Chumstick Wildfire Stewardship Coalition

Name of Contact Hilary Lundgren, Director
Chumstick Wildfire Stewardship Coalition
Contact Information 360-464-7501
hilary@chumstickcoalition.org
www.chumstickcoalition.org

Overview

With a population of 1,965, the City of Leavenworth is highly dependent on its natural amenities to support its substantial tourism industry. A mountainous landscape limits cell phone and internet coverage, requiring local wildfire practitioners to rely on mailers and community events to communicate prescribed fire activities. In 2016, a total of 800 acres was treated through prescribed burns (large scale burns have not been conducted in the last ten years on the National Forest in the Leavenworth area). The Chumstick Wildfire Stewardship Coalition (CWSC) performed the following actions in a 6-week window on three-quarters of their allocated outreach budget. Expanded community outreach for prescribed burns was conducted in the Leavenworth area from funding made available by Washington House Bill 2928.

Table 1.4: Community Outreach Activities in Leavenworth, WA

Implementation Timeframe: Before the Burn		
Activity	**Target Audience**	**Purpose and Description**
Perform Community Needs Assessment	**Community Stakeholders**	As a first step, the Coalition contacted local stakeholders who frequently communicate with the public (Chamber of Commerce, Hospital, Department of Transportation, Emergency Management Office, Firewise Communities). • A 12-question survey inquired about local outreach strategies and their procedures to process questions of smoke in the community. • A community stakeholder meeting was held with land management agencies to identify outreach objectives and establish a smoke sensitive population list. • An outreach working group was formed to develop a complaint and inquiry tracking process and strategies for an outreach campaign. The focus was on benefits of prescribed fire to wildlife, aesthetics and health in outreach campaign messaging.

Conduct Community Events	**General Public**	Community events were recently used to message prescribed fire to the public: • The local Salmon Fest, a natural resource educational event, informed 2,000 students and 1,000 adult attendees of the ecological benefits of prescribed fire and included a photo series of Washington burn sites in various stages. • A local Lion's Club meeting was utilized to discuss health concerns of smoke and the actions to mitigate them. After the meeting, the club shared information at highway "coffee breaks" to inform travelers of prescribed fire operations, significantly reducing calls to local dispatch.
Coordinate Complaint Tracking	**General Public**	A complaint tracking system was devised for all major stakeholders identified to receive inquiries regarding smoke (hospital, chamber of commerce, etc.). Per the information recorded, the call volume was 20% of previous years.
Perform Door to Door Outreach	**Affected Residents**	When burn areas were adjacent to development, the local fire department went home to home to inform the residents of the operations.
Conduct Field Tours	**Interested Public**	Fifty residents attended a pre-burn field tour, visiting burn areas in various phases of prescribed fire introduction (ten year, five year, two year, and six months) and the units planned to be burned in the fall: • "The tour allowed the public to see firsthand that prescribed fire is used as a maintenance tool and needs to be introduced on a regular basis." (Hilary Lundgren, CWSC) • A post fire field tour was planned for residents to view the after effects of the prescribed fires, however due to early winter weather conditions, the tour was cancelled.
Maintain Prescribed Fire Map	**General Public**	A Planned Prescribed Fire Activities map was generated by the Forest Service showing the planned burn units, completed burn units, and potential high smoke concentration zones during burn operations. A QR code was included on all mailers, allowing interested residents to quickly view the map information.

Activity	Target Audience	Purpose and Description
Generate Press Releases	**General Public**	In coordination with the outreach working group the local Forest Service Public Information Officer (POI) generated two press releases for the local newspaper. At the same time the Chumstick Coalition developed additional press releases discussing the benefits of prescribed burning.

Implementation Timeframe: During the Burn

Activity	Target Audience	Purpose and Description
Conduct Public Meetings	**Interested Public**	During a prescribed burn, the town of Leavenworth hosted the "Era of mega Fires" presentation with a panel of prescribed fire experts to field questions. Pictures of the burn in progress were sent from Forest Service personnel to be displayed at the meeting to highlight local actions.
Maintain Smoke Sensitive List Notification	**Smoke Sensitive Individuals**	The county emergency management office has an existing alert system sending texts and emails to inform residents of emergency situations: • Alerts were sent out every week to update residents on the progress of prescribed burns in the area. • 2,000 people are registered for the service.
Maintain Social Media	**General Public**	The Forest Service PIO utilized their Facebook and Twitter accounts to provide daily updates to the public. Partnering organizations reposted this information by 9am in the morning.

Implementation Timeframe: After the Burn/ Ongoing Activities

Activity	Target Audience	Purpose and Description
Maintain Webpage	**General Public**	The Chumstick Coalition Website includes the planned prescribed fires map and links to all Chumstick Coalition social media sites.
Distribute Informational Flyers	**General Public**	Due to demographics and geographical challenges in the area, many residents do not use electronic modes of communication. Outreach tactics were focused on a series of direct mailers correlated to community events and actions before, during and after the fire.

The three mailers reached a total of 5,200 residents in the Leavenworth area:

- **Before the Fire, Mailer 1:** focused on prescribed fire definitions and processes while inviting residents to the community meeting and prescribed fire field tour.
- **During the Fire, Mailer 2:** included information on best practices to avoid smoke for sensitive populations.
- **Post Fire, Mailer 3:** informed the public on the location of burns and re- addressed health and safety messages.

Project Communication Examples

Prescribed Fire Mailer describing the burning process in a controlled setting. Source: Chumstick Wildfire Stewardship Coalition

Prescribed Fire Mailer describing the burning process and the benefit of controlling smoke. Source: Chumstick Wildfire Stewardship Coalition

Prescribed Fire Mailer highlighting the burn approval process. The QR code links directly to the prescribed fire map. Source: Chumstick Wildfire Stewardship Coalition

Case Study 5: Lake Tahoe, Nevada

North Lake Tahoe Fire District

Name of Contact	Forest Shafer, Forester North Lake Tahoe Fire District
Contact Information	775-690-7506 fschafer@nltfpd.net www.tahoe.livingwithfire.info

Overview

The Lake Tahoe Basin has 15 land management agencies within four counties in a 200,000-acre area. The local population is 55,000 full time residents, and 75% of homes within the Basin are vacant or are second homes. Many prescribed fires occur close to, or in, developed areas. Coordination of communications for prescribed fire, therefore, is a necessity.

The Tahoe Fire and Fuels Team has a representative from each land management agency in the Basin and some additional partners. The Team is tasked with providing a coordinated message of prescribed fire and smoke to the community. Because of the strong coordination efforts, residents are well informed and highly engaged. Ongoing education and outreach on additional wildfire safety topics such as defensible space, keep community fire issues at the forefront.

Lisa Heron, the Public Affairs Specialist for the Lake Tahoe Basin Management Unit of the Forest Service, is tasked with implementing the established outreach actions of the Fire and Fuels Team. When multiple prescribed fires are conducted at one time in the basin, four hours a week are designated to complete the following tasks.

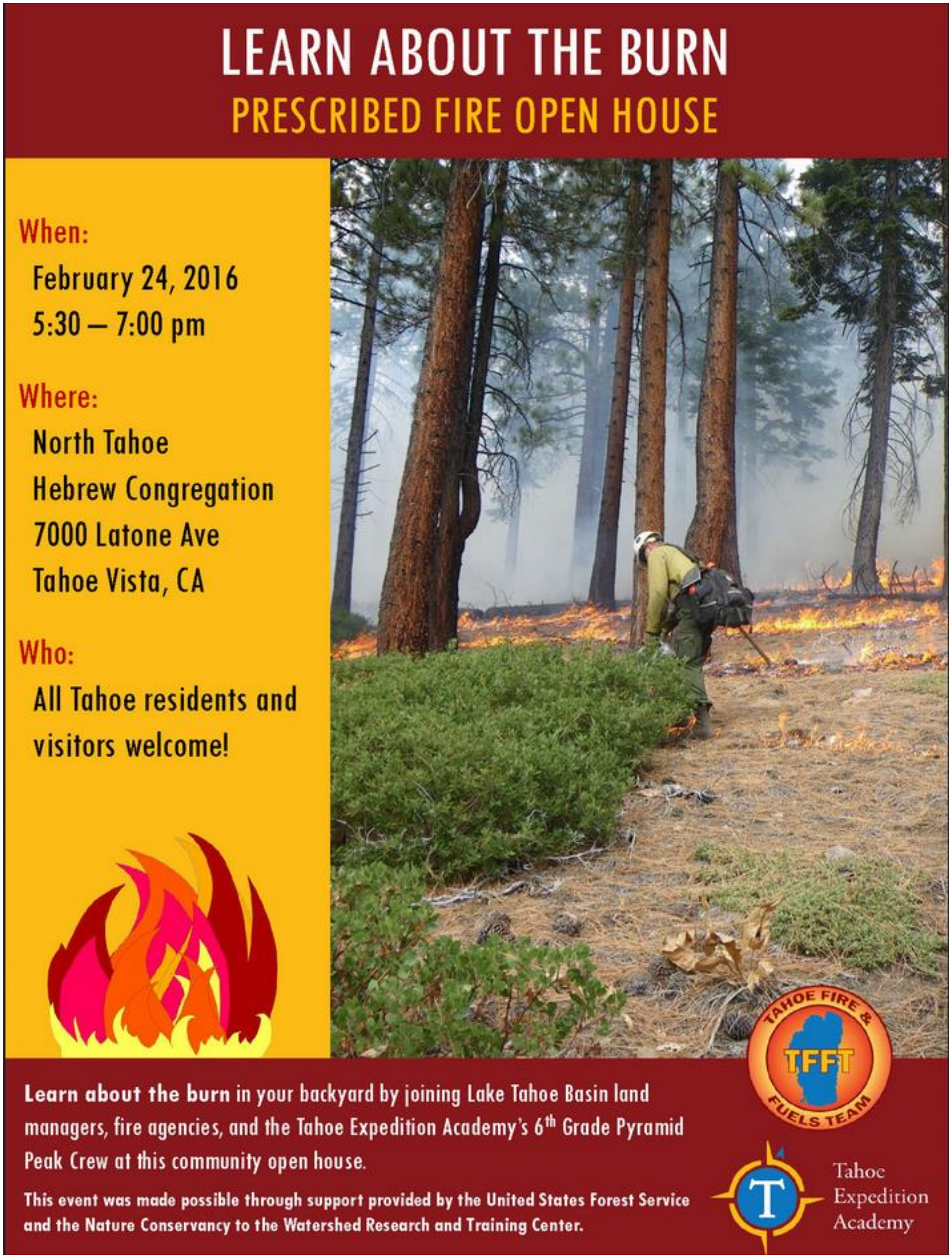
Table 1.5: Community Outreach Activities in Lake Tahoe, NV

Implementation Timeframe: Before the Burn		
Activity	**Target Audience**	**Purpose and Description**
Maintain Agency Coordination	**General Public**	All prescribed fire and smoke activities are coordinated through the Fire and Fuels Public Information Team: • The team consists of Public information officers from seven fire districts, the regional planning agency, CAL Fire, California State Parks, and others. • The team meets once a month for two hours to ensure consistent outreach and messaging to the Lake Tahoe community.

Distribute Informational Flyers	**General Public**	Informational flyers are available on the website and are passed out at community events.
Generate Press Release	**General Public**	The Tahoe Fire and Fuels team develops and distributes a weekly press release including listing all fires planned for the coming week. This information includes: • The name of the burn. • Agency responsible for the burn. • Descriptive location. • Type of burn. • Total acreage. • Date of planned ignition. • Duration of ignition. • Estimated smoke direction.
Implementation Timeframe: During the Burn		
Activity	**Target Audience**	**Purpose and Description**
Maintain Prescribed Fire Map	**Interested Public**	A map of all current prescribed burns allows the public to easily locate the burn areas: • The location and duration of the burns are coordinated with the responsible agency and posted to the website. • This map also connects residents to the information that is provided in the press releases with the addition of the Burn Manager's phone number.
Maintain Smoke Sensitive List Notification	**Smoke Sensitive Individuals**	Smoke sensitive individuals such as the elderly or asthmatics, can sign up for a notification list available through the website. Individuals on this list are notified the day before the burn through an email or text message, allowing them to take precautions during burning operations.
Maintain Social Media Updates	**General Public**	Each agency conducting burns maintains a social media presence to post information about the burns and will post pictures of the fire along with before and after photos: • Partner agencies will re-post messages of prescribed fire to multiply the outreach effort.

		• Facebook and Twitter analytics are used to effectively provide messaging of prescribed fire and smoke.
Implementation Timeframe: After the Burn/ Ongoing Activities		
Activity	**Target Audience**	**Purpose and Description**
Conduct Classroom Presentations	**Tahoe Students**	Fire districts also partner with local sixth grade classrooms to conduct a Prescribed Fire Open House. Certain classrooms have been identified because of an unexpected inversion during a prescribed burn.
Facilitate Community Events	**General Public**	Fire district representatives attend community gatherings such as the region's summer concert series: • The Tahoe Fire and Fuels team also holds monthly or bi-monthly events such as BBQ's, open houses, and wildfire safety expo's. • These events promote discussion of wildfire, including the need for prescribed fire.
Maintain Webpage	**General Public**	The Tahoe Fire and Fuels Team maintains a website during prescribed fire season that contains a prescribed fire and information section, the group's mission statement, a fire ecology section specific to the Tahoe area, and the fire map: • The website describes the steps of implementing a burn plan and previous prescribed fire announcements. • Messaging in this section focuses on the creation of defensible space in the community. • Google analytics are used to effectively craft and update their messaging efforts.

Project Communication Examples



Prescribed Fire Open House Mailer. Source: Tahoe Fire and Fuels Team

Introduction

Local fire departments, in cooperation with state and federal forestry agencies have developed the community wildfire protection plan (CWPP). The CWPP describes how the wildfire threat can be reduced for Tahoe's communities. An important part of Tahoe's wildfire threat reduction plan is the intentional use of fire.

There is a large accumulation of vegetation or "fuel" present in many areas of Tahoe's forests. This fuel is capable of supporting high intensity, uncontrollable wildfires. Frequent, low intensity fires can effectively and safely reduce fuel amounts. The result will be a substantial reduction in the wildfire threat to human life, property, and Lake Tahoe's water quality.

The underlying goal is to manage the forest in a manner consistent with restoring it to pre-1870 conditions. While full restoration may take hundreds of years to accomplish, the steps taken in that direction will provide the benefits of improved forest health and wildfire hazard reduction in the near future.

Setting The Stage

Since fire has been absent for so long, there has been a considerable buildup of fuels. Under these conditions, prescribed burning cannot be safely performed. Work crews and homeowners can remove dead tress, thin live tress, and remove brush. This work creates the conditions necessary to safely reintroduce fire. Typically, there are two types of prescribed burning: understory and pile.

How Understory Burning is Done

The prescribed fire project is a well-planned, carefully orchestrated program involving the disciplines of fire ecology, fire suppression, forestry, and public safety. The important parts of the program are described below.

Training: Personnel have received extensive training and have been certified in prescribed burning.

Preburn Activities: Each winter a multidisciplinary team develops the "Burn Plan" for the upcoming fall burn season. During the summer months work crews start preparing the burn sites by creating firebreaks, clearing around high value trees, thinning dense pockets of brush, etc...

Burn Day: Unfortunately, the specific date of a proposed burn cannot be determined very far in advance. A "Go/No-Go Checklist" is used to decide if an understory burn can be safely and effectively conducted. If the necessary conditions are not optimal, the burn will be postponed until conditions "come into prescription." The illustration presented at right portrays a typical understory burn.

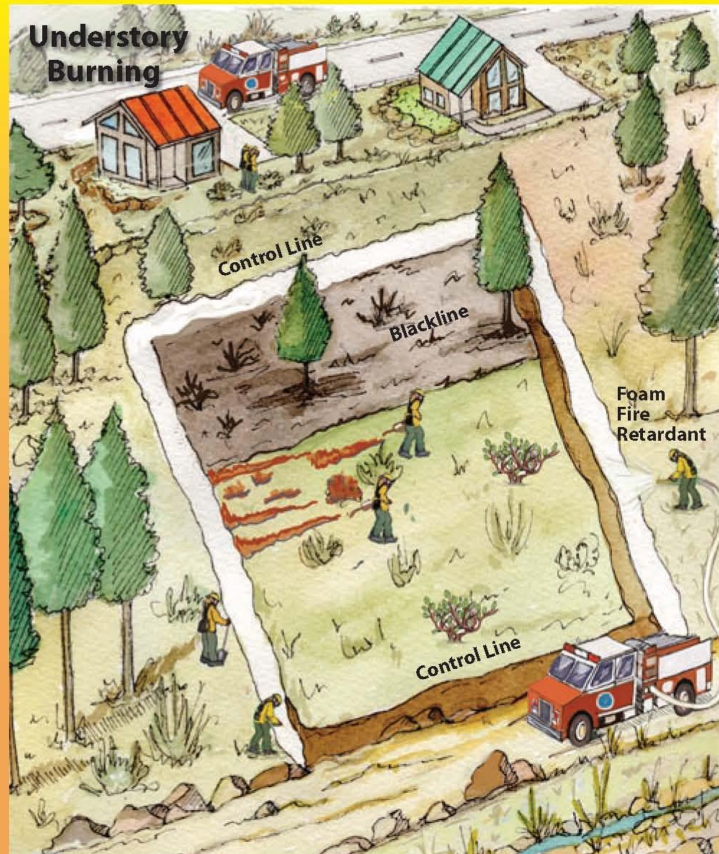
Tending the Burn: Burns are attended to minimize smoke production and maximize fuel consumption. Personnel closely monitor the site until the burn project is completed.

How Pile Burning is Done

Forestry work crews create burn piles when working in forested areas that do not allow efficient removal of the cut limbs and other tree and brush debris generated by these activities. This cut material, or slash, can serve as a fire hazard and a breeding ground for insect pest species. Consequently, it is important that this material be disposed of in a manner that does not cause harm to the forest or excessive cost and effort. When no roads or access ways are available, this material is usually burned on site. Burning slash is the most cost effective and efficient means for disposal of this hazardous material.

Pile Burning: When work crews thin a forest stand, they will stack the material into piles approximately 6 feet wide and 4 feet tall. These piles will be located away from other flammable material and will be spaced so as to create defensible zones between piles. In some areas there may be numerous piles. These piles are then left for several months to allow for sufficient drying of the material. When safe conditions exist, usually late fall through early spring, the piles will be ignited and burned in place. Areas where piles have been burned will appear charred and will include partially burned wood chunks.

Pile Burning Safety: Burning activities are conducted by experienced crews. Areas around the piles are cleared of ground fuels to prevent fire from spreading into the wildland. Training, preburn activities, burn day procedures and tending the burn are all held to the same high standards as listed above for understory burning.



What Can a Homeowner Expect?

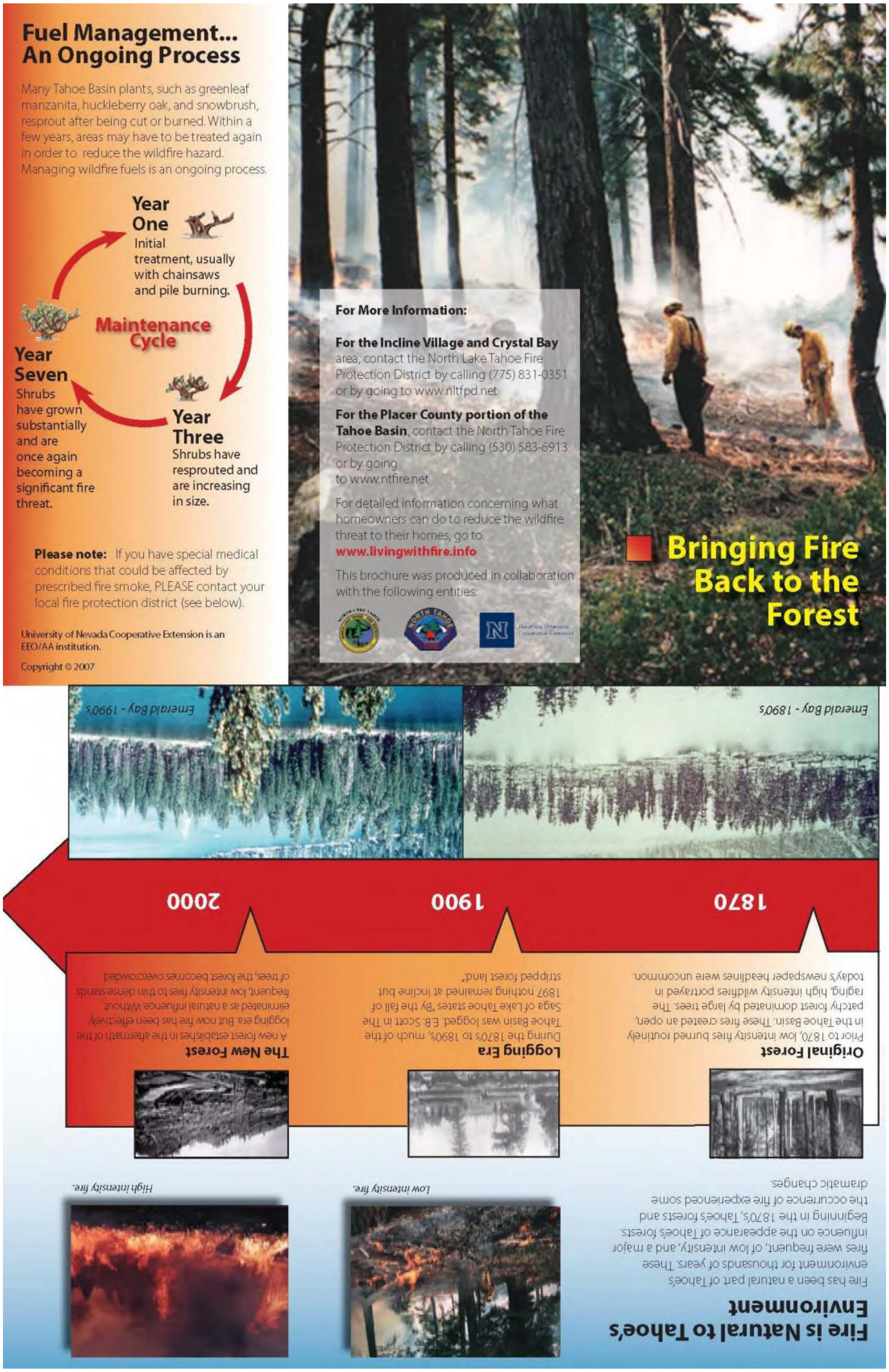
Although there are important benefits from burning, there may be some undesirable side effects. These include:

Smoke: Personnel go to great lengths to ensure that prescribed fire smoke will not significantly inconvenience homeowners or contribute to respiratory problems. Smoke, however, is a natural product of fire and some amounts are unavoidable.

Smell: A "campfire smell" will be present in your neighborhood for several days after the burn.

Scorching: Some scorching of lower tree branches is to be expected. After the fire, some needles will turn orange and eventually drop from the tree.

Barren Look: On understory burns, the treated site may appear charred and lifeless. This is a temporary condition. The following spring many shrubs will resprout and wildflowers may appear.



Informational Flyers explaining the maintenance cycle and the tactics used in prescribed fire. Source: Tahoe Fire and Fuels Team

Case Study 6: Winthrop, Washington

Methow Valley Ranger District

Name of Contact	Meg Trebon Former Assistant Fire Management Officer Okanogan-Wenatchee NF Methow Valley Ranger District
Contact Information	509-996-4032 mtrebon@fs.fed.us Methow Valley Ranger District Web Page

Overview

The Methow Valley's 4,000 residents have experienced a significant amount of fire in recent years, including the Okanagan and Carlton Complex fires. Fire and smoke has therefore become a sensitive subject despite a history of prescribed fire in the area. To effectively guide communications to residents, The Methow Valley Ranger District has continued to use their Prescribed Fire Public Information Action Plan. The goals of this plan are to "inform and when possible, educate people about prescribed fire use and impacts and provide channels to receive and respond to public comments and concerns." Many of its activities are highlighted below.

Table 1.6: Community Outreach Activities in Winthrop, WA

Implementation Timeframe: Before the Burn		
Activity	**Target Audience**	**Purpose and Description**
Maintain Agency Coordination	**Regional Agencies**	Phone calls are made to other emergency and land management agencies to notify them of burn operations.
Generate Informational Flyer	**Methow Valley Residents**	Each spring a burn plan brochure is sent to valley residents with a registered mailing address: • The brochure outlines the planned burning zones for the coming year. • Additional notifications are sent to homes and businesses who may be directly affected by specific burn operations a week before ignition.
Develop Posters	**General Public/ Hunters**	Campgrounds and trailheads near or in the burn area receive posters with burn plan information three days before ignition.

		• Hunters in the area are targeted using these posters at known dispersed campsites. • Information on these posters are targeted towards hunter safety when burning in the area. Specific messages include: ○ Heavy equipment and personnel traveling on roads. ○ Fire weakened trees in the burn area. ○ Low lying smoke in the morning.
Facilitate Public Meeting	**General Public**	During the NEPA analysis for proposed burn, public input is encouraged to help with the design of the burn project. This opportunity is also used to ask residents which outreach avenues are best to relay prescribed fire and smoke messages.
Maintain Smoke Sensitive List/Direct Contact	**Smoke Sensitive Individuals**	Three days before a prescribed burn, an email is sent to a registered list informing them of the plans to burn: • "This effort to inform the community before ignition operations has been appreciated by residents, and eventually lessened the outreach needed the day of the burn". (Meg Trebon, Methow Valley Ranger District)
Implementation Timeframe: During the Burn		
Activity	**Target Audience**	**Purpose and Description**
Conduct Complaint Tracking	**Affected Residents**	Calls will be returned within a 12-hour window.
Manage Information Hotline	**General Public**	A Burn Information phone line utilizes a recorded message relaying burn activities for the week.
Maintain Smoke Sensitive List/Direct Contact	**Smoke Sensitive Individuals/ General Public**	While prescribed burning is taking place, a daily or weekly email is sent, containing: ○ The location and duration of burns. ○ Pictures of operations taking place. ○ Predictions of smoke in the area and the actions that will be taken to minimize the impacts.

		○ Invitations to the burn sites to witness ongoing operations. In the event of smoke impacting the community, an email is sent explaining the events of the day in detail and the actions that are being taken to correct the issue.
Manage Social Media	**General Public**	Information on the location of the burn is posted on the Forest Service social media sites and webpage.
Implementation Timeframe: After the Burn/ Ongoing Activities		
Activity	**Target Audience**	**Purpose and Description**
Conduct Interviews- Media Event	**General Public**	Local radio interviews disseminate information about burn plans and accomplishments. Successful burn information is communicated using pictures and articles in the National Fire Plan and local media sites, particularly any burning near development.
Distribute Press Release	**General Public**	A follow up press release is conducted with information on the success of past burns, and more detailed information on burning activities planned for the year.
Attend Community Events	**General Public/ Hunters**	Continued education and outreach towards hunters is performed using multiple local and state hunting outlets. This message contains the benefits and reasoning for the timing of prescribed burns, as well as information on fire prevention.

Project Communication Examples

USFS cites prescribed burning's restorative powers

by ADMIN *on* Jun 15, 2016 • 6:37 pm

No Comments

File photo by Marcy Stamper

The Methow Valley Ranger District has been using prescribed burning as part of its dry-forest restoration strategy since the mid-1990s. This Forest Service firefighter worked on a prescribed burn near Little Bridge Creek about 10 years ago.

Prescribed fire article describing the benefits of the burning process. Source: Methow Valley News

Case Study 7: Woodland Park, Colorado

Coalition for the Upper South Platte

Name of Contact Jonathon Bruno
Operations Director
Coalition for the Upper South Platte
Contact Information 719.748.0033; 719.433.6775
jonathan@uppersouthplatte.org
www.cusp.ws

Overview

Teller County and adjacent El Paso County have endured several destructive wildfires in the last fifteen years, including the Hayman Fire (2002), Waldo Canyon Fire (2012), and Black Forest Fire (2013). These events have made the 23,000 Woodland Park residents (Teller County) sensitive to fire and smoke in the area and elevated prescribed fire communications to a high priority for the Coalition for the Upper South Platte (CUSP). Thanks to enormous communication and outreach efforts, such as fielding all citizen inquiries and developing a cohesive message for land management agencies, use of local prescribed fire is possible.

A total of ten hours of outreach work is dedicated to each burn. One and a half hours are allocated to perform outreach the day before and morning of the burn. CUSP has recently been able to scale back its intensive outreach methods due to the success of their messaging efforts in prior years.They continue to experience a limited number of complaints and calls.

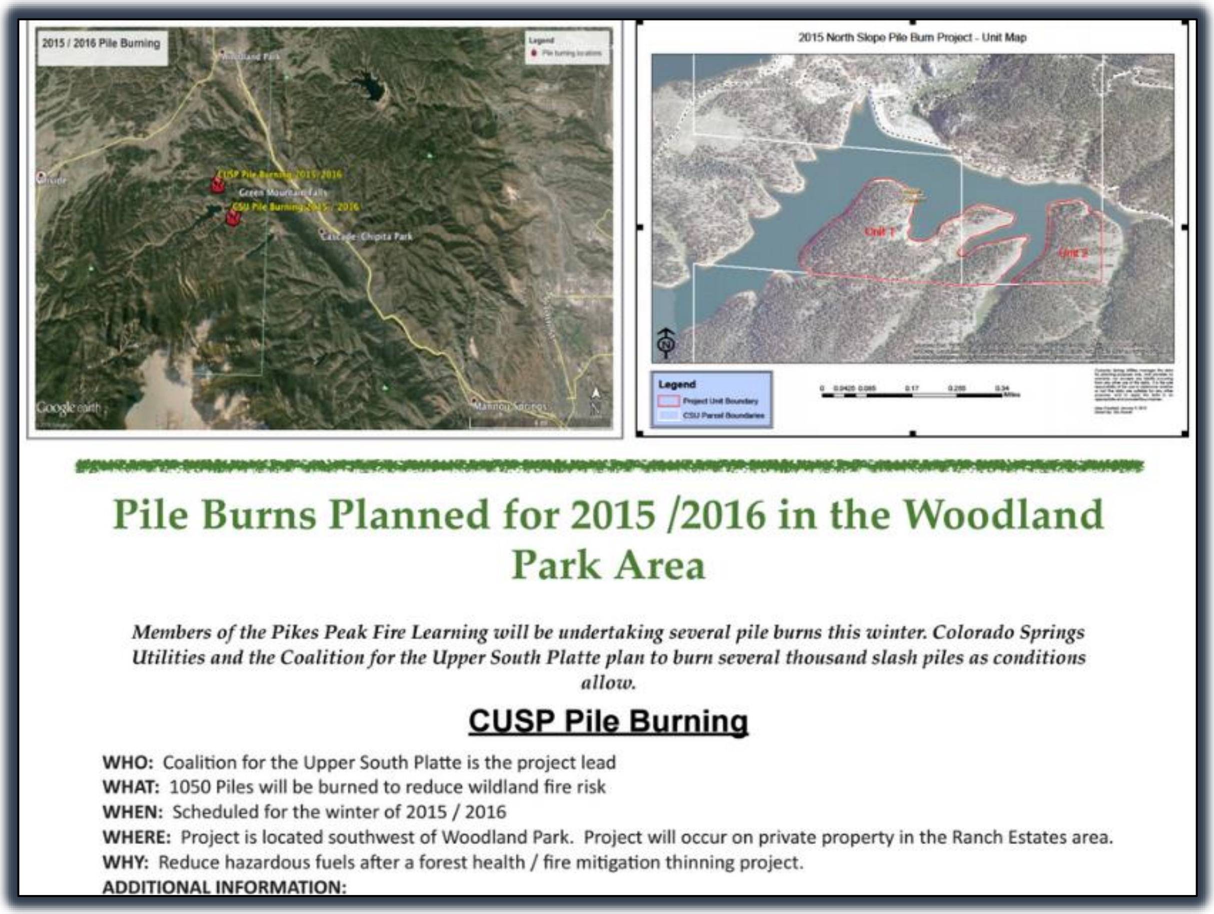
Table 1.6: Community Outreach Activities in Woodland Park, CO

Implementation Timeframe: Before the Burn		
Activity	**Target Audience**	**Purpose and Description**
Maintain Agency Coordination	**General Public**	It is the responsibility of the burning entity to ensure information can be provided to the public by any agency in the area: • Information is sent to all coordinating agencies before ignition. • Providing the public with coordinated messages shows unity and communication between agencies.

Conduct Interviews-Media Event	**General Public**	Forty-eight hours before a specific burn, the media is invited to the burn site to explain the goals and operations of the burn plan.
Generate Press Release	**General Public**	At the start of the prescribed fire season, a blanket press release with anticipated burn site information is posted to social media accounts and sent to local news sources containing: • The location of the prescribed burns. • The goals of the prescribed burns. • Organizations participating.
Distribute Informational Flyer	**General Public**	A "Suppression Team Handout" was generated to quickly communicate CUSP's mission to Woodland Park residents. Depending on the complexity of the burn, post cards can also be utilized to notify residents and provide contact information for further questions.
Implementation Timeframe: During the Burn		
Activity	**Target Audience**	**Purpose and Description**
Post Highway Notification	**General Public**	Roadside signage and electronic sign boards are utilized to notify the public of burning operations while providing contact information.
Maintain Social Media	**General Public**	Social media sites are used heavily with specific identifiers for each individual burn. Videos and pictures are posted to inform the public on smoke impacts, fire effects and post fire monitoring information.
Maintain Complaint Tracking	**Concerned Citizens**	If contacted with smoke or fire concerns, Jon Bruno (Operations Director, CUSP) personally goes and visits with the specific community members. • He discusses specific concerns such as flare ups, fire effects, and smoke. • Jon also brings a portable air quality monitoring machine to alleviate individual's concerns on the health effects of smoke in the area.

Implementation Timeframe: After the Burn/ Ongoing Activities		
Activity	**Target Audience**	**Purpose and Description**
Conduct Field Tour	**Affected Residents**	If burn operations are near development, site visits will be scheduled to discuss post fire conditions and the success of the burn.
Facilitate Community Events	**Interested Public**	Every two years, a "Be Aware, Prepare" wildfire event is held in Woodland Park: • Land management agencies and citizens meet to discuss local forestry practices, and guest speakers discuss all aspects of fire. • While prescribed fire is a focus, a broader picture of how communities can live with fire is the emphasis of the meeting. • Periodic presentations to the Chamber of Commerce and local business groups also promote the use of prescribed fire in the community.
Maintain Webpage	**General Public**	The Coalition's website is updated every week with new information about living with fire.

Project Communication Examples



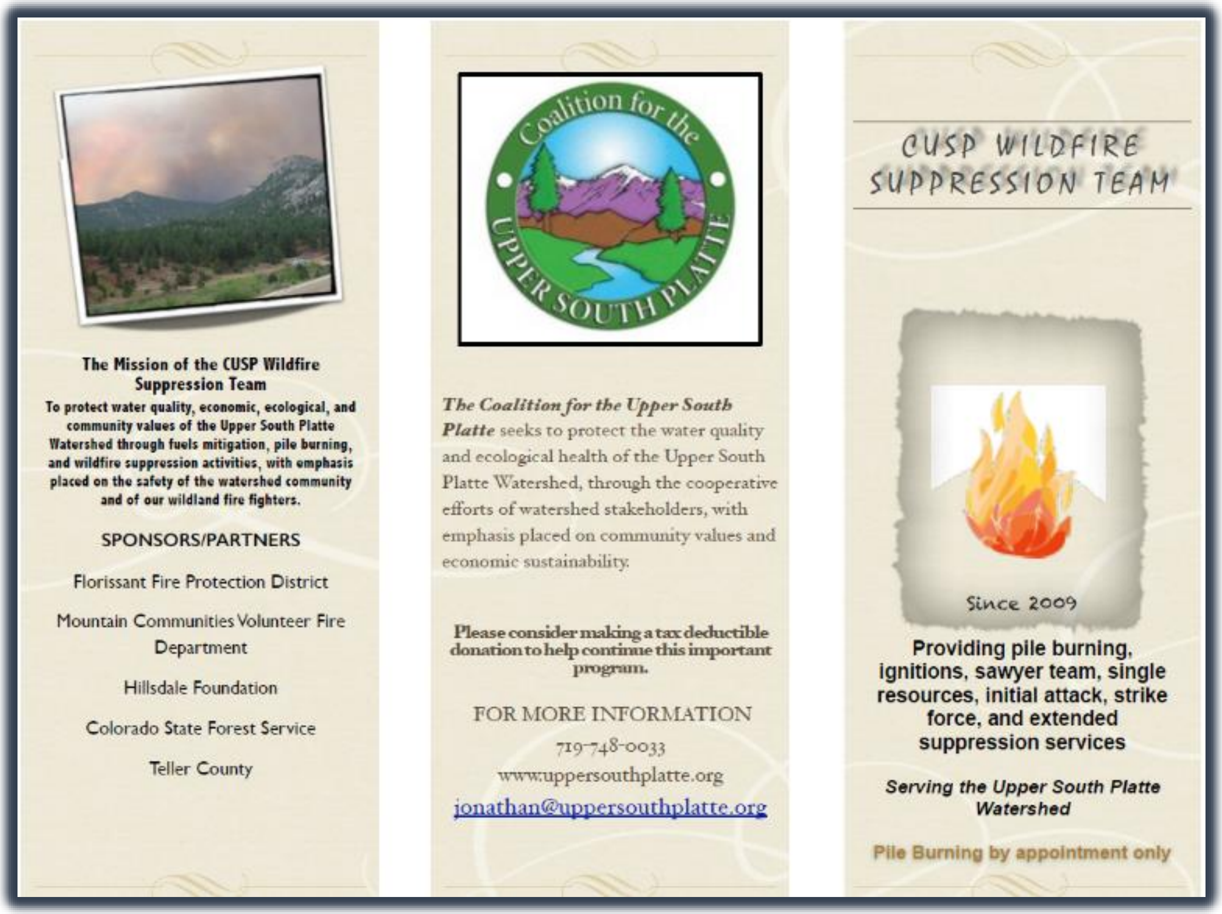
Pile Burns Planned for 2015 /2016 in the Woodland Park Area

Members of the Pikes Peak Fire Learning will be undertaking several pile burns this winter. Colorado Springs Utilities and the Coalition for the Upper South Platte plan to burn several thousand slash piles as conditions allow.

CUSP Pile Burning

WHO: Coalition for the Upper South Platte is the project lead
WHAT: 1050 Piles will be burned to reduce wildland fire risk
WHEN: Scheduled for the winter of 2015 / 2016
WHERE: Project is located southwest of Woodland Park. Project will occur on private property in the Ranch Estates area.
WHY: Reduce hazardous fuels after a forest health / fire mitigation thinning project.
ADDITIONAL INFORMATION:

Press release for a pile burn event. Source: Coalition of the Upper South Platte



Handout describing the Suppression Team and capabilities. Source: Coalition of the Upper South Platte

Additional Resources

National Communication Guides

A 2016 guide produced by the U.S. Environmental Protection Agency, U.S. Forest Service, U.S. Centers for Disease Control and Prevention, California Air Resources Board.

- Wildfire Smoke: A guide for Public Health Officials

A 2010 Smoke Messaging Guide generated by the California Air Resources Board.

- Public Relations: Communicating about Smoke

The NWCG Smoke Committee provides a forum for resource managers to address "technical, regulatory and policy issues related to planned and unplanned fire emissions, and air quality impacts on firefighter and public safety and health."

- NWCG Smoke Committee

Numerous Forest and Fire Publications by the Florida Department of Agriculture and Consumer Services, including the 2013-2020 Prescribed Fire in Florida Strategic Plan.

- Florida Department of Agriculture and Consumer Services: Forests and Wildfire Publications

National Communication Research

A 2012 USDA Forest Service Publication discussing the "public's understanding of fire's role in the ecosystem".

- Research Perspectives on the Public and Fire Management: A Synthesis of Current Social Science on Eight Essential Questions

2016 USDA Forest Service research on the use of Social media to track smoke impacts in a community.

- Social media approaches to modeling wildfire smoke dispersion: spatiotemporal and social scientific investigations

A 2016 Collaborative article by the USDA Forest Service and multiple universities studying homeowner's attitudes towards various management practices.

- Changing Beliefs and Building Trust at the Wildland/Urban Interface

A 1995 National Fire Academy study on the marketing strategy for fuel reduction in Palm Coast, Florida.

- A Marketing Strategy for Wildland Fuel Reduction in Palm Coast, Florida

Southern Group of State Foresters Website

The Southern Group of State Foresters have created a regional campaign to encourage residents to "take a forest break" to enjoy the environment, promote conservation, and support prescribed fire practices.

- Visit My Forest
- GoodFIRES Website

Case Study Contacts

The following table provides a list of all interviewees who participated in this report's case study research. (Note: additional contacts were initiated, but only those who responded to interview requests are included below.)

Interviewees				
Name	**Position**	**Position/Organization**	**Contact Information**	
Forest Shafer	Forester	North Lake Tahoe Fire District	775-690-7506	fschafer@nltfpd.net
Paul Summerfelt	Fire Management Officer	Flagstaff Fire Department	928-213-2509	Psummerfelt@flagstaffaz.gov
Meg Trebon	Former Fire Management Officer	Okanogan-Wenatchee NF Methow Valley Ranger District	509-996-4032	mtrebon@fs.fed.us
Jonathan Bruno	Operations Director	Coalition for the Upper South Platte	719-748-0033	jonathan@uppersouthplatte.org
Alison Green	Program Manager	Project Wildfire	541-322-7129	Projectwildfire.pw@gmail.com
Chris Chambers	Forest Division Chief	Ashland Forest Resiliency Stewardship Project	541-552-2066	Chris.chambers@ashland.or.us
Hilary Lundgren	Director	Chumstick Wildfire Stewardship Coalition	360-464-7501	Hilary@chumstickcoalition.org
Lisa Herron	Public Information Officer	Lake Tahoe Basin Management unit, USFS	530-543-2815	laherron@fs.fed.us