Lower Klamath Project FERC No. 14803

Fire Management Plan

KLAMATH RIVER RENEWAL CORPORATION

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Acronyms and Abbreviations

ARAP	Aerial River Access Point
ASE	Aerial Suppression Extent
BLM	Bureau of Land Management
Cal Fire	California Department of Forestry and Fire Protection
CCR	California Code of Regulations
CDFG	California Department of Fish and Game
CFR	Code of Federal Regulations

CFS	Cal Fire Siskiyou Unit
CPUC	California Public Utilities Commission
CSBFFP	California State Board of Forestry and Fire Protection
DDP	Definite Decommissioning Plan
EVS	EnviroVision Solutions
FDL	Fire Danger Level
FERC	Federal Energy Regulatory Commission
FMP	Fire Management Plan
FSCSC	Fire Safe Council of Siskiyou County
IFPL	Industrial Fire Precautionary Level
KRRC	Klamath River Renewal Corporation
LIFC	Lakeview Interagency Fire Center
LSO	License Surrender Order
LTC	Liability Transfer Corporation
MDS	Monitored Detection System
OAR	Oregon Administrative Rules
OAS	U.S. Office of Aviation Services
ODF	Oregon Department of Forestry
ODF KLD	Oregon Department of Forestry Klamath Lake District
ODF SWO	Oregon Department of Forestry Southwest Oregon District
ORS	Oregon Revised Statutes
OSHA	Occupational Safety and Health Administration
NPS	National Park Service
PAL	Predicted Activity Level
PDM	Power Driven Machinery
PRC	California Public Resources Code
RES	Resource Environmental Solutions, LLC
SCOFMP	South Central Oregon Fire Management Partnership
USBR	U.S. Bureau of Reclamation
USC	United States Code
USFS	U.S. Forest Service
WFT	Wildland Fire Technologies, Inc
WMP	Wildfire Mitigation Plan
WUI	Wildland Urban Interface

Definitions

Analysis area	Area defined by an approximately 50-mile buffer surrounding the four dams of the Lower Klamath Project
ASE area	Area defined by the approximate boundary within which the reservoirs are used for aerial fire suppression
Project	Lower Klamath Project (FERC No. 14803)
Proposed Action	Dam removal and habitat restoration as described in the Definite Decommissioning Plan
Proposed Action area	Lands on which construction activities associated with the Proposed Action may occur. Includes the reservoir footprints and PacifiCorp Parcel B lands

EXECUTIVE SUMMARY

Klamath River Renewal Corporation (KRRC) will implement this Fire Management Plan (FMP) to address fire risks associated with the physical removal of four dams (Iron Gate, Copco No. 1, and Copco No. 2 in California, and J.C. Boyle in Oregon) of the Lower Klamath Project (FERC No. 14803).

PacifiCorp (as owner of the Project), the States of California and Oregon, tribes, and other stakeholders entered into the Klamath Hydropower Settlement Agreement (2016) (KHSA). KRRC is implementing this settlement, which establishes a process leading to dam removal. KRRC has applied to the Federal Energy Regulatory Commission (FERC) to surrender the license for the Project. The FMP is part of the Definite Decommissioning Plan. When FERC issues a license surrender order, KRRC will be legally responsible to implement all commitments in that plan, including the FMP.

KRRC developed the FMP in consultation with Cal Fire Siskiyou Unit, Oregon Department of Forestry Klamath Lake and Southwest Oregon Districts, and local fire departments. It tested the plan using advanced wildfire risk computer modeling that public utility commissions use with respect to utility operations.

The FMP requires KRRC to use best management measures and comply with regulations to prevent and control fire risk associated with deconstruction activities, which will continue for several months. KRRC has engaged Kiewit for this work. Across decades of experience in western states, Kiewit has never caused a damaging fire at a complex construction project like this. KRRC's contractor for habitat restoration, Resource Environmental Solutions, will also follow such best management practices and regulations.

Dam removal will result in the loss of three Project reservoirs, which have been used as water supply for firefighting. It will result in regrowth of vegetation in the reservoir footprints. Under the FMP, KRRC will implement measures to assure that these changes do not result in an increase in wildfire risk in the area. In cooperation with fire agencies, KRRC will install Monitored Detection System cameras in a 570 square-mile area around the Project. It will construct ramps for fire trucks to access the river as well as install dry hydrants for ground crews. It will purchase dip tanks and maintain aerial river access sites for helicopter crews. It will purchase equipment to assist the local communities with defensible space and reducing risk of structure fires. These measures will assure that dam removal does not increase wildfire risk in the area on a long-term basis. Indeed, the expansion of the camera monitoring system will increase the area where early detection and triangulation are currently possible by more than 40%.

KRRC engaged REAX Engineering to evaluate the effectiveness of the FMP. REAX consults to utilities and public utility commissions on management of wildfire risk. Its report is attached to the FMP, along with a peer review by an independent expert in wildfire risk modeling. The report confirms that dam removal will not increase wildfire risk in the area.

1. INTRODUCTION

Klamath River Renewal Corporation (KRRC) will implement this Fire Management Plan (FMP) to address fire prevention and suppression that may be associated with the physical removal of four dam developments (Iron Gate, Copco No. 1, Copco No. 2, and J.C. Boyle) of the Lower Klamath Project (FERC No. 14803), hereafter the Project. The FMP will be included as an Appendix of the Definite Decommissioning Plan (DDP; KRRC, 2020), which will be submitted to Federal Energy Regulatory Commission (FERC) by KRRC. The Proposed Action is defined as dam removal and habitat restoration as described in the DDP. The FMP includes KRRC commitments for fire management that will be effective when FERC issues the license surrender order (LSO), which will approve the DDP and require implementation of the individual management plans, including this FMP.

The FMP includes fire agency regulations and fire prevention and suppression management strategies to combat short-term increases to risk of fire specifically associated with dam removal construction activities. The FMP addresses, in addition, long-term fire management in the Klamath River Basin and incorporates strategies to counter the loss of the three Klamath River reservoirs, which have served as fire suppression resources in the past, and also to provide in the long-term new local and regional fire suppression resources that do not currently exist in the Basin. The FMP was developed in accordance with standards and goals of and in consultation with local, state, and federal fire suppression agencies. The FMP, fire history and ignition risk in the Basin, and the effectiveness of the measures and strategies proposed in the FMP were reviewed in the "Quantitative Wildfire Risk Analysis of the Klamath River Renewal Project," which was completed by Reax Engineering Inc. (Reax) and included herein as Appendix A.

The objectives of the FMP are 1) to prevent or control any fire caused by construction or habitat restoration activities under the Definite Decommissioning Plan, and 2) to avoid a net diminution in firefighting resources or an increase in the fire ignition risk as a result of the loss of the Project reservoirs. The KRRC will implement (and oversee through license surrender) effective and feasible measures to enhance both short- and long-term fire prevention, detection, and suppression in the Basin. KRRC will cooperate with local and regional fire agencies through agreements, as appropriate, to implement measures that counter the loss of any current fire suppression resources. The FMP will terminate when FERC issues notice that license surrender is effective.

The sections below provide: 1) background information relating to fire, 2) relevant agencies and their jurisdictions and regulatory requirements, 3) plan for complying with regulations and best management practices to reduce fire risk in the short-term during Proposed Action construction, and 4) descriptions of the FMP components and analysis demonstrating that the execution of the removal of the Klamath Dams does not increase fire risk in the long-term..

For the FMP and the Reax report (Appendix A), fire-related analysis is conducted and discussed over several areal extents. General basin characteristics, environmental conditions, fire history, and fire agency resources are analyzed over an "analysis area" defined by approximately 50-mile buffer surrounding the four dams. This size of the area was selected to characterize regional conditions without analyzing an unnecessarily large area in physiographically and climatically diverse states of Oregon and California. Fire suppression techniques and effectiveness are discussed within a 570 mi^2 area known as the Aerial Suppression Extent (ASE), which is the approximate boundary within which the reservoirs are used for aerial fire suppression (Figure 1). The boundary of this area was delineated by California Department of Forestry and Fire Protection (Cal Fire) during an in-person meeting (Cal Fire Siskiyou Unit, *pers. comm*., 2019.03.04). The ASE area is bounded by I-5 to the west, the Siskiyou Crest to the North, and high topography to the east and south. This area is most relevant for investigating the broader impacts of the Proposed Action. The ASE area is significantly smaller than the analysis area. A smaller area is known as the “Proposed Action area” and corresponds to lands on which construction activities associated with the Proposed Action may occur. This area, which includes the reservoir footprints and PacifiCorp Parcel B lands, is significantly smaller than the ASE area. We analyze some local-scale effects and construction-related activities over this area.

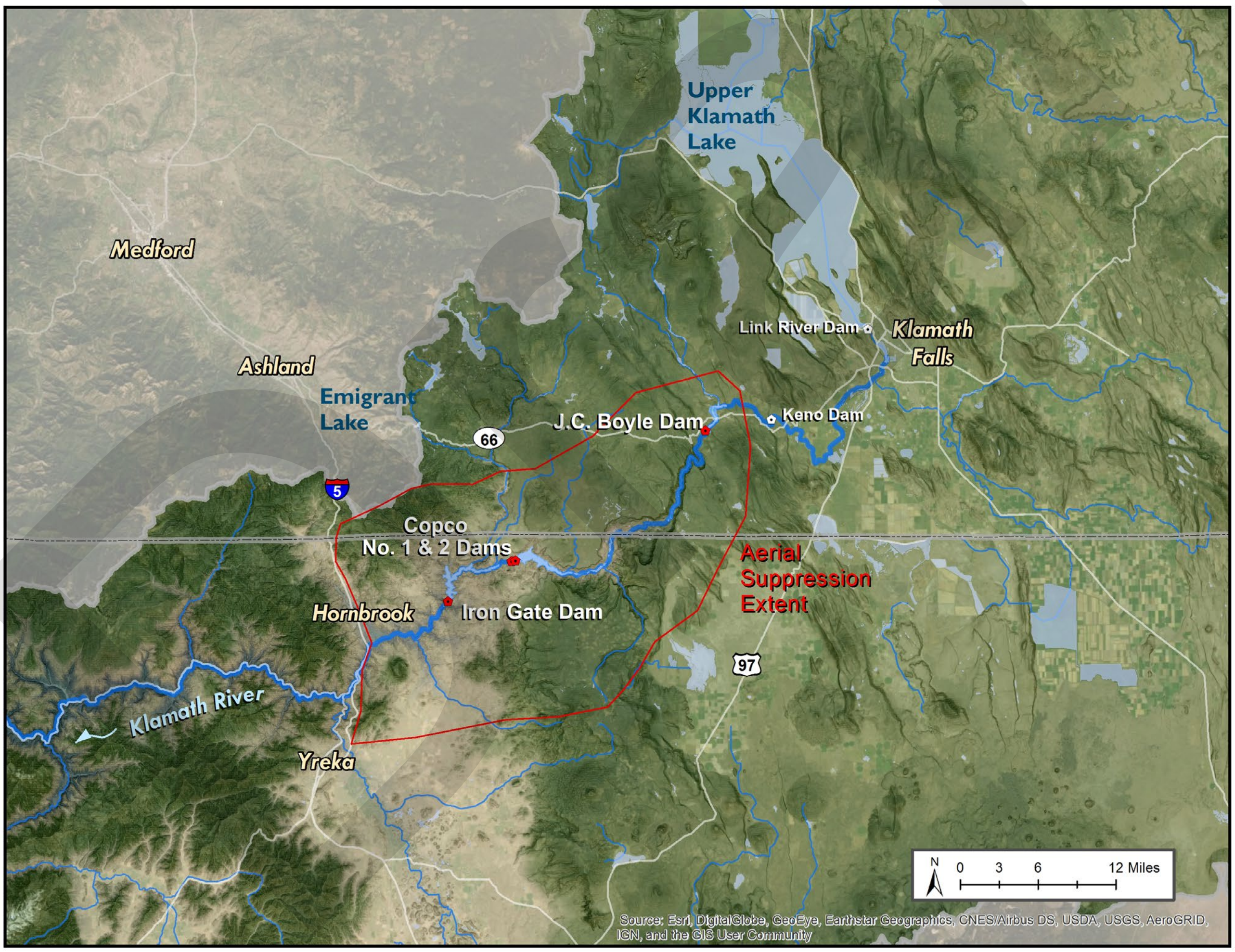

Figure 1. Aerial Suppression Extent (ASE) in the Klamath Basin.

2. BACKGROUND AND OVERVIEW OF FIRE IN THE REGION

The Proposed Action area is located in Northern California and Southern Oregon. Iron Gate, Copco No. 1, and Copco No. 2 dams are located in Siskiyou County, California, and J.C. Boyle is located in Klamath County, Oregon. The Klamath Basin in the analysis area also includes the southern portion of Jackson County, Oregon.

2.1 Environmental Conditions and Fire History

The analysis area surrounding the four Klamath River dams is at risk of wildfires. Cal Fire categorizes the fire threat in the analysis area as high to very high (Cal Fire, 2007). Fire hazard mapping using the Moderate-resolution Imaging Spectroradiometers (MODIS; USFS, 2010) shows the moderate to very high fire threat in the analysis area (Figure 2). Klamath County has identified Wildland Urban Interfaces (WUI), scored the fire hazards for each WUI community, and categorized the fire damage hazard scores as low, moderate, and high (WFT, 2016). J.C. Boyle dam is located in the Keno WUI Community, which has the highest fire hazard score in the county and a “high” ranking (WFT, 2016).

The physiographic, climatic, and ecological characteristics of the analysis area create a high fire hazard. Much of the terrain is steep, rugged, and remote, resulting in sparse access to fires and long response times. The area supports a range of fuel types, including timber, timber with grass understory, grass, brush, oak woodland, desert safe, western juniper, and Ponderosa pine (Cal Fire, 2016). A spatial analysis of fuel types in the analysis area is presented in Appendix A. The Proposed Action activities are primarily in the Shasta Valley planning area, which is 60% grass and shrub vegetation, a light and flashy fuel type (Siskiyou County, 2019). These fuel types (e.g., grass and shrub) burn quickly, which, along with high winds and steep terrain, encourages rapid spread of wildfires (Estes et al., 2017), and rates up to 1.25 miles per hour (mph) have been measured in the area (Siskiyou County, 2019; Stephens et al., 2008). Fire risk is elevated in northern California from June 1 to October 1, based on ignition data (PacifiCorp, 2019); summer temperatures often exceed 100° F and are accompanied by low precipitation and drought conditions (Cal Fire, 2016). In the summer, mountain ranges and local weather patterns support electrical storms often accompanied by strong winds and little to no precipitation (Cal Fire, 2016).

A detailed analysis of fire history in the analysis area conducted with aggregated available datasets of past events is presented in Appendix A, wherein fire occurrences are parsed into human-caused and lightning-caused categories. Human-caused fires tend to cluster along roads (e.g., I-5) and around population centers (e.g., Keno, Klamath Falls, campgrounds), and these events tend to be smaller and more successfully suppressed during initial attack. Lightning is the leading cause of wildfire in the analysis area. Lightning strikes tend to be more randomly distributed than human-caused ignitions but do favor higher elevations. The density of lightning-caused ignitions is very low around Iron Gate Reservoir and low-to-moderate around Copco Lake (Appendix A). In Northern California, lightning was the cause of ignition in 54% of the 1200 records Cal Fire documented from 2007 to 2017. In Klamath County, Oregon, 46% of the fires (and 79% of the burned acreage) on Oregon Department of Forestry (ODF)-protected lands from 2006 to 2015 were caused by lightning, and 20% were caused by debris burning (WFT, 2016). On federal lands in Klamath

County from 2006 to 2015, 81% of the fires were caused by lightning, which accounted for 89% of the federal acreage burned. Most larger fires are categorized as wind-driven fires (Cal Fire, 2016). The combination of high drought index (i.e., dryness) values and high wind velocities promote wildfire ignition and growth (PacifiCorp, 2019).

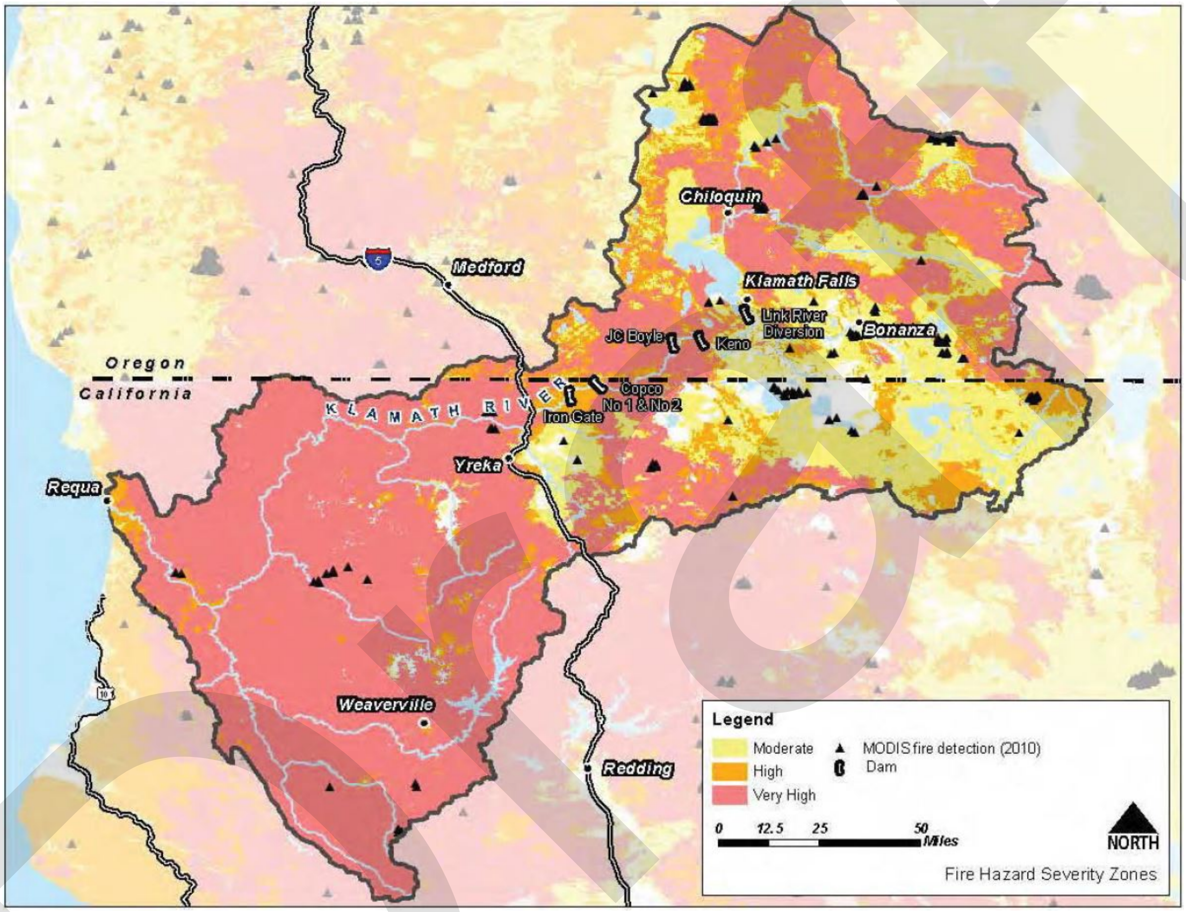

Figure 2. Map of fire hazard in the Klamath River basin generated using MODIS by the USFS. Figure from USBR & CDFG (2012).

2.2 Government and Agency Fire Mitigation Planning

Prevention and mitigation of large, destructive fires has become a recent top priority for California, and electrical utilities are an important consideration in the management of fires. 15 of the 20 most destructive wildfires in California history have occurred since 2000, and 10 of the these have occurred since 2015 (Strike Force, 2019). In the past 20 years, a number of these destructive fires in California have been ignited by elements of overhead utilities systems. In response to these events, the California Public Utilities Commission (CPUC) initiated a multi-phase statewide effort to reduce the risk of wildfire caused by overhead utility systems. This effort included the development of strict regulations for such systems and the creation of fire threat maps (e.g., Figure 3), which incorporate environmental variables, human and infrastructure risk, and the type and density of power generating and transmitting infrastructure. CPUC designates three threat levels: no threat, Tier 2 elevated, and Tier 3 extreme. The area around and upstream of Copco Lake is delineated as a Tier 2 elevated fire threat, as are most of the Klamath Basin areas west of Interstate-5 (Figure 3).

In September 2018, the Governor of California signed Senate Bill (SB) 901 into law. SB 901 provides a comprehensive approach to mitigating and improving resilience against wildfire risk and requires, through CPUC initiative, electrical utilities to develop and annually update wildfire mitigation plans (WMPs) (e.g., PacifiCorp, 2019, 2020) with review and approval from CPUC (Strike Force, 2019). In addition to SB 901, the Governor of California created a strike force, who drafted a report to coordinate the state's efforts and provide a plan for dealing with wildfire, climate change, and the energy sector and for reducing the incidence and severity of wildfires (Strike Force, 2019). The proposed wildfire mitigation and resiliency steps are 1) expand fire prevention activity, 2) make communities more resilient, 3) invest in fire suppression and response (e.g., detection cameras), and 4) call on the federal government to better manage federal forest land (Strike Force, 2019).

On January 8, 2019, the California Governor issued Executive Order (EO) N-05-19, which directed Cal Fire to recommend immediate and medium- and long-term actions to help prevent destructive wildfires with special attention to methods to quickly deploy personnel and resources. EO N-05-19 also described the Governor's proposed 2019-2020 budget, which will include investments in greater use of technology and equipment for the purpose of preventing and fighting wildfire. The Cal Fire response report to EO N-05-19 (Cal Fire, 2019) recommended, among other actions, a number of strategies to reduce fuels on private lands and improve defensible space regulations and enforcement.

2.3 Fire Risks Associated with Power Generation and Transmission

PacifiCorp is responsible for fire risks associated with power generation and transmission from the Lower Klamath Project. PacifiCorp's service area includes all of Siskiyou County, California, and portions of the analysis area in Klamath and Jackson counties in Oregon.

The generation and transmission of power is a potential cause of fires, and utility-caused fires tend to spread rapidly and be among the most destructive (Strike Force, 2019). These potential ignition sources include equipment deterioration/failure, the interaction of power infrastructure with weather and environmental conditions, animals, vegetation, and external factors, operational or mis-operation, and lightning (PacifiCorp, 2019).

PacifiCorp released their first CPUC-required WMP (PacifiCorp, 2019), which describes their utility-related wildfire risk and its steps to mitigate that risk. The area analyzed in their WMP includes the Proposed Action and ASE areas. PacifiCorp queried their outage database in the Northern California service area from 2014 to 2018 for outages related to fire. They found that equipment failure (299 incidents), wind (74), animals (45), and trees (39) are the most numerous causes of fire-related outage per year and have the highest potential for ignition (PacifiCorp, 2019). In the period from 2007 to 2017, PacifiCorp infrastructure has not been an ignition source for any large fires (defined as grass fires >100 acres, timber fires > 5 acres) within their California service area. Several power outages in the analysis area were attributed to PacifiCorp power pole fires or animals interacting with power infrastructure (PacifiCorp, 2019).

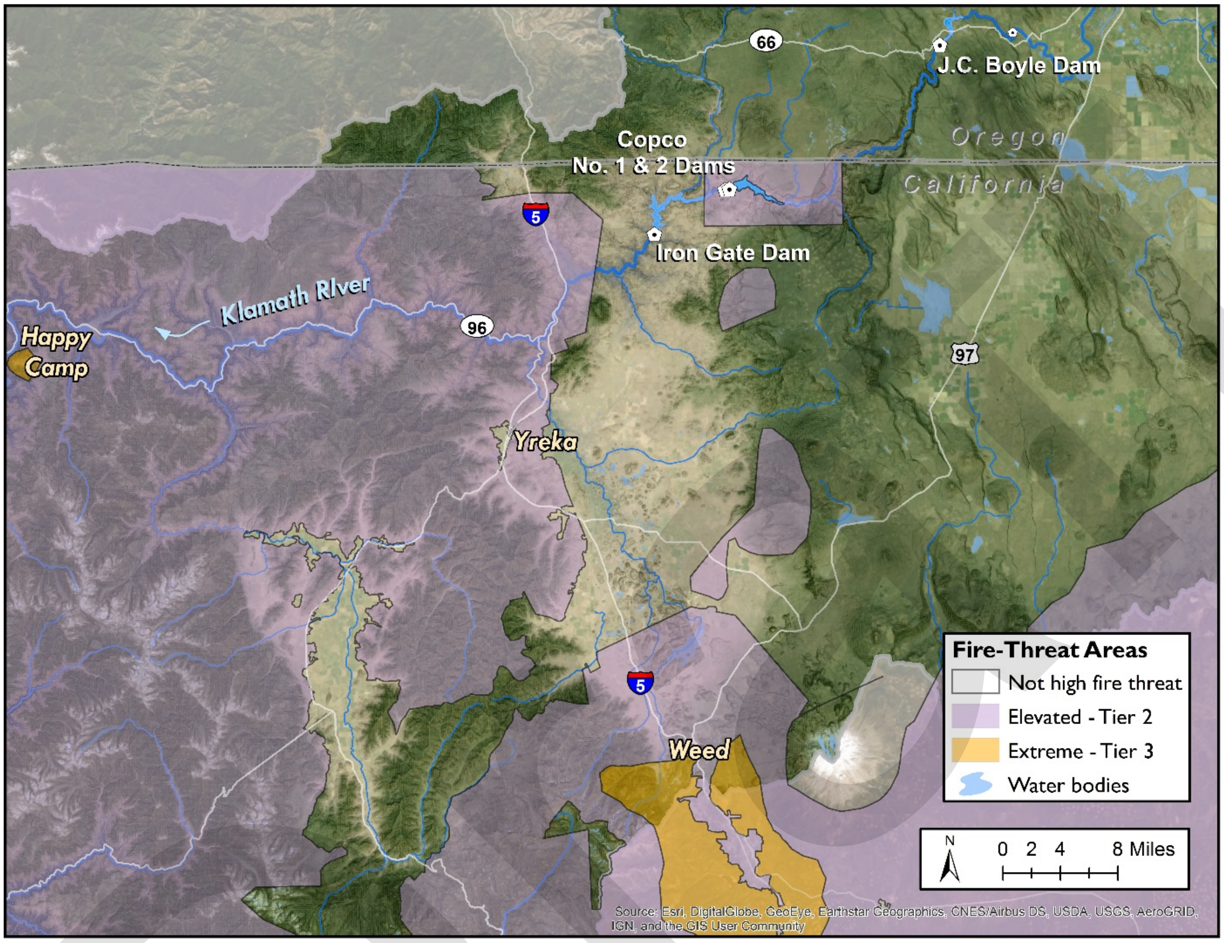

Figure 3. Fire threat map of the Klamath Basin showing California Public Utilities Commission fire threat tier data.

3. FIRE SUPPRESSION AGENCIES, RESOURCES, AND CONSIDERATIONS

3.1 Fire Support and Services

Fire support and services in the ASE area are provided by multiple city, county, state, and federal fire suppression agencies, including USDA Forest Service (USFS), Bureau of Land Management (BLM), the ODF Klamath-Lake District (KLD) and Southwest Oregon District (SWO), Cal Fire - Siskiyou Unit (CFSU), local districts of Klamath and Jackson Counties in Oregon and Siskiyou County, California, and local city and volunteer fire stations (Table 3-1). Fire safety and suppression resources are available from the various agencies in the event of a fire.

Table 3-1. Fire protection agencies in the ASE area, updated table from USBR & CDFG (2012).

Agency	Federal/State/Local	Jurisdiction
USDA Forest Service	Federal	National Forests, federally managed land
Bureau of Land Management	Federal	BLM lands, federally managed land
Cal Fire	State of California	State Resource Lands, California
Oregon Department of Forestry	State of Oregon	State Resource Lands, Oregon
Klamath County Fire District	Local, County of Klamath	Unincorporated County Lands and the City of Klamath Falls
Colestin Rural Fire District	Local, County of Jackson	County Fire District in Jackson County, Oregon
Siskiyou County Fire Protection Districts: Copco Lake, Hornbrook, Montague, South Yreka, Tulelake, Etna, Ft. Jones, Weed	Local, County	Unincorporated County Lands throughout Siskiyou County, California
Mount Shasta Fire Department	Local, City of Mount Shasta	Mt. Shasta Municipal Boundaries
Yreka Fire Department	Local, City of Yreka	City of Yreka Municipal Boundaries

The USFS and BLM are the two federal agencies responsible for fire support and suppression in the ASE area. Both agencies provide wildfire protection primarily on land under their direct ownership and management but will provide support and assistance to other agencies when requested. Federal land near the ASE area is primarily limited to BLM parcels along the Klamath River downstream of J.C. Boyle Dam and along Iron Gate Reservoir and Copco Lake and secondarily to USFS lands south of Copco Lake (Figure 4). The BLM lands in the Proposed Action area are part of the Lakeview District and overseen by the Klamath Falls field office (T. Wilkie, Assistant Fire Management Officer, BLM Lakeview District, *pers. comm.*,2020.06.10).

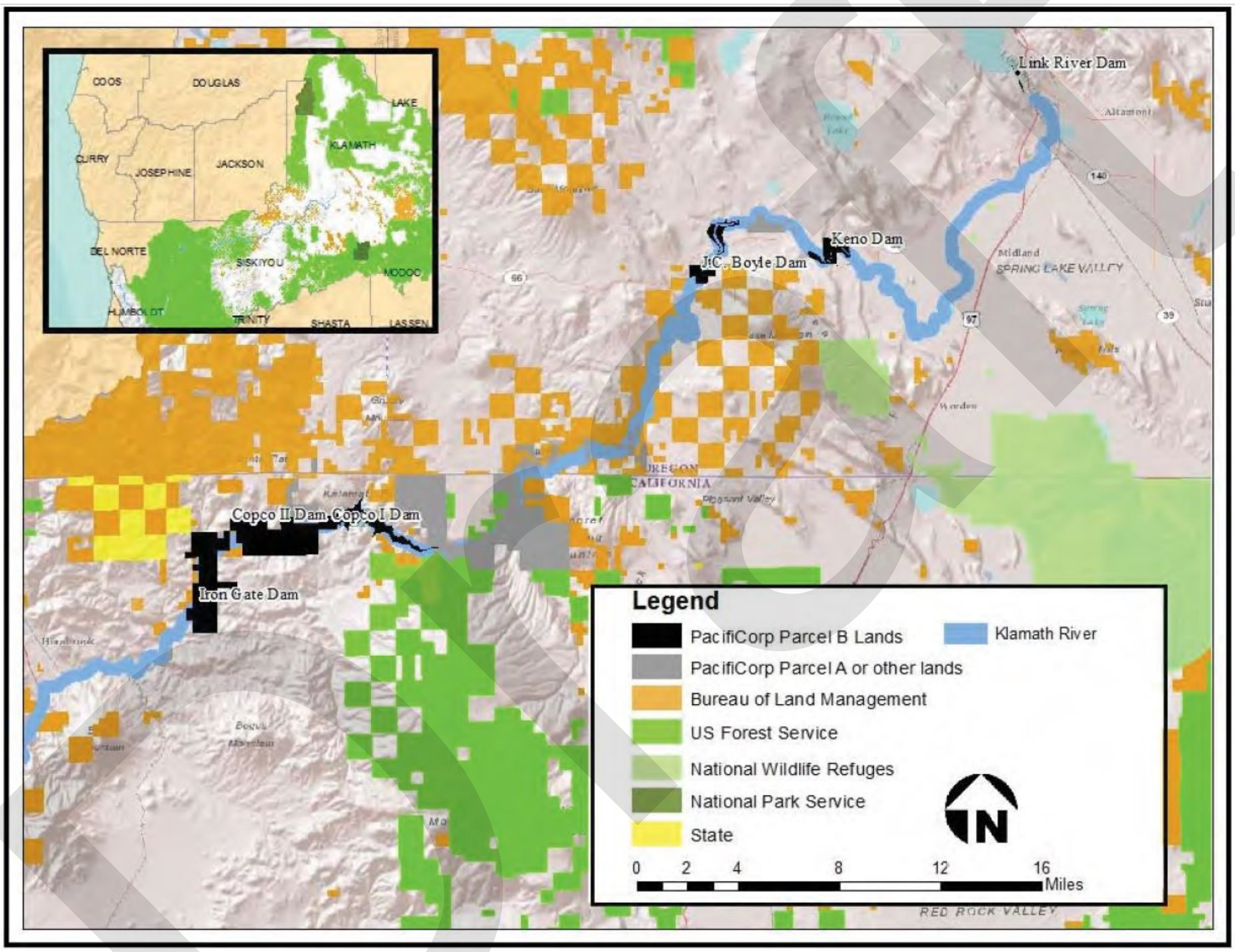

Figure 4. Land ownership around the analysis area. Figure from USBR & CDFG (2012).

The Oregon and California State forestry and fire prevention agencies (ODF and Cal Fire) are the primary fire protection providers in the unincorporated areas in the ASE area. ODF and Cal Fire enforce their respective state laws and regulations, and they coordinate fire support with the local agencies. Cal Fire operates and works with local city, county, and volunteer fire departments. The non-Federal land in Siskiyou County is in the Cal Fire State Responsibility Area (SRA), except lands directly managed by a local entity (e.g., in incorporated areas such as Yreka and Montague). Fire management in Siskiyou County is operated as Cal Fire Siskiyou Unit (CFSU). The Iron Gate and Copco Project sites are located within the CFSU Shasta Valley Battalion 2 area, and the river flows through Battalion 3. Cal Fire stations in the analysis area include the City of Yreka and Hornbrook, which is located 10 miles west of Iron Gate dam. The J.C. Boyle Project site in Oregon is under the jurisdiction of ODF KLD. The ODF KLD is a member of the South Central Oregon Fire

Management Partnership (SCOFMP), which is a cooperative group of agencies including USFS, BLM, US Fish and Wildlife, and Crater Lake National Park. The SCOFMP shares resources to manage fire in the region, which primarily comprises Klamath and Lake counties. Dispatch responsibilities for the SCOFMP are with the Lakeview Interagency Fire Center (LIFC). Jackson County, Oregon, the southern portion of which is part of the Klamath River Basin near the Project, is part of the ODF SWO. The northern portion of Siskiyou County, California, including the Iron Gate Reservoir and Copco Lake Project sites, is included in the fire protection area of ODF SWO that overlaps into California.

The city-operated fire stations in the ASE area include the Yreka and Mount Shasta Fire Departments in California. Many county fire stations are present throughout the analysis area and are associated with Klamath and Jackson counties in Oregon and Siskiyou County in California (Table 3-1).

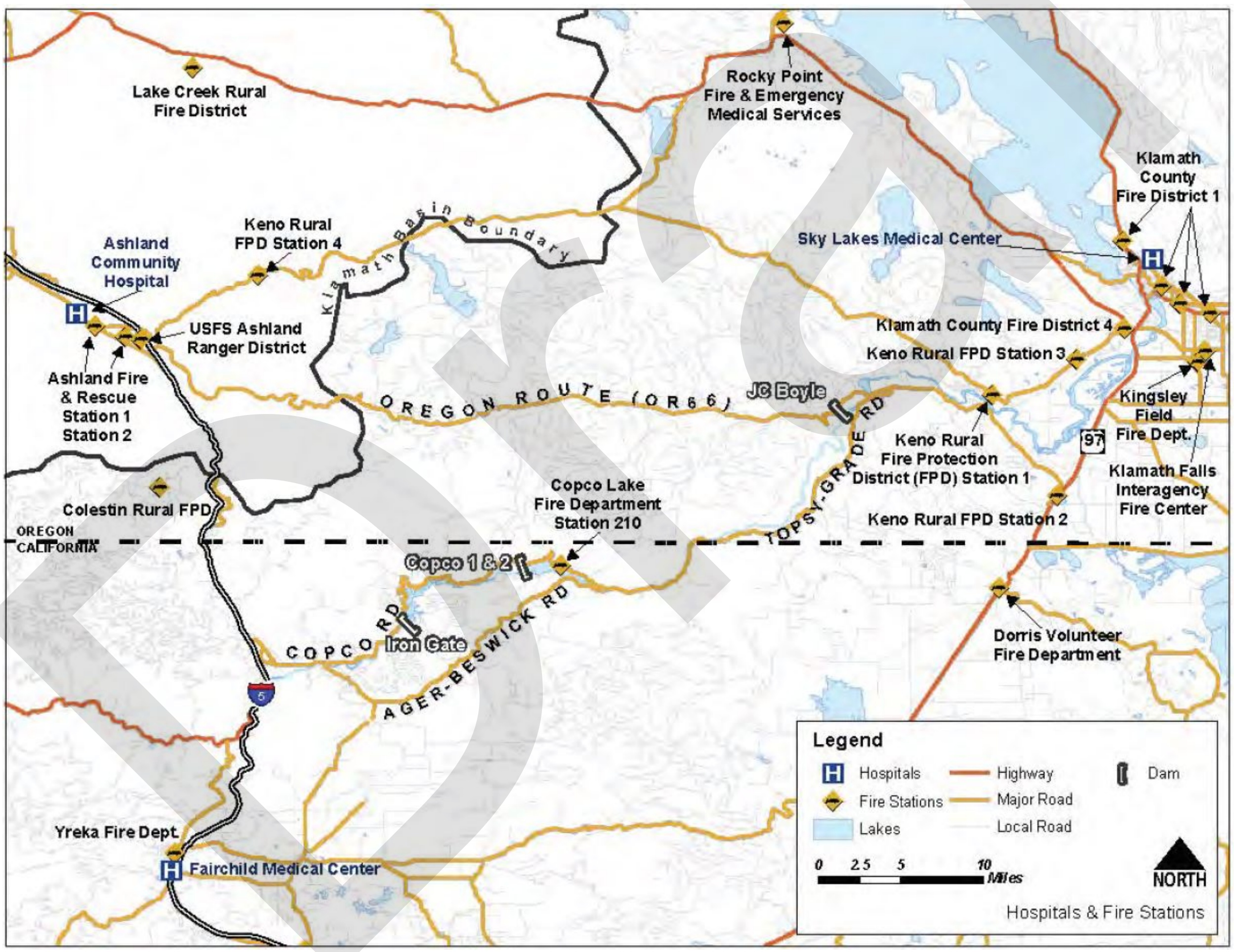

Figure 5. Map of hospitals, fire stations, and major fire routes near the Klamath Dams. From USBR & CDFG (2012). Note, Klamath Falls Interagency Fire Center is now an air tanker base.

In the Oregon Proposed Action areas, primarily ODF KLD is responsible for organizing fire prevention and suppression, and stations and districts that service Oregon are in Table 3-2. ODF KLD operates within the SCOFMP and shares resources and responsibilities with the other agencies therein. Dispatch responsibilities for SCOFMP are handled by LIFC. Klamath County has 17 fire districts and 30 fire stations. Jackson County has several nearby fire districts also capable of providing fire suppression resources, including Greensprings Rural Fire District, Jackson County Fire Districts, and Ashland fire stations. For J.C. Boyle Dam, the closest station is the Keno Rural Fire Protection District Station 1, which is located approximately 6 miles to the east and hosts 2 fire engines, an ambulance, and a water tender among other equipment.

In the California Proposed Action areas, CFSU provides fire suppression resources and coordinates with additional local fires suppression entities (Table 3-2). CFSU has a Cal Fire- and USFS-staffed Emergency Command Center located at the CFSU Headquarters in Yreka that handles dispatching services for Cal Fire, USFS, 30 local government departments, and 5 ambulance companies (Cal Fire, 2016). CFSU is divided into 4 battalions, and the California Proposed Action area is in Battalion 2 (Shasta Valley), which has Cal Fire stations in Yreka and Hornbook. For the Copco and Iron Gate dams, the closest fire stations in the area is Yreka Fire Department and Copco Lake Fire Department Station 210, which services the area surrounding Copco Lake. Jackson County, Oregon, has several nearby fire districts, including Ashland and Jackson County Fire Districts and Colestin Rural Fire District, that can provide additional fire suppression resources.

Table 3-2. Fire services in the analysis area.

County	Fire Protection Services
Siskiyou County, CA	Fire protection is provided by 9 incorporated cities fire protection districts: Yreka, Fort Jones, Etna, Weed, Mt. Shasta, Dorris, Dunsmuir, Montague, and Tulelake. Other nearby fire protection districts and stations in Siskiyou County include Copco Lake Fire Protection District, Hornbrook Fire Protection District, Butte Valley Fire Protection District, Mayten Fire Protection District, and Grenada Fire Protection District. (Cal Fire, 2016)
City of Yreka, CA	Fire services are provided by the Yreka Fire Volunteer Department.
Klamath County, OR	Klamath County is served by 17 fire districts including Klamath County Numbers 1 through 5, Keno, Chiloquin, Central Cascades, Crescent, Oregon Outback, Chemult, Bonanza, Bly, Malin, and Merrill.
Jackson County, OR	Fire protection services provided by Jackson County include Ashland and Medford Fire and Rescue Stations and Jackson County Fire District Stations. Nearby services are provided by Colestin Rural Fire Protection District and Greensprings Rural Fire District.

Several of the fire suppression agencies have fire management and suppression plans that identify resources at risk and resources for fire suppression within their respective jurisdictions and outline protocols that would be initiated in the event of a fire. These plans were consulted in the development of the FMP and provide a continued reference resource. SCOFMP has a plan and set of operation protocols for fire support in the area (SCOFMP, 2015). Klamath County has a Community Wildfire Protection Plan document and companion database to support wildfire prevention and suppression planning efforts in the county (WFT, 2016). CFSU has a Unit Strategic Fire Plan that describes fire prevention goals and resources and guides fire management and fire suppression tactics (Cal Fire, 2016). Siskiyou County has a Community Wildfire Protection Plan, which is a collaborative document between the Fire Safe Council of Siskiyou County (FSCSC), CFSU, and Siskiyou County, developed to inform Siskiyou County communities and residents with fuel reduction treatments and reducing the ignitability of structures in the county (Siskiyou County, 2019).

3.2 Existing Management Resources and Strategies

In this section, we document the existing fire management resources and strategies, explain how they function, and describe other background considerations the influence fire management in the Basin. The locations of existing fire detection and water resources for the ASE portion of the Klamath River Basin are shown in Figure 6.

3.2.1 Fire Detection

Rapid detection and reporting of wildfire ignitions are critical for the effective deployment of initial attack resources and suppression of wildfires before they grow to a large scale. The top goal listed by the CFSU Prevention Bureau is to reduce the total number and severity of fires (Cal Fire, 2016), and Cal Fire has made it an agency-wide goal to contain 95% of all unwanted fires at 10 acres or less (Cal Fire, 2002). California has statewide objectives to maintain an aggressive initial attack policy and utilize emerging technologies to improve emergency response effectiveness (California State Board of Forestry and Fire Protection (CSBFFP) and Cal Fire, 2018). The severity of a given fire is influenced by environmental conditions, but also by the length of time between start and detection. The fuel types and semi-arid climate in the Basin are conducive to the rapid growth of wildfires. Wildfires in the Basin can spread at rates as fast as 1.25 miles per hour (mph) (Siskiyou County, 2019; Stephens et al., 2008). As a result, early detection is critical in the analysis area.

In the Basin, wildfires are typically either reported by 911 calls or spotted from aerial surveillance and fire lookouts (Figure 6). 911 calls are a non-systematic method for detecting and locating wildfires. They require a chance sighting of smoke by a civilian and the ability to place a phone call. The ASE and Proposed Action areas are sparsely populated, and cellular coverage is poor, particularly adjacent to the Klamath River (Figure 7). In some locations, more than 30 minutes may be needed to acquire a cell signal. 911 callers may not properly identify the specific locations of smoke in the steep and rugged terrain in the rural basin. As a result, the exact location of the fire must be determined in the field by vehicle or helicopter, if available, after the 911 call has been received. With few roads and bridges crossing the Klamath River in the Basin, detailed knowledge of a newly ignited fire's location, especially with respect to which side of the Klamath River the reported fire is on, is vital to effectively deploy the appropriate resources in a timely manner. Fire containment is achieved by the construction of fire lines, which typically require ground resources (J. Fried, pers. comm., 2019.08.27). With only a few access roads and bridges crossing the Klamath River, precise and accurate knowledge of fire location can save ground resources minutes to hours of time as they commence initial attack in the Basin.

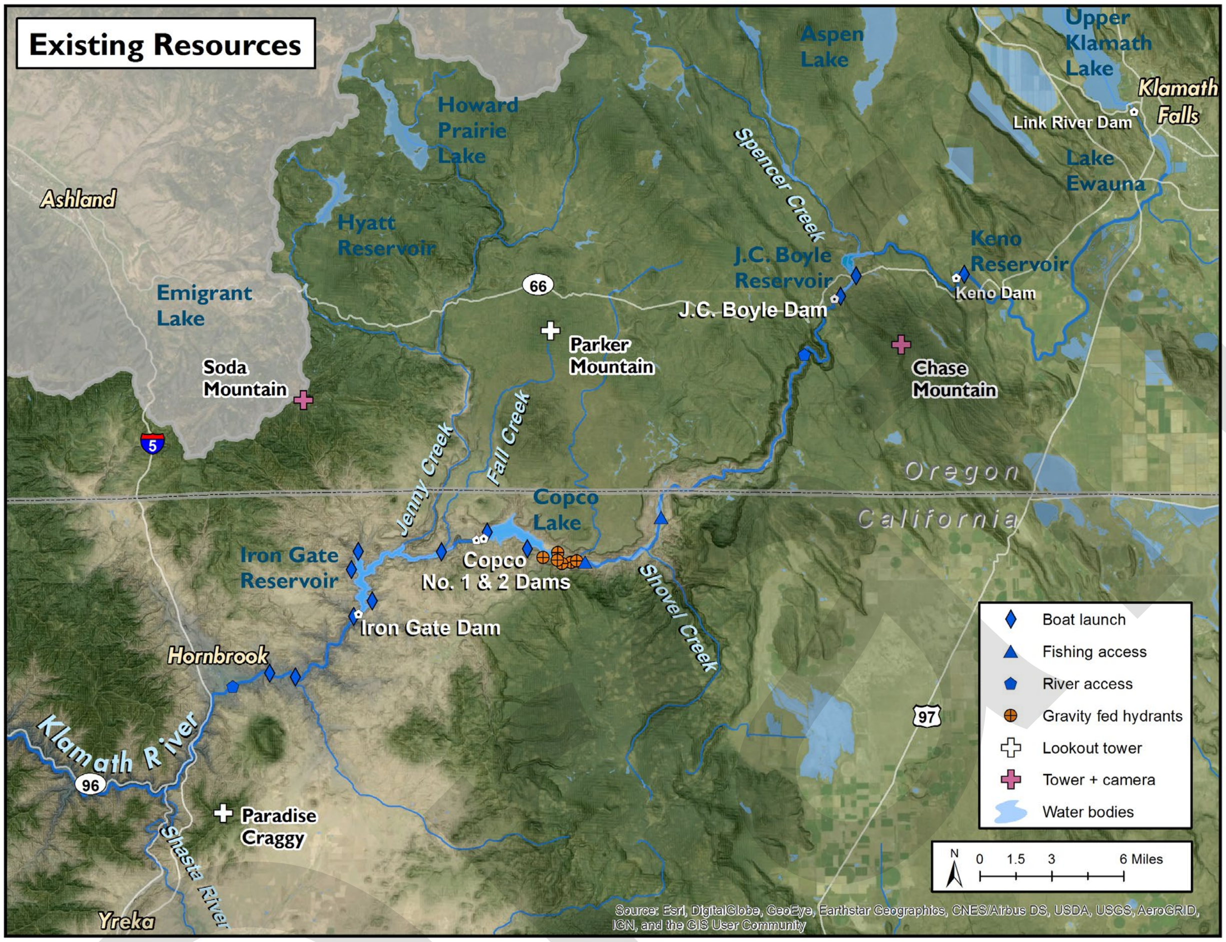

Figure 6. Overview map of the existing fire management resources in the Klamath River Basin near the Project.

Fire lookouts provide an effective vantage for detecting smoke and its location. Historically, fire lookouts have been staffed during fire season, and this practice continues at the fire lookouts at Parker Mountain, Oregon, (staffed by ODF KLD) and Paradise Craggy, California, (staffed by CFSU) (Figure 6). With favorable conditions, the distance at which the human eye is able to detect smoke from a fire lookout is approximately 7 miles. A newer practice in the West is exchanging human presence in the lookouts for video cameras, the live web feed of which can be monitored remotely online (e.g., ALERTWildfire).

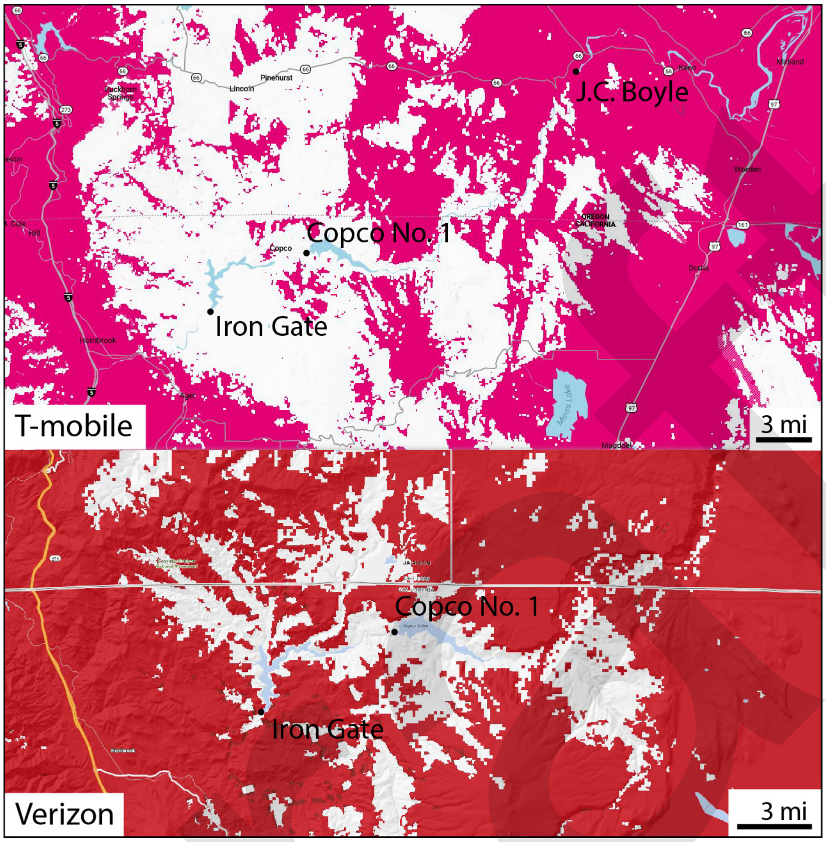

Figure 7. Cell coverage in the ASE area where white indicates "no coverage." Coverage maps generated from their respective carrier websites on May 12, 2020.

The state-of-the-art technique for early detection of wildfires is the "Monitored Detection System" (MDS), whereby high definition imagery and video transmitted from cameras strategically placed at fire lookouts is monitored for smoke by humans at a detection center. The EnviroVision Solutions (EVS) ForestWatch® software integrates the camera feed with a GIS platform, and locations of fires can be triangulated if captured by cameras in more than one location. This, combined with an on-site dispatch center, enables rapid and efficient deployment of initial attack resources from fire stations and in the field. The MDS technology is an improvement over more passive live web feed cameras because it has dedicated staff monitoring it and is integrated with the GIS platform, among other benefits and capabilities. The MDS technology is an improvement over manned lookout towers because the cameras have a greater visible distance than the human eye (e.g., 12 miles vs. 7 miles, respectively depending on conditions; Appendix A) and a single staff member can monitor the feed from many cameras simultaneously.

ODF SWO has had a functional MDS since 2012, and ODF KLD installed one in 2019. Currently, two MDS cameras (one from ODF SWO located on Soda Mountain, OR, and one from ODF KLD on Chase Mountain, OR) are currently directed into the ASE area (Figure 6). The ODF SWO system has been in place since 2012 and has included a dedicated staff for monitoring since 2017. The Chase Mountain MDS camera was installed in 2019.

The viewshed (i.e., visibility coverage) with the existing fire lookouts and two MDS cameras in the ASE area was analyzed in the Reax report (Appendix A) and is shown in Figure 8. Currently, there is coverage by a single observer (camera or fire lookout) at 500 ft above the ground surface for much of the northern portion of the ASE area, but a much smaller fraction of the south side of the ASE area is covered by the existing viewshed. With coverage by only a single observer, it is challenging to decipher, e.g., what side of the Klamath River a fire is located, so it is preferable to have two or more observers to effectively triangulate fire locations.

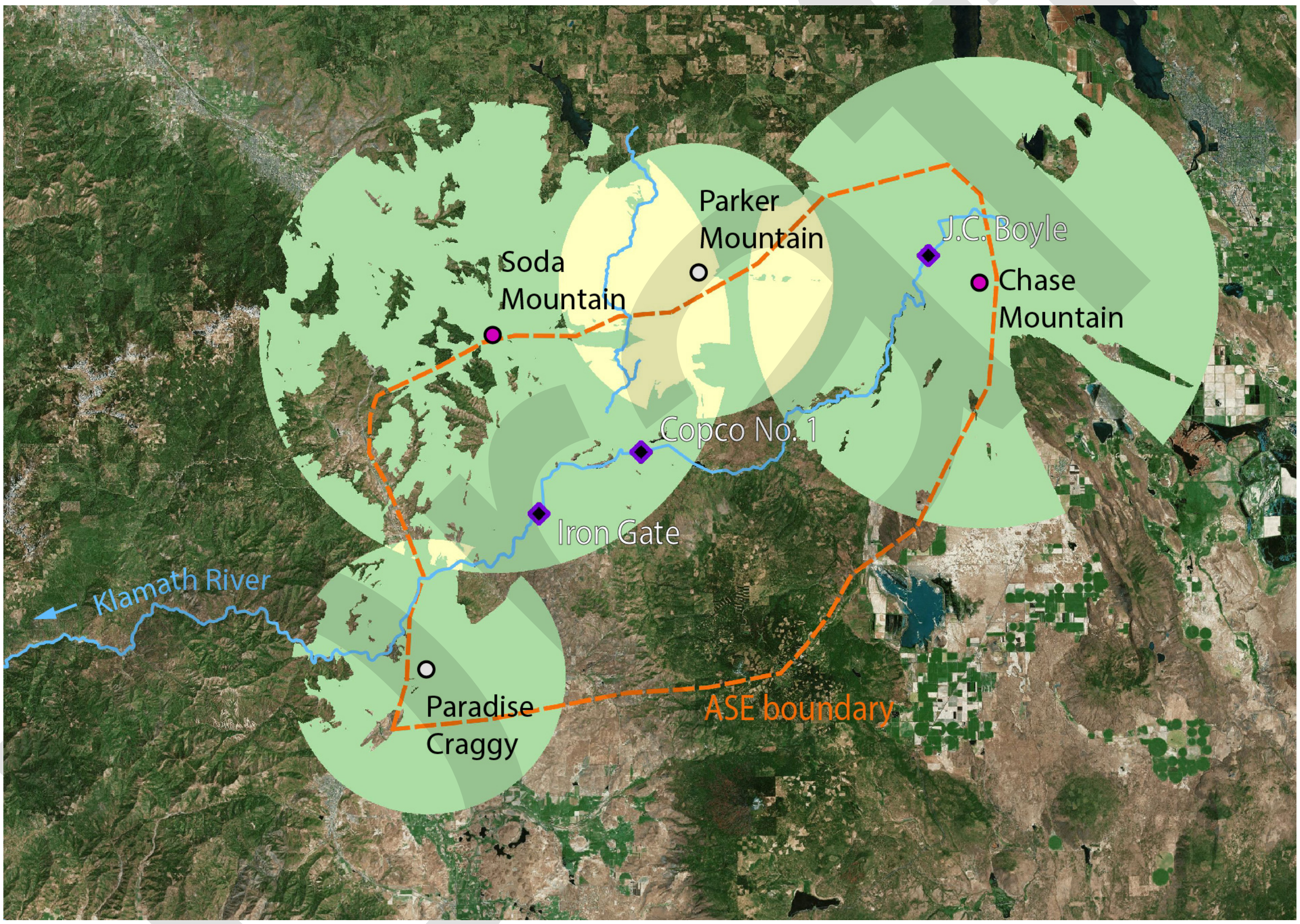

Figure 8. Viewshed analysis at 500 ft above ground surface for existing detection resources with green and yellow indicating visibility by one and two observers, respectively. From Reax report (Appendix A).

3.2.2 Prevention and Preparedness

Community preparedness and pre-prevention is an important component of both ODF and Cal Fire missions. Both agencies direct resources to the education of the local community on fire season proclamation and regulated use restrictions, fire hazards, and defensible space. Defensible space around structures is a legal requirement for California and Oregon residents (CA - PRC 4921; OR – ORS 477.015 - 477.061; OAR 629-044-1000 - 629-044-1110) and critical for preventing structure fires. Increasing the number of defendable homes is on the CFSU Prevention Bureau's list of goals (Cal Fire, 2016) and educating landowners and residents about defensible space and increasing the number and effectiveness of inspections are statewide objectives (CSBFFP and Cal Fire, 2018). The Cal Fire response report to EO N-05-19 (Cal Fire, 2019) explicitly encourages private landowners to engage in fuel reduction projects and proposes several projects to improve community defensible space (Cal Fire, 2019). To assist Siskiyou County residents with creating defensible space, the Yreka Area Fire Safe Council organized a grant-funded 2018 community event called "Chipper Days," whereby a chipper was rented and driven around to chip fuels and debris from private property around the county. Improving defensible space is a top, county-wide priority for many groups in Siskiyou County, including the FSCSC (Siskiyou County, 2019).

3.2.3 Water Sources and Access

Water sources and access to them are vital for fire suppression for both ground-based and aerial crews and for both structure fires and wildfires.

Ground-based resources (e.g., fire engines, dozers, and hand crews; Lee et al., 2012) are typically used for structure fires, initial attack, and line support for wildfires. Ground-based efforts to procure water resources in the ASE area are currently supported with boat launches around the reservoirs and along the river and with a gravity fed hydrant system at Copco Lake. Boat launches and river access points provide dependable access for ground-based resources to draft water from the river and reservoirs. There are currently 12 total boat launches in the ASE area: three boat launches around Iron Gate Reservoir, two around Copco Lake, two around J.C. Boyle Reservoir, and others along the free-flowing Klamath River and Keno Reservoir (Figure 6). Several of these boat launches (e.g., Iron Gate Hatchery, Fall Creek, Copco Cove) have a gravel surface with narrow access roads and are not suitable for use by water tenders and fire engines. The hydrant system at Copco Lake consists of six hydrants that are the primary water sources for the Copco Lake Fire Department to protect the community and structures at the upstream portion of Copco Lake (Figure 6). These hydrants are gravity-fed from a water storage tank, which is filled from a well, and operated by agreement between Copco Lake Mutual Water Company and Copco Lake Fire Department.

Aerial efforts with helicopters, which are used for both initial and extended attack, are a critical component of wildfire suppression and are capable of applying large volumes of water (*cf*. Table 3-3) to remote areas. Firefighting helicopters vary in size and water-carrying capacity and are classified into three types (1 to 3 from largest to smallest). The two mechanisms for aerial drafting of water are snorkels and buckets. Snorkels (e.g., Table 3-3) are only used by Type 1 and Type 2 helicopters and involve lowering a hose directly into a water source and pumping water into an on-board tank. The hoses are on the order of 10 feet in length, so snorkel helicopters must get correspondingly close to the water surface. The water tank capacity can vary from 100 gallons to 3000 gallons depending on the size of the helicopter (Cal Fire, n.d.-a). Buckets are suspended from longlines attached the helicopters and lowered into the water source to be filled. The volume and line length vary, with smaller Type 3 helicopters operating shorter lines with buckets on the order of 100 to 200 gallons (Cal Fire, n.d.-a) and Type 1 helicopters supporting 100 ft to 200 ft lines with bucket capacity of over 2000 gallons (Cal Fire, n.d.-a).

Desired conditions for aerial suppression include well-distributed water sources suitable for drafting by a range of aircraft and drafting mechanisms simultaneously; potentially minimizing the turn-around time between water drops. The suitability of a water source for drafting depends on water depth and the dimensions of the water surface, which relate to the physical space available for a helicopter to safely hover and for the drafting mechanism to draw water. Deeper and wider water sources are easier, faster, and safer choices for drafting. Buckets and snorkels typically need about 3 feet of water depth, but deeper sources are preferred, especially for large buckets. Buckets can be safely used in narrower water bodies than snorkels can because the helicopters do not need to be as close to the water surface.

Specific guidelines for snorkel drafting rotor safety clearance (i.e., the lateral distance between the tips of the helicopter rotors and vegetation, infrastructure, or other obstructions) are not formally established, so it is up to pilot discretion which water sources they feel comfortable drafting from (Cal Fire, n.d.-b; Section 8344.5.2). Experienced pilots often utilize pools narrower than the recommended drafting safety clearance of 150 ft (Table 3-3; L. Winslow ODF SWO, *pers. comm.,* 2019.05.16). Drafting is dangerous, and the hazard is greater for narrow water sources in confined, steep terrain. Proximity of a water source is a key consideration as each mile of travel distance will add several minutes to the draft and drop turn-around time. As such, pilots usually seek the closest suitable drafting source, rather than travel longer distance to access the best water source.

Table 3-3. Comparison of common firefighting helicopters.

Helicopter	Bell Super Huey (UH-1H)	Sikorsky Skycrane (S-64)	Sikorsky Firehawk (UH-70)
Type	2	1	1
No. rotors	1	1	1
Rotor diameter (ft)	48	72	54
Aircraft Length (ft)	57	89	65
Landing zone minimum diameter[1] (ft)	86	135	100
Pool drafting diameter[2] (ft)	348	372	354
Water capacity (gal)	360	2650	1000
Photos[3]			

[1] Minimum diameter for landing is 1.5X the aircraft length (USFS & OAS, 2015).
[2] Recommended safe lateral clearance from tip of rotor during drafting is approximately 150 ft (L. Winslow, ODF-SWO, *pers. comm*., 2019.04.02). Minimum drafting diameter is rotor diameter plus 300 ft.
[3] Photo sources (from left to right): Prestige Worldwide; S. Wright, 2012; www.helis.com

Aerial fire suppression in the ASE area is currently supported by the Klamath River and reservoirs, including Keno Reservoir, Lake Ewauna, and Upper Klamath Lake, as primary water sources. The reservoirs are wide, deep, and lower hazard drafting sources that are capable of supplying water to multiple aircraft of any size simultaneously. The mainstem Klamath River offers suitable drafting locations as well. KRRC identified 96 aerial river access points (ARAPs; i.e., locations with hydraulic conditions appropriate for helicopter drafting) currently in the free-flowing Klamath River from Keno Dam to I-5, and the inventory was reviewed and approved by ODF SWO (ODF SWO, *pers. comm.,* 2019.05.46). Portions of the mainstem Klamath River in the ASE area are around 200 ft wide between tall woody riparian vegetation. This distance is too narrow to meet drafting safety clearance recommendations for Type 1 helicopters with snorkels but does meet the Type 1 minimum landing area requirements (Table 3-3). Type 2 and Type 3 helicopters with buckets currently draft from many parts of the Klamath River, including the reach near Hornbrook (Appendix A) and the narrow confines of the Klamath Canyon between J.C. Boyle Dam and Copco Lake (ODF KLD, *pers. comm.*, 2019.05.16). The ability and willingness to use the Klamath River is dependent on pilot experience and comfort and on environmental variables (e.g., wind speed and direction). Smaller sources (e.g., ponds on private property) will be used opportunistically when they are the closest source to a drop location. For example, on the 2018 Klamathon Fire, two runoff ponds and the free-flowing Klamath River were used as dip sites in addition to Iron Gate Reservoir because they were closer to the drop location (Appendix A).

4. REGULATIONS AND REQUIREMENTS

The FMP is developed to meet or exceed the regulations and requirements set forth by the controlling fire suppression agencies in the Proposed Action area (Figure 4). KRRC will comply with all applicable requirements. Most of the dam deconstruction and reservoir management will take place on private land. Private lands are under the protection of ODF and Cal Fire, agencies that handle state regulations for fire management regarding various construction related activities. Measures for fire preparedness, prevention, and suppression in addition to those prescribed by state and Federal law are described in Section 5 Short-Term Fire Management Plan.

4.1 Federal

Federal agencies (BLM and USFS) manage their respective lands, and regulations only need to be met for construction taking place on federal land. In Oregon, there are several BLM parcels along the Klamath River in the J.C. Boyle Proposed Action area. These parcels are managed as part of the SCOFMP. Fire-related restrictions on these parcels follow the industrial operations requirements and restrictions that correspond to four adjective classes of the Industrial Fire Precautionary Levels (IFPL) (T. Wilkie, Assistant Fire Management Officer, BLM Lakeview District, *pers. comm.*,2020.06.10). In California, a few BLM parcels are located near the Copco Proposed Action footprint. In the California locations, BLM generally defers to restrictions corresponding to the Predicted (or Designated) Activity Levels (PALs) set by the USFS Klamath National Forest and relies on Cal Fire for direct protection responsibilities (L. Brodhead, BLM Redding, *pers. comm.*, 2017.08.29). For logging operations on BLM land in California, contractual fire prevention and suppression measures vary between projects but must typically conform to general Cal Fire and USFS regulations and the input from a BLM Authorized Agent assigned to the contract (L. Brodhead, BLM Redding, *pers. comm.*, 2017.08.29). The USFS owns land that is near Copco Lake but outside of the Proposed Action footprint. Therefore, the FMP does not address specific USFS fire prevention and suppression requirements outlined in the Code of Federal Regulations (CFR) or the United States Code (USC) (e.g., 16 USC 551, 36 CFR

261.50, and 36 CFR 261.52). The Proposed Action will comply with the applicable state regulations described in Sections 4.2 and 4.3, which are comparable with regards to fire related restrictions.

4.2 Oregon Department of Forestry Klamath-Lake District

Oregon law prescribes regulations and minimum requirements for fire prevention and suppression that are applicable in each ODF Fire Protection District during fire season. Oregon fire season is declared by each ODF district and is typically between early June and mid-to-late October. The laws and requirements for all ODF districts are provided in Table 4-1.

ODF districts west of the Cascades crest, which includes ODF SWO, have industrial operations requirements and restrictions that correspond to IFPLs. A different system is in place for ODF districts east of the Cascades crest, such as ODF KLD. Construction operations must follow the regulations in Table 4-1 for all levels of fire danger during fire season. Additional restrictions are enforced when fire hazard is classified as "extreme." ODF does not have general restrictions or requirements when work is performed outside of the fire season.

A permit must be obtained from the ODF state forester for construction activities that involve heavy machinery. The permit is the "Permit for Power-Driven Machinery (PDM)," which is described by Oregon law ORS 477.625. There are fire prevention requirements that accompany the permit that are dependent on the Fire Danger Level (FDL). The PDM permit relates requirements for fire prevention and suppression preparedness to type of machinery and fire hazard. The requirements are more restrictive during "Extreme" adjective class FDL and include the suspension of the operation of tracked machinery between the hours of 1 pm and 8 pm as prescribed by the PDM (ORS 477.625(1a), OAR 629-043-0026(5)). The use of tracked equipment is expected at the Proposed Action sites and, if a PDM was required, would be subject to these restrictions during extreme fire danger. ODF typically informs PDM permit holders of changes in fire hazard and operation requirements. PDM permits expire at each new calendar year and must be renewed.
The ODF forester can grant waivers from the fire prevention and suppression requirements, including the PDM, in some instances. Waivers may be granted in certain project areas for favorable weather conditions, topographic setting, and/or if alternate methods and equipment proposed by the operator provide equal or better fire prevention and suppression.

Table 4-1. 2019 ODF fire season minimum requirements (ODF, 2019).

Topic	Law	Description
No Smoking	ORS 477.510	No smoking while working or traveling in an operation area
Hand Tools	ORS 477.655, OAR 629-043-0025	Supply hand tools for each operation site - 1 tool per person with a mix of pulaskis, axes, shovels, hazel hoes. Store all hand tools for fire in a sturdy box clearly identified as containing firefighting tools. Supply at least one box for each operation area. Crews of 4 or less are not required to have a fire tools box as long as each person has a shovel, suitable for fire-fighting and available for immediate use while working on the operation.

Topic	Law	Description
Fire Extinguishers	ORS 477.655, OAR 629-43-0025	Each internal combustion engine used in an operation, except power saws, shall be equipped with a chemical fire extinguisher rated as not less than 2A:10BC (5 pound).
Power Saws	ORS 477.640, OAR 629-043-0036	Power saws must meet Spark Arrester Guide specifications - a stock exhaust system and screen with < 0.023 inch holes. The following shall be immediately available for prevention and suppression of fire: - One gallon of water or pressurized container of fire suppressant of at least eight-ounce capacity - 1 round pointed shovel at least 8 inches wide with a handle at least 26 inches long - The power saw must be moved at least 20' from the place of fueling before it is started.
Fire Tools, Extinguishers for Trucks	ORS 477.655, OAR 629-043-0025	Equip each truck driven in forest areas for industrial purposes with: - 1 round pointed shovel at least 8 inches wide, with a handle at least 26 inches long - 1 axe or Pulaski with 26 inch handle or longer - 1 fire extinguisher rated not less than 2A:10BC (5 pound).
Spark Arresters and Mufflers	ORS 477.645, OAR 629-043-0015	All non-turbo charged engines must meet Spark Arrester Guide specifications except: - Fully turbo charged engines. - Engines in motor vehicles operating on improved roads equipped with an adequate muffler and exhaust system. - Engines in light trucks (26,000 GVW or less) that are equipped with an adequate muffler and an exhaust system. - Engines in heavy trucks (greater than 26,000 GVW) that are equipped with an adequate muffler and exhaust system. - If a truck engine is not fully turbo-charged, then the exhaust must extend above the cab and discharge upward or to the rear, or to the end of the truck frame. - Water pumping equipment used exclusively for fighting fire. - Engines of 50 cubic inch displacement or less, except ATV's and motorcycles, shall be equipped with an adequate muffler and an exhaust system. - Engines in ATV's and motorcycles must be equipped with an adequate muffler and exhaust system or an approved screen, which completely encloses exhaust system. - Power saws. (See power saw requirements)

Topic	Law	Description
Pump, Hose, and Water Supply	ORS 477.650, 477.625, OAR 629-043-0026, 629-43-0020	Supply a pump, hose and water supply for equipment used on an operation. - Pump must be maintained ready to operate and capable to provide a discharge of not less than 20 gallons per minute at 115 psi at pump level. Note: Volume pumps will not produce the necessary pressure to effectively attack a fire start. Pressure pumps are recommended. - Water supply shall be a minimum of 300 gallons if a self-propelled engine. Water supply shall be a minimum of 500 gallons if not self-propelled (pond, stream, tank, sump, etc.) - One water supply is adequate as long as the operator can deliver water to the fire within 10 minutes - Provide enough hose (500 feet minimum) not less than 3/4" inside diameter to reach areas where power driven machinery has worked. Note: Should a fire occur, the operator must be able to position the water supply in a location where enough hose is available to reach the area worked by power driven machinery. This includes mobile equipment as well as motorized carriages and their moving lines. Moving lines are defined as main lines and haul back lines. This can be achieved in many ways, including the practice of having a water tank and hose attached to a piece of equipment, like a skidgen or skidder, that can get the water to the fire. - Water supply, pump, and at least 250' of hose with nozzle must be maintained as a connected, operating unit ready for immediate use.
Fire Watch Service	ORS 477.665, OAR 629-043-0030	Each operation area is to have a fire watch. Fire watch shall be on duty during any breaks (up to 3 hours) and for three hours after all power-driven machinery used by the operator has been shut down for the day. The ODF KLD has specific fire watch duration prescriptions based on FDL adjective class. - Low = 1 hr fire watch - Moderate = 2 hrs - High to Extreme = 3 hrs Fire watch shall: - Be physically capable and experienced to operate firefighting equipment. - Have facilities for transportation and communications to summon assistance. - Observe all portions of the operation on which activity occurred during the day. Upon discovery of a fire, Fire watch personnel must: First report the fire, summon any necessary firefighting assistance, describe intended fire suppression activities and agree on a checking system; then, after determining a safety zone and an escape route that will not be cut off if the fire increases or changes direction, immediately proceed to control and extinguish the fire, consistent with firefighting training and safety.

Topic	Law	Description
Operation Area Fire Prevention	ORS 477.625, OAR 629-043-0026	- Keep all power driven machinery free of excess flammable material which may create a risk of fire. - Avoid line-rub on rock or woody material, which may result in sparks or sufficient heat to cause ignition of a fire. - Disconnect main batteries from powered components (other than what may be necessary to retain computer memory) through a shut-off switch or other means or leave equipment on ground cleared of flammable material.

4.3 Cal Fire Siskiyou Unit

California law prescribes regulations and minimum requirements for fire prevention and suppression that are applicable during fire season in all lands within the Cal Fire jurisdiction. The California Public Resources Code (PRC) requires preventative fire measures (Table 4-2) that are imposed during the time where a Burn Permit is required under PRC-4423. For Zone B, which includes the northern California counties, this period usually begins May 1 and persists until proclamation of the termination of fire season by a Cal Fire Director. Cal Fire does not require a permit for the use of equipment and heavy machinery on a construction site. State forest and fire laws may be enforced by USFS, BLM, NPS, and certain county fire departments in addition to Cal Fire personnel. The California Code of Regulations (CCR) has specific and generally applicable regulations that pertain to fire prevention and suppression, e.g., requirements for smoking during fire season, but there are no associated permits required. The CCR, PRC, and CFR regulations pertaining to construction sites and logging operations in California and the associated best management practices are described in detail in the Cal Fire *Industrial Operations Fire Prevention Guide* (1999).

Table 4-2. Fire precautionary measures required by California Public Resources Code (PRC) and applicable during any times of the year when burning permits are required unless otherwise stated.

Topic	Law	Description
Fire Causing Equipment	PRC-4427	No person shall use or operate any motor, engine, boiler, stationary equipment, welding equipment, cutting torches, tarpots, or grinding devices from which a spark, fire, or flame may originate, which is located on or near any forest-covered land, brush-covered land, or grass-covered land, without doing both of the following: - First clearing away all flammable material, including snags, from the area around such operation for a distance of 10 feet. - Maintain one serviceable round point shovel with an overall length of not less than 46 inches and one backpack pump water-type fire extinguisher fully equipped and ready for use at the immediate area during the operation. This section does not apply to portable powersaws and other portable tools powered by a gasoline-fueled internal combustion engine.

Topic	Law	Description
Use of Internal Combustion Engines	PRC-4428	No person shall use or operate any vehicle, machine, tool or equipment powered by an internal combustion engine operated on hydrocarbon fuels, in any industrial operation located on or near any forest, brush, or grass-covered land between April 1 and December 1 of any year, or at any other time when ground litter and vegetation will sustain combustion permitting the spread of fire, without providing and maintaining, for firefighting purposes only, suitable and serviceable tools. - A sealed box of tools shall be located, within the operating area, at a point accessible in the event of fire. This fire toolbox shall contain: one backpack pump-type fire extinguisher filled with water, two axes, two McLeod fire tools, and a sufficient number of shovels so that each employee at the operation can be equipped to fight fire. - One or more serviceable chainsaws of three and one-half or more horsepower with a cutting bar 20 inches in length or longer shall be immediately available within the operating area, or, in the alternative, a full set of timber-felling tools shall be located in the fire toolbox, including one crosscut falling saw six feet in length, one double-bit ax with a 36-inch handle, one sledge hammer or maul with a head weight of six, or more, pounds and handle length of 32 inches, or more, and not less than two falling wedges. - Each rail speeder and passenger vehicle shall be equipped with one shovel and one ax, and any other vehicle used on the operation shall be equipped with one shovel. Each tractor used in such operation shall be equipped with one shovel.
Fire Fighting Tools	PRC-4429	In an area of any industrial or other operations on or near any forest-covered land or brush-covered land, there shall be provided and maintained at all times, in a specific location, for firefighting purposes only, a sufficient supply of serviceable tools to equip 50% of the able-bodied personnel for fighting fires. - Tools shall be included shovels, axes, saws, backpack pumps, and scraping tools. - One serviceable headlight adaptable for attachment to at least one-half of the tractor-bulldozers used on the operation. - A sufficient number of canteens and flashlights to equip a third of the able-bodied personnel.

Topic	Law	Description
Water Pumps	PRC-4430	The use or operation of any steam-operated engine or machine equipment, located on or near forest-covered land or brush-covered land, requires - One adequate force pump or water under pressure equivalent to a pump, and not less than 200 feet of hose not less than one inch in diameter for each steam-operated engine or equipment. - The pump or water pressure shall be capable of applying a minimum of 40 pounds pressure at the nozzle on 200 feet of hose, such nozzle to be 0.25 inch or larger in diameter. - If two steam-operated engines or steam equipment are customarily operated within 100 feet of each other, only one engine or piece of equipment need be equipped with pump and hose.
Gas Powered Saws	PRC-4431	No person shall use or operate or cause to be operated any portable saw, auger, drill, tamper, or other portable tool powered by a gasoline-fueled internal combustion engine on or near any forest-covered land, brush-covered land, or grass-covered land, within 25 feet of any flammable material, without providing and maintaining at the immediate locations of use or operation of the saw or tool, for firefighting purposes one serviceable round point shovel, with an overall length of not less than 46 inches, or one serviceable fire extinguisher. The Director of Forestry and Fire Protection shall by administrative regulation specify the type and size of fire extinguisher necessary to provide at least minimum assurance of controlling fire caused by use of portable power tools under various climatic and fuel conditions. The required fire tools shall at no time be farther from the point of operation of the power saw or tool than 25 feet with unrestricted access for the operator from the point of operation.

Topic	Law	Description
Spark Arresters	PRC-4442	- No person shall use, operate, or allow to be used or operated, any internal combustion engine which uses hydrocarbon fuels on any forest-covered land, brush-covered land, or grass-covered land unless the engine is equipped with a spark arrester maintained in effective working order or the engine is constructed, equipped, and maintained for the prevention of fire. - Spark arresters affixed to the exhaust system of engines or vehicles shall not be placed or mounted in such a manner as to allow flames or heat from the exhaust system to ignite any flammable material. - A spark arrester is a device constructed of nonflammable materials specifically for the purpose of removing and retaining carbon and other flammable particles over 0.0232 of an inch in size from the exhaust flow of an internal combustion engine that uses hydrocarbon fuels or which is qualified and rated by the United States Forest Service. - Engines used to provide motive power for trucks, truck tractors, buses, and passenger vehicles, except motorcycles, are not subject to this section if the exhaust system is equipped with a muffler. - Turbocharged engines are not subject to this section if all exhausted gases pass through the rotating turbine wheel, there is no exhaust bypass to the atmosphere, and the turbocharger is in effective mechanical condition.
Exclusion of Outdated, Handheld Internal Combustion Equipment	PRC-4443	No person shall use, operate, or cause to be operated on any forest-covered land, brush-covered land, or grass-covered land any handheld portable, multi-position, internal-combustion engine manufactured after June 30, 1978, which is operated on hydrocarbon fuels, unless it is constructed and equipped and maintained for the prevention of fire.

5. NEAR-TERM MEASURES: CONSTRUCTION-RELATED ACTIVITIES

This section describes near-term fire management associated with construction-related activities for the Proposed Action. The purpose of the near-term fire management plan is to eliminate and/or mitigate fire sources and to prevent loss of life and property by adhering to and implementing all agency regulations and requirements, all applicable standards from the National Fire Protection Association (NFPA), and industry-accepted best workplace practices.

Near-term fire management is divided into two Proposed Action time periods: 1) during Dam Decommissioning and Removal (i.e., Phase 1, 2, and 3A in the DDP [KRRC, 2020]); and 2) during Restoration and Monitoring (i.e., Phase 3B in the DDP [KRRC, 2020]). Dam Decommissioning and Removal corresponds to the period from the commencement of construction activities to the complete removal of the four dams and all associated facilities. Restoration and Monitoring corresponds to the time period from the onset of restoration and monitoring activities, as described in Reservoir Area Management Plan of the Definite Decommissioning Plan (KRRC, 2020), in the de-watered reservoirs to the conclusion of monitoring and restoration activities in the former reservoirs.

The KRRC design-build contractor responsible for fire management during dam decommissioning and removal is Kiewit Corporation. The KRRC contractor responsible for fire management during restoration and monitoring is Resource Environmental Solutions, LLC (RES). The fire prevention and suppression measures and responsibilities described in the near-term measures apply to both Kiewit and RES (the Contractors), but Kiewit and RES will operate and apply this Fire Management Plan independently of one-another.

5.1 Roles and Responsibilities

5.1.1 During Dam Decommissioning and Removal - Kiewit

The KRRC design-build contractor, Kiewit, will comply with all applicable requirements and implement best management practices to prevent, contain, or control any fire associated with construction. Kiewit has never caused a wildfire as a result of one of their construction projects and has a long track record of avoiding and mitigating against wildfires on large construction projects in the fire-prone regions similar to the analysis area. No wildfires were caused by their recent California and western North America construction projects, which include the reconstruction of the Oroville and Folsom dam spillways in the high-fire risk California Sierra foothills. Kiewit successfully mitigated against on-going wildfires and fire risks in remote and rugged terrain on Kwalsa and Upper Stave hydropower construction project in British Columbia.

Kiewit is an industry leader in safety statistics and always employs best practices for their projects. They have Crisis Management and Fire Prevention Plans for each their projects. They refine and adapt site- and conditions-specific fire prevention methods as needed. They routinely have safety meetings and equipment checks. Kiewit practices a fire watch on construction sites, and, for the Kwalsa and Upper Stave project, even conducted a 24/7 watch patrol to monitor conditions associated with the on-going wildfires.

The Kiewit personnel roles and responsibilities pertaining to near-term fire management for the Proposed Action are shown in Table 5-1. The Kiewit Project Manager is in charge of overall fire management, which includes the review and modification of the FMP.

Kiewit has a trained Safety Manager already assigned to the Proposed Action, and he will serve as the fire-specific Safety Officer (see Section 5.1.3), who will be the primary Kiewit contact and fire manager on-site during construction. Kiewit will also have a construction manager to assist the Safety Officer with ensuring the execution of the FMP.

Table 5-1. Kiewit primary leads for fire protection and control.

Title	Plan Responsibilities
Kiewit Project Manager	- Overall fire prevention and control management - Implementation and review of the Fire Management Plan (FMP) - Maintain communication with local firefighting agencies
Kiewit Safety Manager/Officer	- Update on fire conditions and communicate conditions to site personnel - Training of site personnel in the use of fire protection equipment - Check all fire protection systems and equipment are installed and maintained - Enforce all standards, regulations, and best practices described in the FMP
Kiewit Construction Manager	- Check that the necessary resources and processes are in place for the implementation of the FMP - Check that all personnel comply with fire prevention and flammable storage requirements - Check that the necessary resources and processes are in place for the implementation of the FMP - Enforce all standards, regulations, and best practices described in the FMP
Kiewit Superintendents and Field Engineers	- Verify that all personnel are aware of the site fire prevention methods and potential fire hazards. - Responsible for supervising the permit system for hot work operations
Kiewit employees and subcontractors	- Complete all required training as assigned by the FMP - Conduct work operations safely to limit or eliminate the risk of a fire related incident. - Report potential fire hazards to their supervisors as soon as possible - Operate in accordance with FMP

5.1.2 During Restoration and Monitoring - RES

The KRRC monitoring and restoration contactor, RES, will comply with all applicable requirements and will implement best management practices to prevent, contain, or control any fire associated with construction. RES prioritizes safety as its top core value. Whether the focus of their work be geared toward active construction, field work, or monitoring activities, the approach to safety is specific, methodical, deliberate and collaborative. RES has a fully-staffed Environmental Health, Safety and Security (EHS&S) department, led by a Certified Safety Professional (CSP)-credentialed Director and supported by dedicated Specialists embedded within each region to verify that work is completed compliantly, responsibly, and, most importantly, safely.

For each their projects, RES completes team-focused and comprehensive risk assessments, designed to account for hazards specific to project activities. After developing a risk mitigation plan for the identified hazards and applying the hierarchy of controls, RES develops an emergency action plan and a robust communication strategy between personnel and emergency response government organizations. RES checks that requisite training is obtained by all applicable employees (Table 5-2) and includes: California Fire Prevention, OSHA 10/30 Hour Construction, CPR, First Aid, AED, and fire management. Orientations are required for all new RES employees, as well as site contractors. RES will have routine and continuous worksite inspections to create a culture of safety and security excellence, and that RES is focused on being compliant with necessary regulations and requirements. RES will have a Safety Officer (see Section 5.1.3) on site. RES will maintain an open line of communication between all project stakeholders and see that all identified risks or hazards that develop are met with immediate response.

Table 5-2. RES leads for fire protection and control.

Title	Plan Responsibilities
RES Project Manager	- Overall fire prevention and control management - Implementation and review of this Fire Management Plan (FMP) - Maintain communication with local firefighting agencies
RES Environmental Health, Safety, and Security Department (EHS&S)	- Work with and support Safety Officer (see Section 5.1.3) to develop, administer, and maintain the FMP - Check that all fire protection systems and equipment are installed and maintained - Conduct a Fire Risk Survey in applicable facilities - Train employees in recognition, reporting, and controlling fire hazards - Train employees in the use and operations of fire protection/suppression systems and equipment

Title	Plan Responsibilities
RES EHS&S Safety Officer	- Be on-site responsible party for EHS&S department - Update on fire conditions and communicate conditions to site personnel - Check that all fire protection systems and equipment are installed and maintained - Train employees in the use and operations of fire protection/suppression systems and equipment - Train employees in recognition, reporting, and controlling fire hazards - Monitor and check that fuel source hazards are properly stored and handled
RES Supervisors	- Verify that employees receive the required training and notifying their EHS&S Safety Officer when there is a change in operations that creates or increases the potential for a fire related incident - Enforce all standards, regulations, and best practices described in the FMP - Check that the necessary resources and processes are in place for the implementation of the FMP - See that all personnel comply with fire prevention and flammable storage requirements
RES employees and subcontractors	- Complete all required training as assigned by the EHS&S Department and the FMP - Conduct work operations safely to limit or eliminate the risk of a fire related incident. - Report potential fire hazards to their supervisors as soon as possible - Operate in accordance with FMP

5.1.3 Safety Officer

Each contractor, Kiewit and RES, will designate a Safety Officer, and each Safety Officer will be responsible for overseeing fire responsibilities for their respective operations. The Safety Officer will be available and on-call 24 hours a day, 7 days a week in the event of a fire. They will be specifically identifiable on-site (NFPA, 2018). The Safety Officer will be the primary on-site communication linkage to ODF and Cal Fire personnel and will communicate with state and local fire suppression agencies regularly when Proposed Action conditions and locations change and at least weekly during fire season. The Safety Officer for each Contractor will get agency sign-off on the FMP with a target date before construction. Agency communication topics include:

- Reviewing and getting agency approval on the FMP with a target date before construction
- Developing site- and Proposed Action-timeline specific Fire Prevention Plan with a target date before construction and modifying as needed over course of the Proposed Action
- Discussing fire hazards, prevention, suppression, and contingency plans prior to and during construction (NFPA, 2018)

- Identifying water sources (e.g., fire hydrants, reservoirs, rivers, pond) and access points proximal to the operation areas. The Safety Officer will supplement scarce water resources with water storage tanks as needed.
- Identifying fire protection features and fire-fighting resources (NFPA, 2018)
- Identifying existing resources and infrastructure in the Proposed Action areas that are at risk in the event of a fire
- Informing agency contacts of any modifications to existing water resources due to dam removal activities, e.g., the drawdown of the reservoirs
- Evaluating the location, condition, and importance of existing fuel breaks, and determining if fuel breaks need to be modified to envelop the work area

The Safety Officer will be responsible for all on-site fire management for the Proposed Action, verifying that the measures included in the FMP are enacted, and communicating with all Proposed Action personnel. The Safety Officer's on-site duties include:

- Conducting fire hazard assessment of the Proposed Action sites with a target date before construction in an area. The assessment will include an evaluation of fuels and vegetation, landscape characteristics, fire history, fire danger rating, potential fire behavior, fire-fighting capabilities and limitations, and ingress and egress (NFPA, 2018)
- Monitoring and identifying conditions, activities, and operations that create fire hazards and ignition risks within the site (NFPA, 2018)
- Managing all on-site fire prevention and suppression documentation, including information on local emergency services (e.g., local fire stations, hospitals, access roads, evacuation routes, and water sources; Figure 5), and checking that the information for each agency is posted clearly at the Proposed Action site and available to fire watch personnel and on-site workers
- Developing an emergency call-list before construction starts and verifying that tables of emergency contact agencies, their jurisdictions, and phone numbers are clearly posted at each Proposed Action site in case of fire
- Instructing other workers in the required fire prevention and suppression measures, including the use of fire suppression equipment and the protocols in the event of a fire
- Communicating current fire hazards and any changes in prevention and suppression methods on a daily basis
- Checking that all fire suppression equipment (e.g., fire extinguishers, dozers) is well-maintained and located in proper position within the construction site
- Checking that water tanks intended for fire suppression are full during operation hours and during fire watch periods
- Identifying the location of and access to the closest water sources each day to provide direction if fire suppression tanks need to be refilled during fire suppression (NFPA, 2017b)
- Exercising emergency authority to stop and prevent unsafe acts on the Proposed Action site (NFPA, 2018)
- Investigating accidents that have occurred within the incident area and recording the details in a log book (NFPA, 2018)

In the event of a fire, the Safety Officer will immediately contact LIFC dispatch and ODF KLD in Oregon or CFSU in California and subsequently any other pertinent fire suppression agencies. The Safety Officer will then initiate and command fire control activities on the site until relieved by fire suppression professionals. The expected agency or local fire personnel response time is 15 to 60 minutes depending on location of the incident relative to fire suppression departments and resources. All fire suppression activities by Proposed Action personnel will cease with the transfer of command to fire suppression professionals. The goal is to immediately and aggressively extinguish any fire that occurs during construction of the Proposed Action without sacrificing the safety of the workers. If the Safety Officer judges the equipment on-site incapable of suppressing the fire, the Safety Officer will initiate an evacuation of the Proposed Action site.

Local and regional weather patterns and antecedent moisture conditions can significantly impact fire hazards and fire behavior. Lightning is a leading cause of wildfire in Siskiyou County, and most of the larger fires are categorized as wind-driven fires (Cal Fire, 2016). Current and antecedent temperature and precipitation conditions directly influence the amount and condition of fuels. The Safety Officer will consult with ODF and Cal Fire foresters about anticipated weather conditions that may increase fire hazards and frequently update operations and fire response plans to changing environmental conditions. It is possible for favorable weather conditions to result in ODF foresters granting waivers of certain fire prevention and suppression requirements.

5.2 Agency Contacts

Before the LSO, KRRC will supplement the FMP to include a phone tree with relevant agency contacts. Each Contractor will confer regularly with ODF and Cal Fire foresters to discuss Proposed Action progress and updates as they pertain to fire prevention and suppression and fire season designations.

In Oregon, the primary contact agencies are ODF KLD and ODF SWO. The ODF KLD Unit Forester and Stewardship Forester are the preferred contacts for discussion and modification of detailed, site-specific fire management plans, the identification of resources in the Proposed Action area, project management, and fire suppression. KLD will be the first contact agency in the event of a fire at the Oregon Proposed Action site. For Proposed Action activities taking place on BLM land, the primary BLM contact for coordination is the Field Manager of the BLM Lakeview District Klamath Falls field office.

In California, the primary contact agency is CFSU. The CFSU Prevention Specialist is the preferred contact for developing detailed, site-specific fire management plans, the identification of resources in the Proposed Action area, project management, and fire suppression. CFSU will be the first contact agency in the event of a fire at the California Proposed Action sites.

5.3 Fire Prevention and Suppression Measures and Equipment

The description of fire prevention and suppression measures and equipment is divided into those required by Oregon and California (and BLM where applicable) and those that are best practices and part of the National Fire Protection Association (NFPA) standards.

5.3.1 Regulations and Requirements

The FMP includes fire prevention and response methods that are consistent with the regulations and requirements of the various local, county, state, and federal jurisdictions. Precautionary, pre-suppression, and suppression measures will be taken to increase public safety in the Proposed Action vicinity and comply with the fire season regulations and requirements set forth by ODF (Table 4-1) and Cal Fire (Table 4-2). Each Contractor will work closely with ODF KLD Unit Forester and Stewardship Forester and the CFSU Unit Forester and Prevention Specialist to develop effective communication links, evolve plans for fire prevention, suppression, and suppression actions in the event of a fire. ODF KLD will likely assign a Stewardship Forester to the Proposed Action for the duration of the Proposed Action (S. Cantrell, ODF KLD, *pers comm.*, 2017.08.16). Any Proposed Action activities occurring on BLM land will comply with the current IFPL restrictions. The Field Manager of the Lakeview District Klamath Falls field office will coordinate with each Contractor for any Proposed Action activities on BLM land during IFPL restrictions.

Each Contractor will obtain the ODF PDM permit under Oregon statute ORS 477.625 to use heavy machinery during construction. Operation hours of tracked machinery are limited by the PDM permit during extreme fire danger, and these machines will accordingly suspend operations between the hours of 1 pm to 8 pm when required. Additional measures will be taken to keep machinery and the work area clear of excess flammable material. The PDM permit will be renewed annually, if needed, until Proposed Action completion. California does not have restrictions on the hours of operation of equipment and machinery.

Each Contractor will comply with all applicable laws pertaining to fire watch. ODF KLD prescribes fire watch duration based on FDL. Low fire danger requires a 1-hour fire watch, medium requires 2 hours, and high and extreme require 3 hours. ODF alerts all PDM permit holders of upcoming changes in FDL. A 1-hour fire watch is required on BLM lands when IFPL 1 or greater is in effect. California does not have fire watch requirements. Each Contractor will comply with all conditions of hot work permits.

Each Contractor will designate and train several members of their team to be able to serve as the Fire Watch. Fire Watch training, responsibilities, and actions will follow the regulations set forth in ORS 477.665 and OAR 629-043-0030 and the NFPA standards (NFPA, 2019a). The Fire Watch will be trained to recognize the inherent hazards of the work site and hot work operations, how to appropriate respond in the event of a fire, correctly use a fire extinguisher, be familiar with the Fire Watch decision tree (e.g., NFPA, 2019a), and contact fire suppression authorities. They will maintain safe conditions during any hot work operation and will have fire-extinguishing equipment readily available. They will be familiar with the construction site and facilities and the procedures for sounding an alarm in the event of a fire. The Fire Watch will watch for fires in all susceptible areas and try to extinguish them only when the fires are obviously within the capacity of the equipment available. If the Fire Watch determines that the fire is not within the capacity of the equipment, they will sound the alarm.

A primary feature of the FMP is preparedness for fire prevention and response in compliance with Oregon and California state regulations (Table 4-1 and Table 4-2, respectively). Construction vehicles and crews will be outfitted with the appropriate type and number of fire suppression tools, including but not limited to shovels, axes, and fire extinguishers. Required vehicles and machinery will be equipped with functional spark arresters and/or mufflers, where applicable, and spark arrester ports will be routinely cleaned. Gas powered saws, if operated at the Proposed Action site, will maintain the required fire suppression equipment as prescribed by Oregon and California. Water pumping systems conforming to the Oregon and California requirements for water volume, hose dimensions, and pumping rates will be provided at required locations on-site to suppress fires.

5.3.2 Standards and Best Practices

Each Contractor, Kiewit and RES, will conduct work using best management practices in addition to compliance with all federal, state, and local laws. Best practices follow the NFPA standards where available and employ industry-leading best practices. Each Contractor will oversee any sub-contractors, so they strictly adhere to both regulations and best practices.

Best practices that will be employed during the Proposed Action include the following:

- **Employee training.** Each Contractor will require the training of personnel with how to comply with the agency requirements and regulations and with best practices. The training will be required not only for Kiewit and RES employees, but also additional hired contractors and their crews. The Safety Officer will oversee training activities. Basic fire prevention training and education will be conducted during the initial employee safety brief. Additional training will be during bi-weekly safety training. An accurate and updated record of employee training will be in accordance with Occupational Safety and Health Administration (OSHA) standards and requirements. The Safety Officer will be responsible for assigning and training persons to be responsible for 1) maintaining fire protection equipment and systems installed to prevent and/or control ignition of fires, 2) the control and accumulation of flammable or combustible materials and/or substances, and 3) advising personnel about site-specific flammable materials, hazardous processes or conditions, or other potential fire hazards (NFPA, 2019a).
- **Communication.** Each Contractor will establish effective communication lines to the various fire suppression agencies, particularly ODF KLD and CFSU. The Safety Officers will communicate these near-term measures to staff and subcontractors through new-hire orientation, various trainings, toolbox talks, and project meetings so that employees are familiar with fire prevention and control procedures. A temporary communication system will be installed for the duration of deconstruction and restoration activities to establish reliable communication lines between Proposed Action personnel and to agency and emergency contacts.
- **Equipment compatibility.** The Safety Officer and construction supervisors/superintendents will check that fire suppression equipment (e.g., hose connections and fittings) is fully compatible on both the Oregon and California portions of the Proposed Action and with local fire departments (NFPA, 2017b).
- **Good housekeeping.** Good housekeeping will be maintained in work areas to minimize the amount of Class A Materials (e.g., combustible vegetation, debris, rubbish, cloth, trash, and waste material). Class A materials must be kept away from accidental ignition sources, such as hot plates, heaters, welding operations, and be disposed of in appropriate receptacles. No burn fires will be allowed at the work site to dispose of Class A Materials. Materials susceptible to spontaneous ignition (such as oily rags) will be stored in a labeled disposal container. Access and egress routes will be kept clear and free of clutter, slip/trip/fall hazards, and other obstructions.

- **Flammable and combustible material.** Minimize the storage of Class B Materials (e.g., flammable and combustible liquids (oil, grease, paint), flammable gas and aerosols) and use alternative products that are less reactive or combustible, if available. Class B Materials storage areas will be well-ventilated and maintained clear of combustible vegetation and waste materials. Such storage areas will not be used for the storage of other combustible materials. Keep materials that are not non-compatible (chemically reactive) in separate flammable cabinets or different locations. Bulk fuel storage will be located at an approved area at the maintenance yard. Properly dispose of combustible waste in the appropriate receptacles, preferably metal containers with an airtight lid. Approved appliances and pumps will be used to dispense liquids from tanks, drums, or similar containers. Class B Materials will not be used, handled, or stored near or in emergency exits, stairs, or egress paths, nor will they be near welding, cutting, grinding, or spark-producing appliances or equipment. Safety Data Sheets will be reviewed and readily available for chemicals.

- **Spills, leaks, and clean-up.** Report, contain and isolate, and clean-up observed and suspected fluid and gas spills/leaks quickly and in accordance to the Safety Data Sheet of that material.
- **Emergency contacts.** An emergency call-list will be developed before construction. Emergency contacts will be posted by the Safety Officer and readily available in the event of a fire at the construction site. A temporary communication system will be setup to reliably contact emergency personnel.
- **Motorized vehicles and equipment.** Operation of internal combustion engines shall comply with PRC-4428 (Table 4-2). Equipment will be maintained to the working standards of the manufacturer, be kept clean of flammable material and debris, and inspected early in the shift prior to use. Persons operating equipment will be responsible for conducting the daily visual inspection of said equipment. The equipment group will perform routine maintenance on equipment to check that fire prevention measures (spark arrestor, shielding, smoke stacks, etc.) are clean and in proper working order. Inspection and maintenance tasks include ensuring that batteries, hydraulic lines, and fuel lines are in good condition. Equipment will be stored overnight in locations cleared of flammable material. Motorized construction equipment will be located such that the exhausts do not discharge against combustible materials. Vehicles will be restricted to the work site and will not be parked or operated in areas that contain vegetation. Vehicles will be shut down and allowed to cool before refueling. Gasoline powered construction equipment with catalytic converters will be equipped with shielding or other acceptable fire prevention features.
- **Electrical equipment and appliances.** Wiring and cords on electrical equipment and appliances will be inspected for damage (i.e. broken insulation, missing ground pin, signs of being crushed/bent, etc.). Appropriately rated fuses will be used for electrical equipment. Electrical equipment and appliances that have been approved by a Nationally Rated Testing Laboratory will be used. Extension cords will not be used as permanent wiring, nor will multiple extension cords together be connected together. Extension cords will not be pinched, shut, or crushed in doors, cabinets, or other items. Approval of portable heaters by the Safety Officer is required. Portable heaters will be turned off and unplugged before leaving for the day and when the unit is left unattended. Heaters will not be run near trash cans, curtains, or similar materials. Jackets, towels, or similar items will not be placed on heaters. Heaters will have tip-over protection and automatically shut off in the event it is tipped over. Space heaters, fans, coffee makers, and other similar appliances will be turned off when left unattended.
- **Hot work.** Permits will be obtained for hot-works and a fire watch will be completed under the permits.

- **Smoking.** During ODF fire season, smoking is not allowed while working or travelling in an operation area (Table 4-1). Outside of fire season, smoking should be in designated areas that contain cigarette butt collection receptacles. Smoking will be prohibited in all other areas especially flammable and combustible liquid storage areas. Warning signs will be posted. No smoking will be permitted within 25 feet of flammable vegetation and 50 feet of flammable and combustible liquids. Smoking will be prohibited in all vehicles and equipment. E-cigarettes must be recycled and not mixed with regular trash as the lithium ion battery is a potential fire hazard and ignition source.
- **Fire-fighting equipment.** The NFPA recommends (NFPA, 2017b) wildfire plans conform to the local and regional regulations for fire-fighting equipment requirements (i.e., Table 4-1 and Table 4-2). In addition to Oregon and California regulations, each Contractor will comply with these additional best practices. Each Contractor will maintain appropriate required fire suppression equipment and water supply at the work site. Equipment capable of halting the spread of a fire will be kept on-site including bulldozers, motor graders, and excavators. Water storage tanks will be inspected, tested, and maintained in accordance with NFPA 25 (NFPA, 2017a). If roads are needed to access water supplies, they will be designated as water access routes. Fire extinguishers, shovels and other firefighting equipment will be available at work sites and on construction equipment. 20-pound (or two 10-pound) fire extinguisher(s) and 5 gallons of water in firefighting apparatus (e.g., bladder bags), will be made available in areas of high risk for fire. Keep a fire extinguisher within 10 feet of fuel tanks and running gas powered equipment, especially in wooded areas and areas with tall/dry grass. (NFPA, 2017b). Only properly trained individuals shall perform maintenance and inspections on fire protection equipment and systems.
- **After hours.** To the extent workers remain on-site after work hours, aforementioned best practices will be followed while on the Proposed Action site regardless of whether work is ongoing. In the event of an ignition after hours, on-site personnel will immediately alert fire emergency contacts.

Supplementary information to the near-term measures to assist with fire prevention will be added as needed and maintained during construction activities as the Proposed Action develops.

5.3.3 Fire Management Preparation Checklist

Table 5-3. Fire management preparation checklist for the Contractors.

Action	Responsible Party	Completion Date / Frequency
Coordinate with state and federal fire resources (e.g. Cal Fire, ODF, USFS, BLM, local FDs) on fire management activities, fire risks and hazards, Proposed Action updates	Project Manager, Safety Officer	- Target before construction - Routinely during construction not in fire season - Minimum weekly during fire season
Work with ODF KLD and CFSU foresters to develop broad scale contingency plans for fire containment within their respective jurisdictions in the Proposed Action areas.	Project Manager, Safety Officer	- Target before construction - As needed during construction

Action	Responsible Party	Completion Date / Frequency
Inform state foresters of any modifications to existing water resources due to dam removal activities, e.g., the drawdown of the reservoirs	Project Manager, Safety Officer	- Regularly as needed
Secure Permit for Power Driven Machinery from ODF	Safety Officer	- Target before construction - Renewed annually
Communicate on wildland fire season updates and forecasts with ODF and Cal Fire contacts	Safety Officer	- Minimum weekly during fire season - Routinely during non-fire season construction
Verify that emergency contact information is up-to-date and visibly posted at active Proposed Action sites	Safety Officer	- Target before construction - Regularly as needed
Verify locations, check conditions, and maintenance of fire management equipment	Safety Officer, Supervisors/Superintendents	- Daily
Provide personnel with wildland fire training related to equipment, tools, and conditions	Safety Officer	- Target before construction - Bi-weekly refresher and as needed during construction
Communicate current and forecasted wildland fire season updates to personnel	Safety Officer, Supervisors/Superintendents	- Weekly as needed - Daily during fire season
Complete fire watch of required duration following applicable activities and during fire season	Fire Watch	- Daily
Check that vehicles working in and around fire potential areas are equipped with required fire management tools	Supervisors/Superintendents	- Daily
See that Proposed Action sites and personnel comply with best practices described herein, including good housekeeping, treatment of flammable material, and equipment requirements	Safety Officer, Supervisors/Superintendents	- Daily

6. LONG-TERM FIRE MANAGEMENT MEASURES

6.1 Term

The term for the long-term fire management measures will begin on LSO and end when the license surrender is effective. These proposed long-term measures, specifically the fire suppression and detection equipment, will provide fire management benefits long after license surrender is effective though, as a result of the cooperative agreements with fire agency successors. The purchase and installation of the various long-term measures are contingent on such cooperative agreements.

6.2 Objectives and Overview

The objective of the long-term fire management measures and supporting analysis is to assure that the Proposed Action, post-dam removal, will not cause a net diminution in fire-fighting resources in the Basin or increase the fire ignition risks that exist prior to the Proposed Action.

The long-term measures were developed using analytical results from the Reax report (Appendix A) and in consultation with Cal Fire and ODF, among others, in order to better understand the existing needs and opportunities to improve fire prevention and suppression capabilities of the respective agencies. The contacts consulted are described in Section 8. Several common themes emerged from discussions with fire agency personnel as summarized below and were used to guide development of the long-term measures:

- Early detection of fires is critical
- Water sources and access are important
- Local community fire preparedness is vital for protecting residents and infrastructure
- Each fire is unique, so tactics and resources used for suppression are correspondingly unique
- Environmental conditions (e.g., topography, weather, fuel availability, antecedent moisture, ignition type) vary widely between fires
- Resources available for initial attack or a sustained fire suppression effort vary widely depending on locality, time of year, and the distribution of resources to other fires; hence, a diversity of measures are required to address many components and stages of fire management including fire prevention and preparedness, monitoring and detection, and initial attack and suppression.

In the sections below, we first describe the anticipated conditions following dam removal. Then, we propose new and enhanced fire management measures and strategies and discuss the motivation and logistics for each. Finally, we compare existing fire risk with long-term fire risk as a result of the Proposed Action and the proposed management resources in the FMP and explain how the FMP meets its objectives.

6.3 Conditions after Dam-Removal

Some environmental conditions and fire management resources will change in the ASE area as a result of the Proposed Action, and, when the fire management measures described in detail in Section 6.4 are implemented, conditions related to wildfire risk and amount of fire suppression resources will improve. The KRRC will implement the installation of early detection cameras in the ASE area that will significantly reduce wildfire detection and initial attack arrival times. New water access points (i.e., dry hydrants and boat launches) for ground crews will be developed and stationary and portable dip tanks for aerial crews will be provided to supply a diverse and flexible suite of water access fire suppression options. Iron Gate Reservoir, Copco Lake, and J.C. Boyle Reservoir will no longer be available as water sources for aerial fire suppression crews. In place of the reservoirs will be a free-flowing Klamath River. The reservoirs serve as a broad fuel break that can prevent the spread of wildfires. Post-removal, the reservoir footprints will be revegetated, so what was once covered with water will be replaced with potential fuel sources. Potential post-removal vegetation succession is described in Appendix A and was estimated from existing vegetation types and historical imagery.

The restored free-flowing Klamath River will be a water source and a fuel break, albeit a narrower one. KRRC identified 41 potential post-removal ARAPs in the reservoir footprints using high resolution bathymetry and historical topography, photos. and imagery. The majority of the reservoir sediment is silt- and clay-sized sediment (USBR, 2011), which will be easy for the Klamath River to erode and transport. As such, existing deep pools in the mainstem river will not experience infilling from mobilized reservoir sediments and will continue to serve as a water source for aerial fire-fighting crews. There will be ample year-round flow in the Klamath River post-removal. The minimum prescribed post-removal Klamath stream flows from the 2019 National Marine Fisheries Service Biological Opinion (NMFS, 2019) for July and August are 900 cfs and will be even greater the rest of the year. In addition, the dry hydrants will provide water sources, supplied by tributary flow, along major roads. The portable dip tanks will provide mobile water sources that can be deployed in remote locations where water access is currently unavailable.

Power generating facilities, transformers, circuit breakers, and lengths of transmission and distribution lines will be removed at each dam site as part of the Proposed Action as outlined in the Definite Decommissioning Plan (KRRC, 2020). More than 15 miles of transmission and distribution lines and 160 power poles will be removed as part of the Proposed Action (Table 6-1). Most of the Copco line that will be removed is located in a CPUC Tier 2 Elevated Fire Threat area (Figure 3). The area may be reclassified as no fire threat as a result of the Proposed Action.

Table 6-1. Miles of transmission and distribution lines removed by the Proposed Action (KRRC Technical Representatives, 2018).

Project site	Miles of 69-kV line removed	Number of power poles removed
J.C. Boyle	3.5	70
Copco No. 1 & 2	11.2	90
Iron Gate	0.5	-
Total	15.2	160

6.4 Post-Removal Management Measures

This section describes the post-removal management measures (Figure 9) that KRRC will make available to aid with fire prevention and suppression efforts in the Basin following the removal of the dams and demonstrates that post-dam removal firefighting resources are similar to current conditions. The measures include technologies, facilities, and equipment that are both new to the Basin and improvements and upgrades to existing resources in the Basin. KRRC will provide the proposed management measures described in the following subsections.

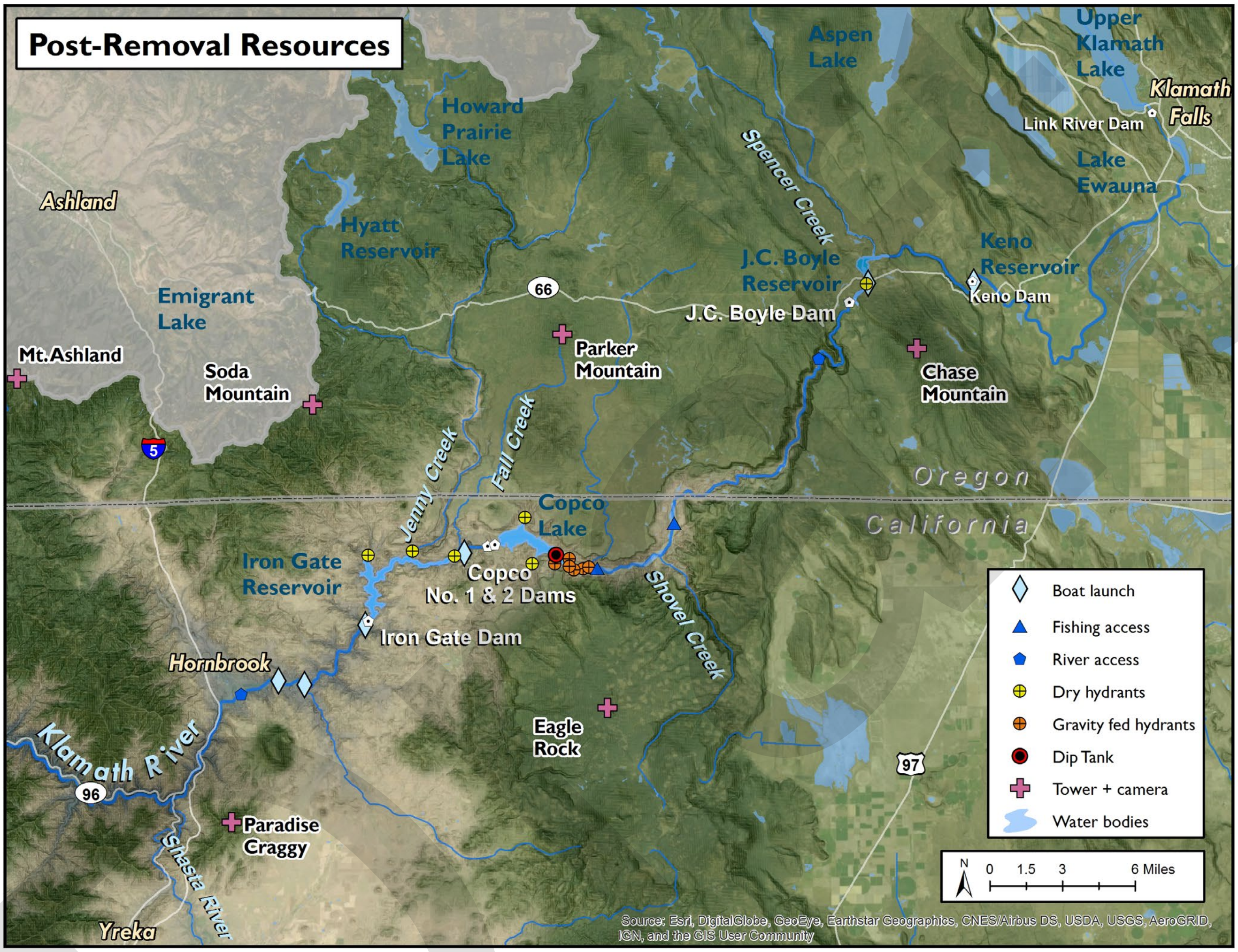

Figure 9. Proposed post-removal long-term fire management measures.

6.4.1 Monitored Detection System (MDS)

As supported by the agencies, KRRC will install new early detection MDS camera technology to improve early fire detection in the Basin, as described below. With high definition cameras, GIS integration, and the ability to triangulate fires, the MDS is a powerful tool for rapidly detecting and locating wildfires (see Section 3.2.1 for description). The MDS can potentially save minutes to hours of time from ignition to the arrival of initial attack resources relative to detections from 911 calls. ODF SWO has had a functional MDS since 2012, and ODF KLD installed one in 2019. Since installation of the ODF SWO system, their number of first fire detections has increased from two in 2012 (when there were not dedicated staff observers) to 24, 69, and 27 first detections when staffed in 2017, 2018, and 2019, respectively. For context, an average number of 14 initial detections from ODF SWO staffed fire lookouts were recorded from 2003 to 2011 with a maximum value of 24 initial detections in 2003. The system also allows for remote monitoring of dozens of fires simultaneously. The MDS technology is scalable, such that additional cameras can be added to a network with all data routed to a single detection center. In San Diego County, firefighters using a network of fire detection cameras were able to pinpoint and confirm the location of the Lilac Fire within 31 seconds. This rapid detection allowed the blaze to be contained before it could grow into a larger devastating fire, for which the conditions were favorable. This result prompted Neal Driscoll, Professor at UC San Diego that has been deploying fire detection cameras in Southern California, to say “early detection is the whole game.”

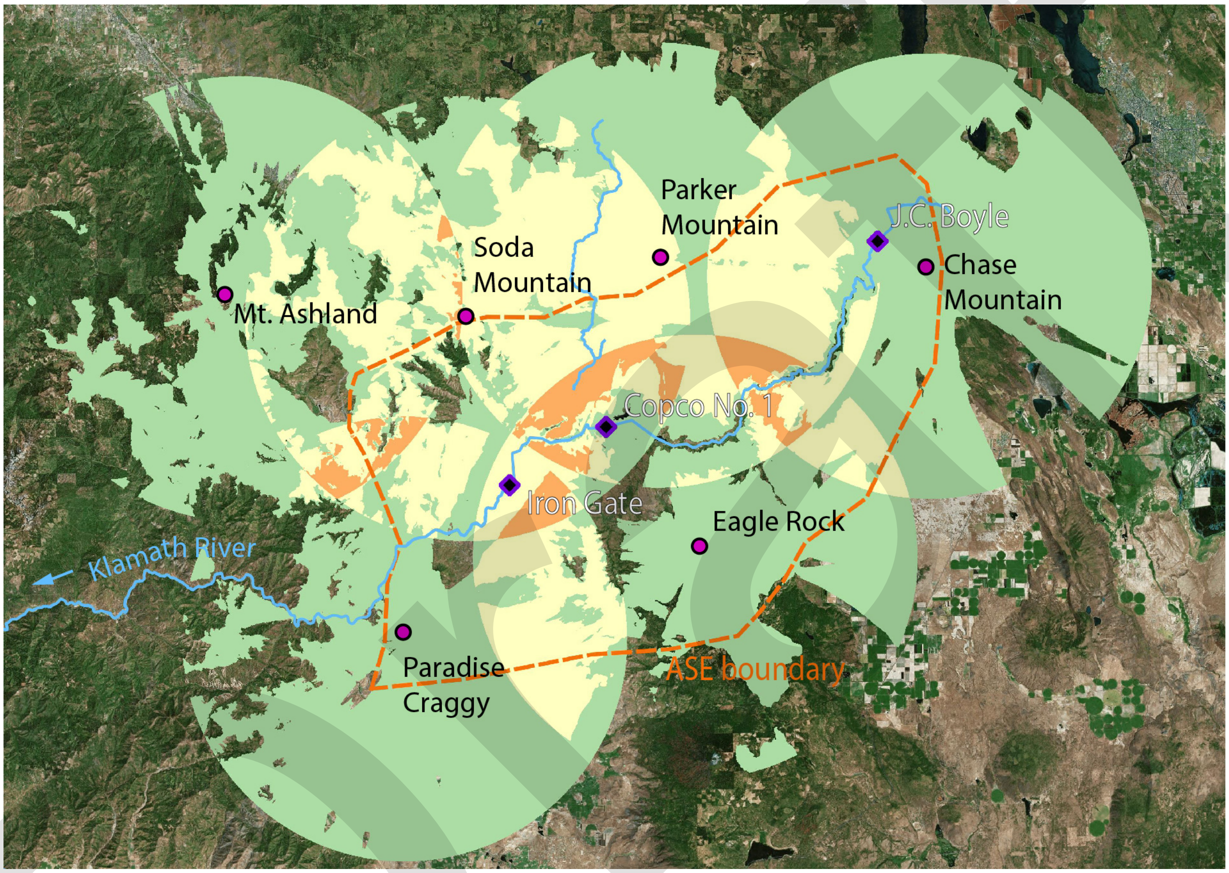

Figure 10. Viewshed analysis at 500 ft above ground surface for contemplated MDS camera locations with green, yellow, and orange indicating visibility by one, two, and three observers, respectively. From Reax report (Appendix A).

As supported by the agencies, KRRC will facilitate the installation of MDS cameras, power sources, and data transmitters at the contemplated locations shown in Figure 9 and Figure 10 and establish a new MDS monitoring center at the CFSU headquarters in Yreka. The contemplated locations include several existing fire lookouts (Parker Mountain, OR, and Paradise Craggy, CA) and the development of two new sites (Mt. Ashland, OR, and Eagle Rock, CA). The contemplated Mt. Ashland and Eagle Rock sites are both located in the Klamath National Forest, and the Parker Mountain and Paradise Craggy locations are currently operated as fire lookouts by ODF and Cal Fire, respectively.

The viewshed analysis of the contemplated MDS camera locations (Figure 10) shows that nearly the entire ASE area, and much of the surrounding area, is covered by at least one observer. Importantly, there is a large amount of the ASE area, including locations near the Klamath River, that is covered by multiple cameras to enable triangulation of fires. Coverage of the full ASE area is not currently possible with just the

Soda Mountain and Chase Mountain cameras, so these additions would be a major improvement to rapid detection and suppression in the area.

The MDS technology does not currently exist at CFSU, so the establishment a new MDS monitoring center at the CFSU headquarters in Yreka and two cameras at Paradise Craggy and Eagle Rock is a major improvement over existing fire detection resources. (Figure 9). The setup of the MDS monitoring station at CFSU headquarters will provide the infrastructure for CFSU to add additional cameras in the county in the future.

ODF SWO and KLD currently use MDS technology with great results, and the additional cameras improve their coverage and improve the existing coverage by adding an additional observer for triangulation and monitoring. The Parker Mountain fire lookout will be integrated into the ODF KLD network of cameras and monitored in their detection center. The Mt. Ashland camera will be integrated into the ODF SWO network of cameras and monitored in their detection center.

KRRC will cover costs of any hardware (instruments, microwave communication system, computer monitoring station) and any associated setup for the contemplated camera locations at Paradise Craggy and Eagle Rock and Yreka office detection center and will cover the cost of the instruments for the contemplated ODF KLD Parker Mountain and the ODF SWO Mt. Ashland sites. KRRC will cover the costs of the EVS ForestWatch® software for CFSU, the one-time site license cost for cameras on Parker Mountain, Paradise Craggy, and Eagle Rock. KRRC will collaborate with Cal Fire, ODF, and USFS (for Eagle Rock and Mt. Ashland contemplated locations) prior to the start of construction to implement this measure. Development of MDS cameras at certain contemplated sites will involve approval by landowners.

6.4.2 Chipper

KRRC will pay for a 9-inch chipper and dump bed trailer combo and a base model truck to haul it that will be owned and maintained by FSCSC to provide frequent and consistent assistance with defensible space to the local community. Defensible space, which is a legal requirement in California and Oregon and a top priority for many groups in Siskiyou County (Siskiyou County, 2019), can significantly reduce the risk of structure fires. Cal Fire urges private landowners to reduce fuels around their structures (Cal Fire, 2019), and the chipper would aid in that effort. FSCSC would administer the use of the chipper and be responsible for maintenance and for scheduling and staffing chipping events.

6.4.3 Hydrant System

The water supply for the existing gravity fed hydrant system at Copco Lake (Figure 13) is maintained by storage tank fed by a groundwater well. This system is not expected to be affected by the drawdown of the reservoirs or the removal of the dam. If directed by Cal Fire, KRRC will ensure its functionality through license surrender.

6.4.4 Dry Hydrants

KRRC will design and construct, as approved, up to six permanent dry hydrants located at or near road crossings of large tributaries to provide additional water sources. Dry hydrants provide a simple and reliable water supply for ground-based firefighting crews to fill fire engines and water tenders. Dry hydrants are passive, unpressurized water supply systems with a screened intake placed in the channel above the channel bed in a location of satisfactory depth (during dry conditions), flow rate, and channel stability. Dry hydrants have an above-ground fire hose connection to which truck-mounted pumps can be connected. Dry hydrants are commonly used as water supply for fighting fires in rural areas. KRRC will design and construct six permanent dry hydrants located at or near road crossings of large tributaries to provide additional water sources (Figure 9; Table 6-2). This measure will be implemented as part of the road and bridge improvements associated with construction and dam removal. Long-term maintenance of the hydrants will be the responsibility of Cal Fire and ODF.

The addition of dry hydrants will add water access to ground-crews that is currently not available around the reservoirs. The dry hydrant network (as an addition to the boat launches and existing hydrant system) will reduce fire suppression responses times and allow for more aggressive responses as tanker refill and rotation times are reduced. The dry hydrants will be placed at bridge crossings over larger tributaries with perennial flow with minimum flow rates of several cfs or greater. The Iron Gate dry hydrants will be along Iron Gate Lake / Copco Road at Camp and Jenny creeks and on Daggett Road at Fall Creek (Figure 12). The Copco Lake hydrants will be along Copco Road at Beaver Creek and along Ager-Beswick Road at Deer Creek (Figure 13). The J.C. Boyle dry hydrant will be located at the Pioneer Park West boat launch to provide more rapid drafting at that location than the boat launch (Figure 14). For convenient, dependable, permanent, and rapid access, the hose connections will be placed on the bridges that are scheduled to be built across each tributary as part of Proposed Action construction measures. Bridges and crossings are desirable given the increased certainty of access to water post-removal and the ability to utilize the structure for mounting the dry hydrant pipe and hose connection.

KRRC will complete the design, permitting, and construction of the dry hydrants in compliance with NFPA standards (NFPA, 2017b) and will consult with agency and local fire personnel during the design phase and get their approval prior to installation of the dry hydrants. Unless advised otherwise by agencies or local fire departments, the location, design, and materials will follow the standards of NFPA 1142 (NFPA, 2017b). The dry hydrants will be designed to provide a minimum flow of 1000 gpm (2.2 cfs) (NFPA, 2017b), which is a fraction of the low flow discharges of the perennial tributaries selected for the hydrants. The screened intakes will be placed in portions of each tributary with the required 1 ft of flow depth below and 2 ft above (NFPA, 2017b). The intake locations will be placed upstream of the crossings to reduce the vertical height that water must be raised during drafting (lift) to less than 10 ft, unless an alternate maximum lift value is specified by firefighting groups. The hose connection fitting provided at the dry hydrant must be compatible with the local and agency pump equipment and conform to the NFPA 1963 standards (NFPA, 2019b).

6.4.5 Boat Launches

KRRC will construct or improve three boat launches to provide water access the Klamath River following dam removal. Boat launches provide simple and reliable water access for ground-based firefighting crews to fill fire engines and water tenders. Most of the existing boat launches around the reservoirs (Figure 6) will no longer function once water levels are lowered during drawdown and dam removal, although Fall Creek will retain its current functionality. KRRC will construct two boat launches, one at J.C. Boyle and one at Copco No. 2 powerhouse (Figure 9; Table 6-2). The new boat launches will have concrete ramps and access roads with dimensions designed to comply with the NFPA standards for width, grade, and turning radius (NFPA, 2017b) and using materials that can support the weight of water tenders and fire engines. The Copco No. 2

Powerhouse boat launch (Figure 13) will be constructed to replace a nearby existing boat launch, Copco Cove, which has an unimproved surface too steep and narrow to be used by water tenders or fire engines. At J.C. Boyle, the Pioneer Park West boat launch will be constructed to replace the existing gravel boat launch at Pioneer Park East. The existing Iron Gate Dam / Hatchery boat launch on river-right downstream of Iron Gate Dam will be improved for fire-fighting purposes.

Table 6-2. Post-removal ground access points as shown in Figure 9.

Proposed Action site[1]	Type	Description
Keno Dam	Boat launch	Existing
J.C. Boyle – Pioneer Park West	Dry hydrant	Proposed
J.C. Boyle - Pioneer Park West	Boat launch	Proposed
Copco – Deer Creek	Dry hydrant	Proposed
Copco – Beaver Creek	Dry hydrant	Proposed
Copco - Copco No. 2 Powerhouse	Boat launch	Proposed
Iron Gate - Fall Creek	Dry hydrant	Proposed
Iron Gate - Jenny Creek	Dry hydrant	Proposed
Iron Gate - Camp Creek	Dry hydrant	Proposed
Iron Gate Dam / Hatchery	Boat launch	Improved
KRCE Campground	Boat launch	Existing
Klamathon Bridge	Boat launch	Existing

[1] Listed from upstream to downstream.

6.4.6 Aerial River Access Points (ARAPs)

KRRC will identify and maintain, through the term of the FMP, aerial river access points (ARAPs) in the former reservoirs (two per reservoir) that meet specific suitability performance criteria to be used by Type 1 helicopters with snorkels. Strategic use of the post-dam removal Klamath River corridor as a water supply for aerial fire suppression is an important part of countering the loss of the reservoirs. Viable water sources need to be perennial and have sufficient flow and accessibility (NFPA, 2017b). Minimum flows in the river will be sufficient to provide adequate water supply even under the heaviest drafting withdrawals. Some reaches of the free-flowing Klamath River are currently used for bucket and longline drafting in the ASE area, and additional locations suitable for drafting ARAPs are expected to form naturally in the reservoir footprints post-removal.

KRRC has analyzed the expected changes in the Klamath River after dam removal and anticipate that there will be at least two ARAPs which will form naturally in each former reservoir and meet the specific suitability performance criteria to be used by Type 1 helicopters with snorkels (Figure 11). ARAPs are expected to have wetted widths and centerline depths greater than 150 ft and 3 ft, respectively, providing an adequate amount of water to target and draft using a snorkel device from the helicopter. A safety clearance diameter of 400 ft is required to reduce the hazards of helicopter drafting due to rotor wash, obstacles, and vegetation that could interact with the rotors. An area satisfying the safety clearance diameter criteria will need to be devoid of woody vegetation taller than 18 inches and lack any other obstacles posing a potential hazard to helicopter rotors (*cf.* USFS & OAS, 2015).

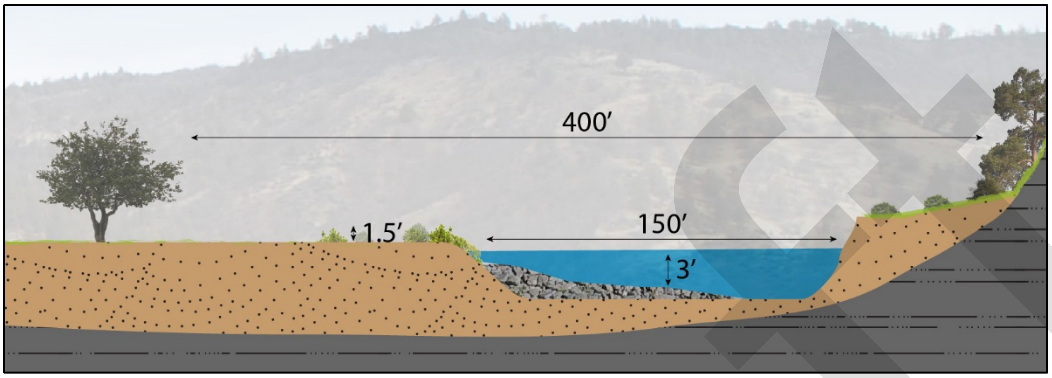

Figure 11. Conceptual cross-section illustrating the performance criteria/minimum requirements for aerial river access points.

The locations of more than 40 potential post-removal ARAPs were estimated within the reservoirs from historical air photos, pre-dam topographic data, and high-resolution reservoir bathymetry (Figure 12, Figure 13, and Figure 14). Analysis of the currently free-flowing sections of the Klamath River in the ASE area yielded nearly 100 locations that met the width and depth criteria, and channel dimensions in the reservoir footprints are expected to be comparable. The prevalent exposed bedrock in the reservoirs will effectively maintain channel dimensions in ARAP locations, and significant filling of new or existing ARAPs with mobilized reservoir sediments is not anticipated in the Project reach given the fine-grained composition of the reservoir sediments (KRRC Technical Representatives, 2018; Appendix H).

Vegetation management of riparian areas may be needed for ARAPs to meet the safety clearance performance criterion. Wetland vegetation will generally be appropriate for meeting the safety clearance criterion because they generally lack woody species and do not grow as tall as typical riparian vegetation. There are areas designated for restoration and emergent wetlands creation, as described in the Reservoir Area Management Plan of the Definite Decommissioning Plan (KRRC, 2020) and in Figure 12, Figure 13, and Figure 14. Vegetation management will not interfere with the objectives of salmonid recovery because the areas are designed emergent wetlands. Any annual maintenance will be targeting treatment of woody, non-wetland species that have grown up around the ARAP and will thereby improve wetland health and function.

KRRC will identify two naturally-occurring ARAPs per reservoir to be maintained through the term of the FMP to meet Type 1 helicopter drafting requirements. The specific location of each ARAP will be selected with coordination from Cal Fire and ODF. The number of ARAPs per reservoir for maintenance was based on recommendations from ODF SWO. The ARAPs will be inspected annually to assess their ability to meet performance criteria for depth, width, and safety clearance. Following inspection, the vegetation surrounding the ARAPs will be managed, if necessary, to meet the safety clearance criterion and to remove all woody species exceeding 18 inches in height. KRRC will work with Cal Fire and ODF to implement this measure.

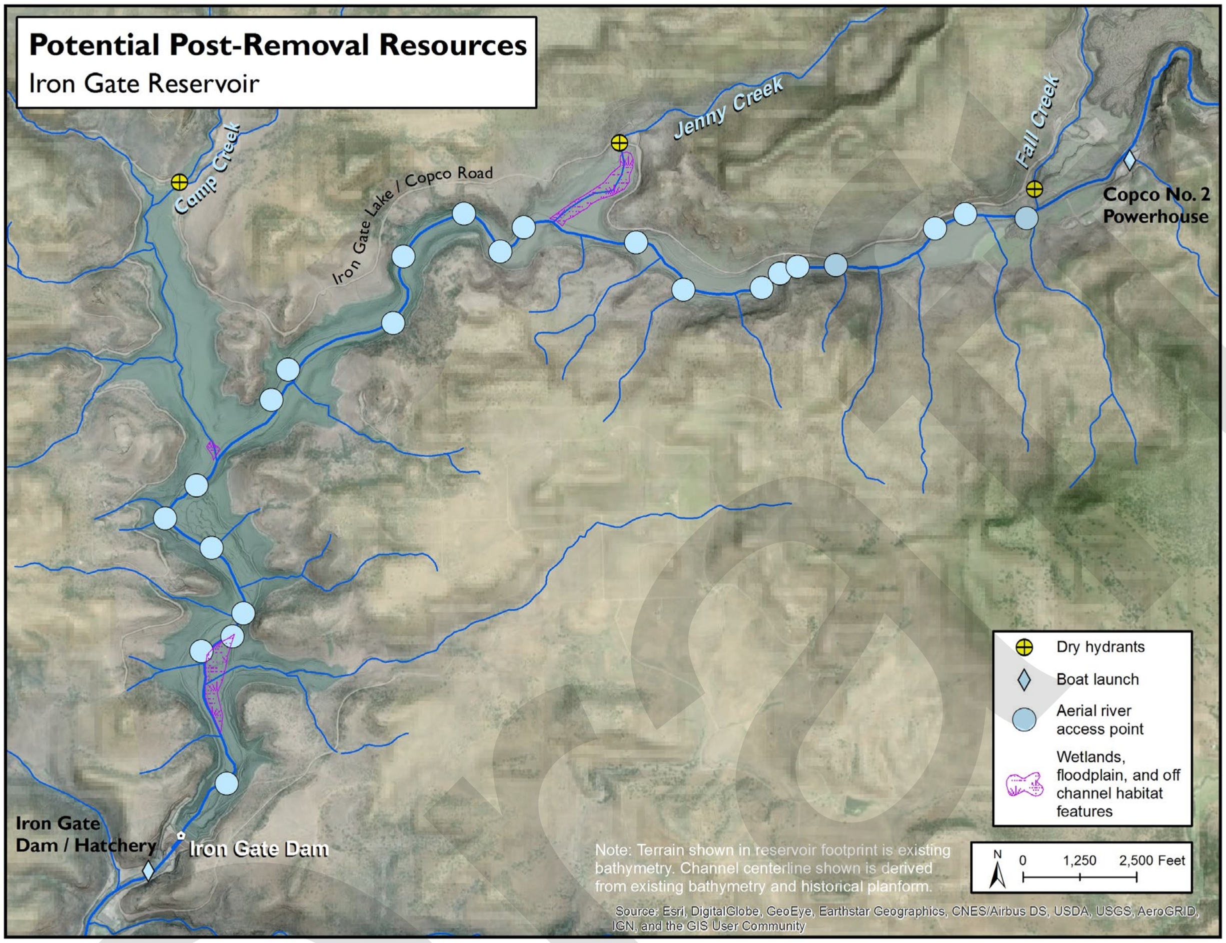

Figure 12. Potential post-removal resources in footprint of Iron Gate Reservoir.

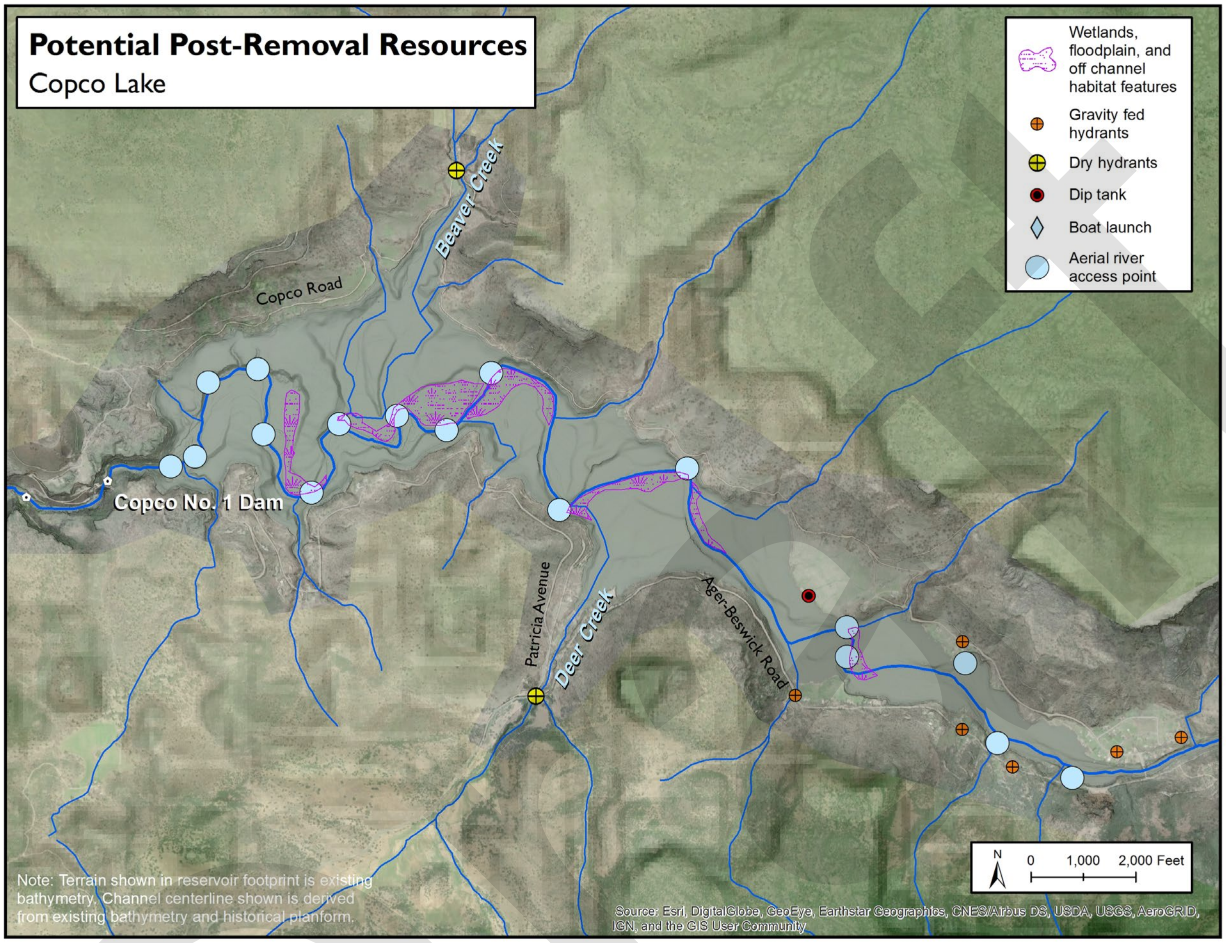

Figure 13. Potential post-removal resources in footprint of Copco Lake.

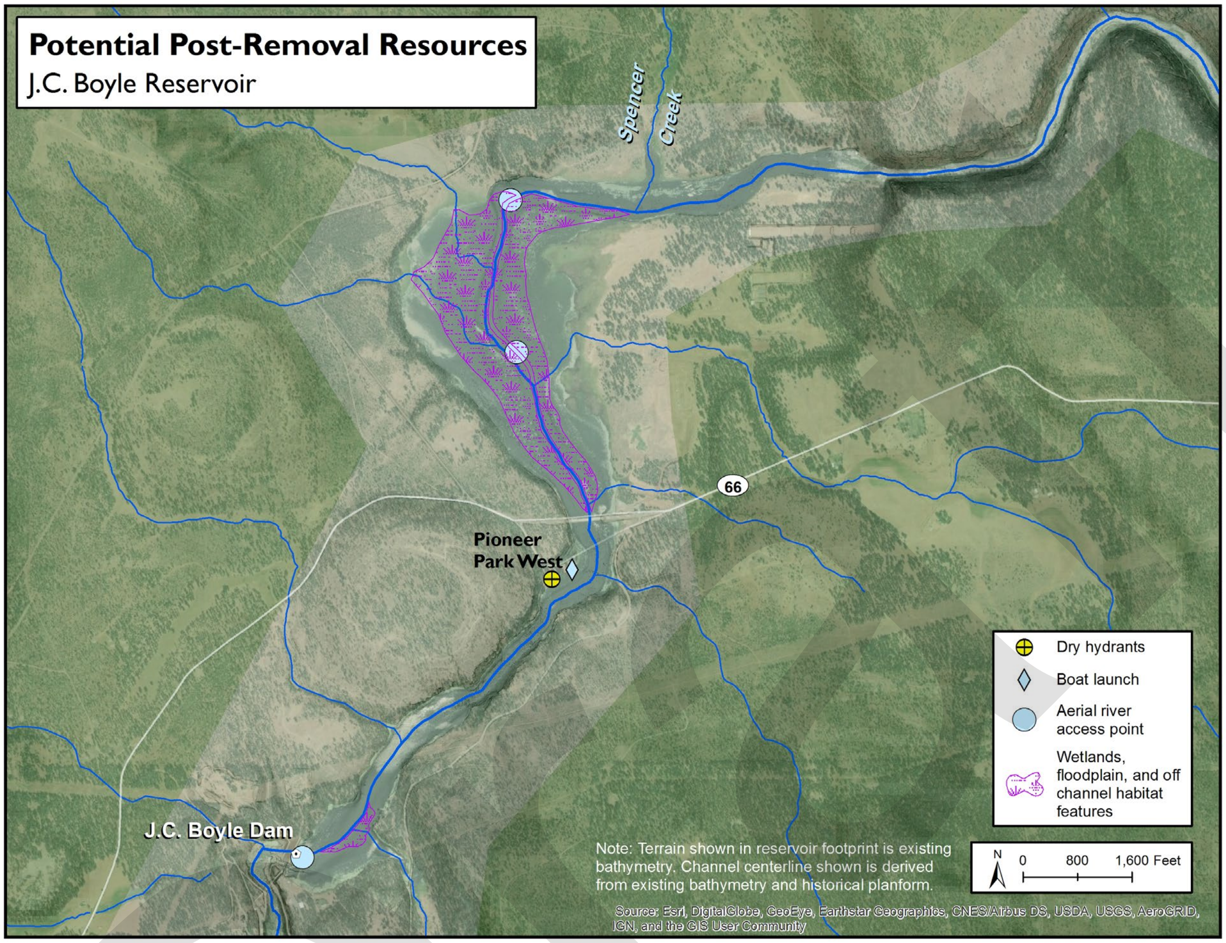

Figure 14. Potential post-removal resources in footprint of J.C. Boyle Reservoir.

6.4.7 Dip Tanks

KRRC will cover the costs of one permanent dip tank near Copco Lake and five portable dip tanks of varying sizes to provide CFSU diverse and flexible additional water sources for aerial drafting efforts. Dip tanks are a proven method for providing reliable alternative water sources for helicopter drafting. Even though there will be ample water supply for drafting in the free-flowing Klamath River, dip tanks can provide yet another method of drafting to complement the boat launches, hydrants, and ARAPs as water sources in the Basin. Dip tanks vary in design and widely in size (i.e., 72 gallons to 20,000 gallons), so they provide the flexibility to customize to fit the needs (e.g., location, volume, dip bucket size) of local and state fire agencies. Larger permanent tanks are rigid, metal, stationary water sources that are refilled by a permanent pumping system. Portable, self-supporting (i.e., no frame required) tanks can be stored, easily transported and erected, and filled rapidly, so they can be deployed to varying locations as needed. Portable, self-supporting tanks can vary widely in size and ease of setup, with larger tanks requiring a thicker and a greater amount of fabric, which increases the weight and reduces the ease of transport and setup. Helicopter sling tanks are smaller, portable, soft-sided tanks that can be air-lifted by helicopters and placed in remote locations needing additional water supply. Portable tanks must be paired with a pump system to be refilled, and therefore must be placed in locations with viable water supply.

As requested, KRRC will provide the following dip tanks to Cal Fire to diversify their water supplies for fighting fires in the ASE area. All tanks, hoses, and pump systems will be NFPA 1142 compliant (NFPA, 2017b) and provide the water volume, refill rates, and hose compatibility needed by fire personnel. Tanks will be sized for compatibility and safety with the bucket sizes of Cal Fire and ODF helicopters. Ownership and maintenance of tanks will be with Cal Fire.

If approved, KRRC will pay for a large (5000 to 20,000 gallon), permanent dip tank to be installed west of the town of Copco Lake (Figure 9) on Parcel B lands at the currently inundated edge of the Copco Lake. This area is a 1500 ft wide grass-covered alluvial fan that is removed from steep valley walls and will easily meet the recommended safety clearance to provide safe helicopter drafting conditions for all helicopters and drafting mechanisms. The tank will hold enough water for several refills of Type 1 snorkel helicopters and will be equipped with a permanent pump capable of refilling the tank from the adjacent Klamath River.

If requested, KRRC will pay for three portable, self-supporting tanks (5000 – 6000 gallons each) with hoses and pumps for refilling to Cal Fire. These portable tanks can be stored in fire department buildings (e.g., CFSU headquarters in Yreka, Hornbrook FD, or Copco Lake FD) or in pre-determined locations either along existing roads in the ASE area and can always be transported elsewhere if needed. There are several strategic locations these tanks could be staged in locked housing. Camp Creek and Jenny Creek both have 150+ ft wide gravel lots near the locations where dry hydrants will be installed, so they provide good helicopter clearance and reliable access to water. These locations could provide a higher elevation drafting alternative to refilling in the Klamath River. The Mallard Cove boat launch at Copco Lake provides a similarly suitable gravel lot staging location for a portable tank near Deer Creek. They can be placed in open areas that meet the drafting criteria for helicopters. Water pumps and hoses will accompany the portable tanks for on-site pumping from ponds, streams, and hydrants. If requested, KRRC will also pay for two portable, helicopter sling tanks (350 gallons each) and pumps and hoses to be housed at CFSU headquarters in Yreka that can be airlifted elsewhere if needed. KRRC will seek an agreement with Cal Fire to implement this measure.

6.5 Evaluation of Post-Removal Fire Risk

The Reax analysis demonstrates (Appendix A), that the proposed long-term fire management measures meet the objectives that the Proposed Action, post-construction, will not increase the risk of fire ignitions that currently exist or cause a net diminution in fire-fighting resources in the Basin. The KRRC believes that the proposed long-term measures proposed meet the objectives and improve firefighting resource availability and decrease ignition risk in the Basin relative to the *status quo*. KRRC's conclusion is supported by the numerical modeling and quantitative analysis performed by Reax (Appendix A).

Reax analyzed the effects of the Proposed Action on wildfire in the Basin with numerical modeling, where stochastic ignition locations and weather conditions would initiate wildfires that burn on the landscape and fuels of the Basin (see Appendix A for a detailed description). This Monte Carlo wildfire modeling generates a burn probability for each location on the landscape. Burn probability is a quantitative measure of the likelihood that a point on the landscape will be impacted by a fire during a given period of time. The Reax wildfire modeling yields an analogous measure, whereby burn probability is the number of times a point on the landscape burned in model runs divided by the total number of model runs. Reax simulated both existing “pre-restoration” conditions with the reservoirs present and a “post-restoration” scenario where the reservoirs have been replaced with vegetation (see Section 6.5.1). In these first simulations, initial attack and fire suppression were disabled. In a second set of simulations, Reax enabled modeling of initial attack and fire suppression to investigate the effects of the early detection measures proposed as part of the Proposed Action, and their effect on reducing initial attack arrival time, on burn probability (see Section 6.5.2).

6.5.1 Burn Probability and Risk of Ignition

The Reax modeling demonstrates quantitatively that the Proposed Action and the replacement of the reservoirs with vegetation will have a negligible effect on burn probability in the ASE area (Table 6-3, Figure 15) and that mean burn probability should decrease as a result of the post-removal fire management measures (Section 6.5.2). In the simulations that do not consider the management measures, the mean burn probability in the ASE area for “pre-restoration” and an average “post-restoration” are 7.73E-06 and 7.75E-06, respectively, which amounts of an average percent change of 0.29% that varies from 0.00% to 0.90% depending on fuel type (Table 6-3). This percent change is negligible and within the range of variability from the stochastic/random nature of the analysis. The environmental conditions related to fire ignition (e.g. lightning, high temperatures, high wind speeds, and drought conditions) will be unaffected by the Proposed Action, so they do not change burn probability or ignition risk as a result of the Proposed Action. There is an increased risk of lightning striking fuel sources rather than water with the loss of the reservoirs, and this risk is captured in the Reax analysis (Appendix A). However, lightning tends to strike the highest objects in the landscape, so the risk of strikes occurring in the “post-restoration” Klamath River valley bottom are much lower (Appendix A). The variability in simulated burn probability as a result of stochasticity of wildfire ignition locations in the ASE area amounts to comparable magnitude of local changes in burn probability to those associated with the loss of the reservoirs (Figure 15). As a result, the Reax analysis demonstrates that burn probability in the ASE area is relatively unaffected by the replacement of the reservoirs with various fuel sources.

Table 6-3. Change in modeled burn probability within ASE area from pre-restoration to post-restoration fuels.

Fuel	Mean burn probability	Percent change[1]
Pre-restoration	7.73E-06	
Post-restoration (short grass)	7.80E-06	0.90%
Post-restoration (grass / shrub)	7.72E-06	0.00%
Post-restoration (timber)	7.73E-06	0.01%

[1] Percent change calculated relative to pre-restoration burn probability.

The risk of ignition for both wildfires and structure fires in the Basin could decrease as a result of the Proposed Action, even without the reductions in burn probability from the management measures. More than 15 miles of power transmission and distribution lines will be removed as part of the Proposed Action. Overhead utilities are an ignition source that has started large fires in California before, and they account for hundreds of ignitions per year in PacifiCorp's Northern California service territory (PacifiCorp, 2019). The removal of these lines could cause the CPUC to declassify the current "Elevated Fire Threat" designation for the Copco Lake area (Figure 3) and replace it with a "No Threat" designation.

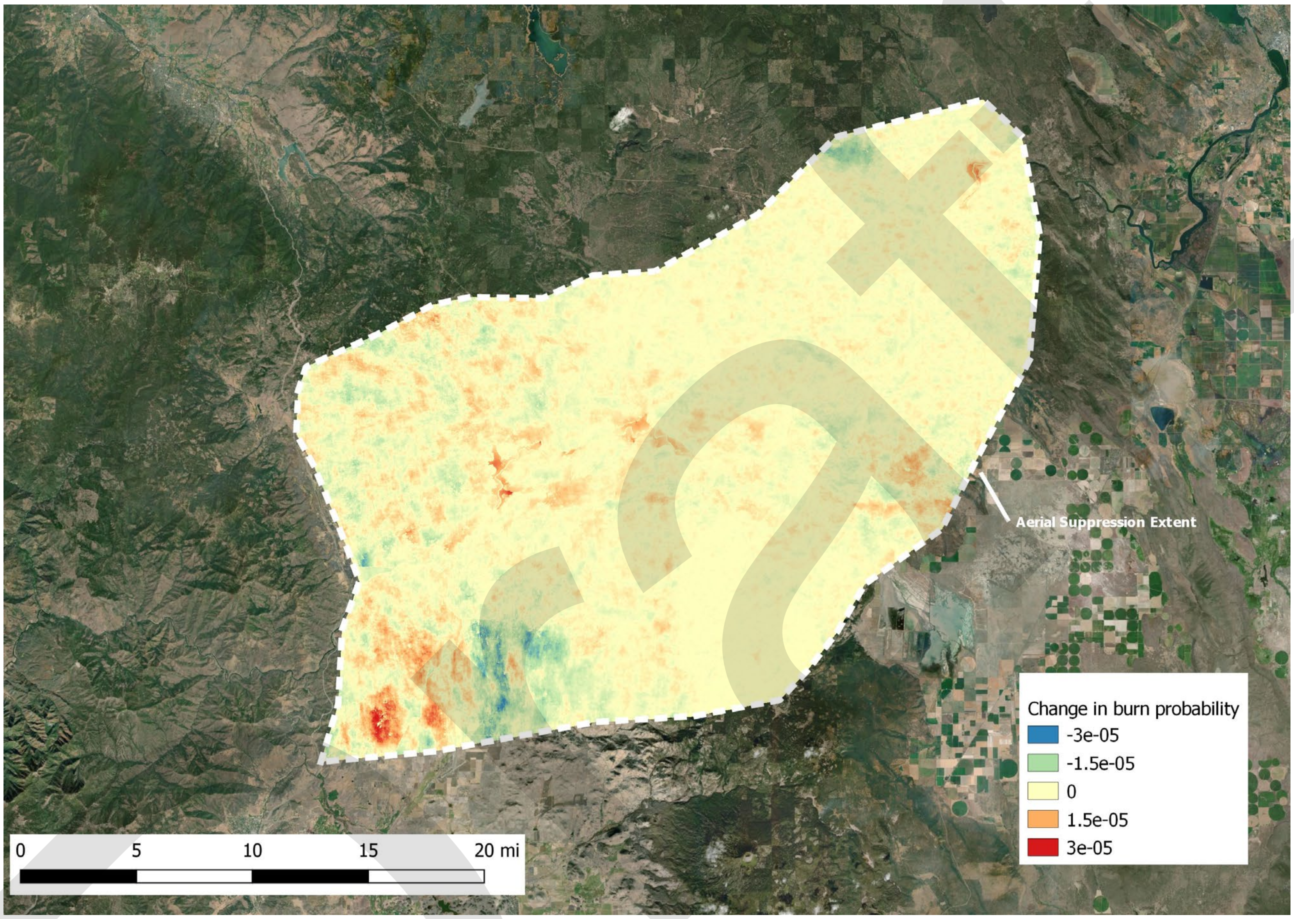

Figure 15. Difference between modeled pre- and post-restoration burn probabilities. Red/orange and blue/green indicate increases and decreases in burn probability, respectively. From Reax report (Appendix A).

The addition of the chipper and dump bed trailer provided to FSCSC should decrease the risk of ignitions unintentionally caused by burning debris piles and thereby decrease the risk of structure fires in the Basin. Some local residents currently comply with defensible space regulations by burning slash and debris from their property (debris burning), and these debris burning piles occasionally get out of control. Debris burning accounted for 5.05% of all large (grass fires > 100 ac, timber fires > 5 ac) fire ignitions in Northern California from 2007 to 2017 and 6.20% (15 of 240 total ignitions) of the ignitions in PacifiCorp's Northern California service territory over the same period (PacifiCorp, 2019). On Cal Fire-protected lands in Siskiyou County from 1919 to 2016, debris burning has accounted for an average of 800 to 1600 acres burned per year and 26 to 43 fires per year in Siskiyou County (Keeley and Syphard, 2018). The chips produced by the chipper will be hauled away in the dump trailer to safe and approved locations, and thereby remove the fuel source from each property. A chipper is not currently available to residents, so the chipper at FSCSC will allow more residences to meet the defensible space requirements

6.5.2 Fire-Fighting Capabilities

The Reax analysis quantitatively demonstrates that by providing new early detection and initial attack capabilities, which can help contain small fires before they grow into large fires, KRRC has offset the loss of the reservoirs as a water source and fuel break. These new capabilities are not currently available in the Basin, so they represent an improvement over the existing resources. Early detection and rapid, efficient deployment of initial attack resources are critical for containing fires in the Basin before they become large, dangerous events. The fuel types, dry and hot conditions, and high winds in the ASE area are conducive to the rapid spread of wildfires, so lowering response time with improved early detection and more capable initial attack resources is critically important. In addition, the much-improved viewshed coverage provided by the new MDS cameras will dramatically improve the ability to monitor on-going fires and efficiently direct and deploy aerial and ground resources.

The viewshed analysis in the Reax report (Appendix A) demonstrates that the ability to detect and triangulate fires will improve dramatically to nearly full coverage of the 568.9 mi^2 ASE area with the additional proposed MDS cameras (Figure 16, Table 6-4). The new cameras increase coverage dramatically in the southern portion of the ASE area and the high fire danger area of the Klamath Mountains west of the ASE area (Figure 16). With the new cameras, 93% of the ASE area is visible at a height of 500 ft above the ground surface (i.e., as an indication of detecting the smoke plume as it rises) as opposed to only 66% with the existing resources (Table 6-4). Importantly, the new cameras increase the percentage of the ASE area over which fire location can be triangulated by nearly 40% (Table 6-4) with much of the increase along the Klamath River (Figure 16). Given the importance for locating which side of the river a fire is burning for effective deployment of initial attack resources, the new triangulation capabilities are tremendously valuable. Nearly the entire basin will have fire detection coverage as a result of the new MDS cameras, and this improvement will translate into more rapid and efficient deployment of fire suppression resources and initial attack success.

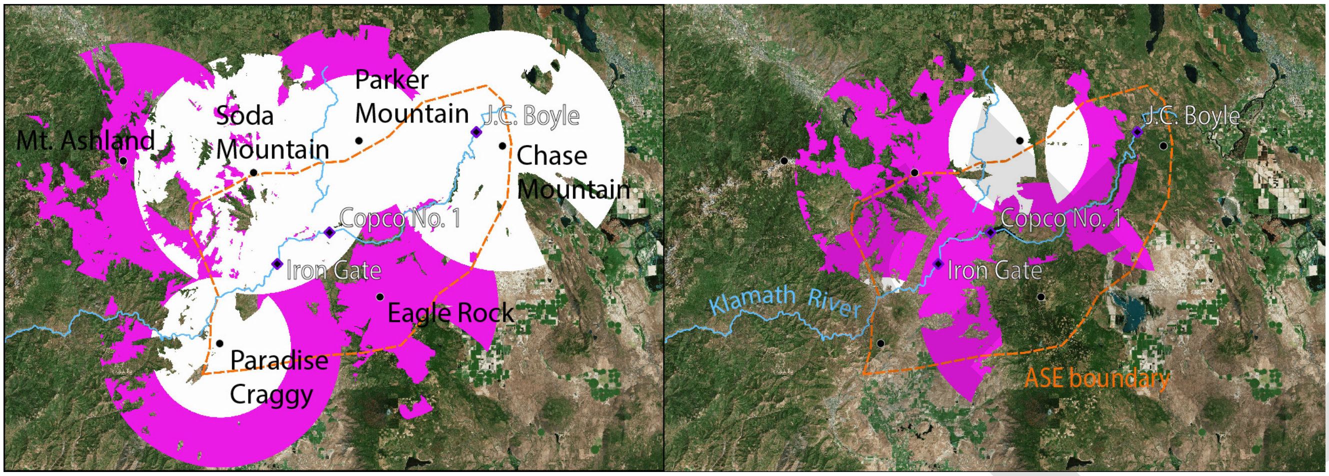

Figure 16. Comparison of pre- (white) and post-Proposed Action viewsheds at 500 ft above ground level with additional coverage (pink) by one observer (left) and multiple observers (right). From Reax report (Appendix A).

The MDS system has proven effective at improving the accuracy and frequency of rapid fire detection. With the proposed set of cameras, the agencies will be able to quickly locate fires anywhere in the ASE area and efficiently deploy initial attack resources. This technology is an invaluable addition to the Basin's fire suppression capabilities because it will shorten by minutes or even hours the initial attack response time from fire ignition to arrival of initial attack resources compared to the current strategies. Currently, fire suppression personnel in much of the ASE area rely on fielding 911 calls, which may be delayed getting into cellular range and may not have specific information on fire location, and then they must search for the fire location in the field. At fire growth and spread rates as fast as 1.25 mph in the area (Siskiyou County, 2019; Stephens et al., 2008), the time savings provided by Proposed Action measures are dramatic. Given that CFSU deals with hundreds of ignitions each year, improvement of initial attack effectiveness by any amount is very significant (*cf*. Fried et al., 2006). In addition, the MDS cameras will increase the speed at which 911-reported fires are accurately located.

Table 6-4. Percentage of ASE area (568.9 mi²) covered from Reax viewshed analysis

	Pre-restoration viewshed			Post-restoration viewshed		
Target height	0 feet	100 feet	500 feet	0 feet	100 feet	500 feet
1 observer	33.4%	45.3%	56.7%	45.9%	51.0%	45.6%
2 observer	1.90%	5.58%	9.63%	8.18%	21.2%	39.8%
3 observer	0%	0%	0%	0.58%	2.44%	7.31%
Total coverage:	35.3%	50.9%	66.3%	54.7%	74.6%	92.7%

To quantify the effect of the early detection and of the proposed fire suppression measures in this plan on reducing burn probability in the ASE area, Reax conducted additional modeling simulations where they enabled initial attack and fire suppression and analyzed varying initial attack arrival times, t_a (Appendix A). As expected, their results show that mean burn probability in the ASE area decreases with decreasing arrival time (Table 6-5, Figure 17). The mean incremental percent change in mean burn probability per 5 minute decrease in t_a is -20.1%, an absolute difference which is nearly two orders of magnitude greater than the average percent change increase (0.29%) in mean burn probability from “pre-restoration” to “post-restoration” conditions (Table 6-5). This result indicates that the even modest improvements in early detection and initial attack arrival time should more than offset the effect of the loss of the reservoirs on mean burn probability in the ASE area. Given that the MDS cameras and other measures should easily offer more than a 5-minute average improvement in initial attack response time, the improvements in burn probability far outweigh the consequences of replacing the reservoirs with vegetation.

The MDS cameras not only assist with more rapid detection of fires compared to, for example, 911 calls, but also in pinpointing fire locations from 911 calls for effective deployment of initial attack resources.

As a result, decreases in initial attack arrival time by more than 5 minutes are likely and should result in large decreases in mean burn probability in the ASE area compared to existing conditions more than offset the impacts of the loss of the reservoirs on mean burn probability.

Table 6-5. Results for mean burn probability from Reax’s wildfire spread modeling

Scenario	Mean burn probability	Percent change in burn probability[1]	Incremental percent change in burn probability[2]
Existing “pre-restoration” conditions	7.73E-06		
No reservoirs, average “post-restoration”	7.75E-06	0.29	
No reservoirs; t_a = 30 mins	1.16E-06		
No reservoirs; t_a = 25 mins	1.08E-06	-6.92%	-6.92%
No reservoirs; t_a = 20 mins	7.69E-07	-33.65%	-28.72%
No reservoirs; t_a = 15 mins	7.03E-07	-39.39%	-8.65%
No reservoirs; t_a = 10 mins	3.76E-07	-67.54%	-46.44%
No reservoirs; t_a = 5 mins	3.40E-07	-70.69%	-9.71%

[1] Percent change in mean burn probability is calculated relative to existing “pre-restoration” conditions. For the initial attack arrival time (t_a) scenarios, percent change is calculated relative to the “No reservoirs; t_a = 30 mins” scenario.

[2] The percent changes are calculated as the change in mean burn probability per 5 minute incremental improvement in arrival time.

The MDS system will add benefit beyond the ASE area to other areas under CFSU and ODF protection. CFSU and ODF protect the extensive mountainous region west of I-5, an area which has a “very high” fire hazard (Figure 2) and an Elevated CPUC fire threat tier (Figure 3). The Paradise Craggy and Mt. Ashland cameras will add important fire detection coverage in this mountainous and forested region, and the Mt. Ashland camera will improve detection around the city of Ashland, Oregon (Figure 16). With the installation of the detection center in the CFSU Yreka office provided by the Proposed Action, additional cameras can be added to the network by CFSU relatively easily and cheaply to improve detection and response capabilities in these high-risk areas.

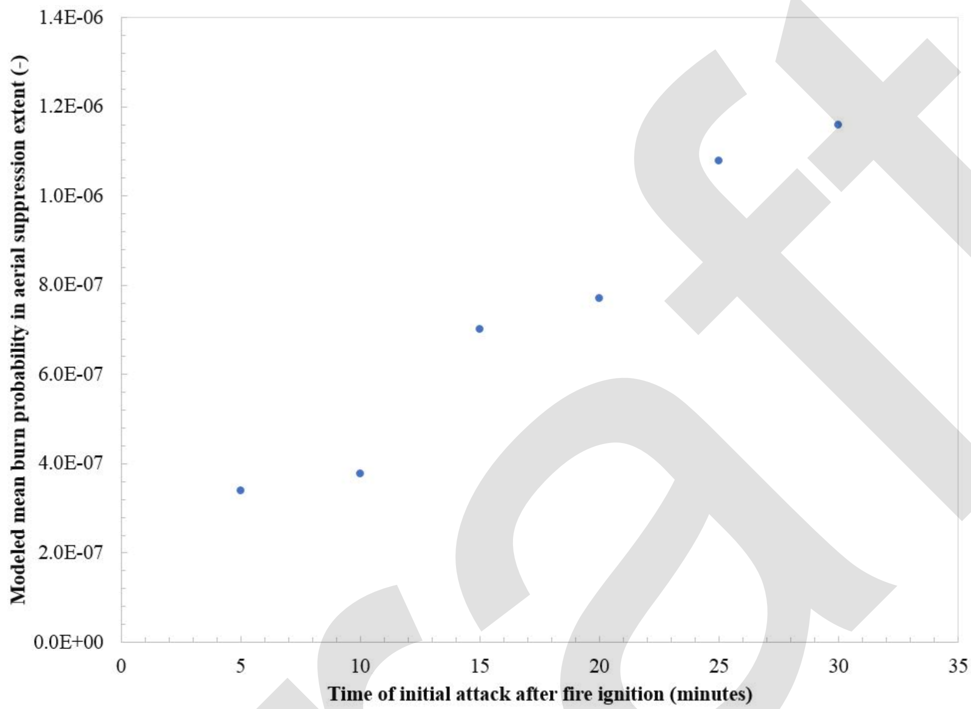

Figure 17. Modeled mean burn probability in ASE area vs. time of initial attack after fire ignition. From Reax report (Appendix A).

Initial attack is often spearheaded by ground crews building containment fire lines, and the ability of ground crews to fight fires in the Basin will improve as a result of the long-term measures. The dry hydrants are new resources that will provide new access to water sources along the major roads in the ASE area for ground-crews and reduce refilling travel times for tenders and fire engines by up to 30 to 60 minutes per turn, depending on fire location, compared to existing boat launches and access points. The Deer Creek dry hydrant (Figure 13) is located in the middle of a relatively dense collection of homes along Ager-Beswick Road to the east and Patricia Avenue to the west and will reduce round-trip travel time between refills by 20 to 30 minutes for fighting structure fires on this southern side of Copco Lake. There are currently 12 boat launches in the ASE area, and there will be a combined 12 boat launches and dry hydrants post-removal. The two new boat launches, which will be specifically designed to accommodate water tenders and fire engines, will be constructed to replace existing gravel-surfaced boat launches that are not suitable for this equipment. The dry hydrants and new boat launches will be an improvement over existing boat launches because they are specifically designed for fire-fighting ground crews. The gravity fed hydrant system at Copco Lake will continue to function, so these capabilities will be maintained post-removal. In addition, initial attack by ground crews will be much more efficient given the improved ability to monitor fire locations in real-time provided by the new MDS cameras.

The free-flowing Klamath River following dam removal is an adequate replacement water source for the loss of the reservoirs with respect to water access, supply, and travel time for helicopter drafting. The loss of J.C.

Boyle will have only a minor impact, given the proximity of Keno Reservoir, which is a better drafting water source than J.C. Boyle Reservoir. Also, two wide, deep pools will be re-exposed in the upstream portion of the J.C. Boyle Reservoir following drawdown. Bucket and longline operations in the other reservoirs should be relatively unaffected by the Proposed Action as dozens of river locations in the reservoir footprints will have suitable width and depth for bucket drafting. Buckets are more commonly used by CFSU and ODF for initial attack than snorkels, so those efforts will be relatively unchanged as a result of the Proposed Action. The anticipated ARAPs should result in at least two locations per reservoir which meet the drafting safety criteria for snorkel helicopters. This should be a sufficient number of drafting locations to limit traffic delays on drafting activities.

Flows in the free-flowing Klamath River following dam removal will be more than sufficient to replenish water even under the most extreme drafting conditions. A large Type 1 snorkel helicopter can hold approximately 2000 gallons and takes about a minute to fill. If a Type 1 snorkel helicopter was drafting continuously, it would extract 2000 gal/min, which is approximately 4.5 cubic feet per second (cfs). For context, the minimum prescribed post-removal Klamath River stream flows from the 2019 National Marine Fisheries Service Biological Opinion (NMFS, 2019) for July and August are 900 cfs, which is equivalent to 400,000 gal/min and is enough flow to support 200 snorkel helicopters drafting continuously. This is an order of magnitude more helicopters than are drafting on even the largest fires, so there is ample water supply for all imaginable circumstances.

The dip tanks will provide additional flexibility and utility for aerial drafting in the ASE area, including capabilities that do not currently exist in the Basin. The permanent dip tank will be a large, safe, and reliable drafting source. The portable tanks can be transported to areas of need and will allow CFSU to create helicopter drafting opportunities in many locations around the ASE area that do not currently support aerial efforts.

While the reservoirs currently offer more wetted area for snorkel drafting than the post-removal river will, it is impossible to say how this difference in wetted area will affect firefighting abilities in the Basin. Each fire has different characteristics and will require different fire suppression strategies and resources. The proximity of a water source to the fire is a primary driver of choice for helicopter drafting, and other sources (e.g., ponds and the free-flowing Klamath River) have been used in favor of the reservoirs on even large campaign fires. Furthermore, the number of drafting helicopters used for a given incident will depend on the scale of the fire but also on the allocation of helicopters to other incidents. Given the improvements in early detection, fewer fires should reach a significant scale.

Maximum potential increases in air attack turn-around time are expected to be smaller than the gains in early detection and initial attack response time. Given the many anticipated locations of ARAPs (e.g., Figure 12, Figure 13, and Figure 14), maximum increases in the distance a helicopter would need to travel to access a suitable drafting location are around 1 mile, and most increases will be much smaller compared to existing conditions. As a rule of thumb, each mile added to a helicopter drafting flight adds 2 to 3 minutes to each round-trip water draft and drop (L. Winslow, ODF-SWO, *pers. comm.*, 2019.04.02). Potential maximum increases in helicopter turn-around times during initial attack will be only a fraction of the potential time saved using the MDS system, so aerial initial attack efforts should be more effective post-removal than the *status quo*.

7. KRRC COMMITMENTS

1) KRRC will implement the measures states in this Fire Management Plan, and summarized below, in order to (a) prevent or control any fire caused by construction or habitat restoration activities under the Definite Decommissioning Plan, and (b) avoid a net diminution in firefighting resources, or an increase in fire ignition risk, as a result of the loss of the Project reservoirs.
2) KRRC will comply with all applicable agency regulations and requirements.
3) KRRC will employ the best workplace practices, as described herein, to mitigate fire risk during construction activities.
4) KRRC will enter into appropriate agreements with fire agencies to implement the following measures:
    - Installation of early detection camera technology for Cal Fire and ODF to improve early fire detection capabilities in the Basin
    - Provision of a 9" chipper-dump bed trailer for FSCSC and base model pick-up truck to haul the trailer to assist with defensible space in Siskiyou County
    - Design and construction of six permanent dry hydrants located at or near road crossings of large tributaries to provide additional water sources
    - Verification of continued functionality of Copco Lake hydrant system through license surrender
    - Construction or improvement of three boat launches to access the Klamath River following dam removal
    - Identification and maintenance, through the term of the FMP, of aerial river access points (ARAPs) in the former reservoirs (two per reservoir) that meet specific suitability performance criteria to be used by Type 1 helicopters with snorkels, and
    - Provision to CFSU of one permanent (5000 to 20,000 gallon) dip tank near the town of Copco Lake, three portable, self-supporting (5000 - 6000 gallon) dip tanks, and two helicopter sling (360 gallons) dip tanks; all with required pumps and hoses.

8. AGENCY CONSULTATION

A record of the agency personnel consulted during the development of the FMP and the topics consulted on is provided in Table 8-1.

Table 8-1. Agency personnel consulted during development of the Fire Management Plan.

Agency	Title of Agency Representative	Topics of Consultation	Dates consulted
Cal Fire	Northern Assistant Region Chief	Long-term fire management	2019.02.15
Cal Fire Siskiyou Unit	Unit Chief	Long-term fire management	2019.02.15 2019.09.04
Cal Fire Siskiyou Unit	Shasta Valley Battalion Chief	Long-term fire management	2019.03.04 2019.05.14 2019.09.04
Cal Fire Siskiyou Unit	Assistant Chief of Operations	Long-term fire management	2019.03.04 2019.05.14 2019.09.04
Cal Fire Siskiyou Unit	Forester	Regulations, near-term fire management	2017.08.10 2017.08.14
Cal Fire Siskiyou Unit	Prevention Specialist	Regulations, near-term fire management	2017.08.14
Copco Fire Protection District	Fire Chief	Contact attempted 2019.04.01; 2019.04.10	
Hornbrook Volunteer Fire Department	Chief	Long-term fire management, existing resources	2019.04.01
Keno Fire Department	Chief	Existing resources	2017.08.09
Oregon Department of Forestry - Klamath Lake District	Protection Unit Forester	Regulations, near-term fire management, long-term fire management, existing resources, monitored detection system	2017.08.16 2019.05.16 2020.04.22

Agency	Title of Agency Representative	Topics of Consultation	Dates consulted
Oregon Department of Forestry - Klamath Lake District	Stewardship Forester	Regulations, near-term fire management	2017.08.16
Oregon Department of Forestry - Klamath Lake District	Management Unit Forester	Regulations, near-term fire management	2017.08.16 2019.05.16
Oregon Department of Forestry – Southwest Oregon District	Forester	Near-term fire management, PDM	2017.08.11
Oregon Department of Forestry – Southwest Oregon District	Assistant District Forester/Medford Unit Forester	Aerial fire suppression	2019.04.02 2019.04.12 2019.04.29 2019.05.16 2019.09.04
Oregon Department of Forestry – Southwest Oregon District	Wildland Fire Supervisor – Dispatch	Monitored detection system	2019.05.16
Oregon Department of Forestry – Southwest Oregon District	Lead Detection Dispatcher	Monitored detection system	2019.05.29 2019.06.12
US Bureau of Land Management – Lakeview District, Klamath Falls Field Office	Assistant Fire Manager	Regulations, jurisdictions	2020.06.10
US Bureau of Land Management – Lakeview District	Manager	Regulations, jurisdictions	2017.08.11
US Bureau of Land Management – Northern California District, Redding Field Office	Forest Ecologist	Regulations, jurisdictions	2017.08.29

9. REFERENCES

Cal Fire, (n.d.-a). Firefighting Aircraft Recognition Guide. http://www.fire.ca.gov/communications/downloads/AviationGuide_FINAL_web.pdf. Accessed 2019.

Cal Fire. (n.d.-b) Cal Fire Operations Handbook. http://calfireweb.fire.ca.gov/library/handbooks/

Cal Fire, 1999. Industrial Operations Fire Prevention Field Guide. July 29, 1999.

Cal Fire, 2007. Fire and Resource Assessment Program. Fire Hazard Severity Zones [computer file]. Sacramento, CA.

California State Board of Forestry and Fire Protection (CSBFFP) and Cal Fire, 2018. 2018 Strategic Fire Plan for California. August 22, 2018.

Cal Fire, 2019. Community Wildfire Prevention and Mitigation Report in response to Executive Order N-05-19. February 22, 2019.

Cal Fire Siskiyou Unit (Cal Fire), 2016. Unit Strategic Fire Plan: Siskiyou Unit. Yreka, CA.

Estes, B.L., Knapp, E.E., Skinner, C.N., Miller, J.D. and Preisler, H.K., 2017. Factors influencing fire severity under moderate burning conditions in the Klamath Mountains, northern California, USA. Ecosphere, 8(5), p.e01794.

Fried, J.S., Gilless, J.K. and Spero, J., 2006. Analysing initial attack on wildland fires using stochastic simulation. International Journal of Wildland Fire, 15(1), pp.137-146.

Governor Newsom's Strike Force (Strike Force), 2019. Wildfires and Climate Change: California's Energy Future. A Report from Governor Newsom's Strike Force. April 12, 2019.

Keeley, J.E. and Syphard, A.D., 2018. Historical patterns of wildfire ignition sources in California ecosystems. International Journal of Wildland Fire, 27(12), pp.781-799.

Klamath River Renewal Corporation Technical Representatives (KRRC), 2020. Definite Decommissioning Plan for the Lower Klamath Project. Prepared for the Klamath River Renewal Corporation.

Lee, Y., Fried, J.S., Albers, H.J. and Haight, R.G., 2012. Deploying initial attack resources for wildfire suppression: spatial coordination, budget constraints, and capacity constraints. Canadian Journal of Forest Research, 43(1), pp.56-65.

Oregon Department of Forestry (ODF), 2019. Fire Season Requirements. https://www.oregon.gov/ODF/Fire/FirePreventionDocuments/2019%20Fire%20Season%20Requirements.pdf

National Fire Protection Association (NFPA), 2017a. NFPA 25 Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems. August 24, 2016.

National Fire Protection Association (NFPA), 2017b. NFPA 1142 Standard on Water Supplies for Suburban and Rural Fire Fighting. June 2, 2016.

National Fire Protection Association (NFPA), 2018. NFPA 1143 Standard on Wildland Fire Management. August 21, 2017.

National Fire Protection Association (NFPA), 2019a. NFPA 51B Standard for Fire Prevention During Welding, Cutting, and Other Hot Work. July 15, 2018.

National Fire Protection Association (NFPA), 2019b. NFPA 1963 Standard for Fire Hose Connections. November 25, 2018.

National Marine Fisheries Service (NMFS), 2019. Endangered Species Act Section 7(a)(2) Biological Opinion, and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Response for Klamath Project Operations from April 1, 2019 through March 31, 2024. NMFS Consultation Number: WCR-2109-11512, WRCO-2019-00113. March 29, 2019.

PacifiCorp, 2019. California Wildfire Mitigation Plan. Implementing Requirements of Senate Bill 901 and Rulemaking 18-10-007. February 6, 2019.

PacifiCorp, 2020. California Wildfire Mitigation Plan. Implementing Requirements of Senate Bill 901 and Rulemaking 18-10-007. February 7, 2020.

Siskiyou County, 2019. Community Wildfire Protection Plan – Siskiyou County. May 21, 2019.

South Central Oregon Fire Management Partnership (SCOFMP), 2015. South Central Oregon Interagency Fire Danger Operating Plan.

Stephens, S.L., Weise, D.R., Fry, D.L., Keiffer, R.J., Dawson, J., Koo, E., Potts, J. and Pagni, P.J., 2008. Measuring the rate of spread of chaparral prescribed fires in northern California. Fire Ecology, 4(1), pp.74-86.

U.S. Bureau of Reclamation (USBR), 2011. Reservoir Area Management Plan for the Secretary's Determination on Klamath River Dam Removal and Basin Restoration. Klamath River, Oregon and California. Technical Report No. SRH-2011-19. Mid-Pacific Region. June 2011.

U.S. Bureau of Reclamation (USBR) and California Department of Fish and Game (CDFG), 2012. Klamath Facilities Removal Final Environmental Impact Statement / Environmental Impact Report. Sacramento, CA.

U.S. Forest Service (USFS), Remote Sensing Applications Center, 2010. MODIS Active Fire Detections for the CONUS [computer file]. Salt Lake City, Utah.

U.S. Forest Service (USFS) and U.S. Office of Aviation Services (OAS), 2015. Interagency Aviation User Pocket Guide. NFES 001373. May 2015.

Wildland Fire Technologies, Inc. (WFT), 2016. Klamath County Community Wildfire Protection Plan 2016 update. Klamath Falls, OR. December 5, 2016.

APPENDIX A – REAX ENGINEERING, INC., QUALITATIVE WILDFIRE RISK ANALYSIS OF THE KLAMATH RIVER RENEWAL PROJECT

Reax Engineering Inc.
Job # 19-0739

Quantitative Wildfire Risk Analysis of the Klamath River Renewal Project

Prepared for Klamath River Renewal Corporation

Revision 1
June 5, 2020

Document Revision History

Job #	Job Name	Client
19-0739	Quantitative Wildfire Risk Analysis of the Klamath River Renewal Project	Klamath River Renewal Corporation

Revision #	Date	Description	
Rev 0	February 26, 2020	Interim draft provided for KRRC review and comment.	
		Prepared by: Chris Lautenberger Darrell Schulte Delaney Seeburger Maria Theodori	**Approved by:** Chris Lautenberger
Rev 1	June 5, 2020	First complete draft.	
		Prepared by: Chris Lautenberger Darrell Schulte Delaney Seeburger Maria Theodori	**Approved by:** Chris Lautenberger
		Prepared by:	**Approved by:**
		Prepared by:	**Approved by:**

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LIST OF ABBREVIATIONS

AI .... Artificial Intelligence
ASE .... Aerial Suppression Extent
CAL FIRE .... California Department of Forestry and Fire Protection
EVS .... EnviroVision Solutions
FFWI .... Fosberg Fire Weather Index
FMP .... Fire Management Plan
FOD .... Fire Occurrence Database
FRAP .... Fire and Resource Program
GIS .... Geographic Information System
IAP .... Incident Action Plans
KRRC .... Klamath River Renewal Corporation
MDS .... Monitored Detection System
MEL .... Most Efficient Level
MFFWI .... Modified Fosberg Fire Weather Index
NARR .... North American Regional Reanalysis
NIFC .... National Interagency Fire Center
NWCG .... National Wildfire Coordinating Group
ODF .... Oregon Department of Forestry
WRF .... Weather Research and Forecasting

EXECUTIVE SUMMARY

Reax Engineering Inc. (Reax) has been retained by Klamath River Renewal Corporation (KRRC) to analyze KRRC's Fire Management Plan (FMP) and quantify the change in fire risk associated with the implementation of the Klamath Hydroelectric Settlement Agreement (KHSA). The KRRC will remove four dams along the Klamath River and adjacent areas. The following factors, among others, are considered as part of this analysis:

- Fire history in the area,
- Vegetation growth in areas that were previously reservoir,
- Potential reduction in the amount of water available for firefighting purposes as a result of reservoir removal,
- Removal of potential ignition sources associated with electrical generation, and
- Fire risk reduction measures such as real-time fire detection monitoring, and introduction of additional water sources for ground crews.

Our findings indicate the amount and accessibility of water for suppression will not be reduced by the removal of the reservoirs created by the dams. The amount of water that is available for extended attack, *i.e.* fires lasting over 48 hours that require staffing and shift changes, likewise will remain unchanged. This water will be available from dip tanks, dry hydrants, and the identified river pools rather than from large, open reservoirs. The river pools do alter the amount of risk to helicopter pilots as the maneuver requires hovering to drop in and out of a canyon. The ability to use water from the Klamath River for fire suppression will not be impacted although the convenience and technical skill required to access that water will be. Furthermore, Upper Klamath Lake and Link Reservoir will still be available for suppression efforts in the northeastern region of the project area.

One of the post-removal resources proposed in the FMP is Monitored Detection System (MDS) consisting of a network of detection cameras. In California and Oregon, there has been an increase in detection camera installations at fire lookouts that were historically staffed. A viewshed analysis was conducted of the existing and planned detection camera locations to assess and compare fire detection coverage of the Klamath Basin both pre- and post-restoration. This was done to determine if the proposed post-restoration fire detection resources provide adequate coverage of the project area within the Klamath River Basin and to quantify the change in detection effectiveness between pre- and post-restoration resources. The post-restoration detection scheme provides a significant increase in detection coverage for the protected area with a corresponding increase in triangulated coverage area. This increase in coverage area will lead to reduced fire detection times and thereby more rapid initial attack responses.

To assess how improved detection times (from cameras) and increased burnable landmass (from dewatering) affect landscape-scale burn probabilities in the project area, a Monte Carlo fire spread analysis was used to analyze several different scenarios within the Aerial Suppression Extent (ASE) defined by CAL FIRE which delineates the land area where water drafted from the existing reservoirs could be used in aerial fire suppression. Based on this analysis and the related analyses of water availability, post-removal suppression resources provided, and the proposed MDS, the probability of containment on initial attack within the ASE will remain unchanged or increase for the following reasons:

- Dewatering causes an insignificant (< 1%) increase in modeled burn probability,
- There is no reduction in water availability for firefighting purposes,
- Fire detection and reporting times will, at worst, remain unchanged but are more likely to be reduced due to the coverage provided by the proposed MDS, and
- Travel time by responding units will remain unchanged.

The salient conclusions drawn from the analyses presented in this report are:

1. There will be no effective decrease in water availability for firefighting purposes following reservoir drawdown due to implementation of measures described in the Fire Management Plan. The ease with which the helicopters and fixed wing aircraft can access the reservoirs will change but the amount of water available will not be affected by dam removal. Furthermore, the dip tanks and dry hydrants provided will offer alternate water sources for suppression efforts independent of water accessibility from the Klamath River.
2. Cameras will provide an effective means of early fire detection in the project area with fire sizes at detection expected to be between 0.01 acres and 0.1 acres. Detection at relatively smaller fire sizes expedites suppression response and increases probability of containment in initial attack.
3. Dewatering of the project reservoirs and reclamation of approximately 1,000 acres of land will have a negligible effect on burn probability.
4. Probability of containment on initial attack shows that early detection associated with installation of fire detection cameras increases probability of containment, consequently reducing modeled mean burn probability. For example, a reduction in average arrival time from 30 minutes to 25 minutes results in a 7% decrease in modeled mean burn probability within the ASE, and a reduction in average arrival time from 30 minutes to 20 minutes results in a 34% decrease in modeled mean burn probability within the ASE.

1.0 INTRODUCTION

Reax Engineering Inc. (Reax) has been retained by the Klamath River Renewal Corporation (KRRC) to quantify the change in fire risk associated with the removal of four dams along the Klamath River and adjacent areas where fire risk may change. The following factors, among others, are considered as part of this analysis:

- Fire history in the area,
- Vegetation growth in areas that were previously reservoir,
- Potential reduction in the amount of water available for firefighting purposes,
- Removal of potential ignition sources associated with electrical generation, and
- Risk reduction/mitigation countermeasures such as real-time fire detection monitoring, introduction of additional water sources for ground crews.

As described in detail later in this report, one of tools used in this work is a Monte Carlo fire spread analysis [1-2] that quantifies landscape-scale burn probability under different scenarios so that the effect of vegetation regrowth, advance warning, *etc*. can be quantified.

This report is organized as follows:

- Section 2 provides background information regarding the KRRC proposed action.
- Section 3 describes fire history in the analysis area.
- Section 4 analyzes pre- and post-restoration state of the analysis area and the proposed changes in suppression and detection effectiveness.
- Section 5 presents the Monte-Carlo fire spread modeling methodology used to quantify changes in landscape-scale burn probability.
- Section 6 summarizes our conclusions.

2.0 BACKGROUND

2.1 Fire management plan

KRRC developed a Fire Management Plan (FMP) [3] to address fire prevention and suppression associated with the physical removal of four hydroelectric dams along the Klamath River (Iron Gate, Copco No. 1, Copco No. 2, and J.C. Boyle). The goal of the FMP is to assure that the dam removals will not cause a net diminution in firefighting resources and that, both during and after demolition, the current fire ignition risk that exists will not increase as a result of the dam removal. Pursuant to this goal, the FMP contains:

- Background on the history of fire in the region,
- Local fire agency jurisdictions and regulatory requirements,
- Descriptions of the short- and long-term FMPs to be implemented by KRRC.

Review and analysis of the FMP is the starting point for the work described in the current report.

2.2 Analysis area and aerial suppression extent

Analyzing fire risk only in an area immediately adjacent to the river course discounts the impact that removing the dams could have on fire risk at greater distances. Conversely, analyzing fire risk in areas at scales approaching the size of California and Oregon is inefficient. For that reason, the analysis area used in this proposed action (Figure 1) is a 50-mile buffer surrounding the four dams slated for removal. The distance of 50-miles was chosen to strike a balance between analyzing an unnecessarily large region and capturing the extent of the area that could be impacted by the dam removal. The analysis area shown in Figure 1 is used primarily for analyzing fire history (Section 3.0) and conducting Monte-Carlo fire spread analyses (Section 0).

A smaller area known as the Aerial Suppression Extent (ASE) as shown in Figure 2 was used as a boundary in the detection effectiveness analysis (Section 4.4). The ASE was also used in analyzing any potential changes in suppression effectiveness due to dewatering the reservoirs. The ASE was defined by CAL FIRE and delineates the land area where water drafted from the existing reservoirs could be used in aerial fire suppression.

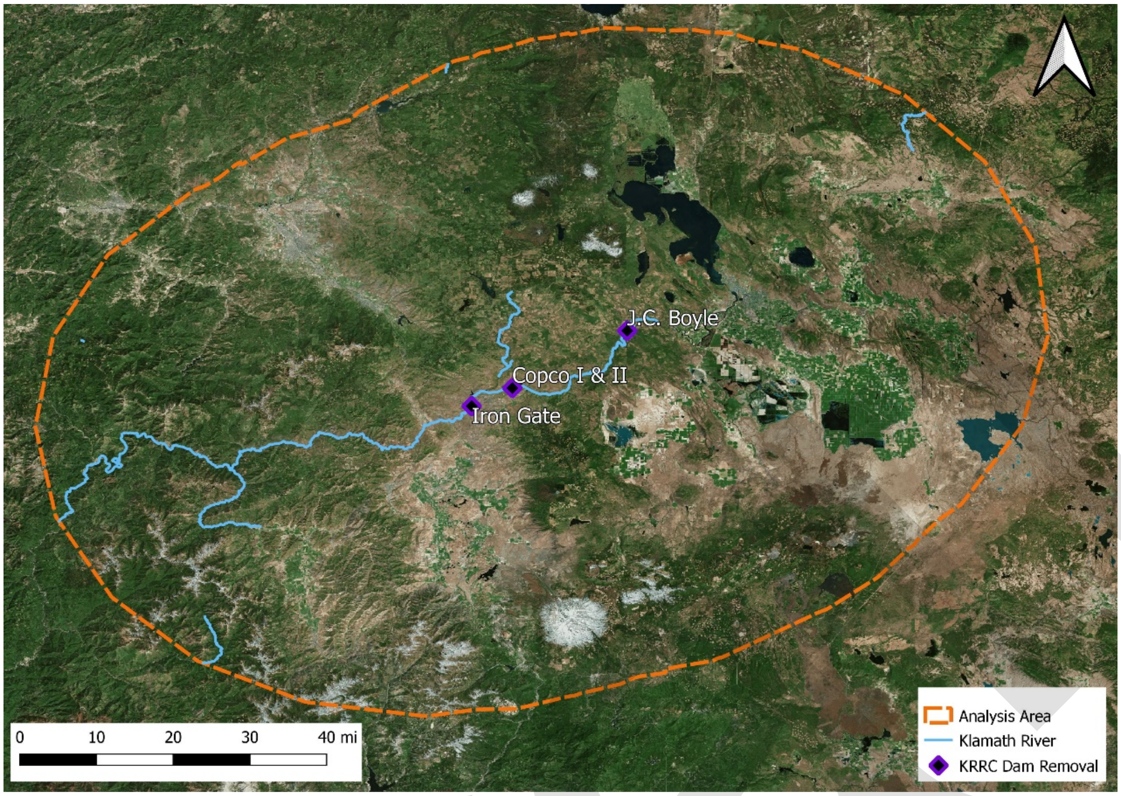


Figure 1. Location of dams in relation to analysis area.

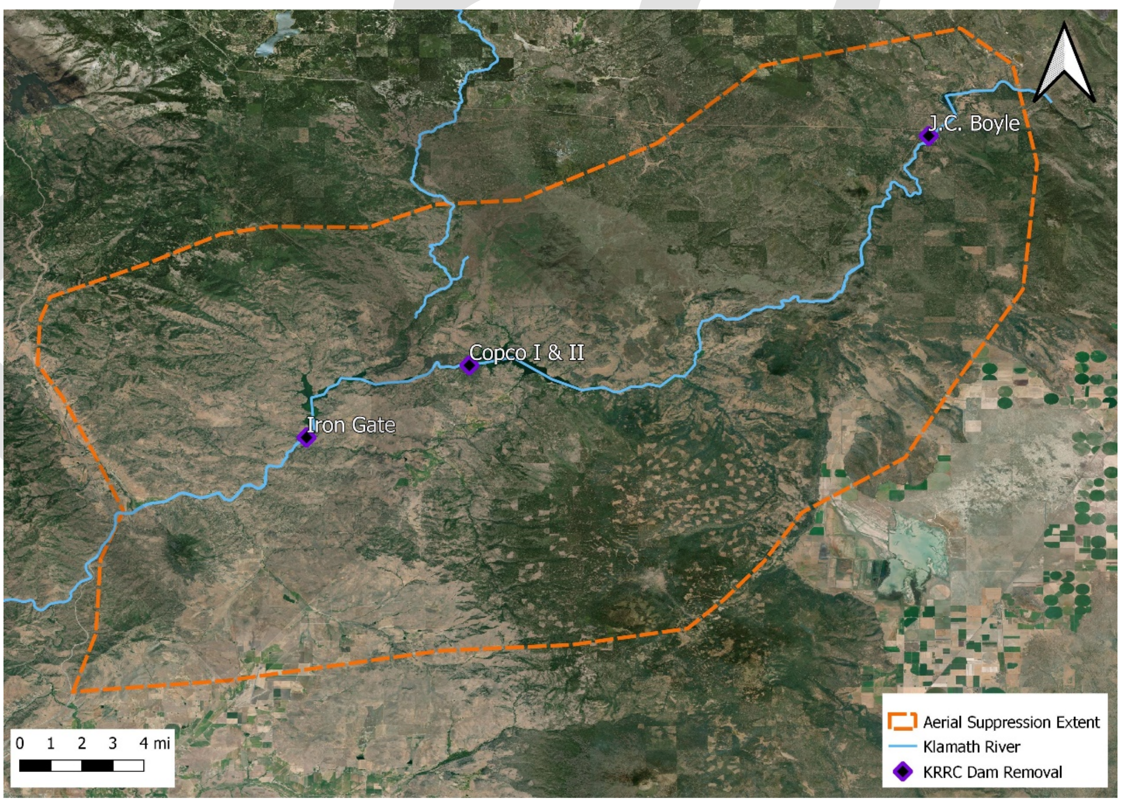


Figure 2. Aerial Suppression Extent.

2.3 Wildfire risk quantification with Monte Carlo fire spread modelling

There is no “one size fits all” approach to quantifying wildland fire hazard or risk. Different approaches may be appropriate under different circumstances. Wildland fire hazard/risk assessment using fire behavior modeling has recently seen increased usage due in part to more powerful computational resources, improved fire models, and readily available geospatial input data. For example, ArcFuels [4-5] provides a desktop-based interface between ArcGIS and widely-used fire behavior models such as FARSITE [6] and FLAMMAP [7].

Keane *et al.* [8] highlighted the potential for Monte Carlo analysis to be used for wildland fire risk quantification. One advantage of such approaches is that fire shadows, islands, and related effects can be captured. For example, with all other factors held constant, an area downwind from an obstacle to fire spread such as a large barren area or water body is less likely to burn than areas upwind from the obstacle to fire spread. Similarly, a patch of highly flammable fuels surrounded by less flammable fuels is less likely to burn [9]. These spatial effects cannot be captured by analyses that consider conditions only at a point, or burn every point as a head fire, but would be captured by analyses that include fire progression. For these reasons, Monte Carlo simulations where fire spread is modeled from tens of thousands of separate ignition locations under a range of weather conditions is one of the most promising tools for quantitative wildland fire risk/hazard assessment.

Monte Carlo fire spread modelling techniques are now being applied in regulatory proceedings. For example, the California Public Utilities Commission (CPUC) recently commissioned development of powerline fire risk maps. The resultant high fire threat district maps were adopted by the CPUC for promulgating fire prevention regulations in 2018. One of the bases for these maps was Monte Carlo fire spread modeling conducted by an Independent Expert Team (IET) led by CAL FIRE. A similar approach has already been applied in Victoria, Australia, to quantify fire risk associated with overhead electrical utility ignited fires [10-14]. The Monte Carlo fire spread modeling techniques applied in this report are similar to those described above and used to develop the CPUC high fire threat district maps and map powerline risk in Australia.

3.0 FIRE HISTORY

To understand how fire has historically impacted the analysis area, fire history records for Oregon and California were aggregated and analyzed. Such analysis of past fire history provides context for historical fire sizes, locations, causes, and frequency at which fires occur. It can also provide insight into local hazards or weather events that dramatically influence fire behavior.

3.1 Fire occurrence

The US Forest Service has published a Fire Occurrence Database (FOD) [15] which contains spatial information for wildfires in the United States between 1992 and 2015. Federal, state, and local fire organizations contributed records with minimum requirement that the records include discovery date, final fire size, and a point location accurate to 1-square mile. Where possible, data were transformed to meet the National Wildfire Coordinating Group's (NWCG) data standards. Error-checking was performed, and redundant records were removed where possible, resulting in a database with 1.88 million geo-referenced wildfire records. The FOD also records fire cause, allowing spatial and temporal distinctions to be made. The difference of greatest interest to the KRRC proposed action is between human-caused fires (Section 3.1.1) and lightning-caused fires (Section 3.1.2).

3.1.1 Human-caused fires

Human-caused fires describe a range of possible ignition causes including debris burning, vehicle, utility, campfires, electrical, *etc*. The locations of these types of ignitions often follow linear features, such as roads, or tend to be clustered near centers of human activity such as residential neighborhoods, campgrounds, *etc*. Human-caused ignition locations in the analysis area are shown in Figure 3. These individual ignition locations were used to create the ignition density "heatmap"[1] shown in Figure 4. The heatmap shows clustering around Interstate 5, Highway 3, Mt. Shasta, Hilt, Colestin, Mt. Ashland, Keno, Yreka, Ashland, Medford, and Chiloquin, among others. Road networks and building footprints were overlaid on the heatmap to illustrate the concentration of ignitions near infrastructure (Figure 5, Figure 6).

Human-caused fires tend to be smaller and are more successfully suppressed in the initial attack phase than lightning-caused fires. However, these ignitions are of significant interest despite the higher probability of success in initial attack because large human-caused fires often occur under high winds [16]. This can be attributed to many factors, including expansion of human-caused ignitions into regions and during seasons where wind speeds are climatologically higher and the reduced tactical capacities of aerial suppression efforts during high winds [16].

[1] Created using inverse distance weighted kernel density

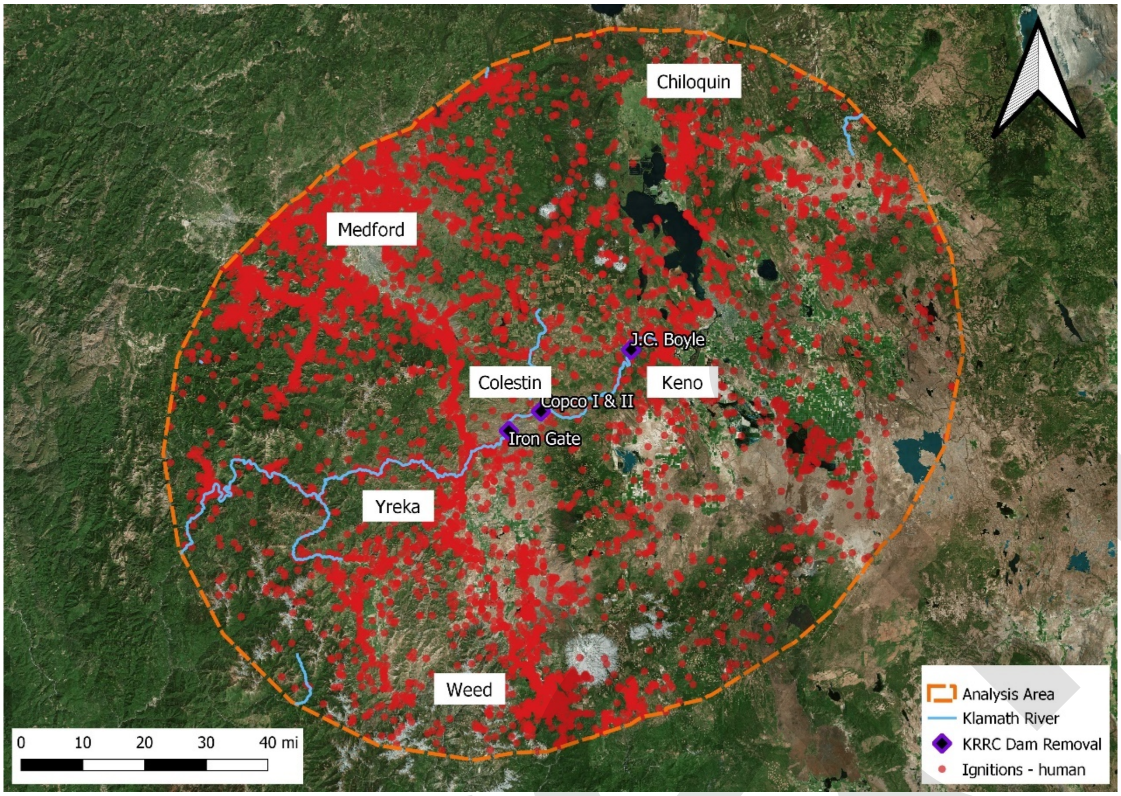


Figure 3. Human-caused ignitions in analysis area.

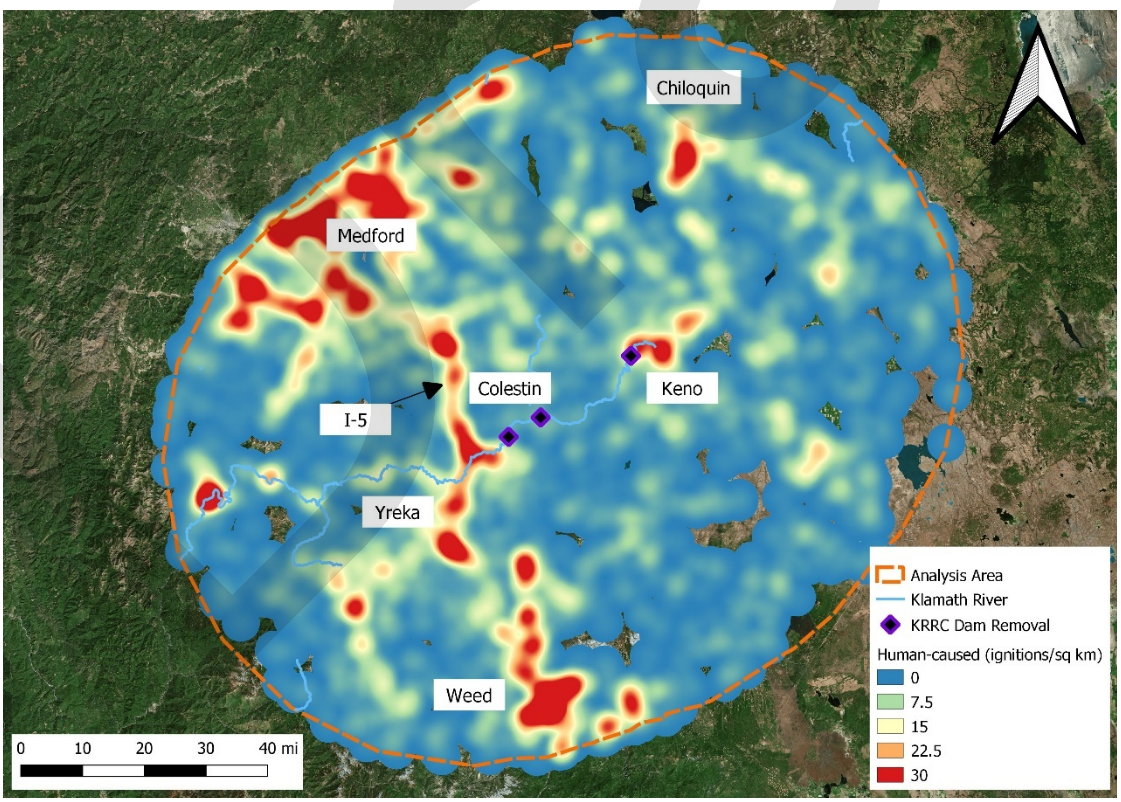


Figure 4. Human-caused fires ignition density.

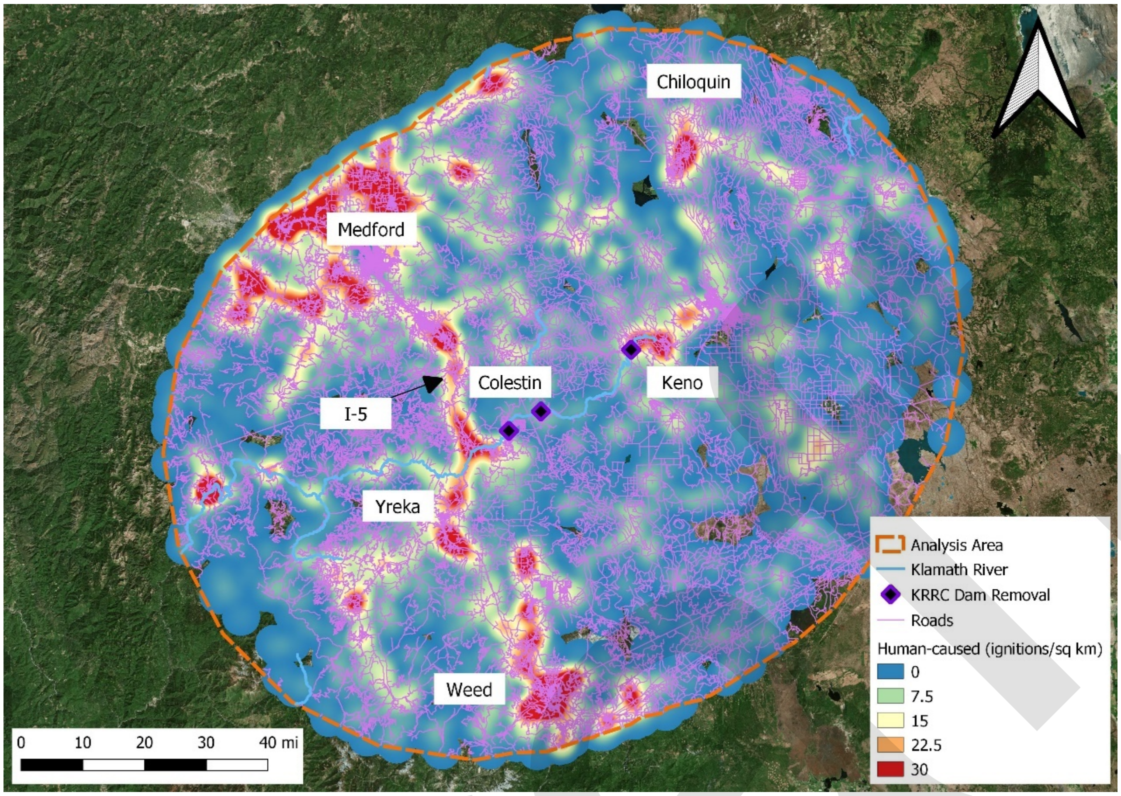


Figure 5. Human-caused fires ignition density and road network.

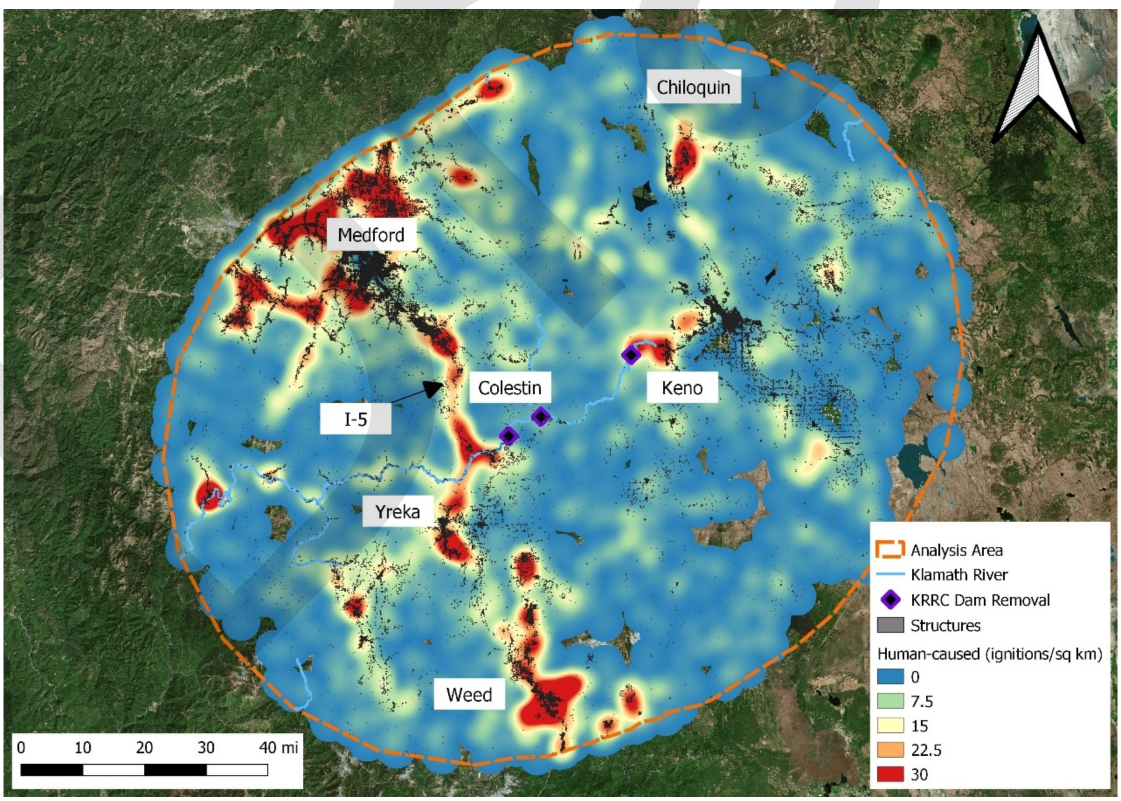


Figure 6. Human-caused fires ignition density and building footprints.

3.1.2 Lightning-caused fires

Locations of lightning-caused ignitions tend to be both more random and more uniform than human-caused fires (Figure 7). Lightning-caused ignitions are indifferent to geographic location and as such display no dominating trends such as following linear features. To show the relative location of lightning-caused ignitions with respect to topography, a heatmap was generated (Figure 8). The distribution of lightning-caused ignitions does not achieve the intense localization that human-caused ignitions exhibited. The lightning-caused fire heatmap is overlaid with a hill shade raster in Figure 9, allowing the correspondence between topography and lightning-caused ignitions to be visualized as lightning-caused ignitions are more prevalent at higher elevations. Lightning-caused ignitions are also less common where certain fuel types are prevalent (*e.g.* wetlands or sparsely vegetated areas).

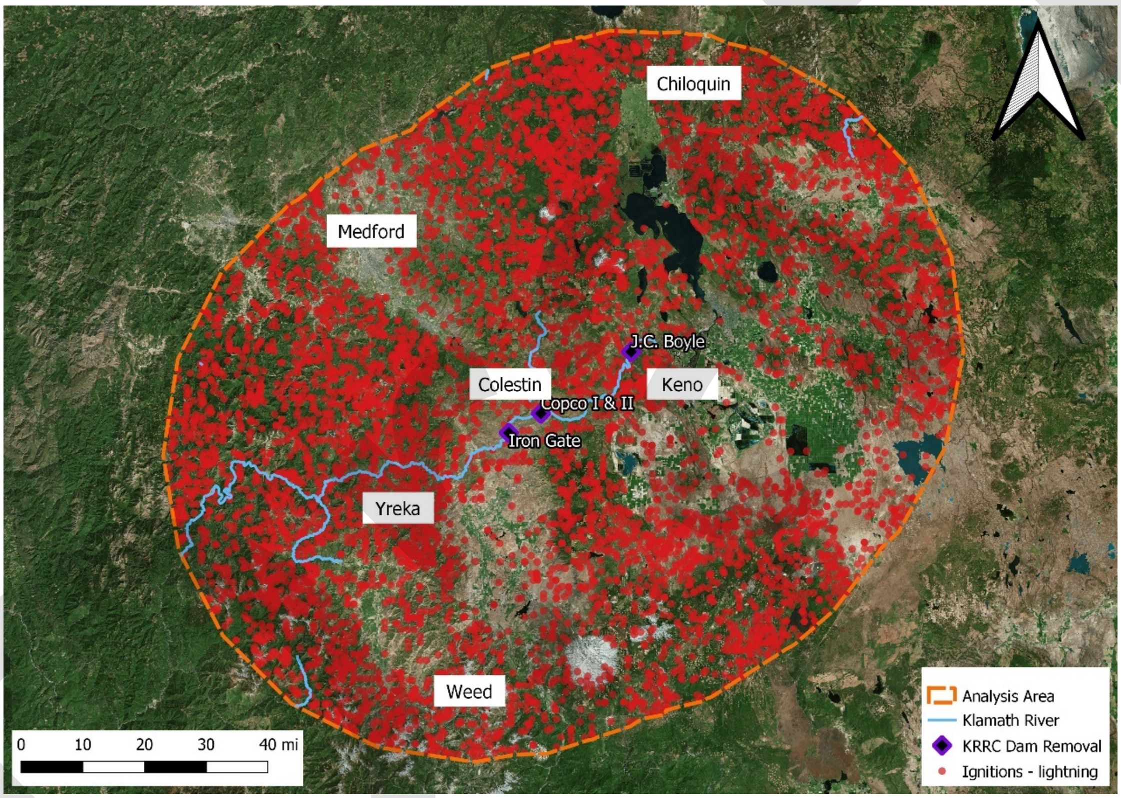


Figure 7. Lightning-caused ignitions in analysis area.

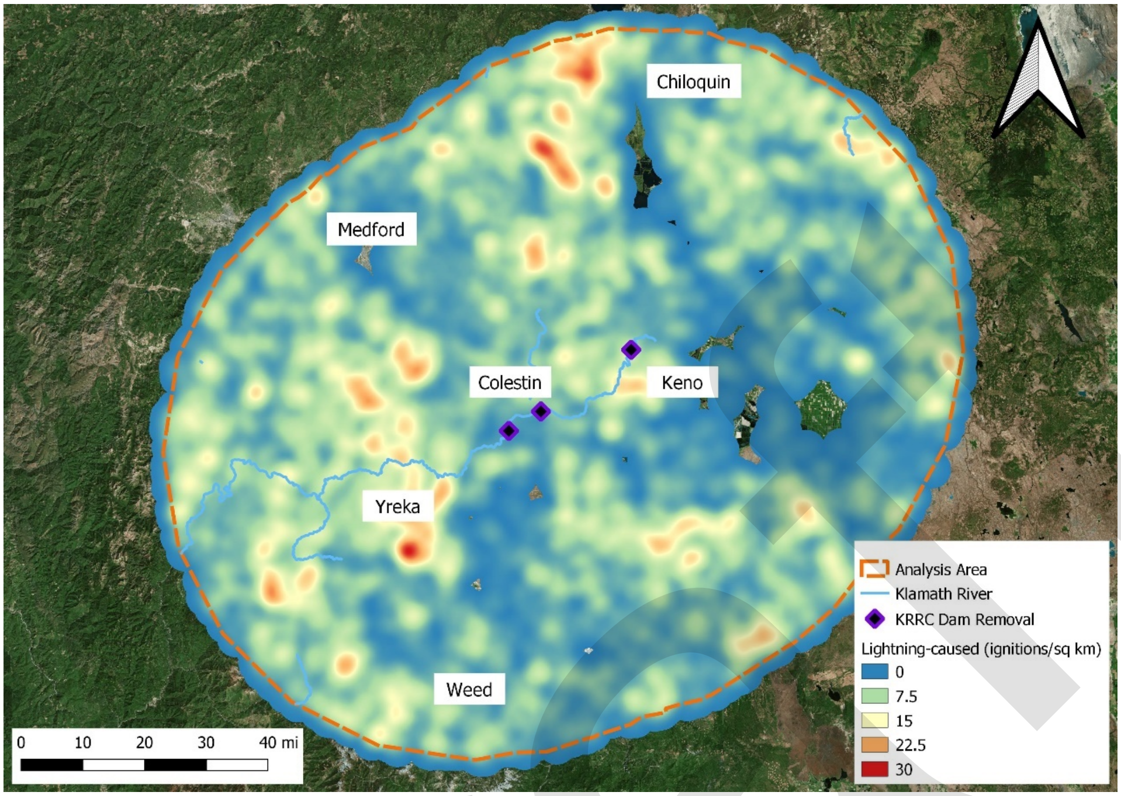


Figure 8. Lightning-caused fires ignition density.

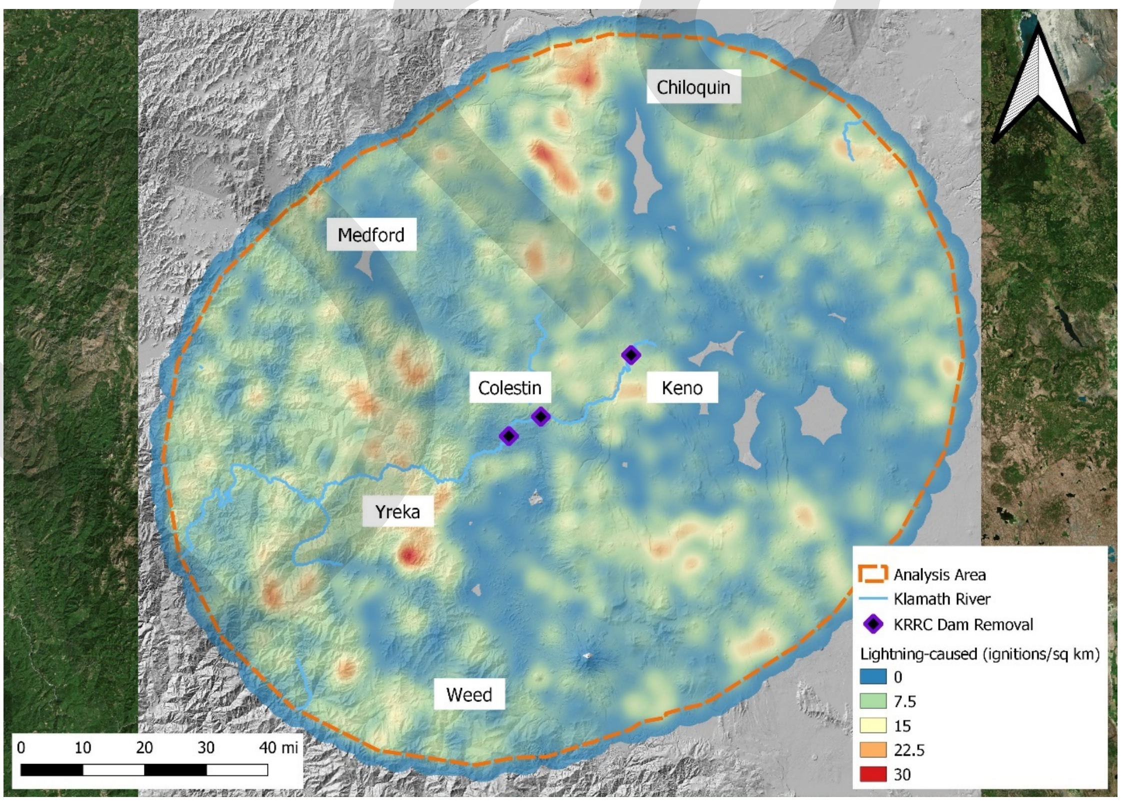


Figure 9. Lightning caused fires ignition density and terrain.

3.1.3 Fires from all causes

Compiling human- and lightning-caused ignitions within the analysis area resulted in an additional heatmap (Figure 10). Trends from all ignitions are visible and can be traced back to the contributing cause. For example, the high-density along linear features reflects the human-caused ignitions while the increase in density across the entire analysis area can be ascribed primarily to lightning-caused ignitions.

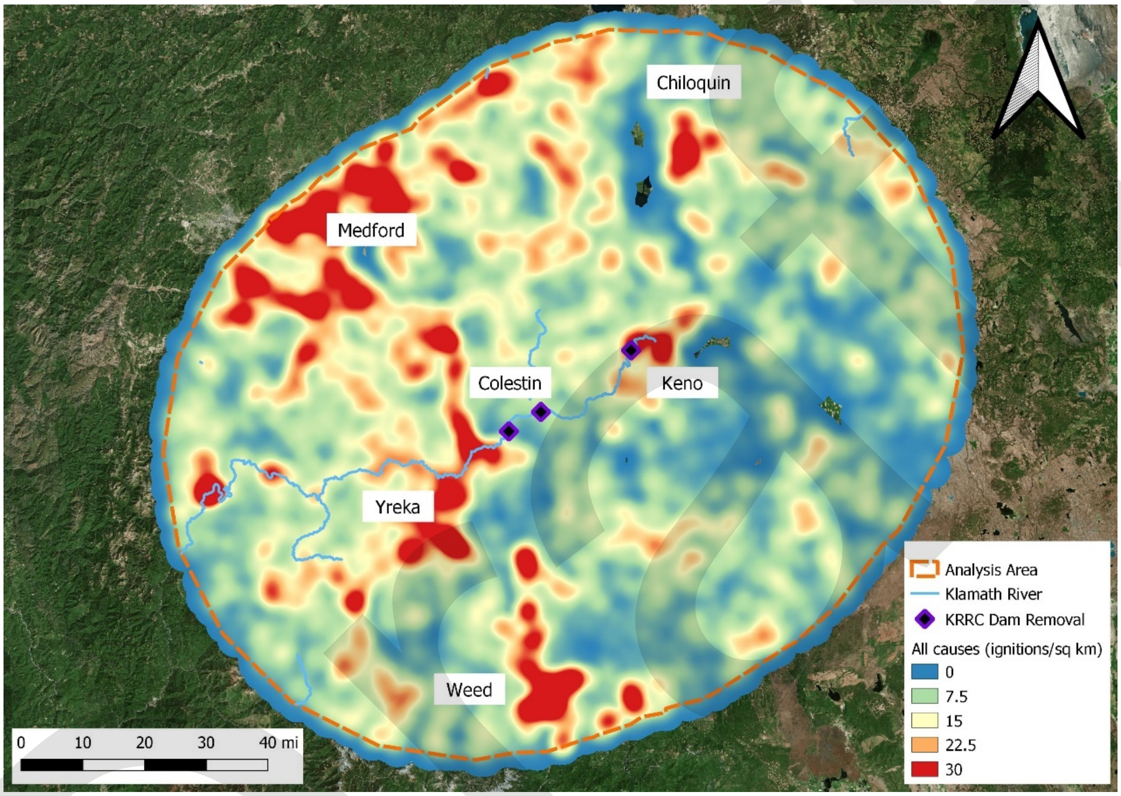


Figure 10. Ignition density – all causes.

3.2 Fire perimeters

Historical fire perimeters in California and Oregon were used to understand historical fire occurrence, particularly large fires, in the analysis area. The CAL FIRE Fire and Resource Assessment Program (FRAP) database [17] was used for ultimate perimeters in California, the National Interagency Fire Center (NIFC) [18] database was used for ultimate perimeters in Oregon, and GeoMAC data [19] were used to map daily progression of large fires. Figure 11 - Figure 15 present fire perimeters from the FRAP database by decade from 1970 – 2018. Figure 16 presents perimeters in Oregon from 2000-2019 (the period of availability).

Of note is the occurrence of very large fires and their frequency. Prior to 2000, two historical fires became large: an unnamed fire in 1926 and the Bogus Escape fire in 1957. There is an almost 30-year fire return interval for the region based on those two fires alone. After 2000 the return frequency has decreased significantly, as can be seen by the four-year lapse between the 2014 Oregon Gulch and 2018 Klamathon fires.

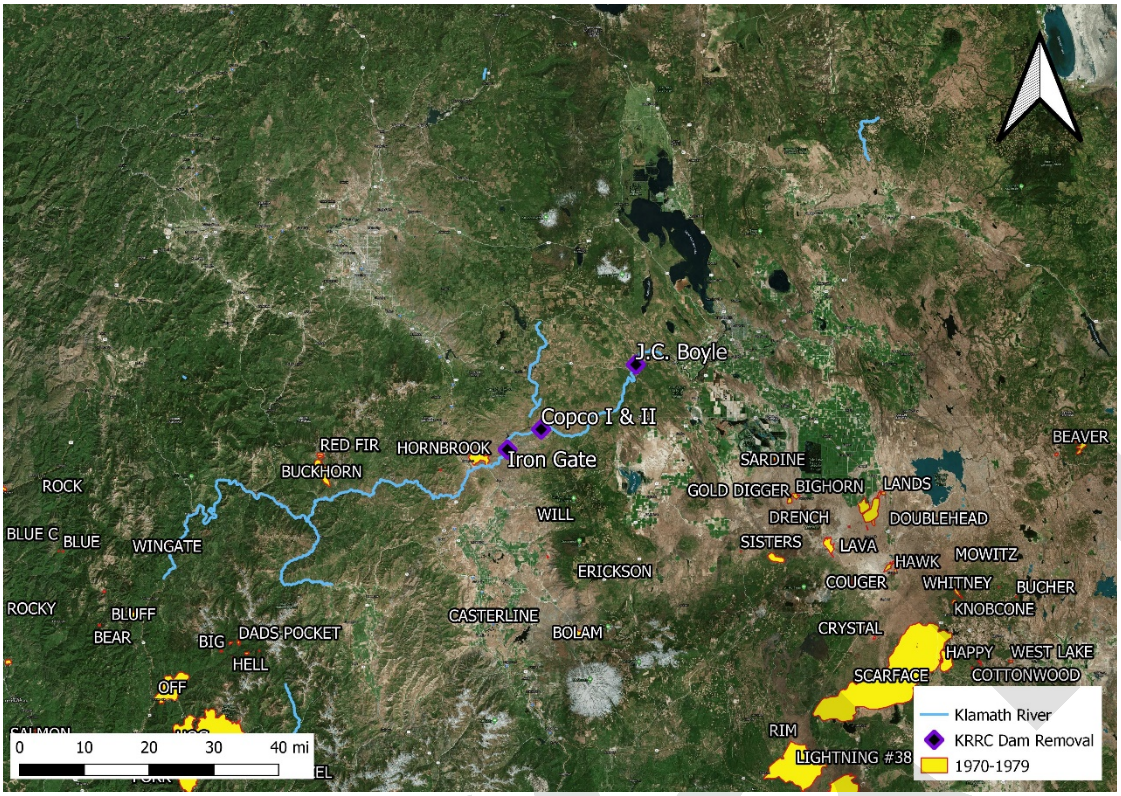


Figure 11. California fire perimeters 1970-1979.

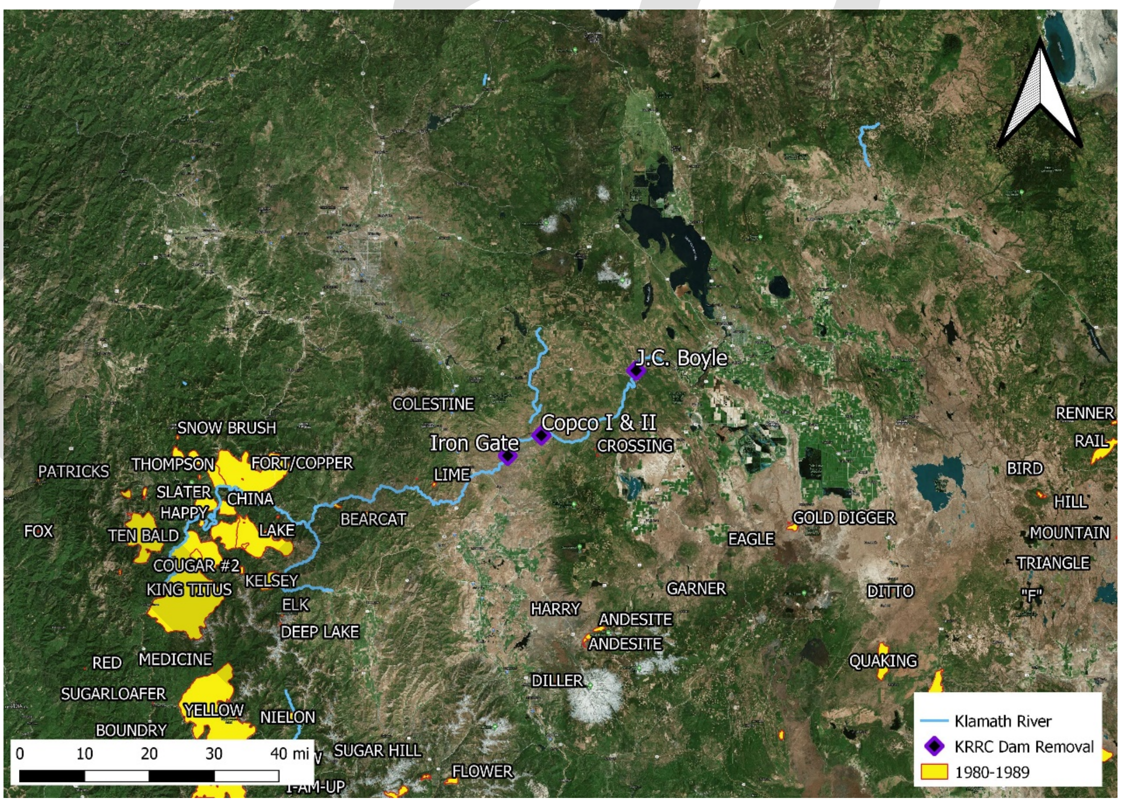


Figure 12. California fire perimeters 1980-1989.

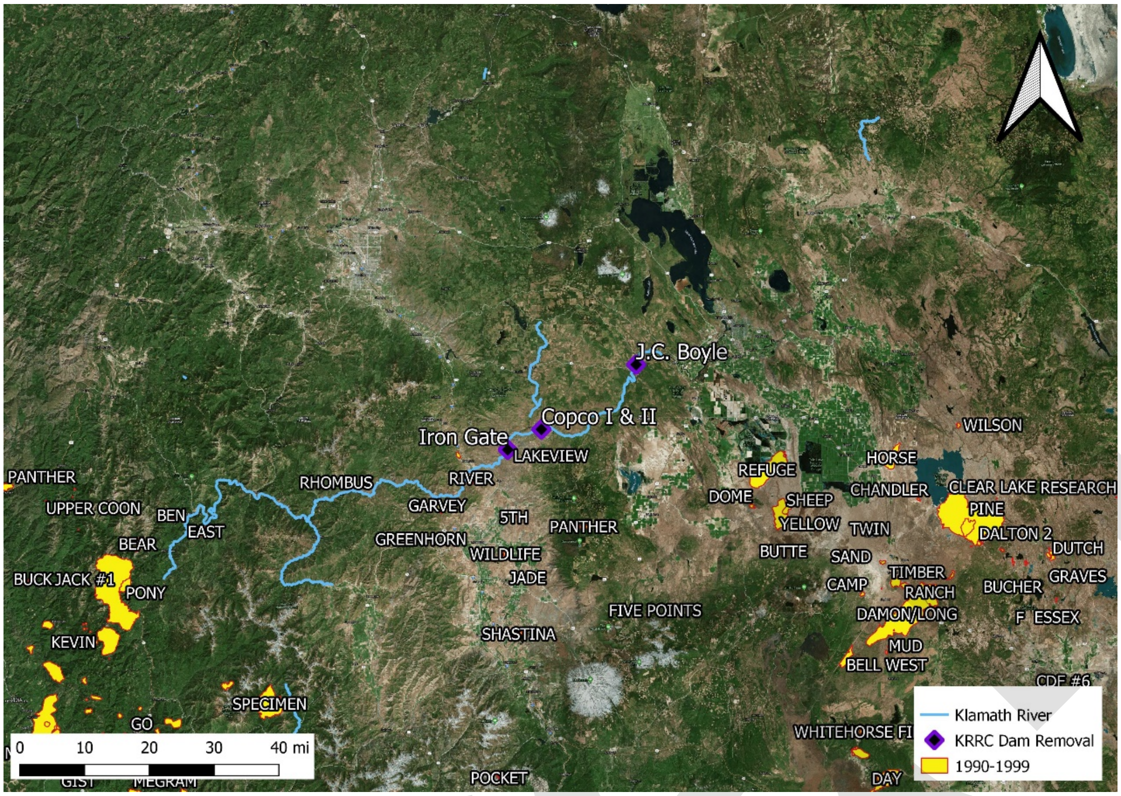


Figure 13. California fire perimeters 1990-1999.

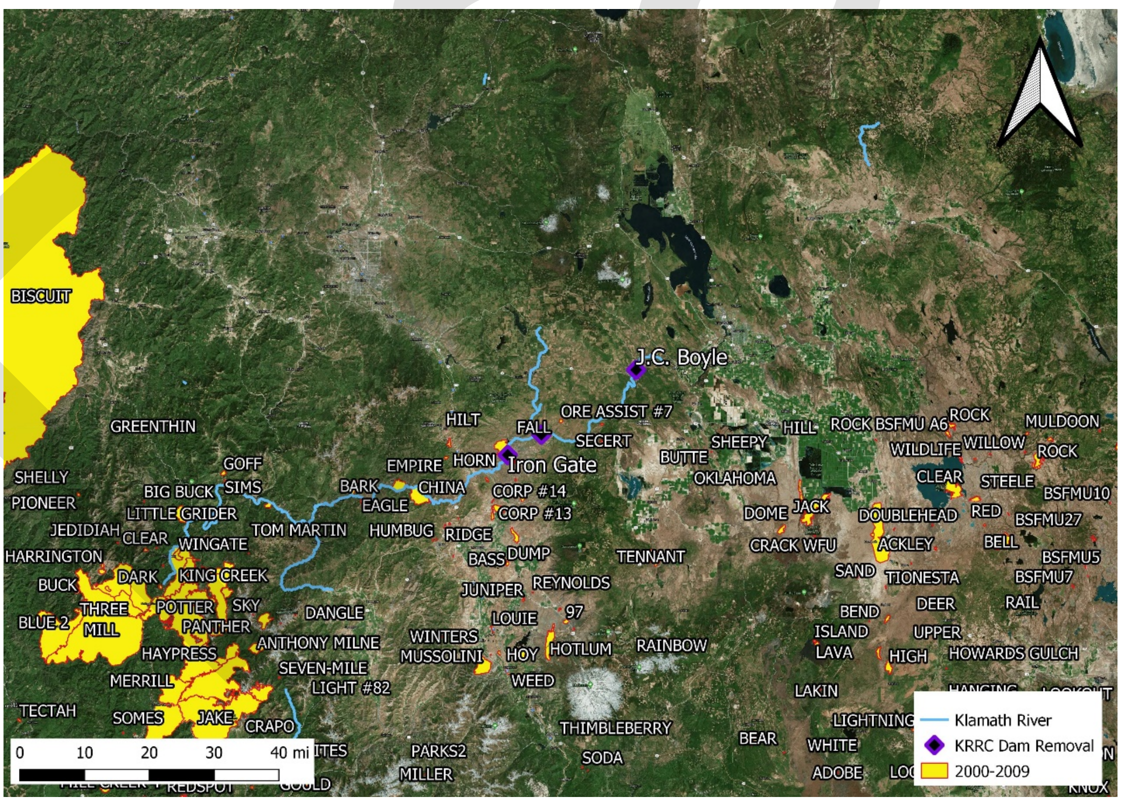


Figure 14. California fire perimeters 2000-2009.

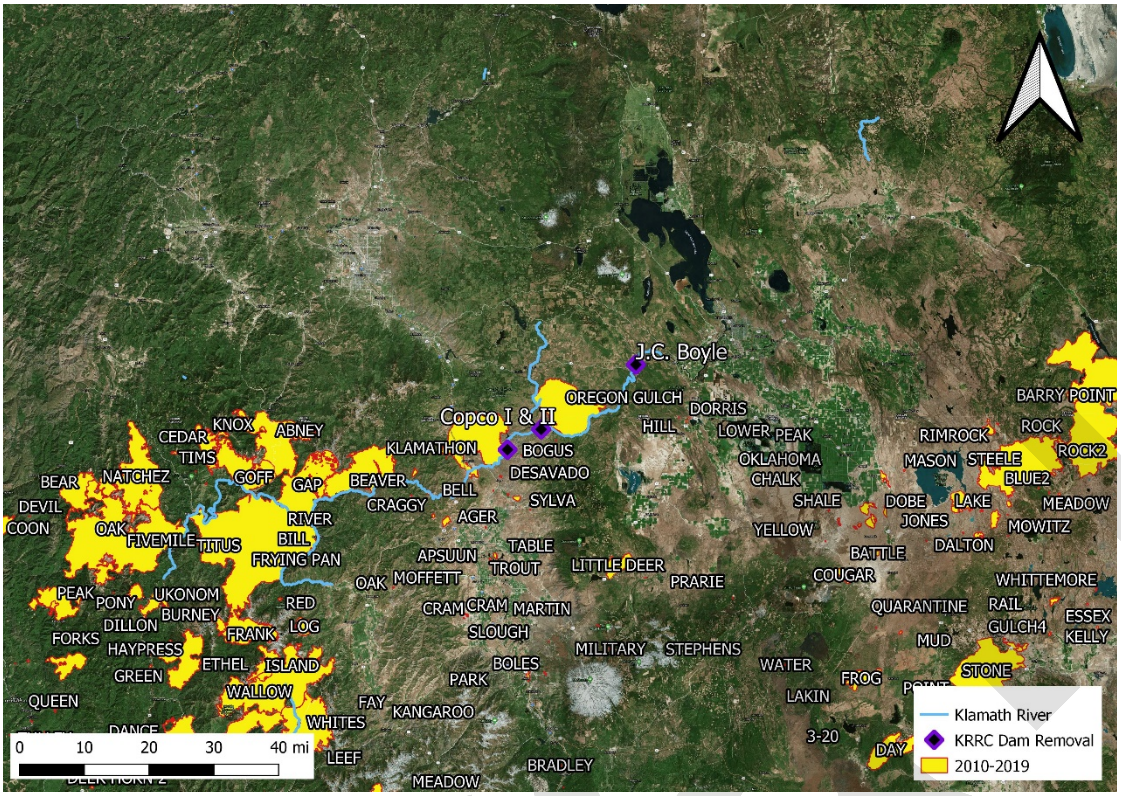


Figure 15. California fire perimeters 2010-2019.

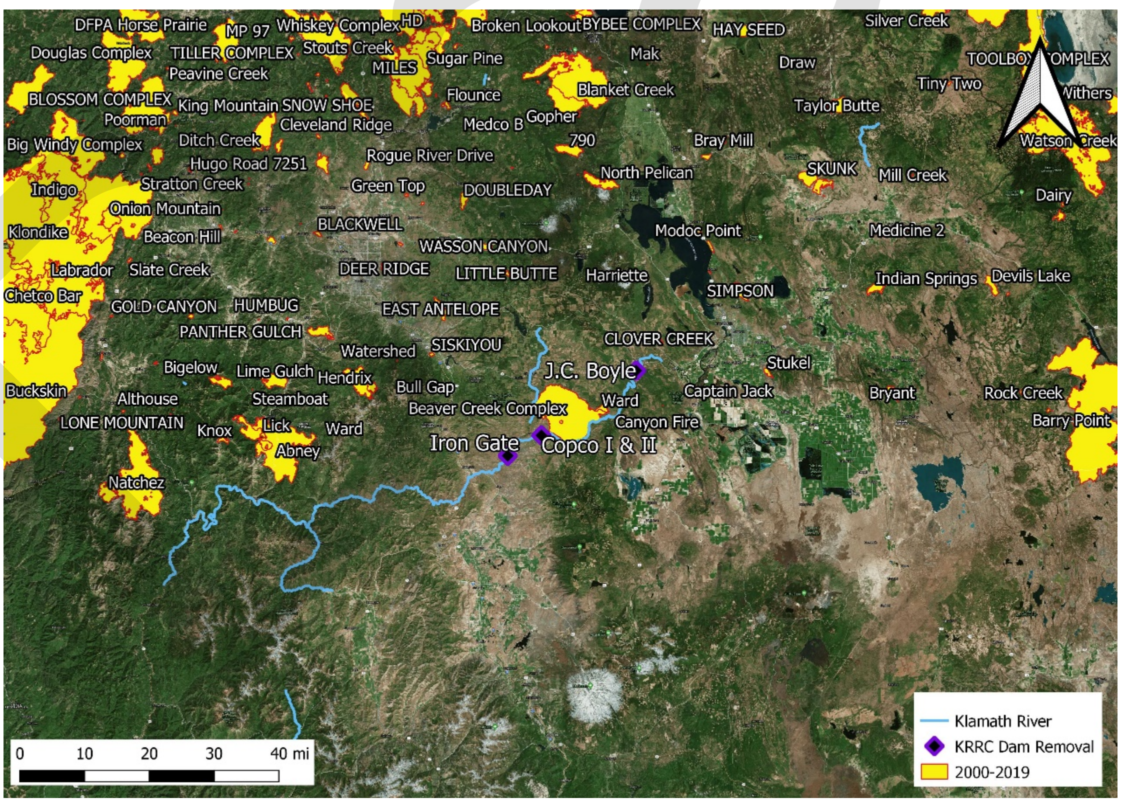


Figure 16. Oregon fire perimeters 2000-2019.

3.3 Large fires occurring in analysis area

Viewing fire perimeters in context with the surrounding landscape shows that most fires in the analysis area have been small, indicating rapid response and effective containment from fire agencies relative to perimeter growth. Several larger escaped fires were examined in greater detail to understand the conditions that led to such extensive growth. As part of assessing these large historical fires, documentation on suppression resources used by local fire agencies in containing the fires were reviewed. The two most significant fires occurring in the analysis area within the last ten years are the 2014 Oregon Gulch Fire (Section 3.3.1) and the 2018 Klamathon Fire (Section 3.3.2).

3.3.1 2014 Oregon Gulch Fire

A lightning strike ignited the Oregon Gulch Fire on Thursday, July 30, 2014. Several red flag warnings were issued for the period between July 28 and August 5 as high winds were expected in addition to warm, dry days. By Friday morning the fire had grown to 7,500 acres. Over the course of two weeks, the fire burned a total of 35,111 acres north and east of the Copco dams. Figure 17 shows approximately daily progression from infrared imaging and satellite fire detection. The southern edge of the fire advanced up to the Klamath River. Oregon Gulch was managed as part of the Beaver Creek Complex (Figure 17) and was declared 100% contained on August 13, 2014.

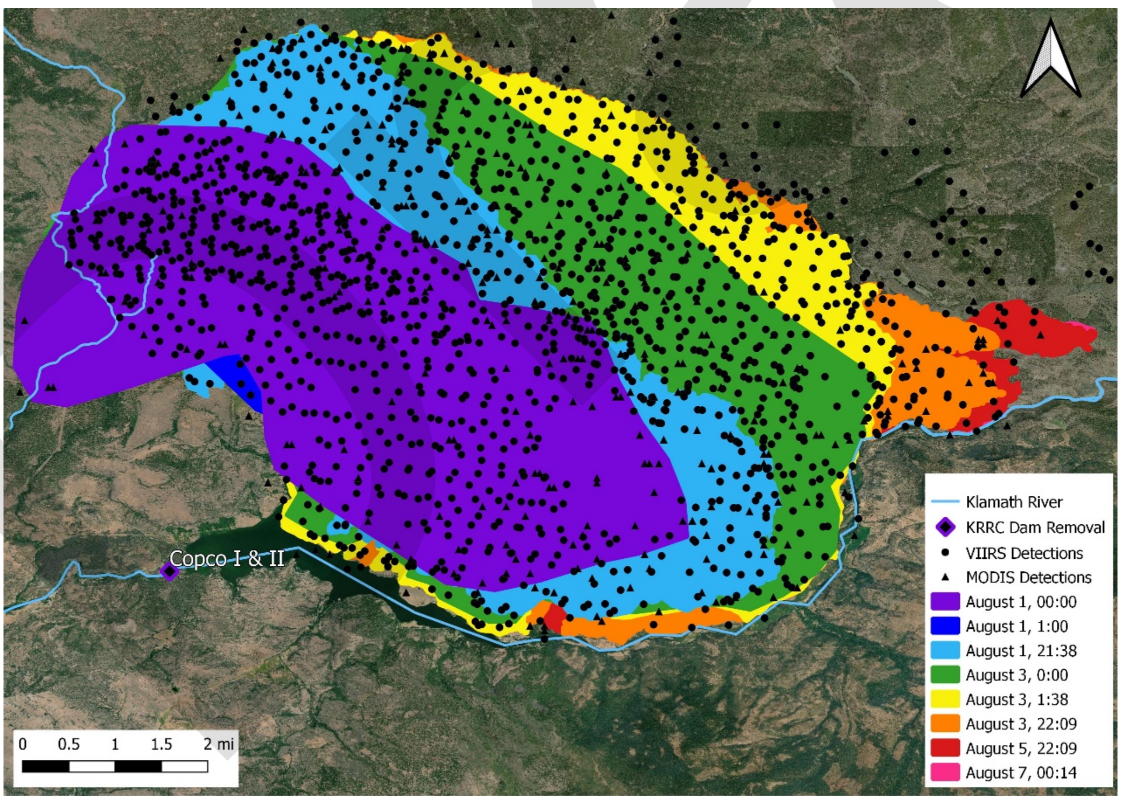


Figure 17. Final perimeter of the 2014 Oregon Gulch Fire.

3.3.2 2018 Klamathon Fire

The Klamathon Fire was reported on July 5, 2018, near Hornbrook, CA. By the following evening, the fire had grown to 9,600 acres. Red flag warnings issued for the area on July 3 and continued through July 6 indicate the presence of strong winds with hot, dry conditions. Aerial suppression efforts relied on five dip sites, two from the reservoir above Iron Gate dam, one from the Klamath river, and two from runoff ponds. The Incident Action Plans (IAPs) available from the NIFC database [18] did not contain ICS 209 forms so specific tactics or number of drops were not able to be determined from publicly-available data. The ICS 220 forms that were available provided the type of resource and time the resource began operating each day. The communities of Hornbrook, Hilt, and Colestin were evacuated in addition to the area around Iron Gate dam. By July 21, 2018, the Klamathon Fire was contained after having burned 38,008 acres (Figure 18). There was one civilian fatality and three non-fatal injuries resulting from the fire. At least 80 structures were damaged or destroyed.

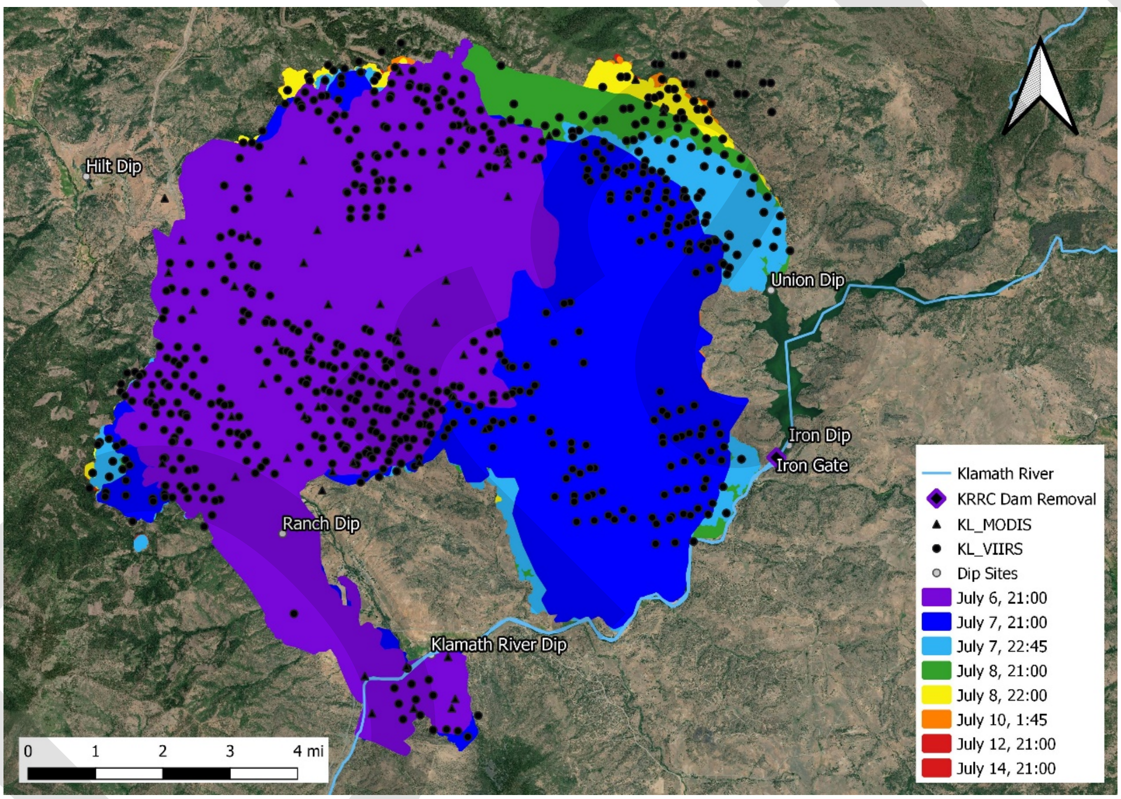


Figure 18. Final Perimeter of the 2018 Klamathon Fire.

3.4 Summary

Historical fire perimeters show that most fires in the analysis area were small with some exceptions. The Oregon Gulch and Klamathon fires were examined in greater detail to understand the conditions surrounding their rapid expansion. Fuel conditions and weather during these two fires makes it unlikely that either fire could have been contained in the initial attack phase, regardless of the number of resources dedicated to the effort. The results of a cost-benefit analysis between number of resources deployed versus rapid containment performed by the federal government are discussed in greater detail in Section 4.5.

4.0 Analysis of the Fire Management Plan's Fire Risk Mitigation Measures

The FMP [3] addresses long-term fire management in the Klamath River Basin, incorporating strategies to offset the loss of the three Klamath River reservoirs that have supported fire suppression resources in the past. The FMP also elaborates on the long-term new local and regional fire suppression resources to be implemented in the Basin. KRRC has committed to implement (and oversee through license surrender) effective and feasible strategies and concepts to enhance both short- and long-term fire prevention, detection, and suppression in the Basin. In this report, the effects of the proposed FMP strategies are analyzed, including change in water availability (Section 4.2), fire occurrence frequency (Section 4.3), detection effectiveness (Section 4.4), probability of containment on initial attack (4.5), and extended attack efficacy (Section 4.6).

4.1 Post-removal resources

A map of post removal resources, excerpted from the FMP [3], is shown in Figure 19. Key drafting points for engines and tenders include 2 new boat launches, six planned permanent dry hydrants to complement the six existing pressurized hydrants and provide viable water access points for ground-based equipment and to support aerial water delivery. In addition, the FMP proposes one large permanent rigid dip tank, three medium-sized, portable self-supporting dip tanks (Figure 20), and two small portable helicopter sling tanks (Figure 21) to complement other aerial drafting resources.

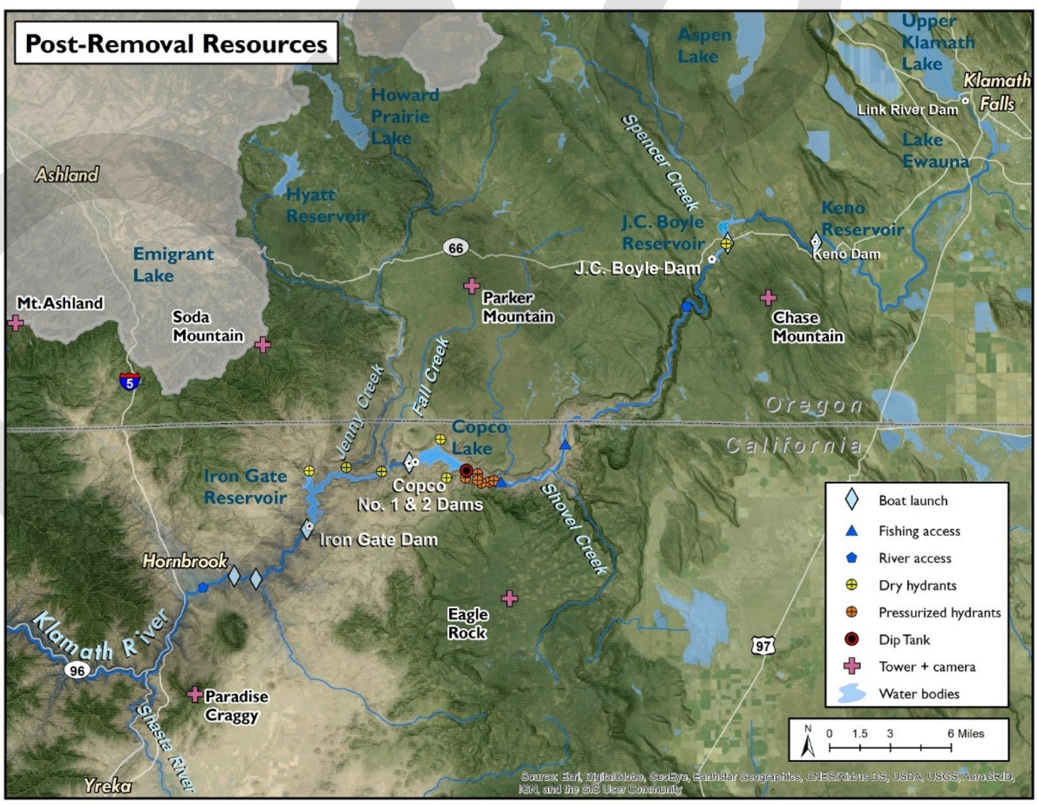


Figure 19. Post-removal management resources provided as part of the long-term FMP [3].

Figure 20. Rigid tank model shown with helicopter snorkel.

Figure 21. Soft-sided tank model being airlifted.

Where available, documentation and data regarding aerial suppression from previous fires were reviewed and analyzed in conjunction with the FMP post-removal resources to address the concerns of local fire agencies with respect to the proposed dam removal and its impact on available water sources.

4.2 Change in water availability

There are currently 96 inventoried river pools of varying risk classes for helicopter bucket work and another predicted 41 helicopter bucket sites of varying risk categories in the current reservoir pool areas (Figure 22) [3]. With around 137 pools for helicopter bucket use and a minimum of 18 other river access sites available for drafting, the ability to use water for fire suppression will not be impacted. The difficulty of using some sites, such as reservoirs, may be impacted but the overall amount of water available should not be affected by dam removal. The minimum post-removal river discharge of 900 ft^3/s will be sufficient to maintain a good water supply for suppression forces. In addition to the various sizes of dip tanks will provide a helpful complement to the mainstem Klamath River for aerial drafting, and the portable tanks provide the ability to create dip sites in locations where they do not currently exist. The six planned permanent dry hydrants will also increase water availability for ground-based equipment relative to the pre-removal condition and can be used in conjunction with the portable dip tanks around the former reservoirs.

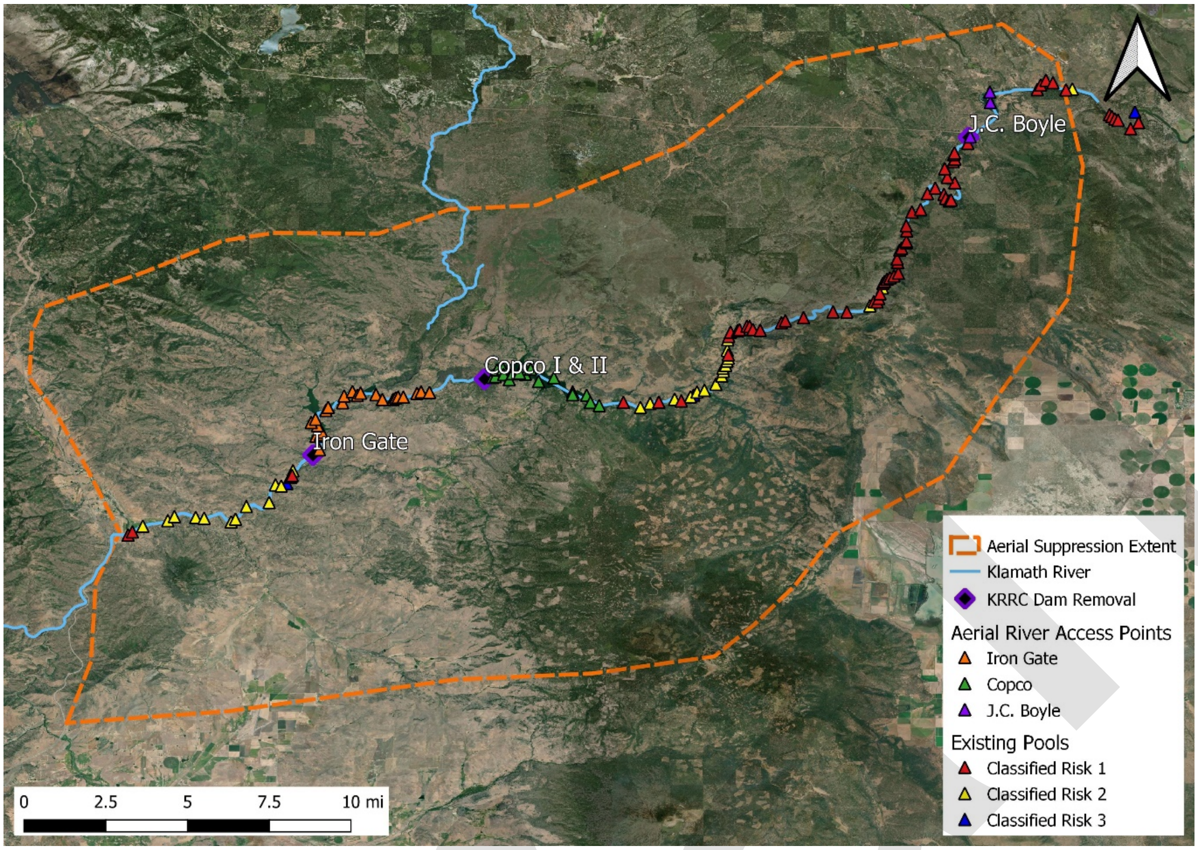


Figure 22. Pre- and Post-restoration dip sites.

4.3 Change in fire occurrence frequency

As part of reservoir dewatering and dam removal, three primary factors may affect future fire occurrence frequency in and around the project location. These factors are summarized and discussed qualitatively in Table 1.

Table 1. Factors affecting post-removal fire occurrence frequency[1].

Factor	Effect	Impact
Decommissioning 15 miles of overhead electrical utilities	Reduce fire occurrence frequency by removal of potential ignition sources	Minor
Dewatering of approximately 1,000 acres of reservoir	Increase fire occurrence frequency by increasing burnable landmass	Minor
Donation of 9" chipper-dump bed trailer and base model pick-up truck	Reduce fire occurrence frequency through reduction in debris burning; high impact on local residential vegetation management	Minor

[1] Impact is on fire occurrence frequency at the landscape scale.

All factors identified here are considered to have a minor impact on future fire occurrence frequency at the landscape scale The removal of overhead electrical utilities and use of a chipper for improving defensible space should impact fire occurrence frequency locally, particularly as it relates to structure fires. On this basis, reservoir dewatering and dam removal is anticipated to have a negligible change on fire occurrence frequency at the landscape scale. Fire occurrence will continue to meet historical averages; however, the cause of these future fires will change as a result of the removal of existing electrical utilities with a potentially corresponding increase in some other human-caused ignitions, *e.g.* campfires. After de-watering, average fire size and fire occurrence frequency will follow historic averages for the area.

4.4 Change in fire detection efficiency

One of the primary goals of KRRC's FMP is to minimize the likelihood of large-scale fire development such that a fire can be suppressed or contained. A critical component of the overall strategy is reliable, rapid fire detection following an ignition, including accurately placing the ignition location and prompt notification of responding authorities. The shorter the length of time between fire start and fire detection, the higher the probability of a successful initial attack. In the past, fires were commonly spotted and reported by personnel at staffed fire lookout towers. Today there are various methods of detection and new technologies available such as the use of sensors, cameras, and satellites.

In California and Oregon, there has been an increase in detection camera installations at fire lookouts that were historically staffed. Fire size at the time of detection by cameras generally scales with distance from the camera. With cameras, fires can be detected at much smaller sizes than are possible with the human eye alone. The Oregon Department of Forestry (ODF) reports that it is possible for a camera to detect fires on the order of 1/100th of an acre within 10 miles. Beyond 10 miles, cameras can typically detect fires at 1/10th of an acre.

Existing fire detection resources and the proposed post-restoration resources provided in the Klamath River Basin are discussed in detail in the FMP and are summarized here. A viewshed analysis identifies areas on Earth's surface that are visible from a specific location [20, 21] and is used in this work to:

1. Determine if the proposed post-restoration fire detection resources provide adequate coverage of the project area within the Klamath River Basin, and
2. Quantify the change in detection effectiveness between pre- and post-restoration schemes.

4.4.1 Existing fire detection scheme

As described in the FMP, there are four existing lookout towers that are used as surveillance vantage points for fire detection in the project area of the Klamath Basin and one that has been decommissioned. Three of these towers are in the ODF South West Oregon or Klamath Lake jurisdiction and one tower is in the CAL FIRE Siskiyou Unit jurisdiction. Two of the ODF lookouts are equipped with fire detection video camera systems, while the remaining two lookouts are staffed with fire service personnel during fire season. See Table 2 and Figure 23 for the locations and specifications of each of the four existing lookouts.

Table 2. Existing lookouts for fire surveillance in the Klamath Basin.

Tower Name/Location	Elevation (ft)	Tower Height[1] (ft)	Longitude	Latitude	Camera System
Paradise Craggy, CA	4,890	6	-122.54669	41.81476	No
Parker Mountain, OR	5,165	50	-122.27865	42.10527	No
Chase Mountain, OR	6,349	20	-121.99415	42.09461	Yes
Soda Mountain, OR	6,049	10	-122.47882	42.06447	Yes

[1] Tower heights were determined from online resources [22-25]

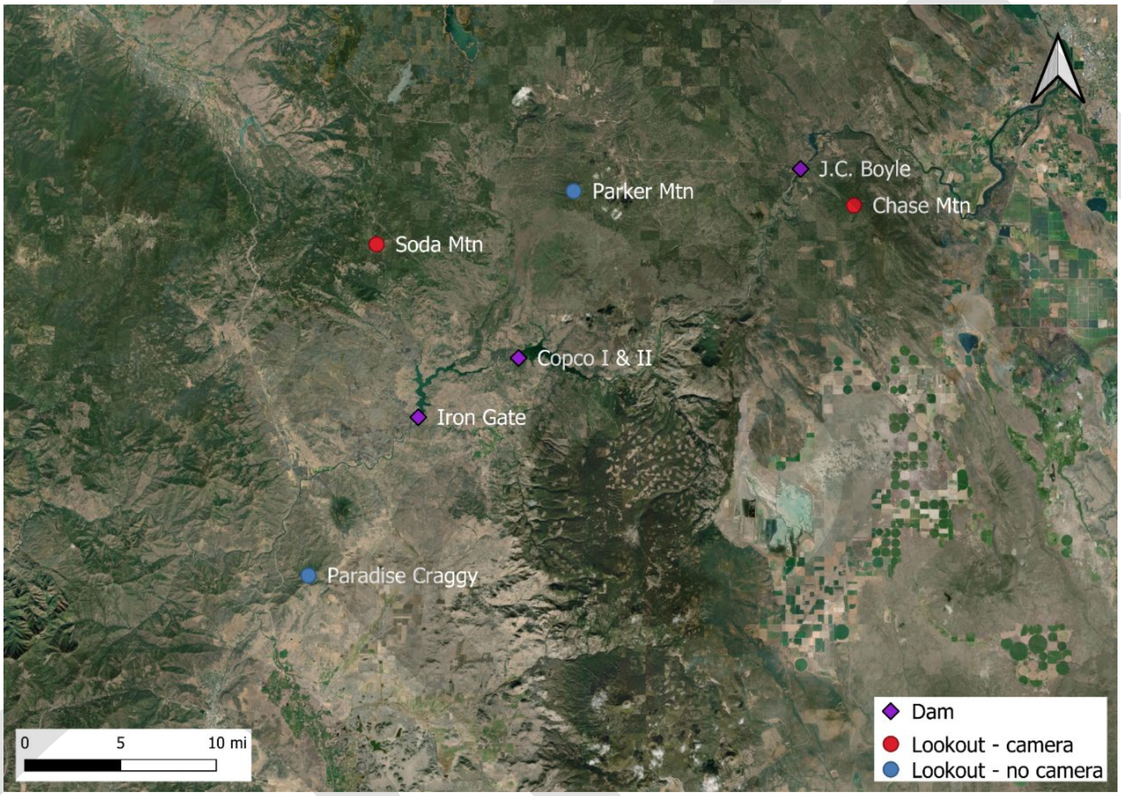


Figure 23. Existing lookouts for fire surveillance in the Klamath Basin.

4.4.2 Post-restoration fire detection scheme

The post-restoration fire detection scheme uses a Monitored Detection System (MDS) consisting of five lookout towers equipped with video surveillance cameras for around-the-clock, remote fire monitoring. The MDS technology transmits high definition video and images from cameras to an integrated Geographic Information System (GIS) platform that is monitored by dedicated staff. The software that enables this integration is EnviroVision Solutions (EVS) ForestWatch [26]. This software also enables triangulation of the fire location if more than one camera captures the fire.

The cameras that are recommended by EVS for use with the ForestWatch system are industrial Pelco cameras that can automatically rotate 360º, have an auto-detection surveillance distance of up to 12.4 miles (20 kilometers), and can be manually and remotely controlled. The infrared and near-infrared capabilities allow the cameras to see through haze and nighttime conditions.

The MDS cameras will be provided at Parker Mountain and Paradise Craggy so that each of the four existing lookouts in the Klamath Basin has a camera. Additionally, one new tower will be sited on Eagle Rock Mountain, CA. A sensitivity study of the viewshed at varying tower heights and location coordinates was conducted to determine optimal siting for the Eagle Rock camera. A camera will also be placed on an existing tower on Mt. Ashland. The post-restoration fire detection scheme is shown in Figure 24 and presented in Table 3 with changes from the existing scheme highlighted in gray.

Table 3. Post-restoration MDS camera locations for fire surveillance in the Klamath Basin.

Tower Name/Location	Elevation (ft)	Tower Height[1] (ft)	Longitude	Latitude	Camera System
Paradise Craggy, CA	4,890	6	-122.54669	41.81476	Yes
Parker Mountain, OR	5,165	50	-122.27865	42.10527	Yes
Chase Mountain, OR	6,349	20	-121.99415	42.09461	Yes
Soda Mountain, OR	6,049	10	-122.47882	42.06447	Yes
Eagle Rock[2], CA	6,970	10	-122.24138	41.87664	Yes
Mount Ashland, OR	7,533	10	-122.71688	42.08073	Yes

[1] Tower heights were determined from online resources [22-25]

[2] This tower is not yet constructed. The elevation and location coordinates were approximated.

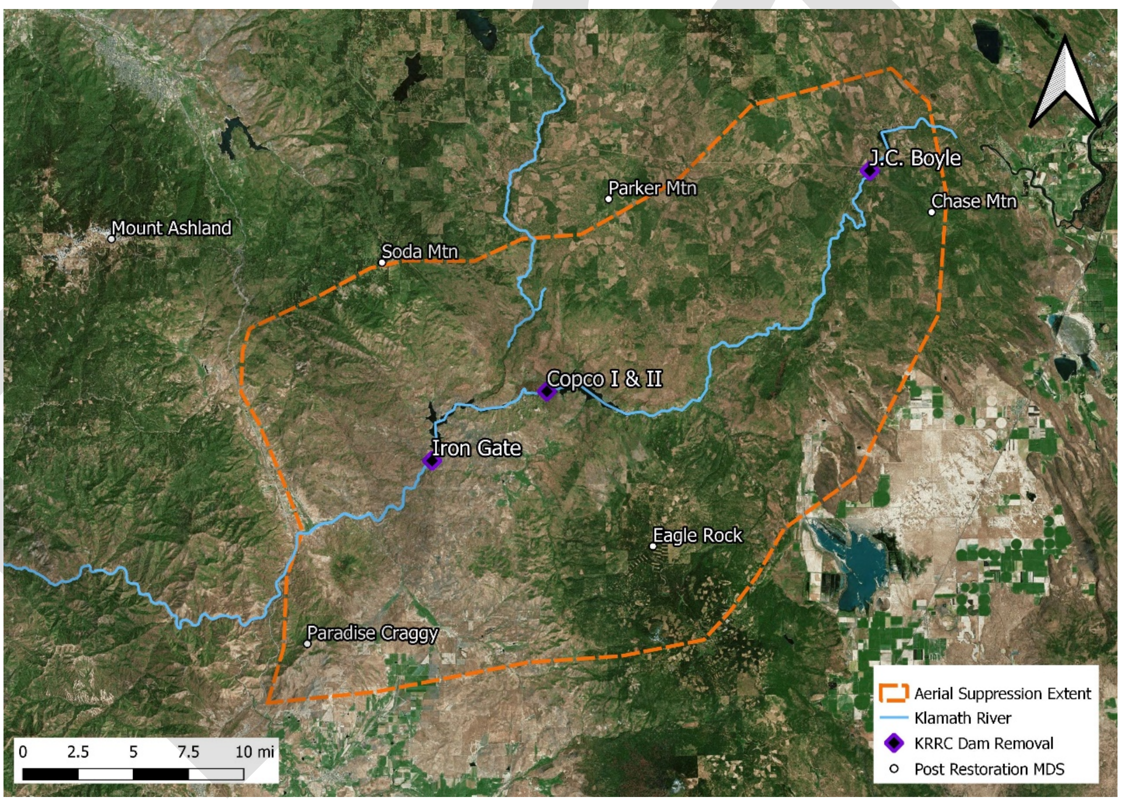


Figure 24. Post-restoration MDS camera locations for fire surveillance.

4.4.3 Detection coverage viewshed analysis

A viewshed analysis was conducted of the existing and planned detection schemes to assess and compare fire detection coverage of the Klamath Basin both pre- and post-restoration. The inputs for the analysis are given in Table 4 and explained below. The results and limitations of the analysis are discussed in the following subsections.

Table 4. Viewshed analysis inputs for the pre- and post-restoration fire detection schemes.

Detection Scheme	Monitoring Location	Camera System	Radius of Visibility (mi)	Observer Height[1] (ft)	Target Height (ft)
Pre-restoration	Paradise Craggy Tower	No	7	6	0, 100, 500
	Parker Mountain Tower	No	7	50	0, 100, 500
	Chase Mountain Tower	Yes	12	20	0, 100, 500
	Soda Mountain Tower	Yes	12	10	0, 100, 500
Post-restoration	Paradise Craggy Tower	Yes	12	6	0, 100, 500
	Parker Mountain Tower	Yes	12	50	0, 100, 500
	Chase Mountain Tower	Yes	12	20	0, 100, 500
	Soda Mountain Tower	Yes	12	10	0, 100, 500
	Eagle Rock Tower	Yes	12	10	0, 100, 500
	Mount Ashland Tower	Yes	12	10	0, 100, 500

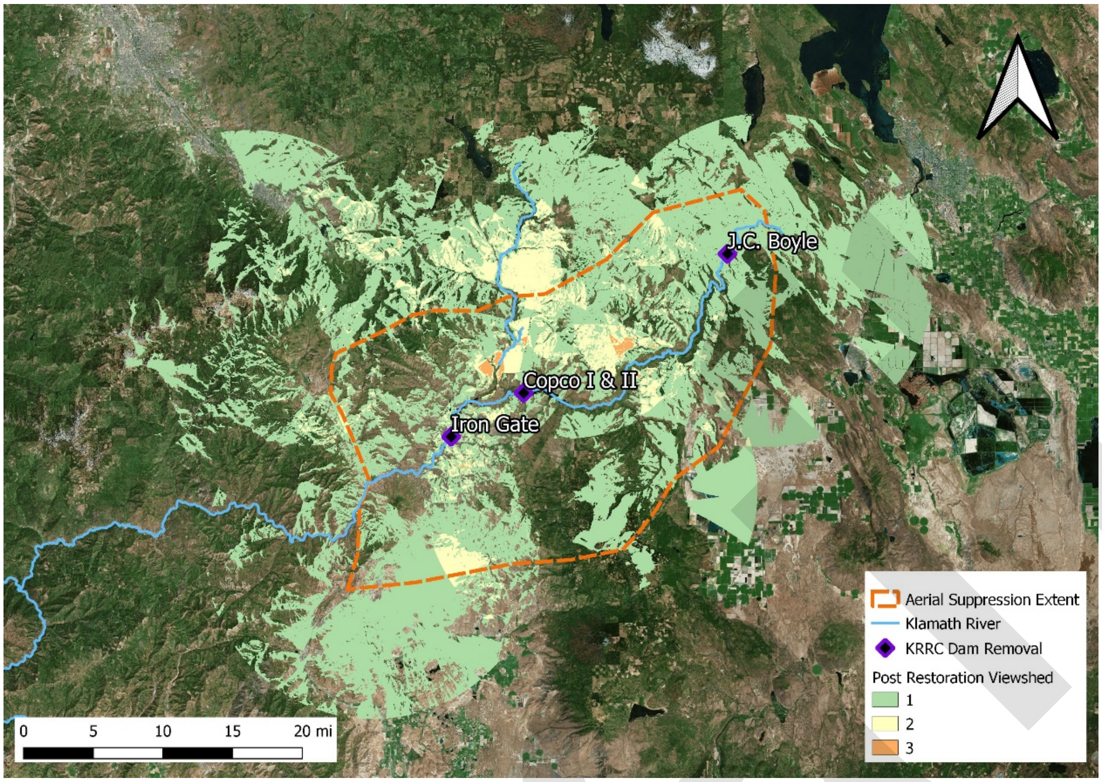
[1] Observer height is relative to the ground and assumed to be the same height as the tower.

In the pre-restoration scheme, a horizontal 7-mile radius of visibility for human eye detection is applied for the two tower locations that are not equipped with a camera system at present [27]. Based on the EVS camera specification, which states a 12.4-mile maximum surveillance distance [26], a rounded value of 12 miles was applied for the cameras' radius of visibility in both pre- and post-restoration schemes. This analysis includes the effect of earth curvature on visibility but does not include visibility obscuration due to haze or smoke in the lower atmosphere. The human eye and camera "observer" heights are relative to the ground elevation and assumed to be at the same height of the towers listed in Table 3.

Three iterations of the analysis were conducted to determine the visibility to specified target heights of 0 feet (ground level), 100 feet above the ground (at or above canopy height), and 500 feet (clear of the canopy and low hills). These values were chosen based on a literature review of similar analyses [28-29]. The non-zero target heights represent a smoke layer above ground that follows the contour of the terrain. This is factored in the analysis because both the human eye and the ForestWatch system will detect smoke signatures before flaming fire at the ground level. As the smoke rises, it typically needs to clear interference from terrain and vegetation to be detected [28], as shown in Figure 25. The ability for detection of smoke plumes at lower or near-surface heights enables faster alerting and initiation of suppressing action. It is further beneficial for the detection systems to achieve visibility coverage extending beyond the lateral boundary of the desired detection coverage area because external fires may encroach into the Klamath Basin. For this reason it is also important to monitor and provide coverage of regions adjacent to the Klamath Basin that fall outside the ASE [28].

Figure 25. Example of smoke plume detection from a camera in the ALERTwildfire network [30].

The post-restoration detection viewshed results are first presented to illustrate coverage provided by the cameras as well as “blind spots” where no camera has visibility to the specified target height (Figure 26). The green areas indicate the target height is visible to one camera; the yellow areas indicate two of the six cameras can view the location; and orange indicates three cameras. There are no locations that are simultaneously visible to more than four cameras, at least up to a target height of 500 feet as analyzed here. The results are displayed with an overlay of the ASE as this is understood to comprise the area of operation for CAL FIRE’s aerial suppression equipment. With the planned removal of the four dams, this area was identified as a concern by CAL FIRE as they perceived the potential for the fire risk to increase following restoration of the Klamath River to its natural watercourse.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Post Restoration Viewshed
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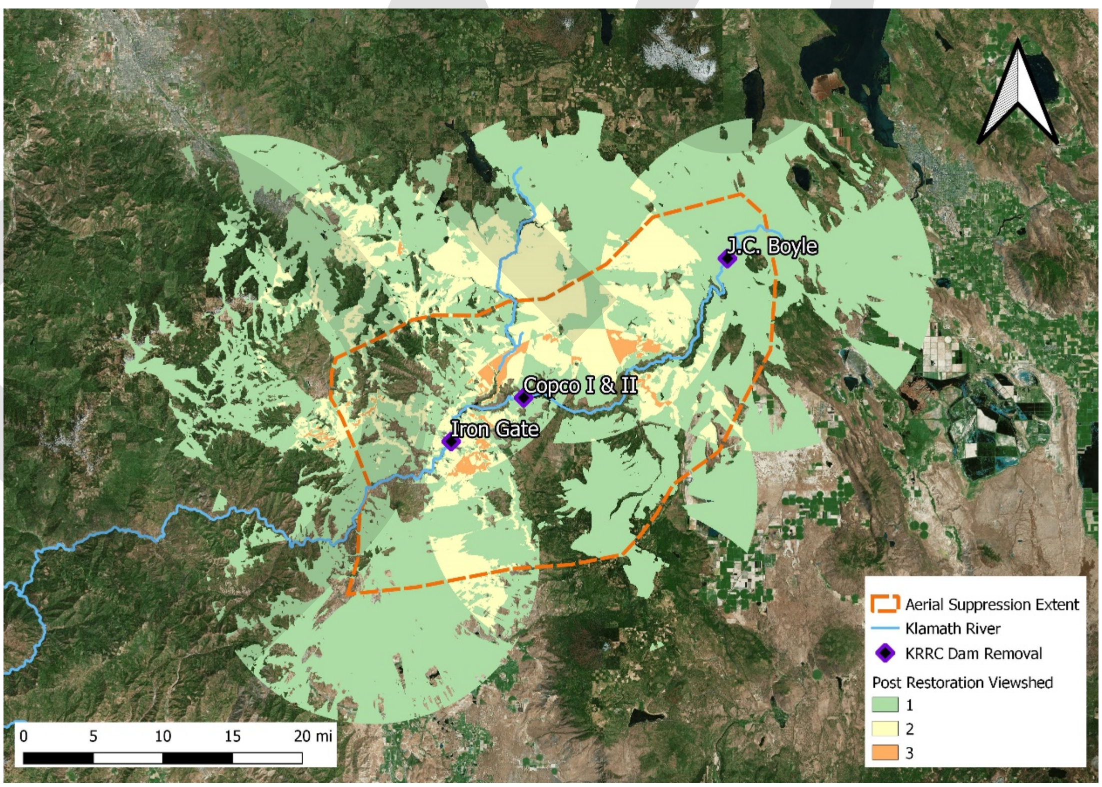
(a)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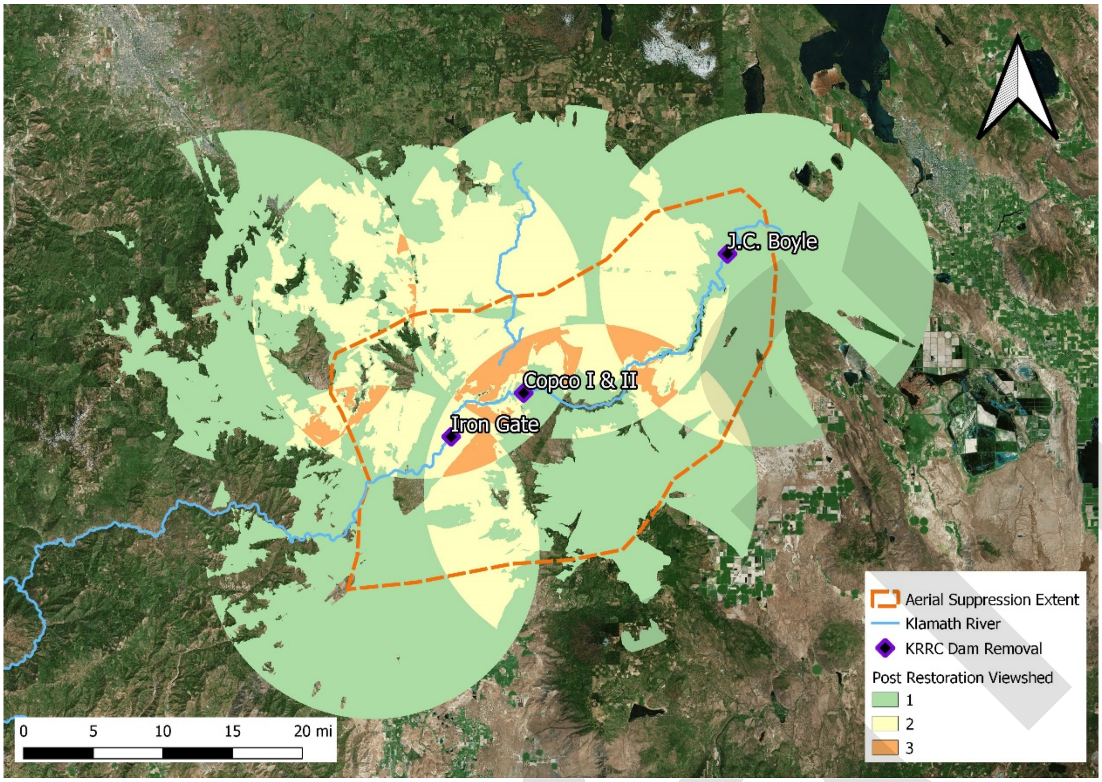


(c)

Figure 26. Post-restoration fire detection camera viewshed, results at target height of (a) 0 feet, (b) 100 feet, and (c) 500 feet above ground surface, overlaid with the aerial suppression extent.

The total land area included in the ASE boundary is approximately 570 square miles. By performing geospatial analytics on the viewshed raster (image) results files, the proposed post-restoration fire detection scheme was determined to provide 92% coverage of the protected area in the ASE boundary at a target height of 500 feet, 74% coverage at a target height of 100 feet , and 54% coverage at the ground surface. Coverage extends into surrounding areas of interest up to 12 miles in each cardinal direction and beyond the perimeter of the ASE. Additionally, roughly 20% of the detection coverage area is visible to multiple cameras at a target height of 100 feet, allowing for triangulation in the early stages of fire growth.

Table 5. Percent coverage of ASE[1].

	Pre-restoration viewshed			Post-restoration viewshed		
Target height	0 feet	100 feet	500 feet	0 feet	100 feet	500 feet
1 camera	33.4%	45.3%	56.7%	45.9%	51.0%	45.6%
2 cameras	1.90%	5.58%	9.63%	8.18%	21.2%	39.8%
3 cameras	0	0	0	0.58%	2.44%	7.31%
Total coverage:	35.3%	50.9%	66.3%	54.7%	74.6%	92.7%

[1]ASE total area 568.9 sq. mi

Figure 27 shows comparative views of the coverage between the existing and post-restoration detection resources. The first column is at a target height of 0 feet, the second column is at a target height of 100 feet, and the third column is at a target height of 500 feet. The pink areas in images 3a, 3b, and 3c highlight the increase in detection coverage provided by the post-restoration resources. The pink areas in images 4a, 4b, and 4c highlight the increase in triangulated detection coverage provided by the post-restoration resources.

The post-restoration detection scheme provides a 39% increase in detection coverage at 500 feet target height, a 45% increase at 100 feet target height, and a 54% increase at ground surface for the ASE. Triangulation coverage of the protected area is increased significantly under the post-restoration detection scheme at each target height.

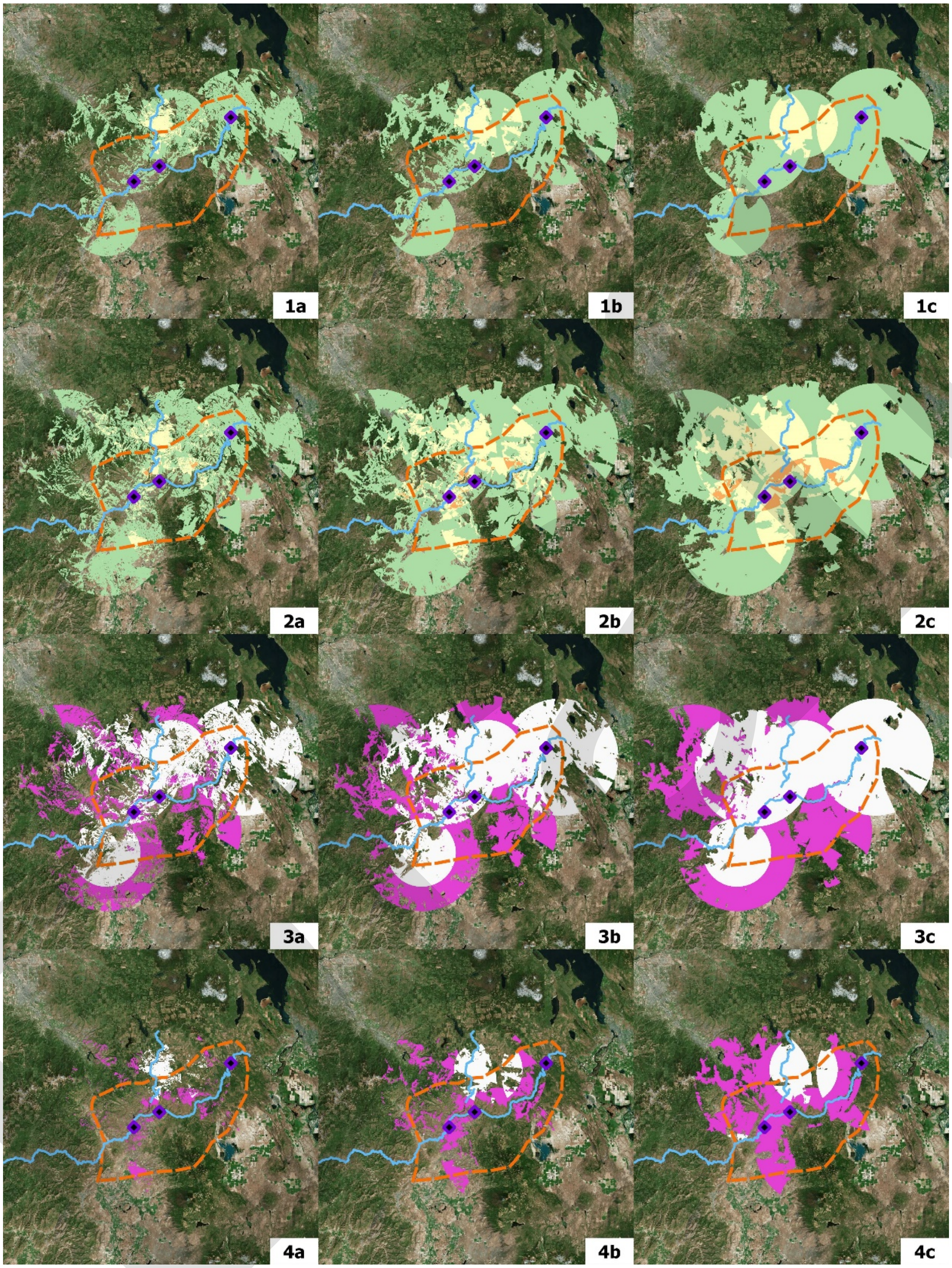


Figure 27. Comparative views of the existing resources viewshed (1a, 1b, 1c) and post-restoration resources viewshed (2a, 2b, 2c) at target heights of 0 feet, 100 feet, and 500 feet, respectively from left to right. The pink areas (3a, 3b, 3c) highlight the increased coverage provided by the post-restoration resources, contrast to the existing resources coverage indicated in white. The pink areas (4a, 4b, 4c) highlight the increase in triangulated area coverage provided by the post-restoration resources, contrast to the existing resources triangulation coverage in white.

4.4.4 *Limitations of viewshed analysis*

The limitations of a viewshed analysis, especially in the context of understanding detection effectiveness, are enumerated below:

1. The analysis was reliant on the assumptions of the camera locations, heights, and radius of visibility. These assumptions were investigated by manual adjustment of camera locations based on satellite imagery of tower locations and by validation of the Eagle Rock camera height through a manual sensitivity study.
2. The viewshed analysis does not account for visibility obscuration due to possible haze or smoke. Note, however, that the EVS-recommended cameras specifications include the ability to see through haze and smoke.
3. The viewshed analysis is based on tower locations that already have a fire lookout and would therefore present minimal implementation expenses while providing a significant increase in MDS coverage. These locations are not fixed and may be changed after conferring with ODF and CAL FIRE about optimal siting.
4. Using a viewshed analysis with a smoke plume as the target is more representative of wildland fire detection than using the ground level as the target. It is much more common for fires to be reported because someone saw smoke than because someone saw physical flames. In this analysis, a smoke plume viewshed was approximated by using a target height of 500 ft. This height would allow the smoke to clear intervening terrain and vegetation and be "seen" by the detection network and is similar to elevations used in the literature. However, smoke plume detection has inherent uncertainties due to atmospheric stability and wind, both of which influence how the fire and subsequent smoke plume grow. Because of these uncertainties, deduction of fire size from smoke plume alone becomes intractable.

4.4.5 *Satellite-based fire detection technology*

Several commercial and non-commercial satellite-based fire detection technologies were evaluated for feasibility of implementation as an option for supplementary coverage of the Klamath Basin. The available technologies typically involve an algorithmic system that uses artificial intelligence (AI) and machine learning techniques to mine and manipulate publicly available, remote-sensed data. The systems can produce fire detection alerts or maps in near real-time to support end-user decision-making. Detections may be verified by various means to reduce omissions and commissions, for example, such as with "ground truth" validation from high-resolution (3-5 meters) imagery acquired at least once per day. Satellite-based technology provides several benefits over other detection methods, including fewer false positives, higher reliability, better precision, and earlier detection.

One of the available, non-commercial satellite-based options is the fire detection and characterization (FDC) data product from NOAA and UW-Madison [31, 32]. The algorithm ingests data from the latest GOES-R Series satellites which are equipped with an Advance Baseline Imager that has significantly improved resolution and fidelity of fire detections from previous GOES sensors. Lag time for the data between collection and post-processing is 4.4 minutes at a spatial resolution of 2 kilometers [32]. Because of this, the product generally still relies on data from additional satellites (with greater latency) for accurate fire characterization. The GOES-EFD

(Early Fire Detection) product [33] is another non-commercial option that is an improvement to the existing FDC product and is anticipated to be available in the next few years. Development of the product is a collaborative effort led by UC Davis. Initial validation stages of the EFD prototype are complete and have shown promising results for earlier detections with fewer false alarms, and at least 4× more precise geographic location of ignitions, as compared to similar existing products [34].

Initial testing of the commercial technologies has shown that satellite-based fire detection may detect fire events on average approximately 10 minutes after it was first reported by civilians via phone in populated areas during the day. However, for night-time detections, particularly in areas with low population density, fires may be detected by satellites more than an hour before detected manually. The two commercial offerings that were evaluated come at high cost on the order of \$100,000+ per year for solutions-based systems, or \$5,000 per month for subscription-based services. Since they offer minimal improvement in daytime detection effectiveness relative to camera technology, commercial satellite-based options are currently not recommended for implementation at this time.

The marked improvement in recent development of both commercial and non-commercial options for satellite-based fire detection is made possible by technological advancement in the newly released GOES-R satellites and sensor equipment. In the coming years, it is expected that the GOES-EFD product will be publicly available. Our recommendation is to monitor the release of this fire detection technology and implement the product at that time for enhanced coverage of the Klamath Basin.

4.5 Change in initial attack probability of containment

Approximately 90% of wildland fires in the U.S. are suppressed in the first 48 hours. The other 10% are not successfully suppressed initially usually because of an extreme but rare combination of fuel conditions and fire weather and can become campaign fires such as the Klamathon Fire.

The “10 AM policy”, *i.e.* fires were to be under control by 10:00 am the following day, which guided Forest Service wildfire suppression until the mid-1970s made sense in the short term as wildfires are much easier and cheaper to suppress when they are small [35]. The federal government has studied the atmospheric conditions conducive to fires escaping initial attack in depth and determined that it is unrealistic to keep increasing the suppression capacity nationally beyond a certain budgetary level. On average, 98.9% of wildfires on public land in the U.S. are suppressed before they exceed 120 hectares but larger fires account for 97.5% of all suppression costs [36]. Put differently, no matter how many resources are mobilized on a fire, fires occurring when fire weather indices are above their 90th percentile values may not be successfully suppressed in the first 48 hours.

Traditionally the federal fire budget was based on the most efficient level (MEL) of funding for suppression forces. Analysis showed that funding up to 90% of the MEL was cost-effective, but additional funding to try to catch that last 10% of fires was not cost-effective because the highest 10% of fires are usually the longest and most severe project fires. The federal government determined that it could not afford to staff forces at any level higher than the identified 90% MEL and therefore the federal budget is typically at or near this 90th percentile level.

The few fires that escape initial attack, such as the Klamathon Fire, are the ones that burn the most area. Success in initial attack is dependent on several factors including weather conditions, fire detection time, fire service arrival time, fire spread rates, fire line production rate, resource drawdown, and budget constraints. Recognizing the importance and effectiveness of the initial attack phase, CAL FIRE has a stated suppression acreage goal for all fires is 10 acres. ODF has a similar qualitative suppression goal of keeping fires as small as possible.

Due to the significant impact initial attack success or failure has on fire growth and intensity, numerous studies have been conducted assessing initial attack effectiveness. As proposed Keating *et al.* [37], for the purposes of assessing initial attack effectiveness, new ignitions can be classified into three categories:

- Category A: Fires likely to remain small regardless of initial attack due to low spread rate or marginal burning conditions
- Category B: Fires that can be prevented from becoming large through initial attack
- Category C: Fires that will become large independent of initial attack due to rapid spread rate or spotting

Note that these categories are different from federal fire size class codes [38] wherein fires are categorized Class A through L based on final size. Since initial attack success rate is close to 100% for Category A fires and close to 0% for Category C fires, of greatest interest here is Category B fires and understanding how early detection may affect initial attack effectiveness.
Several approaches have been applied to model initial attack effectiveness. Fried and Fried [39] developed a technique for simulating fire containment based on the balance between containment line production rate and fire perimeter growth. This has become the basis for the CONTAIN module in the BehavePlus fire modeling system [40]. Rodrigues *et al*. [29] showed the probability of initial attack success can be calculated as a combination of time to detection, travel time, fire spread potential, and available resources. Reimer *et al*. [41] investigated suppression effectiveness by pairing burn probability and containment probability calculations.

The approach used here to quantify initial attack probability of containment is based on the analysis of Hirsch *et al.* [42] who leveraged expert judgment to quantify initial attack effectiveness as a function of fire size and head fire fireline intensity, *i.e.* intensity at the main advancing fire front, at the time of initial attack commencement. Hirsch *et al.* [42] developed an expression for probability of containment (*POC*) as a function of fire size (*A*) and fireline intensity (*I*) which is given as Equation 1:

$$POC = \frac{E}{1+E} \tag{1a}$$

$$\ln E = 4.6835 - 0.7043 \times A - 0.00041 \times I - 0.000052 \times A \times I \tag{1b}$$

In Equation 1, *A* has units of hectares and *I* has units of kW/m. Since trends in probability of containment are not immediately apparent upon inspection of Equation 1, probability of containment calculated from Equation 1 is tabulated in Table 6 as a function of fire size and head fire fireline intensity at the time of initial attack. Although the qualitative trends in Table 6 are logical, *i.e.* containment probability increases with smaller fires, lower intensity, or both, the Hirsch *et al.* [42] study was based on expert opinion from Canadian firefighters so differences in suppression tactics between Canadian and U.S. agencies are not reflected in Table 6.

Table 6. Probability of containment as a function of fire size and head fire fireline intensity at commencement of initial attack from Equation 1 [42].

Fire size (hectacres)										
10	77%	64%	49%	34%	22%	13%	8%	4%	2%	1%
9	82%	71%	58%	43%	29%	19%	11%	6%	4%	2%
8	86%	78%	66%	52%	38%	26%	16%	10%	6%	3%
7	89%	83%	73%	61%	48%	34%	23%	15%	9%	5%
6	92%	87%	80%	70%	57%	44%	31%	21%	14%	8%
5	94%	90%	85%	77%	66%	54%	41%	30%	20%	13%
4	95%	93%	89%	83%	74%	64%	52%	40%	29%	20%
3	97%	95%	92%	87%	81%	73%	63%	51%	39%	29%
2	97%	96%	94%	91%	86%	80%	72%	62%	51%	40%
1	98%	97%	96%	94%	90%	86%	80%	72%	63%	52%
	1000	**2000**	**3000**	**4000**	**5000**	**6000**	**7000**	**8000**	**9000**	**10000**
	Fireline Intensity (kW/m)									

In order to use Equation 1 (or Table 6), for each ignition location the time of initial attack commencement relative to the time of fire ignition (t_{ign}) must be established. This can be viewed as the sum of fire detection time (t_d), report time (t_r), and travel time (t_t):

$$t_{initial\ attack} - t_{ign} = t_d + t_r + t_t \quad (2)$$

Of the terms on the right hand side of Equation 2, fire detection time and report time are potentially reduced by deployment of fire detection cameras as described in Section 4.4.

In conclusion, probability of containment on initial attack will remain unchanged or increase because:

1. There is no reduction in water availability for firefighting purposes (Section 4.2),
2. Fire detection and reporting times in areas covered by the proposed MDS will likely decrease and will remain unchanged in areas not covered by the proposed MDS, and
3. Travel time by responding units will remain unchanged or decrease.

4.6 Change in extended attack efficacy

The amount of water that is available for initial and extended attack, *i.e.* fires lasting over 48 hours that require staffing and shift changes, will remain unchanged. However, the ease with which water can be retrieved will change slightly. Rather than having access to large, open reservoirs constituting minimal concern for both fixed wing and rotary pilots, the identified river pools will require slightly more time and skill for rotary winged aircraft to retrieve water. Fixed wing aircraft, like the CL415 Bombardier, require at least three-quarters of a mile of quasi-straight water with a minimum depth of six feet to scoop. The pools do alter the amount of risk to helicopter pilots as the maneuver requires hovering to drop in and out of the canyon. The narrowness and variable winds induced in the river canyon increases the difficulty for the pilot. Additionally, hovering to fill buckets as well as a slight increase in haul time when returning to fires will cause an overall increase in haul time.

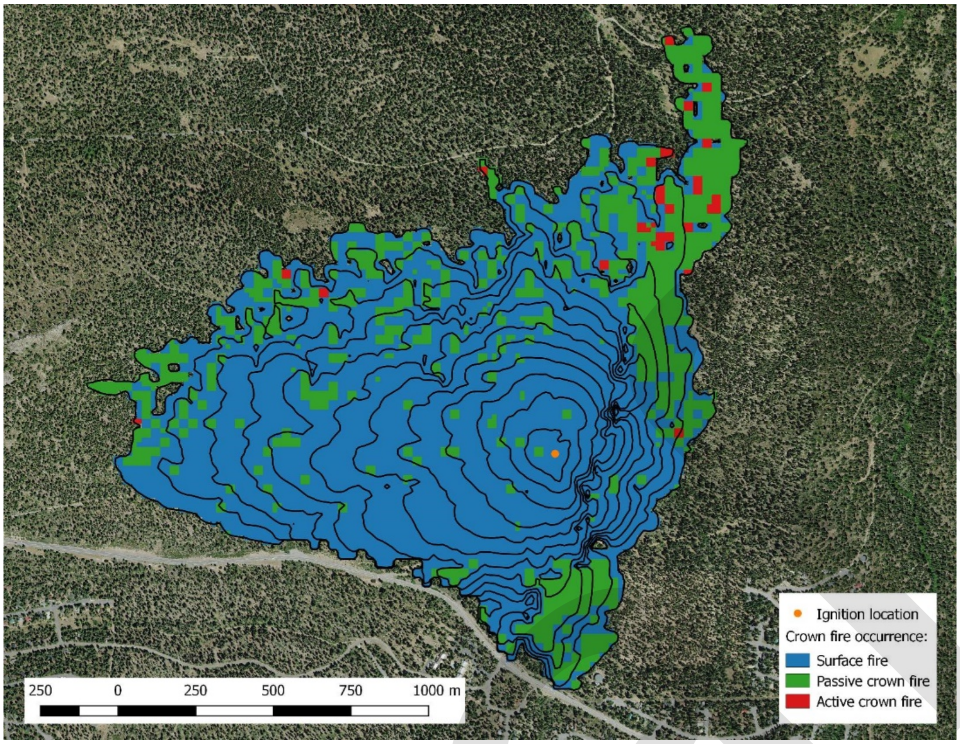
5.0 Effect of Reservoir Dewatering and Early Detection on Landscape-Scale Burn Probability

As described in Section 2.3, wildland fire hazard/risk assessment using fire behavior modeling has recently seen increased usage due in part to more powerful computational resources, improved fire models, and readily available geospatial input data. In this work, we apply ELMFIRE [1] (Eulerian Level Set Model for Fire Spread) to quantify landscape-scale burn probability.

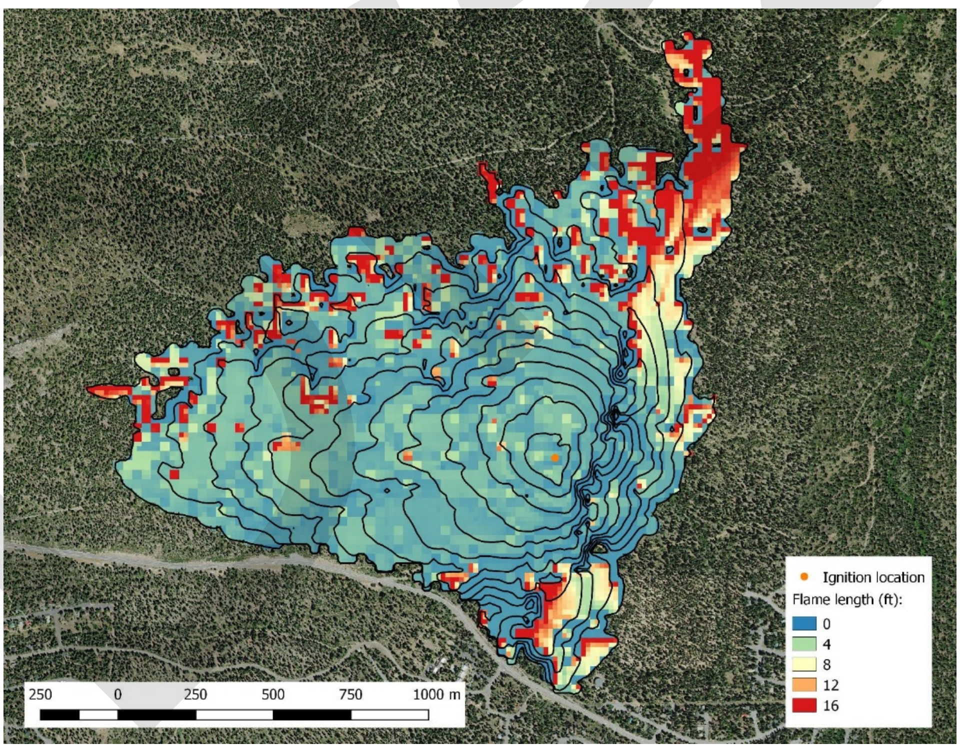
5.1 Monte-Carlo fire spread model: ELMFIRE

ELMFIRE's computational engine is similar to other two-dimensional fire simulators such as FARSITE [6] or PHOENIX RapidFire [10-14] in that it calculates surface fire spread rate using the Rothermel surface spread model [43, 44], assumes that each point along the fire front behaves as an independent elliptical wavelet [45] with length to breadth ratio determined semi-empirically [6, 46], and simulates transition from surface to crown fire using the Van Wagner criterion [47] (with passive/active crown fire spread rates calculated from Cruz *et al*. [48]). ELMFIRE tracks the fire front using a narrow band level set method [49], a numerical technique for tracking curved surfaces on a regular grid.

To demonstrate how ELMFIRE simulates fire spread, Figure 28 shows 24-hours of fire progression from an individual ignition site. The black contour lines in Figure 28 a represent fire front position at 2-hour intervals. Figure 28a also shows which parts of the burned area experienced surface fire (blue), passive crown fire (green), or active crown fire (red). Figure 28b similarly shows fire perimeter contours and flame length variation within the fire perimeter. Flame length (the distance measured from the average flame tip to the middle of the flaming zone at the base of the fire; measured on a slant when the flames are tilted due to effects of wind and slope [50]) is highest in areas that burn as heading fires or that experience crown fire, and lowest in areas that burn as a flanking or backing fire or as a surface fire. In this example, fire area after 24 hours of spread is approximately 560 acres.



(a)



(b)

Figure 28. Sample ELMFIRE fire spread simulation for individual fire ignition. (a) Fire type (surface fire, passive crown fire, or active crown fire). (b) Flame length.

5.2 Fuels

Fuel and topography layers in the analysis area were obtained from the LANDFIRE Remap (LANDFIRE 2.0.0) database [51-52] at a resolution of 30 m. Topography layers include elevation, slope, and aspect. Fuel layers include surface fuel model (in the Scott and Burgan 40 system [53]), canopy height, canopy cover, canopy base height, and canopy bulk density.

5.2.1 Pre-restoration

Existing vegetation rasters from LANDFIRE Remap were assessed for the types of vegetation expected in the areas surrounding the reservoirs (Figure 29). The numerical values of the fuel types do not provide insight into fire behavior, but the descriptions provided by Scott and Burgan [53] do. The major fuel types found around the Iron Gate and Copco reservoirs are described as follows:

- 91 (Urban/Developed) – consists of urban and suburban development that does not support wildland fire spread.
- 98 (Open Water) – land covered by open bodies of water such as lakes and rivers.
- 99 (Bare Ground) – land devoid of sufficient fuel to support wildland fire spread such as deserts, rock outcroppings, and beaches.
- 102 (Low Load, Dry Climate Grass) – primary carrier of fire is semi-continuous grass.
- 121 (Low Load, Dry Climate Grass-Shrub) – primary carrier of fire is grasses and small (1 ft.) shrubs together with moderate fire spread rate.
- 122 (Moderate Load, Dry Climate Grass-Shrub) – primary carrier of fire is grass and medium (1-3 ft.) shrubs together with high fire spread rate.
- 165 (Very High Load, Dry Climate Timber-Shrub) – primary carrier is heavy forest litter with a small tree or shrub understory with moderate fire spread rate.
- 186 (Moderate Load Broadleaf Litter) – primary carrier is moderate load broadleaf litter with moderate fire spread rate.

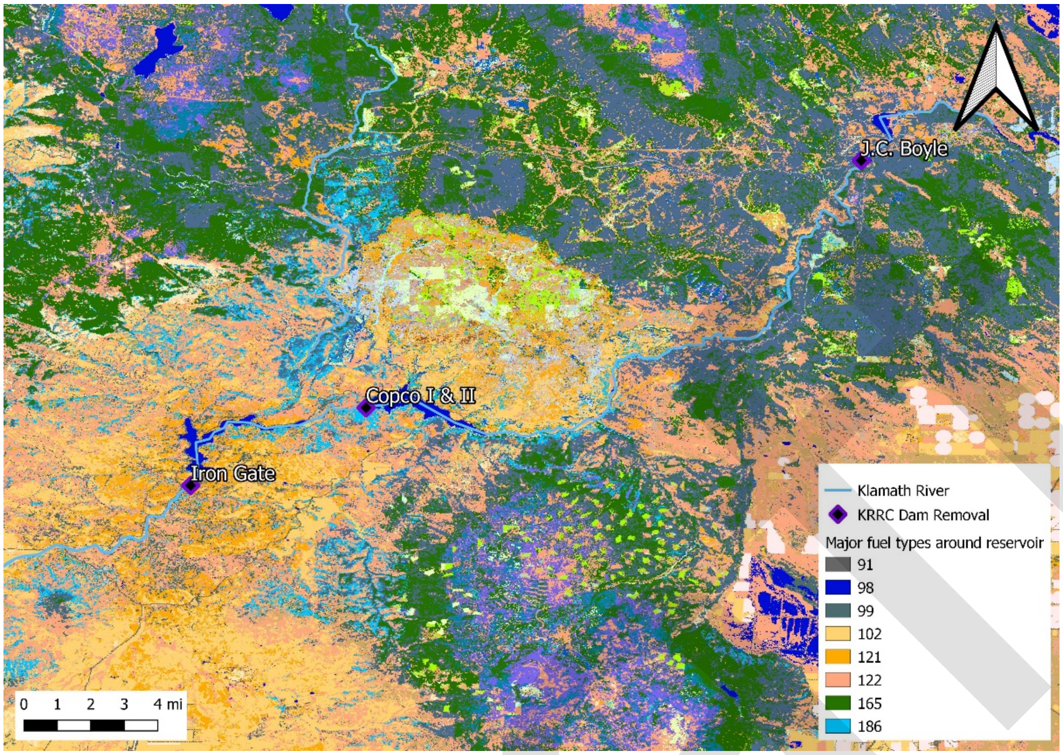


Figure 29. Iron Gate and Copco surface fuel (pre-restoration).

5.2.2 Post-restoration

Vegetation re-growth after dam removal was estimated using historical imagery and existing vegetation types surrounding the areas to be reclaimed. Existing vegetation typically is a good surrogate for expected re-growth in an area of similar soils, *etc*. The Fuels Classification and Characterization System (FCCS) [54] was utilized as well as LANDFIRE data [51-52] for the analysis area (Figure 30, Figure 31). The 30 m resolution LANDFIRE vegetation type data was compared to the FCCS existing vegetation to verify the potential vegetation for the site.

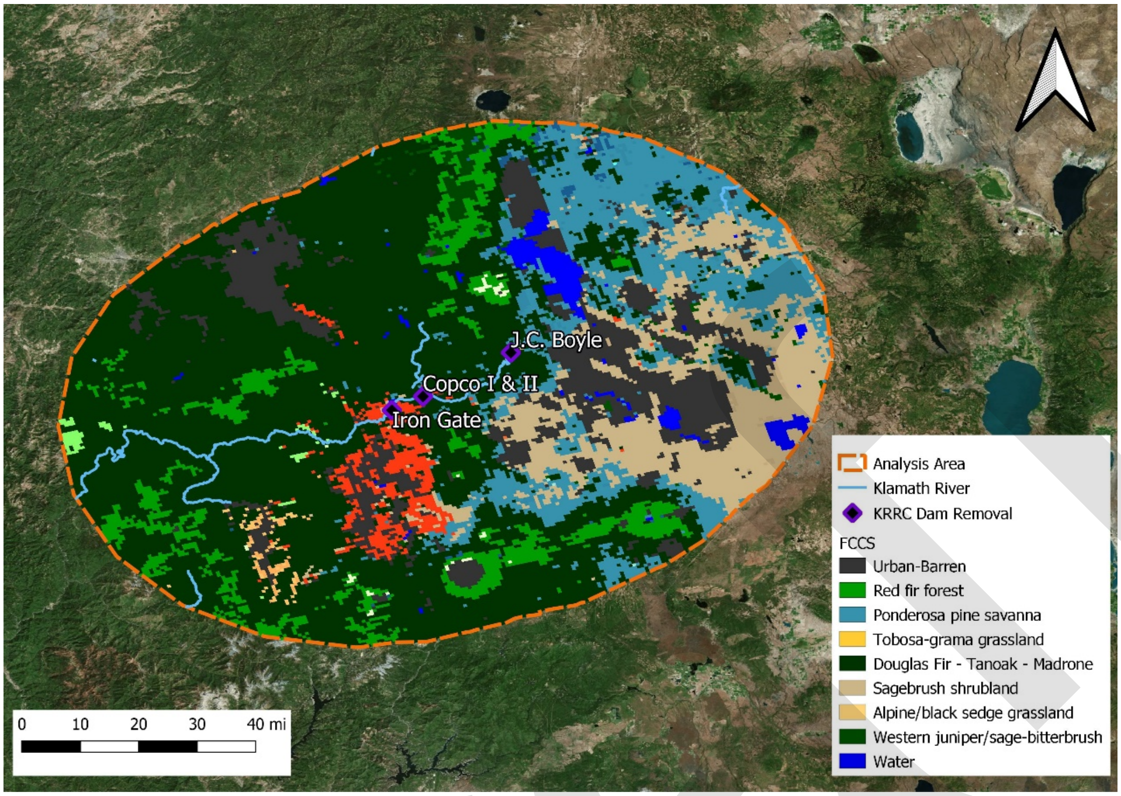


Figure 30. FCCS existing vegetation types.

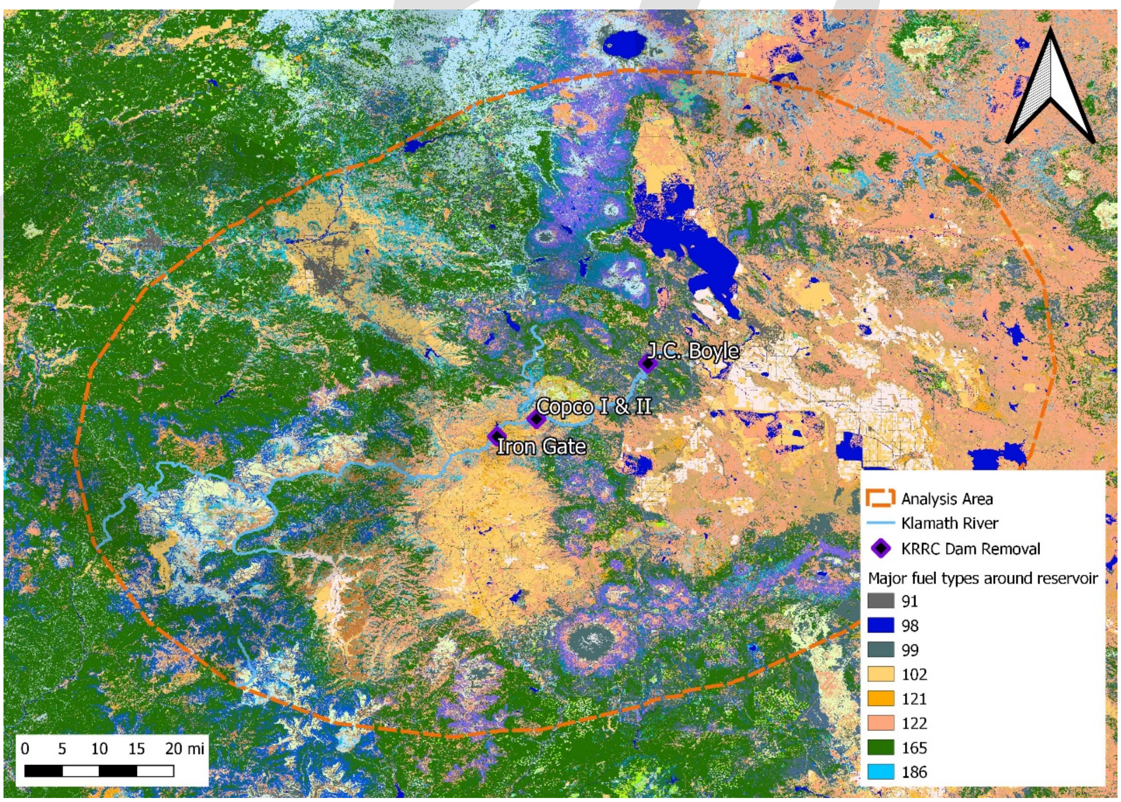


Figure 31. LANDFIRE 2.0.0 (Remap) existing vegetation types.

Initial re-growth is assumed to be in the grass-forb stage for up to the first ten years after the dams are removed. An example of post-restoration fuels is shown in Figure 32 with reclaimed land as fuel model 101 (short grass). Simulations of fire growth and spread assumed this regrowth condition.

The second decade in grass dominated areas will remain grass. In shrub-chaparral areas the second ten-year increment (10-20 years) will move into a shrub-grass and in the third ten-year increment the vegetation will return to a shrub-chaparral vegetation type, such as the Chamise chaparral shrubland adjacent to the Iron Gate Dam area. Grass-forb and chaparral-shrub vegetation types have a relatively short developmental cycle and are considered mature within 30 years of re-establishment.

After the first ten-year increment forested areas will move into a shrub-grass type for the next ten years, followed by a timber-grass type as reforestation grows above the initial grass-shrub stages. These stages will be followed by a timber type that will mimic the existing timber type in the immediate area, such as the Jeffery pine, Ponderosa pine, and Douglas-fir forests around the Copco I and II site.

Once the revegetated timber areas reach the fifth ten-year increment it is assumed that they will be similar in type to the surrounding areas of vegetation but will not be in a similar age class or stage of development.

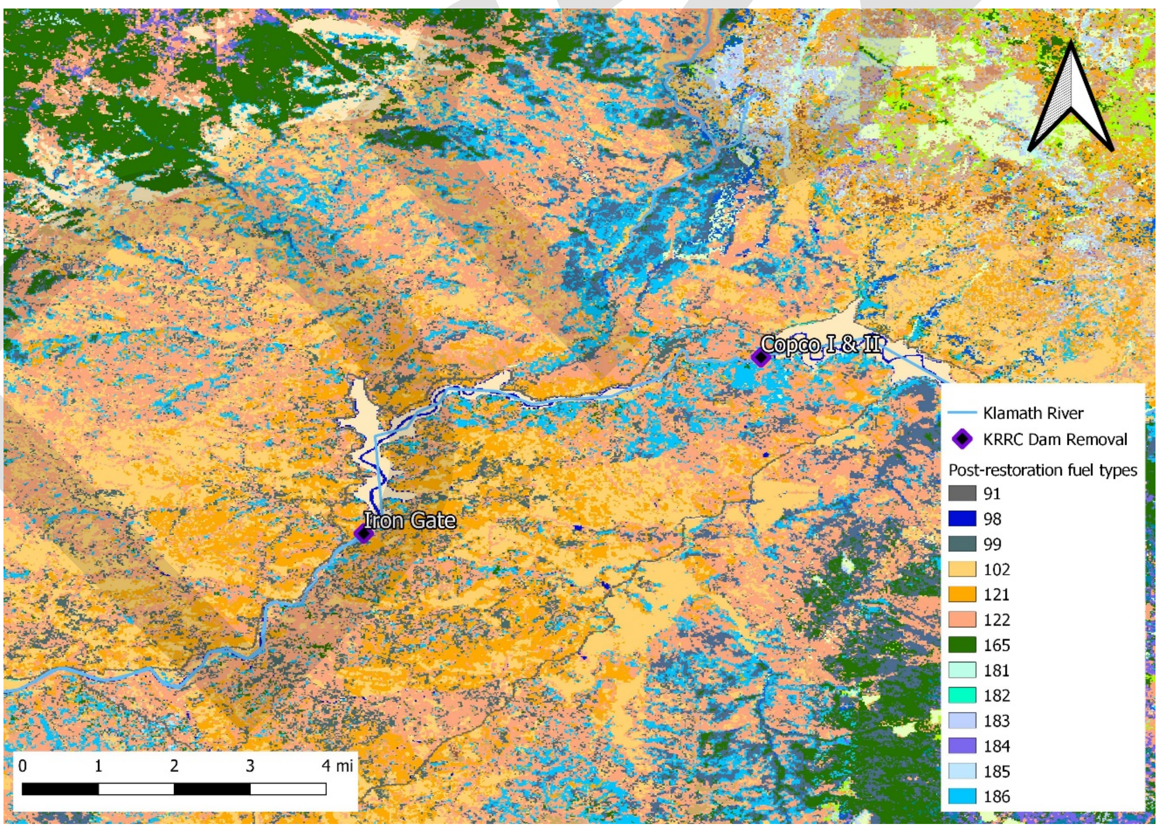


Figure 32. Iron Gate and Copco surface fuels post-restoration.

5.3 Fire weather

The general approach to developing requisite wind and weather inputs involves using the North American Regional Reanalysis (NARR) dataset [55] in conjunction with a fire weather filter to identify days of historic weather significance. The Weather Research and Forecasting (WRF) model is then used to generate wind and weather fields only for those days identified as being significant from a fire weather perspective.

The NARR dataset is maintained by the National Centers for Environmental Prediction, the National Weather Service, and the National Oceanic and Atmospheric Administration. It is a gridded meteorological dataset that provides a "snapshot" of the atmosphere every 3 hours at approximately 32 km resolution. Being a reanalysis, NARR is a hybrid of weather modeling and meteorological observations (surface observations of temperature, relative humidity, wind speed/direction, and precipitation, weather balloon observations of wind speed/direction and atmospheric, sea surface temperatures from buoys, satellite imagery for cloud cover and precipitable water, *etc.*). Ingested data include not only surface (meaning near ground level) quantities but also upper atmosphere quantities as well. The NARR dataset is available from 1979 when modern satellites first became available to current day, with a lag of a few weeks.

Although NARR's 32 km resolution is too coarse to be useful for fire spread modeling purposes, it can be used to identify historical fire weather days to be recreated at higher resolution using WRF. The basic idea is to determine dates for each 32 km by 32 km NARR pixel in the analysis area where the most severe fire weather conditions have occurred between 1979 and 2018. The primary advantage of identifying historical fire weather events using reanalysis data, instead of surface (weather station) observations, is that the NARR dataset is both spatially and temporally uniform whereas point observations are not.

5.3.1 Methodology

The first step to identify historical fire weather days is selection of a single criterion that can be used to identify the most severe fire weather conditions in the NARR dataset. While there are many possibilities, a modification to the Fosberg Fire Weather Index (FFWI) [56] was selected. FFWI combines temperature, relative humidity, and wind speed into a single index ranging from 0 to 100, with 100 corresponding to a wind speed of 30 mph and fine fuel moisture content of 0%. The FFWI formula is presented as Equation 3:

$$\mathrm{FFWI} = \eta\sqrt{\left(1 + U^2\right)} \tag{3}$$

where U is the 20-ft wind speed in miles per hour and η is a function of equilibrium moisture content, M_{eq}:

$$\eta = 1 - 2\left(\frac{M_{eq}}{30}\right) + 1.5\left(\frac{M_{eq}}{30}\right)^2 - 0.5\left(\frac{M_{eq}}{30}\right)^3 \tag{4}$$

In Equation 4, M_{eq} is calculated as [57, 58]:

$$
M_{eq} = \begin{cases} 0.03 + 0.28 \times \mathrm{RH} - 0.00058 \times \mathrm{RH} \times \mathrm{T} & \text{for RH} < 10\% \\ 2.23 + 0.16 \times \mathrm{RH} - 0.0148 \times \mathrm{T} & \text{for } 10 \le \text{RH} < 50\% \\ 21.1 - 0.4944 \times \mathrm{RH} + 0.00557 \times \mathrm{RH}^2 - 0.00035 \times \mathrm{RH} \times \mathrm{T} & \text{for RH} \ge 50\% \end{cases} \tag{5}
$$

where RH is relative humidity in percent and T is temperature in °F.

FFWI is very sensitive to wind speed, and less sensitive to relative humidity and temperature. For example, FFWI is 80 for a wind speed of 50 mph and an equilibrium moisture content of 10%, but only 73 for a wind speed of 25 mph and an equilibrium moisture content of 2%. Ignition of a wildland fire and growth to threatening scales may be more likely under the latter conditions but spread rates for an already established wildland fire could be higher under the former conditions.

It has been found that using a Fosberg Fire Weather Index (FFWI) could result in "off season" (generally, during the winter, *i.e.* after significant rains) days being falsely identified as fire weather days. To avoid these problems, a Modified Fosberg Fire Weather Index (MFFWI) is used in this work to identify wind events that occur simultaneously with low relative humidities and high temperatures. MFFWI is defined as follows:

$$
\mathrm{MFFWI} = \mathrm{FFWI} \times \frac{P_{ign}}{100} \tag{6}
$$

where P_{ign} is Schroeder's ember ignition probability [59] as given in Table 7 as a function of fuel temperature and fine fuel moisture content. The data were originally published [59] with temperatures in degrees Fahrenheit and this convention is retained here. It is seen that the ember ignition probability is strongly sensitive to moisture content, and less sensitive to temperature.

Table 7. Ignition probability by woody embers/firebrands as tabulated by Schroeder [59].

Fuel	*Fine Fuel Moisture Content (%)*														
Temp (F)	*1.5*	*2.0*	*2.5*	*3.0*	*4.0*	*5.0*	*6.0*	*7-8*	*9-10*	*11-12*	*13-16*	*17-20*	*21-25*	*26-30*	*>30*
30-39	87	80	74	69	59	51	43	34	25	17	10	4	1	0	0
40-49	89	83	77	71	61	53	45	36	26	18	11	5	1	0	0
50-59	92	85	79	73	63	54	47	37	27	20	11	5	2	0	0
60-69	94	88	81	76	65	56	49	39	29	21	12	6	2	0	0
70-79	97	90	84	78	68	59	51	41	30	22	13	6	2	0	0
80-89	100	93	87	81	70	61	53	42	31	23	14	7	2	1	0
90-99	100	96	90	84	73	63	55	44	33	24	15	7	3	1	0
100-109	100	99	93	86	75	66	57	46	35	26	16	8	3	1	0
110-119	100	100	96	89	78	68	59	48	36	27	17	9	3	1	0
120-129	100	100	99	93	81	71	62	51	38	29	18	9	4	1	0
130-139	100	100	100	96	84	74	65	53	40	30	20	10	4	1	0
140-149	100	100	100	99	87	77	67	55	42	32	21	11	5	2	0
150-159	100	100	100	100	90	80	70	58	45	34	22	12	5	2	0

First, 10 m wind components, 2 m temperature, and 2 m relative humidity are extracted from the NARR dataset and converted to GeoTiff files at 3-hour intervals from 1979 to 2019 (41 years). 10 m wind components were used to calculate 20 ft wind speed, in mph, and wind azimuth, in degrees. FFWI and MFFWI were then calculated at 3-hour intervals using the formulas presented above. Because rapidly spreading fires often cause significant damage in the first ~6 hours of a burn period, MFFWI values were averaged over a 6-hour period.

Next, the 6-hr average files were processed to determine the maximum 6-hr average MFFWI that occurred on a particular calendar day. Finally, for each 32 km by 32 km pixel in the NARR dataset, the ~15,000 (41 yr × 365 days/yr) daily maximum MFFWI values were sorted from high to low, with the date carried along and sorted analogously. These were then written to two (MFFWI and date) stacked GeoTiff rasters such that the first band contains the highest MFFWI value over 40 years and the date corresponding to the highest MFFWI. The second band contains the second highest MFFWI and date corresponding to that MFFWI, and so on.

With historical weather dates now identified, a 41-year (1979-2019) fire weather climatology was developed using the WRF model to recreate historical days of fire weather significance across the analysis area. Approximately 200 days were included in this climatology, but for fire modeling purposes this data set was distilled to the most severe 50 days for a given location within the analysis area. High-resolution (1.2 km) hourly gridded fields of relative humidity, temperature, dead fuel moisture, and wind speed/direction were extracted from this analysis and provided as input to a Monte-Carlo-based fire modeling analysis.

5.4 Stochastic selection of ignition locations and wind/weather conditions

In order to capture a range of potential ignition locations, ignitions are distributed randomly (but not uniformly) within the analysis area shown previously as Figure 1. Modeled ignition density, meaning the number of ignitions per unit area, varies spatially across the analysis area in a pattern that mimics past fire occurrence. To accomplish this, the Figure 10 ignition density map from all fire causes is read into ELMFIRE so that ignitions can be distributed accordingly.

For each random ignition location, the weather stream is also selected randomly from the 50 most severe fire weather days (based on MFFWI) for that ignition location. Six hours of weather data, corresponding to approximately one burn period, are extracted from the fire weather stream, and provided as input to the fire spread simulations.

5.5 Quantification of dewatering impact on modeled landscape-scale burn probability

Burn probability is used here to quantify how dewatering and conversion of ~1,000 acres of water affects fire potential. Burn probability is the likelihood that a point on the landscape will be impacted by fire during a given period, usually one year (*i.e.*, annual burn probability). However, in this work burn probability is taken as the number of times a pixel on the landscape burned in a model run divided by the total number of model runs to facilitate comparison between different hypothetical scenarios.

Burn probability is determined by running ELMFIRE with stochastic ignition locations and weather data (Section 5.4). Separate runs were conducted with pre-restoration and post-restoration fuel layers. In both cases, initial attack and fire suppression were disabled, so the resultant burn probability figures do not reflect any effect that early detection and suppression may have on probability of containment.

Figure 33 shows the difference between modeled pre-restoration and post-restoration burn probability. The color-scale is such that areas in yellow indicate no change in burn probability, areas in blues and greens indicate a reduction in burn probability (attributed to the stochastic/random nature of this analysis), and areas in orange and red indicate an increase in burn probability (due to reservoir dewatering and/or the stochastic/random nature of this analysis). The primary region of change occurs in the reservoir basins where land previously covered by water was converted to vegetation. Within the aerial suppression extent, modeled mean burn probability increases by less than 1% for a range of post-restoration fuels (short grass, grass/shrub, and timber understory) as shown in Table 8.

Table 8. Changed in modeled mean burn probability within aerial suppression extent from pre-restoration to post-restoration fuels.

Fuel	Mean burn probability	Relative change
Pre-restoration	7.73×10^{-6}	-
Post-restoration (short grass / FM101)	7.80×10^{-6}	0.90%
Post-restoration (grass / shrub FM 122)	7.73×10^{-6}	0.00%
Post-restoration (timber / FM 165)	7.73×10^{-6}	0.01%

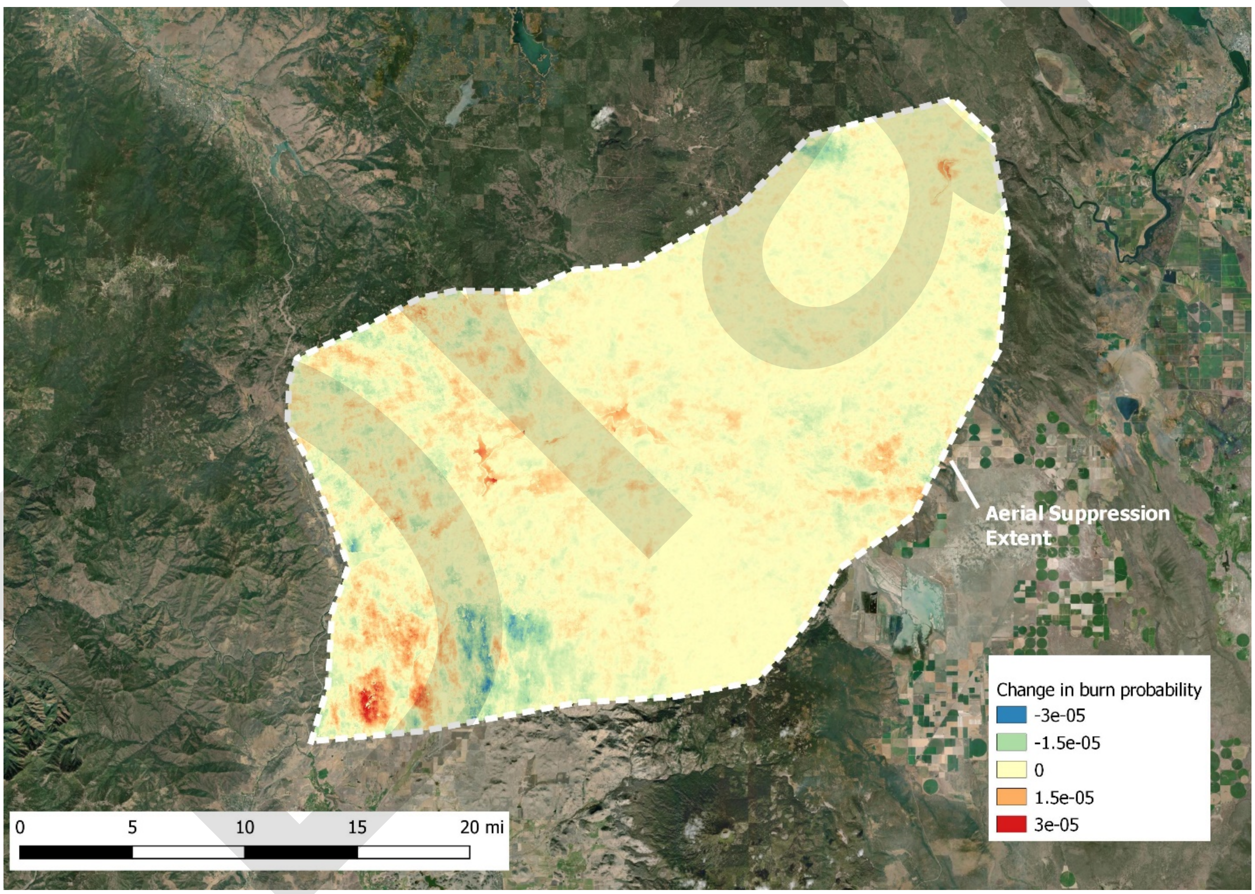


Figure 33. Difference between modeled pre-restoration and post-restoration burn probability.

5.6 Quantification of early detection time impact on modeled landscape-scale burn probability

While the simulations discussed in Section 5.5 are intended to quantify how creation of additional burnable landmass affects modeled landscape-scale burn probability, simulations in the current section are intended to address how reduction in detection and travel times as discussed in Section 4.5 impact initial attack success rate and landscape-scale burn probability.

When initial attack modelling is enabled in ELMFIRE, for each combination of ignition location and time of ignition the following occurs at the time of initial attack commencement relative to time of ignition ($t_{initial\ attack}$ - t_{ign}):

1. Fire size is calculated
2. Head fire fireline intensity is calculate as the maximum fireline intensity across all burning pixels
3. Equation 1 is used to calculate probability of containment from fire size and head fire fireline intensity
4. A random number between 0 and 1 is generated. If this random number is less than the probability of containment, then fire is considered contained and fire growth is halted. If this random number is greater than probability of containment, fire growth continues unchecked.

This allows ELMFIRE to quantify how changes in detection time, *e.g.* due to installation of fire detection cameras, affects landscape-scale burn probability. Since it has already been shown in Section 4.5 that initial attack effectiveness will increase or remain unchanged after dewatering and implementation of the FMP, a range of initial attack times from 5 minutes to 30 minutes was modeled. Figure 34 plots modeled mean burn probability within the aerial suppression extent (Figure 2) as a function of initial attack time. It is seen from the plot that small reductions in time of initial attack (*e.g.*, from 30 minutes to 25 minutes) reduce modeled mean burn probability by a an amount that is greater than any increase in burn probability associated with dewatering.

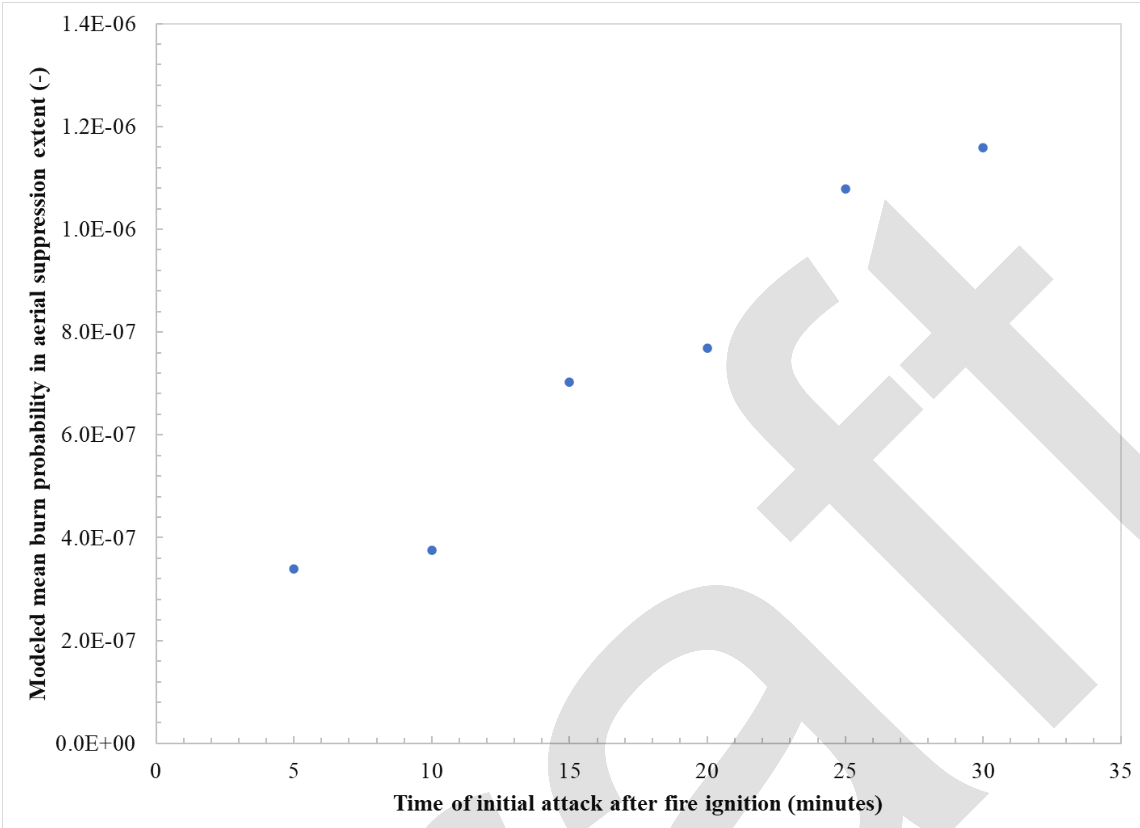


Figure 34. Change in modeled mean burn probability within aerial suppression extent as a function of initial attack time relative to fire ignition.

6.0 CONCLUSIONS

The salient conclusions drawn from the analyses presented in this report are:

1. There will be no effective decrease in water availability for firefighting purposes following reservoir drawdown due to implementation of measures described in the Fire Management Plan [3]. The ease with which helicopters and fixed wing aircraft can access the reservoirs will change. Helicopters will have to hover and drop/raise in and out of dip sites potentially increasing the overall haul time depending upon pool/river width and hazards in the area. However, the amount of water available will not be affected by dam removal.
2. Cameras will provide an effective means of early fire detection in the project area. Detection of most fires is expected at fire sizes between 0.01 acres and 0.1 acres. The post-restoration detection scheme provides a minimum 39% increase in detection coverage at the target heights used for the ASE. Triangulation coverage of the protected area is increased significantly under the post-restoration detection scheme at each target height.
3. Dewatering of the project reservoirs and reclamation of approximately 1,000 acres of land increases modeled mean burn probability by a negligible amount (< 1% in the aerial suppression extent).
4. Probability of containment on initial attack shows that early detection associated with installation of fire detection cameras increases probability of containment and reduces burn probability. Small reductions in initial attack time after fire ignition (*e.g.*, from 30 minutes to 25 minutes) more than compensate for the modeled increase in burn probability, especially considering the relative increase in burn probability was < 1%. For example, a reduction in average arrival time from 30 minutes to 25 minutes results in a 7% decrease in modeled mean burn probability within the ASE, and a reduction in average arrival time from 30 minutes to 20 minutes results in a 34% decrease in modeled mean burn probability within the ASE.

7.0 REFERENCES

[1] Lautenberger, C., "Wildland Fire Modeling with an Eulerian Level Set Method and Automated Calibration," *Fire Safety Journal* **62**: 289-298 (2013).

[2] Lautenberger, C., "Mapping areas at elevated risk of large-scale structure loss using Monte-Carlo simulation and wildland fire modeling," *Fire Safety Journal* **91**: 768 – 775 (2017).

[3] Klamath River Renewal Corporation, "Fire Management Plan Appendix 01," June 2020.

[4] Vaillant, N.M., Ager, A.A., Anderson, J., and Miller, L., "ArcFuels User Guide and Tutorial: for Use with ArcGIS 9®," United States Department of Agriculture Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-877 June 2013.

[5] Vaillant, N.M., Ager, A.A., and Anderson, J., "ArcFuels10 System Overview," United States Department of Agriculture Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-875, March 2013.

[6] Finney, M.A., "FARSITE: Fire Area Simulator – Model Development and Evaluation," United States Department of Agriculture Fore Service Rocky Mountain Research Station Research Paper RMRS-RP-4 Revised February 2004.

[7] Finney, M. A., "An overview of FlamMap fire modeling capabilities," in Fuels Management--How to Measure Success, Ed. P.L. Andrews and B.W. Butler, Portland, OR, 2006.

[8] Keane, R.E., Drury, S.A., Karau, E.C., Hessburg, P.F., and Reynolds, K.M., "A Method for Mapping Fire Hazard and Risk Across Multiple Scales and its application in fire management," *Ecological Modeling* **221**: 2-18 (2010).

[9] Parisien, M.-A., Walker, G.R., Little, J.M., Simpson, B.N., Wang, X., and Perrakis, D.D.B., "Considerations for Modeling Burn Probability Across Landscapes with Steep Environmental Gradients: an Example from the Columbia Mountains, Canada," *Natural Hazards* **66**: 439-462 (2013).

[10] Tolhurst, K.G., Shields, B., and Chong, D., "Phoenix: development and application of a bushfire risk management tool," *The Australian Journal of Emergency Management* **23**: 47–54 (2008).

[11] Chong, D., Tolhurst, K., and Duff, T., "Incorporating Vertical Winds into PHOENIX RapidFire's Ember Dispersal Model," Technical Report, Bushfire CRC/University of Melbourne, 14 December 2012.

[12] Chong, D., Tolhurst, K., and Duff, T., "PHOENIX RapidFire 4.0's Convective Plume Model," Technical Report, Bushfire CRC/University of Melbourne, 16 December 2012.

[13] Chong, D., Tolhurst, K., and Duff, T., "PHOENIX RapidFire 4.0 Convection and Ember Dispersal Model," Technical Report, Bushfire CRC/University of Melbourne, 16 December 2012.

[14] Chong, D., Tolhurst, K., Duff, T., and Cirulis, B., "Sensitivity Analysis of PHOENIX RapidFire," Technical Report, Bushfire CRC/University of Melbourne, 7 May 2013.

[15] Short, Karen C. 2017. Spatial wildfire occurrence data for the United States, 1992-2015 [FPA_FOD_20170508]. 4th Edition. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2013-0009.4

[16] Abatzoglou, J. T., Balch, J. K., Bradley, B. A., Kolden, C. A., "Human-related ignitions concurrent with high winds promote large wildfires across the USA," *International Journal of Wildland Fire* **27**: 377-386 (2018).

[17] https://frap.fire.ca.gov/frap-projects/fire-perimeters/

[18] https://ftp.nifc.gov/public/incident_specific_data/
[19] https://rmgsc.cr.usgs.gov/outgoing/GeoMAC/historic_fire_data/
[20] https://github.com/zoran-cuckovic/QGIS-visibility-analysis
[21] Cuckovic, (2016). Advanced viewshed analysis: A Quantum GIS plug-in for the analysis of visual landscapes. *Journal of Open Source Software*, 1(4), 32, doi:10.21105/joss.00032
[22] http://nhlr.org/nhlr.org/lookouts/us/ca/paradise-craggy-lookout/
[23] http://nhlr.org/nhlr.org/lookouts/us/or/parker-mountain-lookout/
[24] http://www.firelookout.com/or/chasemtn.html
[25] http://nhlr.org/nhlr.org/lookouts/us/or/soda-mountain-lookout/
[26] https://evsolutions.biz/hardware/
[27] Kucuk, Omer, Topaloglu, Ozer, Altunel, Arif, Çetin, Mehmet. (2017). Visibility analysis of fire lookout towers in the Boyabat State Forest Enterprise in Turkey. Environmental Monitoring and Assessment. 189. 10.1007/s10661-017-6008-1.
[28] Heyns, A., du Plessis, W., Kosch, M., Hough, G., "Optimisation of tower site locations for camera-based wildfire detection systems," *International Journal of Wildland Fire*. Preprint (2019).
[29] Rodrigues, M., Alcasena, F., Vega-Garcia, C., "Modeling initial attack success of wildfire suppression in Catalonia, Spain," *Science of the Total Environment* **666**: 915-927 (2019).
[30] http://www.alertwildfire.org/
[31] https://www.goes-r.gov/education/docs/fs_fire.pdf
[32] http://cimss.ssec.wisc.edu/goes_r/meetings/awg2010/Presentations/0608_145_Schmidt.pdf
[33] http://www.cstarsd3s.ucdavis.edu/systems/goes-efd
[34] Alexander Koltunov, Susan L. Ustin, Brad Quayle, Brian Schwind, Vincent G. Ambrosia, Wei Li, "The development and first validation of the GOES Early Fire Detection (GOES-EFD) algorithm," Remote Sensing of Environment, Volume **184**, 2016, Pages 436-453.
[35] Donovan, G.H., Brown, T.C., "Be careful what you wish for: the legacy of Smokey Bear," *Front Ecological Environment* **5**(2): 73-79 (2007).
[36] Christiansen, Victoria, "Opportunities to Improve the Wildland Fire System," *Fire Continuum Conference*, May 21, 2018.
[37] Keating, E.G., Morral, A.R., Price, C.C., Woods, D., Norton, D.M., Panis, C., Saltzman, E., and Sanchez, R., "Air Attack Against Wildfires: Understanding U.S. Forest Service Requirements for Large Aircraft," RAND Corporation, 2012.
[38] https://www.nwcg.gov/sites/default/files/data-standards/pdf/values.pdf
[39] Fried, J.S. and Fried, B.D., "Simulating Wildfire Containment with Realistic Tactics," *Forest Science* **42**: 267-281 (1996).
[40] Heinsch, F.A. and Andrews, P.L., "BehavePlus Fire Modeling System, Version 5.0: Design and Features," USDA Forest Service Rocky Mountain Research Station, General Technical Report RMRS-GTR-249, December 2010.
[41] Reimer, J., Thompson, D. K., Povak, N., "Measuring Initial Attack Suppression Effectiveness through Burn Probability," *Fire* **2(4)**: 60 (2019).
[42] Hirsch, K.G., Corey, P.N., and Martell D.L., "Using Expert Judgment to Model Initial Attack Fire Crew Effectiveness," *Forest Science* **44**: 539-549 (1998).
[43] Rothermel, R.C., "A Mathematical Model for Predicting Fire Spread in Wildland Fuels," USDA Forest Service, Research Paper Int-115, January 1972.
[44] Albini, F.A., "Estimating Wildfire Behavior and Effects," USDA Forest Service General Technical Report Int-30, 1976.

[45] Richards, G.D., "A General Mathematical Framework for Modelling Two-Dimensional Wildland Fire Spread, *International Journal of Wildland Fire* **5**: 63-72 (1995).
[46] Anderson, H.E., "Predicting wind-driven wild land fire size and shape," United States Department of Agriculture Forest Service, Intermountain Forest and Range Experiment Station, Research Paper INT-RP-305, 1983.
[47] Van Wagner, C.E., "Conditions for the Start and Spread of Crown Fire," *Canadian Journal of Forest Research* **7**: 23-34 (1977).
[48] Cruz, M. G., Alexander, M. E., and Wakimoto, R.H., "Development and testing of models for predicting crown fire rate of spread in conifer forest stands," *Canadian Journal of Forest Research* **35**: 1626–1639 (2005).
[49] Sethian, J.A., "A fast marching level set method for monotonically advancing fronts," *Proceedings of the National Academy of Sciences* **93**: 1591-1595 (1996).
[50] nwcg.gov/course/ffm/vert-horiz-and-slope/41-flame-length
[51] Rollins, M.G., "LANDFIRE: a nationally consistent vegetation, wildland fire, and fuel assessment," *International Journal of Wildland Fire* **18**: 235-249 (2009).
[52] http://landfire.cr.usgs.gov/viewer/
[53] Scott, J.H. and Burgan, R.E., "Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel's Surface Fire Spread Model," United States Department of Agriculture Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-15 (2005).
[54] https://www.fs.fed.us/pnw/fera/fft/fccsmodule.shtml
[55] National Centers for Environmental Prediction/National Weather Service/NOAA/U.S. Department of Commerce: NCEP North American Regional Reanalysis (NARR). Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. Dataset. http://rda.ucar.edu/datasets/ds608.0/.
[56] Fosberg, M.A, "Weather in Wildland Fire Management: The Fire Weather Index," *Conference on Sierra Nevada Meteorology*, American Meteorological Society, pp. 1-4 (1978).
[57] Simard, A.J., "The Moisture Content of Forest Fuels – 1. A Review of the Basic Concepts," Canadian Department of Forest and Rural Development, Forest Fire Research Institute, Information Report FF-X-14, Ottawa, Ontario, 47 pp.
[58] Goodrick, S.L., "Modification of the Fosberg fire weather index to include drought," *International Journal of Wildland Fire* **11**: 205-211 (2002).
[59] Schroeder, M.J., "Ignition probability," USDA Forest Service. Fort Collins, CO. RMRS unpublished report, 1969.

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