Understanding Connections Between Fuels Management, Fire Disturbance, and Streams

In this interview, Natalie Collar shares ways in which waterways experience fire and the effects of adjacent fuels management on stream systems.

Kayla: Can you start by sharing how you got started working in fire-affected watersheds?

Natalie: I am from a small town in the foothills of northern California's Sierra Nevada called Paradise. I grew up with parents that were very aware we lived in a very fire-prone area. They were always aware of fuels and maintaining defensible space around their house to the extent they could. I also had a lot of neighbors that weren't or who didn't have the resources to. The entire town of Paradise was destroyed in 2018 in California's costliest and most fatal wildfire to date. Ninety-five percent of the 30,000 people that lived there lost their homes and businesses in one day. That's about 14,000 structures. Eighty-five people died.

It was a tragedy and I wish the November 2018 Camp Fire had never happened, but I am thankful for the unique, very personal perspective it provided me about the wildfire victim's experience. I think it helped me to become a better fire scientist; most people working in wildfire engineering and science are not directly affected by the hazard they deal with professionally. Yes, wildfire is a natural phenomenon, but it can still have devastating consequences for life and property. We were evacuated a few times growing up but fire never really came into town until after I left. I went to undergrad in Santa Barbara where fire activity was pervasive as well. A lot of my professional work involves post-fire debris flows and other hydrogeomorphic hazards, including how to predict their likelihood of occurrence in a pre-fire context. I feel privileged to have gained a deeper understanding of some of the conflicting perspectives that come with management decisions.

KS: Can you speak to some things resource managers might consider when they're planning multi-objective fuels reduction projects in and around riparian areas?

NC: I think the important thing to know about fuel or forest management actions in riparian areas is that they're typically being conducted because the riparian area itself has been substantially altered, either through intentional land management or natural or anthropogenic disturbances, and that has triggered the need for proactive fuels management and often concurrently habitat restoration. Some of those management or disturbance pressures might be wildfire itself—maybe it's more wildfire-prone because of fuel densification after a century of fire suppression, and that's actually kicked that riparian area and abutting upland area into a different fire regime where now we have plants that are not adapted to higher burn severities or more frequent fire activity. Maybe this area has been infested by exotic species. Prescribed burns and mechanical thinning and other management actions are often used to suppress those non-endemic species. Maybe there's been

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timber harvesting or grazing in the area. There are a lot of reasons why you might get to the point where you're conducting fuel treatment activities in riparian areas and I think it's important to think about what your objectives are. It is also important to acknowledge that some objectives may compete with one another, requiring managers to think about which objective(s) to prioritize over others. Resource managers often start by identifying which resources in the management area are most critical to humans or sensitive species. Is this a high-yield source water area? Are there any threatened or endangered species present? That's going to trigger different types of management questions. One of the most common reasons fuel management campaigns are conducted in riparian areas is to reduce the likelihood of moderate to high burn severity. But oftentimes, managers try to layer riparian habitat restoration and ecosystem restoration on top of fuel management objectives. Sometimes those objectives compete, sometimes they harmonize.

KS: What are some of the potential downsides and constraints of fuel management in and around riparian areas?

NC: Managers need to be cognizant of any potential trade-offs between how their management activities might impact landscape processes and ecosystem function versus how wildfire itself could. A lot of impacts from management fully overlap with the impacts that fire itself can have in riparian and upland areas.

Riparian areas tend to be less flammable than upland areas because of their higher soil moisture and vegetative water content—the water table is typically closer to the ground surface and there are more phreatophytes. This means it requires a lot more heat energy to make potential fuel sources combustible and to sustain an ignition source. Riparian areas are often used as natural fuel breaks in fire management, along with other natural landforms like ridge lines and rocky outcrops. Fire typically gets into the riparian area when an ignition source successfully ignites a fire in drier upland fuels and then travels down into the riparian area through gullies and steep ravines, oftentimes during extreme fire weather. If fuel treatments have been conducted in the upland area but not in the adjacent riparian corridor, that creates a break in the continuity of the fuel treatment; you don't want your riparian area to be the fuel source that bumps the fire activity into a more extreme state. Again, there are some competing pressures there, so managers have to determine which objectives are most important when planning a fuels management campaign.

Another potential downside for fuel management in riparian areas is a reduction in shading of the stream corridor. Shading is important because stream temperature plays important roles in nutrient cycling, behavioral patterns of aquatic biota, fish distribution in the stream channel, and more. For example, if a fuels management project reduced cover by mechanically thinning the canopy or removing ladder fuels, or if prescribed burning is implemented to reduce herbaceous material and/or new woody growth along the waterway, all of that is going to reduce shade, which can increase stream temperature in the summer. In the winter, interestingly, the opposite effect can occur where stream temperatures decrease because you permit radiant cooling that would otherwise potentially be moderated or buffered by overhanging riparian vegetation. Another potential downside could be altering organic matter inputs to the aquatic food web. If a food source is coming from within your study area, we call that autochthonous. If it's being transported from outside of your project area into it, we call that allochthonous. Because most stream reaches are directly and indirectly connected to processes upstream, upslope, and even vertically into the canopy, allochthonous carbon and organic matter inputs tend to dominate in systems that are in equilibrium. When you reduce the amount of woody vegetation being delivered to the stream, you are removing a potentially very important allochthonous carbon input. Greater reliance on autochthonous sources may be required for months to years to come. Streamside management can be considered a disturbance to that food web since fish rely on the invertebrates that thrive in habitat created by large woody debris. This can create trickle-up effects to the higher chains in the food web depending on what is happening with primary food sources. Another potential downside related to large woody debris is the potential habitat complexity reduction that occurs when large woody debris inputs are suppressed. Habitat complexity is important for aquatic ecosystem form and function, such as when in-channel debris creates lower-velocity refugia habitat for fish during high flows.

Another thing to consider is how management actions can alter the soil hydraulic properties that control how water moves through the subsurface. For example, heavy machinery can decrease porosity and saturated hydraulic conductivity by compacting soils, thereby changing local hydrology and soil biogeochemical processes which can affect stream water quality. Riparian areas often have finer textured soils with higher water-holding capacity than non-riparian areas, which can render them more vulnerable to compaction or even to alteration of what's happening with microbes in the soil column. Management activities in and of themselves can also rearrange the amount, size and orientation of surface woody materials. One example of this is what happens in mechanical chipping and mastication operations. We use mulch to increase soil water holding capacity and to buffer soils from erosive raindrop impact, but these changes need to be accounted for when thinking about landscape processes. Mulch cover can change the rates and types of chemical reactions occurring in the soil if it alters soil temperature, for example.

Constraints also affect which management options are available. Some examples include:

- Potential presence of threatened endangered or sensitive species
- Old-growth habitat
- Cultural resources in the area
- Lack of agreement among resource specialists
- Funding sources
- Landscape and ownership continuity
- Limited scientific information on effects of fuels treatment on aquatic and riparian areas
- Aesthetic and recreational impacts

KS: What kind of things should folks be taking stock of before a fire, or when they're planning fuel treatments?

NC: Oftentimes the vegetation in riparian zones remains intact after fire, either because fire didn't actually burn close to the stream or because severities were lower there. So the acute impacts of the fire are not present or not as obvious by waterways. But, it's really important to recognize that it's often the riparian areas that get hit by the post-fire hydrogeomorphic response. When it rains after a fire and runoff response is amplified, all that water is heading towards your stream network. That can have devastating consequences.

The first thing I think about is what's happening with the region's fire regime, how often and at what intensity do you expect to experience fire in a given area? It is also worth thinking through whether the historic fire frequency is consistent with present-day conditions. Fuels in North America are denser now than they were a century ago due to the Forest Service's 20th-century 10 am fire suppression policy, which can create conditions that deviate from the historic fire return interval. Given aridification trends, some areas will likely experience more extreme and/or frequent fire behavior in the future, so planning for that becomes a part of the equation. Unfortunately, an increasingly non-stationary climate can make it really hard to use the past as a blueprint for how to move forward. The next thing I'd suggest is taking stock of what is happening in your watershed and in your management zone specifically. The world is extremely heterogeneous, meaning wildfire resiliency planning has to be site-specific. One plan does not fit all. Looking at how vegetation communities are distributed throughout your watershed, topographic shape, and other characteristics that influence how fire moves across and interacts


Landsat aerial image of the November 8, 2018 Camp Fire that destroyed Paradise, CA.


Painting by Natalie's twin sister, Noelle Phares, a professional artist in Denver, CO (www.noellephares.com), depicting a plume of smoke. Painting title: "Plume." Painted in 2022.


The street Natalie grew up on in Paradise, CA, shortly after the 2018 Camp Fire. Photo taken by Natalie Collar.

At the 2022 Hermit's Peak-Calf Canyon burn scar (New Mexico) in October 2022. Photo taken by Natalie Collar.

with your landscape is a good place to start. Luckily, there is a lot of information out there on how various species do and do not tolerate fire. Understanding how the different parts of your watershed will respond to fire disturbance is fundamental to upping your pyrology game.

My colleagues and I are frequently hired to conduct pre-fire hazard assessments, requiring us to catalog or inventory what is at risk in a given area. The scope of this depends a lot on the setting and can get more complex where development mixes with large fuel loads, such as in the wildland-urban interface and intermix. Understanding what your potential values at risk are is really important. I work in an industry that is often focused on the built landscape, which is so important, but I do try to be a voice for the natural environment too (like many others do also). I hope that the protection of environmental resources when feasible, not just because of what they provide us but because they are important and worthy in and of their own right, is always part of the conversation one day soon.

I think understanding potential recovery pathways for vegetation within a watershed is really important. Vegetation can respond in so many different ways to fire. Some evolutionary adaptations that facilitate survival are recolonization success includes epicormic or coppice sprouting, root suckers, basal sprouting, and thick bark. Certain species rely on tissues/plant organs underground to survive the fire and to continue growing, like Aspen. Aspens often live along waterways and they spread via rhizomes. In postburn environments, I've seen so many tiny Aspens growing up in and around streambeds because what was there before has been wiped out. Fire created a gap that the most competitive colonizers exploit. That is part of natural succession. On the other side of that might be lodgepole pine, whose post-fire recolonization success hinges on their serotinous cones that open up during fire. The parent tree itself might not survive, but her seeds get spread and enjoy the post-fire carbon-rich soil. Wind and water can also disperse propagules. Fire triggers flowering and fruit production of certain species. If the fire doesn't burn very hot or its residence time is short, the seed bank may be preserved and with vegetation removed, the light limitations for germination and shade-intolerant species in general are reduced or removed.

KS: Can you speak to the physical, chemical, and biological effects of fire on watershed landscape processes and how that relates to stream structure and function?

NC: Hydrology is the science of how water moves through the environment. There are many things that influence how much precipitation you get and how much of that precipitation input is lost to evapotranspiration or becomes groundwater or runoff. For example, evapotranspiration rates are influenced by what we call atmospheric demand, or your vapor pressure deficit, how much water is available in the soil for plants to use, and how much solar radiation is hitting the vegetation surface.

In a water budget, the biggest input is typically precipitation as rain or snow. Your biggest loss is not how much water runs off into streams or percolates down to the water table, it's how much water evaporates back up in the atmosphere via evaporation from open water surfaces, including water on vegetation that has been intercepted, and of course, from water being taken into plants via root structures and then lost to the air surrounding the plant via evapotranspiration through leaf stomata. In more arid locations, upwards of 80% of the water that falls on a watershed might be evaporated back into the atmosphere.

In some areas, one of the biggest changes we've seen in climate recently is higher air surface temperatures. There's a relationship between how much water the atmosphere can hold and temperature called the Clausius-Clapeyron relationship. It describes why warmer air requires more water to saturate and reach 100% relative humidity. What we call "temperature" is simply a measure of how fast molecules are moving in a given space. With higher temperatures, water molecules are simply moving faster be they in solid, liquid, or vapor phase. As temperatures increase, the molecules move faster and are more likely to escape the liquid phase and transform into the vapor phase. That's why higher air temperatures hold more water on average, there are just more molecules that manage to escape the liquid phase into the vapor. Because of that, we have higher atmospheric water vapor demand when temperatures get higher—it takes more water to saturate hotter air, and more terrestrial water gets lost to the atmosphere via evapotranspiration.

That all matters because fire can alter evapotranspiration rates (among other relevant hydrologic processes) where it changes vegetation structure and function. Suddenly, some of that water that would have otherwise been lost back to the atmosphere via evapotranspiration might now be available to run off downstream because vegetation isn't using it. I published a series of articles about this topic in the **Journal of Hydrology** over the last three years.

The second change to note is how modifying vegetation changes the way that a landscape responds to a storm event. When you remove vegetation, you remove some of the material that buffers the erosive impact of raindrops as they fall onto the soil surface. Canopy foliage is no longer there to intercept raindrops, and reduced grass and herbaceous vegetation cover also increases the amount of erosion that rainfall can cause.

Fire itself can really alter soil structure. The ash that's generated during fire can clog soil pores and reduce infiltration. Hydrophobicity is another effect, although it occurs in a much more heterogeneous way than is often acknowledged. Hydrophobic soil lenses can develop when waxy compounds on plant leaves, which are typically a water loss prevention strategy for intact vegetation, get vaporized by the hot temperatures of the fire. Those vaporized hydrophobic waxy compounds follow the thermal gradient down into the soil column and then re-coalesce to coat soil particles when the temperature is low enough for the vaporized molecules to move back into a more solid phase. That hydrophobic soil layer can now impede water infiltration until it breaks down. A couple of caveats: if fire burns hot enough and/or sticks around long enough, that material can re-vaporize and the hydrophobic soil layer can get annihilated before the fire is even over. It is also important to recognize that many areas have naturally occurring water-repellent soil layers even without fires, including parts of the Pacific Northwest. All these things can increase runoff which in turn increases stream power and subsequently, the sediment carrying capacity of that runoff. The amount of discharge has a direct relationship with the amount of sediment it can move, and those are always in what geomorphologists call Lane's balance. More discharge means that water will pick up and carry more sediment. That has huge consequences for potential debris flow production and nuisance erosion. You don't have to get devastating debris flow to be highly impactful to a waterway; sediment itself is considered a pollutant in certain contexts.

Another big deal with hydrology and fire is surface energy balances. A tree with dark needles, say an Engelmann spruce, will absorb a fairly high fraction of the shortwave solar radiation that hits it and then will re-emit some of the energy it absorbed as longwave radiation. In contrast, grains of snow reflect most of the light that hits them meaning they have high albedos. Fire itself can shift the surface energy balance of a local environment. If that spruce burns and its needles are removed, now that solar radiation penetrates all the way down to the lighter soil surface because less of it is getting absorbed preemptively by the needles. The relatively lighter soil surface reflects more of the radiation than the darker needles would have because of the differences in their optical properties, so you're changing the energy balance mechanics in numerous ways. When you remove or kill evergreen species, newly-exposed mineral soils tend to be exploited by deciduous trees in the boreal forests of Canada, for example, which typically have lighter-colored leaves than the conifers that dominated the landscape before the fire in this conceptual example. Again, that can lower the total albedo because of that shift in the optical properties of the ground cover. Maybe the ash from the fire commingles with and gets incorporated into the snowpack, darkening it. The pack will now absorb more solar radiation and melt off faster. That's one reason why we tend to see earlier melt times after a fire, which can shift the timing of peak flows, leading to greater asynchrony between snowpack accumulation and peak water


At the 2020 Echo Mountain burn scar (Oregon) in January 2021. Photo taken by Natalie Collar.

demand which typically occurs later in the summer during the growing season in the northern hemisphere.

KS: How do all of the changes brought on by fire affect stream structure?

NC: Changes in sediment inputs can certainly alter the dimension, plan, and profile of a stream. Streams are always trying to find their most probable state; they're trying to find this perfect balance of discharge and sediment transport. If discharge increases, you'll see a corresponding uptick in sediment carrying capacity. Not just from upstream inputs, like hillslopes, but in the channel itself. More lateral migration might start to occur at outer stream bends because the water in the stream is now hungrier for sediment—it will start to pluck sediment grains from the channel bank. Because of this, I think allowing waterways enough space to move around and do their thing after fire is important, although not always possible due to development constraints.

On the biogeochemical side, there is such a shift in what is coming in, for months to potentially years after a fire. In terms of potential chemical compounds, polycyclic aromatic hydrocarbons are oftentimes produced from partially combusted organic matter, like logs and trees. Greater nutrient export is often observed, and that has big water treatment implications. I talk a lot about this and important post-fire considerations in an article I recently published in the Journal of Environmental Management.

As far as stream function and structure and how it relates to food chains, it's really typical to see high algae growth, which has important implications for dissolved oxygen concentration, solar penetration into the water column, and so on.

KS: Following fire in source water collection areas, what can managers do to preserve or enhance hydrologic function? Are there any proactive or responsive steps people can be thinking about to make the best out of the situation that they're in?

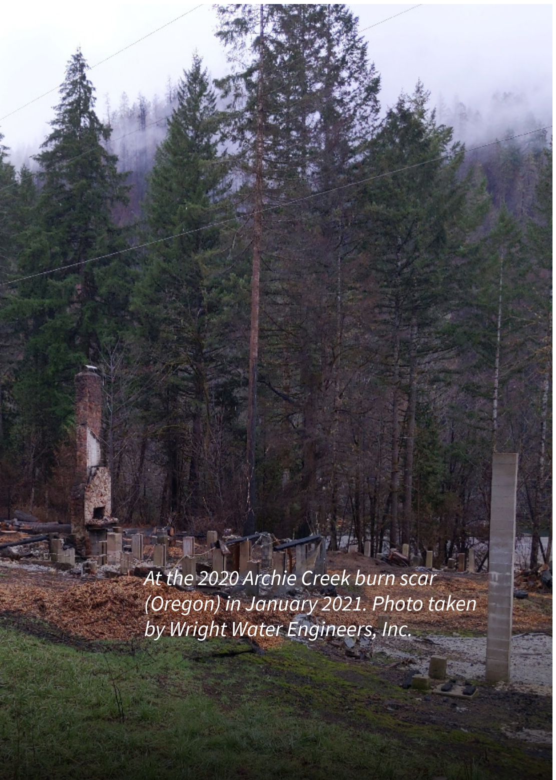
NC: Incorporating fire resiliency planning into your forest management plan is critical. Managing potential fuel densities and patterns and potential ignition sources can reduce the changes of high severity fire. Another thing is not putting potential values at risk in harm's way. Humans like to put structures in fire-prone areas because it's nice to live among trees, but it behooves us to think smartly about where and how we're allowing development. There are a lot of good resources for fire-aware zoning and building codes that local communities can model their own policies after.

We typically prescribe erosion reduction best management practices after the fire occurs—you're not going to be hydro-mulching a vegetated hillslope. But you can plan for the things you might need in place before a fire happens. It's easier to respond to an emergency when you have a plan in place. Who is on your must-call list? Where are you going to get your funding from? Working out what the phone tree ahead of time can be really useful. Pre-event agreements with contractors and supply procurement can reduce the amount of time and effort spent when you're actually experiencing the emergency.

KS: Do you see a lot of that pre-fire planning happening or are most agencies still in a responsive mode?

NC: I'm seeing more and more pre-fire planning. Private and public clients are hiring us to conduct flood and debris flow hazard modeling before fires occur, and to help them understand where their infrastructure may be vulnerable to post-fire hydrogeomorphic hazards.

My company does a lot of water supply planning, and I just wrote a paper that was published in the Journal of Environmental Management about what water utilities can do to think about


At the 2020 Archie Creek burn scar (Oregon) in January 2021. Photo taken by Wright Water Engineers, Inc.


At the 2022 Hermit's Peak-Calf Canyon burn scar (New Mexico) in October 2022. Photo taken by Natalie Collar.

this. Those facilities can be retrofitted to deal with the variable source water quality that you're going to get after a fire to deal with increased amounts of sludge and backwash water. On the water supply side, utilities with relatively small, homogeneous, local water supply portfolios tend to be more vulnerable to fire-related water supply disruptions because the chances of their entire source water area burning in a single fire event are higher. Utilities in that position can reduce their risk exposure by diversifying their supply portfolios, such as with standing, flexible agreements with other water utilities that guarantee an alternative water supply should theirs be compromised. Colorado has a lot of funding set aside for grants under, for example, the state-led Wildfire Ready Watersheds program. Wright Water Engineers was part of a technical team that conducted a statewide susceptibility of post-fire hazards under that program. The program also prepared guidance for how communities can write their own Wildfire Ready Action Plan and provides funding support for communities to do so.

KS: What are some of the regional nuances and factors that can affect the ways different ecological and human communities respond to wildfire?

NC: Landslides are a prominent post-fire hazard in the Pacific Northwest because of the high infiltration rates of your volcanic soils. Among other things, soils on steep slopes are stabilized by the tensile strength of tree roots. After a fire it could take many years for a fire-damaged tree to fall, but once it does, the shear strength provided by the reinforcing roots is diminished, escalating landslide hazard. During your long, drizzling storm events, that rain will infiltrate into soils and eventually increase pore water pressures. With the shear strength of the soils reduced, it now takes less rain and lower soil water pore pressures for a slope to fail.

One other site-specific nuance is what is controlling the success outcome of an ignition. In the southwestern US, fires are typically fuel-limited. Let's take Arizona as an example. The fuels in arid Arizona are almost always dry enough to burn, so what is driving or constraining fire frequency is the amount of time it takes for the fuel source to build up sufficiently to sustain and carry fire. By contrast, the Pacific Northwest is climate-limited. The wetter parts of the PNW always have enough fuel to burn, but that potential fuel source isn't combustible until it has dried out enough to carry an ignition source. That scenario requires a severe seasonal or multi-year drought. It seems to me that the recent increases in aridification may have more dire impacts on fire-related losses in climate-limited areas because they have the fuel. That fuel is just waiting to dry out enough to be flammable.

KS: Is there anything else that you wanted to cover that we didn't get to?

NC: I'd like to acknowledge how many different hats everyone is expected to wear in 2023 and the difficulties associated with that. I am currently a full-time consultant at an engineering firm and a part-time researcher. In order to be productive and competitive I have to be a data scientist, I have to have working knowledge of multiple coding languages, big data management and cloud computing skills, awareness of the ever-shifting landscape of artificial intelligence and machine learning, and so much more. I have to be a statistician; anyone conducting publishable research does. It requires scientists to be ever adaptive, especially as the pace of technological advancement increases exponentially. I must be an expert graphic and content creator—I have to be my own little brand. I am supposed to have a social media presence online (I don't, but it's so heavily pushed in this industry). I'm supposed to be an excellent technical writer; writing a peer-reviewed manuscript for a good journal is very humbling. I am constantly out there at conferences and meetings, sharing my latest research. Not to mention the required expertise in one's own discipline, hydrology in my case. Every day, I spend half an hour looking at the publications that came out the day before to stay on top of the newest literature. That is a commitment that I've made, but it takes a lot of time. It's a big commitment to be willing to talk about these topics that really matter to people and that potentially influence public health and welfare and safety.

At Detroit Lake in the 2020 Beachie Creek burn scar (Oregon) in January 2021. Photo taken by Natalie Collar.