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Impacts of wildland fire on water quality

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Water quality refers to the physical, chemical, and biological characteristics of water in reference to a particular use. Among the physical characteristics of interest to hydrologists and watershed managers are sediment concentrations, turbidity, and water temperature. Dissolved chemical constituents of importance include nitrogen, phosphorus, calcium, magnesium, and potassium. Some of these nutrients are adsorbed on organic and inorganic sediment particles. Bacteriological quality is also important if water is used for human consumption or recreation. The processes in the hydrologic cycle directly or indirectly affect the magnitude of soil erosion and, as a consequence, the transport and deposition of sediment in water. They also affect the physical, chemical, and biological quality characteristics that collectively determine the quality of water.

Figure 1. Ash slurry flow in an ephemeral drainage after the Rodeo-Chediski Fire, Apache-Sitgreaves National Forest, Arizona, USA in 2002.

Increases in streamflow discharges following a fire can result in little to substantial effects on the physical, chemical, and biological quality of the water in streams, rivers, and lakes [1]. The magnitude of these effects is largely dependent on the size, intensity, and severity of the fire, and on the condition of the watershed at the time of burning. Higher postfire streamflow discharges can result in an additional transport of solid and dissolved materials into stream channels or other water bodies, adversely affecting the quality of water for human, agricultural, or industrial purposes. The most obvious effects are produced by suspended and bedload sediments. These components of water quality are important for municipal water supplies because of the costs of treating sediment loaded water and long-term reservoir capacity loss due to sedimentation.

Increased soil erosion, or sediment, is often the most viable effect of a fire other than the loss of vegetation by burning. Maintaining a vegetative cover or a cover of litter and other organic material on the soil surface of a watershed is the best means of preventing excessive soil erosion rates. However, fire can cause the loss of these protective covers and in turn cause excessive soil erosion and soil lost from the burned site [1, 2, 3].

Wildfires generally produce more sediment than prescribed burning. The large inputs of sediment into a stream following a wildfire can tax the transport capacity of the stream and lead to channel deposition (aggradation). However, prescribed burns by their design do not normally consume extensive layers of litter or accumulations of other organic materials. Hence, generally resulting in less sedimentation than a wildfire.

Suspended sediments and turbidity are often the most dramatic of water quality responses to fire. Turbidity is an expression of the optical property of water that scatters light [3]. It reduces the depth to which sunlight can penetrate into water and, therefore, influences the rate of photosynthesis. In-

Figure 2. Dropping of fire retardant, San Bernadino National Forest, California, USA.

creased suspended sediment concentrations that produce turbidity after a fire can result from erosion and overland flow, channel scouring (due to the increased streamflow discharge), landslide accumulations in stream channels, or combinations of all three actions. [1]. Less is known about the effect of fire on turbidity than on the sedimentation processes. It has been observed that postfire turbidity levels in stream water are affected by the steepness of the burned watershed. Turbidity increases after fires are generally a result of the postfire suspension of ash and silt-to-clay sized soil particles in water as well as coarse, burned woody debris (Fig. 1).

Water temperature is a critical water quality characteristic of many streams and aquatic habitats. Temperature controls the survival of certain flora and fauna in the water that are sensitive to water temperature. The removal of streambank vegetation by burning can cause water temperature to rise, leading to thermal pollution, which in turn can increase biological activity in a stream [2,3]. Increased biological activity places a greater demand on the dissolved oxygen (O_2) content of the water, one of the more important water quality characteristics from a biological perspective. Severe wildfires can function like streamside timber clearcuts in raising the temperature of streams due to direct heating of the water surface. Increases up to 16.7°C have been measured in streamflows following fire, and following timber harvesting and fire in combination. Another important aspect of the temperature is the increase in fish mortality posed by stream temperature increases. The main concerns relative to aquatic biota are the reduction in the concentrations of O_2 that occurs with rising temperatures, fish pathogen activity, and elevated metabolic activity. All of these can impair the survivability and sustainability of aquatic populations and communities. Dissolved O_2 contents are affected by temperature, altitude, water turbulence, aquatic organism respiration, aquatic plant photosynthesis, inorganic reactions, and tributary inflow. Dissolved O_2 concentrations less than 10 ppm (less than 10 mg L^{-1}) are lethal to salmonid fishes. Temperature increases of 1-5 °C by fire may not be problematic for salmonid fish at sea level but may become relevant for salmonids at high altitude where waterbodies have lower O_2 saturation values than lowland waters. Fishes adapted to warm water can tolerate warmer stream temperatures and O_2 contents below 10 ppm (10 mg L^{-1}), and are not as easily impacted by O_2 concentration declines.

Dissolved chemicals come from a variety of sources in watersheds such as geologic weathering, decomposition of photosynthetic products into inorganic substances, and large storm events. Vegetative communities accumulate and cycle large quantities of nutrients in their biological role of linking soil, water, and atmosphere into a biological continuum [2,3,]. Nutrients are cycled in a largely orderly (tight) and often predictable manner until a disturbance alters their distribution. One such disturbance is fire. The effects of fire on the nutrient capital (status) of a watershed ecosystem are largely manifested by a rapid mineralization and dispersion of plant nutrients. Nitrogen as NO_3-N, NH_4-N, and organic-N are most commonly studied and most important as indicators of fire disturbance [1]. Most of the attention of hydrologists and watershed managers relative to water quality responses to fire focuses on NO_3-N because it is highly mobile. The potential for increased NO_3-N concentratations in streamflow after burning is attributed mainly to accelerated mineralization and nitrification [2] and reduced plant demand. These postfire effects are short lived, usually lasting only a year or so. The changes in NO_3-N concentrations in response to burning vary. Some investigators have found no significant change in the postfire NO_3-N concentrations in streamflows, while others report increases in NO_3-N concentrations in either the soil solution or streamflow [2]. Regardless of the burning treatment or treatment combinations on watersheds, NO_3-N concentrations in the streamflow are usually well below maximum allowable concentrations for water quality standards.

Fire retardants are frequently used in the suppression of wildfires. Although their effects on the soil-water environment are not a direct effect of fire, their use in the control of wildfires can produce adverse environmental impacts. The main environmental concerns with fire retardant use are: 1) effects on water quality and aquatic organisms, 2) toxicity to vegetation, and 3) human health effects. Ammonium-based fire retardants (diammonium phosphate, monoammonium phosphate, ammonium sulfate, or ammonium polyphosphate) play an important role in protecting watershed resources from destructive wildfires (Fig. 2). However, their use can affect water quality in some instances, and they can also be toxic to aquatic organisms. Nitrogen-containing fire retardants have the potential to affect the quality of drinking water, although the research on the applications of these retardants to streams has largely focused on their impacts on aquatic environments. A number of studies have noted that the amount of fire retardant used and its placement on the landscape are the two main factors determining the degree of environmental impact. Thus, planning of placement and operational control of aircraft releasing fire retardant are critical for minimizing impacts on streams and lakes and their biota

Summary: When a wildland fire occurs, the principal concerns for change in water quality are: 1) introduction of sediment, 2) potentially increasing nitrates, especially if the foliage being burned is in an area chronic atmospheric deposition, 3) possible introduction of heavy metals from soils and geologic sources within the burned area, and 4) introduction of fire retardant chemicals into streams that can reach levels toxic to aquatic organisms. The magnitude of the effects of fire on water quality is primarily driven by fire severity, and not necessarily by fire intensity. Fire severity is a qualitative term describing the amount of fuel consumed, while fire intensity is a quantitative measure of the rate of heat release. The more severe the fire, the greater the amount of fuel consumed and nutrients released, and the more susceptible the site is to erosion of soil and nutrients into the stream where they could potentially affect water quality. Wildfires usually are more severe than prescribed fires. As a result, they are more likely to produce significant effects on water quality. Use of prescribed fires gives the opportunity to control the severity of the fire and to avoid creating large areas burned at high severity. The degree of fire severity is also related to the vegetation type. For example, in grasslands the differences between prescribed fire and wildfire are small and effects to the water quality are then minor. Because of the larger amount of fuel consumed in a wildfire in forested environments, the impacts of fire on water quality are much higher than after a prescribed fire. Canopy-consuming wildfires are of the greatest concern due to the increase in soil erosion after the loss of vegetation. These canopy-consuming wildfires present the worst-case scenario in terms of water quality. The differences between wild and prescribed fire in shrublands are probably intermediate between those seen in grasslands and forest environments.

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