EFFECTS OF FIRE ON SOIL AND WATER

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The article below presents the direct and indirect effects of fire on soil and water. A numerical simulation is completed to assess the temperature at the ground level and few special computer programs, used in wildland fire and its effects.

Keywords: wildland fire, water pollution, soil heating, effects of fire.

1. Introduction

The two issues, effects of fire on soil and effects of fire on water are taken together in this research, because soil and water are connected one with another in many ways. Assessing fire effects on soil and water is of a great importance, if we take in consideration that wildland fire is more and more an important problem, and most of the water we use, has its springs in the mountains, where wildland fires often occur. Also, as we will see in the research, soil affected by fire can be subject to erosion, action that, sooner or later, will have an important negative impact on the environment.

2. Soil. Effects of fire on soil

All fires, regardless of whether they are natural or human-caused, alter the cycling of nutrients and the biotic, physical, moisture, and temperature characteristics of soil. In many cases however, these impacts are either negligible or short-lived and thus have little, if any, impact on the overall ecosystem. In some cases however, the impact of fire on soil conditions can be moderate to severe.

Variable amounts and combinations of minerals, organic matter, air, and water produce a wide range of physical, chemical, and biological properties of a soil. However, these properties are not randomly distributed but occur in an orderly arrangement of horizontal layers called soil horizons. The arrangement of these layers extending from the surface litter downward to bedrock is referred to as the soil profile. A schematic profile is shown in figure 1, but some soils have horizons that are not so distinct. The uppermost layers consist mainly of organic

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matter in various stages of decomposition. The surface litter layer is made up of undecomposed organic material that retains the features of the original plant material (leaves, stems, twigs, bark, and so forth). Immediately below the undecomposed layer is another organic layer that is in various stages of decomposition. It is called the fermentation layer (F-layer). In the F-layer, some of the original plant structure may still be discernable depending on the extent of decomposition. The lowermost surface organic matter layer is the humus layer (H-layer) that is completely decomposed organic matter. The H-layer is an important site for nutrient availability and storage. The finely decomposed organic matter in the H-layer is also the source of aggregating substances that combine with the mineral soil particles in the upper inorganic horizons to produce soil structure.[4]

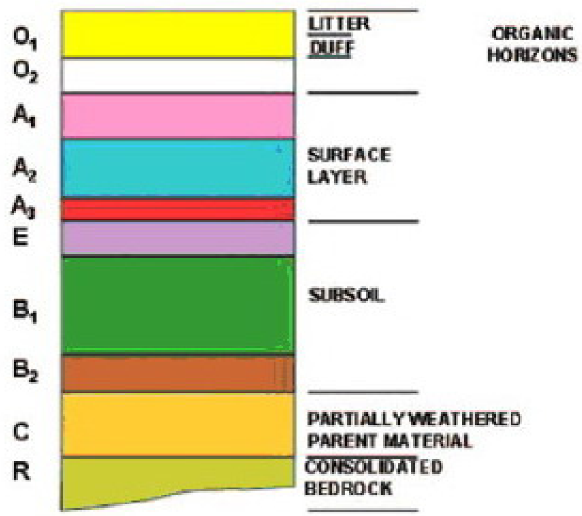


Fig. 1. Soil profile schematic

The original plant structure is no longer identifiable in the H-layer. The combined F-and H-layer is commonly referred to as the duff. More recent designations have been developed for the L-, F-, and H-layers described above. Current taxonomic terminology refers to the organic horizon as the O horizon. The L-layer is referred to as the Oi or O_1 horizon. The F-layer is designated as the Oe, or part of the O_2 horizon and the H-layer is denser than the Land F-layers and is designated as the Oa or O_2 horizon. The mineral soil horizons begin with the uppermost part of the A-horizon and extend downward to bedrock. Depending upon the age and development of the soil profile, there can be several intermediate mineral horizons (for example, E-, B-, and C-horizon). The A horizon is the top mineral layer, and the upper part of this horizon often contains large quantities of finely decomposed organic matter (humus). The mineral E horizon is located immediately below the A-horizon. It is the site where substantial amounts of silicate, clay, iron, aluminum, carbonate, gypsum, or silicon are lost by weathering and leaching that occurs during soil development. Materials leached downward from the E-horizon accumulate mainly in the B-horizon. In well-developed (mature) soil profiles, the original rock structure can no longer be recognized in the B-horizon. The C-horizon is unconsolidated parent rock material remaining above the R-horizon that is made up of hard consolidated bedrock.

The overall degree and longevity of impact of fires on soil is determined by numerous factors including fire severity, temperature, fire frequency, soil type and moisture, vegetation type and amount, topography, season of burning, and pre- and post-fire weather conditions.

Fire can impact a variety of soil physical and chemical properties including the loss or reduction of structure and soil organic matter, reduced porosity, and increased pH. These changes can also result in various indirect impacts including increased hydrophobicity (water repellency) which results in decreased infiltration and increased runoff which often results in increased erosion. Most of these changes to the soil, including a loss or reduction of structure and reduced porosity, are caused by an alteration in soil chemistry resulting from complex interactions among geomorphic processes, climate, vegetation, and landforms. Organic matter is also consumed or lost during a fire. This is dependant on the soil moisture content of the organic layer of the soil profile, fire severity and the subsequent precipitation. Any alteration in soil organic matter is significant.

Changes in soil organic matter may also cause hydrophobicity. This phenomenon occurs during the combustion process when distilled aliphatic hydrocarbons migrate into the soil profile and condense on soil particles to form a water repellent layer. Hydrophobicity, which typically results in reduced infiltration rates, appears to be most common in dry, coarse textured soils that are heated to 349 to 399 °F (176 to 204 °C). These effects however, are usually short-lived, generally disappearing after the first year.[4]

Vegetation removal, combined with the above changes in soil physical properties, will typically result in erosion following a fire. Whether or not erosion occurs, is not only dependant on fire-influenced changes (bare soil, soil structural changes, altered hydrology etc.), but also on a variety of topographical factors, including slope and aspect, and climatic factors, such as rate and amount of precipitation. Since root systems of top-killed shrubs and trees assist in maintaining soil stability, erosion may not occur immediately; instead, it may be delayed several years following a fire. Other factors such as soil texture also influence the erosion potential of a site. For example, in general, coarse-textured soils are considered more erodible than fine textured soils. Overall, a variety of factors including slope steepness, aspect, soil texture, vegetation recovery time, the amount of residual litter and duff and climatic factors such as the timing, intensity, and amount of precipitation, all interact with one another to determine a sites susceptibility to erosion. When compared to unburned sites, the overall extent of erosion will vary considerably from excessive, to little, if any change. The agent responsible for erosion is also dependant on local climatic and topographic parameters. Past studies have found post-fire erosion to be facilitated by wind, water, and/or gravity. This includes all of the following types of erosion: raindrop splash, sheet and rill erosion, soil creep, and mass wasting.

Following vegetation removal, an increase in soil temperature is often experienced. Numerous factors contribute to this increase including, the removal of vegetative cover, consumption of fuels, thinning or removal of the litter and/or duff layer, the enhanced “black body” thermal characteristics of the charred material on the soil surface (National Wildfire Coordinating Group 2001). The removal of vegetation is significant since plant residue (stubble), litter and duff cover, all moderate soil temperatures by intercepting direct sunlight and moderating the loss of soil heat by radiation.

Higher surface temperatures often enhance seed germination and plant growth as well as cause deeper annual soil thawing (in northern areas). This latter effect is significant, as it can increase both the depth and the temperature of the rooting zone. All of these effects, combined with increased nutrient availability, are hypothesized as being the reason why plant growth is often stimulated following a fire. In fact, increased soil temperatures may actually be more important than increased nutrient availability. Reduced shade combined with increased soil temperatures, may however, impact nutrient cycling by allowing the soil surface to dry, thus decreasing soil microbial activity.

An important feature when assessing the effect of fire on soil properties is the temperature at which nutrients are volatilized or that irreversible damage occurs to a particular soil property. This temperature is called the threshold temperature (DeBano and others 1998). Temperature thresholds have been identified for numerous physical, chemical, and biological properties. [5]

3. Effects of fires on water

Fire affects water quality. Research shows changes in water include 1) increase in sediments, 2) increase in stream temperatures, and 3) increase in nutrients. These are all forms of water pollution if we leave aside the substances and foams used by firefighters to extinguish fires, and flow away along with the water. [5]

Stream temperatures increase after a fire because the vegetation that usually hangs above the banks, shading the water, is no longer there. The sun heats up the water. These higher temperatures cause problems to fish and other species whose habitat is normally cold water. The increased nutrients in the water can lead to algal blooms. This can also harm aquatic wildlife living in the streams.

Increases in stream flow following a fire can result in little to substantial impacts in the physical, chemical, and biological quality of water in streams, rivers, and lakes. The magnitude of these effects is largely dependent on the size, intensity, and severity of the fire, the condition of the watershed when rainfall starts, and the intensity, duration, and total amount of rainfall. Post fire streamflow can transport solid and dissolved materials that adversely affect the quality of water for human, agricultural, or industrial purposes. The most obvious effects are produced by sediments which can negatively affect the municipal water supply quality. [4]

Water quality refers to the physical, chemical, and biological characteristics of water relative to a particular use. Important characteristics of interest to hydrologists and watershed managers include sediment, water temperature, and dissolved chemical constituents such as nitrogen, phosphorus, calcium, magnesium, and potassium. Bacteriological quality is also important if water is used for human consumption or recreation; this is the case with many waters that are both within, and that drain from, forested lands. A water quality standard refers to the physical, chemical, or biological characteristics of water in relation to a specified use.

4. Fire computer simulation

The practical CFD method is used to predict, for an open fire presented below the yield of temperature at the ground level.

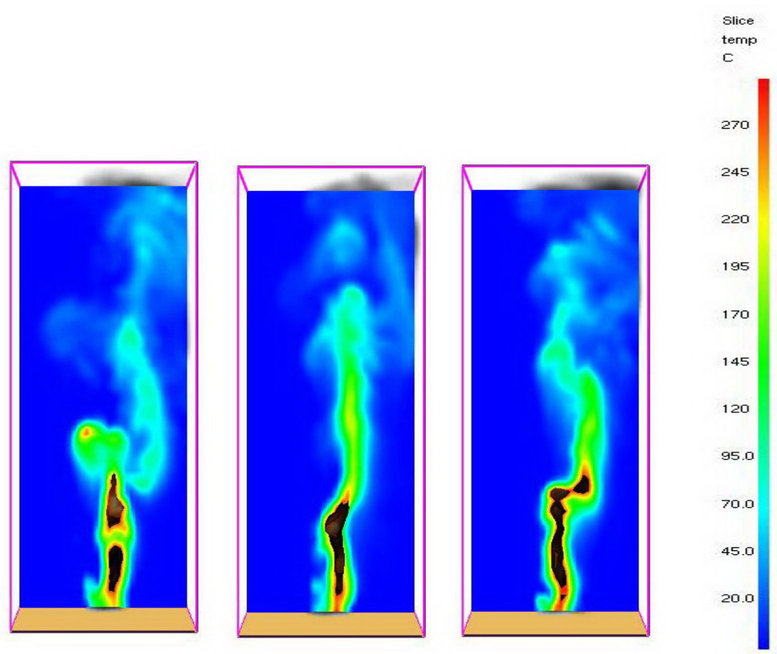
Fig.2. Fire simulation, main view (smoke) at time 580 s

The Fire Dynamics Simulator (FDS) code is a computational fluid dynamics model for simulation of fire-driven fluid flow developed by the National Institute of Standards and Technology.

It solves numerically a form of the Navier-Stokes equations appropriate for low speed, thermally-driven flow with an emphasis on smoke and heat transport from fires.

As a physical limitation of the mixture fraction approach to modeling combustion, we have the assumption that fuel and oxygen burn instantaneously when they are mixed. [1-3]

In the present research one have developed a three-dimensional model of a square shaped kerosene spill, which ignited, create the so called pool fire. The simulation is made in a computational domain with the dimensions: 30m width, 30 m length, and 80 m height. Total amount of cells involved in the hydrodynamic calculus is 144.000. The liquid fuel used for simulation is kerosene, with a spill thickness of 10 cm; the ambient temperature is 20° C, windspeed 0,8 m/s and the total time duration for simulation is 600 seconds.



a) b) c)

Fig.3. Temperature in the simulation, at a) 200s, b) 400s, c) 600s burning time

The simulations were conducted on a computer with 2400 MHz, Intel core 2 Duo processor and 1024 MB DDRAM. Figure 3 presents images of the simulation, with emphasize on the temperature, at 200, 400 and 600 seconds of simulation. In the right side of the figure, one can see the temperature colour meter. [2]

Characteristics of the simulation: the spill diameter (the side of the square) is 6 m, wind speed is 0.8 m/s, and the program made 14425 reiterations in 8.27 hours.

5. Results of the simulation

The graphic below (figure 4) gives the temperatures at ground level, in the centre of the burning kerosene spill.

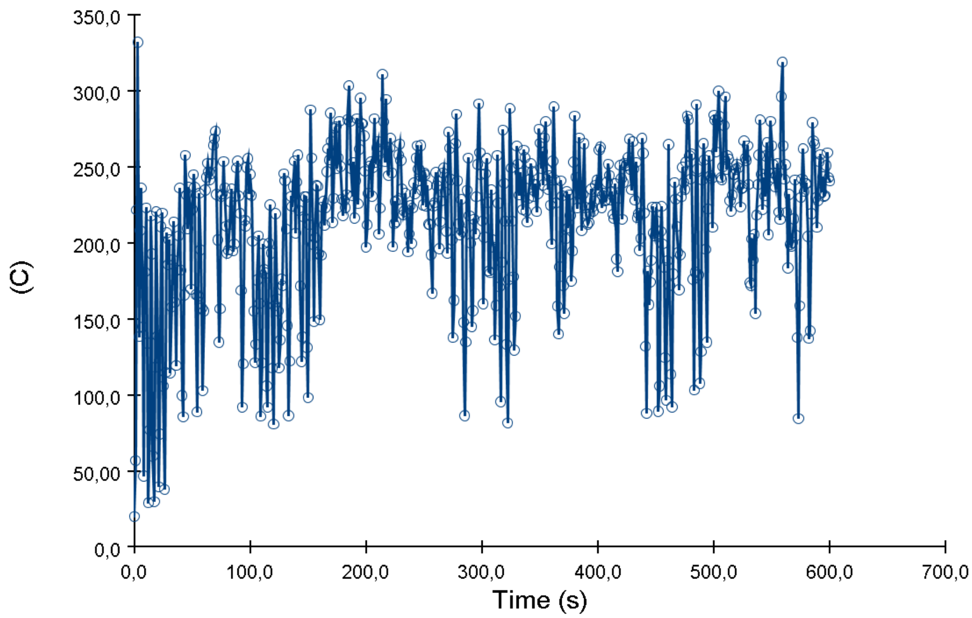


Fig.4. Graphic of temperatures at ground level, in the centre of the spill

One can observe that maximum temperature of approximate 325 °C, is reached several times at 5 s, 210 s and 580 s, along the 600 s of the simulation.

As explained above, temperature is very important, it can destroy the equilibrium and the structure of the soil, that will eventually give up, and an erosion phenomenon occur then. That is why other programs such as FOFEM, WEPP,WATSED concentrates on this problem only.

6. Conclusions

The research above gave some general guidelines that prove the importance of keeping the environment out of uncontrolled fires, as they can and they will alter the quality and equilibrium of soil and water, water that will transport ash and pollutants into our homes even. Maybe the plants, the forests will grow back, but if soil will loose its characteristics and stability, very hard or impossible will be restoring everything back.

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