WATER RESEARCH COMMISSION

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The WRC operates in terms of the Water Research Act (Act 34 of 1971) and its mandate is to support water research and development as well as the building of a sustainable water research capacity in South Africa.

TECHNICAL BRIEF

Water and fire management

Pyrohydrology in African savannas

A completed WRC project has, for the first time, investigated the effect of fire management in the Kruger National Park on soil hydrology.

Background

Soils are vital in supporting healthy and functioning ecosystems. Besides providing a medium for plant growth, soils play a major role in ecosystem functioning through nutrient cycling and water filtration through the system.

Thus, when soils are degraded important ecosystem services are affected. Degraded soils may not be able to store and filter water as efficiently, thereby affecting water quantity and quality.

In turn, this has a detrimental effect on catchment hydrological processes. Soils may a major role in landscape hydrology by providing a medium for water distribution and storage.

This complex relationship between soil and water has been described as interactive, meaning that the physical, chemical and biological properties of soil influence the manner in which water is transported and stored within the landscape which impacts the ecosystem.

African savannas and water

As with many other biomes around the world, the structure and production of African savannas are controlled by the spatio-temporal availability of water. These savannas are considered complex and dynamic systems, which are co-dominated by grasses and trees.

Fore, along with fluctuations in water availability, nutrients and herbivory is regarded as one of the primary drivers responsible for controlling these heterogeneous savannah systems. Although savanna vegetation has been described a resilient and relatively well-adapted to fire, it is believed that frequent-occurring fires can prompt long-term soil degradation, changing the soil hydrology and ultimately reducing ecosystem productivity.

In African savannas where fire is a key driver controlling ecosystem functioning, and more specifically, in the Kruger National Park where fire is used as a management tool, there was found to be a lack of understanding regarding the impacts of long-term fire management on soil hydrology.

During the early 1950s a long-term fire experiment was initiated in the national park using experimental burn plots. These burn plots offered a unique opportunity to determine the effects of long-term fire treatments on soil hydrology on contrasting geologies in African savannas.

Methodology

The study was conducted on different soil type stemming from the two dominant geologies in Kruger National Park,

African savannah in the Kruger National Park following a fire.

i.e. granites and basalts. The effect of varying fire regimes on various parameters were investigated on various burn plots between the granites and basalts. A breakdown of these tests are summarised in Table 1.

Soil hydraulic properties were determined using a tension disc infiltrometer to measure the unsaturated hydraulic conductivity at the soil surface and a Guelph permeameter to measure saturated hydraulic conductivity between 2 and 7 cm of the soil surface.

Soil compaction was determined using a drop-cone penetrometer while soil organic matter (total carbon) was measured using an analytic Leco TruMac Series machine. The water retention capacity was inferred by measuring soil water potential with a WP4-t dewpoint potentiometer. Furthermore, vegetation characteristics such as grass biomass and basal cover were measured using a disc-pasture meter and nearest-distance-to-tuft method, respectively.

Rainfall simulations were used to measure the effect of different fire regimes on surface runoff and sediment yields. Rainfall was simulated at two different intensities, which were applied 24 hours apart, on the annual and no burn plots on the granitic experimental burn plots.

The subsequent surface runoff was measured and sediment collected for analysis using a spectrophotometer and the actual measurement (weight) of sediment. The soil water balances on the different burn plots were measured by using remote-sensing analyses to determine evapotranspiration rates and applying the HYDRUS 3D model to simulate water balances for the different fire regimes in question.

Study results

The study revealed that it is rather the time following a fire, and not necessarily frequency, which resulted in decreased soil infiltration, with slowest infiltration rates immediately after the fire. Findings suggested that fire primarily affected infiltration rates at the soil surface and that these fire effects would dissipate within approximately two years – suggesting the soil's ability to recover; at least in terms of their hydrological function.

Soil compaction, which is recognised for impeding soil infiltration, was attributed to soil processes such as raindrop impact and splash but deeper compaction was linked to high herbivore concentrations trampling the soil.

In addition, long-term fire management effects on soil organic matter content and soil water retention was investigated. Besides promoting soil fertility, soil organic matter is considered hydrophilic and aids in soil water retention. Although alluding to greater organic matter on the fire-suppressed plot on the granitic experimental burn plots, there were no statistically-significant differences found across the varying fire frequencies.

However, on the basaltic experimental burn plots, organic matter content varied between the various fire frequencies. Unlike the granitic plots where it is believed that fire intensities are not substantial enough to transfer heat deep into the soil and consume organic matter, it is thought that the huge contrast in above-ground biomass between the basaltic burn plots is, in fact, responsible for the contract in organic matter contents.

Consequently, soil water retention was found to be greatest on the fire-suppressed no burn plots. The ability of the soil to retain moisture, especially at low water contents, is crucial in a post-fire environment in order to facilitate re-establishment of vegetation.

A reduction in vegetation cover is believed to be responsible for the increased runoff rates observed on the annual burn plots in the granitic region of Pretoriuskop. Reduced

Table 1: A breakdown of the different tests applied on the various Experimental Burn Plot strings

Geology	Section	Experimental Burn Plots	Hydrological Tests	Plots
Granites	Pretoriuskop	Numbi	Soil hydraulic properties, Runoff simulations, Soil water balance	Annual and No Burn plots
		Kambeni	Soil hydraulic properties, Runoff simulations, Soil water balance	Annual, No Burn and Variable Fire Regime
Basalts	Satara	N'wanetsi	Soil hydraulic properties, Soil water balance	Annual, No Burn and Variable Fire Regime
		Satara	Soil water balance	Annual and No Burn plots

vegetation or surface cover will result in less rainfall interception and thus exposing the soil surface to direct raindrops known to compact soil surfaces and inhibit infiltration.

More runoff was generated from the annual plots compared to the no burn plots at the 200 mm/h rainfall intensity 24 hours after the 157 mm/h intensity was applied. The effect of fire on the amount of runoff generated as well as the rate of runoff increases as rainfall intensity increases.

Surprisingly, less sediment was yielded off the annual burn plot. It is believed that this phenomenon is due to compacted soil, which required more energy (higher rainfall intensities over longer periods) to dislodge and redistribute more sediment.

Fire regimes influence the various soil properties which, in turn, impact the soil water balance on the burn plots. On the granites, it was found that due to the reduction in vegetation on the annually-burned plots there were lower evapotranspiration rates measured.

Stemming from a reduction in evapotranspiration, more water was subsequently available in the soil medium to percolate and potentially recharge groundwater. However, there were conflicting trends measured on the basaltic experimental burn plots.

The key hydrological mechanisms and their interactions which were highlighted during this study are summarised in Figures 1 and 2. These mechanisms were almost identical between the dominant granitic and basaltic geologies.

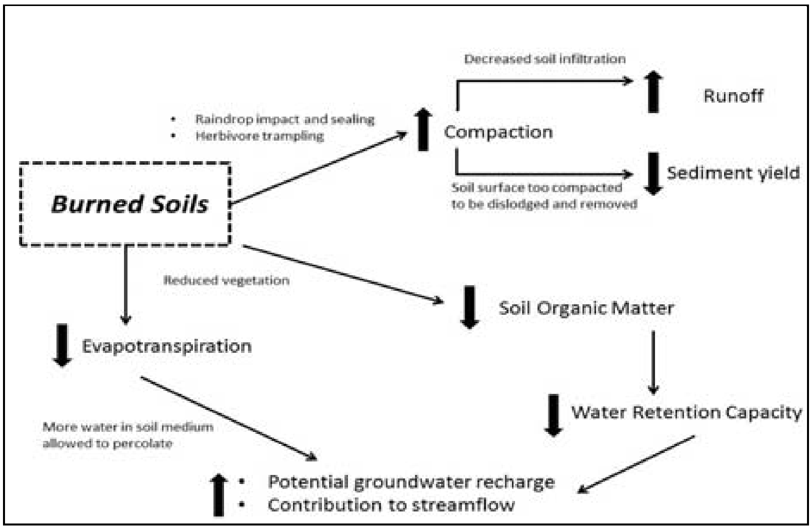

Figure 1 – The mechanisms observed on the annually-burned soils on granitic and basaltic experimental burn plots.

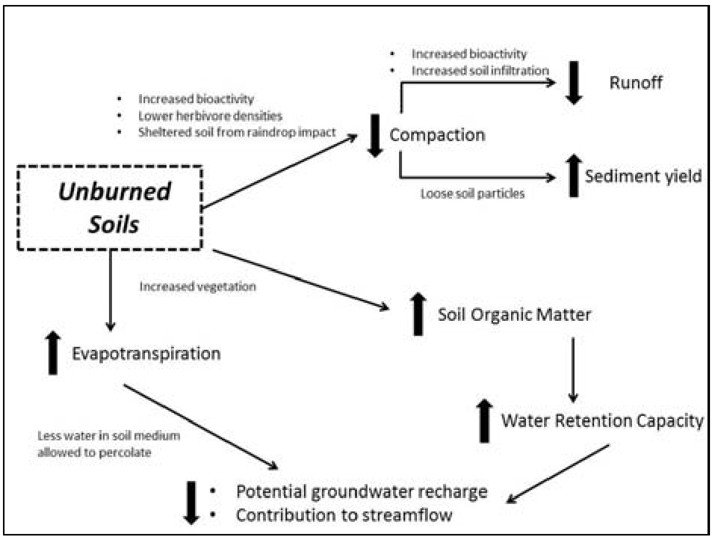

Figure 2 – The mechanisms observed on the unburned soils on the granitic and basaltic experimental burn plots.

Conclusions

Fire effects are complex owing to many interrelated factors which all play a role in influencing each other. Fire impacts on soil hydraulic processes, ultimately influencing soil water balances. These impacts may have cascading effects on large-scale catchment processes.

The effect of fire frequencies on soil hydraulic properties is negligible considering that it is actually the time following a fire which plays a significant role on soil hydrology in a savannah ecosystem. The reduction in hydraulic conductivity were primarily observed at the soil surface, suggesting that savannah fires may lack the high intensities required and/or due to its rapid burning behaviour, does not have sufficient contact time to transfer heat beyond the soil surface. Furthermore, data suggested that after two years following the fire, soil infiltration rates improved suggesting that soils are capable of recovery relatively soon.

Even though soils were compacted both by fire (indirectly) and herbivores (directly), this did not impact soil hydraulic properties significantly. It is believed that decreased infiltration rates observed were likely due to hydrophobicity.

In this case, the influence of soil compaction by fires and herbivores on soil hydrology is considered negligible. However, compacted soils affected sediment yield by maintaining its structure due to the extra cohesion between soil particles, thus preventing soil redistribution.

With the water-holding capacities of the soil influenced by above-ground biomass and organic matter, the effect of fire frequencies on the ability of the soils to retain moisture at low water contents is critical to understand, seeing as it is one of the most important properties in a post-fire environment.

Vegetation cover and soil properties were found to influence the onset of runoff generation. After performing rainfall simulations in order to compare the effect of historical fire regimes (annual vs no burning) on the runoff and sediment yield generated, it was discovered that long-term fire management unequivocally affects the amount of runoff generated from the savannas of the Kruger National Park.

It is likely that long-term fire management practice, i.e. fire frequency, will affect the rate of evapotranspiration losses from savannas in the park. Additionally, these fire regimes affect soil properties and soil water balances, which ultimately control the distribution of water through the landscape.

The impact of fire on soil water balances was found to be significant in both the granitic Pretoriuskop area, characterised by sandy soils and higher rainfall, as well as the basaltic Satara area, characterised by clayey soils and lower rainfall.

Since fire impacts the availability of water within a catchment it is critical that a suitable fire management regime is applied in order to ensure that water distribution in the catchment is not adversely affected.

Besides the need for research in African savannas which focuses on the impact of fire on soil hydrology it is a vital aspect for management in the Kruger National Park to take cognisance of, especially seeing as fire is applied as a management tool to control and manipulate vegetation structure and composition. This study provides valuable insight not only into the relationship between water and fire but also how other factors, such as soil, vegetation and herbivores all interact within a water-controlled savanna landscape.

Further reading:
To order the report, ***Pyrohydrology in African savannas*** (**Report No. 2146/1/14**) contact Publications at Tel: (012) 330-0340, Email: orders@wrc.org.za or Visit: www.wrc.org.za to download a free copy.