The recovery of saturated hydraulic conductivity under different stages of forest succession in Agua Salud and Los Santos, Panama

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Introduction

Deforestation and land-use changes in the tropics is becoming an increasingly controvertial topic. Changes from primary forest into agriculturally utilized lands is causing changes in soil structure and soil hydrological properties. This causes alterations to the hydrological flowpaths and drainage of the area. Alterations in land-use gravely affect the system through increasing rates of soil compaction and erosion leading to soil degradation as well as nutrient depletion.

In this study we shall examine the recovery of soil hydrological properties under secondary forest vegetation. A good indicator for this regeneration is the saturated hydraulic conductivity. This soil parameter determines how fast water can percolate through the soil under saturated conditions and is therefore a good indicator for the effect of land-use changes on the soil properties. Low values at the surface, for example, cause an interruption of vertical percolation and promotes overland flow during times of intense rainfall. Reforestation is seen as a means of reducing surface run-off and increasing the water flow through the profile.

In this study the recovery and regeneration of the saturated hydraulic conductivity shall be examined under different stages of forest regeneration. This was conducted in two locations: in the Los Santos province (south Panama) and in the Agua Salud watershed (central Panama).

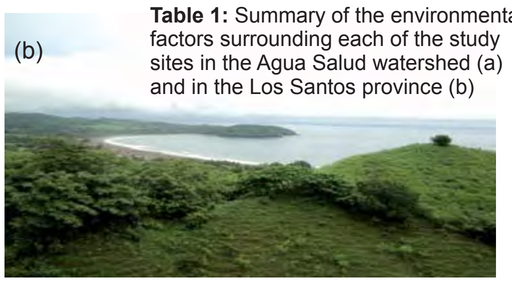


Table 1: Summary of the environmental factors surrounding each of the study sites in the Agua Salud watershed (a) and in the Los Santos province (b)

	Agua Salud	Los Santos
Annual Rainfall	2300mm	1800mm
Temperature	27°C	25 - 31°C
Underlying Geology	basalt	basalt
Soil Texture	Silty clay to clay	Clays to silty clay loams
Soil pH	4.4 to 5.8	6.8
Vegetation	Tropical forest	Dry tropical forest

Agua Salud (a)

Los Santos (b)

Methods and Materials

The Agua Salud project area is located in central Panama in the watersheds of Río Agua Salud and Río Mendoza, which drain into the Panama canal. The study area is characterized by a strongly dissected pre- tertiary basalt plateau with narrow interfluves. The climate of the study area is tropical with a distinct dry season from mid-December through April.

The Los Santos province is located on the Peninsula of Azuero on the pacific coast of Panama. It is characterized by hilly terrain with a dry climate and seasonal rainfall. Around 1940 to 1950, the previously dry tropical forest was turned into pasture for cattle ranching and now only a few pockets of the original forest remain. The entire area is now used for low intensity cattle grazing.

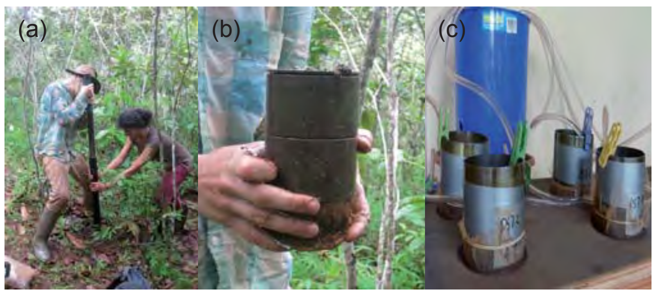


Fig. 1: Process of sample extraction: (a) withdrawing a sample from the soil, (b) extracting an undisturbed soil core, (c) measuring the water flux through a saturated soil sample

Agua Salud	Pasture (4 plots)	SF* 5 to 8 years (4 plots)	SF* 12 to 15 years (4 plots)	Mature Forest (4 plots)	160 samples in 16 plots
Los Santos	Pasture (3 plots)	SF* 5 years (2 plots)	SF* 10 to 13 years (3 plots)	Mature Forest (2 plots)	200 samples in 10 plots

Table 2: The comparable land cover types that were sampled in Agua Salud and Los Santos as well as the number of plots and samples collected in both locations

In this study the space-for-time approach was used to measure the saturated hydraulic conductivity (Ksat) on our two study sites. This method is applicable as on both sites the abiotic parameters (such as geology, soil and climate) are more or less homogenous and are therefore not taken into consideration. The amount of plots sampled in each land-use class in both locations is visible in Table 2.

In this study, a two-step-sampling-design was involved. The first step was to randomly select the plots out of a number of possible plots for each land use. Then, once they were selected, stratified random sampling was used, dividing the plots into 3 strata: upslope, midslope and downslope. This was done in order to avoid point clusters and have a more even distribution of points along the slope. In Agua Salud, five samples were taken in the upslope and midslope strata, summing up to ten samples per plot. In Los Santos, on the other hand, ten samples were taken in each stratum making a total of twenty per plot.

The samples were extracted using a standard coring device in order to obtain relatively undisturbed samples. These samples were saturated over a period of 64 hours and then the volume of water flowing through, per unit of time, was measured. After this the saturated hydraulic conductivity (Ksat) of the soil sample was calculated using darcy's equation.

Results

The results show an overall recovery of the saturated hydraulic conductivity under secondary forest regeneration in both locations. The Agua Salud data shows an increase in Ksat values corresponding to the age classes of different land covers. Ksat at 0 - 6 cm has relatively similar medians at 23.8 and 38.2 mm/h on pastures and secondary forests of 5 years, and an increase in the older secondary forests of 12 years to the mature forests at 157.8 and 232.6 mm/h (Fig. 2). Again here, the values of Ksat at the second depth of 6 to 12 cm, do not show a clear difference and remain uniformly low, with medians spanning from 8.7 to 35.8 mm/h.

Agua Salud	Minimum	Maximum	Median (A)	Median (B)
Pasture	0.02	1762.0	23.8	30.2
SF* 5 years	0.0	910.0	38.2	35.4
SF* 12 years	0.0	1381.0	157.8	24.9
Forest	0.32	1229.0	232.6	8.7

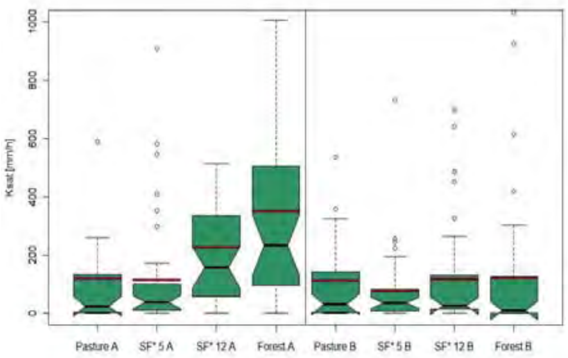


Fig. 2: Ksat values for the Agua Salud land covers at two depths: 0 – 6cm (**A**) on the left and 6 – 12cm (**B**) on the right (*SF 5- Secondary forest of 5 years; SF 10- Secondary forest of 12 years)
Outliers: Pasture (A) – 17612.0; Pasture (B) - 1288.0; Secondary forest 12 years (A)- 1381.3; Forest (A)- 1228.5, 1148.4, 1007.7; Forest (B)- 1032.7

The distribution of the Los Santos data at a depth of 0 – 6 cm shows an increase in Ksat values from the pasture level, featuring a median of 106.1 mm/h, to the secondary forest of 5 years with a median of 127.5 mm/h, to the secondary forest of 10 to 13 years, with a median at 218.1 mm/h (Fig. 3). The median of the Ksat data of the mature forest seems, however to be at a much lower at 94.1 mm/h, more than twice as small as that of the older secondary forest. The values of Ksat at the depth of 6 - 12 cm, do not show this variability, the medians all being closer and ranging from 21.6 mm/h (Pasture) to 47.1 mm/h (Secondary forest of ten years), and again featuring an unusually low rate for the forest vegetation at 16.7 mm/h.

Los Santos	Minimum	Maximum	Median (A)	Median (B)
Pasture	0.04	777.3	106.1	21.6
SF* 5 years	2.44	1318.0	127.5	98.7
SF* 10 years	0.06	2574.0	218.1	47.1
Forest	0.19	1262.0	94.1	16.7

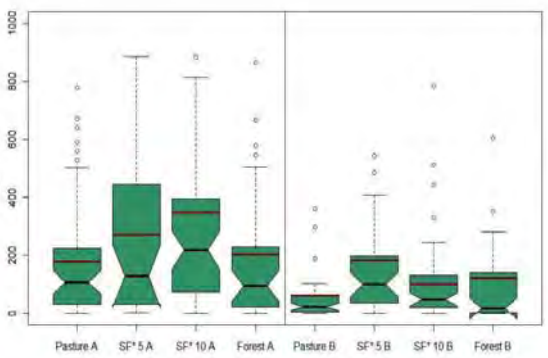


Fig. 3: Ksat values for all the land-use types in the Los Santos province at two depths: 0 – 6cm (**A**) on the left and 6 – 12cm (**B**) on the right. (*SF 5- Secondary forest of 5 years; SF 10- Secondary forest of 10 years) Outliers: Pasture (B)- 1049.1; SF 5 years (A)- 1318.5, 1077.9; SF 5 (B)- 1882.9; SF 10 (A)- 2574.2, 1917.9, 1224.6; Forest (A)- 1261.8; Forest (B)- 1803.5

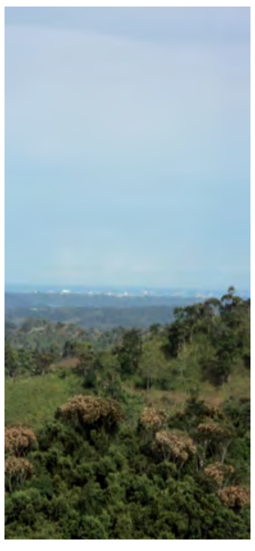
Conclusions

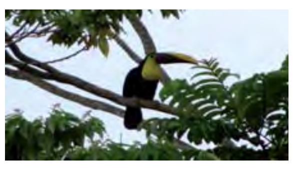
The data for Agua Salud shows a clear increase in Ksat with older age of vegetation, indicating a recovery of the saturated hydraulic conductivity from pasture to mature forest at 0 - 6 cm. At 6 to 12 cm there is again no indication of a steady increase, but generally low and miscellaneous values.

Los Santos also shows a clear tendency of increasing Ksat values at 0 - 6 cm, pointing at a recovery from pasture level to the secondary forest of 10 to 13 years. The mature forest, on the other hand, shows unexpectedly low values. This could be due to cattle that we observed while collecting the samples. Several studies (J.J.Drewry 2006, Martinez and Zinck 2004) have been conducted that corroborate to the evidence of soil compaction and homogenization through animal treading. This damage leads to a decrease in the saturated hydraulic conductivity of the soil.

Differences between the two depths (0 – 6cm (A) and 6 – 12cm (B)), at which Ksat was measured are present on both study sites. This is a clear indication of the recovery of Ksat in effect. In Los Santos this is not the case, the difference between the two depths not being significant.

On the whole, recovery of Ksat in Agua Salud and Los Santos shows the expected tendency of improvement of soil hydrological properties from the pasture level over to stages of older secondary forest succession. The exception is the mature forest in Los Santos which displays no indication of regeneration of Ksat and shows similarity to Ksat levels of pastures in Los Santos, due to animal treading. The differences in Ksat between the two depths become more prominent in older stages of the secondary forest succession, pointing out that the recovery of Ksat and therefore that of the soil properties is taking place in the upper levels of the soil body. This promotes the formation of lateral flow-paths rather than vertical percolation into the ground. Low Ksat values on the pasture sites could cause a higher surface run-off on these land covers due to a lower permeability close to the surface, which leads to higher rates of erosion. The older secondary forests increase the saturated hydraulic conductivity of the soil at the surface and are expected promote more of a subsurface lateral flow-path as the permeability of the soil decreases with depth. Here less overland flow is likely to occur and therefore less erosion and nutrient depletion.





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