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EVALUATING A RUNOFF HARVESTING TECHNIQUE USING A 3D COUPLED SURFACE-SUBSURFACE HYDROLOGICAL MODEL

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Summary. In arid and semi-arid zones runoff harvesting techniques are often applied to increase the water retention and infiltration on steep slopes. Additionally, they act as an erosion control measure to reduce land degradation hazards. Both in literature and in the field, a large variety of runoff collecting systems are found, but a rigorous evaluation of their efficiency is lacking. Therefore, detailed measurements were performed on a semi-arid slope in central Chile to allow identification of the effect of a simple water harvesting technique on soil water availability. For this purpose, twenty two TDR-probes were installed and were monitored continuously during and after a simulated rainfall event. These data were used to calibrate the 3D distributed flow model HydroGeoSphere, to assess the surface runoff components and the subsurface soil water redistribution simultaneously as influenced by the water harvesting technique, both under simulated and natural rainfall conditions. Preliminary results show a clear advantage of the harvesting technique in terms of additional water storage in the soil domain, but also indicates that correct design of these techniques under various soil physical and climatic conditions can improve water harvesting efficiency.

1 INTRODUCTION

Arid and semi arid zones are characterized by an important deficiency in water availability for plant growth. On the other hand, precipitation often comes in the form of short bursts of high intensity rainfall, causing rapid saturation of the uncovered soil surface and promoting soil erosion, flash floods and mud flows in extreme cases. In Andean arid lands, a range of agricultural solutions for these conditions were implemented by a large number of indigenous communities, as extensively documented by Denevan[1]. These technologies were designed to improve the crop environment, increase labor efficiency, enhance sustainability, improve productivity, and to minimize risks from unpredictable climatic conditions. The fact that many of these systems are still used under present day conditions is a strong indication that they are sustainable. Pandey et al.[3] investigated the apparent link between climate changes resulting in droughts and the increase in the use of water harvesting techniques (WHT) throughout past civilizations, indicating that WHT can partly alleviate the negative climatic conditions. They also stated that traditional systems would become more efficient if scientific attempts would be combined to enhance the productivity of local knowledge systems.

Recent developments in soil hydrology allow the use of complex distributed models to describe hydrological processes at the field scale. These advances in soil hydrology make it now feasible to use these complex models to evaluate and improve ancient irrigation structures and related soil-management and irrigation practices. The work presented here describes a method to evaluate the water balance of a simple WHT using a parameter estimation procedure which combines a Marquardt-Levenberg nonlinear parameter optimization with a numerical model solving the variably saturated flow equation and surface flow equations simultaneously.

2 METHODS

2.1 Field Site

All field measurements were performed on a hillslope near the town of Quebrada de Talca, in the greater Elqui Valley, Chile. The study area has an arid Mediterranean climate, and, based on data from 1980 to 2000, characterized by an average annual precipitation of 170 ± 122 mm, of which more than 70% is produced in the southern winter season[2].

2.2 Field measurements

To study the water balance of an infiltration trench in more detail, a field plot of 6 x 2 m was selected on the hillslope and consisted of the trench with its impluvium. Twenty two 30-cm long Time Domain Reflecometry (TDR) probes, connected to a TDR100 device and datalogger were installed horizontally at a depth between 7 and 45 cm below the soil surface. A rainfall event with an intensity of 120 mm h-1 was simulated for 20 minutes using a rainfall simulator similar to the one described by Verbist et al.[5].

During the simulated 20-min long rainfall event, the advancing of the wetting front was monitored with the TDR probes and soil-water content was further monitored after the rainfall event until no significant changes were observed for a 24 hours period, which was 4 days from the start of the rainfall simulation.

After the rainfall simulations, soil texture, bulk density and the soil water retention characteristic were determined on twenty five undisturbed soil samples taken using standard sharpened steel 100 cm3 Kopecky rings at various depths (0-5 cm, 15-20 cm, 25-30 cm and 35-40 cm) at 1 m interval distance along the slope. Soil texture was determined with the pipette method, whereas organic matter measurements were based on the Walkley and Black method.

Infiltration measurements were performed at the selected field plot to quantify the field unsaturated and saturated hydraulic conductivity (Ksat) as an input parameter for the modeling phase. Six different measurement methods for Ksat were applied: the pressure infiltrometer, the single and double ring method, the inverse auger hole method, the tension infiltrometer and the rainfall simulator. Methods used to derive Ksat values from the measured infiltration rates can be found in Verbist et al.[6,7].

2.3 HydroGeoSphere

The model consists of a fully-integrated numerical model capable of simulating surface-subsurface water flow in a three dimensional framework. Transient overland flow is described by the diffusion wave approximation of the Saint-Venant equation, while the three-dimensional variably saturated form of the Richards' equation governs flow processes in the subsurface[4].

3 RESULTS AND DISCUSSION

3.1 Field Measurements

Input parameters for the 3D model are presented in Fig.1[6,7], showing the Ksat calculated with 6 different methods and the water retention curve fitted to the measured water content-pressure head couples. These measurements are used as a first estimate of the model parameters used in the optimization procedure, as well as to define the parameter range.

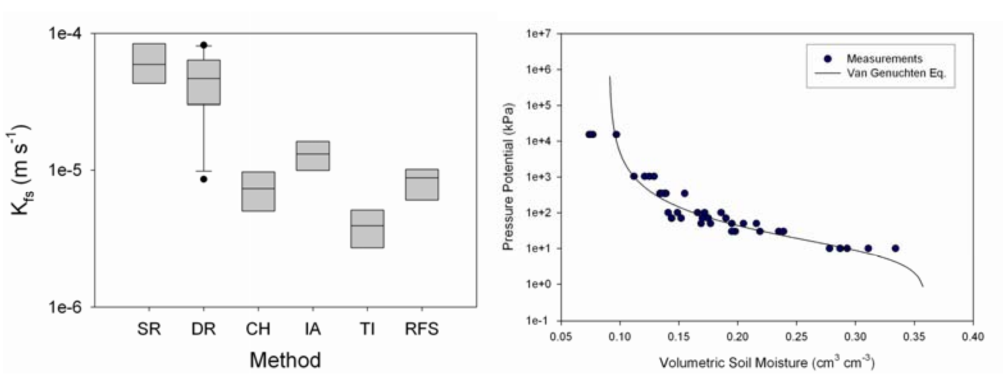

Figure 1: Measured hydrophysical properties of the test plot, with SR the single ring infiltrometer, DR the double ring infiltrometer, CH the constant head method, IA the inverse auger hole method, TI the tension infiltrometer and RFS the rainfall simulator.

3.2 Model Calibration

An essential part of modelling efforts consisted in calibration of the HydroGeoSphere model to observed field measurements under simulated rainfall. In a first step, the model was calibrated on the measured runoff (Fig.2a), showing good correlation with the observed trend. In a second phase, the measured water contents with the TDR probes were compared with model output and optimized to represent the wetting front more closely. Third, both data sets were used to achieve maximum agreement with both superficial and subsurface water flow.

The calibrated model showed clearly the processes observed in the field experiment, such as the accumulation of runoff in the trench until overflow occurred (Fig.2b), confirming its ability to represent the complex infiltration process in and around the water harvesting technique.

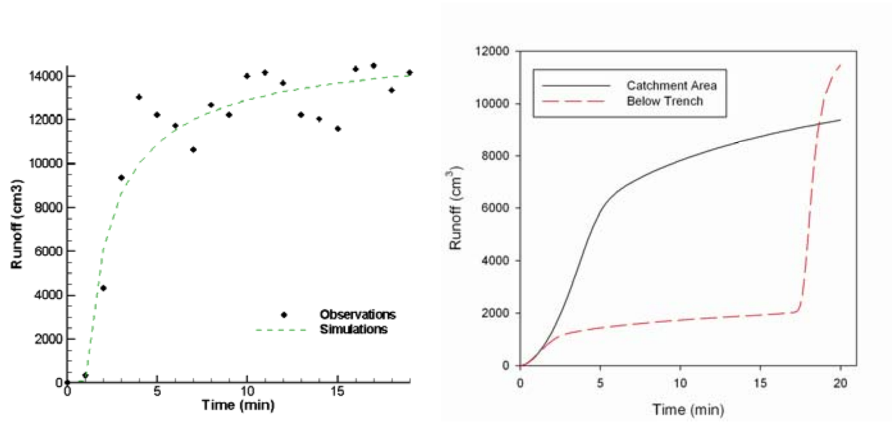

Figure 2. Modelled versus measured runoff (left) and runoff above and under the infiltration trench (right)

3.3 Rainfall-Runoff during the 2008 Wet Season

As a test case, the 2008 wet season was used as an input in the calibrated model, to evaluate the efficiency of the water harvesting technique to reduce runoff production and increase infiltration locally. The rainfall amount of 49.8 mm, was distributed over 11 wet days, with a maximum rainfall intensity of 6.6 mm hr-1 (Fig.3a). The model with infiltration trench showed prolonged infiltration after the rainfall had stopped (Fig.3b) and was capable of reducing the runoff amount considerably, compared to a slope without any conservation measures (Table 1).

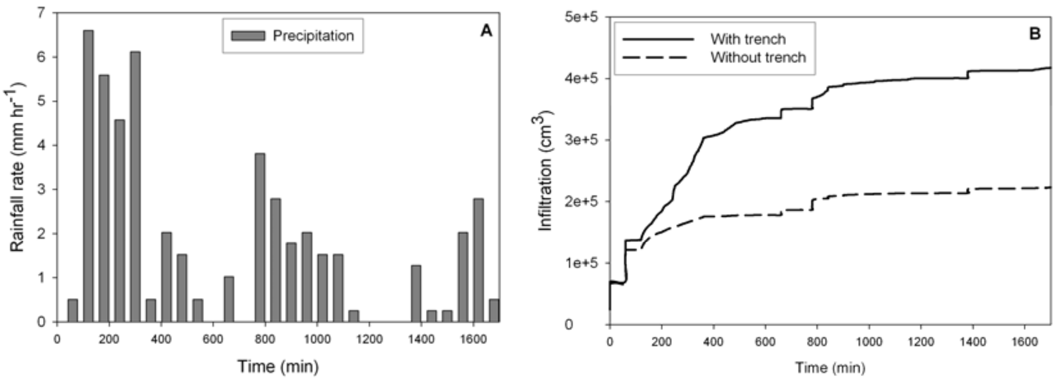

Figure 3. Precipitation amount (a) and corresponding cumulative infiltration with and without the infiltration trench (b)

	With Trench	Without Trench
	(mm)	
Precipitation	50	50
Infiltration	35	19
Runoff	15	31

Table 1. Water balance of the slope with and without infiltration trench for the 2008 wet season.

9 CONCLUSIONS

Thanks to recent advances in hydrological modelling capabilities, a new method could be developed to evaluate water harvesting techniques under simulated and natural conditions. After very detailed calibration of the coupled surface-subsurface HydroGeoSphere model, rainfall-runoff was effectively represented, and infiltration-redistribution showed good agreement with measured data sets. When applied to a short wet season, the model indicated a clear advantage of the water harvesting technique, with an increase in infiltration by 84% due to the infiltration trench and a significant reduction of runoff losses. Nevertheless, 30% of total rainfall was still lost when using the technique, indicating that better design might improve its water harvesting capabilities considerably. The proposed methodology would be the indicated tool to do so, given its versatile model conditions.

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