MEASURING PRECIPITATION, INFILTRATION AND WATER DISCHARGE ON A CATCHMENT SCALE FOR SOIL EROSION MODELING IN THE SOUTH PACIFIC REGION.

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Abstract
The work presented here was done in the framework of the CROPPRO project. CROPPRO aims to provide assistance to Pacific Island countries with the development of integrated farming approaches for sustainable crop production in environmentally constrained systems. The project focuses on the development of tailor-made farming approaches for major crop-soil units aiming at maximizing agricultural production and minimizing environmental deterioration. Special attention is paid to knowledge transfer and participatory, culture-sensitive training for stakeholders and end-users.

One aspect of the work within the framework of CROPPRO projects is the continuous measurement of the dynamic features of the catchment hydrology. These data are needed to calibrate the LISEM model that is used to evaluate different land use scenarios.

The work presented in this paper focuses on methods used and results obtained using various measuring methods and equipment, with respect to precipitation, slope hydrology, and catchment discharge. Two catchments on Fiji and Samoa were instrumented with automatic rain gauges to measure precipitation and precipitation intensity spatially, with data loggers equipped with Frequency Domain Reflectometry (FDR) sensors installed on a slope to measure the water content profile and sub-surface flow. At the outlet of the catchments a flume was constructed to measure outflow using ultrasonic water level sensors, and sediment content using automatic samplers. A sample of data collected using these systems is presented.

Additional Keywords: soil, TDR, FDR, automatic systems, soil moisture, modelling.

Introduction

The increasing population pressures and emerging trends of socio-economic marginalisation of rural populations are putting a heavy strain on the delicate ecosystems of the Pacific Island Countries. In response to the rapidly increasing demands for food, Pacific farmers abandon traditional farming systems to adopt high input commercial production methods for short term gains, which are often unsustainable, in particular on sloping lands. The resulting erosion causes rapid depletion of soil fertility as well as pollution of ground- and open-water systems.

The CROPPRO project aims to provide assistance to Pacific Island countries with the development of integrated farming approaches for sustainable crop production in environmentally constrained systems. The project specifically addresses the relation between agricultural activities and the surrounding environment, and focuses on the development of tailor-made farming approaches for major crop/soil units aiming at maximising agricultural production and minimising environmental deterioration. In accomplishing these goals, the LISEM soil erosion model is put to work in order to evaluate the effects of various different land use options. In order to feed the model with the desired data, a range of automatic devices was installed in the field to acquire this data. This paper briefly describes a number of setups and shows the measurement results for two pacific island countries; Fiji and Samoa.

Materials and Methods

The main goal of the data collection was to calibrate the LISEM model that will be used later on to evaluate alternative land use scenarios. For this purpose two sites representative catchments on Fiji and Samoa were selected.

Field site Fiji

The catchment on Fiji is located on the main island Viti Levu, 7.2 km North-North East of Suva. The area that drains its water to the location where the flume is installed is 4.71 km^2. Height differences are approximately 100 meters with the lowest point in the South East, where the stream leaves the catchment, and the highest area in the North. Characteristic profile features include clayey textures and dark brown A horizons overlying yellowish red and red B horizons, the horizon sequence being Ah, (AB), Bw and C. Combined thickness of A and B horizons varies from 50 to over 100 cm. C horizons are reddish strongly weathered parent material which are clayey and friable to firm. The particle size family is very fine and the mineralogical class is kaolinitic. During high intensity rain events, the soil structure of all recently cultivated soil types is unstable and rapidly lost. Many areas in the catchment, which were formerly covered by this soil, are now eroded to bare rock. Food crops are mainly root crops (cassava, taro or dalo, yams), vegetables (cabbage, tomatoes) and fruits (mango, banana, pineapple). Regarding cash crops, sugarcane, rice, cocoa and ginger are important.

Field site Samoa

The catchment that was selected is called the Alafua catchment, which is located in north central Upolu, near the capital city of Apia. The catchment (2.75 km2) drains through the Papaseea stream, which connects to two other streams at a location next to the University of the South Pacific. The islands are composed of a mass of successive olivine basalt flows, varying in age from the early Pleistocene to the present century (Kear and Wood, 1959). Due to this, the Samoan soils are mainly volcanic soils derived from basalt and basic andesite. The majority of the soils of Samoa belong to the Inceptisol soil order (Schroth, 1970). The catchment's terrain is steep land that reaches up to 500 metres in elevation. The hills dissect the study area, causing steep slopes that are completely covered with tropical rainforest or shrub, in which up to now agriculture is practised sporadically. Towards the edges of the catchment, along the shores, the land is flatter and the concentration of arable lands is higher. As the catchment encompasses a wide range of different slopes, they were classified as zero (<5 %), moderate (5-15%) and high (>15%). Like many islands in this region, the main crops grown here are coconut, banana and taro. Furthermore, parts of the land are covered with dense rainforest or scrub.

Characteristic for the soils in both catchments, having a volcanic parent material, is their very high hydraulic conductivity (up to 1,000 cm/day), high porosity (up to 70%), and low bulk density (down to 620 kg/m^3). Other authors also found these remarkable characteristics in volcanic soils (Fontesa, 2003). These properties make the behaviour of the soil profiles to rain storms, in terms of soil erosion and hydraulic behaviour, very specific.

Used equipment

The table below shows the equipment that was used during the course of the project. The LISEM model needs a number of input parameters, such as soil data (physical data, soil moisture measurements), rain data, and discharge measurements, but also plant characteristics (a.o. leaf area index, coverage etc.) and geographical data organised in maps. The table below only shows the equipment used for the rain, water content and discharge measurements.

Table 1. An overview of the equipment of which the data is represented in this paper.

Measurement	Measuring device	Amount	Manufacturer
Rain.	ARG100, 0.2mm tipping bucket rain gauge, equipped with OnSet Hobo Event data logger.	5	Environmental Measurements Ltd, GB.
Soil water content automatic.	ECHO FDR water content sensors, 3 of each connected to 3 OnSet hobo 4-channel industrial loggers.	9 (3 locations)	Decagon, USA.
Water discharge from the catchment.	Flume equipped with automatic 6712 sampler and 710 ultrasonic flow meter.	1	ISCO Inc. USA.

The rain gauges were divided across the catchments in order to get a good idea about the variation in rainfall. In case of the Samoa catchment, it turned out that the upland (200 meters above the elevation of the flume location and higher) received considerably more rain that the lower parts of the catchment. The automatic FDR stations, each having 3 FDR sensors connected to them, were installed on slopes with slope angles average for the selected catchments. The purpose of these stations was to analyze the behavior of the rain falling on these slopes. Since these FDR stations only produce data for a very limited area, the manual TDR device was used to measure the soil moisture status on sample plots throughout the catchment. The flume, equipped with the automatic flow meter and sampler, was used to measure the amount of water leaving the catchment and to measure the amount of sediment contained in the runoff. These data are especially important to calibrate the soil erosion model.

Analysis

Figure 1 shows the hydrograph recorded by the water sampler located at the flume. Also the rain intensity recorded by rain gauge 2 is put into this graph. The time delay between start of the rain event and the moment the flume starts recording increasing water levels is about ¾ of an hour. It is difficult to determine wether the discharge is produced. One possibility is surface runoff; another is subsurface flow that leaves the soil profile at the bottom of the slopes and end up in the channels. This could well be possible since some soil profiles are quite shallow (down to 5cm deep). This causes the infiltrated water to reach the bedrock relatively quickly and run off trough the profile, along the bedrock, to the bottom of the slope where it enters the streambed and follows its way to the discharge point. An indication for this mechanism can be found in the fact that the discharge wave fades away relatively quickly after the rain stops, compared to observations in other catchments in eg. China (Van den Elsen, 2003). In this particular loess catchment the rise of water level in the flume was comparable, but the discharge went on much longer than can be seen here. An explanation for this is that profiles found on Fiji are shallow and the hydraulic conductivity is relatively high, making the profiles drain very quickly.

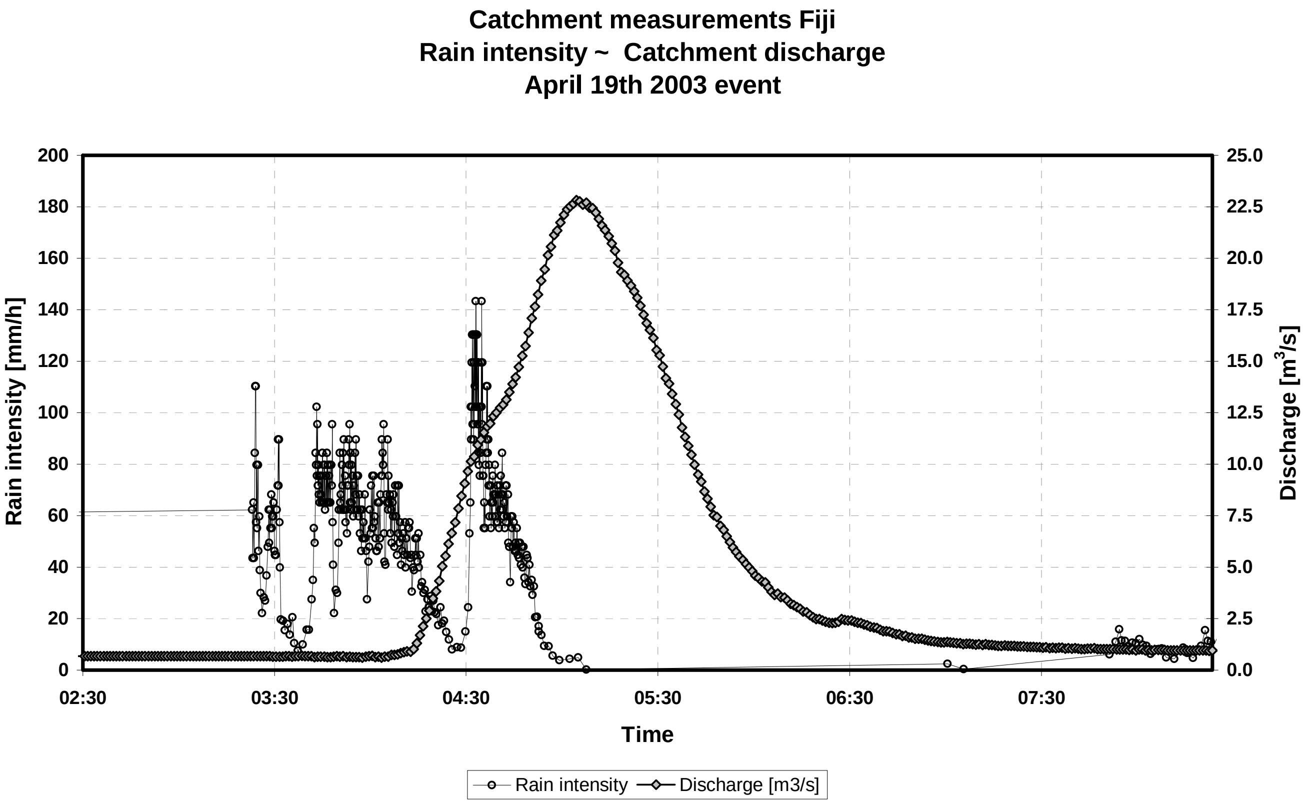

Figure 1. Rain intensity and discharge from the catchment vs. time.

Figure 2 shows the rain intensity of the April 19th 2003 storm and the soil water content measured on two different locations on a slope. The slope is a long (115 m) steep slope, the angle varying between 18^0 and 34^0. The continuously monitoring FDR stations are located on this slope (three stations, of which the upper one has not been functioning properly). The cover of this slope changed during the fieldwork period: taro was harvested around May 10th, and the soil was left fallow until the beginning of August. Then cassava was planted at the end of August. On each of the two locations, three water content sensors were installed at depths of -10, -20 and -40cm. The solid markers in Figure 2 correspond to the three sensors of the upper station, while the open markers represent the lower station.

Due to the relatively slow measuring interval of the FDR stations, it is difficult to determine the response time of the water content sensors to rainfall. What can be seen from the figure is that the response is about immediate. What can be seen clearly is that the sensors at all three depths react equally to the rainfall. This can be explained by the high conductivity of the soil. In general, the water content measurements of the lower FDR station are lower than those of the FDR station higher up the slope. This can be explained by the deeper soil profile which would logically drain the water easier to deeper layers than a shallow profile that would contain the water longer.

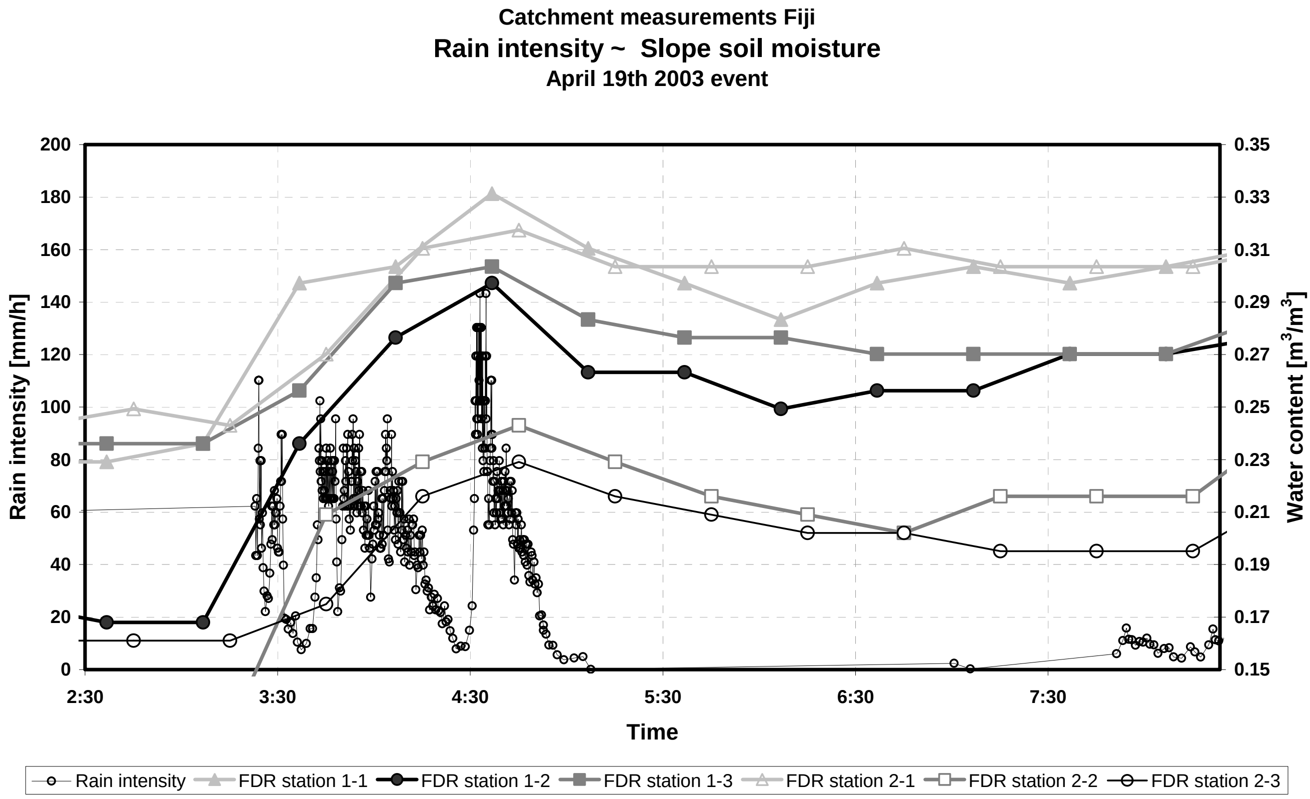

Figure 2. Rain intensity and soil water content on two positions on a slope, each measured at three depths, in time. The solid bullets are measured by the upper FDR station, the open bullets represent the lower FDR station. The sensors were installed at -5, -10 and -20 cm.

Results and Discussion

A literature search does not produce many projects where researchers have obtained complete soils erosion data sets in the pacific region. The data obtained in this project is unique in the sense that is shows data obtained in an area with volcanic material as the parent material, making the catchment and soil characteristics much different than areas with non volcanic parent material. The high conductivity make the soil drain quite quickly, causing problems with high water levels further downstream quite quickly. The high volume, high intensity tropical storms that often ravage the area certainly contribute to this. Hortonian, or infiltration excess, overland flow will not easily occur due to the high infiltration capacity, but surface sealing can occur quite quickly, especially on some bare fields, causing runoff to be produced. In this case erosion damage can be severe. Subsurface flow is an important aspect of the hydrology, due to the shallow profiles and the high conductivity of the soil profiles.

Conclusions

Soil erosion on the pacific islands Fiji and Samoa is not a common occurrence. Only when storms exceed a certain rain intensity threshold, or when surface sealing occurs, is runoff produced and soil erosion occur. The high conductivity of the volcanic soils, together with the shallow soil profiles causes subsurface flow to be an important factor on these islands.

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