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Experimental Variant Slope Soil Tank for Measurements of Runoff and Soil Erosion

Lihu Yang, Simin Qu, Yifan Wang and
Xianfang Song

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Abstract

Rainfall-runoff processes and the related soil erosion are pivotal research regions in hydrology, soil science, and environment science. Thus, physics model experiments in laboratory scale on the aspect of measuring runoff and soil are one of the best tools in this field. This chapter aims to specify the experimental variant slope soil tank at home and in the USA. The developing of experimental soil tank of variant slopes with artificial simulating rainfall system will assist to understand soil water motivation, runoff yield, and nonpoint source pollution.

Keywords: experimental variant slope soil tank, artificial rainfall simulation system, runoff, soil erosion

1. Introduction

Rainfall-runoff processes and the related soil erosion are highly complex and are affected by many parameters, such as rainfall depth and intensity, soil characteristics, and slope morphology. Early studies showed that general slope parameters influencing runoff generation and soil erosion are slope gradient, length, and shape [1]. Thus, it is critically important to understand hydrological and sedimentological processes in the field or in the laboratory. The major disadvantage in field is their lack of experimental control, and the performance of experiments is wholly dependent upon the vagaries of the weather. The magnitude of such significant variables as the changes of slope gradient, length, shape, or wetness of the catchment cannot be preselected. A laboratory experiment provides control over hydrological

variables which is notably absent in the monitoring of experimental and representative basins [2]. Therefore, an experimental variant slope soil tank is used to create artificially the conditions under which hydrological processes occur for quantifying how the inflow rate affects erosion processes in the world.

2. Experimental variant slope soil tank

The study on experimental variant slope soil tank began in the 1950s at home and abroad. The famous labs were Ven Te Chow Hydrosystems Lab at the University of Illinois at Urbana-Champaign in the USA and runoff laboratory of Institute of Geography, Chinese Academy of Sciences, in China. Later, many types of experimental soil tank were developed by Xi'an University of Technology, Institute of Soil and Water Conservation Chinese Academy of Sciences, Beijing Normal University, and Hohai University.

Ven Te Chow from the University of Illinois at Urbana-Champaign in the 1950s developed a kind of hydrological process. These processes include rainfall hydrographs for catchment areas of varying permeability; the abstraction of groundwater by wells, both with and without surface recharge from rainfall; and the formation of river features and effects of sediment transport. This tank measures 24.25 ft. long, 9 ft. wide, and 7.5 ft. deep and has a volume of approximately 12,000 gallons (45,000 L; **Figure 1**). The tank has a fixed elevation platform at its "upstream" end and two movable plate sections that can be used to set a bottom slope. These plates can be set to provide a constant slope along their entire length or can allow for a break in slope at the junction in the two plates. The tank is equipped with an overflow stand-pipe to maintain a constant water surface in the tank.

An experimental variant slope soil tank was installed in the runoff laboratory of Institute of Geography Chinese Academy of Sciences in 1965 ([3]; **Figures 2 and 3**). It was the first device in China that was used for study the rainfall-runoff and soil water movement. The tank was 8.0 m long, 3.0 m wide, and 1.0 m deep, with drainage holes at the surface and bottom to facilitate water discharge. The slope gradient ranges from 0 to 30°. A runoff collector was installed at the bottom of the soil tank, which was used for collecting runoff samples during the experimental



Figure 1. The margins tank of Ven Te chow Hydrosystems lab.



Figure 2. Runoff laboratory of Institute of Geography, Chinese Academy of Sciences.



Figure 3. The experimental variant slope soil tank in the runoff laboratory of Institute of Geography.

process. A rainfall simulator system was used to apply rainfall. This rainfall simulator can be set to any selected rainfall intensity ranging from 0.3 to 3.0 mm/min by adjusting the nozzle size and water pressure. The fall height of raindrops was set at 16 m above the ground, which allows all the raindrops to reach terminal velocity prior to impact with the soil surface.

A new experimental sink of runoff and erosion was reinstalled in the Geographic Sciences Museum of Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (IGSNRR, CAS) in 2014 (**Figure 4**). It consists of two metal rectangular boxes,



Figure 4. The new experimental sink of runoff and erosion in IGSNRR.

10 m long, 3 m wide, and 0.8 m high, and each one is located under artificial rainfall system. The slope of the experimental sink could be adjusted automatically from 0 to 35°. One 5 cm hole is cut into the downslope end of each plot. A short metal stub pipe is welded onto the hole to form an outlet. Two water flow monitors are horizontally set up in front of each box for the measurement of the runoff. For simulated rainfalls, runoff volume measurements and sediment sample collection are performed every 5 s and 5 min, respectively.

The experimental variant slope soil tank of State Key Laboratory Base of Eco-hydraulic Engineering in Arid Area in Xi'an University of Technology is manipulated by test water tank of constant waterhead ([4, 5]; **Figure 5**). The size of tank is 5.5 m long and 0.3 m wide and 0.6 deep. The range of slope is from 0 to 30°. The tank is divided into three parts of sub-tank with length of 2.0, 2.0, and 1.5 m, setting a dust-pan-shaped water gathering area in the terminal of tank. From top to bottom, this tank is divided into four parts; every layer of soil has a tight connection without separating and mixing mutually.

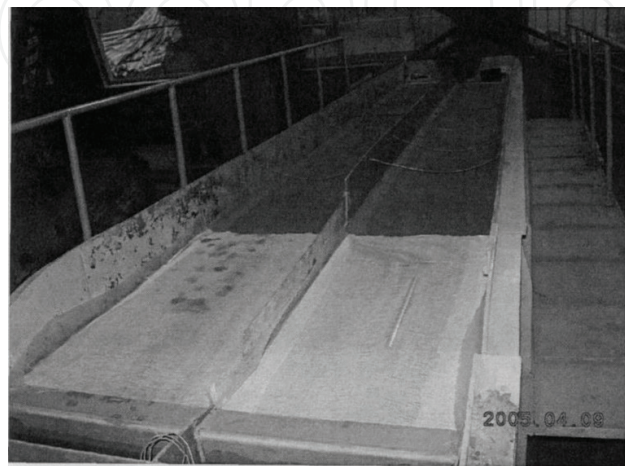


Figure 5. The experimental variant slope soil tank in Xi'an University of Technology.

The radioactive sources of ^{137}Cs ($34\text{--}44 \times 10^7$ Bq) were used in this equipment to measure the water content. A hole ($\Phi 8$ mm) in the lead was made to produce a beam into the detector. Discharge testing system is consisted of a water tank ensuring steady water pressure, water pipes connecting every component, a water meter controlling discharge, and a steady-flow flume to stabilize and homogenize water flow.

The experimental soil tank of Institute of Soil and Water Conservation, Chinese Academy of Sciences, is installed on the ground fixedly using hydraulic system regulating slope (**Figure 6**). The slope varied from 0 to 30° of slope regulating step 5° . The size of tank is 8 m long \times 3 m wide \times 1 m deep, with many drainage holes (2 cm aperture) at the bottom [6]. The inflow experiment equipment consisted of an overflow tank to produce inflow water and a runoff collector to collect runoff samples. The overflow tank was attached to the upper end of the soil pan; the runoff collector was installed at the bottom of the soil pan [7].

A rainfall simulator system was used to apply rainfall. Computer self-control system can control four independent rainfall zones in different rainfall intensities, which composed of jet rainfall simulator and side rainfall simulator. The jet rainfall simulation system was introduced from Japan, with the rainfall height of 18 m, the rainfall intensity varying from 30 to 350 mm/h, and the biggest duration of rainfall of 12 h. The side rainfall simulation system was developed by Institute of Soil and Water Conservation Chinese Academy of Sciences. Its rainfall height is 16 m meeting the demands of final speed of raindrops. The rainfall intensity variation range is 40–260 mm/h, and the biggest duration of rainfall is 12 h [8].

The experimental variant slope soil tank in State Key Laboratory of Earth Surface Processes and Resource Ecology of Beijing Normal University is approximately 1 m long \times 0.2 m wide \times 0.05 m deep, using polyvinyl chloride as whole material (**Figure 7**). The projected area on the horizontal plane of soil plate for every slope is 50 \times 50 cm. On the side of outflow, a V-type collector with more than 2.5 cm of height on other three sides is set up to prevent soil material in the tank spilling out during rainfall procession. Before packing soil into the tank, a good water permeability cloth is paved at the bottom of tank plate to ensure well drainage and evitable soil particle leakage of soil tank in experiment procession. At the bottom of tank, nine leakage drain holes (diameter is 5 mm) are distributed uniformly to make soil water freely permeate. The slope of tank ranges from 0 to 60° .



Figure 6. Experimental variant slope soil tank in Institute of Soil and Water Conservation Chinese Academy of Sciences.



Figure 7. The experimental variant slope soil tank in Beijing Normal University.

The artificial rainfall simulation testing ground is approximately 300 m², concluding 15 trough rainfall simulators, which have various combinations of types of sprayer, water pressure, and rainfall intensity. Every trough rainfall simulator has three swayed sprinklers, spacing at 1.1 m, installed with the height of 5.2 m [9, 10].

The slope-adjustable soil tank is made of welding steel plates splitting into two parts of the main tank and overflow tank in State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering of Hohai University (**Figure 8**). The two tanks are connected by four holes at the bottom. Effective volume of main tank measures 12 m long × 3 m wide × 1.5 m deep, while that of overflow tank measures 1.5 m long × 10 m wide × 6.2 m deep. The whole tank is divided into two 1.5-m-wide parts, varying from 0 to 30° under the drive of hydraulic pressure. The decision of its size is optimized profoundly after referencing international



Figure 8. The experimental slope-adjustable soil tank in Hohai university.

comparison of similar design products and former research results. The width of half tank is 1.5 m considering that boundary dimension effect can be ignored under this size. What's more, taking into consideration of the most lower than 1.5 m vadose zone in humid region in the south, depth of tank is determined to be 1.5 m, meanwhile soil water and plant root activities are mainly concentrated within this range in the arid and semiarid region.

The total area of rainfall simulation hall is 468 m², divided into I(18 × 18 m²) area of 10 m high and II(18 × 8 m²) area of 20 m high. The biggest rainfall intensity can achieve to 5 mm/min (300 mm/h). Based on two poles' control, the facility has 77 rainfall sprinklers in the whole distributed 5 water pipes. There are two solenoid valves controlling water inflow in every side of pipes. Among the pipes at least 15–16 rainfall sprinklers are distributed which are controlled by solenoid valves. These solenoid valves are departed into two groups based on test which can combine randomly and controllably, respectively.

3. Water monitoring and sample collection system

Rainfall monitoring system: Rainfall gauges are installed uniformly, recording the average value as rainfall intensity of the whole rainfall. The dataset is collected by computer automatically with 0.1 mm of precision. Laser rainfall intensity monitor is installed in Experimental Hall of Water and Soil Process of IGSNRR. It is composed of an array of laser transmitters and receivers. It achieves the rain non-touch measurement using orthogonally multiplexed laser beams according to the light attenuation law. The measurement error is less than 2%.

Discharge monitoring system: A simple and effective artificial flow measurement is applied for the monitoring system. Because water flows out from pipe, the discharge can be measured using a volume-known container and a stopwatch at the outlet.

Soil water potential monitoring system: The method of automatic collection of soil water potential is to transfer soil water potential (kPa) measured by negative pressure meter into electronical signals (mV) and then transfer analog signals into digital signals through A/D converter inputting the computer. Finally, the signals mentioned above are translated into soil negative pressure value based on mV-negative pressure relationship after calibration. The computer gives commands and instructions getting through specialized microcontroller and makes choice between sections and channels, to realize sample automation.

Water and soil collection system: Surface water collection system has a simple mechanism. Runoff flows into sampling bottles through water pipe collected at regular intervals. Collecting soil water corporates with soil water vacuum extraction device, which distils soil samples in a vacuum and then condensates water using liquid nitrogen.

The set of system consisting of various monitoring devices can develop runoff generation mechanism of different underlying surface, movement law of soil water, pollution law of nonpoint source pollution, migration and transformation law of pollution in soil, soil erosion law, and landslide formation mechanism.

4. Main results

Under the condition of experimental variant slope soil tank, some studies on hydrological physical mechanism experiment can be conducted, for example, rainfall-runoff formation under conditions of different rainfall intensity, surface slope and underlying surface, the law of surface water-biowater-groundwater cycle and transformation, pollution on migration, and transformation in unsaturated soil water. The margins tank has been used in the past to examine the characteristics of two-dimensional mudflows, the gully formation by turbidity currents [11], and the feasibility of using jets to manage sediments in a combined sewer overflow storage reservoir. The experimental soil tank can also be used to analyze the soil infiltration feature during rainfall [12, 13] and hydrodynamic mechanism of soil erosion [14] in Institute of Soil and Water Conservation, lateral downslope unsaturated flow in Hohai University [15], soil water movement using gamma ray in Xi'an University of Technology [5, 16], and rainfall-runoff relationship for different rainfall intensities in Institute of Geography [17]. Solute transport experiments have used tank arrangements for various purposes, including migration of infiltrated NH_4 and NO_3 in a soil and groundwater system [18], bioavailable phosphorus loss in runoff [19], and enrichment mechanisms of phosphorus [20].

5. Conclusion

The successful study of variant slope soil tank with artificial rainfall simulation system provides a basic foundation for hydrological and aquatic environmental experiment research under controlled conditions. After the operation of several years, this system has a reliable performance and stable manifestation. It is of great importance for studying rainfall-runoff relationship, establishment of conceptual hydrological model, migration and transformation of pollution material in soil water environment, and soil erosion and sediment yield study.

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Author details

Lihu Yang^{1,2*}, Simin Qu³, Yifan Wang³ and Xianfang Song^{1,2}

*Address all correspondence to: yanglihu@igsnr.ac.cn

1 Key Laboratory of Water Cycle and Related Land Surface Processes, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China

2 University of Chinese Academy of Sciences, Beijing, China

3 College of Water Resources and Hydrology, Hohai University, Nanjing, China

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