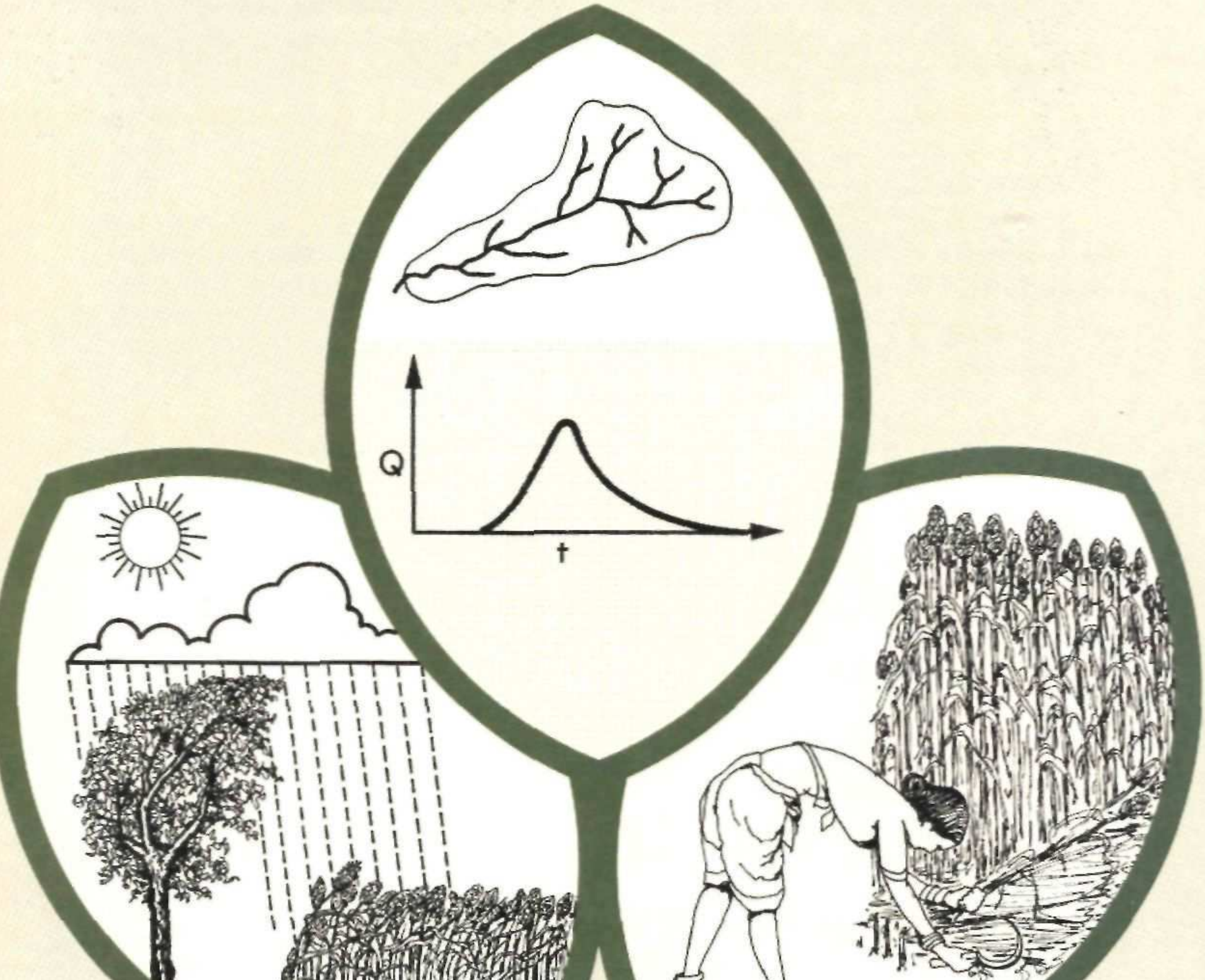
Small Watershed Hydrology

Summary Proceedings of a Workshop
22–24 November 1988



International Crops Research Institute for the Semi-Arid Tropics

Abstract

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Thirty-four participants from research institutions in India and one from Thailand joined ICRISAT scientists at the workshop. Presented in this volume are the welcome address, abstracts of the papers, and the recommendations, which cover instrumentation, structures, databases, data analysis and transfer, modeling, soil and water conservation, vegetation, plant production and water use, local cooperation, and information network.

Resume

Reference : ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), 1989. Hydrologie des petits bassins versants: comptes rendus sommaires d'un colloque sur Le role de l'hydrologie des petits bassins versants en agriculture pluviale, 22-24 nov. 1988, Centre ICRISAT, Inde. Patancheru, A.P. 502 324, Inde : ICRISAT.

Trente-quatre participants provenant des instituts de recherche de l'Inde et un de la Thailande se sont reunis avec des chercheurs de l'ICRISAT au colloque. Sont presents dans cette publication, l'allocution de bienvenue, les resumes des communications et les recommandations portant sur divers sujets couverts dans le colloque tels que instrumentation, structures, bases de donnees, analyse et transfert des donnees, modelisation, conservation de l'eau et du sol, vegetation, production vegetale et utilisation de l'eau, cooperation au niveau local et le reseau d'information.

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Small Watershed Hydrology

Summary Proceedings of a Workshop on The Role of Small Watershed Hydrology in Rainfed Agriculture

22-24 November 1988

ICRISAT Center, India

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh 502 324, India.

1989

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Preface

ICRISAT hosted a workshop on "The Role of Small Watershed Hydrology in Rainfed Agriculture" from 22-24 November 1988 at ICRISAT Center. Some 30 participants from research institutions in India and one from Thailand joined ICRISAT scientists in their deliberations.

The workshop aimed at exploring linkages for collaborative research by reviewing past experience, and as a basis for a new research agenda. As the scientists represented wide experience on watershed hydrology, the discussions achieved a general perspective through exchanges of information and ideas.

Presented in this volume are the welcome address, the recommendations of the workshop, and abstracts of the papers. The Indian Society of Dryland Agriculture is planning a special issue of its journal to incorporate many of the papers presented at the workshop.

While man cannot control weather, he can cushion the impact of adverse weather conditions—manifested in drought and floods—on rainfed agriculture by learning to plan and manage his land and water resources more efficiently. ICRISAT hopes that this volume and the one proposed by the Indian Society of Dryland Agriculture will help us move forward.

L.D. Swindale
Director General
ICRISAT

Welcome Address

J.L. Monteith

Program Director, Resource Management, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh 502 324, India

May I first welcome you to the city of Hyderabad, to the institution of ICR1SAT, to the Resource Management Program within which this watershed meeting is organized, and to the workshop itself. Hyderabad, ICRISAT, and the Resource Management Program provide a convenient framework for a few introductory remarks.

Those of you who can stay till Friday will have an opportunity of seeing the most important historic relic in this area—the fort of Golconda, which was occupied by the kings of the Qutb Shahi dynasty in the 16th and 17th centuries. But in the year 1685 Golconda was besieged by the Mughal emperor, Aurangzeb, as he made his way south through the Deccan. The siege lasted 7 months and, according to tradition, the siege was broken as a result of treachery within the fort rather from loss of morale. But I suspect that when you look at the site of Golconda you may begin to think with scientific, analytical minds about other possible explanations for the end of this siege. Golconda is too small a watershed to support a population of troops and courtiers and a king with many queens. I think it is more likely that the main reason for the fall of Golconda was a shortage of water or of food and fodder. A lump of granite in the middle of the Deccan does not provide a very hospitable environment for a besieged army, or a very manageable watershed for that matter. In modern terms, I suppose we could say there was an acute lack of sustainability about the system.

Now, 300 years later, another fortress has been built on the outskirts of Hyderabad, called ICRISAT, and a fence has been built around it—not an elephant-proof structure like the large gates that you will see, but an accessible fence provided you come in at the right place and make your presence known to the guards! From the start, watershed work played a very important part in ICRISATs activities. The site was chosen on the boundary of a black Vertisol and a red Alfisol, and it offered experimental watersheds on both these major soil types. When you go round the farm, you will see these watersheds, which were first developed by Bert Krantz. They were designed to ensure that water and soil were both managed in the best possible way: to conserve water in the soil profile when needed but to shed excess, especially at the beginning of the monsoon; to control the flow of excess water and to store it so that it could be reused. These watersheds are still being managed operationally and are producing crops with excellent yields, demonstrating that it is possible to have a sustainable system of agriculture with good management of the environment.

That brings us to the Resource Management Program, which began in 1986 as a result of the marriage of Economics and Farming Systems. This was an arranged marriage, but the partners had known each other for some time and were happy to settle down together. The full fruits of their union have still to be seen, but increasingly we work together and seek ways of combining the physical, biological, and economic sciences in common projects. The first Director of the Resource Management Program, Dr M. von Oppen, returned to a post in Germany at the end of 1986 and I then arrived. ICRISAT was perhaps looking for someone whose surname began with M, to carry on the work of a Program which involves four main Ms: Measurements, Mechanisms, Models, and Management.

We start with the importance of **measurements** of the environments of cropping systems in the semi-arid tropics, including physical measurements of the kind that you are principally concerned with, biological measurements of crops and their pests and diseases, weeds that affect crop production, and measurements of the economic and social systems in which farmers and their families operate.

We are ultimately concerned with the **management** of these systems and it would, of course, be possible to jump straight from measurements to management, hoping by some intuitive process to find the right way to manage an environmental system. But this would be a risky procedure. We believe that we have to be concerned with a whole chain of processes. The first is to understand the environment in which crops grow in the semi-arid tropics, by looking at the **mechanisms** that are involved. Again it would be possible to go straight from an understanding of mechanisms to management, but the snag is that mechanisms may operate in a particular way only in a particular year or at particular sites. It is essential to be able to generalize from a limited set of measurements (and even from a limited understanding of mechanisms) to other sites and to other seasons. This is where the use of good **models** becomes imperative.

You will hear at this meeting about models that describe hydrological processes. In Resource Management, we are also concerned with models of crop production, with economic models, with farm models, and so on. We believe that modeling is essential for the effective synthesis of measurements and of our understanding of mechanisms. From models, we can ultimately produce much more reliable and robust schemes for the management of cropping systems.

Dr Sachan has told me that, in developing the program, he was considerably helped by the enthusiastic and quick response to his call for papers, of which there are approximately 40. I congratulate the organizers for the efficient way in which they have collected this material, and I also thank all of you who have come ready to talk about your work, to tell us about progress, and to discuss ways in which you hope to move forward. It occurred to me that this workshop is in itself a kind of watershed, and I wish that, in the course of this meeting, you will be blessed by an abundant rainfall of good ideas, that your conclusions will all be as watertight as you wish your watersheds to be, and that you will all benefit from a runoff of new enthusiasms and new initiatives to share with your colleagues when you get home. I hope, too, that the visitors to Hyderabad will be able to strengthen their links with work at ICRISAT and at CRIDA, so that all our efforts can move forward in a more coordinated way in the future.

Recommendations

During the deliberations of the workshop, five small working groups addressed specific issues arising from the papers presented, and each group presented its own set of recommendations to a plenary session. These were then briefly discussed and some amendments accepted. The following is a synthesis, subsequently developed, of the sets of recommendations of all five groups.

Physical Resources

(a) Instrumentation. New techniques are needed to improve the reliability and relevance of measurements relating to basic processes, such as infiltration under rain, transpiration and soil evaporation (better models needed), unsaturated and saturated subsoil water movement, rainfall interception by vegetation, shallow overland flow, stream flow, and soil movement as bed and suspended load. The advantages and benefits of newer technologies (such as electronic pluviometers) are recognized and these should be adopted wherever possible, but there is a need to develop simple, robust instruments and methods (even for common measurements such as soil water content) that can be used by relatively unskilled workers.

(b) Structures. A range of new materials and techniques is available for building water flow control structures. These materials and techniques should be evaluated as early as possible, because they offer the scope to combine synthetic and traditional materials to reduce costs and prolong the life of the structures. Examples include the use of treated timber or geocretes to reinforce earthen structures, the use of natural fiber filters in recharge structures, and combinations of natural and synthetic materials as liners to seal tanks and canals.

(c) Databases. The compilation of a complete inventory of resources in watersheds under development should be taken up as a matter of priority. The existing data bank on developed watersheds should be expanded. It is essential that watersheds (especially demonstration watersheds) should be adequately instrumented and monitored on a scale sufficient to properly determine the effects of changed management and land-use practices. Existing normal practices should be continued as a control where appropriate.

(d) Data analysis and transfer. Hydrological records should be collected and stored at designated centers. This information should be processed rapidly in a standardized format, and the database should be readily available for potential users. This applies particularly to rainfall. Microcomputer processing should be used to make data more readily available.

(e) Modeling. Hydrological processes are complex, and they operate over a range of scales. Models provide the best known means to integrate these processes, and to interpret responses to various factors. Universally valid watershed models are still some way off, but efforts to develop these should continue, with an initial emphasis on relatively simple process models using standardized, readily available or easily measured input parameters and requiring minimal computational resources. Wherever possible, complex models should be avoided because the necessary input parameters are rarely available.

(f) Soil and water conservation. The evaluation of traditional and innovative ways of conserving water and soil should be continued. The aim should be to develop practices that improve productivity in addition to conserving soil, so that they are acceptable to farmers. A range of management practices may have a role to play in a particular watershed and the need for combinations, such as modified tillage practices, grass strips, bunds, and tanks should be more generally recognized. The long-term effects of particular management practices on soil and water resources and resulting costs and benefits for the community need to be evaluated.

Biological Resources

(a) Vegetation. There is a pressing need to gather more information on local species, which could be used in improved watershed management systems. Many local species have attributes that would allow them to play a role in improving productivity, but information on their hydrological impacts, appropriate propagation, and management methods is often scarce. Also needed is a proper evaluation of the impact of exotic species and, particularly, their effect on pests and diseases.

(b) Plant production and water use. It is recognized that any intervention that influences hydrology in a watershed may have complex repercussions. For example, reforestation will reduce soil erosion and deposition in reservoirs, but it will also reduce runoff and groundwater recharge. There is a need to consider the various and sometimes conflicting forms of production, and to allocate inputs to each so as to optimize the use of water within the system. This requires a good understanding of different soil types, appreciation of how the hydrological and biological components operate and interact, and careful evolution of management practices.

Human Resources

(a) Local cooperation. When the management of a watershed is to be improved, the people in the local community should be involved from the initial planning stages, so that they are active participants in the success of the project. "People's involvement" has been the key to success in some watersheds, and it would be useful if the methods used to encourage successful participation could be made more widely known. Because acceptance by the community is so important for improved management, socioeconomic constraints and people's attitudes should be studied to encourage collaboration and develop goodwill.

(b) Information network. There is a need for better liaison and collaboration between institutions, and the development of a network should be considered. It was suggested that ICRISAT could assist in the initiation of the network to be developed by participating organizations. This workshop contributed to this goal by establishing contacts and by creating awareness of the range and location of activities. Important areas for liaison are instrumentation, data collection and processing, standardization of methodology, training on particular topics, and the development and use of field manuals and models for impact evaluation and planning purposes. A newsletter could be a useful vehicle for informal communication.

Abstracts

Watershed Water-Balance Methodologies: Techniques and Development and Research Priorities

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Water-balance technology is a standard hydrologic process, based on the basic physical principle of conservation of mass. In its application to small watersheds, where responses of hydrological processes are quite fast, the proper choice of a shorter time base is necessary. Since the response time is short, the use solely of the conservation of mass principle is often not sufficient to describe the hydrologic phenomenon, i.e., the runoff process. In this paper, an attempt has been made to review various water-balance methodologies presently in use. For the overall water-balancing requirement in watersheds, the lumped parameter method has been found to be mostly in use. Several areas of research priority are suggested, the most important of which involves taking a national policy decision to monitor various sizes of watersheds over varying agroclimatic zones, and with different cultural practices, over long periods of time.

Water Balance of Agricultural Watersheds

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Field experiments to study the water balance of agricultural watersheds were conducted at the Central Research Station, Punjabrao Krishi Vidyapeeth, Akola (Maharashtra), during the period 1980-81. Five agricultural watersheds with well defined catchment areas were selected within the main farm area. The watersheds varied in shape, land slope, and size, which ranged from 5.53 to 9.41 ha.

Various hydrological data were collected systematically. Rainfall was recorded by an automatic syphon-type guage, installed at the meteorological station of the Central Research Station farm. Surface runoff was measured with the help of Parshall measuring flumes and stage-level recorders. Evapotranspiration was estimated from the measured pan evaporation data. Soil samples were collected from the experimental watersheds to estimate the soil moisture changes during the period of study. To evaluate the groundwater contribution from agricultural watersheds, fluctuations in groundwater level were recorded from May 1980 to April 1981 at the experimental area. Twenty-eight observation wells (23 open wells and 5 piezometers), located within and close to the experimental watersheds, were selected for study.

Based on hydrological data, the average water balance of the experimental watershed was estimated. It was observed that the availability of total water during the year 1980-81 was 471.77 mm. Of this, about 48% was comprised of soil moisture, 12% of surface runoff, and about 9% of groundwater recharge.

Water Balance Study in a Small Groundwater Basin

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Optimum development of any water resource and its management depend on the potential available. With the increasing use of groundwater for agricultural, industrial, and municipal needs, the annual extractions of groundwater are far in excess of net recharge from natural sources. Consequently water levels are declining, resulting in crop failure. On the other hand, overirrigation results in the problem of excessive salts and waterlogging. Water-balance study is an appropriate technique for planning of groundwater development. A small groundwater basin under the catchment of Pariyat, of about 10 000 ha, was studied for different components of the water-balance equation, namely recharge due to rainfall, consumptive use of the crops, groundwater draft, irrigation supplied, runoff from the basin, and subsurface inflow and outflow from the basin. Aquifer parameters of different formations were determined, with the help of pumping and recuperation tests in existing open wells. Infiltration tests were conducted to estimate the recharge due to rainfall. Rainfall and runoff data were obtained from the gauging station at Pariyat tank, which is the outlet of the basin. This estimation was further clarified from the recorded fluctuation of water levels in the basin. The present stage of utilization of the groundwater potential and its future prospects are also discussed.

Water Balance and Erosion Rates of Vertisol Watersheds under Differential Management

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Hydrologic data from two small watersheds on a Vertisol at ICRISAT Center have been analyzed for 12 years (1976-1987). One of these watersheds has an improved management system that includes double cropping and a broadbed-and-furrow (BBF) land treatment, leading to a grassed waterway. The second watershed has a traditional management system, characterized by rainy-season fallowing, postrainy-season cropping, and flat culture. The runoff/rainfall ratios averaged 0.13 for the improved system, as compared to 0.25 for the traditional. A comparison of weekly runoff of the two watersheds demonstrates the role of land management and crop cover in assessing the potential for runoff recycling. The paper estimates soil moisture changes, evapotranspiration, bare soil evaporation, and deep percolation on a watershed basis, using a hydrologic model (RUNMOD), and discusses its implications. An interesting conclusion of this analysis is that deep percolation is greater for the improved system than for the traditional. The annual soil erosion averaged 1.46 t ha^{-1} for the improved system, and 6.38 t ha^{-1} for the traditional.

Evaluation of Hydrological Parameters for Dryland Agriculture in Southern Rajasthan

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Agricultural production from dryland areas has received considerable emphasis in recent years of planned development. Though precipitation is a critical element of the hydrologic cycle in dryland agriculture, evaluation of other hydrological parameters (infiltration, runoff, evapotranspiration, and soil moisture, etc.) also becomes essential. Statistical analysis of these parameters can be utilized for prognostic estimates of agricultural production from dryland agriculture.

This paper reports on an evaluatory study of hydrological parameters, carried out in Bhinder block of Udaipur district in southern Rajasthan. The study area (24° 19' to 24°44' N, 73° 52' to 74° 21' E), covering 1030.60 km^2, had 71.41% of its area under dryland agriculture. About 84% of the precipitation was received in the June-September period. Detailed analysis was undertaken of precipitation characteristics affecting agricultural production. Other elements of water balance of the area, i.e., soil-moisture utilization, soil-moisture surplus, and soil-moisture deficit, and their statistical variance, were incorporated. An attempt was also made to correlate these elements from the study area with different levels of agricultural production.

Rainfall Interception in Mixed Cropping Canopies

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The alteration of hydrological phenomena by vegetative canopies is a function of rainfall characteristics, canopy structure, cropping pattern, and bed configuration. In many parts of the world, mixed cropping, i.e., planting one tall-growing cereal crop together with another short-growing fiber or grain legume crop in the same field, is prevalent. In deciding the best cropping pattern for conserving water and minimizing soil erosion, the mechanics of interception and modification of ground rainfall pattern is an important subject, and it has been of much topical interest recently. The intercepted water contributes toward reducing evapotranspiration and creating humidity in fields with a standing crop.

Throughfall, stem flow, and net interception in mixed crop canopies were studied under field conditions at Samaru (Nigeria) during the 1981 wet season. The throughfall of a light rain spell (< 5 mm) in a mixed crop canopy was half of that under the canopy of a single crop formed by paired-row planting. The throughfall of heavy rainfall (> 41 mm) was nearly equal in both types of canopies. Accumulated temporary interception was in the range of 23-42% of the 436 mm rainfall measured at full canopy stage. Part of the temporary interception moved down along stems of crops.

The stem flow in maize (*Zea mays* L.) was 17% of light rainfall (< 5 mm), 14% of medium rain (5-21 mm), and 7% of moderately heavy rain (> 21 mm). The net interception in maize with a companion crop was nearly 2 mm for light rain and medium rain, and 4-6 mm for moderately heavy rain.

Characterizing Spatial Variability of Rainfall and Assessing its Impact on Productivity of Two Typical Soils at ICRISAT Center

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Estimates of both spatial and temporal variability of rainfall are needed for optimum use of land and water resources, and to maximize crop production. The effectiveness of rainfall is modified by soil types and crop growth stages. We conducted a study at ICRISAT Center (Patancheru) near Hyderabad, India (18° N, 78° E, 545 m above mean sea level), for a 6-year period (1983 to 1988), to quantify and characterize the impacts of rainfall variability on soil water, runoff, and crop yield.

A network of 28 rain gauges was located in a 13.5 km^2 area. Daily rainfall was measured in 23 nonrecording and 5 recording rain gauges. There was a significant variation of rainfall over the test site on a daily, monthly, or seasonal basis. In 1988, as an example, we recorded 900 mm rainfall from I June to 31 October at the Meteorological Observatory. However, the rainfall measured at other rain gauges ranged between 677 and 1020 mm.

A modified curve-number model was used to estimate soil water and runoff for two agricultural watersheds (Alfisol: 1.2 ha; Vertisol: 3.4 ha). Sorghum yields were simulated for these two watersheds, using a crop simulation model, RESCAP (a general crop model based on the processes of resource capture). Simulated values of soil water, runoff, and crop yields were compared with the observed data to assess the performance of the models for two soils and rainfall environments over the 6 years (1983 to 1988).

Based on preliminary analyses, the following conclusions can be made:

i) For research watersheds in the semi-arid tropics, intensive instrumentation is required to collect the minimum amount of data needed on crops, soils, and weather, to relate crop production to environmental factors, and

ii) For shallow soils, the network of rain gauge stations has to be more intensive than in deep soils because the differences in the amount of water stored in shallow soils have a larger effect on agricultural production.

Monitoring Small-Plot Runoff with Tipping Buckets

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Conventional methods of measuring discharge rates and volumes, using weirs, flumes, orifices, velocity meters, etc., may have serious errors, particularly where relatively small volumes have to be measured. The tipping bucket principle, widely used in measuring rainfall, provides an alternative for small catchments. The use of tipping buckets for measuring runoff is not new. A tipping bucket consists of two chambers symmetrical about a central wall. These chambers pivot on an axle and bearing, located on the line of symmetry, so that the bucket assembly can rotate between two stops. When the assembly is resting on a stop, the bucket is stable and the inlet delivers water into the filling chamber. As the water level rises, the centre of gravity moves and the axle rotates to the other stable position, emptying the full chamber and bringing the empty chamber under the water inlet. By measuring the volume of water required for each tip and counting the number of tips, the flow rate and volume can be measured. Tipping buckets with a tip volume of approximately 6 L have been used to measure runoff rates from 140 m^2 plots in the recent rainy season.

Careful design and installation of the buckets is essential for accuracy. For best results, the tip volume for each bucket should be measured over a range of flow rates, and the tip rate monitored with a datalogger.

Installation of Monolith Lysimeters for Evaluation of Agricultural Hydrology

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Data on agricultural hydrology are needed in the solution of many watershed management problems. The solution of these problems requires the systematic and quantitative measurement of different agricultural hydrologic events, such as surface runoff, deep percolation, and evapotranspiration. With the help of lysimeters, complete knowledge of all the components of the agricultural hydrologic cycle is possible. Lysimeters may contain either disturbed or undisturbed soil profile. Lysimeters that contain disturbed soil are called the Tilled in* type and those that have undisturbed soil block are designated as the 'monolith' type.

A battery of 12 monolith type lysimeters were designed, fabricated, and then installed at the Crop Research Centre of the G.B. Pant University of Agriculture and Technology, Pantnagar. These lysimeters contained the undisturbed soil cores of silty clay loam soil. The inside diameter of the lysimeter was kept at 112.8 cm to provide an enclosed area of one square meter. The depth of the lysimeter was kept at 142 cm, which provides sufficient root-zone depth for most crops. An area was graded downhill from the location of the installed lysimeters, for setting up of auxiliary equipment. Each lysimeter is connected with the runoff collector tank and the percolate collector tank. Evapotranspiration was determined from the water-balance equation by accounting for precipitation, irrigation, runoff, storage, and percolation. The techniques for installation of monolith lysimeters are discussed in detail.

Simple Rotary-Type Runoff Sampler

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An automatic rotary-wheel type sampler was developed. The sampler was made of an impeller wheel, coupled with a cup-mounted endless chain conveyor, and rotated on its horizontal axis utilizing the force of falling water. The sampler was tested, using nappe of l'H-flume. The relationship between discharge and RPM of the wheel was strongly linear (r^2 = 0.99, $P < 0.01$). The relationship between discharge and sampling ratio was, however, logarithmic (r^2 = 0.98, $P < 0.01$), which suggests that further modification is needed in the design of the sampling cups. With an additional arrangement for counting the revolutions of the wheel, the sampler will serve as a useful tool for measurement and for sampling runoffs with low rates.

Innovative Designs Using Timber Cribs, Ferro Cement, Low-Cost Membranes, and Filter Fabrics

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This discussion note describes innovative design approaches, using new materials and methods of construction, comprising cribs of small timber and bamboo, soil reinforcement, ferro cement, membranes, and filter fabrics. These techniques, which have been used on major projects over the last 10 years, have a potential for application in small watershed development. Various components of the project can benefit from the 'new' materials technology. Results of case studies are presented, indicating the prospects for cost reduction and improvement of performance with regard to stability, seepage control, and resistance to scour. The 'new' materials make it possible to build the Structures in stages, thereby permitting progressive upgradation, which would facilitate beneficiary participation. The materials technology already developed for synthetic materials is proposed to be modified for the use of local material and biomass-based materials.

Rainwater Management for Stabilizing Productivity of Drylands

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In most dryland tracts of India, the rainfall pattern is erratic and high-intensity storms occur frequently, causing runoff and soil erosion. Traditionally the surface runoff collects from different small watersheds through interconnected waterways, streamlets, and rivulets into a tank at the end of a large watershed area. The donor catchments, however, do not benefit in this traditional system of water storage.

Presently the emphasis is on developing in situ moisture conservation techniques, which include land treatment, tillage, etc. Even after adopting these techniques, considerable runoff occurs. Recent research experiences show that small dugouts are feasible at farmers' fields for the collection of runoff, which could be used at the appropriate time. Check dams can act as percolation tanks and help in groundwater recharge, which can be exploited for limited irrigation.

The soil conditions of the site determine the efficiency of dugout ponds. Seepage losses may not be a problem in heavy soils, but they are a big drawback in light soils.

To maximize output from harvested water, the use of much smaller quantities of water than used in traditional irrigation has been found efficient in the short term. The results available from different centers suggest that the harvested water should be applied to protect the rainy-season crop if a dry spell occurs during the season or if the rains cease early. If the harvested water is not so applied, then it can be used for raising a second crop on a limited area. The payoff from the use of harvested water is appreciably high.

Payoffs from Hydrologic Improvements in Watersheds—1987 Drought Experiences

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The development of dryland agriculture on the basis of watersheds was launched as a national program by the Government of India in 1983. The Indian Council of Agricultural Research, in collaboration with state governments, established 47 model watersheds all over the country. Of these, 30 model watersheds were surveyed, master plans prepared, priorities and budgets allocated, and training programs conducted by the Central Research Institute for Dryland Agriculture, Hyderabad; in addition, regular evaluation and monitoring was carried out. Operational research programs, aimed at resource management, were initiated *in* 16 of these watersheds. The watershed program involves five kinds of activities: (1) engineering measures for improvement of water resources; (2) mechanical and agronomic measures for in situ soil and water conservation; (3) improved crop husbandry practices for meeting the food and fodder requirements of human beings and livestock; (4) alternate land-use systems for efficient use of lands as per land capability; and (5) providing improved infrastructure for credit and for marketing of the produce. The principal objective was to demonstrate optimal utilization of natural resources, such as soil, water, and vegetation, through improved dryland technology.

The watershed development program succeeded in: creating a dependable water resource in the watershed; reducing runoff and soil loss; and increasing the productivity, cropping intensity, and fertilizer use in the area. The program has, by and large, resulted in modifying the hydrology of the watersheds in terms of reducing runoff and improving the groundwater table. During the century's worst drought in India, of 1987, the impact of the watershed program was clear and visible. The parameters of growth showed distinct improvement, based on hydrological changes by way of soil and water conservation measures. More systematic research on hydrology, agrometeorology, forestry, horticulture, agriculture, and economics is suggested on watersheds. The socioeconomic implications of such programs have to be clearly understood and documented.

Resource Conservation through Watershed Management for Improving Productivity

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Soil erosion, consequent to unscientific management of land, has resulted in reduction of basin retention capacity of the catchment for rainwater, as well as siltation of reservoirs downstream. As a result, droughts and floods have become unavoidable consequences, arising out of the disrupted natural resources equilibrium, the occurrence of which needs to be prevented for posterity. Earlier experiences have proved that organizing rural developmental programs on a watershed basis, based on the study of climate, land, and plant resources on the one hand and man and animal resources on the other, brings in improvement of productivity on a sustained basis. This concept has been tested at Chinnatekur watershed in Kurnool district of Andhra Pradesh, covering an area of 1120.11 ha receiving a rainfall of 654 mm. A scientific land-use plan has been developed, after conducting a resources survey. Conservation measures, such as contour trenching in nonarable lands, diversion bund/drain to separate agricultural lands, graded bunds of 0.75 sq m cross-section with 0.1 % grade at vertical intervals of 1.0 m connected to natural depressions and to waterways/gullies, treatment of gully with check dam, ring bunds, and nala bunds have been organized to conserve natural resources. In order to make effective utilization of conserved resources, different conservation practices at the terrace level, water harvesting structures at the field level, and wells wherever feasible, were organized to reduce the risks of farming. Crops/varieties and management practices were changed to enhance production. The per hectare cost of developing the area on an integrated basis was Rs 1891.58. Monitoring of the project revealed that runoff from agricultural lands is 12.5% while from forest land it is only 5.0%, and when the harvested water was recycled, yields improved by 46% in groundnut across 2 years. Graded bunds alone improved groundnut yields by 16.3% over no bunds (577 kg ha^{-1}) and border strips brought 30.1%. Among different water harvesting structures, earthern ones cost the least (Rs 4.45 m^3 storage), compared to masonry structures (Rs 24-27 m^{-3} storage). These structures, when properly organized, improved groundwater storage and increased the command area under the existing wells by 25.1 %. As a result of closure to grazing, the grass yields from nonagricultural lands improved to 4400 kg ha^{-1}, while in the control it was only 480 kg ha^{-1}. Consequent to development of the watershed, the per capita income increased from Rs 1443 to Rs 3246 at the end of 3 years, indicating its economic viability.

An Integrated Approach to Watershed and Command Area Development

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The concept of major multipurpose river valley projects, initially advocated by Indian planners, proved luxurious and could not fulfill any of the purposes for which it was intended. It is agreed in many forums that small watershed hydrology in rainfed areas could play a key role in sustaining the green revolution. This paper presents an integrated approach to pinpoint the role of small watershed hydrology in rainfed agriculture. A systems approach is presented in three phases, consisting of a preliminary survey, data collection, and control measures, using socioeconomic status and attitudes of the farmers. Emphasis is laid on the need for a cooperative venture and the Government's responsibilities, through a case study of Tabageria Irrigation Cooperative Society Ltd. Economics of the existing and improved allocations of land, through a multigoal systems approach, clearly indicate why the Government's goals of production and labor maximization are not achieved, because farmers consider cultivation as an industry to maximize profit. Another case study has been appended to focus on the design criteria for percolation ponds in particular, and tanks in general. Economic analysis was made of ponds of different capacities and crop allocations, keeping in view the water balance Though the designs and capacity evaluation are location specific, the methodology is universal. The study clearly exposes the limitations of the present policy.

Study on Hydrology of a Small Eroded Shiwalik Watershed Managed for Rainwater Harvesting and Its Utilization

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Low productivity of rainfed agriculture in Shiwaliks has been responsible for the dependence of poor farmers on adjoining forests, and this has led to denudation and soil erosion problems. In the Operational Research Project of Sukhomajri, located in the foothills of Haryana, rainwater (otherwise going waste and causing severe erosion from a small 1.52 ha hilly forest watershed) was harvested by constructing a 6.5-m high earthen dam to store 0.93 ha-m of water. An underground pipeline (15 cm diameter, 220 m long) conveyed water, using gravity, from a reservoir to 2.0 ha of rainfed farmland, which was developed by land leveling and shaping. The hydrology of this watershed was studied for 5 years (1982-87), along with its potential for increasing production from both catchment and command areas.

The system was designed with 50% runoff from a mean annual rainfall of 1200 mm. The annual rainfall in these years varied from a maximum of 1587 mm in 1983 to a minimum of 625 mm during 1985. The observed runoff was 828 and 129 mm during these two extreme rainfall years, constituting 52.2 and 20.6% of the annual rainfall. There was reduction in water yield with improvement in vegetation cover. Small storms, which did not produce any runoff, constituted 10-12% of the total rainfall in 1982 and 1983. This increased to 27% in 1986, and 25% in 1987. Seepage losses from stored water varied from 2 to 7 mm day^{1}, depending upon the depth of stored water. After allowing 10% for dead storage, 13% for seepage, and 12% for evaporation from September to end of December, the harvested water was sufficient for 3 irrigations of 7 cm each (one to maize near maturity, two to wheat at presowing and at crown root initiation stage) for 1.7 ha in the lowest and 2.8 ha in the highest monsoon rainfall year. Because of conducive soil conditions for high runoff and low seepage losses, more water yield could be obtained. The manifold increase in crop production by supplemental irrigation reduced the farmers* dependence on forests, and they started protecting the catchment to prolong the life of the much needed reservoir.

Studies on Runoff, Soil Loss, and Productivity of A Small Agricultural Watershed

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A study was conducted for 6 years (1981-86) to assess the runoff, soil loss, and productivity of a small agricultural watershed (1.48 ha) by adopting soil and water conservation measures, proper land-use pattern, and improved agronomic practices. The watershed was developed into five terraces by land leveling (1% slope), field bunding, and making arrangement for proper disposal of runoff water. The runoff from all the fields was measured at one point with an automatic stage-level recorder, and soil loss by collecting samples from flowing runoff water. Agricultural crops were raised in the three lower terraces, and in the upper two terraces where the soil was poor and gravelly; *Leucaena leucocephala* for fodder and fuel and *Eucalyptus hybrid* for fuel were grown. During the 6 years, monsoon rainfall varied between 481.7 mm (1984) and 775.6 mm (1983), with a mean of 578.8 mm. Runoff was minimum (17.84%) in 1983, and maximum (31.17%) in 1982. Mean runoff was 24.99% (14.46 cm). Peak discharge of 0.103 m^3 ha^{-1} was recorded in the first year (1981). There was consistent decrease in peak discharge from 1981 to 1985 (0.103 to 0.065 m^3 ha^{-1}). Soil loss varied from year to year. It was least (0.855 t ha^{-1}) in 1985 and maximum (4.270 t ha^{-1}) in 1983, with a mean value of 2.488 t ha^{-1}.

The yield of crops fluctuated from year to year. Mean yields of maize, pulses, and sorghum fodder (air dried) were 1190, 370, and 7450 kg ha-[1], respectively, under rainfed conditions. Leucaena produced on average 7.4 t ha^{-1} of air-dried fodder and 9.45 t ha^{-1} of fuel, when harvested periodically. If harvested annually, the yield of air-dried fodder was 41 ha^{-1}, and of fuel 18.061 Eucalyptus, when harvested after a 3-year rotation, produced 47.76 t ha^{-1} of air-dried fuelwood.

The agricultural watershed, on average, produced 14.46 cm runoff, which can be collected in a dugout farm pond. It can be used either to give a life-saving irrigation to kharif (rainy-season) crops, if the rains end early, or as presowing irrigation to one hectare of agricultural land to ensure better germination of rabi (postrainy-season) crops.

Hydrological Planning for Maximizing Biomass Productivity

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Hydrological planning for small watersheds generally aims at reducing runoff and soil erosion, as well as increasing infiltration. However, the hydrology planning is not optimized to utilize the water conserved for maximum biomass production. This discussion note presents an overview of simultaneous methods for plant productivity, covering all types of vegetative cover. Tree crops play a strategic role, but little information is available for establishing the parameters for yield response of tree crops with limited water in semi-arid tracks. Postulations have been made with regard to yield response of tree crops, grasses, shrubs, trees, field crops, and empirical verification of biomass productivity, along with limited observational data. This note presents a plea for improved modeling, so that watershed planning will be oriented toward maximizing biomass productivity without undue compromise of the erosion prevention and soil conservation. The approach outlined is expected to contribute to development of an ecologically sustainable production system, on the basis of 'affordable external inputs* and use of rational hydrological planning approaches.

Role of Agroforestry in Watershed Management and Development-Research Priorities

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Natural resources like soil and water are best managed on a watershed basis. Conservation and optimal utilization of natural resources are the principal objectives of any watershed development program. The three main components of such a program are: soil and water conservation, crop production, and alternate land-use systems. The role of agroforestry in watershed management and development is highlighted.

Suitable agroforestry systems that could be successful on arable and marginal lands have been identified, and their main features are described. Tree planting methods for different situations have also been described.

Research priorities have been set out under two major heads, on-station and on-farm. Under on-station research, it is important to perfect the nursery and establishment techniques under rainfed conditions. Studies on economizing water use during the nursery phase, which in some cases may run to 6-9 months or more, are important. Optimum size of pits; amount of farmyard manure, diammonium phosphate, and benzene hexachloride to be added to each pit; weed management up to one year after establishment; subsequent water management; pruning; and stacking are some of the important aspects to be considered. Crops most compatible with the given tree species have to be identified, and the improved agronomic practices for the crops grown in the alleys have to be formulated. All aspects of tree x crop interaction, involving rainwater and nutrient management, need attention.

On-farm research is more challenging. The best agroforestry system has to be worked out for each of the land-capability classes obtainable in a watershed. Stability of income and sustainability of production should get primary consideration in selecting the most useful system for a watershed. Based on the experience gained in CRIDA, suitable farming systems involving agroforestry have been listed for different rainfall situations and soil types.

Socioeconomic considerations and aspects relating to transfer of technology are also mentioned.

Hydrology and Semi-Arid Black Soils with Reference to Soil and Water Conservation in Small Watersheds

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Black soils, which are a major soil resource of the Deccan plateau, are problematic from the soil and water conservation point of view. One estimate puts the average soil loss from these soils at 68 t ha^{-1} annually. The water losses are also large, resulting in a

degraded environment, low crop yields, and a poor economy. Attempts are being made to conserve the soil and water resources through watershed management. However, few systematic attempts have been made to study the causes for erosion of these resources and to quantify them.

Studies conducted at the Central Soil and Water Conservation Research and Training Institute, Research Centre, Bellary, have revealed that the reasons for the heavy soil and water losses can be traced to: (1) uneven, ill-distributed, and intense rainfall; (2) unfavorable soil characteristics, resulting in flow infiltration; and (3) undulating topography. Analysis of ten years' rainfall and runoff data from terraced agricultural catchments indicated that the rains in September and October produce the maximum runoff of 2.5 cm and 2.3 cm, respectively. Under controlled conditions, the annual average runoff from small agricultural catchments was 10.5 cm (20% of average annual rainfall), while the soil loss was 2.3 t ha^{-1}.

The paper also attempts to establish relationships between the rainfall and soil and water losses. Typical runoff hydrographs are presented.

Planning and Managing Manmade Forests in the Hydel Catchments of the Nilgiris

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The wealth of the plains depends upon the health of the hills. In the Nilgiris, the rivers Moyar and Bhavani and their tributaries are the major sources of various hydroelectric and irrigation projects of Tamil Nadu. These reservoirs provide an estimated 40% of the hydroelectric power generation in Tamil Nadu. The Nilgiri plateau forms a strategic part of the catchments of these rivers, and scientific land use is quite essential to enable these reservoirs to serve longer. The major portion of these catchments was originally under natural grasslands with pockets of 'Shola' forests, which are now found as remnants. The present land use in the district consists of crops like potato and other vegetables, and plantations of tea and coffee. Of late, large-scale conversion of agricultural fields into tea plantations through Government subsidies is on the increase, which brings tremendous soil loss (about 40 t ha^{-1} annually) if proper soil and water conservation measures are not adopted in the catchments. Large-scale planting of *Eucalyptus globulus* (blue gum) trees was taken up in many of these catchments, through different 5-year plans, for the production of fuel, industrial materials, etc. Of the many useful alien trees introduced in the district, blue gum and black wattle *(Acacia mearnsii)* have been extensively used for afforestation.

Catchment studies (over 64 ha) conducted by the Central Soil and Water Conservation Research and Training Institute, Research Centre, Udhagamandalam, at Glenmorgan revealed a reduction of about 16% on average in the expected water yield from the open grasslands when the blue gum plantations were raised in these watersheds for the first rotation of 10 years (1972-1982). However, the plantations of blue gum do not add significantly to the sediment load in the reservoirs and are as effective as protected grasslands. During the first half of the second rotation (1983-1987), the reduction in total flow has further increased to about 25%, while the seasonal distribution of total flow during the lean period has reduced by 50%. Similar trends were observed in the larger catchments of Parson's Valley (1450 ha), where a mixed land use of grasslands and natural 'Shola' forests have been converted into manmade forests of black wattle and blue gum. These plantations are observed to have better moderating effects on instantaneous flow, when compared to grasslands, and the percentage of moderation varied from 27 to 80%, depending upon antecedent moisture conditions. As such, careful planning and management of manmade forests in the hydel catchments of the Nilgiris are called for. This paper discusses some important aspects of planning and managing manmade forests, in relation to the economic development of the nation in general, and the hilly regions in particular.

Watershed-Based Land Development for Efficient Soil and Water Conservation Practices in Red Soils of Southern Karnataka

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Failure of crops as a result of floods and droughts in arid, semi-arid, and humid regions emphasizes the need for a proper approach, involving suitable agricultural practices, to conserve all available resources for optimizing crop production.

In India, there is a large scope for the development and management of runoff water potential. Assessment of water potentials and study of the recharge process and water balances should be done on a watershed basis, before taking up large-scale development programs. Management of watersheds with utmost care, involving a multidisciplinary and integrated approach, is required to achieve optimum yield and minimize risk.

Systematic studies on the management of red soil watersheds in Karnataka are few. Intensive studies were initiated only after 1978 by AICRPDA at their Bangalore center. Resource conservation studies have also been taken up on a watershed basis and the idea extended to on-farm studies.

Model watershed development studies, involving the entire complex of development, management, and allocation of resources, as well as decisions relative to agricultural production and productivity, have been initiated in Karnataka since 1983 on a large scale. This paper attempts to highlight the major observations, decisions, implementation, and recommendations from those studies.

Land development on a watershed basis can be more easily achieved if reallocation of lands is done through consolidation of holdings, with each holding having a contour or graded line as a boundary.

Watershed-based farming systems, using graded bunds, graded border strips, and the bed-and-furrow system with grassed waterways and small farm ponds, show a good potential for reduced soil erosion, better moisture conservation, improved surface drainage, and possibilities of supplemental irrigation to increase cropping intensity and crop yields by protective irrigation.

Field Evaluation of Microwatersheds

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Nearly 60% of the precipitation in arid and semi-arid regions is lost by evaporation. Microwatershed-based cropping has been known to redistribute precipitation to a small crop area where water is concentrated, resulting in deeper infiltration into soil. Cumulative evaporation is thus reduced, and available soil water increased. The success of rainfed farming depends on the effective inducement and collection of runoff, and on its efficient utilization by agricultural crops. Since uncertainties of runoff inducement are difficult to reconcile with crop requirements, it is crucial to choose crops that can make use of long-term storage of water in the soil. These considerations favor deeply rooted, perennial, drought-resistant crops, such as *Zizyphus* and *Citrus* species.

Field experiments are being conducted at the Central Soil Conservation Research Farm, Chhalesar, Agra, since 1986, with a view to finding appropriate microwatershed shapes for enhancing productivity and increasing water-use efficiency in deep alluvial soils, susceptible to gully erosion. The five microwatersheds cover several combinations of shape and surface cover, as, for example, contour watersheds, V-shaped watersheds, and diagonal watersheds. The first two are partly covered with polythene sheet from the upstream side; they are under study along with a control (no treatment for their runoff-inducement efficacy and soil-loss behavior). All the microwatersheds are shaped to a 5% slope, and their runoff is channeled into collection tanks.

Runoff-inducement efficacy ranged from 40-70%, and it was different for different shapes and surface covers with daily rainfall spells. This is because of variation in rainfall, the intensity of storms, and the antecedent moisture regime in the microwatersheds. The trend of runoff-inducement efficacy became clear with the weighted mean data. The V-shaped micro watershed induced nearly 8% more runoff than contour watersheds. Partial covering (50% polythene sheet cover from the upstream side) induced nearly 5% more runoff than that without a cover. The diagonal watershed induced 43% runoff, whereas the corresponding value for the control was only 2%. The runoff-inducement efficacy was also highly variable with respect to season of rainfall, and it was less during winter than during the rainy season.

The maximum volume of runoff water collected (2764 L) was with the diagonal catchment, as runoff from the entire watershed was diverted to the plants. The V-shaped microwatershed, covered with a polythene sheet, generated more runoff water (1941 L) than the contoured watershed. With various treatment combinations, it was thus possible to create a wide range of water potential for plantation crops.

Soil-moisture storage in the profile close to plantation was maximum with the diagonal microwatershed, followed by the contour microwatershed. Various, spatially different moisture regimes were created by the microwatersheds. The crops' performance will indicate the suitability of microwatersheds for various semi-arid agroecological zones.

Runoff and Soil Loss as Influenced by the Land-Use Systems in Small Watersheds of Bundelkhand Region*

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Studies were undertaken at the Indian Grassland and Fodder Research Institute, Jhansi, with the objective of investigating runoff and soil loss under different land-use systems in small watersheds. Three such experiments were conducted.

In the first experiment, sorghum/pigeonpea intercrop (S+P) and cowpea were grown in contour-bunded and unbunded plots. The annual runoff, expressed as percentage of rainfall, was in the following order: S+P, unbunded (27.3%) > cowpea, unbunded (21.2%) > S+P, contour-bunded (14.8%) > cowpea, contour-bunded (4.2%). Similar trends were observed for soil loss.

In the second expriment, we observed higher runoff and soil loss from bare plots as compared to those with sown pasture, the 3-tier planting system, and improved natural grassland.

These results show that the maximum soil loss from cropped areas occurs within the first 15 days after sowing, which needs to be minimized through the use of suitable mechanical conservation practices.

Influence of Soil Conservation Measures on Runoff Yield

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The runoff pattern from a watershed depends mainly on the nature and distribution of rainfall, which is a random phenomenon beyond human control. At the same time, it is also a function of watershed characteristics, which can be influenced to a great extent by appropriate treatments. With this idea, a study was undertaken to evaluate the influence of soil conservation measures on runoff yield.

The CTAE (College of Technology and Agricultural Engineering) watershed was selected for the study. In this watershed, soil and water conservation treatment programs are being carried out systematically since 1978 under appropriate technical

* Authors could not attend, but the paper was considered in the discussions and recommendations.

guidance. The experimental watershed is representative of similar ones in the southern region of Rajasthan, with eroded land of almost identical patterns. Included were various land treatment measures and such structural measures as retention and retardation.

Relevant data were compiled for the watershed, after analyzing the mass curves and runoff hydrographs. No significant relationship was observed between rainfall and runoff when individual incidents were considered. However, a nearly linear relationship was observed when accumulated quantities were plotted by expressing both the series logarithmically. To evaluate the effects of soil conservation measures on runoff, annual data series, as well as data series of the whole period under study, were used (1982 to 1986). A rating curve for the runoff gauging station was drawn by measuring velocities at different stages with the help of a float and a current meter.

Separate analysis was done for each year. Except in 1983, the runoff was decreasing during the period understudy. The corresponding figures of runoff for the year 1982, 1983, 1984, 1985, and 1986 were 10.49, 15.93, 9.18, 7.75, and 6.67% of rainfall, respectively. It was thus concluded that soil conservation measures have a definite effect on reducing runoff.

Effect of Land Management Practices on Small Watershed Hydrology

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Studies were conducted on a watershed of 174 ha, typically representing the Aravalli Hills, at the Soil and Water Conservation Demonstration Centre of the College *of* Technology and Agricultural Engineering (CTAE), Udaipur, to evaluate the effect of various watershed management practices on hydrologic aspects. The experiments were carried out in two phases, namely, on microwatershed level (28 m^2) and on selected small watersheds (1.06 and 2.95 ha) mainly consisting of class VI and VII lands.

The watershed was treated with fencing, continuous and staggered contour trenches, pits, and plantations. The microwatershed studies revealed that 44% of runoff water and 15% of soil can be conserved by these practices. The maximum runoff occurred on the day of highest rainfall (amount), whereas maximum soil loss was observed with maximum rainfall intensity. A multiple linear regression equation was developed among rainfall amount, intensity, and runoff volume. Results the following year from small watersheds showed that an additional 35% of the total annual average rainfall can be conserved (about 1570 m^3 ha^{-1} of water annually) by applying such practices, which is a good amount in the arid region for groundwater recharge and for initiating afforestation. These findings are being utilized to develop the watershed at CTAE, and they are also applicable to the Aravalli hill range.

Water Yield as Affected by Land Uses in Upland Watersheds*

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The hydrological behavior of a watershed is affected by land use and its extent and management, besides other watershed characteristics. A watershed may have various land uses. Water yield, in turn, is influenced by the type of vegetation and its management. Improper land and vegetation management practices, combined with biotic interference, are counterproductive for the proper hydrological functioning of a watershed.

The forested watersheds are largely confined to upper catchments of various water-resource projects, and to catchments of flood-prone areas. The management of vegetation in upland watersheds is of special interest to hydrologists to increase the annual yield of usable water for downstream users, and to reduce runoff volumes and peak discharges for moderating floods.

The results of experimental watershed studies (carried out in India and elsewhere) in relation to water yield alterations are critically examined. It is observed that no attempt has been made to establish the water yield from various land uses in such a way that this information could be readily used. This paper attempts to present the water-yield variation from various land uses in terms of the rainfall to runoff ratio, which has been termed as runoff efficiency. The effects of removal of forest cover, or conversion of forest land to other uses, on water yield are discussed, as are the effects of catchment size in relation to water yield from forested catchments. As studies in India and elsewhere have been done largely on small watersheds, the results obtained have limited applicability to larger watersheds.

Land Management Practices in Small Agricultural Watersheds

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The land management practices adopted in small agricultural watersheds have a significant influence, both on the agricultural production and on the hydrology of the watershed. An attempt is made to review present land management practices, and to indicate their influence on the overall hydrological behavior of small agricultural watersheds.

The land management practices considered are bench terracing, contour and graded bunding, field bunding, and the broadbed-and-furrow system. Their general applicability, advantages, and disadvantages are outlined. Each of these measures, coupled with the plot shape, has different influences on the hydrological behavior of the

* Authors could not attend, but the paper was considered in the discussions and recommendations.

watershed, which consists of total runoff from the watershed, peak runoff, and sediment yield. Each parameter assumes importance, particularly when the small watersheds are used for water harvesting.

A review is made of the available information regarding the hydrological influences of the land management practices, and suggestions are made for further research in this area.

Trends in Runoff and Sediment Flow due to Conservation Measures*

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The paper presents the findings of a study conducted to evaluate the response of a watershed, which has been subjected to afforestation and other soil conservation measures. The watershed is located between the lower Himalayan and Shiwalik ranges, below the snow line, and it measures 1035 km^2. The analysis of data for the pretreatment (1970-74) and posttreatment (1978-82) periods exhibits a decrease in water yield of up to 24%, and a reduction in soil loss from the catchment of 28%. The runoff coefficient (runoff/rainfall) has also decreased by more than 19%, indicating that enhanced soil moisture is available for plant use. A least square regression was performed to predict streamflows from the catchment, and to quantify the impact of treatments on water yield and on soil loss from the watershed.

Hydrologic Modeling of Small Agricultural Watersheds—the ICRISAT Experience

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The hydrologic response of a watershed integrates the effects of several complex processes and interactions, involving land and soil features, climate, vegetation characteristics, and management changes. Modeling has been used as a tool for designing soil and water management practices and structures.

Two important soils of the semi-arid tropics, Alfisols and Vertisols, are represented at ICRISAT Center. The paper reviews the development of three models, based on data from watershed studies on these soils. The models are (a) RUNMOD, (b) a modified curve number technique with soil moisture accounting, and (c) a numerical technique model. The first two models require calibration at a given site, whereas the third model can be used without calibration. The three models have different data

* Authors could not attend, but paper was considered in the discussions and recommendations.

requirements. As an example, the first model requires daily rainfall amount and duration; the second model requires only daily rainfall amount; and the third model requires data on storm intensity and duration. The paper discusses the merits and demerits of these models and suggests directions for future research.

A New Approach to Predict Sediment Yield from Small Ungauged Watersheds

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This study proposes a dimensionally homogeneous and statistically optimal model for prediction of sediment yield from small ungauged watersheds. Ten dimensionless geomorphic parameters were evaluated from toposheets, and these were further grouped for physically significant factors, such as steepness, shape, and geological factors, by using principal component analysis and analytical vari-max rotation. The average annual sediment production rate(SPR) of 20 small watersheds of Upper Damodar Valley (India) was nondimensionalized by dividing it with the square root of the drainage area. Regression analysis were performed, using as dependent variable the dimensionless SPR factor (SPR/A), and as independent variables three geomorphic parameters, taken one at a time from each of three different physically significant factors. A total of 24 combinations of independent variables were tried, and the best-fit model for prediction of SPR identified. This model can be safely used for predicting the sediment yield of small ungauged watersheds having similar geomorphic and climatic features.

Watershed Modeling for Yield Assessment

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Assessment of water yield is basic to the design and operation of an irrigation project. Yield assessment is usually made after the analysis of historical streamflow data for basins where the data are available for adequate periods. In the absence of streamflow records, empirical formulae or curves are used to assess the yield from the rainfall data. Obviously, such empirical relationships do not completely encompass the dynamic nature of hydrological processes operating in the basin. There is still another category of drainage basins: those with a much longer rainfall record but a very short streamflow record. Parametric simulation modeling can be used in such basins for developing relationships among physical parameters and catchment response, using the available streamflow records and then using these parameters to synthesize the nonrecorded hydrologic sequence. Most of the conceptual models having such capabilities are quite complex. They have elaborate data requirements, which render them

unsuitable for small watersheds where we need to make yield assessments for minor irrigation schemes. The Tank model, which is a continuous water-balance model, has the potential of being used in the situations discussed. The model is comparatively simple and its data needs are limited. The paper presents a case-study application of this model, which distinctly brings out its usefulness. It further demonstrates that with improvements in input data, the model performance improves further.

Rainwater Management for Crops in a Rainfed Area

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Efficient rainwater management is the key to success in rainfed farming, for which adequate research information is not available. Keeping this in view, investigations were carried out on systematic management of rainwater, both in situ and in farm ponds for supplemental irrigation, for a rainfed area in northern Punjab. Weekly rainfall amounts and weekly evapotranspiration of the main crops were studied, using Gamma distribution. Early-maturing local maize, wheat on sandy loam, and sunhemp mulch-wheat on loamy sand soils were found to be the most suitable in the study area. Criteria were also developed for identifying critical dry spells and their duration in rainfed regions, for planning supplemental irrigation. It was found that chances of planning for presowing irrigation are 100%, with full benefit, for wheat, whereas they are only 55.5%, with partial benefit, for the maize crop.

The technical and economic feasibility of in situ water conservation measures for rainfed areas were studied, and sets of the most suitable measures were selected for both the soils of the study area. The lowest assured weekly, periodical, and seasonal runoff amounts were estimated and studied at different probability levels. Both periodical and seasonal runoff distribution were found suitable for tank design. The tasseling-silking stage of maize and the presowing stage of wheat were found most critical for supplemental irrigation. Monetary returns from presowing irrigation of wheat were 3.5 times that of maize. A detailed technoeconomic evaluation of irrigation systems indicated that for only one supplemental irrigation spell of 10 days in a year, portable diesel engine pumping sets with PVC pipes are most suitable.

A comprehensive computer program was developed for designing tanks of inverted truncated pyramid shape, having a square base and 1:1 side slope, and for computing their cost and expected available water at the time of irrigation. The benefit-cost ratio of a tank designed on best probability levels of seasonal runoff is more than that of periodical runoff, and it varies from 1.60 to 4.56 for sandy loam soils, and from 1.13 to 3.99 for loamy sand soils. It is possible to develop specific, technoeconomically viable plans for rainwater management in rainfed areas through rational analysis of rainfall, identification of critical irrigation periods, incorporation of appropriate in situ water conservation measures, estimation of runoff into scientifically designed storage tanks, and adopting a suitable irrigation system.

Mathematical Modeling of Upland Erosion

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A mathematical model was developed to simulate overland flow and sediment delivery from the fallow upland phase of the small watersheds. The overland flow was simulated by using the shallow water continuity equation and the kinematic wave approximation to the equation of motion. Manning's equation was used to determine flow discharge rate. The model employs the approach of Mein and Larson, based on the original Green and Ampt approach, to simulate the rainfall excess rate for varying rainfall conditions. It requires saturation moisture deficit, along with effective saturated conductivity and average suction at the wetting front of the soil profile. To simulate saturation moisture deficit, a soil water-balance approach and sinusoidal variation of evaporation during the day time were used. The dynamic conservation of mass equation was used to simulate sediment routing. Erosion was computed using empirical rill and interrill erosion relationships. Modified Yalin's equation was used to compute the transport capacity of flow for nonuniform sediment mixtures. A scheme was employed to distribute excess transport capacity to the particles having a deficit transport rate. The solutions to the governing partial differential equations of flow and sediment were obtained, using the explicit finite element technique. The numerical solution to the equation of flow for a simple flow plane, receiving uniform steady state rainfall excess rate, was compared with the analytical solution. The sediment yield model was validated with the published soil erosion data, and a good agreement obtained between the observed and computed sediment yield. The model has the ability to evaluate various soil conservation measures for their adoption potential on small watersheds.

Quantification of Erosion and Runoff with Cropping and Management Practices for Watershed Modeling

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In India, most watersheds in dryland areas are ungauged and hydrological data on them are very limited. Therefore, simulation experiments could be a means to obtain empirical answers provided a mathematical model could be developed, based on the data.

A runoff-erosion study was undertaken on replicated Wischmeiser plots, with a 4% slope, having fallow, alfalfa, and barley sown along and across the slope treatments. Rainfall duration and intensity were simulated by means of sprinkler irrigation. Both soil loss and runoff were profoundly influenced by the treatments and by rainfall duration and intensity. Fallowing is most susceptible to runoff and erosion. Runoff

and soil loss were found to increase considerably as the duration and intensity of rainfall increased.

Hydrographs produced a pattern commonly obtained under situations of short-duration, intense rainstorms.

A model based on the unit hydrograph is proposed to predict runoff from ungauged watersheds for resource planning and for management of watershed development in dryland areas. Application of the model for observed values is also presented, as an example of how the model can be used.

A Hydrological Model for Small Agricultural Watersheds

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A two-parameter model is developed to predict surface runoff and deep percolation from rainfall on agricultural watersheds. The root zone of the soil (one of the parameters) is divided into two layers, the top layer being smaller. The input to the model consists of daily weather data, including rainfall. The rainfall first fills the top layer to saturation, and any excess will appear as surface runoff. The moisture in the top layer is then redistributed over a depth just enough to bring it to the field capacity. Any excess moisture over that required to bring the entire root zone to field capacity infiltrates further downward, recharging the groundwater. The moisture in the top layer is subject to direct evaporation at a rate that depends on the weather parameters and moisture tension. This is the only evaporation before sowing. After a crop is sown, evapotranspiration occurs, depleting the moisture in the root zone, again depending on the weather parameters and tension. An actual evapotranspiration model is used to predict moisture depletion at higher tension values. A daily soil moisture account is maintained, to provide initial conditions for the simulation on each succeeding day. Three categories of land use are considered: bare soil, purely rainfed cropland, and irrigated cropland. The depth of the top layer of soil, which represents the parameter to be calibrated, is determined from runoff and rainfall records. In the region around Bangalore, this depth amounts to 75 mm. It is found from the model that most of the groundwater recharge in this region is from rainfall on bare soils and irrigated land.

Hydrology-Based Model for Prediction of Runoff and Sediment Yield with Limited Data for Agricultural Watersheds

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Information available at the G.R. Halli watershed (Chitradurga Dist., Karnataka) on the observed rainfall, resultant runoff volume, and quantity of soil held behind a storage structure under different cropping systems for the years 1985 and 1986 was

used as basic input data for preparation of this paper. This agricultural watershed (120 ha) is in a red soil area.

Runoff prediction was made based on the nonlinear Threshold Rainfall Runoff model. The logic of the model is that the amount of rainfall that will contribute to the storm runoff is strongly influenced by the basin soil moisture conditions prevailing at that time, and this is viewed as the major source of nonlinearity in the relation between rainfall and runoff. In order to accommodate such nonlinear effects in the model, a threshold mechanism was introduced whereby the rainfall was split into two sequences on the basis of basin wetness. In its current form, the threshold mechanism employs the antecedent precipitation index to split the rainfall into two sequences, one having a fast response and the other a slow response for production of runoff.

Sediment yield from the watershed was predicted on the basis of models that require runoff inputs that can be attached to a hydrologic model. The universal soil loss equation (USLE) was modified as the Modified Universal Soil Loss Equation (MUSLE) by replacing the rainfall energy factor with the runoff factor, making it applicable to individual storms. The daily runoff volume and peak rate of runoff are the required inputs for this model. For computation of peak rate, the available equation for peakflow-runoff volume relationship was used. Since the catchment is practically undisturbed from 1981, the sediment loss, runoff volume, and other hydrological parameters from 1981 to 1984 were estimated by using the runoff and sediment yield model, already mentioned.

For planning important water resource projects, especially in drought-prone areas, hydrologists must also give a statement of the probability of rainfall, soil loss, peak flow, etc. Therefore, an attempt is also made herein to analyze the various parameters in terms of probabilistic models.

A Water-Yield Model for Small Semi-Arid Watersheds of India*

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The problem of water scarcity threatens crop production in the semi-arid tropics of India. A physically based hydrological model for the small watersheds in the region would help practicing hydrologists and engineers in evaluating various measures of water conservation and in adopting the most efficient one. The present study was undertaken with a view to develop one such model, relatively simple in concept and with a reasonable data demand.

The model integrates processes such as infiltration, soil-moisture redistribution, and evapotranspiration; it predicts storm runoff, soil moisture storage, evapotranspiration, and deep percolation on a daily basis. The infiltration from unsteady rainfall is computed by using the Green-Ampt-Mein-Larson equations, following a procedure similar to Chu's. Finite difference techniques are used to solve Richard's equation for one-dimensional soil-water flow. The sink term in Richard's equation is computed

*** Presented by V.V.N. Murty in the absence of the authors**.

from Refsgaard's model for evapotranspiration, with some minor modifications. The model was validated against measured data on runoff and soil moisture from two small watersheds in India under two extremes of land use. Close agreement between the measured and predicted values was found in all cases, except for the first runoff event in the early part of the season in all years, which is attributed to soil cracking. A sensitivity analysis was done to investigate the relative importance of the model parameters in the simulation process.

Since the model has been developed on a physical basis, it can have a wide range of applications, besides the prediction of surface water yield. It can be used for scheduling irrigation, estimating natural recharge of groundwater, determining effective rainfall, and evaluating the impact of land-use changes on the water yield of a watershed.

Development of Synthetic Unit Hydrographs for Small Watersheds in the Aravalli Hill Range of Rajasthan

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Most watersheds in the Aravalli hill range in Rajasthan are ungauged. Estimating the total amount and peak rate of runoff for these ungauged small watersheds is of paramount importance for the development of these watersheds. Synthetic unit hydrographs can be used to develop runoff hydrographs for ungauged watersheds. In this paper, synthetic unit hydrographs, using only watershed characteristics and rainfall data, have been developed for estimating runoff characteristics.

The studies were conducted on a small watershed of 143.3 ha at the Soil and Water Conservation Demonstration and Training Centre of the College of Technology and Agricultural Engineering, Udaipur. The watershed typically represents the Aravalli hill range, comprising of hillocks of various slopes, heavily eroded and under land-capability classification from class III to class VII. The watershed is situated in a subtropical continental, subhumid monsoonal type of climate.

Altogether 22 physiographic characteristics of the watershed, representing linear aspects of the drainage system, and areal and relief aspects of the watershed, were determined. In all, 42 hydrographs for the years 1982-87 were analyzed. Four methods have been used for development of synthetic unit hydrographs: Snyder, Clark, SCS method, and CWC procedure. Since all these methods for developing synthetic unit hydrographs were originally developed for large catchment areas ranging from 25-2500 km^2, their relevance to small watersheds is tested for the actual development of synthetic unit hydrographs. Synthetic unit hydrographs are developed for various durations of excess rainfall: 15, 30, 45, 60, 120, and 180 minutes. The following conclusions emerge: the Snyder method can be used as it is for small watersheds also, and it is the best method to develop design hydrographs; the Clark method is not suitable for small watersheds; the SCS method can be used with slight modifications in the coefficients; and the CWC method can only predict the approximate peak discharge.

The Effect of Farming Systems on Hydrological Behavior in Hilly Microwatersheds

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Soil erosion/degradation and depletion in the availability of drinking water are major problems for resource management in hilly regions. The severity of these problems has increased gradually, with an increase in biotic interferences. Traditional food production systems (farming systems) are reported to be hazardous to land and water resources. Hill slopes are the worst affected areas. Shifting cultivation, growing of tuber crops on raised beds, pineapple cultivation along the slopes and homestead areas, resulted in soil erosion, respectively, to the extent of 5.10-83.30, 40.00-50.00, 24.00 62.00, and 16.81 t ha^{-1} annually, whereas the extent of soil erosion in natural bamboo forest was found to be 0.04-0.52 t ha^{-1} annually.

Studies on watershed-based farming systems during the last 12 years have indicated the feasibility of bringing soil erosion on steep slopes within permissible limits while practicing agriculture, horticulture, livestock, forestry, and mixed land-use systems. Contour bunds, bench terraces, half moon terraces, grassed waterways, dugout/embankment type of water harvesting structures (seasonal/perennial), and microwatersheds are the major conservation measures required for land and water management in steep hill slopes. The hydrological behavior of microwatersheds in respect of surface flow (runoff) under different farming systems was found quite similiar to that of forest land use.

Soil erosion, runoff, and rainfall relationships have been developed, using monthly and annual values from the microwatersheds/plots. The major findings presented in this paper, to explain the hydrological behavior of watershed-based farming systems in hilly areas, are: the sinusoidal nature of relationship between runoff, soil loss, and slope; introduction of the conservation factor (accommodating the effect of conservation measures, land use, and human or animal interference) for estimating runoff, peak runoff, and soil erosion from microwatersheds; and the concepts of cumulative rainfall, runoff, and soil loss for developing relationships.

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