The Quality of
Agricultural Research Service
Watershed and Plot Data

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U.S. Department of Agriculture
Agricultural Research Service
Agricultural Reviews and Manuals•ARM-W-31/August 1982

FOREWORD

Background and Purpose

Experimental observations are the key to our understanding of natural phenomena and constitute an essential component of most major scientific discoveries. At the laboratory scale, these experimental observations can be, and generally are, made in carefully controlled environments. The level of control that is used in studies at this scale is usually matched to the accuracies desired and to the sensitivity of the measurements to environmental changes. As the physical scale of the process or system being studied continues to expand, the costs of environmental control escalate rapidly, ultimately compelling the scientist to use experimental approaches that are more appropriate for environments which are complex, transient, and largely uncontrolled. Experimental watersheds constitute "natural" research laboratories where complex hydrologic processes interact within a highly heterogeneous and poorly defined system to transform random, uncontrolled inputs into highly variable, time-dependent outputs. Not suprisingly, the experimental strategy and level of instrumentation for watershed studies demands compromise, with professional judgment establishing the optimum balance between the accuracy of system characterization and the human and financial resources available for conducting the study.

In evaluating the performance of such large complex systems where year to year responses frequently vary by an order of magnitude and where system responses at shorter time scales usually vary by several orders of magnitude, continuity of the recorded observations is often perceived as an overriding factor in experimental design. Depending on the study objectives and the resource constraints, accuracy and precision of some measurements may be justifiably sacrificed for increased durability and reliability of field instrumentation. Such research strategies have been and continue to be widely used in hydrologic studies, both nationally and internationally. During the past two decades, a rethinking of this research philosophy has occurred. In this period, our understanding of most of the key hydrologic processes that transform precipitation to streamflow has been substantially advanced. Furthermore, societal concerns about environmental degradation have necessitated significantly greater use of predictive procedures in developing broad planning strategies, and in establishing regulations and policies for environmental quality control. As a direct consequence of these developments, and the rapid advances in communications and computer technologies, the need to reassess earlier experimental strategies coupled with the need to evaluate the accuracy of hydrologic instrumentation over wider ranges of operating conditions, have been surfaced as important and potentially far-reaching issues by several ARS scientists.

In attempting to address these emerging program needs, Dr. T. J. Army, Deputy Administrator, NPS-ARS, requested that a survey be conducted to identify the key instrumentation and data quality concerns of the ARS watershed research program. This survey would document the data acquisition systems currently in use, would identify problems encountered in maintaining instrumentation performance, and would recommend instrumentation development and testing projects for inclusion in an agency program aimed at ensuring data quality. The material presented in this report represents the program's response to this request.

Instrumentation Needs and Recommendations

The instrumentation need mentioned most often in the report is flow measurement, particularly measurement of flows heavily laden with sediment. In addition to flow-measuring devices, a method of measuring flow depths other than by conventional stilling wells and float gages is needed to overcome stilling well lag and problems caused by sediment deposition.

The second major instrumentation need is for a sediment sampling system to withdraw representative samples that can be used to compute total sediment transport rates and sediment size distributions.

Electronic data acquisition, transmission, and reduction is a third major instrumentation need. The advantage of centralized data recording is that it will place all recording on a common time base and eliminate existing time synchronization problems. Backup battery power with the batteries charged by solar and wind generators is an auxiliary need. The effect of lightning on electronic systems is a problem mentioned in several reports. Experienced electronic technicians are essential to install and maintain modern instruments.

Other important needs and problems mentioned include adequate training of observers, effect of wind and snow on precipitation catches, difficulties with digital equipment, the adverse effects of travel restrictions, and lack of a national ARS effort to develop and test instruments and procedures for watershed research.

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REPORT ON QUALITY OF WATERSHED AND PLOT DATA FROM
THE SOUTHWEST RANGELAND WATERSHED RESEARCH CENTER

by

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INTRODUCTION

The mission of the Southwest Rangeland Watershed Research Center (SWRWRC) is to study the hydrology of rangeland watersheds and the effects of changing land uses and practices on the hydrologic cycle. This includes the study of rainfall, which is natural input to the watersheds; the quality and movement of water on the surface of the watershed; erosion from the watersheds and from the channels within them; sedimentation within the channels and reservoirs; and the present and potential uses of available water. Primary emphasis is on:

(1) Understanding and evaluating the effects of changing land use, including range renovations and conservation practices, and

(2) Developing the principles for such understanding in order to apply the results and findings from research areas to areas having little or no research data.

Scientists at the Research Center use the data from experimental areas in Arizona and New Mexico to study the quality and quantity of water from southwestern rangelands. Information obtained from these rangeland watersheds is used to determine the present and future potential water resources of the watersheds, which includes managing the use of the water for competing local and downstream users; establishing soil, water, and grazing management systems for increasing and stabilizing forage production; providing design concepts and criteria for flash flood and sedimentation control; and monitoring the movement of nonpoint source pollutants on semiarid rangelands. Simulation models have been developed that transfer climatologic and hydrologic data and concepts to predict the hydrologic response of ungaged areas.

The work at what is now the Southwest Rangeland Watershed Research Center was initiated by the Research Division of the Soil Conservation Service (SCS) in the late 1930's with the work on small watersheds near Safford, AZ and Albuquerque NM. Work on the Walnut Gulch Experimental Watershed, in southeastern Arizona, and the Alamogordo Creek Experimental Watershed, near Santa Rosa in eastern New Mexico, was initiated at about the same time that the research program of SCS was transferred to the newly formed Agricultural Research Service (ARS) in 1954. Research on these new larger watersheds soon showed that there were serious problems with streamflow measurement, and that there was an urgent need for a precalibrated measuring device capable of accurately measuring flow even when it carried heavy sediment loads and when flow rates fluctuated widely and rapidly.

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DATA AQUISITION PROGRAM

2.1 Precipitation: Precipitation studies in the southwestern United States are unique because of the dominance of high-intensity air-mass thunderstorms of limited areal extent that dominate the annual precipitation totals. About 2/3 of the annual precipitation total of 10 to 20 inches occurs during the summer monsoon season. Accurate definition of such storms requires a dense network of recording raingages, which creates some unique maintenance problems. The problems include the demands for servicing the mechanical recorders (they must be serviced weekly, or even more often during stormy periods), digitizing the records for subsequent analysis, and finally, maintaining the mechanical components (including the clocks). At the SWRWRC, a significant amount of the financial and people resources have been devoted to this problem. The weighing-type raingages currently used in this work are almost 40 years old and, although they operate well, could be improved with a central recording system, especially for synchronizing the time base of the hydrologic network. Furthermore, the existing raingages are not capable of describing the dynamic nature of rainfall rates. The differentiation of the integrated pen trace produced by the existing weighing record is subject to considerable subjective (operator of the digitizer) error. The rainfall intensity for very short periods (less than 5 minutes) is important to infiltration work and for erosion studies.

Approximately 90 scientific papers have been prepared by the Center staff describing the climatic/precipitation characteristics of the region. Osborn et al. (1972) stated that 1400 raingages would be required on Walnut Gulch to ensure a correlation coefficient (r) of 0.9 between adjacent gages (a spacing of 1000 feet). Renard and Brakensiek (1976) prepared a synopsis of the precipitation patterns in the western United States and contrasted seasonal characteristics within the region.

2.2 Runoff: Runoff in ephemeral streams creates some extraordinary problems of measurement. The streamflow is generally of short duration -- a response to periods of excess precipitation that are characterized by extreme spatial and temporal variability. The channels, which are dry 99.9% of the year, are characteristically steep (0.5 to 5.0%), with the result that the flow velocity is often near that for critical depth. Furthermore, the sediment supply is essentially infinite, so that the sediment transport rate (both suspended and bedload) is high. The combination of high velocities, rapidly changing flow depths (depth changes of >1.0 foot per minute), and high sediment loads preclude field measurements with conventional technology like current meters. Thus, precalibrated measuring devices (laboratory-rated devices) are essential in obtaining quality data. These problems led to a significant effort by scientists at the SWRWRC and at the Stillwater, Oklahoma Water Conservation Structures Laboratory to develop a supercritical measuring device for these flow characteristics. The details of these supercritical flumes, their rating problems, as well as problems of construction and operation, have been described by Osborn et al. (1963), Gwinn (1964), Quashu et al. (1966), Gwinn (1970), Smith and Lane (1971), Smith and Chery (1974), and Smith et al. (1981) (see figures 1, 2, and 3).

Efforts to obtain prototype verification of these laboratory-rated flumes have also been extensive, and have occupied a sizeable portion of the staff time and funds. For the 10-year period from 1961 to 1970, funds were transferred from the SWRWRC to the Stillwater, Oklahoma laboratory for partial support of the flow measurement research. Thus, each of the supercritical measuring flumes constructed at the larger watersheds operated by the Center (watersheds >500 acres) were individually laboratory rated, which involved building a scale model of both the flume and the upstream and downstream channel.

Prototype verification involved: (1) observations of the water surface profiles in the approach channel and in the flume itself; (2) low flow ratings using a current meter; (3) larger scale-models of the flume floor section; (4) use of dyes with constant injection for dilution testing; (5) use of a magnetic induction velocity meter to measure velocity; and (6) full-scale model testing of a prototype involving a modification of the Walnut Gulch flume which was subsequently named a Santa Rita flume.

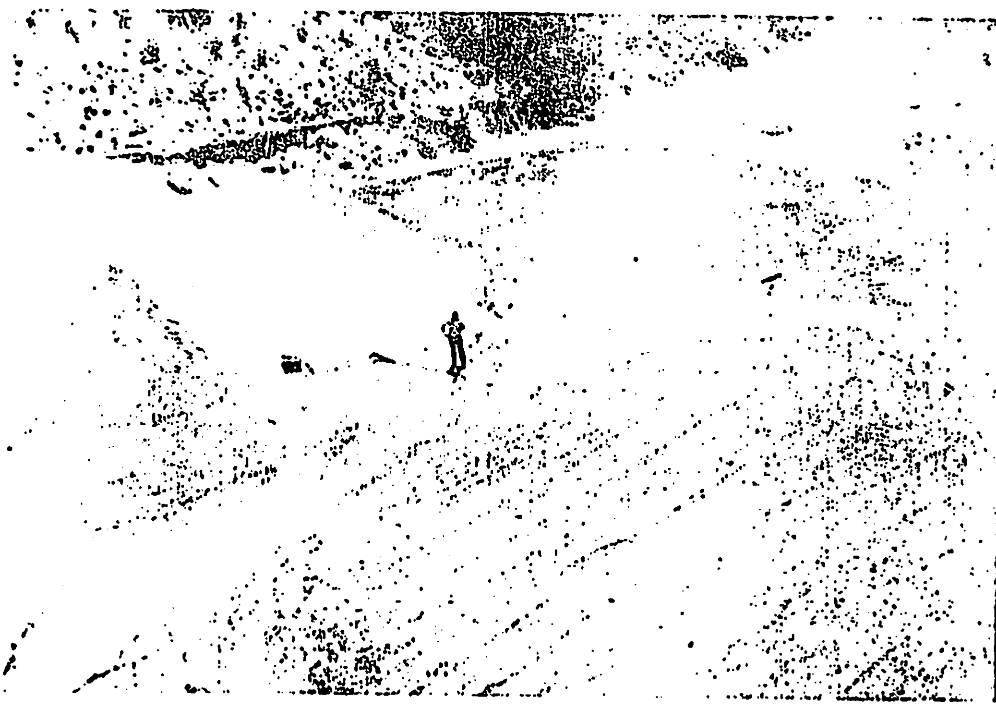

Fig. 1. A view of the flume completed at the outlet of the 58 sq. mi. Walnut Gulch Experimental Watershed in June 1954. The small flow on this date was held in the barrow pit associated with the construction. The structure was destroyed by flows during the first runoff season.

Details regarding most of this prototype verification are included in the USDA Technical Bulletin entitled, "Supercritical Flow Flumes for Measurement of Sediment Laden Flow", by Smith et al. (1981). The prototype verification work involving measurement with fluorescent dyes on Walnut Gulch, (at Flumes 6 and 1), was only partially successful. Rhodamine WT and Pontacyl pink dyes were injected at constant discharges across the flow width immediately upstream from the measuring station. Samples were collected about 500 feet below the flume after the flow had been mixed in the hydraulic jump. Unfortunately, the dyes used, although water soluable, also adhered to the clay fractions in the flow. Thus, concentrations of the dye in the mixed sample were sensitive to the time after the sample collection at which the fluorometer measurements were taken, with an approximate error rate of 50% involved in only a 6- to 12-hour delay. Attempts were made to use a salt for the tracer. However, the Arizona State Health Board would not approve use of the fluoride salt, and most other salts investigated had appreciable, but not consistent, background loads in the runoff from the area.

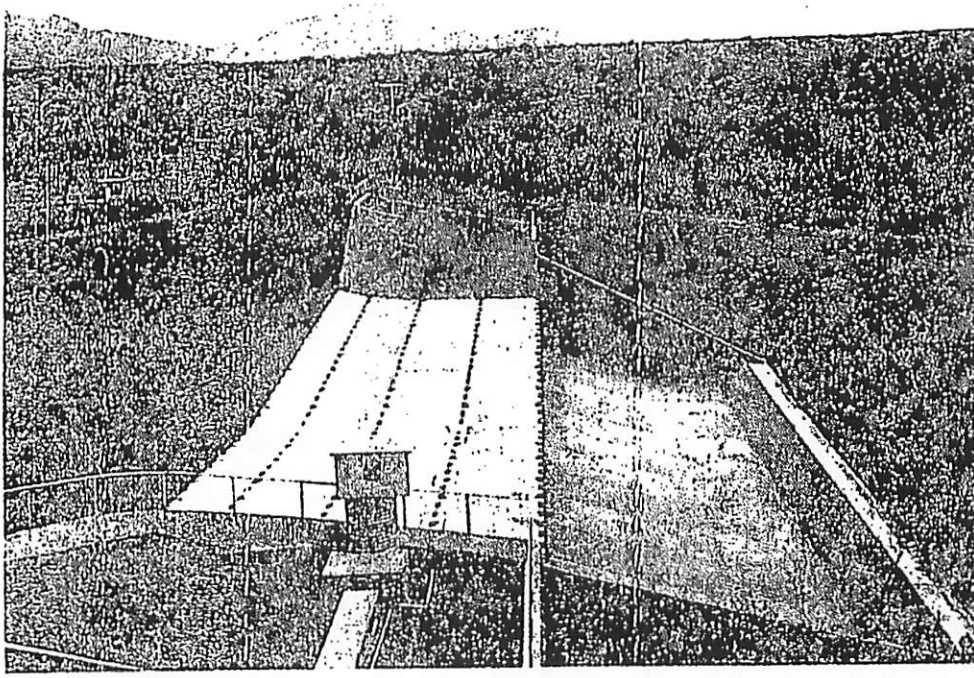

Fig. 2. A view of the runoff measuring structure at the outlet of the Walnut Gulch Experimental Watershed completed in 1964. The energy dissipator in the right portion of the picture was required to prevent scour and increased the cost of the structure. When the bedrock is capable of dissipating the energy, this additional concrete is not required. The new structure is much larger than the original (22,000 cfs vs. 5,000 cfs).

Runoff measurements (rates and volumes) have also been made and are continuing in connection with plot studies at the SWRWRC. Some of the earlier studies involved volumetric measurements only. Subsequently, a volumetric tank was equipped with a water level recorder and an orifice part way up the tank. Thus, outflow from the plot was determined from a combination of volume change plus the discharge from the orifice. Accurate runoff measurements were obtained with this method, although some problems were encountered with trash collecting on the screen behind the orifice. Unfortunately, the method cannot be used to measure sediment loss.

In some recent work with a rotating boom rainfall simulator for determining plot erosion, some very small flumes (0.05 ft floor width and 0.50 ft deep) were developed (Santa Rita flume design). Aliquots of the water/sediment/chemical mixture are obtained at the flume exit. This also has proven quite satisfactory, although a sloping approach box and plot trough must be used to ensure that sediment does not deposit in the approach and measuring section. The use of supercritical measuring devices does result in some loss of sensitivity in the depth-discharge relationship.

2.3 Sediment Concentration: Perhaps one of the more important problems of measurement in watershed research is that associated with erosion/sediment transport/sediment yield research. In our estimation, this is one of the more serious problems we have

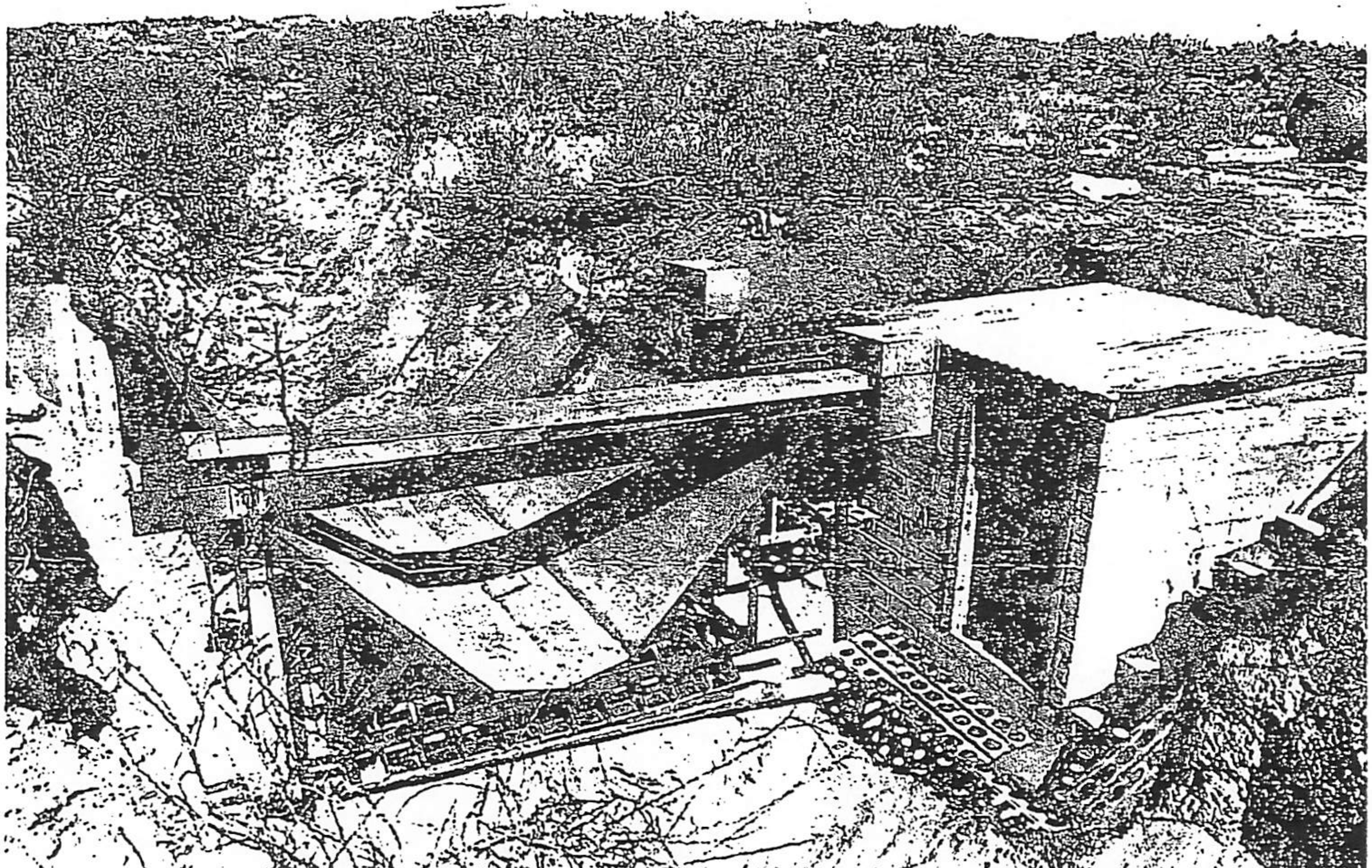

Fig. 3. The Santa Rita-type supercritical measuring flume shown has a peak measuring capacity of 100 cfs. This prefabricated measuring device has been equipped for water quality sampling. Aliquots of the water-sediment-chemical mixture are collect at the overfall with the traversing slot (at left edge of flume) and deposited in the shelter house in the right foreground. The structure is 3 feet deep at the flume exit.

encountered. The state-of-the-art technology here has lagged seriously behind other facets of our work. By and large, field data are still being collected using equipment developed decades ago, although the advent of pumping samplers has helped to provide samples at remote sites throughout individual storm events.

At the SWRWRC, a concerted effort was made in the mid 1970's to develop sampling equipment capable of sampling the entire flow cross-section. The sampling scheme developed, which is currently used at most small watersheds (peak flows <100 cfs), involves a moveable slot that traverses the flow, diverting an aliquot of the flume outflow (water/sediment mixture) onto some fixed slots. The fixed slots further reduce the sample size (figure 3). The subsequent split is deposited in a modified Chickasha-type sampler table, with each sample then being associated with a discrete time on the hydrograph. The unit, which operates from batteries charged by a photovoltaic charger, has a variable speed drive mechanism for the moveable slot. The speed control allows the desired sample size to be obtained regardless of the flume discharge rate. Construction of these units with stainless steel, galvanized sheet metal, or plastic ensures that the aliquots can also be used for chemical concentration determinations. Details of this sampling scheme are given by Renard et al. (1976). Recent unpublished modifications of this sampler include a constant speed for the traversing slot with the end of sampling preset when each bottle is half filled.

Pumping samplers used at some runoff-measuring stations with H-flumes, have unique problems associated with the sampler intake. The intakes used at SWRWRC are patterned after those used at Coshocton, OH and consist of a pipe with equally spaced holes, mounted and hinged at the streambed, and buoyed by a float at the end. These devices sample the entire flow depth. Questions regarding the sampling efficiency for holes in the upstream, downstream, or sides of the pipes need to be resolved. Similarly, such a device may provide reasonable estimates of the finer sediment fractions but ignores the load moving in close contact wth the streambed. There are also unresolved problems associated with debris collecting on the pipe and restricting the flow through one or more intakes.

Our observation has been that there are severe problems associated with sediment sampling at many experimental sites. State-of-the-art procedures are to pump an aliquot of the water/sediment/chemical mixture from a fixed position in some portion of a flume or weir. At best, such a scheme raises serious questions. The suspended sediment concentration can be described by (Rouse, 1949, p. 800):

$$\frac{C}{C_a} = \exp\left(\frac{-w(y-a)}{\varepsilon}\right)$$

where C = the concentration of sediment at a distance y above the bed,
C_a = the concentration at some reference level a, above the bed,
w = the fall velocity of sediment particles in the fluid,
and ε = the sediment transfer coefficient

Thus, the concentration of pump samples must be corrected because they are collected at a depth whose relation to the total depth is changing throughout the hydrograph. Current efforts generally ignore this problem and generally ignore the problem of the coarse fraction moving close to the bed (usually referred to as bedload). In many environments, the so-called bedload discharge can be a significant fraction of the total load -- our experience with H-flumes is that the bedload is often twice the suspended load.

At the large watersheds on Walnut Gulch, samples for determination of suspended sediment concentration are collected using equal-transit-rate principles with US-D-48 hand samplers when we can wade the flow. When the flow is too deep for wading, a US-P-63 depth-integrating sampler is lowered from a cableway. Such measurements are generally made at only two of the watershed locations because of manpower constraints. When the cableway sampling procedure is used, samples are generally collected at, or near, the channel centerline. These procedures also can introduce considerable error, because the samples from one cross-section hardly represent the mean for the section. Because of the rapidly changing flow depths, this is the best information that can be obtained using currently available equipment. Bedload or coarse material transport at the flume exit is determined periodically using a traversing slot. The data indicate that bedload transport is highly variable, not necessarily proportional to the water discharge rate but, rather, associated with passage of dunes and/or antidunes through the measuring flume.

2.4 Chemical Transport (Concentration): The concentration of dissolved and adsorbed chemicals in the runoff from experimental watersheds operated by the SWRWRC is closely related to the sediment sampling. Where the traversing slot samplers are located with Santa Rita-type flumes, the concentrations of cations and anions represent good estimates of the concentrations of the flow. Laboratory equipment that we use for the concentration determinations include atomic adsorption spectrophotometer and a Technicon* autoanalyzer, which are considered to be the best techniques currently available. When adsorbed chemicals are involved, the data problems associated with the representativeness of the sediment sample also can be assumed to apply. The traversing slot samplers, as mentioned earlier, are constructed using materials that should minimize contaminations.

Chemical composition of precipitation has also been monitored by the SWRWRC using equipment designed by Schreiber and Cooper (1978). Heavy sulfur concentrations (pH <4) have been measured with some frequency (Osborn and Cooper, 1981). The equipment seems to work very well.

DATA QUALITY PROBLEMS

3.1 Precipitation: One major problem with the precipitation studies is that each sampling point uses an independent time reference (clock). Therefore, in attempts to describe the timing of thunderstorm cell buildup, the lack of synchronization can cause timing errors to become very significant. As an illustration, consider a room full of people, each with his own wristwatch. Although the mean time is probably near the actual time, the deviation from that mean is likely to be appreciable, with a range of, perhaps, ±10 to 15 minutes. Our raingage clocks are similarly independent. Furthermore, the 24-hour per revolution time scale used by the raingages operated at the SWRWRC means that intensities for short time intervals are subject to large error (e.g., a 2-min intensity may well be ±50%). Central recording with electronics, such as that being used by the USDA Sedimentation Laboratory for the Goodwin Creek study in Mississippi, appears to be a viable alternative. Unfortunately, the resources required for such a network would require a large one-time commitment of funds, which is not feasible with the funding currently available at the project.

3.2 Runoff: The runoff devices used at the SWRWRC are, in our estimation, the best currently available. If the number of requests for design information are an indication, quite a few of our peers agree with us. Furthermore, the correct utilization of information presented in Chapter 2, Runoff, in Agricultural Handbook 224 (Brakensiek, et al., 1979), should minimize improper use of runoff-measuring devices by engineers and scientists designing data collection programs for water resources research. Unfortunately, people using runoff measurement information often have not had adequate training to assist them in selection of an appropriate device.

*Trade names are included for information of the reader and do not constitute endorsement by the United States Department of Agriculture.

There are, however, problems at both our locations and in general with runoff records because of difficulties with station maintenance. The problems have involved such things as plugged intakes, improper setting of the point of zero flow, and making improper adjustments in water-level recorders. Many of these problems result from inadequate training of field personnel, poor communication between the field people and the data processing people, use of shortcuts, or inadequate understanding of the possible errors involved (data sensitivity). Perhaps the USDA-ARS agency should develop some training guidelines for present and new employees.

3.3 Sediment Concentration: Many of the problems with sediment concentration are associated with selection of an appropriate sampling point. Current sampling techniques generally consist of collecting a sample at a fixed point in converging or diverging flow in a flow measurement device. Information is insufficient in the literature to assist in a logical decision for such problems. Furthermore, procedures need to be developed for correcting or adjusting point sampling data to that representative of the whole flow cross section.

Once a sample is collected, the time-consuming methods for determining both the concentration and the particle-size distributions cause problems. The particle-size distribution has assumed tremendous significance in the last decade because of interest in water quality and the role of sediments as scavengers and transporters of various chemicals. A recent study by Schiebe, Welch, and Cooper (unpublished report, 1981) indicates that some of the new equipment used for particle size determination give widely different results as compared with the conventional pipette method. Work to improve the speed of determining partice-size distribution is very important, and furthermore, research is needed to define the role of aggregates versus primary particles in both sediment and chemical transport.

In summary, although we recognize that there are many problems with data on sediment concentration, we suggest ARS may be in a position to be the leader, both nationally and internationally, in developing more accurate methods of sampling for sediment in flow.

3.4 Chemical Concentration: Research at the SWRWRC on chemical concentrations associated with runoff has not involved a major commitment on our part. If runoff water quality determinations are to be meaningful, instrumentation must also consider rainwater composition. Thus, it is difficult for us to state the potential problems with such data. Many such programs, however, do involve samples that decompose in time because of high temperatures. Thus, the sampling equipment must be serviced frequently, and time dependent concentrations must be determined immediately, which often means that employees must work overtime or, at best, samples must be refrigerated. Thus, the research requires accurate runoff data, accurate sediment concentration data (for determining concentrations of adsorbed chemicals), and then accurate laboratory equipment for chemical concentration measurement.

RECOMMENDATIONS FOR INSTRUMENTATION RESEARCH

1. Test the sampling efficiency of the traversing slot sampler. For example, we assume that the aliquot entering the slot is representative of the sediment in transport, but the assumption has not been verified. Such verification would be somewhat like what has been done for samplers developed by the Federal Interagency Sedimentation Project in Minneapolis.

2. Develop reliable means for indirect measurement of flow depths to eliminate intake lags in conventional water-level recorder systems. Check bubble gages versus conventional water-level recorders as a means of replacing intake systems which are subject to sediment plugging. Define the drawdown caused by water moving over slotted plates.

3. Develop criteria and equipment for measuring in situ concentrations of sediment and chemicals. Such a program would also require definition of the best location within a control section for collecting such data (for example, at converging or diverging sections of the flow, or, perhaps turbulence could be introduced below a measuring station to facilitate more representative sampling).

4. Develop an efficient and economical telemetering and data recording system for hydrologic instruments including raingages, water-level recorders, soil moisture and water quality samplers. Such work should also include developing transducers to sense the hydrologic signals which might include using radar, sonar, lasers, etc.

5. Develop equipment to monitor the position of a streambed during the passage of an individual flood wave.

6. Develop training programs to teach continuing or new employees the best techniques available for recording hydrologic data.

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