Extract of publication no. 66 of the I.A.S.H.
Symposium of Budapest, pp. 286-298

INSTRUMENTATION OF EXPERIMENTAL WATERSHEDS (1)

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INTRODUCTION

The Agricultural Research Service and its predecessors in the U.S. Department of Agriculture have been engaged in research on the behavior of small agricultural watersheds since the early 1930's, and have instrumented and collected data on various phases of the hydrologic cycle from more than 300 such watersheds. Fifty percent of these experimental watersheds ares maller than 10 hectares, and about 75 percent are smaller than 100 hectares. Approximately 15 percent exceed 10 square kilometers and 5 percent exceed 100 square kilometers. The total drainage area of one major river reach now under study exceeds 2 500 sq. kilometers.

Objectives of the studies have included : (1) the accumulation of basic rainfall-runoff data, primarily for design of soil and water conservation structures; (2) study of the effects of land-use and treatment practices on the runoff and sediment production from upstream watershed source areas; and (3) evaluation of overall effects of watershed management and protection programs on flood expectancies, and net water and sediment yields of larger complex watersheds.

Minimum instrumentation of Agricultural Research Service experimental watersheds provides for continuous recording of both intensity of precipitation and the rate of surface runoff. Measurements of other watershed outputs may include, depending on the objectives of the experiment, evaporation and transpiration, subsurface flows, and sediment in the runoff. Additional input and environmental variables measured on some watersheds include radiant energy components, soil and air temperatures, wind, soil moisture content, groundwater levels, and varying soil surface and vegetative cover conditions. The most critical and the most costly items of experimental watershed instrumentation, generally, are those required for adequate sampling of the rainfall, and for sufficiently precise and reliable measurement of the runoff.

RAINFALL MEASUREMENT

Generally, comparatively long records exist characterizing the rainfall of a locality which, if adequate information on rainfall-runoff relations is also available, will enable the prediction of runoff for purposes of engineering planning and design. Determination of rainfall-runoff relations requires a relatively short period of measurement, and the basis for runoff prediction can thus be acquired sooner and with a higher degree of confidence than if such predictions are based on runoff experience alone. Also, if an objective of experimentation is to evaluate specific watershed and climatic influences on the runoff, precise knowledge of the rainfall variates is of prime importance. Measurement of the coordinate rainfall is essential to the maximum usefulness of any experimental watershed data.

The immediate problem in planning for adequate rainfall measurement on experimental watersheds is to determine the number and spacing of raingages needed.

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This depends on the time and spacial variabilities of rainfall in the locality, which differ widely with climate. Experience of the Agricultural Research Service is that the tendency is for too few raingages.

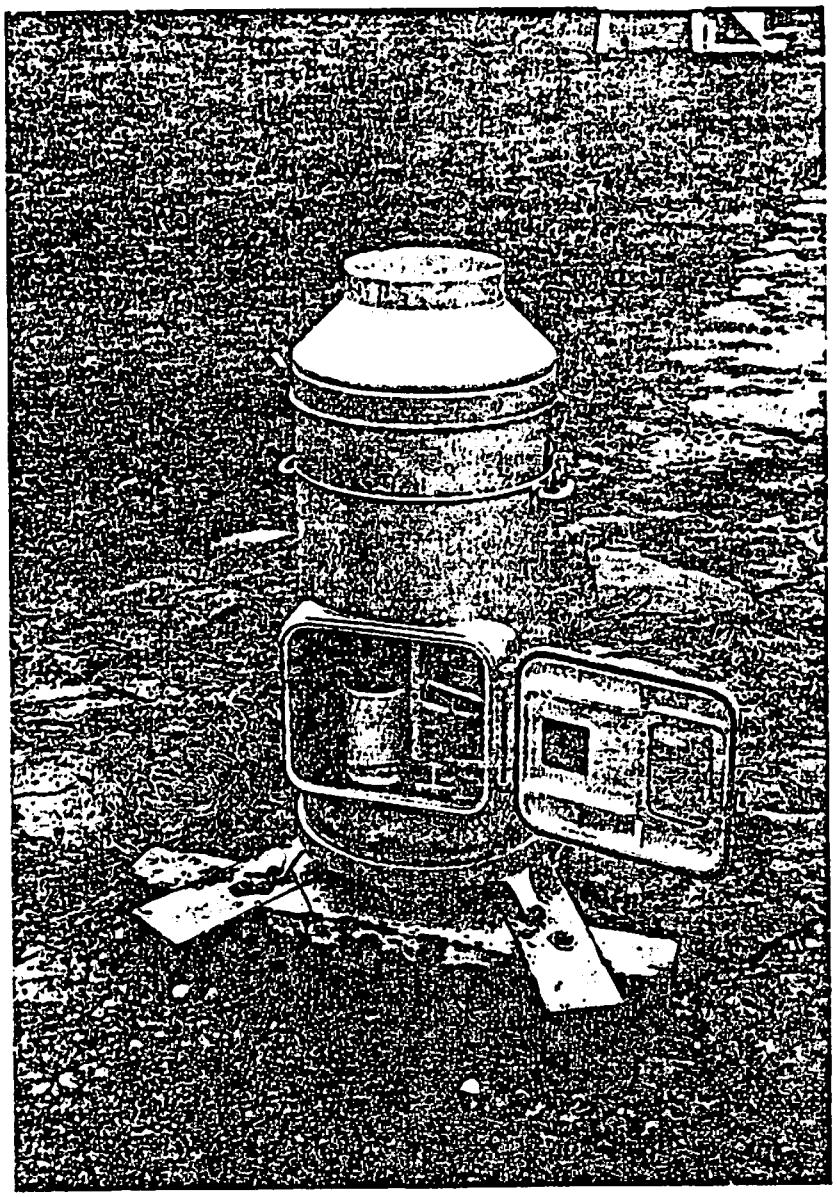

Fig. 1 — Weighing-Type Recording Raingage.

The transposition of rainfall data over very long distances is not feasible. This is especially true if major storms are of the convective or thunderstorm type, or if topographic relief has material effect on the areal distribution of rainfall in frontal-type storms. Errors in the estimates of storm and seasonal totals of rainfall of several hundred percent may easily result from transposition of rainfall records over a few kilometers under such conditions, and differences in the times of occurrence and intensity-duration patterns are even more variable.

For studies of basic watershed hydrologic influences, the time relations of rainfall and runoff are very significant. It is essential to measure not only storm or daily totals of rainfall, but also the times of occurrence and time-depth distributions of the rainfall at various locations within a watershed. Recording-type raingages are essential (fig. 1).

On watersheds maintained by the Agricultural Research Service (USDA 1963), the number of gages recording rainfall intensities averages one for watersheds up to about 150 hectares in area, two for those up to 200 hectares, three for 1 000 hectares, to a minimum density of around one gage per 800 hectares. On semiarid watersheds in the Western United States, however, a substantially denser network of gages is needed. Here, the maximum watershed size for one gage is regarded to be under 20 hectares, and the minimum density of a gage net to be about one per 250 hectares. It has been estimated that 80 percent of the convective storm cells in the Southwestern United States cover an area of only about 200 hectares (Agr. Res. Serv. 1962).

Multiple gages on a watershed are usually spaced for approximately uniform areal coverage. On small watersheds having a single raingage, it should be located near the centroid of the area. A raingage located at the watershed outlet, for convenience of proximity to the runoff measuring station, has a minimum areal representation on the watershed. In regions where runoffs occur as a result of very local, intense thunderstorms, as in the desert areas of the Southwestern United States, rainfall measured only at the outlet of the watershed may bear little relationship to the runoff.

Recording raingages used in the United States are generally weighing type with orifice diameter approximately 20.6 centimeters (8 inches). The ratio of the depth scale to actual depth of rainfall is generally 1 : 1, with multiple-traverse recording mechanisms used where more than about 15 cm (6 inches) of total capacity is needed. Time scales are varied, depending on resolution needed. On small watersheds with a single intensity-recording gage, the scale is generally based on one chart drum revolution in 6 hours or approximately 5 cm per hour, with scale graduations permitting time readings to the nearest minute. On larger watersheds rainfall intensity gages have chart drum speeds of one revolution in 12 hours, or even in 24 hours. A recording gage with a drum speed of one revolution per week (daily graduations) is usually operated in conjunction with the faster-cycle recorders, merely for dating the storm incidents. Rainfall intensity determinations are not made from gages having chart speeds less than about 1.25 cm per hour (24 hours per drum revolution), and even this speed is too slow for accurate determination of rainfall intensities for intervals shorter than about 15 minutes.

Shielding of recording gages from wind turbulence is considered to be necessary in some locations. Where this is done, the Alter-type shield (Alter 1937) is most commonly used.

Snow measurement

Generally snowfall on the Agricultural Research Service experimental watersheds is measured also by the recording raingages. Rain funnels, used in the summer to reduce splash and evaporation losses of the rainfall catch, are removed in winter for snow measurement. Some antifreeze compound, usually ethylene-glycol, is put into the gage catch containers at the start of the record period, and some light oil or other evaporation suppressant may also be used. The winter precipitation may then be allowed to accu-

mulate in the gage until either the antifreeze concentration becomes too low or there is a possibility of the recording capacity of the gage being exceeded. The gage, however, continues to require servicing at weekly intervals to maintain its chart drive in operation.

Where ground accumulation of snow is important, snow depths are measured, either by depth soundings at the recording gage sites or at other fixed locations, and samples are collected for determination of the water content of the snow. At a few locations on large experimental watersheds, where important flood runoff or water yield results from snowmelt, periodic snow sampling is done along regular snow survey courses, using snow sampling tubes, from which the cores are weighed to determine their water content (USDA 1961).

Continuous records of the snowfall and of the water content of accumulated ground cover of snow on experimental watersheds can now also be accomplished by means of automatic snow-weight recording devices. The University of Idaho, in research under auspices of the U.S. Department of Agriculture, developed a "snow pillow", whereby the weight of snow impressed on a thin, flat plastic bag on the ground, containing a nonfreezing liquid, actuates an electronic pressure transducer (Warnick 1960). Records from this device have been transmitted from remote locations by telemetering (Duncan 1963). Telemetering, accumulating type, total precipitation gages adapted to heavy snow regions are also available (Chadwick 1964).

Other climatic and meteorologic measurements

Efforts are made at several Agricultural Research Service watershed research locations to broadly evaluate climatic influences. At some locations weather stations are maintained, which include a standard U.S. Weather Bureau evaporation pan with its anemometer for recording total wind movement (fig. 2), a recording raingage, and sheltered thermometers for measurement of maximum and minimum daily air temperatures. Usually the thermometer shelter also contains a recording hygro-thermograph. In such cases the maximum and minimum thermometers are usually read weekly for calibration of the thermograph record, and weekly psychrometer readings are made for calibration of the hygrograph. At some locations only the temperature-humidity records are collected, without pan evaporation data. In a few places soil temperatures have been recorded. Such general climatic data are useful for broad interpretation of anomalies in the rainfall-runoff data, and for adjusting watershed research results for application in climatic situations varying from that where the data were obtained.

In a few cases more specific and precise meteorologic measurements are being made on experimental watersheds to directly evaluate evaporation and transpiration for detailed studies of influences on the water budget of a watershed or some definitely bounded hydrologic subunit within a watershed. In such efforts, in addition to a standard weather station in the immediate area, radiant energy components and sensible heat and moisture transfers between the soil and atmosphere are measured. Such studies involve complex and extensive instrumentation for watershed representation, and to date such experimentation has been mainly on development of methods and equipment.

Soil moisture

Where rainfall-runoff relations are under intensive investigation, soil moisture measurements are a necessary part of the experiment. Soil moisture measurements are being obtained on 40 percent of the watersheds currently under study by the Agricultural Research Service. The high cost of the operation prevents obtaining this important data on more of the watersheds.

Soil moisture measurements are usually made weekly to biweekly, depending on

the rainfall pattern and on the rate of soil moisture change. These measurements are used to relate rates of soil moisture losses to land surface cover and climatic environment. Since vegetation materially influences the extraction of soil moisture, the measurements are made at various depths in the root zone. Several different methods are employed to make these observations.

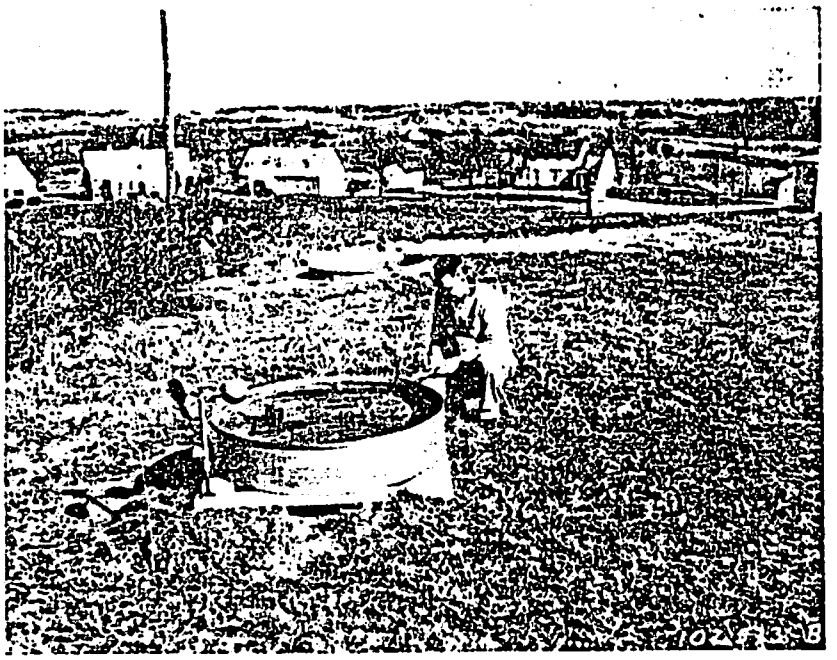

Fig. 2 — Standard U.S. Weather Bureau Evaporation Pan. Weather Station at a major Watershed Research location.

The neutron scatter method is used extensively (van Bavel 1963). Access tubes to receive the probe are installed in the major soil and land-use areas of the watershed. The probe is lowered into the tube to each preselected depth and a count obtained which is converted to soil moisture as a percent of volume by means of a prior calibration. The method is relatively rapid but it does have disadvantages. It cannot provide reliable determinations in the top 0.2 to 0.5 meter of the soil. This is a distinct limitation on the method for evaluating antecedent soil moisture influences on runoff. Calibration of the instrument must be checked frequently. Where soil has a tendency to crack, the readings may be inaccurate. Free water must be kept out of the tube. Also, there are the hazards of handling radioactive material. Despite these problems and limitations, the simplicity of operation of the meter makes it attractive and it finds increasingly widespread use.

The gravimetric method involves no field instrumentation but it does require a laboratory with a precision balance and a drying oven, plus the appropriate sampling equipment. Two disadvantages of the gravimetric method are the disturbance of the experimental area and the labor required.

The electrical resistance method eliminates the destructive effect of frequent sampling of the experimental area and also eliminates the considerable labor involved. Bouyoucos or other type resistance blocks (Thorne 1956) are placed in the soil at the depths to be measured. Resistance to electrical current flow is a function of the moisture content of the block which is in equilibrium with soil moisture. Resistance is measured with a Wheatstone bridge and converted to soil moisture percent by a prior calibration developed for the specific soil. This method is simple and rapid, but it cannot be used where soluble salts in the soil are excessive.

Tensiometers can be used to make nondestructive soil moisture determinations. The instrument consists of a porous cup sealed onto a mercury manometer tube or vacuum gage. The cup and tube are filled with distilled water and sealed. The cup is placed in the soil at the level at which moisture measurements are to be made. Water moves into and out of the porous cup as soil moisture content changes. The resulting pressure changes are observed and translated into soil moisture changes. Tensiometers are more accurate than resistance blocks in the wet range of soil moisture. At tensions greater than about three-fourths atmosphere the water column breaks and the instrument no longer functions.

Groundwater measurement

Where an objective of the research is determination of net water yields, the groundwater inflow-outflow and storage changes must be accounted for. An effort is usually made in planning the instrumentation of experimental watersheds to select runoff-measuring sites where either there is a natural geologic cutoff, or the measuring structure can be built to cut off any appreciable groundwater outflows. However, where the runoff-measuring structure is built to intercept normal groundwater outflows the hydrology of the watershed under study has to some degree been rendered artificial. Because of this, and because in some cases at points where surface runoff measurements are needed the cutoff of groundwater flows is impractical, it becomes more feasible on some watersheds to separately evaluate the subsurface outflow through the valley-fill materials by groundwater-level measurements. Depending on the geology underlying the surface watershed, there may also be other sections of groundwater outflow or of inflow which must be similarly accounted for.

A basic net of observation wells is planned, based on geologic exploration by drilling and seismic refraction measurements, for evaluation of groundwater storage changes. Where significant groundwater inflows or outflows to or from the study watershed are indicated, additional well courses are constructed. Field pumping tests of wells and laboratory tests of drill cores are made to evaluate hydraulic characteristics of the aquifer materials, in order that storage and flows may be estimated from the records of water table or piezometric levels and gradients. Where groundwater levels fluctuate rapidly, in relation to rainfall and surface flows, some or all of the wells are equipped with recorders.

Groundwater measurements are currently made on about 27 percent of the Agricultural Research Service experimental watersheds exceeding 10 hectares in area, and on about 50 percent of those exceeding 10,000 hectares. It is planned that groundwater measurements will be initiated on several additional watersheds, and that more wells will be added on several of the large watersheds.

Runoff measurement

Principles of Meter Selection

Runoff is generally the most important hydrologic quantity to be evaluated for a watershed. Although accurate measurement is often quite difficult, by selection of an

appropriate runoff measuring device and by care and diligence in its operation, an accuracy of 5 percent in the estimate of runoff is believed to be possible.

The best meter is one that will make it possible to attain the objectives of the experiment at a minimum cost. If the objective is only to obtain measurements of peak flow for flood frequency analysis, then simplicity, maximum capacity, and stability are the hydraulic criteria governing selection. If, however, a measure of the total surface flow is required, the meter then must have suitable sensitivity for flow measurement of the minimum to the maximum rates expected.

An approach to establishing the minimum flow requiring accurate measurement is to estimate the flow distribution characteristics from knowledge of similar watersheds in the locality. The most useful portrayal of this characteristic is a plotting of the percentage distribution of accumulated annual flow volume versus runoff rate. This diagram may be entered with, say, the 95-percent figure to determine the minimum flow rate which must be measured accurately to obtain an estimate of the annual flow accurate at the $\pm$ 5 percent level. Application of this principle in the United States shows that a meter of greater accuracy is needed in the low flow range in the eastern and northwestern sections of the country, where an appreciable part of the runoff occurs at low rates, than in the southwestern section, where storm runoff is of short duration and very little occurs at the low rates.

The amount and character of sediment in the flow must be considered in the design of a runoff meter. If sediment load is large and of coarse texture, provision must be made to pass it with the flow; otherwise, the accumulated sediment deposits can alter the measuring characteristics of the flow meter. If sediment load is moderate and the study of short duration, accumulation of deposits above the structure during the life time of the experiment may be tolerated. The flow meter must be shaped so that any floating debris will readily pass the station and not be lodged in the structure.

The physical characteristics of the site have great influence on the performance of the meter. If the approach channel is steep and the measuring device is a critical-depth meter, sufficient contraction of the flow cross-section must be provided so flow will be at critical depth in the control section. This contraction can be achieved by narrowing the structure or by raising the invert of the flow meter. The channel hydraulic roughness must also be considered. The nature of the bed and banks of the site, whether rock or alluvial fill, will influence the structural, if not the functional design of the flow meter.

Economic considerations affect meter selection. However, to choose a meter simply because it is inexpensive would be false economy, if it could not do the job required of it. Generally, it is better not to start a study until it can be adequately financed. The frequency and ease of necessary servicing must also be considered in analyzing the economics of the research operation.

In some locations existing drainage structures can be used for flow meters. Culverts are particularly suitable for adaptation to flow measurement. However, they usually require modification to permit accurate measurement of the low flows. The Virginia V-notch weir (USDA 1962) developed by the U.S. Department of Agriculture and the weir sills designed by Villemonte (Ree 1954) are used to modify culverts. The advantages of using existing culvert structures are the savings in the cost of construction and ready access to the runoff measuring site.

Calibration

The relation between the measured depth of flow and the rate of flow can be established by field measurement or by laboratory model tests. Field calibration by current meter is highly desirable because the calibration is directly usable. However, field calibration can seldom be accomplished on small watersheds because the flows are of too short a duration and are unsteady. Therefore, precalibration by model experiments is usually necessary. These model tests can be of the general type for the rating

of a standard structure, or can be specific for the rating of a particular structure. Any qualified hydraulic laboratory can do this rating.

Head Measurement

The depth-time record of the flow should permit accurate runoff calculations. This accuracy will be governed by the minimum increment of depth for the minimum readable increment of time. In the United States, experience has indicated that a recording instrument with a 5 : 12 ratio of pen travel to depth change and a time scale of about 1.5 meters per 24 hours is satisfactory for watersheds up to 100 hectares in size. From 100 to 1,000 hectares the chart speed can be reduced to about 0.75 meter per 24 hours, and for watersheds of more than 1,000 hectares the speed can be reduced further to about 0.38 meter per day. For some watersheds as large as 15,000 hectares, but having streams with very rapid stage changes, chart speeds of about 0.75 meter per 24 hours are used.

Sensing elements for the recording instruments are floats, selfbalancing gas manometers (bubbler gages), or pressure transducers. Since float-operated instruments are mechanical and thus most easily maintained, they are used most commonly. The main difficulty experienced with these instruments is that in sediment-laden streams their stilling wells and well-intake systems tend to fill with sand. One way to cope with this difficulty is to have small multiple-intake openings to limit sand entering and to use a pipe between the intake openings and the float well that is large enough to hold all sediment that may enter during a storm and still maintain free communication between the intake opening and the well. The intake system must then be cleaned following each flow.

These general principles of runoff meter selection and design will be employed to explain the choice of runoff meters used by the Agricultural Research Service on more than 300 experimental watersheds. The watersheds will be grouped by size.

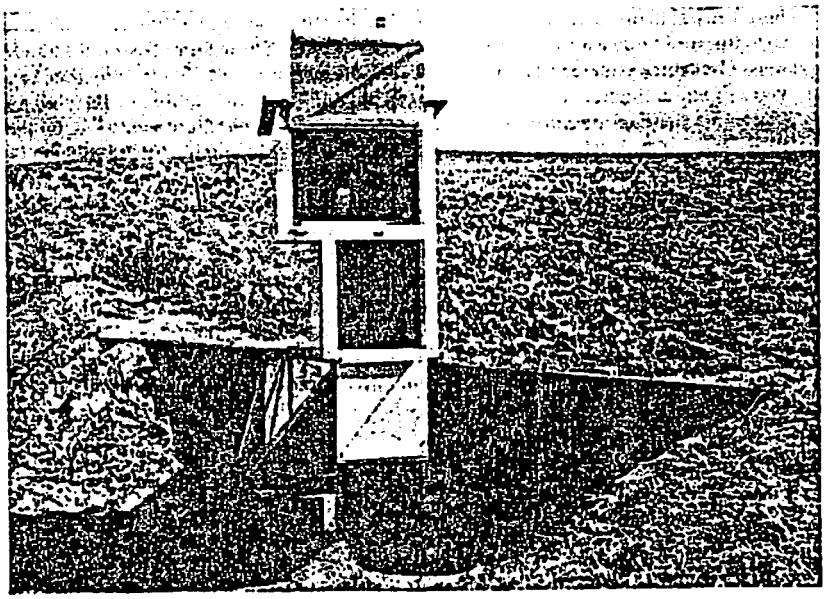

Fig. 3 — Small H-flume and Water-level Recorder.

Watersheds 0.25 to 10 Hectares

Watersheds ranging from 0 . 25 to 10 hectares in size are generally equipped with H-flumes (fig. 3). This flume is a standard measuring device developed by the U.S. Department of Agriculture (USDA 1962). It is trapezoidal in plan and has vertical side walls. These walls are cut back at the exit, thus producing a trapezoidal opening. This exit shape provides satisfactory sensitivity over the full range of flows. Flumes are usually fabricated of sheet metal but some are built of concrete or wood. Standard rating tables available for these flumes are applicable to any installation having a reasonably tranquil approach. Flume sizes for which designs are available range from about 0.15 meter to 1.37 meters in depth. Their sizes correspond to discharge rates of .0085 cm, to 2.37 cms, respectively. Accelerating flows through the flume tend to keep it clear of trash. Heavy sediment flows leave deposits in the flume which tend to adversely affect its accuracy. The addition of a sloping floor in some cases has alleviated this condition. The flume operates best with free outfall; however, it can tolerate tailwater up to 30 percent with but 1 percent effect on the discharge rate.

Parshall flumes (Parshall 1928) were used earlier on small watersheds, but they suffered loss of accuracy due to sediment deposition. They have been replaced with H-flumes or special trapezoidal flumes.

Watersheds 10 to 100 Hectares

Watersheds in this size group are usually equipped with V-notch weirs (USDA 1962). These are broad-crested weirs constructed of concrete and built with side slopes of 2 : 1, 3 : 1, or 5 : 1, with 3 : 1 being the most common (fig. 4). These weirs are very

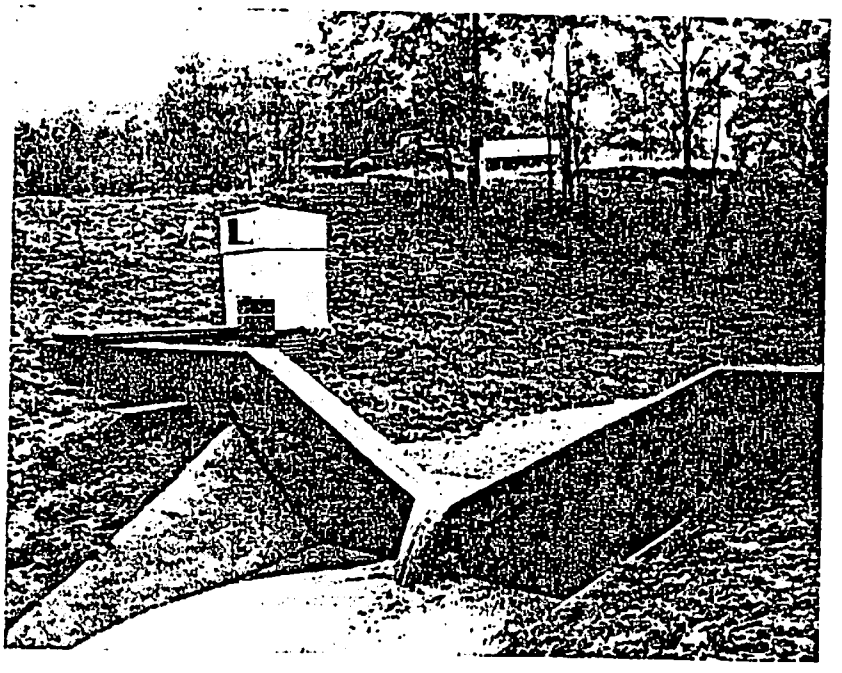

Fig. 4 — Small V-notch Broad-crested Weir.

satisfactory where sediment loads are not extremely heavy. They are simple to construct and ratings are available which include corrections for velocity of approach. The intake for the head measurement for these weirs is located 3 meters upstream. Where sediment loads are heavy, deposition affects the depth-discharge relation for the weir. However, except with extreme sediment loads, the approach channel tends to stabilize once deposition reaches the notch. For some weirs the installation of a paved channel between the weir crest and the gage well intake has been used to maintain a constant approach condition and a constant rating.

Parshall flumes also find considerable use in this size category. Usually these are modified flumes, without the recovery section, since free outlet conditions are usually obtainable. They lack sensitivity in the low flow range. Some are equipped with an auxiliary low flow device, a parabolic deep-notch weir located immediately downstream of the flume. Throat widths of these flumes vary with the expected peak flow and range from 0.3 to 3 meters (approximately). Most of the flumes are constructed of concrete, with a few in the western part of the United States built of wood, and some of the small ones of sheet metal.

Some culvert measuring stations are found in this size group. A culvert is suitable if the entrance alone controls the upstream flow depth. The entrance is usually modified by the addition of a weir to provide sensitivity in the low flow range. It has been found that the transition of the depth-discharge relation from the low flow controlled by the weir to the high flows controlled by the culvert entrance is smooth and that the depth-discharge relation for the combination is unique and reversible. However, the relation between depth and discharge in the transition range cannot be predicted and each such structure must be calibrated. Usually these calibrations are made in a hydraulics laboratory by scale model studies, since the watersheds are too small to permit calibration by current meter.

Watersheds 100 to 1,000 Hectares

V-notch weirs predominate in this size category also. However, the side slopes of the crest are more often 5 : 1 than 3 : 1, because of the need for greater flow capacity. A few Parshall flumes are used in this group, all of large size with throat widths exceeding 3 meters.

Artificial controls for strictly current-meter-rated stations first make their appearance in this size category. These are usually paved sills extending across the channel bed and conforming, generally, to the channel cross-section. A low point is provided in the sill for the concentration of low flows to permit their more accurate rating. These are low cost runoff measuring stations which are subject to channel control and have limited accuracy.

Natural channel control stations also make their first appearance in this size group, though there are but few. These are selected straight reaches of channels for which a depth-discharge relation is obtained by current meter measurement. Where vegetal growth can vary in the channel during the year, such stations have low accuracy.

Three Tombstone flumes (Osborn 1963, Gwinn 1964) are used on watersheds in this size category (fig. 5). This flume is a supercritical flow meter developed by the U.S. Department of Agriculture to measure the flash flows of steep streams, heavily laden with sediment. A unique feature of this flume is that the point of head measurement is in the throat, or narrowest part, of the flow meter. This part of the flume is always free of sediment deposits and thus a constant metering section is maintained. The meter is susceptible to approach channel effects and each one must be individually rated. Laboratory model tests are used for these ratings, since field calibration by current meter is virtually impossible under such flow conditions.

Another recent development in flow meters suitable for watersheds in this size class or larger is the drop-box weir developed by Washington State University under the

Watersheds larger than 10,000 Hectares

Natural channel controls predominate in this watershed class. Seldom can a site be found where a measuring structure can be built on a large stream without being affected by back water. Under these conditions, channel control is nearly as effective as a measuring structure and much less costly. The main expense with a channel control station can be the cableway needed for the current metering operation.

Several watersheds in this size category that are subject to flash flows—which renders field calibration unfeasible—have precalibrated measuring structures. The largest such watershed has a drainage area of over 24,000 hectares. The structure in this instance is a SCOV weir, a forerunner of the drop-box weir previously discussed, also developped by Washington State University. Two Tombstone flumes and one other special structure are found in this watershed group. The largest structure is a Tombstone flume having a capacity of 637 cubic meters per second. Its throat width is 36.6 meters, and maximum flow depth, 5.2 meters.

Sediment measurement

Sediment Production

Sediment production rates are estimated by periodic, detailed land surveys to determine microtopographic changes resulting from sheet erosion, gullying and alluvial fan development, stream channel cross-section and alignment changes, and channel bed scour and aggradation. Permanent installations required are only monumentation of survey controls. Small plots are also instrumented in headwaters areas of some experimental watersheds for runoff sampling and measurement to determine erosion rates under particular rainsite conditions.

The total runoff from a number of small (unit-source) watersheds is collected in stock water ponds or other small reservoirs, and sediment production rates determined by periodic surveys of the accumulated sediments in the ponds.

Sediment Transport and Net Yield

Study of sediment transport influences, as they relate sediment production to the net sediment yield of a watershed, requires two types of measurements : (1) Sampling and analyses of the flows to determine the sediment transported past successive downstream stations in the channel system, and (2) coordinate determinations by periodic surveys of erosion and alluviation within the channel reaches under consideration.

On very small watersheds where the runoff is measured by small H-flumes, automatic continuous sampling of the runoff is generally by means of the Coshocton wheel-type sampler (Harrold 1949, Parsons 1955). On watersheds having flows carrying mainly colloids and silt, and a light fine-sand load, samples have also been simply diverted through a system of vertically aligned orifices in the side wall of the 0.91 meter (3 feet) depth H-flumes. The orifices were sized and spaced to divert an aliquot of the total flow, and the fraction diverted was further reduced to a practical volume for storage of a composite sample, by a slot-type splitter (Kohnke 1943).

No satisfactory equipment is presently available for automatic and complete sampling of streamflows greater than about 1 cubic meter per second. On watersheds where V-notch broad-crested weirs are used for the runoff measurement, sediment sampling has generally been limited to occasional manual sampling, because flows are too flashy and unpredictable to permit a regular manual sampling procedure. Single-stage automatic samplers (ICWR 1963) have been used extensively in the past few years. with moderate success. They are especially useful in conjunction with manual sampling,

sponsorship of the U.S. Department of Agriculture. This meter, like the Tombstone flume, is designed to measure flows in steep, sand-laden streams. It has, however, greater sensitivity in the low flow range than the Tombstone flume. Its form is much more complex and its use has been limited to watersheds having prolonged low flows.

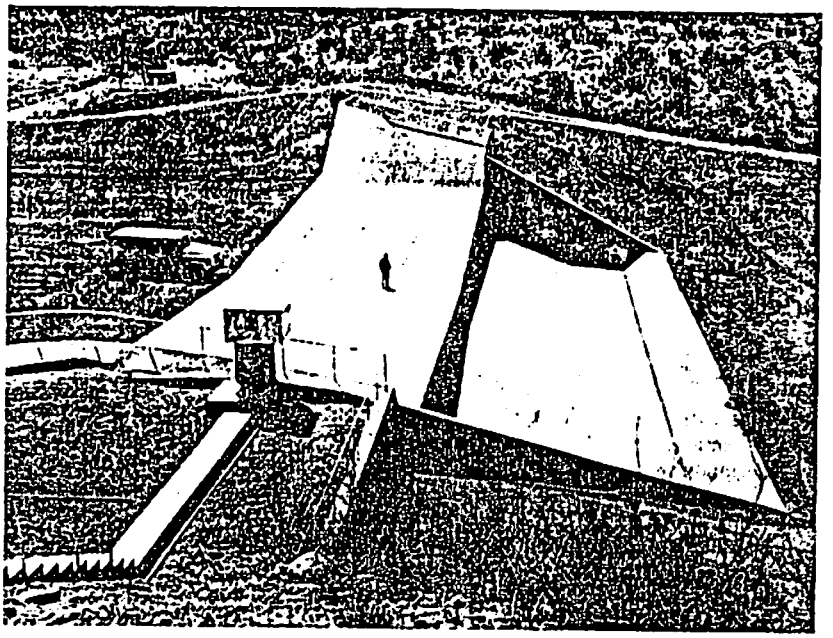

Fig. 5 — Tombstone-type precalibrated runoff measuring flume. Capacity : 637 cubic meters per second.

Watersheds 1,000 to 10,000 Hectares

Artificial controls are used to a larger extent than any other device in this group of watersheds. However, most of these are found on the older watersheds. Today the trend is to install precalibrated, full-control meters on the large watersheds as well as the small. Natural channel control stations also find considerable use with these watersheds. However, as with the artificial controls, these are being replaced with precalibrated meters.

A low flow control and measuring station developed by the U.S. Department of Agriculture has proved very satisfactory in providing accurate measurement of the low flows for the larger streams. The low flow control is a V-notch weir installed in the stream channel. Its low point is placed as high above the streambed as possible without causing an increase in the upstream water level during flood flows. The higher the V-notch can be placed, the more of the total flow it can control. At higher flows, the control is gradually submerged and at the infrequent peak flows the station reverts to channel control. Before installing a control, an analysis is made of the flow distribution characteristics and of the normal flow depth in the stream to ascertain whether the control can be effective over a sufficient range to make its installation worthwhile.

The Tombstone and Washington State University type precalibrated flumes described above for smaller watersheds are suitable for this size class as well.

On a number of larger watersheds, regular manual sampling is done, using dip samplers. The dip samplers are operated by wading when flow depths and velocities permit, and otherwise from cableways or bridges. The sampling is done in the proximity of a flow-measuring station, to permit integration for determination of the total sediment movement represented.

Dip samplers cannot collect samples of the relatively coarse materials being transported close to the streambed. Only where free fall occurs over a structure, can total load samples be regularly collected, and it has been generally necessary to rely on rough estimates of the bedload fraction. The Agricultural Research Service is working on development of more efficient methods and equipment for total load sampling.

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