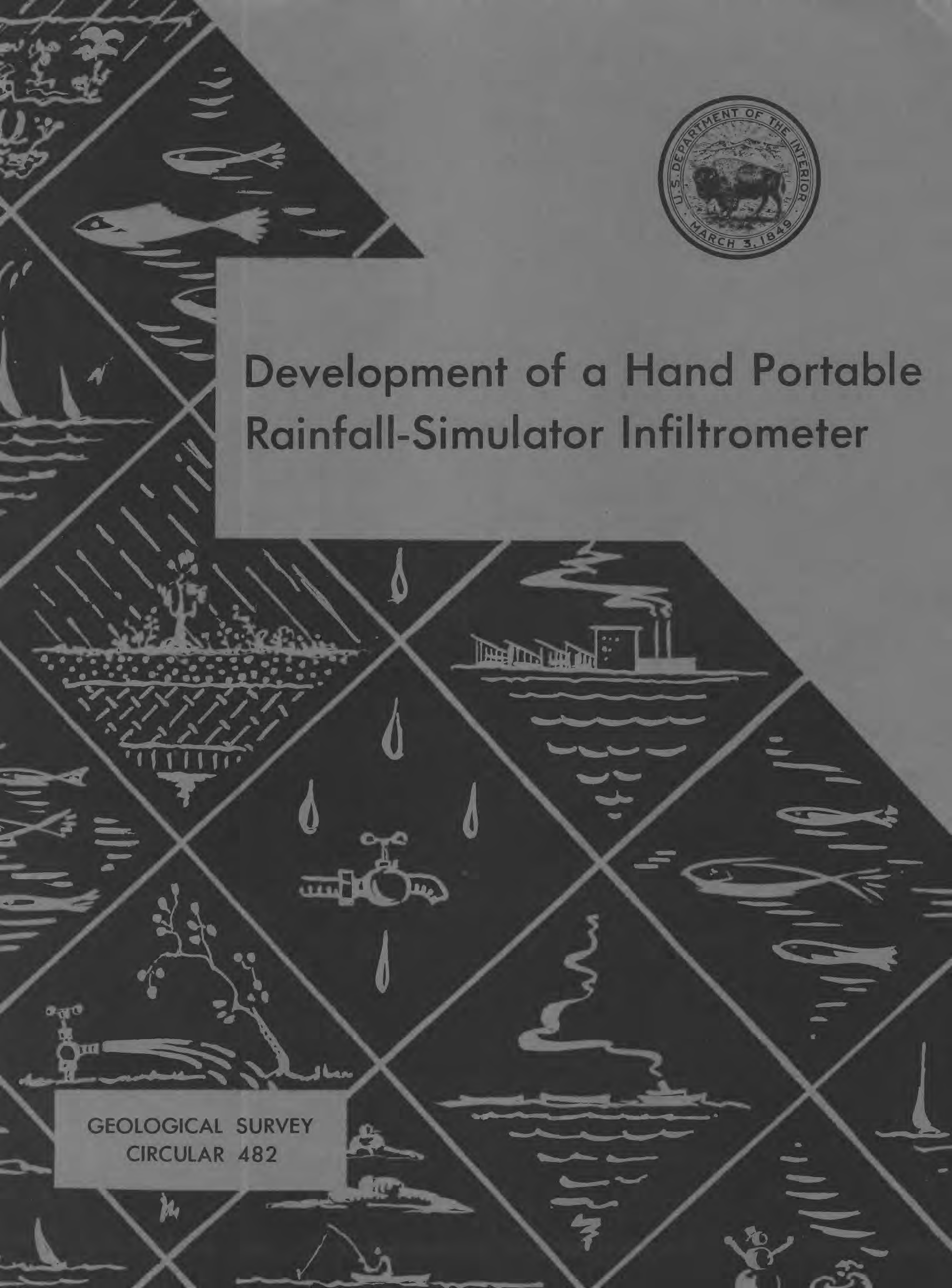

Development of a Hand Portable Rainfall-Simulator Infiltrometer

GEOLOGICAL SURVEY CIRCULAR 482

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By I. S. McQueen

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ABSTRACT

Comparisons of relative infiltration of summer thundershowers into undisturbed and treated western dry lands are necessary for guidance of future treatment practices.

A system designed for measuring infiltration of simulated rainfall into small plots of undisturbed soil that can be hand-carried to sites inaccessible to vehicles has been developed. Disturbance of surface soil by driven plot frames or cylinders, a primary source of errors in infiltration measurement, has been eliminated in this design. Water requirements have been reduced to 1 or 2 gallons per measurement; so, distilled water or controlled chemical solutions can be used. Accurate measurements can be made rapidly and economically.

INTRODUCTION

Water and accurate inventories of its movement and disposition are becoming vitally important in the national economy. This importance is especially true in the arid and semiarid areas of the western States, where economic development is limited by perpetually inadequate water supplies. Of the total water supplied to a drainbasin as precipitation, a large portion, variously estimated to be from 50 to 90 percent, enters the soil and is either used by vegetation or lost by evaporation. The entry of this water into the soil and its subsequent disposition are subjects of intense study, but progress in the studies is limited by lack of adequate measuring methods.

Precipitation in the drier portions of the western States is sporadic and variable; therefore experiments in infiltration and runoff cannot be conducted economically by waiting for natural storms of the necessary magnitude. The alternative to natural precipitation is artificial simulated rainfall applied to small plots. This report describes an instrument and system for measuring the infiltration of simulated rainfall into the undisturbed surface of soil. The instrument is referred to as the USGS. microrainulator infiltrometer in this report.

The cost of building and operating a rainfall simulator for infiltrometer measurements is roughly proportional to the plot size. However, errors in infiltration measurements are generally greater for small plots, and any infiltrometer system, therefore, must be a compromise between the ideal of a plot large enough to reduce errors to a tolerable minimum and the limitations imposed by economics and practicability. Increased accuracy can be obtained with a small plot by eliminating or compensating for sources of error and by making duplicate measurements on adjacent similar plots.

The instrument described here was designed to measure infiltration with a high degree of accuracy and with minimum cost. Errors inherent in earlier infiltrometer designs have been eliminated wherever possible.

PRINCIPLES OF INFILTRATION MEASUREMENT

Infiltration is usually measured indirectly as the difference between the water applied to a given area and that portion of the water applied that does not enter the soil (runoff). It is expressed in units of depth per unit of time—in the United States, this is generally inches per hour.

Data from small infiltrometer plots have not been successfully correlated with rainfall and runoff or other field infiltration data. This lack of success may be because of the variability of infiltration rates with time and location, but it is also partly a result of measuring errors that are inherent in the design of the instruments.

Factors in the design of an infiltrometer and in the infiltration process that may influence measurements are not clearly defined in the literature. However, the following are known to be important and should be considered in the design of an infiltrometer system:

1. Disturbance of soil structure during the installation of a plot frame or infiltrometer ring.

2. Lateral movement of water past the plot boundary.

3. Changes in the geometry or relative effectiveness of the system of forces that induce or control water movement.

4. Movement of soil particles, dislodged during water application, into the pores of the surface strata.

5. Hydration and swelling of expansive type clay minerals.

6. Moisture content of the soil matrix prior to application of water to the surface.

7. Prior disturbance of soil structure by plants and animals.

8. The effects of temperature on soil characteristics and water viscosity.

9. Plot size and shape.

10. Heterogeneity of soils.

Any ring, tube, or plot frame forced into the soil surface to delimit an infiltrometer plot will disturb a part of the plot area. Water movement into the disturbed zone may be increased to several times the natural infiltration rate. On agricultural soils that are plowed or cultivated the additional disturbance of the driven plot frame is not considered important, and many infiltrometer designs have disregarded it. On undisturbed soils where infiltration is limited by impeding zones at or near the surface, any disturbance or the surface structure or condition should be avoided if accurate measurements are to be made. This disturbance is more critical on small plots because the disturbed area is a larger percentage of the total plot area.

Lateral movement of water past the plot boundary is generally considered to be a primary source of error in artificial infiltration measurements. Attempted methods to minimize it have included (1) a deeper penetration of longer infiltrometer rings, (2) larger ring diameters, (3) buffer zones (double ring infiltrometers), and (4) prewetting of the plot area. These methods have been used extensively on agricultural soils, but because they involve the use of driven plot frames or rings that inevitably disturbs the soil and increases infiltration, they are unsuitable for untilled or virgin soils. An alternative suggested by Marshall and Stirk (1950) involves a correction factor based on the relative volume of moistened soil inside and outside of the plot area following a measurement. If this correction is valid, then lateral movement past the plot boundary can be tolerated where the disturbance of a plot by a driven ring or frame cannot.

The direction of movement and velocity of a drop of water at the soil surface are determined by the system of forces acting on the water. As infiltration into dry soil starts, the capillary force gradient, established at the wetting front (Bodman and Coleman, 1943) is the primary force inducing movement. This movement is opposed by viscous frictional resistance in the water. As the length of the flow paths increases with movement of the wetting front, the frictional resistance increases. If no forces other than the capillary gradient and frictional resistance are involved, the quantity of water infiltrated would be proportional to the square root of time ($y = kt^{\frac{1}{2}}$, where y is the depth of water infiltrated in time t, and k is a constant depending on the units used and the permeability of the soil).

An infiltration equation commonly appearing in the literature is in the form $I = A\,t^{B}$, where I is the depth of infiltration, A is a constant, t is the time since the start of infiltration, and B is a dimensionless positive exponent smaller than unity. In this equation, A has been defined as a measure of the average infiltration rate for the first unit time interval (Swartzendruber and Huberty, 1958). The exponent B is an indicator of the changes in the system of force with time, and AB is a combination parameter indicating the instantaneous rate at the end of the first unit of time. If B is close to 0.5, it may be assumed that capillary forces are controlling infiltration. The deviation of B from 0.5 is a measure of the relative importance of other forces and factors in controlling infiltration. Gravity forces and hydraulic pressures, such as ponding, cause higher values for B.

Natural raindrop impact dislodges soil particles and moves some of them into the pores of the soil surface. In order to include the effects of this action in an infiltration measurement or to obtain a measure of soil erodibility, the water must be applied as simulated rain. The simulated rainfall should duplicate the type and intensity of storms characteristic of the area where measurements are being made.

The energy of natural rainfall is extremely variable during a storm and between storms. Even if a rainfall simulator could be programed to duplicate exactly the energy distribution of a given storm, there is no insurance that the chosen program would be representative of the most common occurrence. Also, computation of infiltration from a variable application rate would be cumbersome. A constant rainfall intensity having a constant kinetic energy, if it is within the range of energy levels commonly occurring, is more satisfactory than a changing rate.

The kinetic energy of a falling body is equal to one half the mass times the square of the velocity. For a given unit of precipitation (for example, one inch), the energy is a function of the velocity. The data of Laws and Parsons (1943) indicates that the average diameter of rain drops in a storm having an intensity of 1 inch per hour is 2.25 mm. A drop of this size would require a free fall of 10 meters to reach a terminal velocity of 7 meters per second (Laws, 1941). A drop of 5 mm in diameter falling 3 meters would have the same velocity and therefore the same energy per unit of rain. Both the drop size distribution and the energy of natural rainfall can not be practically duplicated, but a larger drop falling a shorter distance has the same energy per unit of rain and therefore a similar erosive force.

Soil particles are removed either suspended in the excess water accumulating on and running off of the soil surface or carried by drops of water splashed from the plot. For studies where erodibility of the soils is important, measurements of the quantity of soil particles removed should be made. Methods of collecting and measuring sediments should be compatible with the use to be made of the data.

If the information desired is the contribution of a given soil to the rate of silting of a reservoir, the sediments may be measured as wet volumes. If the weight of soil removed is required, it may be necessary to retain all the runoff water and sediments and take them to a laboratory for analysis.

Expansion of clay minerals during hydration reduces the volume of soil pores and, therefore, the infiltration rate. Ions from salt dissolved in water may influence the expansion of clay minerals. In general, sodium will increase swelling and thus decrease infiltration, whereas calcium may have the opposite effect. In order to simulate natural conditions, the water applied by an infiltrometer should be of nearly the same chemical composition as natural rainfall. Distilled water is similar to natural rainfall, but its cost is prohibitive in most infiltrometer tests.

Infiltration into moist soil is generally slow because capillary force gradients are small and clay minerals are expanded, thus constricting flow channels.

Insects, rodents, and plants alter the structure of soil and provide channels for flow in excess of natural rates through the undisturbed soil mass. The channels may be opened or closed during a measurement by raindrop impact. This alternation causes abrupt changes in infiltration rates.

Water temperature influences the infiltration rate in two ways: (1) Warm water has a lower viscosity and therefore produces higher infiltration rates; (2) increased soil temperature increases the volume of the soil grains, and therefore the volume of the voids decreases, resulting in lower infiltration rates. The effect of temperature, however, is so slight that it can be disregarded for most infiltration measurements.

The accuracy of infiltrometer measurements is influenced by the size and shape of the plot. Plot sizes have ranged from as much as several acres in infiltration ponds to as small as rings of 2 or 3 inches in diameter. Shapes most often used are rectangular or circular. Increased infiltration leading to erroneously high measured rates generally occurs at the plot boundary either as capillary underflow or as accelerated flow rates through the disturbed soil. The relative magnitudes of these errors are a function of the ratio of boundary length to the plot area; to minimize the errors, this ratio should be as small as possible. It can be shown that the ratio is smallest for an equilateral and regular polygons. For a given area, the ratio becomes smaller as the number of sides increases. This relation indicates that the ratio is smaller for a circular plot than for a polygon of the same area. The ratio decreases as the plot size increases. The plot having the best shape, therefore, is a circle. The size will be controlled largely by economics and the requirements of portability.

Because soils are heterogeneous, the infiltration rates for the soils within a given basin have a wide range of values. In order to obtain an accurate average value, either the entire basin must be measured or a statistically adequate sampling of point values distributed throughout the basin must be obtained.

INFILTROMETER REQUIREMENTS

In setting up requirements for a new infiltrometer system, the purpose of the measurements and the conditions existing that might influence them must be considered. The USGS microrainulator infiltrometer described herein was designed for research on wild dry lands in the western United States. These lands are not tilled, and any disturbance of the surface structure introduces errors into the measurements.

Most measurements made with this instrument are comparisons between adjacent treated and untreated or vegetated and nonvegetated plots. A measurement of differences is more important than a determination of actual natural rates.

The methods of conducting research on the wild lands and remote locations of some research sites impose rigid portability and water-use requirements that could only be met with an extremely small instrument.

The following specific requirements were set up to guide selection and design of the USGS infiltrometer:

1. The accuracy and constancy of measurements should be equal to or better than other infiltrometer systems currently in use.

2. It should be portable. It is to be transported in field vehicles such as pickup trucks, carryalls, or sedan delivery trucks. It should be portable by hand to inaccessible sites if necessary.

3. Water requirements should be as small as possible, consistent with accuracy requirements.

4. It should not disturb the surface structure of the soil during installation or operation.

5. It should provide a means for preventing lateral movement of water past the plot boundary, or, for measurement of and correction for such lateral movement.

6. It should provide for collection and measurement of water and sediments splashed out of the plot separately from water and sediments accumulating on the plot. Water should be allowed to accumulate on the plot only to the depth necessary to cause runoff under natural storm conditions.

7. Energy of simulated rain should correspond to the average energy level of natural storms.

8. Rainfall intensity should be controlable over a wide range and should be stable at any intensity chosen for a given test.

9. Installation and operation of the instrument should be rapid and convenient. Data obtained should require little or no computation.

10. The instrument should operate satisfactorily under adverse conditions, such as high winds.

DESIGN OF MICRORAINULATOR INFILTROMETER

Several types of infiltrometers currently in use elsewhere were investigated to determine their adaptability for use on undisturbed plots of dry wild lands in the western United States. An infiltrometer developed at Iowa State College and described by Adams,[1]

[1] See also Adams, J. E., 1956, A rainfall simulator and the erodibility of some Iowa soils: Iowa State College, Unpub. Ph. D. thesis.

Kirkham, and Nielson (1957) has several features that were adaptable to our requirements. Preliminary design and development of the USGS instrument, using some of these features, were started in 1957. The first instrument was completed and subsequently tested in the laboratory and field in 1958, and a second instrument having an improved design was constructed for use in 1959.

Details of the USGS microrainulator infiltrometer in its present form are shown in figure 1. The instrument comprises several units: (1) A reservoir and control unit; (2) a rainulator; (3) a supporting tripod and wind screen; (4) a base unit containing a splash shield; and (5) a system for measuring runoff water and sediment. The units are described in the following paragraphs.

RESERVOIR AND CONTROL UNIT

The reservoir and control unit performs three functions: (1) It supplies water to the rainfall simulator (rainulator), (2) measures the quantity of water supplied, and (3) controls the hydraulic head and consequently the rate of application of the rainulator. It is essentially a calibrated Mariotte bottle and an added bubbler tube to extend the controlled level below the reservoir and to provide for more sensitive control. The unit is calibrated to measure the depth of water applied to the plot area either in inches or in centimeters. The spacing of the calibration marks is computed from the ratio of the square of the plot diameter to the square of the diameter of the reservoir. If the reservoir is 3.5 inches in diameter and the plot is 5.75 inches in diameter, the ratio is $5.75^2/3.5^2 = 2.698$. Therefore, 2.698 inches on the reservoir represents one inch of precipitation or 2.698 centimeters on the reservoir represents one centimeter of precipitation.

THE RAINULATOR

The rainulator utilizes the same principles of flow control and drop formation described by Adams, Kirkham and Nielson (1957), but the materials and methods of construction are different. In the design described by Adams, Kirkham, and Nielson, drops were formed on the ends of glass capillary tubes set in a plastic matrix, and flow was limited by a pin made of re-drawn chromel wire inserted through each tube. However, capillary tubing and wire of the proper size and uniformity to give the needed range of application rates was not available here. As an alternative, capillary-size holes drilled through a block of plastic with pins made of standard size chromel wire were tested and adopted. Adams reported (written communication, 1958) application rates of 4.03 to 4.32 inches per hour with minimum hydraulic head of 6 mm. With careful drilling, we achieved uniform application rates as low as 0.8 inch per hour with a minimum hydraulic head of 1 inch. A final drilling with a No. 57 drill provided available rates of 1 inch to 15 inches per hour.

Drop size is controlled by the geometry of the bottom surface of the simulator head and by the properties of the plastic from which the head is machined. Adequate drop size control has been obtained by three different methods: (1) projections simulating the ends of glass capillary tubing have been machined in plexiglas by use of a spot-face tool; (2) similar projections have been produced by casting plastic in a mold; and (3) countersinking the capillary holes as shown in the detail of figure 1, which allows an easy control of drop size that is proving very effective.

SUPPORTING TRIPOD AND WIND SCREEN

The instrument is supported over the infiltration plot by adjustable tripod legs such as are used in levelling or planetable mapping. The windscreen is a length of 6-inch OD plastic tubing hung in an aluminum ring that is supported by the tripod legs. A bulls-eye-type level mounted on the support ring indicates when the wind screen is vertical. A steel rod half an inch in diameter extends up from the support ring to hold the reservoir and control assembly. The rainulator fits in the top of the wind screen. An alternate method of mounting the infiltrometer utilizing a standard planetable tripod is shown in figure 2B. This method was designed for easier positioning over the plot, but the instrument was found to be sensitive to wind disturbance.

BASE AND SPLASH SHIELD

Two forms of base units used with the infiltrometer are shown in figure 1. Both bases are designed to be sealed to the soil surface with bentonitic clay. The plastic base is used for special studies where the

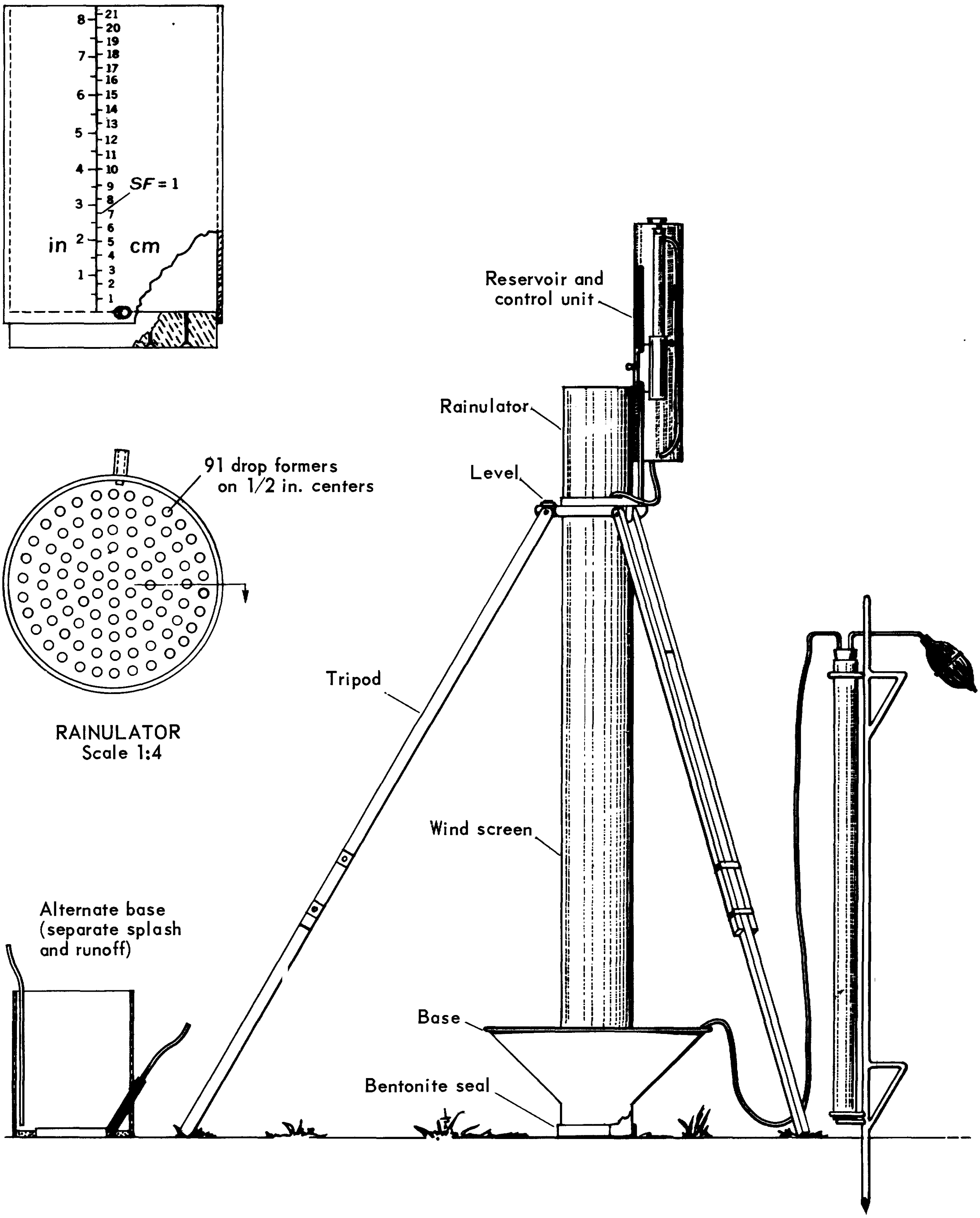
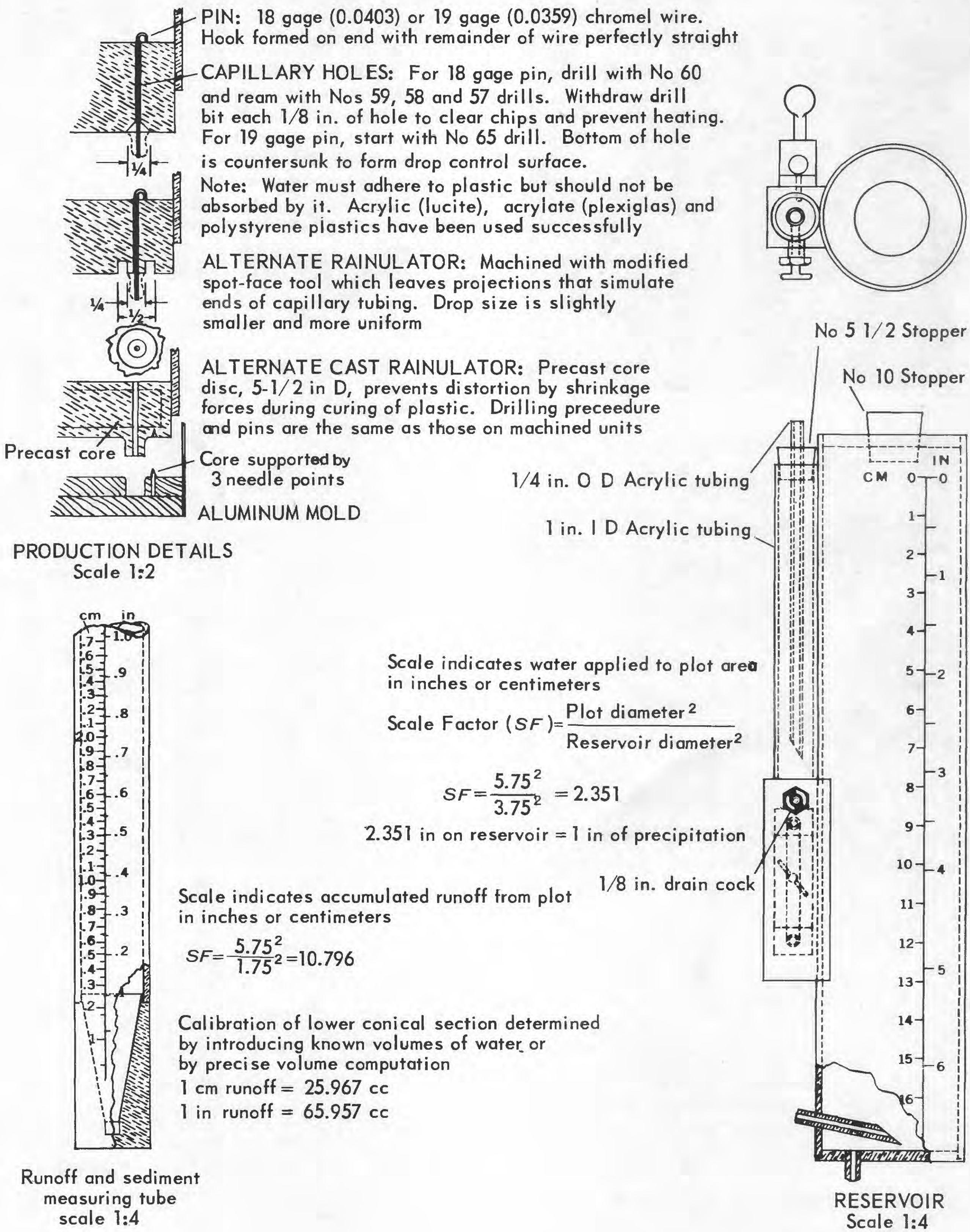


Figure 1.—Details of USG!



microrainulator infiltrometer.

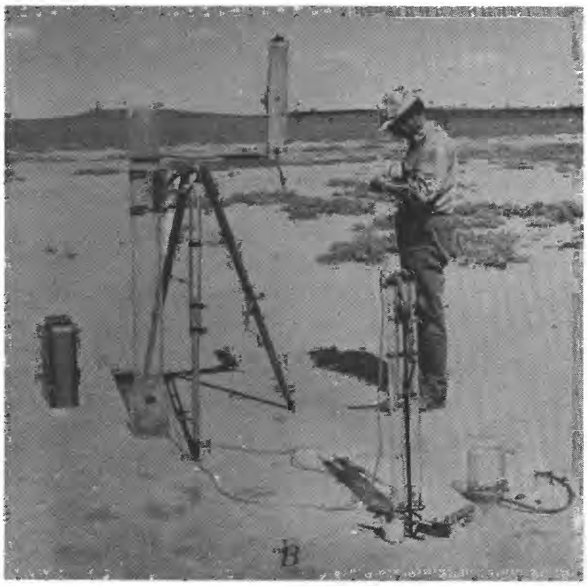


Figure 2.—USGS microrainulator infiltrometer in use. A, near Carrizo, Ariz., showing preferred support assembly. B, near Fort Peck, Mont., showing alternate tripod assembly.

water and sediments splashed from the plot are measured separately from the water accumulating on the soil surface as runoff. Where separation of the splash and runoff is not necessary, the metal base is more economical and easier to use. A base similar to that described by Adams may be used if the soil is sandy and structureless or has been tilled.

RUNOFF-WATER AND SEDIMENT MEASURING SYSTEM

Excess water and suspended sediments are withdrawn from the plot to calibrated accumulator tubes through flexible plastic tubing by applying a partial vacuum to the accumulator tubes. The vacuum is produced by rubber gas-sampling pumps. The accumulator tubes are 2-inch OD rigid plastic tubing having bottoms machined from 2-inch OD plastic rod. In order to provide for accurate measurement of sediment volumes, the tube bottoms are accurately machined cones. The accumulator tubes are calibrated to measure the depth of water and sediment removed from the plot in centimeters or in inches.

TESTS OF INFILTROMETER PERFORMANCE

The individual units of the USGS microrainulator infiltrometer were thoroughly tested in the laboratory during development. The complete system was tested in the field for two years. As a result of the tests, some minor modifications were made in the instrument and the operating procedures.

LABORATORY TESTS

The rainulator unit was tested in the laboratory for uniformity of rainfall pattern, drop size, and range of application rates.

The uniformity of the rainfall pattern was checked by counting the drop rates from randomly selected capillaries, by observing the wetting pattern on absorbent paper, and by observing the erosion pattern on a series of test plots. In all tests the uniformity was judged to be good to excellent. The drop size, measured by weighing a given number of drops and computing their average volume, was found to be equivalent to a sphere 5.61 mm in diameter. Calibrations of all the measuring units was checked in the laboratory. A final test of the calibrations was made by setting the instrument up on an impermeable floor and by operating it at a low application rate. In the test the water applied equaled the runoff plus a small correction for evaporation.

FIELD TESTS

Field tests included a series of infiltration measurements on a variety of wild natural undisturbed soils in Colorado, Wyoming, and Montana. During the measurements operating procedures and accessories were developed and tested.

In September of 1958, the U.S. Forest Service conducted a series of infiltration measurements in connection with the Badger Wash cooperative hydrologic study using a "Rocky Mountain" type F infiltrometer. The study provided an excellent opportunity to make comparative measurements with an instrument that has been in use for several years. Measurements were made on 16 plots near those of the Forest Service tests and in the same soil types. Results are summarized in table 1. The application of a t test to the paired data indicates that no significant difference in the mean values of results was obtained on soils that were measured by both instruments. ($t = 0.258$; with 15 degrees of freedom, a value of t greater than 2.947 would have to be obtained in order to define a significant difference at the 1 percent level.)

As a further check on the comparative performance of these infiltrometers, the data from the various plots were separated according to soil type. Four pairs of measurements were made in sandy soil; 4 pairs of measurements, in a mixed sandy shale soil; and 8 pairs of measurements, in a shale-derived soil. The t values for the soil groupings indicate the following: (1) On the sandy soil, there is a 30 percent chance that the difference in the mean values is not due to the characteristics of the instruments ($t = 1.19$), (2) on mixed soil, there is no statistically

Table 1.—*Comparison of infiltration rates as measured by USGS microrainulator infiltrometer and U.S. Forest Service "Rocky Mountain" infiltrometer*

[The infiltration rate is the average rate for a 40- to 60-minute interval]

Plot	Particle size distribution (millimeters)				Infiltration rate (inches per hour)		Difference
	Gravel 2.0	Sand 2.0–0.05	Silt 0.05–.002	Clay 0.002	USGS microrainulator	USFS "Rocky Mountain"	
				Sandy-soil type			
12-1	9	42	38	11	3.45	2.76	0.69
12-2	4.6	42.4	42	11	4.53	2.21	2.32
33-1	9.6	42.9	31.5	16.0	2.37	3.08	-.71
33-2	5.5	56	29.5	9.0	4.23	3.57	.66
Mean	7.2	45.8	35.2	11.8	3.64	2.90	----------
				Mixed-soil type			
7-1	0.7	38.3	43.3	17.7	0.81	0.68	0.13
7-2	10.9	32.1	40.9	16.1	1.38	1.88	-.50
35-1	12.3	31.7	38.0	18.0	1.29	1.11	.18
35-2	21.2	27.7	32.9	18.2	1.35	1.06	.29
Mean	11.3	32.4	38.8	17.5	1.21	1.18	----------
				Shale-soil type			
8-1[1]	7.8	17.2	51.7	23.3	0.30	0.99	-0.69
8-2	4.2	17.3	54.2	24.3	.60	.84	-.24
9-1	1.1	17.9	54.0	27.0	.81	1.01	-.20
9-2	1.2	12.8	56.5	29.5	.39	.86	-.47
18-1	2.1	15.7	53.2	29.0	.81	.98	-.17
18-2	4.1	14.6	53.8	27.5	.84	.98	-.14
32-1	2.6	13.0	54.2	30.2	.51	.87	-.36
32-2	1.0	11.2	55.3	32.5	.42	.45	-.03
Mean	3.0	15.0	54.1	27.9	.58	.87	----------

[1]Mapped as mixed-soil type but grain-size distribution is closer to shale-soil type.

significant difference in the mean values ($t = 0.14$), and (3) on the shale soil, there is a significant difference at the 1 percent level ($t = 3.83$).

From the results of this comparison with the "Rocky Mountain" type F infiltrometer, certain relative characteristics of the USGS microrainulator infiltrometer can be deduced. On sandy soil the USGS microrainulator infiltrometer may indicate a higher infiltration rate because of greater capillary flow past the plot boundary. A correction can be made for this rate by excavating the wetted soil following a measurement and by measuring the relative volume of wetted soil outside of the plot boundary. On shale-derived soils, the USGS microrainulator infiltrometer consistently indicated a lower infiltration rate than the "Rocky Mountain" infiltrometer.

Infiltrometers generally indicate infiltration rates that are higher than actual, because of soil disturbance at the plot boundary, lateral movement past the plot boundary, or failure to form pneumatic back pressures in the limited area covered. The consistently lower rate indicated by the USGS microrainulator infiltrometer shows that it is more accurate on fine textured soil. If corrections are made for lateral movement past the plot boundary, the instrument is more accurate on all types of undisturbed soils. Disturbance of the soil structure by a driven plot frame is a primary source of inaccuracies in infiltration measurements.

FIELD OPERATION PROCEDURES

In use of this instrument for measurement of infiltration, runoff, and erosion, some procedures may be modified to speed up operations or to provide specific information that may not always be required. Figure 2A and B shows two models of the instrument in operation. The basic procedure for use of the instrument is presented in the following paragraphs.

SITE PREPARATION AND INSTALLATION OF THE BASE

The first step is to locate precisely and mark the plot according to requirements of the given study. A plastic cylinder is positioned on the plot to facilitate preparation. Vegetation and litter are cleared from the area outside the plot for a distance of 3 or 4 inches by clipping the vegetation at the soil surface and around the plot boundary. The infiltrometer base is positioned on the plot and sealed to the cleared soil surface with bentonite. The plot is normally not prewetted so that the test may simulate the effect of a thunder shower on dry soil; however, when measuring infiltration resulting from gentle long-continued rains, prewetting of the soil or long term continuous or intermittent application of simulated rain may be used.

ASSEMBLY OF THE RAINULATOR

With the base in place, the supporting tripod and wind screen are positioned so that the wind screen is vertical and is centered directly over the plot. The reservoir, control unit, and rainulator head are installed on the supporting tripod, and the reservoir is filled with water. For the first measurement made, the rainulator unit should be prewet by setting it on a clean surface and pouring water into it. This should be done prior to preparation of the plot in order to give a longer time for stabilization of the flow rate.

The pickup tubes for excess water are installed in the base so that water will be withdrawn from the soil surface on the downslope side of the plot. The measuring tubes can be placed anywhere that is convenient for easy reading, commonly a few feet downslope from the plot.

MAKING THE MEASUREMENT

To start an infiltration measurement, water is poured into the rainulator unit to a level higher than required to give the desired application rate. The timing is started, and the water level in the unit is read when the first drops fall. When the water in the rainulator unit drops to the level that previous experience has shown will produce the desired application rate, the reservoir flow control unit is adjusted to maintain this level. As water accumulates on the plot, it is pumped into the measuring tubes. As each 5-minute interval ends, the pumping of excess water is interrupted, and the water levels in the reservoir and the rainulator unit are read and recorded. Before pumping is resumed, the water and sediment levels in the accumulator tubes are read and recorded.

Infiltrometer Data Sheet

Date July 17, 1960 Operator I. S. McQueen

Project Plant-Soil-moisture relations Soil Moisture Field capacity- rain yesterday

Location Willow Flat Montana Sage- wheat grass community Cover on plot Rock Chips- 50 per cent No vegetation

Time	Scale Reading cm Rainulator H_1	Reservoir H_2	Runoff H_3	Water Applied Increment ΔA	Cumulative A	Infiltration I $(A-H_3)$	Sediment	Remarks
0940	2.00	0	0	0	0	0		
0945	1.29	.10	0	0.81	0.81	0.81		
0950	1.35	1.12	0.30	.96	1.77	1.47		
0955	1.39	1.98	.75	.82	2.59	1.84	0.02	
1000	1.31	3.00	1.40	1.10	3.69	2.29	.025	Water temp 29° C.
1005	1.32	3.98	2.11	.97	4.66	2.55	.035	
1010	1.33	4.88	2.80	.89	5.55	2.75	.045	
1015	1.30	5.75	3.46	.90	6.45	2.99	.050	
1020	1.33	6.77	4.11	.99	7.44	3.33	.065	
1025	1.32	7.70	4.84	.94	8.38	3.54	.070	
1030	1.32	8.64	5.60	.94	9.32	3.72	.075	
1035	1.32	9.64	6.29	1.00	10.32	4.03	.080	Lateral spread not
1040	1.32	10.56	7.02	.92	11.24	4.22	.085	measured because
								of pre-wetting by
								storm.

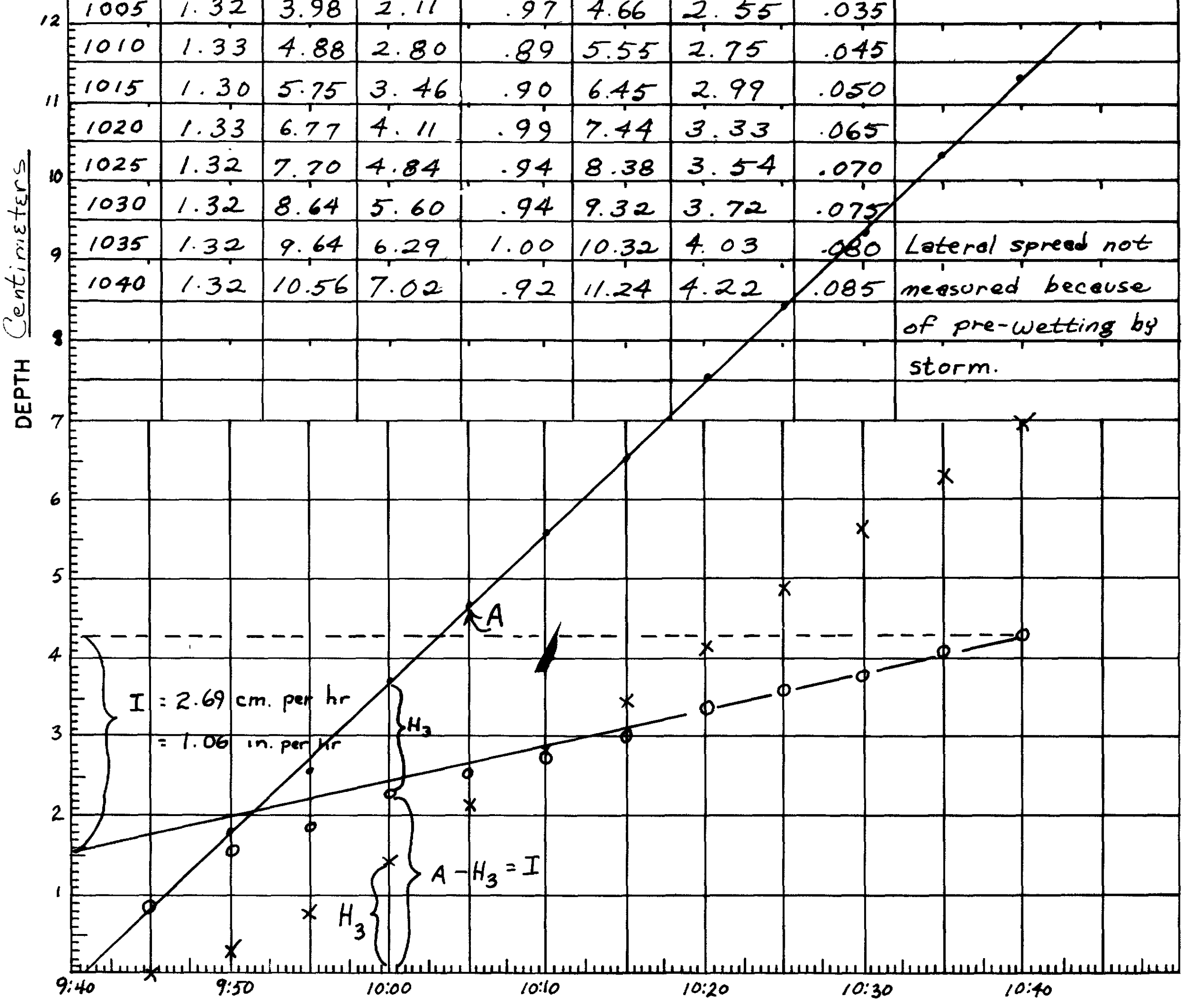


Figure 3.—Typical set of field notes obtained with USGS microrainulator infiltrometer.

DATA RECORDING AND COMPUTATIONS

Typical field data are shown in figure 3. Measurements are recorded at the end of each 5-minute interval, and the infiltration is computed and plotted on a cumulative basis. Rates of application, runoff, and infiltration are obtained from accumulative curves, or they may be computed as average rates for any given time interval.

The data were recorded and computed as follows (columns are counted from left to right):

Column 1.—The time is recorded to the nearest minute. However, the readings of the levels in the rainulator (H_1) and reservoir (H_2) should be made within 10 seconds for accurate work.

Column 2.—Depth of water in the rainulator is recorded to the nearest 0.1 mm or 0.01 inch if conditions will permit.

Column 3.—The volume of water removed from the reservoir is recorded to the nearest 0.1 mm or 0.01 inch of water on the plot area. If the level in the rainulator remains constant the change in the reservoir is the depth of water applied to the plot during the interval.

Column 4.—The total water accumulated in the runoff measuring tubes (H_3) is recorded to the nearest 0.1 mm or 0.01 inch of water on the plot area. If splash and runoff are collected separately, this value is the sum of the two measurements.

Column 5.—The water applied as simulated rainfall during the preceding 5-minute interval (ΔA) is computed from columns 2 and 3 as the change in the reservoir minus the change in the level in the rainulator.

Column 6.—The total water applied since the start of the test (A) is computed either from column 5 or from columns 2 and 3.

Column 7.—The total infiltration since the start of the test (I) is computed as the total water applied minus the total water accumulated in the runoff measuring tubes. For precise work this value may be corrected for evaporation.

Column 8.—The accumulation of wet settled particles in the runoff measuring tube is measured to the nearest 0.001-cm depth on the plot area. If the weight of eroded material is needed, it may be estimated from the wet-depth data, or the water and sediments may be retained for accurate weight determination in the laboratory.

Correlation of depth of sediments accumulated in the measuring tube with the weight of the settled particles for 47 samples obtained near Fort Peck, Mont., indicated the average unit weight of the sediments (dry-weight) to be 0.906 gm/cc (or 56.6 lbs/cu ft). The coefficient or correlation is 0.901, and the relationship is $W = 151.8d - 3.6$, where W is the weight of sediment in grams and d is the depth of sediment in the accumulation tube in centimeters. By introducing the proper conversion factors into the foregoing relationship, a reading of 1 cm of sediments in the measuring tube represents 57 tons of sediment per acre.

Column 9.—Additional observations made during the test are recorded to aid in the evaluation of data.

As all calibrations are in units of depth of water on the plot area, the rate of application can be computed immediately for any given time interval, and the instrument can be adjusted to apply the desired or prescribed rate in the succeeding intervals.

When a test is completed, the flow from the reservoir is stopped, and the rainulator unit is removed from the infiltrometer. Postrun measurements and sampling, as required in the project plans, may be performed. The wetted soil may be excavated and volume measurements may be made to define the relative movement of water past the plot boundary. The excess water may be retained for chemical analyses. The sediments in the excess water may also be retained for laboratory studies and gravimetric measurements. When all postrun measurements are completed, the instrument is then moved to the next plot or disassembled for transport.

CONSTRUCTION NOTES

During the development and testing of the infiltrometer system, certain methods and materials were found to produce the desired results. These are discussed here for the benefit of those who may want to construct the instrument.

The capillary holes in the simulator head must be drilled with extreme care. Drills as small as the No. 60 when working in plastics will not clear the chips from a hole, and they cannot be cooled adequately. To prevent binding of the chips or melting of the plastics, do not drill more than an eighth of an inch of hole without withdrawing the bit for clearing and cooling. The initial drilling constructs a hole the same size or slightly smaller than the wire size to be used for pins. The holes are then reamed to the proper size in two or three steps using a hand drill and successively larger drill bits.

Drill diameters do not increase in uniform increments, which causes some difficulty in hole construction. No. 18 gage chromel A wire is used for the flow-control pins in the capillaries, because this is the size that Adams used. The required hole diameter, to provide the desired range of application rates with 18-gage pins, is 0.044 inch; this is between the No. 57 and No. 56 drill sizes. No. 19 gage wire (0.036 in.) is recommended for use because it permits closer control of the hole size. For No. 19 gage wire the initial drilling should be with a No. 65 drill.

Control of drop size requires a surface to which the drops can cling until they grow to the required volume before falling off. A flat face one-fourth inch in diameter—similar to the end of a glass capillary tube—will support a drop 5.5 mm in diameter. This type of surface has been formed by machining a plastic block with a modified spot-face tool or by casting in molds.

As an alternate drop-forming surface, we found that if the capillary holes drilled in a plastic block are countersunk, the drops will cling to the conical countersink surface and their size will be influenced by the diameter of the countersink. This type of control surface seems to be more effective than the flat faces, and it is easier to construct.

The plastic material used as the rainulator should have certain physical characteristics. It should be wettable so that waterdrops will cling to it readily. If waterdrops do not cling to the size-control surfaces, their size will be uncontrolled. The dimensions of the plastic should be stable in contact with water. The material should not absorb water and swell, and it should not soften. Any change in the dimensions of the capillary holes due to swelling or abrasion will result in a changing flow rate. Plexiglass, polystyrene, and metallic-filled epoxy resin have been used; of these, the plexiglass is the most satisfactory.

EVALUATION OF THE SYSTEM

The infiltrometer system was tested and used during three field seasons. It produced results that comply with the requirements set for it. Its extreme portability, low water requirements, simplicity of operation, and versatility make it a useful instrument for hydrologic studies.

Table 2 shows a comparison between the USGS microrainulator infiltrometer and three other infiltrometers that are being used for research on western United States lands. The U.S. Forest Service "Rocky Mountain" infiltrometer, described by Dortignac (1951), is one of a long series of sprinkler-type infiltrometers pioneered by the Flood Control Group of the Soil Conservation Service and adopted by the U.S. Forest Service.

The infiltrometer described by Osborn (1950) was developed for the U.S. Soil Conservation Service in Texas and Oklahoma. It uses a drip screen to simulate controlled precipitation, and it has gone through several stages of development.

The infiltrometer described by Barnes and Costel (1957) is an adaptation of the drip screen type described by Osborn. It has been redesigned so that it can be mounted on a pickup truck, and water requirements have been reduced considerably. However, the 50 to 60 gallons per hour required is still too much to permit use of distilled water or chemical solutions.

When working on nonuniform soils, the USGS microrainulator infiltrometer may be expected to show some scatter in the results because the smaller plot size permits more precise definition of point values and less integration of larger areas. As the cost of operation is less than one-fourth of the operating cost of the older systems, more measurements can be made to provide a statistical integration.

Lateral movement of moisture past the plot boundary is a source of inaccuracy with

Table 2.—*Comparisons between infiltrometers*

Reference	USGS microrainulator	U.S. Forest Service "Rocky Mountain" (Dortignac, 1951)	Soil Conservation Service (Osborn, 1950)	Agricultural Research Service (Barnes and Costel, 1957)
Method of raindrop production.	Drops form on plastic surface around metal pins.	Type F nozzle.	Drops form on pieces of yarn attached to muslin screen.	Drops form on pieces of yarn 2 in. in length attached to muslin screen.
Drop size (diameter in millimeters).	5.6	Produces wide range of drop sizes.	5	5
Control of application rate.	Controlled by hydraulic head in rainulator tank as maintained by reservoir control assembly.	Rate depends on pressure at nozzles and number of nozzles. Pressure is controlled manually.	Rate depends on pneumatic pressure in supply tanks. Pressure is maintained by gasoline motor driven compressor.	Rate depends on pressure at nozzle distributing water to drip screen. Pressure is supplied by gasoline driven centrifugal pump or air compressor and is controlled by pressure regulating valves.
Normal application rate (inches per hour).	4	4	6	3
Range of rates (inches per hour).	1–15	2–6. Extremes of range result in uneven distribution.	2–10	2–5. Rate depends on nozzle size used.
Measurement of application rate.	Measured each 5-min interval as total water applied.	Plot frame incorporates a rain gage trough that is calibrated periodically.	Prerun and postrun measurements with pan; rain gage troughs on plot; gages outside of plot.	Prerun and postrun measurements with pan installed over plot frame.
Drop-fall distance (meters).	1.5	Variable	4.3	2.6
Energy of rain ($j/cm^2/cm$ at normal application rate).	0.137. Slightly less energy per unit of rainfall than natural rain of the same intensity.	0.153	0.453. Exceeds thunderstorm of 7.2 inches per hour intensity in detaching capacity.	0.154

Equivalent natural storm (inches per hour).	1.9	2.1	5.2	2.1
Area of plot (sq in).	29.97	288	216	576
Wetted area (sq ft).	0.208	30–50	15	13
Water requirements (gallons per hour).	1–2	600	200	50–60
Manpower requirements per unit.	1	2 or 3	2	2
Sampling frequency measurements per unit per day.	4–5	1–2	3–4	3–4
Man hours per measurement.	$1\frac{1}{2}$–2	6–16	4–8	4–8
Transportation requirements.	Hand-portable—two units and water supply for 2 weeks operation have been transported in one station wagon.	Two $\frac{1}{2}$-ton or one $1\frac{1}{2}$ ton stake bed truck plus one $\frac{1}{2}$-ton tank truck for water supply.	Unit is permanently mounted on a one-ton stake bed truck. One $\frac{1}{2}$-ton tank truck required for water supply.	Mounted on $\frac{1}{2}$-ton pickup. Requires pickup or sedan delivery for water supply and supplimentary transportation.

this system. This should be corrected for by the method suggested by Marshall and Stirk (1950). Disturbance of the soil surface and lateral movement of infiltrating water past the plot boundary both cause the indicated infiltration rates to be high. With no correction for lateral movement, the system indicated lower infiltration rates when compared with the results from the "Rocky Mountain" infiltrometer. When corrections are made for lateral movement, results with this system can be considered very good.

Calibration of the system in terms of depth on the plot has simplified measurements and the computation of results. This helps to eliminate recording errors and detects anomalous behavior, such as sudden changes in the infiltration rate during a measurement.

The infiltrometer system is convenient, versatile, and economical. Results obtained with it are comparable with other systems in use in the United States.

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