2001

Studies in Hydrology and Water Quality of Agricultural Watersheds

Coshocton, Ohio

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SOIL and WATER CONSERVATION
RESEARCH DIVISION
3001 U.S. AGRICULTURAL RESEARCH SERVICE
U. S. Department of Agriculture
AND THE OHIO SOIL CONSERVATION COMMITTEE

in Cooperation with
3011 OHIO AGRICULTURAL RESEARCH AND DEVELOPMENT CENTER
Wooster, Ohio

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FIG. A-1.—Welcome to the Research Station.

Studies in Hydrology and Water Quality of Agricultural Watersheds

LLOYD L. HARROLD*

FOREWORD

The North Appalachian Experimental Watershed research station near Coshocton, Ohio, serves directly the agricultural, industrial, rural, and urban water information needs of the hill land of southeastern Ohio, western Pennsylvania, western West Virginia, and portions of eastern Kentucky. Indirectly, the findings of this research program are applicable to a much larger area in the humid sections of the United States.

Many years ago, large areas of dense woods and tall grass in this region were cleared and broken for cultivation. Advancing civilization brought land operations which increased flood damage and destroyed good water supply systems through silting of reservoirs and the clogging of river channels with debris washed from the land. Waste of soil and water diminished crop production. It was apparent that something had to be done to prevent flooding, supply good water, maintain clean rivers, and produce large amounts of high quality food. There was a need to develop facts on what should be done and how to evaluate the effect of farmland changes on whole watersheds.

In 1935, the U. S. Dept. of Agriculture Soil Conservation Service selected an area 10 miles northeast of Coshocton on State Route 621 and established a research station to study water, land use, crops, and erosion on individual farm fields and on entire watersheds. This site was chosen because it typified much of the agricultural land in the unglaciated Allegheny Plateau. It was a part of the Muskingum Watershed Conservancy District—an 8,000-square-mile flood prevention and water recreational development. In January 1954, the station was transferred to the Agricultural Research Service, U.S. Dept. of Agriculture.

In the 1960's, the concern over pollution of the nation's environment reached alarming proportions. Agriculture's contribution to pollution of the land, water, and air needed to be identified and corrective measures developed and applied on the land and to agricultural product processing industries. In 1966, research work was started on the watersheds of the Coshocton Station to determine the transport mechanism of dieldrin—a persistent insecticide—from cropland into surface water bodies. Surface movement of plant nutrients was added to the study in the first year and animal waste studies soon thereafter. Study of transport of herbicides, insecticides, and plant nutrients over the land surface and downward through the soil into underground water bodies began in 1967 on the Coshocton monolith lysimeters.

Visitors come to this station from many nations to seek knowledge of research techniques and findings pertaining to the effect of land management on watershed hydrology and pollution. Several thousand persons from the U.S.A. and foreign countries, including students, clubs, farm organizations, and many others, visit the station annually.

Some highlights of the research in agricultural hydrology and water quality are presented in this publication.

A. RESEARCH FACILITY

The U. S. Dept. of Agriculture and the Ohio Agricultural Research and Development Center cooperate in the planning and operation of experiments on this watershed research station (Fig. A-1). These studies are designed to advance knowledge in the science of good land and water use.

A 1,047-acre land block (Fig. A-2) controlled by the U. S. Dept. of Agriculture consists of about 470 acres of cropland, 270 acres of permanent grassland, and 307 acres of woodland. Different farming practices are studied over a period of years to discover and test new and better ways of using the sloping land of Appalachia for a more permanent and productive agriculture. The main objectives include prevention of floods, increased water use efficiency by crops, lessened sediment transport, and the improvement of water quality. Observations of water flow and transport of agricultural chemicals and animal waste are related to land shape, soil, geology, land use, and climate to develop mathematical models of watersheds which will be usable in predicting water flow and degree of pollution for ungaged watersheds in the region.

Several factors make soil and water resource conservation imperative in this area. First, the depth of productive top soil is shallow. Its capacity to absorb heavy summer rainwater is usually high. Loss of soil depth by erosion results in loss of crop productivity and less storm rainfall absorption. Large sedi-

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*Research Supervisor, Soil and Water Conservation Research Station, Coshocton, Ohio.

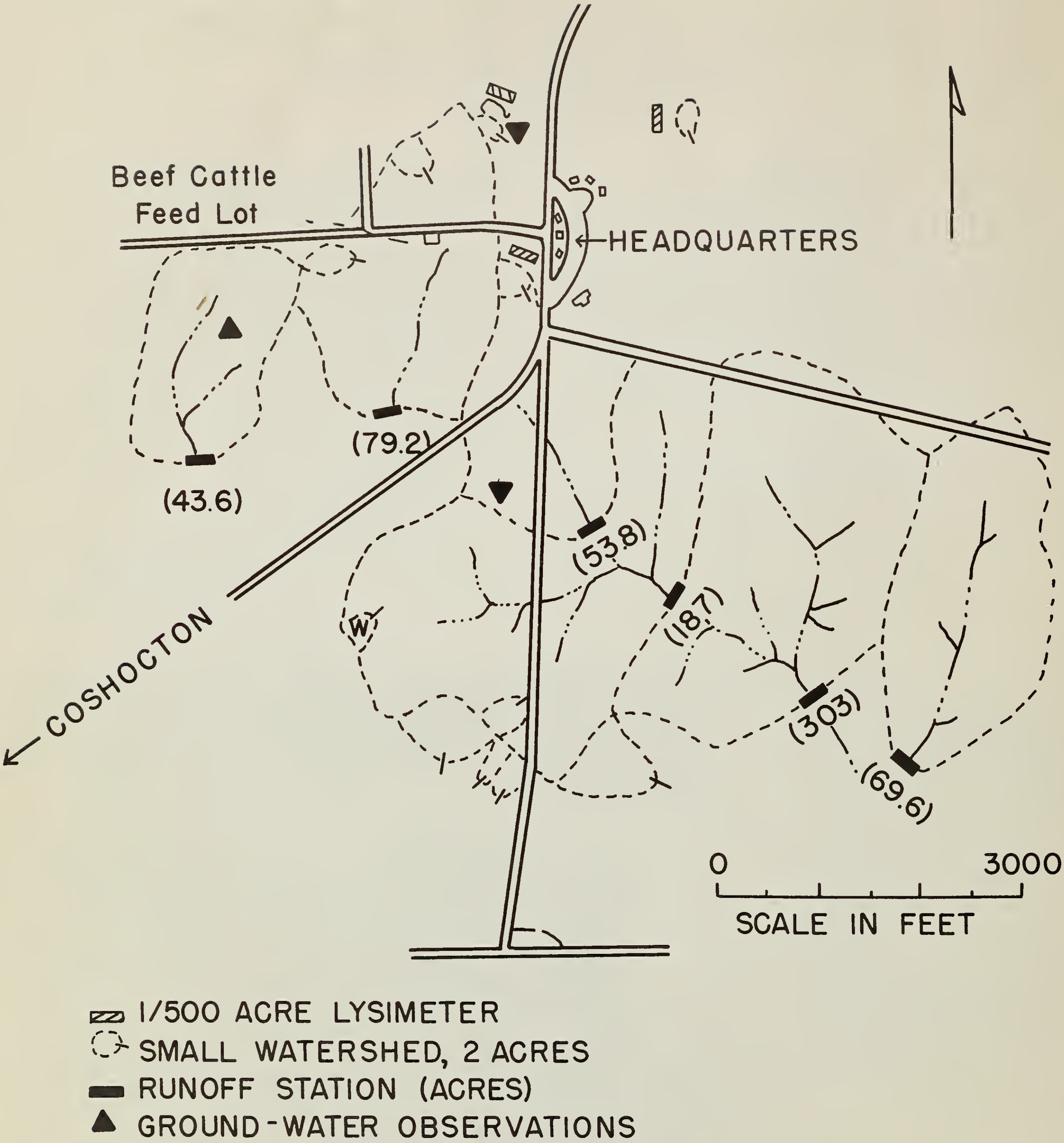


FIG. A-2.—North Appalachian Experimental Watershed, controlled land.

ment loads go into streams and reservoirs. More storm rainfall runs off and floods are larger. More storm runoff and greater sediment loads cause more pollution in water bodies.

Secondly, with the increasing demand for water by every segment of our society, the incentive for obtaining the most efficient use of water for crop production makes water conservation vital to on-site agriculture and to downstream communities.

Physical features of the land surface, land management, soil, and geology are important items in developing practical knowledge of the study watershed flow systems. The bedrock of the area consists of cyclic deposits of sandstone, shale, limestone, coal, and clay which frequently outcrop on the steep side slopes of the narrow valleys. The soils are of residual Muskingum-Keene complex and associated series: Rayne, Berks, and DeKalb (Fig. A-3). Profiles are moderately well and well drained, with 3 to 5 feet of soil over weathered bedrock. Silt loam surface textures with granular structures predominate.

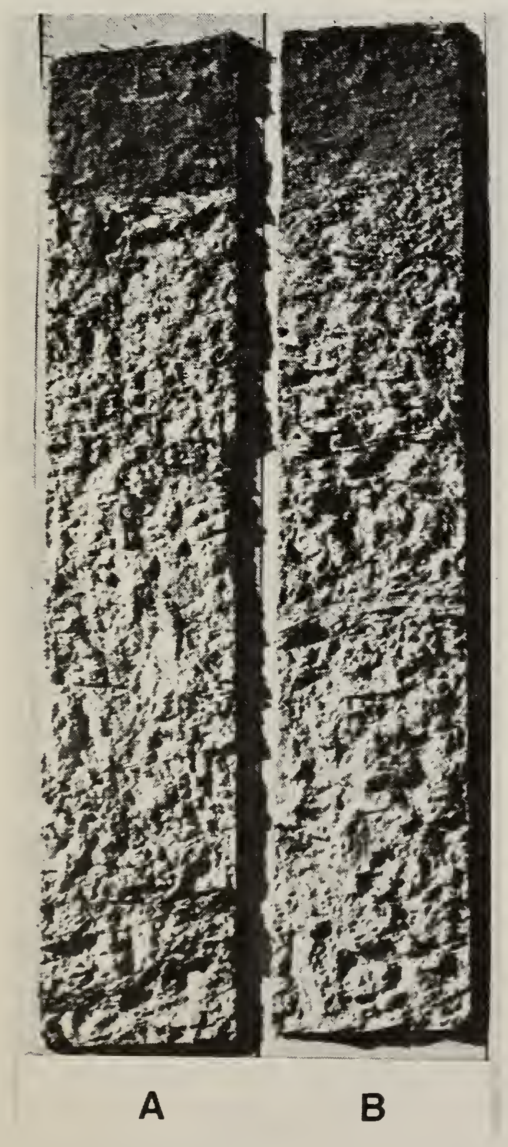


FIG. A-3.—Profile of the station's residual soils. A—Keene silt loam; B—Rayne silt loam.

Watersheds on the government-controlled land range from 1 to 303 acres (Fig. A-2). Most of the detailed research program is carried out on this station land. Watersheds of 1 to 10 acres are units of cropping systems and are comprised mostly of one major soil type, with land slope of one major class. They are used to evaluate effects of land management on surface flow, mainly storm runoff, and soil and pollutant transport by surface flow (Fig. A-4). Stream gages for the larger watersheds are located below the points where the channel cuts through aquifers which supply dry weather flow. Their data represent measures of water yield.

At three lysimeter sites (Fig. A-2), a number of 8-foot deep natural soil blocks (Fig. A-5) are equipped to measure surface runoff, percolation to groundwater recharge, and crop use of water (evapotranspiration). These are described in detail later.

Physical and chemical analyses of soil and water samples collected on the experimental watersheds are made in the station's soil laboratory.

FIG. A-4.—Runoff gage and automatic flow sampler.

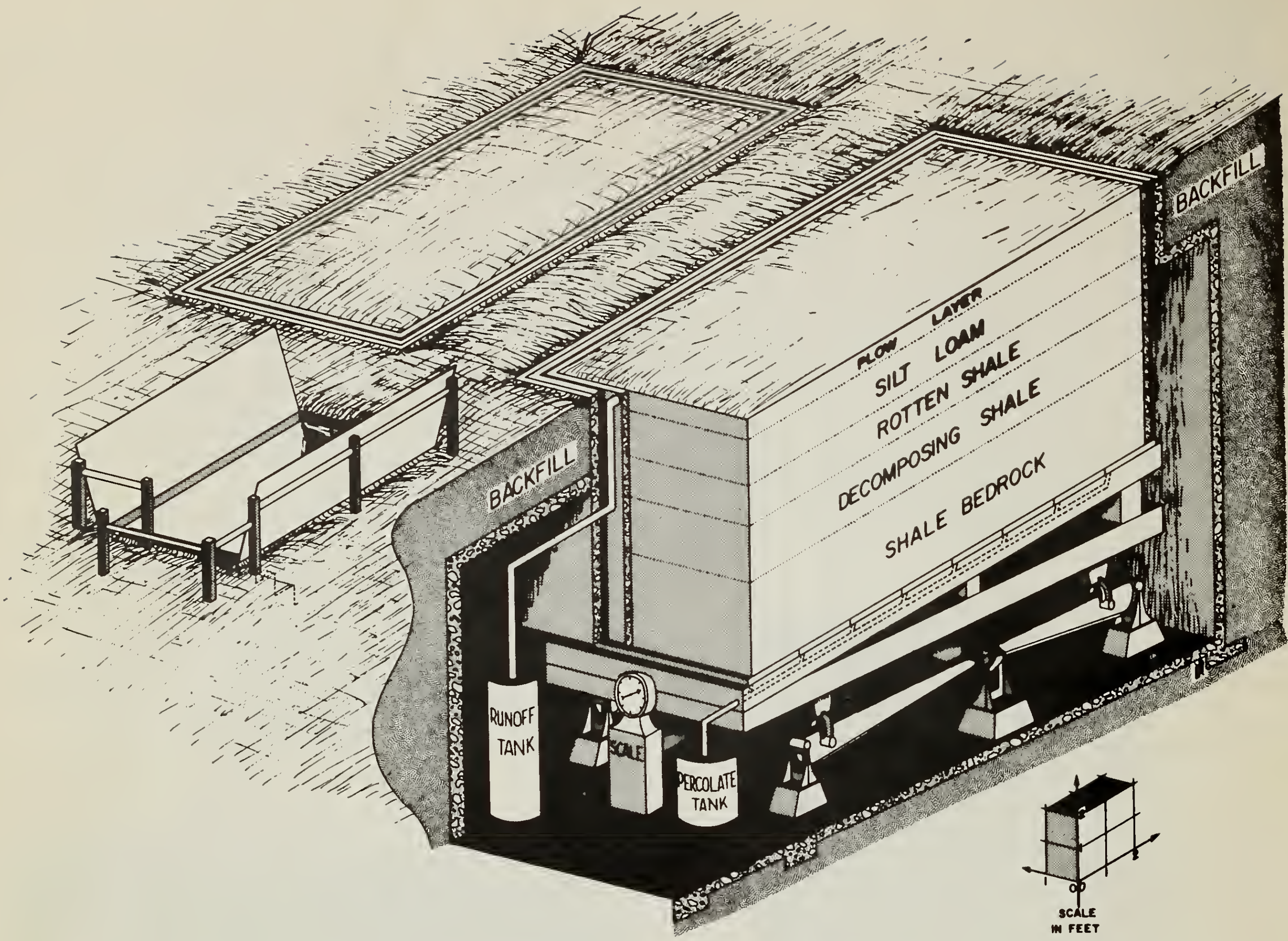


FIG. A-5.—Monolith lysimeter 8 feet deep and 6.22 x 14-foot surface, with runoff and percolation gages and weight recorder.

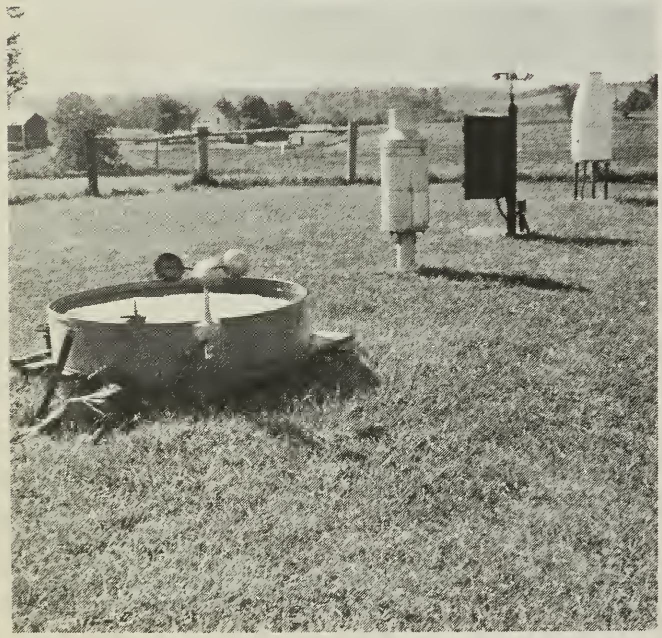


FIG. A-6.—Part of the meteorological index yard.

A meteorological station (Fig. A-6) is operated to provide data on precipitation, evaporation, barometric pressure, solar radiation, air temperature, humidity, wind movement, and soil temperature and water content. Precipitation gages are located near the various experimental watersheds.

A number of rainfall and runoff gages are located on privately owned land adjacent to the station (Fig. A-7). These gaged watersheds range from 122 to 4,580 acres. Data from the U. S. Geological Survey Station further downstream are available to extend the research results up to an area of 17,500 acres.

Land use in the Mill Creek and the Little Mill Creek watersheds, adjacent to the station land, is typical of the problem area. It consists of 30 percent woodland, 27 percent pasture, 21 percent rotation meadow, 18 percent cultivated crops (mostly corn and wheat), and 4 percent miscellaneous. The 4-year cropping sequence is corn, wheat, meadow, meadow.

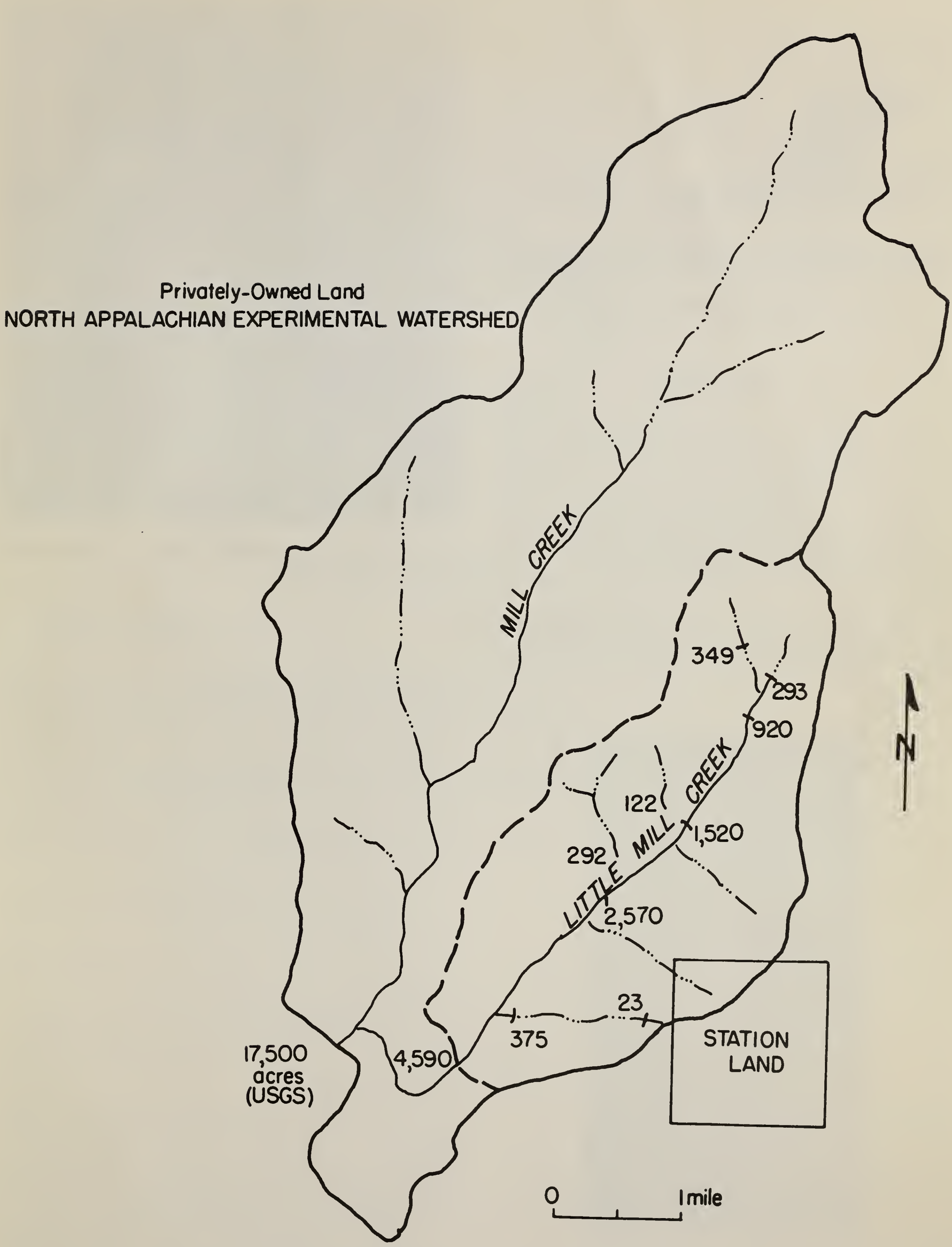


FIG. A-7.—Large watersheds.

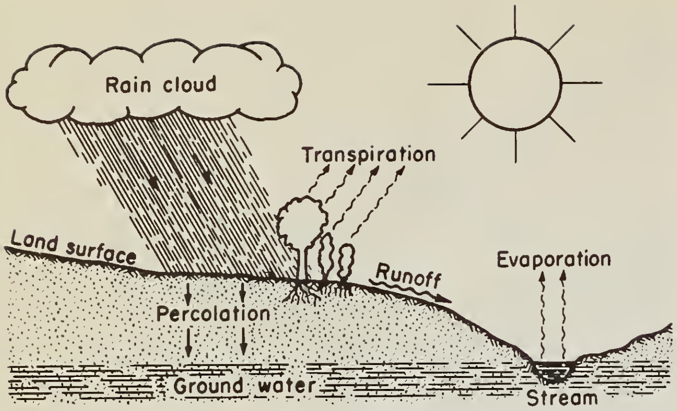


FIG. B-1.—Simplified hydrologic cycle.

B. HYDROLOGY

The hydrologic or water cycle has no beginning or ending, but can be considered as beginning with moisture in the atmosphere (Fig. B-1). Water is evaporated into the atmosphere from land and water surfaces, is lifted, and eventually condenses and returns to the earth's surface as precipitation. Precipitation which falls on the land as rain, hail, dew, snow, or sleet is of particular concern to man and agriculture.

Weighing gages (Fig. B-2) record the time and depth of precipitation falling on experimental watersheds.

FIG. B-2.—Weighing gage.

FIG. B-3.—Cooperative observer reading rain depth in glass tube.

Size of local storms, their intensity, and their frequency are being investigated by a network of 1,700 volunteer observers in the Wayne-Holmes-Stark-Tuscarawas County area. Rain depths are observed in small glass tube gages (Fig. B-3). Data from these gages, along with rainstorm radarscope pictures from the U. S. Weather Bureau Station at the Akron-Canton Airport, provide data for drawing maps of extent and severity of local severe summer rainstorms which cause much damage to upstream areas.

Map of storm rainfall determined from cooperator's readings is shown in Fig. B-4.

Monthly precipitation pattern depicted in Fig. B-5 shows a greater amount in the growing season months—ideal for agricultural needs.

Intense rainfall occurs mostly in the growing season (Fig. B-6). Amount of rain falling at high rates causes the greatest floods on small watersheds and the most soil erosion.

Soil water is greatest in the late winter and early spring (Fig. B-7) and the soil has little capacity for absorbing additional storm rainfall. Soil water depletes rapidly in the growing season, even though rainfall is high (Fig. B-5), because crop use of water and evaporation is greater than rainfall. Soil water increases in the late fall-winter period when evaporation is low and is less than precipitation.

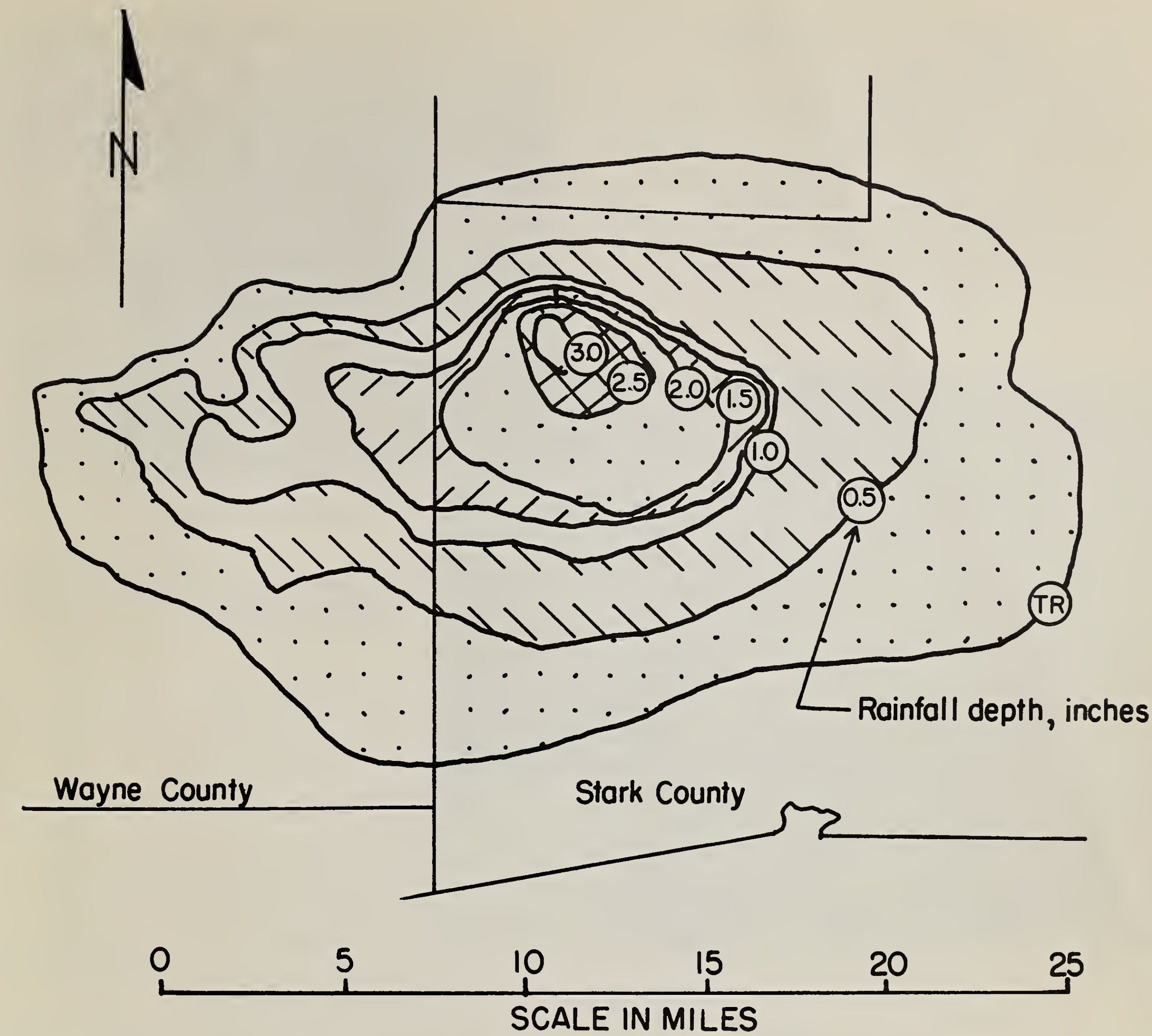


FIG. B-4.—Isohyetal map of July 31, 1967, storm.

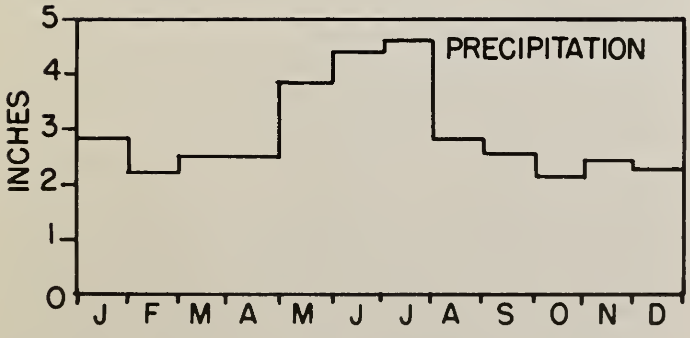


FIG. B-5.—Seasonal pattern of monthly precipitation.

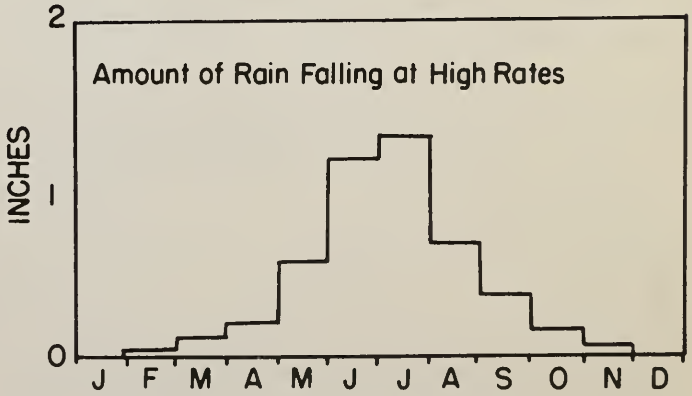


FIG. B-6.—Seasonal pattern of amount of rain falling at rates more than 1 inch per hour.

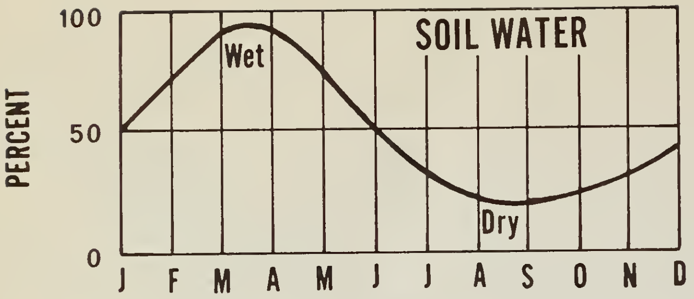


FIG. B-7.—Seasonal trend of soil water.

Most of the *surface runoff* from small agricultural watersheds (Fig. B-8) results from local, summer rainstorms (Fig. B-9).

As the soil *sponge* is not normally saturated in the summer, these rains should be mostly absorbed into the soil. Improved soil management is needed to develop high water absorption rates in cropland soil.

Some flow comes from seepage where the stream channel cuts into ground-water reservoirs. Seeps occur mainly at the middle to lower elevations of the larger watersheds shown in Figs. A-2 and A-7. In these large basins, much streamflow results from large-area rainstorms and snowmelt coming at a time when the soil is very wet. The greatest monthly runoff amounts on the larger watersheds occur in the January-April period (Fig. B-10).

Soil surface sealing, caused by excessive soil tillage and raindrop splash and compaction, limits storm rainfall intake. Studies of surface sealing, crusting, and cracking are made by the soils laboratory staff (Fig. B-11). The water intake rate of vegetated soil surface = 6 inches per hour and the water intake rate of crusted bare soil = 0.5 inch per hour.

Percolation, or drainage of soil water downwards toward the ground-water reservoir, is measured by lysimeters (Fig. A-5). It is strongest (Fig. B-12) when soil water content is greatest (from February to April, Fig. B-7) and weakest when soil water is the least.

Level of ground water in wells (Fig. B-13) is influenced by percolation recharge to ground water and seepage from the ground discharging to surface

FIG. B-8.—Runoff from small agricultural watershed.

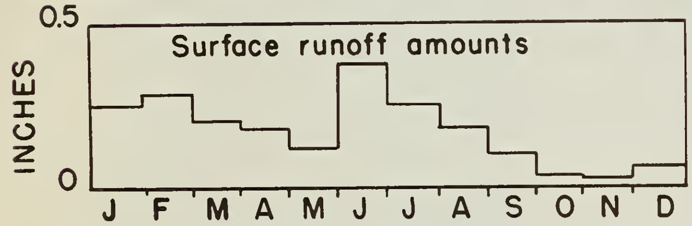


FIG. B-9.—Average monthly surface runoff from 2-acre watersheds.

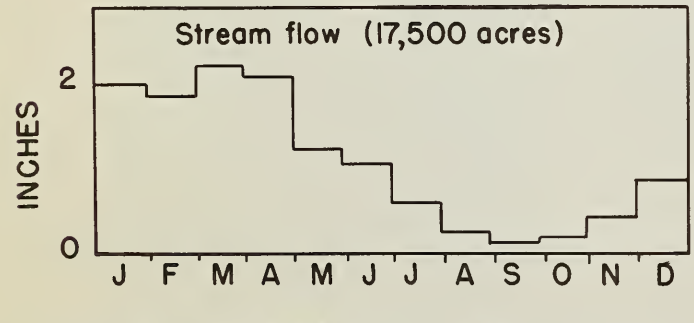


FIG. B-10.—Average monthly stream flow from large watershed.

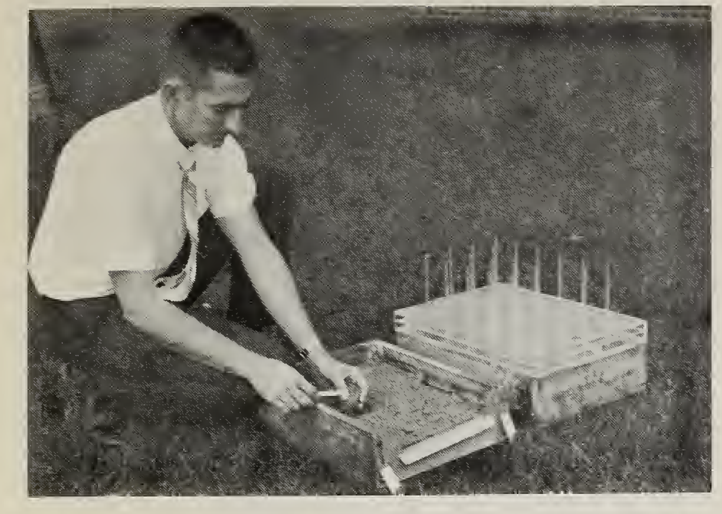


FIG. B-11.—Soil surface crusting and cracking studies.

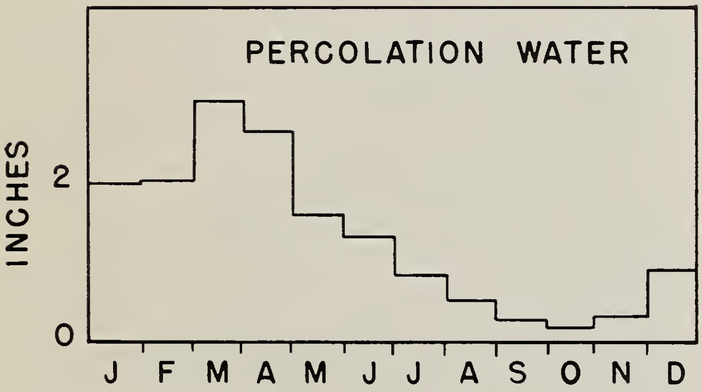


FIG. B-12.—Seasonal pattern of percolation water to ground water.

streams. The rising water level in ground-water wells occurring during the period of high soil water (Fig. B-7) indicates that percolation recharge (Fig. B-12) exceeded seepage discharge. Percolation, diminishing in the summer and fall season, is less than seepage from ground water and thus the water level in wells drops.

Evapotranspiration (ET), evaporation from soil plus transpiration (crop use of water), is greatest in the season of high air temperature and solar radiation. As the corn plants increase in leaf area, ET increases until the plants mature (Fig. B-14). These relationships were derived from lysimeter (Fig. A-5) weight records.

The seasonal trend of evapotranspiration (ET) for an alfalfa-bromegrass meadow reflected the solar radiation and air temperature trend. Cutting of hay crops sharply reduced ET as leaf area of the plants was reduced to almost zero. Regrowth of leaves reestablished the evaporation surface and ET resumed its high rates.

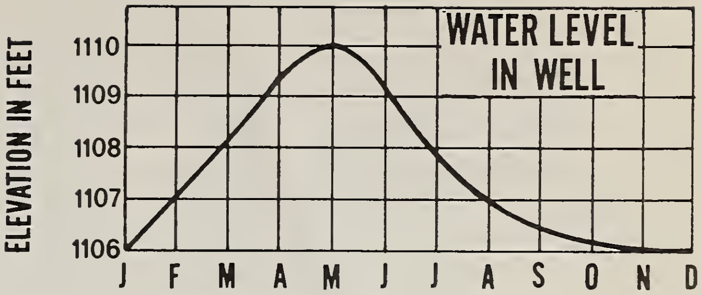


FIG. B-13.—Seasonal trend of ground-water levels in wells.

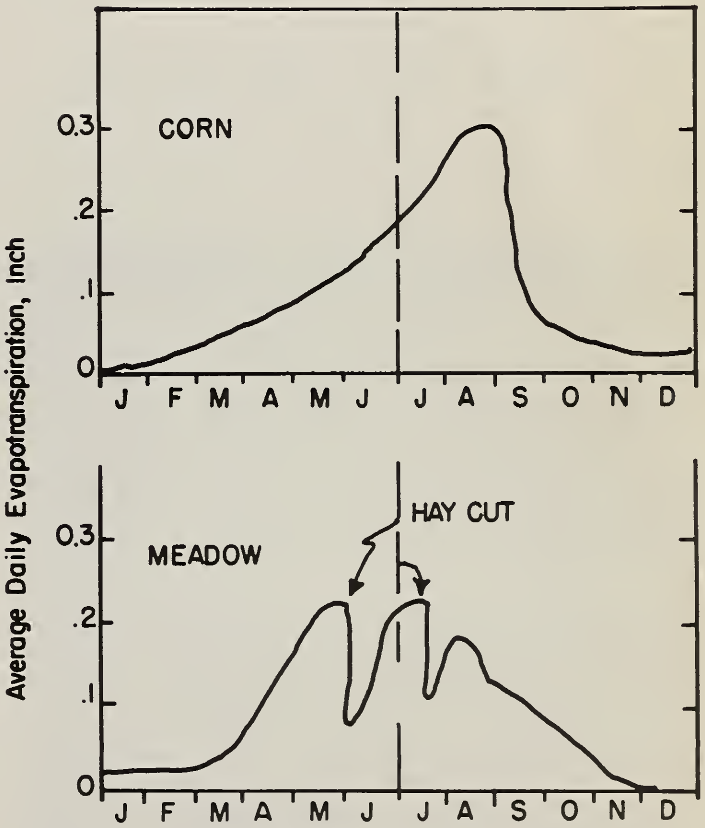


FIG. B-14.—Seasonal trend of evapotranspiration for corn and meadow.

In dry seasons, ET water use by shallow-rooted crops is less than that for deep-rooted crops (Fig. B-15). Percolation and total water yields to streamflow for the shallow-rooted crops are greater. In wet seasons, there is little difference.

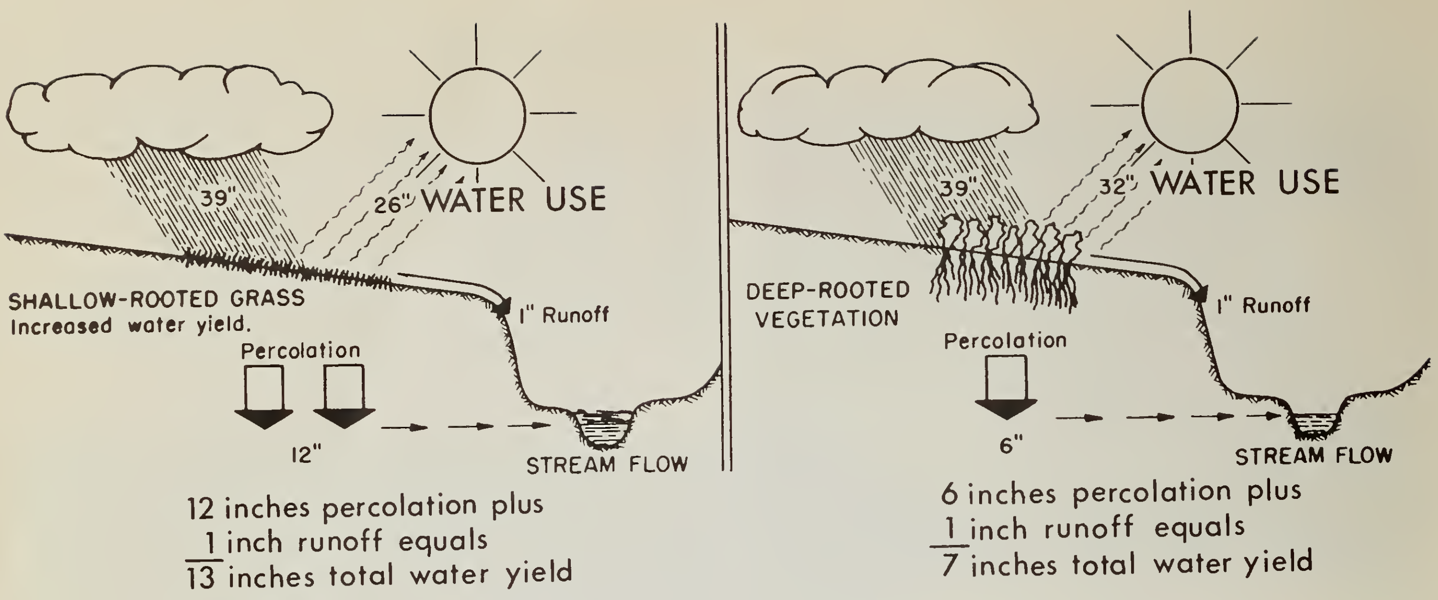


FIG. B-15.—Evapotranspiration (ET) affects water yields.

C. WATER QUALITY AND POLLUTION

Water quality is affected by farming practices. Pollution studies of surface and subsurface water at the Coshocton Research Station are designed to evaluate on-site and downstream water quality and to relate the results through mathematical models to land use, chemical applications, and watershed characteristics. Results of surface and subsurface studies are presented in the following sections.

Surface Water

Soil erosion from farmland contributes sediment to surface water. It is the greatest source of agricultural pollution. Soil erosion (Fig. C-1) from cropped fields is greatest on cornland and least on grassland.

FIG. C-1.—Soil erosion contributes sediment to surface water.

Average annual soil loss	
Rotation plowed cornland, sloping rows	7 tons/acre
Rotation plowed cornland, contour rows	2 tons/acre
No-tillage mulch cornland, contour rows	Trace
Wheatland	1 ton/acre
Meadow	Trace

Soil loss under severe test, July 5, 1969 (5 in. rain in 12 hrs.)	
Rotation plowed cornland, straight sloping rows	22 tons/acre
Rotation plowed cornland, contour rows	3 tons/acre
No-tillage mulch cornland, contour rows	0.03 ton/acre

No-tillage corn is comprised of:

February	Apply banyard manure on sod or corn residue
April	Apply atrazine and 2,4-D to kill grass and weeds
May	Plant corn in sod (Fig. C-2) or corn residue (Fig. C-3)
October	Harvest corn. Average yields:
	Plowed corn 110 bu./acre
	No-tillage corn 119 bu./acre

Mulch prevents soil erosion and retains more soil water by reducing soil water evaporation.

Reduction of sediment delivery to surface water by conservation tillage and no-tillage corn farming reduces the transport of those farm chemical pollutants strongly attached to soil particles, such as phosphorus and insecticides.

Plant nutrient pollutants, especially nitrogen and phosphorus, are of widespread public concern. The

FIG. C-2.—Planting corn in sod not yet killed by herbicides.

FIG. C-4.—Runoff samples in field refrigerator are obtained for determining pollutants in water and on soil particles washed off farmland.

nitrate form of nitrogen readily dissolves and is carried into surface waters by storm runoff. Phosphorus is strongly attached to soil particles soon after application and therefore contributes to water pollution, mainly by means of soil erosion and sediment transport.

Runoff sampling equipment on 2-acre watersheds fills gallon jugs in a field refrigerator (Fig. C-4). Refrigeration prevents sizable chemical and biological changes in the samples. Solids (sediment) are separated from liquids and both are analyzed (Fig. C-5) to determine concentration of pollutants and the means of movement—by liquid or by solid transport. Much of the chemical analyses of samples has been done by the U. S. Soils Laboratory, Beltsville, Md.

Runoff samples at the outlet of the 303-acre watershed (Fig. A-2) are taken to determine the move-

FIG. C-3.—Planting corn in corn residues. Herbicides prevent grass and weed growth.

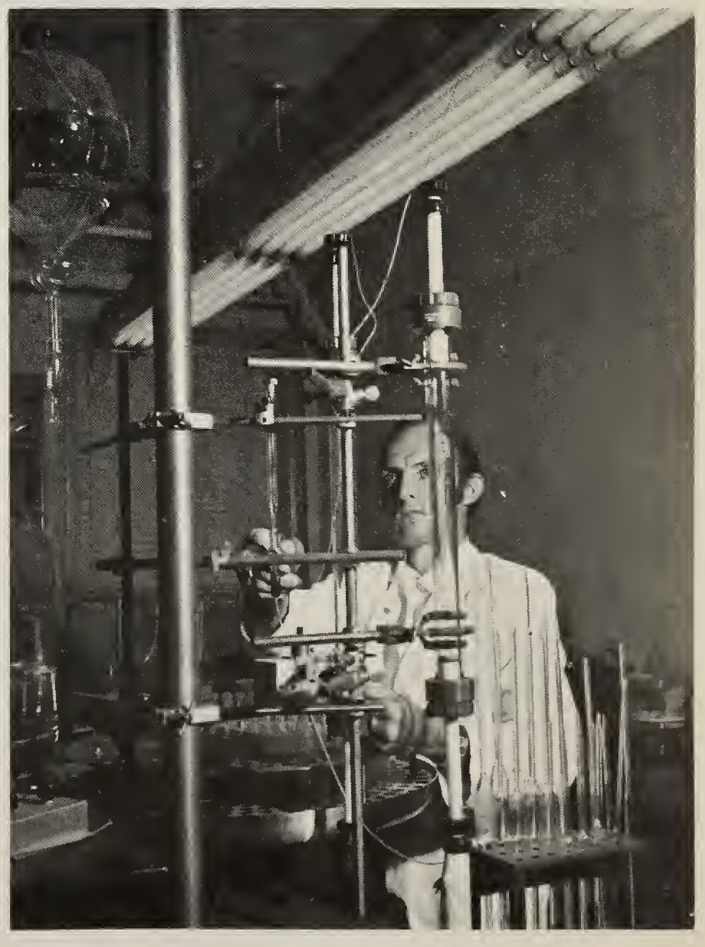


FIG. C-5.—Analyzing runoff samples to detect agricultural pollutants.

FIG. C-6.—Applying insecticides to farm watershed.

ment of nutrients and pesticides into stream systems. Preliminary results on nitrate and phosphorus transport are given below.

Annual transport of nitrate nitrogen in solution at Coshocton:

Woodland	0.92 lb./acre/year
Farmland	3.85 lb./acre/year

Annual amount of nitrate in rainwater:
16 lb./acre/year

Annual transport of phosphorus (P) in solution at Coshocton:

Woodland	0.04 lb./acre/year
Farmland	0.07 lb./acre/year

Pesticides are applied to farmland and measured in runoff samples. Samples are taken, refrigerated, separated into solids and liquids, and analyzed. *Dieldrin,* a persistent insecticide, was sprayed on a plowed field (Fig. C-6) and disked into the upper 3 inches of soil before planting corn. Only one application was made in the study period. *Less than 1% of the dieldrin applied was lost in runoff water.*

Methoxychlor was applied to the surface of a field lysimeter (Fig. A-5). Runoff carried low concentrations for more than 1 year.

Herbicides were applied to row-cropped watersheds to kill grass and weeds. Runoff samples were mainly analyzed at OARDC, Wooster. 2,4,5-T was applied to the grass of a field lysimeter. Rapid degradation was indicated by high concentrations in runoff water immediately following treatment, grading to low concentrations a few months later.

Animal waste pollution from a small beef cattle barnlot (Fig. C-7) is evaluated from refrigerated field samples. Both liquid and solid transport are evaluated. Enriched water from this 0.4-acre lot (Fig. A-2) combines downstream with runoff water from 75 acres of mixed cropland (20% corn). When sampled again, it is found to be largely diluted by relatively clean water from grass and woodland.

Washoff from the beef cattle barnlot can be diverted to a storage pit and later pumped through a sprinkler irrigation system onto a nearby pasture or cropped field (Fig. C-8).

Crop pollution from dieldrin applied to soil was evaluated in a cornfield. The plant was essentially free from dieldrin, except for the leaf. Dieldrin had volatilized from the soil to the air and deposited on the leaf. Volatilization studies of air transport of dieldrin were made by special sampling equipment in and above the corn canopy (Fig. C-9). About 3% of the dieldrin applied was lost to the atmosphere above the treated urea, much greater than the 0.07% lost in runoff water. Very little dieldrin was found in the air above the corn 100 feet downwind from the treat-

FIG. C-7.—Animal waste from a beef cattle barnlot is gaged and sampled.

FIG. C-8.—Animal waste storage pit.

ed area. Horizontal transport from the treated area was small.

Subsurface Water

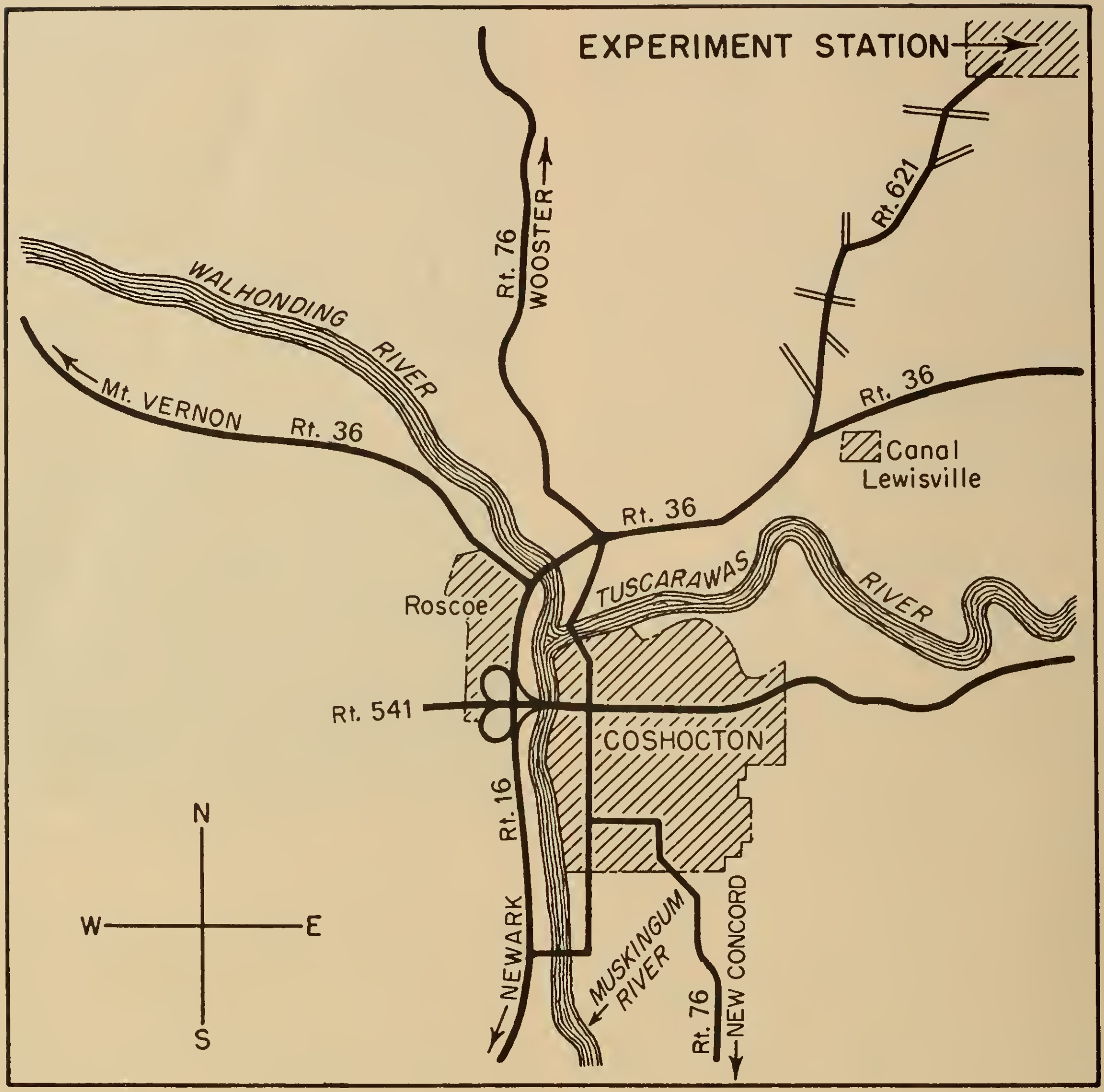
Subsurface or ground-water pollution is evaluated from percolation water samples taken at the 8-foot depth of field lysimeters (Fig. A-5). This is at least 6 feet below the shallow crop root system. None of the persistent insecticide methoxychlor and only a trace of 2,4,5-T were found in these percolation samples in the 14-month period following surface application.

Nitrate nitrogen delivery to ground water beneath a 4-year crop rotation (C-W-M-M) lysimeter averaged 4 lb. per acre per year. There was no measurable phosphorus in percolation water. These chemical fertilizer applications averaged 1 lb. of N and 18 lb. of P plus 3 tons of barn manure and bedding per acre per year in a 4-year rotation. Alfalfa meadows and rainfall added nitrogen to the 7 lb. applied.

SUMMARY

The research program at the North Appalachian Experimental Watershed at Coshocton, Ohio, is designed to be relevant to an ever-changing agriculture. New problems constantly arise which require answers in terms of water quantity and quality. The background of years of data on hydrology and land use provide a means of interpreting the results of current, short-term studies.

FIG. C-9.—Air pollution study equipment.



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