MONITORING NUTRIENT LOSSES FROM SMALL WATERSHEDS[1]

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The southeastern United States is a region where fertilizer use and precipitation are relatively high. During 1972, a total of 10.7 million tons of fertilizer materials were used which included 1.4, 0.9, and 1.2 million tons of N, P_2O_5, and K_2O, respectively (6). The average annual precipitation ranges between 50-60 inches over most of the region; 40 to 70% of this precipitation is lost as runoff (2, 15). Evapotranspiration normally exceeds precipitation from early spring to early fall over much of the area.

These characteristics would appear to favor the transport of native soil and fertilizer nutrients to surface and ground water, particularly during the winter and early spring. However, there is little indication that fertilizer nutrients, particularly N, will accumulate in surface or ground water except where such water remains stagnant or nearly so.

Soil P is virtually inseparable from the soil itself and for the most part is transported and stored with eroded materials. Little is known about factors governing the rate of release of plant nutrients in sediments to associated bodies of water. Since recent comprehensive literature reviews on the subject of nutrient removal and losses from soils are available, no attempt will be made to do so in this paper. The reader is referred to publications by Barrows and Kilmer (1), Soileau (11), Viets (16), and Kilmer and Barber (7).

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PROBLEMS OF STUDYING NUTRIENT TRANSPORT

In spite of more than a century of research dealing with water and nutrient movement in soils, we are still unable to refute claims that fertilizers are contributing excess nutrients to our rivers, lakes, and wells. Why is this true? There are many reasons, but perhaps the main ones are these:

1. First and foremost, the problem of accurately measuring nutrient losses through transport in runoff and base flow is difficult and rather complex. Water volumes must be accurately measured, storm characteristics must be described, representative sampling must be carried out, and suitable control data must be established.

2. In the past, this nutrient transport was viewed primarily from a soil chemistry and crop production standpoint. Water quality aspects received virtually no attention.

3. Many of the earlier lysimeter installations made no provision for surface runoff. Thus, abnormal hydrologic conditions usually existed and leaching losses of nutrients were greatly magnified, particularly from shallow installations.

4. Nutrient loss data in runoff as measured in the past by workers at the old USDA soil erosion experiment stations were usually obtained by total analysis which included sediment. These data are of limited value when one attempts to apply them to our present nutrient enrichment problems.

5. Fertilizer use gained its greatest impetus during and following World War II. The annual consumption of N fertilizer, for example, has increased from about 1 million tons in 1950 to about 8 million tons in 1972. Hence, controlled studies involving modern fertilizer use and water quality are urgently needed. If fertilizer use is curtailed, many farmers would simply go out of business and food prices would skyrocket. An estimated one-third to one-half of our agricultural production depends upon fertilizer use. Thus, our choice must be based on practices that permit agricultural production without pollution if we are to sustain an adequate supply of food and fiber.

6. Nutrients are released at varying rates from all soils, even in the absence of fertilization. The natural weathering of rocks and minerals, as well as the oxidation of organic matter, provides a source of nutrients even in the absence of man's activities. The extensive world peat deposits, formed in the long distant past, are good examples of "natural eutrophication."

Nitrogen and P are the nutrients of greatest interest, although there is increasing evidence that other nutrients may be important limiting factors in accelerating the eutrophication process. Nitrogen is of particular interest, not only from the eutrophication standpoint, but because of the effects of excess nitrates in water on human and animal health. However, NO_3 effects on human health (methemoglobenemia) are not presently considered to be a problem in the United States (13).

As you all know, NO_3 is an exceedingly mobile anion, and it can enter surface and ground water by three main pathways: (A) surface runoff, (B) leaching, and (C) volatilization and subsequent deposition by precipitation, or by direct NH_3 absorption by surface water.

Phosphorus is also of much interest to water biologists (8). Unlike nitrates, phosphates are rapidly fixed in soils and hence move very little except that there is some downward movement in very sandy soils where high P rates are used. Present evidence indicates that very little P moves in runoff and then primarily in conjunction with eroded material. Both P and K supplies are building up in our better agricultural soils that have been fertilized and cropped for a few decades (3). This indicates that P and K are not readily moved out of the soil system.

RUNOFF PLOTS AND WATERSHEDS

Runoff Plots

Numerous studies have been made by land-grant universities and the USDA dealing with soil, water, and nutrient losses under various conservation practices. Runoff plots are well suited to this type of activity and much valuable information has been learned. However, nutrient loss data obtained through these studies are of generally limited value when one attempts to relate these data to fertilizer use. This is particularly true of work carried out prior to the current concern over water quality (1). Runoff plot studies have certain obvious advantages including control of soil, crop, and treatments. When used in conjunction with a rainfall simulator (10, 18), precipitation characteristics can also be controlled within limits.

The Tennessee Valley Authority (TVA) in 1965 started a cooperative study with the USDA in a "fertilizer movement in runoff study" at Watkinsville, Georgia. A rainfall simulator was employed over fallow and sod plots located on a Cecil sandy loam having a 5% slope. Fertilizer N losses in runoff were exceedingly low as shown in Table 1.

Table 1. Runoff losses* from fallow and sod after 5-inch simulated rainfall.

Surface condition	Water lost inches	Soil lost tons/acre	N fertilizer lost %
Fallow	4.13	17.47	2.3
Sod	0.63	0.15	0.15

*200 pounds per acre of N as ammonium nitrate surface-applied to plots on Cecil sandy loam of 5% slope (18).

Similar studies of this nature have been made by Moe, Mannering, and Johnson of Purdue (8), as well as other workers. There are also distinct disadvantages associated with runoff plots: (a) only nutrients lost in runoff are usually measured, (b) the data are difficult to interpret because of the system employed, and (c) agricultural conditions cannot wholly represent those present in farmers' fields. Plots providing for the measurement and sampling of both runoff and base flow would come close to meeting the ideal. The University of Illinois' installations near Joliet are of this nature. The plots are underlain by impervious glacial till, and thus have well-defined surface and subsurface boundaries. In effect, these are large lysimeters minus some of the shortcomings that lysimeter installations possess. The Illinois setup is an unusual one and comparable conditions are not likely to be commonly found elsewhere in the U.S. There are other methods of studying nutrient transport including tile drains, lysimeters, farm ponds, and the monitoring of streams, lakes, and wells. The latter methods are apt to provide only circumstantial evidence because control or comparative data are difficult to obtain. This difficulty is common to all studies of this nature.

Watersheds

While the utility of small plot studies is recognized, nutrient loss research on a Watershed basis is highly desirable. There are two basic approaches to obtaining control data in watershed studies. The paired watershed concept involves two or more watersheds as nearly adjacent to one another as possible. One is left untreated to provide a control for obtaining comparative data. This approach provides a relatively rapid means of obtaining data, since several treatments can be studied simultaneously. Unfortunately, no two watersheds have been found to possess the same hydrologic characteristics and the paired concept is faulty in this respect. The second approach, the single watershed involves a period (usually a year or more) of "no treatment" followed by imposing suitable controlled variables. This approach has the advantage of employing the same site for control and experimental data. However, precipitation characteristics may vary from year to year resulting in data interpretation difficulties unless long-term periods of study are undertaken. This is true for all watershed work involving hydrology.

Requirements of Watersheds Suitable for Nutrient Loss Studies

Ideally, a watershed to be used for nutrient loss studies should possess the following characteristics:

- Be representative of agricultural practices in the area where located.

- Boundaries, both surface and subsurface, should be sharply defined to permit the measuring and sampling of all discharge water originating only within these boundaries.

- Be accessible by car.

- Permit the installation of a weir plus measuring and sampling equipment.

While not an absolute necessity, proximity to electric power is highly desirable for servicing sampling equipment and heating cables where below freezing temperatures are encountered. A knowledge of past hydrologic behavior is also extremely helpful in the interpretation of nutrient loss data. Studies in the Tennessee Valley have included the following watersheds:

White Hollow--forested, 1,715 acres, Union County, Tennessee. Under hydrologic study since 1935.

Waynesville--two pastured watersheds, 3.5 and 4.5 acres, Waynesville, North Carolina. Under hydrologic study since 1952.

Haynes--pastured (grazed), 12.5 acres, Clyde, North Carolina. Initiated December 1968.

Bear Creek--two forested watersheds, about 130 acres each, near Haleyville, Alabama. Under hydrologic study since 1966.

A rather detailed description of the instrumentation and operation of these watersheds follows, with particular emphasis on the Haynes installation.

A 2-month search in six river basins within the Tennessee Valley produced only two possible watersheds, both in the mountainous watershed of the French Broad River in western North Carolina. Preliminary surveys were made and a 12-acre area near Clyde was selected. The site (Haynes Watershed) was subsequently leased for a 3-year period with options to extend this to six years. It is a grazed pasture.

Topographically, the basin is an elongated ellipse, approximately 1,400 feet long and 400 feet wide, with sharply defined ridge lines delimiting the watershed from higher land masses. The soils and slopes (average--15%) are typical of those in the Blue Ridge province of the Southern Appalachian physiographic region. The A-horizon is estimated to average 6 inches in depth and is composed of loam having moderately high permeability. This is underlain by a friable clay loam of moderate permeability. Underlying rocks are metamorphic, composed mainly of granite gneiss and schists, with few joints or solution channels to contribute to deep seepage losses (9).

The site was considered to be ideal for a study of this type because experience on other western North Carolina watersheds had indicated that watersheds having soils of this type would yield relatively large amounts of runoff under average storm conditions (13).

A concrete gravity dam, approximately 30 feet long, was built with V-notch and rectangular-notch weirs providing for measurement of stream flow rates and volumes. A mechanical, splitter-type sampler was installed near the right abutment of the dam. This removes 1/350 of the total stream flow and funnels it into a concrete storage tank on the right bank so that representative samples can be taken once each week for laboratory analysis.

We realized at the outset that there were disadvantages to using this type equipment for water quality studies. The rather tortuous route through a maze of baffles and splitting sections provides numerous opportunities for contamination of the sample, and the 7-day retention period in the concrete tank (exposed to elevated air temperatures during the summer) allows accelerated microbial and chemical degradation of the nutrient constituents. In addition, there are a number of strictly mechanical problems which are normally encountered: blockage of the proportioning notch by trash and insects, blockage of various portions of the flow path by ice during cold weather, and overcoming surface tension effects at the weir notch and weir plate during extremely low flows.

In an effort to overcome the possibility of contamination, we have used epoxy coatings on all metal and concrete parts which touch the stream flow sample. Most of the mechanical problems have been solved with the addition of trash screens and intermittent air jet at the weir notch, and built-in heaters in the sampler and storage tank. The air jet, incidentally, has proved to be very effective in eliminating notch blockage by such things as seeds and insect larvae; in addition, it inhibits the formation of ice at the weir notches so that record can continue throughout the year. Storage tank heat is essential during cold weather because the composite sample must be fully thawed before a representative portion of it can be removed for analysis.

Even with these improvements, however, the mechanical splitter probably remains unsuited for collection of water quality samples. There is no simple and practical way to overcome the difficulties posed by lengthy storage in a loosely covered tank, nor can the surface tension effects on weirs be eliminated at low flows. Thus, when it was proposed to add a number of other watersheds to the nutrient loss study, efforts were begun to find a better solution to the requirements.

A number of commercial stream flow and effluent samplers were investigated during this period, but none were found which would provide dependable, representative samples at proportional rates. It was learned, however, that Dick Fredriksen, U.S. Forest Service, Corvallis, Oregon, was using a much modified version of a pumping type sediment sampler to collect nutrient samples from forested watersheds in the Cascade Mountains (5). After a visit to Corvallis and the Cascades, much exchange of correspondence, a stint at our own drawing board, some painstaking assembly in the laboratory and field, we completed construction of two units at our Waynesville, North Carolina, watersheds.

These samplers are constant-volume, discrete interval instruments which provide proportionality by taking 220 ml samples at intervals varying from once each 60 minutes to once each 3 minutes. These individual samples are then channeled to a single storage tank where they are composited and hand-sampled once each week for laboratory analysis.

These samplers differ from Fredriksen's, primarily in that we designed our own digital logic and solid-state control system to replace his electro-mechanical unit. We also provide refrigera_ed storage for the composite sample so as to inhibit any chemical change before collection and freezing for shipment to the laboratory.

The fact that this is a modified sediment sampler is one of its major strong points. Since P, a nutrient under investigation in this study, is attracted primarily to soil particles rather than remaining free in the water solution, it is especially important to gather representative samples of both water and suspended sediment. Deposited sediment is also sampled periodically as it is removed during cleanouts.

Precipitation can contribute potentially significant amounts of nutrient materials to a watershed, particularly in industrialized areas, so an instrument was designed and built to collect both dry and wet fallout samples. This automatic device, located on the Haynes watershed, has two containers, one of which remains open during dry weather while the other is closed. When precipitation of any type occurs, the moisture sensor and its electronic circuit reverse this situation, closing the dry fallout collector and opening the one which will receive precipitation.

A can-type bulk precipitation collector was used before the construction of this automatic sampler. It remained operational for about a year after installation of the automatic sampler in order to correlate the two groups of data.

We later added a commercially available Wong precipitation sampler at the Waynesville watersheds, modified to collect both wet and dry fallout and to use our standard collection container.

In addition to the instruments described, we also have equipment at three other watersheds which have been included in the study. Two pumping-type samplers are installed on watersheds which are located on the upper Bear Creek in northern Alabama and an existing splitter-type sampler at White Hollow in eastern Tennessee has been renovated for water-quality work. The newest pumping-type samplers at Bear Creek differ from our Waynesville units in that they are uni-junction transitor circuits in place of the digital logic. They are control units which were designed by the Interagency Sedimentation Project for use with their own sediment sampling equipment (4). We are presently comparing these two different approaches to the problem of providing proportional pumping intervals.

At the Bear Creek watersheds we also collect bulk precipitation samples from epoxy coated rain gage containers.

Our experience in this area has been, on the whole, quite gratifying. We are satisfied at this stage that our research to the problem of sampling stream flow for nutrient determinations--by using equipment suited for both water and suspended sediment sampling, by providing for reasonably sized sample volumes at frequent intervals, by compositing samples to yield total nutrient losses with minimum laboratory analysis, and by providing refrigerated storage for untreated samples prior to collection--is perfectly satisfactory. Our early sample analyses yielded reasonable values for nutrient constituents, and we have set up a series of cross-checks (grab sampling at the weir outfall each week, periodic daily sampling from both the weir outfall and the sample storage tanks, and integrated depth sampling from the weir pools) to assess our performance and alert us to any inconsistencies which might occur.

We are presently concerned primarily with refining our logic and control system. We now span approximately 6-1/2 cfs of stream flow with a total of 20 different sampling intervals at our Waynesville samplers; our Bear Creek units will provide 35 intervals; however, the ideal is an infinite number of intervals so that the final sample approaches a true finite proportionality.

Hydrologic data presentations are in the form of tabulated stream flow volumes by sampling period, continuous stream flow hydrographs showing total runoff and separations of surface and ground flows, and precipitation rates and amounts. Estimates of deep seepage losses and evaluations of flow patterns within the watersheds will also be made during the course of the study. Special hydrologic studies or evaluations will be made as the need may arise.

From laboratory analyses of nutrient concentrations, it will be possible to obtain total loss figures in pounds, which may then be related to background, or control, losses, and also later, measured inputs with fertilizer, precipitation, and grazing animals. Analyses of plant uptake and retention by the soil will, of course, be included in the budgeting process.

At the present we are determining N, P, K, and S losses from six watersheds in the Tennessee Valley. Nitrogen is fractionated into NH_4-N, NO_3-N, and total N. We have done some preliminary work with B, Zn, and Mn losses, and expect to enlarge our program with these micronutrients in the future since there are indications that micronutrients may play an important role in eutrophication.

We feel that this work is important not only from the standpoint of water quality but from the standpoint of fertilizer-use economics as well.

Operation and Data Collection
Haynes Watershed, Clyde, North Carolina

This watershed was placed under study in December 1968. Measurements and analyses of discharge water samples were carried out on a "no treatment" basis until April 1970, when N, P_2O_5, and K_2O were applied at the rate of 100 pounds each per acre. Soil samples were taken and a vegetation survey made prior to fertilizer application. An additional 100 pounds of N per acre (as ammonium nitrate sulfate) is applied each year in mid-August. Cages were installed to protect the vegetation (chiefly fescue) from grazing cattle. The vegetation in the cages is clipped periodically and samples taken for nutrient uptake determinations. Typical results from this study are shown in Table 2.

Table 2. Nutrient additions and losses, Haynes Watershed, Clyde, North Carolina.

	1969-1970 Unfertilized	1970-1971 Fertilized
Rainfall (inches)	35.6	38.4
Runoff (inches)	3.8	2.5
Nutrients in rain (lb/A)		
N	4.7	18.5
P	3.0	1.5
K	5.9	7.5
S	22.5	38.4
Nutrients in topdressed fertilizer (lb/A)		
N	0	200
P	0	44
K	0	83
S	0	17
Nutrients in runoff (lb/A)		
N	0.9	1.0
P	0.04	0.03
K	4.2	2.3
S	1.4	1.0

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