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Quantification of Pollutants in Surface Runoff From Agricultural Lands in Brookings County, South Dakota

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QUANTIFICATION OF POLLUTANTS IN SURFACE RUNOFF FROM AGRICULTURAL LANDS IN BROOKINGS COUNTY, SOUTH DAKOTA

BY

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QUANTIFICATION OF POLLUTANTS IN SURFACE

RUNOFF FROM AGRICULTURAL LANDS IN

BROOKINGS COUNTY, SOUTH DAKOTA

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Doctor of Philosophy, and is acceptable as meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by this candidate are necessarily the conclusions of the major department.

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QUANTIFICATION OF POLLUTANTS IN SURFACE RUNOFF FROM AGRICULTURAL LANDS IN BROOKINGS COUNTY, SOUTH DAKOTA

Abstract

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Under the supervision of Professor James N. Dornbush

Surface runoff from snowmelt and rainfall was measured in eastern South Dakota from seven sites (7.18 to 18.69 acres) during 1971 and 1972. All sites had single crops which included corn, oats, pasture and hayland. All land was farmed under normal farming conditions.

Samples were taken periodically throughout each runoff event, and a single composite sample was made from the individual samples for a particular site. The composite sample represented the entire runoff event. The amount of rainfall and the runoff flow were measured.

Determinations on the composite sample included total coliform, fecal coliform, fecal streptococcus, soluble pesticides, specific conductance, raw and soluble chemical oxygen demand, raw and soluble total kjeldahl nitrogen, raw and soluble total phosphorus, suspended solids, total residue and nitrates. In addition, ammonia-nitrogen was determined for some samples; and when possible, pesticide determinations were made on mud samples.

Runoff samples from 91 snowmelt events and 32 rainfall events were collected over the two year period. The first year represented a season of below normal precipitation and the second year was a year of above average precipitation.

Sediment losses were considerably below losses predicted by the "universal" soil-loss equation. This was attributed to differences in runoff plot size and local hydrologic conditions. Most of the sediment lost was from the cultivated fields and only small amounts washed off fields in permanent grass. Most of the soil-loss happened during short duration, highly intense summer rainstorms.

Coliform and fecal coliform levels were consistently greater than accepted surface water quality criteria. The fecal coliform to fecal streptococcus ratio appears to indicate contamination from a nonhuman source, as expected.

Pesticide concentrations were low in both water and sediment samples. Analyses generally showed levels below the analytical test limits.

Nutrient losses ranged from 0.03 to 3.0 lb/acre/yr of nitrogen and from 0.01 to 0.72 lb/acre/yr of phosphorus. Considerable amounts of nutrients were found to be soluble and/or associated with snowmelt runoff.

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Implementation of this project would not have been possible without the cooperation of the individuals who owned and operated the land where the research sites were located. Mr. Marvin Lamb was the landowner for Sites No. 1, 2, 3, and 4; Mr. Dean Duff owned the land for Site No. 7, and Mr. M.G. Olson farmed the drainage areas for Sites No. 8 and 9. Mrs. Kayt Daum owned the land which contains Sites No. 8 and 9.

Mr. M.R. Cheeseman, Brookings County Highway Superintendent, and Mr. Ken Pittinger, Oakwood Township Road Chairman, gave their permission for sampling station installations within the road right of way.

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I. INTRODUCTION

Agricultural Wastes

In the past, the disposal of agricultural wastes received only limited attention. Barnyard manure piles were common, and the drainage from fields and pastures ran unchecked into nearby draws and streams. With present day agricultural practices and the current national concern for the environment, it was inevitable that agricultural wastes would be viewed as probable sources of pollution.

Agricultural wastes can be divided into many categories for discussion. General categories would include solid wastes, wastes from confined feeding operations, and field drainage. Pasture runoff would be considered as field drainage.

Solid waste disposal is not thought to be a serious problem on the average farm. Usually each farmstead has its own solid waste disposal area, and any adverse environmental conditions probably affect only those who utilize the disposal site.

Livestock enterprises which practice confined feeding have received considerable attention concerning the nature of their wastes. Various investigators such as Loehr, Miner and Taiganides have published extensively regarding pollutional characteristics of animal wastes, factors affecting feedlot runoff, and treatment and disposal methods. The interested reader is referred to the above authors for information concerning this topic (1)(2)(3)(4).

Pollution resulting from agricultural runoff can be immensely important as was pointed out in a recent report released by the South Dakota Water Resources Research Institute which states (5):

> Runoff from agricultural land is currently the largest and most complex pollution problem in South Dakota. . . Organic or chemical pollution from animal manure, coupled with siltation, pesticide and fertilizer pollution, all combine to produce an important and complex problem.

It seemed that a study of the pollutional contributions of agricultural runoff would be both timely and important. Nitrogen and phosphorus are known to contribute to lake eutrophication. Little was known regarding the quality of agricultural runoff. Consequently, the effectiveness of controlling pollution from municipal and industrial discharges, while leaving agricultural runoff unchecked, was unknown. A task group of the American Water Works Association has recently completed a study of nitrogen and phosphorus in water (6). They concluded that:

> There is little data available concerning the influence of natural rural drainage upon the quantities of nutrients in water.

In 1967, the South Dakota Committee on Water Pollution adopted water quality criteria for the surface waters of South Dakota. The Committee recognized that agricultural runoff affected the quality of the surfaces waters, but not knowing the extent of the problem, they decided to concentrate on only the point sources of pollution. Considering land runoff, the Plan of Implementation of the "Water Quality Standards" reveals a need to "COOPERATE WITH OTHER AGENCIES IN STUDY OF POSSIBLE METHODS OF CONTROL" (7).

Thus it seemed that a knowledge of the characteristics of land runoff would be valuable information. This information would be important

not only because it would advance the state of knowledge in this area, but also would be usable information to those concerned with the water quality of surface waters. A research project was therefore undertaken to determine the quality and quantity of agricultural runoff.

Objectives of this Research

The general objective of this project was to quantify the pollutional constituents of agricultural surface runoff. It was desired to determine contributions of constituents in terms of quantity per unit acre per unit time for various land uses.

It was also considered important to know the reduction in waste discharges that may be obtained by sedimentation. Determination of the fraction of pollutional constituents associated with the suspended solids or sediment load carried with the surface runoff would be an objective aimed at relating the potential of soil conservation practices to the improvement of the runoff quality.

In as much as possible, it was also an objective of this study to relate the quality of surface runoff to numerous factors peculiar to specific drainage basins. This would allow extrapolation of the findings to drainage basins in other areas having different climatic conditions, other land uses, and various physical factors.

Scope of this Research

This project pertained to surface runoff from cultivated fields, permanent grass and alfalfa lands, and grazed pasture. The runoff from confined feeding operations was not evaluated. All field conditions were natural and uncontrolled. Simulated rainfall was not used, and an

attempt was not made to influence the land operators with respect to land management practices.

The initial project year (1970) did not include an entire runoff season, and some of the laboratory results were affected by the sample preservation method used. Consequently, data for only the second and third years were used. Seven sites were sampled for snowmelt and rainfall runoff during the 1971 and 1972 runoff seasons.

Sampling was executed any time that runoff occurred. Manual sampling and flow measuring were employed for spring runoff, while automatic sampling and flow measuring equipment were used during rainfall events. Samples were brought into the laboratory and a composite sample was made for each site. All the bacteriological, physical and chemical determinations were then conducted on these composite samples.

II. LITERATURE REVIEW

Physical and Chemical Quality of Agricultural Runoff

The consequences of unchecked water pollution are so broad that concern over our water resources becomes the common bond between technical people, elected officials and the general public. All of these groups, albeit only recently for some, now recognize agricultural runoff as a potential source of water pollution.

Iowa Congressman Fred Schwengel addressed himself to this problem at a recent symposium concerned mainly with animal wastes (8). He stated that animal wastes represent only half of the problem, and that we must become concerned with pesticides, fertilizers, and nutrients in land runoff. From a congressional standpoint, he was concerned that billions of dollars might be spent on pollution control without any substantial benefits because agricultural runoff had not been considered.

Cecil H. Wadleigh, Director of the Soil and Water Conservation Research Division of the Agricultural Research Service, echoed Congressman Schwengel as he stated: "It is urgent that we rapidly alleviate the grave dearth of qualitative and quantitative information on the phosphorus in runoff and drainage water from agricultural and forested lands. . ." (9-96). Wadleigh extensively discussed the problems involving wastes from agricultural and forested lands in a U.S. Department of Agriculture publication (9).

General Quality

Estimates of annual losses of sediment and nutrients from rural areas tend to stagger one's imagination. Approximately 4 billion tons of sediment are washed into United States streams each year (9-6). Eliassen and Tchobanoglous estimated nitrogen and phosphorus contributions from rural agricultural land at 1,500 to 15,000 and 120 to 1,200 million pounds per year, respectively. Annual contributions from rural non-agricultural land were estimated as 400 to 1900 million pounds of nitrogen and 150 to 750 million pounds of phosphorus (10).

Hunt discussed farming activities and the associated problems of water pollution (11). He noted that total fertilizer usage decreased in New York between 1950 and 1959 although fertilizer use per cultivated acre increased. Annual fertilizer applications of 7 lb ammoniacal nitrogen and 0.8 lb NO_3-N per acre were made. He also observed that nutrient losses from erosion are greater than expected because the finer particles are sorted out and washed away. These finer particles contain humus and mineral matter and are usually very fertile.

The majority of investigators who have studied agricultural runoff have conducted stream surveys and the data are generally limited to nutrient contributions. However, a few researchers have compiled general quality data from agricultural surface runoff (12)(13)(14), and these data are presented in Table I along with data from an urban area for comparison (15).

A 173 acre cultivated site in eastern South Dakota was sampled by Benson (12) and McCarl (13) during 1969 and 1970. Samples were preserved by freezing without presenting data to verify the method used. The

TABLE I. - General Quality of Surface Runoff from Nonpoint Discharges

Item	Benson (12)	McCarl (13)	Weibel, et *al.* (15)	Weidner, et al. (14)
Land use	Farmland	Farmland	Residential	Research plots and apple orchard
BOD, mg/l	5 - 30	3 - 15	2 - 84	3 - 8.4
BOD, lb/acre/yr	-	6.9	33	3.7 - 120
COD, mg/l	50 - 360	70 - 780	20 - 610	40 - 68
COD, lb/acre/yr	-	246	240	27.8 - 1300
Solids, mg/l	90 - 5000 SS	180 - 6000 SS	5 - 1200 SS	500 - 575 TS
Solids, lb/acre/yr	-	2,040 SS	730 SS	185 - 13,200 TS
Total phosphorus, mg/l	0.26 - 2.4 Soluble P	0.04 - 0.60	0 - 1.4 Soluble P	0.42 - 0.98
Total phosphorus, lb/acre/yr	-	0.07	0.8 Soluble P	0.36 - 9.0
Org. N + NH_3, mg/l	1.3 - 20.3	2.8 - 17	0.1 - 7	-
Total nitrogen mg/l	-	12.9 - 33.2	0.2 - 9	4.9 - 9.0
Total nitrogen, lb/acre/yr	-	8.4	8.9	0.8 - 237

quality of both snowmelt and rainfall runoff was recorded. A summary of their data is shown in Table I. Total annual contributions were computed by McCarl for the 1970 runoff season (13). Annual loads of 2,040 lb/acre of suspended solids, 6.9 lb/acre of BOD, 246 lb/acre of COD, 8.4 lb/acre total nitrogen and 0.07 lb/acre of total phosphorus were reported.

Weibel _et al._ (15) reported on the general quality of runoff water from a 27 acre residential area in urban Cincinnati. About 730 lb/acre/yr of SS were measured of which 22% were volatile. The BOD and COD were 33 lb/acre/yr and 240 lb/acre/yr, respectively.

Weidner _et al._ (14) obtained runoff quality data from two 1.5 acre watersheds near Coshocton, Ohio and also from a 5-acre apple orchard at Ripley, Ohio. Most of the material losses occurred during the summer months as a result of high intensity rainstorms. The organic losses, as measured by BOD and COD, were small. BOD values ranged from 3.7 to 120 lb/acre/yr and COD losses ranged from 27.8 to 1300 lb/acre/yr.

Soil Losses

Soil erosion by water is a common geological phenomenon. It accounts for many of the variations in topography of the land about us. Normal processes of erosion work slowly and continuously. Accelerated erosion, which is more rapid than normal erosion, has become a cause for concern in recent decades.

Walker and Wadleigh discussed water pollution as it relates to land runoff. They estimated that the sediment yield of the Mississippi River Basin averages 390 ton/sq mi/yr. Soil losses are not the only

consideration. They also estimated that each 1000 tons of sediment carries about 1000 pounds of phosphorus fixed to its surface (16). Nutrients lost from the land are often greater than expected because the finer and more fertile soil particles are sorted out and washed away (17-229).

Three types of water erosion are generally considered; sheet, rill, and gully. In sheet erosion, the soil is lost from the entire slope. The term rill erosion is used when tiny, irregularly dispersed gullies are evident along with the sheet erosion. When small or large ravines are cut, the erosion is called gully erosion. Sheet erosion is more important than gully erosion because it is more destructive (18).

Walker indicated that sheet erosion is more expensive than gully erosion as he discussed the role of silt in water pollution (18). He estimated that sediment losses could be reduced by 43 to 92% by soil conservation programs, and that the cost of these programs should be offset by increased crop production within four years.

Several investigators have obtained data regarding soil losses from various sized fields and plots. McGuinness et al. described the eight small natural watersheds which the Agricultural Research Service had been evaluating near Cashocton, Ohio from 1945 to 1956 (19). The watersheds were matched into four pairs and subjected to a four year rotation of corn, wheat, and two years of meadow.

The study compared the effects of improved farming practices with prevailing farming methods. The improved practices decreased soil and water losses except during extremely intense storms. Average peak rate reductions of water losses for the improved methods were 0.82 in./hr for

corn, 0.22 in./hr for wheat, and 0.04 in./hr for meadow (19). Weidner et al. reported long term, average soil losses as high as 7.7 ton/acre/yr for these same watersheds (14).

Soil losses and nitrate-nitrogen losses were measured by Daniel et al. from some small plots in Oklahoma from 1930 to 1939 (20). Crops studied included continuous cotton, wheat, clover, woods, and hard-fallow. Soil losses averaged from 0.001 to 34.5 ton/acre/yr.

Data from small plots (13.3 ft by 72.6 ft) in western Minnesota were reported by Holt (21) and Timmons et al. (22). Two-year average soil losses were given by Holt at 0 to 7 ton/acre/yr (21), and average annual losses of 2.2 to 21.4 ton/acre were reported for 1961 to 1967 (22).

Sediment from some larger watersheds was measured by McCarl (13) and Dragoun and Miller (23). An annual load of about 1 ton/acre was received from a 173 acre area under cultivation (13-41). A 481 acre watershed being farmed by conventional methods was compared with a 411 acre watershed on which improved farming practices such as terraces and grassed waterways were used. About 75% of the unimproved acreage was cultivated, while 60% of the improved land was cultivated (23). Over a four year period, the sediment yield for the unimproved area was 8.4 ton/acre and 4.5 ton/acre for the improved field. They concluded that sediment reductions of 50% or more could be realized by implementing soil conservation measures. The reduction was primarily due to a decrease in water yield. Runoff on the unimproved land averaged 3.9 in./yr while the average runoff from the improved acreage was 2.9 in./yr (23).

The Department of Agronomy at Cornell University conducted a three part study to evaluate the factors which control soil and nutrient movement from the land. An artificial rainfall simulator was used on small test plots for one part of the study, and the largest erosion loss was from continuous corn. Another part used larger test plots (0.8 acres each) and natural rainfall conditions. The use of mineral fertilizers resulted in physical deterioration of the soil and subsequently increased surface runoff and soil losses. Incorporating crop residues into the soil was recommended, as well as proper timing of fertilizer applications. The third part of the project was an algal nutrient study. Results from the algal nutrient study were inconclusive (24).

In an attempt to define soil erosion and allow prediction of soil losses, researchers studied specific aspects of the erosion process. The severity of raindrop erosion was investigated by Ellison (25). In particular, he studied the effects of raindrop impact and splash. He speculated that raindrop splash caused most of the severe sheet erosion near hilltops. He concluded that infiltration and runoff were dependent upon raindrop erosion. The use of vegetal canopies and mulches to prevent raindrop erosion was proposed.

Epstein and Grant evaluated some of the factors which define the different erodibility characteristics of soils by using a rainfall simulator on six soil types (26). Soil losses reached a maximum during the first 10 minutes of simulated rainfall for four of the soils, but no peaking effect was noted on the other two soils. They also cast doubts on obtaining realistic erodibility values by using simulated rainfall.

In the early 1960's, researchers were attempting to formulate a soil-loss equation. Rogers et al. used an artificial rainmaking device to generate runoff on small plots, 35 ft to 75 ft long (27). The purpose was to further define coefficients in a soil-loss equation. Most of the variations in soil-loss data were explained by rainfall amounts multiplied by rainfall intensity.

Finally, after more than 20 years of development and based on the work of many contributors, a generally accepted soil-loss equation came into being. This equation is commonly known as the "universal" soil-loss equation. The history of its development, as well as a detailed explanation of the equation, can be found in a handbook compiled by the Agricultural Research Service (28).

The basic soil-loss equation is:

$$A = RKLSCP \qquad \text{Eqn. (1)}$$

Where:

A = Soil-loss per unit area

R = Rainfall factor

K = Soil-erodibility factor

L = Slope-length factor

S = Slope-gradient factor

C = Cropping-management factor

P = Erosion-control practice factor

This equation is based on the data obtained from many small plots scattered throughout the United States and Puerto Rico. It is generally accepted by agricultural people as representing acreage soil losses for cropland east of the Rocky Mountains (28).

Eutrophication

Eutrophication is the overfertilization or accelerated aging of natural bodies of water. It is important to this study because the surface runoff from agricultural land carries various nutrients which affect the rate of aging of surface waters. A complete review of the literature concerning eutrophication is not presented. However, an attempt will be made to briefly acquaint the reader with the topic and provide reference sources for further reading if desired.

Large growths of algae and aquatic weeds are common consequences of overfertilization. These plants, similar to plants grown on land, require various nutrients for sustained growth. The concept of one or two "limiting nutrients" is found throughout the literature. Researchers have generally based their hope of controlling eutrophication by limiting the amounts of nitrogen and phosphorus, two nutrients which are essential for growth.

Weiss discussed the process of eutrophication and how phosphorus relates to this process (29). The concept of limiting macronutrients and the quantities of these nutrients needed to cause profuse growth of phytoplankton were debated. It was concluded that the interrelationships of the various plants and nutrients are quite involved and that much uncertainty still exists.

Stewart and Rohlich directed the preparation of a comprehensive report regarding eutrophication for the California State Water Quality Control Board (30). References by various authors throughout the world are included in the bibliography. Topics covered include physical,

chemical, and biological considerations, some case histories, methods of measuring eutrophication, and research needs.

A group of experts headed by Schraufnagel studied the fertilization of Wisconsin's lakes and streams. They investigated the various nutrient sources including runoff from rural acres. Field data were not collected, but nutrient quantities were estimated. Surface runoff contributions from rural lands were estimated at 0.03 to 3 lb/acre/yr for nitrogen and 0.003 to 1 lb/acre/yr for phosphorus. They estimated that ground water would contribute more nitrogen, as nitrates, than surface runoff (31).

An American Water Works Association Task Group studied nutrients in relation to water quality. They reported on the particular forms of nutrients which are of concern to water treatment practices, aquatic plant growth in water supplies, and problems associated with excessive plant growth in general (32). Estimates were made which indicated that more than half of the surface waters in the United States are affected by these problems of nutrient enrichment. An excellent bibliography of 79 references is included with the report.

Another source of information on eutrophication is an article written by Fruh (33). This work lists 66 references and covers nutrient sources from the atmosphere, groundwater, watershed runoff, agricultural runoff, urban drainage, and wastewater effluents.

A comprehensive report on eutrophication was written by Volenweider for the Organization for Economic Co-operation and Development. The report is a consolidated report of the available literature (up until late

1967) on eutrophication with special attention given to the part played by nitrogen and phosphorus. It is currently available in either English, French, or German editions (34).

Nutrient Contributions

The nutrients carried to surface waters by agricultural runoff are an important facet of eutrophication. Information regarding the nutrients in agricultural or rural runoff; and in particular, that which provides quantitative data on nitrogen and phosphorus in agricultural runoff was reviewed.

A major problem of nutrients is the stimulation of growth of algae and other aquatic plants in streams and reservoirs. A report on the various sources of these nutrients was completed by an American Water Works Association Task Group (6). They reported on various sources including domestic, industrial, rural, urban, and farm animal wastes. It was concluded that the single largest contributor of nitrogen and phosphorus to water supplies was agricultural runoff.

Bauman and Kelman warned about requiring cities and industries to install advanced waste treatment equipment without identifying agriculture's contribution to the waste load of a stream (35)(36). They made weekly stream measurements for flow, BOD, COD, SS, turbidity, nitrogen, and phosphorus in the Des Moines River between Boone and Des Moines, Iowa. Exact quantities of nutrients from various sources could not be determined, but they were able to conclude that nitrogen and phosphorus removal from municipal and industrial discharges would be beneficial for flowing streams. However, removal of nitrogen and

phosphorus may not benefit impounded waters because the major sources of nutrients for these bodies of water are nonpoint discharges.

Walker and Wadleigh felt that phosphorus was the most serious nutrient carried with sediment and estimated that 1000 pounds of phosphorus were fixed to the surface of each 1000 tons of sediment (16). Schraufnagel _et al_. estimated nutrient contributions due to surface runoff from rural acres at 0.03 to 3 lb/acre/yr of nitrogen and 0.003 to 1 lb/acre/yr of phosphorus. Ground water was a suspected source of considerable nitrates (31).

Harmeson _et al._ collected extensive nitrate information on Illinois waters. In general, the nitrate levels have been increasing since 1945 and are highest in agricultural areas which have fertile, well-drained soils (37). Smith determined the nitrates in surface water runoff from two rainstorms in Missouri (38). Nitrate nitrogen losses varied from 0.01 to 0.8 lb/acre depending on the crop cover. He concluded that improved soil fertility treatments can provide adequate soil cover, reduce runoff and erosion and effectively limit nutrient losses.

Samples from a stream which drains a watershed in Kansas were obtained by Stoltenburg (39). Total phosphate and nitrate concentrations varied with the stream flow. During periods of low flows, phosphate levels of 0.18 to 0.30 mg/l and nitrate concentrations of 0.2 and 4.2 mg/l as NO_3 were common. During high flows, phosphate and nitrate concentrations reached 4.0 mg/l and 45 mg/l respectively. Ammonia concentrations varied from 0.16 to 0.30 mg/l NH_3-N at low flows to

1.8 mg/l NH_3-N during surface runoff. It was estimated that 35% of the applied nitrogen and 20% of the applied phosphate were lost in storm runoff events.

Nelson and Pomkens studied the forms and amounts of phosphorus removed by surface runoff from fertilizer and unfertilized plots by using a rainulator apparatus to apply the water. Water was applied at a rate of 2.5 in./hr at intervals of 1, 20, and 42 days. Fertilizer was spread on the 12 ft by 35 ft plots at rates of 0, 50, and 100 pounds per acre (40).

Initially the phosphate phosphorus (PO_4-P) concentration was about .08 ppm for all plots. Phosphorus levels on the control plot dropped to about 0.05 ppm PO_4-P while it rose to 0.5 and 0.3 ppm PO_4-P on the plots fertilized with 100-pound and 50-pound rates, respectively. Fluctuations in the phosphorus content of the runoff water occurred during the remaining events. It was concluded that the phosphate concentration in runoff water was related to the rate of phosphate application, and that about 1% of the applied phosphate was removed as soluble phosphate (40).

Schultz presented an interesting approach to estimating nutrient contributions which he calls a balance sheet method (41). An example based on an agricultural subbasin of the Genesee River basin in New York was presented. The method accounts for nutrient additions and losses from commercial fertilizers, animal manures, precipitation, crop production, and legume fixation. The remaining nutrients were assumed to have entered surface waters. Agriculture's nutrient contribution

was calculated at 18.1 lb/acre/yr of nitrogen and 2.9 lb/acre/yr of phosphorus. Some necessary assumptions were made to arrive at these values and field data were not procured to verify the method.

Various investigators have evaluated the nutrient contributions from rural areas. These data are presented below and summarized in Table II. Three frequently quoted works were authored by Sawyer (42), Slyvester (43), and Englebrecht and Morgan (44).

Sawyer (42) estimated the nitrogen and phosphorus present in agricultural runoff by sampling streams which did not receive municipal or industrial discharges. The higher nutrient values came from areas which contained marsh lands. Annual contributions of 7 lb/acre/yr of nitrogen and 0.4 lb/acre/yr of total phosphorus were reported. Critical nutrient levels in support of algal blooms were listed at 0.30 ppm for inorganic nitrogen and 0.01 ppm for inorganic phosphorus.

Slyvester reported on nitrogen and phosphorus loads from irrigation surface return flows in the Washington Yakima Valley. Nitrogen values ranged from 2.5 to 24.0 lb/acre/yr and phosphorus varied from 0.9 to 3.9 lb/acre/yr. Also listed were some nutrient values from forested areas which were subject only to some logging and road construction. Based on stream samples, total nitrogen varied from 1.3 to 3.0 lb/acre/yr and total phosphorus ranged from 0.3 to 0.8 lb/acre/yr (43).

Engelbrecht and Morgan estimated the amount of phosphorus related to land drainage by deducting the phosphorus contributed from sewage treatment plant effluents. Samples were collected from the Kaskaskia River in Illinois and reflected phosphorus contributions from six

TABLE II. - Nutrients in Rural Runoff

Land Use	Stream Flow or	Surface Runoff	Nitrogen, lb/acre/yr	Phosphorus, lb/acre/yr	Remarks	Reference
Forest and Grazing Area	X		0.65 NO_3-N 0.90 Total N	0.33 Total P	Little cultivated land, Data extrapolated from 2 months sampling	55.
Farmland	X		7.0 Total N	0.4 Total P	General farming conditions	42.
Forested Areas	X		1.3-3.0 Total N	0.3-0.8 Total P	Some logging and road construction	43.
Diversified Farming		X	2.5-24.0 Total N	0.9-3.9 Total P	Irrigation return flows	43.
Farmland	X		-	0-15 Ortho plus Hydrolyzable P_2O_5, as P	Heavily cultivated land. Data extrapolated from 6 summer months	44.
Research Plots		X	3.1-6.4 Total N	0.03-0.21 Total	Natural conditions, small plots	21.
Farmland		X	8.4 Total N	0.07 Total P	173 acre cultivated site in corn and oats	13.
Research Plots and Orchard		X	0.8-237 Total N	0.36-9.0 Total P	Natural conditions, 1.5 acre plots, 5 acre orchard	14.

TABLE II. - continued

Land Use	Stream Flow	Surface Runoff	Nitrogen, lb/acre/yr	Phosphorus, lb/acre/yr	Remarks	Reference
Farmlands and Forested Areas	X		1.7-11.4 Total N	0.38-8.63 Total P	1939-1940 Study in Tennessee Valley Watershed	47.
Research Plots		X	0-1.2 NO_3-N	-	Natural conditions, small plots	20.
Farmland	X		7.35 NO_3-N	0.05 Ortho and Poly PO_4	No significant point discharges	51.
Farmland	X		3.8 Total N	0.24 Total P	20% forest, 80% crop land and pasture	52.
Rangeland	X		0.56 NO_3-N	0.021 Soluble P 0.067 Total P	Primarily grazing, no chemicals added	48.
Farmland and Pasture		X	3.6 Total N	1.1 Total P	Higher than normal runoff, frozen sample storage	53.
Farmland and Pasture	X		4.0 Total N	0.2 Total P	Mostly pasture, 6 mo. data, frozen sample storage	50.
Irrigated Field			3.1 Total N	0.07 Total P	Subsurface drainage, no fertilizer applied	49.
Research Plots		X	3.9 Total N	1.2 Total P	Small control plots with no applied manure, frozen sample storage	54.

heavily cultivated drainage areas ranging in size from 12 to 5220 square miles. Determinations were made for orthophosphate and hydrolyzable phosphate as P_2O_5. Total phosphorus was not determined but was estimated at 20% to 30% more than the ortho plus hydrolyzable P_2O_5. Reported values of ortho plus hydrolyzable P_2O_5 ranged from 0-15 lb/acre/yr as P (44).

Nutrient losses from small plots in western Minnesota were reported by Holt (21), Holt et al. (45), and Timmons et al. (22). Based on data collected for two years, Holt lists measured values of 3.1 and 6.4 lb/acre/yr of nitrogen and 0.03 to 0.21 lb/acre/yr of phosphorus (21). Timmons et al. extrapolated these data based on soil-loss information for seven years and estimated annual nutrient losses at 31 to 183 lb/acre of nitrogen and 0.85 to 1.1 lb/acre of phosphorus (22). Large quantities of soluble phosphorus were observed in snowmelt runoff from alfalfa plots. This loss of soluble phosphorus was verified by a laboratory investigation conducted by Timmons et al. (46). Alfalfa and bluegrass crops contributed substantial amounts of soluble nutrients.

Some historical insight can be gained by nutrient contributions from two studies made during the 1930's. Nine watersheds representing several hundred thousand acres of forests and farms were sampled for about one year. Results showed a range in total nitrogen of 1.7 to 11.4 lb/acre/yr and total phosphorus variations of 0.35 to 8.05 lb/acre/yr (47). Daniel et al. (20) measured nitrate-nitrogen in surface runoff from small plots in Oklahoma from 1930 to 1937. Nitrate-nitrogen losses from continuous cotton, wheat, clover, woods, and hard-fallow ranged from 0.001 to 1.192 lb/acre/yr.

More recent data can be found from several sources. McCarl measured 0.07 lb/acre/yr of total phosphorus and 8.4 lb/acre/yr total nitrogen from a 173 acre cultivated field in South Dakota (13). Weidner et al. reported annual losses of 0.8 to 237 lb N/acre/yr and 0.36 to 9.0 lb P/acre/yr from two 1.5 acre watersheds and a 5 acre apple orchard in Ohio (14).

A 30,000 acre drainage basin in southwestern Ontario used primarily for summer pasture was the subject of research by Campbell and Webber (48). Little or no chemicals or fertilizers were used on the land. As expected, low nutrient loads were measured. Annual values of 0.56 lb/acre/yr of NO_3-N, 0.021 lb/acre/yr of soluble phosphorus, and 0.067 lb/acre/yr of total phosphorus were reported.

An indication of the nutrients in subsurface irrigation drainage is apparent from data presented by Johnson et al. (49). The drainage beneath four irrigated fields in the San Joaquin Valley of California was measured. One of the fields did not receive any fertilizer and its drainage contained 3.1 lb N/acre/yr and 0.067 lb P/acre/yr.

The Department of Biological and Agricultural Engineering at North Carolina State University at Raleigh sampled the discharge from Site F, an area draining 75 acres of pasture, corn, and orchard (50). Samples were frozen prior to analysis. Data was not presented to verify the sample preservation method used. Extrapolating six months of data yields results of 4.0 lb/acre/yr of nitrogen and 0.6 lb/acre/yr of phosphate.

Wang and Evans reported on the nutrient observations made in an extensive study of Lake Bloomington in central Illinois (51). The average precipitation and runoff are 36.5 and 9.05 in./yr, respectively. The drainage area did not have any important point discharges. The total annual runoff of nitrate-nitrogen was given as 4700 lb/sq mile and the annual contribution of phosphorus was 32 lb/sq mile.

Waste discharges in the Potomac River Basin were evaluated by Jaworski and Hetling (52). An estimated 5,840 sq miles were in cropland and pasture. This area yielded 0.24 lb/acre/yr of phosphorus and 3.8 lb/acre/yr of nitrogen. The major source of all nutrients was from wastewater. However, agricultural runoff contributed 65% of the nutrients attributed to land runoff although agricultural land represented only 38% of the total area. The remaining area was in forest or urban land.

Personnel from the University of Wisconsin instigated surface runoff studies from both natural watersheds and small research plots (53)(54). Samples were frozen and stored prior to analysis with a Technicon Autoanalyzer at a University of Wisconsin laboratory. Data verifying the preservation method used was not presented.

Surface runoff from natural watersheds of 22.8, 52.5, and 171 acres was sampled by Witzel et al. (53). Runoff data for one year, including some snowmelt runoff, were obtained. The smallest site was in pasture, and the remaining sites were in pasture, hayland, and cultivated crops. Commercial fertilizers and animal manures were used. The annual average surface runoff is about 1.75 in. of which 75% results from snowmelt or rainfall on frozen soil. The particular year in question had about twice the average annual runoff and gave nutrient loads of

3.6 lb/acre of nitrogen, 1.1 lb/acre of phosphorus, and 7.6 lb/acre of potassium. Average annual contributions were estimated at 2 lb/acre/yr, 0.6 lb/acre/yr, and 4 lb/acre/yr of nitrogen, phosphorus and potassium, respectively.

Minshall et al. used various manure applications on eight small plots (10 ft by 40 ft) and evaluated the effects of the applications on the quantities of nutrients in the surface runoff (54). Data were collected for three years. Annual nitrogen losses were 11.3 lb/acre for fresh manure applications, 3.59 lb/acre for fermented manure, and 3.20 lb/acre for liquid manure. This was compared to 3.89 lb/acre/yr of nitrogen which was obtained from a control plot which had not received any manure. Annual phosphorus losses were 2.62 lb/acre for fresh manure, 0.72 lb/acre for fermented manure, and 0.86 lb/acre for liquid manure. Phosphorus lost from the control plot was 1.17 lb/acre/yr.

Winter nutrient losses on unmanured plots were found to be less than losses from manured summer plots. These unmanured plots lost more nutrients than the manured plots during the summer, however. They concluded that manure should be spread only on unfrozen ground, and the manure should be incorporated into the soil as soon as possible (54).

Jennelle and Grizzard studied the eutrophication of a Virginia lake. Stream samples were taken at various tributaries and nutrient sources were identified as wastewater discharges, rural runoff, and urban runoff. Rural runoff contributed 710 lb PO_4/day, 456 lb NO_3-N/day, and 176 lb total kjeldahl nitrogen/day. Sampling was for a two month period, and the data shown in Table II are extrapolated to an annual basis. They concluded that even if expensive nutrient removal from

municipal and industrial discharges was practiced that enough nutrients would still be added to cause rapid eutrophication to continue (55).

Loehr discusses the important aspects of nutrients in rural and agricultural runoff (56). He compares nutrient levels from various sources by compiling data based on work by others. Some of the data shown are incorrect because of printing errors. Most of Loehr's sources have been listed in Table II, and the corrected values were used.

Considerable studies regarding eutrophication and nutrient sources have been made on the lake system near Madison, Wisconsin. Excessive aquatic growth in Lake Mendota prompted an investigation into its nutrient sources by Lee et al. (57). Field data were not collected, but estimates of nutrients from various sources were made. Estimates of 0.003 to 0.04 lb/acre/yr of phosphorus and 0.03 to 3 lb/acre/yr of nitrogen from rural areas were offered.

The minimum values listed above by Lee et al. (57) are for woodlands and are based on some work by Sylvester. Values for forested areas by Sylvester (43) are listed in Table II and are several times the minimum values mentioned by Lee et al.

A recently released study on the same Madison, Wisconsin river and lake system by Fitzgerald et al. used chemical and bio-assay methods to determine the effects of phosphorus (58). A study in the early 1940's showed that one of the lakes was accumulating phosphorus as a result of the sewage treatment plant at Madison, Wisconsin. The effluent of this plant was rerouted around the lake in 1958. A 1971 survey indicated that the phosphorus content of the river increased between the inlet and

outlet of the lake. This increase was attributed to additional phosphorus from the lake and its drainage area. They also concluded that it was important to determine the sources of the phosphorus before initiating costly phosphorus removal programs.

Other Considerations

Other researchers have concerned themselves not only with the nutrients in agricultural runoff but with its general chemistry as well. For example, the TVA study by Flippin, which has been mentioned previously, also contains information regarding exchangeable bases, calcium, magnesium, and potassium (47).

Kohnke reported on the anions and cations present in runoff water in Indiana (59). Watershed size varied from 1.5 to 32 acres. A dairy barn was located on one watershed, and some of the watersheds were pastures. In general, the initial concentration of ions was higher than the concentration obtained at peak flows. The predominant cation was calcium and the major anion was bicarbonate.

The interactions of the chemical constituents in a stream which drained a 100 acre watershed in east-central Pennsylvania was investigated by Gburek and Heald (60). The watershed consisted of 90% cultivated land, 8% pasture, and 2% miscellaneous. Two separate storms in 1969 were sampled during and after direct runoff to the stream. Determinations were made for pH, conductivity and water-soluble sodium, potassium, calcium, magnesium, nitrate, chloride, sulfate, and phosphate. Sulfate, pH, and phosphate did not follow any particular pattern. Conductivity was deemed to be the single most representative parameter. They

concluded that the water quality of the stream was directly affected by hydrologic changes, and that the anions and cations responded quickly to changes in the hydrograph (60).

Henderson attempted to put water pollution in its proper perspective in a recent article (61). He warned that recent years have produced pseudoecologists and pseudoenvironmentalists along with exaggerations, distortions, half-truths, bias and a doomsday attitude. Nevertheless, he stated that: "Of these numerous sources, surface land runoff unquestionably is the greatest contributor on a national scale of water and contained solids of most types..."

Summary

Various aspects of the chemical and physical quality of agricultural runoff have been measured by many investigators. The usual method has been to analyze stream samples from watercourses that drained rural or remote areas.

The runoff from agricultural lands apparently has a low organic content, but may be high in total and suspended solids. The BOD concentration will normally be less than the BOD allowed by some effluent standards, 30 mg/l. However, suspended solids concentrations of 5000 mg/l and 6000 mg/l were reported.

The amount of sediment lost in runoff water has been one of the more studied phases of agriculture. Several investigators, primarily those connected with the Agricultural Research Service, have evaluated sediment losses from small research plots. Reported losses of from 2 to 30 ton/acre/yr were common. Losses from larger watersheds ranged from

1 to 8.4 ton/acre/yr. A soil-loss equation has been developed, and it is generally accepted as providing soil-loss information for the area east of the Rocky Mountains.

The excessive fertilization of water, eutrophication, can be caused by agricultural runoff waters. The nutrients present in agricultural runoff have prompted many different studies. A summary of the nutrients in rural runoff has been presented in Table II. Total nitrogen in surface runoff generally ranged from about 1 to 20 lb/acre/yr while total phosphorus varied from about 0.1 to 10 lb/acre/yr.

Various anions and cations present in runoff waters also have been studied. Changes in the concentrations of these ions appear to reflect the hydrologic changes of the watershed.

Bacteriological Indicators of Water Quality

Indicator organisms are usually used to designate the bacteriological quality of a water or wastewater. The bacteriological examinations are important in that they imply the presence or absence of a potential health hazard. Fecal contamination of a water resource is particularly important, especially if the contamination can be attributed to human sources.

At a South Dakota symposium, Middaugh discussed the problems associated with differentiating between animal and human sources of pollution by bacteriological indicators (62). The presence of total coliform organisms implies that suspect bacteria are present, but they do not indicate the source of pollution. The test for fecal coliforms is more selective because it eliminates positive results because of soil

bacteria and indicates fecal contamination. However, the presence of fecal coliforms still does not reveal the source of pollution. Fecal streptococci were also discussed as possible indicators of fecal contamination.

In a more recent symposium Middaugh *et al*. discussed the possibilities of using some very selective indicators to distinguish between animal or human fecal pollution. These were indicators such as *Streptococcus bovis* or certain *Salmonella* species (63). Some of the procedures appear promising, but additional work remains to be done in unknown areas. One such area is the determination of survival characteristics of *Streptococcus bovis* after animal discharges reach a surface water.

As early as the mid-1950's investigators recognized the problem of distinguishing between animal and human fecal contamination of water. Cooper and Ramadan studied the physiological and biochemical characteristics of fecal streptococci taken from the feces of humans, bovine animals, and sheep. The isolated organisms were split into six groups. One group represented the typical *Streptococcus faecalis* group, while the other groups were something other than typical *S. faecallis.* Their results showed that two of the groups of fecal streptococci were derived entirely from humans, two groups were traced directly to animal sources (over 90%); but that two groups were mixed and were not characteristic of a particular source (64).

Geldrich discussed the use of bacteria as indicators of the sanitary quality of water, and the techniques involved in testing for fecal coliforms (65). He presented data (65-102) relating the average densities of fecal coliforms and fecal streptococci present in the feces

of humans, ducks, sheep, chickens, cows, turkeys, and pigs. He advocated a fecal coliform to fecal streptococcus ratio (FC/FS) to indicate whether contamination was from a human or animal source. A FC/FS ratio less than 0.6 would indicate that the fecal source was non-human.

A FC/FS ratio for a water sample of 1.0 or more is now thought to be a result of human sources, while ratios below 1.0 are thought to result from animal sources. Evans et al. tend to verify this ratio by their study of urban stormwater (66). Nine rainfall runoff events were sampled for total coliform, fecal coliform, and fecal streptococcus organisms from a 27 acre residential district in Cincinnati. Fecal contamination was evident from the biological indicators, although the stormwater source did not have any domestic waste contamination. In seven of the nine samples, the ratio of fecal coliforms to fecal streptococcus was less than 0.84.

Several investigators have attempted to determine the bacteriological quality of rural areas by sampling streams which drained areas devoid of municipal or industrial point discharges (67)(68)(69)(70)(71)(39). Investigations of this nature are intended to define the pollutional load from non-point discharges. Ground water which would enter the stream was not considered separately.

Walter and Bottman collected weekly samples from two watersheds in a recreational area in Montana to determine concentrations of coliform and enterococcus organisms (67). One watershed, with its reservoir, was open to public recreational activities while the other watershed had been closed to the public since 1920. Common recreational

activities practiced on the open watershed were swimming, boating, camping, and fishing. Coliform counts increased as the summer progressed, and enterococci counts increased as the water flowed downstream from the reservoirs. Coliform counts from the closed watershed were greater than those from the open watershed in 74% of the tests. Similar results were obtained for enterococci organisms in 59% of the tests. Animals were thought to have been nearer the water in the area closed to the public, and this proximity was offered as a reason for higher counts from the closed watershed. No actual animal counts were made in either area.

Twelve separate streams in forested areas were sampled once or twice by Lowe and Wilson (68). All the sampling points were remotely located from known human habitation. Determinations were made for pH, coliforms, enterococci, and stormy fermentation (a name given to a test because of the action of <u>Clostridium perfingens</u> in milk). Coliform counts ranged from 0 to 12,000/100 ml, enterococci densities ranged from 0 to 3,500/100 ml, and <u>C. perfingens</u> levels varied from 0 to 790/100 ml. They concluded that 11 of the 12 streams were polluted, but they could not determine the source of pollution.

Runoff from a 0.75 sq km watershed in Vermont was sampled by Kunkle for two years (69). The watershed had 37% of its area in hayfields, 38% in pasture and 25% in forested land. About 150 head of cattle were grazed at the headwaters of the watershed during the first year, but they were not on the site after the spring of the second year. Samples were obtained from a stream just below the watershed during normal runoff as

well as when storm water runoff was occurring. Much of the annual runoff resulted from spring snowmelt, but data were reported only for rainstorms.

During periods of storm runoff, total coliform and fecal coliform densities would rise. Maximum densities of 50 or more times the non-storm runoff levels were obtained. Seven summer storms showed median total coliform concentrations from 5,500 to 80,000/100 ml and median fecal coliform levels of 1,100 to 14,000/100 ml. Over 90% of the storm runoff observations for both total and fecal coliforms were greater than acceptable criteria for swimming waters. Kunkle concluded that fecal coliforms were the better indicator of pollution in his study (69).

Kunkle has also sampled some mountain streams for bacteria in conjunction with Meiman (70)(71). One study obtained counts on fecal coliform, total coliform, and fecal streptococcus bacteria from 604 samples taken at ten stations in the Colorado Rocky Mountains (70). The other investigation recorded bacterial densities for the same indicators from two sites on a mountain stream located 1.5 miles apart. A total of 3,102 observations were made in this later study (71).

Both studies revealed fluctuations in numbers of bacterial indicators. Total coliforms varied from 0 to 300 colonies/100 ml, fecal coliform and fecal streptococcus values ranged from 0-75 colonies/100 ml, and FC and FS densities would increase to several hundred per 100 ml. The fecal coliform organisms were found to be most sensitive for detecting animal fecal contamination. Fecal coliform to fecal streptococcus ratios greater than one were obtained from locations below cattle

grazing areas. The fecal streptococcus organisms were thought to be drastically affected by the cold water temperatures involved in the studies (70)(71).

Stoltenberg studied the Soldier Creek basin in northeastern Kansas, an agricultural area of about 290 square miles (39). There were not any point sources of pollution within the basin. About 15% of his samples were obtained during storm runoff. The total coliform, fecal coliform, and fecal streptococcus duration curves were all similar and ranged from about 10 to 100,000 bacteria per 100 ml. He concluded that:

> These relationships suggest that there is no great predomination of bacteria type existing under mixed agricultural and natural conditions. Classically, it has been indicated that the percentage of fecal coliform organisms occurring from unpolluted soil or vegetation is a small portion of the total coliform population, comprising up to a maximum of about 15 per cent. The Soldier Creek data indicates the fecal coliform organisms occurring regularly in substantially greater proportions than this. Of the 200 bacteriological samples analyzed 110 showed the FC count comprising greater than 50 percent of the TC count; and likewise, 67 samples showed the FC count greater than 80 percent of the TC count. These figures tend to indicate that coliform counts from agricultural and natural sources may not be predominantly non-fecal types as previously reported. Comparing the fecal coliform and enterococcus groups, it was found that the average FC/FS ratio for 199 samples was 0.8, indicating again no significant predomination of organism type.

The above conclusion must be viewed with some apprehension. Stoltenberg ignores the important factors of bacterial die-off and the dilutional effects of groundwater. The basin under question has a shallow groundwater table, being from 10 to 100 feet below the ground surface. A number of small springs are in this basin (39). Dilution by ground water reduces the magnitude of the differences between indicator densities. Only 15% of Stoltenberg's samples were obtained during storm

runoff events, so the majority of the test organisms had been exposed to an adverse environment for a considerable period of time before sampling.

Many factors affect the rate of die-off within a particular group of organisms. Even more factors affect the die-off rate when one considers different groups of organisms, e.g. total coliform and fecal coliform. Zerfas showed that the survival times of fecal coliforms and fecal streptococci were temperature dependent, and the rate of die-off was not similar between the two groups of organisms (72-55).

Geldrich et al. (73) and Geldrich and Kenner (74) present data which agree with the above. Die-offs of streptococcus strains were compared with fecal coliforms and Salmonella typhimurium. The sources of the organisms and the media used were various stormwaters. They also found that the die-off rates varied with the particular strain used and that the rates were temperature dependent. The substantial numbers of fecal streptococci that were present were attributed to insects and organisms on vegetation. Many of the fecal streptococci which exist on vegetation are not associated with fecal coliforms and probably do not have any sanitary importance (74).

A study to estimate the contribution of agriculture and/or urban runoff to part of a northern lake was undertaken by Claudon et al. (75). The work was done on Lake Mendota near Madison, Wisconsin. The major sources of organisms were from a residential storm sewer and a washwater drain at the University of Wisconsin Experimental Farm. They found 27

of 53 samples to be positive for Salmonella. They concluded that runoff, even diluted runoff, can regularly add Salmonella to a recreational lake.

Published results of only three investigations which examined natural surface drainage from agricultural lands were found. Two of these investigations were conducted on a 173 acre watershed near Brookings, S. Dak. Benson (12) sampled the watershed during one storm in 1969, and McCarl (13) sampled the same watershed during the 1970 season. Benson obtained samples for total coliform, fecal coliform, and fecal streptococcus throughout a rainfall runoff event. Densities of the organisms generally varied with the flow for the first quarter of the event, but random densities were obtained throughout the remainder of the event (12-42).

McCarl obtained microbial densities for total coliform, fecal coliform, and fecal streptococcus organisms for seven runoff events in 1970 (13). Six of the runoff events resulted from rainfall, but one was a snowmelt runoff event which occurred between rainfall events. McCarl concluded that the concentrations of the organisms generally varied with the suspended solids and organic matter present in the runoff. Analysis of the fecal coliform to fecal streptococcus ratio led him to believe that animals rather than humans were the source of the fecal pollution. Manure had previously been spread on the drainage basin (13-45).

Results of the runoff from six watersheds near Coshocton, Ohio, were reported by Weidner et al. (14). One watershed contained 303 acres, three had 1.5 acres each, and two were sized at 7.5 acres each. The 303 acre basin had mixed cover, and two of the 1.5 acre sites were in a

4-year rotation of corn, wheat, and meadow. One of the 7.5 acre watersheds was strip-cropped, and the other was not. The remaining 1.5 acre watershed was used to study special pesticide applications and mulch planting techniques.

The researchers determined the densities of total coliform, fecal coliform, and fecal streptococcus organisms in the runoff from five watersheds. For some of the watersheds, 90% of the samples exceeded 1000 total coliforms per 100 ml; and this figure was exceeded in 50% of the samples from all of the watersheds. Densities of fecal streptococci were greater than fecal coliform organism densities so they concluded that". . .pollution is from animals rather than humans, as one would expect" (14).

A review of the literature indicates that very little work has been done regarding bacteriological densities for indicator organisms in agricultural surface runoff. Most of the available data resulted from stream samples where the effects of ground water and bacterial die-off rates were not considered. Indicator organism data for only a single snowmelt runoff event were located. Data for this particular event did not adequately reflect snowmelt runoff from a winter's accumulation of snow.

Pesticides in Agricultural Runoff

The production and use of pesticides has grown throughout the United States and the world. During the period from 1963 to 1967, for example, the United States production of synthetic organic pesticides

increased by more than 37 percent. The synthetic organic pesticides include almost all of the known pesticides (76-1).

Agriculture has continued a large demand for pesticides, particularly for corn crops. In a recent year, 57% of the corn planted in the United States was treated with herbicides, and 33% with insecticides. Sometimes large areas are treated from the air, but weather and other practical considerations occasionally limit this method (76-12).

In a South Dakota symposium, Greichus spoke about the residual properties of these agricultural chemicals. These residual properties allow the pesticides to be transported by wind, water, and soil to areas other than where they were applied (77).

The personnel at the Southeast Water Laboratory of the U.S. Environmental Protection Agency in Athens, Georgia have intensively studied insecticide runoff from agricultural land. Nicholson, Grzenda, and others have reported this work in several journals and at various meetings (78)(79)(80)(81)(82)(83).

Nicholson lists three main problems that must be considered when relating pesticides to water quality. The first problem stems from very high pesticide concentrations which result in fish kills or other aquatic damage. The second problem is the outcome of exposing aquatic life to low-level, long-term dosages of pesticides; and the third problem results when pesticides are processed through municipal water treatment facilities. Land runoff is a prime source of the entry of pesticides into surface water resources (81).

At a recent conference, Nicholson expressed the public's concern over pesticides. The focal point of this concern has become DDT. Several countries have banned the use of DDT, and Hungary has banned all organochlorine insecticides (79).

Nicholson and his co-workers showed that several insecticides can enter a watercourse in conjunction with runoff water. He discussed two fish kills which occurred and mentioned instances where fish-eating birds have been poisoned. This poisoning was thought to have occurred from the biological magnification process (80).

Greichus also traced the build-up of pesticides in the food chain by examining the fat of different South Dakota fish, birds, and animals. The various pathways of insecticide residues in an aquatic environment were discussed, and data regarding the concentrations of insecticides in the Lake Poinsett ecosystem were presented (77).

Data pertaining to the pesticides in California's environment were presented by Bailey and Hannum (84). They obtained over 630 samples from surface waters, agricultural drainage, sediments, and aquatic organisms. The concentrations of pesticides in the surface waters correlated with the extent of agricultural development, and the use of pesticides associated with this development. Chlorinated hydrocarbons were found to persist longer and have higher concentrations than other pesticides collected from tile drainage. Concentrations in sediments were found to be much higher than in water. Results also indicated a tendency for the pesticides to concentrate in the higher food chain organisms.

Weibel et al. collected rainfall and runoff samples at some watersheds near Coshocton, Ohio. Specific examples of rainfall transmitting pesticides were documented. In one storm, chlordane, heptochlor epoxide, DDE, DDT, dieldrin, and 2,4,5-T were all detected. Runoff water from a field of winter wheat contained 0.43 µg/l of organic chlorine. The concentration of organic chlorine gives an estimate of the pesticide concentration because a large number of pesticides contain organic chlorine (85).

The fate of agricultural chemicals after they are applied to the land is an important consideration in regard to the quality of agricultural surface runoff. If chemicals are loosely held by the soil, they could be leached into the groundwater or dissolved into surface runoff. If they are tightly held by the soil particles, soil losses become doubly important.

Several researchers have investigated pesticides in the soil environment (86)(87)(88)(89)(90). Lichtenstein stated that some insecticides such as aldrin and parathion are tightly attached to soil particles and that only small amounts may be removed by water. He recognized that surface waters could become contaminated from insecticides being adsorbed onto the soil and subsequently being washed from the field by runoff water (86).

McCarty and King correlated the extent of pesticide adsorption with the clay content of the soil used. They found that the rate of movement of a pesticide in the soil was inversely related to the amount of adsorption (87). The actual method of clay adsorption and the factors affecting this adsorption became topics for research by several

investigators. White and Mortland discussed clay-organic interactions and decided that the soil minerals most responsible for adsorption were those found in clay, and that the attraction of the organic cations to the clay was proportional to their molecular weight. They listed several mechanisms for bonding, and said that the clay particles were active because of their small particle size and relatively large specific surface (88).

Huang and Liao (89) also studied clay mineral adsorption of pesticides, and they present a wealth of data regarding individual pesticide adsorption rates with various adsorption media. They disagree with White and Mortland, however, as they state that the "...adsorptive capacities of the clay minerals are not correlated to their ion exchange capacities or specific surface areas".

Bailey et al. (90) also studied the adsorption mechanisms of a clay, montmorillonite. They stressed that the pH of the clay system plays an important role in the adsorption process. Adsorption mechanisms for both basic and acidic organic compounds were given.

Actual data concerning the level of pesticides in streams are important to a runoff study particularly if the streams drain predominantly agricultural areas. Several investigators have reported field information from some stream studies.

One of the problems previously mentioned by Nicholson dealt with pesticides being passed through municipal water treatment facilities (81). A four-year field study where this problem occurred was reported by Thoman and Nicholson (82). The Flint Creek watershed of Alabama drains a 400 square mile cotton farming area. Agriculture is the basic

industry and cotton is the principal crop. Toxaphene, BHC, and DDT were the most commonly used insecticides in the basin. Insecticides were not applied from the air to any extent.

Just below the watershed, a town of 7,000 people drew its water for the community. An extensive sampling program revealed that toxaphene and BHC were present in both the raw and finished water throughout each year of the study. DDT was not recovered. The lack of DDT in the water was attributed to "...its strong affinity for organic matter in the soil, and to its extreme insolubility in water" (82).

Grzenda _et al_. reported on stream samples taken from a mountain stream which carried the runoff from a 4,000 acre hardwood forest in North Carolina. DDT was sprayed by airplane in 1961 to halt an infestation of a hardwood defoliating insect, _Ennomos subsignarius._ DDT residues were detected in the stream and ranged from 0.346 to 0.005 ppb. Controlled spot-applications were practiced the following year on 49% of the basin after which DDT residues were not detected in either stream or sediment samples (83).

Endrin is often used in sugar cane production. Numerous fish kills in Louisiana were attributed to endrin without substantiating data. Consequently, Lauer _et al._ studied the surface waters to determine if the charges were justified. Endrin was recovered from all the streams sampled and surface runoff was listed as the main source of endrin. Heaviest recoveries were reported during the first runoff event after an endrin application (91).

Data from a survey of 3 of the Great Lakes and 56 major drainage basins of the United States were discussed by Nicholson (79) and

Nicholson and Hill (78). The original data for the discussion were obtained in 1964 by Weaver et al (92). The widespread distribution of dieldrin, endrin, DDT and DDE was noted. However, concentrations of all pesticides in water were less than 1 ppb. Additional stream surveys since then have verified these results (79).

The literature pertaining to pesticides seems to indicate that they are widespread in the environment, being spread by water, soil, and air. Most existing data were obtained from stream samples, although the personnel at the Southeast Water Laboratory have insecticide information for agricultural runoff. Weibel et al. also related pesticides to some organic chlorine measurements from some small watersheds near Coshocton, Ohio (85). Data regarding pesticide levels in agricultural runoff waters for the upper mid-west were not found.

III. METHODS AND PROCEDURES

General

In order to quantify the pollutants in runoff from agricultural lands in eastern South Dakota, it was considered essential that runoff quantity and quality be measured at representative sites. The general approach was to select small watersheds (7 to 20 acres) which had drainageways leading to a culvert. The effluent from the culvert was channeled through a flow measuring device, and samples were obtained from either the exit of the culvert or the flow measuring device.

Site investigations and selections were made in the spring and summer of 1970, and all selected sites are within 20 miles of Brookings, South Dakota. Equipment design, fabrication and installation were completed by the fall of 1970. Landowners, operators, and local county and township road authorities were contacted to ensure cooperation.

Sampling and laboratory determinations were conducted on samples collected during the 1971 and 1972 runoff seasons. Sampling operations and laboratory procedures were tried on some of the sites during most of the 1970 runoff season. These preliminary tests were used to formulate reliable field and laboratory techniques and procedures.

Three laboratories on the SDSU campus were used for testing the samples. Bacteriological samples were examined in the Bacteriology Department's laboratories in the Dairy-Bacteriology building, and pesticide determinations were performed by Station Biochemistry personnel in the pesticide laboratory of the Animal Disease Research and Diagnostic Laboratory. The remaining physical and chemical tests were conducted in the sanitary engineering laboratories in Crothers Engineering Hall.

Both snowmelt and rainfall runoff samples were obtained. Sites were sampled manually during spring snowmelt and an automatic sampler was used during rainfall runoff events.

Site Selection

Prior to searching for suitable research sites, a description of an ideal drainage basin was developed. This description was to be used in site selection to minimize field drawbacks affecting data interpretation.

In general, the ideal site was to be located near Brookings as well as near someone willing to watch the site and assist in sampling. The basin was to have one crop cover, be uniformly farmed, and drain to a single point where electrical connections were available. Access to the site was to be on an all-weather road and the land operator must be willing to provide land use information, e.g. fertilizer application rates. The soil should generally be representative of eastern South Dakota, and aerial photos, soil maps, and topographic maps of the area should be available. The ideal drainage basin was never located.

Seven sites were selected. Four of the sites were located during January of 1970 and the remaining sites were selected later in the summer. Figure 1 shows the general location of the sites which are all located in Brookings County.

The chosen sites generally follow the criteria of the ideal site. They all have one crop cover and drain to a single point. The approach roads were not ideal, but did allow sampling as necessary. Fertilizer information was obtained from the land operators.

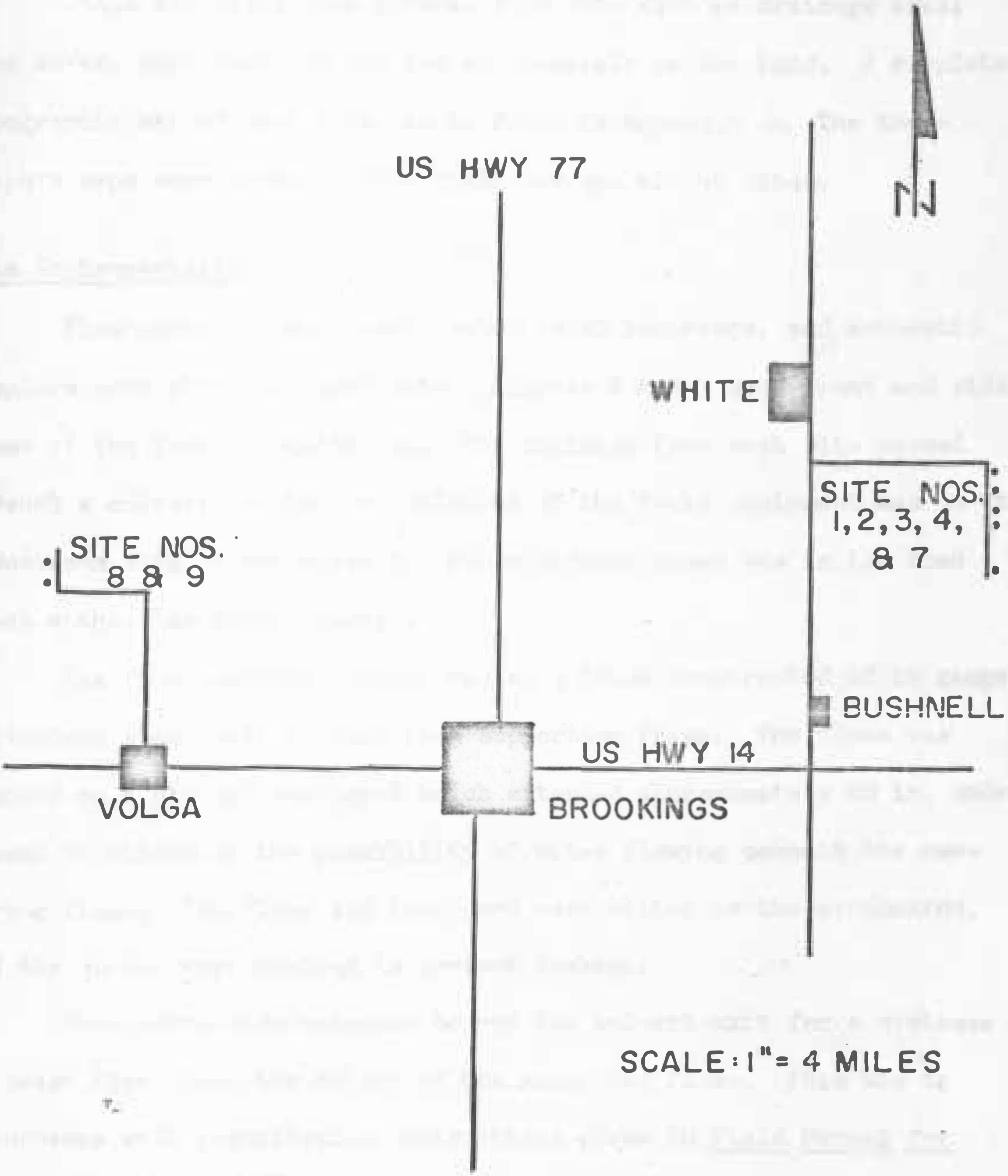

FIGURE 1.- General site locations with respect to Brookings, S. Dak.

Table III lists some general site data such as drainage area, crop cover, soil type and the use of chemicals on the land. A complete topographic map of each site can be found in Appendix A. The topographic maps were prepared from field surveys of the sites.

Site Instrumentation

Flow measuring equipment, water level recorders, and automatic samplers were placed at each site. Figures 2 and 3 show front and side views of the field installation. The drainage from each site passed through a culvert and the installation of the field equipment was on the downstream side of the culvert. All equipment shown was in the road ditch within the right-of-way.

The flow measuring device was an H flume constructed of 14 gauge galvanized steel with a black iron supporting frame. The flume was mounted on a plywood headboard which extended approximately 20 in. underground to eliminate the possibility of water flowing beneath the measuring flume. The flume and headboard were bolted to the sideboards, and the joints were caulked to prevent leakage.

Sideboards were extended beyond the culvert exit for a distance of at least five times the height of the measuring flume. This was in accordance with installation instructions given in Field Manual for Research in Agricultural Hydrology (93-31) to avoid velocity disturbances upstream from the flow measuring device. The distance between the sideboards was equal to the flume width. Sideboards were 4 ft by 8 ft sheets of exterior plywood and extended a minimum of 15 in. below the ground surface to eliminate leakage during runoff events.

TABLE III. - Site Data

Item	Site 1	Site 2	Site 3	Site 4	Site 7	Site 8	Site 9
Area, acres	7.18	8.77	10.12	8.77	15.51	18.68	9.79
Crop cover, 1970	Oats	Oats	Alfalfa, brome grass	Alfalfa, brome grass	Pasture	Corn	Corn
Crop cover, 1971	Oats	Oats	Alfalfa, brome grass	Alfalfa, brome grass	Pasture	Oats	Oats
Crop cover, 1972	Corn	Corn	Alfalfa brome grass	Alfalfa, brome grass	Pasture	Idle acres	Idle acres
Soil texture	Sandy clay loam	Sandy clay loam	Sandy clay loam	Loam	Sandy clay loam	Sandy clay loam	Sandy clay loam
Chemicals used	Yes	Yes	Yes	Yes	No	Yes	Yes
Legal description	NW 1/4, Sec. 23, R48W, T111N, 5th.PM	NW 1/4, Sec. 23, R48W, T111N, 5th.PM	SW 1/4, Sec. 23, R48W, T111N, 5th.PM	SW 1/4, Sec. 23, R48W, T111N, 5th.PM	NW 1/4, Sec. 26, R48W, T111N, 5th.PM	SE 1/4, Sec. 29, R51W, T111N, 5th.PM	NE 1/4, Sec. 29, R51W, T111N, 5th.PM

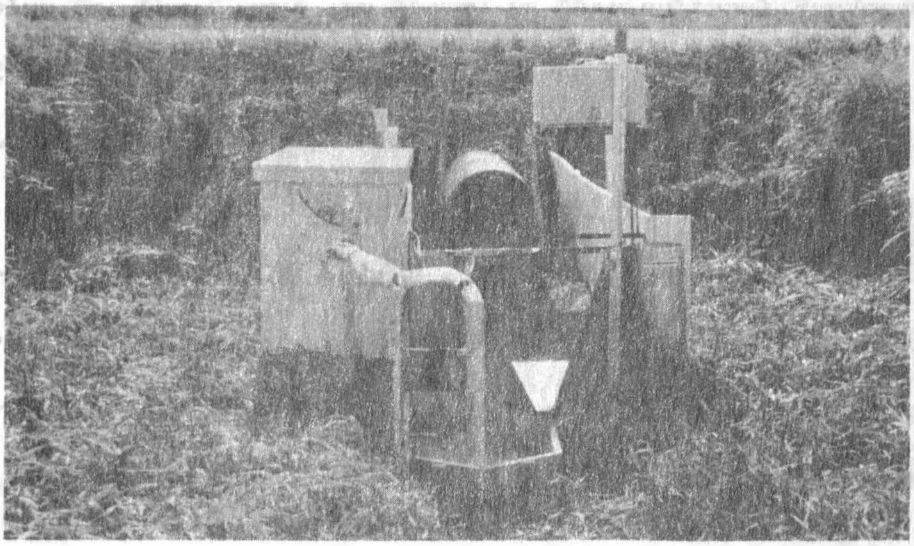

FIGURE 2.-Front view of field installation showing H flume with self-starting stage recorder on the right and automatic sampler on the left.

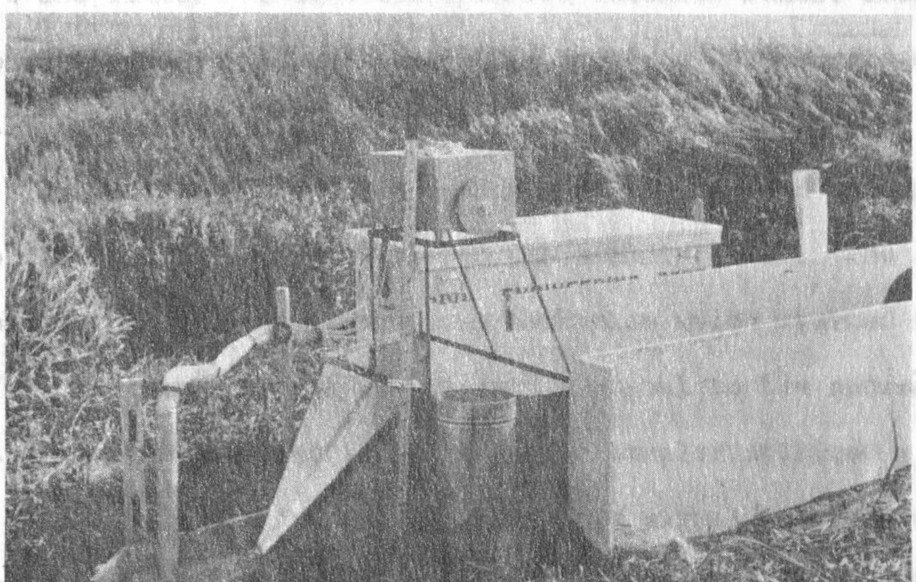

FIGURE 3.-Side view of field installation, note the construction and sampling position of the sampler head.

Sites No. 1, 2, 3, and 4 were equipped with a 1.5 H flume; while Sites No. 7, 8, and 9 were provided with a 2.5H flume. Dimensions and rating tables for the flumes are listed in "Agricultural Handbook No. 224" (93-25).

A Leupold Stevens Type F water level recorder was used to measure the depth of flow in the flume during rainfall runoff events. A continuous record of the depth was traced on a graph by the recorder. The depths were later converted to flow measurements using the rating table previously mentioned. The recorder was equipped with a self-starting device which actuated when the depth of flow through the flume reached 0.05 ft.

During spring snowmelt, the water in the recorder's stilling well was prone to freeze even though the water was still flowing freely in the culvert and flume. Consequently, spring snowmelt runoff measurements were obtained manually using a staff gauge. The recorder was used for rainfall events only.

As flow would commence from the culvert and proceed through the flume, the float would start to rise in the stilling well. The movement of the float actuated the self-starting mechanism which started the recorder. The recorder was modified to send a signal to the automatic sampler at predetermined time intervals. The sampler utilized a vacuum principle to obtain a runoff sample each time a signal was received.

A wooden catch-basin was designed and fabricated to assist in obtaining representative samples when using the automatic sampler. The catch-basin would intercept about one-half of the flow, and allow mixing to occur as the sample was being taken. The automatic sampler head was

located 1 1/4 in. above the floor of the catch-basin. A drainage notch in the front of the catch-basin assisted in sample collection by retarding the runoff water at low flows. The notch and catch-basin were fashioned to maintain a self-cleansing unit, however. Figure 3 shows the positioning of the sampler head and the catch-basin.

Plastic rain gages which could measure rainfall of up to 6 in. were placed at Sites No. 1, 4, 7, and 9. These plastic rain gages were manufactured by Edwards Manufacturing Co. of Albert Lea, Minnesota. Sites No. 2 and 8 were equipped with a recording rain gage which recorded precipitation with respect to time. Rainfall intensity could then be calculated. The recording rain gages were manufactured by the Bedford Instrument Co. of Baltimore, Maryland. These recording or weighing rain gages are of U. S. Weather Bureau approved design with an 8 in. diameter opening. They also had the capability of measuring rainfall of 6 in. or less.

Sampling Snowmelt Runoff

Samples of snowmelt runoff were taken manually from each site at periodic intervals throughout each day. On a normal day, about five or six samples were taken from each site. More frequent sampling was deemed unnecessary because of the relatively uniform qualities of the runoff.

Each time that sampling occurred, two individual samples were collected. One sample was obtained in a sterile plastic bag for bacteriological testing. Another sample was obtained in a clean glass container. All samples were marked for identification. Two composite

samples were made after the day's sampling was completed; one from the plastic bags and one from the glass containers.

Depth measurements were taken from the H flumes throughout each runoff day. Usually depths were measured and recorded at one-half hour intervals from about 8 AM to 6 PM. Readings were taken at less frequent intervals thereafter, since the flow would normally have dimished by this time. Readings were taken with a staff gage and recorded to the nearest one-hundredth of a foot.

Sampling Rainfall Runoff

Because of the short duration and unpredictable occurrence of a summer rainstorm, it was not possible to collect these runoff samples manually. An automatic sampler was therefore used to obtain rainfall runoff samples. Manual sampling was sometimes employed to supplement those samples collected by the automatic sampler. Manual sampling was especially necessary for those rainfall events which had a duration of more than four hours.

Desirable criteria developed for the automatic sampler for the project included that it be self-starting, obtain a large volume sample, and collect representative samples of the total flow. The self-starting feature was necessary because the research sites were remotely located and personnel were unavailable at short notice to collect samples. A sample volume in excess of 1,500 ml was needed for the laboratory determinations. Because of the anticipated quality changes that would occur throughout a runoff event, it was necessary that the final composited sample depict the entire runoff period. Also since electrical power

was not available at the remote locations, any sampler which needed an electrical hook-up was unsuitable.

A satisfactory sampler to meet these criteria could not be purchased. Many of the commercial samplers required 110 volt electrical energy to drive a sampling pump. Other samplers obtained a composite sample comprised of individual aliquots collected at fixed time intervals and because the volume of each individual aliquot was the same, the composite sample would not be representative of the runoff event. Still other samplers could not be adapted to become self-starting when flow began. Because of these shortcomings, an automatic, self-starting sampler was designed to satisfy the requirements of the project.

The sampling unit designed for this project incorporated the flow measuring device, an H flume equipped with a water level recorder, as an integral part of the sampling unit. Flow through the flume started the sampling sequence.

The sampler contained 12 sample bottles (about 2 liters each) which had been evacuated. As the vacuum was released on one of the bottles, a water sample was drawn into the bottle. The sampler was connected electrically to attachments on the Leupold & Stevens Type F water level recorder equipped with a self-starting clock. Power was supplied by two 6 volt dry cell batteries wired in series to make a 12 volt system. The operational sequence of the sampler was as follows:

1. The float on the water level recorder would rise when water started to flow and an automatic clock starter actuated the recorder clock.

2. As the clock ran, it caused the recording pen to move across the sheet. An attachment to the recording pen periodically completed an electrical circuit as the pen traveled across the recorder.

3. Upon completion of the electrical circuit, a solenoid was actuated which tripped a mechanism which released the vacuum held in one of the bottles.

4. As the vacuum decreased, the water sample was collected through individual hoses connecting each bottle to the sampler head.

Figure 4 shows an overall view of the interior of the sampler. Each bottle had an intake hose with a solenoid operated clamp which pinched off a rubber hose to contain the vacuum in the bottle until released. A vacuum of about 24 in. Hg was applied to the 12 individual bottles, contained within the sampler. The water sample entered the bottle which was under negative pressure. The sampler head consisted of glass tubing connected to Tygon tubing. The glass tubing was protected by an aluminum tubular shield.

Figure 5 shows some of the details of the hose clamping system. The hose clamps were manually latched and an electrical solenoid released the clamp as the solenoid received a signal from the recorder. With all of the solenoid-operated clamps engaged vacuum was applied to the bottles using a vacuum pump and a portable generator, through a common manifold. The manifold was located on the backside of the crosspiece at the top of the sampler through which the 12 hoses pass. After the proper amount of vacuum had been attained, a Hoffman "H" clamp was tightened on each hose to seal each bottle individually until the vacuum was released by the solenoid clamp. For the top row of the solenoid-operated clamps shown in Figure 5, the two hoses on the left are pictured in the clamped position whereas the four clamps on the right have been opened by the solenoid.

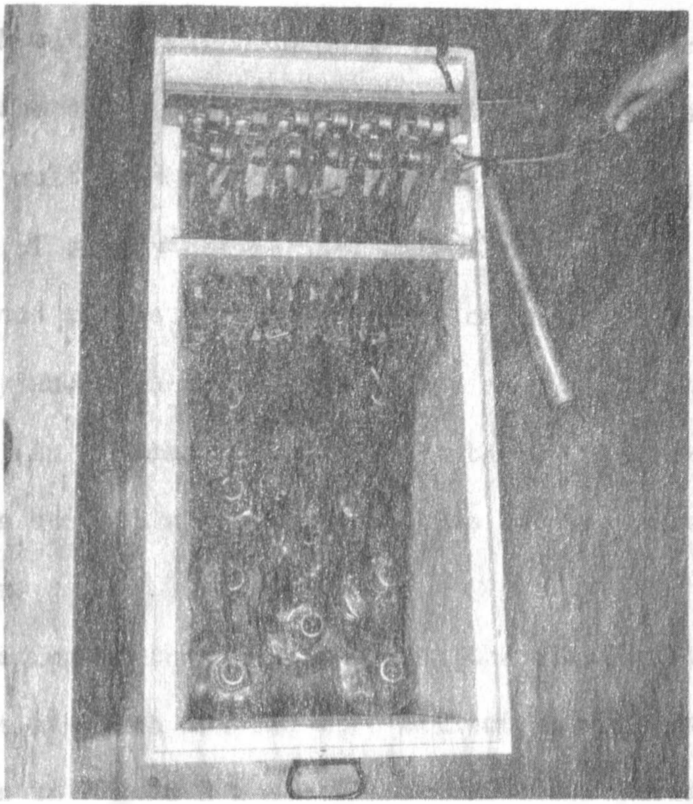

FIGURE 4.-Interior view of sampler.

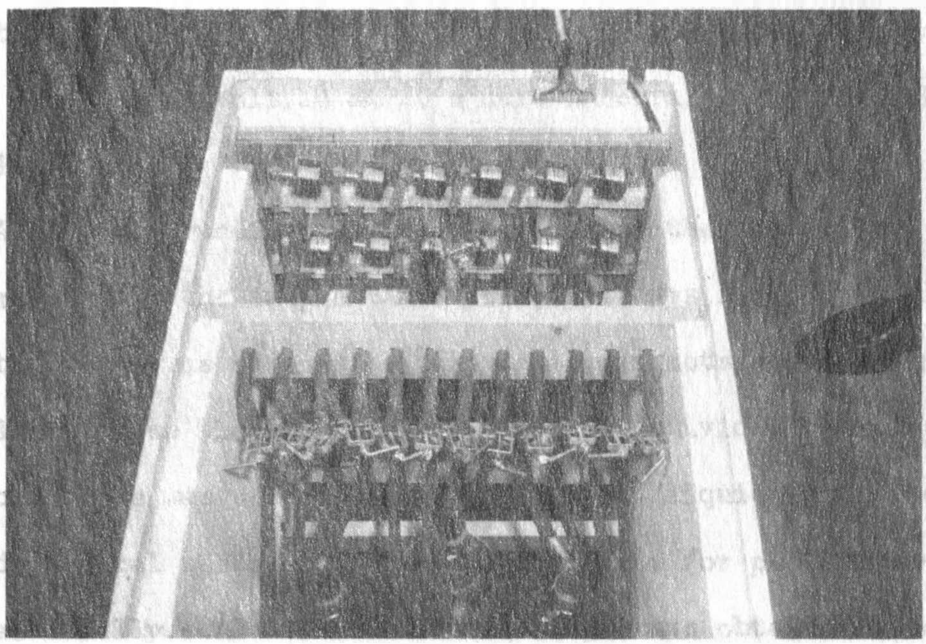

FIGURE 5.-View of solenoid controlled clamping system for the sampler.

Figures 6 and 7 show the modifications made to the Leupold and Stevens Type F water level recorder. A multi-conductor cable connected the sampler, where the battery and solenoids were contained, to the recorder by the multi-connector plug shown in Figure 6. A plastic strip with two rows of screws was mounted directly above the pen path on the recorder. These screws served as electrical connections which were wired to the battery and solenoid clamps in the sampler through the multiconductor cable. An attachment fastened on the pen carriage served as a switch to make contact with both screws as the pen traveled the length of the chart drum.

The spacing of the contacts along the plastic strip determined the time intervals at which samples were collected. The particular level recorder shown in Figure 7 was equipped for a four hour runoff event, and after starting would collect 12 individual samples in succession. Time intervals for collection were two samples each at 5 minute intervals, 2 at 10 minute intervals, 4 at 20 minute intervals, and 4 at 30 minute intervals.

After each runoff event the samples and the stage level chart were removed from the sampler and the sampler was reset. A single liquid composite sample was made using individual aliquots representing the flow volume at the time of collection of the individual samples. This single composite was used for bacteriological, liquid pesticide, chemical, and physical tests. A separate mud sample for pesticide determinations was usually collected. This mud sample was obtained after the runoff was finished by scraping mud deposits from various points where fresh sediment was apparent. The mud sample was used as an indication

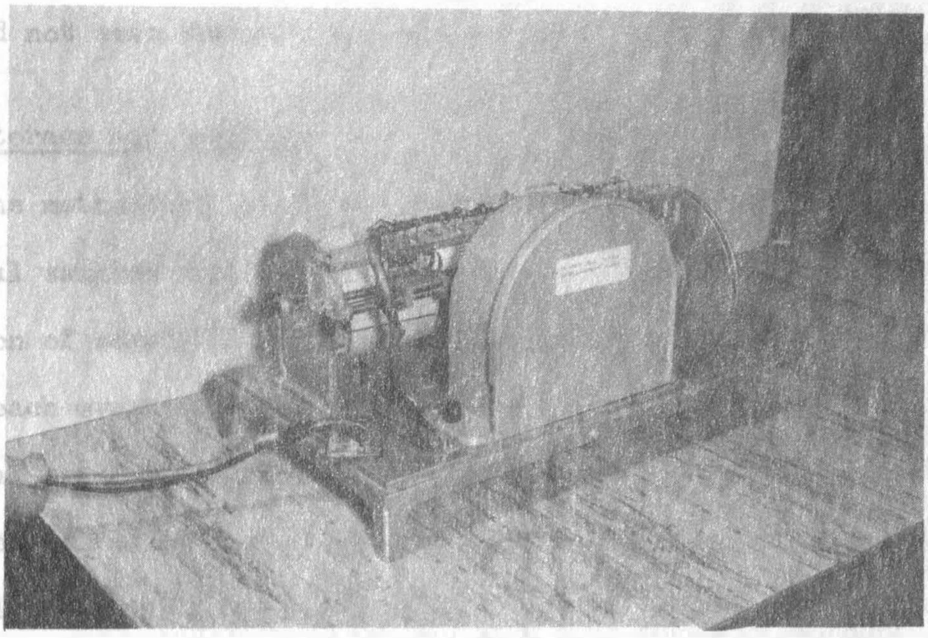

FIGURE 6.-Type F water level recorder with modifications to activate automatic sampler.

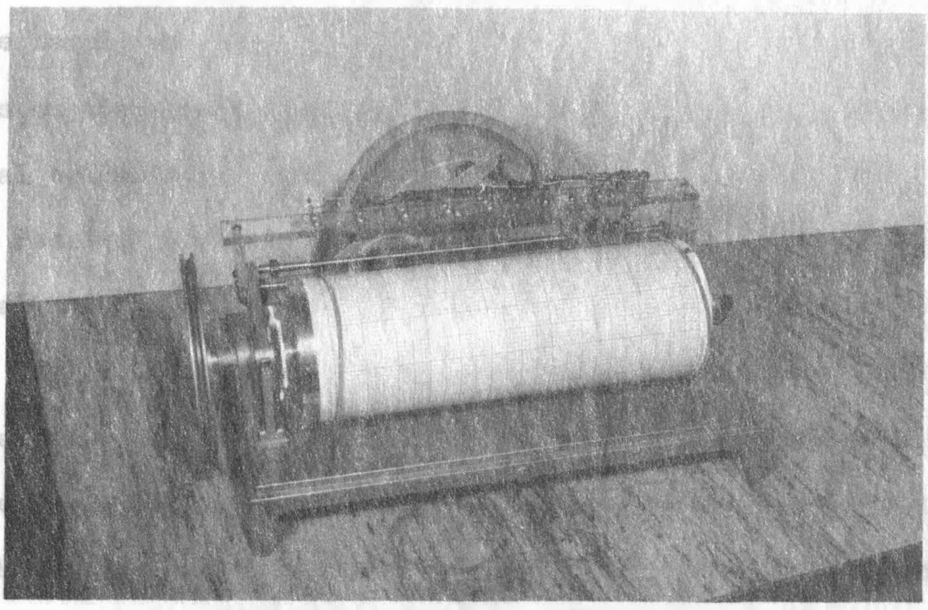

FIGURE 7.-View of level recorder showing mounting of plastic strip.

of the pesticide associated with sediment. If fresh sediment accumulations did not seem obvious, mud samples were not taken.

Sample Storage and Handling

The methods of sampling runoff were the manual collection of individual samples during snowmelt runoff, and the automatic and manual collection of samples during rainfall runoff. A single composite sample for each event was then made from the individual samples. Each individual sample represented a certain percentage of the total flow, therefore the volume taken from the individual sample was this percentage multiplied by the required volume of the composite sample.

Figure 8 depicts the processes followed during snowmelt runoff. Discrete samples were held at 4°C prior to compositing. Compositing was completed within 12 to 28 hours after sample collection. Part of the composite sample was then frozen for later analysis. Laboratory determinations on the remaining sample portion were finished within one week of initial collection. Samples were stored at 4°C during this one week period. Passing the sample through the 0.45 micron filter allowed the determination of the soluble fraction of certain constituents; namely, chemical oxygen demand, total kjeldahl nitrogen, and total phosphorus.

Certain determinations were thought to be affected by freezing and these were conducted on fresh, unfrozen aliquots. All determinations, which were carried out on a sample which was preserved by freezing, were verified by utilizing a test set of samples to determine the concentration of the particular parameter before and after frozen storage. Because of time limitations during snowmelt runoff, the

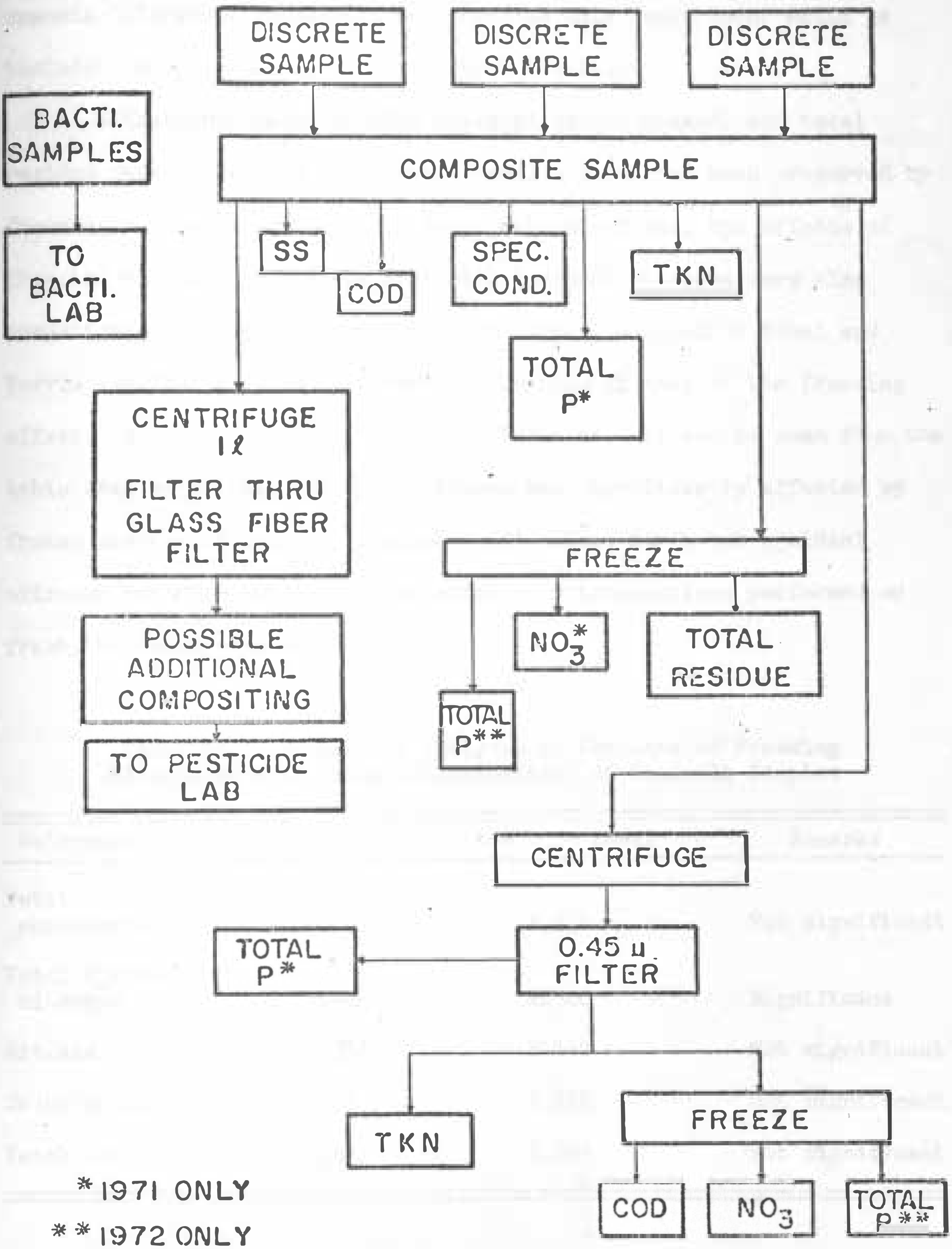

FIGURE 8.-Flow diagram for snowmelt determinations.

ammonia determination was not performed as this constituent would be included in the total kjeldahl nitrogen results.

Nitrate-nitrogen, soluble chemical oxygen demand, and total residue were determined on snowmelt samples which had been preserved by freezing. In addition to these three determinations, the effects of freezing on total phosphorus and total kjeldahl nitrogen were also investigated. A t-test based on a procedure presented by Steel and Torrie (94-79) was used to determine the significance of the freezing effects, and the results are shown in Table IV. It can be seen from the table that only total kjeldahl nitrogen was significantly affected by frozen storage of snowmelt samples. All values for total kjeldahl nitrogen reported herein were obtained by determinations performed on fresh, unfrozen samples.

TABLE IV. - Summary of Analysis of Variance of Freezing Effects on Analytical Determinations of Snowmelt Samples

Determination	t	t @ 0.05 Level	Remarks
Total phosphorus	0.083	2.262	Not significant
Total kjeldahl nitrogen	2.41	2.306	Significant
Nitrate	0.316	2.262	Not significant
Soluble COD	1.92	2.262	Not significant
Total residue	0.91	2.365	Not significant

Initially during 1971 the pesticide determinations were made on each snowmelt composite sample. Because the concentrations were below the analytical limits of the tests, later pesticides analyses were made on a sample representing a composite of two or three days flow.

The analytical determinations of the rainfall runoff samples were made on fresh, unfrozen composites. All determinations made of the snowmelt samples were also made of the rain runoff samples. In addition, ammonia was determined, and pesticide analyses were conducted on a sediment sample as well as the water portion of the runoff. Rainfall runoff samples were stored at 4°C until tested. All determinations on rainfall runoff samples were completed within one week of collection.

Bacteriological Determinations

Total coliform, fecal coliform, and fecal streptococcus determinations for all composite samples were made under the direction of Dr. Paul Middaugh. The density (MPN/100 ml) was found using the multiple-tube fermentation technique described in the 12th and 13th Editions of "Standard Methods" (95)(96). Both the fecal coliform and fecal streptococcus technics utilized the confirmed test; the fecal coliforms were confirmed by using brilliant green lactose bile broth, and the fecal streptococci were confirmed by using ethyl violet azide broth. Fecal coliforms were determined using technics requiring EC medium and a temperature of 45°C.

During periods of snowmelt runoff, bacteriological samples were collected in sterile plastic bags, stored at 4°C, and then composited according to flow. Tests were started on the composite samples approximately 16-24 hours after initial collection.

Individual bacteriological samples were not collected for rainfall runoff events. A single composite sample was made from the discrete samples which the automatic sampler had collected, and the bacteriological sample was a portion of this composite sample. Tests were initiated on the bacteriological samples within approximately 12 hours after initial collection by the automatic sampler.

Pesticide Determinations

Pesticide analyses were performed under the direction of Dr. Y. A. Greichus. All water samples were analyzed by the procedures described in The Identification and Measurement of Chlorinated Hydrocarbon Pesticides in Surface Waters (97-22). The following insecticides were included; lindane, heptachlor, aldrin, heptachlor epoxide, DDE, DDD, DDT, and dieldrin; while herbicides included the triazines, simazine and atrazine.

On all snowmelt samples, pesticide data were obtained on only the runoff waters; sediment was excluded by filtration according to "Standard Methods" (96-537). On rainfall runoff samples, data were obtained on both the water and sediment portions of runoff.

Pesticide composites for rainfall runoff represented a single event. However, because of the low concentrations of pesticides in the snowmelt runoff; the snowmelt samples were composited over a longer time period which was normally of two to three days duration.

Determinations Using the Auto Analyzer

Several of the analyses were made by using a basic autoanalyzer system as manufactured by the Technicon Corporation. Components used

included proportioning pumps and manifolds, heating baths, a continuous digester, colorimeter, and recorder. Tests conducted using the autoanalyzer were soluble chemical oxygen demand, raw and soluble total phosphorus, raw and soluble total kjeldahl nitrogen, ammonia, and nitrate.

Methods used on the autoanalyzer are based on "Standard Methods" (95). They are basically the same procedures as used in the laboratories of the Environmental Protection Agency and listed in Methods for Chemical Analysis of Water and Wastes 1971 (98). Specific laboratory methods used were obtained from the Technicon Corporation and are shown in Table V.

Industrial Method 1-68W was used for total phosphorus although the method is specified for orthophosphate. Total phosphorus samples were prepared by sample digestion on a hot plate as described in Methods for Chemical Analysis of Water and Wastes 1971 (98-254). Glassware was cleaned with 1:1 HCl.

TABLE V. - Autoanalyzer Methodology

Test	Technicon Methodology	
Soluble chemical oxygen demand	Industrial Method	26-69W
Raw and soluble total phosphorus	Industrial Method	1-68W
Raw and soluble total kjeldahl nitrogen	Industrial Method	30-69A
Ammonia	Industrial Method	19-69W
Nitrate	Industrial Method	32-69W

Other Physical and Chemical Determinations

All remaining analytical determinations were conducted in accordance with "Standard Methods" (95)(96). Parameters so measured were total suspended matter, total residue, chemical oxygen demand, and specific conductance.

Total suspended matter was determined by passing the sample through glass fiber filter disks positioned on a membrane filtering apparatus. The filters were dried at 103°C and allowed to cool in a desiccator before weighing. Blanks were handled in the same way as the filters to account for any weight loss of the filters upon drying. Suspended matter was computed from the weight gain obtained after drying.

The test for total residue on evaporation specifies a drying temperature of 103°C to minimize losses of volatile materials which may be present. Coors porcelain evaporating dishes were used, and were preweighed to a constant weight. Sample volumes of 100 ml were evaporated on a water bath and the dishes were dried to a constant weight in an oven, cooled and weighed. The weight gain represented the total residue of the sample.

Chemical oxygen demand determinations were conducted using the standard dichromate reflux method with sample volumes of 20 ml. Specific conductance values were obtained using a Type RC conductivity bridge as manufactured by Industrial Instruments, Inc. of Cedar Grove, N. J. The cell constant was checked periodically and the samples were allowed to warm up to room temperature before the conductivity was measured. Conductivity valves were adjusted to a value at 25°C by using a graph based on a 0.01 M KCl solution.

IV. EXPERIMENTAL DATA AND RESULTS

General

All the data presented herein were collected during the calendar years of 1971 and 1972. The runoff season for each year was established as starting on January 1 and concluding on December 31 of that year. Runoff for each season includes all the runoff from snowmelt during the spring, as well as the runoff which resulted from rainfall throughout the year.

Laboratory determinations were conducted in three general areas; (a) bacteriological, (b) pesticides, and (c) physical and chemical. The results from each of these areas will be presented individually. Throughout this discussion, the term runoff will be construed as meaning surface runoff only.

Hydrologic Aspects of the Runoff

All the research sites are located within Brookings County and within 20 miles of Brookings, South Dakota; an area that annually receives about 20.4 inches of precipitation. Over 80% of the precipitation occurs as rainfall, and the annual snowfall averages 23 inches (99).

Runoff in the area ensued from two general conditions. The first runoff situation occurred in the spring with the melt of the accumulated snow. The snowmelt runoff may be interrupted periodically by subfreezing temperatures or it may continue for an extended period until snow no longer remains.

Rainfall runoff is the second general condition. Surface runoff from rainfall begins when the infiltration capacity of the soil is exceeded by the rate of precipitation. The infiltration capacity may be exceeded by a high intensity rainstorm or a long duration storm. During the long duration storm the pores eventually become saturated and runoff occurs. The rainfall runoff resulting from these two situations is considerably different, as will be discussed later.

Table VI, a precipitation summary, indicated that 1971 was probably about an average year with regard to precipitation, while 1972 was considerably above average. The rainfall data collected at Sites No. 2 and 8 are considered to be more accurate because recording rain gages approved by the United States Weather Bureau were used at these sites. The other sites were equipped with plastic Tru-Chek gages as manufactured by the Edwards Manufacturing Co. of Albert Lea, Minnesota. Because Sites No. 1 and 2 are adjacent, and Sites No. 8 and 9 are adjacent; it appears that the recorded rainfall from the plastic rain gages averaged about 3% to 5% high.

TABLE VI. - Precipitation Summary at Research Sites From Mid-March to Mid-November

Site No.	Type of Gage	1971 Rainfall (in.)	1972 Rainfall (in.)
1	Plastic	19.96	26.56
2	Recording	19.05	24.49
3 & 4	Plastic	19.70	25.88
7	Plastic	19.64	26.35
8	Recording	18.11	27.93
9	Plastic	18.58	28.93

Table VII shows the increase in the number of runoff events for the 1972 season. Comparing the total runoff events for the two years causes speculation regarding the amount of runoff which results from rainfall during a normal year.

TABLE VII. - Frequency of Runoff from Rainfall

Year	Average No. of Days of Rainfall	Actual Days of Rainfall Runoff	Number of Events of Rainfall Runoff
1971	49	2	2
1972	64	14	30

Actually 1971 can not be considered as a normal year with respect to rainfall. While the total amount of rainfall was normal, the seasonal distribution of the rainfall was quite abnormal. Almost one-third of the total rainfall came after August which resulted in a limited runoff because of the established crop cover. Mr. Lytle, an Associate Professor of Agricultural Engineering at South Dakota State University, reflected the local concern over the rainfall in an August 1971 issue of the <u>Brookings Daily Register</u> (100):

> Lytle said the normal rainfall is 12.69 inches and Brookings has received only 9.34 inches to date. There has only been a trace of rainfall recorded in Brookings in the last two weeks.
>
> In July Brookings received 1.13 inches of rain compared to the 2.58 normal rainfall. In June the average is 3.91 inches, but Brookings received only 1.56 inches. Lytle explained that such a shortage of rain as Brookings had in June occurs only once in every 16 years.

Considerably more rainfall than usual was recorded during 1972. A substantial amount of this rain was received in late spring and early summer before cover became established on the cultivated fields which was reflected in the large increase of rainfall runoff events for 1972. In May of 1972, a total of 9.35 in. of rain was recorded at Site No. 8 and 7.97 in. was recorded at Site No. 2. This May of 1972 was the wettest May on record and ranks as the second or third wettest month since record keeping began in 1893 (99).

Therefore, as far as rainfall runoff is concerned; the two years of study can be considered as approaching the maximum and minimum conditions. The first year, 1971, was a minimal rainfall runoff year because the precipitation occurred when the ground cover was well established. The second year, 1972, approached a maximum rainfall runoff condition because much of the rainfall occurred when the ground was unprotected.

Several factors affect both the quantity and quality of surface runoff. Some of these factors are surface and subsoil type and formation, ground cover, intensity and frequency of precipitation, the total amount and duration of rainfall, the topography of the area, land management practices, and the time of the year.

To fully evaluate the effect of each factor was beyond the scope of this project. However, some of the above factors are quite pertinent to the runoff patterns obtained for a particular site; and they will be referred to as the runoff results are presented.

Figures 9 and 10 illustrate the runoff patterns for each of the two project years. A comparison between the two years regarding the relative proportion of snowmelt and rainfall runoff is quite interesting.

The first year had an almost negligible amount of rainfall runoff. Figure 9 shows that all of the sites, with the exception of Site No. 8, had snowmelt as their only surface runoff. Rainfall runoff accounted for only about 0.2% of the year's runoff volume on this single site.

Figure 10 indicates that the rainfall runoff for all the sites during the second year was substantially greater than for the first year. The primary reason for this difference was the change in seasonal rainfall distribution. These figures also point out variations in the amount of snowmelt runoff. Only sites No. 3 and 7 experienced the same approximate magnitude of snowmelt runoff, and Site No. 9 did not have snowmelt runoff. The previous year Site No. 9 had 1.66 in. of snowmelt runoff.

Obviously the conditions affecting snowmelt runoff will not be the same from year to year. Snowfall will vary, evaporation will change, the rate of thawing for the soil and the snow will differ; and in general, it is difficult to correlate conditions from year to year. However, it was very apparent to even the most casual observer that only small amounts of snowmelt runoff would be measured on Sites No. 1, 2, 8, and 9 during 1972. All four of these sites had been in the fallow state since the fall of the previous year and the wind had kept the sites almost clear of snow throughout the winter. The effects of wind erosion were evident.

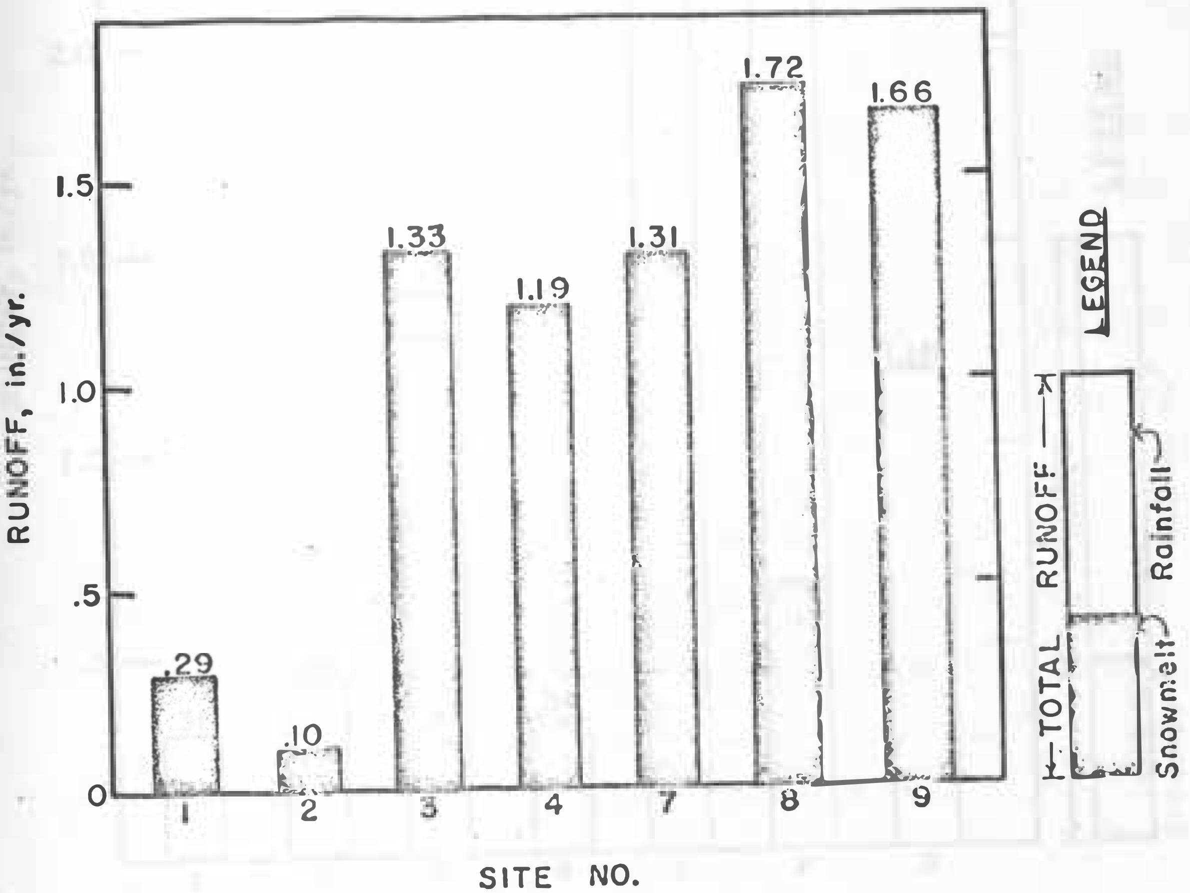

FIGURE 9—Runoff pattern for 1971.

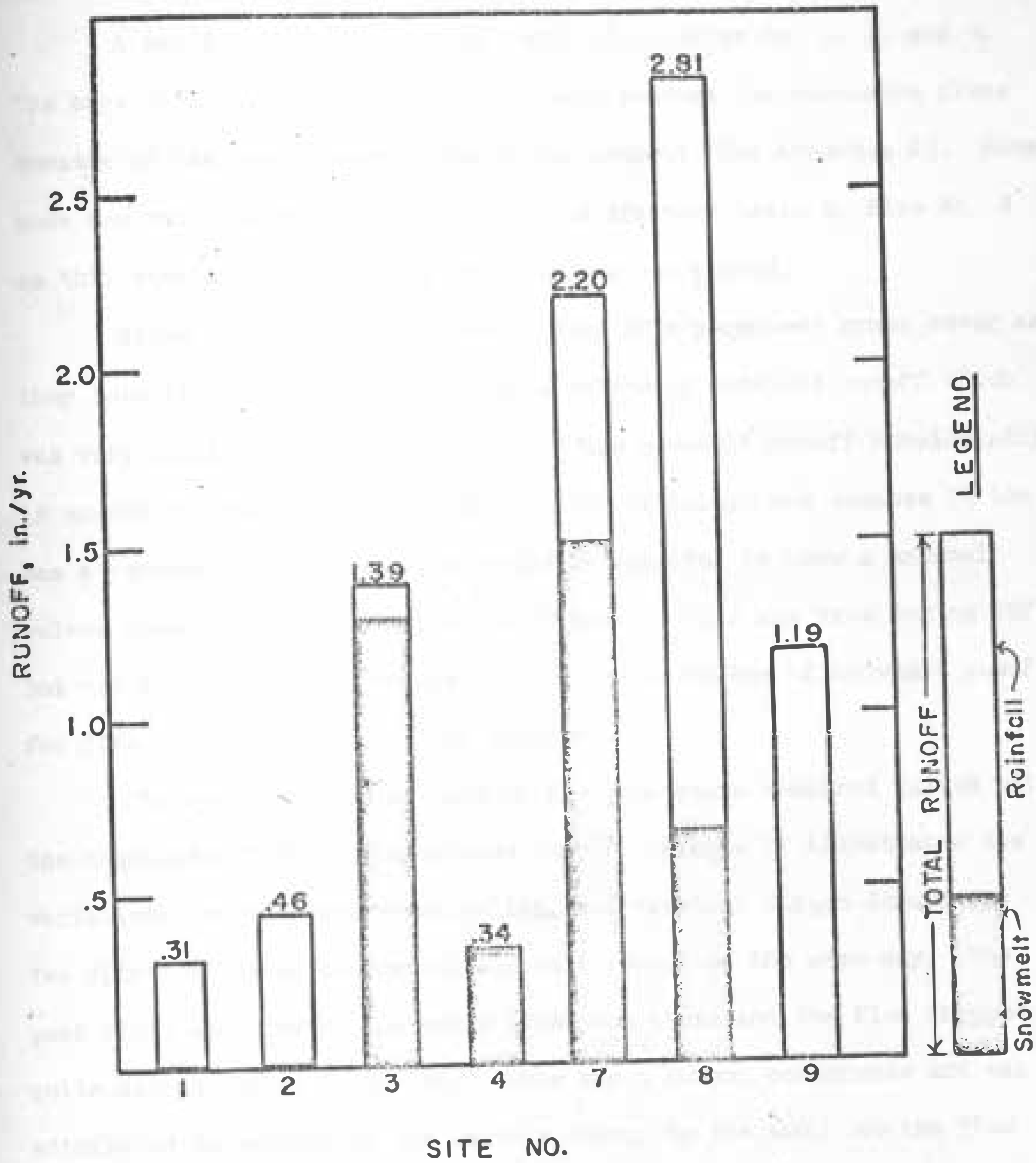

FIGURE 10.– Runoff pattern for 1972.

A small amount of snow was retained on Sites No. 1, 2, and 9. The snow which melted on Site No. 9 never reached the measuring flume because of the small natural depression present (See Appendix A). Some snow was retained near the summit of the drainage basin on Site No. 8 as this particular segment of the area was not plowed.

Sites No. 3 and 7 show the effects of a permanent grass cover as they both retained the snow and had a volume of snowmelt runoff which was very similar. Although Site No. 4 has snowmelt runoff considerably in excess of the cultivated fields in its vicinity, and because it too has a permanent grass cover; it would be expected to have a snowmelt volume resembling that of Sites No. 3 and 7. This was true during 1971 but not during 1972. A reason for the lesser volume of snowmelt runoff for Site No. 4 for 1972 was not apparent.

The concentration of many of the parameters measured varied with the magnitude of the instantaneous runoff. Figure 11 illustrates the variations in flow, suspended solids, and chemical oxygen demand for two different sites undergoing snowmelt runoff on the same day. The peak flows came during the early afternoon hours and the flow dropped quite rapidly later in the day. This was a common occurrence and was attributed to warming of the earth's canopy by the sun. As the flow increased, so did the concentration of the suspended solids and the chemical oxygen demand. Note, however, that even though the flow on Site No. 7 was almost twice that of Site No. 8; the variation in suspended solids and chemical oxygen demand was much more pronounced for Site No. 8 than for Site No. 7. This variation again demonstrates the

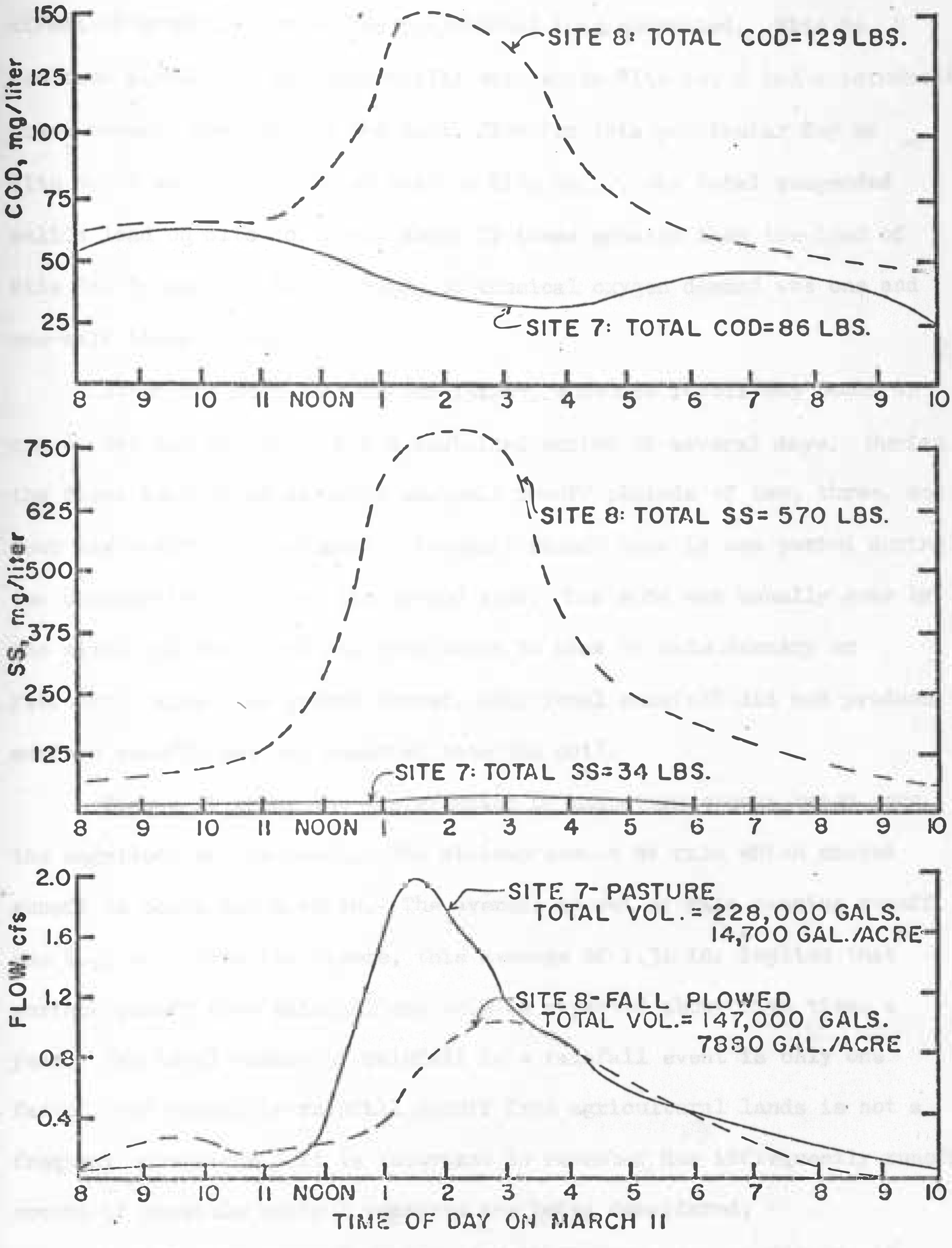

FIGURE 11.- Effects of crop cover on snowmelt runoff.

effect of ground cover on the pollutional load generated. Site No. 8 had been plowed and was essentially bare while Site No. 7 had a permanent grass cover. Even though the total flow for this particular day on Site No. 8 was about half of that on Site No. 7, the total suspended solids load on Site No. 8 was about 17 times greater than the load of Site No. 7; and the total pounds of chemical oxygen demand was one and one-half times greater.

Depending upon weather conditions, snowmelt runoff may occur in one or two day spurts or for a sustained period of several days. During the first year three separate snowmelt runoff periods of two, three, and four day's duration occurred. Snowmelt runoff came in one period during ten consecutive days for the second year. The snow was usually gone by the middle of March and may have begun to thaw in late January or February. After the ground thawed, additional snowfall did not produce surface runoff, but was absorbed into the soil.

Figure 12 shows the distribution of rainstorm events based upon the magnitude of the event. The minimum amount of rain which caused runoff to occur was 0.40 in. The average amount of rain causing runoff was 1.31 in. From the figure, this average of 1.31 in. implies that surface runoff from rainfall can only be expected about five times a year. The total amount of rainfall in a rainfall event is only one factor, but certainly rainfall runoff from agricultural lands is not a frequent occurrence. It is important to remember how infrequently runoff occurs if possible control measures are being considered.

The flow hydrograph for a rainfall runoff event on Site No. 8 is shown in Figure 13. Notice how quickly the flow peaked after runoff

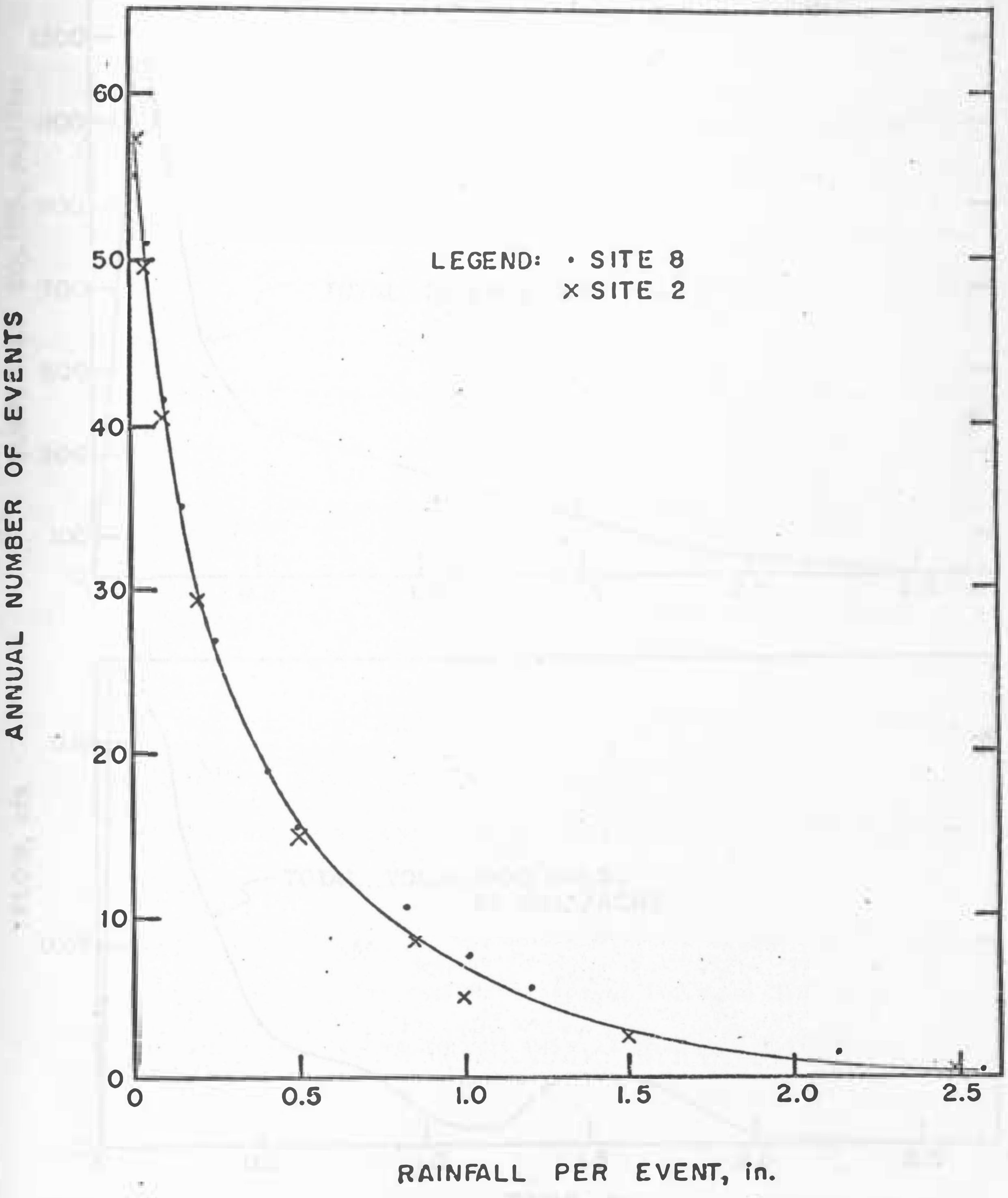

FIGURE 12.—Distribution of rainfall events.

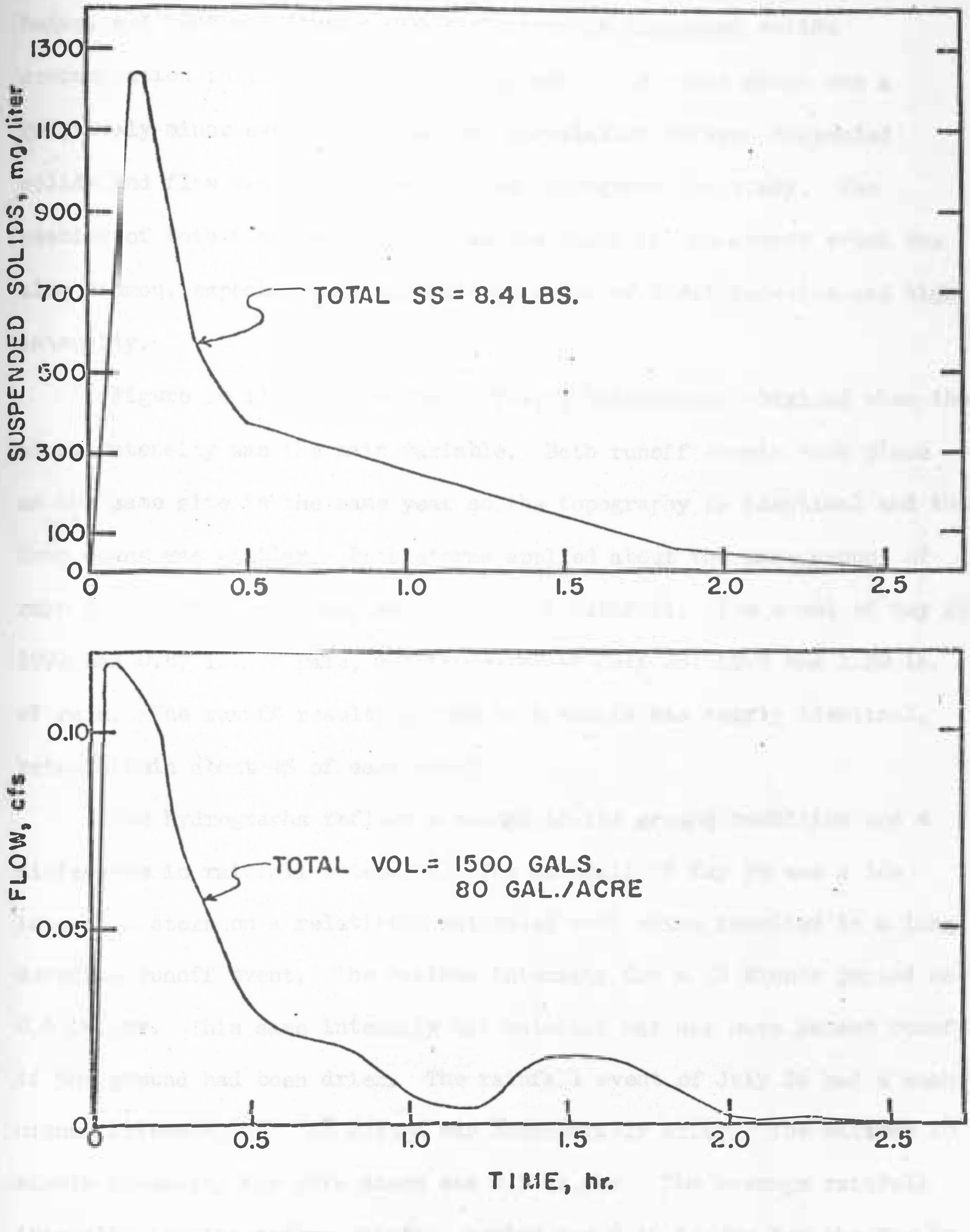

FIGURE 13.- Variations in flow and suspended solids for Site 8 on June 8, 1971.

began, and also how closely the variations in suspended solids concentration followed the flow hydrograph. The event shown was a relatively minor event, but the same correlation between suspended solids and flow was noticed many times throughout the study. The peaking of both flow and solids near the start of the runoff event was also common, especially if the rainstorm was of short duration and high intensity.

Figure 14 illustrates the different hydrographs obtained when the storm intensity was the main variable. Both runoff events took place on the same site in the same year so the topography is identical and the crop cover was similar. Both storms applied about the same amount of rain to the drainage area, about 1 in. of rainfall. The event of May 29, 1972 had 0.87 in. of rain, and the event of July 26, 1972 had 1.20 in. of rain. The runoff resulting from both events was nearly identical, being within about 4% of each other.

The hydrographs reflect a change in the ground condition and a difference in rainfall intensity. The rainfall of May 29 was a low intensity storm on a relatively saturated soil which resulted in a long duration runoff event. The maximum intensity for a 10 minute period was 0.6 in./hr. This same intensity and rainfall may not have caused runoff if the ground had been drier. The rainfall event of July 26 had a much higher intensity and the ground was considerably drier. The maximum 10 minute intensity for this storm was 2.7 in./hr. The average rainfall intensity for the entire rainfall period was 0.16 in./hr for the May 29 event and 1.1 in./hr for the July 26 event.

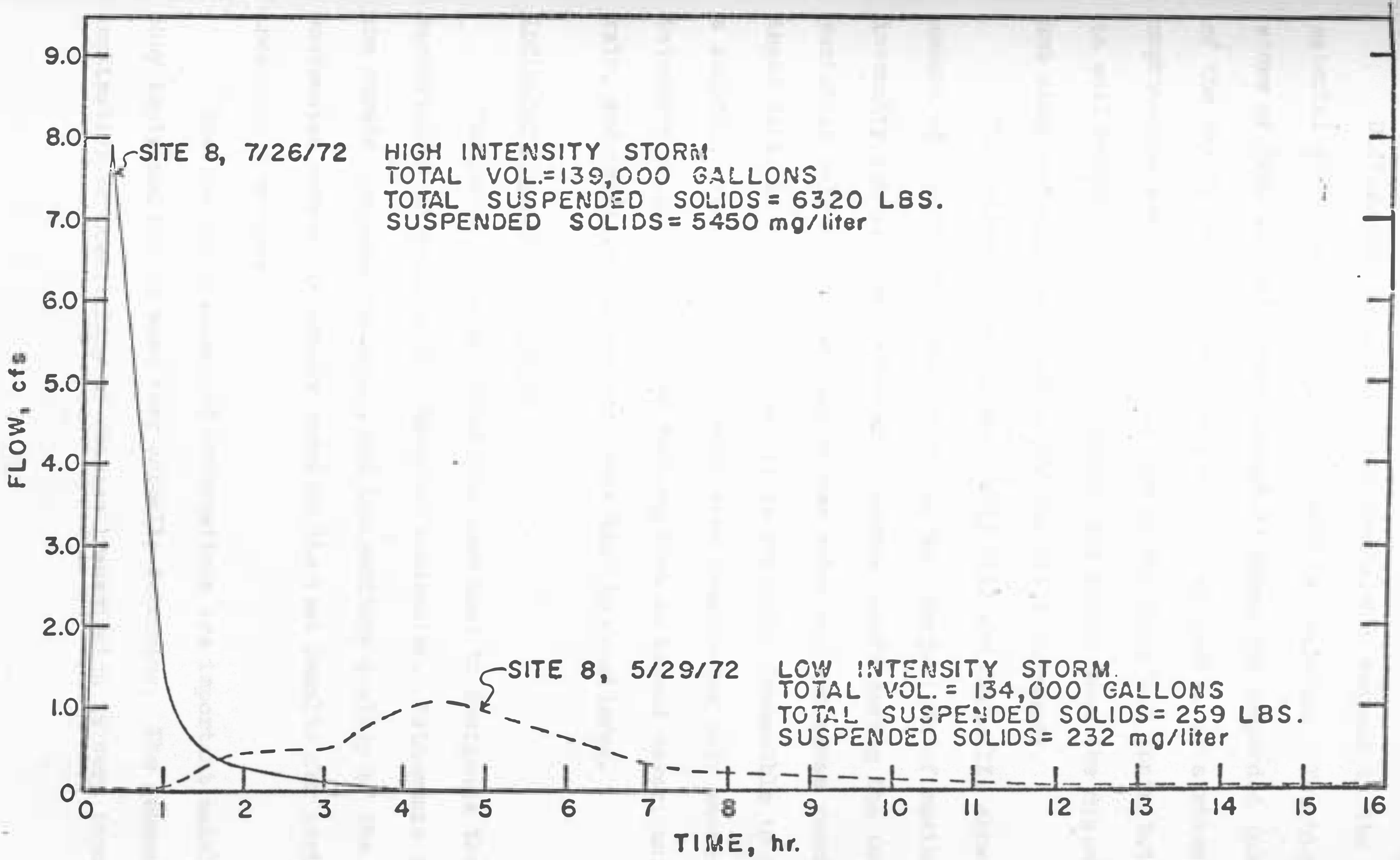

FIGURE 14— Hydrograph comparison of a low intensity storm and a high intensity storm.

Differences between the two events with respect to the amount of material which was washed off the field is presented. The high intensity storm of July 26 contributed almost 25 times the suspended solids load of the May 29 event. The impact of the raindrop as it strikes an unprotected soil is undoubtedly one of the important contributing factors to soil erosion (17-224). Pollution may result when the dislodged soil and other materials are washed off the field in runoff.

The following two tables, Table VIII and Table IX, show the amount of runoff, the total rainfall, and the periods of maximum intensity for all the storms which caused runoff during the two year period as well as some similar storms which did not cause runoff. From these data, it can be seen that it is virtually impossible to predict if a rainfall event will cause runoff when considering only amount and intensity of rainfall. Other factors such as ground cover, antecedent rain, and condition of the soil must also be considered.

Indicator Organisms in Runoff

Indicator organisms have long been used to designate the bacteriological quality of a water or wastewater. Pathogenic bacteria are rarely isolated routinely, and the sanitary quality of the water or wastewater sample is usually based on the test results for certain indicator organisms.

Routine bacteriological examinations are important mainly in what they imply and not in what they actually determine. The general health implication or possibility of disease transmission is very important.

TABLE VIII. - Intensity and Amount of Rainfall Causing Runoff

Site & Date	Runoff (in.)	Rainfall (in.)	Maximum Intensity (in./hr)	
			10 min Duration	20 min Duration
8, 6/ 8/71	0.003	1.07	0.9	0.8
8, 6/29/71	0.001	1.24	1.2	0.9
8, 5/ 1/72	0.014	2.57	-	-
9, 5/ 1/72	0.008	2.57	-	-
8, 5/12/72	0.001	1.11	0.7	0.4
1, 5/22/72	0.007	1.65	2.4	1.5
8, 5/22/72	0.003	1.42	2.5	1.6
8, 5/23/72	0.010	0.42	1.0	0.6
8, 5/24/72	0.044	0.67	1.2	0.7
1, 5/28/72 AM	0.013	0.92	1.2	0.9
1, 5/28/72 PM	0.008	0.56	0.6	0.6

TABLE VIII. - Continued

Site & Date	Runoff (in.)	Rainfall (in.)	Maximum Intensity (in./hr) 10 min Duration	20 min Duration
8, 5/28/72	0.085	0.82	1.8	1.6
1, 5/29/72	0.011	0.76	0.6	0.5
2, 5/29/72	0.021	0.70	0.6	0.5
7, 5/29/72	0.001	0.78	0.6	0.5
8, 5/29/72	0.264	0.87	0.6	0.6
9, 5/29/72	0.190	0.88	0.6	0.6
8, 6/18/72	0.887	2.13	3.9	2.6
9, 6/18/72	0.688	2.13	3.9	2.6
8, 6/19/72	0.244	0.42	1.8	1.2
9, 6/19/72	0.165	0.40	1.8	1.2
8, 7/8/72	0.110	1.02	1.2	1.1

TABLE VIII. - Continued

Site & Date	Runoff (in.)	Rainfall (in.)	Maximum Intensity (in./hr)	
			10 min Duration	20 min Duration
8, 7/14/72	0.004	0.46	2.2	1.0
8, 7/21/72	0.195	0.97	1.5	0.9
9, 7/21/72	0.001	0.96	1.5	0.9
8, 7/26/72	0.274	1.20	2.7	2.4
9, 7/26/72	0.134	1.23	2.7	2.4
1, 7/28/72	0.266	2.15	4.0	2.7
2, 7/28/72	0.433	1.93	4.0	2.7
3, 7/28/72	0.101	2.50	4.0	2.7
4, 7/28/72	0.008	2.50	4.0	2.7
7, 7/28/72	0.701	2.85	4.0	2.7

TABLE IX. - Some Storms Which did not Cause Runoff

Site & Date		Rainfall (in.)	Maximum Intensity (in./hr) 10 min. Duration	20 min Duration
2,	6/29/71	1.83	1.5	1.2
8,	6/ 6/71	0.50	1.5	1.3
2,	6/18/71	0.66	2.1	1.8
2,	8/18/71	0.85	2.1	2.1
8,	8/30/71	2.35	0.9	0.9
2,	7/ 6/72	0.64	0.6	0.4
8,	7/12/72	0.70	1.8	1.8
2,	7/26/72	1.18	1.8	1.3

The degree of health hazard is implied from the routine bacteriological determinations.

The most common bacteriological test for water and wastewater samples is the total coliform test. Coliforms are generally the preferred indicator of fecal contamination in water. The majority of the organisms which give a positive coliform test can be grouped into three species: Esherichia coli, Aerobacter aerogenes, and Aerobacter cloaeceae.

Esherichia coli are normally found in the intestinal tract of man and animals, and they represent about 90% of the coliforms discharged in fecal matter. Aerobacter aerogenes occur naturally on plants, grain, and soil; but they may also be found in the feces of man and animals. Aerobacter cloaceae are also found in the feces of man and animals as well as in the soil. The primary disadvantage of the coliform group as an indicator of fecal contamination is that their presence does not always indicate fecal contamination but may be the result of other foreign matter such

as grain, plants or soil. This disadvantage is particularly important when evaluating bacteriological determinations from agricultural runoff samples.

Because of the aforementioned disadvantage, other bacteriological indicators of fecal contamination have been proposed. Two of these indicators are those bacteria belonging to the fecal coliform (FC) and fecal streptococcus (FS) groups. Fecal coliforms are the members of the coliform group associated with the feces of man and animals. The predominant member of the fecal coliform group is _E. coli_. Those streptococci which belong to the fecal streptococcus group are, according to the 13th edition of "Standard Methods" (96-688), as follows:

(1) _Streptococcus faecalis_

(2) _Streptococcus faecalis_ var. _liquefaciens_

(3) _Streptococcus faecalis_ var. _zymogenes_

(4) _Streptococcus durans_

(5) _Streptococcus faecium_

(6) _Streptococcus bovis_, and

(7) _Streptococcus equinus_

Table X shows a comparison of fecal coliform and fecal streptococcus densities found in the feces of warm blooded animals (65-102). The significant item is that the fecal coliform to fecal streptococcus ratio for all sources other than man is less than one. Therefore, the use of both fecal coliform and fecal streptococcus indicators will probably provide more reliable information regarding the sanitary quality of a water than information based on total coliform data alone. Water

or wastewater samples with FC/FS ratios of more than one can be said to be contaminated by human feces and should be regarded as containing possible pathogenic organisms. Samples with FC/FS ratios of less than one are said to be contaminated from a nonhuman source, and the resulting health hazard is less than the hazard resulting from human sources.

TABLE X. - Comparison of Fecal Coliform and Fecal Streptococcus Densities in Feces of Warm Blooded Animals (65)

Animals	Fecal coliform (million/gram)	Fecal streptococci (million/gram)	Ratio FC/FS
Man	13.0	3.0	4.4
Duck	33.0	54.0	0.6
Sheep	16.0	38.0	0.4
Chicken	1.3	3.4	0.4
Cow	0.23	1.3	0.2
Turkey	0.29	2.8	0.1
Pig	3.3	84.0	0.04

All of the research sites are located in fairly remote areas and human fecal contamination was not expected. About 10% of the 123 runoff samples had fecal coliform counts higher than the fecal streptoccus enumerations. The previous statement regarding the FC/FS ratio being less than one for a sample from a nonhuman source would appear to have about a 90% confidence level. Because of uneven bacterial distribution in a sample, the precision of the multiple tube fermentation test is considered to be rather low. A 90% confidence level is actually quite

high, and should be considered as satisfactory. Even though the indicator organism counts became quite high at times, it would appear that the actual health hazard was low.

The South Dakota water quality standards specify total coliform and fecal coliform as two of the water quality parameters to be considered as water quality criteria for the surface waters of the state. Four of the seven beneficial uses listed in the standards have limits set for one or both of these parameters. These limits are shown in Table XI and will be referred to as the runoff bacteriological data are discussed.

TABLE XI. - Bacteriological Criteria for Selected South Dakota Beneficial Uses of Water

Beneficial Use	Total Coliform	Fecal Coliform
Domestic water supply (with coagulation, sedimentation, filtration and disinfection or its equivalent.)	Not to exceed a MPN or MF or 5,000/100 ml as a monthly average value; nor to exceed this value in more than 20% of the samples examined during any one month; nor to exceed 20,000/100 ml in more than 5% of the samples examined in any one month.	
Recreation		
a. Immersion sports-swimming, water skiing, skin diving and other sports.	Not to exceed a MPN or MF of 1,000/100 ml as a monthly average; nor to exceed this value in more than 20% of the samples examined in any one month; nor to exceed 2,400/100 ml on any one day during the recreation season.	Not to exceed a concentration of 200/100 ml as a monthly average; nor to exceed this value in more than 20% of the samples examined in any one month; nor to exceed 500/100 ml on any one day during the recreation season.

TABLE XI. - Continued

Beneficial Use	Total Coliform	Fecal Coliform
b. Limited Contact Recreation--fishing, boating, sailing, picnicking, and other water related sports.	Not to exceed a MPN or MF of 1,000/100 ml as a monthly average; nor to exceed this value in more than 20% of the samples examined in any one month; nor to exceed 2,400/100 ml on any one day during the recreation season.	Not to exceed a concentration of 1,000/100 ml as a monthly average; nor to exceed this value in more than 20% of the samples examined in any one day during the recreation season.
Intermittent stream	Not to exceed a MPN or MF of 20,000/100 ml as a monthly average value; nor to exceed this value in more than 20% of the samples tested in any one month; nor to exceed 50,000/100 ml in any of the samples tested.	
Irrigation	The MPN or MF shall not exceed 5,000/100 ml as a monthly average; nor shall the number exceed 10,000/100 ml in any one sample.	The concentration shall not exceed 1,000/100 ml as a monthly average; nor shall the number exceed 2,000/100 ml in any one sample.

The method described in Steel and Torrie (94-161) was used to present the bacteriological data. The logarithm of the density of the indicator organism was regressed on the percent of time that the density was equalled or exceeded. The regression lines were computed for the various crop covers representing all the samples obtained from runoff from a particular ground cover. In other words, data for the fall plowed regression lines include results from Site No. 1, 2, 8, and 9 for 1972; while data for the pasture regression lines are from samples from only Site No. 7, but the samples were collected over a two year period.

Figure 15 displays the effect of different crop covers on the frequency of total coliform counts present in snowmelt runoff. In general, the runoff from fields which had minimum cover showed higher total coliform densities. The plots of the coliform counts from those fields with heavier cover are similar. Fields with heavier cover are those with oats stubble, permanent brome grass and alfalfa, and permanent pasture, and the regression lines from these fields exhibit low coliform densities and have similar slopes. One regression line has a disparate slope, and the plot for this line was based upon data taken from fields which were fall plowed and remained barren through the winter.

When comparing the criteria of Table XI with the actual data for Figure 15, it can be seen that the total coliform limits for the different beneficial uses are often exceeded. Criteria for only the beneficial use categories of intermittent stream and domestic water supply need be considered because the criteria for the beneficial uses of recreation and irrigation apply only during their respective seasons. It is doubtful that criteria for recreation and irrigation would apply when snowmelt runoff was occurring.

The average total coliform density to be generally considered is 5,000/100 ml, from Table XI. The criteria listed in Table XI apply only to stream water quality. However, it is important to compare these criteria to the quality of agricultural runoff water because the runoff may contribute water to the stream and the runoff will affect the stream water quality. Referring to Figure 15, this value was exceeded about 50% of the time for those fields with heavy ground cover and more than

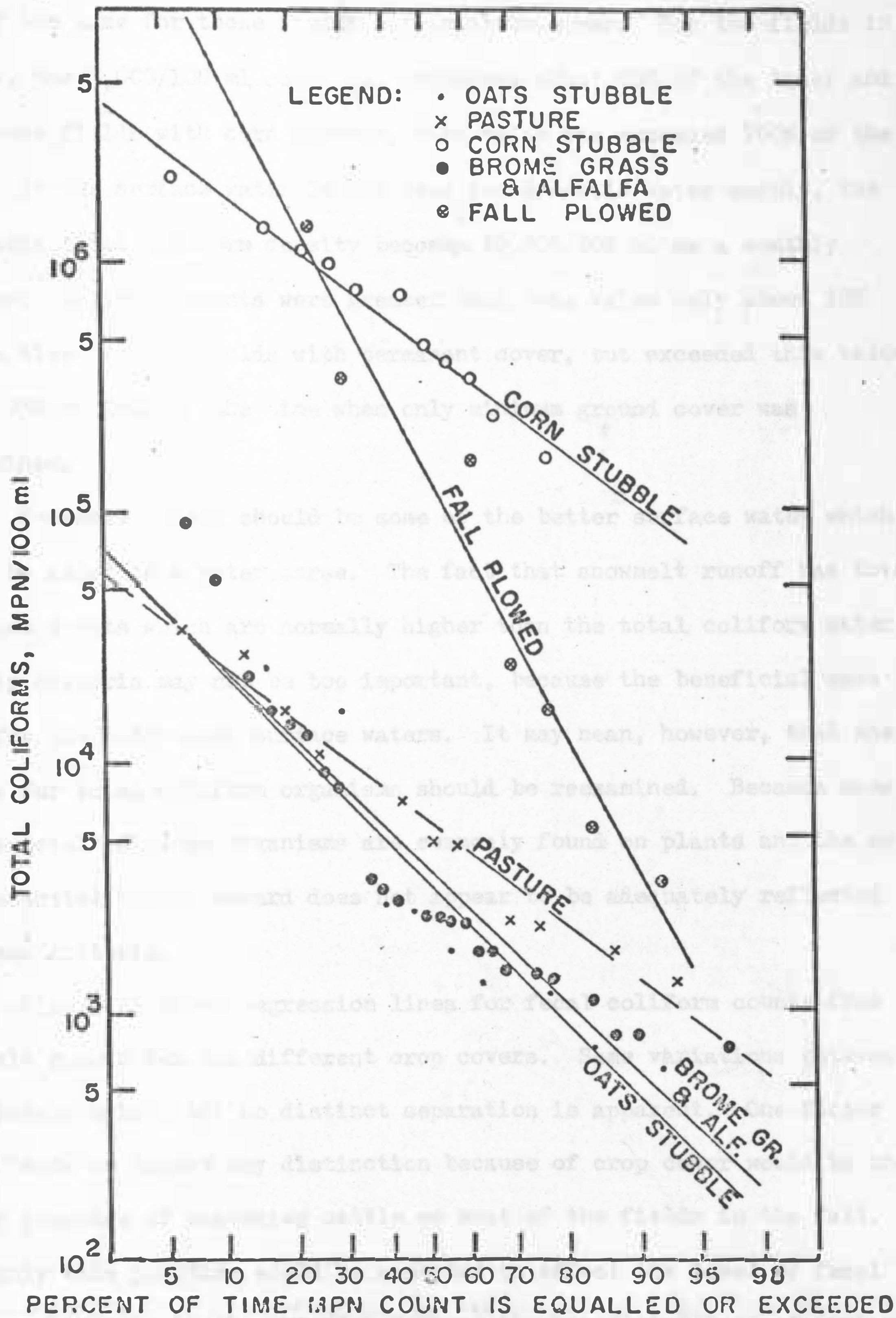

FIGURE 15.- Total coliforms in snowmelt runoff.

50% of the time for those fields with minimum cover. For the fields in fallow, the 5,000/100 ml count was surpassed about 90% of the time; and for those fields with corn stubble, this value was exceeded 100% of the time. If the surface water is not used for domestic water supply, the allowable total coliform density becomes 20,000/100 ml as a monthly average. Coliform counts were greater than this value only about 10% of the time for the fields with permanent cover, but exceeded this value about 75% to 100% of the time when only minimum ground cover was maintained.

Snowmelt runoff should be some of the better surface water which would be added to a watercourse. The fact that snowmelt runoff has total coliform counts which are normally higher than the total coliform water quality criteria may not be too important, because the beneficial uses vary for the individual surface waters. It may mean, however, that the limits for total coliform organisms should be reexamined. Because some of the total coliform organisms are commonly found on plants and the soil, the potential health hazard does not appear to be adequately reflected in these criteria.

Figure 16 shows regression lines for fecal coliform counts from snowmelt runoff for the different crop covers. Some variations between crop covers exist, but no distinct separation is apparent. One factor which tends to remove any distinction because of crop cover would be the common practice of pasturing cattle on most of the fields in the fall. Certainly this practice would be expected to affect the level of fecal coliforms present in the runoff. Because the beneficial uses of surface waters for irrigation and recreation are not enforced during times of

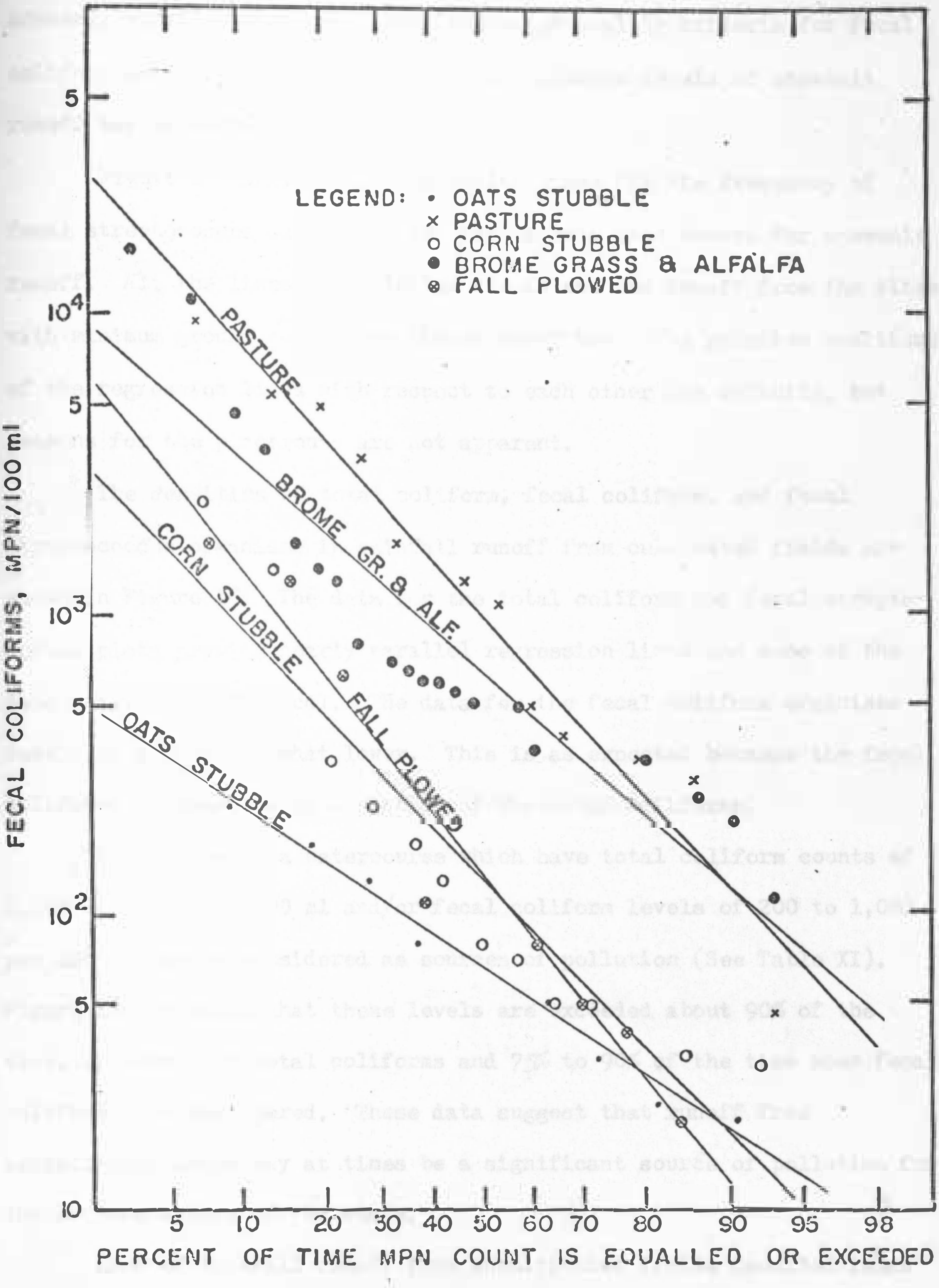

FIGURE 16.- Fecal coliforms in snowmelt runoff.

snowmelt runoff, there are no surface water quality criteria for fecal coliform organisms with which the fecal coliform levels of snowmelt runoff may be compared.

Figure 17 exhibits the regression lines for the frequency of fecal streptococcus occurrence for the various crop covers for snowmelt runoff. All the lines have similar slopes and the runoff from the sites with minimum ground cover show higher densities. The relative positions of the regression lines with respect to each other are definite, but reasons for the placements are not apparent.

The densities of total coliform, fecal coliform, and fecal streptococcus organisms in rainfall runoff from cultivated fields are shown in Figure 18. The data for the total coliform and fecal streptococcus plots provide nearly parallel regression lines and some of the data points are identical. The data for the fecal coliform organisms result in a plot somewhat lower. This is as expected because the fecal coliforms represent only a portion of the total coliforms.

Discharges to a watercourse which have total coliform counts of 1,000 to 5,000 per 100 ml and/or fecal coliform levels of 200 to 1,000 per 100 ml can be considered as sources of pollution (See Table XI). Figure 18 indicates that these levels are exceeded about 90% of the time, or more, for total coliforms and 75% to 90% of the time when fecal coliforms are considered. These data suggest that runoff from agricultural lands may at times be a significant source of pollution for the surface waters of the state.

Lack of rainfall runoff from uncultivated fields resulted in an insufficient amount of data on which to base any conclusions. These

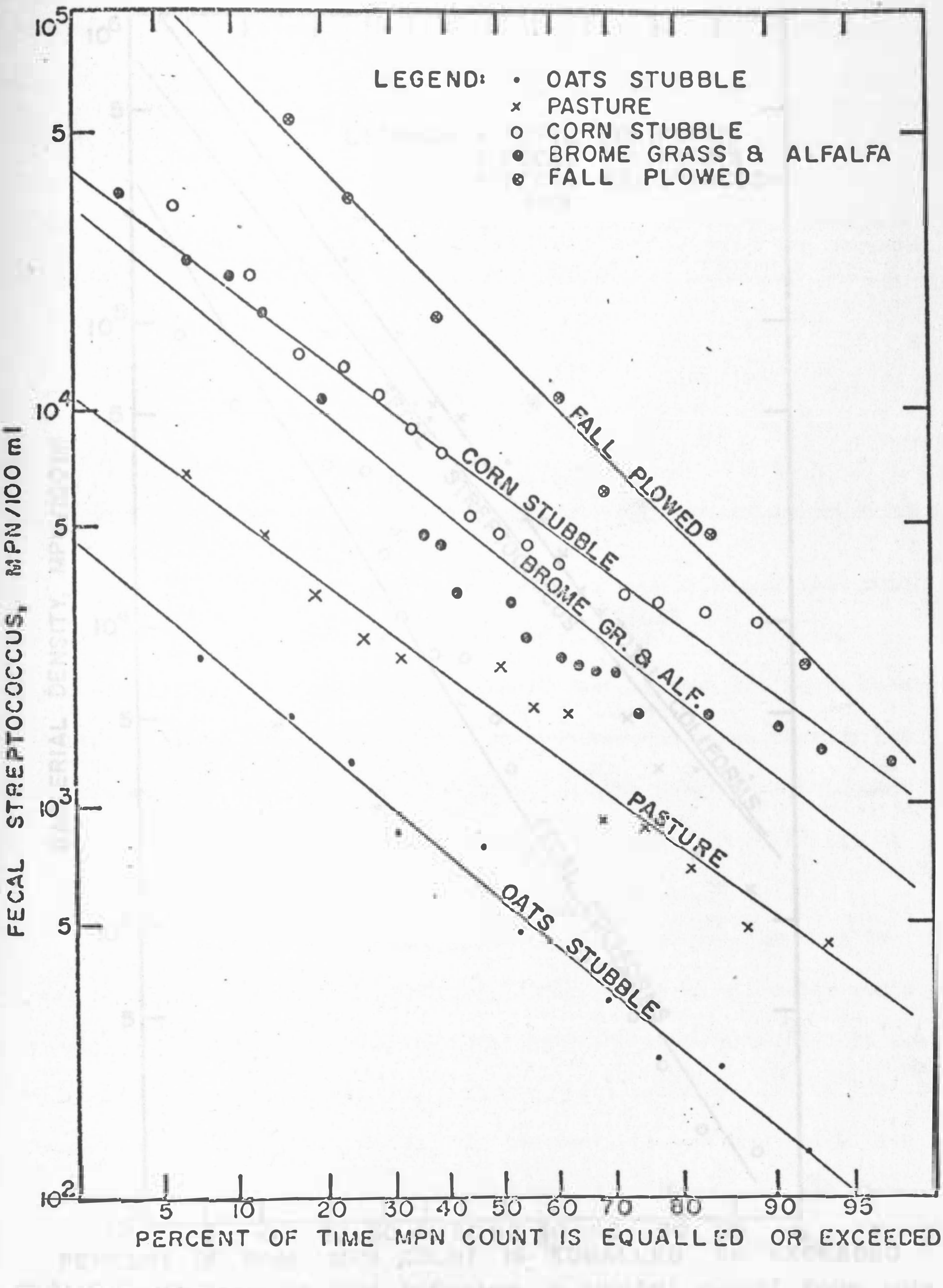

FIGURE 17.-Fecal streptococcus in snowmelt runoff.

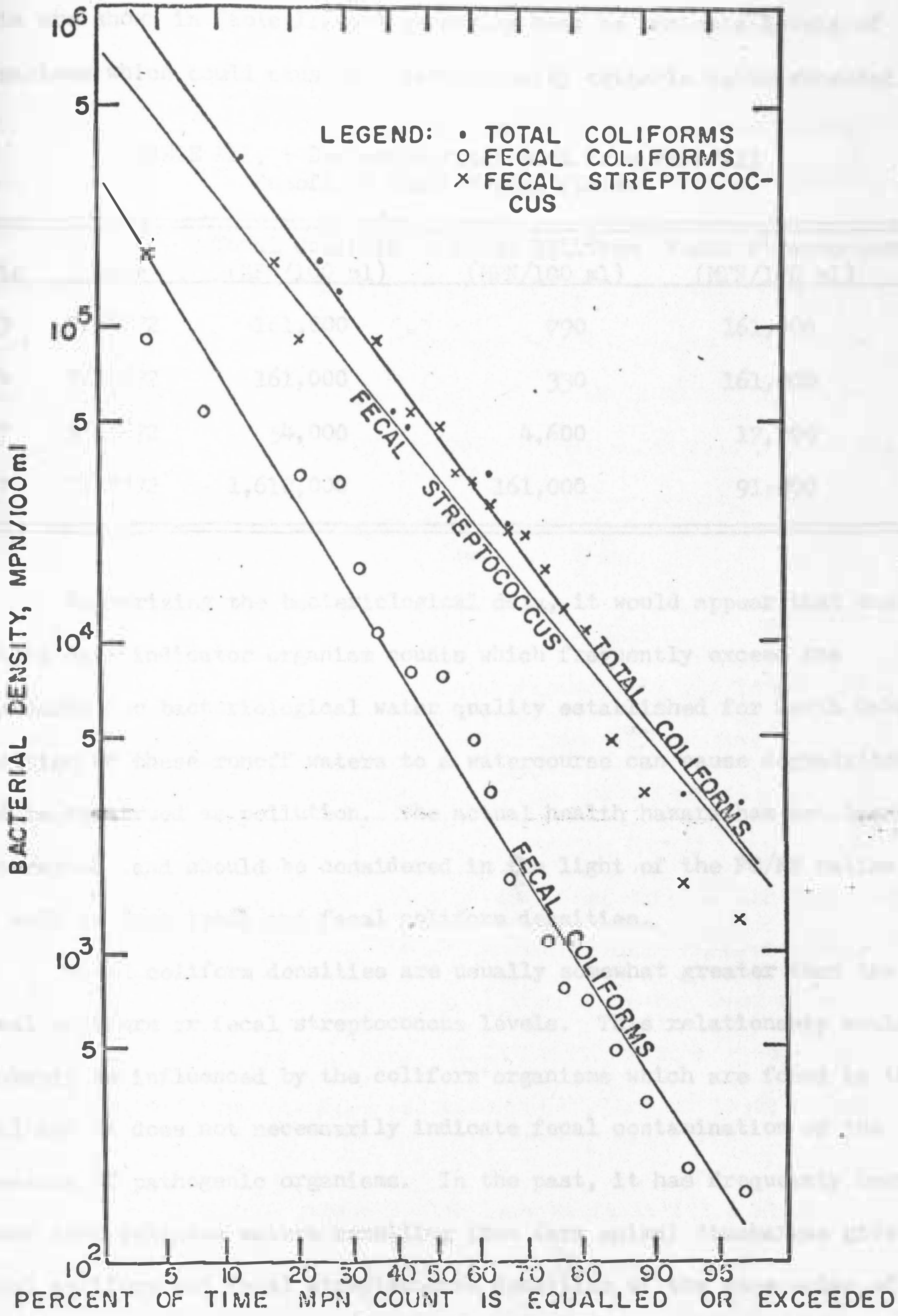

FIGURE 18-Bacteriological indicators in rainfall runoff from cultivated fields.

data are shown in Table XII and generally seem to indicate levels of organisms which could cause the water quality criteria to be exceeded.

TABLE XII. - Bacteriological Data from Rainfall Runoff on Uncultivated Fields

Site	Date	Total Coliform (MPN/100 ml)	Fecal Coliform (MPN/100 ml)	Fecal Streptococcus (MPN/100 ml)
3	7/28/72	161,000	790	161,000
4	7/28/72	161,000	330	161,000
7	5/29/72	54,000	4,600	17,200
7	7/28/72	1,610,000	161,000	91,800

Summarizing the bacteriological data, it would appear that runoff waters have indicator organism counts which frequently exceed the standards for bacteriological water quality established for South Dakota. Addition of these runoff waters to a watercourse can cause degradation and be construed as pollution. The actual health hazard has not been determined, and should be considered in the light of the FC/FS ratios as well as just total and fecal coliform densities.

Total coliform densities are usually somewhat greater than the fecal coliform or fecal streptococcus levels. This relationship would probably be influenced by the coliform organisms which are found in the soil and it does not necessarily indicate fecal contamination or the presence of pathogenic organisms. In the past, it has frequently been found that polluted waters resulting from farm animal discharges give total coliform and fecal streptococcus densities of the same order of magnitude (74-R336).

It would appear that the current water quality standards should recognize the quality of agricultural runoff as providing a basis for water quality improvement. Agricultural runoff is a nonpoint source of water pollution; and consequently, it is virtually uncontrollable. Criteria which establish water quality parameters at levels less than the levels present in agricultural runoff or other nonpoint sources may be unrealistic. Perhaps a better approach would be to establish the water quality criteria at levels which reflect the quality of streams from agricultural areas and then attempt to improve the quality of the runoff. Subsequent sampling would establish any improvements in agricultural runoff quality which could be obtained.

Pesticides

Concern over degradation of the environment by pesticides has developed in recent years. Organochlorine insecticides have been outlawed in Hungary. Other countries, including the United States, have expressed their concern by restricting or banning certain pesticides.

The wide acceptance and usage of some insecticides and herbicides has resulted in their becoming virtually ubiquitous. Determinations for these pesticides are often positive even when there has been no known usage of the chemicals in the area. Some investigations report the travel of pesticides in the atmosphere and also the finding of these compounds in rainfall (85).

The United States Public Health Service conducted a study to determine the distribution of chlorinated hydrocarbon insecticides in the major drainage basins of the United States and collected water

samples for analysis from 41 states. They found widespread distribution of dieldrin, endrin, DDT, and DDE (92). Samples in the Brookings County, S. Dak. study were also investigated for these four insecticides which the USPHS has found to be widespread. In addition, analyses were made for aldrin, lindane, heptachlor, heptachlor epoxide, DDD, atrazine, and methoxychlor.

Because most of these pesticides are relatively insoluble in water, it was quite likely that they might be associated with the soil particles in runoff. Consequently, sediment or mud samples were investigated when samples could be obtained. Only small amounts of soil were present in snowmelt runoff. Therefore, only filtered runoff samples were used for pesticide determinations during snowmelt. If enough soil was washed from a site when rainfall runoff occurred, mud samples as well as filtered water samples were examined.

Data for all the pesticide samples were evaluated together without any designation regarding the site from which the sample was obtained. The results of the pesticide analyses are shown in Tables XIII and XIV. In general, the level of all the pesticides present in the runoff seems to be quite low, and the majority of the concentrations were below the analytical test limits.

Table XIII presents the findings for 75 filtered samples. These 75 samples include the filtered snowmelt samples and the filtered rainfall runoff samples. The vast majority of the data are below the analytical test limits and all values are less than one part per billion (ppb). These results agree with the USPHS study which reported that all the pesticide concentrations were less than one ppb (92). A

TABLE XIII. - Ranges of Pesticide Concentrations for Filtered Runoff Samples

Concentration (ppb)	Aldrin	DDT	DDE	DDD	Atrazine, Diedrin, Lindane, Heptachlor, Heptachlor Epoxide Endrin, Methoxychlor
Below limits*					
Snowmelt	49**	44	48	44	49
Rainfall	24	24	15	25	26
.05 - .09		Does		Does	
Snowmelt	0	not	0	not	0
Rainfall	1	apply	3	apply	0
.10 - .30					
Snowmelt	0	4	1	5	0
Rainfall	0	2	8	1	0
.31 - .50					
Snowmelt	0	1	0	0	0
Rainfall	0	0	0	0	0
.51 - .75					
Snowmelt	0	0	0	0	0
Rainfall	1	0	0	0	0
Total	75	75	75	75	75

*Analytical test limits: 0.05 ppb for Aldrin, DDE, Dieldrin, Lindane, Heptochlor, Heptachlor Epoxide, and Endrin. 0.10 ppb for DDT, DDD, Atrazine and Methoxychlor.

**Numbers indicate the number of samples with concentrations in each range.

TABLE XIV. - Ranges of Pesticide Concentrations for Sediment Samples

Concentration (ppb Dry Wt.)	Aldrin	DDT	DDE	Atrazine	Dieldrin, DDD, Lindane, Heptachlor, Heptachlor Epoxide Endrin, Methoxychlor
Below limits*	11**	20	15	23	24
5.0 - 9.9	2	*	2	0	0
10 - 15	3	1	3	0	0
16 - 25	0	2	3	0	0
26 - 50	1	1	0	0	0
51 - 75	1	0	0	0	0
76 - 100	3	0	0	0	0
100 - 150	0	0	0	0	0
150 - 200	1	0	1	0	0
200 - 250	0	0	0	0	0
250 - 300	2	0	0	0	0
> 300	0	0	0	1	0
Total	24	24	24	24	24

*Analytical test limits: 5.0 ppb for Aldrin, DDE, Dieldrin, Lindane, Heptachlor, Heptachlor Epoxide, and Endrin. 10.0 ppb for DDT, DDD, and Methoxychlor 100 ppb for Atrazine.

**Numbers indicate the number of samples with concentrations in each range.

distribution of the pesticide concentrations for the sediment samples is shown in Table XIV. A total of 24 samples were collected, and the majority of the samples had concentrations of pesticides which were less than the analytical test limits.

Chemical and Physical Characteristics

The basic project objectives were to find the concentrations of the runoff's constituents, and also to determine the total contribution of these constituents on an annual basis. The chemical and physical characteristics of runoff are related to the drainage area, the nature of the runoff and the land management practices.

Two broad categories of runoff were observed. They resulted from snowmelt runoff and rainfall runoff. Runoff from snowmelt generally had a low suspended solids content, often less than 20 mg/l, and exhibited a characteristic yellow-tan color. Snowmelt runoff typically started slowly and reached a peak during the early afternoon hours when the effect of the sun's rays was most pronounced.

Rainfall runoff generally had a much higher suspended solids content than snowmelt runoff, sometimes reaching the several thousand mg/l range. It too showed color; but usually not of the same intensity as snowmelt runoff, particularly if allowed to settle. Runoff resulting from rainfall tended to be a more violent event of much shorter duration. The runoff hydrograph may have reached its peak only a few minutes after runoff began. Runoff then continued to taper off until the event was finished.

The dissolved material present was fairly uniform as measured by the specific conductance determination. Values ranged from 69 to 352 µmhos/cm for the two year study. Median specific conductance for snowmelt runoff was 124 µmhos/cm. The range of specific conductance for rainfall runoff was wider being 45 to 538 µmhos/cm. The median specific conductance value was 210 µmhos/cm. A general observation would be that the quality of rainfall runoff as measured by specific conductance, is more variable than snowmelt runoff.

The mean concentrations of the runoff parameters are presented in Table XV. These are averages of concentrations and are not weighed with respect to flow. Some interesting observations are apparent.

Note the prominent differences between rainfall and snowmelt runoff data. In all cases, the number of snowmelt events exceeds the number of rainfall events for a particular site. This difference is most notable for the sites with permanent grass cover, Sites No. 3, 4, and 7. Obviously, few rainfall runoff events occurred on uncultivated lands. For these sites, the uncultivated fields averaged less than one rainfall runoff event per site per year.

Another notable comparison between rainfall and snowmelt runoff is the difference in the concentration level which occurred for some of the parameters. This difference is particularly true with respect to solids data. A substantial change in magnitude is apparent when the mean suspended solids for Site No. 1 during rainfall runoff is compared to its counterpart for snowmelt runoff, for example. Comparing the average mean values of 51 mg/l and 12 mg/l of suspended solids with 1,400 mg/l reveals about a 45 fold increase for rainfall runoff.

TABLE XV. - Mean Concentrations of Runoff Parameters

Site & Time	Total Residue (mg/l)	Suspended Solids (mg/l)	Specific Conductance (μmhos/cm @ 25°C)	Total Phosphorus (mg/l) Raw	Total Phosphorus (mg/l) Soluble	Nitrate (mg/l N)
Site 1						
Snowmelt '71	171	51	132	0.47	0.35	0.5
Snowmelt '72	107	12	115	0.44	0.43	0.9
Rainfall '72	1670	1400	396	1.08	0.31	0.6
Site 2						
Snowmelt '71	158	29	134	0.41	0.30	0.5
Snowmelt '72	137	35	117	0.53	0.41	1.1
Rainfall '72	2260	2150	71	2.30	0.27	1.1
Site 3						
Snowmelt '71	125	17	121	0.47	0.19	0.6
Snowmelt '72	152	22	125	0.56	0.15	1.0
Rainfall '72	141	64	73	0.30	0.16	0.3
Site 4						
Snowmelt '71	118	13	111	0.41	0.19	0.6
Snowmelt '72	149	24	121	0.57	0.13	1.0
Rainfall '72	75	17	60	0.40	0.27	0.3

TABLE XV. - Continued

Site & Time	Total Residue (mg/l)	Suspended Solids (mg/l)	Specific Conductance (μmhos/cm @ 25°C)	Total Phosphorus (mg/l) Raw	Total Phosphorus (mg/l) Soluble	Nitrate (mg/l N)
Site 7						
Snowmelt '71	154	21	154	0.74	0.34	0.8
Snowmelt '72	145	13	139	0.60	0.28	1.0
Rainfall '72	222	38	251	0.49	0.31	0.4
Site 8						
Snowmelt '71	150	35	135	0.40	0.25	0.8
Snowmelt '72	324	121	198	0.45	0.19	2.5
Rainfall '71	940	552	133	1.27	0.27	2.6
Rainfall '72	1360	1160	285	1.08	0.14	2.1
Site 9						
Snowmelt '71	143	20	144	0.46	0.30	0.6
Rainfall '72	395	173	215	0.50	0.19	0.9

TABLE XV. - Continued

Site & Time	Total Kjeldahl Nitrogen (mg/l N) Raw	Total Kjeldahl Nitrogen (mg/l N) Soluble	COD (mg/l) Raw	COD (mg/l) Soluble	Ammonia (mg/l N)	Number Of Samples
Site 1						
Snowmelt '71	1.3	0.9	35	24	-	8
Snowmelt '72	1.3	1.3	22	20	-	1
Rainfall '72	2.0	1.1	174	31	0.2	5
Site 2						
Snowmelt '71	1.2	1.0	34	25	-	5
Snowmelt '72	1.4	1.2	21	11	-	3
Rainfall '72	5.7	2.0	275	19	0.2	2
Site 3						
Snowmelt '71	2.5	1.7	56	37	-	9
Snowmelt '72	3.4	2.3	73	39	-	6
Rainfall '72	0.8	0.7	22	16	0.2	1
Site 4						
Snowmelt '71	2.2	1.6	50	35	-	9
Snowmelt '72	3.3	2.2	74	40	-	6
Rainfall '72	0.8	0.7	22	20	0.2	1

TABLE XV. - Continued

Site & Time	Total Kjeldahl Nitrogen (mg/l N) Raw	Total Kjeldahl Nitrogen (mg/l N) Soluble	COD (mg/l) Raw	COD (mg/l) Soluble	Ammonia (mg/l N)	Number Of Samples
Site 7						
Snowmelt '71	3.4	2.6	73	48	-	9
Snowmelt '72	3.4	2.2	64	39	-	7
Rainfall '72	1.7	1.2	49	30	0.3	2
Site 8						
Snowmelt '71	2.3	2.2	57	47	-	9
Snowmelt '72	2.8	1.9	61	29	-	9
Rainfall '71	3.1	1.0	82	30	0.2	2
Rainfall '72	2.9	1.0	179	20	0.1	13
Site 9						
Snowmelt '71	2.6	2.5	60	48	-	9
Rainfall '72	1.3	0.7	39	16	0.1	6

The magnitude of the suspended solids increase varied from site to site, but this increase was especially conspicuous for the cultivated sites. Apparently, runoff from rainfall has better quality if it results from permanent grassland.

The uncultivated sites (Sites No. 3, 4, and 7) show relatively little change in parameter concentrations when comparing snowmelt to rainfall runoff. In fact, several of the mean concentrations are much less for rainfall runoff than for snowmelt. The nitrogen and phosphorus levels for uncultivated sites tended to be higher for snowmelt events than for rainfall runoff. Just the opposite was true for the cultivated sites. Freezing and thawing help rupture organic molecules which produces material more easily dissolved or carried in the runoff. Because more organic material was available on the noncultivated sites, they often had snowmelt nutrient levels higher than the cultivated fields. Rainwater does not remain on the fields as long as water resulting from melted snow. Any increase in nutrient levels for rainfall runoff was probably associated with suspended matter washed from the fields. This would account for the increase in nutrients from rainfall runoff for the cultivated lands.

The oxygen demand present in the runoff was measured by the chemical oxygen demand test. A comparison between the biochemical oxygen demand, BOD, and the chemical oxygen demand, COD, was conducted during the initial project year on some frozen runoff samples. The data from these samples were probably affected by the storage technique, but should be sufficiently reliable to draw some generalizations.

The 5-day and ultimate BOD's of the frozen samples were in the 10-20 mg/l and 20-70 mg/l ranges, respectively. The 5-day BOD to COD ratio was quite low, being about 0.18 for snowmelt runoff and even lower for rainfall runoff. Deoxygenation coefficients were also very low, usually ranging from 0.02 to 0.05. These data indicate that much of the organic material was not readily available for biological oxidation, and that the rate of oxidation was very low. The organic materials present were probably representative of cellulose and hemi-celluloses which would degrade very slowly. All of the mean COD values shown in the table are low enough to indicate that oxygen demand from agricultural watersheds is not a problem.

Nutrient levels are of interest because of the continuing emphasis on eutrophication problems. Levels of nitrogen and phosphorus which have often been quoted as causing nuisance algal growths in lakes are 0.01 mg/l of inorganic phosphorus and 0.3 mg/l of inorganic nitrogen. It is believed that these particular levels were first quoted by Sawyer (42). Total phosphorus was measured during this study instead of inorganic phosphorus because in a lake's ecosystem there is a continuing conversion from one phosphorus form to another. Even organic phosphorus which is bound up in the bottom sediments of a lake may later be used to increase biological activity (101-260). In a recent article, Loehr also agrees with this concept as he states that: "The phosphorus of concern to environmental quality is associated with that adsorbed on sediment and with the interchange of phosphorus from bottom deposits in bodies of waters with the upper waters"(56). This same reasoning applies to the nitrogen values although some differentiation in nitrogen forms was made.

All mean concentrations of nitrate alone equal or exceed the 0.3 mg/l level, sometimes reaching above 2 mg/l. Adding ammonia to the nitrate amplifies the inorganic nitrogen contribution of runoff waters. Ammonia had a nearly constant level, varying only from 0.1 to 0.4 mg/l N for all rainfall events. Ammonia was not measured for snowmelt runoff, but was included with organic nitrogen in the total kjeldahl nitrogen determination.

Phosphorus data show concentrations many times in excess of 0.01 mg/l. Even soluble phosphorus levels in snowmelt runoff were in the 0.2 to 0.3 mg/l P range and consequently, practices aimed at retaining the soil, such as sediment traps, would not greatly decrease the phosphorus load discharged from a field.

The above nitrogen and phosphorus levels suggest that agricultural runoff may be an important contributing factor to lake eutrophication. Further expenditures for advanced treatment for municipal and industrial wastewater plants may be superfluous if a significant reduction in lake eutrophication is the intention of such expenditures and agricultural runoff is not controlled.

Table XVI gives the total yearly contributions of the runoff constituents in lb/acre/yr. The increase in soil loss during 1972 when compared to 1971 for the four cultivated sites (Sites No. 1, 2, 8, and 9) was evidenced by the total residue and suspended solids values. The primary reason for this increase in soil loss, as well as the increases in other constituents, was the above average precipitation which occurred in 1972. This is an additional indication of the effect of crop cover on runoff.

TABLE XVI. - Yearly Runoff Contributions of Selected Runoff Constituents

		Constituent (lb/acre/yr)						
Site	Year	Total Residue	Suspended Solids	Chemical Oxygen Demand	Total Phosphorus as P	Total Kjeldahl Nitrogen	Nitrate-N	Total Nitrogen
1	1971	11.7	3.9	2.4	0.03	0.10	0.03	0.13
	1972	408	404	40.1	0.21	0.24	0.06	0.30
2	1971	3.3	0.6	0.7	0.01	0.02	0.01	0.03
	1972	294	296	33.2	0.25	0.45	0.05	0.50
3	1971	37.4	5.1	14.7	0.11	0.68	0.22	0.90
	1972	39.8	4.3	16.9	0.11	0.98	0.39	1.37
4	1971	25.9	3.5	11.4	0.10	0.65	0.15	0.80
	1972	9.5	1.1	4.1	0.03	0.22	0.07	0.29
7	1971	40.4	7.21	19.8	0.19	0.95	0.23	1.17
	1972	63.4	13.7	29.7	0.24	1.04	0.48	1.52
8	1971	59.8	17.5	23.1	0.16	0.86	0.26	1.12
	1972	953	840	129	0.72	1.95	1.05	3.00
9	1971	52.5	10.3	22.7	0.18	0.94	0.26	1.20
	1972	145	101	16.0	0.17	0.41	0.11	0.52

The annual soil loss for each site did not exceed 1/2 ton/acre/yr. This is in sharp contrast to some long-term reported values of Missouri and Ohio studies. Reported cultivated field soil losses from a small plot study in Missouri were from 2.78 to 19.72 ton/acre/yr (17-229). Soil losses from the 1.5 acre fields in Ohio averaged 2.16 ton/acre/yr. The maximum annual loss occurred on corn fields at a rate of 7.70 ton/acre/yr (14).

Agricultural experts seek to establish soil conservation practices to allow a tolerable erosion of less than 3 to 4 ton/acre/yr (102). This would seem to indicate that the erosion rate is satisfactory for the sites under consideration. Yet most of the cultivated sites exhibit some of the common signs associated with soil erosion such as sub-soil protrusion on the ridges, silting in road ditches, some gullying, and rock outcrops. The land-owner of two of the cultivated sites is presently considering a permanent grass cover to decrease his soil losses.

Climatic factors undoubtedly provide at least a partial explanation for the differences in soil losses between this study and the two studies mentioned above. Both Ohio and Missouri annually average about twice the precipitation and about ten times the runoff as the research sites evaluated in this study (103). Differences in rainfall intensity, amount of snowmelt runoff, soil type, slope, and farming practices would be considerations. Also, the studies may not be comparable because of the size of the research areas being investigated. Small 90 ft long plots and 1.5 acre areas may tend to measure soil movement instead of actual soil losses.

Table XVII shows the amounts of chemical fertilizers which were applied to each site. The commercial fertilizers, applied at various rates, have been converted to pounds of nitrogen and phosphorus per acre. These data can be compared with the annual nitrogen and phosphorus contributions as presented in the two previous tables. However, important conclusions resulting from such a comparison were not evident.

TABLE XVII. - Fertilizer Applications to Research Sites

Site	Nitrogen, lb N/acre/yr		Phosphorus, lb P/acre/yr	
	1971	1972	1971	1972
1	52.2	60	11.5	26.4
2	52.5	60	11.5	26.4
3	91.5	250	0	0
4	91.5	250	0	0
7	0	0	0	0
8	29	0	6.2	0
9	29	0	6.2	0

Loehr (56) compares the results of several investigators with regard to nitrogen and phosphorus levels in runoff. After making the corrections previously mentioned, the total annual contributions of nitrogen and phosphorus listed in Tables XVI appear to be in the same range that Loehr indicates that others have reported.

The annual oxygen demand, as measured by COD, resulting from the agricultural runoff was very low. The maximum contribution was from Site No. 8 during 1972 when a chemical oxygen demand of 129 lb/acre/yr

was determined (See Table XVI). This value approximates the daily load which would be contributed from the treated effluent of a secondary wastewater treatment plant engaged in the treatment of the wastes from about 3,000 people. Conceivably the organics present in agricultural runoff could cause significant pollution if the proper conditions existed. However, considering the biodegradability of these organics as well as the rate of biological degradation; it seems unlikely that important oxygen demand will result from agricultural runoff.

A pictorial summary of all the runoff for both years is expressed in Figure 19. The number beneath each pie chart, with the exception of the area chart, represents the total quantity contributed during the two year study. For example, 23,687 lb of suspended solids was washed off the seven sites in both years.

The total runoff area was divided into cultivated land, pasture, and alfalfa and brome grass. Sites No. 1, 2, 3, and 4 were under cultivation and the summation of their areas was 56.3% of the total research area. In addition, Site No. 7 was the pastured area, and Sites No. 3 and No. 4 comprised the alfalfa and brome grass segment.

Some interesting observations were made. One of the most striking was the relationship between rainfall runoff and its total contribution. While rainfall runoff comprised only 32.2% of the total runoff, it was responsible for 93.7% of the suspended matter and 61.8% of the COD lost in the runoff. Thus, almost all of the soil loss was caused by only about one-third of the runoff.

It would appear that pollution from agricultural runoff would be effectively reduced if rainfall runoff was eliminated, or if complete

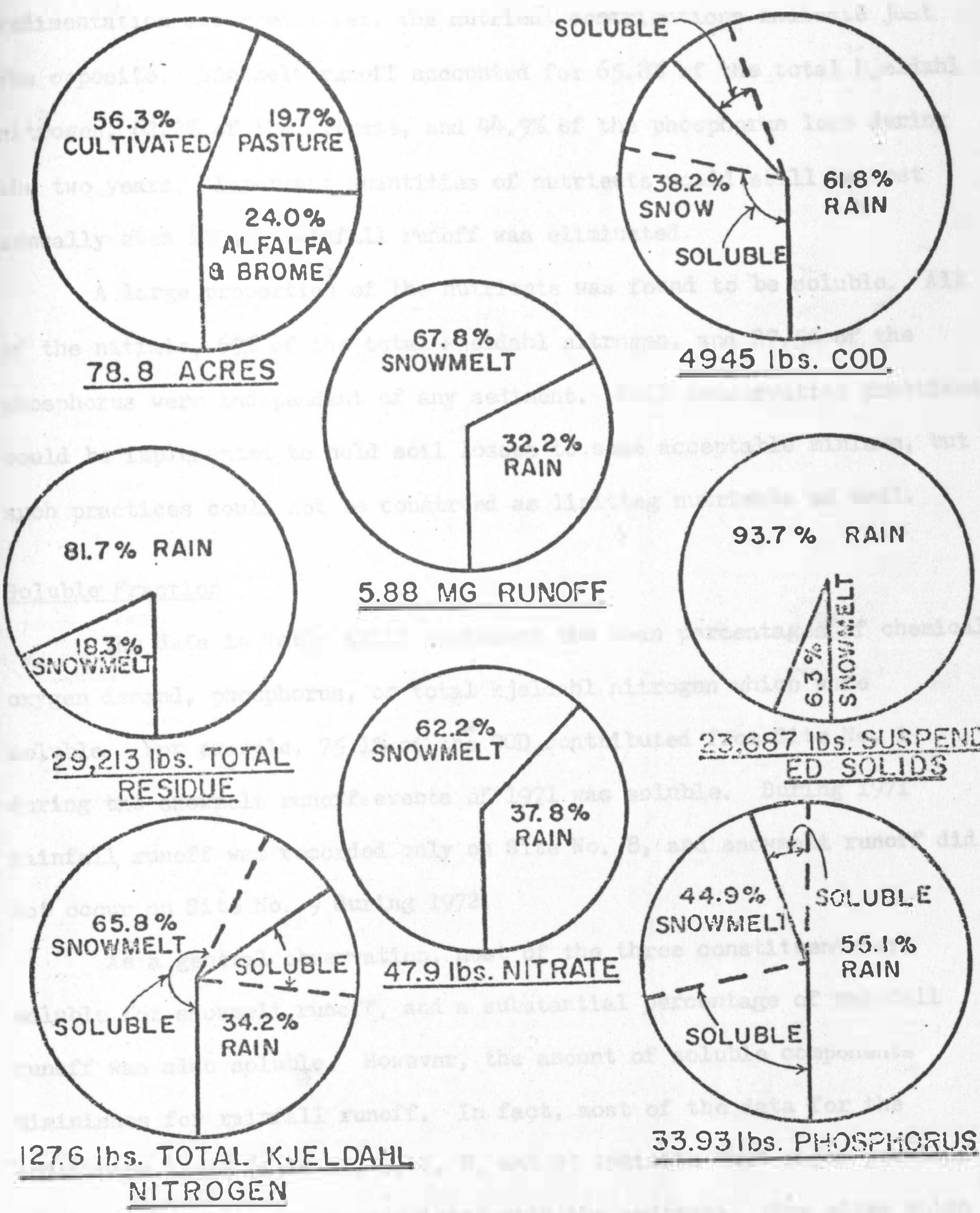

FIGURE 19- Breakdown of total runoff contributions for 1971 and 1972.

sedimentation occurred. Yet, the nutrient contributions indicate just the opposite. Snowmelt runoff accounted for 65.8% of the total kjeldahl nitrogen, 62.2% of the nitrate, and 44.9% of the phosphorus lost during the two years. Important quantities of nutrients would still be lost annually even if all rainfall runoff was eliminated.

A large proportion of the nutrients was found to be soluble. All of the nitrate, 69% of the total kjeldahl nitrogen, and 27.5% of the phosphorus were independent of any sediment. Soil conservation practices could be implemented to hold soil losses to some acceptable minimum, but such practices could not be construed as limiting nutrients as well.

Soluble Fraction

The data in Table XVIII represent the mean percentages of chemical oxygen demand, phosphorus, or total kjeldahl nitrogen which were soluble. For example, 75.1% of the COD contributed from Site No. 1 during the snowmelt runoff events of 1971 was soluble. During 1971 rainfall runoff was recorded only on Site No. 8, and snowmelt runoff did not occur on Site No. 9 during 1972.

As a general observation, most of the three constituents are soluble for snowmelt runoff, and a substantial percentage of rainfall runoff was also soluble. However, the amount of soluble components diminishes for rainfall runoff. In fact, most of the data for the cultivated lands (Site No. 1, 2, 8, and 9) indicate that major portions of the constituents were associated with the sediment. The sites which are permanently covered with grass continued to have a high percentage

TABLE XVIII. - Percentage of COD, Phosphorus, and Total Kjeldahl Nitrogen Which was Soluble

Site	Mean Percentage Snowmelt - 1971			Mean Percentage Snowmelt - 1972			Mean Percentage Rainfall - 1971			Mean Percentage Rainfall - 1972		
	COD*	P*	TKN*	COD	P	TKN	COD	P	TKN	COD	P	TKN
1	75.1	72.8	75.9	90.9	97.7	100.0	-	-	-	48.8	56.1	69.5
2	75.1	69.9	82.8	48.1	72.4	82.1	-	-	-	7.4	12.6	16.3
3	67.3	43.1	72.2	54.4	34.2	67.1	-	-	-	72.7	53.3	87.5
4	72.0	48.6	79.5	52.6	27.2	67.0	-	-	-	90.9	67.5	87.5
7	67.8	50.0	77.6	61.3	52.0	70.2	-	-	-	63.9	64.1	73.3
8	81.8	62.2	89.4	55.5	47.5	72.8	37.9	21.1	31.1	26.7	24.9	41.9
9	82.1	66.4	98.2	-	-	-	-	-	-	46.2	43.3	57.9

* COD = Chemical oxygen demand
P = Phosphorus
TKN = Total kjeldahl nitrogen

of the three parameters remaining soluble. The effects of crop cover on runoff quality are, therefore, demonstrated once again.

Soil-Loss Equations

Several factors contribute to the rate at which soil erosion occurs. Among the more influential are (a) frequency, duration and intensity of rainfall, (b) soil type and cover, (c) land management practices, and (d) the topography of the drainage basin.

Soil-loss prediction procedures have been attempted for over 30 years. Currently, the most accepted method uses the "universal" soil-loss equation developed by the U.S. Agricultural Research Service. This equation has been under development for more than 20 years and has had many contributors and modifications (28).

The basic soil-loss equation is

$$A = R\,K\,L\,S\,C\,P \qquad \text{Eqn. (1)}$$

where:

A = Soil loss per unit area

R = Rainfall factor

K = Soil-erodibility factor

L = Slope-length factor

S = Slope-gradient factor

C = Cropping-management factor

P = Erosion-control practice factor

This equation is based on data obtained from many 13 ft by 72.6 ft plots located at several research sites throughout the United States and Puerto Rico. An explanation of the factors and examples of their use are presented in "Agricultural Handbook No. 282" (28).

An estimate of the average annual soil loss for Site No. 8 according to the "universal" soil-loss equation was made. The rainfall factor, R, has a value of about 110 for the area surrounding Site No. 8. The soil has been classified as a sandy clay loam. Computed K values for sandy clay loams vary from 0.31 at State College, Pa. to 0.36 at Watkinsville, Ga. (28). The majority of the soil on Site No. 8 is classified as a Poinsett-Buse-Pierce or Poinsett silt loam. These soils have assigned K factors of 0.28 to 0.32 with a soil loss tolerance of about 4 ton/acre/yr (104). A K factor of 0.30 was used.

For field application of the soil-loss equation the two topographic factors, L and S, are combined into a single factor, LS. This factor is the expected ratio of soil loss per unit area when compared to the soil loss from a "unit plot." A "unit plot" has a slope of 9% and is 72.6 ft long. Using the appropriate methodology for a concave slope as described in the handbook (28), Site No. 8 was determined to have an LS factor ranging from 0.5 to 0.7. A value of 0.6 was used for LS.

The cropping management factor, C, is specific for a certain location and is dependent upon the tillage the land receives. A method for evaluating C for the various farmlands in South Dakota has been published by the Soil Conservation Service (104). Site No. 8 would have an approximate C factor of 0.25.

The remaining factor to be evaluated was P, the erosion-control practice factor. Control practices such as contouring, terracing, or strip-cropping were not practiced on Site No. 8, and P, therefore, had a value of 1.0.

Calculation of the average annual soil loss for Site No. 8 becomes

$$A = R\ K\ L\ S\ C\ P$$

$$= (110)\ (0.30)\ (0.6)\ (0.25)\ (1.0)$$

$$= 4.95 \text{ ton/acre/yr} \sim 5 \text{ tons/acre/yr}$$

Comparing this value of 5 ton/acre/yr with a maximum measured loss of less than 1/2 ton/acre/yr, during a wet season, indicates a possible discrepancy with measured values.

The measured soil-loss value of about 1/2 ton/acre/yr for Site No. 8 should be higher than the average because 1972 was a year of above average precipitation, snowmelt losses were included, and the value for total residue was used while actual soil losses may be more accurately reflected in terms of suspended solids. However, the measured value is much less than the calculated soil loss from the "universal" soil-loss equation.

The main reason for the difference between the "universal" soil-loss equation and the measured soil losses is thought to be related to the equation which was designed to evaluate soil movement on the field, not to measure actual amounts of sediment transported from the drainage area. Most of the sites evaluated in this study have concave slopes which tend to retain the soil which would be washed from the steeper slopes. It may be concluded that the "universal" soil-loss equation does not appear to be applicable for evaluating soil losses which leave the drainage basin, at least for areas similar to the research sites evaluated in this project.

For the purposes of estimating agriculture's contribution to stream or lake pollution, there is some merit in having a soil-loss equation which would encompass several kinds of field conditions for a particular area. An equation which would consider both snowmelt and rainfall runoff could have the following form:

$$\text{Soil Loss} = A_c(K_{c_1} I_{s_c} + K_{c_2} I_{r_c}) + A_p(K_{p_1} I_{s_p} + K_{p_2} I_{r_p}) + A_g(K_{g_1} I_{s_g} + K_{g_2} I_{r_g}) \qquad \text{Eqn. (2)}$$

Where:

A_c = Area of cultivated land, acres

A_p = Area of pasture, acres

A_g = Area of permanent grassland, acres

K_{c_1} = Emperical runoff constant for snowmelt on cultivated land, lb/acre/in. of runoff

K_{c_2} = Emperical rainfall runoff constant, for cultivated land, lb/acre/in. of runoff

K_{p_1} = Emperical snowmelt runoff constant for pasture, lb/acre/in. of runoff

K_{p_2} = Emperical rainfall runoff constant for pasture, lb/acre/in. of runoff

K_{g_1} = Emperical snowmelt runoff constant for permanent grassland, lb/acre/in. of runoff

K_{g_2} = Emperical rainfall runoff constant for permanent grassland, lb/acre/in. of runoff

I_s = Inches of snowmelt runoff,

I_r = Inches of rainfall runoff,

Subscript depends on cover: c=cultivated, p=pasture, g=grass

Soil Loss = Suspended solids lost, pounds

Proposed values for the empirical runoff constants for this geographical area are shown in Table XIX. The constants are based on fields which have non-uniform 2% to 8% slopes and are generally concave.

TABLE XIX. - Empirical Runoff Constants

Constant	K_{c_1}	K_{c_2}	K_{p_1}	K_{p_2}	K_{g_1}	K_{g_2}
Proposed Value	10 or 45*	350	4.5	13.5	3	10

* Use 10 if crop residue remains on field over winter,
Use 45 if fall plowing is employed.

Only two years of runoff data are available with which to evaluate the equation. However, these two years would appear to be maximum and minimum runoff years for the geographic area under consideration. A comparison of measured sediment lost and the emperical runoff equation is shown in Table XX.

TABLE XX. - Comparison of Measured Sediment Losses with Calculated Sediment Losses

Item	1st Yr	2nd Yr
Measured Soil Loss, lb/yr	655	22,434
Calculated Soil Loss, lb/yr	606	21,314
% Deviation	-8.08	-5.25

Obviously, data from two years on a few selected pieces of land cannot be used to establish a soil-loss equation for general use. This particular approach, however, may gain favor with those in pollution control work who have the responsibility of delineating agriculture's role in water pollution.

V. CONCLUSIONS

Scrutinizing the data and results leads to the following conclusions for the geographical area studied:

1. Considerable quantities of nutrients were present in the agricultural runoff, and these have important implications regarding lake eutrophication. Nutrient losses ranged from 0.03 to 3.0 lb/acre/yr of nitrogen and from 0.01 to 0.72 lb/acre/yr of phosphorus. The form of the nutrients is also of consequence. Most of the annual nutrient load comes from snowmelt runoff, and a large percentage is in a soluble form. Soil conservation practices will probably not be effective measures for retarding lake eutrophication from the nutrients in agricultural runoff.
2. Annual soil losses were much lower than anticipated. Soil losses ranged from less than 10 lb/acre/yr to a maximum of less than 1000 lb/acre/yr. The present "universal" soil-loss equation did not appear to be suitable for estimating the potential of water pollution from agricultural lands for the geographic area studied.
3. Most of the sediment in runoff waters was from cultivated fields with relatively small amounts originating on areas in permanent grass. The bulk of the soil losses, as well as losses of those constituents associated with the soil, occurred during short duration, high intensity rain storms.

Almost all the soil lost during the 2 year study can be attributed to approximately the 1/3 of the runoff which was caused by rainfall. The instantaneous concentration of soil in the rainfall was directly related to the flow rate.

4. Total coliform and fecal coliform densities in runoff frequently exceed those limits specified in some surface water quality standards. However, runoff waters from agricultural lands are probably not a potential health hazard and FC/FS ratios should also be considered. Total coliform counts are usually greater than either fecal coliform or fecal streptococcus levels. The highest total coliform and fecal streptococcus counts for snowmelt runoff were attributed to cultivated fields.
5. Pesticide concentrations and organic matter in the runoff waters from snowmelt and rainfall were low. Most sediment samples also had pesticide concentrations below the analytical test limits.
6. Each site consistently had more snowmelt runoff events than rainfall runoff events. Almost all of the runoff occurs from snowmelt for fields in permanent grass.
7. Fall plowing reduces the amount of snow retained on the fields over the winter months. Although runoff was reduced, this practice appeared to increase the erosion potential from wind.

8. Rainfall runoff was an infrequent and unpredictable event and can be expected to occur only a few times each year, generally during spring and early summer when crop cover is light and rainstorms are more frequent.
9. When comparing individual parameter concentrations from rainfall and snowmelt runoff, the runoff from cultivated areas showed wider variations than runoff from uncultivated areas.

VI. AREAS OF FUTURE RESEARCH

The following areas related to this investigation are suggested for the consideration of future researchers.

1. The nutrient contributions of general agricultural runoff should be separated into surface water and groundwater components. This could be done on a stream which drains the runoff from a remote area and also received its water from an underground aquifer. Both the quality of the stream and the groundwater feeding the stream should be monitored. This research would be important because it would be virtually impossible to limit the soluble nutrients present in groundwater.
2. The quality and quantity of runoff from larger areas should be evaluated. The large drainage basin could be subdivided into smaller areas. The total contribution of flow and other parameters in the runoff from the small areas could be determined by using equations based on this study and work done by others. The summation of the computed runoff would be compared with the measured runoff from the large basin. The objective of the project would be the estimation of quantities of nutrients and other constituents from large areas.

3. The feasibility of building natural terraces in agricultural fields by erecting small soil barriers should be investigated. These barriers would be placed in a field and retain much of the sediment which would otherwise be lost. Over a period of years, the retained soil would build a natural terrace. Barriers could not cause important restrictions in the use of the field, and could be made of an organic material which would degrade after the natural terraces were formed.

4. The current study to provide additional information regarding the average annual contribution of the various constituents could also be continued.

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APPENDIX A

Topographic Maps of Research Sites

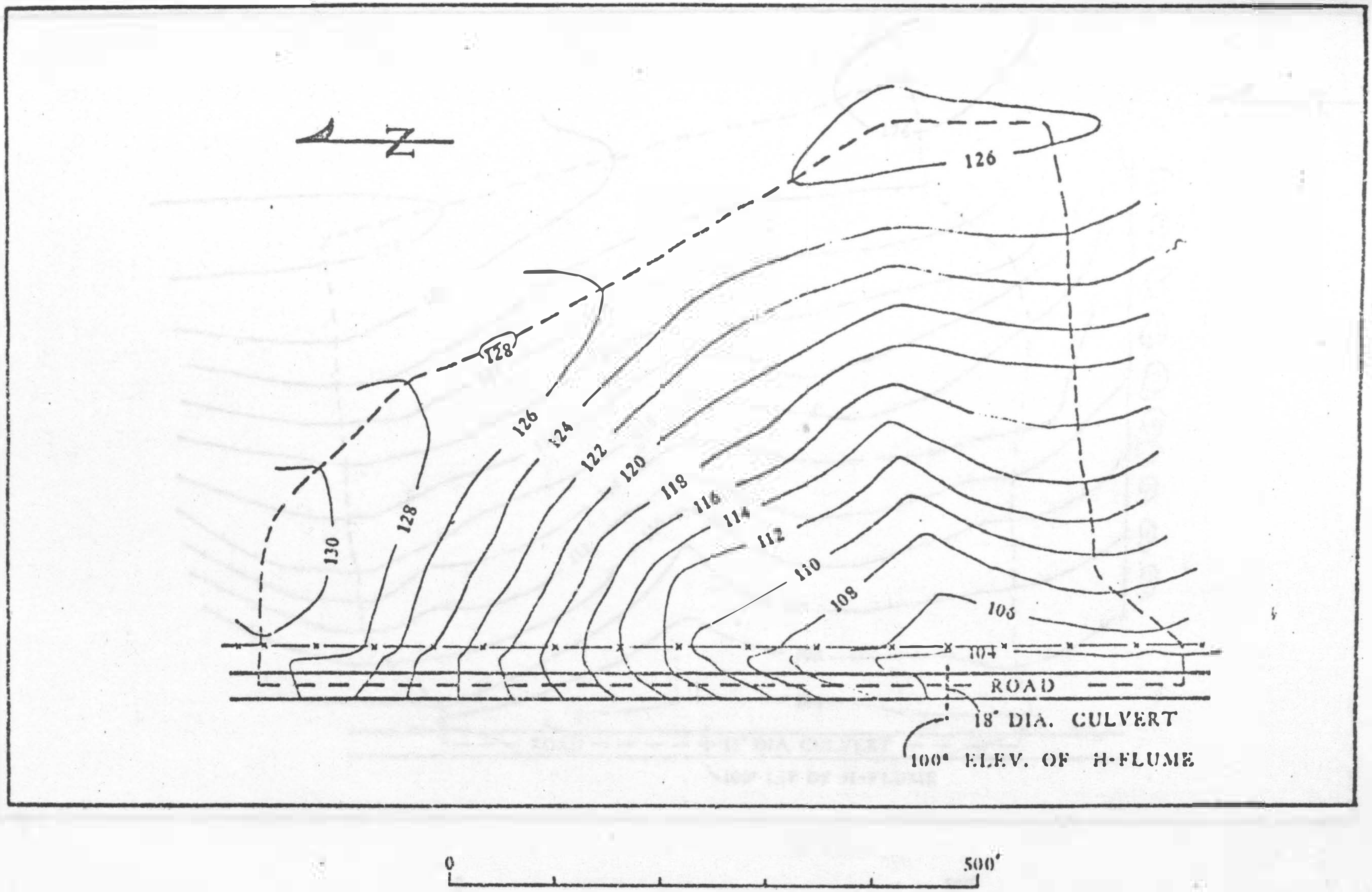

FIGURE A1. - Site 1

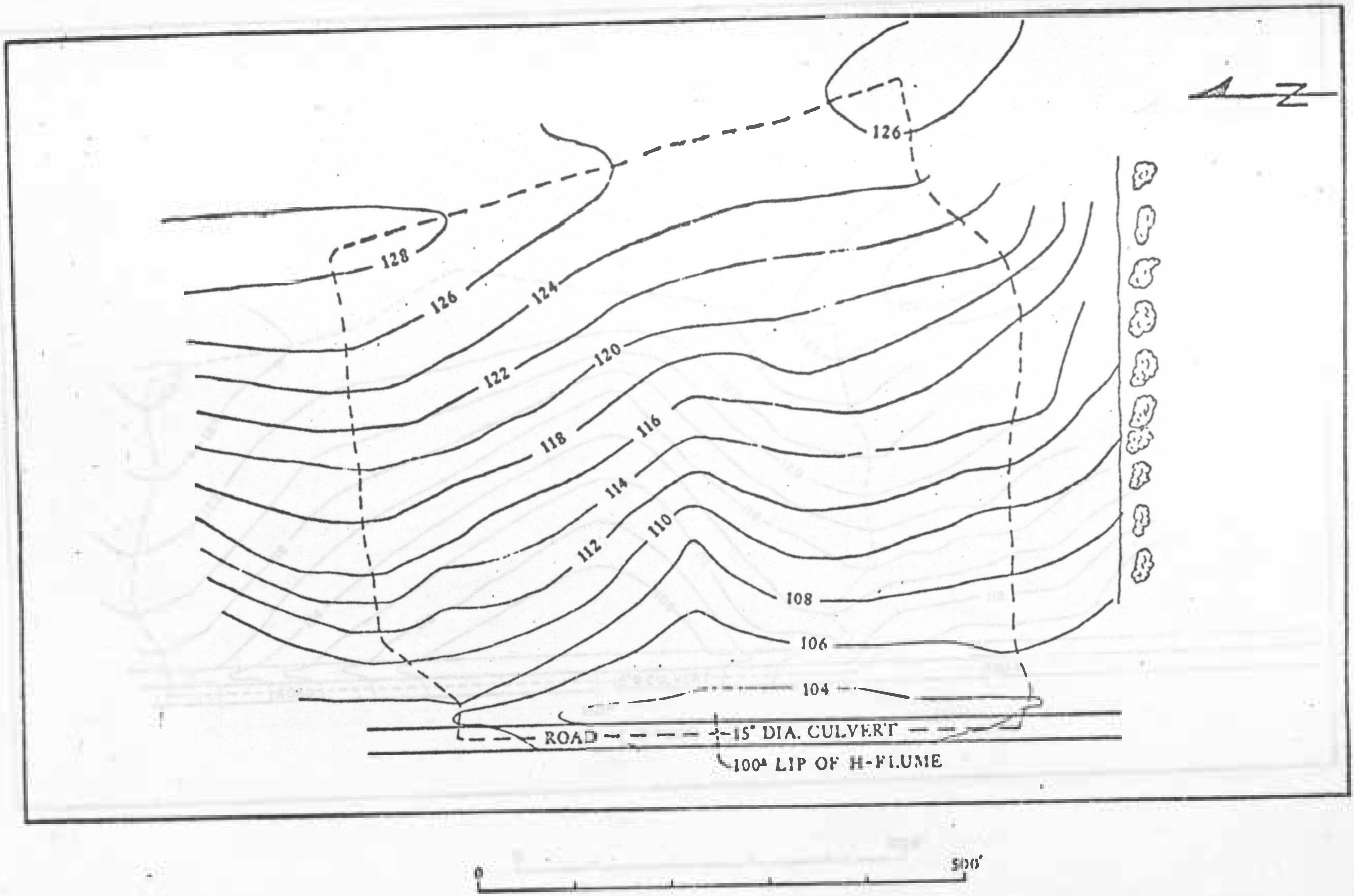

FIGURE A2. - Site 2

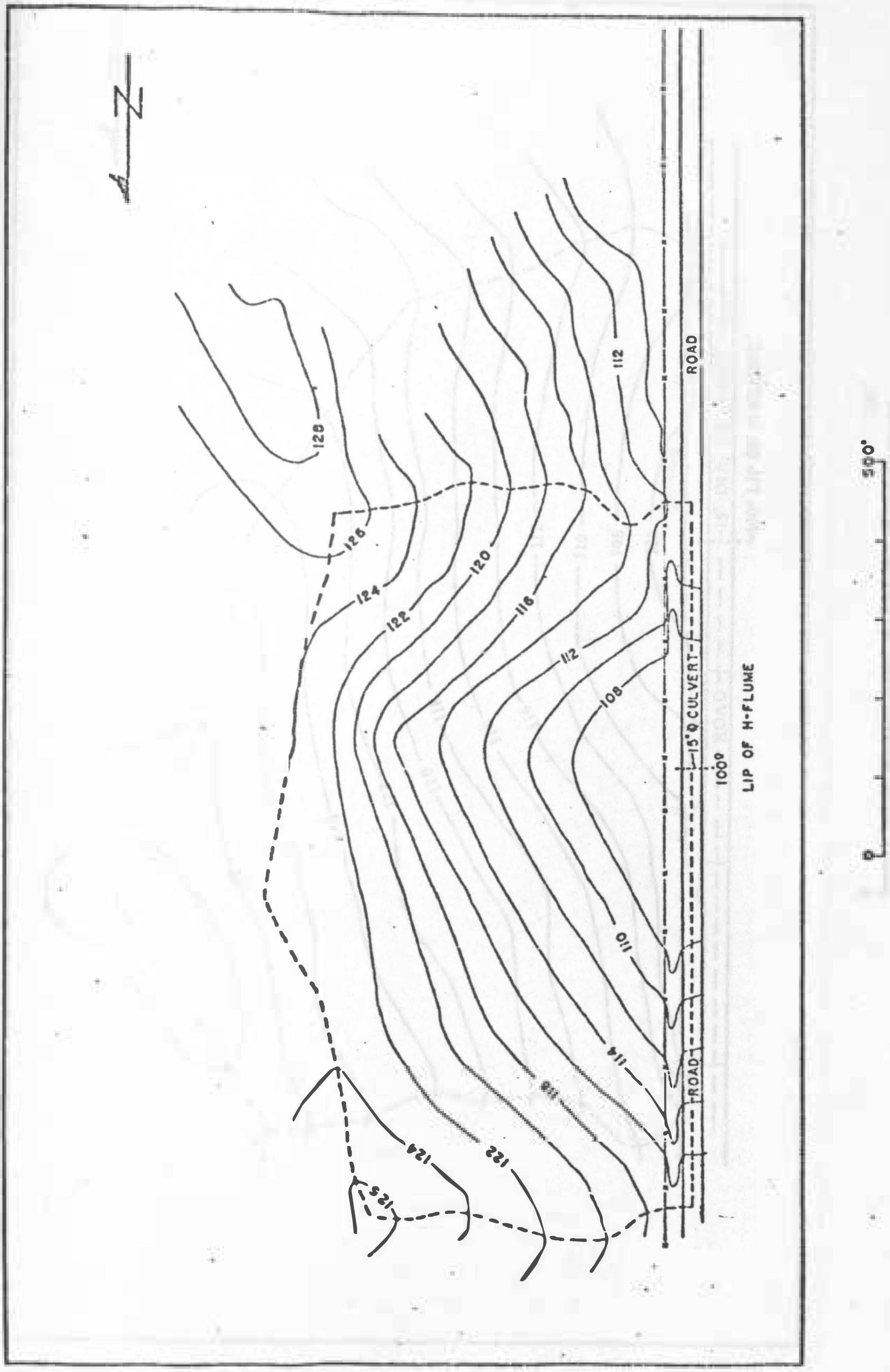

FIGURE A3. - Site 3

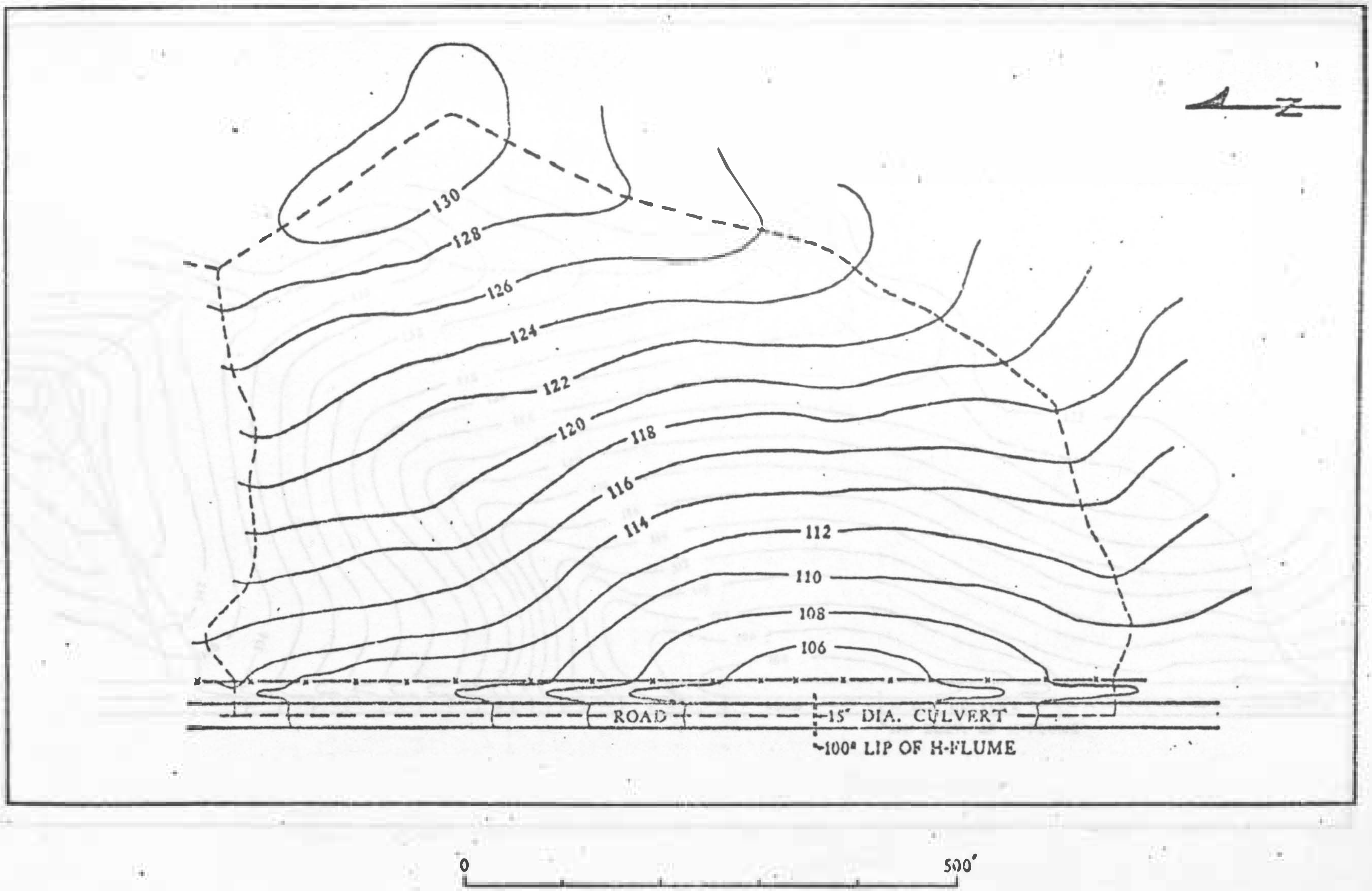

FIGURE A4. - Site 4

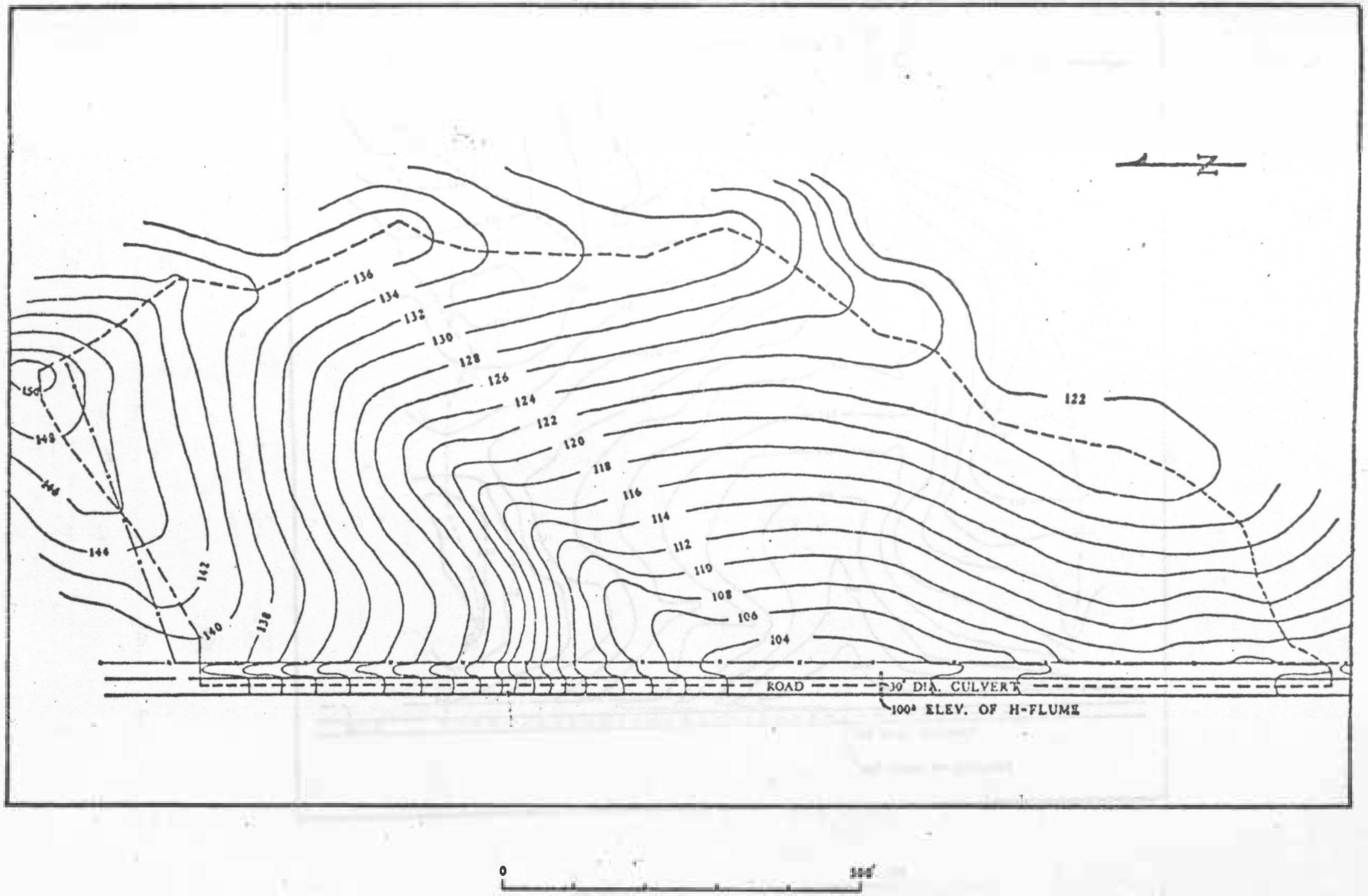

FIGURE A5. - Site 7

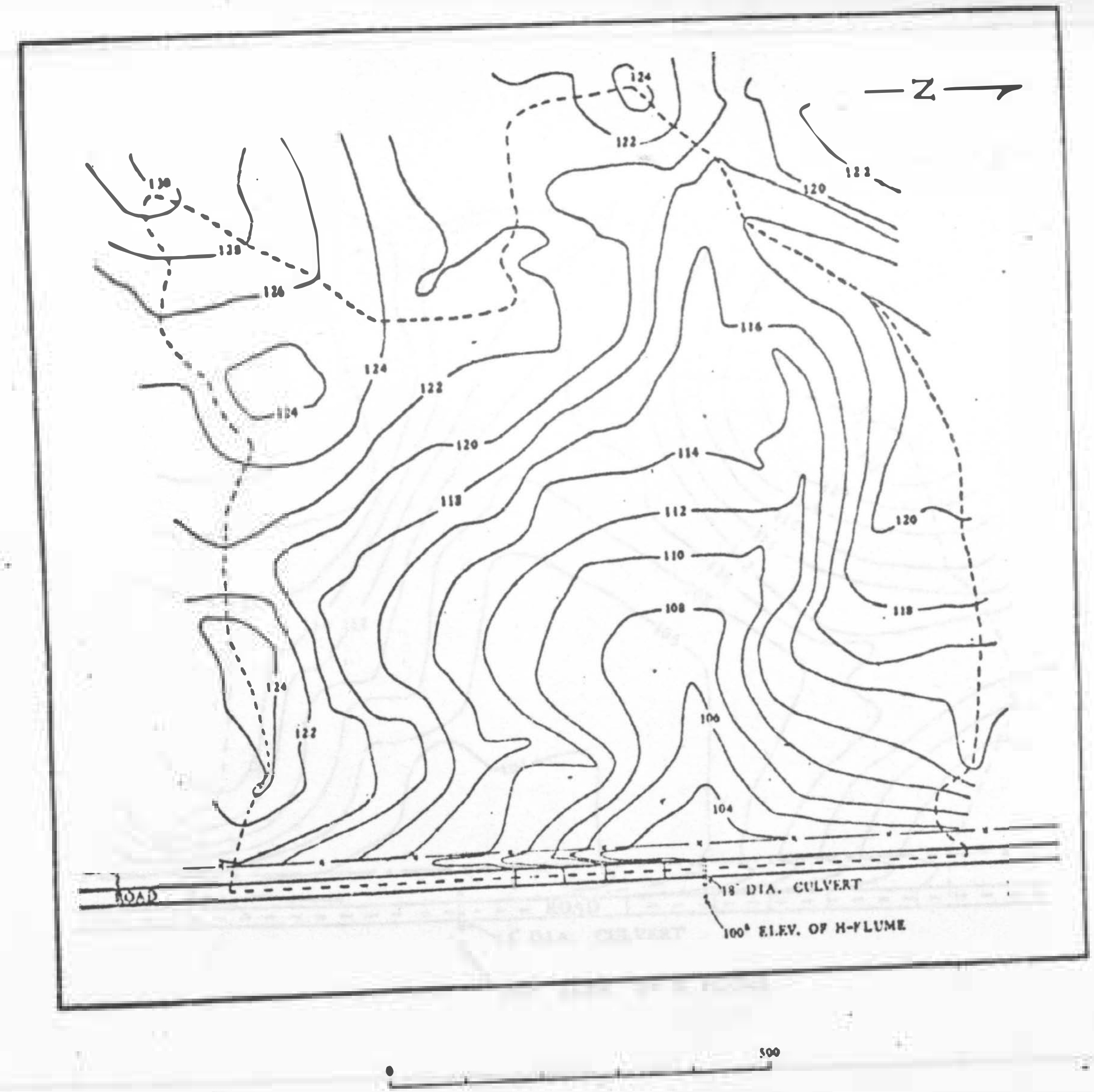

FIGURE A6. - Site 8

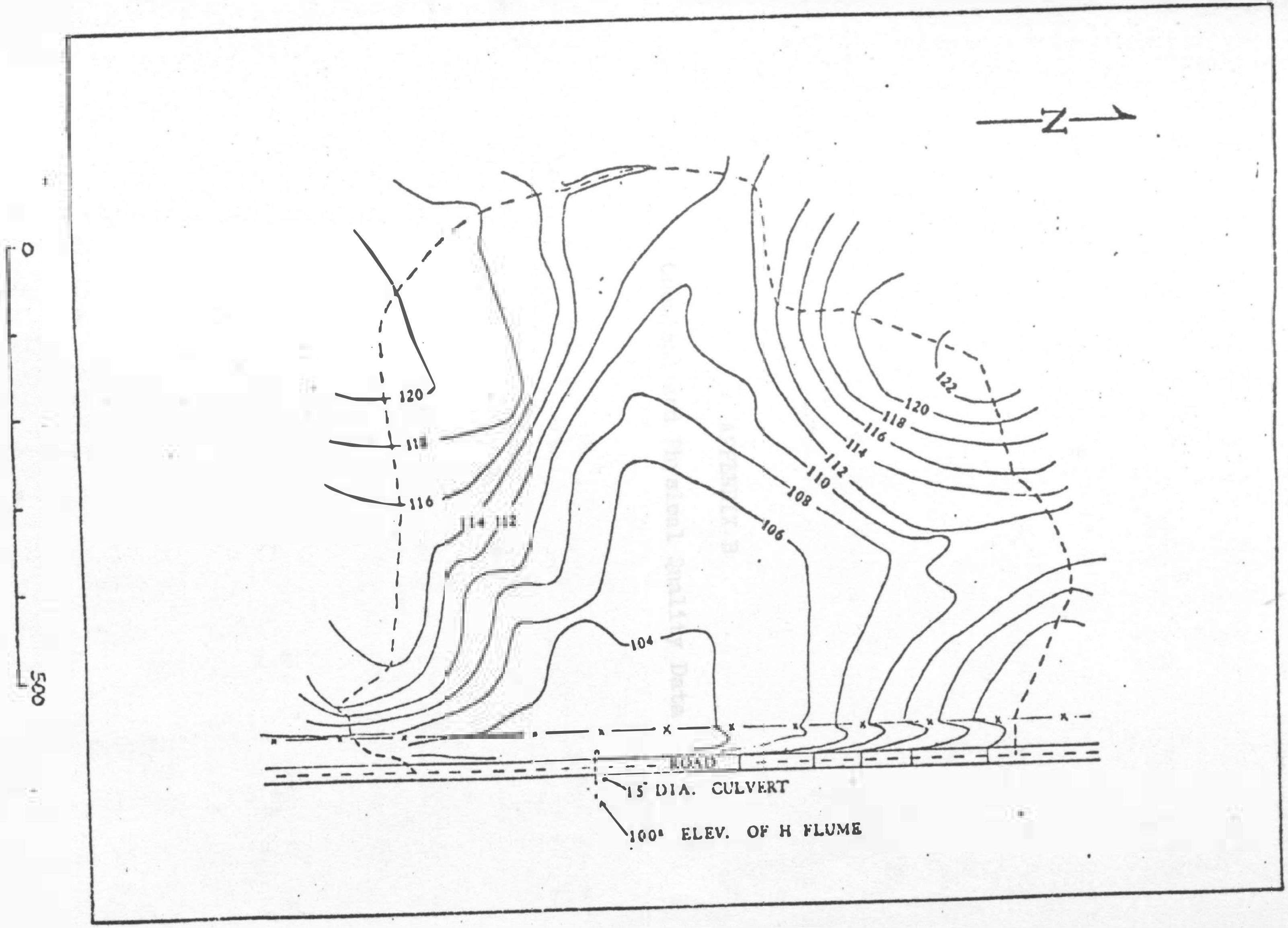

FIGURE A7. - Site 9

APPENDIX B

Chemical and Physical Quality Data

Site No. 1
Area = 7.18 acres
Cover: Oat stubble and oats

Table B1. - Chemical and Physical Quality Characteristics of Agricultural Runoff
Brookings County, South Dakota - 1971

Characteristic*		Feb 16	Feb 17	Feb 18	Feb 25	Feb 26	Mar 11	Mar 12	Mar 13
Volume (gal)		1,900	9,100	2,400	7,200	6,800	6,200	18,200	6,300
Specific conductance (μmhos/cm @ 25°C)		190	170	179	106	107	97	107	103
Suspended solids		77	25	11	18	5	27	90	157
Total residue		220	186	171	132	102	93	202	260
COD	Raw	51	34	32	28	26	23	44	38
	Soluble	25	26	32	28	13	32	24	12
Total kjeldahl nitrogen	Raw	1.4	2.0	1.0	0.9	0.9	1.3	1.7	0.9
	Soluble	1.1	1.1	1.0	0.8	0.5	1.2	1.0	0.7
Total phosphorus as P	Raw	0.98	0.55	0.39	0.28	0.25	0.28	0.41	0.61
	Soluble	0.82	0.48	0.38	0.21	0.18	0.17	0.26	0.26
Nitrate as N		1.0	0.6	0.5	0.4	0.3	0.5	0.3	0.2
Total nitrogen		2.4	2.6	1.5	1.3	1.2	1.8	2.0	1.1

*All concentrations in milligrams per liter except as noted.

Site No. 2
Area = 8.77 acres
Cover: Oat stubble and oats

Table B2. - Chemical and Physical Quality Characteristics of Agricultural Runoff
Brookings County, South Dakota - 1971

Characteristic*		Feb 16	Feb 17	Feb 18	Feb 25	Feb 26
Volume (gal)		2,000	7,900	2,100	6,100	5,000
Specific conductance (µmhos/cm @ 25°C)		192	148	154	87	90
Suspended solids		63	45	17	14	5
Total residue		232	188	149	136	87
COD	Raw	51	36	36	28	20
	Soluble	27	27	30	25	15
Total kjeldahl nitrogen	Raw	1.6	1.2	1.1	1.3	1.0
	Soluble	1.6	1.4	1.0	0.6	0.6
Total phosphorus as P	Raw	0.93	0.40	0.30	0.22	0.18
	Soluble	0.70	0.30	0.27	0.13	0.09
Nitrate as N		1.0	0.4	0.3	0.3	0.4
Total nitrogen		2.6	1.6	1.4	1.6	1.4

*All concentrations in milligrams per liter except as noted.

Site No. 3
Area = 10.12 acres
Cover: Brome grass and alfalfa

Table B3. - Chemical and Physical Quality Characteristics of Agricultural Runoff
Brookings County, South Dakota - 1971

Characteristic*		Feb 16	Feb 17	Feb 18	Feb 25	Feb 26	Mar 10	Mar 11	Mar 12	Mar 13
Volume (gal)		144,000	80,300	2,300	37,800	3,100	30,500	33,100	25,000	8,000
Specific conductance (µmhos/cm @ 25°C)		99	129	177	82	122	107	117	117	136
Suspended solids		17	17	17	6	5	19	25	23	21
Total residue		129	130	155	92	131	110	145	130	102
COD	Raw	34	43	63	52	44	78	85	70	38
	Soluble	23	36	40	41	41	48	53	35	17
Total kjeldahl nitrogen	Raw	1.5	2.4	2.6	1.9	1.7	3.3	4.0	3.6	1.2
	Soluble	1.5	1.6	1.9	1.5	1.3	2.3	2.5	1.4	1.0
Total phosphorus as P	Raw	0.20	0.37	0.55	0.27	0.28	0.63	0.77	0.66	0.52
	Soluble	0.13	0.20	0.31	0.12	0.10	0.22	0.18	0.21	0.22
Nitrate as N		1.0	0.8	1.2	0.4	0.4	0.3	0.4	0.5	0.2
Total nitrogen		2.5	3.2	3.8	2.3	2.1	3.6	4.4	4.1	1.4

*All concentrations in milligrams per liter except as noted.

Site No. 4
Area = 8.77 acres
Cover: Brome grass and alfalfa

Table B4. - Chemical and Physical Quality Characteristics of Agricultural Runoff Brookings County, South Dakota - 1971

Characteristic*		Feb 16	Feb 17	Feb 18	Feb 25	Feb 26	Mar 10	Mar 11	Mar 12	Mar 13
Volume (gal)		51,000	41,000	2,500	19,200	19,900	44,100	47,600	45,100	11,800
Specific conductance (μmhos/cm @ 25°C)		98	125	178	69	94	107	101	112	115
Suspended solids		18	19	16	7	3	11	17	18	11
Total residue		105	126	161	87	156	110	109	116	94
COD	Raw	43	43	63	36	34	72	68	66	28
	Soluble	28	34	38	33	30	49	53	33	19
Total kjeldahl nitrogen	Raw	1.6	1.9	2.5	1.3	1.3	2.8	3.5	3.5	1.3
	Soluble	1.6	1.8	1.6	1.0	1.2	2.4	2.5	1.6	1.1
Total phosphorus as P	Raw	0.21	0.36	0.42	0.18	0.16	0.52	0.72	0.62	0.46
	Soluble	0.13	0.17	0.23	0.07	0.09	0.26	0.23	0.22	0.28
Nitrate as N		1.1	1.0	1.1	0.6	0.6	0.4	0.4	0.4	0.1
Total nitrogen		2.7	2.9	3.6	1.9	1.9	3.2	3.9	3.9	1.4

*All concentrations in milligrams per liter except as noted.

Site No. 7
Area = 15.51 acres
Cover: Grassland - pastures

Table B5. - Chemical and Physical Quality Characteristics of Agricultural Runoff
Brookings County, South Dakota - 1971

Characteristic*		Feb 16	Feb 17	Feb 18	Feb 25	Feb 26	Mar 10	Mar 11	Mar 12	Mar 13
Volume (gal)		118,000	117,000	6,200	46,600	15,600	19,800	127,000	90,000	9,800
Specific conductance (µmhos/cm @ 25°C)		121	114	252	115	116	151	137	148	229
Suspended solids		37	17	23	18	4	17	23	28	23
Total residue		157	113	248	119	120	143	127	148	208
COD	Raw	55	53	121	62	48	74	76	86	85
	Soluble	39	36	76	45	44	50	55	41	48
Total kjeldahl nitrogen	Raw	2.3	2.7	5.6	2.5	1.9	3.1	3.6	4.9	4.1
	Soluble	2.3	2.2	5.6	1.6	1.8	2.4	2.5	2.0	2.9
Total phosphorus as P	Raw	0.36	0.40	0.97	0.53	0.31	0.72	0.86	1.04	1.43
	Soluble	0.27	0.20	0.41	0.26	0.21	0.34	0.33	0.38	0.63
Nitrate as N		1.2	1.0	2.4	0.6	0.6	0.4	0.4	0.4	0.3
Total nitrogen		3.5	3.7	8.0	3.1	2.5	3.5	4.0	5.3	4.4

*All concentrations in milligrams per liter except as noted.

Site No. 8
Area = 18.68 acres
Cover: Corn stubble and oats

Table B6. - Chemical and Physical Quality Characteristics of Agricultural Runoff Brookings County, South Dakota - 1971

Characteristic*		Feb 16	Feb 17	Feb 18	Feb 25	Feb 26	Mar 10	Mar 11	Mar 12	Mar 13
Volume (gal)		131,000	137,000	3,200	50,800	33,300	13,000	232,000	218,000	52,600
Specific conductance (µmhos/cm @ 25°C)		117	127	209	120	111	121	113	121	176
Suspended solids		73	32	75	13	2	7	41	58	14
Total residue		185	140	203	143	82	137	153	150	153
COD	Raw	53	40	61	56	44	83	64	76	40
	Soluble	35	31	38	45	42	72	55	70	36
Total kjeldahl nitrogen	Raw	2.0	2.2	2.4	1.7	1.7	4.6	3.0	1.7	1.7
	Soluble	2.0	2.0	2.0	1.3	1.8	3.6	2.4	2.9	1.7
Total phosphorus as P	Raw	0.51	0.39	0.56	0.30	0.21	0.46	0.41	0.40	0.34
	Soluble	0.35	0.32	0.50	0.18	0.19	0.27	0.16	0.05	0.20
Nitrate as N		0.9	0.9	1.6	0.8	0.7	0.6	0.5	0.5	0.6
Total nitrogen		2.9	3.1	4.0	2.5	2.4	5.2	3.5	2.2	2.3

Table B6. - Continued

Characteristic*		June 8	June 29
Volume (gal)		1,500	340
Specific conductance (µmhos/cm @ 25°C)		127	138
Suspended solids		675	430
Total residue		1,110	770
COD	Raw	94	70
	Soluble	27	33
Total kjeldahl nitrogen	Raw	3.4	2.8
	Soluble	0.9	1.0
Total phosphorus as P	Raw	1.32	1.21
	Soluble	0.23	0.30
Nitrate as N		2.6	2.6
Ammonia as N		0.2	0.3
Total nitrogen		6.0	5.4

*All concentrations in milligrams per liter except as noted.

Site No. 9
Area = 9.79 acres
Cover: Corn stubble and oats

Table B7. - Chemical and Physical Quality Characteristics of Agricultural Runoff
Brookings County, South Dakota - 1971

Characteristic*	Feb 16	Feb 17	Feb 18	Feb 25	Feb 26	Mar 10	Mar 11	Mar 12	Mar 13
Volume (gal)	50,000	177,000	1,400	12,400	3,900	6,900	74,800	93,800	19,700
Specific conductance (μmhos/cm @ 25°C)	157	128	189	130	120	140	152	120	164
Suspended solids	27	24	16	16	3	11	30	40	12
Total residue	205	125	155	122	140	135	155	127	127
COD Raw	67	57	45	66	42	93	86	46	38
Soluble	55	37	35	52	44	71	69	39	34
Total kjeldahl nitrogen Raw	2.0	2.5	2.2	2.5	2.0	4.5	4.0	1.7	1.7
Soluble	2.4	2.5	2.0	2.1	2.0	4.5	3.8	1.6	1.7
Total phosphorus as P Raw	0.58	0.44	0.46	0.43	0.27	0.56	0.60	0.45	0.32
Soluble	0.48	0.43	0.33	0.31	0.21	0.39	0.33	0.08	0.17
Nitrate as N	0.6	0.9	1.1	0.7	0.7	0.5	0.7	0.4	0.2
Total nitrogen	2.6	3.4	3.3	3.2	2.7	5.0	4.7	2.1	1.9

*All concentrations in milligrams per liter except as noted.

Site No. 1
Area = 7.18 acres
Cover: Plowed and oats

Table B8. - Chemical and Physical Quality Characteristics of Agricultural Runoff
Brookings County, South Dakota - 1972

Characteristic*		Mar 11	May 22	May 28 AM	May 28 PM	May 29	July 28
Volume (gal)		170	1,400	2,600	1,600	2,200	51,800
Specific conductance (μmhos/cm @ 25°C)		115	358	502	538	444	136
Suspended solids		12	208	34	51	28	6,700
Total residue		107	460	378	416	346	6,730
COD	Raw	22	75	55	45	34	660
	Soluble	20	45	30	24	24	30
Total kjeldahl nitrogen	Raw	1.3	2.1	1.4	1.3	1.2	3.8
	Soluble	1.3	1.5	1.3	1.1	0.9	0.9
Total phosphorus as P	Raw	0.44	0.78	0.49	0.38	0.26	3.50
	Soluble	0.43	0.58	0.37	0.35	0.09	0.14
Nitrate as N		0.9	0.2	0.2	0.4	1.5	0.8
Ammonia as N			0.2	0.2	0.2	0.1	0.2
Total nitrogen		2.2	2.3	1.6	1.7	2.7	4.6

*All concentrations in milligrams per liter except as noted.

Site No. 2
Area = 8.77 acres
Cover: Plowed and oats

Table B9. - Chemical and Physical Quality Characteristics of Agricultural Runoff Brookings County, South Dakota - 1972

Characteristics*		Mar 11	Mar 13	Mar 15	May 29	July 28
Volume (gal)		170	590	600	5,000	103,000
Specific conductance (µmhos/cm @ 25°C)		107	124	120	97	45
Suspended solids		19	28	59	1,360	2,940
Total residue		103	162	145	1,560	2,950
COD	Raw	6	34	24	221	328
	Soluble	3	25	5	22	16
Total kjeldahl nitrogen	Raw	1.1	1.9	1.2	7.0	4.3
	Soluble	0.9	1.7	0.9	1.3	0.6
Total phosphorus as P	Raw	0.56	0.62	0.42	2.11	2.49
	Soluble	0.55	0.59	0.10	0.42	0.13
Nitrate as N		0.4	1.6	1.4	1.8	0.4
Ammonia as N					0.4	0.1
Total nitrogen		1.5	3.5	2.6	8.8	4.7

*All concentrations in milligrams per liter except as noted.

Site No. 3
Area = 10.12 acres
Cover: Brome grass and alfalfa

Table B10. - Chemical and Physical Quality Characteristics of Agricultural Runoff
Brookings County, South Dakota - 1972

Characteristic*		Mar 7	Mar 10	Mar 11	Mar 12	Mar 13	Mar 14	Mar 15	July 28
Volume (gal)		257,000	16,400	48,300	6,600	23,600	1,700	1,400	27,800
Specific conductance (µmhos/cm @ 25°C)		108	116	86	174	159	137	93	73
Suspended solids		6	13	16	22	28	22	44	64
Total residue		119	129	96	249	212	148	114	141
COD	Raw	51	62	37	150	123	63	24	22
	Soluble	50	25	28	76	65	27	5	16
Total kjeldahl nitrogen	Raw	3.3	3.6	2.3	5.6	4.4	3.5	1.1	0.8
	Soluble	2.6	2.6	1.9	3.9	3.2	1.7	0.5	0.7
Total phosphorus as P	Raw	0.28	0.33	0.32	0.86	0.91	0.83	0.36	0.30
	Soluble	0.14	0.19	0.05	0.06	0.14	0.27	0.22	0.16
Nitrate as N		1.4	1.3	0.7	1.8	1.3	0.5	0.2	0.3
Ammonia as N									0.2
Total nitrogen		4.7	4.9	3.0	7.4	5.7	4.0	1.3	1.1

*All concentrations in milligrams per liter except as noted.

Site No. 4
Area = 8.77 acres
Cover: Brome grass and alfalfa

Table B11. - Chemical and Physical Quality Characteristics of Agricultural Runoff
Brookings County, South Dakota - 1972

Characteristic*		Mar 7	Mar 10	Mar 11	Mar 12	Mar 13	Mar 15	July 28
Volume (gal)		40,300	10,700	21,400	530	4,300	950	1,900
Specific conductance (µmhos/cm @ 25°C)		100	109	92	181	165	81	60
Suspended solids		12	13	16	18	33	54	17
Total Residue		121	130	108	190	229	116	75
COD	Raw	49	56	45	127	139	30	22
	Soluble	44	21	30	72	67	5	20
Total kjeldahl nitrogen	Raw	3.0	2.9	2.4	4.6	5.2	1.5	0.8
	Soluble	2.2	2.2	1.9	3.1	3.1	0.7	0.7
Total phosphorus as P	Raw	0.34	0.31	0.37	0.74	1.08	0.56	0.40
	Soluble	0.08	0.22	0.07	0.14	0.14	0.10	0.27
Nitrate as N		1.1	1.0	0.7	1.3	1.4	0.2	0.3
Ammonia as N								0.2
Total nitrogen		4.1	3.9	3.1	5.9	6.6	1.7	1.1

*All concentrations in milligrams per liter except as noted.

Site No. 7
Area = 15.51 acres
Cover: Grassland - Pasture

Table B12. - Chemical and Physical Quality Characteristics of Agricultural Runoff
Brookings County, South Dakota - 1972

Characteristic*		Mar 7	Mar 10	Mar 11	Mar 12	Mar 13	Mar 14	Mar 15	May 29	July 28
Volume (gal)		200,000	38,500	228,000	39,200	91,400	18,400	2,600	460	295,000
Specific conductance (μmhos/cm @ 25°C)		130	131	97	157	163	117	177	423	79
Suspended solids		3	5	18	10	24	18	15	15	60
Total Residue		126	139	101	161	198	144	147	319	125
COD	Raw	53	63	45	67	110	73	39	38	60
	Soluble	45	33	29	46	63	31	23	27	34
Total kjeldahl nitrogen	Raw	3.2	3.3	2.5	3.3	4.7	3.9	2.6	1.6	1.8
	Soluble	2.5	2.6	1.9	2.2	3.6	2.1	1.6	1.1	1.4
Total phosphorus as P	Raw	0.30	0.36	0.45	0.69	0.90	0.85	0.62	0.48	0.49
	Soluble	0.31	0.18	0.17	0.25	0.44	0.31	0.32	0.37	0.25
Nitrate as N		2.0	1.4	0.8	0.7	1.0	0.4	0.6	0.3	0.4
Ammonia as N									0.2	0.4
Total nitrogen		5.2	4.7	3.3	4.0	5.7	4.3	3.2	1.9	2.2

*All concentrations in milligrams per liter except as noted.

Site No. 8
Area = 18.68 acres
Cover: Plowed and weeds

Table B13. - Chemical and Physical Quality Characteristics of Agricultural Runoff Brookings County, South Dakota - 1972

Characteristic*		Mar 6	Mar 8	Mar 9	Mar 10	Mar 11	Mar 12	Mar 13	Mar 14	Mar 15
Volume (gal)		4,400	650	2,300	36,800	147,000	37,000	81,000	29,700	4,000
Specific conductance (μmhos/cm @ 25°C)		167	225	190	152	136	169	166	224	352
Suspended solids		152	10	21	278	463	36	106	18	7
Total residue		332	190	183	711	560	190	280	211	258
COD	Raw	59	37	33	129	105	50	65	41	31
	Soluble	37	22	11	35	30	35	35	33	26
Total kjeldahl nitrogen	Raw	3.2	2.8	4.3	3.8	2.5	2.0	2.4	2.4	2.1
	Soluble	2.1	1.6	1.6	2.3	2.0	1.8	2.2	2.1	1.8
Total phosphorus as P	Raw	0.58	0.32	0.34	0.83	0.64	0.35	0.34	0.39	0.28
	Soluble	0.25	0.23	0.20	0.25	0.15	0.14	0.17	0.18	0.18
Nitrate as N		2.4	4.3	2.9	1.6	1.0	1.6	1.9	2.6	4.4
Total nitrogen		5.6	7.1	7.2	5.4	3.5	3.6	4.3	5.0	6.5

Table B13. - Continued

Characteristic*		May 1	May 12	May 22	May 23	May 24	May 28	May 29
Volume (gal)		7,200	180	1,800	5,100	22,300	43,400	134,000
Specific conductance (umhos/cm @ 25°C)		170	204	206	460	514	429	376
Suspended solids		270	220	192	54	32	609	232
Total residue		540	578	422	401	432	914	550
COD	Raw	44	55	44	53	46	115	67
	Soluble	14	5	25	44	34	20	24
Total kjeldahl nitrogen	Raw	1.6	1.3	2.0	2.0	1.6	3.1	1.8
	Soluble	0.6	0.9	1.1	1.4	1.4	1.0	0.8
Total phosphorus as P	Raw	0.74	1.07	0.52	0.35	0.24	0.76	0.42
	Soluble	0.22	0.25	0.28	0.27	0.16	0.13	0.12
Nitrate as N		1.5	1.2	3.0	4.3	2.7	1.2	1.1
Ammonia as N		0.1	0.1	0.2	0.2	0.1	0.2	0.1
Total nitrogen		3.1	2.5	5.0	6.3	4.3	4.3	2.9

Table B13. - Continued

Characteristic*		June 18	June 19	July 8	July 14	July 21	July 26
Volume (gal)		450,000	124,000	55,300	1,900	99,100	139,000
Specific conductance (µmhos/cm @ 25°C)		219	280	181	213	284	165
Suspended solids		1,066	1,430	1,360	1,803	2,410	5,450
Total residue		1,290	1,610	1,460	1,605	2,530	5,330
COD	Raw	152	182	176	258	362	774
	Soluble	19	13	4	27	18	18
Total kjeldahl nitrogen	Raw	2.8	3.4	2.4	5.8	5.6	4.9
	Soluble	0.9	0.9	0.9	1.1	0.6	1.1
Total phosphorus as P	Raw	1.17	1.58	0.93	1.60	2.06	2.55
	Soluble	0.08	0.14	0.04	0.06	0.03	0.05
Nitrate as N		1.8	1.2	2.0	3.3	2.0	1.8
Ammonia as N		0.1	0.2	0.2	0.1	0.1	0.1
Total nitrogen		4.6	4.6	4.4	9.1	7.6	6.7

*All concentrations in milligrams per liter except as noted.

Site No. 9
Area = 18.68 acres
Cover: Plowed and weeds

Table B14. - Chemical and Physical Quality Characteristics of Agricultural Runoff
Brookings County, South Dakota - 1972

Characteristic*		May 1	May 29	June 18	June 19	July 21	July 26
Volume (gal)		2,200	50,600	183,000	43,800	170	35,700
Specific conductance (µmhos/cm @ 25°C)		139	319	110	272	253	199
Suspended solids		40	45	577	90	105	182
Total residue		290	290	690	341	385	372
COD	Raw	21	34	79	23	34	44
	Soluble	4	16	13	17	21	26
Total kjeldahl nitrogen	Raw	0.9	1.2	1.7	1.4	1.4	1.2
	Soluble	0.3	0.9	0.6	0.9	0.9	0.9
Total phosphorus as P	Raw	0.36	0.24	0.82	0.37	0.69	0.51
	Soluble	0.19	0.16	0.07	0.11	0.42	0.21
Nitrate as N		0.4	1.7	0.1	0.3	2.5	0.4
Ammonia as N		0.0	0.1	0.1	0.1	0.3	0.2
Total nitrogen		1.3	2.9	1.8	1.7	3.9	1.6

*All concentrations in milligrams per liter except as noted.

APPENDIX C

Bacteriological Quality Data

Site No. 1
Area = 7.18 acres
Cover: Oat stubble and oats - '71
Plowed and corn - '72

Table C1. - Bacteriological Quality Characteristics of Agricultural Runoff Brookings County, South Dakota

Date	Total Coliform (MPN/100 ml)	Fecal Coliform (MPN/100 ml)	Fecal Streptococcus (MPN/100 ml)
Snowmelt 1971			
February 16	16,100	80	220
February 17	1,200	230	1,720
February 18	1,300	170	330
February 25	1,300	< 100	1,300
February 26	585	< 100	230
March 11	16,100	5	2,400
March 12	> 24,000	33	790
March 13	> 24,000	23	490
Snowmelt 1972			
March 11	5,420	630	4,900
Rainfall 1972			
May 22	13,000	490	54,200
May 28 AM	54,200	54,200	10,900
May 28 PM	3,300	330	4,900
May 29	3,100	1,090	1,700
July 28	10,900	33,000	172,000

Site No. 2
Area = 8.77 acres
Cover: Oat stubble and oats - '71
Plowed and corn - '72

Table C2. - Bacteriological Quality Characteristics of Agricultural Runoff Brookings County, South Dakota

Date	Total Coliform (MPN/100 ml)	Fecal Coliform (MPN/100 ml)	Fecal Streptococcus (MPN/100 ml)
Snowmelt 1971			
February 16	2,700	20	790
February 17	> 400	50	330
February 18	1,720	130	130
February 25	2,490	50	870
February 26	715	50	50
Snowmelt 1972			
March 11	330	40	10,900
March 13	3,300	1,300	2,300
March 15	24,000	1,720	54,200
Rainfall 1972			
May 29	13,000	4,900	33,000
July 28	348,000	8,000	49,000

Site No. 3
Area = 10.12 acres
Cover: Brome grass and alfalfa

Table C3. - Bacteriological Quality Characteristics of Agricultural Runoff Brookings County, South Dakota

Date	Total Coliform (MPN/100 ml)	Fecal Coliform (MPN/100 ml)	Fecal Streptococcus (MPN/100 ml)
Snowmelt 1971			
February 16	2,210	1,720	2,400
February 17	3,480	3,480	2,400
February 18	16,100	16,100	2,210
February 25	700	600	2,700
February 26	2,300	650	2,300
March 10	1,700	330	2,200
March 11	3,100	---	24,000
March 12	1,400	1,410	1,700
March 13	7,900	330	1,400
Snowmelt 1972			
March 7	9,200	240	1,600
March 10	1,400	500	34,800
March 11	92,000	330	10,900
March 12	92,000	4,600	17,200
March 13	22,100	700	22,100
March 14	790	110	1,720
March 15	490	0	1,300

Table C3. - Continued

Date	Total Coliform (MPN/100 ml)	Fecal Coliform (MPN/100 ml)	Fecal Streptococcus (MPN/100 ml)
Rainfall 1972			
July 28	161,000	790	161,000

Site No. 4
Area = 8.77 acres
Cover: Brome grass and alfalfa

Table C4. - Bacteriological Quality Characteristics of Agricultural Runoff Brookings County, South Dakota

Date	Total Coliform (MPN/100 ml)	Fecal Coliform (MPN/100 ml)	Fecal Streptococcus (MPN/100 ml)
Snowmelt 1971			
February 16	2,400	790	3,300
February 17	1,090	490	4,600
February 18	1,300	1,300	3,480
February 25	2,390	595	1,700
February 26	1,450	330	1,700
March 10	3,480	490	4,900
March 11	2,400	542	3,300
March 12	1,090	490	4,900
March 13	1,720	348	790
Snowmelt 1972			
March 7	2,780	240	> 1,600
March 10	800	200	10,900
March 11	13,000	330	3,300
March 12	14,100	10,900	4,900
March 13	54,200	700	4,900
March 15	700	0	4,900
Rainfall 1972			
July 28	161,000	300	161,000

Site No. 7
Area = 15.51 acres
Cover: Grassland - pasture

Table C5. - Bacteriological Quality Characteristics of Agricultural Runoff Brookings County, South Dakota

Date	Total Coliform (MPN/100 ml)	Fecal Coliform (MPN/100 ml)	Fecal Streptococcus (MPN/100 ml)
Snowmelt 1971			
February 16	1,720	1,090	220
February 17	1,300	1,300	2,300
February 18	34,800	9,180	3,480
February 25	465	280	450
February 26	2,300	395	1,800
March 10	2,300	---	700
March 11	7,000	490	2,300
March 12	2,200	46	2,400
March 13	4,600	330	900
Snowmelt 1972			
March 7	> 16,000	5,420	920
March 10	4,900	1,300	2,700
March 11	27,800	1,720	1,750
March 12	10,900	3,300	4,900
March 13	7,000	4,900	7,000
March 14	7,000	330	2,300
March 15	1,720	40	490

Table C5. - Continued

Date	Total Coliform (MPN/100 ml)	Fecal Coliform (MPN/100 ml)	Fecal Streptococcus (MPN/100 ml)
Rainfall 1972			
May 29	54,200	4,600	17,200
July 28	161,000	161,000	91,800

Site No. 8
Area = 18.68 acres
Cover: Corn stubble and oats - '71
Plowed and idle acres - '72

Table C6. - Bacteriological Quality Characteristics of Agricultural Runoff Brookings County, South Dakota

Date	Total Coliform (MPN/100 ml)	Fecal Coliform (MPN/100 ml)	Fecal Streptococcus (MPN/100 ml)
Snowmelt 1971			
February 16	> 16,090	130	3,300
February 17	> 16,090	50	3,480
February 18	> 160,900	1,410	9,180
February 25	765,000	< 100,000	4,100
February 26	730,000	< 100,000	33,300
March 10	400,000	20	4,900
March 11	1,300,000	31	11,000
March 12	> 240,000	33	4,600
March 13	2,100,000	79	14,100
Rainfall 1971			
June 8	130,000	17,200	22,100
June 29	34,800	4,900	92,000
Snowmelt 1972			
March 6	> 16,000	49	> 1,600
March 8	160,000	80	10,900
March 9	> 160,000	20	54,200
March 10	> 160,000	0	6,300
March 11	> 160,000	110	17,200

Table C6. - Continued

Date	Total Coliform (MPN/100 ml)	Fecal Coliform (MPN/100 ml)	Fecal Streptococcus (MPN/100 ml)
March 12	> 1,600,000	110	34,800
March 13	> 1,600,000	80	17,200
March 14	1,600,000	80	4,900
March 15	348,000	0	10,900
Rainfall 1972			
May 1	3,300	200	1,300
May 12	4,900	170	13,000
May 22	34,800	700	160,900
May 23	14,100*	700*	2,300*
May 24	17,200*	790*	7,000*
May 28	34,800	10,900	54,200
May 29	34,800	1,720	91,800
June 18	160,900	34,800	27,800
June 19	24,000	790	91,800
July 8	49,000	34,800	91,800
July 14	161,000	91,800	34,800
July 21	348,000	8,000	49,000
July 26	348,000	33,000	23,000

* Delayed coliform test.

Site No. 9
Area = 9.79 acres
Cover: Corn stubble and oats - '71
Plowed and idle acres - '72

Table C7. - Bacteriological Quality Characteristics of Agricultural Runoff Brookings County, South Dakota

Date	Total Coliform (MPN/100 ml)	Fecal Coliform (MPN/100 ml)	Fecal Streptococcus (MPN/100 ml)
Snowmelt 1971			
February 16	> 16,090	230	1,300
February 17	16,100	330	1,300
February 18	> 160,900	220	3,480
February 25	979,000	< 10,000	2,940
February 26	730,000	< 10,000	5,420
March 10	1,090,000	70	13,000
March 11	340,000	33	22,100
March 12	1,300,000	2,400	7,900
March 13	460,000	49	3,100
Rainfall 1972			
May 1	110	20	790
May 29	34,800	3,300	3,300
June 18	91,800	34,800	160,900
June 19	13,000	1,090	17,500
July 21	91,800	7,900	161,000
July 26	161,000	7,900	91,800

APPENDIX D

Pesticide Data

Table D1. - Results of Pesticides Analyses on Filtered Samples

(All values in ppb, unless noted.)

Date	Site 1	Site 2	Site 3	Site 4	Site 7	Site 8	Site 9
2/16/71	*	*	*	*	*	*	*
2/17/71	*	*	*	*	*	*	*
2/18/71	*	*	*	*	*	*	*
2/25/71 & 2/26/71	.15 DDD .2 DDT	*	.12 DDD	*	.27 DDD .14 DDT	.18 DDD .10 DDT	.18 DDD .17 DDT
3/10/71 to 3/13/71					.14 DDE		
3/11/71 to 3/13/71	.33 DDT						
6/8/71						.2 DDE .1 DDT	
3/6/72						*	
3/7/72			*	*	*		
3/8/72 & 3/9/72						*	
3/11/72	*						
3/10/72 to 3/13/72			*	*	*	*	
3/14/72 & 3/15/72			*		*	*	
3/15/72				*			

Table D1. - Continued

(All values in ppb, unless noted.)

Date	Site 1	Site 2	Site 3	Site 4	Site 7	Site 8	Site 9
5/1/72						*	*
5/12/72						*	
5/22/72	*					.06 DDE	
5/23/72						*	
5/24/72						*	
5/28/72 AM	.24 DDE .13 DDD .10 DDT					.06 Aldrin .17 DDE	
5/28/72 PM	.22 DDE					.08 DDE	
5/29/72	*	*			*	*	*
7/8/72						.61 Aldrin .12 DDE	
7/21/72						*	*
7/26/72						.10 DDE	
7/28/72	*	*	.15 DDE	.19 DDE	.06 DDE		

* Below analytical test limits

Table D2. - Results of Pesticides Analyses on Filtered Samples

(All values in ppb, unless noted.)

Date	Site 1	Site 2	Site 7	Site 8	Site 9
6/8/71				10 Aldrin 5 DDE 1 Dieldrin 10 DDT	
6/29/71				3.4 Lindane 5.8 Aldrin 22.9 DDE 5.3 Dieldrin	
5/1/72				*	*
5/12/72				*	
5/22/72				*	
5/24/72				*	
5/28/72 AM	100 Aldrin 23 DDE 42 DDT				
5/28/72 PM	262 Aldrin			5 Aldrin 16 DDE	
5/29/72	10 Aldrin 13 DDE 19 DDT	40 Aldrin	59 Aldrin	194 Aldrin	10 Aldrin 12 DDE
6/18/72 & 6/19/72				*	14.17 ppm Atrazine
7/8/72				290 Aldrin 170 DDE	
7/14/72				*	
7/21/72				*	*

Table D2. - Continued

Date	Site 1	Site 2	Site 7	Site 8	Site 9
7/26/72				89 Aldrin	
7/28/72	89 Aldrin 12 DDE 17 DDT	*			

* Below analytical test limits