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Quality and Quanity of Surface Runoff from a Cropland Area in South Dakota During 1970

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QUALITY AND QUANTITY OF SURFACE RUNOFF

FROM A CROPLAND AREA IN SOUTH DAKOTA

DURING 1970

BY

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

Thesis Adviser — Date

Head, Civil Engineering Department — Date

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INTRODUCTION

In a message to Congress on February 10, 1970, President Nixon (1) stated:

> Water pollution has three principal sources: municipal, industrial, and agricultural wastes. All three must eventually be controlled if we are to restore the purity of our lakes and rivers.
>
> Of these three, the most troublesome to control are those of agricultural sources: animal wastes, eroded soil, fertilizers, and pesticides.

In the past, pollution from agricultural sources has received far less attention than pollution from industrial and municipal sources. Point sources of agricultural pollution such as livestock confinement feeding operations have received more attention by researchers than the runoff from cultivated cropland.

The 1967 Conservation Needs Inventory performed by the United States Government reported 1,438 million acres of non-federal rural land, including 437.6 million acres of cultivated cropland (2). Every year 500,000 acres of cropland are lost from productive use as cropland due to soil erosion (3-37). An average of one million acres of urban land and other built-up areas such as highways are developed each year. Most of this land must come from agricultural areas (4-74). Because the population of the United States is approximately doubling every forty years (5-5), it is obvious that more food will have to be produced on less land.

In order to produce sufficient food on less land, it appears that existing cropland will have to be farmed more intensively with greater use of fertilizers and pesticides. However, the general public fears that the use of these substances will have extremely harmful effects on the overall environment.

The problems of pollution from cropland runoff are indeed complex because the runoff comes from such a large land area. Furthermore, it cannot be readily collected and treated in the same manner as domestic sewage or industrial wastes. Research to more fully evaluate the characteristics of runoff from agricultural areas would appear to be the first step in approaching the problem.

The general objective of this investigation was to determine the characteristics of runoff from an agricultural drainage basin located in eastern South Dakota. The specific objectives of this investigation were:

1. To determine the average concentrations and total loads of polluting materials in runoff from a small agricultural drainage basin located near Brookings, South Dakota, during 1970.

2. To investigate the variations in concentrations of various polluting materials with such factors as rainfall intensity, runoff volume and soil cover conditions.

PAST RESEARCH CONCERNING THE QUALITY OF RUNOFF FROM AGRICULTURAL LAND

Research regarding the quality of agricultural runoff has been relatively limited in comparison to that devoted to most other sources of water pollution. Much of the research has been concerned with only one particular pollutant such as nitrogen, phosphorus or sediment. Unfortunately most of the studies conducted have encompassed a time period of only one or two years, and thus do not always provide statistically reliable values for annual losses.

Because of concern in the field of soil and water conservation, research concerning the relationships between precipitation, runoff and erosion has been extensive. Ellison (6) performed tests on bare soil with simulated rainfall and found that considerable amounts of soil were carried downhill by the splash from raindrops as well as by water flowing over the soil surface. When falling raindrops struck either the soil surface, or a thin film of water covering the soil surface, particles of soil and water were splashed into the air. The splashed soil was predominantly moved downhill. Raindrop splash was actually found to carry higher percentages of larger particles and aggregates than surface flow. Soil loss due to raindrop splash became greater as raindrop size, raindrop velocity, rainfall intensity and wind velocity increased (6).

Rogers, *et al.* (7) also performed experiments with simulated rainfall. A 75 ft by 12 ft plot of sandy loam soil on a 7 per cent slope lost 8.79 tons per acre of soil when subjected to a $2\frac{1}{2}$ inch rainfall at an intensity of $2\frac{1}{2}$ inches per hour. An identical rainfall created 24 hours later produced 11.98 tons per acre loss. It was reported that soil loss became greater with increasing slope length, degree of slope, rainfall intensity, rainfall amount and with higher antecedent moisture conditions (7).

Sawyer (8) conducted an extensive study from 1942 to 1944 of all types of waste discharges into the lakes around Madison, Wisconsin. His primary concern was the nitrogen and phosphorus contributions to the lakes. The nitrogen and phosphorus contents of runoff from agricultural areas were evaluated by studying the contributions from drainage basins with no domestic or industrial pollutant sources. It was found that agricultural drainage contributed approximately 7 lbs/ac/yr of nitrogen and 0.4 lbs/ac/yr of phosphorus. As a result of his study, Sawyer reported that nuisance algal growths developed in lakes when the concentration of inorganic phosphorus exceeded 0.01 mg/l, and the concentration of inorganic nitrogen exceeded 0.3 mg/l.

Sylvester (9) studied the nitrogen and phosphorus content of drainage water from irrigated land in the Yakima River Basin of Washington. Samples of surface drainage from four drainage basins of areas 252, 150, 13 and 2 square miles were studied from March, 1959, to March, 1960. Total nitrogen losses varied from 2.5 to 24 lbs/ac/yr with a mean concentration of 1.4 mg/l. Total phosphorus losses varied from 0.9 to 3.9 lbs/ac/yr with a mean concentration of 0.25 mg/l (9).

Engelbrecht and Morgan (10) studied agricultural drainage during 1956 and 1957 in Illinois. They estimated the phosphorus contributions of agricultural drainage to the total amount of phosphorus in streams by subtracting the amount of phosphorus contributed by domestic sewage. Samples were collected from six drainage basins of areas of 12, 125, 1050, 1980, 2680 and 5220 square miles. The estimated annual loads from the drainage basins varied from 0 to 15 lbs/ac/yr (as phosphorus) with a mean concentration of 0.35 mg/l. Analyses were performed for ortho and hydrolyzable phosphoric acid (P_2O_5). Total phosphorus was not determined, but was estimated to be 20-30 per cent higher (10) than the ortho and hydrolyzable P_2O_5.

Benson (11) studied the characteristics of runoff during 1969 from a 173-acre agricultural drainage basin located near Brookings, South Dakota. During 1969 crops on the drainage basin consisted of corn, oats and flax (11-18). Benson sampled runoff from three sources: snowmelt, rainfall and a combination of snowmelt and rainfall. Average concentrations of the various constituents are shown in Table 1. Because Benson did not obtain flow data the average concentrations are arithmetic averages, and they do not account for varying loads of pollutants per runoff event. As can be seen in Table 1, relatively high concentrations of total and suspended solids were present in the runoff. The solids content of rainfall runoff was much greater than that of snowmelt runoff. In snowmelt runoff the suspended solids constituted about one-third of the total solids, whereas in rainfall runoff, suspended solids accounted for over 90 per cent of the total solids. Benson noted that the solids content of the runoff generally varied with the intensity of the rainfall producing the runoff. For example, a rainfall of 2.1 in/hr intensity produced a peak suspended

Table 1. Mean, Minimum, and Maximum Concentrations of Constituents in Runoff from the Small Agricultural Drainage Basin in South Dakota during 1969 (11-31)

Determination	Mean Concentration* (mg/l)		
	Snowmelt Runoff	Snowmelt plus Rainfall Runoff	Rainfall Runoff
Biochemical Oxygen Demand (5-day)	5.7 (0.9-17)*	30	8.1 (5.0-10.4)*
Chemical Oxygen Demand	52 (22-126)	152	357 (146-517)
Total Solids	303 (161-588)	2,442	5,124 (3,692-7,850)
Suspended Solids	91 (17-174)	2,170	4,968 (3,545-7,780)
Volatile Suspended Solids	25 (7-46)	372	767 (575-975)
Total Kjeldahl Nitrogen	3.2 (1.3-8.1)	8.0	16.6 (12.1-20.3)
Soluble Phosphorus	0.33 (0.08-0.78)	0.36	0.17 (0.09-0.27)
Total Number of Composite Samples	6	1	3

*Note: Values in parenthesis are minimum and maximum concentrations for composite samples.

solids concentration of 12,000 mg/l and a rainfall of 3.72 in/hr intensity produced a peak of 30,000 mg/l (11-33).

The biochemical oxygen demand (BOD) of the runoff water was relatively low for all runoff events during 1969. The BOD of the runoff resulting from a combination of snowmelt and rainfall was substantially higher than for all other runoff events.

Manure had been spread on the drainage basin throughout the winter; organic matter in the manure had probably undergone very little bacterial decomposition due to low temperatures. The comparatively high BOD of the runoff was attributed to the dislodging of organic matter by rainfall (11-32).

Benson noted that the runoff contained appreciable amounts of nitrogen and phosphorus during all runoff events. He concluded that nitrogen and phosphorus concentrations were far in excess of the concentrations expected to support profuse growth of algae under quiescent conditions with adequate sunlight (11-34).

Seven bacteriological samples were collected during one runoff event. The most probable numbers (MPN) of total coliform, fecal coliform and fecal streptococcus organisms were found to be very high and greatly exceeded the densities of organisms specified in existing water quality standards. Fecal coliform densities ranged from 800 to 2,300,000 organisms/100 ml. The high organism densities were attributed to manure which had been spread on the drainage basin (11-41).

Benson (11-43) attempted to determine how reductions in suspended solids concentrations would effect the concentrations of other insoluble constituents by performing analyses on both raw and centrifuged samples. Almost complete reductions of suspended solids and BOD were attained by centrifugation. The average chemical oxygen demand (COD) reduction was 72 per cent. The centrifugation procedure reduced the chemical oxygen demand of the samples to a uniform minimum value of about 40 mg/l regardless of the initial COD. In a similar manner for the Kjeldahl nitrogen, an average reduction of 83 per cent and a uniform minimum value of about 1.4 mg/l after centrifugation was reported. As a result of his study, Benson concluded that the polluting characteristics of runoff from agricultural land could be substantially reduced by the removal of suspended solids; this removal could be facilitated by retaining the runoff water on land for a sufficient period of time to permit the suspended material to settle (11-43).

Extensive research on the overall quality of agricultural runoff in Ohio has been conducted by the personnel of the Cincinnati Water Research Laboratory (12). Most of their runoff quality data were collected from two 1.5 acre watersheds near Coshocton, Ohio, during 1963 and 1964. However, silt loss data for the two watersheds were available from 1945; by use of correlations between silt losses and total solids, and between total solids and other runoff constituents, the annual loads shown in Table 2 were extrapolated. Table 3 shows the mean concentrations of the various runoff constituents when the crop on the watersheds was wheat (12). There was very little difference in the concentrations of the constituents between watersheds 113 and 118. In fact, the higher concentrations of constituents in runoff were found in samples from the watershed which was under improved practice.

Watershed No. 113 was under improved land management practice including contour tillage, high level of fertilization, liming to pH 6.8 and a clover-alfalfa-timothy mixture for meadow. Watershed No. 118 was under prevailing practice including straight-row tillage across the slope, low level of fertilization, liming to pH 5.4 and an alsike clover-red clover-timothy mixture for meadow. Although greater amounts of fertilizer and manure were applied under improved practice, pollutional loads were far less than for land under prevailing practice. This decreased pollutant load illustrated the value of good land management in reducing soil loss and water pollution due to agricultural runoff (12).

The seasonal occurrence of runoff was also studied by personnel of the Cincinnati Water Research Laboratory. It was found that 85 per cent of the annual waterborne soil loss occurred in the period from May to September when rainfall intensities were high, drop size was large and the duration of storms was short (12).

Tests for total coliform, fecal coliform and fecal streptococcus organisms were performed on runoff from five agricultural watersheds near Coshocton, Ohio. Microbial densities in the runoff from all watersheds exceeded a bathing water criterian of 1000 counts/100 ml of

Table 2. Calculated Average Annual Loads from Watersheds in Ohio (12)

Watershed No.	Cover	TS (lb/acre)	BOD (lb/acre)	COD (lb/acre)	P (lb/acre)	Total N (lb/acre)
113	Corn	3,660	27.5	480	2.7	88
118	Corn	13,200	120.0	1,300	9.0	237
113	Wheat	480	3.7	64	.36	11
118	Wheat	1,730	15.5	170	1.2	31
113	Meadow	Trace	-	-	-	-
118	Meadow	Trace	-	-	-	-

Note: Lb/acre x 1.12 = kg/ha.

Table 3. Mean Concentrations of Constituents per Storm, with Land in Wheat in Ohio (12)

Constituent	Concentration in Given Watershed (mg/l)	
	118	113
TS	500	540
BOD	2.9	7.2
COD	40	80
Total N	6.0	9.0
PO_4	1.3	1.8

total coliform in 50 per cent of the samples. Watersheds had received from 4 to 6 tons per acre per year of manure (12).

Kohnke (13) was primarily concerned about the chemistry of runoff because of the loss of plant nutrients and consequently the loss of soil fertility due to runoff. He performed research in Indiana during 1941 on the chemical constituents of runoff water and the variations of concentrations with time. Surface runoff from a 3.5 acre pastured woodland watershed and percolation water from the drain tile of a 32-acre watershed with mixed pasture and cropland cover were studied. It was concluded that surface runoff is generally high in solid soil particles (especially clay and organic matter), high in total nitrogen and adsorbed phosphorus, but low in soluble salts. On the other hand, percolation water from a drain tile contained relatively high concentrations of soluble salts, but little or no organic matter, phosphorus and colloids. He also found that total solids concentrations roughly varied with flow (13).

Losses of plant nutrients as a result of soil erosion in the Tennessee River system were determined by the Tennessee Valley Authority. Samples of silt and water were collected at seven locations in the Tennessee River System. Four locations on tributary streams had drainage areas of 685, 1474, 421 and 2571 square miles respectively. Three locations on the main river had drainage areas of 8913, 21400 and 38530 square miles respectively. Samples were collected at frequent intervals during a 1½-year period in 1939 and 1940. The drainage areas were primarily cultivated cropland. Losses of 23.8 lbs/ac/yr of nitrogen and 5.7 lbs/ac/yr of phosphorus were reported (14).

Timmons, et al. (15) conducted studies in Minnesota involving the nutrient content of runoff from cropland under various cropping conditions including fallow, continuous corn and a corn-oats-hay rotation. The study was conducted for two growing seasons during 1966 and 1967 on small plots (72.6 ft by 13.3 ft) on a 6 per cent slope. Total nitrogen losses ranged from 0.1 to 90 lb/ac/yr with a mean concentration of about 29 mg/l. Total phosphorus losses ranged from 0.1 to 0.5 lb/ac/yr with a mean concentration of 1.0 mg/l (15).

A summary of water quality data collected in past research is shown in Table 4. Wide variations in loads and concentrations have been reported within the individual research projects as well as among the various research projects.

The quality of runoff water from agricultural land has been studied in various manners. Sawyer (8), Sylvester (9), Engelbrecht and Morgan (10) and Flippin (14) estimated the quality of agricultural runoff by stream sampling. Benson (11) and Weidner, et al. (12) sampled runoff directly from cultivated drainage basins. Timmons, et al. (15) collected runoff samples from small experimental plots. Land areas used in research have ranged in size from areas exceeding 30,000 square miles in the Tennessee River System (14) to 0.02-acre plots near Morris, Minnesota (15).

Table 4. Summary of Research Concerning the Quality of Runoff from Agricultural Land

Constituent	Reference	Concentration (mg/l)	Annual Load (lbs/ac/yr)
Total Nitrogen	Sawyer (8)		7
	Sylvester (9)	1.4	2.5-24
	Flippin (14)		23.8
	Weidner, *et al.* (12)		11-237
	Timmon, *et al.* (15)	29	0.1-90
Kjeldahl Nitrogen	Benson (11)	1.3-20.3	
Total Phosphorus	Sawyer (8)		0.4
	Sylvester (9)	0.25	0.9-3.9
	Flippin (14)		5.7
	Timmons, *et al.* (15)	1.0	0.1-0.5
Total Hydrolyzable Phosphorus	Weidner, *et al.* (12)		1.2-39
Total Soluble Phosphorus	Benson (11)	0.08-0.36	
Ortho plus Hydrolyzable Phosphorus	Engelbrecht and Morgan (10)	0.35	0-15
BOD	Weidner, *et al.* (12)		3.7-120
	Benson (11)	0.9-30	
COD	Weidner, *et al.* (12)		64-1,300
	Benson (11)	22-517	
Total Solids	Weidner, *et al.* (12)		480-13,200
	Benson (11)	161-7,850	

A review of the literature indicated that there had been very little research performed in which runoff was collected at the outlet of drainage basins during storms and in which the overall runoff quality including nutrients, oxygen-demanding materials and solids concentrations were determined. The only research found including these conditions was that performed by Benson (11) and by Weidner, *et al.* (12).

DESCRIPTION OF THE AREA

The drainage basin from which the runoff samples were collected is located approximately four miles north of Brookings, South Dakota, in Section 36 of Sterling Township. The area of the drainage basin is 0.27 square miles or 173 acres (11-16). The soil on the drainage basin is predominantly a combination of Vienna and Kranzburg loam and Brookings silty clay loam (16). The outlet of the drainage basin is a 3 ft high by 4 ft wide concrete box culvert passing under Highway 77. Figure 1 shows the general location of the drainage basin. The runoff water flows into a tributary of North Deer Creek which in turn in a tributary of the Big Sioux River.

This drainage basin is one of 80 located throughout South Dakota being studied jointly by the United States Geological Survey and the South Dakota Highway Department in a project entitled, "Investigation and Analysis of Flood Hydrographs from Small Drainage Basins in South Dakota". In order to obtain rainfall and runoff data automatically, a digital rainfall and stage recorder and a staff gage have been placed near the inlet of the culvert.

Samples of runoff from this drainage basin were collected and analyzed by Rick D. Benson during 1969. His results were reported in a Master of Science thesis entitled The Quality of Surface Runoff from a Farmland Area in South Dakota during 1969 (11). His results have been summarized in the previous section of this thesis.

Most of the drainage basin (90 per cent) is in the western one-half of the section which is owned by James Christophersen. Mr.

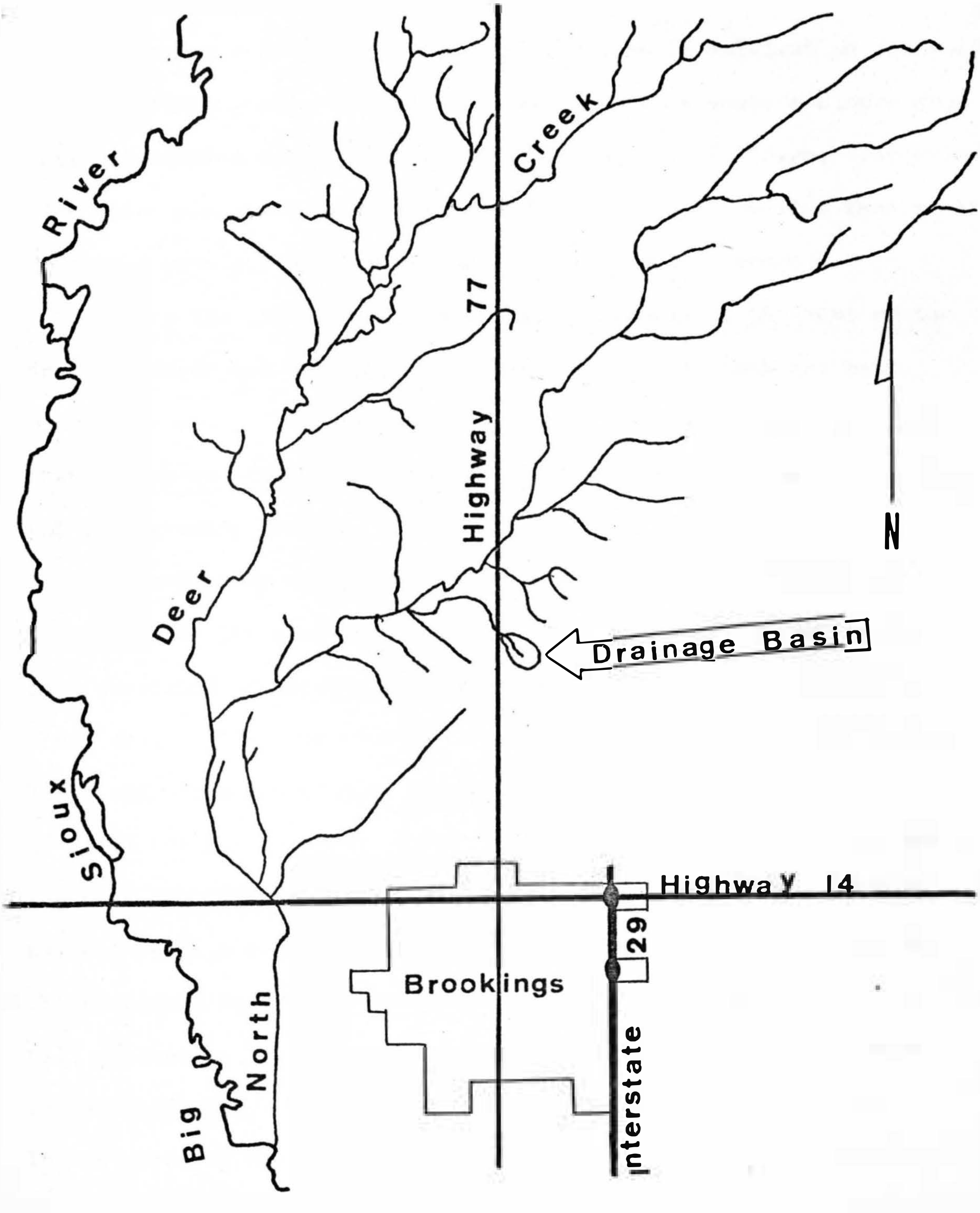

Figure 1. Diagram showing general location of agricultural drainage basin

Christophersen reported that the land had been in cultivation for about the past fifty years. For at least the past five years a simple crop rotation between corn and oats had generally been followed. Interviews with other operators of land in the drainage basin revealed that their practices were essentially the same as Mr. Christophersen's.

During the 1970 growing season approximately 75 per cent of the drainage basin had been planted to corn and 25 per cent had been planted to oats. All crops were planted in straight east-west rows that ran up-and-downhill. Figure 2 shows the cropping pattern during the 1970 growing season.

The oats crop was planted in late April of 1970. During the previous year the land had produced corn. Seedbed preparation for oats consisted of disking the cornstalks and planting oats with a press drill. The oats crop was harvested by combining in mid-August, 1970, and straw was chopped and spread on the field.

All but thirty acres of corn had been in oats the previous year. The oats stubble had been chisel-plowed immediately after the 1969 harvest in late August and again in mid-September. The stubble was chisel-plowed in the spring of 1970 and corn was planted with a buffalo-till planter in mid-May, 1970. This corn was harvested by picking in late September, 1970; the cornstalks were left on the field. Thirty acres of the southern end of James Christophersen's cornfield had been in corn the previous year. Corn on this land was planted in early June, 1970, and harvested for silage in early October, 1970.

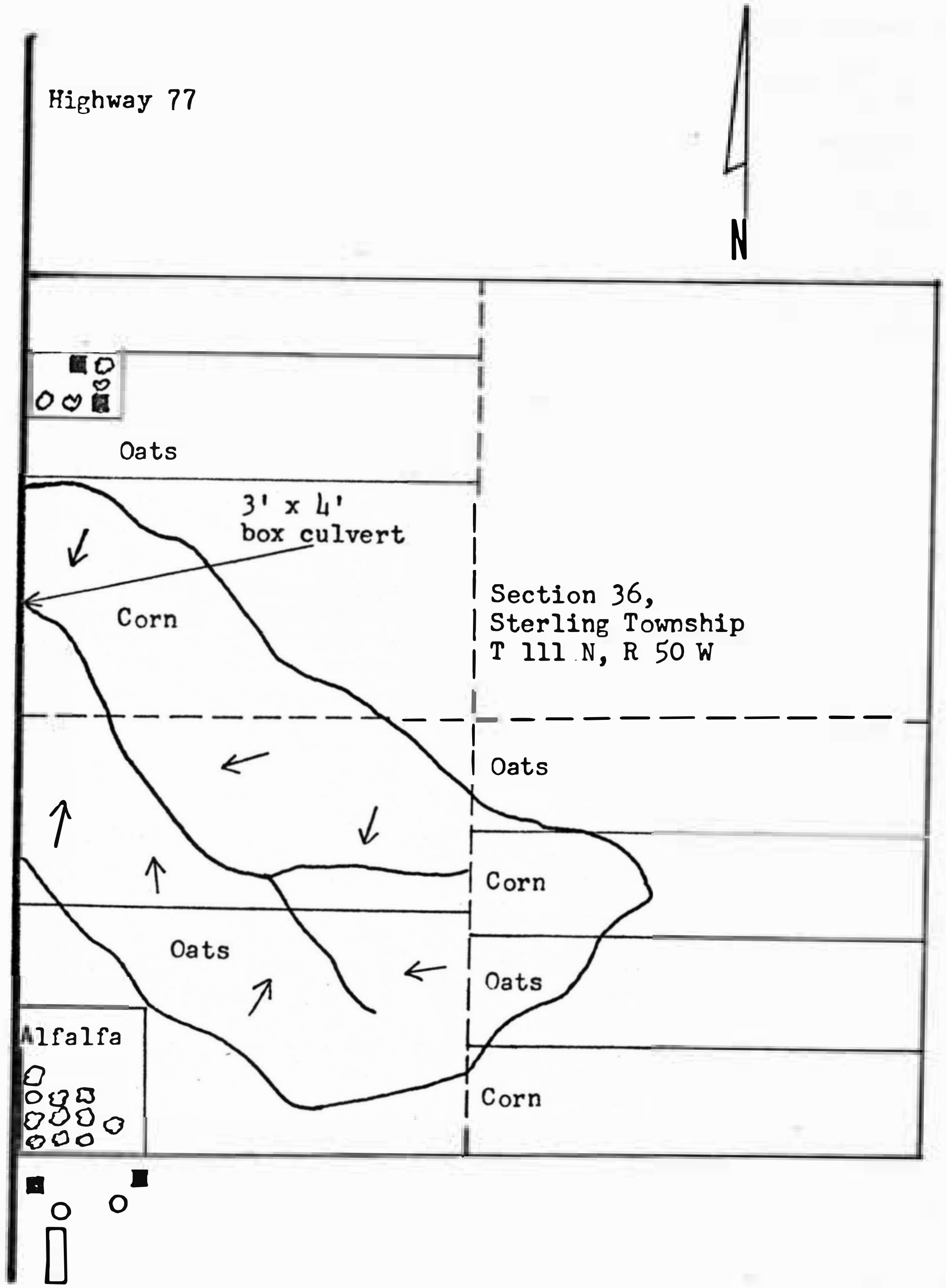

Figure 2. Diagram showing crop cover on the drainage basin during the 1970 growing season

Table 5 describes the history of the applications of various fertilizers, herbicides and insecticides to the drainage basin between the 1969 and 1970 harvests. Manure from James Christophersen's dairying operation had been spread on the drainage basin throughout the fall and winter of 1969 and 1970 until early June, 1970 just before the planting of the thirty acres of corn for silage. No grazing by livestock had been permitted since fall of 1968.

Table 5. Applications of Fertilizers, Herbicides, and Insecticides to the Small Agricultural Drainage Basin between 1969 and 1970 Harvests

Item	Approximate Date of Application	Rate of Application	Remarks
Barnyard Manure	See Remarks	Unknown	Applied to entire drainage basin fall 1969 to June 1, 1970
Commercial Fertilizer			
80% Anhydrous Ammonia	Oct. 1, 1969	100 lb/ac	Applied to oats stubble
29-14-0	April 25, 1970	100 lb/ac	Applied to oats at time of planting
8-32-16	May 15-20, 1970	70 lb/ac	Applied to corn at time of planting
Insecticides			
20% Aldrin	May 15-20, 1970	2½ lb/ac	Applied to all but 30 ac of corn at time of planting
10% Carbamate	May 15-20, 1970	7 lb/ac	Applied to 30 ac of corn which did not receive aldrin at time of planting
Herbicides			
40.6% 2,4-D	June 2, 1970	1 pint/ac	Applied to oats
	June 11, 1970	1 pint/ac	Applied to corn
76% Atrazine	June 6, 1970	½ lb/ac	Applied to corn

EXPERIMENTAL PROCEDURE

The investigation was conducted in two major phases. The first phase involved the collection, analyses for bacterial densities, pH and specific conductance measurements and preservation by freezing of individual grab samples of the 1970 runoff events. The second major phase consisted of performing various analyses for nutrients, solids, pesticides, and oxygen-demanding materials on the thawed samples in late summer and fall of 1970.

Grab samples were collected at 15 to 30-minute intervals during periods near the peak stage when rapid changes in discharge were taking place. Low flows of long duration were sampled at intervals ranging from one to three hours. At the time of collection of each grab sample, the stage (water surface elevation) of the water flowing through the culvert was recorded.

Plastic bags inside one-half gallon paper cartons were used as containers for samples analyzed for nutrients, solids, oxygen-demanding materials and pesticides because this type of container was readily available and also suitable for freezing. Two such containers of each sample were collected so that duplicates of each grab sample were available. Shortly after collection (usually less than eight hours), the samples were taken to the laboratory where specific conductance and pH measurements were performed. Samples were then placed in a freezer maintained at about -15°C. The estimated time period required for complete freezing of each sample was 20 hours. Samples were stored in a freezer at about -15°C until they were removed for thawing several months later. Approximately 24 hours before analyses for nutrients, solids and oxygen-demanding materials were begun, samples were removed from the freezer and allowed to thaw and warm to room temperature.

Except for samples collected during the March 3 runoff event, grab samples for bacteriological analysis were collected concurrently with the samples which were analyzed for nutrients, solids, pesticides and oxygen-demanding materials. Samples for bacteriological analysis were collected in special sterile plastic bags and submitted to the Bacteriology Department at South Dakota State University within twelve hours after collection. Analyses were made for most probable number (MPN) of total coliform, fecal coliform and fecal streptococcus organisms per 100 ml of sample.

One of the duplicates of each grab sample was thawed in late August and analyzed for total solids, suspended solids and biochemical oxygen demand. Specific conductance and pH determinations were repeated on the samples after thawing. In mid-November of 1970 the remaining duplicate grab samples were thawed and composited. One composite sample for each of the eight runoff events was prepared for analysis.

Grab samples were composited by considering each grab sample to represent a volume of water under the hydrograph of the runoff event involved. Flows for constructing the runoff hydrograph were determined by a curve relating stage or water surface elevation to discharge (stage-discharge rating curve) for the box culvert.

One special problem encountered in handling and compositing samples was that of keeping a representative amount of suspended material in all aliquots of sample. To minimize this problem, magnetic-stirring devices, siphons and pipets with enlarged openings were utilized in transferring and measuring samples.

A portion of each composite sample was centrifuged and filtered through a membrane filter having openings of 0.45 micron diameter. Tests on filtered samples were performed in order to determine the concentrations of constituents in solution.

A Technicon AutoAnalyzer was used to perform the following analytical determinations on both the raw and filtered composite samples: ammonia nitrogen, nitrate and nitrite nitrogen, total Kjeldahl nitrogen and total phosphorus. In addition, the chemical oxygen demand of the soluble portion of the samples was determined by use of the Technicon AutoAnalyzer.

The following determinations were performed on the raw composite samples as prescribed in the 12th edition of Standard Methods for the Examination of Water and Wastewater (17): COD, total solids and specific conductance. BOD determinations were made by using a Weston and Stack dissolved oxygen probe in accordance with a method described in FWPCA Methods for Chemical Analysis of Water and Wastes (18-65). Suspended and volatile suspended solids were determined by use of glass fiber filters according to a procedure prescribed by Wyckoff (19). Analyses for solids, nutrients, and oxygen-demanding materials on all composite samples were conducted in duplicate.

One-liter portions of each raw composite sample were submitted to the Experiment Station Biochemistry Department at South Dakota State University. Analyses for various pesticides were performed by use of a gas chromatograph. Lindane, heptachlor, aldrin, heptachlor epoxide, dieldrin, DDE, DDD and DDT were the insecticides for which analyses were conducted. Herbicides for which analyses were performed were atrazine and simazine.

PRESENTATION AND DISCUSSION OF DATA

Precipitation and Runoff Data

Precipitation data were collected in several different manners throughout 1970. It was hoped that data from the United States Geological Survey recording rain gauge could be used, but such data were not available at the time of this writing. After April 14, 1970, precipitation data were collected by use of Tru-check[1] rain gauges. Intensity of rainfall was determined by reading a rain gauge near the culvert inlet at frequent intervals during runoff-producing rainfalls. Precipitation data for the period of January 1 to April 14 were obtained from the recording rain gauge atop the Agricultural Engineering Building on the South Dakota State University campus. In late June of 1970, a recording rain gauge with an 8-day clock was obtained and installed near the inlet of the 3 ft by 4 ft box culvert. However, no runoff-producing rainfall occurred after June 19. Data on the precipitation received during 1970 are shown in the Appendix.

The United States Geological Survey had installed a graduated staff gauge near the upstream side of the outlet culvert. At the time of collection of each grab sample, the stage was read from this gauge although no means of converting stage to discharge was available at the times when samples were collected. Throughout the investigation, attempts were made to make discharge measurements. On May 31, 1970,

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[1]A Tru-check rain gauge is a tapered plastic fence post rain gauge of six-inch capacity.

some discharge measurements at low flows (less than 30 cfs) were made with a Price current meter. However, these data did not provide sufficient information for developing a stage-discharge rating curve. In late August of 1970, a stage-discharge rating curve for the culvert was obtained from the United States Geological Survey. This curve had been computed on the basis of discharge measurements made by the United States Geological Survey during snowmelt of 1969. It was noted that the portion of this curve below 30 cfs did not coincide with the measurements performed on May 31. United States Geological Survey Hydraulic Engineer, Larry Becker, commented that their curve was probably not reliable at low flows.[2] Because no other data for discharges above 30 cfs were available, a combination of the May 31 measurements and the data from the United States Geological Survey was used in developing the stage-discharge rating curve shown in Figure 3.

The dotted line in Figure 3 represents data obtained from the United States Geological Survey which was not used. The solid line represents the stage-discharge rating curve used for calculating proportions for compositing samples and for calculating flow volumes.

Measurable precipitation occurred on approximately 70 days during 1970, but runoff occurred only on eight separate occasions as shown in Table 6. Only one snowmelt, on April 23, produced runoff from the drainage basin. In order to describe each of the runoff-producing

[2]Letter from Larry Becker, United States Geological Survey, Huron South Dakota, to Terry A. McCarl, September 15, 1970

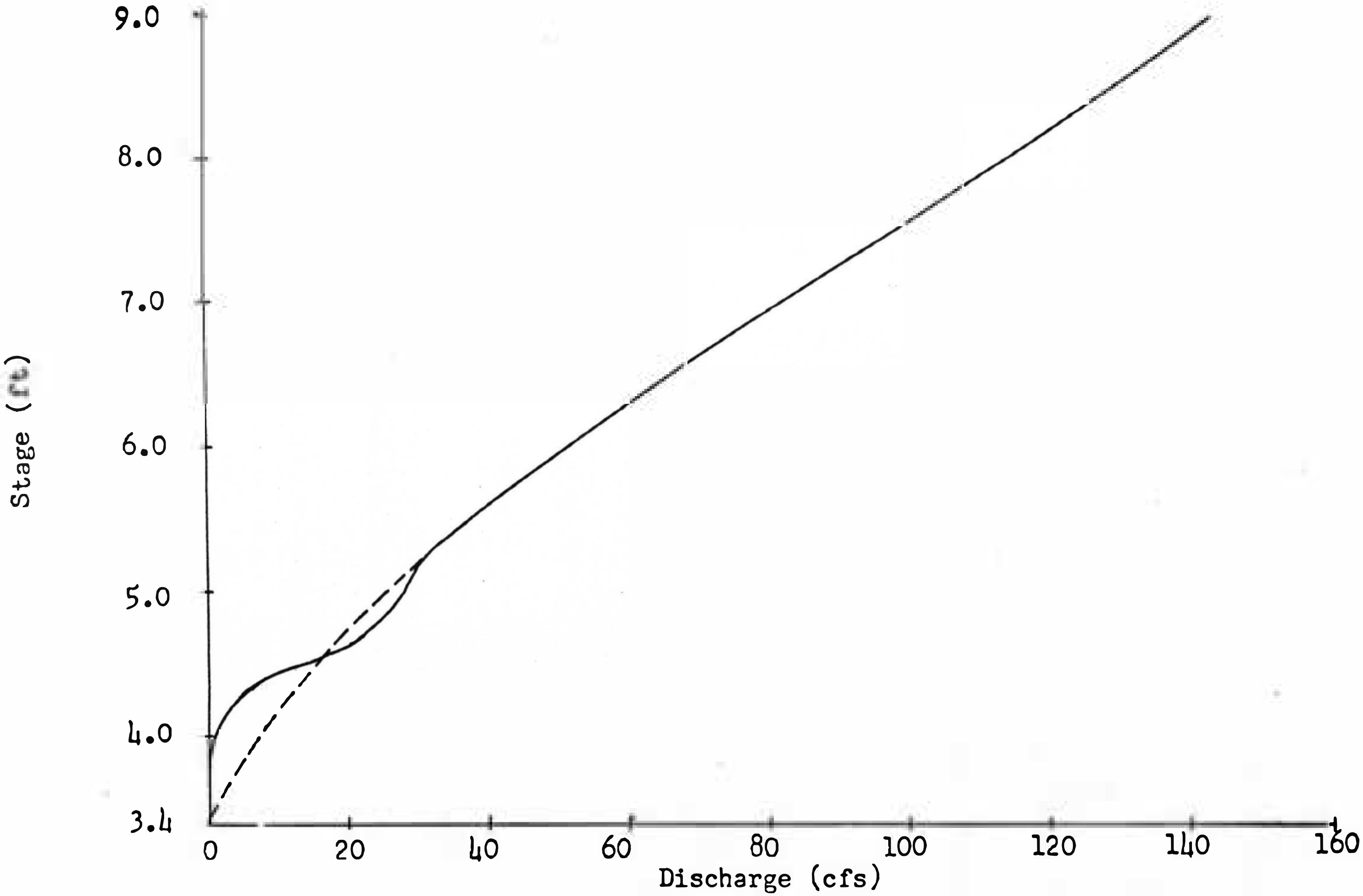

Figure 3. Stage-discharge rating curve for the 3 ft x 4 ft box culvert at the outlet of the drainage basin

Table 6. Characteristics of Runoff-Producing Rainfalls during 1970 on the Small Agricultural Drainage Basin

Date	Maximum Intensity in a 15-Minute Period (in/hr)	Maximum Intensity in a 30-Minute Period (in/hr)	Total Rainfall Volume (in)	Runoff Volume (in)
March 3	1.08	1.02	0.87	1.14
April 15	0.32	0.26	0.35	.00751
April 19	0.32	0.28	0.41	.0144
April 23	*	*	0.57	.0283
May 28	0.96	0.70	1.21	.00115
May 31	2.80	1.48	.79	.281
June 16	3.20	2.20	2.08	1.20
June 19	0.68	0.62	0.58	.00254
			Total	2.67

*Snowmelt

rainfalls, maximum intensities observed during periods of both 15 and 30 minutes and total rainfall volume were used.

On March 3 a rainfall of 1.1 in/hr intensity with rainfall volume of 0.87 inches produced 1.14 inches of runoff. The excess runoff was attributed to snow melted by the rain and to the frozen ground preventing infiltration.

Although the drainage basin received approximately 22 inches of precipitation during 1970, only 2.67 inches of runoff were produced. Over 98 per cent of this runoff volume was attributed to three high-intensity rainfalls occurring on March 3, May 31 and June 16.

All runoff events occurred before substantial crop cover was on the drainage basin. A 1.26-inch rain with a maximum 15-minute intensity of 1.6 inches per hour on July 18 failed to produce runoff. The failure to produce runoff was attributed to the crop cover and to a low moisture content in the soil prior to the rainfall.

Variations in Runoff Quality

Table 7 shows the concentrations and loads of chemical constituents for each of the eight runoff events occurring in 1970. The volume of runoff for each runoff event and the concentrations of the various constituents found in the composite sample representing that event were used to calculate the loads in pounds.

Wide variations in both concentrations and loads among the various runoff events were observed. Variables appearing to exert major influences on runoff quality were intensity of rainfall producing

Table 7. Concentrations and Loads of Runoff Constituents from the Small Cropland Area in 1970

Item	Date							
	Mar 3	Apr 15	Apr 19	Apr 23	May 28	May 31	June 16	June 19
Rainfall (in)	0.87	0.35	0.41	0.57	1.2	0.79	2.1	0.58
Max. Rainfall Intensity in a 15-min. period (in/hr)	1.1	0.32	0.32		0.96	2.8	3.2	0.68
Runoff (in)	1.14	.00751	.0144	.0283	.00115	.281	1.20	.00254
Total Solids								
mg/l	2,060	1,540	722	587	3410	6,530	4,450	3320
lbs	92,500	453	407	665	155	72,000	210,000	331
Suspended Solids								
mg/l	1,960	990	180	330	3370	5,980	4,190	3050
lbs	88,000	291	102	374	153	66,000	198,000	304
% Volatile	14.5	18.5	23.3	15.1	16.8	9.8	12.7	15.1
Specific Conductance (mmhos/cm at 25°C)	160	741	596	404	160	96	171	434
Biochemical Oxygen Demand								
mg/l	15	5.3	3.4	5.4	6.5	4.2	10	6.5
lbs	670	1.6	1.9	6.1	0.32	46.4	470	.6
Chemical Oxygen Demand								
mg/l	300	220	80	70	560	780	430	410
lbs	13,400	65	45	79	25	8600	20,300	41
Total Phosphorus								
mg/l	.15	.55	.60	.05	.08	.04	.08	.05
lbs	6.7	.16	.34	.06	.004	.44	3.8	.004
Nitrate Nitrogen								
mg/l	3.7	26	25	11	2.8	1.7	4.0	9.1
lbs	170	7.6	14	12	.12	19	190	.91
Ammonia Nitrogen								
mg/l	.50	.54	.36	.20	.61	.57	.61	.61
lbs	22	.16	.20	.23	.028	6.3	29	.061
Organic Nitrogen								
mg/l	9.2	6.7	4.0	2.6	14.6	16.3	8.3	11.6
lbs	410	2.0	2.2	2.9	0.66	180	390	1.16
Total Nitrogen								
mg/l	13.4	33.2	29.9	13.8	18.0	18.6	12.9	21.3
lbs	600	9.8	16	15	.81	200	610	2.1

the runoff, crop cover, soil conditions, temperature and moisture conditions preceding rainfall. Widely varying conditions throughout the 1970 runoff season precluded the formulation of definite relationships between the above variables and concentrations of various constituents. However, several trends were observed in interpreting the data in Table 7. Rainfalls of high intensity generally produced runoff with relatively high concentrations of total and suspended solids, COD, and organic nitrogen, and with relatively low concentrations of nitrate nitrogen, total phosphorus, and total dissolved solids (as indicated by specific conductance measurements). The inverse was generally true for runoff produced by rainfall of low intensity.

The May 31 runoff event occurred as a result of the second highest intensity rainfall producing runoff during 1970. Of the total rainfall volume, about 36 per cent became runoff. The sample representing this event contained the highest concentrations of total and suspended solids, organic nitrogen, and COD; the lowest total phosphorus and nitrate-nitrogen concentrations and the lowest specific conductance were also reported.

The June 16 runoff event occurred as the result of the highest intensity rainfall during 1970. Runoff representing 57 per cent of the rainfall was determined for this storm. Because of a severe electrical storm about the time of peak flow on June 16, a sample was not obtained at this time. Almost all of the composite sample representing this event consisted of one grab sample collected after the peak flow had subsided. It was considered that the composite sample for the June 16 runoff event was not wholly representative of the runoff from that particular storm. It is probable that considerably higher concentrations of total and suspended solids would have been found in a truly representative composite sample. In spite of the limitations of the sample actually obtained, the concentrations of the various constituents found in the June 16 sample were similar to those found in the May 31 sample.

The only runoff event caused by snowmelt occurred on April 23. It appeared that the April 23 snowmelt had an effect on the drainage basin similar to the effect of a low-intensity rainfall. Rainfalls of low intensity on April 15 and 19, and snowmelt on April 23 produced runoff with similar characteristics. In the case of all three events, less than 5 per cent of the rainfall left the drainage basin as runoff. All three events occurred when the drainage basin was quite well protected from erosion by a cover of crop residues from the previous growing season. Total and suspended solids concentrations of the three events were substantially lower than the concentrations of these materials for the other runoff events. Suspended solids concentrations were less than 1000 mg/l and total solids concentrations were less than 2000 mg/l. The runoff from these events was also relatively low in organic nitrogen (less than 7 mg/l) and COD (less than 300 mg/l). The runoff from these events also exhibited higher nitrate concentrations than determined for other events (greater than 10 mg/l). The highest total phosphorus concentrations (about 0.6 mg/l) occurred on

April 15 and April 19. The total phosphorus concentration of the snowmelt runoff on April 23 was very low and comparable with that found for events other than the April 15 and 19 events. The specific conductance of the April 15 and April 19 samples was higher than that observed for the other samples, and the specific conductance of the sample from the April 23 snowmelt was also rather high (greater than 400 mmhos/cm at 25°C).

As previously stated, it appeared generally true that rainfalls of low intensity produced runoff with high concentrations of nitrate and total dissolved solids (as indicated by specific conductance measurements). In the case of low-intensity storms, the runoff water could have been expected to be in contact with the soil of the drainage basin for relatively long periods of time. The water was probably retained in depression storage on the drainage basin for several hours until these depressions overflowed and the water reached the channel leading from the drainage basin. While in depression storage, there was probably sufficient time for ions to dissolve from the soil particles, and consequently, solutions with relatively high concentrations of dissolved solids were developed. It is apparent that the nitrate ion was one of the ions reaching a relatively high concentration. Because less than 5 per cent of the rainfall became runoff, these solutions of dissolved solids were apparently not appreciably diluted.

In general, the runoff from the low-intensity rainfalls was low in total and suspended solids, organic nitrogen and COD. It seems probable that the rather gentle rainfall and snowmelt were not capable of dislodging and transporting large quantities of soil particles and associated organic matter. If soil particles had been dislodged, many were probably removed by settling while the runoff water sat in depression storage on the drainage basin.

In the case of the runoff events caused by high-intensity rainfall (May 31 and June 16), it is probable that high energy imparted by raindrops dislodged soil particles because the rapidly flowing runoff transported large quantities of soil from the drainage basin. Consequently, high concentrations of total and suspended solids were attained. Relatively high COD and organic nitrogen concentrations were also found in the runoff water indicating that organic matter was removed with the soil particles. With the high-intensity rainfall it is probable that the shorter runoff time allowed only a limited number of ions to dissolve. Because such high percentages of the rainfall became runoff, the solutions of ions in runoff water were probably diluted so that low concentrations of ions such as nitrate and phosphate were found.

The March 3 runoff event was a rather unusual occurrence. Although the rainfall producing the runoff was of relatively high intensity (greater than 1 in/hr in a 15-minute period), concentrations of COD, total solids and suspended solids were low compared to the concentrations found from other runoff events caused by high-intensity rainfall (May 28 and 31, June 16 and 19). The nitrate concentrations and specific conductance were very similar to those of the June 16 sample. Apparently the frozen ground with a light cover of snow resisted the energy of the high-intensity rainfall. Consequently, suspended solids were not dislodged as readily as when the ground was thawed. The BOD concentration of the March 3 runoff was substantially higher than the BOD for all other runoff events. The higher BOD was attributed to manure which had been spread on the drainage basin prior to the storm. Because of low temperatures and consequent low levels of bacterial activity, it is probable that the organic matter in the manure had only been stabilized to a small degree.

Runoff events of May 28 and June 19 were similar in some respects. In both cases the soil probably contained considerable moisture prior to the rainfalls causing the runoff events. Prior to the rainfall causing the May 28 runoff event, a total volume exceeding an inch of rainfall was received on the drainage basin on May 26 and 27. On June 19, the soil had probably retained considerable moisture from the 2.09 inch runoff-producing rainfall of June 16. For both the May 28 and June 19 runoff events, total and suspended solids concentrations were similar (about 3000 mg/l). Other constituents having similar concentrations for both events were COD (560 and 410 mg/l), organic nitrogen (14.6 and 11.6 mg/l) and total phosphorus (0.08 and 0.05 mg/l). The reason for the greatly differing specific conductivities (160 and 434 mmhos/cm at 25°C) and nitrate (2.8 and 9.1 mg/l) for the May 28 and June 19 runoff events respectively was not apparent. Concentrations of all the constituents for the May 28 and June 19 runoff events were generally between those for the higher rainfall intensity events

(May 31 and June 16) and the lower rainfall intensity events (April 15, 19, and 23).

It appeared that total phosphorus concentrations were generally high for the lower-intensity storms such as April 15 and 19 when the concentrations were about 0.6 mg/l. The sample representing the May 31 runoff event exhibited the lowest total phosphorus concentration (about 0.04 mg/l). Because of the inconsistencies, such as the 0.05 mg/l concentration for the snowmelt on April 23, it appears that total phosphorus concentrations did not necessarily vary with rainfall intensity.

Ammonia nitrogen was almost constant at 0.50 mg/l for all runoff events. The greater portion of the inorganic nitrogen was in the nitrate form.

Average Concentrations and Annual Loads of Constituents in Runoff

Table 8 shows the average concentrations of the various chemical constituents and the ranges in concentration among the eight composite samples. Average concentrations were calculated from the total annual load of a particular constituent and the total annual runoff volume. As discussed in the previous section, wide ranges in the concentrations of the various constituents were found among the eight composite samples.

A study of the characteristics of runoff from agricultural and urban areas in Ohio performed by Weibel, *et al.* (20) compared concentrations and annual loads of constituents in runoff with those in sanitary sewage. A domestic waste flow of 100 gallons per capita per

Table 8. Concentration of Constituents in Runoff from the Small Agricultural Drainage Basin during 1970

Constituent	Average Concentration (mg/l)	Range in Concentration (mg/l)*
Total Solids	3,570	587-6,530
Suspended Solids	3,350	180-5,980
BOD	11	3.4-15
COD	405	70-780
Total Nitrogen	14	12.9-33.2
Inorganic Nitrogen	4.4	2.3-26
Total Phosphorus	0.13	0.04-0.60

*Range in concentration is among eight composite samples.

day (gpcpd) and the following concentrations in mg/l were considered by Weibel, et al. as representative of sanitary sewage: BOD, 200; COD, 350; suspended solids, 200; total nitrogen, 30; and total phosphorus, 8 (20). These above domestic sewage characteristics were used in evaluating the runoff from the drainage basin involved in this investigation.

The average suspended solids concentration in runoff from the drainage basin was about seventeen times as large as could be expected in a typical domestic sewage. Suspended solids accounted for about 94 per cent of the total solids.

The average concentration of total oxidizable organic matter in the runoff, as measured by the concentration of COD, was comparable to that of normal domestic sewage. However, the extremely low BOD tends to indicate that the organic material was not readily oxidized biologically. Therefore, the BOD of the runoff did not appear to be an important pollutant in evaluating the pollution potential of the runoff.

The average total nitrogen concentration was about 50 per cent and the average total phosphorus concentration was only about 2 per cent of concentrations in typical domestic sewage. The concentrations of inorganic nitrogen and inorganic phosphorus were of interest because of the relationships between these substances and the possible stimulation of algal growths in surface waters. Inorganic phosphorus concentrations of the samples were not determined in the research, but it was felt that an estimate could be made from the total phosphorus concentrations on the basis of related studies. Engelbrecht and

Morgan (10) estimated that total phosphorus concentrations were about 20 per cent higher than the inorganic phosphorus concentrations. On this basis, the average concentration of inorganic phosphorus for runoff samples collected in this investigation were estimated at about 0.1 mg/l.

From the ranges of concentrations in Table 8, it was observed that inorganic nitrogen and estimated inorganic phosphorus concentrations in all composite samples exceeded the critical concentrations suggested by Sawyer (8). These critical concentrations, as previously discussed, were 0.3 mg/l for inorganic nitrogen and 0.01 mg/l for inorganic phosphorus. Therefore, these constituents in the runoff from the drainage basin considered in this investigation would probably support algal concentrations in nuisance proportions in lakes, provided that other conditions were favorable.

Table 9 shows the total annual amounts of certain constituents removed from the drainage basin. The constituents shown are those commonly considered in evaluating wastewaters.

Considering the annual loads of pollutants reported in Tables 7 and 9, it may be shown that the March 3, May 31 and June 16 runoff events carried the preponderance of the total annual load of constituents. These three runoff events resulting from high-intensity rainfall accounted for the following percentages of the total annual loads: suspended solids, 99.6%; COD, 99.3%; BOD, 98.7%; total phosphorus, 91.2%; and total nitrogen, 97.0%.

Table 9. Amounts of Constituents Removed in Runoff from the Small Agricultural Drainage Basin during 1970

Constituent	Total Pounds	Annual Loads (lbs/ac/yr)	Population Equivalent per Acre per Year*
Suspended Solids	353,000	2,040	34
BOD	1,200	6.9	.12
COD	42,600	246	2.5
Total Nitrogen	1,460	8.4	.93
Total Phosphorus	12	.07	.04

*Based on a domestic waste flow of 100 gpcpd, and the following concentrations: BOD, 200 mg/l; COD, 350 mg/l; SS,200 mg/l; Total N, 30 mg/l; and Total P, 8 mg/l (20)

In order to evaluate the pollution potential of runoff from the drainage basin, it was considered desirable to calculate a population equivalent per acre of drainage basin. A population equivalent is the ratio of the amount of suspended solids, BOD or other substances in a waste flow to the per capita amount of these respective substances normally found in domestic sewage. The population equivalent concept is commonly used in evaluating waste discharges which are relatively continuous as is generally the case with industrial wastes.

By using the waste flow of 100 gpcpd and the concentrations prescribed above by Weibel, et al. (20), the following annual per capita contributions in pounds were calculated: BOD, 60; COD, 100; suspended solids, 60; total nitrogen, 9; and total phosphorus, 2. These per capita contributions were divided into the annual per acre loads of constituents from the drainage basin to determine the population equivalent shown in Table 9.

There are severe limitations concerning the use of the population equivalent concept in evaluating the pollution potential of runoff from the drainage basin; the concept does not take into account the highly intermittent nature of the runoff. As previously discussed, nearly all of the total annual load of pollutants was removed during three runoff events.

Comparison on the basis of the population equivalent concept showed that the annual suspended solids contribution greatly exceeded those of other constituents. On a suspended solids basis, each acre had a population equivalent of 34 persons. On the bases of all other constituents, the population equivalent per acre was 2.5 or less. It may be concluded that suspended solids was the pollutant of greatest magnitude in the runoff from a standpoint of both concentration and total annual load.

Microbial Densities in Runoff

Grab samples for bacteriological determinations were taken concurrently with the grab samples for other determinations during all runoff events except the March 3 event. Total coliform, fecal coliform and fecal streptococcus determinations were performed on the samples by personnel of the Bacteriology Department of South Dakota State University. Needing determinations performed on fresh samples, and not having a basis for compositing the grab samples at the time of collection, determinations were performed on each of the grab samples. The minimum, maximum and median densities for each runoff event are shown in Table 10.

Fecal coliform organisms are characteristically inhabitants of the intestines of warm-blooded animals. Other types of coliforms may be found in soil, on plants and insects (21-22). According to the National Technical Advisory Committee to the Secretary of the Interior, it is necessary to consider all fecal coliform organisms as indicative of dangerous contamination. No satisfactory method is currently available for differentiating between fecal coliform organisms of human and of animal origin (21-22). In runoff from the small agricultural drainage basin, total coliform concentrations were generally many times greater than the fecal coliform concentrations. It is

Table 10. Most Probable Number of Organisms/100 ml in Runoff from the Small Agricultural Drainage Basin during 1970

Date	Number of Samples		MPN - Organisms/100 ml Total Coliform	Fecal Coliform	Fecal Streptococcus
April 15	7	Median	3,300	500	3,300
		Maximum	7,900	1,300	7,900
		Minimum	500	200	500
April 19	5	Median	330	20	230
		Maximum	790	20	790
		Minimum	130	20	130
April 23	5	Median	2,300	20	230
		Maximum	7,900	130	490
		Minimum	230	20	230
May 28	3	Median	49,000	13,000	23,000
		Maximum	230,000	49,000	49,000
		Minimum	33,000	33,000	7,900
May 31	9	Median	240,000	8,000	33,000
		Maximum	16,090,000	80,000	230,000
		Minimum	79,000	800	23,000
June 16	7	Median	230,000	33,000	130,000
		Maximum	1,300,000	79,000	5,420,000
		Minimum	49,000	4,900	79,000
June 19	2	Median	49,000	7,900	49,000
		Maximum	49,000	33,000	49,000
		Minimum	49,000	7,900	49,000

probable that large numbers of coliforms not of the fecal subgroup were predominantly organisms of soil and plant origin.

When animal wastes rather than human wastes are the source of water pollution, the ratio of fecal coliform to fecal streptococcus is generally less than one. The magnitude of the fecal coliform to fecal streptococcus ratio has been used as an indicator of whether bacterial pollution is from agricultural activities or urban centers (22-12). The presence of fecal organisms in runoff from the drainage basin may be attributed to manure which had been spread on the drainage basin throughout the previous fall, winter and spring. Analysis of runoff samples indicated that the source of pollution was from animals rather than from humans because fecal streptococcus concentrations generally exceeded fecal coliform concentrations.

The concentration of all three types of organisms generally varied with the suspended solids and organic matter content of the composite samples. High-intensity rainfall apparently dislodged large quantities of soil and associated organic matter; consequently large quantities of organisms were dislodged.

The South Dakota Committee on Water Pollution specifies that the density of fecal coliform organisms in water used for immersion sports shall not exceed 500 organisms per 100 ml on any one day during the recreation season (21). Only the April 19 and April 23 runoff events did not greatly exceed this criterion. Although the fecal organisms in the runoff were from animals and would probably not pose a major disease threat to humans, it would be possible in monitoring fecal coliform densities in lakes to obtain false indications of health hazards.

Pesticide Residuals in Runoff

A one-liter portion of each of the eight thawed composite samples was submitted to the Experiment Station Biochemistry Department at South Dakota State University for analyses. Results of the analyses are shown in Table 11. The concentrations shown in Table 11 are all very small in comparison to criteria set by the National Technical Advisory Committee to the Secretary of the Interior (21). This committee recommended the following permissible criteria for public water supplies: aldrin, 17 ppb; lindane, 56 ppb; dieldrin, 17 ppb; and DDT, 42 ppb (21-20).

An attempt was made to qualitatively relate the pesticides detected to the pesticides applied to the drainage basin. As shown in Table 5, the only insecticides applied to the drainage basin between the 1969 and 1970 harvests were aldrin and carbamate compounds. The only herbicides applied were atrazine and 2,4-D compounds. Interviews with all persons owning or operating land included in the drainage basin revealed that no other pesticides had been applied in recent years. Therefore, aldrin was the only insecticide detected which was known to have been applied to the drainage basin. Dr. Yvonne Greichus of the Experiment Station Biochemistry Department at South Dakota State University stated that soil microorganisms can oxidize aldrin to dieldrin, and this process may account for the

Table 11. Measured Pesticide Concentrations in Runoff from the Small Agricultural Drainage Basin during 1970

Date of Sample	Pesticide Type	Concentration (ppb)
March 3, 1970	*	
April 15, 1970	DDD	0.1
	DDT	0.1
April 19, 1970	*	
April 23, 1970	*	
May 28, 1970	Lindane	0.9
	Aldrin	0.6
	Dieldrin	0.3
May 31, 1970	Aldrin	0.2
	Dieldrin	0.2
June 16, 1970	*	
June 19, 1970	Aldrin	0.1
	Dieldrin	0.1

*Pesticide concentrations below analytical confidence limits presence of dieldrin in some of the samples. Lindane, DDT and DDD, as well as aldrin and dieldrin, are widespread in the environment according to Dr. Greichus and probably could have been found in the runoff water in the concentrations as shown in Table 11 even if they had not been applied directly to the drainage basin. It was noted that the highest concentrations of aldrin and dieldrin were detected in the sample from the May 28 runoff event which occurred soon after the application of an aldrin compound on May 15-20 (Table 5).

Dr. Greichus further stated that several limitations were present both in the sampling procedure and in the analytical determinations for pesticides. The samples were collected and frozen in plastic bags, and because pesticides can adhere to plastic quite readily, some loss of pesticides could have occurred through this means. Furthermore, determinations were performed by gas chromatography on the runoff samples after several hours of settling had taken place. Because of the great affinity between soil particles and pesticides, there is a strong possibility that many of the pesticides were adsorbed on soil particles which had settled. As a result of the above limitations, measured pesticides concentrations would probably tend to be somewhat lower than the true concentrations.

Because of limitations in the handling of samples for pesticides determination, it was difficult to draw conclusions on the pesticide pollution potential of the drainage basin. Implications were that the pesticide concentrations were not of a magnitude which would indicate great pollution.

Solids Separation as a Means of Waste Reduction

In order to obtain an indication of the effects of solids removal on waste reduction, determinations of COD and total Kjeldahl nitrogen were made on both raw samples and on samples filtered through a 0.45 micron membrane filter. Overall reductions of 94 per cent of COD and 80 per cent of total Kjeldahl nitrogen were obtained. Data are shown in the Appendix.

It was estimated that a suspended solids reduction of about 98 per cent could be effected by several hours of detention. The characteristics of the suspended solids appeared changed due to coagulation in the freezing process; the results of any standard settling test would probably have been invalid.

Implications of the experiment were that removal of suspended solids by settling could greatly reduce the pollution potential of agricultural runoff. Conservation measures such as dams would provide detention of the runoff and facilitate removal of suspended solids by settling. Also, soil conservation practices reducing the loss of soil by erosion would be particularly beneficial from the standpoint of pollution abatement.

Effects of Sample Preservation by Freezing

Specific conductance measurements were made on forty-six individual samples before freezing and after thawing. The results are plotted in Figure 4 and tabulated in the Appendix. A regression line was obtained on a plot of the specific conductance values before and after preservation by freezing. The regression line was a

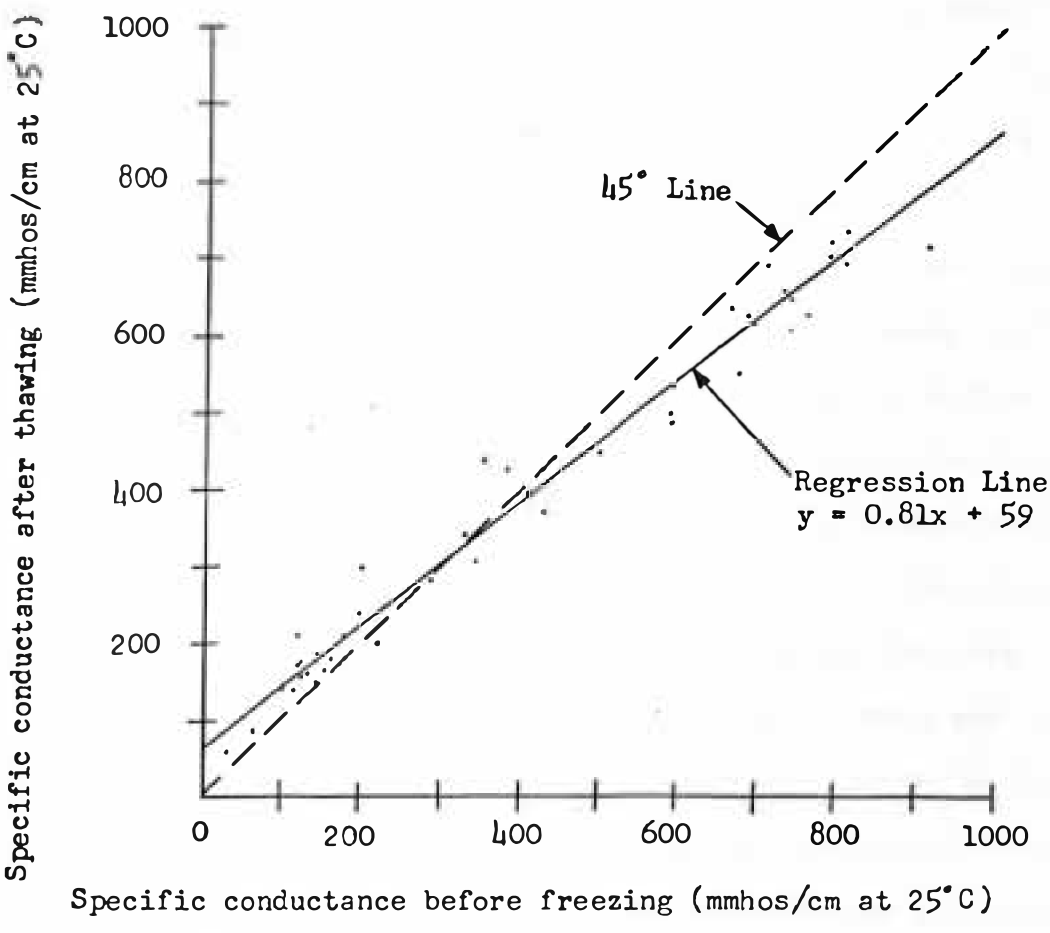

Figure 4. Specific conductance of agricultural runoff samples before and after preservation by freezing

straight line which intersected the 45-degree line at 300 mmhos/cm at 25°C. A correlation coefficient of 0.988 was obtained. It appeared that most samples of initial specific conductance below 300 mmhos/cm at 25°C were higher after thawing. In contrast, most samples of initial specific conductance higher than 300 mmhos/cm were lower after thawing.

Samples initially exhibiting low specific conductance values were also those samples which had high concentrations of soil particles. Ions adsorbed to soil particles were probably dissolved in the solution during the time periods before freezing and between thawing and warming to room temperature. It is probable that the initial solution was unsaturated and ions could easily have been dissolved.

Samples initially high in specific conductance and consequently high in dissolved solids tended to have a lower specific conductance after preservation by freezing. A possible explanation for this phenomena is that colloidal and ionic materials were forced into a concentrated condition during the freezing process. Due to the ions and colloidal material being pushed together, the repulsive forces due to like charges were overcome. The van der Waals forces, which bring about attraction between particles of like charge, caused colloidal particles to coagulate and ions to be adsorbed on colloidal particles. Hence, the concentration of ions in solution which could be indicated by specific conductance was reduced.

The samples with initially high specific conductivity did not have high concentrations of soil particles. Therefore, it was probably not possible for the specific conductance to increase appreciably due to ions being dissolved in the solution as was the case of the samples of initially low specific conductivity and high soil particle concentration.

Implications were present that freezing did cause some change in the ionic characteristics of the water. Such ions as nitrate, ammonium and phosphate in the water may have undergone some changes due to the freezing process.

Changes in the pH of the samples as a result of preservation by freezing tended to be erratic. About 75 per cent of the samples exhibited higher pH values after preservation by freezing. The increase in pH could probably be attributed to the escape of carbon dioxide from the samples as a result of agitation after thawing.

Very little research has been done on the use of freezing as a means of sample preservation. Morgan and Clarke (24) performed research on preservation by freezing of domestic wastewater samples. Samples were divided into four portions. Analyses were performed immediately on one portion and the other three portions were preserved by freezing. The three portions were then thawed and analyzed after two, three, and six day periods respectively. They reported no significant change in COD, solids, ammonia, total Kjeldahl nitrogen, nitrate and nitrite among the various portions. Fogarty and Reeder (25) performed research on the effects of freezing on BOD results and found that freezing did not affect the BOD values within the limits of the test.

SUMMARY AND CONCLUSIONS

The characteristics of surface runoff from agricultural cropland were evaluated by studying the quality, quantity and frequency of runoff from a 173-acre drainage basin near Brookings, South Dakota, during 1970. The entire drainage basin was under cultivation during 1970 with a corn crop on approximately 75 per cent of the area and an oat crop on the remaining 25 per cent.

Precipitation on the cropland occurred on about 80 days during 1970; the total volume was approximately 22 inches. Runoff occurred on eight days and the total runoff volume was approximately 2.7 inches. Discharge and stage measurements were made during runoff events in order to quantify the runoff volumes.

Samples were collected during each runoff event occurring in 1970. Samples were analyzed for solids, nitrogen and phosphorus compounds, oxygen-demanding materials, coliform and streptococcus organisms and various pesticides. Freezing was used as a means of sample preservation prior to analysis.

Analysis of data obtained during this investigation led to the following conclusions:

1. The runoff events which removed most of the pollutants from the drainage basin were caused by rainfalls of relatively high intensity. For these events, a substantial percentage of the rainfall became runoff.

2. The polluting substance of greatest magnitude in runoff from the drainage basin was suspended solids. About one ton per acre of suspended solids was removed from the drainage basin during this investigation.
3. Inorganic nitrogen and phosphorus in the runoff from all runoff events were present in sufficient concentrations to support algal growths in nuisance proportions in lakes, providing other algal growth conditions were present and favorable.
4. Large amounts of biologically-resistant materials were present in the runoff water as indicated by chemical oxygen demands many times larger than biochemical oxygen demands.
5. Runoff from the drainage basin contained high concentrations of fecal organisms. For all but two of the runoff events during 1970, fecal and total coliform densities greatly exceeded those prescribed for immersion sports in South Dakota's water quality standards.
6. Tests by filtration to remove suspended solids showed that 94 per cent of COD and 80 per cent of total Kjeldahl nitrogen were directly associated with suspended solids.
7. Freezing as a means of sample preservation caused some changes in the specific conductance of runoff samples. Changes were both positive and negative, depending on the magnitude of the specific conductance.

8. Due to limitations in sampling and analysis, no conclusions could be drawn concerning pesticide concentrations in the samples.

AREAS FOR FUTURE STUDY

1. A continuation of the study of the quality of runoff from this drainage basin for several years would provide more complete information in estimating annual loads of pollutants. Further attempts should be made to obtain a more accurate stage-discharge rating curve for the outlet culvert.
2. A study of agricultural land runoff using controlled pesticide and fertilizer applications and various conservation practices would provide valuable information.
3. Since indications were present in this investigation that freezing as a means of sample preservation does induce some quality changes, a thorough study of characteristics of samples before and after freezing would be valuable.
4. Studies of the characteristics of runoff from several drainage basins of widely varying sizes could provide information on how the area of a drainage basin affects the runoff characteristics.

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APPENDIX

Records of Measurable Precipitation Received

on the Drainage Basin During 1970

Date	Precipitation	Date	Precipitation	Date	Precipitation
Jan		May		Sept	
1	.02	23	.63	7	.08
16	.06	25	.54	9	.15
22	.15	28	1.21*	14	.05
25	.43	29	.47	15	.18
		31	.79*	17	.37
Feb 11	.02			21	.05
		June		24	.07
Mar		11	.32	25	.20
2	.03	13	.75		
3	.97*	15	.13	Oct	
5	.01	16	2.09*	7	.43
10	.03	19	.58*	8	.50
11	.01			11	.56
19	.22	July		25	.37
20	.02	2	.08	27	.13
24	.07	3	.01	29	.02
25	.33	6	.07	30	.20
27	.01	7	.02		
29	.01	13	.05	Nov	
30	.01	14	.23	8	.86
		18	1.26	16	.27
April		19	.36	17	.57
12	.48	27	.05	26	.20
13	.37	29	.50		
15	.35*			Dec	
18	.03	Aug		10	.31
19	.76*	2	.09	11	.03
20	.04	7	.85		
22	.57*	12	.10		
		15	.05		
May		28	.30		
11	.20	31	.05		
14	.09				

*Denotes runoff-producing rainfall or snowmelt.

Note: Records from January 1 to April 15 were obtained from the Weather Research Laboratory, Agricultural Engineering Department, South Dakota State University.

Specific Conductance Measurements of Runoff Samples

Before and After Preservation by Freezing

Date	Specific Conductance Before Freezing (mmhos/cm at 25°C)	Specific Conductance After Thawing (mmhos/cm at 25°C)	Date	Specific Conductance Before Freezing (mmhos/cm at 25°C)	Specific Conductance After Thawing (mmhos/cm at 25°C)
March 3, 1970	114	138	May 28, 1970	195	293
	126	172		111	143
	120	209		156	177
	126	156			
	129	159	May 31, 1970	58	88
	129	158		33	62
	129	166		122	169
	156	165		159	183
				176	207
April 15, 1970	664	636		229	254
	742	654		326	340
	732	660		500	453
	762	695		581	494
	788	723			
	807	742	June 16, 1970	313	308
	910	725		197	236
	967	954		145	149
				144	186
April 19, 1970	758	630		136	146
	807	714		224	195
	788	708		337	320
	685	630			
	675	552	June 19, 1970	383	433
	807	693		354	443
April 23, 1970	738	606			
	433	369			
	285	279			
	410	399			
	588	488			

Total Kjeldahl Nitrogen Concentrations of Runoff Samples

and Per Cent Reduction by Filtration through a 0.45 Micron Filter

Date of Composite Sample	TKN of Raw Sample (mg/l)	TKN of Filtered Sample (mg/l)	Per Cent Reduction
March 3	9.7	2.9	70.1
April 15	7.2	3.7	48.6
April 19	4.4	3.3	25.0
April 23	2.8	1.8	35.7
May 28	15.2	1.1	92.8
May 31	16.9	0.8	95.3
June 16	8.9	1.2	86.5
June 19	12.2	1.1	91.0
Annual Average*	10.0	1.9	81.0

*The annual average concentrations were determined by dividing the total annual load by the total annual runoff volume and converting to units of mg/l.

COD Concentrations of Runoff Samples and Per Cent Reduction in COD by Filtration through a 0.45 Micron Filter

Date of Composite Sample	COD of Raw Sample (mg/l)	COD of Filtered Sample (mg/l)	Per Cent Reduction
March 3	300	41	86.3
April 15	220	38	82.7
April 19	80	36	55.0
April 23	70	22	68.6
May 28	560	15	97.3
May 31	780	13	98.3
June 16	430	16	96.3
June 19	410	15	96.3
Annual Average*	405	26	93.6

*The annual average concentrations were determined by dividing the total annual load by the total annual runoff volume and converting to units of mg/l.