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Stream Pollution from Cattle Feedlot Runoff

Richard K. White
The Ohio State University
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State of Ohio
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STREAM POLLUTION FROM CATTLE BARNLOT (FEEDLOT) RUNOFF

by

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ABSTRACT

This project has established that solids, BOD and COD transport in barnlot runoff is significant. (A barnlot, as distinguished from a feedlot, has less than 100 head of cattle wintered in a lot with access to a barn for feeding, watering and/or sleeping. The barnlot is typical for about two-thirds, 700,000, of the beef cattle raised in Ohio.) Runoff usually occurs with rainfall of one-half inch or more.

BOD concentrations and transport were established to be higher in the winter and significantly less in the summer. Antecedent soil moisture conditions significantly affect the amount of solids, BOD and COD in the runoff, with increased amounts following extended periods without rainfall. A significant reduction of solids and BOD in the runoff was effected by using a grassed waterway or runoff collection pond and irrigation.

KEY WORDS

Water Quality; Barnlot Runoff; Feedlot Runoff; Stream Pollution; FCST Category: VB.

PROJECT PERSONNEL

Faculty

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INTRODUCTION

Runoff from livestock feeding operations has become a public concern. Fish kills, unsightly floating debris, contamination of streams, ponds, and lakes have been attributed to runoff from these sources. The extent to which downstream waters are enriched or polluted by animal wastes carried in runoff from barnlots was the objective of this research.

A distinction is made for use in this study between beef feedlots and barnlots. In many areas small herds of 20 to 100 head of beef are wintered in barnlots where the animals have access to the barn for sleeping and in many cases, feeding and watering. As much as 75% of the manure may be deposited in the barn and is subsequently hauled and spread on cropland. The animals are usually pastured during the summer. In contrast, the feedlot is usually larger, the animals are in the lot the year-round and in many cases no housing is provided. All of the manure is deposited on the lot. Because of these differences in management of barnlots and feedlots, the runoff characteristics can be expected to differ.

The 1969 Census of Agriculture, U. S. Department of Commerce, reported that in Ohio there were 17,723 farms that had cattle (non-dairy) with 20 to 99 head for a total of 695,142 animals and 1,997 farms that had 100 and over head for a total of 394,601 animals. These statistics show that a majority of the cattle in Ohio are raised in small herds. Many of the small herds are wintered in barnlots. A similar pattern may be expected for many areas in the eastern part of the United States, making barnlot runoff quality a problem worthy of investigation.

OBJECTIVES

1. To measure the solids content, biochemical oxygen demand (BOD) and chemical oxygen demand (COD) of the runoff of a beef barnlot operation typical of farms in Ohio.
2. To identify the effect of rainfall and runoff patterns and seasonal conditions on the barnlot runoff quality.
3. To evaluate the stream pollution potential of runoff from a beef barnlot.

EXPERIMENTAL SITE

The data for the studies reported herein were obtained from the North Appalachian Experimental Watershed (NAEW), located about ten miles north of Coshocton, Ohio in the Muskingum River Basin. The NAEW was started in 1935 and is being operated by the Soil and Water Conservation Branch of the Agricultural Research Service of the U. S. Department of Agriculture. The experimental area lies south of the limits of glaciation, at a latitude of 40° 22' North and in an elevation range of 800 to 1300 feet above mean sea level. This site typifies much of the agricultural land in the unglaciated Allegheny Plateau as indicated in the shaded area of Figure 1.

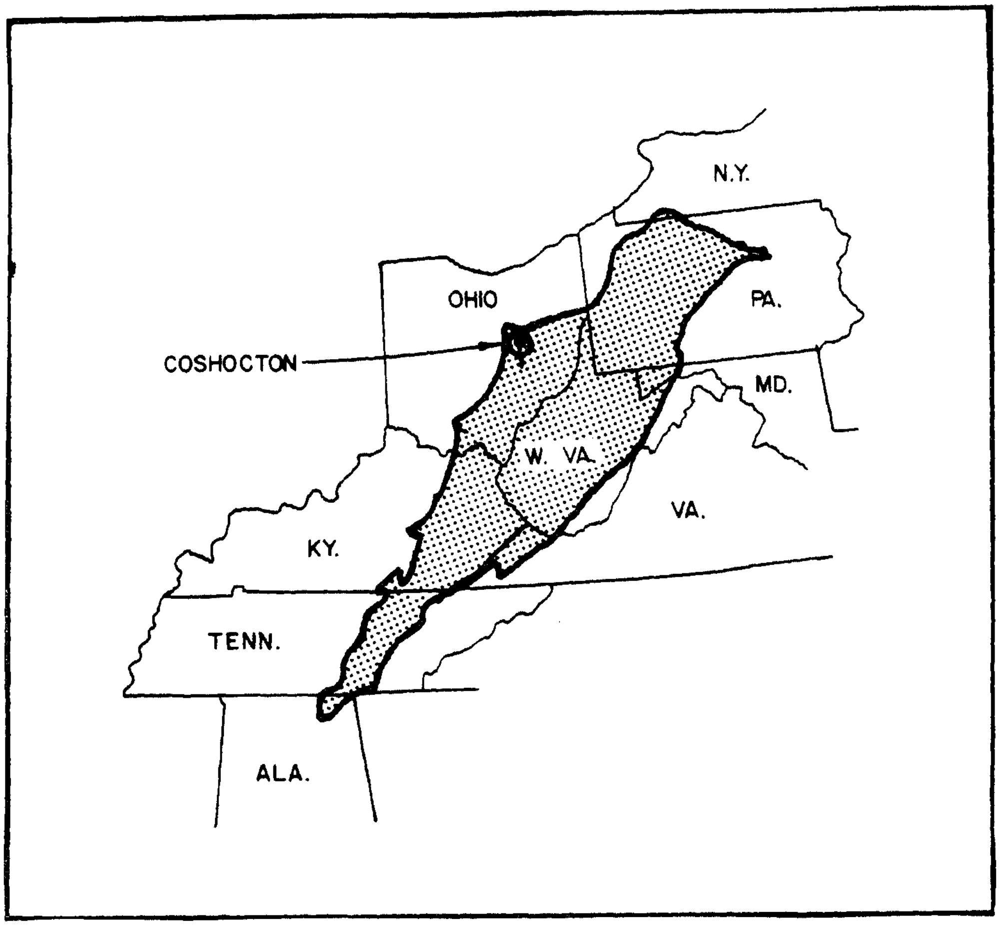

Figure 1. Sight Map of Coshocton and the Allegheny-Cumberland Plateau Physiographic Province.

Barnlot

An unpaved barnlot is shown as Watershed No. 163, within a larger Watershed No. 177, in Figure 2. The 0.42 acre (0.17 hectare), unpaved barnlot is located on Clarksburg silt loam having a 13% slope with a southern aspect. The confinement of 150 steers per acre (370/hectare) in the winter and early spring period greatly altered the natural soil and surface conditions. Knee-deep mud and manure characterize the surface in the wet, cool season

MAP OF NORTH APPALACHIAN EXPERIMENTAL WATERSHEDS

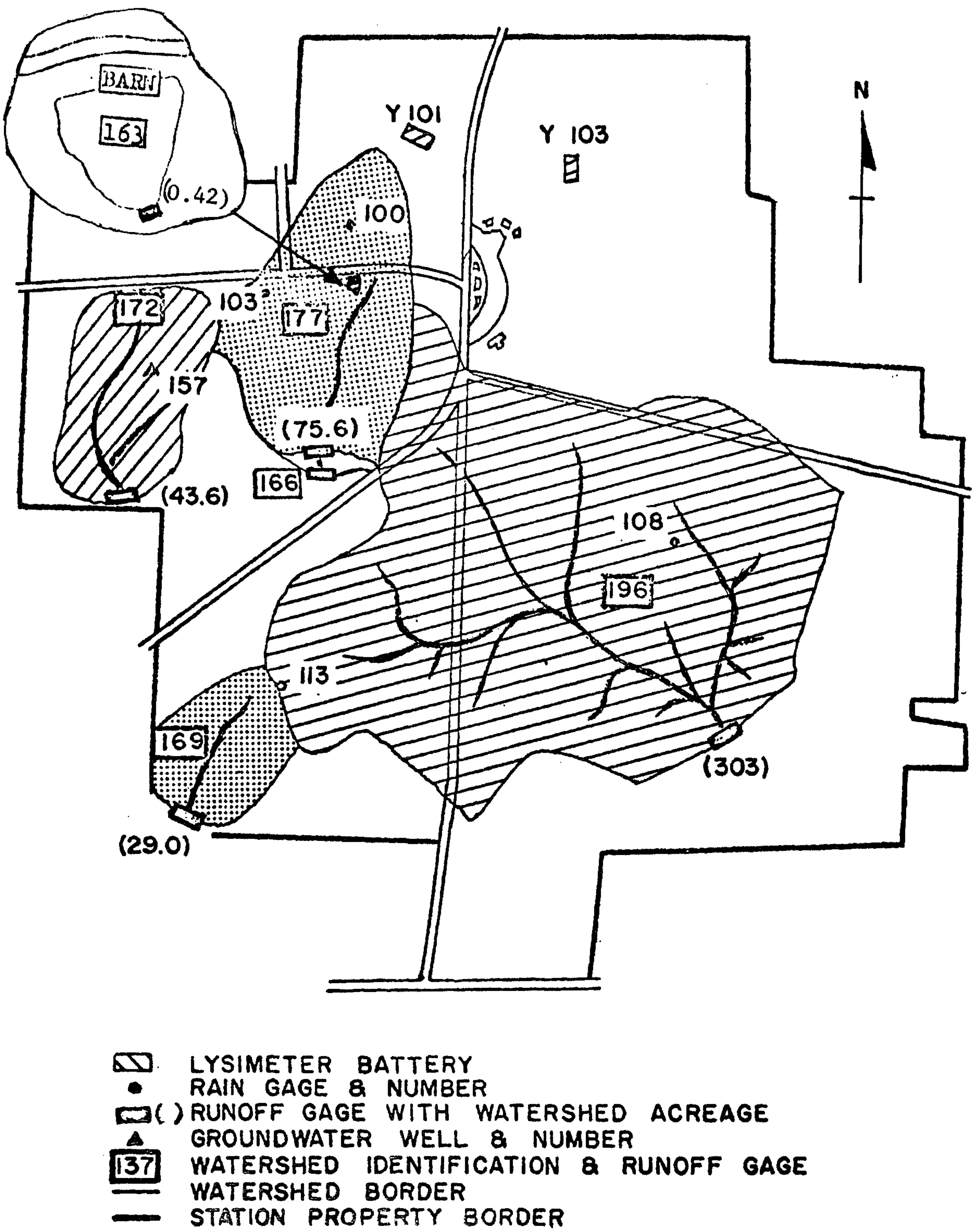

FIGURE 2

with a hard-packed, smooth surface in dry, warm periods. These influence rainfall-runoff relations.

Sixty beef steers were placed in the barn and barnlot in November and confined there until mid to late May, when they were turned out to pasture.

Normally, the barnlot is idle until the following November, with the exception that in 1970 there were 16 steers in the lot during July and August. The cattle received feed and water in the barn and were self-fed grass-legume silage from the trench silo. Most of the manure was deposited in the barn with an estimated one-fourth to one-third of the manure deposited in the barnlot. Figure 3 shows the barnlot with cattle. The trench silo is shown in the upper center and the gage and sampling station in the lower left.

Climate

The precipitation pattern at the study area conforms to the Ohio River Valley Pattern. Summertime rainfall is featured by the convective-type storm usually of high intensity but short duration and covers a small area. Winter precipitation is mainly due to cyclonic-type storms generally of low intensity but long duration and covering a large area. Snowfall is not a major source of precipitation at the station. The average snowfall amounts to 24 inches per year, which is about 5 percent of the total precipitation. Based on a 31-year record (1937-68), the average annual precipitation at the station is 37.16 inches and ranges from a recorded minimum of 27.61 to a maximum of 48.92 inches.

Figure 3. Beef Cattle in Barnlot (Watershed No. 163).

PROCEDURES

Rainfall, recorded by NAEW, was available for use by this project. Runoff was measured from the barnlot, Watershed No. 163 (0.42 acres), continuously and from the larger, encompassing Watershed No. 177 (75.6 acres).

Sampling

All the barnlot runoff is discharged into an intermittent waterway through an H-flume as shown in Figure 4. The inlet for the automatic sampler is located in the cylindrical container shown in Figure 4 into which the water flows. Details of the sampling equipment are given in references 1 and 4. The samples were collected in gallon bottles kept in a refrigerator ($4^{o}C$) at the field site (Figure 5). Similar runoff monitoring and periodic sampling were conducted for Watershed No. 177.

The sampling procedure was initiated by flow through the flume and a preset sequence determined the frequency of sampling. Larger intervals of time were set for the winter, cyclonic-type storms rather than for the spring and summer convective-type storms, which are usually of high intensity and of short duration.

Events having little total runoff, all of which occurred at low runoff rates, were not sampled as were some larger storms that closely followed sampled events. A few other events were not sampled because of power or equipment failure.

Figure 4. Runoff Monitoring and Sampling Equipment.

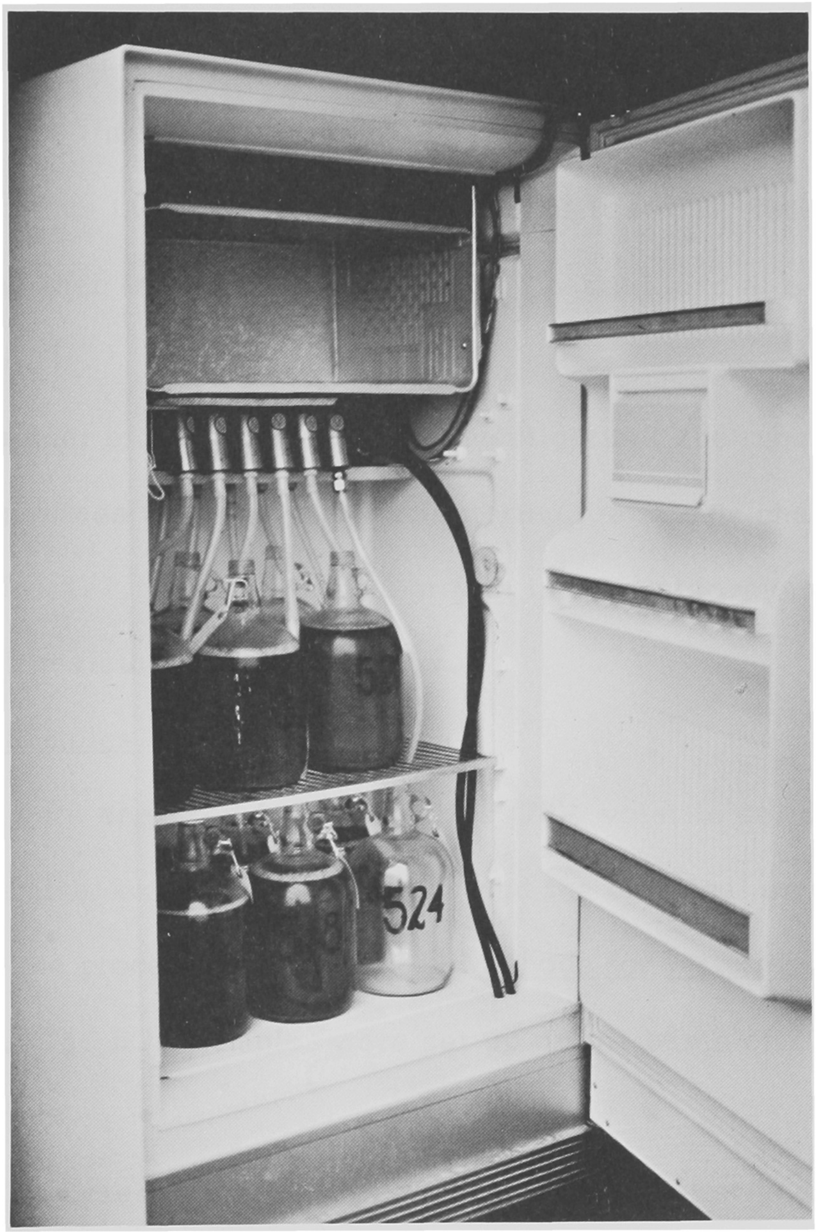

Figure 5. Refrigeration of Samples at Field Site.

Runoff Management

From May 1970 to the end of the year, runoff from the barnlot was diverted to a lined, holding pit (2). It was held there for several days following rainfall to allow time for the surrounding pastureland's soil moisture to decrease and thus increase the potential for infiltration. The stored barnlot runoff was then irrigated onto this nearby pastureland at a rate to preclude runoff.

The remainder of the period of this investigation, the runoff traversed a 500 m long, grass waterway prior to entering the stream channel below Watershed No. 177. The vegetative growth in the waterway was very dense, offering much resistance to stream flow.

Analyses of Samples

Samples were analyzed for total solids (TS), volatile solids (VS), the 5-day biochemical oxygen demand (BOD) and the chemical oxygen demand (COD) using the procedures in Standard Methods for Water and Waste Water Analysis (5). The BOD samples were set up on the basis of 20 ppm of VS on a wet basis.

Nutrient analyses of the barnlot runoff during the first year of this project were conducted by NAEW and were reported in part by Edwards, et al. (2). In December of 1971 through the end of the sampling period, several events that were sampled extensively were tested for nitrogen (ammonia, nitrate/nitrite and total nitrogen). Standard test procedures were used.

RESULTS

Rainfall-Runoff Data

The rainfall and runoff data for the period March, 1970 through April, 1972 are presented in Figures 6 and 7. Units on the ordinate axis are in terms of the surface area of the barnlot. The runoff events that are starred are the ones for which samples were analyzed. Some of the runoff events had one sample analyzed, usually just after peak flow, while others had samples taken throughout the event analyzed.

Storm Characteristics

Figure 8 illustrates the runoff characteristic of a winter, cyclonic or low pressure area type storm. The runoff characteristic of conventional or thunderstorm type of rainfall is shown in Figure 9. Both of these events were sampled throughout the runoff event and the TS and BOD analyses are shown in the figures. The TS values for the cyclonic event ranged from 0.8 to 1.2 percent (wb) and for the convectional type storm, 0.06 to 0.55 percent (wb). The BOD values varied for the events, respectively, 146 to 245 mg/l and 9 to 37 mg/l.

Another runoff curve for a convectional-type storm is shown in Figure 10. The points at which samples were taken are marked on the curve. This particular storm had each of the samples analyzed for nitrogen as well as the other parameters and these data are given in Table 1.

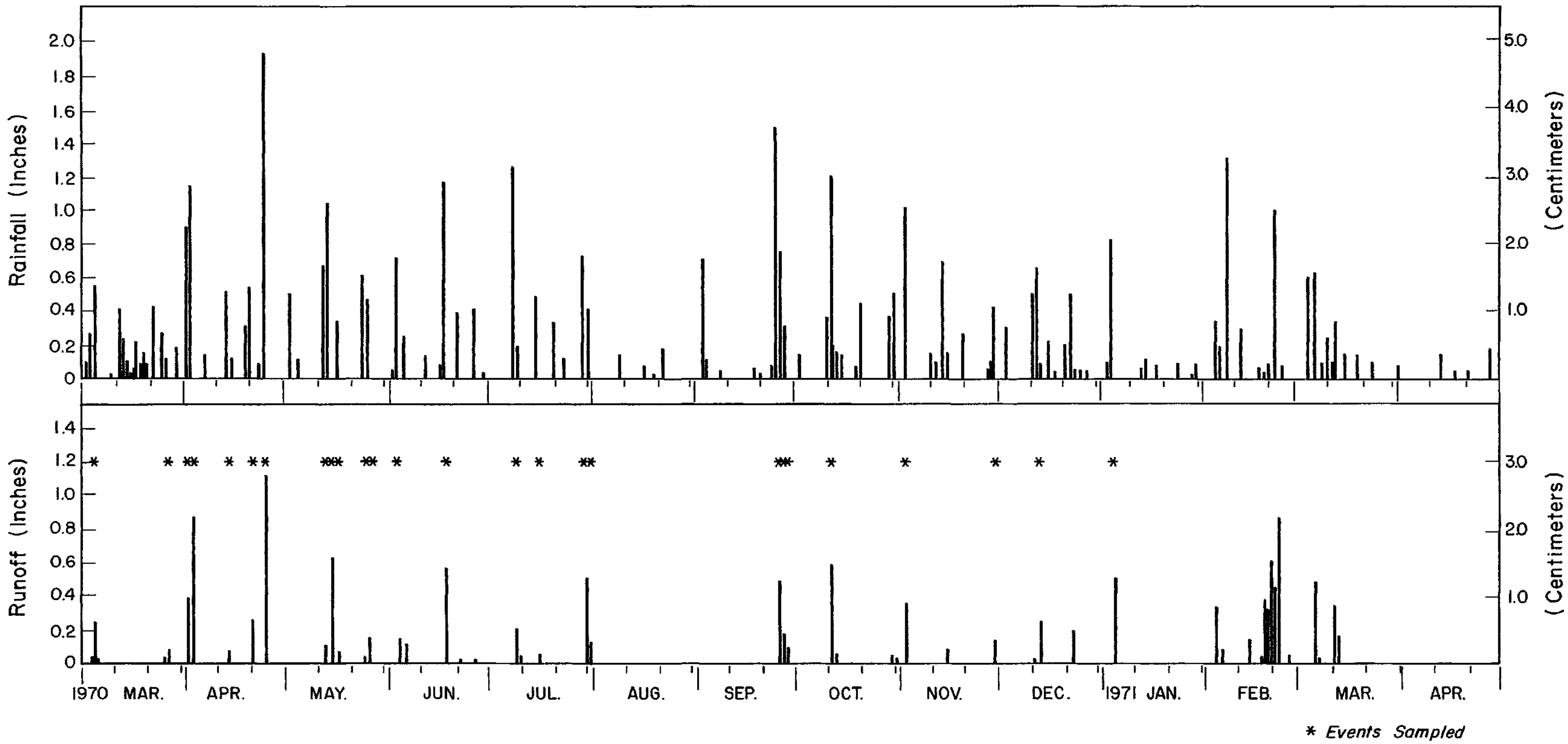

Figure 6. Rainfall and Barnlot Runoff (March 1970– April 1971).

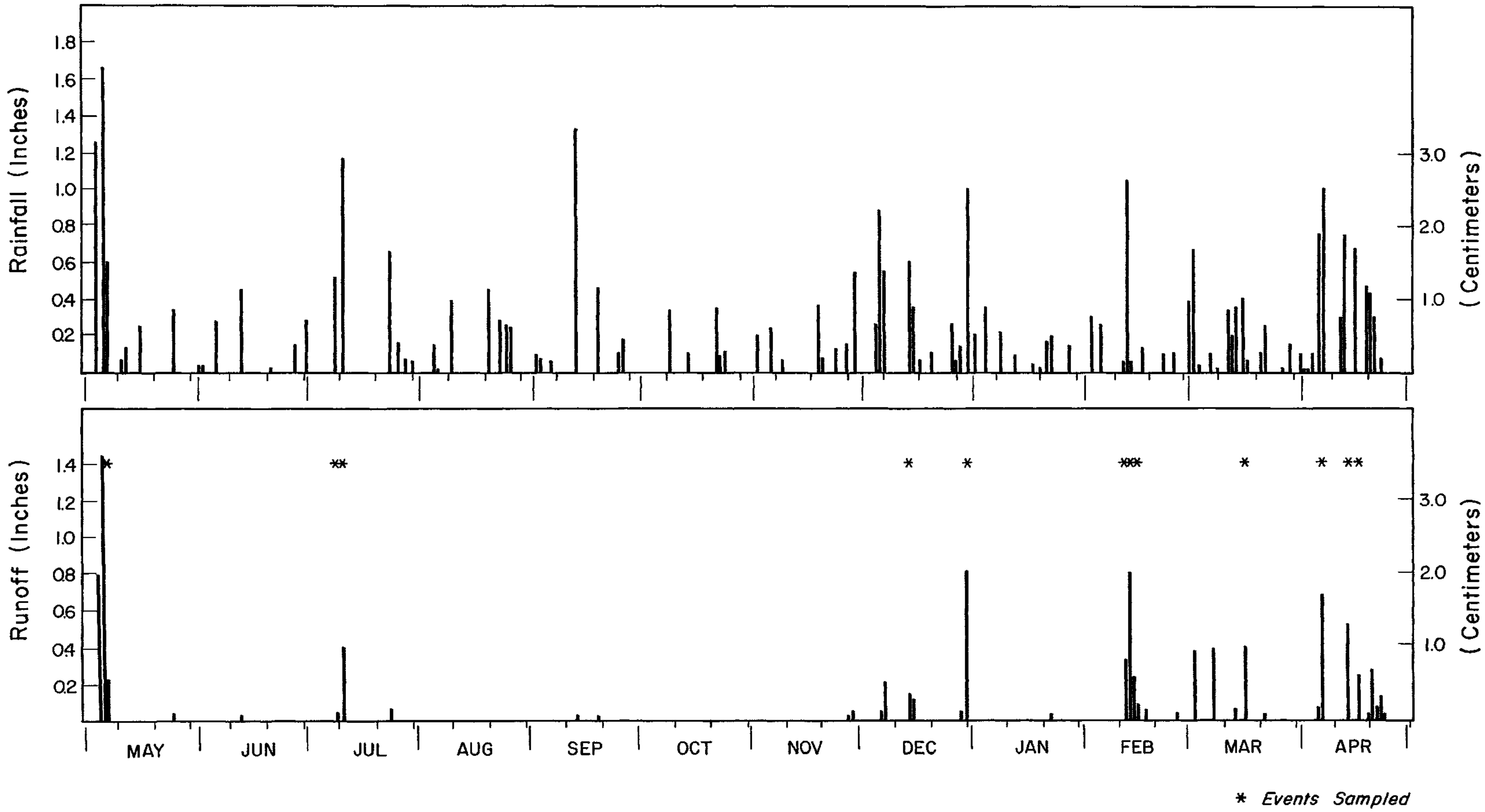

Figure 7. Rainfall and Barnlot Runoff (May 1971-April 1972).

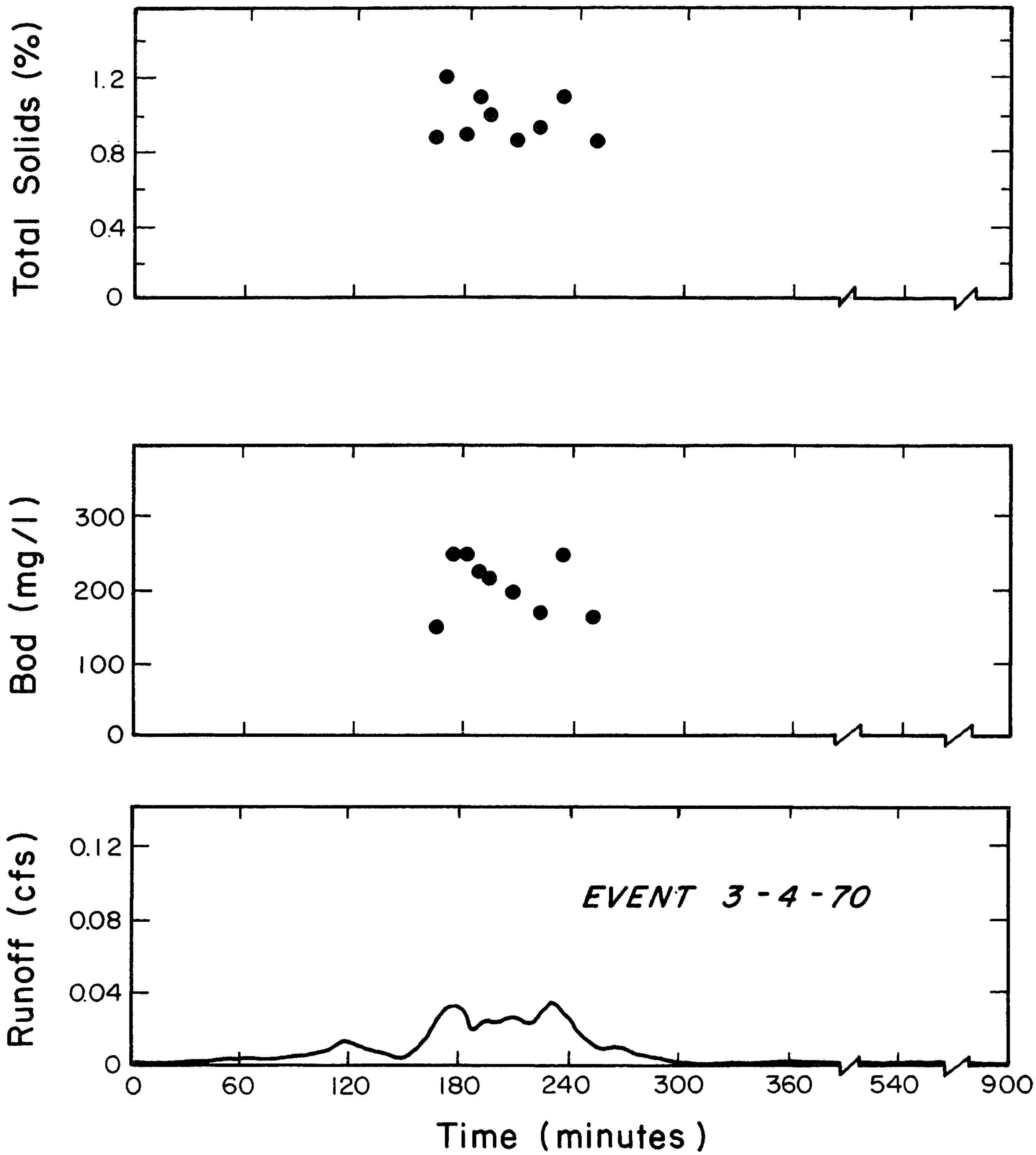

Figure 8. Runoff, BOD and TS from Cyclonic Event.

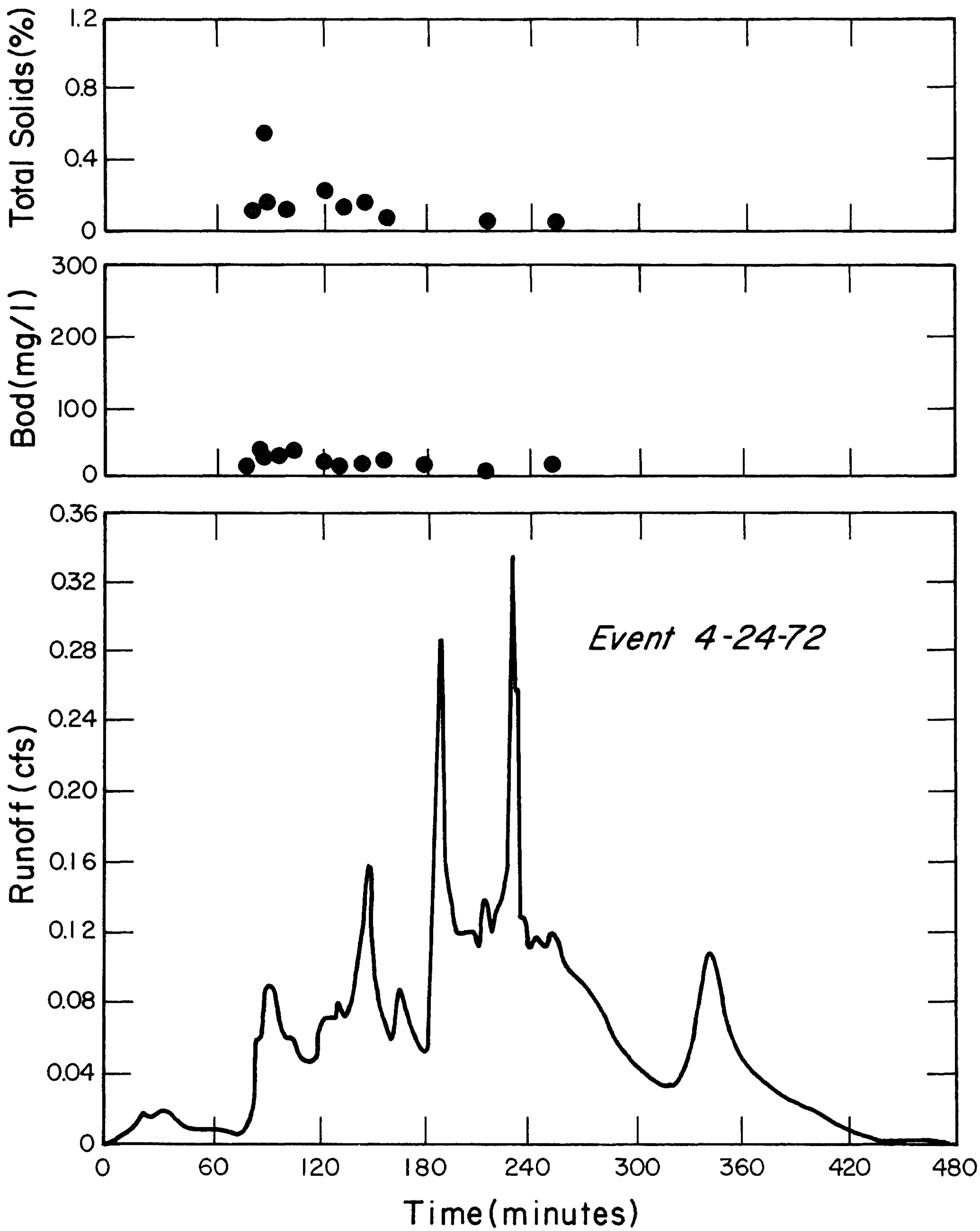

Figure 9. Runoff, BOD and TS from Convectional Type Event.

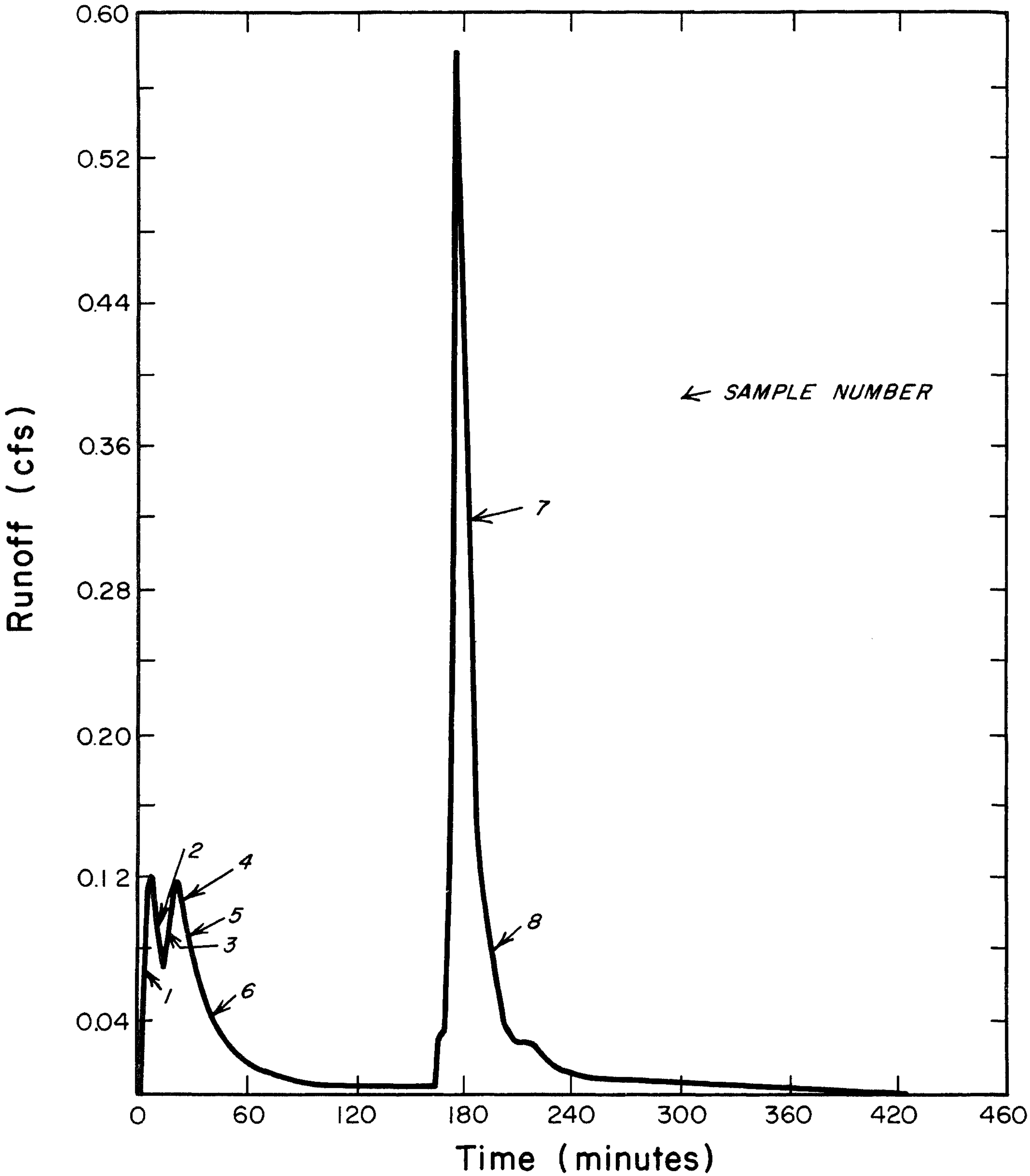

Figure 10. Runoff for Event 4-13-72.

Table 1 . Analyses of Event 4-13-72.

Sample Number	Total Solids (% wb)	Volatile Solids (% db)	BOD (mg/1)	COD (mg/1)	Nitrogen (% TS)		
					NH_3	NO_2 + NO_3	Total
1	1.6	29.1	300	6040	0.19	0.02	1.46
2	1.2	34.4	700	5900	0.43	0.03	2.03
3	1.6	36.2	750	5610	0.50	0.03	2.06
4	0.7	39.5	600	3770	0.69	0.04	2.47
5	0.7	39.2	580	4020	0.70	0.04	2.86
6	0.6	40.4	470	3240	0.65	0.05	2.55
7	1.0	34.1	450	4790	0.34	0.02	1.64
8	0.7	36.0	380	3530	0.47	0.03	2.71

Table 2 presents data pertaining to each sampled runoff event and the results of sample analyses. The runoff value is for the 0.42 acre surface area of the barnlot. The total transport values were obtained by multiplying a linearly interpolated concentration value by the corresponding volume of runoff. The percent values were obtained by dividing total transport by total runoff. The percent TS ranged from 0.1 to 1.2 percent. The percent VS was mostly between 30 to 40 percent. The COD concentrations ranged from 350 to 6380 mg/l, while BOD concentrations ranged from 9 to 744 mg/l. The column on the right gives the number of samples that were collected and analyzed for each runoff event.

Figure 11 is a plot of the total solids transport versus runoff data contained in Table 2. With the exception of a few events, the runoff is closely related to the solids transport.

Table 3 gives monthly runoff data for the barnlot from March, 1968 through April, 1972. Figure 13 is the average monthly barnlot runoff for the same period. Figure 12, which is a comparison of runoff from small and large watersheds from Harrold (3), is included for comparison with the runoff from the barnlot. It is noted that the barnlot runoff pattern does not follow that for the small watersheds.

Figure 14 presents the mean BOD concentration in the upper graph and the BOD transport in the lower graph for the events sampled from March, 1970 through April, 1972. There is a pronounced increase in the mean BOD

Table 2. Runoff and Analyses for Sampled Events from March 1970 through April 1972.

Event	Time* RB	Time* RE	Time* ET hrs,min	Runoff in.	Runoff cm.	TS % WB	TS Transport kg	VS % DB	BOD mg/l	BOD Transport g	COD mg/l	COD Transport kg	Samples per Event
1970													
3-4	0300	0730	4,30	0.27	0.7	0.89	104	31.4	176	2017	3970	45.6	9
3-26	0900	1115	2,15	0.12	0.3	1.0	54	29.3	208	1115	5450	29.6	3
4-1	2140	1420	16,40	1.20	3.0	0.98	518	29.0	126	6569	4460	233.0	4
4-13	1731	1925	1,56	0.06	0.2	1.20	33	29.3	151	417	4320	11.9	5
4-20	0110	0600	4,50	0.24	0.6	0.88	94	21.9	88	918	4320	45.2	3
4-24	0113	1015	9,02	1.08	2.7	0.09	44	35.1	14	658	350	16.5	12
5-12	1703	2010	3,07	0.10	0.2	0.36	16	29.9	30	131	2410	10.4	3
5-13(a)	0300	0730	5,30	0.55	1.4	1.10	263	31.1	51	1211	1200	28.6	1
5-13(b)	1227	1605	3,38	0.07	0.2	0.5	15	17.0	85	28	3070	9.4	1
5-16	1110	1415	2,05	0.05	0.1	0.3	6	30.0	28	60	950	2.0	1
5-25	1813	0245	8,32	0.13	0.3	0.24	11	31.3	14	62	550	2.4	2
6-3(a)	0544	0715	1,31	0.11	0.3	0.10	5	30.9	17	80	350	1.6	1
6-3(b)	1232	1345	1,13	0.03	0.1	0.13	2	32.0	9	12	450	0.6	1
6-17	0206	0500	2,56	0.55	1.4	0.14	35	27.1	20	489	450	10.8	3
7-8(a)	1507	1550	0,43	0.09	0.2	0.20	8	26.2	22	89	610	2.5	1
7-8(b)	1646	1742	0,56	0.10	0.3	0.18	8	22.9	19	87	500	2.3	1
7-15(a)	1701	1735	0,34	0.02	0.1	0.12	1	32.1	13	11	430	0.4	1
7-15(b)	1945	2035	0,50	0.02	0.1	0.14	1	32.7	20	19	480	0.4	1
7-30(a)	0153	0221	0,28	0.05	0.1	0.33	7	26.5	49	107	1160	2.5	1
7-30(b)	0857	0945	0,48	0.07	0.2	0.40	12	27.9	67	202	1330	4.1	1
9-25	0737	1220	4,43	0.49	1.2	1.00	214	27.0	231	4869	3270	69.0	2
9-26	1631	1900	2,29	0.19	0.5	0.90	72	26.0	140	1130	2980	24.3	2
10-11	0345	0900	5,15	0.59	1.5	0.40	110	30.2	205	5309	1880	67.0	2
11-2	1122	2030	9,08	0.35	0.9	0.47	72	31.0	210	3188	1780	27.1	2
11-29	1307	1940	6,33	0.13	0.3	0.80	47	34.6	475	2711	3610	20.6	1
12-12	0330	1230	9,00	0.20	0.5	0.67	75	34.5	566	6329	3150	35.3	1

Table 2 (continued)

Event	Time*			Runoff		TS		VS	BOD		COD		Samples per Event
	RB	RE	ET hrs,min	in.	cm.	% WB	Transport kg	% DB	mg/l	Transport g	mg/l	Transport kg	
1971													
1-4	0015	0805	7,50	0.50	1.3	1.01	235	32.7	490	10700	4660	101.8	13
5-7	1735	0100	7,25	0.23	0.6	0.63	64	38.7	150	1530	3230	32.9	1
7-9	0319	0400	0,41	0.04	0.1	0.36	7	30.3	259	500	1130	2.2	2
7-11	0510	1245	7,35	0.37	0.9	0.16	27	31.6	38	610	590	9.7	6
12-14	1302	1635	3,33	0.13	0.3	0.46	26	37.9	322	1800	2120	11.9	5
12-30	0631	1306	6,35	0.81	2.1	1.00	350	38.5	555	19400	5150	180.1	13
1972													
2-12	1158	2315	11,17	0.31	0.8	0.26	33	50.8	640	8230	1880	24.2	7
2-13	2330	1200	12,30	0.79	2.0	0.64	225	46.0	547	19200	5120	179.6	5
2-14	1245	1800	5,15	0.22	0.6	0.96	53	41.1	744	7120	4870	46.6	6
3-16	1100	2000	9,00	0.37	0.9	1.15	186	37.2	568	9180	6380	103.0	8
4-7	2230	0948	11,18	0.67	1.7	0.45	140	37.7	238	7420	2180	67.8	12
4-13	0017	0845	8,28	0.50	1.3	0.88	191	36.1	470	10210	4330	94.1	8
4-16	0753	2000	12,07	0.23	0.6	0.65	27	42.0	600	5940	3860	38.2	3

*RB = Runoff begins; RE = Runoff ends; ET = Elapsed time.

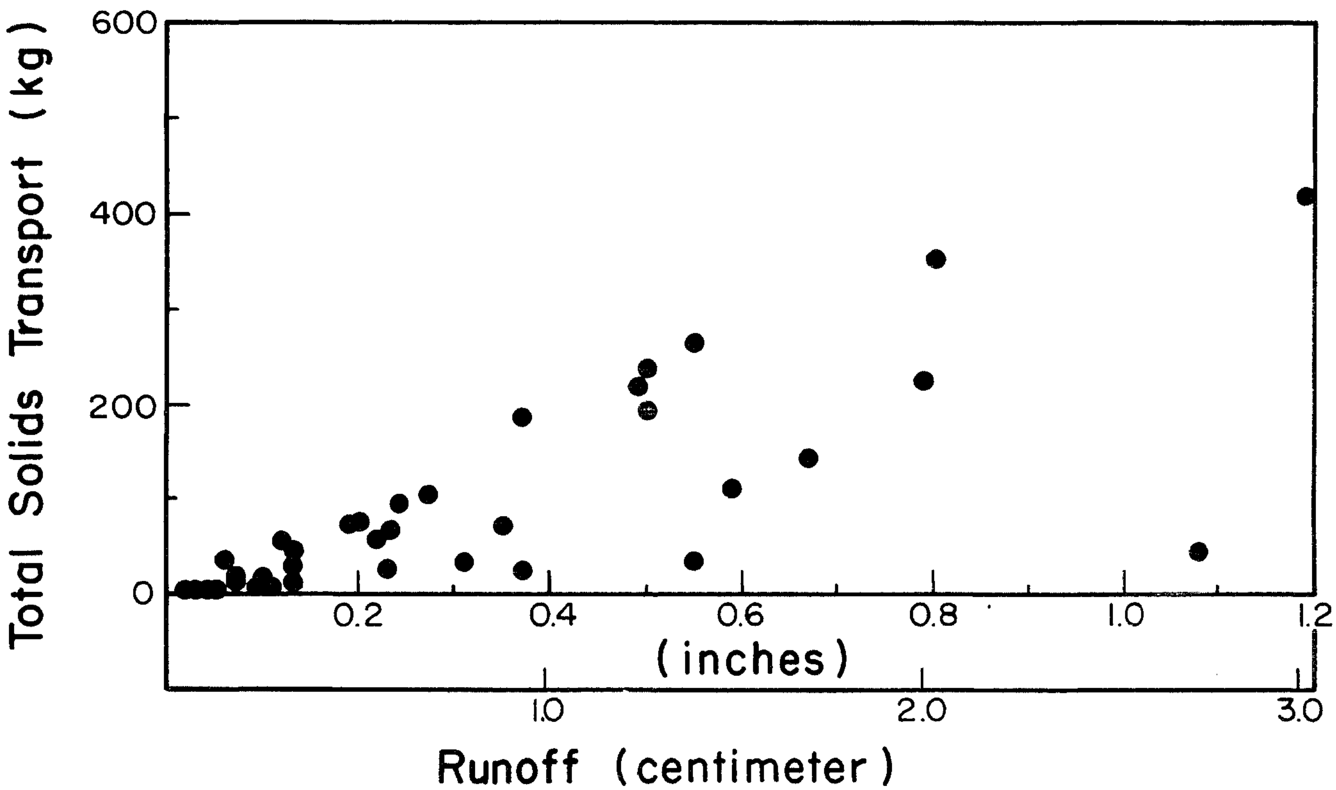

Figure 11. Total Solids Transport versus Runoff.

Table 3. Monthly Barnlot Runoff (Inches).

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1968			1.96[a]	0.36	3.02	0.48	1.30	0.01	0.00	0.14	0.55	2.01
1969	1.09	0.16	0.44	0.28	1.01	1.62	6.64[b]	0.16	0.06	0.23	0.50	0.32
1970	1.89	0.85	0.40	2.61	0.94	0.83	0.90	0.00	0.77	0.75	0.58	0.49
1971	0.50	3.22	1.03	0.00	2.48	0.02	0.41	0.00	0.03	0.00	0.06	1.30
1972	0.02	1.46	0.84	1.90								
Mean	0.88	1.42	0.93	1.03	1.86	0.74	2.31[b]	0.04	0.22	0.28	0.42	1.03

a. Record began 3-11-68.
b. July 1969 6.64" runoff (Normal Mean about 0.7).

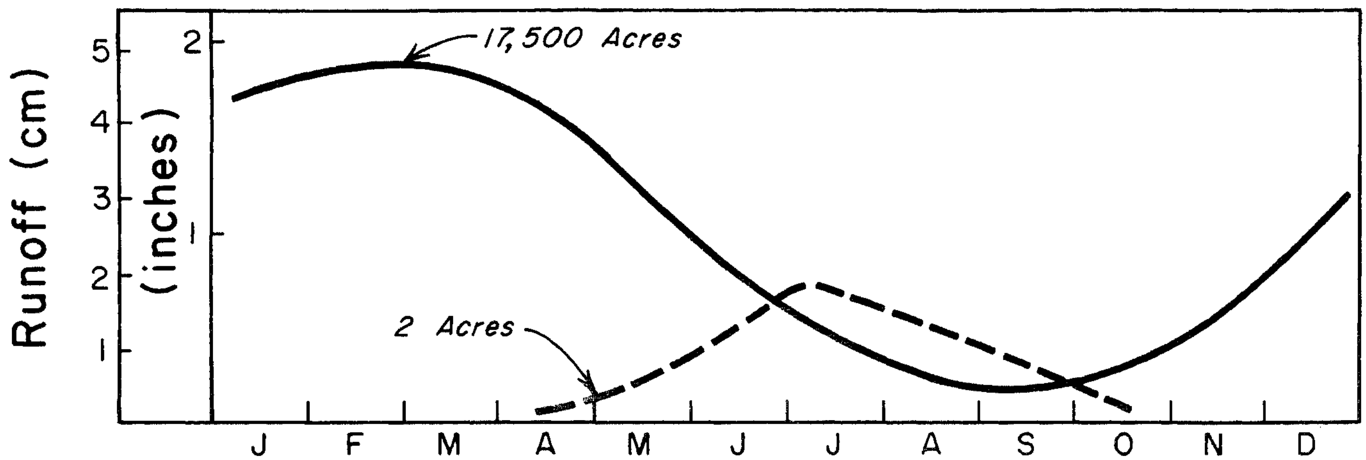

Figure 12. Comparison of Runoff from Small and Large Watersheds in the same Study Area (from Harrold, 1961).

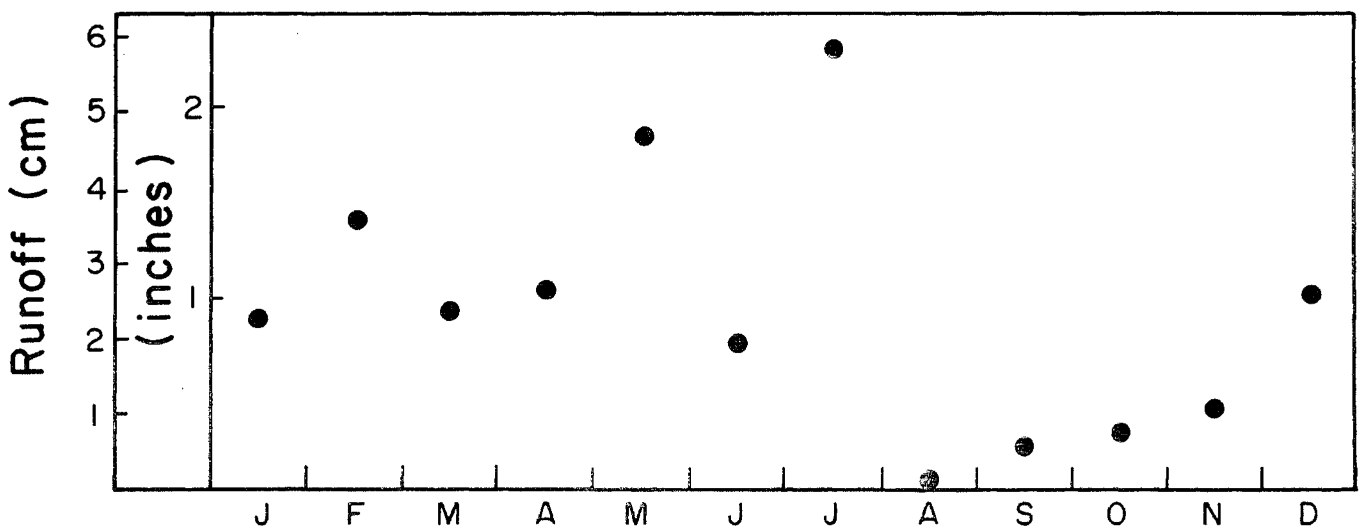

Figure 13. Average Monthly Barnlot Runoff-0.42 Acres. (March, 1968 through April, 1972).

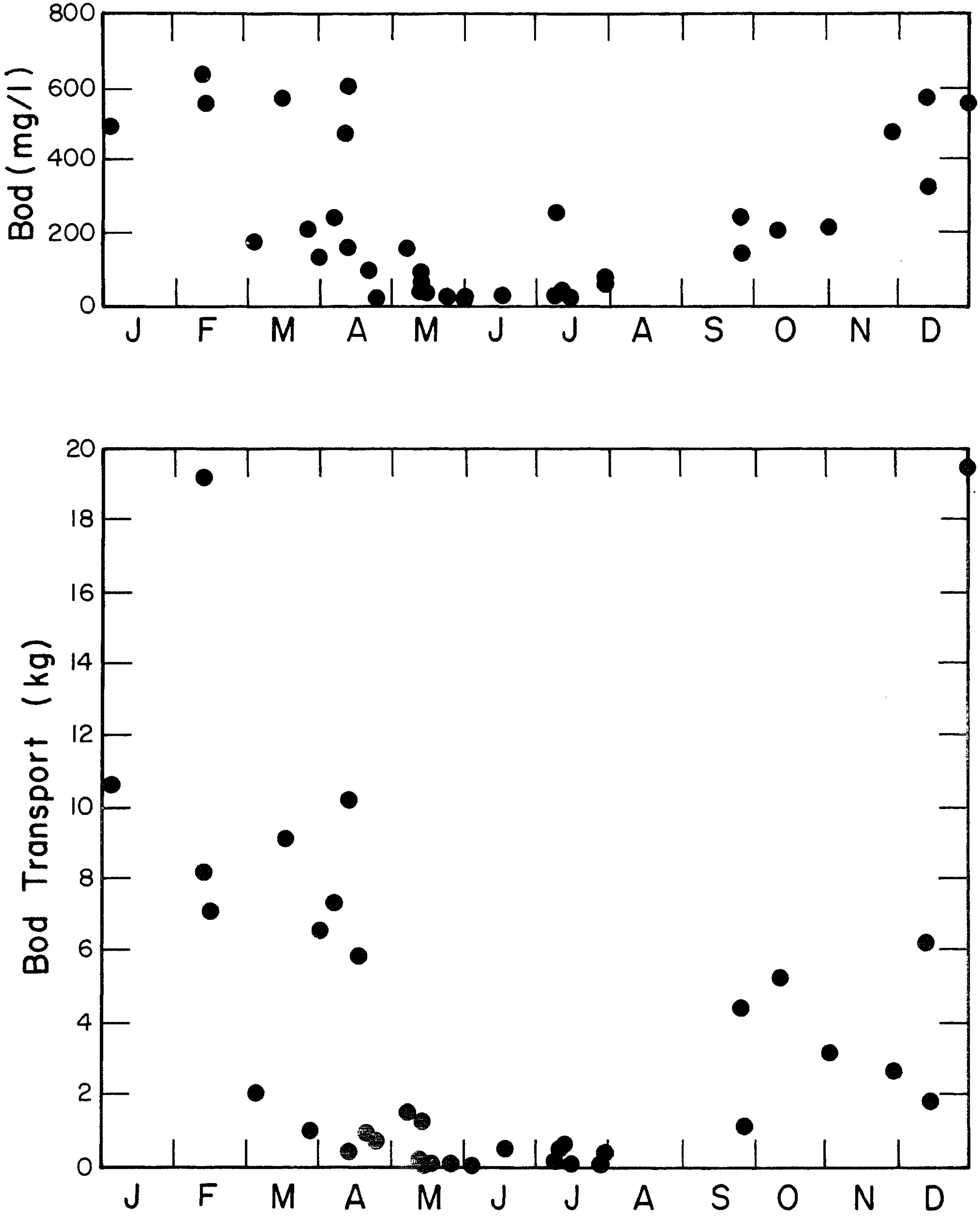

Figure 14. Mean BOD and BOD Transport for Sampled Events (March, 1970 through April, 1972).

and in the BOD transport during the winter months. The months of May through August consistently have low BOD values.

Nitrogen analyses for several events listed in Table 4 were conducted, even though nitrogen analysis was not an objective of this study. The transport rate of total nitrogen is in the range of 0.2 g/1 (45 lb/acre-in.) The variation in total nitrogen based on percent of TS was much greater than the variation in rate of transport.

The dilution effect of runoff from the surrounding watershed (No. 177) and runoff control management practice are evidenced in Table 5. It is not possible to partition out the effect of management practices that were utilized, e.g., diversion pond and irrigation in 1970 and 500 m long grass waterway 1971 and 1972. The data does not seem to indicate a difference in the effectiveness of these two management practices.

DISCUSSION OF RESULTS

A comparison of the rainfall graph and the runoff graph in Figures 6 and 7 shows that runoff generally occurs when the rainfall exceeds 1.3 m (0.5 in.). With moist antecedent conditions, runoff can occur for smaller storm events. During the winter period, runoff sometimes exceeds rainfall, which can be expected considering snow melt and frozen ground conditions.

Table 4. Nitrogen Analyses for Indicated Events.

Event	Ammonium % of TS	Nitrate-Nitrite % of TS	Total Nitrogen % of TS	Transport	
				Rate g/l	Event Kg
1971					
12-14	0.72	0.04	3.12	0.14	8.1
12-30	0.17	0.02	1.92	0.19	6.7
1972					
2-12	3.42	0.10	8.28	0.22	2.8
2-13	0.62	0.04	3.60	0.23	8.1
2-14	0.80	0.03	2.43	0.23	2.2
4-13	0.43	0.03	2.03	0.18	3.9

Table 5. Comparison of Runoff from Barnlot (WS 163) with Surrounding Watershed (WS 177).

Event	Watershed No. 177				Ratio WS 163/WS 177		
	TS (%)	VS (%)	BOD (mg/l)	COD (mg/l)	TS	BOD	COD
1970							
3-26	0.01	20.1	2	16	100	100	340
5-25	0.01	29.6	1	20	5	14	27
7-8	0.01	20.2	3	16	20	7	38
9-25	0.04	18.0	3	53	25	77	62
9-26	0.05	15.0	4	49	18	35	61
10-11	0.05	17.1	11	110	8	19	17
11-2	0.01	18.6	3	35	47	70	51
1971							
1-4	0.03	18.8	6	47	14	82	100
5-7	0.04	24.9	8	82	16	19	39
12-14	0.03	37.3	6	41	15	56	52
12-30	0.06	28.1	11	108	17	55	48
1972							
3-16	0.04	35.2	10	108	29	57	59
4-7	0.03	29.0	4	30	15	59	73
4-13	0.03	31.7	4	49	29	117	88

The wide variation in mean concentration of TS and BOD, as shown in Figures 8 and 9, cannot be explained on the basis of the type of storm; for intuitively the higher intensity, convectional storms should have had the larger concentrations. It is noted that the event of Figure 8 was preceded by a 15-day period without rainfall and a 22-day period without runoff; while the event of Figure 9 , which had significantly lower concentrations, had rainfall and runoff 4 days earlier. This indicates that time between rainfall and runoff events and antecedent moisture conditions of the barnlot affect runoff quality. TS and material of high BOD accumulate on the barnlot during periods without rainfall and runoff. Conversely, the material removed in a recent event is not available to be transported.

If the TS and BOD concentrations are higher, as shown in Figure 8 and Table 1, as compared to Figure 9, a larger variation in concentration is present. This relationship was generally consistent throughout the period of study: higher mean values of TS and BOD were associated with higher variations about the means. When concentrations were low, variations were low. Therefore, when low concentrations can be expected, a few samples taken at peak runoff stages are sufficient to define the entire runoff event. Events having high concentrations of TS and BOD in the runoff need to be sampled more intensively to accurately determine transport.

Transport of TS is strongly affected by the volume of runoff as indicated in Figure 11. There is some scatter of points due to a few events having high runoff volumes and low TS concentrations.

Transport of BOD is not as closely related to volume of runoff as is the transport of TS, mainly because of the seasonal fluctuation in BOD concentration (Fig. 14). BOD is highest during the winter months and lowest during the summer months. Even in the Summer of 1970, when 16 steers were in the barnlot, the BOD concentration of the runoff did not increase. The higher July value shown on the graph was in 1971, and was preceded by two months without runoff. It appears that the BOD is related to the ground surface temperature. In the winter when the ground is cold, the oxidation of organic material is slowed, so that the BOD in the runoff is higher. When the ground begins to warm in the spring, bacterial activity in the soil increases, oxidizing the organic material and reducing the BOD in the runoff. It is noted that the BOD test reflects organic material that is readily oxidized which is the same material that soil bacteria would oxidize first.

The rise in BOD, beginning in September before surface temperatures become cold, can be explained by the dry antecedent condition for runoff events during this time of year. As discussed earlier, a dry period before a runoff event allows the concentration of TS and BOD to increase.

Low BOD transport during the summer months is important to stream water quality. It is during the summer when the streamflow is low that the capability of the stream to receive BOD loading is the lowest. Even after extended dry periods, summer BOD concentrations were low enough that transport from the barnlot was not large (Figure 14, lower graph). High BOD transport occurred only during the cooler months when dissolved oxygen content of the streams was high. Once the BOD transport versus month relationship is established, an estimate of the yearly transport can be obtained.

The monthly runoff data plotted in Figure 13 from Table 3 shows a pattern emerging which would be somewhat like that of large watersheds, as shown in Figure 12. The evident departure of the barnlot runoff pattern from that of small watershed might be explained in part by a decrease in the infiltration rate due to the cattle hooves packing the soil during their confinement and the lack of vegetation on the barnlot.

Nitrogen analyses are reported in Tables 1 and 4. The variation of nitrogen content was not as large as that of TS or BOD. It would be possible to characterize the nitrogen content of a runoff event with fewer samples. There were not enough nitrogen analyses run to determine a nitrogen transport pattern.

Subsequent research should attempt to characterize the nitrogen transport, as the data indicated the amount of nitrogen in the runoff was significant.

Management practices for runoff from a barnlot, intuitively and as shown in Table 5, do lessen the potential for barnlot runoff to pollute streamwaters. Further research is needed to establish the effects of specific runoff management practices.

SUMMARY

Runoff for a 16-month period from a 60-head, beef cattle barnlot was sampled and analyzed for TS, VS, BOD and COD. This 0.17-hectare (0.42 acre) barnlot is typical of many feeding operations in the eastern United States.

Runoff usually occurs when rainfall exceeds 1.3 cm (0.5 in.). The transport of TS is related to the volume of runoff, i.e., more runoff gives larger transport of solids. Both BOD concentration and BOD transport are higher in the winter and smaller in the summer months, paralleling the capability of downstream waters to dilute the BOD load. BOD concentrations are larger following periods of dry, antecedent conditions.

Concentrations of TS, BOD and COD in the runoff are variable. Events having higher concentrations have more variability and consequently need to be sampled frequently throughout the event in order to accurately establish transport. VS was consistently between 20 and 40 percent of TS on a dry weight basis.

The amount of solids, BOD and COD in the runoff from barnlots is larger enough to be significant to stream water quality. Runoff management practices are needed to lessen the pollutional impact on receiving streams.

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