Surface Runoff and Nutrient Losses of Fennimore Watersheds

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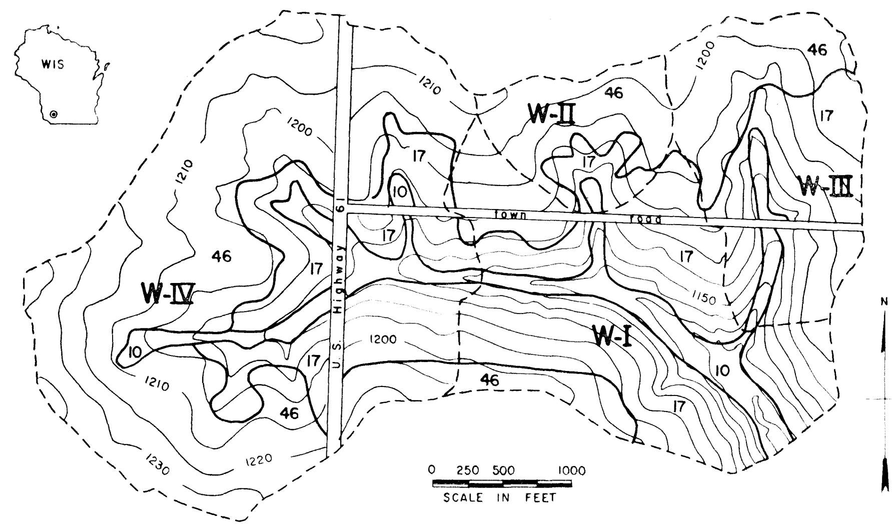
INDUSTRIAL and municipal wastes, urban storm runoff, and farm waste management and fertilization practices are under close scrutiny as sources of pollution of our natural waters. There is an immediate need for reliable information on the seriousness of farm waste disposal and fertilization methods on stream and lake pollution. If nutrient losses of nitrogen (N), phosphorus (P) and potassium (K) in the surface runoff from farms are found to be excessive, the livestock farm operator may be required to change his waste disposal method by constructing solid waste or liquid manure storage facilities, either of which will entail considerable expenditures. Such demands should not be made unless it can be shown that current practices make a comparatively important contribution to the water pollution problem.

The investigation reported here covering only 1 yr, 1967, is an attempt to provide some of the necessary answers. These data, however, must not be interpreted as normal, since 1967 winter runoff was about twice the 29 yr average.



SOIL CHARACTERISTICS									
SYMBOL	TYPE	W-I		W-II		W-III		W-IV	
		ACRES	%AREA	ACRES	%AREA	ACRES	%AREA	ACRES	%AREA
17	DUBUQUE SILT LOAM	137.7	41.7	4.7	20.3	30.3	57.7	47.3	27.6
10	GENESEE COMPLEX SILT LOAM	26.7	8.1	0.3	1.3	3.5	6.7	10.5	6.1
46	TAMA SILT LOAM	165.6	50.2	17.8	78.4	18.7	35.6	113.2	66.3
	TOTALS	330.0	100.0	22.8	100.0	52.5	100.0	171.0	100.0

FIG. 1 Map of Fennimore Watersheds.

DESCRIPTION OF AREAS

Four small watersheds were established by the ARS near Fennimore, Wisconsin, in 1938, and have been operated continuously since that time. The original purpose of this study was to determine precipitation-runoff relations on moderately permeable silt loams of the Upper Mississippi Valley upland loessial soils. The watershed sizes are 22.8, 52.5, 171 and 330 acres. The three smaller areas are a part of the 330 acre watershed. Records collected from these areas have included: precipitation; runoff; air temperature and humidity; soil moisture and crop cover. Fig. 1 shows topography, soils and watershed characteristics of these areas. All areas are equipped with broad-crested V-notch concrete weirs, stilling well and continuous waterstage recorders.

Topographic Features

The Fennimore watersheds lie just north of Military Ridge in the unglaciated area of Southwestern Wisconsin. They are in the western upland physiographic region of the state. These areas have well defined waterways and a range in slope from 1 to 20 percent with prevailing slope of 6 to 8 percent.

Geology

Galena and Platteville (Upper Magnesian) dolomite make up the bedrock which underlie these watersheds. The dolomite slopes south with a drop of only 5 or 6 ft per mile. These rocks lie at depths of more than 48 in. over most of the area although small areas have only 12 to 15 in. of soil cover.

Soils

As shown on the map, Tama and Dubuque account for over 90 percent of the soils on these watersheds. These are both moderately permeable silt loams which are included in Soil Conservation Service hydrologic group B. Organic matter in the plow layer of these soils is generally in the range of 3 to 4 percent. These soils have formed under prairie in a thick blanket of silt. The silt probably originated on the flood plain of the Mississippi River and was blown onto the uplands about the time of the last glacial period.

Tama silt loams are deep, silty, well drained soils which occupy the upland ridges with slopes ranging from 1 to 6 percent. The natural fertility of these soils is high. Permeability is moderate and the moisture supplying capacity is quite high. Normally the soils are leached and are slightly to strongly acid unless limed.

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* Numbers in parentheses refer to the appended references.

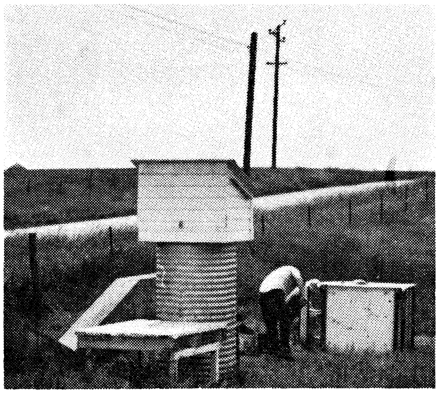

FIG. 2 Field installation.

Cover

All areas except W-II (22.8 acres) have generally been in a 3 to 5 yr rotation with about 30 percent each cultivated, hay and pasture each year and the other 10 percent in roads, buildings or idle lands. W-II has been nearly 100 percent pasture for at least 5 yr. It was last 50 percent in corn for 3 yr from 1954 to 1956. There is perhaps ¼ acre silt delta immediately above the weir which existed above the road before this weir was built in 1938.

In the early years of the study considerable difficulty was encountered from ice forming in the stilling wells which resulted in the loss of valuable records during winter and spring thaws. Recently, gas burners have been installed in two of the wells to guard against the loss of these winter runoff records.

Instrumentation and Data Collection

In June 1966 semi-automatic runoff samplers were installed on the three small watersheds and a report was later prepared on the fertilizer applications and nutrients lost for the year ending with June 1967 (3)*. This sampler, the development of which has been reported by Witzel et al (4) is known as the Wilschwitz automatic sampler. The sampler collects a series of samples at various stages on both the rising and falling limbs of the runoff hydrograph.

A view of one of the field installations is shown in Fig. 2. Samples on the rising stage are collected in one set of quart glass jars set at 4-in. intervals vertically with the inlet of the lowest bottle at the elevation of the weir notch. Samples on the falling stages are collected in another set of glass jars pivoted to swing to an inverted vertical position as the water rises. They continue swinging counter clockwise, tip over and collect samples as the water recedes. Considerable difficulty was encountered with these because the lower bottles froze in and failed to pivot. Thus one or two of the final samples are lost on the falling stages when ice has interfered. In addition to these samples, the ARS observer at Fennimore has on occasion collected manual samples.

TABLE 1. WINTER 1966-67 PRECIPITATION, RUNOFF AND FERTILIZER NUTRIENT LOSSES, WATERSHED W-II (22.8 ACRES PASTURE), FENNIMORE, WISCONSIN

Date	Precip., in.	Moisture in snow, in.	Runoff in.	Fertilizer applied, lb*			Nutrients lost in runoff, lb		
				N	P	K	N	P	K
1966									
Dec. 27	0.09s			380	83	315			
Dec. 28	0.46s								
Dec. 29		0.83							
1967									
Jan. 4	0.11s								
Jan. 6	0.40		Snow surveys indicate most of Jan. 6						
Jan. 7			precipitation stored in snow blanket						
Jan. 10		1.29							
Jan. 16	0.18s								
Jan. 17		1.54							
Jan. 22			0.21						
Jan. 23			0.44						
Jan. 24	1.08		1.12				61.85	15.25	102.8
Sub.	2.32		1.77						
Feb. 1	0.13s								
Feb. 4		0.59							
Feb. 5	0.23s								
Feb. 12	0.05s	0.83							
Feb. 15	0.10s								
Feb. 18	0.06s								
Feb. 21		0.88							
Feb. 23	0.05s								
Feb. 28		0.98							
Mar. 9			0.30					no samples	
Mar. 10			0.35						
Mar. 15	0.04s								
Mar. 19	0.33s								
Mar. 20	0.60s	1.03							
Mar. 23			0.07						
Mar. 24			0.51				7.66	0.68	12.9
Totals	3.91		3.00	380	83	315	69.51	15.93	125.7
							× 3.00/2.35		
Adjusted for days with no samples							88.7	20.6	160.5
Pounds per acre				16.7	3.64	13.8	3.89	0.90	7.04

* Based on pasture days before Oct. 15, 1966.

All samples taken had 1 ml of a 10^{-5} molar solution of 2, 4 di-nitrophenol added to each pint to inhibit bacterial action. Samples are frozen and held in this condition until they can be analyzed. Generally only a few hours elapse between collection of samples and placing them in the freezer but any collected in late PM, such as the January 24 storm, were not frozen until the following day. Analyses of all 1967 samples were made with an auto-analyzer in the University of Wisconsin Sanitary Engineering Laboratory during October-November, after a 9-month storage period.

Each of the farm operators in these watersheds was interviewed to determine dates and amounts of manure and commercial fertilizers applied and the number of animal days on pasture. From these an estimate was made of the total nitrogen (N), phosphorus (P) and potassium (K) added to each of the three small watersheds during the period of July 1, 1966, through June 1967. Manure on these dairy farms was spread as it became available during the winter and was not stock piled. However, W-II was in hay and pasture and received no manure during late fall and winter. The estimated amounts of N, P and K applied to these watersheds were as follows:

Watershed area	N	P	K
	(Pounds per acre in parentheses)		
W-II—22.8 acres	380 (16.7)	83 (3.64)	315 (13.8)
W-III—52.5 acres	2074 (39.5)	452 (8.61)	1721 (32.8)
W-IV—171 acres	2986 (17.4)	651 (4.56)	2478 (17.5)

Basic Data and Analytical Methods

Soluble phosphorus. Procedure. To 25 ml of field sample was added 0.5 ml of 11 N. sulfuric acid and the sample allowed to stand overnight. The sample was then subjected to automatic analysis by the molybdatestannous chloride method in a Technicon Autoanalyzer (2). Overnight treatment, as

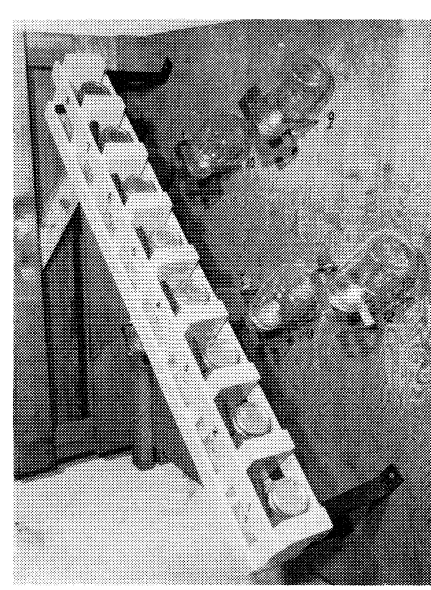

FIG. 3 Rack with sample jars.

stated, hydrolizes the meta-, pyro-, and other poly phosphates to orthophosphates. This treatment also makes soluble other inorganic phosphates which may have been in the suspended form.

Total phosphate. Procedure. To 50 ml of field sample in a 125 ml Erlenmeyer flask was added 1.0 ml of 11 N sulfuric acid and 0.4 g of potassium persulfate. The mixture was boiled for 30 min, cooled and made up to original 50 ml and then subjected to automatic analysis.

Table 1 is a chronological record of data obtained for watershed W-II for the period December 27, 1966, through March 24, 1967. The moisture content of the snow on each date shown in this table was determined from a total of 29 random samples. The runoff on each date was computed from the stage graph and a table of stage-discharge relations. The adjusted total nutrient loss is based on the assumption that the concentration of nutrients during periods sampled were the same as those dates where no samples were taken. The total runoff was 3.00 in. with no samples for 0.65 in. of this total. Thus the nutrient losses were computed as 3.00/2.35 times the actual sample results.

Table 2, giving computations for nutrient losses, for the period January 22-24, on watershed W-III which was caused by melting snow and a 1.08 in. rain shows that except for the first and last samples the percent total runoff represented by each sample varied between 8.3 and 17 percent. These 10 samples appear to be adequate and the N and P losses in mg per l do not show extreme variations. The K loss, however, is much higher during low rates of runoff early and late in the storm period.

Table 3 is a summary of fertilizer applications and N, P, K losses for January through September on the 3 watersheds. On W-II, the small area pastured only through October, the per acre losses were about the same as on the other areas which were about one-third cultivated and received winter manure applications. This may be because of heavy accumulation of manure left by the cattle in the pond area immediately above the weir. The percentage of applied fertilizer lost on W-III was less than on the other areas but it also had only two-thirds as much runoff as the other two watersheds. W-III has somewhat shallower soils and normally has less surface runoff than the other watersheds.

The December-March monthly runoff values for W-II and W-IV for the 29 years of record (1939-67) are shown in Table 4. This shows that runoff for January 1967 was the highest recorded in the 29 years and was about seven times the average for that month. The total December-March runoff of 3 in. was exceeded only five times in 29 years or an average of once each 6 years. The average December-March runoff for the 29 years was only 1.4 in. or approximately half that for 1967. Thus the nutrient losses for 1967 are perhaps at least double what one might normally expect. Other factors that might affect the amount of nutrient losses on these watersheds would include a marked change in livestock populations or increased fertilizer applications.

Concurrent investigations in the same general physiographic region include plant nutrients in the base flow of southwestern Wisconsin streams (1) and surface runoff losses from a series of eight continuous corn plots on the University of Wisconsin Experimental Farm near Lancaster (5).

Conclusions

For W-III on which the estimated fertilizer applications on a per acre basis were about double that of the other areas, the loss of N and K was a lower percentage than for the other areas. This area, which includes parts of two farm barnyards, has shallower soils than the others and has regularly produced less runoff.

The relatively high percent of nutrients lost on the pastured area, which received no winter manure, may be due to the cattle leaving a large amount of their droppings in the ponded area immediately above this weir. Eliminating cattle from this ponded area might provide a different result from the pasture watershed.

On the basis of the 1967 data, a year when nearly all surface runoff resulted from rain on frozen ground and melting snow, the nitrogen, phosphorus and potassium losses were about the same as the Lancaster station plots which received no winter manure application. The nutrients loss in surface runoff however were much greater than those in the base flow of southwestern Wisconsin streams.

Annual surface runoff on these areas has averaged about 1.75 in. of which more than 75 percent has been from rain on frozen ground and melting snow. The 1967 winter runoff therefore was about twice normal. On the basis of this one year we might expect

TABLE 3. FERTILIZER APPLIED AND NUTRIENTS LOST IN RUNOFF, FENNIMORE, WISCONSIN, WATERSHEDS, JAN. THROUGH SEPT., 1967

Watershed No.	Area, acres	Fertilizer applied, lb			Nutrient lost, lb		
		N	P	K	N	P	K
W-II	22.8	380*	183*	315*	88.7	20.6	147.7
W-III	52.5	2074*	452*	1721*	233	71.0	382.5
W-IV	171.	2986*	651*	2478*	570	182.5	1355.0
Totals	246.3	5440	1186	4514	891.7	279.8	1885.2
Avg lb per acre		22.1	4.82	18.3	3.62	1.14	7.7

Watershed No.	Fertilizer applied, lb per acre			Nutrient lost, lb per acre		
	N	P	K	N	P	K
W-II	16.7	3.64	13.8	3.89	0.90	6.48
W-III	39.5	8.61	32.8	4.44	1.35	7.30
W-IV	17.4	3.81	14.5	3.33	1.07	7.92

* From Wilke Report.

TABLE 2. RUNOFF AND FERTILIZER NUTRIENT LOSSES FROM TWO SNOWMELT PERIODS ON WATERSHED W-3 (52.5 ACRES) FENNIMORE, WISCONSIN

Jan. 22-24, 1967, rain 1.08 in. plus snowmelt

Sample No.	Runoff				Nutrient loss mg per liter			Nutrient loss, lb		
	Range in stage	Inches	Percent of storm total	Million pounds	N	P	K	N	P	K
197	1.10-1.48	0.0013		.015	8.50	2.46	16.8	0.13	0.04	0.25
203	1.48-1.64	0.2203	16.1	2.56	8.40	2.28	17.3	21.5	5.84	44.3
179	1.64-1.61	0.1743	12.8	2.08	13.20	2.85	22.0	27.4	5.92	45.7
177	1.10-1.30	0.1157	8.5	1.38	14.70	3.20	31.5	20.3	4.42	43.5
183	2.10-2.32	0.1129	8.3	1.34	7.00	2.40	6.2	9.4	3.22	8.3
181	2.44-2.54	0.1985	14.5	2.36	5.30	2.13	6.2	12.5	5.02	14.6
201	2.45-2.20	0.2319	17.0	2.76	6.40	1.57	4.3	17.7	4.34	11.9
202	2.11-2.04	0.1501	11.0	1.70	5.65	1.91	6.7	10.1	3.42	12.0
190	1.77-1.73	0.1314	9.6	1.56	5.55	5.00	3.7	8.7	7.80	5.8
205	1.45-1.41	0.0291	2.1	.35	6.0e	1.8e	17.7	2.1	.63	6.2
Totals		1.3655		16.195				129.83	40.65	192.5
					Pounds per acre			2.47	0.775	3.67

Mar. 23-24, 1967, snowmelt

Sample No.	Runoff				Nutrient loss mg per liter			Nutrient loss, lb		
	Range in stage	Inches	Percent of storm total	Million pounds	N	P	K	N	P	K
516	1.10-1.20	0.0370	7.9	0.440	9.75	4.80	3.20	4.29	2.11	1.42
494	1.40-1.52	0.0392	6.2	0.466	13.10	7.15	0.005	6.11	3.34	.002
505	1.81-1.90	0.2000	42.7	2.377	6.80	1.50	21.0	16.15	3.54	49.95
482	2.06-	0.1585	33.9	1.883	12.80	2.50	25.4	24.10	4.70	47.85
495	1.81-1.71	0.0339	7.2	0.404	6.60	3.60	21.0	2.66	1.45	8.48
Totals		0.4686		5.570				53.31	15.14	107.70
					Pounds per acre			1.015	0.288	2.05

TABLE 4. WINTER RUNOFF, FENNIMORE, WISCONSIN, WATERSHEDS

Year	W-II—22.8 Acres					W-IV—171 Acres				
	Dec.	Jan.	Feb.	March	Total	Dec.	Jan.	Feb.	March	Total
1939	0	0.05	0	0	0.05	0	0.01	0	0.01	0.02
40	0.05	0	0	0.32	0.37	0	0	0	0.42	0.42
41	0	0	0.07	0.23	0.30	0	0	0.10	0.55	0.65
42	0	0	0	0	0	0	0	0	0	0
43	0	0	0.05	0.25	0.30	0	0	0.05	0.20	0.25
44	0	0.16	1.07	1.00	2.23	0	0.25	0.94	1.35	2.54
45	0	0	0	0	0	0	0	0	0	0
46	0	1.35	0.26	1.97	3.58	0	1.30	0.35	1.83	3.48
47	0.12	0.28	0.54	0.45	1.39	0.20	0.40	0.54	0.50	1.64
48	0	0	2.51	1.06	3.57	0	0	2.86	1.09	3.95
49	0	1.14	0	0.41	1.55	0	0.97	0	0.84	1.81
1950	0	0.07	0	0.55	0.62	0.03	0.10	0	0.80	0.93
51	0	0	0.16	0.33	0.49	0	0	0.21	0.37	0.58
52	0	0.40	0.10	0.45	0.95	0.01	0.50	0.10	0.40	1.01
53	0	0	0.81	0.41	1.22	0	0.02	0.85	0.35	1.22
54	0	0	0	0	0	0	0	0	0.08	0.08
55	0	0	0.30	0.17	0.47	0	0	0.20	0.36	0.56
56	0	0	0.05	1.02	1.07	0	0	0.07	1.17	1.24
57	0	0.19	0.22	0.02	0.43	0	0.26	0.32	0.03	0.61
58	0.01	0	0.27	0.04	0.32	0.04	0	0.37	0.02	0.43
59	0.01	0	0	4.84	4.85	0	0	0	3.36	3.36
1960	0	0.36	0.01	1.01	1.38	0.01	0.64	0	1.40	2.05
61	0	0	0.58	1.08	1.66	0	0	0.71	1.42	2.13
62	0	0	0	0.42	0.42	0	0	0	0.78	0.78
63	0	0	0.05	2.95	3.00	0	0	0.01	3.00	3.01
64	0	0.10	0	0	0.10	0	0.02	0	0	0.02
65	0.01	0.20	1.58	1.39	3.17	0	0.32	1.61	1.83	3.76
66	0	0.01	1.64	0.02	1.67	0.02	0.01	1.29	0.02	1.34
67	0.05	1.77	0	1.23	3.05	0.01	1.62	0.05	1.12	2.79
Avg.	0.01	0.24	0.35	0.75	1.35	0.01	0.22	0.37	0.80	1.40

to lose 3.6 lb of nitrogen, 1.1 lb of phosphorus and 7.7 lb of potassium per acre in the surface runoff. This is three times as much nitrogen, 10 times as much phosphorus and four times as much potassium as in the base flow of streams in this same general physiographic region.

In a year of average runoff, assuming nutrient losses directly proportional to runoff, the losses would be reduced to 2 lb nitrogen, 0.6 lb phosphorus and 4 lb potassium per acre. Further investigations are required to check on this assumption and to see how typical the 1967 data are.

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