Circular 111

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION

Nonpoint Rural Sources of Water Pollution

by SHUNDAR LIN

ILLINOIS STATE WATER SURVEY
URBANA
1972

CONTENTS

Printed by authority of the State of Illinois-Ch. 127,IRS,Par 58.29
(12-72-2000)

NONPOINT RURAL SOURCES OF WATER POLLUTION

by Shundar Lin

ABSTRACT

A literature survey was made to gather information for defining the quantity and characteristics of nonpoint water pollution sources from rural areas. Major constituents of such pollution include fertilizers, pesticides, erosion and sediment, and animal wastes. Studies showed that nitrogen and phosphorus from surface runoff and subsurface drainage are often greater in concentration than that from sewage effluents. Pesticides are only slightly soluble in water, and about 5 percent of that applied may enter waterways through surface runoff and erosion. Soil erosion and nutrient losses can be minimized by conservation measures and proper fertilizer application. With the exception of sediment transport, farm animal wastes can be the most serious sources of pollution from farm lands. The effluent quality of current animal waste treatment processes is substantially less than that achievable for domestic sewage. Conventional sewage treatment processes cannot be directly applied to animal wastes. Research on the handling, treatment, and disposal of animal wastes is woefully lacking.

INTRODUCTION

This report summarizes information from the literature concerning the major potential sources of surface water pollution from farm lands. It delineates the factors in regard to nonpoint rural water pollution sources that should be included in water quality management programs. Considered are commercial fertilizers, pesticides, erosion and sediment, and animal wastes.

In the past, pollution from rural sources has been a minor consideration, if considered at all, in the development of comprehensive water quality management programs. However, changes in agricultural practices, consistent with the desire to increase productivity per unit land area to meet increasing consumer demands, are bringing about adverse changes in the water quality of lakes and streams.

In Illinois there is no substantive evidence that any major changes in water quality are the direct result of agricultural practices alone; nor are any of the changes brought about by rural land use considered irreversible. Nevertheless, the potential for serious degradation of streams and lakes in Illinois does exist because of current trends in farming and livestock practices.

The information in this report has been compiled from studies made in other parts of the United States as well as in Illinois, and should be useful to water pollution control agencies, agricultural interests, and consulting engineers. The material has been prepared under the general supervision of Ralph L. Evans, Head of the Water Quality Section of the Illinois State Water Survey, and Dr. William C. Ackermann, Survey Chief.

FERTILIZERS

The principal components of commercial fertilizers that possess the potential for degrading the quality of surface waters are nitrogen and phosphorus. The nitrate-nitrogen form causes the most apprehension. Whereas the soil retention capacity for phosphorus in most areas of Illinois is great, the nitrates are quite soluble and move readily with water drainage patterns. Regardless of the chemical formulation used for a nitrogen source (over 90 percent of that used in Illinois is anhydrous ammonia), the nitrogen applied must be converted to the leachable nitrate form to be most beneficial to plants.

The use of fertilizers in the United States has increased substantially during the past three decades. The application of nitrogen in commercial fertilizers has risen from less than 400,000 tons in 1940 to about 7,000,000 tons in 1970; in Illinois, nitrogen applications increased from about 120,000 tons in 1960 to 600,000 tons in 1968. Commensurate with this increasing use of fertilizers is an upward trend in nitrate concentrations in some surface waters in Illinois.[1,2] These waters, located principally in east-central Illinois, are in areas where the highest proportion of row crops are maintained, the greatest acreages of soybeans are grown, the most intensive application of commercial fertilizer is practiced, and the highest percentage of land is equipped for artificial drainage.[3] Although nitrate-nitrogen levels have increased in these surface waters, there is no indication that any problems they may create will be related to over-enrichment or eutrophication. Rather, of principal concern is the relationship of nitrate concentration to public health in drinking water supplies.

Aldrich[4] is of the opinion that shifts in cropping practices, that is, the replacement of close growing noncultivated small grains (oats and wheat) with clean cultivated row crops (corn and soybean), have been instrumental in increasing nitrate concentration in farm drainage.

The importance of each of the principal sources of nitrate from agricultural lands, which include humus, livestock wastes, nitrogen-fixing crops, crop residuals, and free-living soil organisms as well as commercial fertilizers, has not been clearly defined. Nor has the collective influence of soil temperature, pH, texture, structure, permeability, humus content, fertilizer application, and precipitation been delineated with respect to nitrate concentrations in surface waters. The Illinois Pollution Control Board, after a substantial series of hearings, concluded that more research would have to be undertaken before rational limitations on fertilizer use could be imposed.[5] Although such unknowns preclude reliable predictions of nitrate and phosphorus emissions from fertilizers to the aquatic environment, pertinent observations of others are reviewed below.

Nitrogen

Although most of the values cited in this section are in terms of total nitrogen, the leachable nitrogen (nitrate nitrogen) generally makes up about 85 to 95 percent of the total nitrogen in crop land drainage. The use of fertilizer for selected crops in some states is listed in table I.[6] The application rate of nitrogen in pounds per acre ranges from 58.0 to 125.3 for corn, from 9.7 to 29.6 for soybeans, and from 17.8 to 58.9 for wheat. Among the states listed, Illinois has the highest application rates for all plantings except corn.

Table 1. Fertilizer Use on Selected Crops in Selected States, 1971 (Ref. 6)

State	Area harvested (10^3 *acres*)	Acres receiving (%) Any fertilizer	N	P_2O_5	K_2O	Rate of application (*lb/a*) N	P_2O_5	K_2O
Fertilizer Use on Corn Harvested for Grain								
Pennsylvania	1,036	98	97	98	96	81.1	65.1	54.2
Ohio	3,526	99	99	99	99	90.0	69.7	73.1
Indiana	5,509	99	99	99	98	112.6	75.6	94.4
Illinois	10,170	96	95	89	87	112.8	67.4	64.2
Michigan	1,700	98	98	97	97	101.0	66.4	80.8
Wisconsin	2,099	97	97	96	96	61.0	65.1	70.7
Minnesota	5,725	94	94	92	92	95.9	59.8	60.5
Iowa	11,570	95	94	89	84	100.5	57.5	51.7
Missouri	3,092	99	99	88	87	125.3	52.7	48.7
S. Dakota	2,679	51	51	39	17	58.0	27.0	13.1
Fertilizer Use on Soybeans Harvested for Beans								
Ohio	2,494	42	37	42	42	11.7	37.6	38.8
Indiana	3,377	52	46	50	52	10.5	28.6	41.6
Illinois	7,150	20	12	17	20	29.6	41.2	47.8
Minnesota	2,851	10	8	10	10	9.7	25.0	37.7
Iowa	5,440	11	7	11	11	10.2	33.9	45.4
Missouri	3,605	17	14	17	17	14.0	30.0	38.7
Fertilizer Use on Wheat Harvested for Grain								
Ohio	981	100	100	100	100	42.4	57.3	55.3
Indiana	735	99	99	97	97	52.0	55.7	52.9
Illinois	983	99	99	95	86	58.9	64.4	53.0
Michigan	570	96	96	84	84	41.2	61.4	52.2
Minnesota	1,508	87	87	87	65	23.7	31.4	16.9
Missouri	848	94	94	63	63	49.0	39.2	40.2
N. Dakota	8,982	66	63	64	5	17.8	26.1	8.9
S. Dakota	2,288	43	41	39	4	19.1	21.1	7.1

Aldrich[3] states that, with corn, little nitrate nitrogen accumulates in the soil profile at application rates ranging from 100 to 150 pounds of nitrogen per acre, some accumulates at rates from 150 to 240 lb/a, but a substantial accumulation occurs at 240 to 300 lb/a annually.

Efforts to relate nitrate-nitrogen concentration in agricultural runoff to commercial nitrogen application have not been successful. The difficulty arises from the inability to identify the original source of the nitrate nitrogen. The general question remaining to be answered is: What proportion of the leachable nitrate originates from applied ammonium, mineralization of humus, and plant residues?

White-Stevens[7] claims that nitrogen losses to aquifers and surface waters from fertilized agricultural areas in Connecticut amount to 10 percent of the nitrogen applied. Enfield[7] reported that the application of 400 pounds per acre (lb/a) of ammonium nitrate on a 13 percent slope followed by 5 inches of rain in 2 days resulted in runoff nitrogen at 1.7 percent of that applied or about 6.7 lb/a. This is not a good example for Illinois conditions because of the type of fertilizer selected, the slope involved, and the excessive application rate used; it does demonstrate the differences encountered in predicting sources of nitrogen in agricultural drainage.

Lee[8] suggests that drainage from unfertilized farms in the vicinity of Madison, Wisconsin, contained nitrogen in the order of 0.03 pounds per acre per year (lb/a/yr), and values many times this amount occurred when applied nitrogen was used in great excess of requirements.

Sawyer[9] in his 1947 work near Madison, Wisconsin, found nitrogen contributions in surface runoff from highly developed agricultural areas ranging from 5.95 to 8.12 lb/a/yr. In studies at Coshocton, Ohio,[7] the average annual loss of nitrate nitrogen from farm land over a 3-year period was 3.86 lb/a, whereas that from woodland averaged 0.92 lb/a. Sylvester[10] found nitrogen losses of 2.5 to *2k* lb/a/yr in the surface drainage from the Yakima Valley, Washington, and 0.2 to 0.3 lb/a/yr in the surface runoff from forested areas.

Studies in Champaign County, Illinois, cited by Aldrich[3] suggest that nitrate loss is a function of rainfall. The following examples are given:

Low rainfall	7.7 lb/a NO, leached from soil
Average rainfall	10.8 lb/a NO, leached from soil
High rainfall	16.0 lb/a NO. leached from soil

Harmeson[11] estimated the average nitrate-nitrogen export through tile drains to be 14.1 lb/a from a 340-acre tract in Champaign County to which an average of 110 to 125 lb/a of nitrogen had been applied. For a subsurface drainage study in

San Joaquin Valley, California, Johnston et al.[12] reported 12, 23, and 99 lb/a/yr of nitrogen loss in three separate fertilized areas, while only about 3 lb/a/yr was observed from a non-fertilized area. Minshall et al.,[13] from studies of large subsurface drainage areas in Wisconsin, reported annual losses in base flow of 1.0 lb/a/yr of nitrogen. These losses appear low. The concentrations of nitrate nitrogen in farm drain tiles have been reported[2] for several counties in Illinois. They include the following:

Champaign County	21 to 99 mg/1	Warren County	34 to 71 mg/1
Livingston County	40 to 72 mg/1	Woodford County	58 to 94 mg/1
Tazewell County	20 to 72 mg/1	McLean County	59 mg/1 (1 sample)

Some other investigators[10,12,14] have reported on the concentration of nitrogen in surface runoff and tile drain systems. Table 2 contains a summary of the quantities and concentration of nitrogen observed in rural land drainage.

It is generally conceded by agronomists that not only is the over-use of nitrogen fertilizer undesirable but its under-use is equally indefensible. According to Viets[15] over-use is uneconomical and enhances nitrogen losses to the environment, whereas under-use would likely result in a more costly food supply and increased erosion of valuable farm land.

Until some definable relationships have been developed for the variables 1) soil type, 2) cropping practices, 3) precipitation, and 4) fertilizer management, predictions regarding likely nitrogen emissions from farm land in Illinois must depend on a catalogue of observations and watershed data similar to that summarized in figures 1 and 2. Figure 1 shows the range of observed nitrate concentrations in watersheds in Illinois[1,2] for the period 1945-1969. Figure 2, which is based upon tonnage reports [16,17] and county areas,[18] summarizes the pounds per acre of nitrogen applied during the period July 1970 through June 1971.

Phosphorus

As mentioned earlier, the retention capacity of most agricultural soils for phosphorus is so great that fertilizer applications are not likely to have a significant effect on phosphorus content in drainage waters from field tile outlets.

Table 2. Nitrogen in Rural Drainage

Description	Location	Amount (*lb/a/yr*)	Concentration (*mg/l*)		Reference
Surface runoff					
13% slope, 400 lb/a added, 5 inch rain		6.7			7
Intensely cultivated area	Wisconsin	5.95-8.12			9
Farmland, Naches soil	Washington	10.45	0.08-4.7	(1.34)*	10
Farmland, Sagemoor sandy loam	Washington	18.5	0-6.0	(1.67)	10
Farmland, Esquatzel fine sandy loam	Washington	24.0	0.08-6.3	(2.23)	10
Farmland, Naches fine sandy loam	Washington	2.45	0.02-1.9	(0.59)	10
Farmland, winter wheat	Ohio		2.2-12.7	(9.0)	14
Farmland	Ohio	3.86			7
Forested areas	Washington	2.96	0.05-0.72	(0.28)	10
Forested areas	Washington	1.30	0.03-0.31	(0.19)	10
Forested areas	Washington		<0.01-0.04	(0.02)	10
Forested areas	Ohio	0.92			7
Subsurface drainage					
Cultivated farmland	Illinois	14.1	20-99		11,2
Naches loam, sweet corn	Washington	56	0.4-5.6	(2.9)	10
Esquatzel and Selah loam, wheat	Washington	54	0.4-4.4	(2.1)	10
Ahtanum loam, barley pasture	Washington	92	0.2-6.8	(2.7)	10
Sagemoor loam, grapes, hay	Washington	166	0.1-10.9	(4.5)	10
Varied soils, apples	Washington	38	0.09-6.7	(2.1)	10
Fertilized area	California	12-99	1.8-62.4	(25)	12
Non-fertilized area	California	3			12
Farmland	Ohio	2			7

**Averaged concentrations in parentheses*

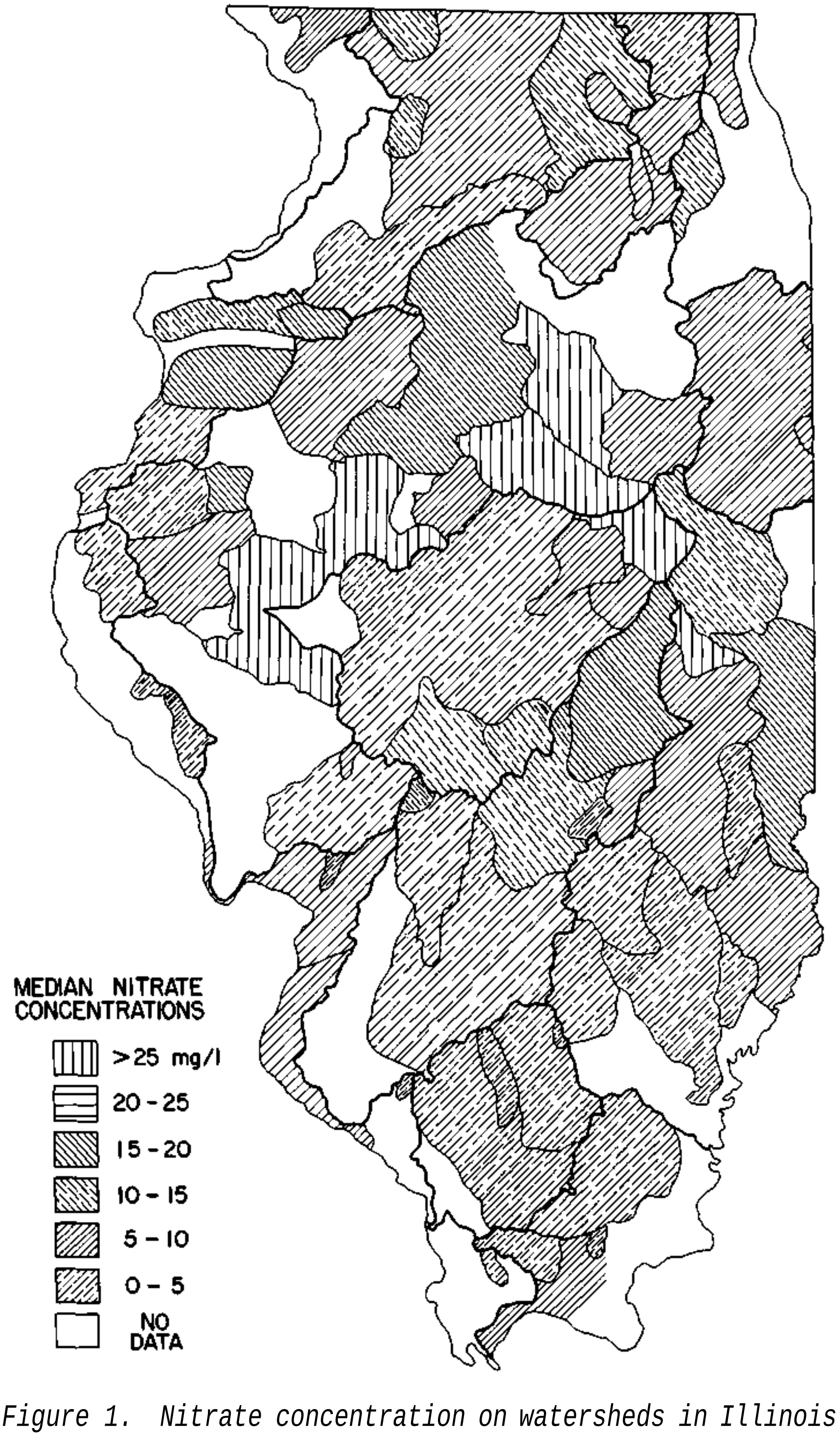

Figure 1. Nitrate concentration on watersheds in Illinois

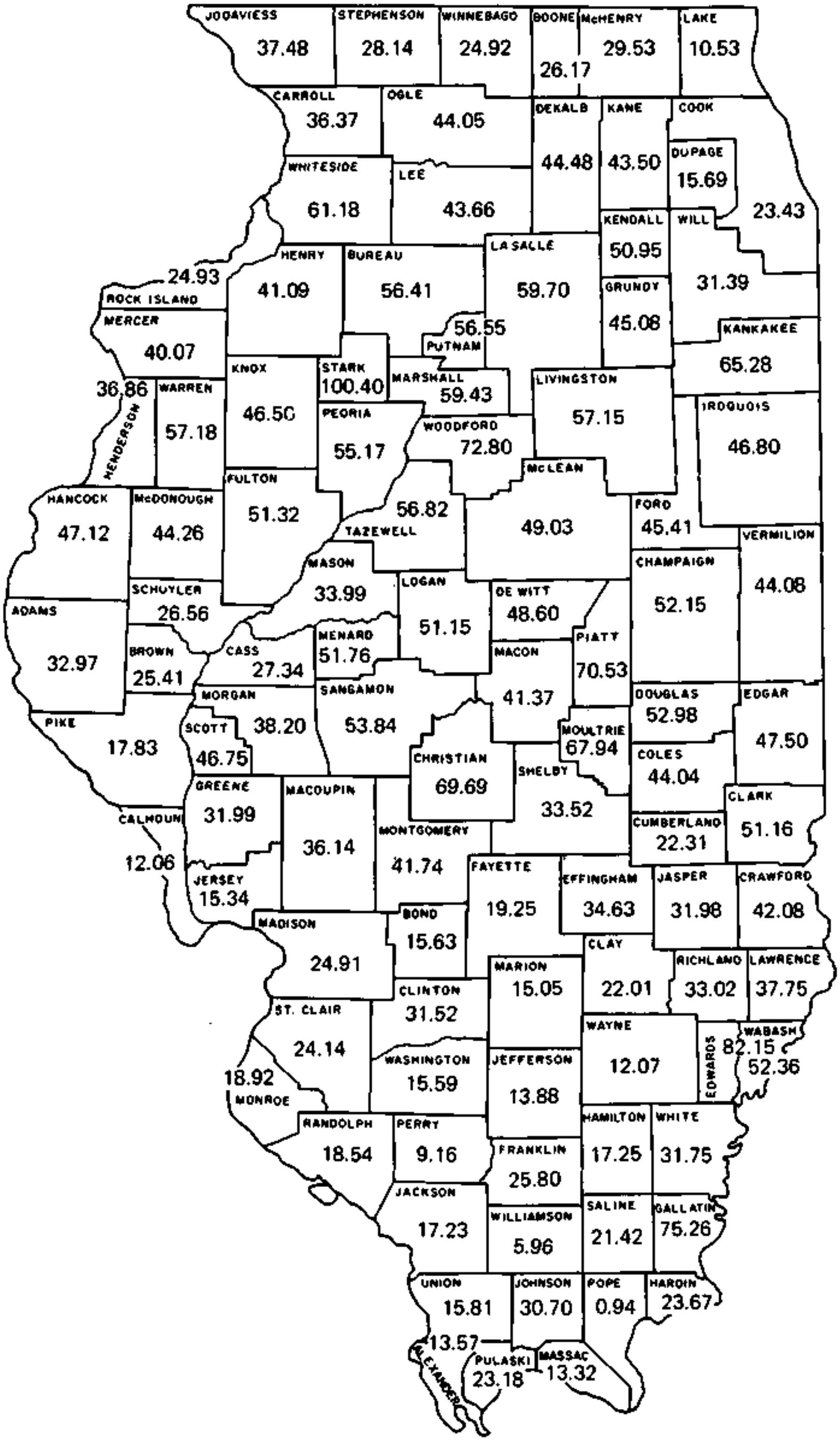

Figure 2. Fertilizer nitrogen applied (lb/acre) July 1970-June 1971

The areas likely to differ include muck, peat, and organic soils. Many surface soils in Illinois *are* unnecessarily high in phosphorus content for optimum economic yields.[3] Since phosphorus is held tightly to soil particles, most of the phosphorus carried into streams and lakes by erosion would be in the sediment rather than in the solution, and thus would not be directly available for algal growth. Phosphorus in sediment, however, can be resuspended into water by scouring, and subsequent exchange processes could make the phosphorus available for biological growth. Thus it is important to minimize the introduction of phosphorus to lakes and streams regardless of its form, i.e., in solution, in organic matter, or associated with soil particles.

The general use of phosphorus for agricultural purposes in selected states is included in table 1. The application rates of phosphorus (P_2O_5) in lb/a/yr range from 27.0 to 75.6 for corn, from 25.0 to 41.2 for soybeans, and from 21.1 to 64.4 for wheat. As in the case of nitrogen application, Illinois has the highest rate of phosphorus usage except for corn.

Generally only 10 to 30 percent of the phosphorus added to a soil is utilized by a current crop. The remaining phosphorus, tightly bound to the soil, is presumably available for subsequent years. Aldrich[3] points out that the runoff of soluble phosphorus from surface applications on rather steeply sloping land is on the order of 1 percent under extreme rainfall conditions.

Sridharam and Lee[19] estimated that the rural runoff in the Fox-Wolf drainage basin, Wisconsin, contributed 33.5 percent of the total phosphorus in the basin. Sawyer[9] estimated losses of about 0.4 lb/a/yr from agricultural areas in the vicinity of Madison, Wisconsin. At Coshocton, Ohio,[7] phosphorus losses were reported to be 0.06 lb/a/yr from farm land and 0.04 lb/a/yr from woodland.

A study[20] involving corn planted on silt loam suggested a loss of 1.8 lb/a/yr on a 20 percent slope; on similar soil but at an 8 percent slope, the loss was only 0.5 lb/a/yr.

The work of Engelbrecht and Morgan[21] involving a survey of phosphorus sources on the Kaskaskia River basin in Illinois is summarized in table 3. It is calculated from values in table 3 that the overall mean loss from cultivated land at 6 sampling stations is 0.17 lb/a/yr as P, with means ranging from 0.02 to 0.37 lb/a/yr.

Table 3. Estimates of Phosphates Contributed by Land Drainage to Kaskaskia River, 1956 (Ref. 21)

Location	Cultivated land (*sq mi*)	Orthophosphate plus MIC* P_2O_5 from drainage (%)† Low	Mean	High	Orthophosphate plus MIC P_2O_5 from drainage (*lb/day/sq mi*) Low	Mean	High
Bondville	10.6		100		0.01	0.19	0.77
Above Ficklin	109	11	55	92	0.01	0.18	1.89
Shelbyville	842	2	43	99.6	0	3.04	57.80
Vandalia	1505	6	23	99	0.01	1.56	14.77
Carlyle	1850	36	54	93	0.07	0.40	1.78
New Athens	4020	1	33	88	0	0.37	1.76
Overall mean§			45			1.40	

*Maximum inorganic condensed
†Phosphorus from agricultural drainage to total P from all sources
§The overall mean contribution of orthophosphate plus MIC P_2O_5 from land drainage was 1.40 lb per day per square mile. The figure for Shelbyville seems to be inordinately high and if it is not considered in the average one can arrive at a figure of 0.54 lb/day/sq mi. It is not mentioned in the report why the land drainage at Shelbyville should have such a high concentration. Equivalent phosphate figures as orthophosphate would be 0.95 and 0.35 lb/day/sq mi.

Johnston et al.[12] in their studies of tile drains reported similar results, i.e., 0.2 to 0.48 lb/a/yr in California.

The amount and the concentration described above as well as values derived from other studies[10,14,22,23] are summarized in table 4. The extent and intensity of phosphorus applications based upon reports previously cited for Illinois are depicted in figure 3.

From the estimates made by a Task Group of the American Water Works Association,[22] as summarized in table 5> it is clear that agricultural runoff is a major potential source of nitrogen and phosphorus to the aquatic environment. The amount of agricultural phosphate transported to streams and lakes, according to Engelbrecht and Morgan,[23] depends on the following factors: nature and amount of phosphates in the soil, mode of drainage, topography, intensity and distribution of rainfall, rates of infiltration and percolation, and probably others. Unfortunately, the effect of the losses of agricultural fertilizers on water quality has not been well defined.

Table 4. Phosphorus in Rural Drainage

Description	Location	Amount (lb/a/yr)	Concentration (mg/l)		Reference
Surface runoff					
Intensely cultivated area	Wisconsin	0.37-0.41			9
Farmland	Ohio	0.06			7
Farmland, Naches soil	Washington	1.28	0.11-0.24	(.17)*	10
Farmland, Sagemoor sandy loam	Washington	2.88	0.12-0.38	(.26)	10
Farmland, Esquatzel fine sandy loam	Washington	3.88	0.13-0.65	(.36)	10
Farmland, Naches fine sandy loam	Washington	0.92	0.14-0.30	(.22)	10
High erosion areas		30-50			7
Corn, silt loam, 20% slope	Ohio	1.8			20
Corn, silt loam, 8% slope	Ohio	0.5			20
Cultivated land	Illinois	0.02-0.37 (.17)			21
Farmland, winter wheat	Ohio		0.08-1.08	(.56)	14
Cultivated land, 11 sq mi	Illinois		<0.01-0.21	(.03)	23
Forested areas	Washington	0.74	0.02-0.14	(.07)	10
Forested areas	Washington	0.77	0.03-0.20	(.12)	10
Forested areas	Washington	0.33	0.01-0.09	(.02)	10
Forested areas	Ohio	0.04			7
Subsurface drainage					
Naches loam, sweet corn	Washington	3.4	0.07-0.28	(.17)	10
Esquatzel and Selah loam, wheat	Washington	8.1	0.20-0.46	(.32)	10
Ahtanum loam, barley and pasture	Washington	8.9	0.18-0.47	(.26)	10
Sagemoor loam, grapes, hay	Washington	7.1	0.08-0.41	(.20)	10
Varied soils, apples	Washington	2.5	0.08-0.17	(.13)	10
Fertilized area	California	0.02-0.48	0.05-0.23	(.08)	12
Farmland	Ohio	<0.04			7
Farmland	Wisconsin	0.1			7
Lipimeter studies	Illinois		0.1-0.4	(.25)	22

*Averagedconcentrationsinparentheses

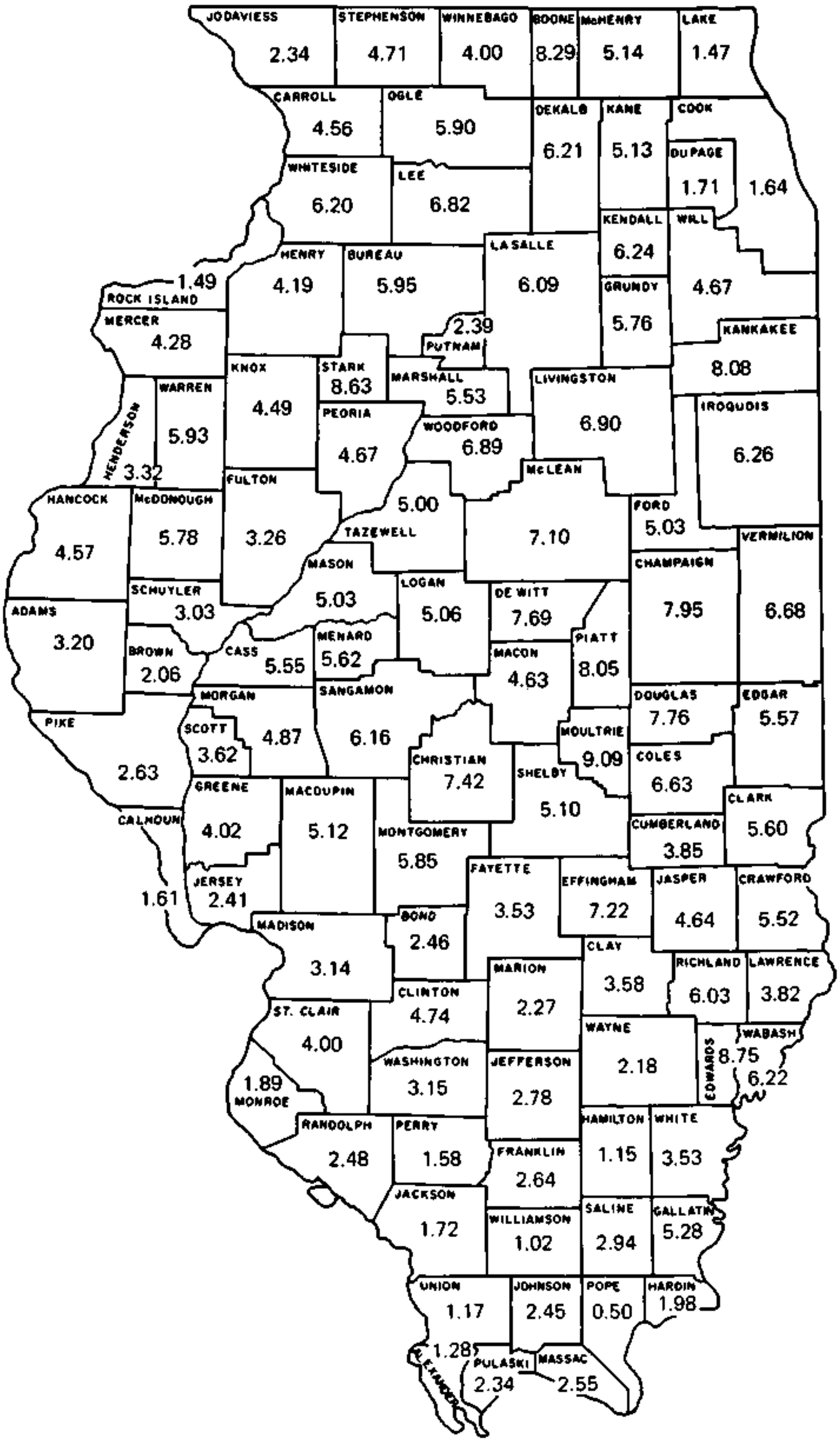

Figure 3. Fertilizer phosphorus applied (lb/acre) July 1970-June 1971

Table 5. Estimate of Nutrient Concentrations from Various Sources (Ref. 22)

Source	Nitrogen 10^6 *lb/yr*	Nitrogen Usual conc. in drainage (*mg/l*)	Phosphorus 10^6 *lb/yr*	Phosphorus Usual conc. in drainage (*mg/l*)
Domestic waste	1,100-1,600	18-20	200-500	3.5-9
Industrial waste	>1,000	0-10,000	*	*
Rural runoff				
Agricultural land	1,500-15,000	1-70	120-1200	0.05-1.1
Non-agricultural land	400-1,900	0.1-0.5	150-750	0.04-0.2
Farm animal waste	>1,000	*	*	*
Urban runoff	110-1,100	1-10	11-170	0.1-1.5
Rainfall**	30-590	0.1-2.0	3-9	0.01-0.03

**Insufficient data available to make estimate*
***Considers rainfall contributed directly to water surface*

PESTICIDES

The distribution of agricultural pesticides in the aquatic environment is principally a function of soil erosion and air currents. It is generally agreed that pesticides applied to agricultural lands that are not prone to erosion present minimal hazards, whereas those applied to soils easily eroded by water or wind, or to thin soils and rock outcrop areas, can become water contaminants.

Reliable data on the use of pesticides in Illinois, with the exception of herbicides, are not available according to a representative of the Illinois Department of Agriculture. Similarly, data regarding concentrations of pesticides in Illinois surface waters are lacking. Accordingly the discussion that follows is principally a summary of studies which, with judgment, may be of value in assessing the potential for concern about pesticides in Illinois surface waters.

Weibel et al.[14] during investigations in Cincinnati, Ohio, demonstrated that a variety of pesticides can be transported by air currents and deposited in areas remote from the origin of application. They postulated that high winds coincident with dust clouds could under conditions of only trace precipitation deposit pesticides. Some of their results are given in table 6.

Table 6. Pesticide Contents from Trace Precipitation, Cincinnati, January 26, 1965 (Ref. 14)

Pesticide	Concentration (mg/l)*
Chlordane	0.5
Heptachlor epoxide	0.04
DDE	0.2
DDT	0.6
Ronnel	0.2
Dieldrin	0.003
2,4,5-T	0.04
Total organic chlorine	1.3
Total organic sulfur	0.5

*Based on air-dried weight of dust

Table 7. Percent of Recovered Pesticides in Water, Eroded Soil, and Plot Surface Samples (Ref. 26)

Sample	Aldrin	Dieldrin	DDT
Runoff water	1.6	1.4	0.3
Eroded soil	3.6	3.3	6.0
Plot surface	94.8	95.4	93.7

Investigations for chlorinated hydrocarbon content in the waters of the Mississippi River and its tributaries by Barthel et al.[24] found residuals from agricultural and non-agricultural sources; however, no evidence was found of an accumulation in the sediments of the streams due to agriculture applications.

The movement and distribution of DDT and Toxaphene in heavy clay soil was studied by Swoboda et al.[25] on three watersheds in Texas. They found that less than 16 percent of the DDT and less than 22 percent of the Toxaphene applied over a 10-year period were recovered in the upper 5 feet of the soil. From 60 to 70 percent of the DDT and from 90 to 95 percent of Toxaphene recovered were found in the upper 12 inches of the soil. The downward leaching of the DDT was attributed to large vertical cracks occurring in the prairie land.

Hann[26] conducted a laboratory study of the movements of aldrin, dieldrin, and DDT by water transport and soil erosion. He suggested that the three pesticides were only slightly soluble in water and any downward movement due to percolation was small. His results are summarized in table 7.

Brown and Nishioka[27] reported on a surveillance program involving the collection of mixtures of suspended material and sediment from 11 selected streams in western states. Analyses were made for aldrin, DDD, DDT, dieldrin, endrin, heptachlor, heptachlor oxides, lindane, and three herbicides (2,4-D; 2,4,5-T; and silvex). No herbicides were detected during the period covered by the report. All insecticides were found at one time or another but not at all stations. The quantities observed were small, ranging from less than 5 parts per trillion for lindane to 110 parts per trillion for DDT.

Marston et al.[28] reported on the application of the herbicide amitrode by aerial spray on 100 acres of sub-basin in the Astoria, Oregon, watershed. Measurable amounts of the substance were found in water samples collected near the downstream edge of the sprayed area during and for 5 days after spraying. The maximum concentration of 0.155 μg/l was found 30 minutes after spraying commenced. At the end of the 2-hour application period the concentration was 0.026 μg/l.

Marston et al.[29] observed measurable amounts of endrin in streamflow for 2 hours after the start of the aerial broadcasting of endrin-coated Douglas fir seeds on a 175-acre clear cut watershed. Endrin was also detected following a winter freshet 6 days after seeding. The total amount of endrin found during these two periods of runoff was only 0.006 lb/sq mi or 0.12 percent of the endrin applied. This was much lower than the 11.3 percent loss observed during laboratory studies when the endrin-treated seed was soaked in distilled water for 32 days.

The average concentration of malathion found on exposed filter paper during ultra-low volume aerial spraying was 1 mg/sq ft or about 65 percent of the applied dosage.[30] The maximum concentration of malathion found in nearby waters was 0.5 mg/l. Residual chlorinated hydrocarbon in the sprayed area consisted principally of DDT and BHC isomers. Waters sampled in the area generally contained less than 1 μg/l of individual chlorinated pesticides.

A report summarizing the results of five annual surveys (1964-1968) for chlorinated hydrocarbon pesticides in surface waters in the U. S. suggests widespread occurrences of these compounds.[31] Concentrations of dieldrin, endrin, DDT, DDE, DDD, lindane, and BHC were not detectable in the Ohio River at Cairo, the Illinois River at Peoria, and the Mississippi River near East St. Louis. In general the number of detection occurrences in the U. S. peaked in 1966 and have since sharply declined. Dieldrin, DDT, DDE, and DDD were the compounds most frequently detected. The maximum concentrations found did not exceed the permissible limits suggested for domestic water supplies; however, the concentration often exceeded the environmental limits for fish recommended by the Federal Committee on Water Quality Criteria.

The routine monitoring[32] of a number of Iowa rivers for chlorinated hydrocarbons over a 3~year period has shown the presence of dieldrin, DDT, and DDE in a majority of the samples taken. Dieldrin occurred more frequently than either of the other residues. The authors conclude that occurrence of these pesticides in water is a function of agricultural activity and quantities of surface water runoff. Another Iowa report[33] in which the pesticide levels in fish were reviewed indicated that species of fish feeding on the bottom of streams appear to aggregate larger amounts of dieldrin than species whose feeding habits are less directly related to bottom silts. Predator game fish with their different feeding habits had levels well below dieldrin limits (0.3 mg/l) even in areas where dieldrin levels in catfish had been high. The authors concluded, "Since turbidity correlates with pesticide levels in streams, it is felt that better soil conservation practice, holding the agricultural chemicals on the fields where they belong, is the most logical method of improving the problem."

If the lack of data on insecticide use and the meager data available on pesticide concentrations in Illinois surface waters are reflective of the situation in Illinois, then there is no serious problem. Conditions meriting concern, and perhaps preventive measures, would be associated with watersheds subject to undue soil erosion.

SOIL EROSION AND SEDIMENTATION

Another form of agricultural pollution is the siltation of lakes and streams caused by lack of proper soil conservation practices. One of the long term effects of soil erosion is the entry of phosphorus and pesticides attached to eroded soil particles into waterways.

Table 8. Effects of Different Cropping Systems on Runoff and Erosion (Ref. 7)

Cropping practice	Soil loss (*ton/a/yr*)	Runoff (% of rainfall)
Continuous bluegrass	0.34	12.0
Rotation of corn, wheat, clover	2.78	13.8
Continuous wheat	10.09	23.3
Continuous corn	19.72	29.4
Fallow	41.65	30.7

The simplicity of normal soil erosion forces is well understood. A falling raindrop, under still air conditions, possesses a velocity of about 30 fps. The impact of rain at this velocity has an inherent soil detaching power of as much as 75 tons per acre per year. Soil erosion is subsequently enhanced by the rate and quantity of surface runoff. The first effort of any soil conservation measure is to dissipate the velocity; the second is to reduce surface runoff.

Well-balanced cropping practices are one important measure used by agriculturalists in minimizing soil erosion. The effects of different cropping practices are shown in table 8.

The total land area in Illinois is about 35.7 million acres; 24.4 million acres are used for tilled crops. In 1967, about 72 percent of the tilled soil was devoted to corn and soybeans. An inventory[34] of conservation needs indicates that 66 percent of this crop land acreage is not adequately treated. The most needed conservation practices, with the percent of crop land involved, are:

Contour farming	10.5 percent
Terraces or diversion	10.5 percent
Cover crops	20.0 percent
Crop rotation	9.0 percent
Drainage	13.0 percent

A review of the acreage of crop land on a county by county basis showed that 77 of the 102 counties in Illinois required additional treatment on 60 percent or more of the total crop land within their boundaries. The locations of these counties and their respective conservation needs on a "percentage of crop land" basis are designated in figure 4.

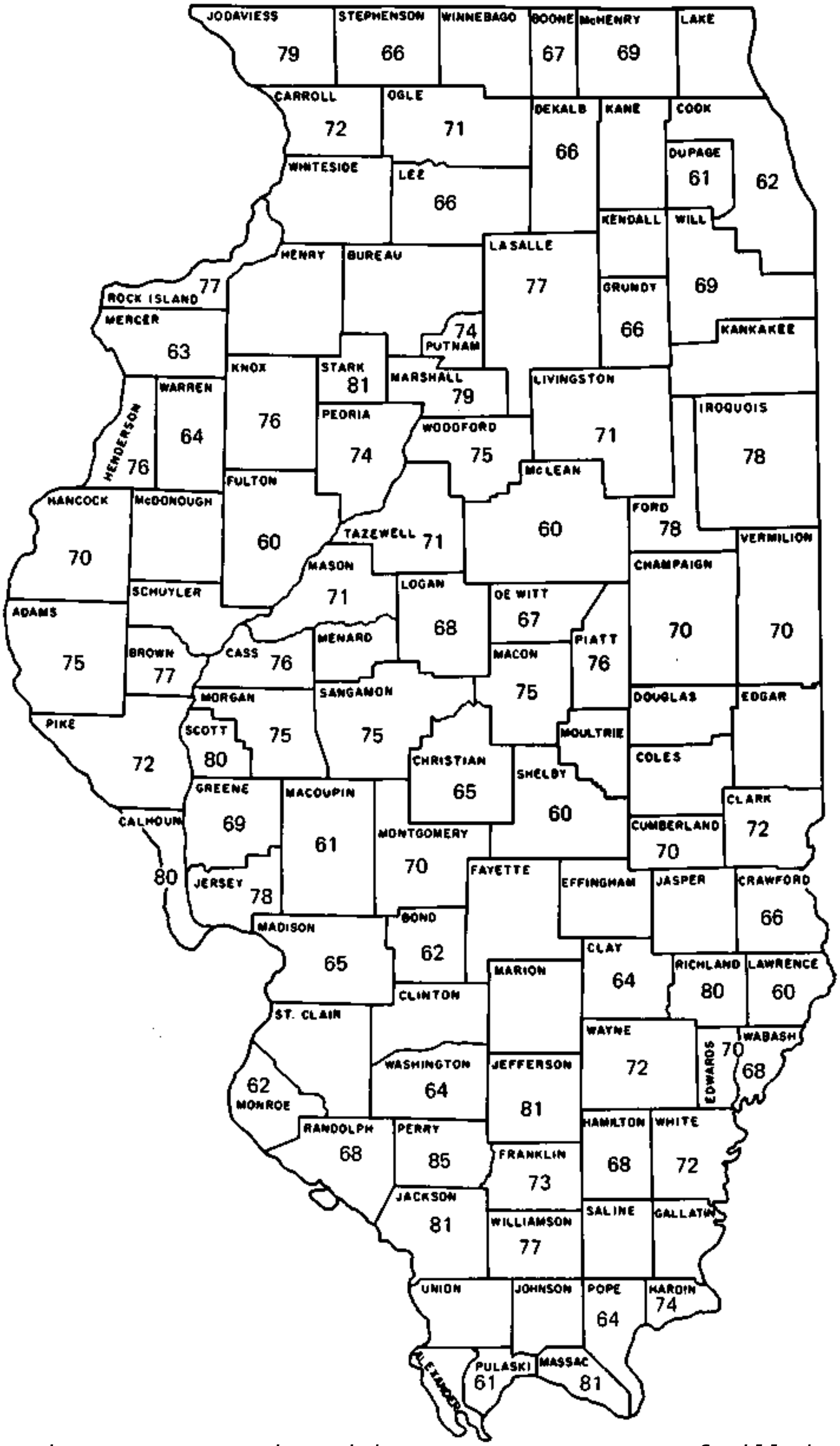

Figure 4. Counties with 60 percent or more of tilled area requiring soil conservation practices

ANIMAL WASTES

Table 9 shows that the farm animal population in Illinois during the past few years reached some stability and that the animal population, with the exception of sheep and lambs, increased substantially in the United States. The increased demand for meat in this country is due not only to population growth but also to the increased consumption of beef and broilers. The overall meat consumption per capita during the period increased 15 percent while that for beef increased about 30 percent.[35] The increase in animal production necessitated by the demand has not been made without significant changes in livestock management practices.

Whereas livestock production was once a diffuse operation, the trend now is toward centralization. Also at one time the grain and roughage produced on the farm was used for livestock production and the manure generated was returned to the land; now with centralized operations, feed is often imported and even if land is available for manure spreading the practice becomes, from a profit standpoint, a questionable one in comparison with available commercial fertilizers. Thus an increasing number of livestock producers are faced with the disposal of highly concentrated low volume waste flows in confined areas, and the technology to handle such disposal has not been developed. The wastes are a potential hazard to ground

Table 9. Number of Animals on Farms 1969-1971 (Ref. 37)

Place	Year	Cattle and calves	Hogs and pigs	Sheep and lambs	Chickens	Turkeys
Illinois	1969	3,345,000	7,279,000	304,000	10,780,000	36,000
	1970	3,278,000	6,551,000	295,000	10,969,000	29,000
	1971*	3,245,000	7,468,000	257,000	10,969,000	31,000
U. S.	1969	109,885,000	60,632,000	18,332,000	419,635,000	6,604,000
	1970	112,303,000	56,655,000	17,411,000	433,640,000	6,769,000
	1971*	114,568,000	67,540,000	16,937,000	442,783,000	7,462,000

*Preliminary information

and surface waters; and their water pollution potential includes impairment of bacteriological quality, depletion of dissolved oxygen, increased nutrient enrichment, and complications in water treatment.[36] The adoption of rules and regulations by water pollution abatement agencies and their collaborative water quality monitoring programs have magnified the dilemma of livestock producers.

Quality and Characteristics

The unit volumes and weights, moisture and chemical constituents, and pollutional characteristics of livestock wastes as documented by many investigators are summarized in tables 10, 11, and 12, respectively. Many variables including housing and management, diet, storage, and handling practices influence the amount and quality of animal waste produced. Loehr[35] suggests that the average weight of manure produced daily as a function of animal body weight will be 8 percent for dairy cattle, 6 percent for beef cattle, 6 percent for hogs, and 5 percent for laying hens. The application of his estimates is shown in table 13. As noted by Benne et al.[43] and summarized in table 11, one of the principal constituents of animal waste is nitrogen.

Some investigators[35,43] have used population equivalents to estimate the relative contribution of animal waste compared with domestic waste of human origin. Average per capita equivalents for chickens, swine, and cattle as proposed by Loehr[35] are included in table 13. From the tabulated per capita equivalents from table 13 and the 1971 animal population estimates for Illinois given in table 9, it would appear that the animal wastes in Illinois exceed the domestic sewage wastes produced by humans by factors of 3.2:1 on a BOD_5 basis and 6.5:1 on a total dry solids basis. Although the use of population equivalents is a convenient way to relate the strength of livestock waste to that of humans and to characterize the magnitude of the waste, it is not appropriate for use when considering the treatability of wastes from confined livestock operations.

Recently Taiganides and Stronshine[51] suggested the term "Animal Equivalent" (AE) for comparing the impact of animal wastes on the environment. They reasoned that the comparison of animal waste to human waste on the basis of BOD is irrelevant because the water content and the biodegradabi1ity of each are quite different.

Table 10. Volumes and Weights of Animal Manures

Animal (*avg weight in lb*)	Wet manure (feces and urine) Volume (*cu ft/day/head*)	Weight (*lb/day/head*)	Reference
Cattle (1000)		38.5-74.0	38,40,42
Dairy cattle (1200-1400)	1.3-1.6	90-100	7,39,40,41
Beef cattle (950)	1.0		41
Beef cattle (800-1000)	1.2	75	39
Steers, heifers, young stock		50	7,40
Calves		25	7
Horses, ponies	0.9	56	7,39
Hogs (100)		2.8-9.5	38,40
Sows		14	7
Pigs (feeder)		10	7
Swine (150-200)	0.15-0.28	8.5	39,41
Sheep (ewes)		12	7
Sheep (lambs)		8	7
Sheep (100)	0.07-0.11	4	39,44
Poultry (4-5)	0.004-0.006	0.25	39,41
Hens (layers), chicken (hatchery), turkeys (heavy)		0.31	7
Hens (pullets), turkey (broiler)		0.16	7
Chickens (broiler)		0.09	7
Turkey (hatchery)		0.31	7

Table 11. Physical and Chemical Constituents of Animal Manures (Ref. 43)

Animal	Moisture content (%)	Pounds per ton of manure N	P	K	S	Ca	Fe	Mg	VS	Fat
Dairy cattle	79	11.2	2.0	10.0	1.0	5.6	0.08	2.2	322	7
Fattening cattle	80	14.0	4.0	9.0	1.7	2.4	0.08	2.0	395	7
Hog	75	10.0	2.8	7.6	2.7	11.4	0.56	1.6	399	9
Horse	60	13.8	2.0	12.0	1.4	15.7	0.27	2.8	386	6
Sheep	65	28.0	4.2	20.0	1.8	11.7	0.32	3.7	567	14

Table 12. Pollutional Characteristics of Animal Manures
(Pounds per day per head)

Animal (*weight in lb*)	TS	VS	SS	COD	BOD_5	Reference
Dairy cattle (1000-1400)	6.8-16.4	5.7-8.3		5.8-8.4	1.3-2.0	39,44,45
Beef cattle (800-1000)	3.6-9.0	3.2-7.0		3.26	1.0-1.5	39,45,46
Steers, heifers, young stock			0.5-2.0		0.4-1.6	7
Horses, ponies		8.0	1.90		1.4	7,39
Hogs (150)		0.60			0.32	39
Swine (100)	0.5-0.97	0.35-0.80	0.47	0.47-0.96	0.28-0.43	44,47,48,49
Pigs (feeder)			0.34		0.38	7
Sows			0.18		0.41	7
Sheep (100)		0.86			0.25	39
Sheep (ewes)			0.21		0.32	7
Sheep (lambs)			0.11		0.32	7
Poultry (4-5)	0.06-0.07	0.04-0.05		0.50-0.57	0.015	39,44,50
Hens (pullets), turkey (broiler)			0.011		0.013	7
Chicken (broiler)			0.008		0.009	7
Turkey (hatchery)			0.020		0.030	7

Table 13. Average Animal Waste Characteristics (Ref. 35)

	Pounds per animal per day			Per capita equivalent*		
Species	BOD_5	Total dry solids	Total Kjeldahl nitrogen	BOD_5	Total dry solids	Total Kjeldahl nitrogen
Chickens	0.015	0.06	0.003	0.11	0.09	0.11
Swine	0.30	0.90	0.05	1.7	1.7	1.5
Dairy cattle	1.0	10	0.40	8	18	12
Beef cattle	1.0	10	0.30	6	18	9

**The values are determined from the animal waste divided by human waste based on average characteristics in municipal sewage, i.e. 0.17 lb BOD5 per capita per day, 0.55 lb total solids per capita per day, and 0.033 lb total nitrogen per capita per day, and expressed as number of people equivalent to one animal.*

Table 14. BOD_5 Ratio and Water Content of Sewage and Animal Wastes (Ref. 51)

Parameter	Domestic sewage	Animal manure
$BOD_5/BOD_{ultimate}$ (%)	80	40-60
Waste classification	liquid	solid
Water content (%)	99.99	75-80

Table 15. Animal Equivalent (AE) of Livestock Wastes for Various Waste Parameters (Ref. 51)

Basis of comparison	Quantity (*lb/day/AE*)	Number of livestock per AE: Hen	Broiler	Turkey	Steer	Dairy cow	Sheep	Horse	Pork pig
Live weight (*lb*)	1000	4.4	3	12	1000	1500	140	1000	150
Raw manure	46	158.6	232	58.1	1	0.33	9.13	1.04	6.01
Total solids	7.9	106.9	156.7	39.2	1	0.60	5.27	0.45	7.60
Volatile solids	6.5	120.8	177.1	44.3	1	0.61	5.1	0.61	7.58
BOD_5	1.28	81.0	118.6	29.7	1	0.47	9.59	2.44	3.87
COD	7.3	98.9	144.8	36.2	1	0.37	4.32		6.81
N	0.63	144.5	211.9	53.0	1	1.18	10.51	2.08	10.59
P_2O_5	0.095	27.9	40.2	10.2	1	0.65	4.51	0.90	3.65
K	0.142	91.5	134.2	33.5	1	0.64	3.27	0.54	9.81

A brief summary of these differences is given in table 14. They define an AE a's an animal with a live weight of 1000 pounds excreting 46 pounds of manure per day. This is representative of one beef cattle. Suggested animal equivalents for other livestock animals are set forth in table 15.

Feedlot Runoff

Feedlots are now recognized as potential sources of pollution to ground and surface waters, but proper management procedures to minimize their influence on water quality remain uncertain. The handling of runoff from feedlots obviously requires methods differing from that for solid wastes. The quantity and frequency of occurrence of feedlot runoff is dependent upon the hydrology of the region; the quality is governed by animal density, degree of shelter for solid wastes, and the topography of the area.

Studies by Miner et al.[52] showed that the highest concentrations of COD, N, SS, and bacteria densities occurred in feedlot runoff during warm weather after cattle manure had been thoroughly soaked. They also found that runoff from a concrete surfaced lot contained considerably higher concentrations than that from a nonsurfaced lot under similar conditions. There appears to be little satisfaction in either case if groundwater as well as surface water is a consideration. In their studies[52] COD ranged from 2800 to 19,000 mg/l, suspended solids from 1400 to 12,000 mg/1, and ammonia nitrogen from 20 to 140 mg/1 in the runoff from the concrete lots. Average phosphate concentrations were about 50 mg/1 from concrete lots. An empirical formula was derived from the studies in an attempt to estimate COD and Kjeldahl-N concentrations in feedlot runoff. The formula is:

$$C = (k)(1/R)^{1/3}(K_t)(K_m) \qquad (1)$$

where

C = the concentration in mg/l

k = a constant

R = the rainfall rate in inches/hour

K_t = $0.08\ (1.0324)^t$, a temperature correction factor

t = the temperature in °F

K_m = a feedlot moisture correction factor (dry = 0.6; moist = 0.8; and wet = 1.0)

For concrete lots, the values of *k* are 14,000 mg/1 for COD and 500 mg/1 for Kjeldahl-N; for non-surfaced lots, the *k* values are 7000 mg/1 for COD and 300 mg/1 for Kjeldahl-N.[52]

Madden and Dornbush[53] reported that 5 percent of the total waste generated may leave the feedlot in surface runoff, with the remaining being either removed by cleaning operations or decomposed on the feedlot surface. Their evaluation of runoff characteristics from several confined operations are summarized in table 16. Although extreme variations were noted, the cited values are useful in estimating the annual pollution load from similar types of operation.

Table 16. Runoff Carried Waste, South Dakota 1969-1970 (Ref. 53)

Type of operation	Feedlot area (*acre*)	Average slope (%)	Distance from feedlot to sampling location (*ft*)	Average annual precipitation (*inches*)
Commercial beef finishing	11.75	6	150	25.2
Fat lamb finishing	52.68	8-15	500	25.2
Fat lamb finishing	31.20	8-10	300	25.2
Dairy confinement	0.32	4	0	20.4
Animal nutrition-beef	14.9	2	200	20.4
Beef feeding	3.59	3	25	25.2

	Runoff carried waste (*lb/a/yr*)					
	Total Kjeldahl-N	COD	BOD_5	Total PO_4	Total solids	Volatile solids
Commercial beef finishing	982	14,316	3369	298	18,315	9065
Fat lamb finishing	41	643	120	25	1,428	718
Fat lamb finishing	73	1,245	168	31	2,207	991
Dairy confinement	1012	12,770	2428	391	20,678	7552
Animal nutrition-beef	628	8,116	1820	1296	10,942	6620
Beef feeding	89	1,543	522	25	2,743	1375
Mean*	470	6,439	1404	341	9,385	4387

**Mean values do not take into consideration the individual feedlot differences; only general projections should be made from these values*

Swanson et al.[54] found that phosphorus transport is closely related to solids transport which is directly affected by rainfall intensity. Ammonia and nitrate-nitrogen concentrations decreased with continuing precipitation indicating rapid leaching of these compounds from feedlot surfaces. It was observed that runoff recurring several hours after a precipitation event resulted in a higher NH_4-N concentration in the runoff but did not increase the N0,-N concentration. Swanson et al.[54] concluded that runoff from feedlots may contain 75 times the phosphorus

Table 17. Effluent Quality of Anaerobic Lagoons Treating Livestock Wastes (Ref. 35)

Livestock waste	Swine	Poultry	Beef	Beef
Loading rate (*VS/day/10^3 cu ft*)	0.36-3.9	4-11	85	255
pH	6.7-8.0	6.8-7.9	6.5-7.5	6.5-7.5
Total solids (*mg/l*)			4780	5900
Volatile solids (*mg/l*)	850-2330		2870	3710
Volatile acids (*mg/l*)	75-528		120	400
Alkalinity (*mg/l*)	1120-2220		2000	1400
BOD_5 (*mg/l*)		320-1350	1340	1420
COD (*mg/l*)	940-3850	590-2550	4700	5500
Total nitrogen (*mg/l*)		113-290	360	500

Table 18. Effluent Quality of Aerated Processes Treating Livestock Wastes (Ref. 80)

	Treatment process			
Variable	Oxidation ditch	Laboratory	Aerated lagoon*	Aerated lagoon**
Animal waste	swine	swine	swine	beef cattle
BOD_5 (*mg/l*)	10-20	13	60	500-1,000
COD (*mg/l*)	370-570	260	440	10,000-40,000
Ammonia-N (*mg/l*)	13-17	6	40	100-1,000
Nitrate (*mg/l*)		230	3	0-400
Phosphate (*mg/l*)				50-2,500
Chloride (*mg/l*)	425			1,000-3,000

**After solids separation*
***Contents of mixed liquor*

content, 30 times the NH_4-N content, and up to 4 times the NO_3-N content of that in runoff from fallow ground.

Waste Treatment and Disposal

Loehr[35,55] and Taiganides[56] have prepared comprehensive reviews regarding the treatment processes tried for farm animal wastes. Of the numerous processes attempted, researchers have reported on aerobic digestion,[46,57-61] aeration,[57,62,63] aerobic lagoons,[64-67] anerobic lagoons,[56,59,68] composting,[69,70] chemical treatment,[68,71-74] trickling filters,[71,75] and land disposal.[76-83] Generally the treat-

Table 19. Recommended Engineering Design Parameters for Wastes from Animals Reared in Confinement (Ref. 51)

Parameter	Dairy cattle	Beef cattle	Pork pigs	Sheep	Hens*
Raw manure per day (% *live weight*)	9.4	4.6	5.1	3.6	6.6
Total solids (% *wet basis*)	9.3	17.2	13.5	29.7	25.3
Total solids (% *live weight*)	0.89	0.79	0.69	1.07	1.68
Volatile solids (% *TS*)	80.3	82.8	82.4	84.7	72.8
Volatile solids (% *live weight*)	0.72	0.65	0.57	0.91	1.22
BOD (% *TS*)	20.4	16.2	31.8	8.8	21.4
BOD (% *VS*)	25.4	19.6	38.6	10.4	29.4
BOD/COD (%)	13.8	17.4	30.7	7.8	23.2
Nitrogen (% *TS*)	4.0	7.8	5.6	4.0	5.9
P_2O_5 (% *TS*)	1.1	1.2	2.5	1.4	4.6
K (% *TS*)	1.7	1.8	1.4	2.9	2.1

"Values for turkeys assumed identical for purpose of calculation

ment techniques used were those that have been successfully applied to human wastes. Unfortunately, the same degree of success has not been achieved with animal wastes.

This is demonstrated in tables 17 and 18 which suggest the quality of effluents to be expected from anaerobic lagoons and various aerobic processes. Although a considerable reduction is achieved, the high organic residual contained in the effluents, coupled with excessively high nutritional content and often undesirable coloration, keeps them from being satisfactory for discharge to lakes and streams. It is apparent that a new viewpoint is necessary in developing feasible means for handling and treating animal wastes by mechanical or chemical means. In the development of new processes the design parameters suggested by Taiganides and Stronshine[51] in table 19 would seem to be helpful.

Until more sophisticated treatment methods are develop'ed and proved worthy, the controlled use of land as a means of animal waste disposal is the procedure of choice. Land provides a natural treatment system for animal wastes and an effective means to minimize stream pollution. Even in cases where disposal sites are poorly located or managed, or where pastured animals have access to streams, the amount of pollutants that reach stream waters is a very small proportion of the potential contaminants from animal wastes deposited in the watershed.[84] Robbins

Table 20. Yearly Mean Stream Water Quality from Agricultural Land Runoff, North Carolina (Ref. 81)

Variable	Sites F	E	K	P	X	Z
No. of animals (*1000 lb live weight basis*)	0[a]	50[b]	20[c]	42[d]	38[e]	21[f]
Watershed area (*acres*)	75	35	50	65	5	25
Soil type	sandy loams	sandy and fine sand loams	loamy sands	fine sandy loams	sandy loams	sandy loams
Slope (%)	0-25	0-15	0-6	2-10	2-10	0-25
Stream flow (*cfs*)	0.109	0.040	0.047	0.055	0.006	0.020
Study period	12/68-8/69	12/68-8/69	4/69-8/69	6/69-4/70	2/70-4/70	11/69-4/70
FC (10^3 *organisms/100 ml*)	10.0	1.90	37.0	9.6	0.2	30.7
BOD_5 (*mg/l*)	2.0	4.7	6.4	5.2	2.65	9.8
N (*mg/l*)	1.4	3.7	1.7	3.5	62	2.6
PO_4 (*mg/l*)	0.2	1.2	1.9	1.2		1.1

[a]*Free of domestic animal wastes*
[b]*200 sows on 3 acres of dry lots plus wastes from 300 confined hogs spread on 5 acres*
[c]*200 hogs on 6 acres of dry lots*
[d]*60 tons of poultry wastes plus shavings spread on 15 acres, yearly*
[e]*22 tons of poultry wastes spread on 4 acres, once*
[f]*35 beef animals on 15 acres of pasture*

et al.[81] point out that not only is land spreading a very effective way to minimize water pollution from animal wastes but also the added nutrients can be utilized by vegetative cover, which in turn could inhibit erosion and thus result in less enrichment than that from watersheds devoid of farm animal wastes. Their observations of several sites where the land spreading of animal wastes was practiced are included in table 20.

Minshall et al.[82] demonstrated the undesirability of applying fresh, fermented, or liquid manure on frozen ground and the desirability of incorporating it into the soil by mechanical means whenever feasible.

Animal wastes in confined areas are the most significant stream pollution sources in rural areas of the state. The organic loadings, as a pollution potential, probably exceed that of the human population; and these loadings cannot be treated by conventional means. Within current technology the most practical means for controlling, handling, and disposing of animal waste in a manner that will minimize stream pollution involve 1) using a feed ration that will lessen the quantity of waste and improve its treatability, 2) preventing uncontrolled feedlot runoff, 3) providing adequate waste storage facilities, and 4) maintaining a controlled program of waste disposal on the land surface.

REFERENCES

1 Harmeson, R. H., F. W. Sollo, Jr., and T. E. Larson. 1971. *The nitrate situation in Illinois.* Journal of American Water Works Association v. 63(5): 303-310.

2 Harmeson, R. H., and T. E. Larson. 1970. *Existing levels of nitrates in waters—the Illinois situation.* Proceedings of Twelfth Sanitary Engineering Conference, University of Illinois, Urbana, p. 27-39.

3 Aldrich, S. R. 1972. *Supplemental statement regarding plant nutrients.* Illinois Pollution Control Board, 42 p.

4 Aldrich, S. R. 1970. *The influence of cropping patterns, soil management and fertilizer on nitrates.* Proceedings of Twelfth Sanitary Engineering Conference, University of Illinois, Urbana, p. 153-176.

5 Aldrich, S. R. 1972. *Opinion of Illinois Pollution Control Board in the matter of plant nutrients.* Illinois Pollution Control Board, 7 p.

6 Crop Reporting Board. 1972. *Crop production.* U. S. Department of Agriculture, CrPr 2-2 (2-72), release of February 9, 1972, 12 p.

7 *Agricultural pollution of the Great Lakes basin.* 1971. Report by Canada and the United States, U. S. Environmental Protection Agency, Water Quality Office, 178 p.

8 Lee, G. F. 1970. *Eutrophication.* University of Wisconsin, Water Resources Center, Madison, Occasional Paper No. 2, p. 12-13.

9 Sawyer, C. N. 1947. *Fertilization of lakes by agricultural and urban drainage.* Journal of New England Water Works Association v. 61(2):109-127.

10 Sylvester, R. 0. 1961. *Nutrient content of drainage water from forested, urban and agricultural areas.* *In* Algae and Metropolitan Wastes, Transactions of the 1960 Seminar, Robert A. Taft Sanitary Engineering Center Technical Report W6l-3:80-87.

11 Harmeson, R. H. 1971. *Nitrate concentrations and nitrate-nitrogen loads in Illinois surface waters: status and trends.* Testimony at Illinois Pollution Control Board Hearing, Urbana, Illinois, 12 p.

12 Johnston, W. R., F. Ittihadieh, R. M. Daum, and A. F. Pillsbury. 1965. *Nitrogen and phosphorus in tile drainage effluent.* Soil Science v. 29:287.

13 Minshall, N., M. S. Nichols, and S. A. Witzel. 1969. *Plant nutrients in base flow of streams in southwestern Wisconsin.* Water Resources Research v. 5(3): 706-713.

14 Weibel, S. R., R. B. Weidner, J. M. Cohen, and A. G. Christianson. 1966. *Pesticides and other contaminants in rainfall and runoff.* Journal of American Water Works Association v. 58(8):1075-1084.

15 Viets, F. G. 1971. *Water quality in relation to farm use of fertilizer.* Bioscience v. 21(10):46O-467.

16 Illinois Department of Agriculture. 1971. *Illinois commercial fertilizer tonnage report July-December 1970.* Springfield, 90 p.

17 Illinois Department of Agriculture. 1972. *Illinois commercial fertilizer tonnage report January-June 1971.* Springfield, 129 p.

18 Illinois Conservation Needs Committee. 1970. *Illinois soil and water conservation inventory.* University of Illinois, Urbana, 192 p.

19 Sridharan, N., and G. F. Lee. 1972. *The role of sediments in controlling phosphorus concentrations in lower Green Bay, Lake Michigan.* Presented at the 15th Conference on Great Lakes Research, April 5-7, Madison, Wisconsin.

20 Missingham, G. A. 1967. *Occurrence of phosphates in surface waters and some related problems.* Journal of American Water Works Association v. 59(2): 183-211.

21 Engelbrecht, R. S., and J. J. Morgan. 1959. *Studies on the occurrence and degradation of condensed phosphate in surface water.* Sewage and Industrial Wastes v. 31(4):458-478.

22 Task Group Report 261OP. 1967. *Source of nitrogen and phosphorus in water supplies.* Journal of American Water Works Association v. 59(3):344-366.

23 Engelbrecht, R. S., and J. J. Morgan. 1966. *Land drainage as a source of phosphorus. In* Algae and Metropolitan Wastes, Transactions of the 1960 Seminar, Robert A. Taft Sanitary Engineering Center Technical Report **W6l**-3:74-79.

24 Barthel, W. F., J. C. Hawthorne, J. H. Ford, G. C. Bolton, L. L. McDowell, E. H. Grissinger, and D. A. Parsons. 1969. *Pesticides in water, pesticide residuals in sediments of lower Mississippi River and its tributaries.* Pesticides Monitoring Journal v. 3(1):8—66.

25 Swoboda, A. R., G. W. Thomas, F. B. Cady, R. W. Baird, and W. G. Kinsel. 1971. *Distribution of DDT and Toxaphene in Houston Black clay on three watersheds.* Environmental Science 6 Technology v. 5(2):141-145.

26 Hann, C. T. 1971. *Movement of pesticides by runoff and erosion.* Transactions of American Society of Agricultural Engineers, paper 70-706, v. 11(4):445-449.

27 Brown, E., and Y. A. Nishioka. 1967. *Pesticides in selected western streams—a contribution to the national program.* Pesticides Monitoring Journal v. l(2):38-46.

28 Marston, R. B., D. W. Schults, T. Shiroyama, and L. V. Snyder. 1968. *Amitrol concentrations in creek waters downstream from an aerially sprayed watershed sub-basin.* Pesticides Monitoring Journal v. 2(3):123-128.

29 Marston, R. B., R. M. Tyo, and S. C. Middendorff. 1969. *Endrin in water from treated Douglas fir seed.* Pesticides Monitoring Journal v. 2(4):167-171.

30 Guerrant, G. 0., L. E. Fetzer, Jr., and J. W. Miles. 1970. *Pesticide residues in Hale County, Texas, before and after ultra-low volume aerial application of malathion.* Pesticide Monitoring Journal v. 4(1): 14-19.

31 Lichtenberg, J., J. W. Eichelberger, R. C. Dressman, and J. E. Longbottom. 1970. *Pesticides in surface waters of the U. S., a 5-year summary, 1964-1968.* Pesticides Monitoring Journal v. 4(2):71~86.

32 Johnson, L. G., and R. L. Morris. 1971. *Chlorinated hydrocarbon pesticides in Iowa rivers.* Pesticides Monitoring Journal v. 4(4):**216-21**9.

33 *Pesticide levels in fish from Iowa streams.* 1970. A Report from the State Hygienic Laboratory, University of Iowa, Iowa City, 6 p.

34 *Illinois soil and water conservation needs inventory.* 1970. University of Illinois College of Agriculture Cooperative Extension Service, Urbana, 192 p.

35 Loehr, R. C. 1969. *Animal wastes—a national problem.* American Society of Civil Engineers Journal of the Sanitary Engineering Division v. 95(SA2):189-221.

36 Loehr, R. C. 1970. *Control of nitrogen from animal wastewaters.* Proceedings of Twelfth Sanitary Engineering Conference, University of Illinois, Urbana, p. 177-186.

37 U. S. Department of Agriculture. 1971. *Agricultural statistics, 1971.* U. S. Government Printing Office, Washington, D. C, p. 306, 332, 344, 411, and 425.

38 Taiganides, E. P., and T. E. Hazen. 1966. *Properties of farm animal excreta.* Transactions American Society of Agricultural Engineers v. 9(3):374-376.

39 Fogg, C. E. 1971. *Livestock waste management and the conservation plan.* Proceedings International Symposium on Livestock Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan, p. 34-35.

40 Morris, W. H. M. 1971. *Economics of waste disposal from confined livestock.* Proceedings International Symposium on Livestock Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan, p. 195-196.

41 Hart, S. A. 1960. *The management of livestock manure.* Transactions of American Society of Agricultural Engineers v. **3(2)**:**78-8O**.

42 Hegg, R. 0., and R. E. Larson. 1971. *The waste pattern of beef cattle on slatted floors.* Proceedings International Symposium on Livestock Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan, p. 70-72.

43 Benne, E. J., C. R. Hog land, E. D. Longnecker, and R. L. Cook. 1961. *Animal manures—what are they worth today?* Michigan State University Agricultural Experiment Station, E. Lansing, Bulletin 231.

44 Hart, S. A., and M. E. Turner. 1965. *Lagoons for livestock manure.* Journal of Water Pollution Control Federation v. 37(11):1578-1596.

45 Witzel, S. A., E. McCoy, L. B. Polkowski, 0. J. Attoe, and M. S. Nichols. 1966. *Physical, chemical, and bacteriological properties of farm wastes (bovine animals)* . Proceedings National Symposium on Animal Waste Management, American Society of Agricultural Engineers, p. 10-14.

46 Loehr, R. C, and R. W. Agnew. 1967. *Cattle wastes—pollution and potential treatment.* American Society of Civil Engineers Journal of Sanitary Engineering Division v. 93(SA4):72-91.

47 Okey, R. W., and S. Balakrishnan. 1971. *The economics of swine waste disposal.* Proceedings International Symposium on Livestock Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan, p. 199-203.

48 Taiganides, E. P., T. E. Hazen, E. R. Baumann, and D. Johnson. 1964. *Properties and pumping characteristics of hog wastes.* Transactions American Society of Agricultural Engineers v. 7(2) : 123-124.

49 Clark, C. E. 1965. *Hog waste disposal by lagooning.* American Society of Civil Engineers Journal of Sanitary Engineering Division v. 91(SA6):27~4l.

50 Dornbush, J. N., and J. R. Anderson. 1964. *Lagooning of livestock in South Dakota.* Proceedings of 19th Industrial Waste Conference, Purdue University, Lafayette, Indiana, p. 317-325.

51 Taiganides, E. P., and R. L. Stronshine. 1971 - *Impact of farm animal production and processing on the total environment.* Proceedings International Symposium on Livestock Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan, p. 95-98.

52 Miner, J. R., R. I. Lipper, L. R. Fina, and J. W. Funk. 1966. *Cattle feedlot runoff—its nature and variation.* Journal of Water Pollution Control Federation v. **38(10):1582-1591.**

53 Madden, J. M., and J. N. Dornbush. 1971. *Measurement of runoff and runoff carried waste from commercial feedlots.* Proceedings International Symposium on Livestock Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan, p. 44-47.

54 Swanson, N. P., L. N. Mielke, J. C. Lorimore, T. M. McCalla, and J. R. Ellis. 1971. *Transport of pollutions from sloping cattle feedlots as affected by rainfall intensity, duration, and recurrence.* Proceedings International Symposium on Livestock Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan, p. 51-55.

55 Loehr, R. C. 1971. *Alternatives for the treatment and disposal of animal wastes.* Journal of Water Pollution Control Federation v. 43(4):668-678.

56 Taiganides, E. P. 1969. *Mission impossible: dispose of animal wastes.* Proceedings of 24th Industrial Waste Conference, Purdue University, Lafayette, Indiana, p. 542-549.

57 Jeffrey, E. A., W. C. Blackman, and R. L. Ricketts. 1963. *Aerobic and anaerobic digestion characteristics of livestock wastes.* University of Missouri Engineering Series Bulletin 57.

58 Hart, S. A. 1963. *Digestion tests of livestock wastes.* Journal of Water Pollution Control Federation v. 35(6):748-757.

59 Agnew, R. C, and R. C. Loehr. 1966. *Cattle-manure treatment techniques.* Proceedings National Symposium on Animal Waste Management, American Society of Agricultural Engineers, p. 81-84.

60 Cassell, E. A., and A. Anthonisen. 1966. *Studies on chicken manure disposal: Part I, laboratory studies.* New York State Department of Health Research Report 12.

61 Johnson, C. A. 1965. *Disposal of dairy manure.* Transactions American Society of Agricultural Engineers v. 8(1):110-112.

62 Dale, A. C, and D. L. Day. 1966. *Some aerobic decomposition properties of dairy cattle manure.* Presented at the American Society of Agricultural Engineers Winter Meeting, Chicago, Illinois.

63 Irgens, R. L., and D. L. Day. 1966. *Laboratory studies of aerobic stabilization of swine wastes.* Journal of Engineering Research v. 11:1-10.

64 Forsyth, R. J. 1965. *The collection of manure from housed livestock.* Journal and Proceedings of the Institute of Agricultural Engineers v. 21:124-134.

65 Kountz, R. R., and N. H. Wooding. 1963. *Lagoons for the disposal of farm wastes.* Presented at the Animal Waste Meeting, North Atlantic Section, American Society of Agricultural Engineers, Orono, Maine.

66 Converse, J. C, G. L. Pratt, R. L. Wetz, R. G. Butler, and J. L. Parsons. 1966. *The effect of low volume and high volume aeration in a hog lagoon.* Presented at the American Society of Agricultural Engineers Winter Meeting, Chicago, Illinois.

67 Smith, R. J., T. E. Hazen, and J. R. Miner. 1971. *Manure management in a 700-head swine-finishing building; two approaches using renovated waste water.* Proceedings International Symposium on Livestock Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan, p. 149-153.

68 Nordstedt, R. A., L. B. Baldwin, and C. C. Hortenstine. 1971. *Multistage lagoon systems for treatment of dairy farm waste.* Proceedings International Symposium on Livestock Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan, p. 77-80.

69 Wells, D. M., R. C. Albin, W. Crub, and R. Z. Wheaton. 1969. *Aerobic decomposition of solids wastes from cattle feedlots.* Proceedings of the Cornell University Conference on Agricultural Waste Management, Syracuse, New York, January 13-15, p. 58-62.

70 Willson, G. B. 1971. *Composting dairy cow wastes.* Proceedings International Symposium on Livestock Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan, p. 163-165.

71 Painter, H. A. 1957. *Treatment of wastewaters from farm premises.* Water and Sanitary Engineering and Waste Treatment Journal, March-April.

72 Hammond, W. C, D. L. Day, and E. L. Hanson. 1966. *Treatment of liquid hog manure to suppress odors.* Presented at the American Society of Agricultural Engineers Winter Meeting, Chicago, Illinois.

73 Gates, C. D. 1959. *Treatment of Long Island duck farm wastes.* New York State Water Pollution Control Board Research Report 4.

74 Diebel, R. H., and A. T. Sobel. 1966. *Chlorination of duck waters.* Unpublished data, Department of Agricultural Engineering, Cornell University, Ithaca, New York.

75 Wheatland, A. B., and B. J. Borne. 1964. *Treatment of farm effluents.* Chemistry and Industry, February 29, No. 9, p. 357-362.

76 Webber, L. R., and T. H. Lane. 1969. *The nitrogen problem in the land disposal of liquid manure.* Proceedings of the Cornell University Conference on Agricultural Waste Management, Syracuse, New York, January 13-15, p. 124-130.

77 Dague, R. R. 1970. *Alternatives in cattle feedlot waste management.* Proceedings of the 25th Industrial Waste Conference, Purdue University, Lafayette, Indiana, p. 258-265.

78 Hart, S. A. 1964. *Thin spreading of slurried manures.* Transactions American Society of Agricultural Engineers, v. 7(1):22-25.

79 *How we handle liquid manure.* 1964. Hoards Dairyman v. 109(22):1254-1255,1280-1281.

80 Loehr, R. C. 1968. *Technical and legal controls for the disposal of animal wastes.* Proceedings of the 23rd Industrial Waste Conference, Purdue University, Lafayette, Indiana, p. 507-519.

81 Robbins, J. W. D., G. J. Kriz, and D. H. Howells. 1971. *Quality of effluent from farm animal production sites.* Proceedings International Symposium on Livestock Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan, p. 166-169.

82 Minshall, N. E., S. A. Witzel, and M. S. Nichols. 1970. *Stream enrichment from farm operations.* American Society of Civil Engineers Journal of the Sanitary Engineering Division v. 96(SA2):513-524.

83 McCaskey, T. A., G. H. Rollins, and J. A. Little. 1971. *Water quality of runoff from grassland applied with liquid, semi-liquid, and 'dry' dairy waste.* Proceedings International Symposium on Livestock Wastes, American Society of Agricultural Engineers, St. Joseph, Michigan, p. 239-242.

84 Department of Biological and Agricultural Engineering, North Carolina State University at Raleigh. 1971. *Role of animal wastes in agricultural land runoff.* U. S. Environmental Protection Agency, Water Pollution Control Research Series 13020 DGX 08/71, 115 p.