Generic Environmental Impact Statement on Animal Agriculture:

Final Technical Workpaper (TWP) Related to The Effects of Animal Agriculture on

Water Quality

Prepared for the Environmental Quality Board

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Technical Work Paper

Impacts of Animal Agriculture on Water Quality

by

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Executive Summary

Description of Animal Agriculture in Selected Minnesota Counties

Numbers of Feedlots

We studied 11,468 feedlots in eighteen counties located in southern, central, southeastern, and southwestern Minnesota. Animal units in these 11,468 feedlots are primarily hogs (50.4%), dairy cattle (18.9%), beef cattle (16.5% by A.U.s), chickens (4.1%), and turkeys (4.6%).

Size Distribution of Feedlots

Feedlot size distributions are typically described in terms of the proportions of feedlots that contain a tiny number (1-49) of animal units, those that contain a very small number (50-99) of A.U.s, those with a small number (100-299) of A.U.s, those with a moderate number (300-999) of A.U.s, and those with a large number (>1000) of A.U.s.

The average size distribution for feedlots (by animal units averaged across animal species) in the eighteen counties studied shows that 25% are tiny feedlots, 21% are very small feedlots, 35% are small sized feedlots, 16% are moderate feedlots, and 2% are large feedlots.

The average size of feedlots (by animal units) was evaluated by animal species. In general, the number of animal units per feedlot tends to decrease according to the order:

> Turkeys (moderate) > chickens (moderate) > hogs (small & moderate) >
> dairy (small and v. small) > beef (tiny, small, v. small)

Non-Compliance with Minnesota Feedlot Rules

Roughly 15% of the feedlots in the study area were out of compliance with Minnesota Feedlot Rules (MDA, 2001). The non-compliant feedlots required either runoff controls, storage basin upgrades, or both types of correction to reduce environmental pollution. A majority of the non-compliant feedlots (47%) were for beef cattle, while 27% and 22% of the non-compliant feedlots were dairy and hog feedlots, respectively. Poultry operations accounted for only 2% of the non-compliant feedlots.

Non-compliance in beef feedlots commonly arose from very small partially housed feedlots without runoff controls, open lots, earthen basins, and stockpiling without protective structures. In dairy feedlots, non-compliance was from small partially housed feedlots without runoff controls and earthen basins. With hogs, non-compliance was from small feedlots with partial housing and no runoff controls and earthen basins. Very few instances of non-compliance were observed for moderate or large sized feedlots.

Feedlot Confinement Types

A wide range of feedlot confinement types are used in Minnesota feedlots. Common types include total confinement, partial housing without runoff controls, partial housing with runoff controls, open lot without runoff controls, open lot with runoff controls, and pasture. The risks of polluting surface water due to animal confinement types typically decrease in the order:

Open lot without runoff controls > partial housing without runoff controls >
open lot with runoff controls > partial housing with runoff controls > total confinement

The relative risk for barnyard pollution of surface water (based only on confinement types and assuming all other factors are equal) typically decreases in the order:

Beef > dairy > hogs > chickens = turkeys

Animals listed on the left side of the above ranking have a greater tendency towards partial housing without runoff controls or open lots, while animals on the right have a greater tendency for total confinement.

Feedlot Storage Types

The risk of polluting surface or ground waters by liquid storage techniques decreases as:
Earthen holding basins > concrete block/pits > poured concrete tanks > above ground tanks

The risk of polluting surface waters by solid manure storage techniques decreases in the order:
Daily hauling (no storage) > stockpiling > solid stacking slabs > manure pack in buildings

The risk for polluting surface water based on storage type tends to be greatest from solid manure with smaller sized feedlots rather than larger sized feedlots. Smaller feedlots tend to have a greater likelihood of having daily haul or stockpiling without protective cover. The risk for polluting ground water based on storage type tends to be greatest from liquid manure with larger sized feedlots rather than smaller feedlots. Larger feedlots tend to use earthen storage basins for liquid manure more than smaller feedlots.

Based on the information presented on manure storage systems only, and assuming all other factors are equal, the risk of surface or ground water pollution from feedlots decreases as:

Dairy > beef > hogs > chickens > turkeys

The risk for polluting surface water due to storage of solid manure tends to be greatest with smaller sized feedlots rather than larger sized feedlots. Smaller feedlots tend to have a greater likelihood of having daily haul or stockpiling without protective cover. The risk for polluting ground water due to storage of liquid manure tends to be greatest with larger sized feedlots rather than smaller feedlots. Larger feedlots tend to use earthen storage basins for liquid manure more than smaller feedlots.

Manure Land Application Techniques

Animal manure may be applied to land by broadcasting, injection, irrigation, or broadcasting with incorporation. As the size of an animal feedlot increases, the application methods tend to shift from broadcasting to injection or to broadcasting with incorporation. This trend is more pronounced for hog feedlots than for beef and dairy feedlots. Poultry feedlots rarely use injection or incorporation of manure, rather relying on spreading.

Based on manure application type and manure storage type (especially daily haul operations), and assuming all other factors (such as rate of application and numbers of feedlots) are equal, the risk of polluting surface water from land applied manure decreases in the order:

Daily haul > Non-daily haul broadcast > broadcast + incorporation > injection

Broadcast application of manure is used in over 90% of the turkey and chicken operations, 89% of the dairy operations, 84% of the beef operations, and 65% of the hog operations. Broadcasting and incorporation of manure (as a separate category from just broadcasting) is practiced in 6-7% of the poultry operations, 7% of the dairy operations, 12% of the beef operations, and 18% of the hog operations. Injection of manure is used in 3% of the chicken operations, 4% of the dairy operations, 3% of the beef operations, and 17% of the hog operations.

Rate of manure application has a strong effect on surface and ground water quality. Applying manure at agronomically reasonable N and P rates helps reduce the potential for water pollution. The best method for determining rates involves:

Accurate crop yield goal, Estimate of crop P requirements, Accurate manure P analysis

The worst method for determining rates involves:

No consideration of crop nutrient needs, No manure nutrient analysis

Timing is also very important. The risk of causing water pollution from land applied manure decreases in the order:

Winter > Late summer > Late Fall > Early Summer > Spring pre-plant

Animal Concentrations

Land Area Available for Application of Manure

Except for turkeys, the land available for application of manure was found to increase linearly with the size (in A.U.s) of feedlots. Knowledge of the land available for manure application is crucial information that affects the rates of manure nutrients applied to land. For feedlots with equal numbers of animals and similar management practices, those with less land for manure spreading will have to apply higher rates, resulting in potential application of excess nutrients to the land.

Animal Number Densities

Densities of animals relative to land available for spreading of manure varied considerably across animal species. Figures for turkeys are less certain than those for other animal species due to uncertainties about the land available for spreading of manure. Animal densities (animals/ac) decreased in the order:

Chickens (110) > turkeys (50) > hogs (1.1) > beef (0.3) > dairy (0.4)

In Europe, maximum allowed animal densities are 53.8, 40.5, 6.5, 1.6, and 0.8 animals/ac for chickens, turkeys, hogs, beef cows, and dairy cows, respectively. In Minnesota, chickens and hogs exceed European animal density limits with the greatest frequency. European limits may, however, not be appropriate for Minnesota.

Excess Nutrients Applied to Land

Manure Nutrient Application Rates

Estimates of the average long-term application rates of manure N and P_2O_5 varied by animal species. Rates for turkeys could be inflated due to uncertainty about the area of land available for spreading manure. Rates decreased in the order:

	Turkeys	>	chickens	>	hogs	>	dairy	>	beef
Rate of N (lb/ac):	51	>	46	>	14	>	13	>	3
Rate of P_2O_5 (lb/ac):	139	>	130	>	29	>	26	>	9

FANMAP surveys conducted by the MDA (MDA, 1998) showed that application of excess nitrogen to manured cropland from manure and fertilizer was widespread. University of Minnesota fertilizer recommendations for unmanured lands are typically 110-120 lb N/ac and 50 lb P_2O_5/ac for a corn-soybean rotation. The excess N applied to manured corn from both manure and fertilizer was 54 lb/ac in south central Minnesota, 43 lb/ac in Scott and Carver counties, 23 lb/ac in Lincoln and Pipestone counties, 41 lb/ac in southeastern Minnesota, and 38 lb/ac in central Minnesota.

Availability of Cropland for Land Application of Manure

Ratios of manured land to cropland were estimated in minor watersheds of the study area. Counties with limited additional cropland (<15% remaining) for manure application and low rates of manure N and P application include Rice, Winona, and E. Stearns. Small proportions of counties with limited additional cropland for manure application and high rates of manure N and P application include W. Stearns, E. Morrison, Blue Earth, Martin, Pipestone, Rock, Brown, Nicollet, and Sibley counties. Additional expansion of animal agriculture in portions of these latter counties may be risky from the point of view of water quality.

Impacts of Land Applied Nutrients on Water Quality

Proximity of Feedlots to Streams and Ditches

Density and size of feedlots in close proximity to streams and ditches were evaluated. These two parameters affect the potential for transport of phosphorus from manure to surface water bodies. Counties with dense numbers of very small to moderate sized feedlots near waterbodies include Winona (dairy), Dodge (hogs and dairy), Pipestone (hogs and beef) and Rock (hogs and beef). A moderate density of very small to tiny feedlots occurs in Todd (dairy) and E. Rice (hogs, dairy, beef) counties. A moderate density of small feedlots occurs in W. Stearns (dairy), E. Morrison (dairy), and Jackson (hogs) counties.

Based on proximity to streams, feedlot size distributions, and amount of manure generated, we can identify the feedlots most likely to pose a threat to surface water quality by being out of compliance with Minnesota Feedlot Rules. In central and southeastern Minnesota, the small to moderate sized dairy feedlots pose the greatest threat to surface water quality. In southern and southwestern Minnesota, small to moderate sized hog feedlots pose the greatest threat to surface water quality.

Relative Contributions of Manure and Fertilizer Nutrients Applied to Cropland

Based on the ratios of manure N and P relative to total N and P applied to cropland from manure and fertilizer, manure contributes about 14% of the N applied cropland. Manure contributes about 53% of the P applied to cropland in the eighteen counties studied. These results also mean that fertilizer contributes about 86% of the N applied to cropland, and 47% of the P applied to cropland. Counties of most concern for producing non-point source N pollution from excess manure or fertilizer include Blue Earth, Stearns, Martin, Watonwan, Brown, Rice, and Pipestone. Counties of most concern for producing non-point source P pollution from excess manure or fertilizer include Stearns, Martin, Morrison, Pipestone, Nicollet, and Brown. These contributions do not account for the effect on surface water of spills and runoff from feedlots, or for the effect on ground water of leaching from feedlot storage basins.

Amounts of N and P Applied to Land by Animal Species and Feedlot Size

The total amount of N and P_2O_5 applied to land from manure varies by animal species. Almost 48% of the N and 43% of the P_2O_5 applied to land is generated by hogs. Dairy cattle account for 24% of the N and 21% of the P_2O_5. Turkeys generate 12% of the N and 14% of the P_2O_5. About 9% of the N and 12% of the P_2O_5 is generated by beef cattle. Chickens generate roughly 7% of the N and 9% of the P_2O_5 applied in manure to the land.

The amount of manure nutrients applied to land from feedlots varies by size and animal species. Much (about 40%) of the manure nutrients applied to land arise from moderate sized feedlots. Small and large sized feedlots account for another 25% each of the manure nutrients applied to land.

Excess Nutrients Applied to Land from Manure and Fertilizer

In the seventeen county study area (excluding Scott county), 166,633 tons N/yr and 54,871 tons P_2O_5/yr were applied to cropland from fertilizer. Manure applied to land contributed another 27,765 tons N/yr and 62,085 tons P_2O_5/yr. The University of Minnesota recommended nutrient amounts were 164,526 tons N/yr and 67,398 tons P_2O_5/yr. These figures give 29,871 tons N/yr and 49,560 tons P_2O_5/yr of nutrients applied to land in excess of crop fertilizer recommendations. For the seventeen counties studied, excess nutrients applied to cropland are 18% and 74% of the recommended amounts of N and P_2O_5, respectively, which should be applied to cropland based on University recommendations. This means that nutrients applied to the land from both fertilizer and manure are 18% greater than the N recommendations and 74% greater than the P_2O_5 recommendations. This translates into an excess of 19 lb N/ac and 35 lb P_2O_5/ac.

Of the excess N applied to cropland, about 14% is from manure, while 86% is from fertilizer. Of the excess P which is applied to cropland, about 53% is from manure, while 47% is from fertilizer. Thus, controlling nutrients in surface and ground waters is not merely a matter of adjusting amounts of land applied manure. It is also a matter of making sure that the total amount of nutrients applied to the land from both manure and fertilizer is compatible with crop uptake requirements.

Impacts of Runoff, Seepage, and Spills on Water Quality

Manure spills and runoff or seepage from non-compliant feedlots can have disastrous local effects on water quality. Their effect on regional water quality is, however, negligible. For example, twenty manure spills would discharge 29 tons of N and 20 tons of P_2O_5. In comparison the Minnesota River carries 55,423 tons of nitrate-N/yr and 1,492 tons P/yr. Also, non-compliant feedlots produced 265 tons of N and 573 tons of P_2O_5. This is small in comparison with 27,753 tons of N and 62,077 tons of P_2O_5 applied to cropland from manure.

Policy Summary

The 18 counties studied represent the four regions in Minnesota where most of the animal production occurs. The data collected tends to be more strongly oriented towards larger feedlots than are found in all of Minnesota feedlots.

One of the most difficult policy issues concerns the relative impacts on water quality of runoff and seepage versus the impacts of land applied manure versus the impacts of catastrophic spills. Roughly 15% of all feedlots studied were out of compliance with Minnesota Feedlot Rules, primarily because of risks for runoff and seepage. Non-compliant feedlots produced 265 tons of N and 573 tons of P_2O_5, of which probably less than 5% would ever be lost in runoff or seepage. This is in comparison to 27,765 tons N/yr and 62,085 tons P_2O_5/yr applied to cropland from manure. Thus, we can quickly observe that the magnitude of N and P_2O_5 applied to the land dwarf the amount potentially available to impact surface or ground waters due to non-compliant feedlots. Similarly, if we assume that there are 20 catastrophic manure spills per year in the study area (18 from hog and 2 from dairy operations), and each spill averages 50,000 gallons, the total amount of N or P_2O_5 lost to surface waters would be only 29 tons or 20 tons, respectively. Of course, these spills are both illegal and sensational, and they kill many fish. Their impact on regional water quality patterns is, however, dwarfed by the impact of land applied manure. Thus, from a policy perspective, the primary water quality impact of animal manure is from land applied manure. Non-compliant feedlot runoff or seepage, and illegal spills have a negligible overall impact on regional water quality patterns. Without considering this, there is the real potential that the federal, state, and local governments will spend millions of dollars fixing non-compliant feedlots, without the prospect of making much difference in regional water quality problems.

Another important policy issue concerns the relative impacts on water quality of land applied manure versus land applied fertilizer. The answer varies for the four broad regions studied. Fertilizer N dominates manure N in terms of water quality impacts for south central Minnesota and for southeastern Minnesota. Manure N dominates fertilizer N for southwestern Minnesota and central Minnesota. For phosphorus, fertilizer P and manure P impacts are roughly equivalent in south central Minnesota, while manure P dominates fertilizer P in southwestern, southeastern, and especially central Minnesota. Thus, policy efforts to reduce nitrate levels in surface and ground waters should focus on fertilizer in south central and southeastern Minnesota, and on manure in southwestern and central Minnesota. For fertilizer N, it is important to follow University of Minnesota nutrient guidelines relating to establishment of a reasonable yield goal, and to take proper credits for N from legumes and applied manure. Policy efforts to reduce phosphorus levels in surface waters should focus on a broad spectrum of actions, including use of the phosphorus index, changes to animal feed P contents, greater adoption of crop P based application rates when applying manure to alfalfa and soybeans, and reductions in fertilizer or manure P applications by following nutrient guidelines and soil testing procedures established by the University of Minnesota.

In this study we found that 90% of the manure nutrients applied to land originated from operations with greater than 100 A.U.s. Nutrient management planning tools such as the phosphorus index, manure application planner, and the University of Minnesota fertilizer guidelines should be promoted with this size group of feedlots. Practices which have a large risk for degrading water quality include manure applications using uncalibrated spreading equipment, applying manure without good records of locations where manure was previously spread, applying manure to steep fields in winter, applying manure with no regard for crop nutrient requirements or manure nutrient content, applying manure in close proximity to water bodies, applying fertilizer without following University of Minnesota guidelines, using animal feeding techniques which result in excess nutrient levels in manure, and inadequate control of soil erosion.

At present, we have shown in this study that nutrients from manure and fertilizer are applied in excess of crop needs for the four regions studied. As discussed above, there are several management options available to reduce excess nutrients applied to land from manure and fertilizer. From the perspective of land use planning and permitting, there is also the option of placing limits on the density of animals within a minor watershed. This can be achieved through existing mechanisms using the permitting process, although the permitting process only considers the combined effects of manure and fertilizer applications indirectly when evaluating the amount of land needed for spreading of manure.

An alternative approach to controlling excess land applied nutrients could be developed which is based on limits for animal unit densities per acre of watershed area. We found that there was an excellent linear relationship between animal unit density per acre of watershed area and the amount of excess nitrogen or phosphorus applied to land from manure and fertilizers. The slope and intercept of these linear relationships varied, depending upon the relative importance of fertilizer or manure contributing to the excess nutrients. An analysis of the 274 minor watersheds studied showed that from 12-44% of these watersheds have too many animals if a limit of 0.5 A.U. per acre of watershed area were established. With a limit of 1.0 A.U. per acre, from 1-8% of the watersheds have too many animals. The areas most affected by such limits are in southwestern and south central Minnesota.

As an example of this approach, is animal unit densities were limited to 1.0 A.U. per acre of watershed area, and the watershed area was 10,000 acres, then a total of 1,000,000 chickens, or 30,000 hogs, or 10,000 cattle, or 7,142 dairy cattle would be allowed in the watershed. If an application for expansion or establishment of a new feedlot were received, and the total number of A.U.s in the watershed after the change would exceed the animal density limit of 10,000 A.U.s, then the application could be denied.

Disadvantages of a fixed animal unit density include regional differences in crop types, soils, and management techniques. The use of a fixed limit assumes no improvements in management as discussed on the previous page. Also, the selection of a limiting animal unit density is arbitrary, the linear relationships between animal unit density and excess nutrients applies to land are perfectly linear, without changes in slope that would indicate a significant increase in environmental pollution at a critical animal unit density. Thus, animal density limits as a policy tool have significant disadvantages.

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Impacts of Animal Agriculture on Water Quality

Description of Animal Agriculture in Selected Minnesota Counties

A. Numbers of feedlots

Feedlot inventories were obtained from four geographic regions of Minnesota encompassing eighteen counties (Fig. 1). The first geographic region is southeastern Minnesota, including the counties of Scott, Dodge, Rice and Winona. The second region is central Minnesota, including the counties of Stearns, Todd, and Morrison. The third region is southwestern Minnesota, including Pipestone and Rock counties. The fourth region is south central Minnesota, including the counties of Blue Earth, Brown, Faribault, Freeborn, Jackson, Martin, Nicollet, Sibley, and Watonwan.

The feedlot inventory identifies 11,468 feedlots in the eighteen counties studied, compared to roughly 38,000 feedlots statewide. The four counties in southeastern Minnesota had 2,959 feedlots. The three counties in central Minnesota had 2,880 feedlots. The two counties in southwestern Minnesota had 1,140 feedlots. The remaining nine counties in south central Minnesota had 4,489 feedlots.

Animal units in these 11,468 feedlots (Table 1) are primarily hogs (50.4%), dairy cattle (18.9%), beef cattle (16.5% by A.U.s), chickens (4.1%), and turkeys (4.6%). Counties studied in southwestern Minnesota are dominated by hogs (54%) and beef cattle (36%). Blue Earth, Faribault, Jackson, and Martin counties are quite similar to one another, in that 75-86% of all animal units are hogs, with an additional 9-18% in beef cattle. The other regions are not so simply characterized. Todd and Morrison counties are quite heterogeneous, with from 30-40% dairy cattle, 23-25% chickens, and 11-26% being mixed animal operations. Stearns and Winona counties are also very heterogeneous, having from 48-64% dairy cattle, 16-17% beef cattle, 5-18% chickens and turkeys, and 3-14% hogs. Nicollet and Dodge counties have from 51-62% hogs, 13-18% dairy cattle, 9-10% beef cattle, and 10-15% turkeys, while Brown and Freeborn counties have from 62-76% hogs, 10-15% beef cattle, 9-13% dairy cattle, and from 4-7% chickens and turkeys. Rice, Sibley, and Scott counties have from 37-48% hogs, from 22-28% dairy cattle, and from 12-23% beef cattle. Finally, Watonwan has 55% beef cattle, 15% hogs, 20% dairy cattle and calves, and 8% turkeys.

Based on the above characteristics, we can conclude that there are eight types of animal unit (A.U.) distributions within the counties studied. There is a group dominated by hogs (Blue Earth, Faribault, Jackson, and Martin); a group dominated by dairy cattle (Stearns and Winona); a group dominated by beef cattle (Watonwan); a group rather evenly split between hogs and beef cattle (Pipestone and Rock); a group with roughly equal proportions of hogs versus dairy plus beef cattle (Rice, Sibley, and Scott); a group with nearly equal proportions of dairy cattle and chickens (Todd and Morrison); a group with roughly half hogs and small but similar proportions of dairy, beef, and poultry (Nicollet and Dodge); and a group with two-thirds hogs and small but similar proportions of beef, dairy, and poultry (Brown and Freeborn).

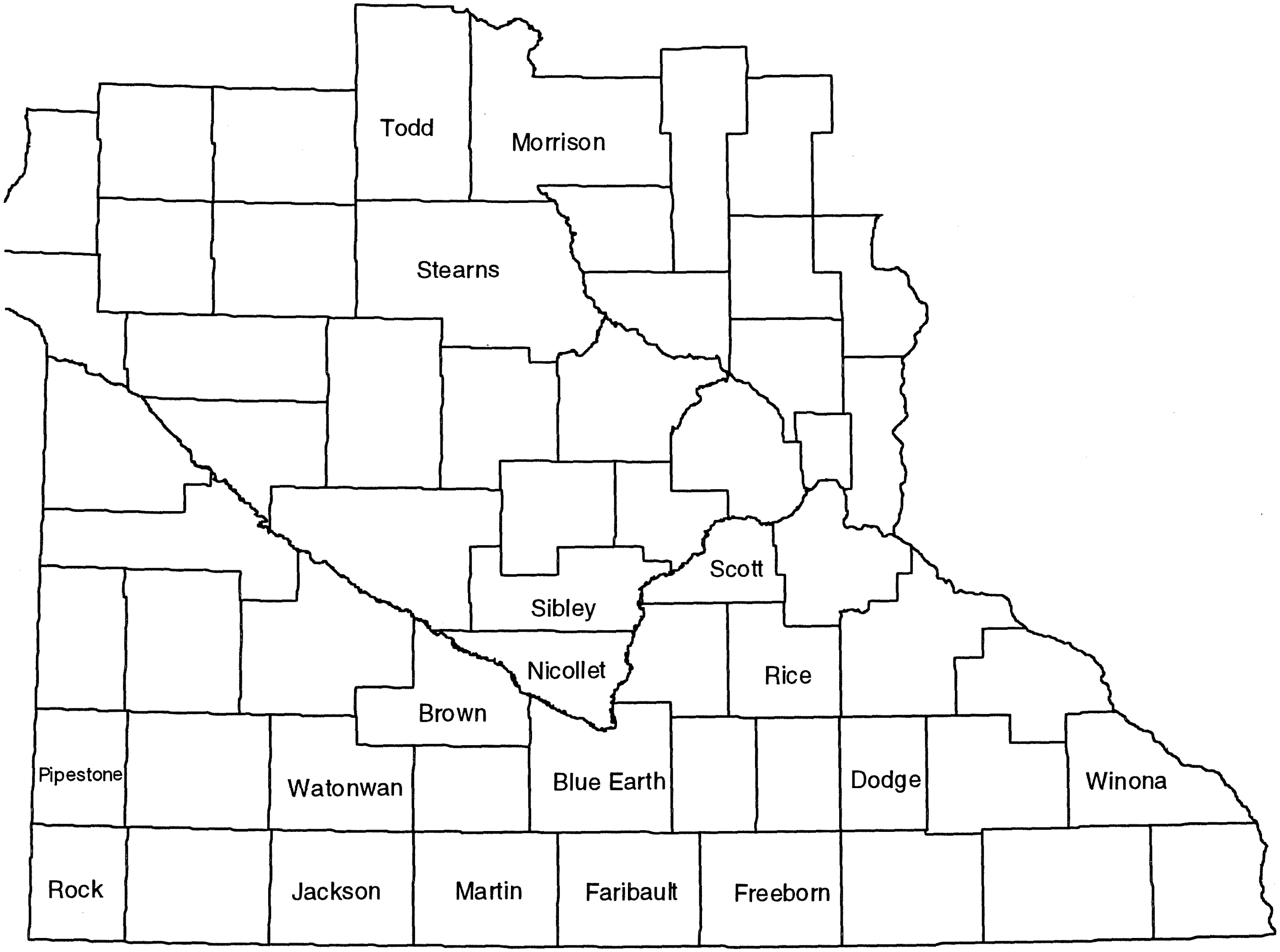


Figure 1. Selected counties in the study.

Table 1a. Number of animal units by county and animal type.

County	Multiple AUs	Beef	Dairy	Calves	Hogs	Sheep	Chickens	Turkeys	Others	Total
	animal units									
Blue Earth	0	16041	3650	1866	144286	169	1149	3266	844	171271
Brown	0	22890	20067	2875	94457	33	1372	9870	60	151624
Dodge	0	5668	11280	0	32241	17	730	6114	7523	63573
Faribault	0	21444	6796	0	93042	167	404	0	2965	124818
Freeborn	0	9815	9209	0	74960	0	2873	1255	988	99100
Jackson	0	24500	3951	1696	106075	749	1212	900	288	139371
Martin	0	33474	1685	143	244205	231	43	2722	1837	284340
Morrison	16307	4971	60014	13	7715	90	37650	22866	167	149793
Nicollet	0	15352	20533	0	97399	97	132	23540	26	157079
Pipestone	0	43808	9485	6809	76257	1351	376	1296	304	139686
Rice	0	31320	41326	0	54993	0	0	0	19391	147030
Rock	0	56455	8109	1441	80080	0	0	0	1590	147675
Scott	8438	4038	11379	0	6980	0	0	0	933	31768
Sibley	0	18673	17505	3984	38940	344	1059	4	560	81069
Stearns	0	51644	144393	6873	41005	35	29401	23603	3600	300554
Todd	25993	7836	30875	0	4609	45	22667	8001	110	100136
Watonwan	0	16011	4079	2028	4538	164	0	2234	243	29297
Winona	6129	11395	46311	0	2368	109	2	3800	2313	72427
All counties	56867	395335	450647	27728	1204150	3601	99070	109471	43742	2390611

Table 1b. Proportion of total animal units by county and animal type.

County	Multiple AUs	Beef	Dairy	Calves	Hogs	Sheep	Chickens	Turkeys	Others
	%								
Blue Earth	0.0	9.4	2.1	1.1	84.2	0.1	0.7	1.9	0.5
Brown	0.0	15.1	13.2	1.9	62.3	0.0	0.9	6.5	0.0
Dodge	0.0	8.9	17.7	0.0	50.7	0.0	1.1	9.6	11.8
Faribault	0.0	17.2	5.4	0.0	74.5	0.1	0.3	0.0	2.4
Freeborn	0.0	9.9	9.3	0.0	75.6	0.0	2.9	1.3	1.0
Jackson	0.0	17.6	2.8	1.2	76.1	0.5	0.9	0.6	0.2
Martin	0.0	11.8	0.6	0.1	85.9	0.1	0.0	1.0	0.6
Morrison	10.9	3.3	40.1	0.0	5.2	0.1	25.1	15.3	0.1
Nicollet	0.0	9.8	13.1	0.0	62.0	0.1	0.1	15.0	0.0
Pipestone	0.0	31.4	6.8	4.9	54.6	1.0	0.3	0.9	0.2
Rice	0.0	21.3	28.1	0.0	37.4	0.0	0.0	0.0	13.2
Rock	0.0	38.2	5.5	1.0	54.2	0.0	0.0	0.0	1.1
Scott	26.6	12.7	35.8	0.0	22.0	0.0	0.0	0.0	2.9
Sibley	0.0	23.0	21.6	4.9	48.0	0.4	1.3	0.0	0.7
Stearns	0.0	17.2	48.0	2.3	13.6	0.0	9.8	7.9	1.2
Todd	26.0	7.8	30.8	0.0	4.6	0.0	22.6	8.0	0.1
Watonwan	0.0	54.7	13.9	6.9	15.5	0.6	0.0	7.6	0.8
Winona	8.5	15.7	63.9	0.0	3.3	0.2	0.0	5.2	3.2
All counties	2.4	16.5	18.9	1.2	50.4	0.2	4.1	4.6	1.8

B. Feedlot Size Distributions

Feedlot size distributions (Fig. 2) are typically described in terms of the proportions of feedlots that contain a tiny number (1-49) of animal units, those that contain a very small number (50-99) of A.U.s, those with a small number (100-299) of A.U.s, those with a moderate number (300-999) of A.U.s, and those with a large number (>1000) of A.U.s.

The average size distribution for feedlots (by animal units averaged across animal species) in the eighteen counties studied shows that 25% are tiny feedlots, 21% are very small feedlots, 35% are small sized feedlots, 16% are moderate feedlots, and 2% are large feedlots (Table 2). These size distributions are significantly different from the distributions for all 38,000 Minnesota feedlots (67% tiny, 17% very small, 11% small, 3% moderate, and 1% large). This is reasonable, since we have chosen the geographic regions of the state where animal agriculture is focused.

The density of feedlots varies considerably across the counties studied. Rice, Stearns, Winona, Pipestone, and Rock counties have the most dense concentrations of feedlots, with significant proportions of the county having less than 522 watershed acres per feedlot. Other counties with significant proportions of dense feedlots include Sibley, Nicollet, and Brown counties. Todd, Morrison, Watonwan, and Blue Earth have the least dense concentrations of feedlot numbers, with more than 1,207 acres per feedlot.

Rice and Winona counties are quite different from the average feedlot size distribution, having significantly greater proportions of tiny sized feedlots than the other counties. On the other hand, Jackson, Martin, Blue Earth, Rock, Pipestone, and Nicollet counties have significantly greater proportions of moderate sized feedlots than the other counties.

The Minnesota Department of Agriculture (MDA) evaluated the proportion of feedlots which were out of compliance with the Minnesota Feedlot Rules for environmental problems (MDA, 2001) in a subset of eleven counties within the eighteen counties we studied. They found that 957 feedlots (roughly 15% of all feedlots) in this subset would not comply with various portions of the Minnesota Rules for feedlots. The non-compliant feedlots required either runoff controls, storage basin upgrades, or both types of correction to reduce environmental pollution. A majority of the non-compliant feedlots (47%) were for beef cattle, while 27% and 22% of the non-compliant feedlots were dairy and hog feedlots, respectively. Poultry operations accounted for only 2% of the non-compliant feedlots. These risks do not include environmental risks associated with land application of manure or air quality, only risks of runoff and leaching from manure storage and confinement facilities. Most county feedlot officers believe the risk of environmental pollution is greater from land application of manure than from runoff and leachate at manure storage and confinement facilities.

According to the MDA study, 25%, 34%, 23%, 16%, and 1% of the environmentally non-compliant beef feedlots were in the tiny, very small, small, moderate, and large size classes, respectively. The majority of environmental risks are probably due to inadequate runoff controls from open lots, partial housing without runoff controls, daily hauling or stockpiling operations. There may also be environmental risks due to seepage from earthen holding basins. According to the MDA, of the dairy feedlots which pose an environmental risk, 8%, 27%, 59%, 5%, and 0%

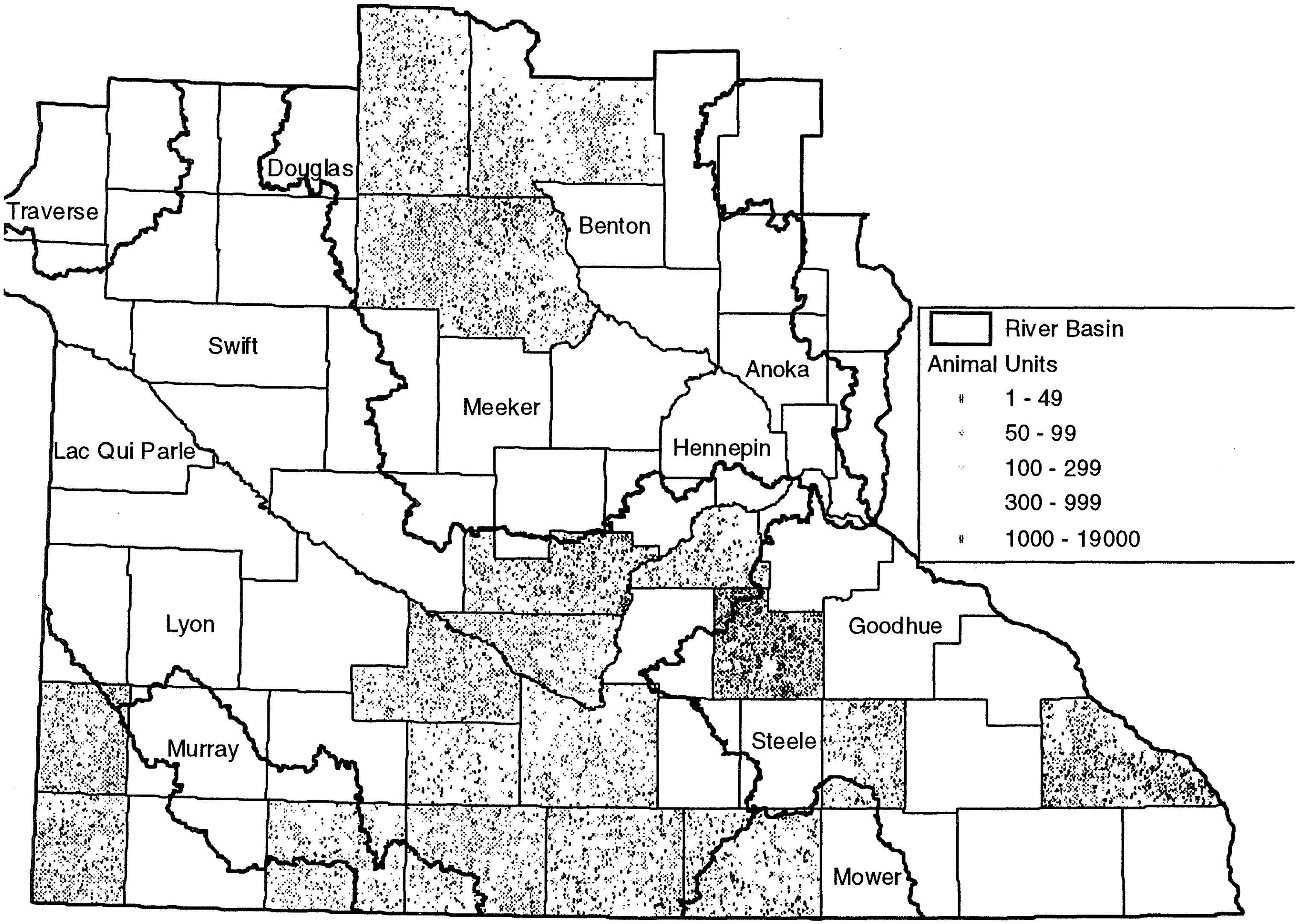


Figure 2. Distribution of feedlot locations in selected counties.

Table 2a. Number of all feedlots by county and size class.

County	Feedlot size in animal units: 1-49	50-99	100-299	300-999	1000+	All classes
	number of feedlots					
Blue Earth	82	64	166	125	34	471
Brown	95	137	251	104	25	612
Dodge	132	89	116	48	5	390
Faribault	156	91	212	113	10	582
Freeborn	144	99	149	84	11	487
Jackson	67	50	172	158	11	458
Martin	51	91	220	223	63	648
Morrison	69	166	289	108	19	651
Nicollet	41	42	193	117	20	413
Pipestone	79	142	206	114	20	561
Rice	768	246	333	97	10	1454
Rock	89	124	205	156	5	579
Scott	74	69	76	11	4	234
Sibley	183	138	239	53	1	614
Stearns	325	338	764	206	22	1655
Todd	95	226	201	42	10	574
Watonwan	67	38	70	27	2	204
Winona	411	274	161	31	4	881
All counties	2928	2424	4023	1817	276	11468

Table 2b. Proportion of all feedlots by county and size class.

County	Feedlot size in animal units: 1-49	50-99	100-299	300-999	1000+	All classes
	%					
Blue Earth	17.4	13.6	35.2	26.5	7.2	100.0
Brown	15.5	22.4	41.0	17.0	4.1	100.0
Dodge	33.8	22.8	29.7	12.3	1.3	100.0
Faribault	26.8	15.6	36.4	19.4	1.7	100.0
Freeborn	29.6	20.3	30.6	17.2	2.3	100.0
Jackson	14.6	10.9	37.6	34.5	2.4	100.0
Martin	7.9	14.0	34.0	34.4	9.7	100.0
Morrison	10.6	25.5	44.4	16.6	2.9	100.0
Nicollet	9.9	10.2	46.7	28.3	4.8	100.0
Pipestone	14.1	25.3	36.7	20.3	3.6	100.0
Rice	52.8	16.9	22.9	6.7	0.7	100.0
Rock	15.4	21.4	35.4	26.9	0.9	100.0
Scott	31.6	29.5	32.5	4.7	1.7	100.0
Sibley	29.8	22.5	38.9	8.6	0.2	100.0
Stearns	19.6	20.4	46.2	12.4	1.3	100.0
Todd	16.6	39.4	35.0	7.3	1.7	100.0
Watonwan	32.8	18.6	34.3	13.2	1.0	100.0
Winona	46.7	31.1	18.3	3.5	0.5	100.0
All counties	25.5	21.1	35.1	15.8	2.4	100.0

are tiny, very small, small, moderate, or large sized feedlots, respectively. The main perceived environmental risks are from poorly engineered earthen holding basins and from partial housing without runoff controls. Serious environmental pollution may also arise after winter spreading of manure in daily haul dairy operations, an indirect consequence of this storage type.

Of hog feedlots which pose an environmental risk, 6%, 33%, 37%, 24%, and 0% are in the tiny, very small, small, moderate, and large size classes. These environmental risks are primarily due to earthen storage basins and partial housing without runoff controls.

The average size of feedlots (by animal units) was also evaluated by animal species (Table 3a-e). Each animal species tends to occur in feedlots having a specific size range unique to each species. Turkey feedlots tend on average to be moderate and large sized feedlots. Chicken feedlots tend on average to be moderate in size. Hog feedlots tend on average to be small to medium sized feedlots. Dairy feedlots tend on average to be small to very small sized feedlots. Beef feedlots tend on average to be tiny, very small, and small sized feedlots. Thus, in general, the number of animal units per feedlot tends to decrease according to the order:

Turkeys > chickens > hogs > dairy > beef.

Only a few counties have significant numbers of turkeys, including Stearns, Morrison, Brown, Dodge, Todd, Winona, Blue Earth, and Martin counties. Similarly, only Morrison, Stearns, Freeborn, and Todd counties have significant numbers of chicken feedlots. Significant numbers of hog, diary, and beef feedlots exist in all the counties studied.

Pipestone, Rock, Jackson, Martin, Nicollet, and Blue Earth counties tend to have hog feedlots that are significantly larger than those in other counties. On the other hand, hog feedlots in Watonwan, Morrison, Todd, Winona, and Rice counties tend to be significantly smaller than those in other counties.

Dairy feedlots in Jackson, Faribault, Nicollet, and Rock counties tend to be larger than feedlots in other counties. Freeborn, Rice, Dodge, and Winona counties tend to have a higher proportion of smaller dairy feedlots than other counties.

Beef feedlots in Brown, Jackson, Martin, and Rock counties are larger than feedlots in other counties. On the other hand, beef feedlots in Dodge, Freeborn, Morrison, Rice, Scott, and Winona counties are smaller than those in other counties.

C. Feedlot Confinement Types

A wide range of feedlot confinement types are used in Minnesota feedlots. Common types include total confinement, partial housing without runoff controls, partial housing with runoff controls, open lot without runoff controls, open lot with runoff controls, and pasture. The risks of polluting surface water due to animal confinement types (Table 4) typically decrease in the order:

Table 3a. Proportion of turkey feedlots by county and size class.

County	Feedlots size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Blue Earth	0.0	0.0	33.3	66.7	0.0	100.0
Brown	8.3	8.3	8.3	50.0	25.0	100.0
Dodge	12.5	0.0	0.0	75.0	12.5	100.0
Faribault	0.0	0.0	0.0	0.0	0.0	0.0
Freeborn	0.0	0.0	33.3	66.7	0.0	100.0
Jackson	0.0	0.0	0.0	0.0	100.0	100.0
Martin	0.0	0.0	50.0	33.3	16.7	100.0
Morrison	0.0	0.0	0.0	63.6	36.4	100.0
Nicollet	0.0	0.0	25.0	25.0	50.0	100.0
Pipestone	0.0	0.0	0.0	0.0	100.0	100.0
Rice	0.0	0.0	0.0	0.0	0.0	0.0
Rock	0.0	0.0	0.0	0.0	0.0	0.0
Scott	0.0	0.0	0.0	0.0	0.0	0.0
Sibley	100.0	0.0	0.0	0.0	0.0	100.0
Stearns	0.0	3.7	3.7	66.7	25.9	100.0
Todd	0.0	0.0	0.0	50.0	50.0	100.0
Watonwan	0.0	0.0	0.0	66.7	33.3	100.0
Winona	0.0	0.0	14.3	85.7	0.0	100.0
All counties	2.8	1.8	9.2	59.6	26.6	100.0

Table 3b. Proportion of chicken feedlots by county and size class.

County	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Blue Earth	20.0	20.0	20.0	40.0	0.0	100.0
Brown	0.0	0.0	50.0	50.0	0.0	100.0
Dodge	0.0	0.0	50.0	50.0	0.0	100.0
Faribault	0.0	33.3	66.7	0.0	0.0	100.0
Freeborn	0.0	0.0	50.0	50.0	0.0	100.0
Jackson	0.0	0.0	0.0	100.0	0.0	100.0
Martin	100.0	0.0	0.0	0.0	0.0	100.0
Morrison	0.0	2.6	21.1	67.1	9.2	100.0
Nicollet	100.0	0.0	0.0	0.0	0.0	100.0
Pipestone	0.0	0.0	0.0	100.0	0.0	100.0
Rice	0.0	0.0	0.0	0.0	0.0	0.0
Rock	0.0	0.0	0.0	0.0	0.0	0.0
Scott	0.0	0.0	0.0	0.0	0.0	0.0
Sibley	80.0	0.0	0.0	0.0	20.0	100.0
Stearns	2.0	2.0	12.0	70.0	14.0	100.0
Todd	18.2	0.0	9.1	27.3	45.5	100.0
Watonwan	0.0	0.0	0.0	0.0	0.0	0.0
Winona	100.0	0.0	0.0	0.0	0.0	100.0
All counties	6.3	2.9	20.1	59.2	11.5	100.0

Table 3c. Proportion of hog feedlots by county and size class.

County	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Blue Earth	7.0	9.3	36.9	36.5	10.3	100.0
Brown	17.5	15.6	38.9	21.7	6.4	100.0
Dodge	16.9	11.9	37.3	31.4	2.5	100.0
Faribault	10.6	13.7	45.5	27.7	2.5	100.0
Freeborn	16.9	12.4	39.8	26.5	4.4	100.0
Jackson	4.4	7.8	42.9	41.9	3.0	100.0
Martin	4.0	10.6	32.3	39.8	13.3	100.0
Morrison	32.4	24.3	18.9	21.6	2.7	100.0
Nicollet	6.4	7.7	39.1	39.1	7.7	100.0
Pipestone	4.7	7.4	33.8	43.2	10.8	100.0
Rice	23.7	14.8	35.0	24.5	1.9	100.0
Rock	11.8	15.8	29.8	41.2	1.3	100.0
Scott	12.9	32.3	25.8	22.6	6.5	100.0
Sibley	16.0	14.6	49.8	17.8	1.8	100.0
Stearns	14.5	10.7	45.0	29.8	0.0	100.0
Todd	23.7	36.8	23.7	15.8	0.0	100.0
Watonwan	54.5	15.9	22.7	6.8	0.0	100.0
Winona	29.6	22.2	25.9	18.5	3.7	100.0
All counties	12.3	12.5	37.8	31.7	5.6	100.0

Table 3d. Proportion of dairy feedlots by county and size class.

County	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Blue Earth	19.4	25.8	45.2	9.7	0.0	100.0
Brown	7.7	32.5	53.8	5.9	0.0	100.0
Dodge	23.0	36.5	37.8	2.7	0.0	100.0
Faribault	20.0	8.0	52.0	16.0	4.0	100.0
Freeborn	28.6	33.3	29.8	8.3	0.0	100.0
Jackson	5.6	11.1	61.1	22.2	0.0	100.0
Martin	27.3	18.2	45.5	9.1	0.0	100.0
Morrison	4.2	29.8	57.5	7.9	0.7	100.0
Nicollet	3.1	10.2	71.4	15.3	0.0	100.0
Pipestone	1.4	23.6	63.9	11.1	0.0	100.0
Rice	23.1	28.9	43.7	4.3	0.0	100.0
Rock	7.0	20.9	55.8	16.3	0.0	100.0
Scott	16.4	32.8	47.7	2.3	0.8	100.0
Sibley	17.2	32.3	46.2	4.3	0.0	100.0
Stearns	8.0	20.2	62.4	9.1	0.3	100.0
Todd	9.2	44.6	39.1	6.9	0.3	100.0
Watonwan	14.3	22.9	54.3	8.6	0.0	100.0
Winona	24.0	39.5	31.5	4.3	0.7	100.0
All counties	13.0	29.5	50.0	7.2	0.3	100.0

Table 3e. Proportion of beef feedlots by county and size class.

County	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Blue Earth	39.1	18.2	34.5	5.5	2.7	100.0
Brown	20.9	29.1	31.8	16.4	1.8	100.0
Dodge	56.4	21.8	20.0	0.0	1.8	100.0
Faribault	37.2	23.9	27.8	11.1	0.0	100.0
Freeborn	56.4	30.1	12.0	1.5	0.0	100.0
Jackson	24.6	21.9	28.1	24.6	0.9	100.0
Martin	12.2	23.8	39.6	23.2	1.2	100.0
Morrison	46.8	31.6	20.3	1.3	0.0	100.0
Nicollet	27.8	18.1	41.7	12.5	0.0	100.0
Pipestone	17.9	34.5	33.9	12.9	0.9	100.0
Rice	62.9	18.3	15.7	3.2	0.0	100.0
Rock	13.4	27.2	39.2	19.4	0.7	100.0
Scott	61.7	21.3	12.8	2.1	2.1	100.0
Sibley	51.3	23.1	22.6	3.1	0.0	100.0
Stearns	43.5	26.7	23.6	6.0	0.2	100.0
Todd	31.8	32.6	33.3	2.3	0.0	100.0
Watonwan	27.8	19.1	35.7	16.5	0.9	100.0
Winona	63.1	31.5	5.0	0.4	0.0	100.0
All counties	39.7	25.6	25.4	8.8	0.5	100.0

Table 4. Relative water quality risks associated with animal housing systems.

	Water type			
	Surface[1]		Ground[2]	
	N[3]	P	N[4]	P
	Relative risk[5]			
Confinement type				
Total confinement	1	1	1	1
Partially housed				
without runoff control	3	3	2/4[6]	1/2
with runoff control[7]	2	2	2/3	1/2
Open lot				
without runoff control	5	5	3/5	2/3
with runoff control[7]	3	2	2/4	1/2
Pasture	4	4	1	1

1 Includes surface runoff and subsurface tile drainage.
2 Percolation to deeper aquifers.
3 Organic N, NH_4-N, NO_3-N
4 NO_3-N
5 1 = very low risk; 5 = very high risk
6 medium textured soil/coarse textured soil
7 Surface and roof water is diverted.

> Open lot without runoff controls > poorly managed pasture > partial housing without runoff controls > open lot with runoff controls > partial housing with runoff controls > total confinement > well managed pasture.

Table 4 rates the environmental risk of various animal housing systems for the impairment of surface and ground water quality. In this rating, we acknowledge that environmental risks are very site-specific, and we assume that other manure management practices are not a factor in assessing housing systems *per se.* Least risk to water quality is found with total confinement systems. Slightly greater risk is associated with partially housed systems with runoff control that diverts surface water inflow and roof water around the confinement area. Risk to water quality is approximately equal for the open lot with runoff control and the partial housing system without runoff control. In these systems, runoff of ammonium-N and organic-N, leaching of nitrate-N into subsurface tile drainage, and surface runoff of phosphorus poses the greatest threat to surface water. Ground water is particularly susceptible to nitrate-N contamination when these systems are located on sandy, coarse-textured soils. Open lots without runoff control show the greatest risk for N and P losses to both surface and ground water. Pasture systems possess the greatest variability with respect to environmental risk. Pastures located in close proximity to surface water or sloping toward waterways or waterbodies exhibit a high degree of risk, especially if densely stocked with livestock. On the other hand, little groundwater impairment risk is associated with well-managed pastures even on sandy soils.

The Minnesota Pollution Control Agency (MPCA) keeps a feedlot permit database, which includes 3,845 records for active feedlots in the eighteen counties studied. The size class distribution for these feedlots (12% tiny, 21% very small, 37% small, 21% moderate, and 9% large) is very similar to the size class distribution for feedlots in the eighteen county feedlot inventory database, with significant discrepancies only in the number of tiny feedlots.

The MPCA feedlot permit database specifies the type of confinement used for dairy, beef, hog, turkey, and chicken feedlots (Table 5a-f). Feedlots for turkeys, and chickens are strongly dominated (87-91% of all operations) by facilities for total confinement, with only 7% of feedlots being partially housed without runoff controls. The vast majority of total confinement operations for turkeys are moderate (58%) to large (35%) sized feedlots. Total confinement feedlots for chickens (Fig. 3a) tend to be moderate sized (44% of all total confinement feedlots), while the remaining chicken operations are evenly distributed between either small (21%) or large (27%) sized feedlots.

Hog feedlots (Table 5d) are strongly dominated (81%) by facilities for total confinement, with 15% of feedlots being partially housed without runoff controls. Hog feedlots with total confinement tend to be primarily small (32%) to medium (31%) sized operations (Fig. 3b). Large sized hog feedlots account for 17% of all total confinement operations. Very small and tiny sized hog feedlots account for 9% and 10% of all total confinement operations, respectively.

Dairy feedlots (Table 5e) are dominated by partially housed operations with (33%) or without (41%) runoff controls, with another 25% of all feedlots being total confinement operations. Less than 1% of dairy feedlots are open lots without runoff controls. Dairy feedlots with partial

Table 5a. Proportion of all feedlots by confinement type and animal type.

Confinement type	Animal type				
	Beef	Chicken	Dairy	Hog	Turkey
	%				
Total confinement	24.7	88.6	25.1	80.9	90.8
Partially housed w/o runoff controls	50.7	7.1	41.2	14.9	7.1
Partially housed w/ runoff controls	17.9	2.9	32.6	3.3	1.0
Open lot w/o runoff controls	4.8	1.4	0.6	0.4	1.0
Open lot w/ runoff controls	1.3	0.0	0.2	0.3	0.0
Pasture	0.1	0.0	0.1	0.0	0.0
Other	0.4	0.0	0.2	0.2	0.0
All types	100.0	100.0	100.0	100.0	100.0

Table 5b. Proportion of turkey feedlots by confinement type and size class.

Confinement type	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Total confinement	0.0	100.0	71.4	94.5	88.6	90.8
Partially housed w/o runoff controls	0.0	0.0	28.6	3.6	8.6	7.1
Partially housed w/ runoff controls	0.0	0.0	0.0	0.0	2.9	1.0
Open lot w/o runoff controls	0.0	0.0	0.0	1.8	0.0	1.0
Open lot w/ runoff controls	0.0	0.0	0.0	0.0	0.0	0.0
Pasture	0.0	0.0	0.0	0.0	0.0	0.0
Other	0.0	0.0	0.0	0.0	0.0	0.0
All types	0.0	100.0	100.0	100.0	100.0	100.0

Table 5c. Proportion of chicken feedlots by confinement type and size class.

Confinement type	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Total confinement	50.0	50.0	92.9	100.0	89.5	88.6
Partially housed w/o runoff controls	37.5	50.0	7.1	0.0	0.0	7.1
Partially housed w/ runoff controls	0.0	0.0	0.0	0.0	10.5	2.9
Open lot w/o runoff controls	12.5	0.0	0.0	0.0	0.0	1.4
Open lot w/ runoff controls	0.0	0.0	0.0	0.0	0.0	0.0
Pasture	0.0	0.0	0.0	0.0	0.0	0.0
Other	0.0	0.0	0.0	0.0	0.0	0.0
All types	100.0	100.0	100.0	100.0	100.0	100.0

Table 5d. Proportion of hog feedlots by confinement type and size class.

Confinement type	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Total confinement	65.3	67.0	78.4	87.8	98.3	80.9
Partially housed w/o runoff controls	28.4	26.2	17.0	8.7	0.8	14.9
Partially housed w/ runoff controls	4.1	5.8	4.1	2.7	0.4	3.3
Open lot w/o runoff controls	1.8	0.5	0.0	0.4	0.0	0.4
Open lot w/ runoff controls	0.0	0.0	0.5	0.2	0.4	0.3
Pasture	0.0	0.0	0.0	0.0	0.0	0.0
Other	0.5	0.5	0.0	0.2	0.0	0.2
All types	100.0	100.0	100.0	100.0	100.0	100.0

Table 5e. Proportion of dairy feedlots by confinement type and size class.

Confinement type	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Total confinement	15.8	17.1	24.3	63.4	80.0	25.1
Partially housed w/o runoff controls	65.3	45.6	38.9	18.8	0.0	41.2
Partially housed w/ runoff controls	16.8	36.3	36.0	16.1	20.0	32.6
Open lot w/o runoff controls	1.1	0.6	0.2	1.8	0.0	0.6
Open lot w/ runoff controls	1.1	0.0	0.2	0.0	0.0	0.2
Pasture	0.0	0.2	0.0	0.0	0.0	0.1
Other	0.0	0.2	0.4	0.0	0.0	0.2
All types	100.0	100.0	100.0	100.0	100.0	100.0

Table 5f. Proportion of beef feedlots by confinement type and size class.

Confinement type	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Total confinement	20.6	27.5	24.9	25.0	25.0	24.7
Partially housed w/o runoff controls	64.3	60.1	46.2	47.4	15.6	50.7
Partially housed w/ runoff controls	6.3	8.0	23.3	22.4	34.4	17.9
Open lot w/o runoff controls	8.7	4.3	4.0	4.6	3.1	4.9
Open lot w/ runoff controls	0.0	0.0	1.7	0.0	12.5	1.2
Pasture	0.0	0.0	0.0	0.0	3.1	0.1
Other	0.0	0.0	0.0	0.7	6.3	0.4
All types	100.0	100.0	100.0	100.0	100.0	100.0

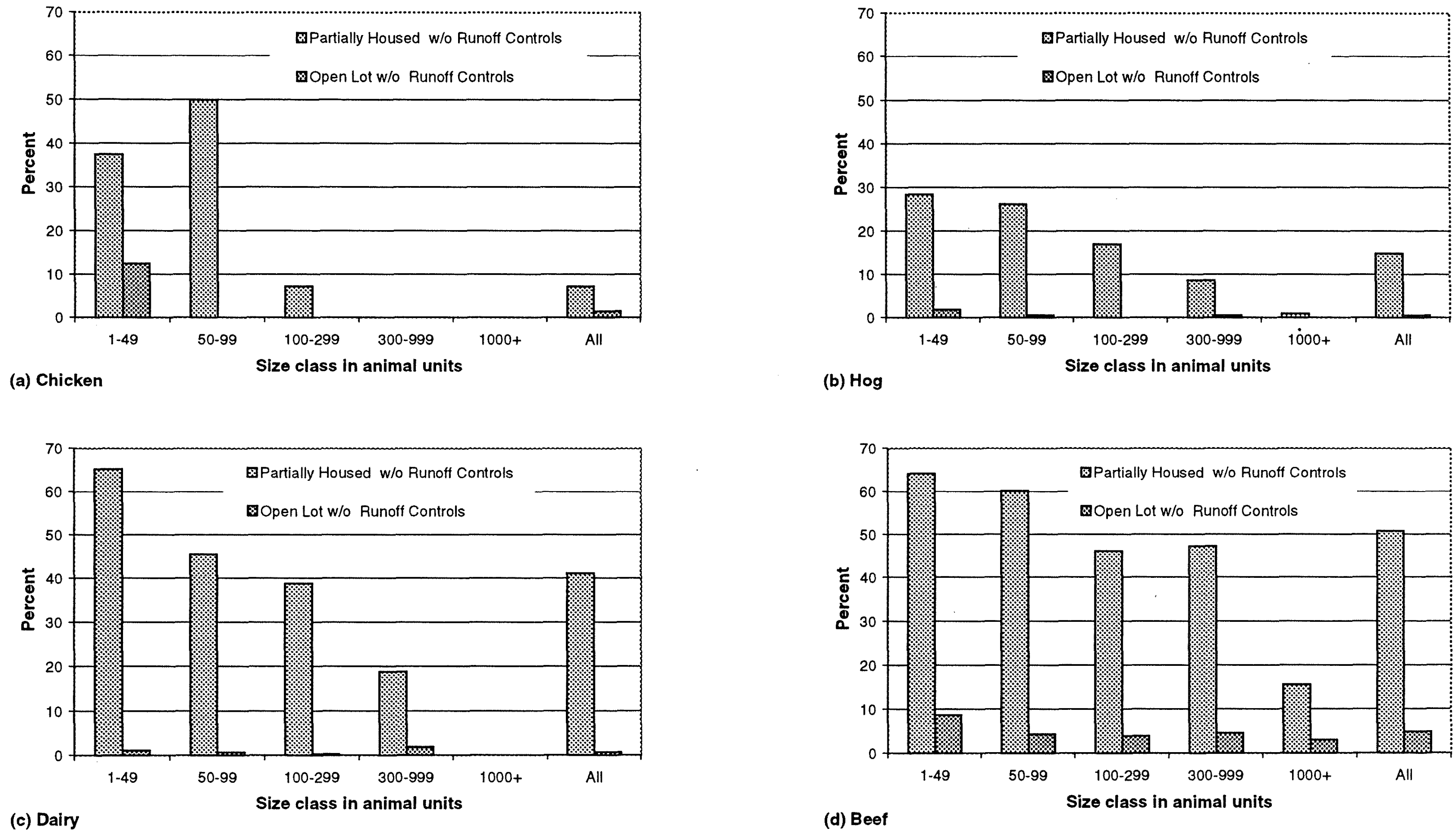


Figure 3. Proportion of (a) chicken, (b) hog, (c) dairy, and (d) beef feedlots using partially housed or open lot confinement types without runoff controls by size class.

housing (with or without runoff controls) tend to be very small or small sized (Fig. 3c). Dairy feedlots with total confinement tend to be small sized, although very small and moderate sized total confinement dairy feedlots are, in total, as numerous as small sized total confinement operations.

Beef feedlots (Table 5f) are dominated by partially housed operations without runoff controls (51%). Another 25% of beef feedlots are total confinement operations, and 18% are partially housed operations with runoff controls. Only 5% of beef feedlots are open lot operations without runoff controls. Beef feedlots with partial housing and no runoff controls (Fig. 3d) tend to be small sized (36% of all partially housed feedlots w/o runoff controls), although it is also rather common to find tiny (21%), very small (22%), and moderate (19%) sized partially housed beef feedlots without runoff controls. Beef feedlots with partial housing and runoff controls are primarily (50%) small sized operations. Another 25% of beef feedlots with partial housing and runoff controls are moderate sized. Beef feedlots with total confinement are 40% in the small size class, with another 14-20% each in the tiny, very small, and moderate size classes. Based on this information, we can conclude that the relative risk for barnyard pollution of surface water (based only on confinement types and assuming all other factors are equal) decreases in the order:

Beef > dairy > hogs > chickens = turkeys

The relative risk for pollution of surface water is greater for smaller sized feedlots than for larger feedlots, primarily because small feedlots tend to have partial housing without runoff controls or are open lots.

D. Feedlot Storage Types

Manure storage techniques are used for either liquid or solid manure. Liquid manure storage types include poured concrete tanks, concrete block/stave pits, earthen holding basins, and above ground tanks. The risk of polluting surface or ground waters by liquid storage techniques (Table 6) decreases in the order:

Earthen holding basins > concrete block/stave pits > poured concrete tanks > above ground tanks.

Solid manure storage types include solid stacking slabs, daily hauling (no storage), stockpiling (no structure), and manure pack in buildings. The risk of polluting surface waters by solid manure storage techniques (Table 6) decreases in the order:

Daily hauling (no storage) > stockpiling > solid stacking slabs > manure pack in buildings.

Manure storage systems greatly influence the risk of N and P from manure being delivered to surface and ground waters, and can be considered point sources. Table 6 rates the environmental risk of various manure storage systems for impairment of ground and surface water quality. In this rating, we acknowledge that environmental risks are very site-specific, and we assume that other manure management practices are not a factor in assessing manure storage systems *per se.*

Table 6. Relative water quality risks associated with manure storage systems.

	Water type			
	Surface[1]		Ground[2]	
	N[3]	P	N[4]	P
	Relative risk[5]			
Liquid Manure				
Above-ground tank (concrete or steel)	1	1	1	1
Below-ground tank (poured concrete)	1	1	1	1
Concrete block, stave pit[6]	2	1	2/3[7]	1
Earthen basin				
clay or synthetic liner, clay soil	1	1	1	1
clay or synthetic liner, sandy soil	1	1	3	1
no liner, clay soil[6]	2	1	3	1
no liner, sandy soil[6]	3	2	5	3
located in Karst area (w/ or w/o liner)	1	1	3	3
Solid manure				
Manure pack in building	1	1	1	1
Stacking/stockpiling				
concrete pad, roof, runoff control[8]	1	1	1	1
earthen pad, roof, runoff control	1	1	2/3	1
earthen pad, no roof, runoff control	3	1	3/5	2
earthen pad, no roof, no runoff control	4	4	3/5	2

1 Includes surface runoff and subsurface tile drainage.
2 Percolation to deeper aquifers.
3 Organic N, NH_4-N, NO_3-N
4 NO_3-N
5 1 = very low risk; 5 = very high risk
6 Practices currently not used in Minnesota.
7 medium textured soil/coarse textured soil
8 Surface and roof water is diverted.

Environmental risk of solid manure affecting surface and ground water is greatly reduced when manure is stored under a roof, or when stored on concrete pads, where surface and roof water inflow are diverted from the storage system. When a roof does not cover the stacked/stockpiled manure, the potential for N to be lost to surface and ground water as nitrate increases greatly, especially if underlain by sandy soils (groundwater), and if stored for long periods of time. The likelihood of phosphorus, ammonium-N, and organic-N being lost to surface water is greatest when a roof is absent and runoff control is not practiced.

Liquid manure storage results in little environmental risk to surface water except when earthen basins without liners are constructed on coarse-textured, sandy soils. Above-and-below-ground poured concrete tanks pose little environmental risk to surface and ground waters. Earthen storage basins with a clay or synthetic liner and constructed on fine-textured, clay soils also pose little risk. The risk for N movement to the ground water increases if constructed on sandy soils, or without a liner. Earthen storage basins constructed in landscapes over karst (fractured limestone and sandstone) pose a moderate risk of N and P losses to both surface and ground water due to the potential for both leaching losses of N and potential sink hole development under the basin.

There is a large diversity of manure storage techniques for animal operations in Minnesota (Table 7a). Beef feedlot storage types (Table 7b) are primarily manure pack in buildings (51% of all beef feedlots) for solid manure, and earthen holding basins (16%) or poured concrete tanks (11%) for liquid manure. Environmentally riskier types of solid manure storage include daily hauling (5%) and stockpiling with no structures (7%). Daily hauling occurs primarily with very small beef feedlots, where it accounts for 12% of the storage types in this size class (Fig. 4a). Other size classes of feedlots have a much smaller incidence of daily hauling. Stockpiling with no structures occurs primarily in the tiny feedlot operations, where it accounts for 13% of the storage types in this size class. As size of the feedlot operation increases, the incidence of stockpiling decreases. Earthen holding basins tend to be more common with larger beef feedlots. For example, 2%, 11%, 20%, 21%, and 33% of beef feedlots in the tiny, very small, small, moderate, and large size classes, respectively, have earthen holding basins.

Dairy feedlot storage facilities (Table 7c) for liquid manure are primarily earthen holding basins (39% of all storage types for dairy feedlots) and poured concrete tanks (13%). For solid manure, dairy feedlots typically have no storage (daily haul operations represent 23% of storage types) or use manure packs in buildings (11%). Daily hauling decreases in frequency as the size of dairy feedlots increases (Fig. 4b). Roughly 36%, 27%, 20%, 12%, and 0% of dairy feedlots in the tiny, very small, small, moderate, and large size classes, respectively, use daily hauling. Earthen holding basins account for 10%, 39%, 41%, 54%, and 53% of the storage types in the tiny, very small, small, moderate, and large dairy feedlots, respectively. Thus, earthen holding basins increase in frequency as feedlot size increases.

Hog feedlots (Table 7d) primarily use poured concrete tanks (61%) and earthen holding basins (11%) for manure storage. Only 13% of hog feedlots use manure pack storage in buildings, and only 6% use daily hauling (no storage). Concrete tanks increase in frequency as feedlot size increases (Fig. 4c), with 85% of the large hog feedlots using them. The frequency of earthen holding basins also increases with feedlot size, with 4%, 10%, 10%, 13%, and 13% of hog

Table 7a. Proportion of all feedlots by storage type and animal type.

Storage type	Animal type				
	Beef	Chicken	Dairy	Hog	Turkey
	%				
Poured concrete tank	11.5	27.5	12.7	61.3	0.0
Concrete block/stave pit	2.7	2.9	1.8	4.6	1.0
Earthen holding basin	16.4	10.1	39.1	10.7	2.0
Aerated lagoon	0.1	0.0	0.2	0.4	0.0
Above ground tank	1.2	5.8	3.3	0.8	0.0
Solid stacking slab	1.9	5.8	4.4	0.4	0.0
Daily hauling (no storage)	5.0	4.3	23.0	6.0	0.0
Stockpiling (no structure)	6.7	8.7	1.7	1.6	11.2
Manure pack in buildings	51.5	33.3	10.9	13.0	83.7
Other	3.0	1.4	3.0	1.2	2.0
All types	100.0	100.0	100.0	100.0	100.0

Table 7b. Proportion of beef feedlots by storage type and size class.

Storage type	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Poured concrete tank	4.8	5.1	13.4	19.6	10.0	11.5
Concrete block/stave pit	0.8	0.7	3.0	4.6	6.7	2.7
Earthen holding basin	2.4	11.6	20.1	21.6	33.3	16.4
Aerated lagoon	0.0	0.0	0.0	0.0	3.3	0.1
Above ground tank	0.0	0.7	2.0	1.3	0.0	1.2
Solid stacking slab	2.4	0.7	2.3	2.0	0.0	1.9
Daily hauling (no storage)	5.6	11.6	2.3	3.9	3.3	5.0
Stockpiling (no structure)	13.6	10.9	4.3	3.3	0.0	6.7
Manure pack in buildings	69.6	56.5	50.5	37.9	33.3	51.5
Other	0.8	2.2	2.0	5.9	10.0	3.0
All types	100.0	100.0	100.0	100.0	100.0	100.0

Table 7c. Proportion of dairy feedlots by storage type and size class.

Storage type	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Poured concrete tank	5.3	8.6	16.5	17.9	20.0	12.7
Concrete block/stave pit	1.1	1.7	2.3	0.9	0.0	1.8
Earthen holding basin	10.5	38.6	40.9	54.5	53.3	39.1
Aerated lagoon	0.0	0.4	0.0	0.0	0.0	0.2
Above ground tank	2.1	1.3	4.9	4.5	6.7	3.3
Solid stacking slab	4.2	5.7	4.0	1.8	0.0	4.4
Daily hauling (no storage)	35.8	27.4	19.7	11.6	0.0	23.0
Stockpiling (no structure)	6.3	2.1	0.9	0.0	0.0	1.7
Manure pack in buildings	29.5	10.8	8.3	6.3	20.0	10.9
Other	5.3	3.4	2.5	2.7	0.0	3.0
All types	100.0	100.0	100.0	100.0	100.0	100.0

Table 7d. Proportion of hog feedlots by storage type and size class.

Storage type	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Poured concrete tank	36.2	39.7	59.5	71.4	85.5	61.3
Concrete block/stave pit	7.7	5.8	7.1	2.1	0.0	4.6
Earthen holding basin	3.6	10.6	10.3	13.4	12.9	10.7
Aerated lagoon	0.0	0.0	0.4	0.8	0.4	0.4
Above ground tank	0.9	1.1	0.9	1.0	0.0	0.8
Solid stacking slab	0.9	0.0	0.5	0.2	0.0	0.4
Daily hauling (no storage)	17.6	14.8	4.6	1.9	0.0	6.0
Stockpiling (no structure)	5.9	2.6	0.9	0.4	0.8	1.6
Manure pack in buildings	25.8	23.3	15.0	7.1	0.4	13.0
Other	1.4	2.1	0.9	1.7	0.0	1.2
All types	100.0	100.0	100.0	100.0	100.0	100.0

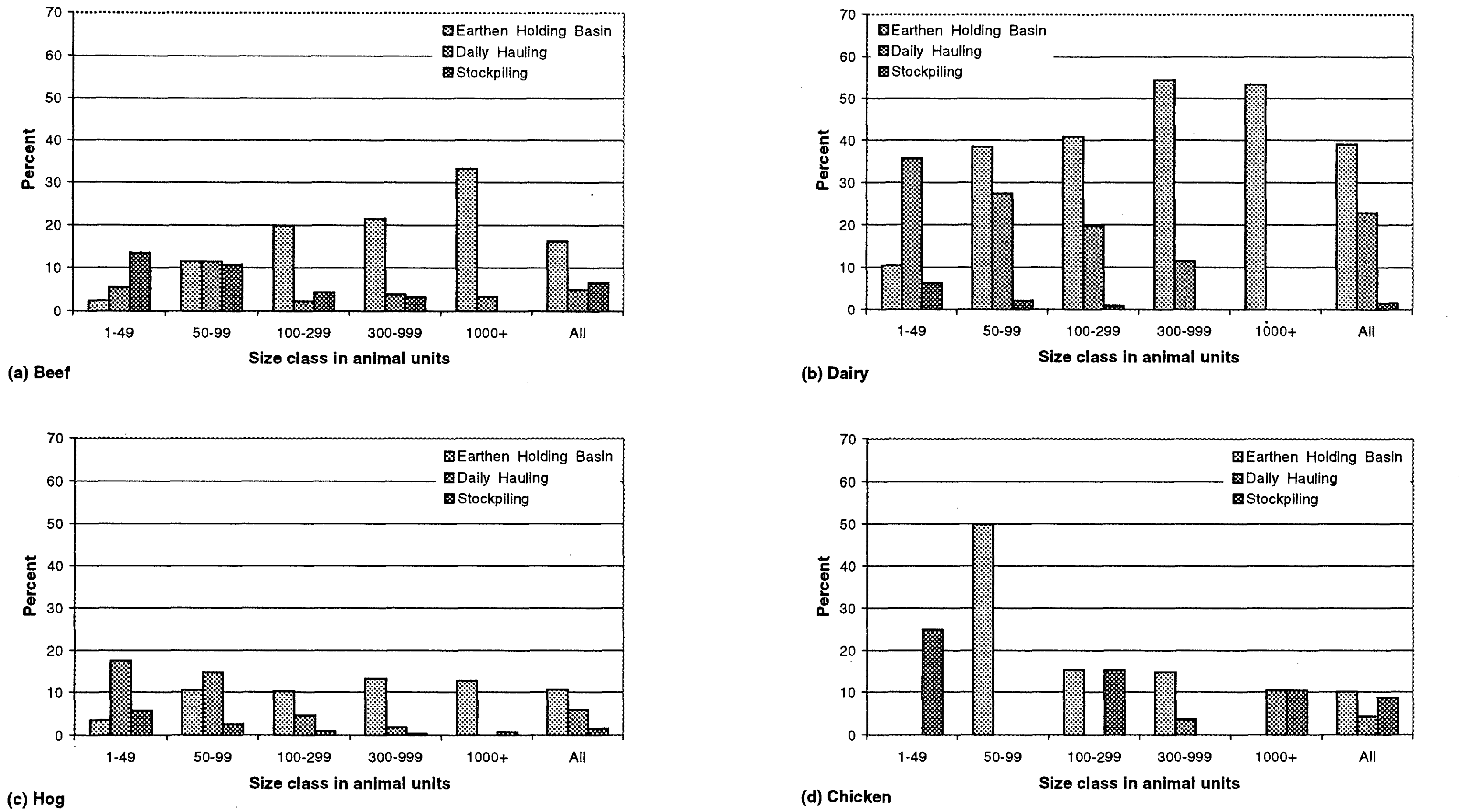


Figure 4. Proportion of (a) beef, (b) dairy, (c) hog, and (d) chicken feedlots using earthen holding basin, daily hauling, or stockpiling storage types by size class.

feedlots using them for tiny, very small, small, medium, and large sized operations, respectively. Daily haul operations decrease in frequency as the size of hog feedlots increases, with 18%, 15%, 5%, 2%, and 0% of feedlots using daily haul for the tiny, very small, small, medium, and large operations, respectively.

Chicken feedlots have a very wide range of storage types (Table 7e). One third of chicken feedlots store manure packs in buildings, while 28% use poured concrete tanks, and 10% use earthen holding basins. Stockpiling of manure with no protection from structures is used in 9% of the feedlots, while solid stacking slabs are used 6% of the time, and daily haul without storage is used in 4% of the feedlots. Finally, above ground tanks are used in 6% of the operations, and concrete block/stave pits are used in 3%. Poured concrete tanks, above ground tanks, and daily hauling operations all increase in frequency as the size of chicken feedlots increases (Fig. 4d). Moderate sized chicken feedlots have the most diverse storage types, with manure packs, poured concrete tanks, earthen holding basins, and solid stacking slabs occurring in 41%, 22%, 15%, and 11%, respectively, of the feedlots.

Turkey feedlots (Table 7f) are dominated by storage of manure packs in buildings (84% of the feedlots), with another 11% of turkey feedlots using stockpiling with no protective structure. There is a small tendency (6%) for the largest turkey feedlots to use earthen holding basins.

Based on the information presented on manure storage systems only, and assuming all other factors are equal, the risk of surface water pollution from feedlots decreases in the order:

Dairy > beef > hogs > chickens > turkeys

The risk for polluting surface water tends to be greatest from solid manure (based only on storage type) with smaller sized feedlots rather than larger sized feedlots. Smaller feedlots tend to have a greater likelihood of having daily haul or stockpiling without protective cover. The risk for polluting ground water tends to be greatest from liquid manure (based only on storage type) with larger sized feedlots rather than smaller feedlots. Larger feedlots tend to use earthen storage basins for liquid manure more than smaller feedlots.

E. Manure Application Methods

Animal manure may be applied to land by broadcasting, broadcasting with incorporation, injection, or irrigation (Table 8a). In general, injection or incorporation of manure leads to smaller risks for polluting surface water than for all other methods. The site-specific risks to water quality from any of these operations also depends on the amount applied, the nutrient content of the manure, the time of spreading relative to rainstorms or snowmelt, the slope of the landscape, the proximity of the land to water bodies or tile intakes, the depth to ground water, conservation practices used, the type of soil, the amount of residual nutrients in the soil, the type of crop and crop yields, and the manure application history.

Most animal manure in Minnesota is broadcast on the land, with this technique alone being used in from 91-93% of the poultry operations(Tables 8b-c), 84-89% of the beef and dairy operations, and 65% of the hog operations. Injection of manure tends to be more prevalent in hog operations

Table 7e. Proportion of chicken feedlots by storage type and size class.

Storage type	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Poured concrete tank	0.0	50.0	30.8	22.2	42.1	27.5
Concrete block/stave pit	12.5	0.0	0.0	3.7	0.0	2.9
Earthen holding basin	0.0	50.0	15.4	14.8	0.0	10.1
Aerated lagoon	0.0	0.0	0.0	0.0	0.0	0.0
Above ground tank	0.0	0.0	7.7	3.7	10.5	5.8
Solid stacking slab	0.0	0.0	7.7	11.1	0.0	5.8
Daily hauling (no storage)	0.0	0.0	0.0	3.7	10.5	4.3
Stockpiling (no structure)	25.0	0.0	15.4	0.0	10.5	8.7
Manure pack in buildings	62.5	0.0	23.1	40.7	21.1	33.3
Other	0.0	0.0	0.0	0.0	5.3	1.4
All types	100.0	100.0	100.0	100.0	100.0	100.0

Table 7f. Proportion of turkey feedlots by storage type and size class.

Storage type	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Poured concrete tank	0.0	0.0	0.0	0.0	0.0	0.0
Concrete block/stave pit	0.0	0.0	0.0	1.8	0.0	1.0
Earthen holding basin	0.0	0.0	0.0	0.0	5.7	2.0
Aerated lagoon	0.0	0.0	0.0	0.0	0.0	0.0
Above ground tank	0.0	0.0	0.0	0.0	0.0	0.0
Solid stacking slab	0.0	0.0	0.0	0.0	0.0	0.0
Daily hauling (no storage)	0.0	0.0	0.0	0.0	0.0	0.0
Stockpiling (no structure)	0.0	0.0	0.0	9.1	17.1	11.2
Manure pack in buildings	0.0	100.0	85.7	87.3	77.1	83.7
Other	0.0	0.0	14.3	1.8	0.0	2.0
All types	0.0	100.0	100.0	100.0	100.0	100.0

Table 8a. Proportion of all feedlots by application method and animal type.

Application method	Animal type				
	Beef	Chicken	Dairy	Hog	Turkey
	%				
Spreading	84.5	91.4	88.8	64.8	92.7
Injection	3.2	2.9	4.2	17.1	0
Irrigation	0.1	0	0.1	0.1	0
More than one type	12.2	5.7	6.9	17.9	7.3
All methods	100.0	100.0	100.0	100.0	100.0

Table 8b. Proportion of turkey feedlots by application method and size class.

Application method	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Spreading	0.0	100.0	100.0	96.3	85.3	92.7
Injection	0.0	0.0	0.0	0.0	0.0	0.0
Irrigation	0.0	0.0	0.0	0.0	0.0	0.0
More than one type	0.0	0.0	0.0	3.7	14.7	7.3
Other	0.0	0.0	0.0	0.0	0.0	0.0
All methods	0.0	100.0	100.0	100.0	100.0	100.0

Table 8c. Proportion of chicken feedlots by application method and size class.

Application method	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Spreading	100.0	100.0	92.9	92.6	84.2	91.4
Injection	0.0	0.0	7.1	0.0	5.3	2.9
Irrigation	0.0	0.0	0.0	0.0	0.0	0.0
More than one type	0.0	0.0	0.0	7.4	10.5	5.7
Other	0.0	0.0	0.0	0.0	0.0	0.0
All methods	100.0	100.0	100.0	100.0	100.0	100.0

(17%) than in beef or dairy operations (3-4%), or in poultry operations (0-3%). Incorporation of broadcast manure within 4 days after spreading is commonly practiced in 18% of hog operations, from 7-12% of dairy and beef operations, and 6-7% of poultry operations (Fig. 5a). From these figures, we estimate that manure is broadcast and incorporated, or injected in 35% of hog operations, 11-15% of dairy or beef operations, and 7-9% of poultry operations.

Injection and incorporation of manure tends to increase in frequency as the size class of hog feedlots increases (Table 8d, Fig. 5b). Roughly 4%, 4%, 12%, 24%, and 39% of tiny, very small, small, moderate, and large hog feedlots, respectively, use injection of manure. Also, 1%, 6%, 11%, 28%, and 38% of tiny, very small, small, moderate, and large hog feedlots, respectively, incorporate manure after spreading. Thus, we see that 5% of tiny feedlots inject or incorporate manure, while 77% of large hog feedlots do. Winter applications of hog manure are most likely from daily haul operations. Only 6% of hog feedlots are daily haul operations.

Injection and incorporation of manure also tends to increase in frequency with the size of beef feedlots (Table 8e, Fig. 5c). Roughly 0%, 1%, 4%, 5%, and 13% of tiny, very small, small, moderate, and large beef feedlots, respectively, use injection of manure. Also, 2%, 6%, 13%, 20%, and 23% of tiny, very small, small, moderate, and large beef feedlots inject manure. Thus, 2%, 7%, 17%, 25%, and 39% of tiny, very small, small, moderate, and large beef feedlots, respectively, inject or incorporate manure. As mentioned in the section on manure storage, about 5% of beef feedlots are daily haul operations. The riskiest time of application in these operations is winter spreading.

For dairy feedlots (Table 8f, Fig. 5d), 1%, 3%, 5%, 11%, and 6% of tiny, very small, small, moderate, and large feedlots inject manure. Another 4%, 2%, 7%, 23%, and 62% of tiny, very small, small, moderate, and large feedlots incorporate manure. Thus, a total of 5%, 5%, 12%, 34%, and 68% of tiny, very small, small, moderate, or large dairy feedlots inject or incorporate manure. As noted in the section on manure storage types, 23% of dairy feedlots have no storage. They use daily haul, including broadcast application of manure to frozen or snow covered soil during winter. This practice has a high potential for polluting surface waters.

In summary, we see that as the size of an animal feedlot increases, the application methods tend to shift from broadcasting to injection or to broadcasting with incorporation. This trend is more pronounced for hog feedlots than for beef and dairy feedlots. Poultry feedlots rarely use injection or incorporation of manure, rather relying on spreading.

Based on the above information, and assuming all other factors (such as rate of application and numbers of feedlots) are equal, the risk of polluting surface water from land applied manure typically decreases in the order:

Daily haul > Non-daily haul broadcasting > broadcasting + incorporation > injection

Table 8d. Proportion of hog feedlots by application method and size class.

Application method	Feedlot size in animal units 1-49	50-99	100-299	300-999	1000+	All classes
	%					
Spreading	95.1	89.5	77.2	47.4	22.6	64.8
Injection	4.0	4.2	11.7	23.8	38.9	17.1
Irrigation	0.0	0.0	0.0	0.2	0.4	0.1
More than one type	0.9	6.3	11.0	28.0	38.1	17.8
Other	0.0	0.0	0.0	0.6	0.0	0.2
All methods	100.0	100.0	100.0	100.0	100.0	100.0

Table 8e. Proportion of beef feedlots by application method and size class.

Application method	Feedlot size in animal units 1-49	50-99	100-299	300-999	1000+	All classes
	%					
Spreading	97.6	92.1	82.6	75.0	61.3	84.5
Injection	0.0	1.4	3.7	4.6	12.9	3.2
Irrigation	0.0	0.7	0.0	0.0	0.0	0.1
More than one type	2.4	5.8	13.7	20.4	25.8	12.2
Other	0.0	0.0	0.0	0.0	0.0	0.0
All methods	100.0	100.0	100.0	100.0	100.0	100.0

Table 8f. Proportion of dairy feedlots by application method and size class.

Application method	Feedlot size in animal units 1-49	50-99	100-299	300-999	1000+	All classes
	%					
Spreading	94.6	95.1	88.8	65.5	31.3	88.8
Injection	1.1	2.8	4.6	10.9	6.3	4.2
Irrigation	0.0	0.0	0.0	0.9	0.0	0.1
More than one type	4.3	2.1	6.7	22.7	62.5	6.9
Other	0.0	0.0	0.0	0.0	0.0	0.0
All methods	100.0	100.0	100.0	100.0	100.0	100.0

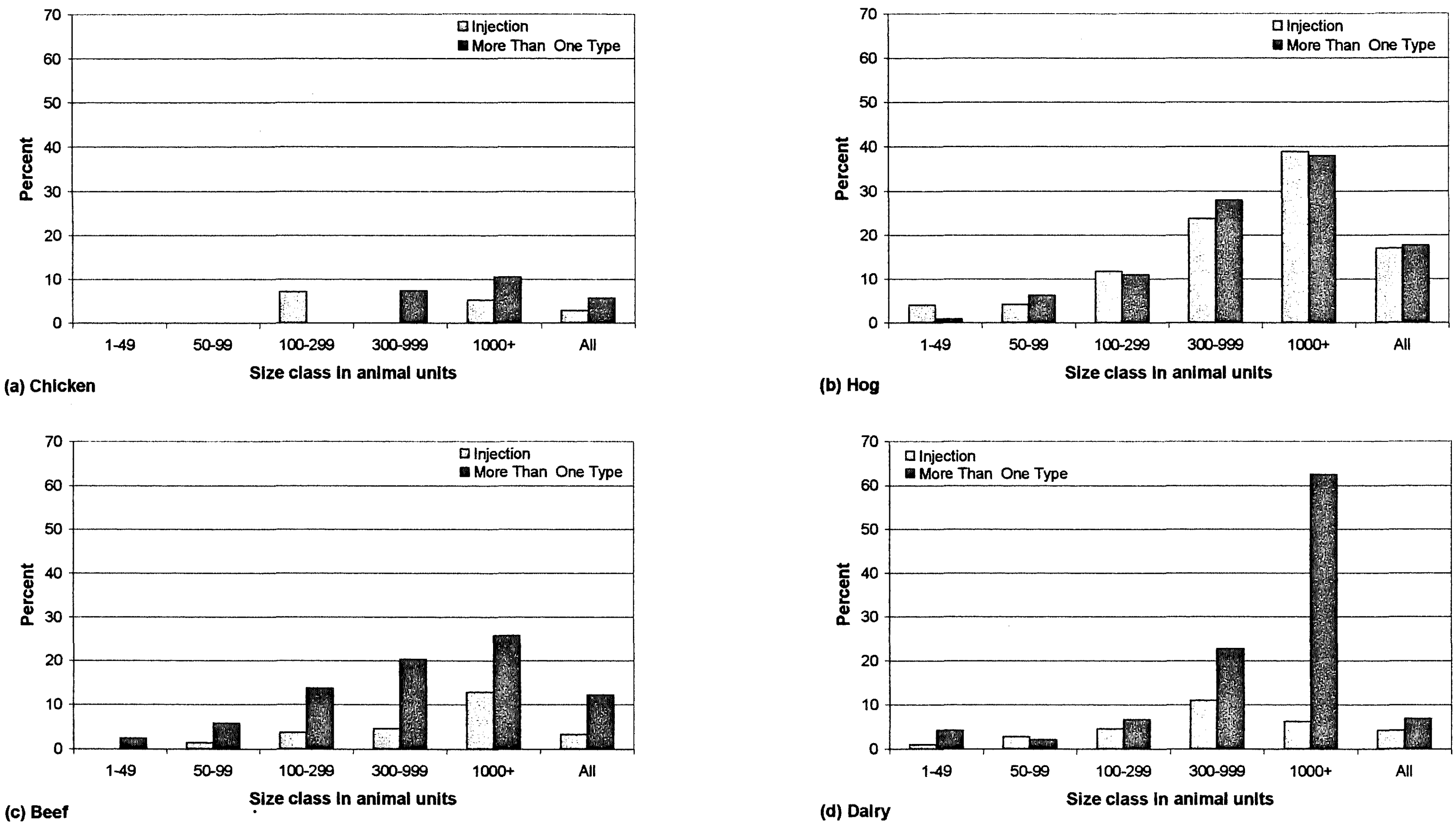


Figure 5. Proportion of (a) chicken, (b) hog, (c) beef, and (d) dairy feedlots using injection or more than one type of method for application by size class.

Nutrients Applied to Soil From Manure

F. FANMAP Surveys of Excess Nutrients Applied to Manured Lands

The MDA conducted FANMAP surveys (MDA, 1998) of selected feedlots in several regions of Minnesota. These surveys included information on rate and method of application, timing of application, and type of crop receiving manure.

In south central Minnesota, most swine manure is applied to corn acres (74%), while 22% is applied to soybeans. Manure is generally applied in the fall (53% of the time) or spring (31%), with 8% being applied in summer, and 8% applied in winter. Application methods include 40% broadcast (no incorporation), 36% broadcast with incorporation, and 24% injection.

In south central Minnesota, the average rates of N and P_2O_5 applied to corn from manure are 58 lb/ac and 102 lb/ac, respectively. The average rates of N and P_2O_5 applied to soybeans from manure are 49 lb/ac and 82 lb/ac, respectively. The average rates of N and P_2O_5 applied to corn from commercial fertilizer are 144 lb/ac and 46 lb/ac, respectively, and the rates applied to soybeans average 3 lb/ac and 54 lb/ac, respectively. The total rate of N and P_2O_5 applied to corn from all sources is 202 lb/ac and 184 lb/ac, respectively. The total rate of N and P_2O_5 applied to soybeans from all sources is 52 lb/ac and 136 lb/ac, respectively. With an N credit for legumes, the total rates of N and P_2O_5 applied to corn are in excess of University recommendations by 54 lb/ac and 169 lb/ac, respectively. The excess N and P_2O_5 applied to soybeans is 52 lb/ac and 121 lb/ac, respectively.

In Scott and Carver counties, hog and dairy manure is applied primarily to corn acres (60%), followed by soybeans (17%), and alfalfa (16%). Manure is applied mostly in fall (36% of the time) and spring (32%), followed by summer (16%) and winter (16%). Application methods include 57% broadcast (no incorporation), 21% broadcast with incorporation, and 22% injection. The average rates of N and P_2O_5 applied to corn from manure are 43 lb/ac and 72 lb/ac, respectively. Rates of manure applied to soybeans and alfalfa are similar to rates applied to corn. In contrast, the average rates of N and P_2O_5 applied to corn from commercial fertilizer are 136 lb/ac and 35 lb/ac, respectively, while soybeans receive 8 lb/ac and 21 lb/ac, respectively. The total rate of N and P_2O_5 applied from all sources to corn is 179 lb/ac and 107 lb/ac, respectively. When a credit for N from legumes is included, the total rates of N and P_2O_5 applied to corn are in excess of University recommendations by 43 lb/ac and 92 lb/ac, respectively.

In Lincoln and Pipestone counties, beef, dairy, and hog manure is applied mainly to corn acres (48%), followed by 21% soybean acres, and 10% small grain acres. Manure is applied 87% in the fall. Application methods include 12% broadcast (no incorporation), 13% broadcast with incorporation, and 75% injection. The average rates of N applied to corn and soybeans from manure are 18 lb/ac and 9 lb/ac, respectively. Commercial fertilizer is applied to corn at average rates of 109 lb/ac and 30 lb/ac, respectively, for N and P_2O_5. Commercial fertilizer is applied to soybeans at a rate of 21 lb P_2O_5/ac. Total rates of N and P_2O_5 applied to corn from all sources are 127 lb/ac and 30 lb/ac, respectively. With a legume N credit of 35 lb/ac, the total rate of N applied is in excess of the University recommendation by 23 lb N/ac.

In the Karst region of southeastern Minnesota, dairy manure is primarily applied to corn acres (83%), followed by small percentages in soybeans, alfalfa, and small grains. The amount of N applied to corn from manure is 42 lb/ac. The rate of commercial fertilizer applied to corn is 90 lb/ac for N and 30 lb/ac for P_2O_5. The average rate of commercial P_2O_5 applied to soybeans is 25 lb/ac. With a credit of 44 lb N/ac for previous legume crops, the total N applied to corn from all sources is in excess of the University recommendations by 41 lb/ac.

In the central outwash sand region, manure is applied primarily to corn acres (54%), followed by alfalfa (15%), and small grain (14%). The average rate of manure N applied to corn is 29 lb/ac, while 53 lb N/ac is applied as commercial fertilizer. Corn receives on average 18 lb P_2O_5/ac. With a legume N credit of 16 lb/ac, the total rate of N applied is in excess of the University of Minnesota's N recommendation by 38 lb/ac.

From these surveys, we see that manured lands can receive rates of nitrogen and phosphorus that are in excess of nutrient guidelines developed by the University of Minnesota. Excess nutrients applied to land increases the risk of surface and ground water pollution.

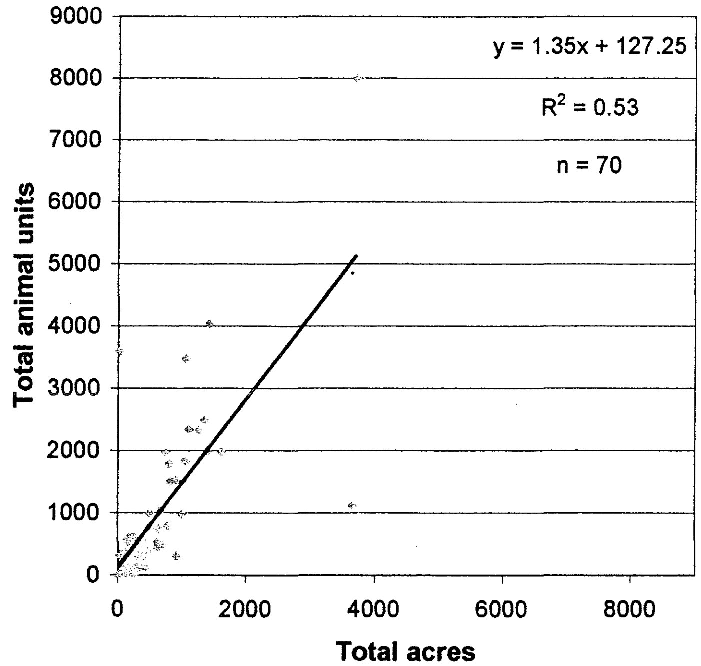
G. Acres of Cropland Available for Manure Application

As part of an MPCA feedlot permit application, owners must specify the total acres of cropland available for manure application. Only a small percentage of these acres are typically used for manure application in any year, according to FANMAP surveys, this is in the range of 30% for corn and 5% for soybean, wheat, or alfalfa acres. The feedlot permit application also specifies the animal units for each species of animal in the feedlot. For each species, we conducted linear regression between the total acres of cropland available for spreading and the number of animal units for each animal species. Except for turkeys, good relationships were observed between land available and animal units in the feedlot.

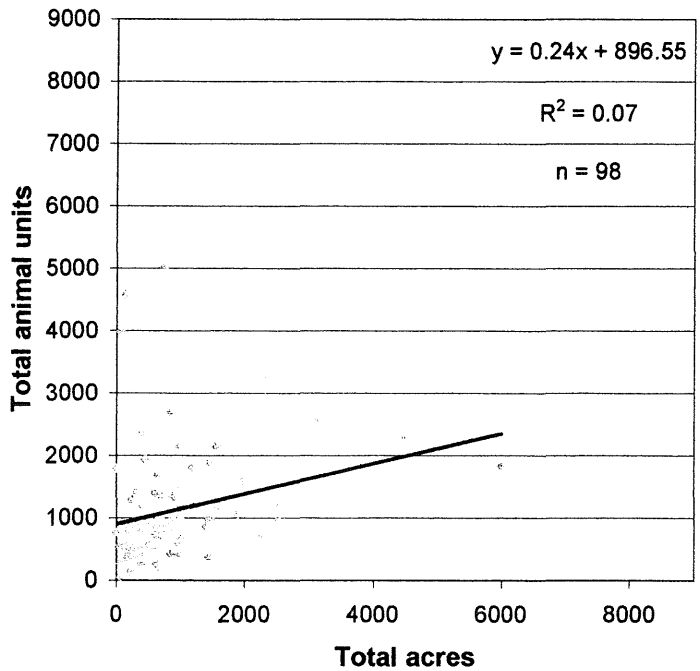
The relation between acres available for spreading and animal units for seventy chicken feedlots in the database was very good (Fig. 6a). As the number of animal units in the feedlot increased, so too did the acres of land available for manure application. The best fit line had a slope of 0.39 and an intercept of 213 acres. The regression line explained 53% of the variability in the database. There were two data outliers, one in which a 3,700 animal unit operation had less than 50 acres of land for manure application, and another in which a 1,100 animal unit operation had 3,600 acres of land for manure application. The regression line for 98 turkey feedlots (Fig. 6b) was a poor fit to the data, but had a slope of 0.27, and an intercept of 613 acres. This poor fit could reflect the prevailing practice in which turkey manure is sold commercially for distribution and land application away from the feedlot.

For 1,710 hog feedlots (Fig. 6c), the regression line between acres of land and animal units explained 33% of the variation in the data. The line had a slope of 0.44, and an intercept of 239 acres. Most of the scatter in this relationship was due to feedlots with upwards of 1.5 acres of land for every hog animal unit. There were few feedlots with as little as 0.25 acres of land for every hog animal unit.

For 753 beef feedlots (Fig. 6d), the regression line had a slope of 0.51, and an intercept of 202 acres. The regression line between animal units and manured land explained 29% of the variation in data. Scatter in the data occurred as a result of both feedlots with greater than 3

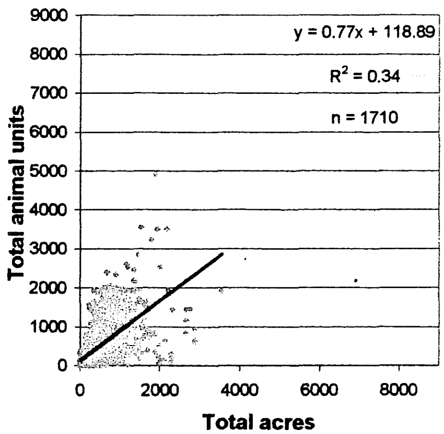


(a) Chicken

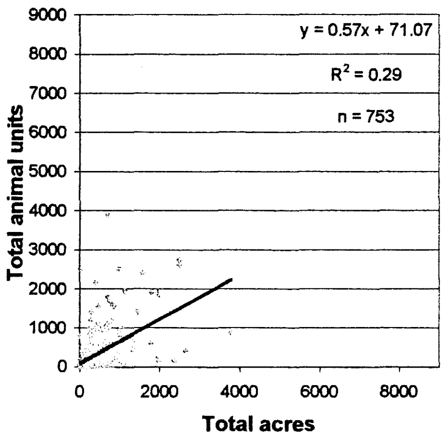


(b) Turkey

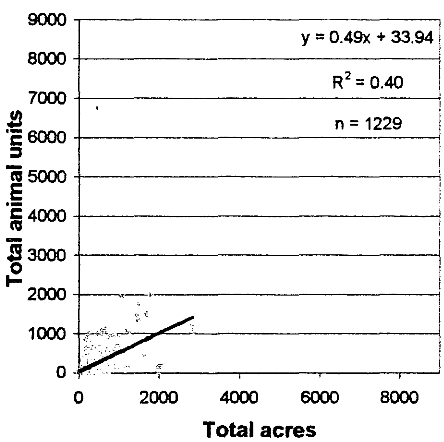
Figure 6. Relationship between total animal units and acres available for manure application for (a) chicken and (b) turkey feedlots.



(c) Hog



(d) Beef



(e) Dairy

Figure 6. Relationship between total animal units and acres available for manure application for (c) hog, (d) beef, and (e) dairy feedlots.

acres of manured land per animal unit, and feedlots with less than 0.3 acres of manured land per animal unit.

The regression line for 1,229 dairy feedlots (Fig. 6e) showed a slope of 0.82, and an intercept of 130 acres. The relationship explained 40% of the database variability. Scatter about the best fit line was mainly due to a few feedlots with greater than 2 acres of land available for every animal unit. A few feedlots had as little as 0.25 acres of manured land for every animal unit.

In summary, except for turkeys, the land available for application of manure increases linearly with the size (in A.U.s) of feedlots. Knowledge of the land available for manure application is crucial information that affects the rates of manure nutrients applied to land. For feedlots with equal numbers of animals and similar management practices, those with less land for manure spreading will have to apply higher rates, resulting in potential application of excess nutrients to the land.

H. Density of Animals

Using the regression lines relating animal units to acres of land available for manuring, we can calculate the amount of land available for manure application for feedlots of different size. The density of animals can then be estimated from the amount of land available for manure application.

As an example, consider 500-A.U. feedlots with average areas of land available for manure spreading based on the regressions in Figs. 6a-e. For 500 turkey A.U.s, we would have 750 acres of land available for manure application (1.5 ac/A.U.), although this acreage is subject to uncertainty because of long-distance hauling of turkey manure. For 500 chicken A.U.s, there are 409 acres of land available (0.82 ac/A.U.). For 500-A.U. hog or beef feedlots, there are 459 acres (0.92 ac/A.U.) or 456 acres (0.91ac/A.U.) available, respectively. For 500 dairy cattle A.U.s, there are 543 acres of land available (1.1 ac/A.U.). From these calculations, we see that the availability of land for manure application varies by animal species. Average land available for manuring (in ac./A.U.) on 500-A.U. feedlots decreases in the order:

Turkeys (1.5 ac/A.U.) > dairy (1.1) > hogs (0.92) = beef (0.91) > chickens (0.82)

Alternatively, we can convert A.U.s to animals, giving the average density of animals per acre of manured land for 500-A.U. feedlots:

Chickens (122 animals/ac) > turkeys (38) > hogs (2.7) > beef (1.1) > dairy (0.65)

Using the same approach, animal densities based on 100-A.U. feedlots (instead of 500-A.U. feedlots) are 39.7, 8.7, 0.88, 0.4, and 0.34 animals/ac for chickens, turkeys, hogs, beef cattle, and dairy cattle, respectively. Thus, animal densities are significantly smaller for 100-A.U. feedlots than for 500-A.U. feedlots.

In Europe, maximum allowed animal densities are 53.8, 40.5, 6.5, 1.6, and 0.8 animals/ac for chickens, turkeys, hogs, beef cows, and dairy cows, respectively. Comparing the European and

Minnesotan sets of animal densities, we see that for 500-A.U. feedlots, densities of chickens and dairy cattle in Minnesota are above the maximum limits allowed for animal feedlots in Europe. Densities of 500-A.U. turkey, hog, and beef cattle feedlots are below those allowed in Europe. On the other hand, densities of 100-A.U. chicken, turkey, hog, dairy, and beef feedlots in Minnesota are all below the maximum limits allowed in Europe.

For all feedlots in the eighteen counties studied, we estimated the animals per acre of land available for application of manure using cumulative probability density functions for the data points shown in Figs. 6a-e. The average densities for chickens (Fig. 7a), turkeys (Fig. 7b), hogs (Fig. 7c), beef (Fig. 7d), and dairy (Fig. 7e)were about 110, 50, 1.1, 0.3, and 0.4 animals per acre. The average densities of chicken and turkey feedlots are above the maximum limits set in Europe. The density of turkeys is subject to uncertainty due to long distance hauling of manure. The average densities of hog, beef, and dairy feedlots are below the maximum limits set in Europe.

Maps for animal densities in all minor watersheds studied and for each animal type are attached. The map for chickens (Fig. 8a) shows that animal densities in over three-fourths of the watersheds having chicken feedlots exceed the critical threshold density (53.8 chickens/ac) established in Europe. Chicken feedlots in Stearns, Todd, and Morrison counties are rarely below this threshold density.

The map for turkeys (Fig. 8b) shows that about half of the watersheds with turkey feedlots exceed the critical threshold density (40.5 turkeys/ac) established in Europe. The map of turkey densities is subject to uncertainty about the area of land available for spreading of manure from each turkey feedlot.

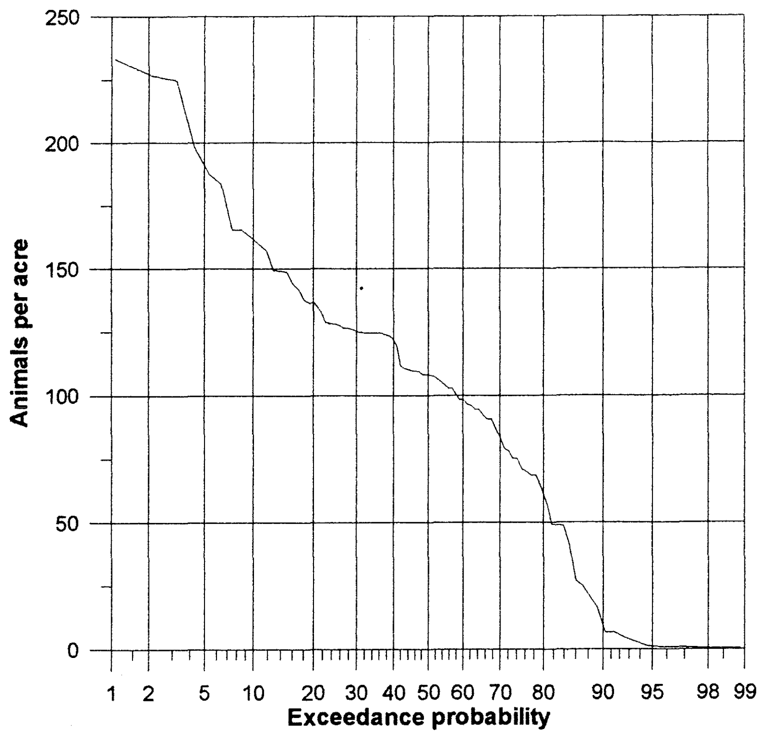
For hogs (Fig. 8c), less than one-fourth of the watersheds with hog feedlots have hog densities greater than the critical threshold value (6.5 hogs/ac) established in Europe. Watersheds with the densest concentration of hog feedlots are located in Blue Earth, Watonwan, Martin, Freeborn, Rock, and Pipestone counties.

Beef feedlots (Fig. 8d) do not generally exceed the European threshold density of 1.6 beef cattle/ac in any of the watersheds evaluated. Dairy cattle (Fig. 8e) also do not generally exceed the European threshold density of 0.8 dairy cattle/ac in any of the watersheds evaluated.

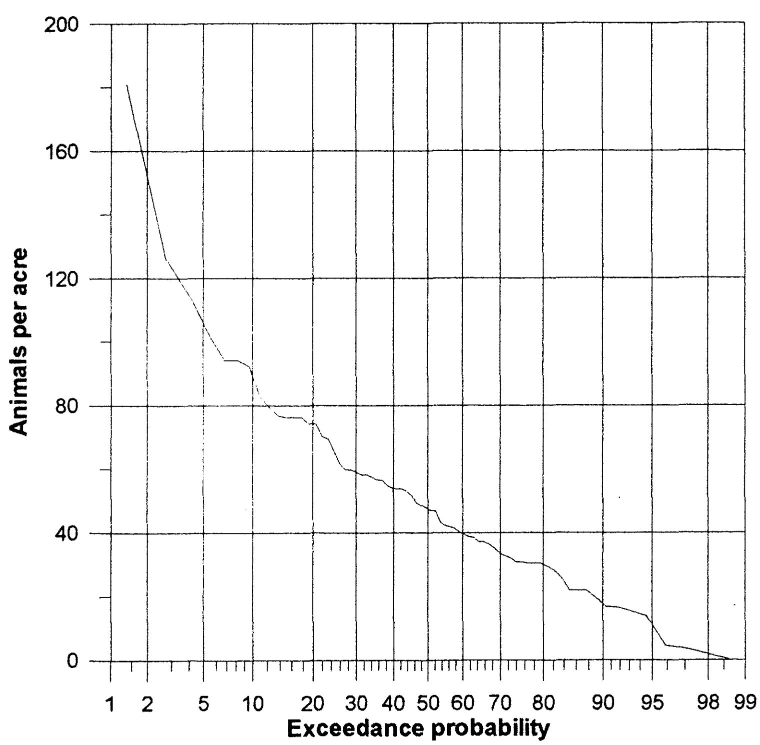
The densities of animals allowed in Europe may not be appropriate for Minnesota conditions. Minnesota methods of confinement and storage differ from those used in Europe.

I. Nutrients Applied to Land

We estimated the amount of land available for application of manure for each feedlot. This was done by using the regression lines relating land available for feedlots of varying animal unit numbers described in section F. The amount of land available was summed over all feedlots within each of the minor watersheds in the eighteen county study area. This gives the total amount of land available for long-term applications of manure within each minor watershed. This amount of land was compared with the amount of cropland within the minor watershed. A



(a) Chicken



(b) Turkey

Figure 7. Probability plots of (a) chicken and (b) turkey feedlot animal density.

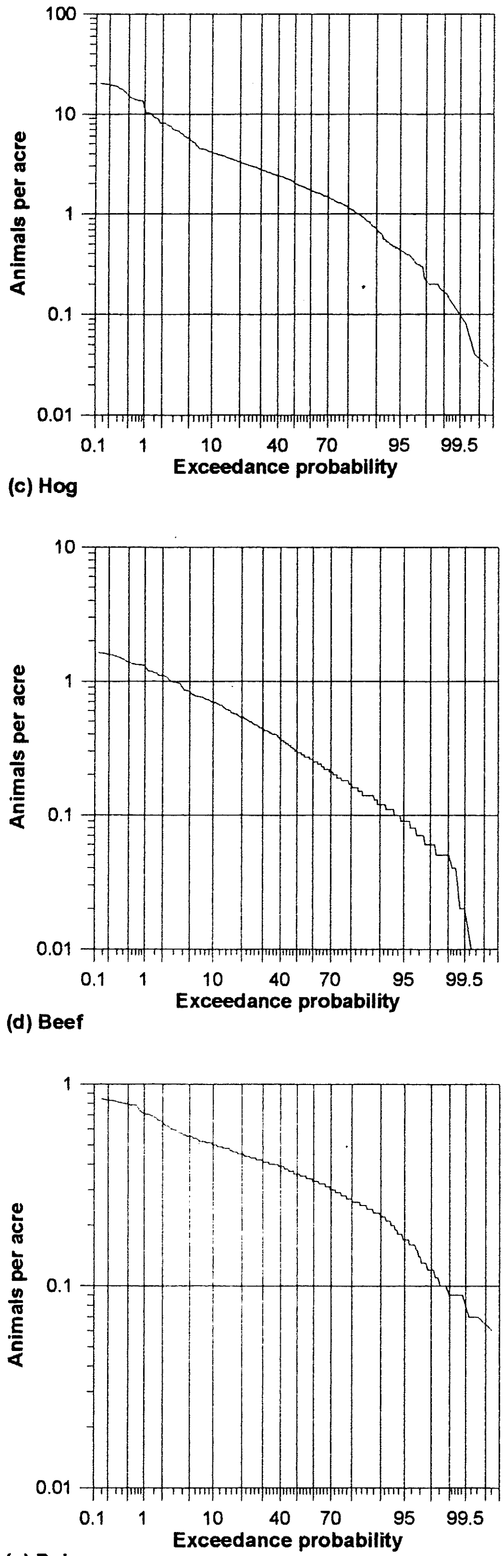


Figure 7. Probability plots of (c) hog, (d) beef, and (e) dairy feedlot animal density.

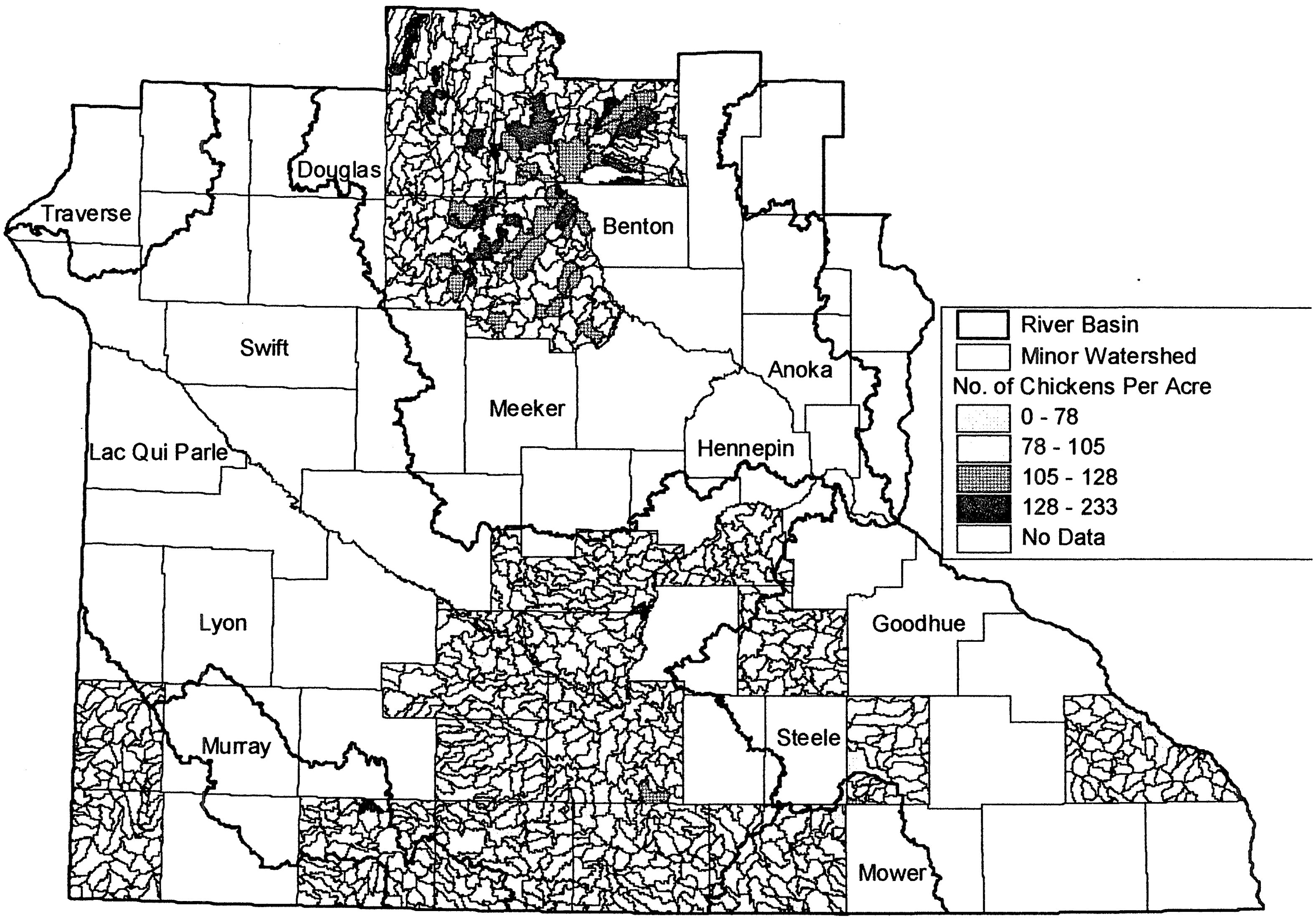


Figure 8a. Chicken density based on land available for manure application within each minor watershed.

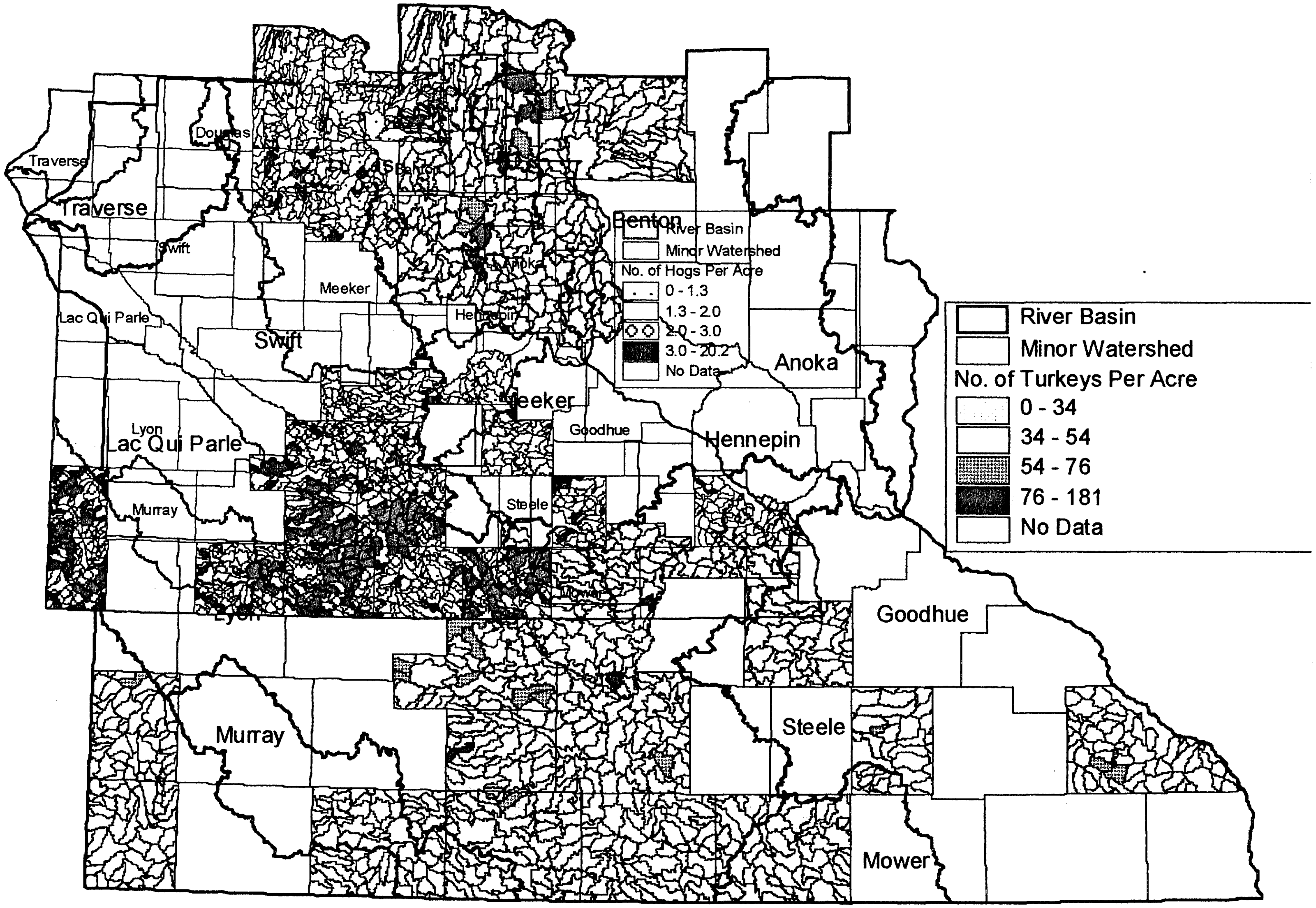


Figure 8b. Turkey density based on land available for manure application within each minor watershed.

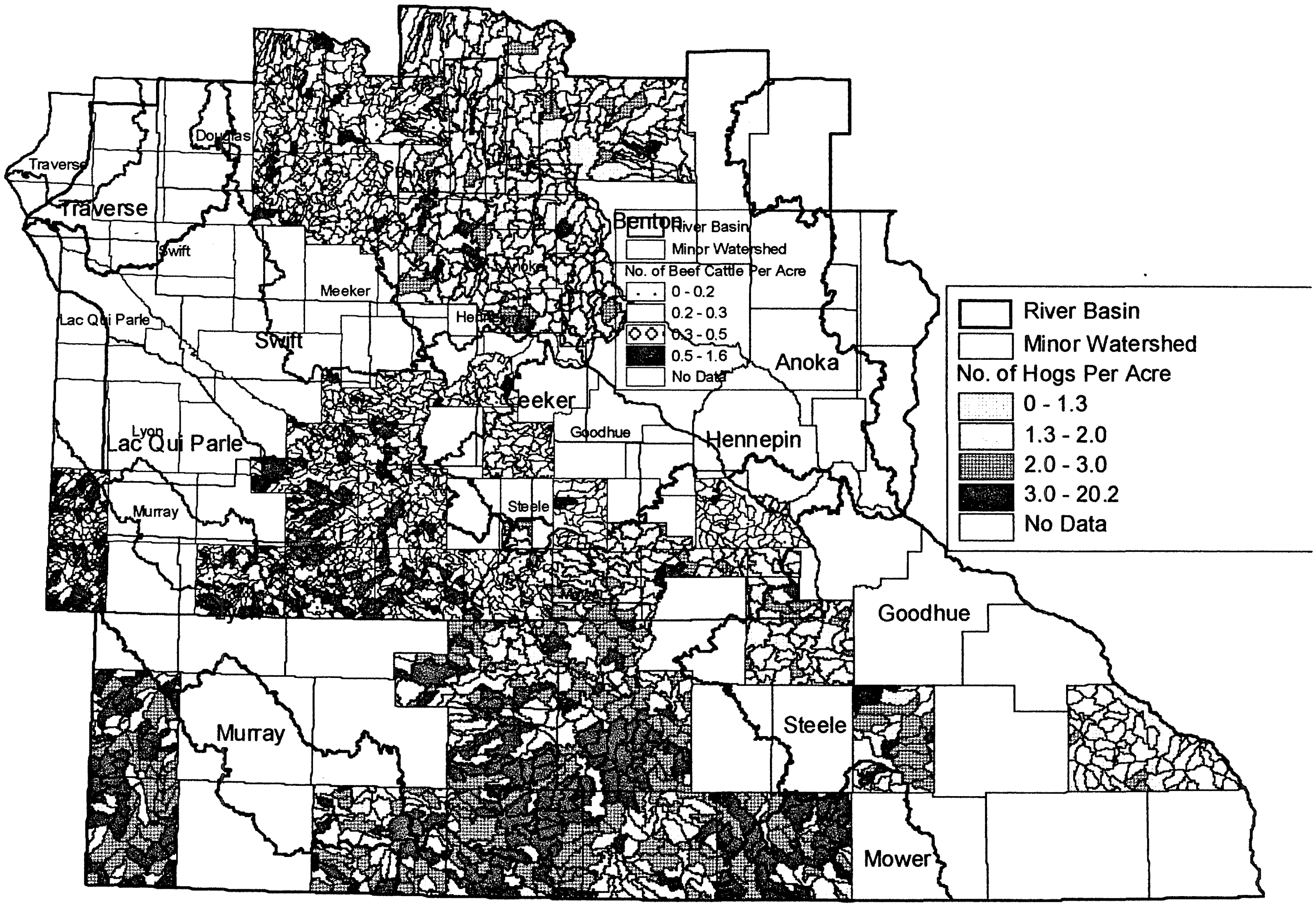


Figure 8c. Hog density based on land available for manure application within each minor watershed.

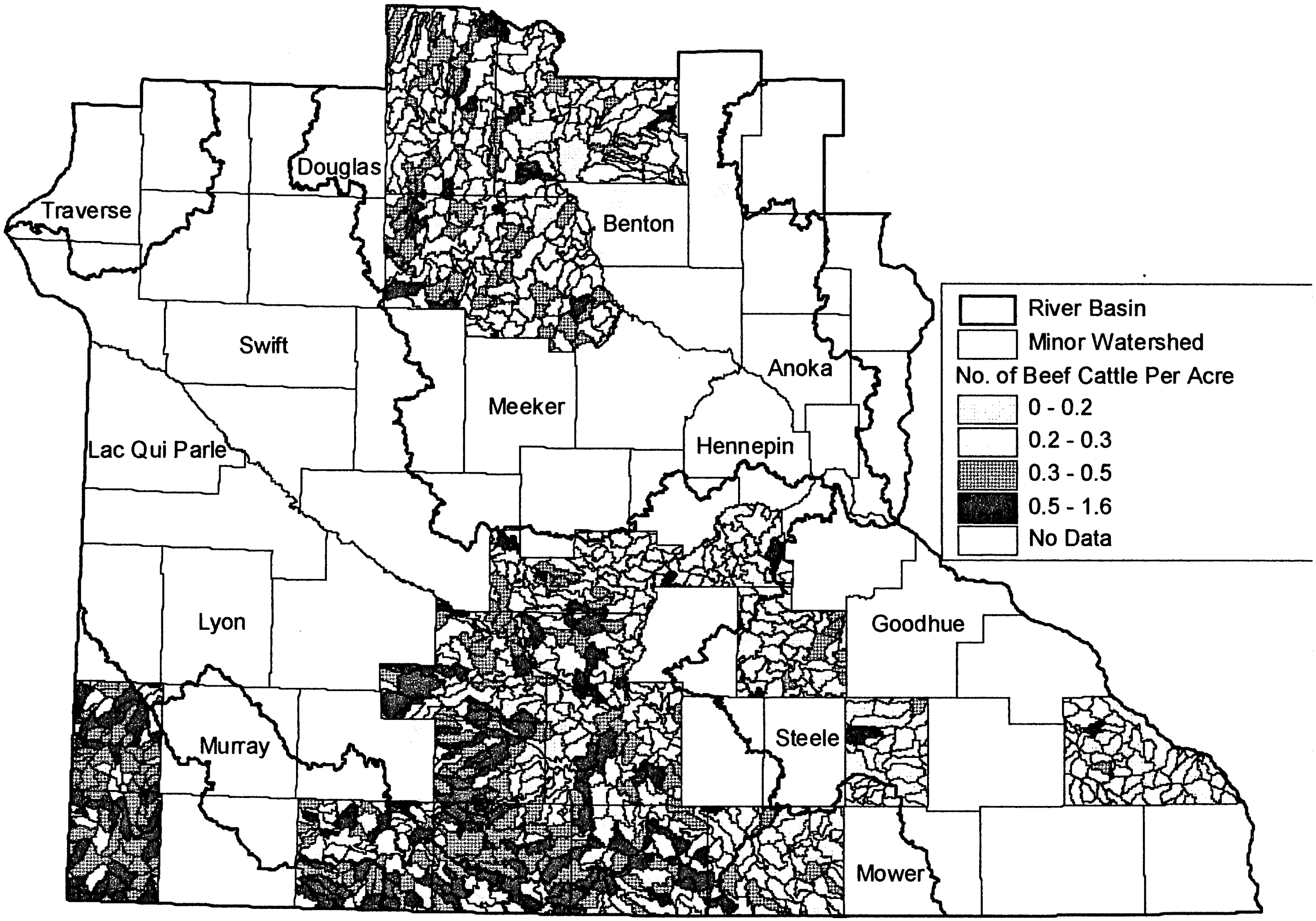


Figure 8d. Beef cattle density based on land available for manure application within each minor watershed.

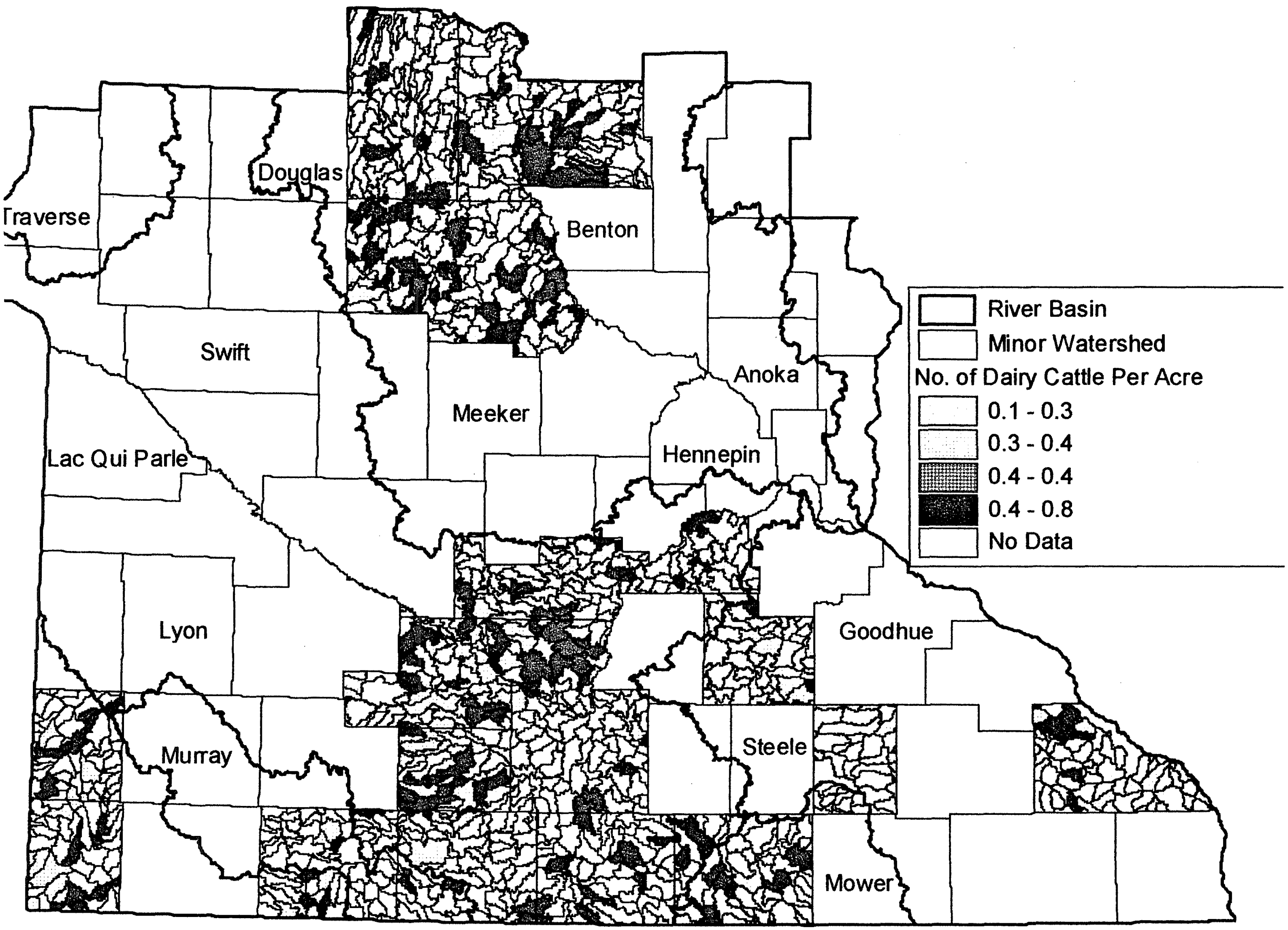


Figure 8e. Dairy cattle density based on land available for manure application within each minor watershed.

second scenario, based on FANMAP survey data, was used to estimate the amount of land available for application of manure in any given year. In this scenario, the amount of land available for long-term applications of manure was divided by two, assuming half the land was in corn, the other half in soybeans, wheat, or alfalfa. The corn acres were then multiplied by 0.3, while the soybean, wheat, or alfalfa acres were multiplied by 0.05. The sum of the resulting corn and soybean, wheat, or alfalfa acres represent the amount of land on which manure is actually applied in a given year.

Amounts of N and P generated by each feedlot in the eighteen county inventory were also estimated using the number of animals, animal type, the daily manure production per animal, and the nutrient content of manure (Table 9). An average manure collection loss was estimated for each region and each animal type based on FANMAP surveys. A weighted average storage loss rate for nitrogen was estimated for each animal type across all types of confinement (Table 10a) and storage (Table 10b) methods in the MPCA feedlot permitting database. A weighted average application loss rate for nitrogen was estimated across animal types and land application methods (Table 10c). Thus, we arrived at estimates of the total N and P applied to the land based on nutrient losses for manure generated from all feedlots in the eighteen county study area.

The amount of N and P applied to the land was summed over all feedlots within each of the minor watersheds in the study area. This gives the total amount of N and P applied to cropland within each of the minor watersheds. The amount of N calculated was then multiplied by 0.55 to estimate the amount of N applied that is available for crop uptake and leaching in the first year after application (Table 10d). After converting P to P_2O_5, the total amount of N and P_2O_5 applied was then divided by the amount of land available for either long-term or single year applications of manure, giving the average rates of N and P_2O_5 applied to land within each minor watershed.

Maps for average application rates of N for minor watersheds in the study area are attached. To put these rates in perspective, the University of Minnesota currently recommends applying roughly 120 lb N/ac to unmanured corn acres in most of the counties studied. For the first scenario involving long-term manure nitrogen applications to all available land, average N rates (Fig. 9a) are within the ranges of reasonable agronomic values in most watersheds, but there is a wide range in rates. The rates range from below 10 lb N/ac to almost 150 lb N/ac. The average rate is about 15 lb/ac (Fig. 11a). One fourth of the rates are above 20 lb N/ac, mostly in the counties of Blue Earth, Martin, and Morrison. For the second scenario involving single-year application rates of nitrogen, average rates applied (Fig. 9b) are much greater than those applied using the long-term scenario. Rates for the single-year scenario vary from 1 lb N/ac to over 800 lb N/ac. Three-fourths of the single-year applied rates of N exceed 58 lb N/ac. This results in the potential for significant over-application of N to cropland if the lands receiving manure are also fertilized with inorganic N fertilizer, without accounting for the N credits from manure. Average rates of commercial N fertilizer applied to most counties in the study area exceed 80 lb N/ac annually, with some average rates approaching 180 lb N/ac.

Maps for average application rates of P_2O_5 for minor watersheds in the study area are attached. To put these rates in perspective, the University of Minnesota currently recommends applying roughly 50 lb P_2O_5/ac to unmanured corn-soybean rotation acres in most of the counties studied.

Table 9. Manure production and characteristics for selected animal types.

Animal type	Size	Total manure production		Nutrient content	
				N	P_2O_5
	lbs	lbs/day	gal/day	lbs/day	lbs/day
Beef and heifers	1000	60	7.1	0.340	0.250
Feeder beef	1000	60	7.1	0.340	0.250
Beef replacement	1000	60	7.1	0.340	0.250
Dairy	1400	120	14.5	0.595	0.240
Calf (dairy)	500	43	5.2	0.213	0.090
Calf (beef)	500	30	3.6	0.170	0.130
Young dairy stock	1000	86	10.4	0.425	0.170
Nursing hogs	50	3.3	0.06	0.028	0.017
Hog	140	9	1.1	0.065	0.046
Chicken	4	0.21	0.026	0.003	0.003
Turkey	18	0.7	na	0.009	0.008

Table 10a. Fraction of manure N and P_2O_5 collected based on FANMAP region.

Animal type	FANMAP region: Central and outwash	Pipestone	Karst	Lincoln	South-central	Bevens	Average
	%						
Beef and heifers	na	21.0	na	49.2	42.3	32.7	36
Feeder beef	57.6	60.2	53.3	56.1	63.4	34.3	65
Beef replacement	na	25.0	na	na	91.0	69.4	62
Dairy	90.7	81.8	77.3	84.7	90.7	86.3	85
Calf (dairy)	na	25.0	na	63.8	na	88.8	59
Calf (beef)	na	25.0	na	63.8	na	88.8	59
Young dairy stock	62.9	na	67.0	63.8	na	79.1	68
Nursing hogs	100.0	100.0	100.0	na	89.0	na	97
Hog	100.0	100.0	100.0	na	91.1	na	98
Chicken	100.0	100.0	100.0	100.0	100.0	100.0	100
Turkey	100.0	100.0	100.0	100.0	100.0	100.0	100

Table 10b. Proportion of total weighted manure N storage losses.

Storage type	Animal type: Beef	Chicken	Dairy	Hog	Turkey
	%				
Poured concrete tank	2.40	5.60	2.60	12.20	0.00
Concrete block/stave pit	0.69	0.69	0.46	1.15	0.23
Earthen holding basin	4.80	3.00	11.70	3.30	0.60
Aerated lagoon	0.00	0.00	0.00	0.00	0.00
Above ground tank	0.20	1.20	0.60	0.20	0.00
Solid stocking slab	0.60	1.80	1.20	0.00	0.00
Daily hauling (no storage)	1.40	1.12	6.44	1.68	0.00
Stockpiling (no structure)	3.36	4.32	0.96	0.96	5.28
Manure pack in buildings	15.60	9.90	3.30	3.90	25.20
Other	1.02	0.34	1.02	0.34	0.68
Total weighted storage loss	30.07	27.97	28.28	23.73	31.99

Table 10c. Proportion of total weighted manure N application losses.

Application method	Animal type				
	Beef	Chicken	Dairy	Hog	Turkey
	%				
Broadcast (no incorporation)	16.80	14.10	17.80	16.25	13.95
Broadcast (incorporated less than 12 h)	2.10	2.35	4.45	3.25	2.33
Sweep	0.08	na	0.10	0.43	na
Knife	0.15	na	0.20	1.28	na
Irrigation	na	na	na	na	na
More than one type	5.88	1.05	1.12	3.60	1.23
Total weighted application loss	20.93	17.50	23.67	24.50	17.50

Table 10d. Proportion of total weighted 1st year available manure N.

Application method	Animal type				
	Beef	Chicken	Dairy	Hog	Turkey
	%				
Broadcast (no incorporation)	10.56	21.15	8.90	11.38	20.93
Broadcast (incorporated less than 12 h)	25.33	32.9	24.48	24.38	32.55
Sweep	0.97	na	1.10	6.80	na
Knife	0.80	na	1.00	5.95	na
Irrigation	na	na	na	na	na
More than one type	5.94	3.48	3.15	11.70	4.06
Total weighted 1st year available N	43.60	57.5	38.63	60.21	57.54

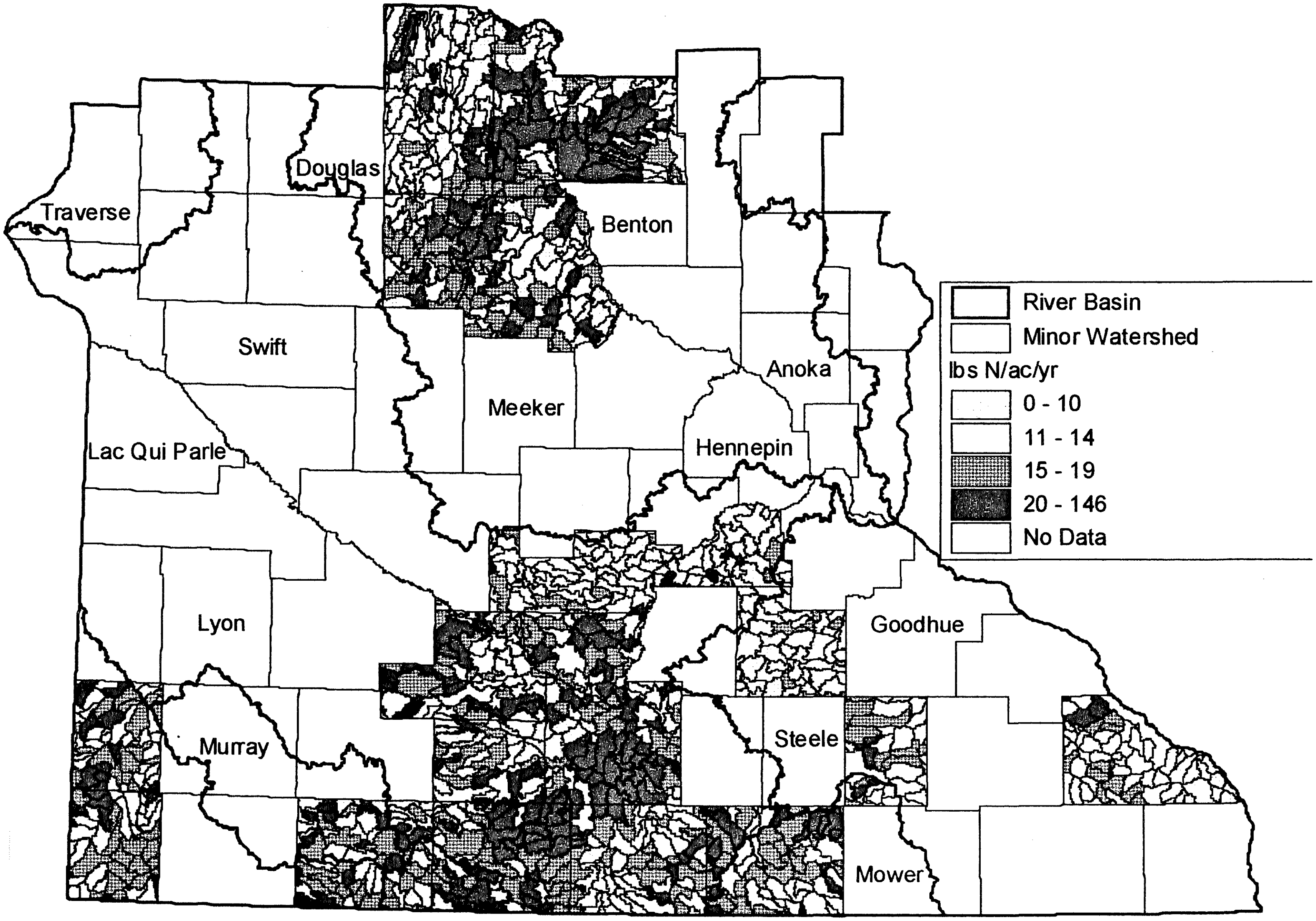


Figure 9a. Long-term manure N application rates.

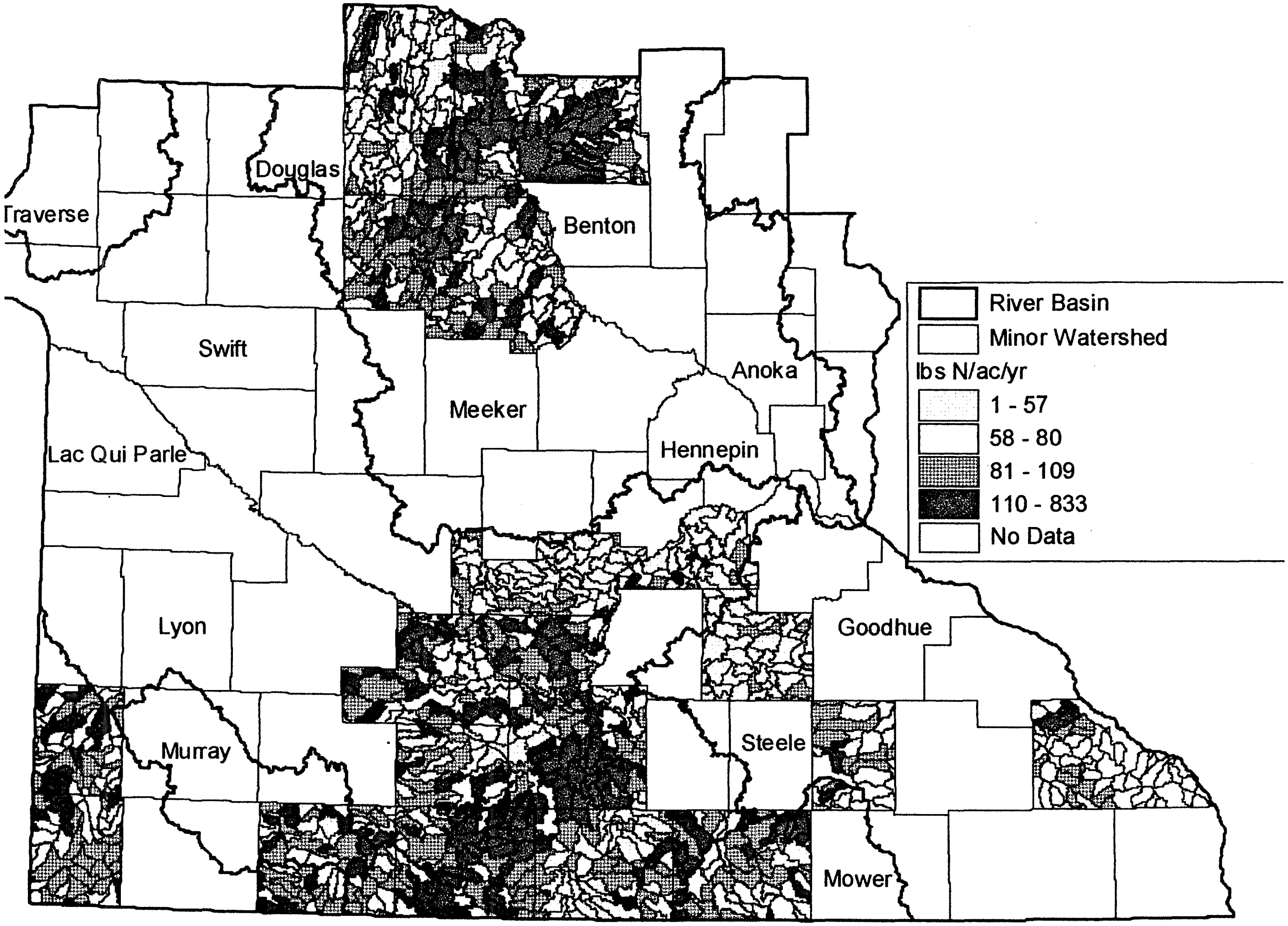


Figure 9b. Single-year manure N application rates.

For the first scenario involving manure P_2O_5 applications to all available land (Fig. 10a), average P_2O_5 rates are agronomically reasonable, ranging from 1 lb P_2O_5/ac to over 41 P_2O_5/ac. The average rate is 30 lb P_2O_5/ac (Fig. 11b). One fourth of the average rates exceed 41 lb P_2O_5/ac, primarily in the counties of Blue Earth, Martin, and Morrison. In the scenario where manure is applied to only a small portion of the available cropland in a given year (Fig. 10b), the single year rates increase greatly, with three fourths of the rates exceeding 121 lb P_2O_5/ac annually. The average single year rate is about 110 lb P_2O_5/ac (Fig. 12b). The main threat to water quality in this case would arise if this rate is applied over the long-term to soil near a waterbody or a surface tile intake, especially if commercial fertilizer is also applied to the same soil. Rates of commercial fertilizer applied to cropland in the study area range from 10 lb P_2O_5/ac to about 100 lb P_2O_5/ac.

Rates of nitrogen and phosphorus applied to land in manure (based on cumulative probability distributions) vary considerably by animal species. The average long-term rates of N and P_2O_5 applied to land in beef manure (Fig. 13ab) are 3 lb/ac and 9 lb/ac, respectively. The average rates applied from dairy manure (Fig. 14ab) are 13 lb N/ac and 26 lb P_2O_5/ac. Hog manure is applied on average at rates (Fig. 15ab) of 14 lb N/ac and 29 lb P_2O_5/ac. Chicken manure is applied at average rates (Fig. 16ab) of 46 lb N/ac and 130 lb P_2O_5/ac. The average long-term rates of N and P_2O_5 applied to land from turkey manure (Fig. 17ab) are 51 lb/ac and 139 lb/ac, respectively. The rates of application for turkeys may be inflated due to uncertainty in the area of land available for spreading manure. On average, the long-term rates of N and P_2O_5 applied to land from manure decrease in the order:

Turkeys > chickens > hogs > dairy > beef

Some managers are good stewards of the land, others are poor. Maximum rates of land applied organic N and P vary widely by animal species. Only 10% of beef feedlots apply N at long-term rates exceeding 10 lb/ac, and P_2O_5 at long-term rates exceeding 30 lb/ac. For dairy feedlots, 10% of feedlots apply N and P_2O_5 at rates exceeding 20 lb/ac and 40 lb/ac, respectively. Only 10% of hog feedlots apply N and P_2O_5 at rates exceeding 30 lb/ac and 60 lb/ac, respectively. Chicken feedlots apply greater than 65 lb N/ac and 175 lb P_2O_5/ac in less than 10% of the operations. Only 10% of turkey feedlots apply N and P_2O_5 at long-term rates exceeding 90 lb/ac and 250 lb/ac, respectively.

The proportion of cropland varies considerably (Fig. 18), with most of southern Minnesota having in excess of 75% of the land in cultivation. In contrast, Morrison, Todd, Winona, Stearns, and Rice counties have some portions where cropland is less than half of the total area. The proportion of cropland on which manure is applied varies considerably across the study area (Fig. 19). This variation is due to two factors, the first being the amount of cropland in the watershed, the second being the density of feedlots. About one fourth of the minor watersheds studied already use more than 85% of cropland for manure applications. These watersheds are located primarily in those areas where cropland is limited, namely; Rice, Winona, and eastern Stearns counties. Rice and Winona have numerous small feedlots. Rice is dominated by hogs, dairy and beef cattle, while Winona is dominated by dairy and beef cattle. It is important to note that policy decisions about expansion of animal agriculture in these counties should not be based solely on the proportion of cropland already used for land application of manure. In Rice and

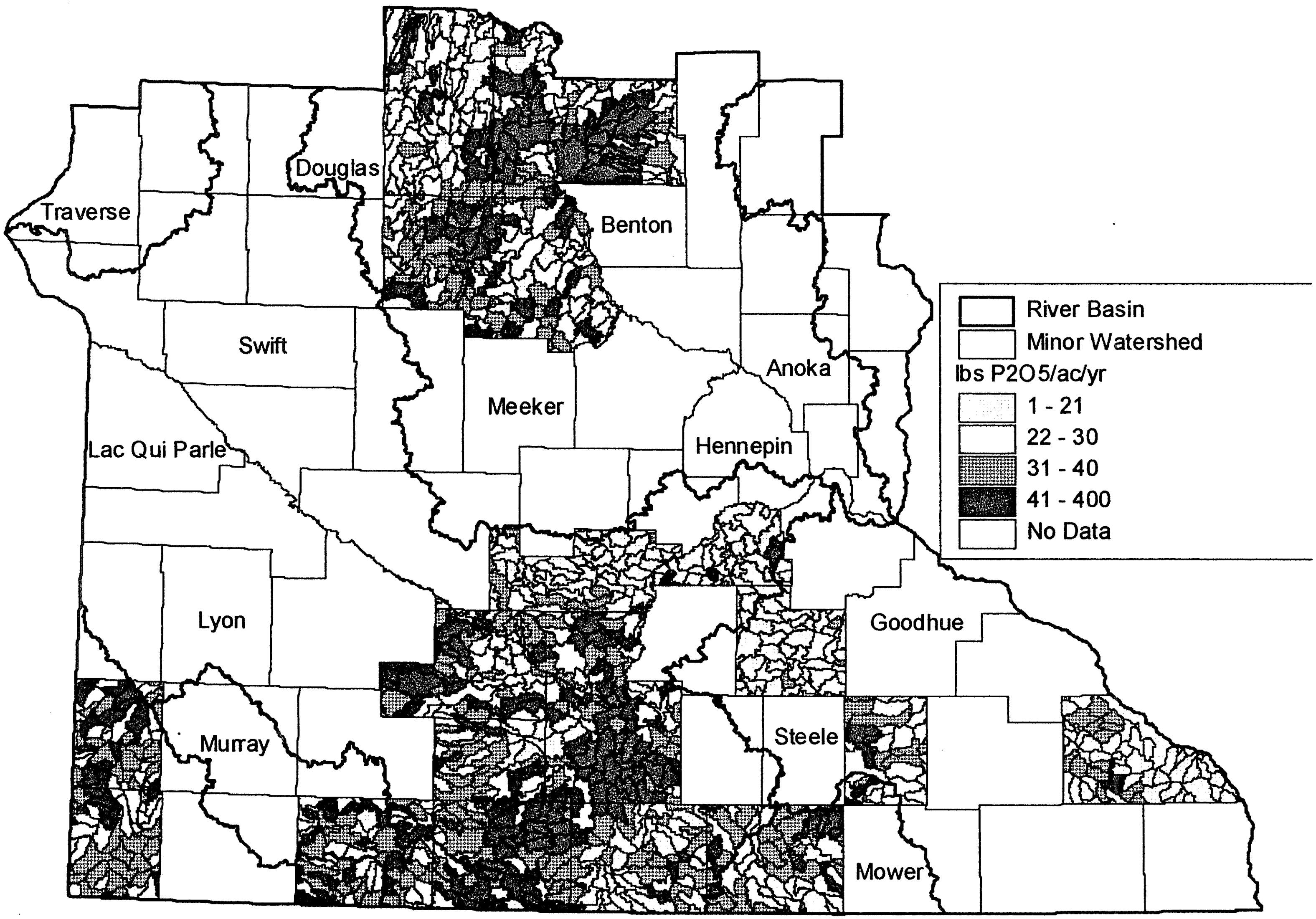


Figure 10a. Long-term manure P_2O_5 application rates.

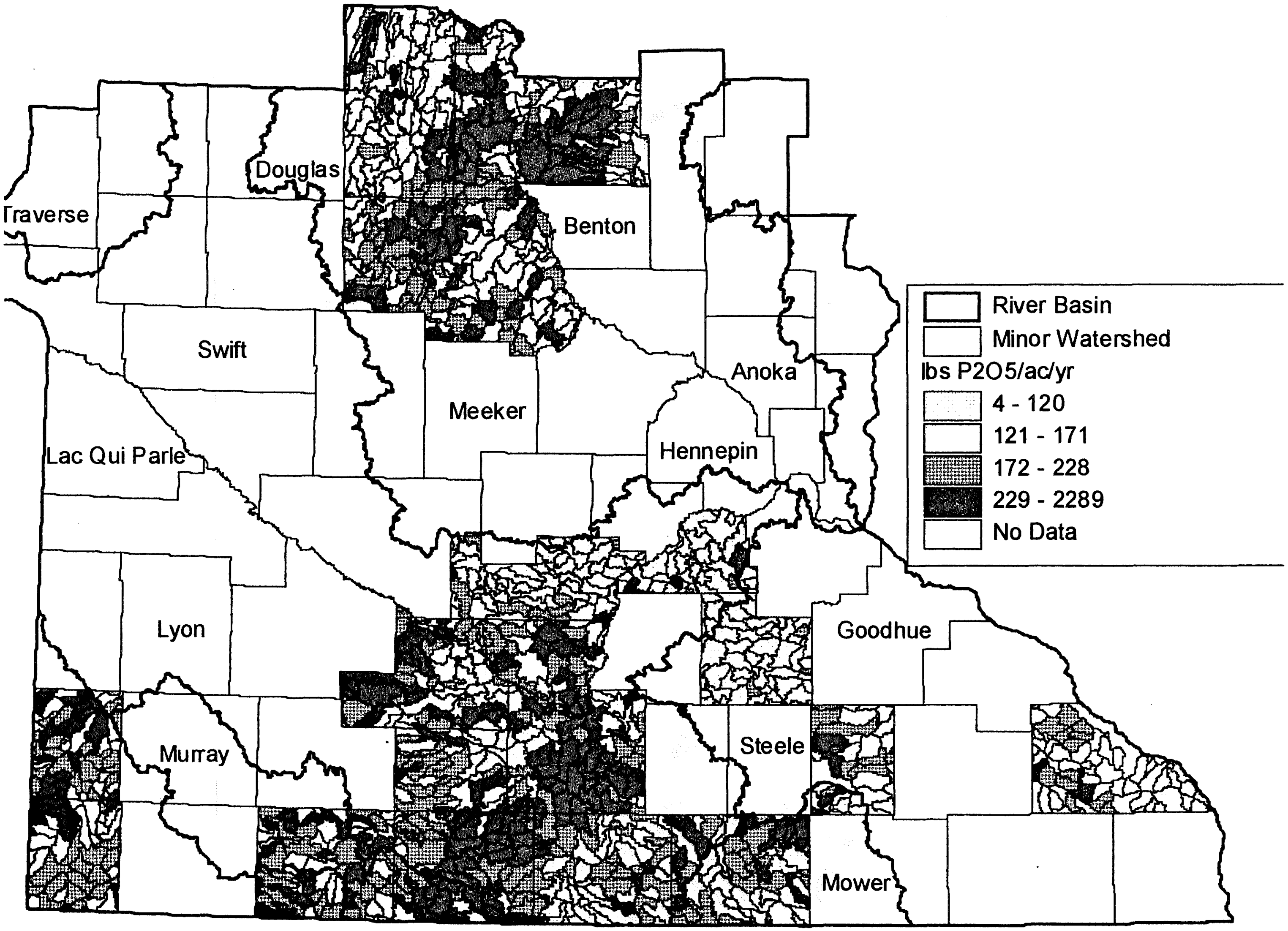
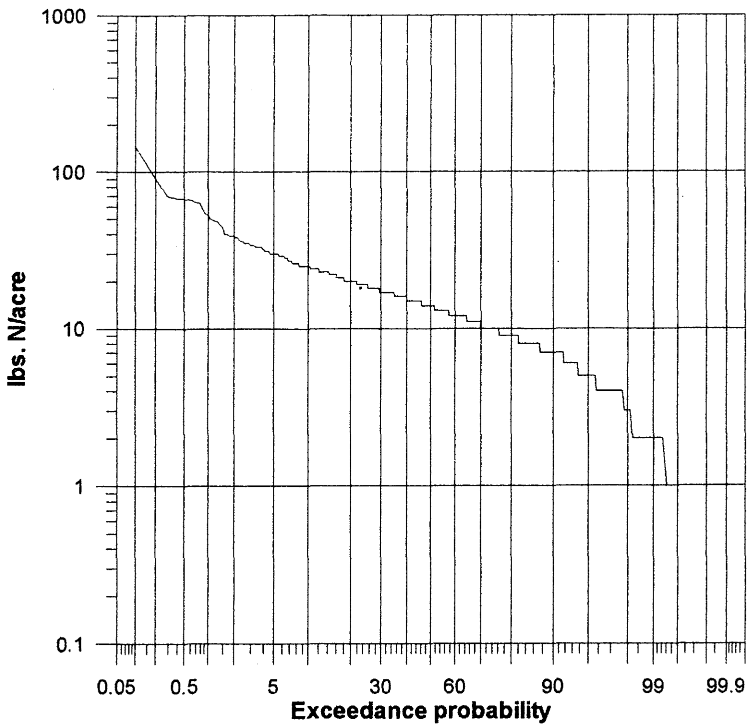
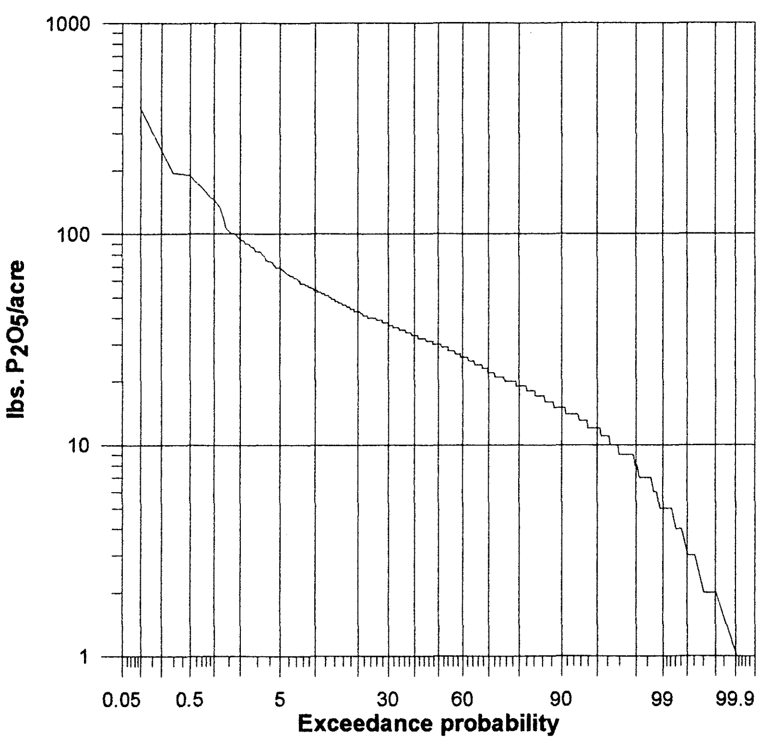


Figure 10b. Single-year manure P_2O_5 application rates.



(a) Nitrogen



(b) Phosphate

Figure 11. Probability plots of long-term manure (a) N and (b) P_2O_5 applications within a watershed.

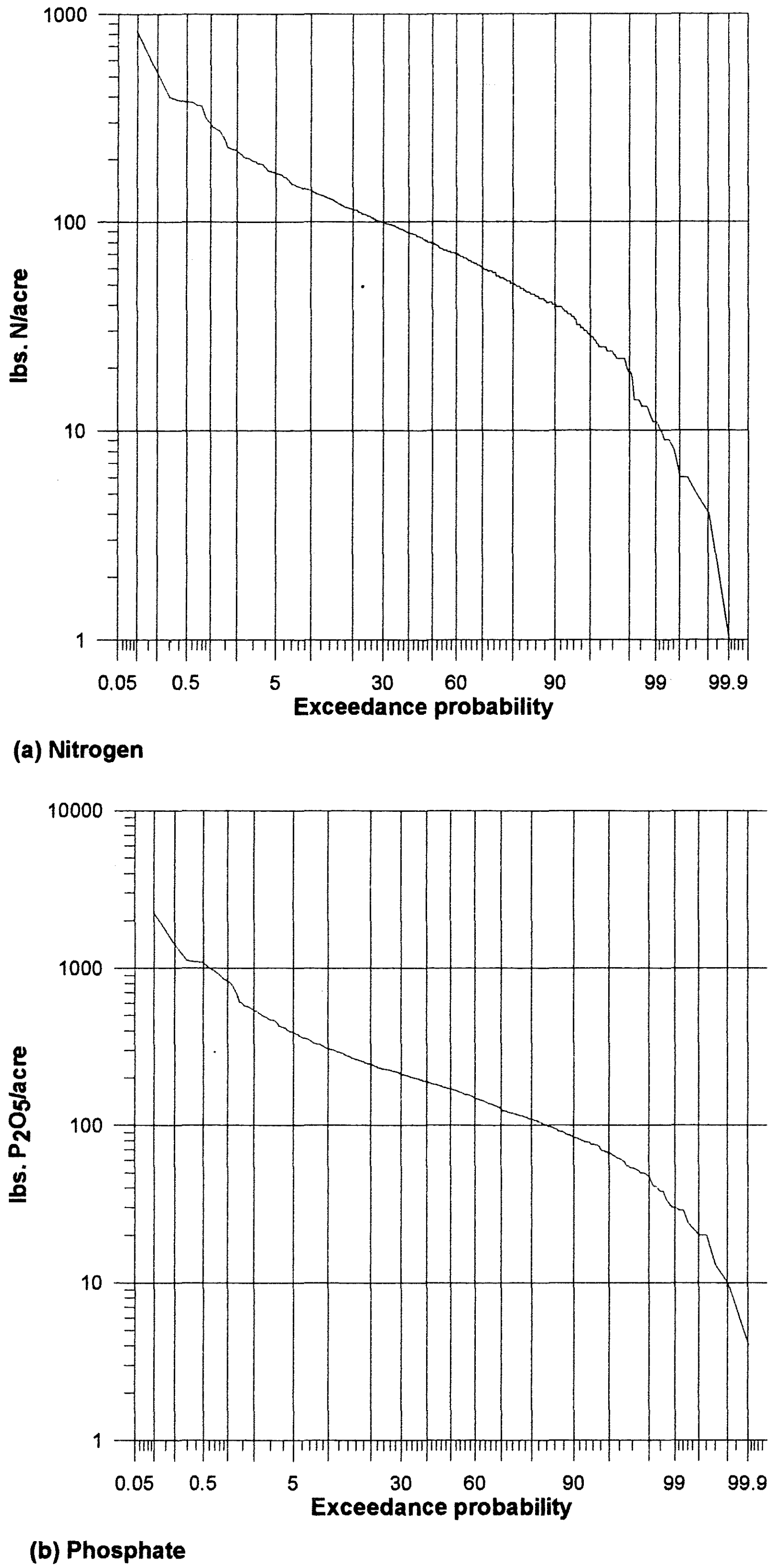
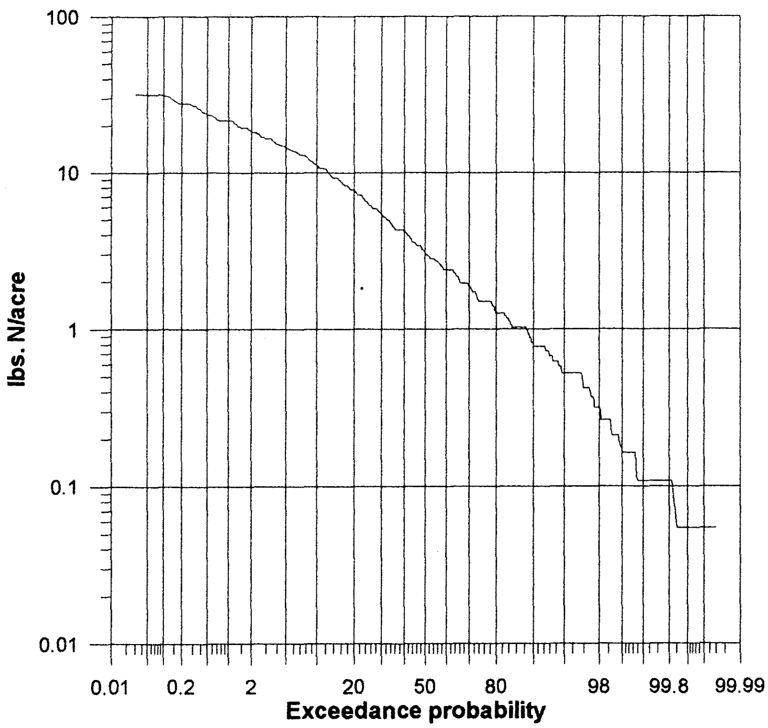
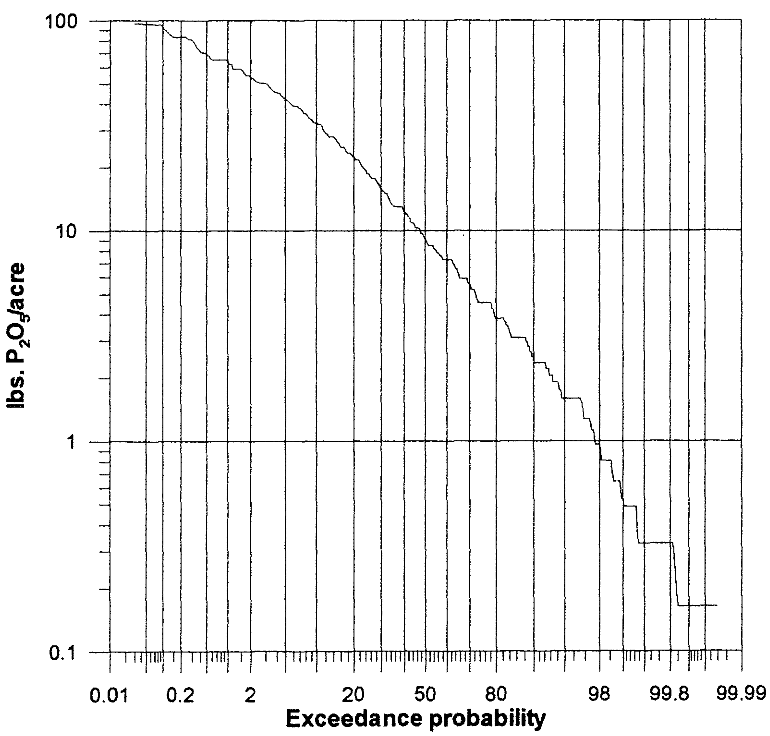


Figure 12. Probability plots of single-year available manure (a) N and (b) P_2O_5 applications within a watershed.

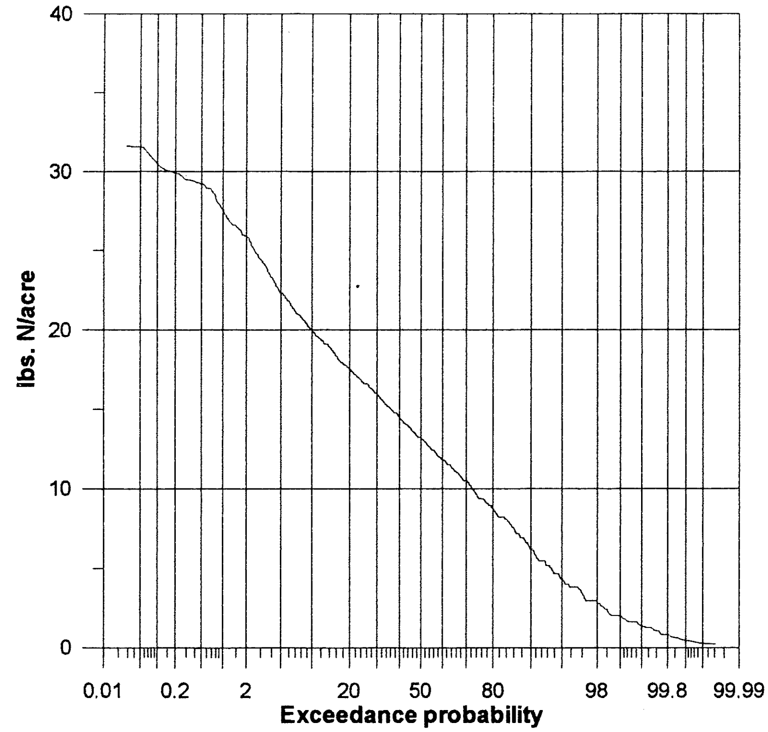


(a) Nitrogen

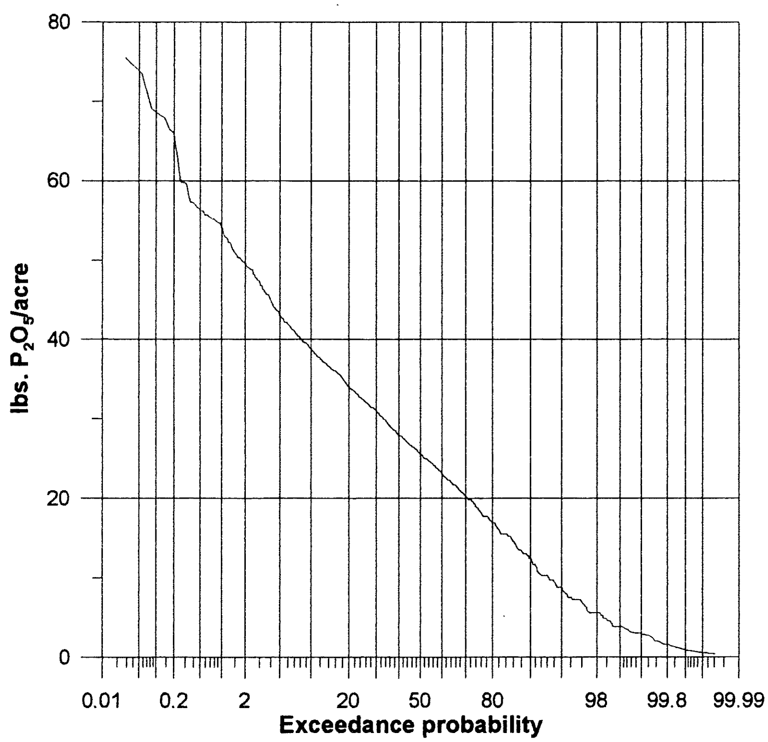


(b) Phosphate

Figure 13. Probability plots of long-term manure (a) N and (b) P_2O_5 applications from beef feedlots.

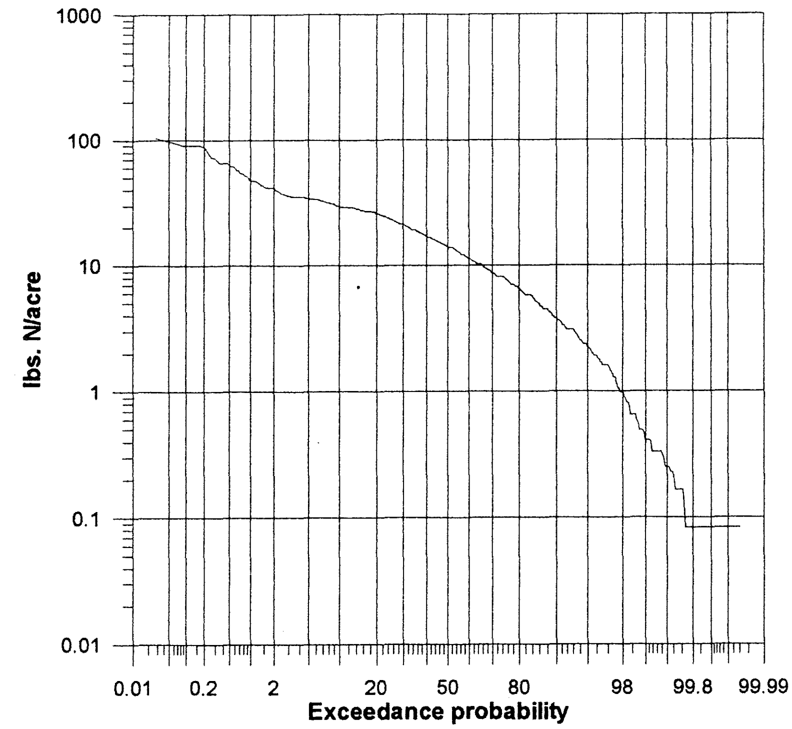


(a) Nitrogen

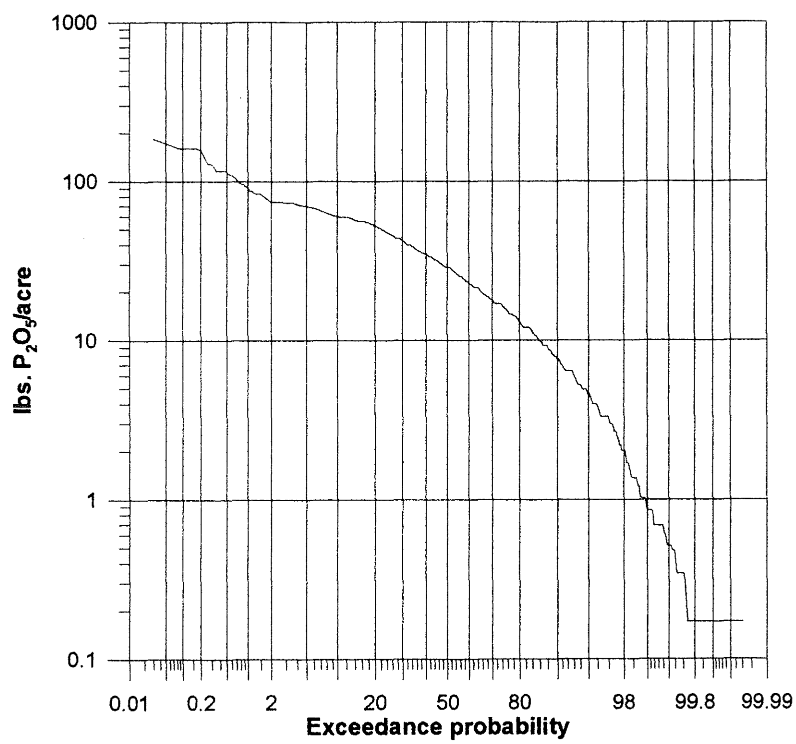


(b) Phosphate

Figure 14. Probability plots of long-term manure (a) N and (b) P_2O_5 applications from dairy feedlots.

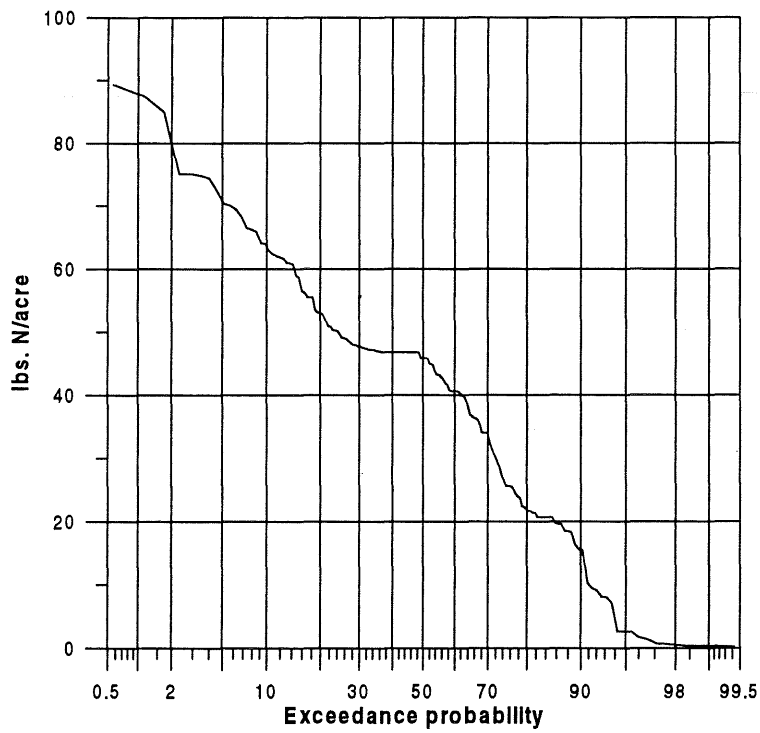


(a) Nitrogen

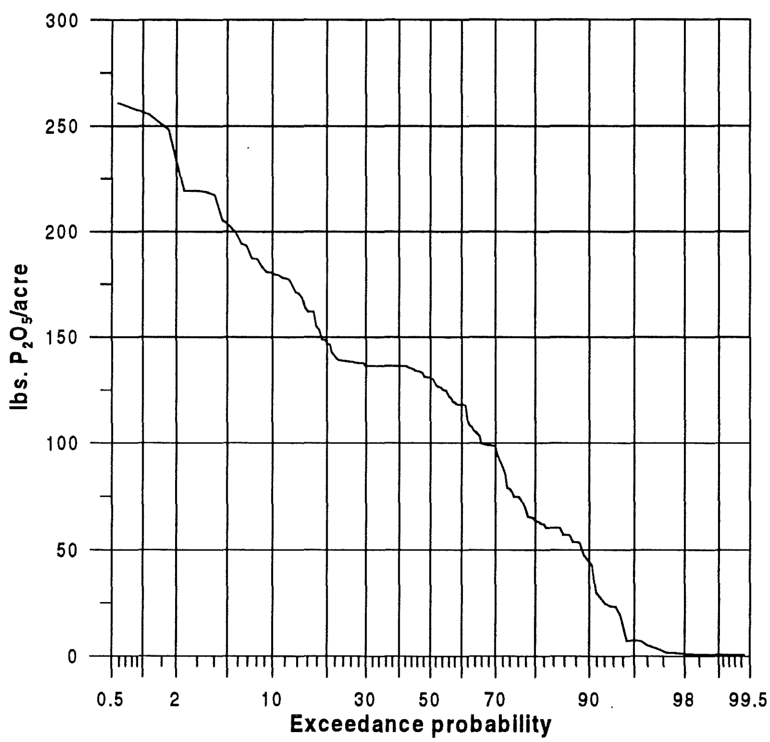


(b) Phosphate

Figure 15. Probability plots of long-term manure (a) N and (b) P_2O_5 applications from hog feedlots.

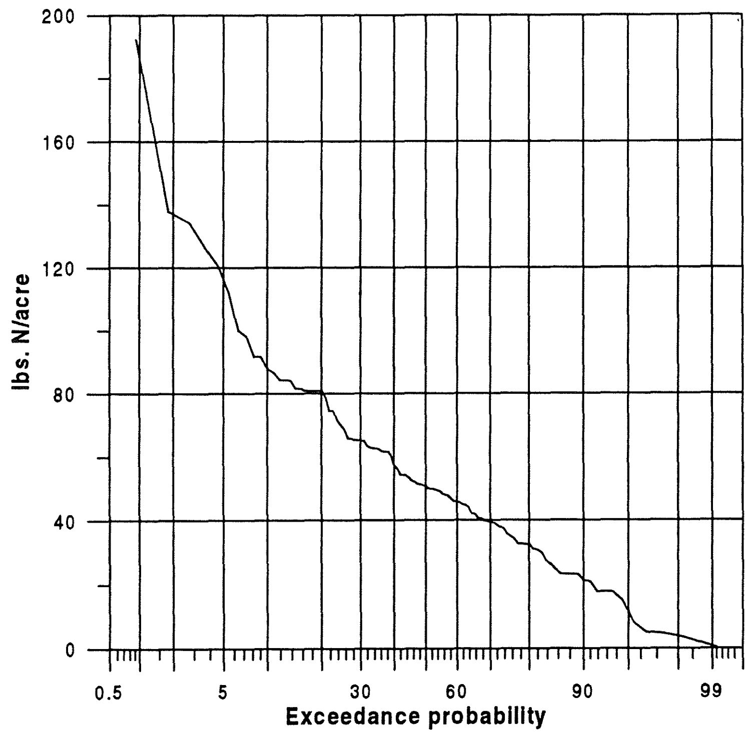


(a) Nitrogen

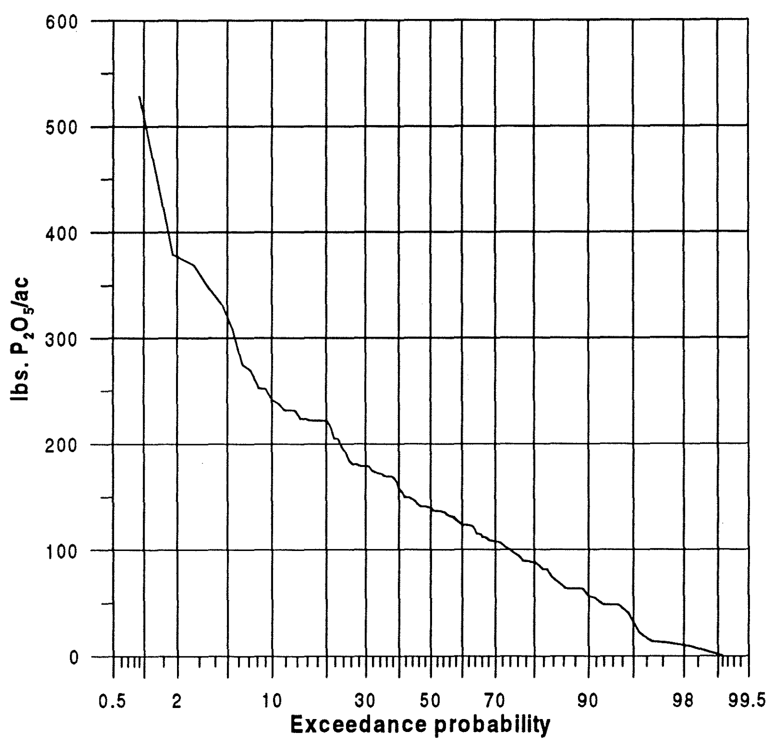


(b) Phosphate

Figure 16. Probability plots of long-term manure (a) N and (b) P_2O_5 applications from chicken feedlots.



(a) Nitrogen



(b) Phosphate

Figure 17. Probability plots of long-term manure (a) N and (b) P_2O_5 applications from turkey feedlots.

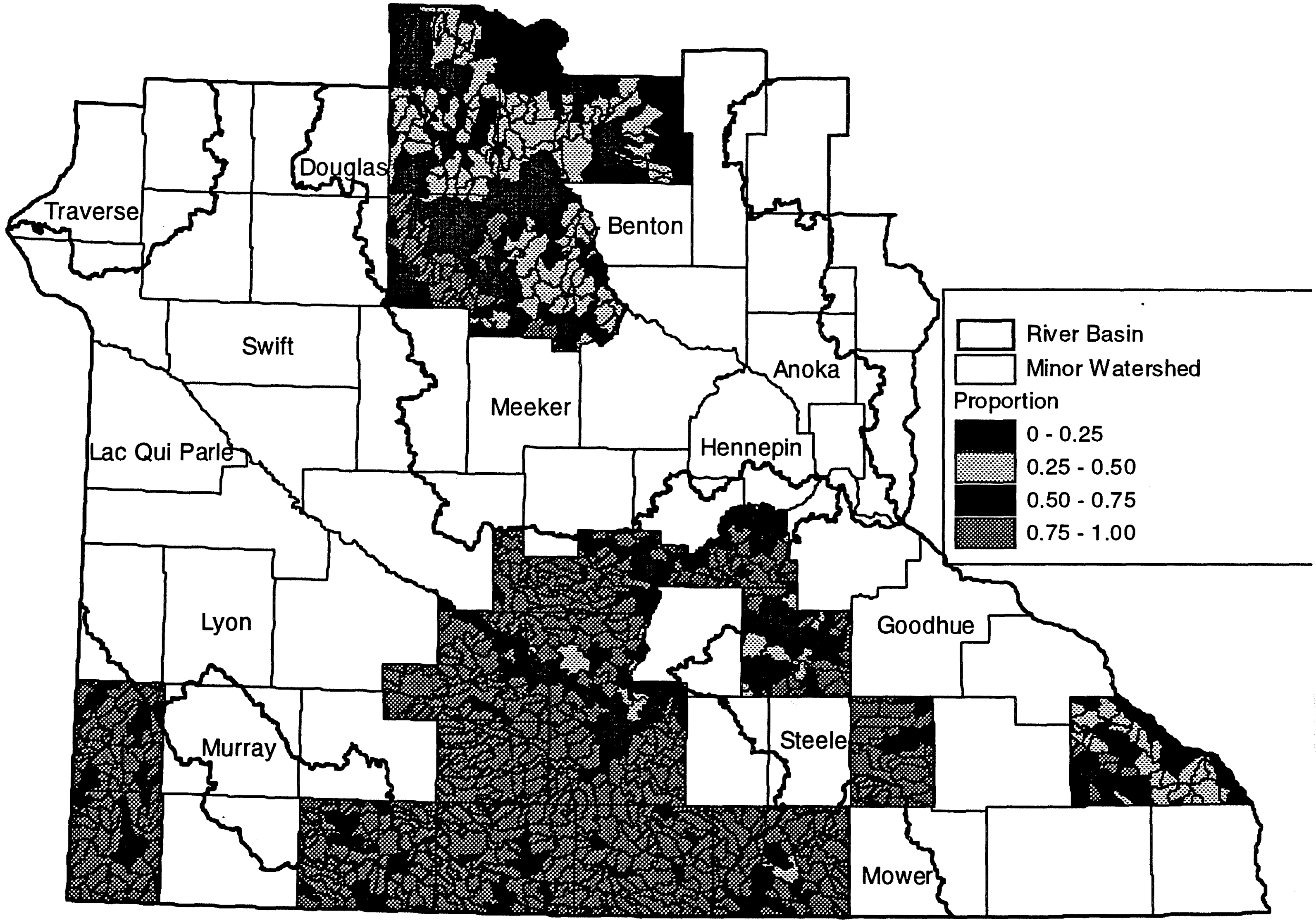


Figure 18. Proportion of the minor watershed comprised of cultivated land.

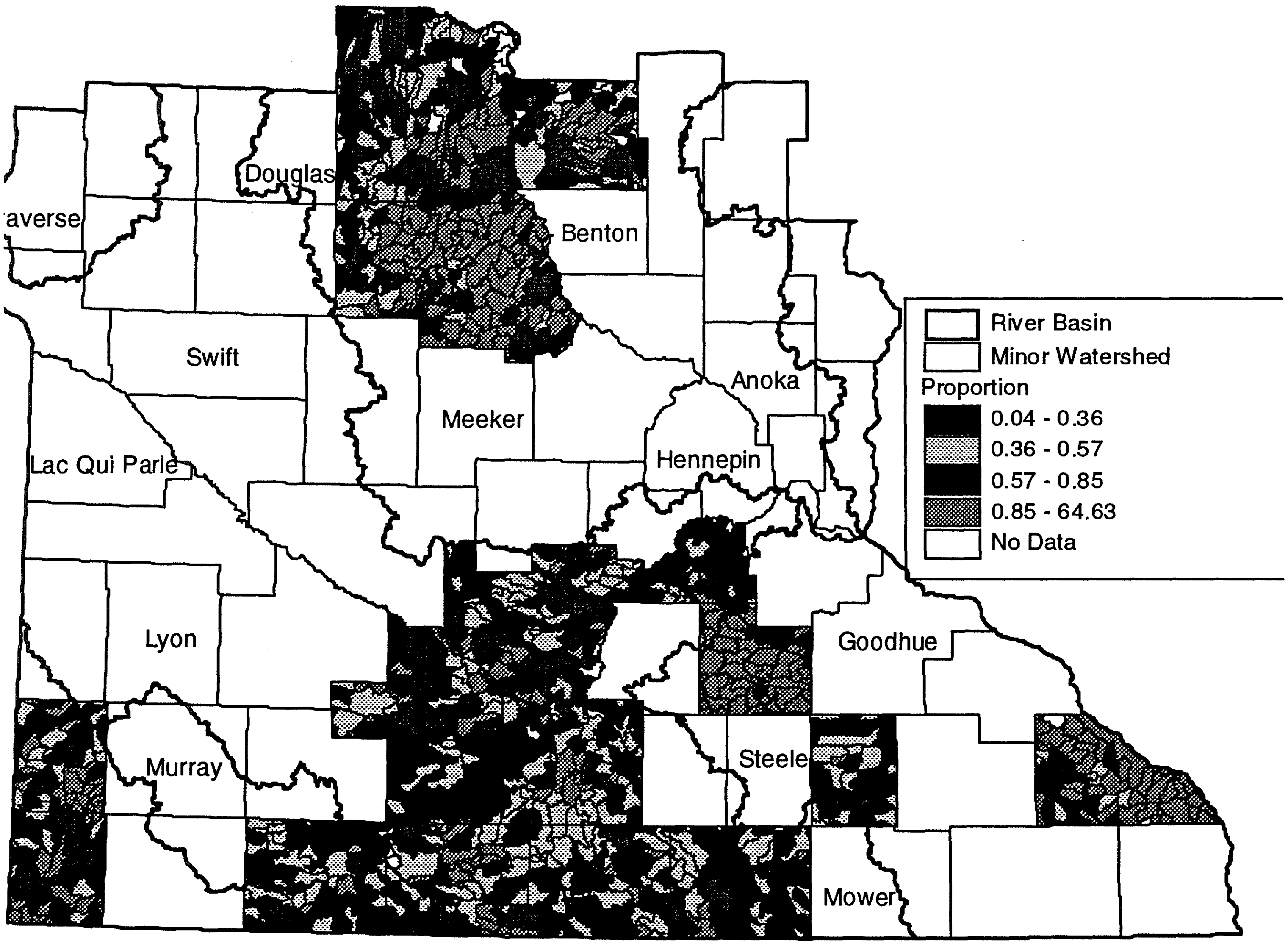


Figure 19. Proportion of cultivated land available for manure applications.

Winona counties, for example, rates of N and P_2O_5 applied to the land are lower in general than in other counties. Expansion of animal agriculture in the latter two counties is not really limited by the lack of available cropland for spreading of manure. Additional manure from expanded animal operations could be applied to existing manured cropland without adding excessive amounts of N and P_2O_5 to the soil.

Counties with small pockets of insufficient cropland for expanded manure applications include western Stearns, eastern Morrison, Blue Earth, Martin, Pipestone, Rock, Brown, Nicollet, and Sibley. More than 75% of the area in watersheds for these counties are cropped. The insufficient cropland for expanded manure application is, in this case, due primarily to a large density of big feedlots. Average rates of N and P_2O_5 applied to the land from existing feedlots are already high in these regions. Additional expansion of animal agriculture in these small areas may be risky from the point of view of water quality impacts.

Based on proximity to streams, feedlot size distributions, and amount of manure generated, we can identify the feedlots most likely to pose a threat to surface water quality by being out of compliance with Minnesota Feedlot Rules. In central and southeastern Minnesota, the small to moderate sized dairy feedlots pose the greatest threat to surface water quality. In southern and southwestern Minnesota, small to moderate sized hog feedlots pose the greatest threat to surface water quality.

J. Proximity of Feedlots to Streams and Drainage Ditches

The risk of water quality impairment by phosphorus is strongly increased by having land with high soil phosphorus levels in close proximity to streams and ditches. Feedlots located in close proximity to streams and ditches have, in general, a greater potential to produce water pollution than feedlots located far from them. Larger feedlots located in close proximity to streams and ditches have, in general, a greater potential to produce water pollution due to land application of manure P than smaller feedlots in close proximity to streams and ditches.

We estimated the proportion of feedlots located within a quarter mile of streams and drainage ditches relative to the number of feedlots in each minor watershed within the study area. The potential for water quality impairment by phosphorus increases as this proportion increases. Roughly one quarter of the minor watersheds in the eighteen county study area have more than two thirds of their feedlots within a quarter mile of streams and ditches. Counties with particularly high proportions of feedlots near streams and ditches (Fig. 20) include Winona, Pipestone, Rock, and Dodge. Intermediate proportions of feedlots near water occurred in Todd, western Stearns, eastern Morrison, eastern Rice, and Jackson counties.

The size distribution of feedlots in close proximity to streams and ditches was studied (Figs. 21a-e). In Winona and Dodge counties a majority of feedlots within a quarter mile of streams and ditches had less than 100 A.U.s. In Pipestone and Rock counties, the majority of feedlots in close proximity to water had from 100 to 299 A.U.s. Feedlots in Todd county in close proximity to water have primarily 50-99 A.U.s. Feedlots in close proximity to water for western Stearns, eastern Morrison, and Jackson counties are primarily 100-299 A.U. feedlots. Eastern Rice

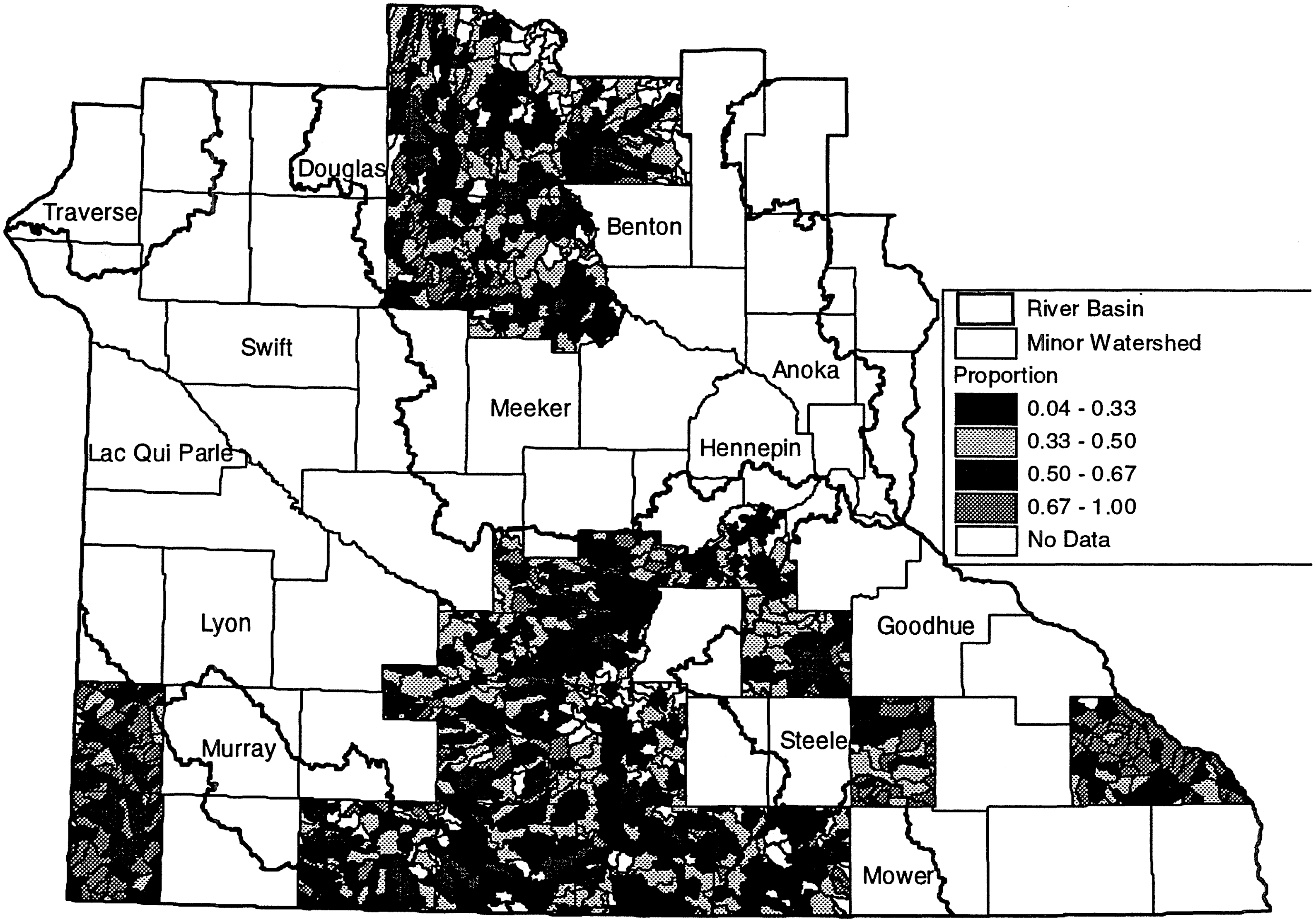


Figure 20. Proportion of feedlots within a 402 m buffer of streams and drainage ditches.

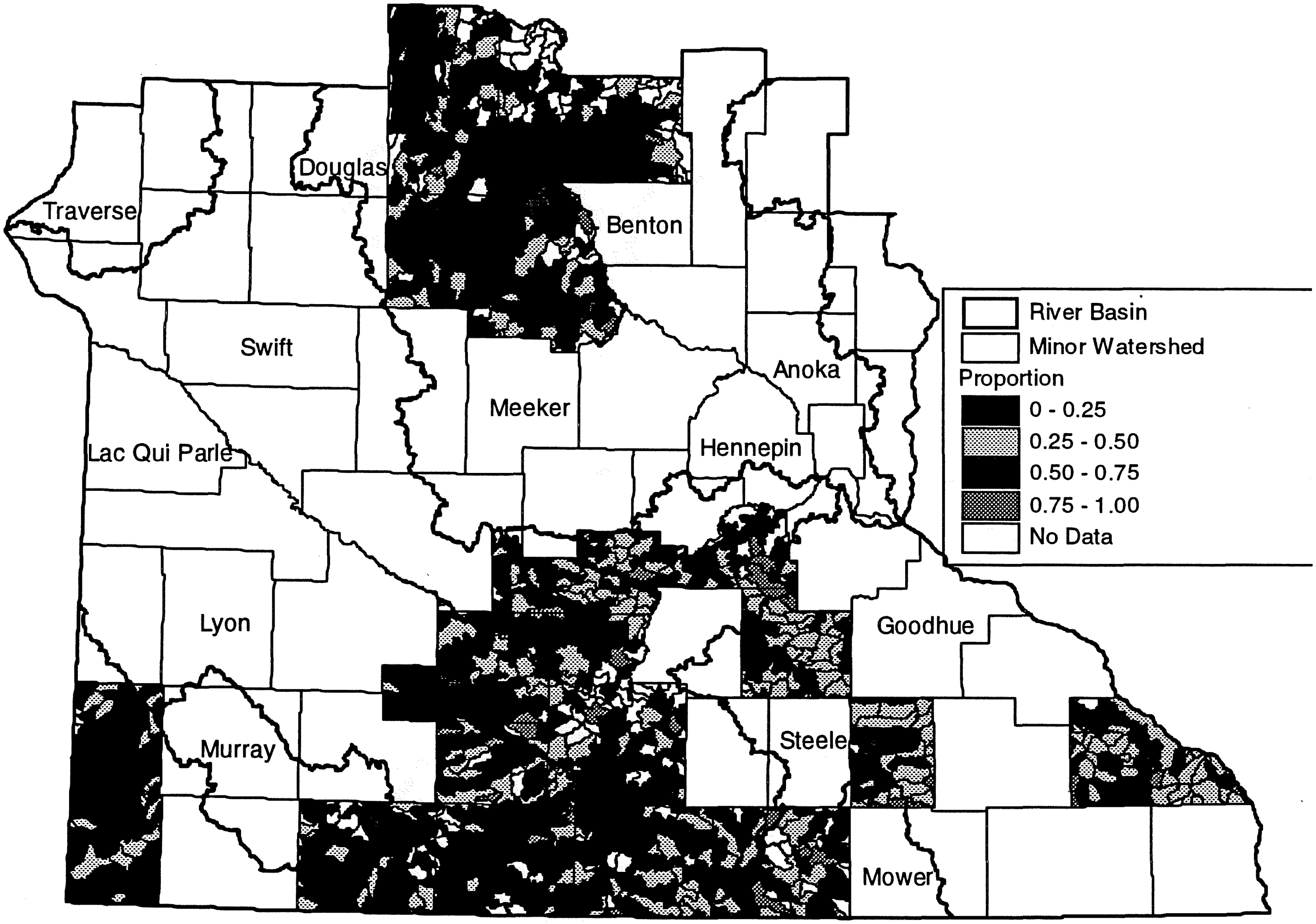


Figure 21a. Proportion of all feedlots within 402 m of streams and drainage ditches consisting of 1 to 49 animal units.

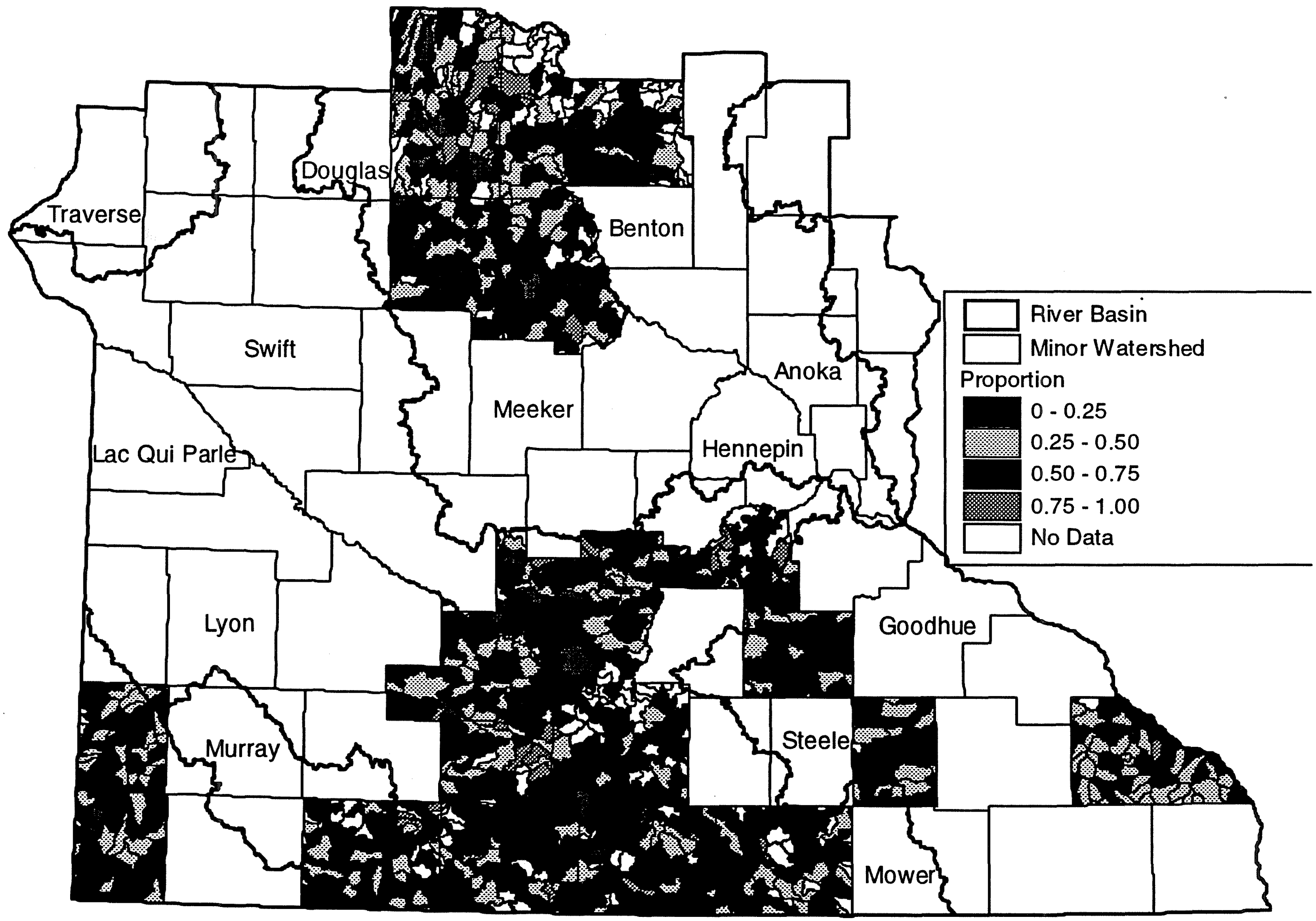


Figure 21b. Proportion of all feedlots within 402 m of streams and drainage ditches consisting of 50 to 99 animal units.

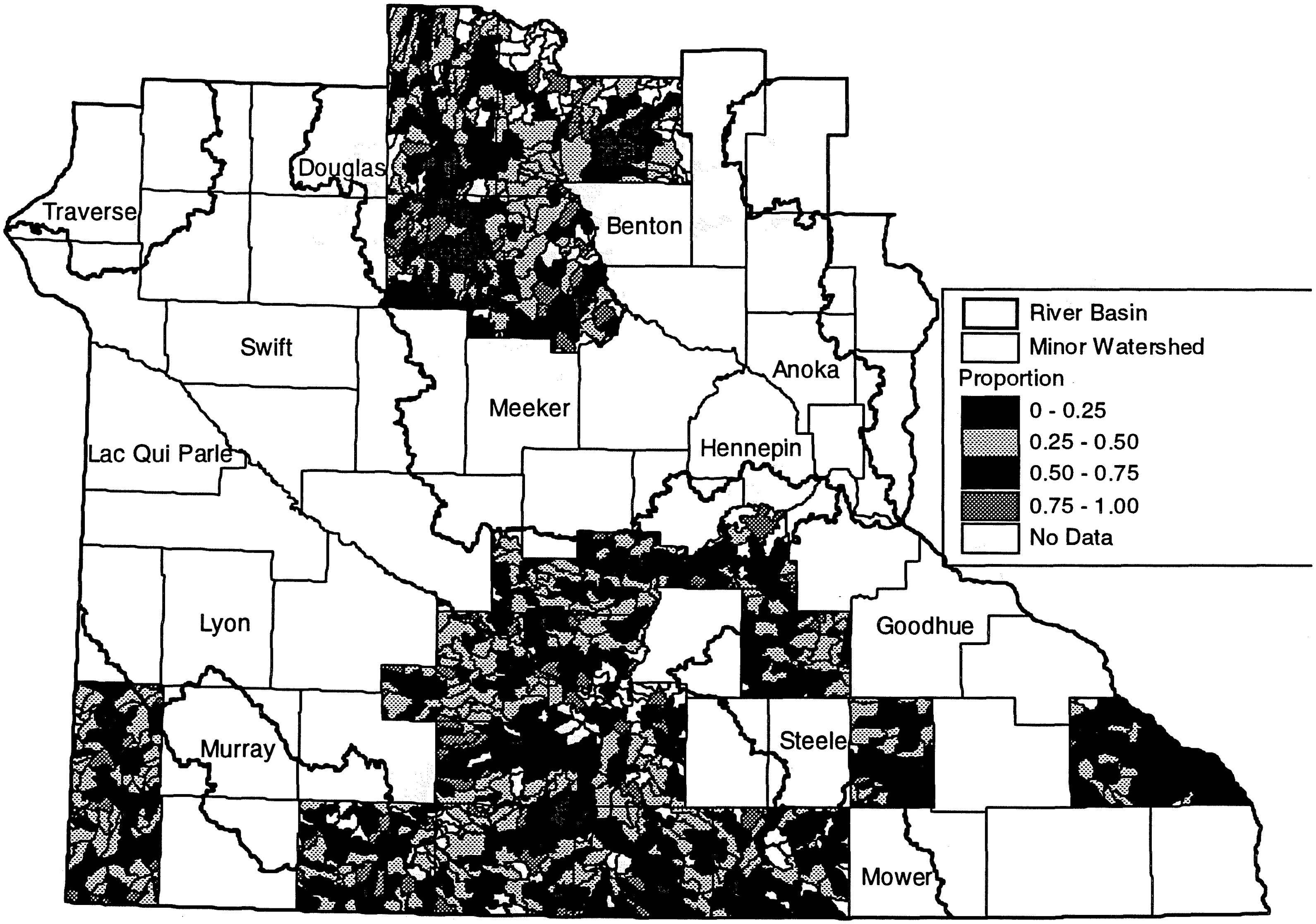


Figure 21c. Proportion of all feedlots within 402 m of streams and drainage ditches consisting of 100 to 299 animal units.

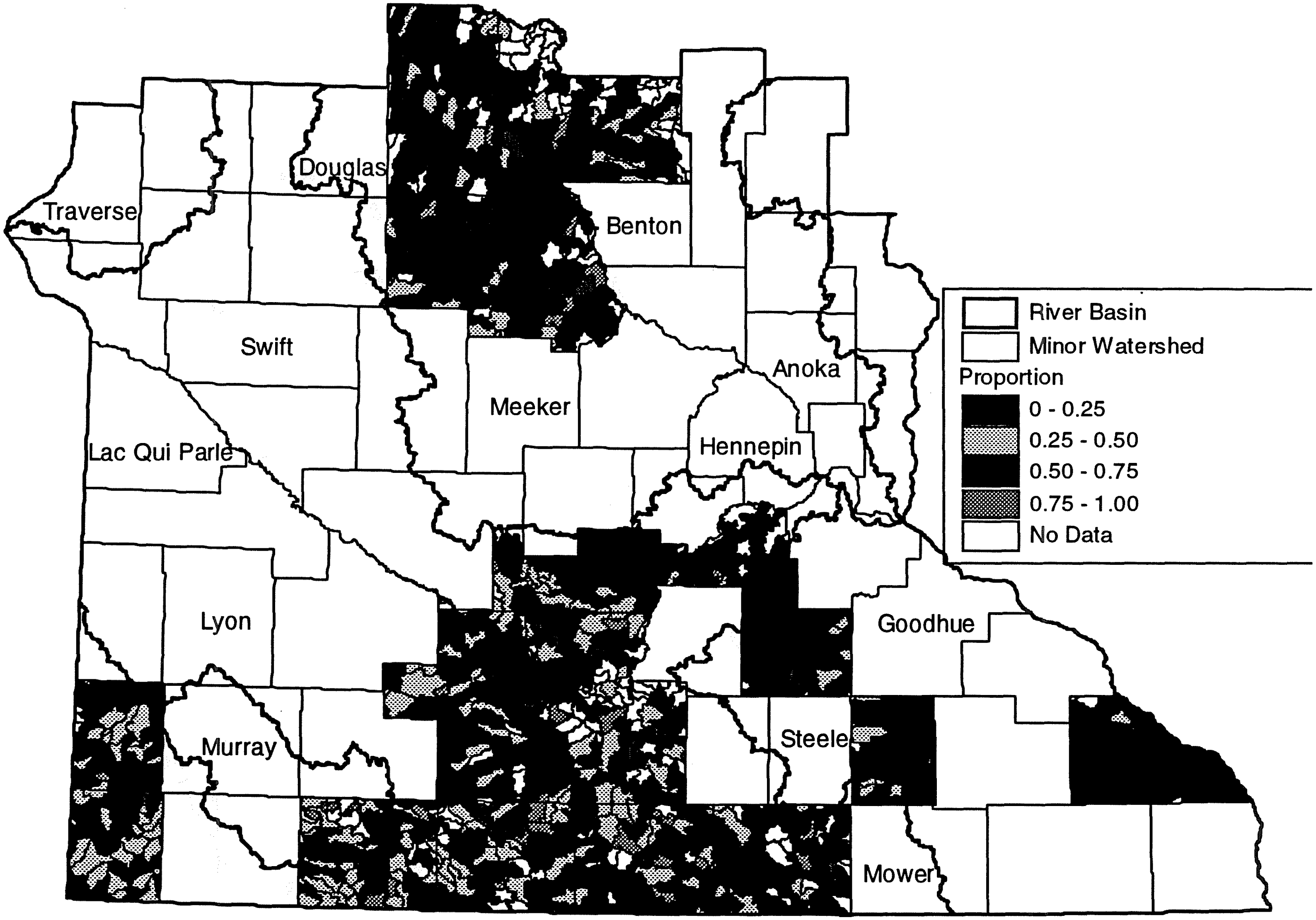


Figure 21d. Proportion of all feedlots within 402 m of streams and drainage ditches consisting of 300 to 999 animal units.

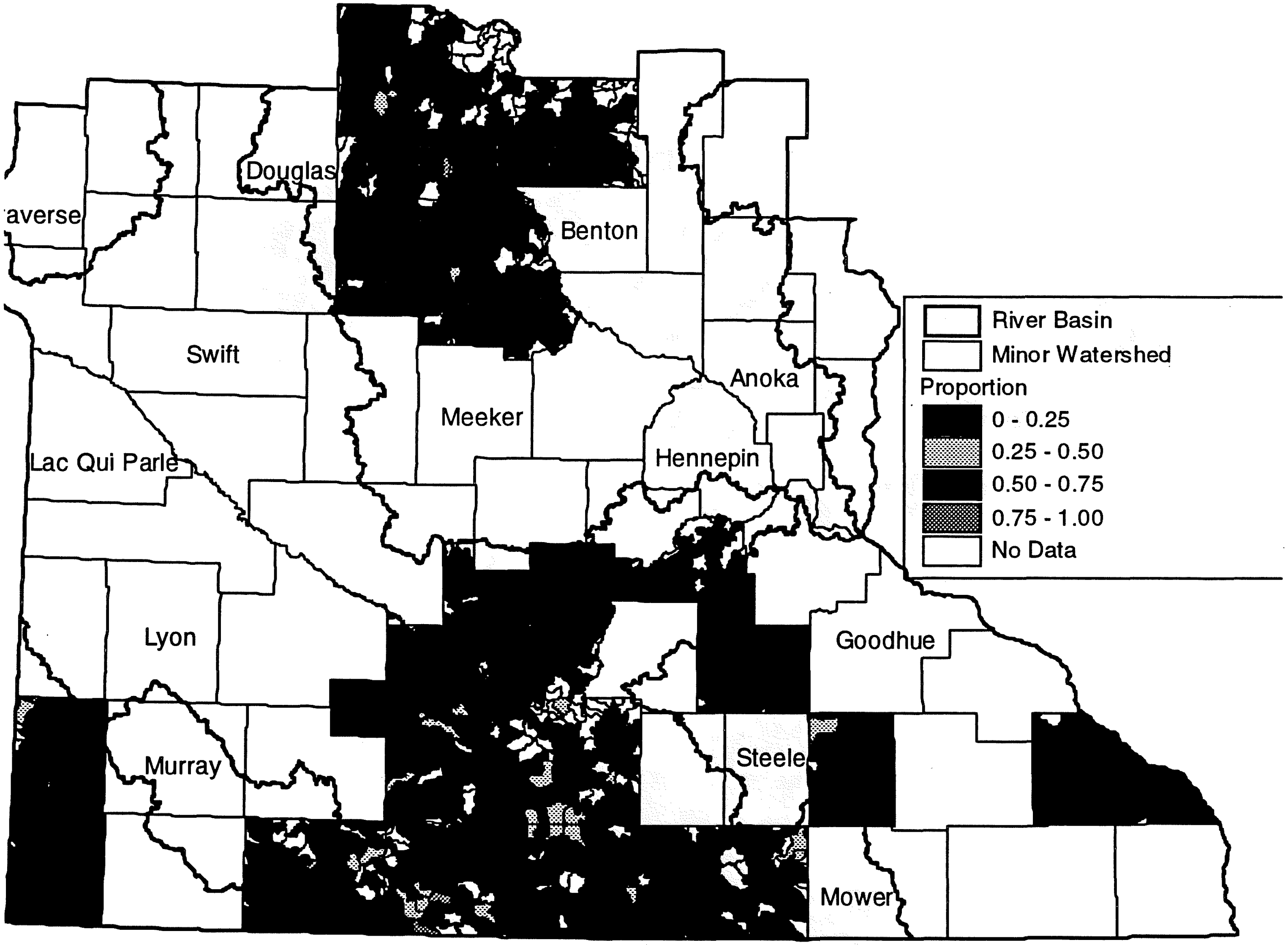


Figure 21e. Proportion of all feedlots within 402 m of streams and drainage ditches consisting of greater than 1000 animal units.

county is dominated by 1-49 A.U. feedlots in close proximity to water. Very few large sized feedlots are located within a quarter mile of streams and ditches.

We can also determine the proportion of animal units in close proximity to water for each minor watershed (Fig. 22). In one quarter of the watersheds studied, greater than 70% of the animal units were located within a quarter mile of streams and ditches. Of greater interest is the proportion of those animal units that are dairy cattle (Fig. 23a), hogs (Fig. 23b), beef (Fig. 23c), chicken (Fig. 23d), or turkey (Fig. 23e). For Winona, Todd, Morrison, and Stearns counties the animals in close proximity to water are primarily dairy cattle. For Pipestone and Rock counties they are primarily hogs and beef. For Dodge county, hogs and dairy cattle make up the majority of animals in feedlots close to water. Rice county has significant proportions of hogs, dairy cattle, and beef cattle in close proximity to water. Feedlots in close proximity to water in Jackson county are dominated by hogs.

<u>Water Quality Impacts of Manure Applied to Land</u>

K. Water Quality Patterns in Four Regions of Minnesota

The four geographic regions studied have distinctly different water quality patterns, and are in different river basins (Fig. 24). Long-term water quality monitoring for total phosphorus concentrations is available for most of these regions, as shown in Fig. 25. South central Minnesota is primarily in the Minnesota River basin (16,200 mi^2 drainage area), a river which generates large loads of nitrogen and phosphorus (59,180 tons N/yr and 1,488 tons P/yr, respectively.) Central Minnesota is primarily in the Upper Mississippi River basin (19,100 mi^2 drainage area), which generates moderate loads of nitrogen and phosphorus (21,059 tons N/yr and 1,088 tons P/yr). During moderate flow years, roughly 90% of the N loads and two-thirds of the P loads in these two basins are from non-point sources, including cultivated and fertilized cropland, and animal agriculture operations.

Southeastern Minnesota is primarily in the Lower Mississippi River basin. As a whole the N and P loads (in contrast to the N and P concentrations) from this region are less well monitored than the loads for the Minnesota and Upper Mississippi River basins. The loads of N and P from this region, however, are probably very similar to those of the Chippewa River at Durand, Wisconsin, just prior to its discharge into the Lower Mississippi River. The Chippewa River has N and P loads of 10,318 tons/yr and 811 tons/yr, respectively, and drains 8,999 mi^2.

The surface water quality loads of N and P (not concentrations) of watersheds draining to the Missouri and Des Moines River basins in southwestern Minnesota are also very poorly known. Based on available information, we estimate that the extent of surface water degradation (based on loads of N and P carried per unit area) in the four regions studied decreases in the following order:

Southern MN > > Southeastern MN > Central MN > Southwestern MN

Groundwater pollution patterns also are distinctly different in each of the four regions (Fig. 26). The worst ground water nitrate levels occur in southwestern Minnesota, where more than 40% of

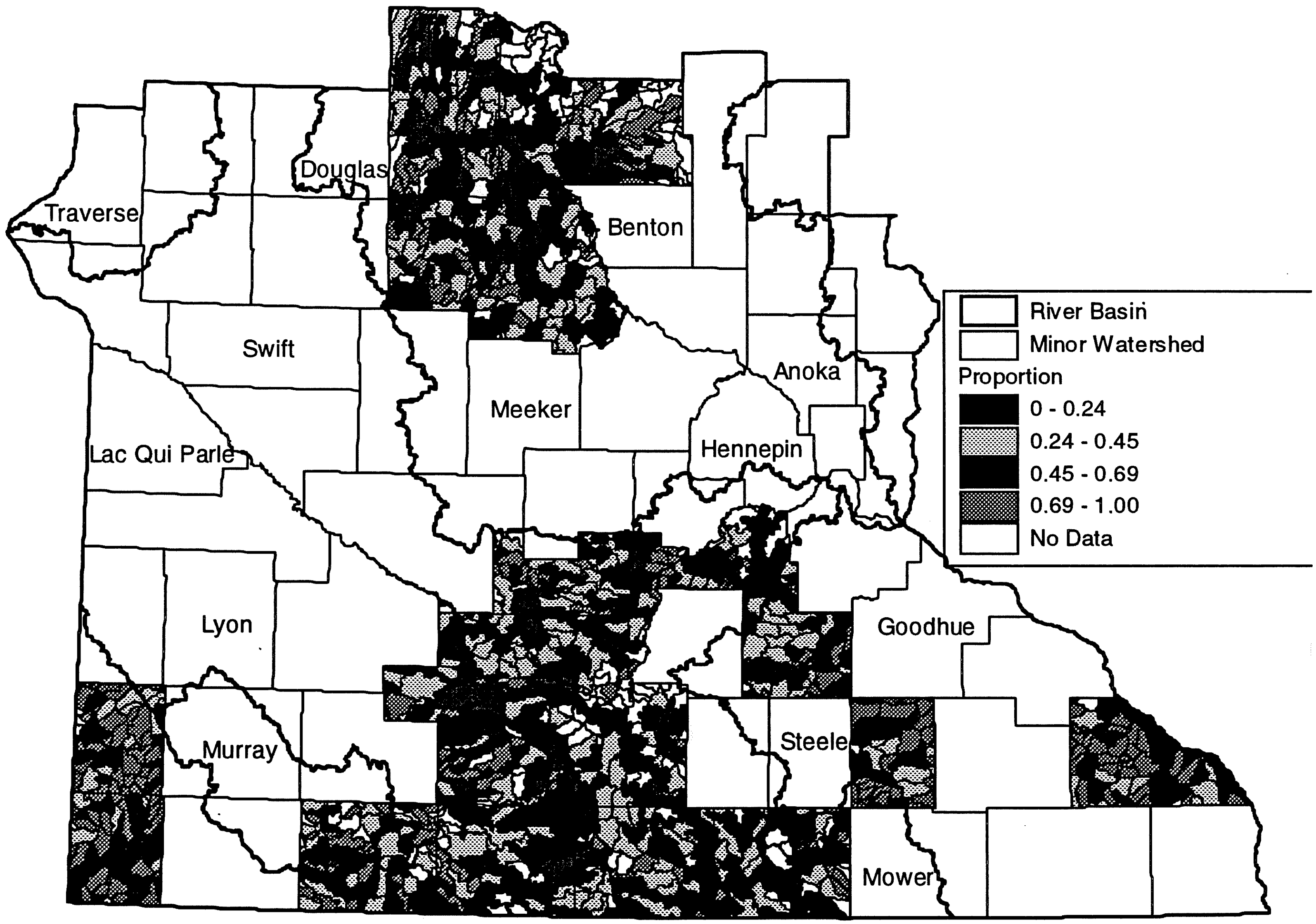


Figure 22. Proportion of animal units within a 402 m buffer of streams and drainage ditches.

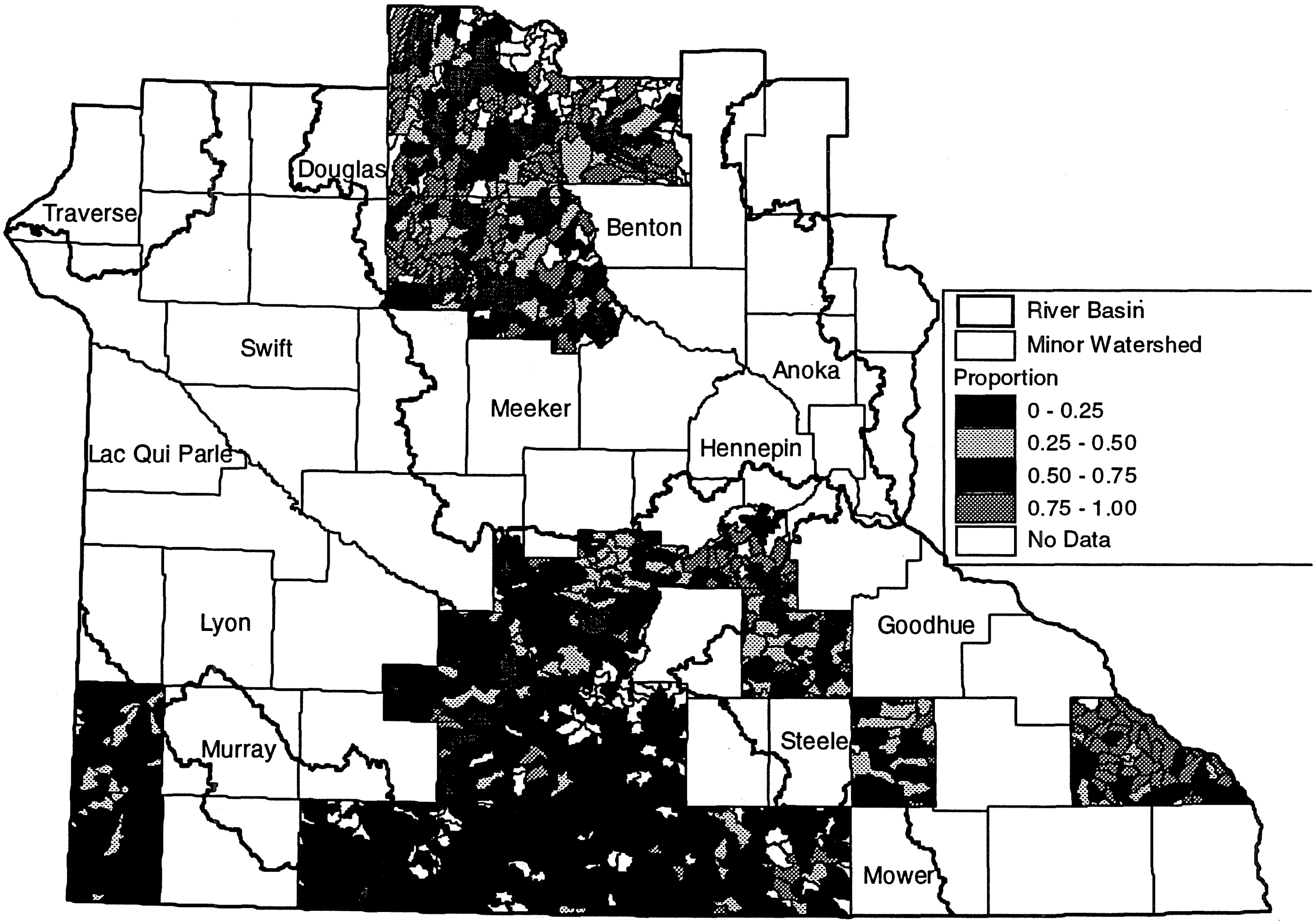


Figure 23a. Proportion of all animal units within 402 m of streams and drainage ditches consisting of dairy cattle.

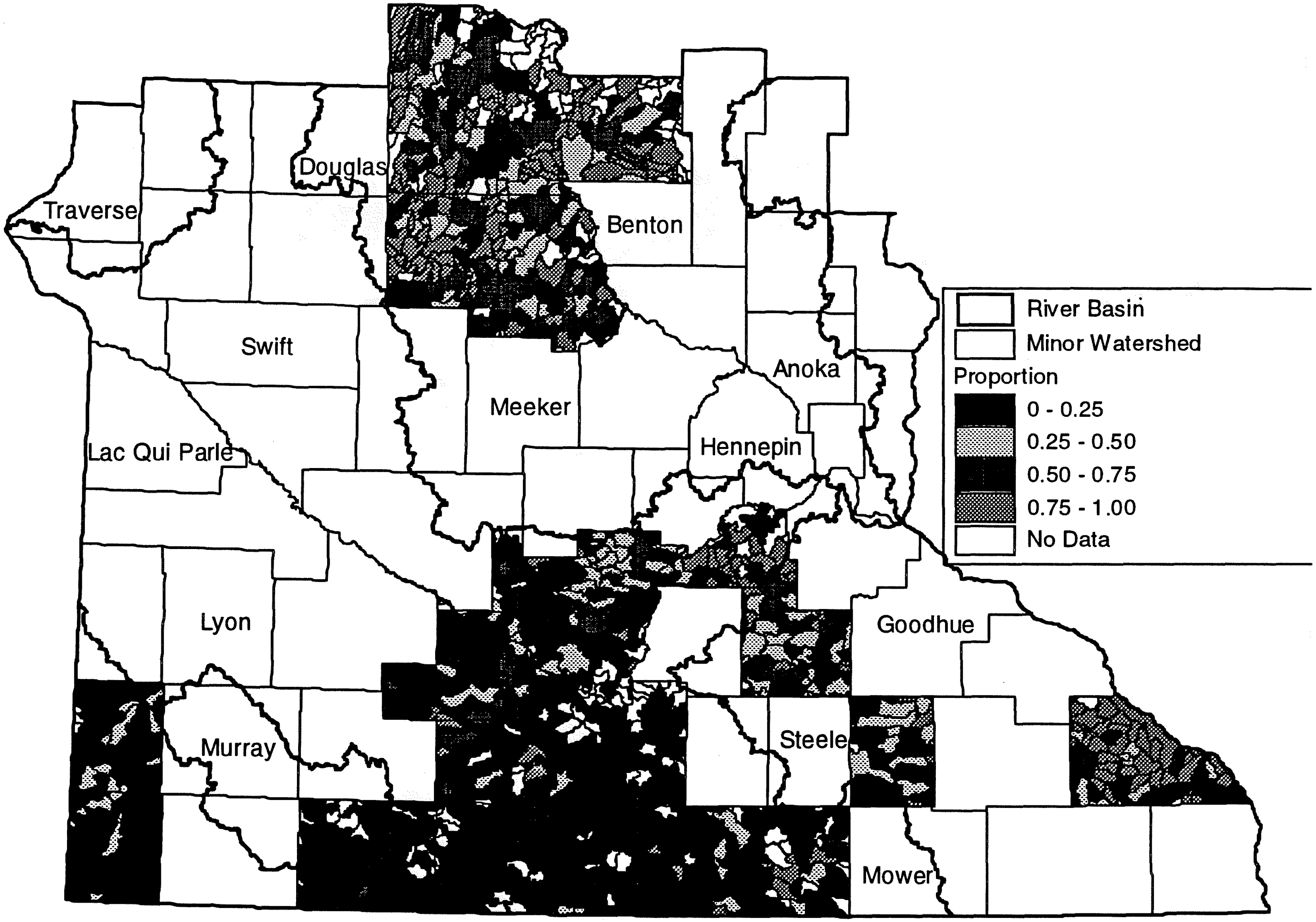


Figure 23a. Proportion of all animal units within 402 m of streams and drainage ditches consisting of dairy cattle.

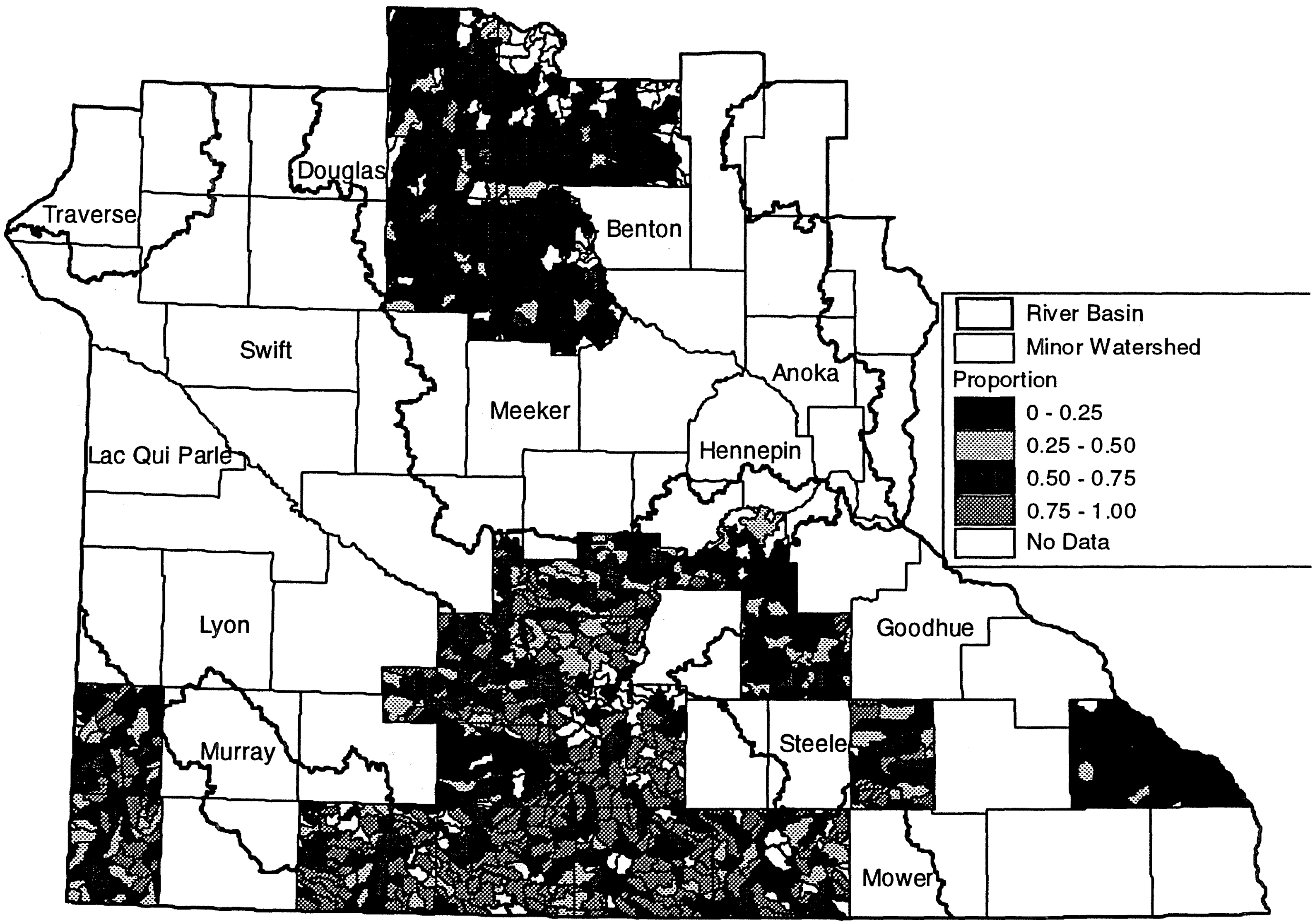


Figure 23b. Proportion of all animal units within 402 m of streams and drainage ditches consisting of hogs.

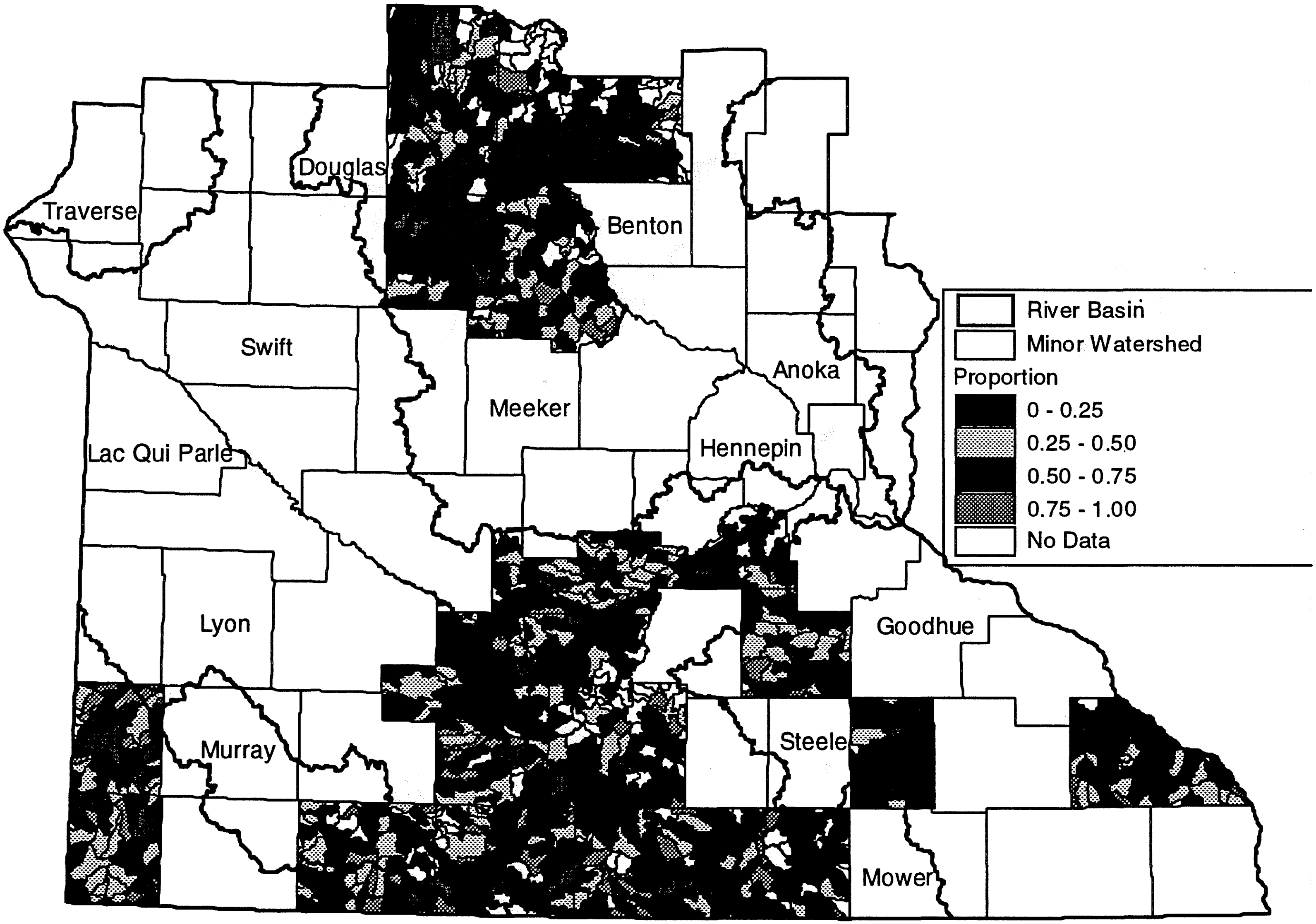


Figure 23c. Proportion of all animal units within 402 m of streams and drainage ditches consisting of beef cattle.

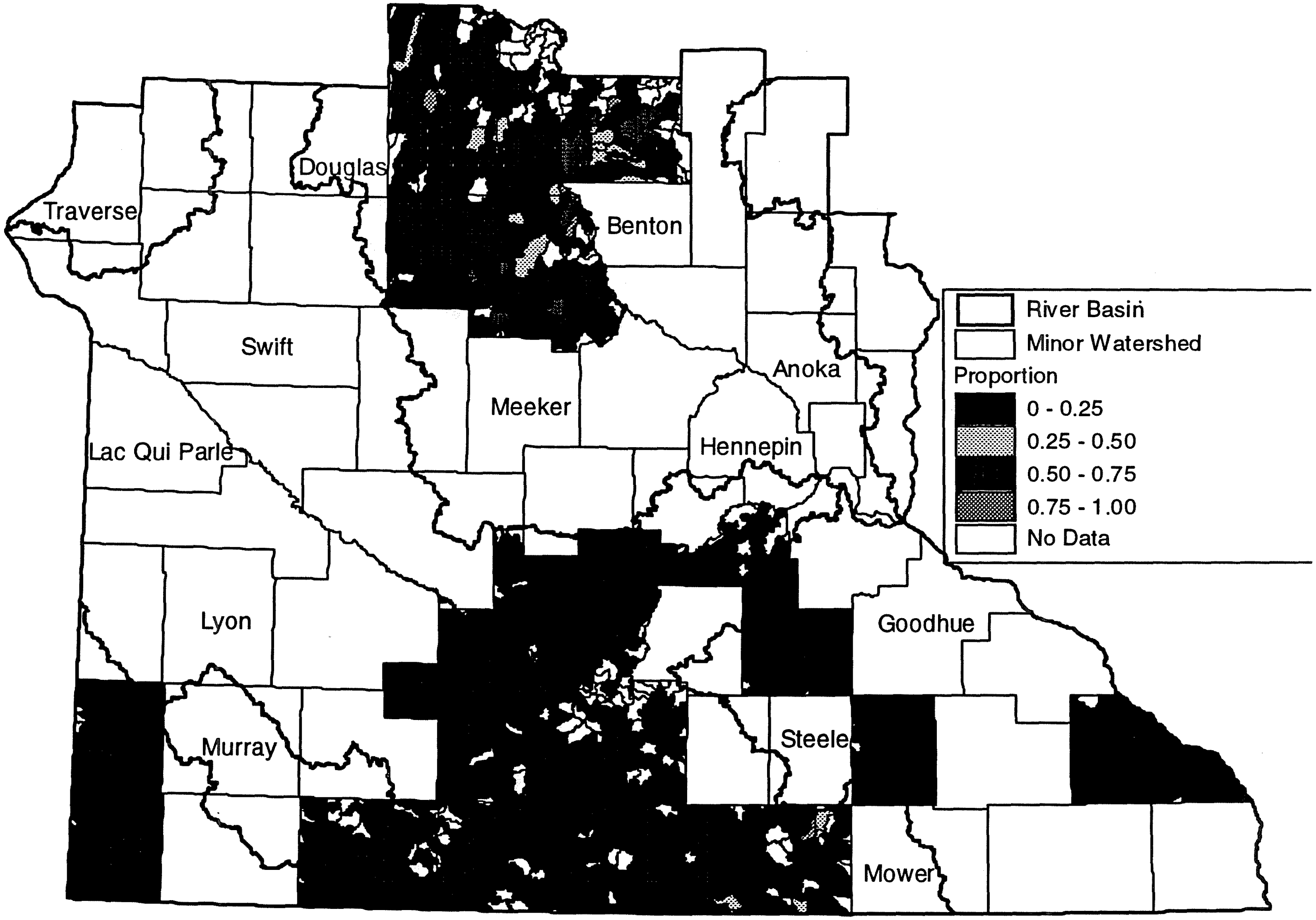


Figure 23d. Proportion of all animal units within 402 m of streams and drainage ditches consisting of chickens.

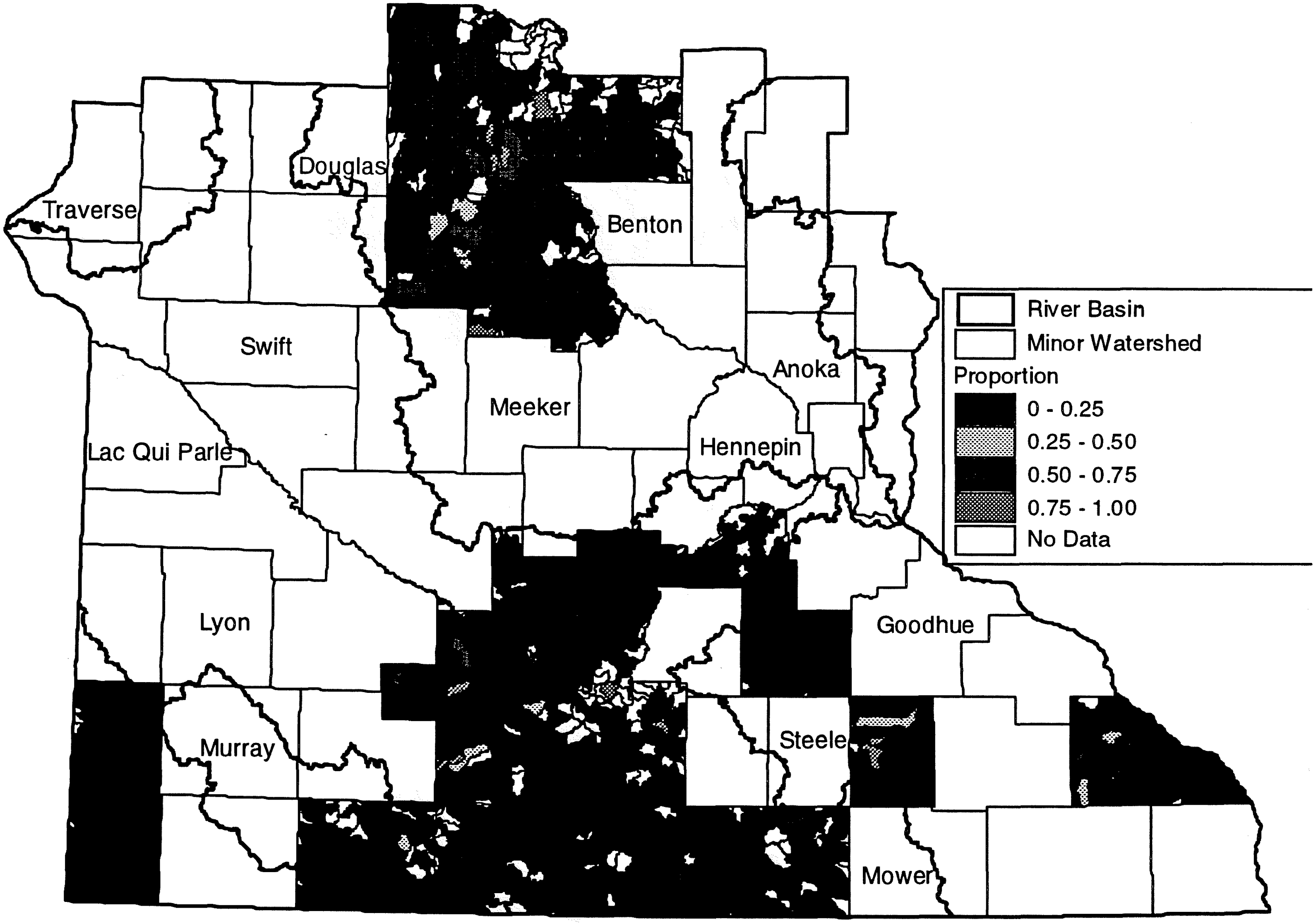


Figure 23e. Proportion of all animal units within 402 m of streams and drainage ditches consisting of turkeys.

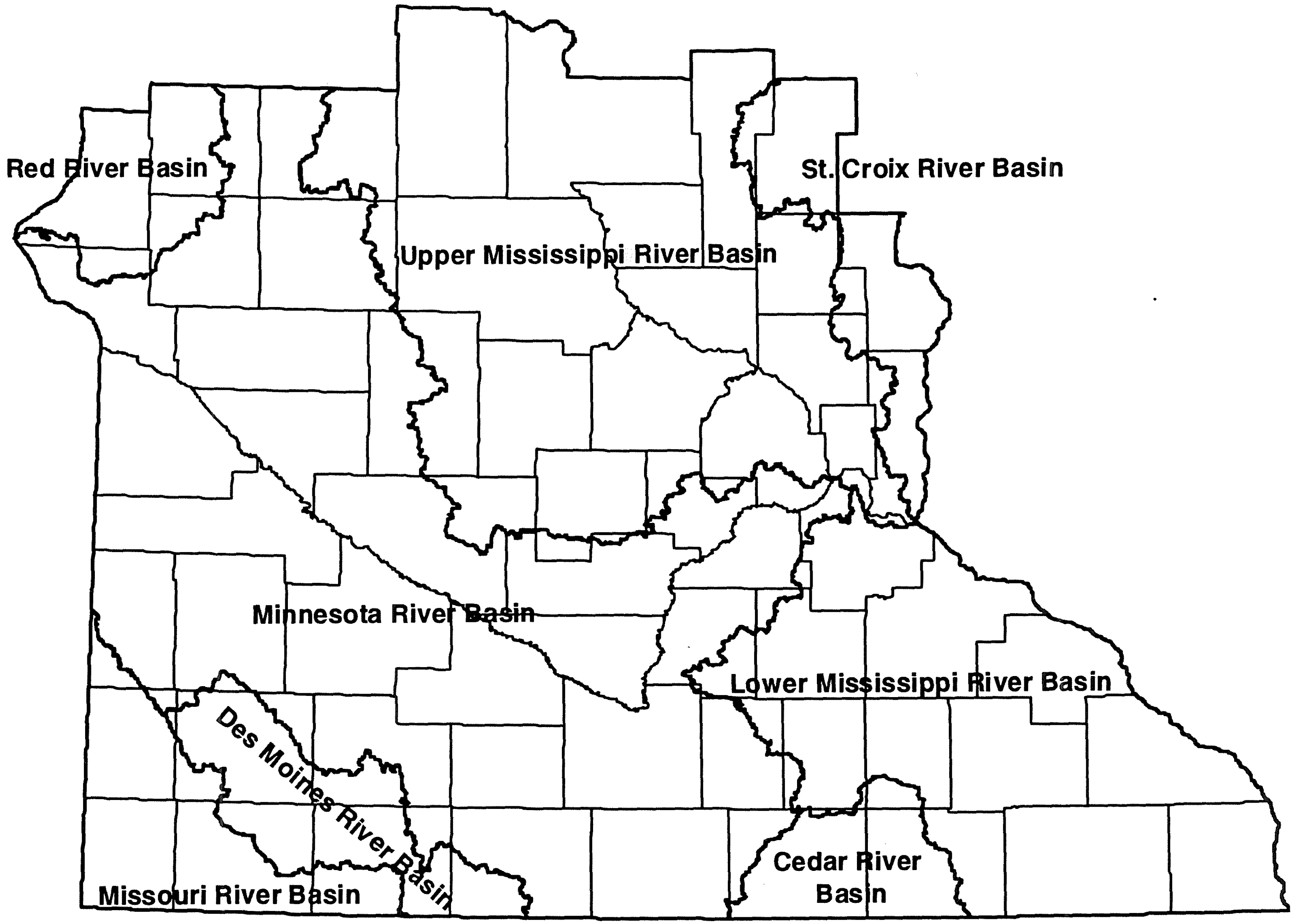


Figure 24. River basins in the study area.

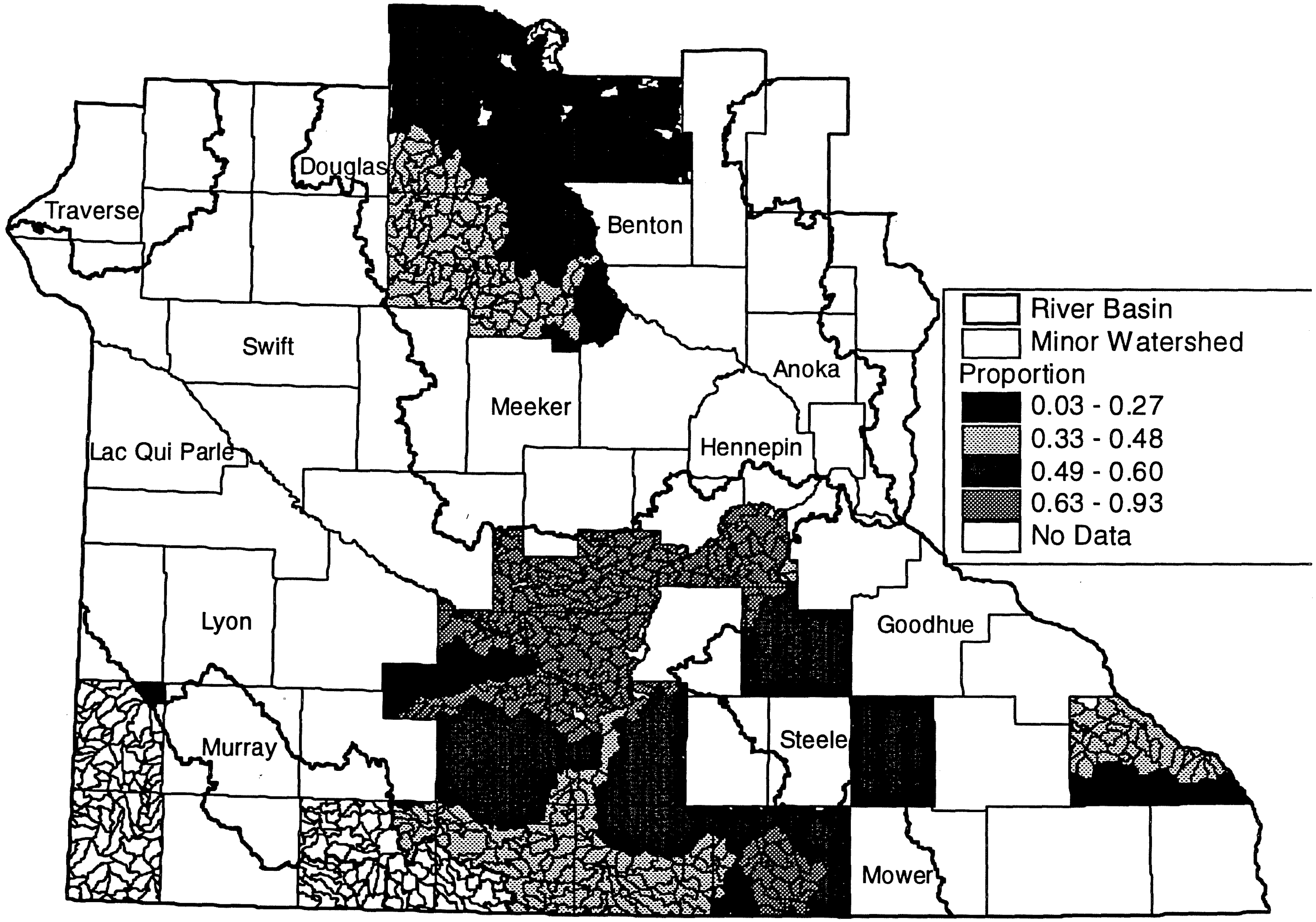


Figure 25. Proportion of surface water samples that exceed 0.25 mg/L at the major watershed outlet.

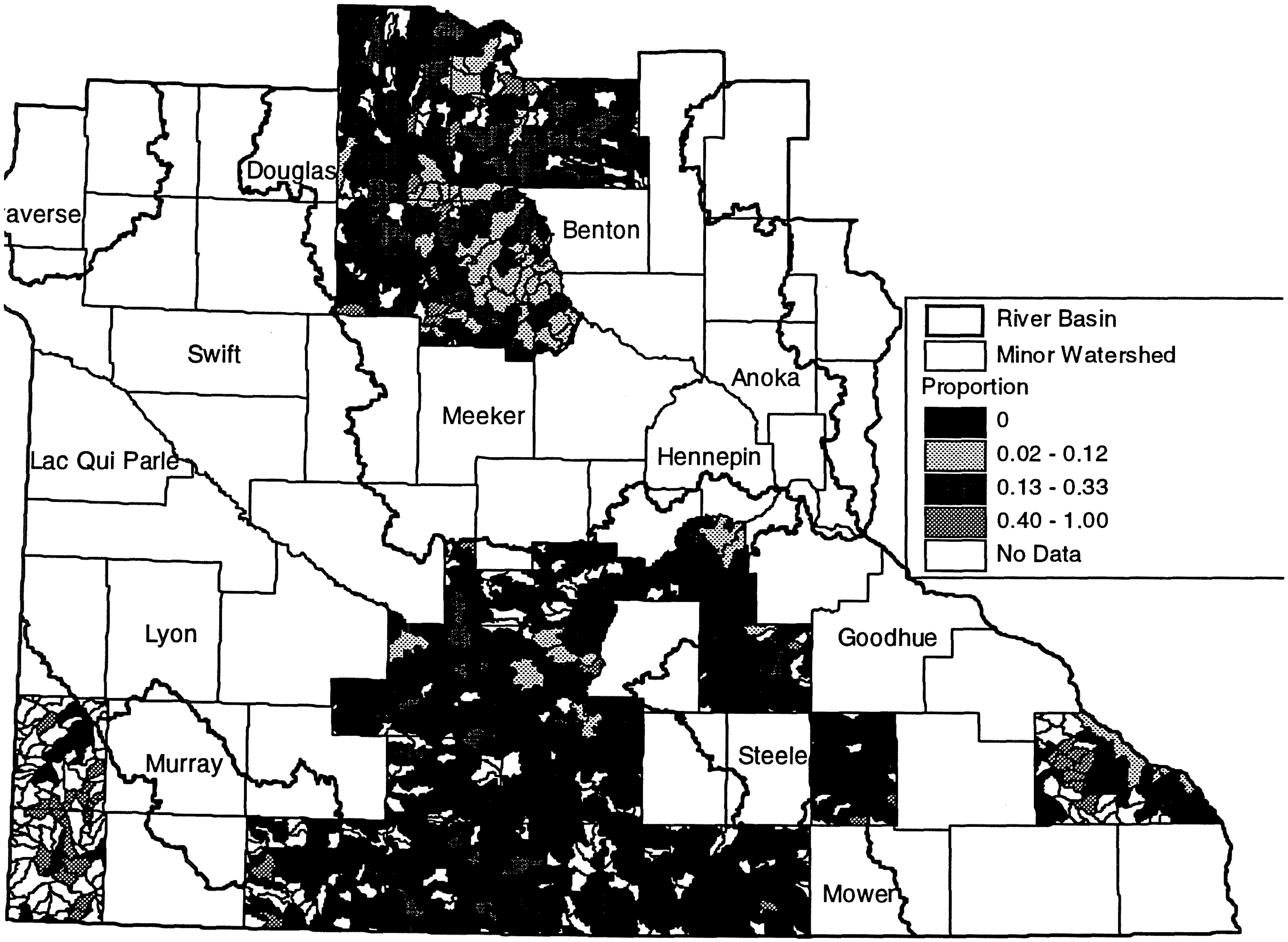


Figure 26. Proportion of well samples that exceed 3 mg/L nitrate-nitrogen.

the wells in some watersheds exceed 3 mg/L nitrate. These are partially a result of the numerous shallow, hand-dug wells located in shallow alluvial material. Another region with serious ground water pollution is on alluvial and coarse textured outwash soils in central Minnesota. Greater than 13% of the wells have nitrate levels exceeding 3 mg/L in a large percentage of Morrison, Stearns, and Todd counties. Ground water pollution by nitrate also occurs in the karst topography of southeastern Minnesota. In some watersheds, greater than 40% of the wells have nitrate levels exceeding 3 mg/L. Ground water pollution by nitrate is much less frequent in southern Minnesota, occurring primarily along the Minnesota River. Thus, the extent of ground water degradation in the four regions studied decreases in the following order:

Southwestern MN > Central MN > Southeastern MN > Southern MN

L. Ranking of Practices Used in Land Application of Manure

Land application of manure for utilization by crops can greatly affect surface and ground water quality on a widespread, non-point basis if not done properly. For all livestock species in Minnesota, most of the manure is spread on the soil surface and with the exception of alfalfa, hay, or pasture land, is incorporated prior to planting by tillage. Thus, cropping system does dictate, to some degree, method of application. Application method is also dictated by the storage system and its capacity. Producers with 12 to 14-mo storage capacity have much greater flexibility than those with 6-mo or shorter capacity. For most producers with liquid manure, the system of choice is to empty their storage in the fall by applying to fields shortly after harvest. Soil conditions are usually drier, compared to spring, and less compaction results. Direct injection into the soil is also a common practice at this time, particularly for hog producers who also desire to limit odor concerns. On the other hand, many smaller dairy operations with solid manure are forced to daily haul their manure. This forces surface application to frozen soils in the winter.

Water quality impacts of animal agriculture from land application of manure depend on several variables (Table 11). These include application rates, application methods, time of application, nutrient content of manure, and quality control and record keeping techniques used during application. Table 11 rates the environmental risk of various manure application systems on the impairment of surface and ground water quality. In this rating, we again acknowledge that environmental risks are very site-specific. We also assume that other facets of manure application are optimized as a particular application practice is rated, i.e., we assume that rate and time of application are optimum as we rate method of application.

Basing the manure application rate on crop P needs presents the lowest environmental risk of any application rate strategy. However, because the rate of N applied with this strategy would usually be less than needed, supplemental fertilizer N would need to be added. Applying manure based on crop N needs usually over-applies P, which raises the risk of surface water contamination. Applying manure with no regard for cropping system represents a "disposal" strategy rather than a crop "utilization" strategy. Thus, the risk of N impairing surface and ground waters is very high. Estimating the proper rate of nutrients to apply depends on the crop grown, the crop yield goal, N credits for mineralization or legumes, and previous applications of manure, and soil tests for available N (where recommended) and P.

Table 11. Relative water quality risks associated with liquid manure application.

	Water type			
	Surface[1]		Ground[2]	
	N[3]	P	N[4]	P
	Relative risk[5]			
Application rate				
Based on crop N needs	2	2	1/2[6]	1
Based on crop P needs	1	1	1	1
No regard to cropping system	5	3	4/5	1/2
Application method				
Knife, disk, or sweep injection	1	1	1	1
Surface broadcast (liquid)				
Incorporate within 12 hours	2	2	1	1
No incorporation	4	5	1	1
Surface broadcast (solid)				
Incorporate within 12 hours	3	3	1	1
No incorporation	4	5	1	1
Application timing				
Fall	2	1	2/3	1
Winter				
Flatland	2	2	2/2	1
Sloping fields	4	4	1	1
Spring, preplant	1	1	1	1
Early summer, sidedress	2	1	2/3	1
Late summer	4	1	4/5	1
Manure analysis				
Laboratory	1	1	1	1
Table values	2	2	2	1
No analysis	4	3	4/5	1/2
Equipment calibration				
Calibrated	1	1	1	1
No calibration	3	2	3/4	1/2

[1] Includes surface runoff and subsurface tile drainage.
[2] Percolation to deeper aquifers.
[3] Organic N, NH_4-N, NO_3-N
[4] NO_3-N
[5] 1 = very low risk; 5 = very high risk
[6] medium textured soil/coarse textured soil

Manure application method has no impact on ground water but surface waters can be greatly affected by both N and P. Direct injection of manure clearly limits risk compared to other application methods. No incorporation of surface-applied liquid and solid manure presents a very high risk for P impairment and a high risk for N contamination.

Time of manure application affects the impairment of surface and ground waters by N more than by P. Although a spring, preplant application presents the lowest environmental risk by N and P for both surface and groundwaters, it is often avoided by farmers because of soil compaction and delayed planting resulting in lower crop yields. The best alternative is a late fall application except on coarse-textured, sandy soils. Winter application on flat soils is likely to have little effect on surface and ground waters, but when applied to sloping fields will increase risk considerably for both N (organic-N and ammonium-N) and P in surface waters. Early summer, sidedress applications have been shown to be relatively low risk, but do present some logistical problems with equipment, row-spacing, and time requirements. Late summer application to harvested pea, sweet corn, or small grain ground presents a high degree of environmental risk. The manure-N will mineralize to nitrate by early fall, which increases greatly the potential for leaching in the late fall and spring before crop growth begins, especially on sandy soils.

Nutrient content of manure can be greatly affected by storage system, inflow of wash or drinking water, and feeding ration. Therefore, using a laboratory analysis of the manure from each storage system as a basis for determining application rate presents much less environmental risk due to over-application compared to using standard table values. In the event that manure laboratory analyses can not be obtained, and laboratory analyses from previous applications are not available, consulting standard tables gives "ballpark" figures, which are considerably better than using no manure analyses at all. Finally, calibration of the manure applicator is essential if the proper rate is to be applied. No calibration of the applicator means guessing at the rate which usually results in over-application (an environmental risk) or under-application (an economic risk).

Proper record keeping is also important for the protection of water quality. Record keeping is important so that manure is not applied to the same parcels of land every year. In addition, it helps to keep records so that the proper manure N credits can be estimated in the subsequent year when deciding how much commercial fertilizer to apply.

M. Relative Impacts on Water Quality from Manure versus Commercial Fertilizer

Water quality in a large watershed depends on many factors, including climate, soils, landscapes, drainage density, landuse, conservation practices, and nutrient management techniques. One major factor affecting the impact of nutrient management techniques on water quality is the amount of excess nutrients applied from manure and commercial fertilizer. For phosphorus, wastewater treatment plants can also have a significant impact on water quality. For example, during an average flow year, wastewater treatment plants upstream of the Twin Cities metropolitan area contribute as much phosphorus to the Mississippi and Minnesota Rivers as the total amounts of phosphorus carried by these two rivers from non-point sources. In the discussion below, however, we will evaluate only the relative impacts on non-point source nutrient pollution of manure and commercial fertilizer.

In the eighteen counties studied, fertilizer sales data from 1997 (Table 12) were used to assess the amounts of N and P_2O_5 available for application to cropland. We omit Scott county from the following analysis, because it is hard to separate the sales of fertilizer for use on cropland from the sales of fertilizer for use on lawns. For the seventeen remaining counties, the amounts of commercial fertilizer N and P_2O_5 applied to cropland were 166,633 tons and 54,871 tons, respectively. The amounts of manure N and P_2O_5 applied to cropland were 27,765 tons (Table 13a) and 62,085 tons (Table 13b), respectively. Based on simple ratios using these data, manure would be expected to contribute about 14% of the N applied to land, and about 53% of the P applied to land. Alternatively, these figures can be interpreted to mean that 84% of N applied to land and 47% of the P is contributed by fertilizer. These percentages will be refined in section P.

The area weighted average percentages of manure nutrients relative to fertilizer nutrients can be estimated for each of the major river basins studied. For the Minnesota River basin, manure N and P represent 19% and 53% of the total nutrients from fertilizer plus manure. These figures can be interpreted to mean that land applied manure accounts for roughly 19% of the N and roughly 53% of the P available for transport to surface or ground water. For the Upper Mississippi River basin, land applied manure accounts for 26% of the N and 73% of the P available for transport to surface or ground water. For the Lower Mississippi River basin, land applied manure accounts for 12% of the N and 55% of the P available for transport to surface and ground water. In southwestern Minnesota, land applied manure accounts for about 12% of the N and 42% of the P available for transport to surface or ground water. Due to a limited number of counties studied, these figures for the Upper Mississippi, Lower Mississippi, Des Moines, and Missouri River basins should be viewed as preliminary.

Stearns county has much greater amounts of N and P applied to land from manure than any other county. Martin and Morrison counties are next highest, followed by Nicollet, Brown, and Blue Earth counties. Most of the manure N and P in Stearns county comes from dairy operations, although turkey operations represent a significant proportion as well. Manure N and P in Martin and Blue Earth counties is overwhelmingly from hog operations. In Morrison county, dairy, chicken, and turkey feedlots account for the majority of the manure N and P. Hogs and turkeys account for most of the manure N and P in Brown and Nicollet counties. The percentage contributions of N from manure relative to manure N plus commercial fertilizer N for each of these counties are 14%, 39%, 22%, 12%, and 9% for Martin, Morrison, Nicollet, Brown, and Blue Earth counties, respectively. The percentage contributions of P from manure relative to total applied P are 43%, 82%, 67%, 52%, and 57% for Martin, Morrison, Nicollet, Brown, and Blue Earth counties, respectively.

Intermediate amounts of N and P applied to land from manure occur in counties such as Pipestone and Rock. About half of the nutrients arise from hog operations, while beef operations contribute between a quarter and a third. The percentage contributions of N from manure relative to total applied N are 18% and 21% for Pipestone and Rock counties, respectively. Manure P accounts for 52% and 57% of the total P applied to land from manure and commercial fertilizer in Pipestone and Rock counties, respectively.

Table 12. 1997 reported fertilizer characteristics for selected counties.

County	Fertilized land	Total fertilizer sold N	Total fertilizer sold P_2O_5	Fertilizer rate N	Fertilizer rate P_2O_5
	acres	tons	tons	lbs/ac/yr	lbs/ac/yr
Blue Earth	204347	19525	3101	191	30
Brown	184937	13608	3877	147	42
Dodge	138090	6097	1837	88	27
Faribault	240719	14991	5628	125	47
Freeborn	201611	11970	3820	119	38
Jackson	191157	8237	3886	86	41
Martin	245975	17495	8039	142	65
Morrison	145357	3933	1344	54	18
Nicollet	126185	7316	2352	116	37
Pipestone	111650	6403	3017	115	54
Rice	106943	8434	1676	158	31
Rock	138886	5503	2393	79	34
Scott	56019	17504	4821	625	172
Sibley	164726	5344	1864	65	23
Stearns	270166	17260	5085	128	38
Todd	131109	1820	634	28	10
Watonwan	127745	11964	4904	187	77
Winona	97992	6733	1414	137	29
Total w/o Scott	2827595	166633	54871	118	39

Table 13a. First year available manure nitrogen by county and animal type.

County	Beef	Chicken	Dairy	Hog	Turkey	All types
	Animal type					
	tons/yr					
Blue Earth	162	19	52	1550	97	1881
Brown	198	17	279	1102	291	1887
Dodge	31	14	148	367	180	740
Faribault	117	8	96	925	0	1145
Freeborn	50	55	112	1033	37	1287
Jackson	169	20	54	1124	29	1396
Martin	192	0	23	2619	82	2916
Morrison	40	769	989	77	690	2565
Nicollet	80	0	274	1000	695	2048
Pipestone	397	6	151	848	38	1440
Rice	168	0	551	599	0	1318
Rock	343	0	107	996	0	1446
Scott	24	0	238	86	0	348
Sibley	103	19	260	445	0	827
Stearns	272	599	2051	414	700	4035
Todd	67	425	664	50	287	1493
Watonwan	158	0	58	150	66	432
Winona	63	0	677	58	112	910
All counties	2633	1951	6783	13443	3305	28113

Table 13b. First year available manure phosphate by county and animal type.

County	Beef	Chicken	Dairy	Hog	Turkey	All types
	Animal type					
	tons/yr					
Blue Earth	480	56	106	3158	267	4067
Brown	582	49	573	2210	800	4214
Dodge	80	40	290	736	496	1641
Faribault	352	22	181	1914	0	2469
Freeborn	146	159	219	2011	102	2636
Jackson	503	59	109	2297	78	3046
Martin	573	1	45	5341	224	6184
Morrison	123	2238	1927	159	1895	6342
Nicollet	224	0	538	2047	1909	4718
Pipestone	1161	19	322	1728	105	3336
Rice	494	0	1064	1186	0	2745
Rock	1015	0	209	1966	0	3190
Scott	72	0	459	178	0	709
Sibley	284	56	533	896	0	1769
Stearns	785	1647	3997	829	1922	9180
Todd	201	1241	1288	103	785	3618
Watonwan	466	0	117	266	181	1030
Winona	189	0	1282	120	308	1900
All counties	7730	5587	13259	27145	9073	62794

Scott and Watonwan counties have the least amount of N and P applied to land from manure, followed by Dodge, Sibley, and Winona counties. Scott county manure N and P arises mainly from dairy operations, with a moderate proportion from hogs. The percentage contributions of N and P from manure relative to total N and P applications are 2% and 13% in Scott county. In Winona county, dairy feedlots contribute the majority of the manure N and P. Manure N and P account for 11% and 57% of the total N and P applied in Winona county. Hogs account for about half of the manure N and P in Dodge and Sibley counties, with dairy feedlots contributing about another quarter. The percentage contributions of N from manure relative to total applied N are 11% and 13% in Dodge and Sibley counties, respectively. The percentage contributions of P from manure are 47% and 49%, respectively for Dodge and Sibley counties.

The total amount of N and P_2O_5 applied to land varies by animal species (Table 13ab). Almost 48% of the N and 43% of the P_2O_5 applied to land is generated by hogs. Dairy cattle account for 24% of the N and 21% of the P_2O_5. Turkeys generate 12% of the N and 14% of the P_2O_5. About 9% of the N and 12% of the P_2O_5 is generated by beef cattle. Chickens generate roughly 7% of the N and 9% of the P_2O_5 applied in manure to the land.

N. Feedlot Size Class and Animal Species Effects on Manure Nutrients

As expected, the amount of manure N and P for each county in the study area varies by the size class of feedlots (Table 14ab). Overall, moderate sized feedlots (300-999 A.U.) account for 41% of the N and 42% of the P_2O_5 applied to land. Small (100-299 A.U.) and large (>1000 A.U.) feedlots account for about another 25% each of the N and P_2O_5 applied to land. Large feedlots contribute over 40% of the N and P_2O_5 applied to land in Nicollet and Todd counties. Large feedlots in Martin county account for about 35% of the N and P_2O_5 applied to land. In general, very small (50-99 A.U.) and tiny (<49 A.U.) feedlots account for less than 9% of the N and P_2O_5 applied to land.

There is a tendency for the percentage contributions of N and P_2O_5 applied to land by feedlot size class to vary with the animal species. Over 60% of the N and P_2O_5 applied to land by turkey feedlots (Table 15ab) is generated by large feedlots. Over 90% of the N and P_2O_5 from chicken feedlots (Table 16ab) is generated by moderate and large sized feedlots. Moderate sized hog feedlots generate about half of the N and P_2O_5 applied to land from hog feedlots (Table 17ab), with another quarter each originating from small or large feedlots. About 70% of the N and P_2O_5 applied to land from beef feedlots (Table 18ab) originates in small and moderate sized feedlots. Half of the N and P_2O_5 applied to land from dairy operations (Table 19ab) originates from small sized feedlots.

O. Excess Nutrients Applied to Land Relative to Fertilizer Recommendations

For each county in the study area, we estimated the proportion of fertilized cropland using 1997 Agricultural Census statistics. The amount of commercial N or P_2O_5 fertilizer sold in each county was available from county agricultural statistics provided by MDA. The amount of manure N or P_2O_5 is known from results in section M. The average University of Minnesota fertilizer recommendations for corn and soybeans in each county were estimated by a soil fertility professor on our team, after accounting for county average crop acreages, yield goals,

Table 14a. Proportion of manure N produced from all feedlots by county and size class.

County	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Blue Earth	1.3	2.2	19.5	49.1	27.8	100.0
Brown	1.6	6.5	26.8	39.7	25.4	100.0
Dodge	3.2	6.8	23.7	51.9	14.4	100.0
Faribault	1.8	4.5	30.0	50.2	13.5	100.0
Freeborn	3.9	7.5	33.6	38.2	16.7	100.0
Jackson	0.6	2.4	23.3	60.4	13.2	100.0
Martin	0.4	2.1	14.1	48.3	35.1	100.0
Morrison	0.8	6.0	23.9	42.1	27.1	100.0
Nicollet	0.5	1.4	19.5	32.8	45.8	100.0
Pipestone	1.2	5.5	25.1	43.8	24.4	100.0
Rice	5.6	12.2	42.8	34.4	5.0	100.0
Rock	1.5	5.0	24.0	63.8	5.8	100.0
Scott	3.6	16.0	43.8	15.6	21.0	100.0
Sibley	4.9	12.0	50.5	30.4	2.3	100.0
Stearns	1.6	6.4	38.3	37.4	16.3	100.0
Todd	1.8	13.5	23.2	19.1	42.4	100.0
Watonwan	5.7	8.3	37.1	36.8	12.1	100.0
Winona	7.2	20.6	35.0	28.7	8.5	100.0
All counties	2.0	6.4	27.7	41.5	22.5	100.0

Table 14b. Proportion of manure P_2O_5 produced from all feedlots by county and size class.

County	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Blue Earth	1.5	2.3	19.8	48.8	27.6	100.0
Brown	1.6	6.2	25.3	40.9	26.1	100.0
Dodge	3.1	6.3	21.8	53.4	15.3	100.0
Faribault	2.0	5.0	30.4	49.8	12.8	100.0
Freeborn	3.9	7.5	32.2	39.5	16.9	100.0
Jackson	0.7	2.6	23.0	60.2	13.5	100.0
Martin	0.4	2.3	14.5	48.0	34.8	100.0
Morrison	0.8	4.9	19.6	44.9	29.9	100.0
Nicollet	0.5	1.3	17.6	29.8	50.8	100.0
Pipestone	1.5	6.3	26.1	42.8	23.2	100.0
Rice	6.5	12.7	42.2	33.8	4.8	100.0
Rock	1.5	5.3	24.3	63.4	5.5	100.0
Scott	4.0	15.8	42.2	15.7	22.3	100.0
Sibley	5.5	12.2	49.5	29.7	3.1	100.0
Stearns	1.8	6.0	34.0	39.4	18.8	100.0
Todd	1.6	11.2	19.9	17.8	49.5	100.0
Watonwan	5.1	7.6	35.0	38.1	14.2	100.0
Winona	7.9	20.3	32.7	31.2	7.9	100.0
All counties	2.0	6.1	26.0	41.7	24.2	100.0

Table 15a. Proportion of manure N produced from turkey feedlots by county and size class.

County	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Blue Earth	0.0	0.0	12.2	87.8	0.0	100.0
Brown	0.5	0.5	2.7	55.2	41.1	100.0
Dodge	0.6	0.0	0.0	72.3	27.2	100.0
Faribault	0.0	0.0	0.0	0.0	0.0	0.0
Freeborn	0.0	0.0	21.5	78.5	0.0	100.0
Jackson	0.0	0.0	0.0	0.0	100.0	100.0
Martin	0.0	0.0	26.6	24.8	48.6	100.0
Morrison	0.0	0.0	0.0	37.4	62.6	100.0
Nicollet	0.0	0.0	0.8	2.7	96.4	100.0
Pipestone	0.0	0.0	0.0	0.0	100.0	100.0
Rice	0.0	0.0	0.0	0.0	0.0	0.0
Rock	0.0	0.0	0.0	0.0	0.0	0.0
Scott	0.0	0.0	0.0	0.0	0.0	0.0
Sibley	100.0	0.0	0.0	0.0	0.0	100.0
Stearns	0.0	0.4	1.2	50.6	47.8	100.0
Todd	0.0	0.0	0.0	19.0	81.0	100.0
Watonwan	0.0	0.0	0.0	35.5	64.5	100.0
Winona	0.0	0.0	5.3	94.7	0.0	100.0
All counties	0.1	0.1	2.1	37.6	60.1	100.0

Table 15b. Proportion of manure P_2O_5 produced from turkey feedlots by county and size class.

County	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Blue Earth	0.0	0.0	12.3	87.7	0.0	100.0
Brown	0.5	0.5	2.7	55.2	41.1	100.0
Dodge	0.6	0.0	0.0	72.3	27.2	100.0
Faribault	0.0	0.0	0.0	0.0	0.0	0.0
Freeborn	0.0	0.0	21.5	78.5	0.0	100.0
Jackson	0.0	0.0	0.0	0.0	100.0	100.0
Martin	0.0	0.0	26.7	24.4	48.8	100.0
Morrison	0.0	0.0	0.0	37.4	62.6	100.0
Nicollet	0.0	0.0	0.8	2.7	96.4	100.0
Pipestone	0.0	0.0	0.0	0.0	100.0	100.0
Rice	0.0	0.0	0.0	0.0	0.0	0.0
Rock	0.0	0.0	0.0	0.0	0.0	0.0
Scott	0.0	0.0	0.0	0.0	0.0	0.0
Sibley	100.0	0.0	0.0	0.0	0.0	100.0
Stearns	0.0	0.4	1.2	50.6	47.9	100.0
Todd	0.0	0.0	0.0	19.0	81.0	100.0
Watonwan	0.0	0.0	0.0	35.5	64.5	100.0
Winona	0.0	0.0	5.3	94.7	0.0	100.0
All counties	0.1	0.1	2.1	37.5	60.1	100.0

Table 16a. Proportion of manure N produced from chicken feedlots by county and size class.

County	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Blue Earth	0.1	5.6	17.7	76.6	0.0	100.0
Brown	0.0	0.0	26.5	73.5	0.0	100.0
Dodge	0.0	0.0	27.4	72.6	0.0	100.0
Faribault	0.0	14.6	85.4	0.0	0.0	100.0
Freeborn	0.0	0.0	29.6	70.4	0.0	100.0
Jackson	0.0	0.0	0.0	100.0	0.0	100.0
Martin	100.0	0.0	0.0	0.0	0.0	100.0
Morrison	0.0	0.3	7.3	67.9	24.5	100.0
Nicollet	100.0	0.0	0.0	0.0	0.0	100.0
Pipestone	0.0	0.0	0.0	100.0	0.0	100.0
Rice	0.0	0.0	0.0	0.0	0.0	0.0
Rock	0.0	0.0	0.0	0.0	0.0	0.0
Scott	0.0	0.0	0.0	0.0	0.0	0.0
Sibley	2.4	0.0	0.0	0.0	97.6	100.0
Stearns	0.1	0.2	3.2	65.2	31.2	100.0
Todd	0.1	0.0	1.0	8.6	90.3	100.0
Watonwan	0.0	0.0	0.0	0.0	0.0	0.0
Winona	100.0	0.0	0.0	0.0	0.0	100.0
All counties	0.1	0.3	5.8	53.9	39.9	100.0

Table 16b. Proportion of manure P_2O_5 produced from chicken feedlots by county and size class.

County	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Blue Earth	0.1	5.3	17.7	76.8	0.0	100.0
Brown	0.0	0.0	26.7	73.3	0.0	100.0
Dodge	0.0	0.0	27.4	72.6	0.0	100.0
Faribault	0.0	14.6	85.4	0.0	0.0	100.0
Freeborn	0.0	0.0	29.7	70.3	0.0	100.0
Jackson	0.0	0.0	0.0	100.0	0.0	100.0
Martin	100.0	0.0	0.0	0.0	0.0	100.0
Morrison	0.0	0.3	7.3	67.8	24.6	100.0
Nicollet	100.0	0.0	0.0	0.0	0.0	100.0
Pipestone	0.0	0.0	0.0	100.0	0.0	100.0
Rice	0.0	0.0	0.0	0.0	0.0	0.0
Rock	0.0	0.0	0.0	0.0	0.0	0.0
Scott	0.0	0.0	0.0	0.0	0.0	0.0
Sibley	2.3	0.0	0.0	0.0	97.7	100.0
Stearns	0.1	0.2	3.4	64.9	31.4	100.0
Todd	0.1	0.0	1.0	8.6	90.3	100.0
Watonwan	0.0	0.0	0.0	0.0	0.0	0.0
Winona	100.0	0.0	0.0	0.0	0.0	100.0
All counties	0.1	0.3	5.9	53.5	40.2	100.0

Table 17a. Proportion of manure N produced from hog feedlots by county and size class.

County	Feedlot size in animal units: 1-49	50-99	100-299	300-999	1000+	All classes
	%					
Blue Earth	0.8	1.6	16.8	50.2	30.7	100.0
Brown	1.7	4.3	24.1	39.9	30.0	100.0
Dodge	2.3	3.3	22.3	59.8	12.4	100.0
Faribault	1.0	3.5	28.2	53.6	13.7	100.0
Freeborn	3.3	5.1	33.6	37.2	20.8	100.0
Jackson	0.3	1.8	23.0	62.2	12.7	100.0
Martin	0.3	1.7	11.9	49.1	37.0	100.0
Morrison	5.2	8.4	18.0	44.7	23.7	100.0
Nicollet	0.5	1.4	17.8	53.4	26.9	100.0
Pipestone	0.3	0.9	14.0	50.9	33.9	100.0
Rice	1.3	4.5	28.3	54.8	11.0	100.0
Rock	1.4	3.6	18.3	70.0	6.6	100.0
Scott	1.2	8.0	18.6	38.3	34.0	100.0
Sibley	2.8	5.6	48.4	43.3	0.0	100.0
Stearns	1.5	2.5	28.7	50.1	17.3	100.0
Todd	4.5	20.1	27.5	47.9	0.0	100.0
Watonwan	9.7	11.6	43.2	35.5	0.0	100.0
Winona	4.1	6.2	16.3	41.6	31.8	100.0
All counties	1.2	3.0	21.5	51.1	23.3	100.0

Table 17b. Proportion of manure P_2O_5 produced from hog feedlots by county and size class.

County	Feedlot size in animal units: 1-49	50-99	100-299	300-999	1000+	All classes
	%					
Blue Earth	0.7	1.6	16.3	50.4	31.0	100.0
Brown	1.7	4.2	23.6	39.6	30.9	100.0
Dodge	2.2	3.2	22.0	60.1	12.5	100.0
Faribault	1.0	3.5	28.2	53.6	13.7	100.0
Freeborn	3.0	4.8	31.9	38.1	22.2	100.0
Jackson	0.3	1.7	22.9	62.2	12.8	100.0
Martin	0.2	1.7	11.8	49.0	37.3	100.0
Morrison	5.2	8.4	18.0	44.7	23.7	100.0
Nicollet	0.5	1.4	17.8	53.2	27.1	100.0
Pipestone	0.3	0.9	13.6	51.0	34.2	100.0
Rice	1.4	4.6	27.6	55.3	11.2	100.0
Rock	1.4	3.5	17.7	71.1	6.3	100.0
Scott	1.2	8.0	18.6	38.3	34.0	100.0
Sibley	2.7	5.6	47.9	43.7	0.0	100.0
Stearns	1.4	2.5	27.8	50.1	18.1	100.0
Todd	4.5	20.1	27.5	47.9	0.0	100.0
Watonwan	9.7	11.6	43.2	35.5	0.0	100.0
Winona	4.0	6.2	16.2	41.5	31.9	100.0
All counties	1.2	2.9	21.0	51.2	23.7	100.0

Table 18a. Proportion of manure N produced from beef feedlots by county and size class.

County	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Blue Earth	6.6	6.0	40.6	17.3	29.4	100.0
Brown	2.6	10.5	26.3	45.8	14.9	100.0
Dodge	12.7	12.7	35.7	0.0	38.9	100.0
Faribault	7.2	13.9	37.0	41.9	0.0	100.0
Freeborn	20.0	33.8	31.0	15.1	0.0	100.0
Jackson	2.6	6.9	24.8	57.6	8.0	100.0
Martin	1.9	8.3	32.1	49.3	8.5	100.0
Morrison	19.1	27.0	45.2	8.7	0.0	100.0
Nicollet	4.3	6.6	48.1	40.9	0.0	100.0
Pipestone	3.7	14.0	37.6	38.1	6.6	100.0
Rice	20.0	19.5	42.1	18.4	0.0	100.0
Rock	1.7	8.2	31.2	54.0	5.0	100.0
Scott	15.4	17.0	14.5	9.2	43.9	100.0
Sibley	15.8	20.5	48.0	15.7	0.0	100.0
Stearns	11.6	18.3	39.9	27.5	2.7	100.0
Todd	9.6	23.6	55.4	11.3	0.0	100.0
Watonwan	4.7	7.8	36.9	44.5	6.2	100.0
Winona	37.7	42.6	16.2	3.5	0.0	100.0
All counties	7.6	13.6	35.8	35.8	7.2	100.0

Table 18b. Proportion of manure P_2O_5 produced from beef feedlots by county and size class.

County	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Blue Earth	6.4	6.1	40.0	17.6	30.0	100.0
Brown	2.7	10.0	25.7	46.3	15.3	100.0
Dodge	14.7	14.4	39.7	0.0	31.1	100.0
Faribault	7.2	13.9	37.0	41.9	0.0	100.0
Freeborn	20.5	33.8	31.5	14.2	0.0	100.0
Jackson	2.6	6.8	24.7	57.7	8.2	100.0
Martin	1.9	8.3	31.7	49.5	8.6	100.0
Morrison	18.8	26.6	46.0	8.6	0.0	100.0
Nicollet	4.5	6.7	47.0	41.8	0.0	100.0
Pipestone	3.7	14.0	37.3	38.1	6.8	100.0
Rice	20.5	19.8	41.5	18.3	0.0	100.0
Rock	1.7	8.2	31.0	54.0	5.1	100.0
Scott	15.4	17.0	14.5	9.2	43.9	100.0
Sibley	16.9	20.2	46.4	16.5	0.0	100.0
Stearns	11.7	18.2	39.9	27.4	2.8	100.0
Todd	9.7	23.7	55.3	11.3	0.0	100.0
Watonwan	4.5	7.7	36.8	44.6	6.4	100.0
Winona	37.7	42.6	16.2	3.5	0.0	100.0
All counties	7.7	13.5	35.4	36.1	7.3	100.0

Table 19a. Proportion of manure N produced from dairy feedlots by county and size class.

County	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Blue Earth	5.1	12.2	48.9	33.9	0.0	100.0
Brown	1.7	19.0	62.8	16.5	0.0	100.0
Dodge	7.0	23.3	53.2	16.5	0.0	100.0
Faribault	3.1	2.1	34.7	31.4	28.8	100.0
Freeborn	6.3	23.7	41.4	28.6	0.0	100.0
Jackson	1.0	3.8	46.2	48.9	0.0	100.0
Martin	5.2	7.2	61.8	25.8	0.0	100.0
Morrison	0.9	13.7	53.1	26.6	5.7	100.0
Nicollet	0.4	3.7	64.6	31.2	0.0	100.0
Pipestone	0.3	10.2	61.8	27.7	0.0	100.0
Rice	5.7	18.4	58.7	17.1	0.0	100.0
Rock	1.5	7.8	53.4	37.3	0.0	100.0
Scott	3.3	18.8	55.9	8.0	14.0	100.0
Sibley	4.4	20.4	58.8	16.4	0.0	100.0
Stearns	1.4	9.5	62.8	23.6	2.7	100.0
Todd	2.6	26.4	43.9	24.3	2.7	100.0
Watonwan	4.5	10.4	64.3	20.8	0.0	100.0
Winona	5.8	23.2	43.3	19.0	8.7	100.0
All counties	2.7	15.1	55.6	22.9	3.7	100.0

Table 19b. Proportion of manure P_2O_5 produced from dairy feedlots by county and size class.

County	Feedlot size in animal units					All classes
	1-49	50-99	100-299	300-999	1000+	
	%					
Blue Earth	5.5	12.7	50.4	31.4	0.0	100.0
Brown	1.6	18.2	62.9	17.2	0.0	100.0
Dodge	7.1	23.4	53.1	16.4	0.0	100.0
Faribault	3.1	2.1	34.7	31.4	28.8	100.0
Freeborn	6.1	23.8	41.9	28.3	0.0	100.0
Jackson	0.9	3.8	45.3	50.0	0.0	100.0
Martin	5.0	7.7	62.4	24.9	0.0	100.0
Morrison	0.9	13.3	51.6	28.0	6.2	100.0
Nicollet	0.4	3.6	64.1	31.8	0.0	100.0
Pipestone	0.3	10.0	63.1	26.6	0.0	100.0
Rice	5.7	18.3	58.9	17.1	0.0	100.0
Rock	1.5	7.9	53.6	37.1	0.0	100.0
Scott	3.3	18.7	55.7	7.9	14.4	100.0
Sibley	4.3	20.3	59.0	16.3	0.0	100.0
Stearns	1.4	9.4	62.5	23.7	3.0	100.0
Todd	2.6	26.2	44.1	24.6	2.6	100.0
Watonwan	4.5	10.0	63.1	22.4	0.0	100.0
Winona	5.8	23.2	43.3	19.0	8.7	100.0
All counties	2.6	15.0	55.4	23.2	3.8	100.0

soil test P levels, legume N credits and mineralized N. These values were multiplied by the fertilized cropland acreage to estimate the amount of recommended N and P_2O_5 which was sufficient for crop production in each county. The difference between the recommended amounts, and the sum of the actual fertilizer applications plus the actual manure applications, represents the excess amount of nutrients applied to cropland in each county. These excesses are based only on crop fertilizer requirements, not on water quality criteria in relation to disposal rates of manure.

University of Minnesota recommended rates of N and P_2O_5 fertilizer applied to cropland are mostly in the range of 120 lb N/ac for corn, and 50 lb P_2O_5/ac for a corn-soybean rotation, in the eighteen counties studied. Pipestone, Stearns, and Todd counties have recommended rates of 110 lb N/ac for corn and 40 lb P_2O_5/ac for a corn-soybean rotation. Excess N and P_2O_5 applied to cropland were estimated based on the sum of total N and P_2O_5 fertilizer sold plus the total N and P_2O_5 applied to land from manure, minus the recommended amounts of fertilizer N and P.

In the seventeen county study area (Table 20), 166,633 tons N/yr and 54,871 tons P_2O_5/yr were applied to cropland from fertilizer. Manure applied to land contributed another 27,765 tons N/yr and 62,085 tons P_2O_5/yr. The University of Minnesota recommended nutrient amounts were 164,526 tons N/yr and 67,398 tons P_2O_5/yr. These figures give 29,871 tons N/yr and 49,560 tons P_2O_5/yr of nutrients applied to land in excess of crop fertilizer recommendations. These translate into excesses of 19 lb N/ac and 35 lb P_2O_5/ac on fertilized cropland.

The amounts of excess N applied to land ranged from a deficit of –3712 tons N in Sibley county to about 14,771 tons/yr in Scott county. The N applications ranged from being 37% less than recommended rates in Sibley county, to over 450% of recommended rates in Scott county. Scott county has large lawn fertilizer sales to the urban population of the Twin Cities metropolitan area. Calculations of recommended N fertilizer do not include the amounts that should be applied to lawn acreage in Scott county. In addition, Scott county has a very low reported amount of fertilized cropland, only 30% of all cropland acres. All other counties report nearly half of the total cropland as fertilized cropland. Therefore, the excess amounts for Scott county are anomalous. Excluding Scott county, the excess applied N amounts were greatest in Blue Earth county, with 9,145 tons/yr of excess N. This is 75% of the recommended N amounts (almost three fourths of the recommended amounts of N), meaning that the total applied N from fertilizer and manure exceeds the University recommendations by 75%. Large excess N applications occurred in almost every county, except for Todd, Sibley, Morrison, Dodge, Rock, and Jackson counties, which all had deficits of N. These deficits could be caused by fertilizer purchased in neighboring counties, but applied in the counties with N deficits.

Based only on the amount of excess N applied from manure and fertilizer, we can rank counties in different regions according to their risk of contributing to surface or ground water pollution. We have omitted Scott county from the ranking due to the unknown influence of urban lawns and the low percentage of fertilized cropland. These rankings are shown below:

Southern Minnesota: Blue Earth > Martin > Watonwan > Brown > Nicollet > Faribault > Freeborn > Jackson > Sibley

Table 20. Nutrient budget for selected counties.

County	Recommended fertilizer rate N	Recommended fertilizer rate P_2O_5	Total recommended fertilizer applied N	Total recommended fertilizer applied P_2O_5	Total manure applied N	Total manure applied P_2O_5	Total fertilizer sold N	Total fertilizer sold P_2O_5	Excess (deficit) N	Excess (deficit) P_2O_5
	lb/ac/yr		tons							
Blue Earth	120	50	12261	5109	1881	4067	19525	3101	9145	2059
Brown	120	50	11096	4623	1887	4214	13608	3877	4399	3467
Dodge	120	50	8285	3452	740	1641	6097	1837	(1448)	26
Faribault	120	50	14443	6018	1145	2469	14991	5628	1692	2079
Freeborn	120	50	12097	5040	1287	2636	11970	3820	1160	1416
Jackson	120	50	11469	4779	1396	3046	8237	3886	(1837)	2153
Martin	120	50	14759	6149	2916	6184	17495	8039	5653	8073
Morrison	120	40	8721	2907	2565	6342	3933	1344	(2224)	4779
Nicollet	120	50	7571	3155	2048	4718	7316	2352	1793	3915
Pipestone	100	40	5583	2233	1440	3336	6403	3017	2260	4120
Rice	120	50	6417	2674	1318	2745	8434	1676	3335	1747
Rock	120	50	8333	3472	1446	3190	5503	2393	(1384)	2111
Scott	110	50	3081	1400	348	709	17504	4821	14771	4130
Sibley	120	50	9884	4118	827	1769	5344	1864	(3712)	(483)
Stearns	100	40	13508	5403	4035	9180	17260	5085	7787	8862
Todd	100	40	6555	2622	1493	3618	1820	634	(3243)	1630
Watonwan	120	50	7665	3194	432	1030	11964	4904	4731	2741
Winona	120	50	5880	2450	910	1900	6733	1414	1763	864
Total w/o Scott	na	na	164526	67398	27765	62085	166633	54871	29871	49560

Central Minnesota:	Stearns > Morrison > Todd
Southwestern Minnesota:	Pipestone > Rock
Southeastern Minnesota:	Rice > Winona > Dodge

There are several reasons for the excess N applications. First is that many fertilizer dealers recommend rates of N fertilizer that are significantly greater than those developed by the University of Minnesota. This is illustrated by the statistical FANMAP survey data collected by the MDA. They showed average rates of N applied to corn acres from commercial fertilizer to be 144 lb N/ac in south central Minnesota, 136 lb N/ac in Scott and Carver counties, and 90 lb N/ac in the dairy counties of southeastern Minnesota. With the exception of southeastern Minnesota, N rates applied in the FANMAP survey exceed University of Minnesota recommendations for unmanured corn acres by from 16 to 24 lb N/ac. If, in our analysis of N excesses in the 18 counties studied, we were to adjust University of Minnesota recommendations downward on manured cropland, the N resulting excesses would be greater than the values reported here.

A second reason for excess N applications is a tendency to apply fertilizer without accounting for N credits from manure or legume crops. Again, FANMAP survey data show that the excess N applied to corn on manured lands was 54 lb N/ac in south central Minnesota, 51 lb N/ac in the St. Peter wellhead protection area, 43 lb N/ac in Scott and Carver counties, 41 lb N/ac in the dairy region of southeastern Minnesota, 38 lb N/ac in outwash soils of central Minnesota, and from 20-33 lb N/ac in southwestern Minnesota. These excesses are from 17-45% of the University recommendations for unmanured corn acres.

A third reason is over-application of manure. Over-application of manure is greatest near barns due to the economics of hauling manure. Manure also is over-applied for the following reasons: 1) because crop nutrient needs are often not considered, 2) because there is no accurate manure analysis on which to base manure N and P contents, 3) because spreading equipment is not calibrated, and 4) because proper records are not kept concerning the amounts and locations of manure spreading.

Excess N applied to land is very susceptible to leaching losses in the form of nitrate. Nitrate can be carried away to ditches and streams through tile drainage. The water quality impacts of excess N applications to soil from manure and fertilizer are serious, being partially responsible for eutrophication in lakes and streams, and a zone of hypoxia in the Gulf of Mexico. In the Minnesota River basin, two-thirds of the total load of 55,423 tons of nitrate-N/yr carried by the Minnesota River at Jordan originates in the Blue Earth, Le Sueur, and Watonwan watersheds. Counties which contribute to the nitrate levels carried in these three watersheds include Blue Earth, Brown, Faribault, Martin, and Watonwan counties, as well as Cottonwood and Waseca counties for which we do not have estimates of excess N. The total amount of excess N applied to land in the five counties we have data for is 25,626 tons N/yr. This excess N ranges from 12% to 75% of the amounts of N recommended by the University of Minnesota, meaning that fertilizer and manure N are over-applied by from 12-75% of recommended amounts. The excess N in these counties (25,626 tons N/yr) is 73% of the nitrate loads carried by the Blue Earth, Le

Sueur, and Watonwan watersheds (34,916 tons N/yr). If data were available for the other two counties, namely Waseca and Cottonwood, the excess N for all seven counties would undoubtedly be greater than 25,626 tons N/yr.

Excess N applied to the land also contributes to ground water contamination. Stearns county has much poorer ground water quality than Todd county. Stearns county also has 7,782 tons/yr of excess N applied to soil, whereas Todd has a deficit of 3,245 tons/yr of N. Winona county has relatively poor ground water due to karst topography. Excess N applications of 1,762 tons/yr in Winona county contribute to nitrate contamination of ground water. Pipestone county has ground water which is seriously contaminated with nitrate, and excess N applications on cropland of 2,257 tons/yr.

Excess P_2O_5 applied to land can be transported to surface water by runoff and erosion. Cropland in close proximity to water bodies or surface tile intakes can contribute disproportionately large amounts of phosphorus to surface waters. Most counties in the study area (except Sibley county) had excess applications of P_2O_5 in comparison to recommendations by the University of Minnesota. The greatest excess P_2O_5 amounts applied to cropland were 8,073 tons P_2O_5/yr in Martin county and 8,861 tons P_2O_5/yr in Stearns county. The smallest P_2O_5 amount was a deficit of 483 tons P_2O_5/yr in Sibley county. The percentages by which excess P_2O_5 applications exceeded University of Minnesota recommendations were 131% and 164% in Martin and Stearns counties, respectively. Other rural counties with large excess P_2O_5 application percentages were Morrison, Nicollet, and Pipestone. Scott county had the largest excess P_2O_5 percentage (295%), again reflecting the impact of P_2O_5 fertilizer usage on urban lawns and the low percentage of fertilized cropland.

FANMAP surveys show that the amounts of P_2O_5 fertilizer and manure P applied to manured cropland are often greater than University of Minnesota recommendations (about 50 lb P_2O_5/ac for a corn-soybean rotation). In south central Minnesota, the average rate of commercial P_2O_5 fertilizer alone applied to manured corn acres is 46 lb/ac. The average rate of applied P_2O_5 fertilizer in Scott and Carver counties is 35 lb/ac. The average rate applied in Lincoln, Pipestone, and Winona counties is 30 lb P_2O_5/ac.

Based only on the amounts of excess P_2O_5 applied to cropland from manure and fertilizer, and excluding Scott county, we can rank the counties studied in terms of their likelihood of contributing to phosphorus pollution of surface waters. The order of this ranking differs from the ranking based on excess N due to differences in the relative amounts of N and P_2O_5 applied from fertilizer and manure within a county. This ranking for P_2O_5 is:

Southern Minnesota:	Martin > Nicollet > Brown > Watonwan > Jackson > Faribault > Blue Earth > Freeborn > Sibley
Central Minnesota:	Stearns > Morrison > Todd
Southwestern Minnesota:	Pipestone > Rock
Southeastern Minnesota:	Rice > Winona > Dodge

Excess P_2O_5 applied to land results from most of the same reasons cited in the section about excess N applications. The primary reasons for excess P_2O_5 applications involve applying manure based on crop N needs, rather than crop P uptake requirements, improper calibration and record keeping during manure spreading, and failure to base a P_2O_5 fertilizer application on soil test P levels or proper crop yield goals.

Excess P_2O_5 applied to the land can cause serious degradation of water quality. During an average year, the Minnesota River transports 1,492 tons P/yr, of which roughly 63% is from fertilized and manured cropland. About 37% of the Minnesota River basin phosphorus load (552 tons P/yr) is contributed by the Blue Earth, Le Sueur, and Watonwan watersheds. These three watersheds include Blue Earth, Brown, Faribault, Martin, and Watonwan counties, as well as Cottonwood and Waseca (for which we have no data on excess P_2O_5). The five counties we have data for give a combined excess P_2O_5 application amount of 18,417 tons/yr, which converts to 8,037 tons P/yr. Only a fraction of this excess has the potential to be transported to surface waters, due to the influence of soil P sorption and the low sediment delivery ratio (5%) typical of eroding soil particles in large watersheds. If only 5% of this excess P was transported to surface waters, it would represent about 400 tons P/yr.

Estimating the exact fraction of excess P_2O_5 transported to surface waters is difficult. Factors that influence P transport include climate, landscape and slope, proximity of land to waterbodies, cropping system and crop yields, soil P levels, amount and timing of excess P applied to soil, method of application, and conservation practices. When excess P is applied to soil, it raises the total P concentration and plant available P levels in surface soil. Research conducted at Waseca and Morris shows that long-term applications of 100 lb P_2O_5/ac/yr to a Webster or an Aastad soil raised soil test Bray-P levels by roughly 2 ppm/yr relative to the Bray-P levels in the same soil receiving 50 lb P_2O_5/ac/yr. Under typical cropping patterns, the application of 50 lb P_2O_5/ac/yr in a corn-soybean rotation does not significantly raise the soil Bray-P levels over many years of cropping.

When Bray-P levels exceed 75 ppm, the concentration of total and soluble P in erosion and runoff has a high likelihood of contributing to eutrophication of surface waters. About 10% and 25% of the soil samples submitted to the University of Minnesota Research Analytical Laboratory from Waseca and Stearns counties, respectively, had Bray-P levels greater than 75 ppm. At Bray-P levels less than 75 ppm, especially for soils in close proximity to surface waterbodies, eutrophication of surface water can still occur. For both these scenarios, it is recommended to use a nutrient management tool such as the Phosphorus-Index to determine management strategies which reduce the potential for phosphorus losses to surface waters.

In summary, for the eighteen counties studied, manure plus fertilizer nutrients applied to cropland are 16% and 74% in excess of the recommended amount of N and P_2O_5, respectively, which should be applied to cropland based on University recommendations. This translates into an excess of 19 lb N/ac and 35 lb P_2O_5/ac beyond University recommendations. For the whole study region, of the excess N applied to cropland which reaches surface or ground waters, about 14% is from manure, while 86% is from fertilizer. Of the excess P applied to cropland which reaches surface waters, about 53% is from manure, while 47% is from fertilizer. Thus, controlling nutrients in surface and ground waters is not merely a matter of adjusting amounts of land applied manure. It is also a matter of making sure that the total amount of nutrients applied to the land from both manure and fertilizer is compatible with crop uptake requirements.

P. Spatial Distributions of Excess Nutrients Applied to Land

The discussion of excess nutrients applied to land in sections M and O is based on county average data. There are some advantages to refining this discussion by using spatial information concerning manure nutrients applied to the land. The main advantage is the ability to quickly visualize minor watersheds where large amounts of excess N and P_2O_5 are applied to the land from fertilizer and manure.

The approach taken is as follows. Calculations of excess nutrients were accomplished using a combination involving the nutrient recommendations for crops from the University of Minnesota, agricultural statistical data on fertilizer applications and fertilized cropland area at the scale of counties, landuse datalayers for crop types, statistical surveys of farmers applying both manure and fertilizer to cropland, animal inventory data for each feedlot in the watersheds, the MPCA state permitting feedlot database, research data on manure N content by animal species and weight, research data on manure N losses for various types of animal confinement, storage, and application methods, and GIS analysis of these datalayers. All of these factors have been previously discussed, but now they are applied at the scale of minor watersheds in the study area.

For south central Minnesota, the manure applied to cropland represents 19% of the excess N and 56% of the excess P_2O_5 applied to cropland (Table 21a). In contrast, fertilizer applied to cropland represents 81% of the excess N and 44% of the excess P_2O_5 (Table 21a). The average rate of excess N applied to cropland from both manure and fertilizer is 53 lb/ac, or an excess which is 44% greater than the University of Minnesota nitrogen guidelines for corn. For phosphorus, the average rate of excess P_2O_5 applied to cropland from both manure and fertilizer is 56 lb/ac, or an excess 186% greater than the University of Minnesota phosphorus guidelines for corn.

In southeastern Minnesota, 80% of the excess N applied to land is from fertilizer, while 20% is from manure (Table 21b). These figures are quite similar to those obtained in south central Minnesota. For phosphorus, 76% of the excess is from manure, while 24% is from fertilizer (Table 21b). In contrast to south central Minnesota, manure accounts for a much greater proportion of the excess phosphorus than fertilizer in southeastern Minnesota. The average rates of excess N and P_2O_5 applied to cropland in southeastern Minnesota are 33lb/ac and 40 lb/ac, respectively. These excesses are much smaller than those obtained in south central Minnesota.

In southwestern Minnesota, manure accounts for a disproportionate amount of the excess nutrients applied to cropland (Table 21c). Excess N applied to cropland is overwhelmingly (61%) from manure, as is excess P_2O_5 (72%). Fertilizer accounts for 39% of the excess N and 28% of the excess P_2O_5 applied to cropland. The average rates of excess N and P_2O_5 applied to cropland are 20 lb/ac and 60 lb/ac, respectively. The rate of excess P_2O_5 is comparable to the rate of excess P_2O_5 in south central Minnesota, while the rate of excess N is much smaller than the excess rates in both south central and southeastern Minnesota.

Table 21a. Excess nutrients applied within minor watersheds of south central Minnesota.

	Manured land		Unmanured land		
	Primary	Secondary	Primary	Secondary	Total
Nitrogen					
Recommended rate (lbs/ac)	120	0	120	0	-
Applied fertilizer rate (lbs/ac)	144	3	165	5	-
Applied manure rate (lbs/ac)	112	93	-	-	107
Manured acres (1000 ac)	111	44	-	-	155
Fertilized acres (1000 ac)	111	44	792	100	1047
Excess manure (tons)	3290	2065	-	-	5355
Excess fertilizer (tons)	4234	66	17822	250	22372
Total excess (tons)	7524	2131	17822	250	27727
Excess manure (percent of total excess)	12	7	-	-	**19**
Excess fertilizer (percent of total excess)	15	0	64	1	**81**
Excess manure rate (lbs/ac)	59	93	-	-	69
Excess fertilizer rate (lbs/ac)	76	3	45	5	43
Total excess rate (lbs/ac)	135	96	45	5	**53**
Phosphorus (P_2O_5)					
Recommended rate (lbs/ac)	30	20	30	20	-
Applied fertilizer rate (lbs/ac)	46	54	54	20	-
Applied manure rate (lbs/ac)	247	195	-	-	232
Manured acres (1000 ac)	111	44	-	-	155
Fertilized acres (1000 ac)	111	44	792	100	1047
Excess manure (tons)	12252	3964	-	-	16216
Excess fertilizer (tons)	2286	1100	9505	0	12891
Total excess (tons)	14538	5064	9505	0	29107
Excess manure (percent of total excess)	42	14	-	-	**56**
Excess fertilizer (percent of total excess)	8	4	33	0	**44**
Excess manure rate (lbs/ac)	221	179	-	-	209
Excess fertilizer rate (lbs/ac)	41	50	24	0	25
Total excess rate (lbs/ac)	262	229	24	0	**56**

Table 21b. Excess nutrients applied within minor watersheds of southeastern Minnesota.

	Manured land		Unmanured land		
	Primary	Secondary	Primary	Secondary	Total
Nitrogen					
Recommended rate (lbs/ac)	120	0	120	0	-
Applied fertilizer rate (lbs/ac)	90	3	150	4	-
Applied manure rate (lbs/ac)	72	39	-	-	62
Manured acres (1000 ac)	68	27	-	-	95
Fertilized acres (1000 ac)	68	27	255	5	355
Excess manure (tons)	627	534	-	-	1161
Excess fertilizer (tons)	788	41	3826	10	4665
Total excess (tons)	1415	575	3826	10	5825
Excess manure (percent of total excess)	11	9	-	-	**20**
Excess fertilizer (percent of total excess)	14	1	66	0	**80**
Excess manure rate (lbs/ac)	18	39	-	-	24
Excess fertilizer rate (lbs/ac)	23	3	30	4	26
Total excess rate (lbs/ac)	41	42	30	4	**33**
Phosphorus (P_2O_5)					
Recommended rate (lbs/ac)	25	15	25	15	-
Applied fertilizer rate (lbs/ac)	30	20	30	20	-
Applied manure rate (lbs/ac)	152	83	-	-	132
Manured acres (1000 ac)	68	27	-	-	95
Fertilized acres (1000 ac)	68	27	255	5	355
Excess manure (tons)	4445	967	-	-	5412
Excess fertilizer (tons)	879	232	638	13	1762
Total excess (tons)	5324	1199	638	13	7174
Excess manure (percent of total excess)	62	14	-	-	**76**
Excess fertilizer (percent of total excess)	12	3	9	0	**24**
Excess manure rate (lbs/ac)	131	71	-	-	114
Excess fertilizer rate (lbs/ac)	26	17	5	5	10
Total excess rate (lbs/ac)	157	88	5	5	**40**

Table 21c. Excess nutrients applied within minor watersheds of southwestern Minnesota.

	Manured land		Unmanured land		
	Primary	Secondary	Primary	Secondary	Total
Nitrogen					
Recommended rate (lbs/ac)	110	0	110	0	-
Applied fertilizer rate (lbs/ac)	100	3	110	5	-
Applied manure rate (lbs/ac)	99	66	-	-	90
Manured acres (1000 ac)	46	18	-	-	64
Fertilized acres (1000 ac)	46	18	506	0	270
Excess manure (tons)	1022	606	-	-	1628
Excess fertilizer (tons)	1028	28	0	0	1056
Total excess (tons)	2050	634	0	0	2684
Excess manure (percent of total excess)	38	23	-	-	**61**
Excess fertilizer (percent of total excess)	38	1	0	0	**39**
Excess manure rate (lbs/ac)	45	66	-	-	51
Excess fertilizer rate (lbs/ac)	45	3	0	0	8
Total excess rate (lbs/ac)	90	69	0	0	**20**
Phosphorus (P_2O_5)					
Recommended rate (lbs/ac)	30	20	30	20	-
Applied fertilizer rate (lbs/ac)	30	21	45	20	-
Applied manure rate (lbs/ac)	250	85	-	-	203
Manured acres (1000 ac)	46	18	-	-	64
Fertilized acres (1000 ac)	46	18	506	0	270
Excess manure (tons)	5128	636	-	-	5764
Excess fertilizer (tons)	614	156	1516	0	2286
Total excess (tons)	5712	792	1516	0	8051
Excess manure (percent of total excess)	64	8	-	-	**72**
Excess fertilizer (percent of total excess)	8	2	19	-	**28**
Excess manure rate (lbs/ac)	224	69	-	-	180
Excess fertilizer rate (lbs/ac)	27	17	15	0	17
Total excess rate (lbs/ac)	251	86	15	0	**60**

In central Minnesota, to an even greater extent than in any other region studied, manure accounts for a disproportionate amount of the excess nutrients applied to cropland (Table 21d). Manure accounts for 79% of the excess N and 93% of the excess P_2O_5 applied to cropland. Fertilizer accounts for only 21% of the excess N and 7% of the excess P_2O_5 applied to cropland. The average rates of excess N and P_2O_5 applied to cropland in central Minnesota are 18 lb/ac and 67 lb/ac P_2O_5. The phosphorus excesses are exceedingly large in comparison with University of Minnesota guidelines for crop nutrients. Because of the large extent of land with coarse textured soils, these findings suggest that there may be a long-term potential for significant leaching of phosphorus to ground water in some portions of central Minnesota.

Spatial depictions of excess N and P_2O_5 applied to cropland in the 18 counties studied are shown in Figs. 27-28. The greatest proportion of minor watersheds with excess N applications is in south central Minnesota. This is the region of the state that also generates the greatest nitrate loadings in surface waters. Several large clusters in Martin county, Blue Earth county, Brown, and Faribault counties have more than 41 lb/ac of excess N applied. Southeastern Minnesota has the second greatest proportion of minor watersheds with excess cropland applications of N, but most of the watersheds receive from 11-27 lb/ac of excess N.

For phosphorus, excess phosphorus applications are found primarily in central, southwest, and south central Minnesota (Fig. 28). Stearns, Morrison, Pipestone, Martin, Blue Earth, and Brown counties all have large proportions of watersheds which receive greater than 65 lb/ac of P_2O_5. Surface water loads of phosphorus are greater from the south central region of Minnesota than from the central or southwestern regions. This is largely because the south central region has a combination of fine textured soils that are prone to runoff and a relatively large mean annual precipitation. In contrast, southwestern Minnesota has a much smaller mean annual precipitation, and central Minnesota has a much greater proportion of coarse textured soils that are not prone to runoff.

Q. Impacts of Runoff, Seepage, and Spills on Water Quality

Thus far, we have discussed mainly water quality impacts from land application of manure. Yet, most people, as well as the popular press, focus their attention not on land application of manure, but on sensational manure losses to surface water from runoff, seepage, and spills. There is no question that these events have disastrous consequences in the local waterways which they affect. These consequences include fish kills, and the delivery of oxygen demanding substances and toxic concentrations of ammonium. In response, many agencies are developing or have developed large budgets to upgrade feedlot facilities in the hopes of preventing catastrophic events.

In what follows, we focus not on the local impacts of these catastrophic events, but on the potential impacts of these events on regional water quality. First, consider manure spills. According to newspaper reports in Minnesota, roughly 20 spills occur per year. Most of these are from hog feedlots, with a few from dairy feedlots (such as the recent spill in Wright county). We assumed that each of these spills discharged 50,000 gallons. One hog manure spill of this magnitude would discharge 1.5 tons of N and 1 ton of P_2O_5. One dairy manure spill of this magnitude would discharge 1 ton of N and 0.4 tons of P_2O_5. Together, twenty such spills (18

Table 21d. Excess nutrients applied within minor watersheds of central Minnesota.

	Manured land		Unmanured land		
	Primary	Secondary	Primary	Secondary	Total
Nitrogen					
Recommended rate (lbs/ac)	110	0	110	0	-
Applied fertilizer rate (lbs/ac)	50	4	110	4	-
Applied manure rate (lbs/ac)	127	79	-	-	113
Manured acres (1000 ac)	102	41	-	-	143
Fertilized acres (1000 ac)	102	41	413	11	567
Excess manure (tons)	2445	1619	-	-	4064
Excess fertilizer (tons)	965	82	0	21	1068
Total excess (tons)	3410	1701	0	21	5131
Excess manure (percent of total excess)	48	32	-	-	**79**
Excess fertilizer (percent of total excess)	19	2	0	0	**21**
Excess manure rate (lbs/ac)	48	79	-	-	57
Excess fertilizer rate (lbs/ac)	19	4	0	4	4
Total excess rate (lbs/ac)	77	83	0	4	**18**
Phosphorus (P_2O_5)					
Recommended rate (lbs/ac)	25	15	25	15	-
Applied fertilizer rate (lbs/ac)	18	3	27	15	-
Applied manure rate (lbs/ac)	289	215	-	-	268
Manured acres (1000 ac)	102	41	-	-	143
Fertilized acres (1000 ac)	102	41	413	11	567
Excess manure (tons)	13536	4100	-	-	17636
Excess fertilizer (tons)	844	57	413	0	1314
Total excess (tons)	14380	4157	413	0	18951
Excess manure (percent of total excess)	71	22	-	-	**93**
Excess fertilizer (percent of total excess)	4	0	2	0	**7**
Excess manure rate (lbs/ac)	265	201	-	-	247
Excess fertilizer rate (lbs/ac)	17	3	2	0	5
Total excess rate (lbs/ac)	282	204	2	0	**67**

Table 21d. Excess nutrients applied within minor watersheds of central Minnesota.

	Manured land		Unmanured land		
	Primary	Secondary	Primary	Secondary	Total
Nitrogen					
Recommended rate (lbs/ac)	110	0	110	0	-
Applied fertilizer rate (lbs/ac)	50	4	110	4	-
Applied manure rate (lbs/ac)	127	79	-	-	113
Manured acres (1000 ac)	102	41	-	-	143
Fertilized acres (1000 ac)	102	41	413	11	567
Excess manure (tons)	2445	1619	-	-	4064
Excess fertilizer (tons)	965	82	0	21	1068
Total excess (tons)	3410	1701	0	21	5131
Excess manure (percent of total excess)	48	32	-	-	**79**
Excess fertilizer (percent of total excess)	19	2	0	0	**21**
Excess manure rate (lbs/ac)	48	79	-	-	57
Excess fertilizer rate (lbs/ac)	19	4	0	4	4
Total excess rate (lbs/ac)	77	83	0	4	**18**
Phosphorus (P_2O_5)					
Recommended rate (lbs/ac)	25	15	25	15	-
Applied fertilizer rate (lbs/ac)	18	3	27	15	-
Applied manure rate (lbs/ac)	289	215	-	-	268
Manured acres (1000 ac)	102	41	-	-	143
Fertilized acres (1000 ac)	102	41	413	11	567
Excess manure (tons)	13536	4100	-	-	17636
Excess fertilizer (tons)	844	57	413	0	1314
Total excess (tons)	14380	4157	413	0	18951
Excess manure (percent of total excess)	71	22	-	-	**93**
Excess fertilizer (percent of total excess)	4	0	2	0	**7**
Excess manure rate (lbs/ac)	265	201	-	-	247
Excess fertilizer rate (lbs/ac)	17	3	2	0	5
Total excess rate (lbs/ac)	282	204	2	0	**67**

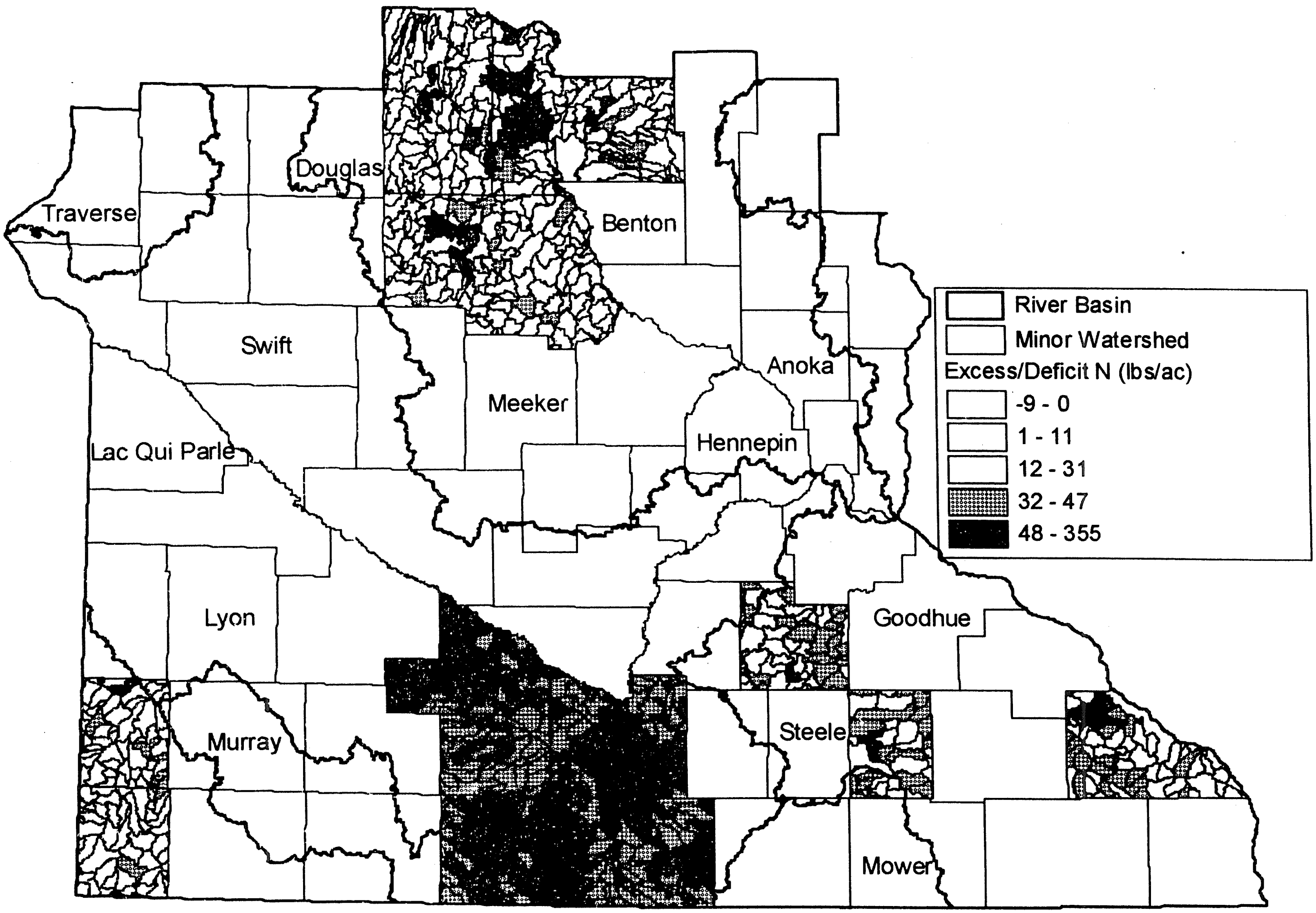


Figure 27. Excess/deficit N application rates for selected counties.

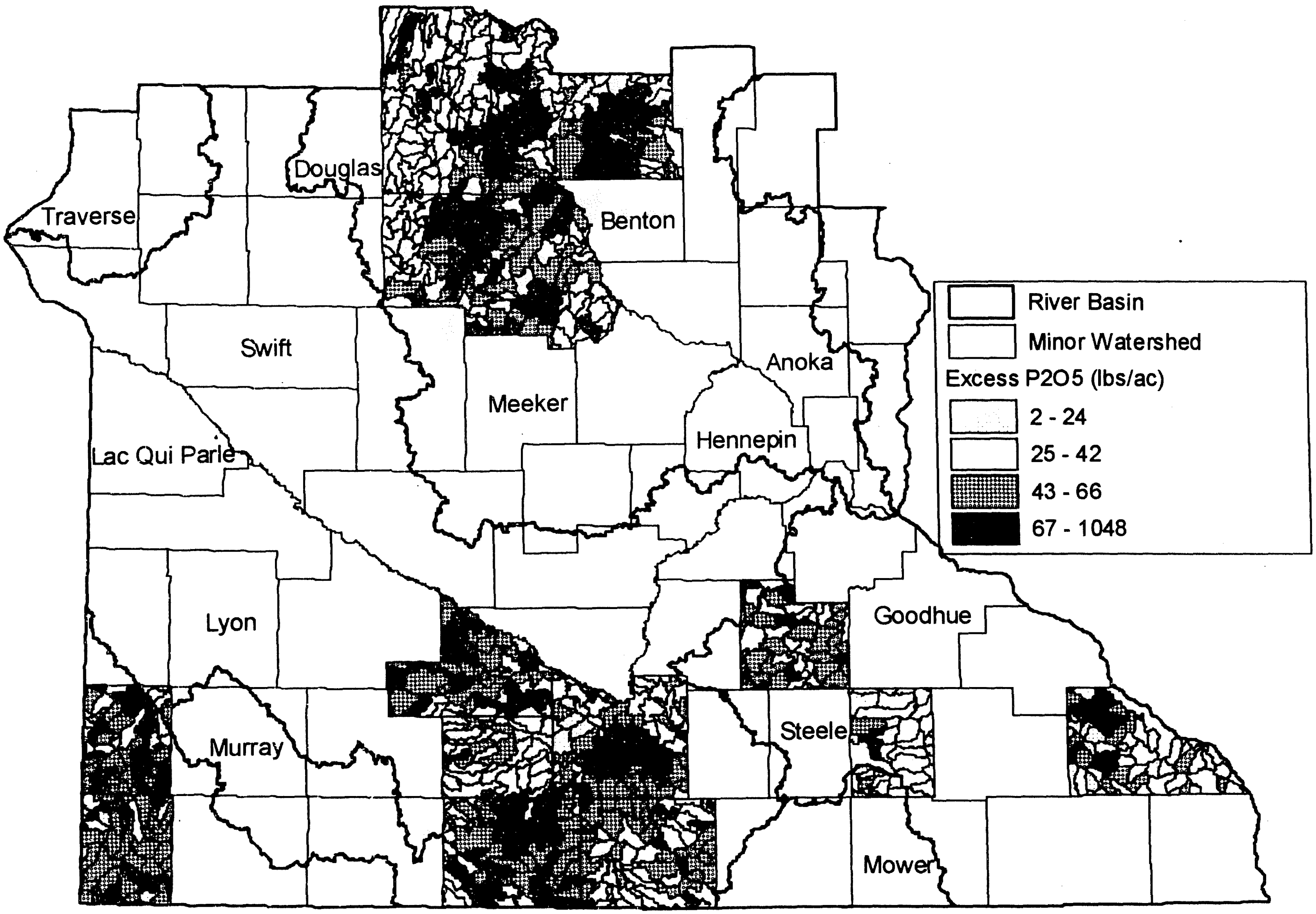


Figure 28. Excess P_2O_5 application rates for selected counties.

Q. Impacts of Runoff, Seepage, and Spills on Water Quality

Thus far, we have discussed mainly water quality impacts from land application of manure. Yet, most people, as well as the popular press, focus their attention not on land application of manure, but on sensational manure losses to surface water from runoff, seepage, and spills. There is no question that these events have disastrous consequences in the local waterways which they affect. These consequences include fish kills, and the delivery of oxygen demanding substances and toxic concentrations of ammonium. In response, many agencies are developing or have developed large budgets to upgrade feedlot facilities in the hopes of preventing catastrophic events.

In what follows, we focus not on the local impacts of these catastrophic events, but on the potential impacts of these events on regional water quality. First, consider manure spills. According to newspaper reports in Minnesota, roughly 20 spills occur per year. Most of these are from hog feedlots, with a few from dairy feedlots (such as the recent spill in Wright county). We assumed that each of these spills discharged 50,000 gallons. One hog manure spill of this magnitude would discharge 1.5 tons of N and 1 ton of P_2O_5. One dairy manure spill of this magnitude would discharge 1 ton of N and 0.4 tons of P_2O_5. Together, twenty such spills (18 from hogs and 2 from dairy) would discharge 29 tons of N and 20 tons of P_2O_5. In comparison to the 55,423 tons of nitrate-N/yr and 1,492 tons P/yr carried by the Minnesota River, the quantities of nutrients discharged to surface waters from manure spills are negligible.

Second, consider runoff and seepage from feedlots that do not comply with Minnesota Feedlot Rules. As shown earlier, 15% of the feedlots in the 18 counties studied are estimated to be non-compliant. Based on the proportions of these feedlots across animal species and size classes (section B), we estimated the amount of N and P_2O_5 produced from all non-compliant feedlots (Table 22ab). Non-compliant feedlots produced 265 tons of N and 573 tons of P_2O_5. In comparison with the 27,753 tons of N and 62,077 tons of P_2O_5 applied to cropland from manure, the non-compliant feedlots represent a negligible amount of regional risk to water quality.

Based on the results in this section, we conclude that the regional water quality impacts of manure spills, and runoff or seepage from non-compliant feedlots is dwarfed by the impacts of land applied manure. Spills, runoff, or seepage can, however, have disastrous local consequences for water quality.

R. Strategies for Reducing Excess Nutrients Applied to Cropland

For each of the four regions studied, the discussion below outlines potential strategies for reducing the amount of excess nutrients applied to cropland. The factors considered include the relative proportions of manured versus unmanured cropland in each region, the rates of manure versus fertilizer nutrients applied to cropland, the percent of excess N and P generated by manure versus fertilizer, and the nutrient application rates recommended by the University of Minnesota. The strategies proposed are based on regional trends, and reflect improvements that can be made through average changes in nutrient management practices. The changes may not be suitable for every farm due to varying site-specific conditions.

Table 22a. Amount of nitrogen produced from all non-compliant feedlot by size class.

County	Feedlot size in animal units				All classes
	1-99	100-299	300-999	1000+	
	tons				
Blue Earth	1.5	5.0	6.6	0.1	13.2
Brown	2.8	8.5	4.8	0.1	16.2
Dodge	1.3	3.1	1.9	0.0	6.3
Faribault	1.6	4.8	4.6	0.0	11.1
Freeborn	2.7	5.8	3.3	0.0	11.8
Jackson	1.0	4.6	6.8	0.0	12.4
Martin	1.5	5.3	11.4	0.2	18.4
Morrison	3.0	13.3	1.5	0.3	18.1
Nicollet	0.8	7.2	4.8	0.3	13.1
Pipestone	3.3	6.2	5.3	0.1	14.9
Rice	5.2	11.2	3.2	0.0	19.5
Rock	2.2	5.5	7.8	0.0	15.5
Scott	1.2	3.5	0.3	0.0	5.0
Sibley	3.0	7.2	1.8	0.0	12.1
Stearns	6.8	34.7	4.2	0.3	45.9
Todd	3.9	7.9	0.7	0.3	12.8
Watonwan	1.4	2.7	1.3	0.0	5.4
Winona	5.0	7.4	0.6	0.0	13.1
All counties	48.1	143.9	70.8	1.9	264.7

Table 22b. Amount of phosphate produced from all non-compliant feedlot by size class.

County	Feedlot size in animal units				All classes
	1-99	100-299	300-999	1000+	
	tons				
Blue Earth	3.7	11.0	13.9	0.2	28.9
Brown	6.4	17.9	10.7	0.3	35.3
Dodge	2.8	6.3	3.9	0.1	13.1
Faribault	4.4	10.5	10.0	0.0	24.9
Freeborn	6.3	11.2	6.6	0.1	24.1
Jackson	2.7	9.9	14.9	0.1	27.6
Martin	3.9	11.7	24.2	0.4	40.1
Morrison	6.6	25.7	3.6	0.8	36.6
Nicollet	1.9	14.7	10.2	0.9	27.7
Pipestone	9.4	15.1	12.4	0.2	37.1
Rice	12.9	22.8	6.7	0.0	42.4
Rock	5.7	12.4	17.7	0.0	35.8
Scott	2.7	6.8	0.7	0.0	10.2
Sibley	7.3	15.2	3.9	0.0	26.4
Stearns	16.5	69.0	9.5	0.7	95.6
Todd	8.5	16.0	1.6	0.8	26.9
Watonwan	3.4	6.1	3.3	0.1	12.8
Winona	11.9	14.3	1.2	0.0	27.5
All counties	116.8	296.5	154.9	4.8	573.0

In south central Minnesota, half of the cropland receives manure over a period of many years. Significant surface water quality degradation occurs as a result of both excess nitrogen and phosphorus. This region has a moderate to very high regional phosphorus index loss potential. According to our analysis (Table 21a), the total excess rate of applied N is 53 lb/ac, and 64% of the excess N occurs from fertilizer applied to unmanured corn. A 10% reduction in applied fertilizer (from 165 lb/ac to 150 lb/ac) would reduce the excess N applied to cropland by 25%. A 15% reduction in applied fertilizer N (from 165 lb/ac to 140 lb/ac) gives a 40% reduction. The average rate of applied excess P_2O_5 in south central Minnesota is 56 lb/ac. For P_2O_5 applied to cropland, 42% of the excess is from manure applied to corn, while 33% of the excess is from fertilizer applied to unmanured corn. Addition of phytase to feed by one-third of hog producers could reduce the supplemental P added to animal feed, and reduce the excess P applied to manured land by 20%. Reductions in applied fertilizer P_2O_5 by 25% (from 54 lb/ac to 40 lb/ac) could reduce the excess P applied to unmanured cropland by 20%, independent of reductions achieved through the use of phytase. The widespread use of the phosphorus index is recommended in this region to assess and manage P loss potentials to surface water.

In southeastern Minnesota, 92% of the cropland receives manure over the long-term. The most common nutrient related water quality problems in this regions are surface water degradation by phosphorus, and ground water degradation by nitrate nitrogen. This region has a high to very high regional phosphorus index loss potential. The average rate of excess N applied to cropland is 33 lb/ac (Table 21b), much less than the excess rate applied in south central Minnesota. About 66% of the excess N results from fertilizer applied to unmanured corn. Adequate credits for N fixed by alfalfa should be given when making a fertilizer recommendation for corn in the first year following alfalfa. Reducing the average rates of fertilizer N applied to unmanured corn by 10% (from 150 lb/ac to 135 lb/ac) would reduce the total excess applied N by 30%. In contrast, cutting the manure N application rates by 50% on corn would only decrease the total excess applied N by 25%. The average rate of excess P_2O_5 is 36 lb/ac in southeastern Minnesota, again much less than the excesses applied in south central Minnesota. The excess P_2O_5 is 62% from manured corn. A 20% reduction in animal feed supplement P contents is highly recommended (reducing P in dairy feed from 0.4% to 0.32% for dry cows or from 0.55% to 0.45% for lactating cows) in order to reduce the excess P applied to cropland. This change in feed P content would result in a 20% reduction in excess P on cropland. A 10% reduction in fertilizer P applications to all land in southeastern Minnesota would result in a 5% reduction in excess P. The continuation of livestock operations with alfalfa as a major crop in this region is recommended to help control erosion. Conversion of land planted in alfalfa to row cropping would lead to serious increases in soil erosion and phosphorus losses to surface water. The P index should be used as a tool to reduce P losses from cropland.

In southwestern Minnesota, 73% of the cropland receives manure over the long-term. The primary water quality risk is from nitrate contaminated ground water. Regional phosphorus index ratings range from low to high in southwestern Minnesota. The average rate of excess N applied to cropland is only 20 lb/ac (Table 21c). About 38% of the excess applied N occurs from manure applied to corn, 23% results from manure applied to soybeans and alfalfa, while another 38% of the excess results from fertilizer N applied to manured corn. Manured lands account for a majority of the excess N applications, and reductions in applied excess N can be best achieved by reducing manure or fertilizer N applications to manured land. A 15% reduction in fertilizer N rates applied to manured corn would give a 13% reduction in excess applied N. Manure available N should not be applied to soybeans in amounts which exceed the ability of the crop to take up nitrogen. A 50% reduction in the rate of manure N applied to soybeans and alfalfa would give a 10% reduction in excess N applied to cropland. For phosphorus, the average rate of applied excess P_2O_5 is 60 lb/ac, which is as large as the excess rates applied in south central Minnesota. About 64% of the excess P_2O_5 is from manure applied to corn. Soil testing for fertilizer P recommendations is strongly encouraged. Reducing fertilizer P applications by one-third on unmanured corn would give a 20% reduction in excess P. The use of phytase in feed for hogs is encouraged. A 25% reduction in excess P could be attained with a one-third reduction in the P content of manure applied to corn. The use of the P index is recommended for improved phosphorus management in this region.

In central Minnesota, 81% of the cropland receives manure over a period of many years. The primary water quality concerns include high nitrate levels in ground water underlying coarse textured soils. The risk for surface contamination by phosphorus is low to moderate based on the regional phosphorus index rating. Phosphorus leaching to ground water may be a long-term risk in regions with coarse textured soils and shallow water tables. The rate of excess N applied to cropland is only 18 lb/ac (Table 21d). About 80% of the excess N is from manure applied to cropland. A 10% reduction in excess N could be achieved with a 25% reduction in the rate of N applied to alfalfa and soybeans from manure. Manure can be applied to alfalfa ground as a preplant application, and a less desirable practice is to apply low rates of manure as a topdress application after cutting based on crop P needs. Topdress applications of poultry manure to alfalfa are not recommended. A 30% reduction in excess N could be achieved with a 25% reduction in the rate of N applied to corn and small grains from manure. Adequate N credits should be given when applying nitrogen fertilizer to corn in the first year following alfalfa. The rate of excess P_2O_5 applied to cropland in central Minnesota is 67 lb/ac, higher than the rates of excess P for any of the other regions studied. Most (93%) of the excess P is from manure applied to cropland. A shift to crop based P requirements for manure applications should be encouraged in this region. In poultry operations, manure composting and addition of phytase to feed are recommended. Dietary modifications in dairy feed (0.32% P in feed for dry cows, 0.45% P for lactating cows) are recommended. A 20% reduction in manure P content would give a 30% reduction in excess P. The use of the phosphorus index is recommended to reduce potential losses of phosphorus to surface waters in this region.

Update to the Literature Review on the Effects of Animal Agriculture on Water Resources

In the Literature Review prepared by this University of Minnesota team in 1999, we were asked to answer ten scoping questions relating to the impacts of animal agriculture on water resources. We reviewed the recent literature published in scientific publications to formulate an answer to these questions and identify research needs where insufficient knowledge was available to provide an answer. This update to the literature review includes articles published since the time of the original literature review. These new articles are reviewed below, organized by the ten scoping questions, and related back to original literature review.

1. To what extent are groundwater and surface water affected by or at risk from animal manure storage, handling, and application?

Surface Water

The original literature review contained several findings with respect to pollution of surface water by animal operations. First, it showed that livestock waste can severely degrade surface water quality by contributing nutrients, sediment, pathogens, and hormones through surface runoff.

Surface Runoff of Nutrients from Manured Lands

The original literature review showed that nutrients in the waste are one important constituent of manure that negatively impact water quality. Nutrients are often carried in runoff from manured fields to surface waters; nutrient losses in runoff increase with the rate of manure applied. Nutrient losses are least when manure is applied in late spring and greatest when manure is applied in fall; they are excessive if manure is applied to frozen soil or snow. Nutrient losses also increase when the time between land application and rainfall is brief. Phosphorus is the primary nutrient lost in surface runoff: Livestock waste can contribute significantly to phosphorus loads in surface waters (7-65% of total load), and less significantly to nitrogen loads (15-37% of total load). Critical areas for phosphorus loss to surface waters are typically those areas high in soil available phosphorus in close proximity to waterbodies; however, phosphorus loss can be negligible if erosion and runoff are controlled in the field.

An article published since the original literature review further confirms these relationships. McFarland and Hauck (1999) studied the relationships between agricultural land uses in sixteen watersheds in central Texas and in-stream stormwater quality. Dairying is the dominant agricultural land use in the watersheds, with other agricultural land uses including production of peanut, range cattle, pecan, peaches, and forage hay.

The study found that as the percent land used for dairy waste application (or dairy cow density or intensive agriculture) in a drainage basin increased, the concentration of nitrogen and phosphorus in stormwater runoff increased. The other agricultural land uses in the basin did not exhibit this positive relationship, indicating that they contribute to non-point source pollution at a much lower level. The study concludes that stormwater runoff of nutrients from dairy waste application fields is the predominant source of nonpoint source nutrients impacting surface water quality in the watersheds.

Additional information has become available on phosphorus loading from land-applied poultry litter since the time of the original literature review. Sharpley (1999) examined the risk to water quality from poultry production, specifically in terms of phosphorus from land-applied poultry litter. The author hypothesizes that there is increased potential for phosphorus runoff into water bodies in areas of poultry production because of the rapid concentration of production that has occurred. This concentration results in the generation of large amounts of poultry litter within small geographic areas, and since there is usually not sufficient cropland nearby on which to spread the poultry litter, in over-application of litter. This is exacerbated by the practice of basing application rates on nitrogen rather than on phosphorus.

The author confirmed this potential in an eight-year study involving bermudagrass field plots in Durant, Oklahoma. The study showed that applying poultry litter to the plots at the recommended agronomic rates for the nitrogen requirements of bermudagrass resulted in an accumulation of soil phosphorus (P). Soil P increased during the three years litter was applied, and decreased for the following three years although it remained much higher than pre-litter application levels. Most of this accumulation was in the top 20 centimeters of the soil, with little change in soil P below that level. P loss in surface runoff increased during the years the litter was applied and continued to be higher in the following three years. A somewhat surprising finding was that P loss in subsurface flow at a depth of 70 centimeters also increased during the years of litter application and for a year afterwards, even though soil P at that level was not significantly higher. This shows the importance to subsurface flow of flow pathways through the soil such as macropores, earthworm holes, and old root channels. P loss in surface runoff was much higher than P loss in subsurface flow.

The author concludes that poultry production and water quality can be compatible in most areas if phosphorus is managed by: 1) basing watershed management on P and the potential for P loss in surface runoff; 2) testing the P content of soils and manures at the farm level before land application; 3) managing transport through conservation tillage, crop residue management, buffer strips, riparian zones, terracing, contour tillage, cover crops, and impoundments (settling basins); 4) identifying critical source areas where high soil P levels coincide with high surface runoff and erosion potential (a P-index); and 5) developing programs that encourage farmer stewardship to achieve agreed upon environmental goals. However, the author also concludes that in some areas the increased number of poultry operations may produce much more P than the crop needs of the region. If alternative uses for the manure or its transportation to areas of need cannot be developed, then poultry production and water quality may not be compatible.

Subsurface Flow of Nutrients from Manured Lands

Large areas of Minnesota are poorly drained and have artificial tile drainage installed to improve soil productivity, which can carry manure constituents from the field into surface water. The major factors which influence losses of nutrients through tile drains include rate of manure application, timing of application, form and method of application, tillage, and cropping system. The original literature review on nutrient losses through tile drains showed that, unlike surface runoff, the most significant contaminant in subsurface tile drain effluent is nitrates. Soluble and total phosphorus losses are generally negligible in comparison to their losses in surface runoff, unless very high rates of manure are applied, or the soil test phosphorus levels have built up to excessive levels. Nitrate losses in subsurface tile drainage increase with the rate of manure or fertilizer applied, unless very high rates of manure are applied on wet soil, when denitrification reduces the losses of nitrogen. Liquid manure applications cause more risk for nitrate leaching to tile drains than surface applications of solid manure, especially when liquid manure is injected. No new literature in this area was found since the original literature review.

Pathogens and Hormones from Manured and Grazed Lands

The original literature review also showed that surface water impairment from pathogens is a great problem in most rural areas of southern Minnesota, causing many rivers and lakes to be unsuitable for swimming. Fecal bacteria in surface waters from lands receiving fresh manure applications can be a significant proportion (over 80%) of the fecal bacteria carried in surface waters. Rate, method, or timing (spring versus fall) of manure application has little effect on fecal bacteria counts in surface runoff, although they are significantly greater after application of manure to snow or frozen soil. Storing and aging manure before land application can result in pathogen runoff concentrations not significantly different from those from unmanured lands. Little information on hormones from manure was available in the first literature review.

No new studies since the original literature review were found on pathogens in surface water (although one article was found on pathogens in groundwater; see Groundwater section below). However, one article published since the original literature review reveals more information on hormones in surface water from manured and grazed lands. This work fills a gap in the original literature review.

Finlay-Moore et al. (2000) assessed the impacts of poultry litter applications on estradiol and testosterone concentrations in soil and runoff water from grazed and ungrazed grasslands in Georgia. Estradiol and testosterone are naturally occurring sex hormones produced by all birds. The author notes that these hormones may be more potent than endocrine disrupters and can appear in soil and ground and surface water.

The study used large plots (0.8 ha) and was conducted over an extended period of time (7 continuous months), so that it closely resembled actual field conditions. The study found that after litter application, runoff concentrations of estradiol and testosterone were significantly increased from levels before litter application. Similarly, soil concentrations of estradiol and testosterone increased significantly after litter application. With both runoff and soil concentrations, the amount of the increase depended on the litter application rate and the time since the application.

The study also found little difference in hormone runoff levels between hayed and grazed lands, showing that grazing animals (beef steers) did not contribute hormones to runoff. However, soil levels of testosterone were significantly higher in grazed plots than in hayed plots, showing that grazing animals did contribute to testosterone levels in soil.

Spills from Manure Storage and Runoff from Feedlots

Catastrophic spills from large manure storage facilities can occur through overflow following large storms, by intentional releases, or less frequently, by collapse of a sidewall (which has never occurred in Minnesota). The original literature review showed that the impacts on surface water quality and aquatic life from manure lagoon and storage basin spills and feedlot runoff can be devastating. The number of documented serious water quality pollution problems involving these events is generally several tens per year in each of the states with high concentrations of feedlots. However, compared to the several thousands of feedlots in most states, this number is typically a small fraction of the total number of operations. No new articles in this area were found since the original literature review.

Groundwater

The original literature review also showed that animal agriculture can heavily affect groundwater. Many factors influence contamination of ground water, including depth and condition of the well, type of soil and geologic material above the aquifer, location of the well, land use surrounding the well (particularly cropland), density of animals and manure handling and application practices, and type of lining on manure storage systems. Ground water contamination from animal agriculture is most likely to occur when intensive animal agriculture occurs in regions having coarse textured soils, shallow ground water, and heavy precipitation.

A new article was found on ground water contamination in coarse textured soils of Otter Tail county (Puckett et al., 1999). Greater than 40% of the wells in this study area exceed 10 mg/L nitrate. Cropland was the dominant landuse (73% of the area), with corn, potatoes, wheat, soybeans, and alfalfa being the primary crops. Dairy and beef cattle operations were relatively sparse. A mass balance nitrogen budget was developed for all sources and sinks of nitrogen in an 82 mi^2 area having intensive agriculture. Fertilizer N applications to cropland totaled 841.3 Mg/yr, while manure applications to cropland totaled 16.8 Mg/yr (2% of the total N applied to cropland). Nitrogen applications to cropland exceeded University of Minnesota recommendations by 25% (an excess of 172 Mg/yr, or 10 lb N/ac/yr excess). Cropland was the single largest source of N leaching to ground water, accounting for 89% of the N leaching. The next largest source was manure applied to pasture (6%). Thus, manure contributed at most 8% of the nitrate leaching to ground water, while fertilizer accounted for about 87%.

Roughly half the excess nitrate leached below the rooting zone was lost by denitrification. Nitrate leaching to ground water was estimated to be three times greater than without intensive agriculture. A model was developed to determine the impact of various changes in land management in Otter Tail county on ground water nitrate levels. The most important variables in this model were crop yield and rate of applied fertilizer N. A 10% deccrease in crop yields caused ground water nitrate levels to increase from 6.1 ppm to 7.9 ppm, while a 10% increase in fertilizer N applications increased the nitrate levels from 6.1 ppm to 7.1 ppm.

Seepage of Nutrients from Manure Storage

The original literature review found that lined manure storage basins and lagoons which are properly constructed, engineered, and managed are generally not a serious threat to ground water quality, unless constructed in coarse textured soils or karst terrain. Unlined earthen manure storage systems generally pose a much greater risk for pollution of ground water by seepage than lined storage facilities.

In a new article since the original literature review, the Minnesota Pollution Control Agency (2001) summarized four ground water monitoring studies in Minnesota between 1994 and 2000. All of these studies were conducted on coarse textured soils, and so represent worst case scenarios for seepage. The first study sampled ground water adjacent to manure systems older than five years, looking at three or four sites for each of the following: open feedlots, feedlots with unlined manure basins, feedlots with earthen-lined basins, and feedlots with concrete-lined basins. Plume lengths exceeded several hundred feet down-gradient of unlined manure basins, ranged from 200 to 400 feet down-gradient of earthen-lined basins and open lots, and were 100 feet or less down-gradient of concrete-lined systems. Most plumes had high concentrations of ammonia, organic nitrogen, organic carbon, phosphorus, chloride, and potassium. The study found maximum concentrations of ammonia of 265 mg/l for unlined basins, 66 mg/l for earthen basins, 36 mg/l for open lots, and 4 mg/l for concrete basins. Maximum phosphorus concentrations were 36 mg/l for unlined systems, 13 mg/l for concrete- and earthen-lined systems, and less than 1 mg/l for open lots.

The second study of groundwater adjacent to 17 newly-constructed (between 1994 and 1997) earthen-lined basins proved inconclusive. While upward trends in the concentration of one or more chemicals associated with liquid manure were observed at seven sites, no trend or a decreasing trend was observed at six sites.

The third study of groundwater beneath three earthen-lined manure basins indicated high concentrations of chloride and high specific conductance in leachate, with highest concentrations occurring in sidewalls.

The fourth study of groundwater beneath an earthen-lined basin with a 0.1 mm-thick polypropylene liner found that nitrogen concentrations in ground water beneath the feedlot had decreased by 55 percent in the 3 years since construction. Concentrations of phosphorus and organic carbon had also decreased.

These studies show that liquid manure storage basins vary in their risk of seepage. Seepage increased in the order unlined earthen basins > open lots > lined earthen basins > concrete pits. Recent studies from Iowa (Quade et al., 2001) indicate that seepage rates from three new earthen manure storage basins in fine textured soils are not a significant source of seepage.

Infiltration of Pathogens and Hormones

The original literature review had little information on contamination of groundwater by pathogens or hormones. However, one new article published since then provides information on movement of pathogens and hormones through groundwater.

Peterson et al. (2000) explored the movement of 17• -estradiol (E_2), fecal coliform, and *Escherichia coli* through the hydrologic system in karst. The authors explain that E_2 is significant because it produces a significant estrogen response in humans and has been linked to the occurrence of breast cancer; it is listed as a carcinogen by the United States Department of Health and Human Services. Because this hormone naturally occurs in animals, livestock manure is a reported source of E_2 loading; furthermore, levels of E_2 in manure are increased with the use of growth hormones in animals (with excretion levels five to six times greater for cattle that are treated with growth hormones than for cattle not treated).

The study examined five springs fed by mantled karst aquifers in Arkansas during a winter recharge event. The area studied is characterized by both poultry and cattle production. The study found that E_2 was present in all five springs, with concentration levels that mimic changes in stage of the recharge event (concentrations peak as stage rises, and are lowest when stage recedes). The authors point out that this behavior is indicative of animal waste being flushed from the surface into mantled karst aquifers.

The study also found that in all five springs, E_2 concentrations followed the same trends as fecal coliform and *E. coli*. In other words, as bacteria counts increase, E_2 concentration increases, and as bacteria counts decrease, E_2 concentration decreases. This shows that E_2 moves through the karst system in a manner similar to other contaminants associated with land-applied animal waste.

The authors conclude that animal waste contributes E_2 to groundwater in areas with a high density of livestock operations. Furthermore, they conclude that organisms that rely on the groundwater are at risk due to exposure to the high E_2 concentrations during peak flow events, and to prolonged exposure to lower level E_2 concentrations at baseflow.

2. How do the effects or risks (from #1) affect the use of water by humans for drinking, recreation, and other purposes?

The original literature review showed that drinking water can be contaminated by pathogens and nitrates arising from animal agriculture. However, it is often difficult to confirm animal agriculture from among the potential sources of contamination, which also include septic systems and human sewage. In terms of pathogens, it is estimated that up to 900,000 illnesses and 900 deaths occur each year from waterborne microbial infections, but the source of contamination in these instances is not known. In terms of nitrates, roughly 7% of the 450,000 private drinking water wells and 1% of the 1,700 public community water supply wells in Minnesota have nitrate-

N levels exceeding the maximum contaminant level (MCL) of 10 mg/L, but again, the percent of these that are affected by animal agriculture is unknown.

Nationally, it is estimated that 36% of rivers and streams and 39% of lakes are impaired, meaning they do not meet the standards set forth in the Clean Water Act and state regulations. The primary cause of impairment in 70% of these rivers and streams was agriculture, including non-irrigated cropland production (36%), irrigated cropland production (22%), rangeland (12%), pastureland (11%), feedlots (8%), animal operations (7%), and animal holding areas (5%).

In Minnesota, about 60% of the surveyed or monitored rivers and streams, and 17% of the surveyed or monitored lakes were classified as impaired. Agriculture was identified as the cause of 90% of the impaired river miles, and 64% of the impaired lake acres. It is unknown to what degree various types of agricultural activities (cropland, feedlots, rangeland, etc.) caused the impairment. In the Minnesota River basin, none of the tributaries is fit for swimming, primarily because of high levels of fecal bacteria.

No new literature in this area was found since the original literature review.

3. How do the effects or risks (from #1) affect fish and wildlife (such as fish kills due to pollution)?

Grazing

The original literature review summarized many reports on the effects of grazing on fish and wildlife in riparian ecosystems, most of which focus on the western U.S. Relatively little is known about grazing impacts on stream and riparian ecosystems in the midwestern U.S. Some studies show that grazing can be a useful tool to enhance wildlife habitat. However, it must be carefully managed to control the frequency, intensity and timing of livestock access to ensure compatible use with wildlife. The negative effects of livestock grazing on habitat for fish and wildlife can include an increase in streambank erosion, reducing habitat availability for both terrestrial and aquatic animals, and a decrease in large woody debris habitat in and near the stream channel in grazed areas. This can have a negative impact on the density and diversity of macroinvertebrates and passerine species birds, although shore birds and water fowl appear to be unimpacted or even positively impacted by grazing. Research on the impacts of grazing on fish is largely inconclusive. No new literature in this area was found since the original literature review.

Manure Management

The original literature review concluded that fish are quite susceptible to the impacts of poor management in animal agriculture. A few serious incidents of feedlot runoff, manure spills, and runoff from manure on frozen ground can lead to the death of thousands of fish. It is widely believed that many fish kills are undocumented, and there is no comprehensive record keeping mechanism for tracking the number or magnitude of fish kills. At least two agencies have responsibility for responding to fish kills but fish kills are not regularly recorded and reported.

Manure management can also have a profound impact on amphibians. In an article published since the original literature review, Rouse et al. (1999) evaluated the potential for nitrate from agricultural sources (animal waste and nitrogen-based fertilizers) and urban sources to affect amphibian survival in North America. The report summarizes various findings on the toxicity of nitrate to amphibians and their prey. Tadpoles of the western chorus frog, northern leopard frog, and green frog suffer from physical and behavioral developmental abnormalities when exposed to as little as 2.5 mg/l of nitrates. Fifty percent of the test individuals died at nitrate levels of 17, 22.6, and 32.4 mg/l, respectively. The tadpoles of the common frog and White=s tree frog suffered similar developmental abnormalities when exposed to 9 mg/l of nitrates, and death occurred in 50% of test individuals at 22.6 mg/l. Adult common frogs exhibited symptoms of acute toxicity when exposed to 6.9 g/m^2 of ammonium nitrate crystals on soil. These findings show that amphibians can be affected by nitrates at relatively low levels.

The study then looked at water quality data for agricultural and urban areas in North America. It found that of 8,545 water quality samples collected from the states and provinces bordering the Great Lakes, 19.8% contained nitrate concentrations that exceeded 3 mg/l; 3.1% of the samples exceeded 10 mg/l. The authors note that average nitrate concentrations in streams traversing agricultural landscapes in North America typically range between 2 and 40 mg/l. Based on the toxicity levels of nitrate to amphibians described above, the authors conclude that nitrate concentrations in a large portion of Great Lakes watersheds are high enough to cause developmental abnormalities and death in amphibians.

4. What are the health risks to humans from contamination of ground and surface waters from animal manure storage, handling, and application?

The original literature review presented two types of risks in drinking water which are related to animal agriculture, excessive nitrate levels and pathogens. Nitrate is a common contaminant found in many wells in Minnesota. It has been known since the mid-1940s that too much nitrate in drinking water can cause serious health problems for infants. Roughly 7% of drinking water wells in Minnesota exceed the Maximum Contaminant Level set by EPA for nitrates in drinking water. Drinking water contamination can occur from nitrogen in fertilizer, septic tank seepage, and animal manure. Fresh animal manure contains a variety of microorganisms which may be pathogenic to humans. The major types of pathogens include bacteria, viruses, parasite eggs, protozoa, and fungi. The potential of disease transmission from land application of animal manure depends upon:

- the number and viability of microbial pathogens in manure, which in turn depends upon the type of treatment it has received;
- the survival of pathogens for a sufficient period of time and in sufficient numbers; and

- the entry of these pathogens into waters and their subsequent ingestion through the mouth as a result of drinking or swimming.

Several new articles dealing with health impacts of water borne pathogens were found since the original literature review.

Incidences of water borne giardia infections in the United States

The Centers for Disease Control (CDC) released a report (Furness et al., 2000) indicating that giardiasis increased from 12,793 cases in 1992 to 27,778 cases in 1996. Giardia is found in both domestic and wild animals, including cats, dogs, cattle, deer, and beavers. The number of states reporting this disease increased from 23 to 43. In 1997, there were from 0.9 to 43.3 cases per 100,000 people for reporting states, with ten states reporting greater than 20 cases per 100,000 people, and an average of 9.5 cases. The greatest number of giardiasis cases occurred in New York, with more than 14% of all cases reported nationally. Minnesota, South Dakota, and Wisconsin were among the states reporting more than 20 cases per 100,000 people. The highest likelihood of giardiasis occurs during the summer and early autumn, corresponding with the greatest frequency of recreational use of surface waters. Two age groups were most susceptible to giardiasis, children aged 0-5 years, and adults between the ages of 31 and 40.

Sources of fecal pollution in rural Virginia watersheds

Hagedorn et al. (1999) studied water samples from Page Brook in Virginia using an antibiotic resistance discriminant and cluster analysis method. A database of over 7,000 fecal streptococcus isolates was tested using known human, livestock, and wildlife sources. For these samples, the antibiotic resistance method correctly identified 87% of the isolates. In 892 known water samples from Page Brook, the method correctly identified isolates 88% of the time. Stream samples highly contaminated with unknown pathogen sources were collected at three sites. The antibiotic resistance method classified 78% of the fecal streptococcus as being from cattle, with small percentages from waterfowl, deer, and other sources. After these findings, cattle access to the stream was reduced by 94% through fencing. As a result, fecal coliform counts were reduced by 94%. These results showed that the antibiotic resistance technique identified sources of pathogens accurately, and that fencing of cattle was an effective method for reducing pathogen contents of streams with heavy cattle populations.

Modeling of Cryptosporidium transport to surface water reservoirs in New York

Walker and Stedinger (1999) developed a model for cryptosporidium transport to a drinking water supply system serving 8 million customers in New York City. The major sources of cryptosporidium in the watersheds studied were dairy calves and human sewage. The study region includes 39 waste water treatment plants with secondary treatment, and over 400 dairy farms. Manure and cryptosporidium oocysts were modeled in surface runoff, with pathways for oocyst degradation, stream routing, and reservoir modeling. Cryptosporidium oocysts from human sewage sources were found to dominate oocysts from dairy sources. This study concluded that sewage effluent was the major source of oocysts in the New York City water supply system.

CDC Surveillance for Waterborne-Disease Outbreaks

Barwick et al. (2000) of the Centers for Disease Control (CDC) summarized waterborne disease outbreaks attributed to pathogens. During 1997-1998, thirteen states reported seventeen outbreaks associated with drinking water, causing 2,038 persons to become ill. Various sources of contamination were identified, including beavers, rodents, raw human sewage, wildlife, pastured cattle, (affecting three persons in Illinois), and chemicals.

Thirty two outbreaks from eighteen states were linked to recreational water, affecting 2,128 persons. One quarter of the outbreaks linked to recreational water were associated with fecal accidents in swimming pools or ornamental fountains. States with the greatest number of outbreaks were Wisconsin (7) and Minnesota (4). In Minnesota, 369 persons were sickened after playing in a fountain at the zoo. The most likely source of contamination was a fecal accident from children playing in the fountain. Most of the cryptosporidium outbreaks in the database were similarly attributed to fecal accidents from children and babies in diapers in swimming pools or fountains. In another Minnesota outbreak, five persons developed gastroenteritis cause by E. coli after swimming in a lake. The source of the bacteria was not identified. Wisconsin had an outbreak of Pontiac fever from a hotel whirlpool which sickened 45 persons. Thirty people became ill after swimming at a public lake beach in Ohio which was fed by water from public latrines.

In conclusion, the CDC surveillance for waterborne disease outbreaks shows that very few outbreaks during 1997-1998 were directly linked to animal agriculture.

5. To what extent are surface waters affected by or at risk from allowing pastured animals (primarily cattle) access to surface waters?

The original literature review found that unmanaged grazing has many negative impacts on streams and their nearby landscapes. Heavy grazing reduces vegetative cover, compacts the soil, reduces infiltration, and increases runoff, erosion and nutrient and sediment yield. In riparian zones, heavy livestock traffic on streambanks decreases erosional resistance of the streambank and contributes to sediment yield, while vegetation removal increases solar insolation and leads to higher stream water temperature. Excrement deposited either in the uplands or directly into waterbodies can lead to elevated levels of nutrients and pathogens. Fish and aquatic invertebrates are sensitive to sediment input, water temperature and excess algae and plant growth due to nutrient input. In contrast, low or moderate grazing have effects that are much less significant than heavy or unmanaged grazing.

A study published since the original literature review further explored the effects of grazing on nutrient and sediment losses to water. Edwards et al. (2000) tried to identify the nutrient losses from grazed lands by measuring the runoff concentrations of nitrogen (N), phosphorus (P), and total suspended solids (TSS) from fescue plots, and relating those measurements to forage management (i.e. forage height) and application of beef cattle manure and manure+urine. Runoff data were collected during simulated rainfall events.

The study found that runoff of N, P, and TSS was dependent on the date of the simulated rainfall event in relation to preceding natural rainfall. Concentrations of N and P were relatively high when little natural rainfall had preceded the simulated rainfall, compared to lower concentrations of N and P when substantial natural rainfall preceded simulated rainfall.

The study also found that the highest runoff nitrate N and total Kjeldahl N concentrations occurred with the forage management treatments with highest forage heights, which the author attributed to relatively low forage uptake of N. In contrast, the same forage management treatments resulted in the lowest runoff P concentrations, which the author attributed to relatively low soil-runoff with higher forage heights. Forage treatment (i.e. forage height or manure/urine addition) did not affect runoff concentrations of TSS and ammonia N.

Finally, the study found that the runoff concentrations of P increased with the addition of manure and manure+urine relative to P runoff from plots that did not receive manure or urine. Similarly, runoff concentrations of nitrate N and total Kjeldahl N increased with the addition of manure/urine, however, this was only true for the greatest forage height. The addition of urine produced no additional runoff quality impacts beyond that of manure alone.

The authors conclude that factors such as amount and proximity of preceding rainfall can have at least as much impact on runoff concentrations of N and P as forage management. The authors also conclude that if forage is managed to promote active growth and thus N uptake, the impact of cattle manure/deposition on runoff N might be negligible. However, this strategy may have the opposite effect with regard to runoff P.

Another new article looked at grazing best management practices in riparian zones to reduce negative effects. Line et al. (2000) evaluated the effectiveness of best management practices (alternate watering systems, livestock exclusion, and riparian vegetation establishment) on reducing nitrogen (N), phosphorus (P), and sediment loading from a dairy cattle pasture along a small North Carolina stream. In an existing heavily-grazed pasture, an alternate watering system was installed, and a fence was installed to exclude dairy cattle from a 335 meter long, 10 to 16 meter wide riparian corridor on either side of the stream. The corridor was then planted with a variety of soft- and hardwood trees.

The study found that weekly discharge and loading rates of nitrogen, phosphorus, and sediments were reduced after the alternate water system and exclusion were implemented. While the alternate watering system appeared to be somewhat effective in reducing nitrite, nitrate, and total suspended solid loads, the decreases were not statistically significant. The main decreases resulted from the section where exclusion fencing was installed. There, the reductions in total Kjeldahl nitrogen, total phosphorus, total suspended solids, and total solids (78.5, 75.6, 82.3, and 81.7% respectively) were statistically significant; however, the reductions in nitrite and nitrate (32.6%) were not.

Thus, the BMPs were effective at reducing loads of total Kjeldahl nitrogen, total phosphorus, and total suspended solids, but were much less effective at reducing the nitrite and nitrate loads. The authors surmise that the nitrite and nitrate loads will decrease as the riparian vegetation becomes established and nutrient uptake increases. The authors conclude that livestock exclusion and riparian vegetation establishment effectively reduce pollutant export from an intensively grazed pasture. However, they note that additional BMPs are needed to further reduce sediment and nutrient loading.

6. How do the various impacts in #1 to #5 vary by species, operation, system type, management, geography, geology, watershed characteristics, and concentration of livestock facilities?

Geology

Minnesota has a wide range of characteristics in soil and geologic sediment properties, hydrogeology and climate, and patterns in runoff and erosion which strongly influence the potential for pollution of surface and ground waters by animal agriculture. The original literature review found that state-wide patterns in degradation in river and lake water quality vary dramatically among the major basins and ecoregions in Minnesota. State-wide patterns in degradation of ground water quality vary primarily in response to soil and sediment properties. No new literature was found in this area.

Geographic Distributions

The original literature review also presented information on the geographic distributions of cattle, hog, chicken, and turkey population densities in Minnesota. In some areas, crude visual comparison of geographic patterns in degraded ground water quality appeared to resemble patterns in cattle population densities; in contrast, there was no clear geographic relationship between degradation of rivers or lakes and animal population densities. No new literature was found in this area.

Concentration

The original literature review found that as size of animal operations increases, the nutrients available for loss to the environment also increase, and as the density of animals in a watershed increases, there is an increasing impact on surface water quality. The critical threshold density depends upon the type of animal, the region and its characteristics, and waste storage, handling, and application methods. No new literature was found in this area.

System Type and Operation Size

The original literature review cited a study in Blue Earth county that found that unlined earthen basins created the primary pollution hazard among feedlots in the county. It also found a tendency for small sized feedlots to be a more frequent pollution hazard than medium or large feedlots. This may occur because medium and larger feedlots tend to be fewer in number, are newer, are better designed, and use improved methods for manure storage, handling, and application than smaller feedlots. No new literature was found in this area.

Species Type

A study released since the original literature review was completed compared water quality impacts of dairy versus pastured beef. Boyer and Pasquarell (1999) compared fecal bacteria densities in karst groundwater resulting from dairy and pastured beef operations in central Appalachia. Contributions of fecal coliform and fecal streptococcus bacteria to the groundwater from a dairy (concentrated livestock densities), and a grass-fed beef operation (dispersed livestock densities) were studied. The authors note that because of the unique geomorphology of karst, the transport of bacteria and other contaminants between surface and groundwater is often rapid, with significant volumes able to move into the subsurface for distances of several kilometers through the karst.

The study found that median fecal coliform and fecal streptococcus densities were highest in cave streams draining the dairy. Median fecal coliform densities in the dairy-impacted stream were greater than 4,000 CFU/100 ml, whereas the median fecal coliform densities in the pasture-impacted streams were less than 10 CFU/100 ml. Similarly, median fecal streptococcus densities in the dairy-impacted streams were greater than 2,000 CFU/100 ml, whereas they were 32 CFU/100 ml in the pasture-impacted streams.

The study also found that agricultural land uses were impacting water quality to the extent that most of the time none of it met the drinking water quality standard for fecal coliform bacteria (<1 CFU/100 ml), and much of the time it did not meet the recreational skin contact standard for fecal coliform bacteria (200 CFU/100 ml).

The authors conclude that the dairy is significantly impacting the water quality of the aquifer, and to a much greater degree than the grass-fed beef operation. They point out that a second dairy in the watershed that had implemented best management practices did not seem to be impacting bacteria densities in the karst aquifers. This demonstrates that best management practices can reduce the potential for affecting water quality in karst aquifers.

Survey of Nutrient Management Practices on Manured Cropland

Since the original literature was surveyed, the Minnesota Department of Agriculture completed a series of FANMAP publications (MDA, 1998) in which surveys of nutrient management practices on manured cropland were summarized. These surveys included information on rate and method of application, timing of application, and type of crop receiving manure.

In south central Minnesota, most swine manure is applied to corn acres (74%), while 22% is applied to soybeans. Manure is generally applied in the fall (53% of the time) or spring (31%), with 8% being applied in summer, and 8% applied in winter. Application methods include 40% broadcast (no incorporation), 36% broadcast with incorporation, and 24% injection.

In south central Minnesota, the average rates of N and P_2O_5 applied to corn from manure are 58 lb/ac and 102 lb/ac, respectively. The average rates of N and P_2O_5 applied to soybeans from manure are 49 lb/ac and 82 lb/ac, respectively. The average rates of N and P_2O_5 applied to corn from commercial fertilizer are 144 lb/ac and 46 lb/ac, respectively, and the rates applied to soybeans average 3 lb/ac and 54 lb/ac, respectively. The total rate of N and P_2O_5 applied to corn from all sources is 202 lb/ac and 184 lb/ac, respectively. The total rate of N and P_2O_5 applied to soybeans from all sources is 52 lb/ac and 136 lb/ac, respectively. With an N credit for legumes, the total rates of N and P_2O_5 applied to corn are in excess of University recommendations by 54 lb/ac and 169 lb/ac, respectively. The excess N and P_2O_5 applied to soybeans is 52 lb/ac and 121 lb/ac, respectively.

In Scott and Carver counties, hog and dairy manure is applied primarily to corn acres (60%), followed by soybeans (17%), and alfalfa (16%). Manure is applied mostly in fall (36% of the time) and spring (32%), followed by summer (16%) and winter (16%). Application methods include 57% broadcast (no incorporation), 21% broadcast with incorporation, and 22% injection. The average rates of N and P_2O_5 applied to corn from manure are 43 lb/ac and 72 lb/ac, respectively. Rates of manure applied to soybeans and alfalfa are similar to rates applied to corn. In contrast, the average rates of N and P_2O_5 applied to corn from commercial fertilizer are 136 lb/ac and 35 lb/ac, respectively, while soybeans receive 8 lb/ac and 21 lb/ac, respectively. The total rate of N and P_2O_5 applied from all sources to corn is 179 lb/ac and 107 lb/ac, respectively. When a credit for N from legumes is included, the total rates of N and P_2O_5 applied to corn are in excess of University recommendations by 43 lb/ac and 92 lb/ac, respectively.

In Lincoln and Pipestone counties, beef, dairy, and hog manure is applied mainly to corn acres (48%), followed by 21% soybean acres, and 10% small grain acres. Manure is applied 87% in the fall. Application methods include 12% broadcast (no incorporation), 13% broadcast with incorporation, and 75% injection. The average rates of N applied to corn and soybeans from manure are 18 lb/ac and 9 lb/ac, respectively. Commercial fertilizer is applied to corn at average rates of 109 lb/ac and 30 lb/ac, respectively, for N and P_2O_5. Commercial fertilizer is applied to soybeans at a rate of 21 lb P_2O_5/ac. Total rates of N and P_2O_5 applied to corn from all sources are 127 lb/ac and 30 lb/ac, respectively. With a legume N credit of 35 lb/ac, the total rate of N applied is in excess of the University recommendation by 23 lb N/ac.

In the Karst region of southeastern Minnesota, dairy manure is primarily applied to corn acres (83%), followed by small percentages in soybeans, alfalfa, and small grains. The amount of N applied to corn from manure is 42 lb/ac. The rate of commercial fertilizer applied to corn is 90 lb/ac for N and 30 lb/ac for P_2O_5. The average rate of commercial P_2O_5 applied to soybeans is 25 lb/ac. With a credit of 44 lb N/ac for previous legume crops, the total N applied to corn from all sources is in excess of the University recommendations by 41 lb/ac.

In the central outwash sand region, manure is applied primarily to corn acres (54%), followed by alfalfa (15%), and small grain (14%). The average rate of manure N applied to corn is 29 lb/ac, while 53 lb N/ac is applied as commercial fertilizer. Corn receives on average 18 lb P_2O_5/ac.

With a legume N credit of 16 lb/ac, the total rate of N applied is in excess of the University of Minnesota's N recommendation by 38 lb/ac.

From these surveys, we see that manured lands can receive rates of nitrogen and phosphorus that are in excess of nutrient guidelines developed by the University of Minnesota. These excesses are from 17-45% of the University recommendations for unmanured corn acres. Excess nutrients applied to land increases the risk of surface and ground water pollution.

7. What are the current and potentially available best management practices and mitigation technologies to prevent against ground and surface water pollution from manure storage, handling, and application, and to what extent are they effective?

Manure Storage

The original literature review identified recommended manure storage practices including providing adequate storage capacity, proper engineering design and siting of storage facilities, diverting and collecting runoff water away from surface water bodies, repairing leaks and cracks promptly, and stockpiling manure on impermeable surfaces.

In a new article, Ham and DeSutter (2000) argue that lagoon design regulations should be site specific in order to avoid the overregulation and underregulation of producers that occurs with statewide blanket regulations based on maximum allowable seepage rates. Because these blanket regulations do not take species, location, and type of waste system into account, they do not adequately assess and address the risk of groundwater contamination. The result is that in some vulnerable areas, groundwater may be at risk (underregulation), and in other areas, groundwater may be overprotected (overregulation).

The authors present a framework for determining site-specific seepage criteria for lagoons based on protecting groundwater from nitrogen contamination. It contains consideration of three factors: 1) toxicity and concentration -- substances in the waste that threaten water quality and public health; 2) input loading -- the seepage rate of contaminants from a lagoon; and 3) aquifer vulnerability -- the risk of waste moving from the lagoon to the ground water. The framework first requires the input of data such as geological assessment and soil analysis of the proposed site, and information on the type of proposed facility and method of waste handling and treatment. It then uses a series of calculations (determining the concentration of ammonium in the effluent, the minimum allowable distance between the lagoon and high water table, the ion adsorption capacity at 0 to 3 meters and total maximum adsorptive capacity, and maximum allowable seepage rate) interspersed with decision points to determine site-specific lagoon design.

Finally, the authors recommend the adoption of performance-based testing of lagoons after construction. They conclude that the combination of site-specific seepage requirements and on-going testing of seepage rates will reduce risk of water quality contamination before it occurs.

Manure Collection
The original literature review also addressed manure collection. Recommended manure collection practices for solid manure include low stocking densities on pastures away from surface water bodies, and impermeable surfaces away from surface waterbodies with proper diversion and collection of runoff on open lots. For liquid systems, the deep pit offers good environmental protection. No new literature was found in this area.

Water Quality Risks From Feedlot Confinement and Storage Types in Minnesota
Since the original literature was surveyed, the Minnesota Department of Agriculture summarized surveys of County Feedlot Officers and Soil and Water Conservation District Staff on the extent of non-compliance of feedlots with the new Minnesota Feedlot Rules (MDA, 2001). This survey encompassed eleven counties with level 2 or level 3 feedlot inventory data.

They found that 957 feedlots (roughly 15% of all feedlots) in this subset would not comply with various portions of the Minnesota Rules for Feedlots. The non-compliant feedlots required either runoff controls, storage basin upgrades, or both types of correction to reduce environmental pollution. A majority of the non-compliant feedlots (47%) were for beef cattle, while 27% and 22% of the non-compliant feedlots were dairy and hog feedlots, respectively. Poultry operations accounted for only 2% of the non-compliant feedlots. These risks do not include environmental risks associated with land application of manure or air quality, only risks of runoff and leaching from manure storage and confinement facilities. Most county feedlot officers believe the risk of environmental pollution is greater from land application of manure than from runoff and leachate at manure storage and confinement facilities.

According to the MDA study, 25%, 34%, 23%, 16%, and 1% of the environmentally non-compliant beef feedlots were in the tiny, very small, small, moderate, and large size classes, respectively. The majority of environmental risks are probably due to inadequate runoff controls from open lots, partial housing without runoff controls, daily hauling or stockpiling operations. There may also be environmental risks due to seepage from earthen holding basins.

According to the MDA, of the dairy feedlots which pose an environmental risk, 8%, 27%, 59%, 5%, and 0% are tiny, very small, small, moderate, or large sized feedlots, respectively. The main perceived environmental risks are from poorly engineered earthen holding basins and from partial housing without runoff controls. Serious environmental pollution may also arise after winter spreading of manure in daily haul dairy operations, an indirect consequence of this storage type.

Of hog feedlots which pose an environmental risk, 6%, 33%, 37%, 24%, and 0% are in the tiny, very small, small, moderate, and large size classes. These environmental risks are primarily due to earthen storage basins and partial housing without runoff controls.

Manure Application

The original literature review found that application rate is the most important manure management practice affecting the potential for contamination of water resources by nitrogen from manure. However, estimating the proper rate is difficult due to variation in nutrient content and availability among manures, and lack of precision in application equipment. Application method is also key. The three most common methods are liquid tank applicators, liquid tow hose irrigation, and box spreaders. Liquid tank applicators have the least environmental impact if manure is injected during application. No new literature was found in this area.

Other Manure Management Practices

The original literature review identified other management practices that can effectively protect water quality including tillage, vegetative filter strips and setback distances, cropping systems, and wetland treatment.

8. To what extent does Minnesota animal agriculture contribute to the hypoxia problem in the Gulf of Mexico?

Hypoxia is a zone of low oxygen levels (< 2 mg/L) covering an area as large as 7,000 square miles in the Gulf of Mexico in 1997, caused in large part by influxes of agricultural nitrogen sources that support excessive growth of diatoms. The primary pathway for nitrogen sources to enter surface waters is after intense rainstorms via subsurface tile drainage systems on poorly drained soils with high organic matter contents receiving excessive rates of nitrogen from fertilizer and/or manure.

The original literature review found that the largest source of nitrogen to the Gulf of Mexico from Minnesota is the Minnesota River basin, which generates roughly 5% of the total nitrogen flux to the Gulf of Mexico. The Mississippi River upstream of the Twin Cities generates roughly 1% of the nitrogen flux to the Gulf. Wastewater treatment plants in the Twin Cities and upstream of the Twin Cities generate around 1% of the total nitrogen flux to the Gulf. Streams in southeastern Minnesota draining to the Upper Mississippi River probably generate about 1% of the nitrogen flux to the Gulf of Mexico. The literature review estimated that animal agriculture in Minnesota contributes less than 1% of the nitrogen entering the Gulf of Mexico. Minnesota also contributes roughly 4% of the total phosphorus flux to the Gulf of Mexico. Wastewater treatment plants are responsible for at least half of this contribution. In comparison, nonpoint sources from the Minnesota and Upper Mississippi River basins are together a smaller source of total phosphorus than wastewater treatment plants.

Two new studies were published since the original literature review was completed that estimate the contributions of Iowa and Illinois to hypoxia in the Gulf of Mexico. While these studies do not focus on Minnesota's contribution to hypoxia, they are of interest because Iowa and Illinois share similar agricultural systems, soils, and climate with Minnesota, so results should be similar to what would be found for Minnesota.

Becher et al. (2000) characterized nutrient concentrations and estimated nutrient inputs, loads, and yields in 1996-1997 for watersheds in eastern Iowa that drain to the Mississippi River. The study used nutrient data from twelve water sampling sites within the study area, along with land use GIS data and county-level agricultural data on crops and numbers of animals from a variety of sources. The study found that animal wastes contributed about 23 percent of the estimated total N and 52 percent of the total P to the study area in 1996. Concentrations of nutrients varied seasonally, with the highest median total N concentrations in June, followed by decreases in August to October, increases in November to January, and decreases in February to March. The authors speculate that the increases in spring and fall are due to field applications of fertilizer and manure at those times. Concentrations of median total P were highest in February, March, and May.

Similarly, the study found that the greatest total N loads discharged to the Mississippi River occur in late spring and early summer, and follow the same seasonal pattern described above. Total P loads discharged to the Mississippi River follow the same seasonal pattern as total N, with the peak loads occurring in May. Overall, the three major watersheds draining eastern Iowa contributed 79,000 metric tons of N and 6,800 metric tons of P (from all agricultural and non-agricultural sources) to the Mississippi River in 1996.

David and Gentry (2000) estimated Illinois= contribution of N and P to the Mississippi River for the 1979 through 1997 water years. The study estimated average loads of 1,374,000 and 117,000 Mg of N and P respectively in the Mississippi River for the water years 1980-1997. The contribution of Illinois rivers to the total Mississippi nutrient load was 18% for N and 12% for P. Since the study estimated that Illinois contributes only 9.6% of the streamflow to the Mississippi, there is a disproportionate flow of nutrients from Illinois rivers to the Mississippi. However, the authors did not believe that manure is an important contributor of nutrients to Illinois surface waters.

9. What is the impact of animal agriculture on water quantity and availability (sustainability of water supply)? How does the use of water by animal agriculture compare with that of other industries in Minnesota?

The original literature review found that livestock water use in Minnesota includes water for consumption, and associated on-farm non-consumption use for the production of milk, meat, eggs and wool. Most of the non-consumption water use on livestock farms is for cleaning of equipment and facilities, with dairy and swine farms being the largest users in this category. The total amount of water consumed by livestock each day in Minnesota is estimated to be about 50 million gallons. The total daily water use on livestock farms (including consumption) is roughly 161 million gallons per day. In comparison to water used by animals, the total water used in Minnesota for power generation, public usage, industrial processing, irrigation and other uses per day is roughly 3.25 billion gallons in 1994. The 161 million gallons of water used in livestock enterprises represents only 5% of the state water usage each day. The original literature review also found that confined animal feedlot operations can reduce water intake because of increased paved surface areas and concentrated animal traffic, which cause increased soil compaction and hence decreased infiltration. No additional literature was found in this area.

10. How does animal manure compare to other types of wastes produced in Minnesota as a source of water pollution?

The original literature review found that the primary sources of nutrients that cause water pollution in Minnesota include animal waste, human waste, migratory wildfowl wastes, fertilizers, and recycled nutrients from the soil. Using several assumptions, it estimated the relative magnitude of the impacts from each source. Among these sources, animal manure was found to be at the lower end of nitrogen production, and in the mid-range of phosphorus production. The review notes that the nitrogen and phosphorus from human waste and migratory wildfowl, while produced in lower quantities than animal waste, are discharged directly into streams and rivers, while only a small fraction of the animal waste eventually reaches surface waters.

Further, the review estimated that very little excess phosphorus is available for losses to the environment. In contrast, it identified a clear state-wide excess of nitrogen applied as fertilizer and manure. However, since many nitrogen sinks are unaccounted for, they may balance this excess. If they do not, then the state-wide excess is a potential risk for degradation of surface and ground water quality.

No new literature was found in this area.

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