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Technical Memorandum

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Subject: Final—Detailed Assessment of Phosphorus Sources to Minnesota Watersheds—Feedlot Runoff

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Overview and Introduction to Feedlot Runoff as a Source of Phosphorus

The primary way that feedlots contribute phosphorus to surface waters, apart from land application of manure, is through open lot runoff during precipitation and snowmelt events. Livestock manure accumulates on outdoor feedlots and is susceptible to runoff before being scraped from the feedlot and applied to cropland. Even after scraping for stockpiling or land application, a thin coating of manure remains on the feedlot surface and a fraction of this manure will wash off during precipitation or snowmelt events.

Overall, a small fraction of the total manure phosphorus generated at feedlots enters waters during precipitation and snowmelt events. Many feedlots do not have an open lot because they keep animals inside the barn most or all of the time, especially poultry, swine and large dairy facilities. Many of those with outdoor open lots collect runoff in impoundments or treat the runoff as it passes through downslope vegetation. Yet many feedlots still maintain open lot runoff that is out of compliance with state feedlot rules, and runoff from these feedlots contributes some phosphorus to waters. Under MN Rules 7020 control of runoff from these feedlots is phased in through October, 2010.

Results of Literature Search and Review of Available Monitoring Data

Typical amounts of phosphorus generated by livestock are described in Midwest Plan Service (2000). The daily P2O5 phosphorus generated per animal is reported as: Beef cattle 0.21 lbs.; Dairy cows 0.42 lbs.; and Swine 0.05 lbs. Most of this manure phosphorus (P) generated will be applied to cropland. However, a fraction of the manure P can be lost in feedlot runoff during precipitation or snowmelt events. Manure nutrients and organic matter (oxygen demand) is often retained in vegetation that is downslope of the feedlot. However, runoff from many feedlots enters flow channels (waterways, road ditches, drainage ditches, intermittent streams or streams) before sufficient phosphorus retention by vegetation can occur. In order to be compliant with MPCA rules, Chs. 7020 and 7050, monthly average discharges must be less than 25 mg/l biochemical oxygen demand (BOD) and less than 1 mg/l phosphorus if discharging into or affecting a lake or reservoir. Feedlots that meet the 25 mg/l BOD standard have phosphorus concentrations that are typically slightly greater than cropland runoff.

Based on a survey of county Soil and Water Conservation District Offices and Environmental offices, the Minnesota Department of Agriculture (MDA) estimates that roughly 34 percent of feedlots need upgrades to meet state regulations (MDA, 2003). In the same report, MDA estimates that approximately four out of every five (79%) of the feedlots needing upgrades need open lot upgrades and the other 21% have other problems not associated with open lot runoff (e.g. unlined manure storage structures). Most feedlots with open lot runoff are from smaller beef, dairy and swine feedlots, with much fewer instances of non-compliance observed for moderate and large sized feedlots (Mulla et al., 2001).

Phosphorus runoff loading from open lot feedlots can be estimated with a feedlot evaluation model developed in Minnesota (Young et al., 1982). The model (FLEval) has been used for many years in Minnesota to evaluate compliance with Minnesota Feedlot runoff rules and to estimate reduced oxygen demand and phosphorus loadings resulting from feedlot improvements. The model was developed to estimate pollutant loadings at the feedlot edge and to account for any contaminant retention/treatment that occurs in downslope vegetation and cropland. The model was developed to predict loading from individual storm events. However, the Board of Water and Soil Resources developed an equation to estimate annual loadings and annual runoff.

Watershed Basin Characteristics

Runoff characteristics of each major watershed basin in the state were developed to simplify and provide a surrogate of the annual amount of phosphorus that leaves the feedlots in that basin due to surface runoff. For example, wet condition runoff is 15.6 inches per year in the Lower Mississippi Basin and 6.1 inches per year in the Red River Basin (see the Basin Hydrology Technical Memorandum). Computer modeling using the Feedlot Evaluation model (FLEval) estimated that 2 percent of the annual phosphorus generated at non-compliant feedlots leaves the feedlot edge in runoff in the Lower Mississippi River Basin during wet years (assuming 15.6 inches of annual runoff at feedlots); whereas only 0.8 percent of the phosphorus leaves the feedlot edge in the Red River Basin (assuming 6.1 inches of annual runoff at feedlots). The annual runoff model inputs for low, average and high flow years were consistent with the runoff amounts used for assessing other phosphorus sources in this project (based on the Basin Hydrology Technical Memorandum).

Approach and Methodology for Phosphorus Loading Computations

Described below is a summary of the steps taken to develop estimates of P loading to waters from open lot runoff:

Step 1. Determine the number of beef, dairy and swine animal units found at all feedlots with open lots (excluding feedlots with 1000 or more animal units).

Step 2. Multiply the results in step 1 by the annual manure P generated by each type of livestock. This provides P generated by livestock in all open lots.

Step 3. Multiply the results in step 2 by the estimated percentage of open lot feedlots that contribute phosphorus during certain storm events. This provides P generated by livestock at feedlots that contribute P to waters.

Step 4. Multiply the results in step 3 by the typical fraction of P that is lost to surface waters during low, average and high flow years. This provides the estimated P loading to surface waters from open lots.

The spreadsheet used to make the calculations for the 4 steps is shown in Table 1. Each of the four steps is described further in the following pages.

Table 1
Estimated Annual Phosphorus Loadings for Outdoor Open Lot Feedlot Runoff to Surface Waters

Major Basin	Animal	P Produced per Animal Unit	Open Lot Animal Units	Manure P Produced from All Open Lots	Assumed Open Lots Contributing P to Waters	Manure P Produced from P Contributing Feedlots	Fraction of P Generated Entering Surface Waters from Non-Compliant Lots by Flow Condition (from FLEVAL)			Estimated TP from Feedlot Runoff by Flow Condition		
		lbs/yr	AU	lbs	fraction	lbs P/yr	fraction Low	fraction Average	fraction High	kg P/yr Low	kg P/yr Average	kg P/yr High
Cedar	Beef	33.5	6,809	228,102	0.35	79,836	0.0036	0.0062	0.0112	130	225	406
	Dairy	47.8	2,529	120,886	0.35	42,310	0.0033	0.0057	0.0102	63	109	196
	Hogs	26.6	9,759	259,589	0.35	90,856	0.0033	0.0057	0.0102	136	235	420
									Basin Total	**330**	**569**	**1,022**
Des Moines	Beef	33.5	48,639	1,629,407	0.35	570,292	0.0009	0.0036	0.0085	233	931	2,199
	Dairy	47.8	3,945	188,571	0.35	66,000	0.0008	0.0033	0.0077	24	99	231
	Hogs	26.6	48,122	1,280,045	0.35	448,016	0.0008	0.0033	0.0077	163	671	1,565
									Basin Total	**419**	**1,701**	**3,994**
Lake Superior	Beef	33.5	3,074	102,979	0.35	36,043	0.005	0.008	0.0107	82	131	175
	Dairy	47.8	3,203	153,103	0.35	53,586	0.0045	0.0073	0.0097	109	177	236
	Hogs	26.6	92	2,447	0.35	857	0.0045	0.0073	0.0097	2	3	4
									Basin Total	**193**	**311**	**414**
Lower	Beef	33.5	238,216	7,980,236	0.35	2,793,083	0.0045	0.0065	0.0099	5,701	8,235	12,543
	Dairy	47.8	200,040	9,561,912	0.35	3,346,669	0.0041	0.0059	0.009	6,224	8,956	13,662
	Hogs	26.6	79,301	2,109,407	0.35	738,292	0.0041	0.0059	0.009	1,373	1,976	3,014
									Basin Total	**13,298**	**19,167**	**29,219**
Minnesota	Beef	33.5	358,579	12,012,397	0.35	4,204,339	0.0012	0.0036	0.0071	2,288	6,865	13,540
	Dairy	47.8	158,480	7,575,344	0.35	2,651,370	0.0011	0.0033	0.0064	1,323	3,969	7,697
	Hogs	26.6	271,561	7,223,523	0.35	2,528,233	0.0011	0.0033	0.0064	1,261	3,784	7,339
									Basin Total	**4,873**	**14,619**	**28,576**
Missouri	Beef	33.5	132,679	4,444,747	0.35	1,555,661	0.0006	0.0033	0.008	423	2,329	5,645
	Dairy	47.8	27,219	1,301,068	0.35	455,374	0.0005	0.003	0.0072	103	620	1,487
	Hogs	26.6	81,589	2,170,267	0.35	759,594	0.0005	0.003	0.0072	172	1,034	2,481
									Basin Total	**699**	**3,982**	**9,613**
Rainy	Beef	33.5	8,993	301,266	0.35	105,443	0.003	0.005	0.0075	143	239	359
	Dairy	47.8	1,668	79,730	0.35	27,906	0.0027	0.0045	0.0068	34	57	86
	Hogs	26.6	116	3,086	0.35	1,080	0.0027	0.0045	0.0068	1	2	3
									Basin Total	**179**	**298**	**448**
Red	Beef	33.5	142,375	4,769,563	0.35	1,669,347	0.0006	0.0022	0.0039	454	1,666	2,953
	Dairy	47.8	54,886	2,623,551	0.35	918,243	0.0005	0.002	0.0036	208	833	1,499
	Hogs	26.6	9,740	259,084	0.35	90,679	0.0005	0.002	0.0036	21	82	148
									Basin Total	**683**	**2,581**	**4,601**
St. Croix	Beef	33.5	28,985	970,998	0.35	339,849	0.0036	0.0062	0.0091	555	956	1,403
	Dairy	47.8	36,362	1,738,104	0.35	608,336	0.0033	0.0056	0.0082	311	1,545	2,263
	Hogs	26.6	1,744	46,390	0.35	16,237	0.0033	0.0056	0.0082	24	41	60
									Basin Total	**1,490**	**2,542**	**3,726**
Upper	Beef	33.5	256,585	8,595,598	0.35	3,008,459	0.0023	0.0044	0.0066	3,139	6,004	9,006
	Dairy	47.8	391,607	18,718,815	0.35	6,551,585	0.0021	0.004	0.006	6,241	11,887	17,830
	Hogs	26.6	53,454	1,421,876	0.35	497,657	0.0021	0.004	0.006	474	903	1,354
									Basin Total	**9,853**	**18,794**	**28,191**
									Statewide Total	**32,017**	**64,564**	**109,804**

Step 1. Beef, Dairy and Swine animal units at open lot feedlots

MPCA's registered feedlot database was used to determine which feedlots had open lots. Of the 29,122 feedlots in this data base 14,367 feedlots indicated that they had an open lot and 3,181 indicated no open lot. Another 11,574 feedlots had a question mark under the open lot heading (or flag). The following five combinations of answers in the data base were considered to be feedlots likely to have an open lot.

1. Open Lot flag = Y and <1000 A.U.s
2. Open Lot flag = ? and Confinement Building flag = N and Total A.U.s < 300
3. Open Lot flag = ? and Confinement Building flag = Y and Manure Storage flag = N and Total A.U.s < 300
4. Open Lot flag = ? and Confinement Building flag = ? and Total A.U.s < 300
5. Open Lot flag = ? and Manure Storage flag = ? and Total A.U.s < 300

All feedlots with more than 1000 animal units were excluded, since discharge to waters is not allowed at these feedlots and they are routinely inspected to ensure compliance with the no discharge standard.

Based on the combinations outlined above, a total of 22,387 feedlots were assumed to have open lots. The distribution of these open lots, along with the remaining feedlot locations from the MPCA's registered feedlot database, is shown in Figure 1. The beef, dairy and swine animal units from these feedlots were tallied to determine the livestock animal units found at feedlots with open lots. This was determined separately for each basin.

Step 2: Manure P generated by livestock

Phosphorus generated for each animal unit of dairy, beef and swine was determined based on information from Midwest Plan Service (2000). By taking the daily P2O5 generation described in that publication, and converting to annual P generated per animal unit (au), the following estimates of annual P generation were developed: Beef cattle 33.5 lbs/au; Dairy cows 47.8 lbs/au; and Swine 26.6 lbs/au. Multiplying these numbers by the number of animal units in each basin provided the annual total P produced by livestock at open lot feedlots in each basin.

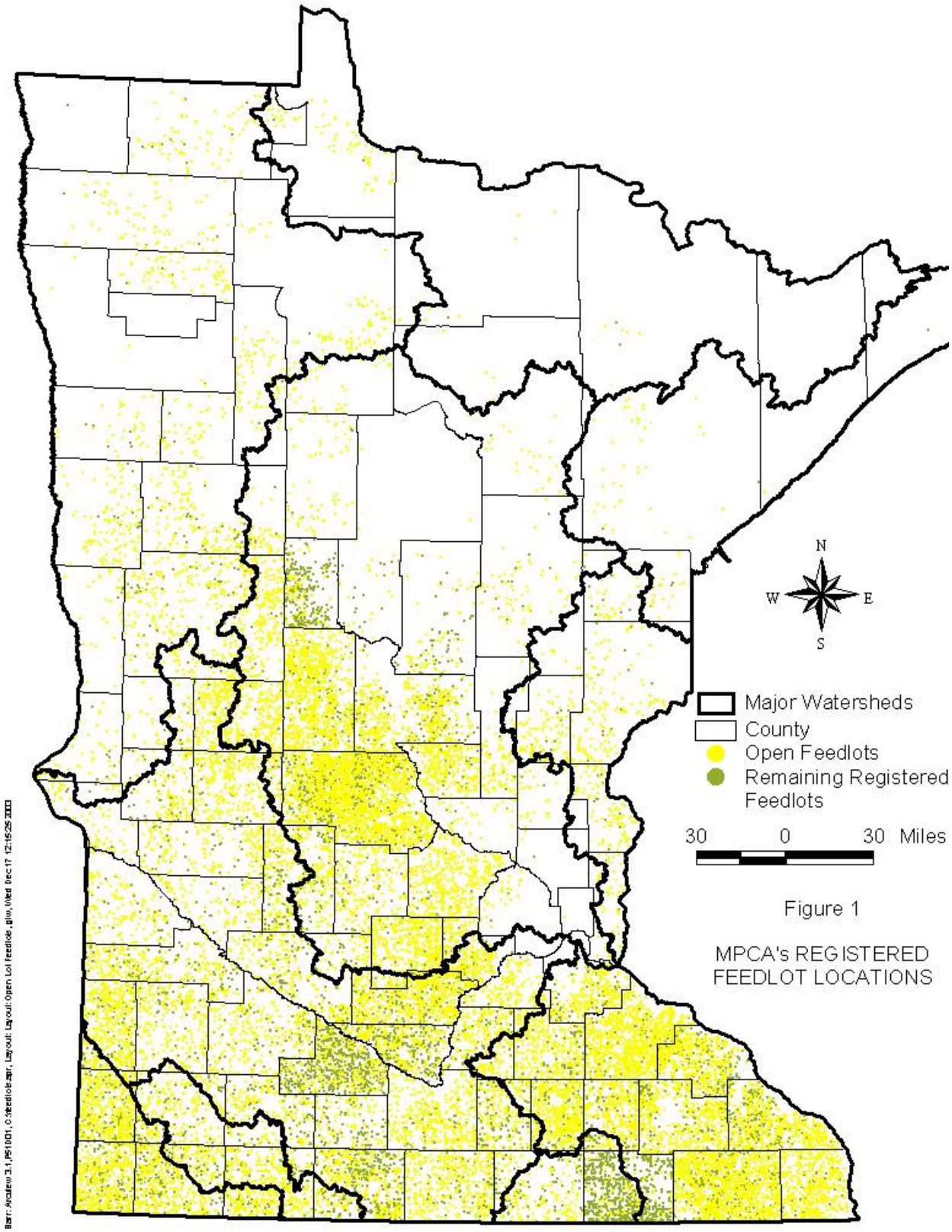

Figure 1

MPCA's REGISTERED FEEDLOT LOCATIONS

Step 3. Percentage of feedlots contributing P in runoff

We assumed that feedlots that are in compliance with Minnesota rules have negligible P runoff. Based on rough MDA estimates (MDA, 2003), we assumed that 27 percent of all feedlots contribute P to surface waters due to open lot runoff. Twenty-seven percent of all 29,122 registered feedlots is 7863 feedlots needing open lot runoff control improvements. With an estimated 22,387 feedlots with open lots in the data base used for this study, the percent of open lots contributing P in runoff is 35 percent (7863/22,387). While this fraction is expected to vary significantly across the state (see discussion of uncertainties and variability), a more detailed geographic-based analysis was not feasible at this time with the readily available information. Therefore, we assumed that 35 percent of open lot feedlots contributed P to surface waters in each of the basins. This fraction is expected to decrease significantly by October 2010, the deadline set in Minn. Rules ch. 7020 for those feedlots in open lot agreements.

We assumed that each animal unit in feedlots with open lot P runoff contributes to open lot runoff in the modeling exercise.

Step 4. Fraction of manure that reaches surface waters

The fraction of manure that reaches surface waters was calculated by dividing expected phosphorus runoff to waters by the total amount of manure that was generated at the feedlots with open lot P runoff.

We used the FLEval model to determine the amount of manure that is expected to leave the feedlot and enter waters at non-compliant feedlots. The following assumptions were made in the FLEval modeling exercise: animal stocking density of 200 square feet per animal; all of the soil in the lot had at least some manure covering the ground; no upslope runoff waters washed through the lot; and downslope vegetation reduced the phosphorus loads found at the feedlot edge by half (typical for less than 50 feet of grassed buffer). With these assumptions, the amount of P expected to reach the discharge point (channelized flow) during wet years ranged from 0.39 to 1.12 percent of the total manure P generated at the feedlots (varying by basin). During dry years the P loading at the discharge point was 0.1 to 0.5 percent across the different basins. While the total amount of P loading increased with increasing animal numbers in the feedlot, the fraction of P lost to the discharge point was independent of animal numbers. The other 99+

percent of manure P that does not runoff is applied to cropland, with a small amount remaining in the feedlot soils or picked up by wind.

Results of Phosphorus Loading Computations and Assessments

Table 1 presents the results of the phosphorus loading computations for runoff from noncompliant open feedlots during low, average and high flow conditions within each of the major basins of the state. The results show that the Lower Mississippi River produces the most phosphorus in feedlot runoff, with similar loadings estimated for the Upper Mississippi and Minnesota River basins. These three basins account for 88, 81, and 78 percent of the total statewide phosphorus loadings from feedlot runoff under low, average and high flow conditions, respectively. On a statewide basis, the total phosphorus loading during an average year is twice as high as the loading during a low flow year, while the high flow loading estimate is approximately 1.7 times higher than the estimate for average flow conditions. Table 1 shows that dairy in the Upper Mississippi River produces the largest amount of manure phosphorus generated from all open lots, followed by beef in the Minnesota River basin.

Due to uncertainties, variability and unaccounted sources described below, the feedlot runoff loading results could be significantly higher or lower in some basins than the results show.

Phosphorus Loading Variability and Uncertainty

Not all potential avenues of phosphorus transport to waters from feedlots were included in this analysis. This analysis did not include runoff from:

- Manure application sites (i.e. from spreading onto cropland) and pastures. This is handled in the report under the category agricultural field runoff;
- Silage leachate runoff, which has high concentrations of phosphorus, but relatively low volumes that add significantly to basin-wide phosphorus budgets;
- Milkhouse wastewater discharges;
- Open lots that are not included in the MPCA feedlots data base, including those feedlots that have not yet registered or those feedlots that are too small to require registration (i.e. under

50 animal units outside of shoreland). This would include many small farms with horses and livestock.

- Feedlots that do not have open lots; incidental runoff from total confinement operations is considered negligible.
- Poultry facilities and field stockpiles associated with poultry operations. Most poultry are raised in total confinement, and the relatively small amount raised outside or from stockpiles was considered negligible for basin-wide analysis.
- Runoff from pasturing animals, including animals with direct access to surface waters.

Several areas of uncertainty and variability exist in the analysis.

Uncertainties about animal units at open lots - The data base used to obtain the information is incomplete. While 29,122 feedlots exist in the data base, incomplete information is available from several counties, and also many smaller feedlots were not required to register. It is possible that the actual number of all feedlots could be several thousand more than indicated in the data base. Additionally, information about the presence of open lots at 11,574 was not available. Information about confinement buildings, manure storage and feedlot size were used to roughly determine which of those were likely to have open lots. Since the missing feedlots are mostly small lots, the added phosphorus loading would not be expected to be more than 25% greater than our current estimates.

Uncertainties about manure P generation – The amount of phosphorus generated by each animal type was provided from average values based on research in the Midwest. The actual P generated is increasingly being reduced through dietary measures. However, this source of variability and uncertainty is considered to be relatively minor.

Uncertainties about the fraction of feedlots that contribute P to surface waters – The percent of open lot feedlots that contribute P to waters varies from basin to basin within the state. Areas with steeper slopes and a more pronounced drainage system will have a higher percentage of open lots with runoff problems. Unpublished county-specific information used to develop the statewide average (MDA, 2003), indicates that the percentage of open lots that may contribute runoff P to surface waters in the Lower Mississippi basin could be much greater than the statewide average, whereas, in the Missouri and Des Moines river basins the fraction of feedlots with open lot runoff problems may be less than half of the statewide average. This variability was not accounted for in

the analysis. The 35 percent of open lots contributing runoff P that was used for all basins in this study is likely to be too low for basins like the Lower Mississippi and too high for other basins. However, due to a lack of basin-specific information, we decided to use the 35 percent figure statewide.

It is likely that some phosphorus is delivered to waters from feedlots that are in compliance with state feedlots rules. No feedlot runoff was accounted from feedlots that were considered to be in compliance with state feedlot rules.

We assumed that all of the animals in feedlots with open lots contribute manure to the open lot. This is not valid at all feedlots, since some of the animals where open lots are found are in total confinement 100 percent of the time. For example, a feedlot may have 100 animal units that use an open lot and may have another 100 animal units kept in total confinement. We did not have information that would allow us to differentiate which animals used the open lot and which were kept in total confinement.

Uncertainties about phosphorus delivery – The FLEval model used to estimate the fraction of phosphorus delivery to waters is currently being upgraded by the University of Minnesota to improve estimates of annual phosphorus loading. We do not know if these upgrades will increase or decrease annual P loading estimates. Several assumptions were made for the FLEval modeling exercise that affected the estimated loading. The P loading results could be either half as much or twice as much as the study results, depending on modeling assumptions about the feedlot size (square feet per animal unit), the effect of downslope vegetation and cropland, and other model inputs.

Another uncertainty is the effect that holding animals in the barns or pastures will have on reducing the fraction of P delivery to waters. Where animals are held in barns or pasture for a long enough time during the day so that less than 100 percent feedlot of the feedlot area has manure on the surface, then the phosphorus loadings would be reduced. In the model we assumed that each animal unit contributed to 200 square feet of feedlot surface that was covered 100 percent manure. Both of these assumptions are variable and affect the modeling results, causing an overestimate of P loading for this part of the loading calculation.

Net effect of the uncertainties

If we look at the primary uncertainties in this exercise we see that some are expected to result in overestimates of phosphorus loading from feedlots and others contributed to underestimates of phosphorus loadings from feedlots. Included below is a summary of these uncertainties:

1. ***Incomplete feedlot data base*, resulting in underestimates by roughly 10 to 25 percent;**
2. ***Not including milkhouse wastewater, silage leachate and spills*, resulting in underestimates of P loading by roughly 5 to 20 percent;**
3. ***Not including P from feedlots in compliance with feedlot runoff regulations*, resulting in underestimates of roughly 1 to 10 percent;**
4. ***Uncertainties in percent of open lots that contribute P to surface waters*, potentially resulting in the Lower Mississippi basin underestimates by as much as 100 percent and overestimates in the Missouri, Des Moines basins by roughly 100 percent, with other basins being closer to statewide averages.**
5. ***Uncertainties about FLEval modeling of annual loading*, with unknown effects; and**
6. ***Uncertainties about how much time the livestock at feedlots with open lots spent in the barn or on pasture*, resulting in overestimates of roughly 10 to 30 percent.**

Recommendations for Future Refinements

Future refinements can be made when the MPCA data base is improved to more clearly indicate whether an open lot exists at each feedlot and when better basin-specific information can be provided about how many feedlots are out of compliance with state feedlot runoff rules and regulations. Additionally, the results can be refined after the FLEval model upgrades are completed by the University of Minnesota and when better information is available about average downslope buffer conditions at non-compliant feedlots. Also, future analyses should incorporate estimates of how livestock time in barns or pastures may reduce the overall fraction of manure P that is delivered to waters.

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