3.2 Estimated Basin Total Phosphorus Amounts Contributed to POTWs and Surface Waters (by Source)

This section is intended to present the results of the total phosphorus loading estimates to surface waters in each basin by source category. The following sections provide a detailed discussion of the results of the phosphorus loading estimates for each source category, including assessments of which major basins are specifically influenced by each source category. The phosphorus loading estimates are also further described in Appendices B through J.

3.2.1 Point Sources

3.2.1.1 Sources and Amounts of Phosphorus Discharged to POTWs

The sources of phosphorus to POTWs and to privately owned treatment facilities were identified and quantified by the methods described in Section 2.2.1.2. The total phosphorus load discharged to POTWs in each basin is presented in Table 3-2. The annual amount of total phosphorus discharged into POTWs in Minnesota is estimated to be 4,468,000 kg/yr. Table 3-2 shows that 53 percent (2,384,900 kg/yr) of the total phosphorus load discharged to POTWs originated from the Upper Mississippi River basin, which includes a majority of the loading to POTWs in the Twin Cities Metropolitan Area. The influent load to the Metro plant represents 75 percent (1,794,400 kg/yr) of the total phosphorus load discharged to POTWs in the Upper Mississippi River basin.

Table 3-2 Total Phosphorus Load Discharged to POTWs

Basin	Total (kg/yr)
Cedar River	105,200
Des Moines River	46,200
Lake Superior	227,000
Lower Mississippi River	501,900
Minnesota River	952,200
Missouri River	26,400
Rainy River	20,100
Red River	150,600
St. Croix River	53,500
Upper Mississippi River	2,384,900
Total	4,468,000

As part of this study, the influent phosphorus discharged into POTWs and publicly owned treatment facilities was separated into its major constituent sources. Figure 3-4A and 3-4B illustrates the contributions of various phosphorus sources to the influent phosphorus loads for the POTWs and privately owned treatment facilities. Both figures show that human waste, followed by commercial and industrial process wastewater, is the largest contributor of phosphorus to POTWs and privately owned treatment facilities in most of the basins. The influent phosphorus load discharged to POTWs and privately owned treatment facilities is also broken down by source category for the entire state in Table 3-3 and 34, respectively. Table 3-3 shows that human waste represents approximately 42 percent of the phosphorus load to POTWs in the state, while commercial and industrial process wastewater represents approximately 27 percent of the influent phosphorus load. Table 3-4 shows that human waste represents approximately 60 percent of the influent phosphorus load to the privately owned treatment facilities throughout the state. Comparing Table 3-3 to Table 3-4 reveals that the total influent phosphorus load to POTWs is approximately 500 times higher than the influent load to privately owned treatment facilities throughout the state.

The human waste component of the influent phosphorus loading to POTWs and privately owned treatment facilities is the single largest influent source in all ten basins. The human waste component comprises between approximately 36 percent and 69 percent on a basin basis and averages approximately 42 percent statewide of the total influent phosphorus loading.

Next to human wastes, a variety of industrial and commercial dischargers constitute the next highest contribution of phosphorus in influent to POTW wastewater. The commercial and industrial dischargers comprised between 5 percent and 35 percent, on a basin basis, and approximately 27 percent of the total phosphorus loads entering POTWs, statewide. The POTWs in the Minnesota River basin receive an average of 35 percent of the influent phosphorus load from commercial and industrial process wastewater sources. This is the only basin in which the commercial and industrial process wastewater contribution approaches the human waste contribution.

Figure 3-4A Average Influent Phosphorus Loading to POTWs & Privately Owned Treatment Facilities by Basin; less than 250,000 kg/yr

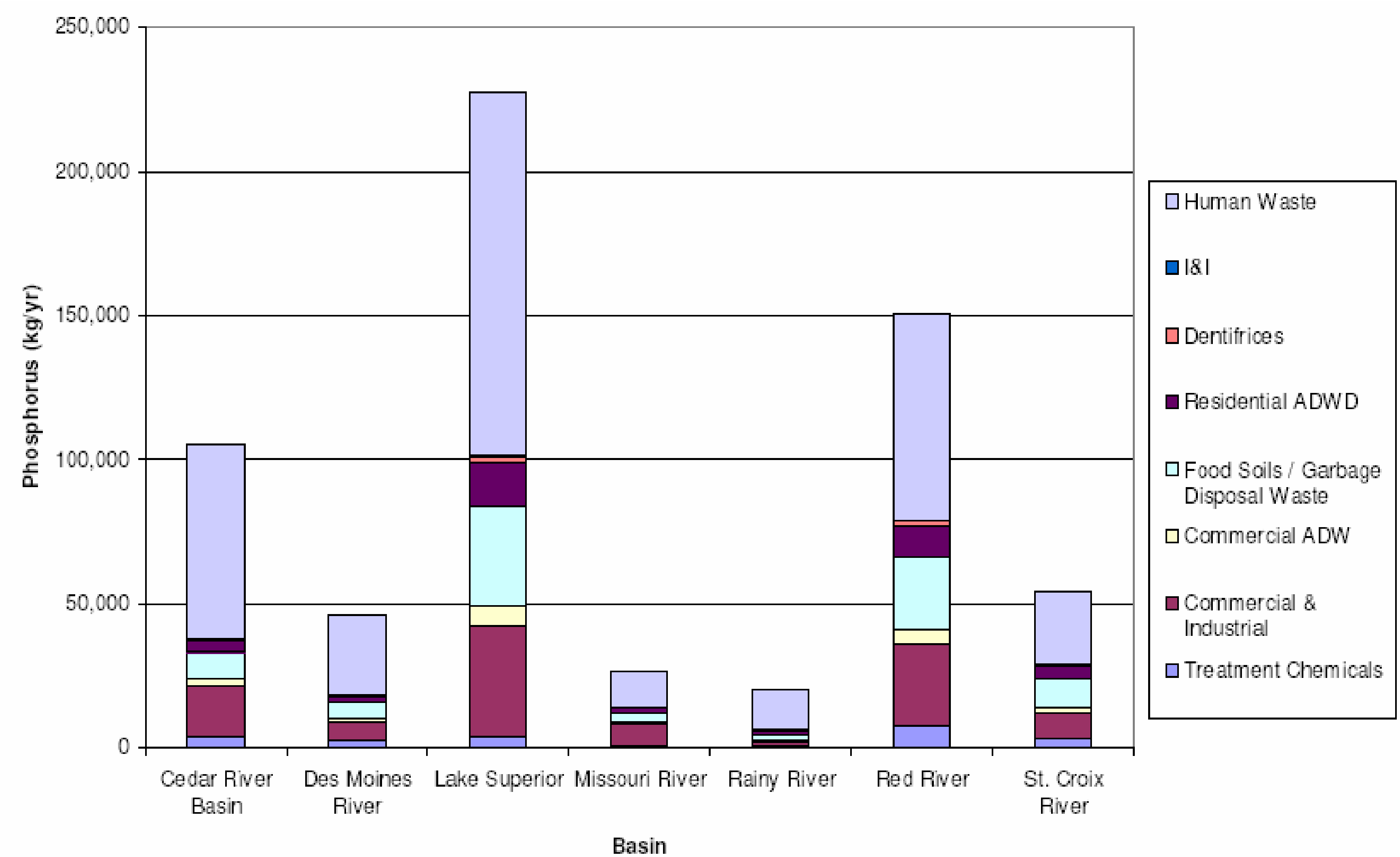

Figure 3-4B **Average Influent Phosphorus Loading to POTWs & Privately Owned Treatment Facilities by Basin; greater than 250,000 kg/yr**

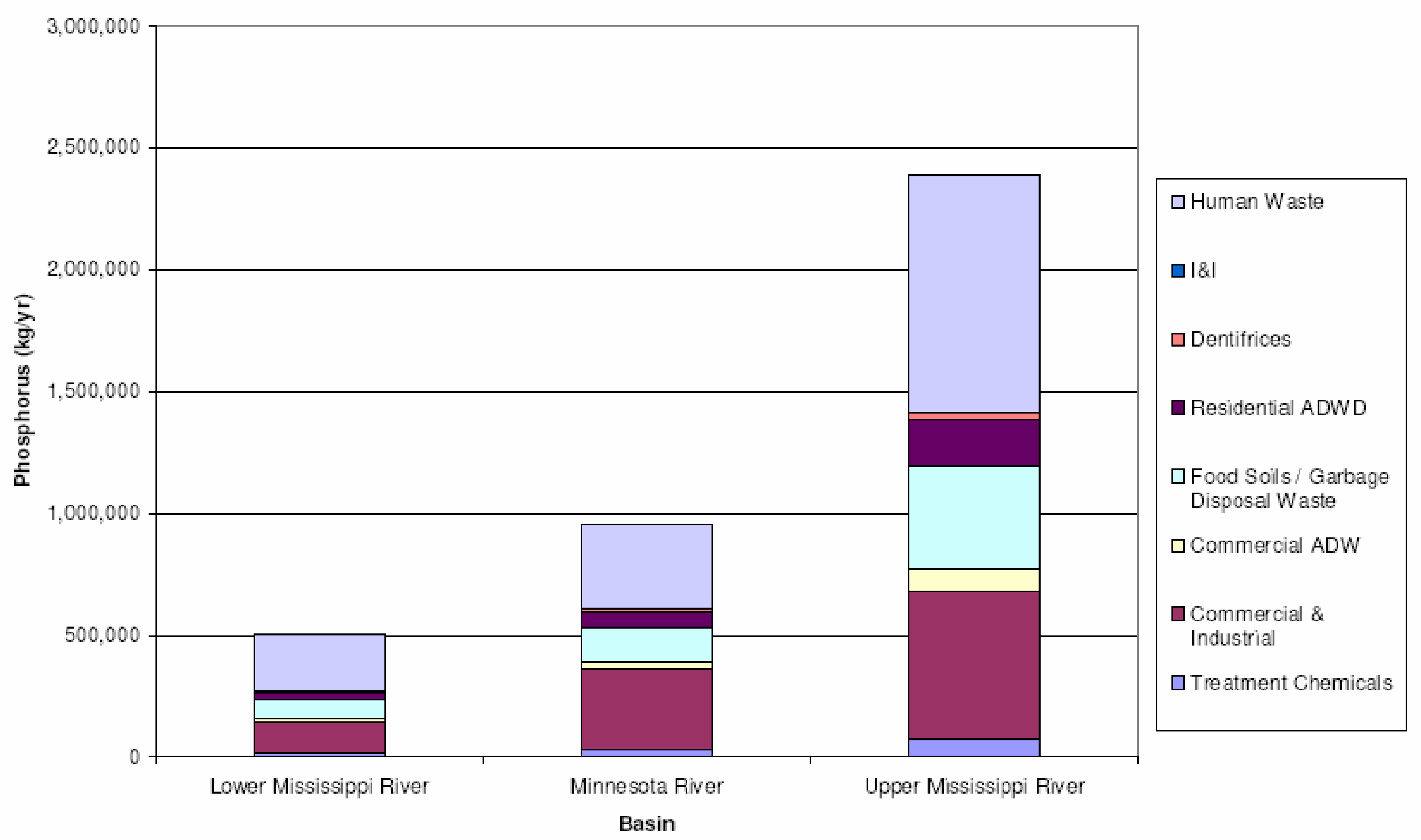

Table 3-3 Estimated Statewide Phosphorus Loadings to POTWs

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		2,986,392		66.8%
Residential Automatic Dishwasher Detergents	324,431		7.3%	
Food Soils / Garbage Disposal Waste	722,873		16.2%	
Dentifrices	43,894		1.0%	
Human Waste	1,895,195		42.4%	
Commercial & Industrial Process Wastewater		1,186,229		26.5%
Commercial & Institutional Automatic Dishwasher Detergent		151,815		3.4%
Water Treatment Chemicals		140,188		3.1%
Inflow & Infiltration		3,333		0.1%
Total		4,467,958		100.0%
EFFLUENT				
Total		1,735,869		100.0%

Table 3-4 Estimated Statewide Phosphorus Loadings to Private WWTP

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		7,804		97.6%
Residential Automatic Dishwasher Detergents	855		10.7%	
Food Soils / Garbage Disposal Waste	2,019		25.2%	
Dentifrices	118		1.5%	
Human Waste	4,813		60.2%	
Water Treatment Chemicals		193		2.4%
Total		7,997		100.0%
EFFLUENT				
Total		3,456		100.0%

The commercial and industrial process wastewater dischargers to POTWs were grouped by four digit NAICS code for each of the basins. The industries that contributed less than 1 percent of the industrial/commercial process wastewater phosphorus load were grouped in the "Other" category. The data suggests that food product processing is the largest contributor of commercial/industrial phosphorus discharged to POTWs. Animal slaughtering and processing (NAICS #3116) was the largest phosphorus contributor, estimated to discharge 168,000 kg/yr. Fruit and vegetable preserving and specialty food manufacturing (NAICS #3114) contributes 132,000 kg/yr, followed by grain and oilseed manufacturing (NAICS #3112) and dairy product manufacturing (NAICS # 3115), at 127,000 kg/yr and 45,000 kg/yr, respectively.

The information obtained regarding food soils and garbage disposal wastes suggests that this source category contributes a moderate amount of phosphorus to untreated wastewater. For the ten Minnesota basins, these amounts range from 8.8 percent to 18.4 percent and averages approximately 16 percent statewide of influent phosphorus totals. The total phosphorus load to POTWs and privately owned treatment facilities from food soils and garbage disposal wastes was estimated to be 725,000 kg/yr.

The residential use of ADWD detergents contributes a relatively smaller amount of phosphorus. For the Minnesota basins, these amounts range from 4.0 to 8.2 percent, and averaged 7.3 percent statewide, of influent total phosphorus discharging into POTWs and privately owned treatment facilities.

Dentifrices contribute a relatively small amount of phosphorus to the influent wastewater stream for each of the basins. These amounts range from 0.5 percent to 1.1 percent (1.0 percent statewide average) of the total influent phosphorus discharged into POTWs and privately owned treatment facilities.

The commercial and institutional use of ADWD detergents contributes a relatively small amount of phosphorus to untreated wastewater. For the ten Minnesota basins, these amounts ranged from 1.9 percent to 3.7 percent, while it was 3.4 percent of all sources for the statewide total influent phosphorus.

A variety of phosphorus-based chemicals are added to municipal water supplies to inhibit and control scale and corrosion, soften water and control pH. The municipal water treatment chemicals phosphorus contribution to POTWs ranged from 1.7 percent to 5.7 percent in each of the basins, and 3.1 percent statewide, of the total influent phosphorus.

The results of this study indicate that inflow and infiltration contribute a negligible amount of phosphorus to POTW influent. The inflow and infiltration contribution was approximately 0.1 percent of the total influent phosphorus load discharged into POTWs.

Subtracting the human waste component from the total POTW phosphorus influent yields the estimated total non-ingested phosphorus load discharged to POTWs. Table 3-5 presents the non-ingested phosphorus loadings to POTWs, by source category, for each basin and throughout the state. The total non-ingested phosphorus load to POTWs is approximately 2,572,900 kg/yr, which is approximately 58 percent of the total influent phosphorus load to POTWs. Commercial and industrial process wastewater represents approximately 46 percent of the total non-ingested phosphorus load. At 28 percent, food soils represent the next largest category of non-ingested phosphorus loading to POTWs. The combined residential ADWD detergent and commercial and institutional ADWD detergent categories represent approximately 18.5 percent of the non-ingested phosphorus loading to POTWs.

3.2.1.2 Phosphorus Loading to Surface Waters

The point source effluent phosphorus loads to each of the ten Minnesota basins and the state were computed using the methods described in Section 2.2.1.3. The estimated point source phosphorus loads to each of the ten Minnesota basins, along with the corresponding flow weighted mean concentrations on an average annual basis, are presented in Table 3-6. The estimated annual phosphorus load to waters of the state is 2,124,000 kg/yr, with a flow weighted mean effluent concentration of 0.6 mg/L. Fifty-six percent of the total point source effluent phosphorus load for the state is being discharged in the Upper Mississippi River basin. Table 3-6 also shows that the flow-weighted mean effluent phosphorus concentrations vary between 0.04 and 5.4 mg/L for the basins.

Table 3-5 Non-Ingested Phosphorus Loadings to POTWs

	Residential ADWD (kg/yr)	Food Soils / Garbage Disposal Waste (kg/yr)	Dentifrices (kg/yr)	Commercial and Industrial Process Wastewater (kg/yr)	Commercial and Institutional ADWD (kg/yr)	Water Treatment Chemicals (kg/yr)	Inflow and Infiltration (kg/yr)	Total (kg/yr)
Basin								
Cedar River	4,200	9,300	600	18,000	2,000	3,800	70	38,000
Des Moines River	2,400	5,300	300	6,600	1,100	2,600	30	18,300
Lake Superior	15,400	34,300	2,100	38,200	7,200	3,900	310	101,400
Lower Mississippi River	32,000	71,452	4,300	132,900	15,000	13,900	320	269,900
Minnesota River	63,100	140,700	8,500	333,200	29,500	31,500	610	607,100
Missouri River	1,400	3,200	200	7,500	700	1,000	20	14,000
Rainy River	1,300	2,500	200	1,000	600	700	20	6,300
Red River	11,200	24,900	1,500	28,000	5,200	7,800	120	78,700
St. Croix River	4,300	9,600	600	8,800	2,000	3,100	50	28,500
Upper Mississippi River	189,200	421,700	25,600	612,000	88,600	71,800	1,790	1,410,700
Total	324,500	723,000	43,900	1,186,200	151,900	140,100	3,300	2,572,900
Percent of Non-Ingested Phosphorus Load to POTWs	12.6%	28.1%	1.7%	46.1%	5.9%	5.4%	0.1%	

Table 3-6 Total Point Source Phosphorus Loads to Surface Waters for Each Basin and the State

Basin	Point Source Effluent Phosphorus Load (kg/yr)	Flow Weighted Mean Effluent Phosphorus Concentration (mg/L)
Cedar River	56,800	2.5
Des Moines River	55,500	5.4
Lake Superior	34,800	0.04
Lower Mississippi River	267,400	0.5
Minnesota River	371,700	0.6
Missouri River	13,200	3.3
Rainy River	44,300	0.6
Red River	78,100	0.8
St. Croix River	22,100	1.3
Upper Mississippi River*	1,180,100	0.9
State Total	2,124,000	0.6

Table 3-7 summarizes the estimated point source phosphorus loads for the three categories of treatment facilities; POTWs, privately owned wastewater treatment systems for domestic sources, and industrial wastewater treatment systems for each basin and the state. POTWs discharge an estimated 1,735,800 kg/yr of phosphorus or approximately 82 percent of the total point source phosphorus load statewide. In the Rainy River and Des Moines River basins, POTWs accounted for only an estimated 9.3 percent and 27 percent of the respective total point source phosphorus loading to each basin. Whereas, POTWs in the Lake Superior, St. Croix River, Missouri River, Upper Mississippi River, and Cedar River Basins accounted for between 91 and 99 percent of the total point source phosphorus loads.

Table 3-7 Point Source Phosphorus Loads by Facility Type

Basin	Publicly Owned Treatment Works (kg/yr)	POTW Flow Weighted Mean Effluent Phosphorus Concentration (mg/L)	Private WWT Systems for Domestic Use (kg/yr)	Private WWT Systems Flow Weighted Mean Effluent Phosphorus Concentration (mg/L)	Commercial and Industrial WWT Systems (kg/yr)	Commercial and Industrial Flow Weighted Mean Effluent Phosphorus Concentration (mg/L)
Cedar River	56,400	3.95	0	NA	390	0.25
Des Moines River	15,100	2.04	0	NA	40,440	10.61
Lake Superior	31,800	0.48	40	0.41	2,970	0.004
Lower Mississippi River	184,000	2.71	270	2.50	83,120	0.34
Minnesota River	237,800	1.84	840	3.73	133,060	0.30
Missouri River	12,400	3.49	20	1.18	750	2.03
Rainy River	4,100	1.06	10	1.06	40,160	0.57
Red River	64,300	2.62	30	3.00	13,810	0.37
St. Croix River	20,400	2.04	300	1.95	1,360	0.21
Upper Mississippi River	1,109,500	2.94	1,960	3.50	68,650	0.35
State Total	1,735,800	2.47	3,470	2.96	384,710	0.29

NA - Not Applicable

The data used for this study is from the years 2001, 2002 and the first half of 2003. During that time period some POTWs have implemented phosphorus removal and others will begin to implement removal in the future. The largest impact is probably phosphorus removal at the MCES' Metro plant, which is required to implement phosphorus removal to meet a 1 mg/L permit limit, which becomes effective December 31, 2005. MCES intends to be meeting the 1 mg/L limit during 2004 (as an annual average), since treatment facilities improvements have been completed. The Metro plant discharges to the Upper Mississippi River basin and had an average phosphorus effluent concentration for the study period of 3.0 mg/L at an average annual phosphorus load to the basin of approximately 870,000 kg/y. A reduction in the phosphorus concentration to 1 mg/L would result in a reduction of an estimated 581,044 kg of phosphorus per year. Because this one facility accounts for approximately 74 percent of the phosphorus load to the Upper Mississippi River basin and an estimated 40 percent statewide, phosphorus removal at this one facility will have a significant impact on the relative phosphorus loads in this basin and the state. Additional but smaller load reductions should be expected as more phosphorus effluent limits are implemented.

The phosphorus removal efficiency in POTWs and privately owned treatment facilities was estimated based on the estimated influent and effluent loads. Table 3-8 shows that the estimated average phosphorus removal is 61 percent in POTWs, and 57 percent for the private facilities, throughout the state. The phosphorus removal efficiencies for all of the POTWs in each basin range from 46 to 86 percent, while the efficiencies for private facilities in each basin are between 47 and 92 percent. By state rule all NPDES permitted discharges in the Lake Superior basin have 1 mg/L effluent limits.

Table 3-8 Phosphorus Removal in POTWs and Privately Owned Treatment Facilities

	POTW			Private		
Basin	Influent Load	Effluent Load	Percent Removal	Influent Load	Effluent Load	Percent Removal
	(kg/yr)	(kg/yr)	(%)	(kg/yr)	(kg/yr)	(%)
Cedar River Basin	105,200	56,400	46%	0	0	
Des Moines River	46,200	15,100	67%	0	0	
Lake Superior	227,000	31,800	86%	500	40	92%
Lower Mississippi River	501,900	184,000	63%	800	300	63%
Minnesota River	952,200	237,800	75%	1,500	800	47%
Missouri River	26,400	12,400	53%	100	20	80%
Rainy River	20,100	4,100	80%	30	10	67%
Red River	150,600	64,300	57%	0	0	
St. Croix River	53,500	20,400	62%	800	300	63%
Upper Mississippi River	2,384,900	1,109,500	53%	4,300	2,000	53%
State-wide	**4,468,000**	**1,735,800**	**61%**	**8,030**	**3,470**	**57%**

The estimated point source effluent phosphorus load to each basin was categorized by POTW size and category, for each of the influent phosphorus source components. The number of facilities is given in parentheses for each of the following sizes and categories:

1. Size (based on Average Wet Weather Design flow)
    a. Small – less than 0.2 mgd (316 facilities)
    b. Medium – from 0.2 mgd to 1.0 mgd (149 facilities)
    c. Large – greater than 1.0 mgd (68 facilities)

2. Waste Treated (% by flow volume treated)
    a. POTWs that serve mainly households and residences - less than 20 % industrial or commercial contributions (128 facilities)
    b. POTWs that have some commercial or industrial contribution – between 20% and 50% industrial or commercial contributions (207 facilities)
    c. POTWs that are dominated by a variety of commercial and industrial contributions – greater than 50% industrial or commercial contributions (198 facilities)

Approximately 88 percent of the phosphorus load discharged statewide from POTWs is from large POTWs (i.e., >1.0 mgd), while 8.5 percent of the point source phosphorus load is from POTWs categorized as medium (i.e., 0.2 to 1.0 mgd) and only 3.5 percent is from small POTWs (i.e., <0.2 mgd). Within the large category, POTWs that have some commercial or industrial contribution (between 20% and 50% industrial or commercial contributions) contribute the majority (72 percent) of the phosphorus load from this category to the basins. The following size categories of POTWs were ranked from high to low, based on their phosphorus load discharged statewide:

1. Large POTWs that have some commercial or industrial contribution – between 20% and 50% industrial or commercial contributions (1,100,000 kg/yr)
2. Large POTWs that are dominated by a variety of commercial and industrial contributions – greater than 50% industrial or commercial contributions (347,000 kg/yr)
3. Large POTWs that serve mainly households and residences - less than 20 % industrial or commercial contributions (83,000 kg/yr)
4. Medium POTWs that are dominated by a variety of commercial and industrial contributions – greater than 50% industrial or commercial contributions (68,000 kg/yr)
5. Medium POTWs that have some commercial or industrial contribution – between 20% and 50% industrial or commercial contributions (65,000 kg/yr)
6. Small POTWs that are dominated by a variety of commercial and industrial contributions – greater than 50% industrial or commercial contributions (23,000 kg/yr)
7. Small POTWs that have some commercial or industrial contribution – between 20% and 50% industrial or commercial contributions (22,000 kg/yr)
8. Small POTWs that serve mainly households and residences - less than 20 % industrial or commercial contributions (14,000 kg/yr)
9. Medium POTWs that serve mainly households and residences - less than 20 % industrial or commercial contributions (14,000 kg/yr)

Privately owned treatment facilities, for domestic use, account for less than half of a percent of the total point source phosphorus load to Minnesota surface waters. This amounts to approximately 10,000 kg/yr of phosphorus to all surface waters in the state.

Commercial and industrial wastewater systems, discharging directly to surface waters, make up the remaining point source phosphorus percentage of approximately 18 percent. They discharge an estimated 385,000 kg/yr to Minnesota surface waters. This study did not attempt to determine each of the major commercial and industrial phosphorus contributors. Noncontact cooling water is a subcategory of point source commercial and industrial wastewater. It is estimated that noncontact cooling water contributes approximately 14,000 kg/yr, or approximately 0.7 percent, of the total phosphorus load to surface waters in the state. In eight of the ten basins, noncontact cooling water accounted for less than one-half of a percent of the total phosphorus load. In the Red River basin, it accounted for 4.5 percent (3,500 kg/yr), and in the Minnesota River basin, it accounted for approximately 1.2 percent (4,500 kg/yr), of the total phosphorus load to the basin.

For this study, it was assumed that the influent components of the POTW's and privately owned treatment facility's phosphorus loads were represented in the treatment plant effluent in the same proportions as in the influent. It is understood that that this may not be the case, that phosphorus from the various sources may not have the same treatability. However, due to the various types of treatment and their variable removal rates, it was not in the scope of this study to estimate the individual removal rates for each type of treatment system, for each source of phosphorus. The commercial and industrial wastewater contributions were separated into those facilities discharging directly to surface waters under their own NPDES permit (Commercial & Industrial Wastewater Systems) and those discharging their wastewater to a POTW for treatment (described in Section 3.3.1.1 as Commercial and Industrial Process Wastewater).

3.2.2 Agricultural Runoff

3.2.2.1 Cropland and Pasture Runoff

As discussed in Section 2.2.2.1.1, phosphorus index values were calculated and compared with field data on phosphorus loss from four sites over five years to estimate phosphorus export conditions for each flow condition, by basin and for the entire state. The following discussion presents the results of the scenarios completed for this analysis to evaluate the impacts of rainfall/runoff conditions, crop residue cover and management practices on the estimated phosphorus risk indices:

- Average Hydrologic Runoff Volume, Average Rainfall Runoff Erosivity, Poor Crop Residue Cover Management Conditions—This scenario was based on long-term average stream flows, average rainfall erosivity, and no crop residue cover due to moldboard plow tillage methods. It is a worst case scenario for tillage methods, but the effects of supporting conservation practices such as contour strip cropping, terracing, and filter strips are here considered. From a practical standpoint, most areas of Minnesota use tillage systems that leave more crop residue than assumed in this scenario, so the phosphorus risks are overestimated in this scenario. As a rough guideline to identify impaired surface waters, Birr and Mulla (2001) suggested that values of the phosphorus index should not exceed 32 in Minnesota watersheds, except in the Red River of the North Basin, where a critical level of 25 should not be exceeded. There are seventeen watersheds in south central Minnesota with a phosphorus index value greater than 32, these include the

Lower Minnesota, Winnebago, Upper Cedar, Hawk Creek-Yellow Medicine, Blue Earth, Lac Qui Parle, Cannon, Rush-Vermillion, Middle Minnesota, South Fork of the Crow, Cottonwood, and Watonwan watersheds. Watersheds such as the Le Sueur, Redwood, Chippewa, Watonwan and South Fork of the Crow also have high phosphorus index scores (ranging from 30-31). It is well known that the Minnesota River basin generates the largest phosphorus losses of any major river basin in Minnesota. Thus, it is not surprising that nine of the twelve major watersheds in the Minnesota River basin have a phosphorus index value that exceeds 30. Watersheds in the northern half of Minnesota generally have phosphorus index values less than 21.

- Average Hydrologic Runoff Volume, Average Rainfall Runoff Erosivity, Average Crop Residue Cover Management Conditions—This scenario is similar to the previous one, except that erosion and phosphorus index values are based on the average crop residue levels as reported in tillage transect surveys. Thirteen watersheds have phosphorus index values that exceed 32, including the Lower Minnesota, Blue Earth, Shell-Rock, Cannon, Rush-Vermillion, Middle Minnesota, South Fork of the Crow, and Watonwan watersheds. These are primarily in the Minnesota River basin and Lower Mississippi River basin. Not as many watersheds have phosphorus index values exceeding 32 in this scenario as in the previous scenario, due to greater crop residue cover in this scenario.

- Average Hydrologic Runoff Volume, Average Rainfall Runoff Erosivity, Best Crop Residue Cover Management Conditions—This scenario was the same as the previous scenario, except that we assumed that conservation tillage leaving 50% of the soil covered by crop residue was practiced on row cropland. From a practical standpoint, most areas of Minnesota use tillage systems that leave less crop residue than assumed in this scenario, so the phosphorus risks are underestimated in this scenario. In general, the increase in crop residue cover produces lower phosphorus index scores in this scenario in comparison with the previous scenario involving average residue cover. Phosphorus index values exceed a score of 32 with this scenario for the Lower Minnesota, Winnebago, Cannon, Rush-Vermillion, and La Crosse-Pine watersheds. Then next highest scores occur primarily in the Minnesota River basin and in southeastern Minnesota, including the Coon-Yellow, Buffalo-Whitewater, Shell-Rock, Root, Hawk Creek-Yellow Medicine, Zumbro, Blue Earth, and Lac Qui Parle watersheds. Most of the northern half of Minnesota shows low risks for phosphorus transport in this scenario.

- Dry Hydrologic Runoff Volume, Dry Rainfall Runoff Erosivity, Best Crop Residue Cover Management Conditions, Cropland Contributing Corridor Based on Perennial Streams and

Ditches—In this scenario, the hydrologic runoff and rainfall runoff erosivity values were typical of dry years. Crop residue cover was based on widespread adoption of conservation tillage. One caveat is that the percent of cropland within 91.4 m of perennial streams and ditches may be unrealistic for this scenario. In dry years the cropland that contributes eroded sediment and runoff to surface waters may be considerably less in area than the cropland that contributes in average years. Thus, the phosphorus index values in this scenario may be overestimated. Phosphorus index values for this scenario are always smaller than those for the scenario based on an average climatic year. The maximum phosphorus index value for watersheds in the dry year scenario is about 29, whereas the maximum value for an average year is about 41. No watersheds exceed the critical phosphorus index value of 32 in this scenario, and none are in the next highest category ranging from 31 to 34 either. Only one watershed, the Lower Minnesota watershed has a phosphorus index score between 27 and 30. Only a handful of watersheds have phosphorus index scores ranging from 22-26, while a majority have scores below 21.

- Dry Hydrologic Runoff Volume, Dry Rainfall Runoff Erosivity, Best Crop Residue Cover Management Conditions, Cropland Contributing Corridor Based on Perennial Streams Only—This scenario is the same as the previous, except that the cropland contributing corridor is reduced in area by assuming that only croplands near perennial streams contribute to phosphorus losses in dry years. This is reasonable, since most ditches flow only sporadically during dry years. No watersheds or agroecoregions have phosphorus index values that exceed 25 or 27, respectively, in this scenario. Only two small watersheds have phosphorus index scores greater than 21, the La Crosse-Pine and Rush-Vermillion watersheds of southeastern Minnesota. This scenario is probably a more accurate representation of the risks of phosphorus transport to surface waters in dry years than the scenario that was based on a contributing corridor around both perennial streams and ditches.

- Wet Hydrologic Runoff Volume, Wet Rainfall Runoff Erosivity, Best Crop Residue Cover Management Conditions, Cropland Contributing Corridor Based on Perennial Streams and Ditches—This scenario indicates the risk of phosphorus transport to surface waters from agricultural land during wet years. It is based on runoff volumes and rainfall runoff erosivity values for wet years, on widespread adoption of conservation tillage, and on a cropland contributing corridor 91.4 m wide around perennial streams and ditches. Comparing this scenario with that for an average climatic year, it is evident that the risks of phosphorus loss have increased by a large amount (phosphorus index scores as high as 43) in a significant number of watersheds and agroecoregions. In the wet year scenario there are 24 watersheds with a phosphorus index score exceeding 32, whereas there were only 5 in the average year scenario. The watersheds exceeding the critical score in wet years are spread across south central and central Minnesota, as well as the Red River of the North basin. It is interesting to note that many of the watersheds in southeastern Minnesota are still below this critical threshold in wet years. This is primarily because of their relatively smaller percent area of cropland within 91.4 m of perennial streams and ditches. As will be shown in the next scenario, if the effects of intermittent streams are considered, the risk of phosphorus transport is considerably increased in southeastern Minnesota.

- Wet Hydrologic Runoff Volume, Wet Rainfall Runoff Erosivity, Best Crop Residue Cover Management Conditions, Cropland Contributing Corridor Based on All Streams and Ditches—This scenario differs from the previous one in that the effects on phosphorus transport of cropland near intermittent streams, which flow during wet years, was considered. The risks of phosphorus transport to surface waters are considerably increased all across Minnesota in comparison to the scenario for wet years which does not consider intermittent streams. Most of the southern two thirds of Minnesota watersheds and agroecoregions exceed the critical phosphorus index score of 32 in this scenario. Only the watersheds and agroecoregions in the far northeastern portion of Minnesota are relatively unaffected by including the effects of intermittent streams on phosphorus transport. This scenario is probably a more accurate representation of the risks of phosphorus transport to surface waters in wet years than the scenario based on a contributing corridor around only perennial streams and ditches.

- Average Hydrologic Runoff Volume, Average Rainfall Runoff Erosivity, Average Crop Residue Cover Management Conditions, Reduced Phosphorus Fertilizer, Cropland Contributing Corridor Around Perennial Streams and Ditches—This scenario illustrates the reductions in risk of phosphorus transport to surface waters (based on a contributing corridor around perennial streams and ditches only) due to reductions in rate of application of phosphorus fertilizer. These reductions were only made in watersheds or agroecoregions that had both high soil test phosphorus levels and high rates of phosphorus fertilizer application. More specifically the reductions were made where STP was greater than 32 ppm and fertilizer P application rates exceeded 27 kg/ha or where STP was greater than 39 ppm regardless of fertilizer P application rates. In both these cases, the rate of phosphorus fertilizer application was reduced to 5 kg/ha. These reductions reduce the risk of phosphorus transport in about one third of watersheds and agroecoregions, namely those units where the soil is generally capable of supplying P for crop production with little or no phosphorus fertilizer application. The phosphorus index values in the

Middle Minnesota, Cottonwood, Lower Minnesota, Rush-Vermillion and Cannon watersheds are reduced significantly in this scenario in comparison to their phosphorus index values for the scenario (scores decrease from generally above 32 to generally below 27), thus bringing them below the critical threshold. Large reductions in phosphorus index values also occur in the Le Sueur watershed.

- Average Hydrologic Runoff Volume, Average Rainfall Runoff Erosivity, Average Crop Residue Cover Management Conditions, Variable Manure Application Method—This scenario involves consideration of the variations in manure application method arising from differences in animal species and manure storage facilities. The baseline scenario assumes that manure is applied and incorporated immediately just before planting a crop. This is most likely an overly optimistic scenario for most manure applications in the state. The phosphorus index values are more realistic for Minnesota watersheds and agroecoregions based on consideration of differences across regions in manure application methods. Phosphorus index scores increase in this scenario relative to the baseline scenario that assumes relatively good methods of manure application. The increases are particularly noteworthy in northern Minnesota, where beef cattle operations are relatively abundant relative to other types of animal production. Beef cattle operations tend to be small, and many lack adequate manure storage facilities. This results in frequent hauling and land application of manure, generally without incorporation, including application of manure during the winter to frozen or snow covered cropland. Small increases in phosphorus index scores also occur in portions of the Red River of the North basin, in areas with relatively abundant beef cattle. These small increases bring the phosphorus index scores close to the critical threshold value of 25 in that region. Phosphorus index scores are relatively unaffected in southern Minnesota in regions where hog production dominates, because hog producers tend to have adequate manure storage and inject their manure rather than spreading it on the soil surface where it is very susceptible to losses by erosion and runoff.

Agricultural phosphorus export coefficients show considerable variation across basins and across climatic conditions (Figure 3-5). Export coefficients (kg/ha) during average climatic conditions vary from 0.54 kg/ha for the Minnesota River basin, 0.4 kg/ha for the Red River basin, 0.39 kg/ha for the Upper Mississippi River basin, and 0.66 kg/ha for the Lower Mississippi River basin. During wet years, the export coefficients are increased to 0.81 kg/ha for the Minnesota River, to 0.54 kg/ha for the Red River, to 0.69 kg/ha for the Upper Mississippi River, and to 0.80 kg/ha for the Lower Mississippi River basin. The export coefficients decrease during dry years to 0.28, 0.13, 0.22, and

0.36 kg/ha for the Minnesota, Red, Upper Mississippi, and Lower Mississippi River basins, respectively.

Phosphorus export coefficients for river basins with relatively sparse agricultural cropland are smaller than the coefficients for river basins with intensive agricultural land use. For example, during average climatic years, the phosphorus export coefficients for the Lake Superior, Rainy, and St. Croix River basins are only 0.24, 0.23 and 0.38 kg/ha, respectively.

Phosphorus loads exported to surface waters from agricultural lands under dry, average and wet climatic conditions are shown in Table 3-9 and Figure 3-6 (based on an analysis of phosphorus index values and export coefficients for major watersheds). Under average climatic conditions, the phosphorus loads are greatest for the Minnesota River basin (517,862 kg/yr), followed by the Red River (384,695 kg/yr), the Upper Mississippi (359,681 kg/yr) and the Lower Mississippi (232,581 kg/yr) River basins. All of the other basins have phosphorus loads that are considerably smaller than the loads in these four basins.

As expected, phosphorus loads exported from agricultural lands to surface waters are considerably greater during wet years than average years. Under wet climatic conditions, the phosphorus loads exported in the Minnesota, Red, Upper Mississippi, and Lower Mississippi River basins are 759,749, 545,247, 652,266, and 282,780 kg/yr, respectively. In dry years the phosphorus loads exported are 262,851, 131,311, 200,865, and 116,810 kg/yr, respectively, for these same basins.

Phosphorus loads from agricultural lands are much smaller for the Rainy, Lake Superior and St. Croix River basins than the basins with larger proportions of agricultural cropland (the Minnesota, Red, Upper and Lower Mississippi River basins). For example, during years with average climatic conditions, phosphorus loads exported from agricultural land to surface waters are only 13,112, 20,713, 59,931 kg/yr for the Lake Superior, Rainy and St. Croix River basins, respectively. Similar comparisons can be made for wet and dry climatic years.

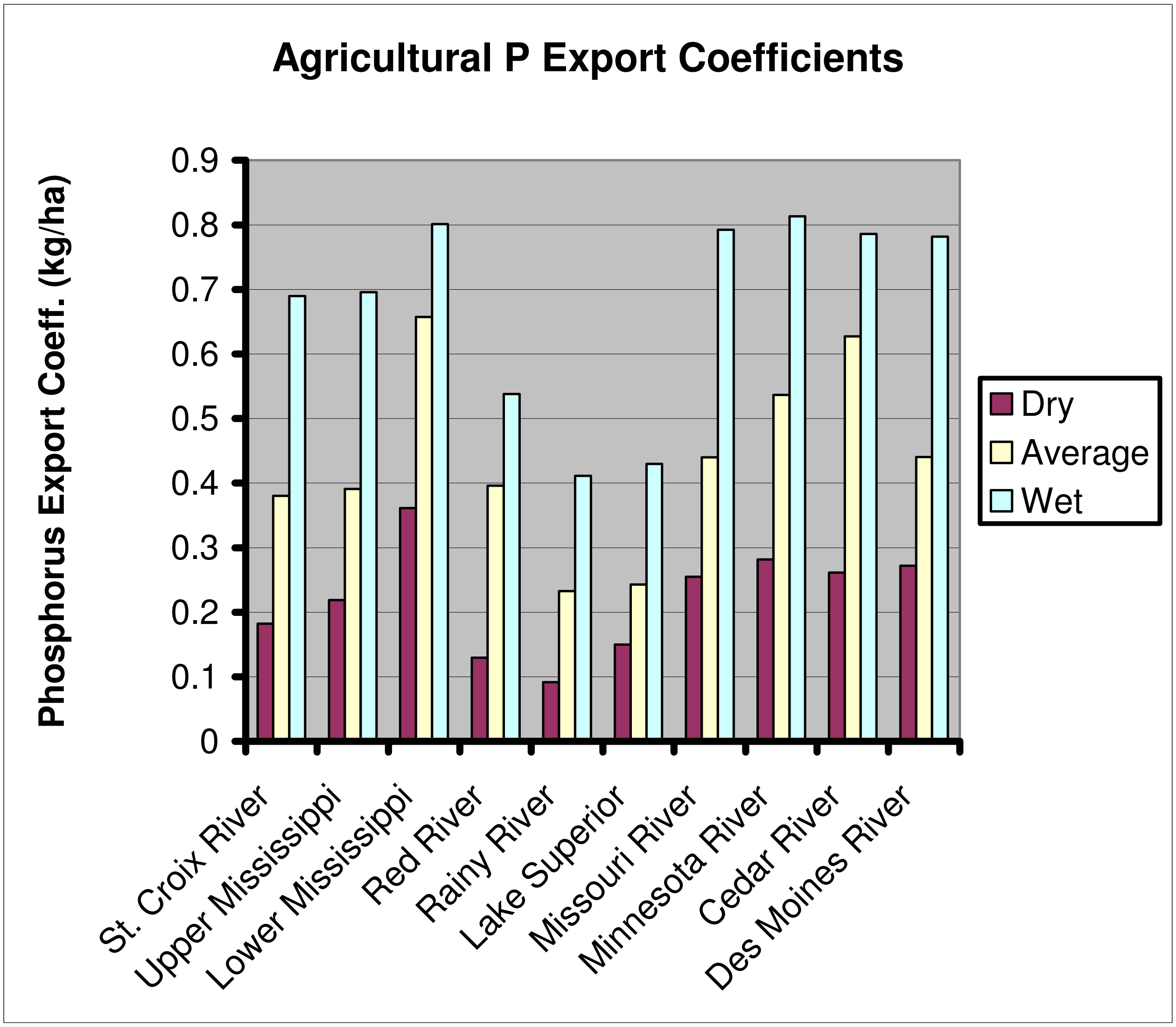

Figure 3-5 Cropland and pasture runoff P export coefficients (kg/ha) for major drainage basins in dry, average, and wet climatic years.

Export coefficients are derived from major watershed based phosphorus index values. These do not include contributions from surface tile inlets or subsurface tile drains.

Table 3-9 Phosphorus Loadings (kg/yr) to Minnesota Surface Waters from Agricultural Cropland by Major Drainage Basin Based on an Analysis of Phosphorus Index Values in Major Watersheds.

	Phosphorus Loads* Exported from Agricultural Land (kg/yr)		
Basin	Dry Year	Average Year	Wet Year
St. Croix River	27857	59931	110046
Upper Mississippi	200865	359681	652266
Lower Mississippi	116810	232581	282780
Red River	131311	384695	545247
Rainy River	8988	20713	36072
Lake Superior	7617	13112	22528
Minnesota River	262851	517862	759749
Missouri River	36055	58758	109222
Cedar River	13722	33270	42444
Des Moines River	24670	37743	73149

*These loads are computed by multiplying the phosphorus export coefficients for each major watershed by the area of cropland within the contributing corridor for the same major watershed, and then summing over all major watersheds with the river basin. An additional 11.1% load is then added to account for phosphorus contributions by overland flow from outside the contributing corridor, excluding the contributions from surface tile inlets and subsurface tile drains.

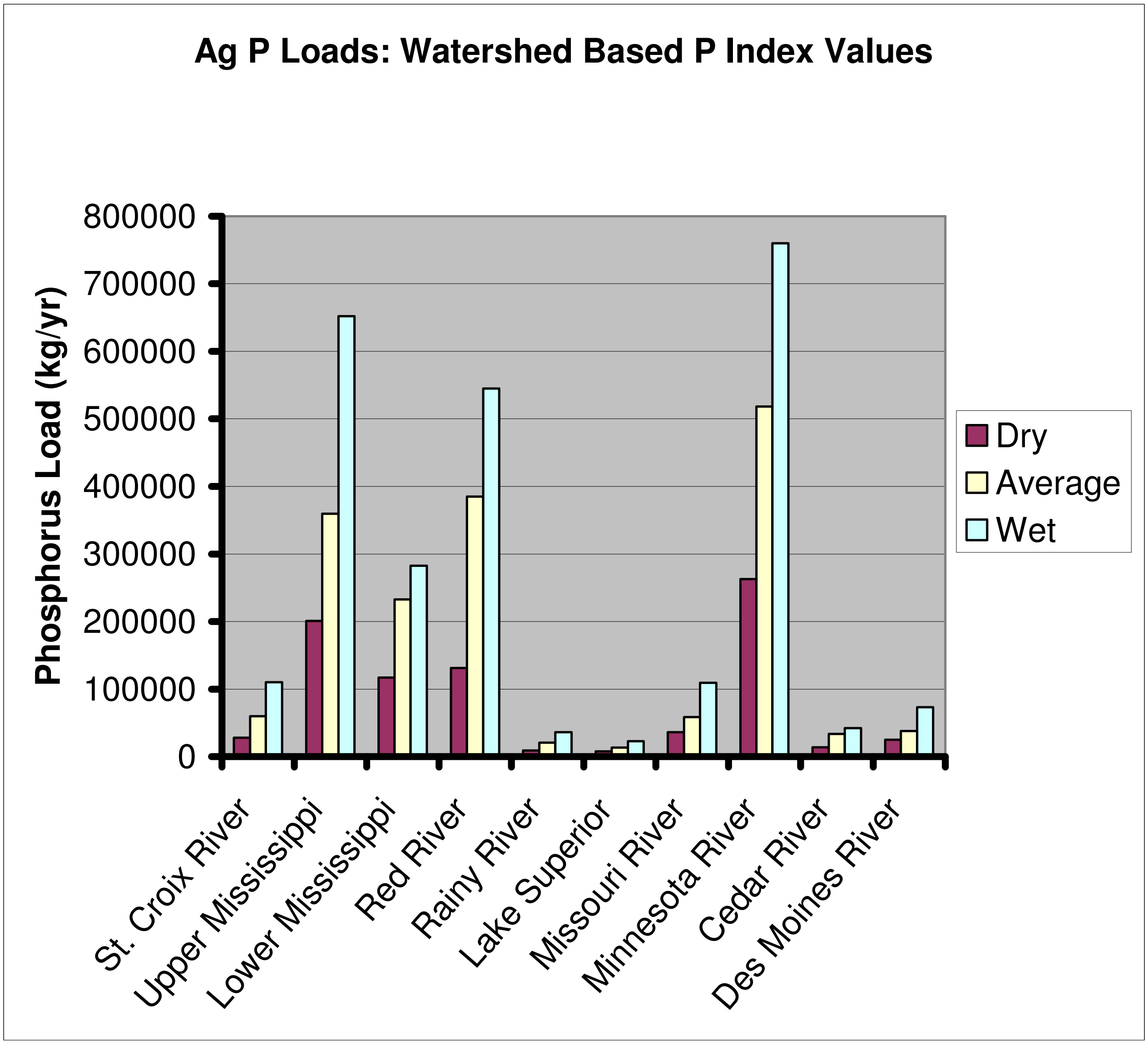

Figure 3-6 Cropland and pasture runoff phosphorus loads (kg/yr) exported to surface waters in major drainage basins of Minnesota under dry, average and wet climatic conditions

These results are based on phosphorus export coefficients derived from major watershed based phosphorus index values. These do not include contributions from surface tile inlets or subsurface tile drains.

The method of estimation used here does not consider the influence that subsurface tile drains and surface tile intakes farther than 100 m may have on phosphorus loadings. As discussed in Section 2.2.2.1.1, the total phosphorus loading from surface tile intakes to surface water bodies in the Minnesota River basin would result in 94,000 kg per year, while the phosphorus loading from subsurface tile drainage is estimated to be 30,000 kg/yr. The combined loading of 124,000 kg/yr is approximately 24 percent of the Minnesota River basin phosphorus loading from cropland within 100 m of surface waters during an average year (517,862 kg/yr). As previously discussed, not enough research data are available to reliably estimate the phosphorus loadings from surface tile intakes or subsurface tile drains to surface waters in the Minnesota River basin during dry or wet climatic years. As a first approximation, scaling the phosphorus loadings from tile drains so that they have the same relative ratio as the phosphorus index based loadings for the Minnesota River basin in dry, average and wet years (262,851; 517,862; and 759,749 kg/yr, respectively) results in estimated phosphorus loadings from subsurface tile drains of 15,227 kg/yr during dry years and 44,013 kg/yr during wet years. Using the same approach, phosphorus loadings from surface tile inlets in the Minnesota River basin during dry and wet years would be 47,711 and 137,906 kg/yr, respectively. As mentioned previously, the phosphorus loadings in dry years are expected to be overestimates.

In summary, the risk of phosphorus transport to surface waters depends on many factors. These include factors affecting soil erosion by water (conservation tillage, landscape steepness, climate), soil test phosphorus levels, rate of application of phosphorus from fertilizer or manure, and method of application of manure. Extensive databases for Minnesota watersheds and agroecoregions were developed to explore the variation in risks of phosphorus transport to surface waters in response to these factors. The results show that phosphorus losses are more sensitive to climatic variability than any other factor. The fraction of cropland near streams and ditches also has a large impact on phosphorus losses, during both wet and dry years. Watersheds and agroecoregions in Minnesota exhibit a considerable amount of variation in the risks of phosphorus loss. In general, the watersheds and agroecoregions with the greatest potential for phosphorus loss are located in the Lower Mississippi and Minnesota River basins. This is because of a combination of high rates of erosion, high rates of phosphorus application from fertilizer or manure, and a high percentage of cropland near streams and ditches. From a basin wide perspective, however, the greatest phosphorus loads are exported from agricultural lands to surface waters in the Minnesota River basin, followed by the Red River, Upper Mississippi, and Lower Mississippi River basins. Basins with relatively small areas of agricultural land use, such as the Lake Superior, Rainy and St. Croix River basins have significantly smaller phosphorus loads exported from agricultural lands to surface waters than basins with significant amounts of agricultural land use. Analysis shows that farmers have made progress in controlling phosphorus losses from agricultural cropland over the last twenty years or more due to accelerated adoption of conservation tillage. Additional progress can be made through continued adoption of best management practices, including reductions in the amount of phosphorus fertilizer applied to cropland when soil phosphorus levels are sufficient for crop production. Improved methods of manure application are also important in northern drainage basins for reductions in phosphorus loads to surface waters. Land retirement programs can be effective at reducing phosphorus loads to surface waters if cropland near surface waters is targeted for retirement.

3.2.2.2 Feedlot Runoff

The results of each of the four steps (discussed in Section 2.2.2.1.2) taken to estimate the phosphorus loadings from noncompliant open feedlots are presented in Table 3-10, along with 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. Table 3-10 shows 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 combined 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 3-10 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 (further described in Appendix D), the feedlot runoff loading results could be significantly higher or lower in some basins than the results show. It should be noted that even though feedlots are a small fraction of total P loading from a basin-wide perspective, some feedlots have been shown to contribute relatively high percentages of P loading to individual lakes and localized water resources.

Table 3-10 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	911	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**

3.2.3 Atmospheric Deposition

As identified in Table 3-11, the estimate of atmospheric phosphorus deposition for each basin is based on the area identified as "water" or "wetland" in the GIS database. Estimates of average wet phosphorus deposition (average precipitation) range from ~ 0.069 kg ha^{-1} yr^{-1} in the Rainy River to 0.212 kg ha^{-1} yr^{-1} in the Cedar River basin (see Table 3-11). When factoring in dry/wet years, Table 3-11 shows that the range in potential wet phosphorus deposition is from approximately 0.059 kg ha^{-1} yr^{-1} in the Rainy River basin (dry year) to 0.273 kg ha^{-1} yr^{-1} in the Cedar River basin (wet year). The estimates of average phosphorus wet deposition (average precipitation) for the respective basins, ranges from approximately 2,100 kg/yr for the Cedar River to approximately 155,850 kg/yr for the Upper Mississippi.

Estimates of average dry phosphorus deposition (assuming average precipitation year) range from approximately 0.028 kg ha^{-1} yr^{-1} in the St. Croix River basin to approximately 0.241 kg ha^{-1} yr^{-1} in the Cedar River basin (Table 3-11). Estimates of average "total" (wet + dry) phosphorus deposition range from ~ 0.102 kg ha^{-1} yr^{-1} in the Rainy River basin (dry year) to 0.513 kg ha^{-1} yr^{-1} in the Cedar River basin (wet year) (Table 3-11). The largest phosphorus loading of approximately 299,044 kg/yr is found in the Upper Mississippi basin. As noted in Table 3-11, dry deposition could only be estimated for an "average" year due to the lack of available data for estimating deposition during a wet or dry year. Therefore, total (wet + dry) estimates for the dry, average, and wet years for each basin in Table 3-11 use the same dry deposition value, which adds some uncertainty to the deposition estimates (further discussed in Appendix E).

Table 3-11 Estimated Total Phosphorus Deposition to Minnesota Basins

Basin	Low Precipitation Phosphorus Deposition [1] (kg ha^{-1} yr^{-1})	Average Precipitation Phosphorus Deposition [1] (kg ha^{-1} yr^{-1})	High Precipitation Phosphorus Deposition [1] (kg ha^{-1} yr^{-1})	Dry Phosphorus Deposition [2] (kg ha^{-1} yr^{-1})	Dry Year Total (wet+dry) Phosphorus Deposition [3a] (kg ha^{-1} yr^{-1})	Average Year Total (wet+dry) Phosphorus Deposition [3b] (kg ha^{-1} yr^{-1})	Wet Year Total (wet+dry) Phosphorus Deposition 3[c] (kg ha^{-1} yr^{-1})	Basin Waters and Wetland Area [4] (hectares)	% of Total Basin Land Area [5]	Waters and Wetland Basin Loading Estimate: Dry Year Total (wet+dry) Phosphorus Deposition [6a] (kg/yr)	Waters and Wetland Basin Loading Estimate: Average Year Total (wet+dry) Phosphorus Deposition [6b] (kg/yr)	Waters and Wetland Basin Loading Estimate: Wet Year Total (wet+dry) Phosphorus Deposition [6c] (kg/yr)
Cedar River	0.1815	0.2118	0.2725	0.2408	0.4223	0.4526	0.5133	9,924	3.7	4,191	4,492	5,095
Des Moines River	0.1452	0.1848	0.2428	0.0686	0.2138	0.2534	0.3114	21,761	5.5	4,652	5,514	6,777
Lake Superior	0.0765	0.0873	0.1053	0.0447	0.1212	0.1320	0.1501	531,000	33.3	64,382	70,118	79,677
Minnesota River	0.1458	0.1854	0.2296	0.0761	0.2219	0.2615	0.3057	300,462	7.8	66,672	78,567	91,850
Mississippi, Lower [7]	0.1253	0.1545	0.1847	0.0925	0.2177	0.2470	0.2771	82,740	5.1	18,016	20,435	22,930
Mississippi, Upper [8]	0.0809	0.1006	0.1228	0.0703	0.1512	0.1709	0.1931	1,548,735	29.7	234,154	264,658	299,044
Missouri River	0.1392	0.1795	0.2349	0.0686	0.2079	0.2481	0.3035	12,016	2.6	2,497	2,981	3,647
Rainy River	0.0590	0.0690	0.0846	0.0431	0.1021	0.1121	0.1277	1,525,718	52.4	155,792	171,065	194,778
Red River	0.0778	0.0975	0.1209	0.1102	0.1880	0.2077	0.2311	1,092,132	23.8	205,367	226,843	252,432
St. Croix River	0.0938	0.1211	0.1488	0.0280	0.1218	0.1491	0.1768	275,251	30.1	33,518	41,032	48,655
State Wide Totals								5,399,738		789,241	885,704	1,004,885

Note:
[1] The phosphorus deposition rates from dry, average and wet precipitation volumes. Dry, average and wet year precipitation volume data based on the 1979-2002 period (using water years 10/1-9/30). The dry period is defined as the 10th percentile frequency value, the average is the 50th percentile and the wet is the 90th percentile. Derived by the MDNR (2003).
[2] Includes coarse and fine dry deposition. Calculations assumed to be for an "average" precipitation year. There is insufficient information to estimate deposition for a dry or wet year; therefore, dry deposition is only estimated for what is assumed to be an "average" year.
[3a] Total deposition = low precipitation phosphorus deposition + dry deposition
[3b] Total deposition = average precipitation deposition + dry deposition
[3c] Total deposition = high precipitation phosphorus deposition + dry deposition
[4] Basin area is that part of the basin within the state's borders designated as "Water" or "Wetland" in the GIS database. Surface water included open water, woody wetlands and emergent herbaceous wetlands as defined by the USGS National Landcover database (~1992). This is a landsat based raster data set developed by the USGS with a minimum mapping unit of 30 meters.
[5] The percentage of the total land area within a river basin that is designated as water or wetland surface water.
[6a] The total phosphorus deposition rate to the basin water or wetland surface waters. The low precipitation deposition rate + dry depositon rate was used to calculate this total.
[6b] The total phosphorus deposition rate to the basin water or wetland surface waters. The average precipitation deposition rate + dry depositon rate was used to calculate this total.
[6c] The total phosphorus deposition rate to the basin water or wetland surface waters. The high precipitation deposition rate + dry depositon rate was used to calculate this total.
[7] Lower Mississippi is that part of the Mississippi downstream of where the St.Croix River merges with the Mississippi.
[8] Upper Mississippi is that part of the Mississippi upstream of where the St.Croix River merges with the Mississippi.

3.2.4 Deicing Agents

The phosphorus loadings for each basin were computed using the deicing agents application rates and concentrations for the lane miles in each basin, as discussed in Section 2.2.2.3. Each basin calculation was completed using the application rates for the respective MnDOT Districts that encompass the basin; whenever the basin includes TCMA counties, those state highway lane miles were calculated using the higher Metro District rates for each county. Table 3-12 presents the phosphorus loading results for each of the basins under the three loading scenarios and a summary for the state-wide total phosphorus loading to surface waters from deicing agents under the same three scenarios.

Table 3-12 Major Basin and Statewide Total Phosphorus Loadings from Deicers for Each Snowfall Scenario

Basin	Snowfall Scenario	Tons of Salt	Tons of Sand	Gallons of Brine	P from Salt, kg	P from Sand, kg	P from Brine, kg	Total P, kg
St. Croix River	Dry Year	37,525	55,343	59,431	170	1893	0.03	2,063
	Avg Year	47,143	88,364	59,431	213	3022	0.03	3,236
	Wet Year	57,862	124,331	59,431	262	4252	0.03	4,514
Upper Mississippi River	Dry Year	214,976	376,477	521,969	973	12876	0.26	13,849
	Avg Year	279,640	600,253	521,969	1266	20529	0.26	21,795
	Wet Year	350,167	835,955	521,969	1585	28590	0.26	30,176
Lower Mississippi River	Dry Year	88,034	132,454	268,117	399	4530	0.13	4,929
	Avg Year	110,716	213,189	268,117	501	7291	0.13	7,793
	Wet Year	136,270	302,924	268,117	617	10360	0.13	10,977
Red River	Dry Year	112,554	240,506	135,874	510	8226	0.07	8,735
	Avg Year	156,495	374,579	135,874	708	12811	0.07	13,519
	Wet Year	204,893	546,846	135,874	928	18703	0.07	19,630
Rainy River	Dry Year	32,576	57,318	160,864	147	1960	0.08	2,108
	Avg Year	41,389	95,993	160,864	187	3283	0.08	3,470
	Wet Year	51,190	138,824	160,864	232	4748	0.08	4,980
Lake Superior	Dry Year	37,625	60,767	91,289	170	2078	0.04	2,249

Basin	Snowfall Scenario	Tons of Salt	Tons of Sand	Gallons of Brine	P from Salt, kg	P from Sand, kg	P from Brine, kg	Total P, kg
	Avg Year	47,755	98,765	91,289	216	3378	0.04	3,594
	Wet Year	59,068	140,577	91,289	267	4808	0.04	5,075
Missouri River	Dry Year	16,903	32,231	25,586	77	1102	0.01	1,179
	Avg Year	23,002	49,589	25,586	104	1696	0.01	1,800
	Wet Year	29,845	68,392	25,586	135	2339	0.01	2,474
Minnesota River	Dry Year	141,111	285,517	251,770	639	9765	0.12	10,404
	Avg Year	193,267	446,062	251,770	875	15256	0.12	16,131
	Wet Year	251,497	589,445	251,770	1138	20160	0.12	21,298
Cedar River	Dry Year	15,504	21,514	43,379	70	736	0.02	806
	Avg Year	19,503	33,493	43,379	88	1145	0.02	1,234
	Wet Year	24,042	46,803	43,379	109	1601	0.02	1,710
Des Moines River	Dry Year	13,370	27,606	18,403	61	944	0.01	1,005
	Avg Year	18,573	42,620	18,403	84	1458	0.01	1,542
	Wet Year	24,447	59,097	18,403	111	2021	0.01	2,132
Statewide Totals	Dry Year	710,178	1,289,734	1,576,683	3,215	44,110	0.77	47,326
	Avg Year	937,483	2,042,906	1,576,683	4,244	69,869	0.77	74,114
	Wet Year	1,189,280	2,853,194	1,576,683	5,384	97,582	0.77	102,966

Table 3-12 shows that the estimated phosphorus loadings associated with heavy snowfall years are approximately twice as high as the loadings associated with low snowfall years, in each basin, with the average years generally falling directly between each of the other snowfall scenarios. In descending order, the three basins experiencing the largest total phosphorus loadings to surface waters, in each snowfall scenario, are the Upper Mississippi, Minnesota and Red River basins. The Upper Mississippi River basin accounts for nearly 30% of the total phosphorus loadings, statewide.

3.2.5 Streambank Erosion

The phosphorus loadings for each basin were computed using the approach and methodology discussed in Section 2.2.2.4. Table 3-13 presents the results of the phosphorus loading computations and assessments for each flow condition, by basin and for the entire state. Table 3-14 compares the phosphorus yield associated with streambank erosion for each flow condition, by basin and the entire state. Table 3-13 shows that the estimated streambank erosion total phosphorus loadings under low flow conditions are approximately an order of magnitude lower than average flow conditions, while the streambank erosion estimates under high flow conditions are about a half an order of magnitude higher than average flow conditions.

Table 3-13 Summary of Total Phosphorus Loading Estimates (kg/yr) for Streambank Erosion

Basin	Low Flow Conditions	Average Flow Conditions	High Flow Conditions
Cedar River	140	12,200	59,600
Des Moines River	130	7,350	47,900
Lake Superior	4,730	35,100	207,000
Lower Mississippi	45,500	322,000	1,280,000
Minnesota River	9,910	200,000	900,000
Missouri River	1,440	16,100	71,600
Rainy River	0	52,700	318,000
Red River of the North	0	8,840	146,000
St. Croix River	20	15,500	98,000
Upper Mississippi	430	79,900	477,800
Statewide Totals	62,300	750,000	3,606,000

Table 3-14 Summary of Estimated Total Phosphorus Yield (kg/km^2/yr) from Streambank Erosion for Average Flow Conditions

Basin	Average Flow Conditions
Cedar River	4.6
Des Moines River	1.9
Lake Superior	2.2
Lower Mississippi	19.7
Minnesota River	5.2
Missouri River	3.5
Rainy River	1.8
Red River of the North	0.2
St. Croix River	1.7
Upper Mississippi	1.5
Statewide Totals	3.4

The relative difference between the estimated phosphorus loadings for each basin (from Table 3-14) corresponds well with the variation of observed sediment yields throughout the State, although sediment yield and streambank erosion loadings would not necessarily be expected to vary the same if other sources of phosphorus and sediment measured in the yield vary significantly. Based on the estimated yield from each basin, the Lower Mississippi River basin loadings are significantly higher than any other basin, followed by the Minnesota and Cedar River basins. This corresponds well with the portion of the State with significant loess deposits, and corresponds with the findings of other researchers (Tornes, 1986; Simon and Rinaldi, 2000; Simon et al., 2003). For each flow condition, the Lower Mississippi River basin streambank erosion estimates from Table 3-13 account for more than a third of the total loading estimated for the State. Under the low flow condition, the Lower Mississippi River basin streambank erosion estimates accounts for more than 70 percent of the total loading estimated for the State.

3.2.6 Individual Sewage Treatment Systems/Unsewered Communities

As discussed in Section 2.2.2.5, population served by Individual Sewage Treatment System (ISTS) or undersewered communities, compliance of treatment systems with performance standards, groundwater conditions, and characteristics of soil absorption field and proximity to surface waters are important factors in determining phosphorus export. The MPCA ISTS LUG spreadsheet provided estimates of the number of full time and seasonal residences served by ISTS, along with the number of failing systems and an estimate for the number of systems which are an ITPHS (Imminent Threat to Public Health and Safety). The population data used for both ISTS and undersewered communities are included in Table 3-15. Table 3-15 also shows the number of residential systems in each basin. The Upper Mississippi River basin accounts for almost one-quarter of the population served by ISTS and more than 60 percent of the unsewered areas population. The Minnesota, Lower Mississippi, Red and St. Croix River basins serve ISTS populations of between 110,000 and 160,000, while the Minnesota and St. Croix River basins have unsewered area populations between 25,000 and 33,000. The remaining basins represent small fractions of the statewide populations served by ISTS and undersewered communities.

Table 3-15 shows the percentages of failing systems and systems which discharge partially treated sewage (or are considered an ITPHS), estimated for each of the basins and the state. These estimates show that the Des Moines River basin has the highest percentage (41%) of ISTS systems considered an ITPHS, followed by the Minnesota and Missouri River basins with 29 and 22 percent, respectively. The St. Croix, Lake Superior, Rainy and Upper Mississippi River basin estimates for percentages of ISTS considered an ITPHS were all less than 8 percent. Table 3-15 shows that the Rainy River basin had the highest (43%), while the St. Croix basin had the lowest (11%), percentages of failing ISTS systems. All of the other basins had estimated percentages of failing ISTS systems between 24 and 35 percent. The high percentage for the Rainy River basin may be partially due to the presence of high water tables relative to the other basins.

Table 3-15 presents the results of the phosphorus loading computations done for the assessment of ISTS and undersewered communities. The last five columns of Table 3-15 show the estimated total phosphorus loadings to surface waters from undersewered communities, direct-to-tile ISTS, all seasonal ISTS, the remaining ISTS, and the total load in each basin (and the state) from all four source categories. On a statewide basis, Table 3-15 shows that more than half of the phosphorus load from undersewered communities/ISTS is coming from permanent ISTS, while approximately 35 percent of the total load originates from undersewered communities. Undersewered communities represent a large percentage of the total load to the St. Croix and Upper Mississippi River basins (56 and 53 percent, respectively). Undersewered communities represent less than 27 percent of the total phosphorus load for the remaining basins. Direct-to-tile ISTS represents 20, 16 and 11 percent of the total phosphorus load in the Cedar Minnesota, and Des Moines River basins, respectively; but less than 8 percent for the remaining basins. The estimated seasonal ISTS contributions are 16 and 18 percent of the total phosphorus loads in the Rainy River and Lake Superior basins, respectively, and less than 7 percent for the remaining basins. The remaining ISTS contributions (from both conforming and nonconforming systems) accounts for more than 40 percent of the total phosphorus load from ISTS/undersewered communities in all of the basins. The highest total phosphorus contribution from the remaining ISTS category is 87 percent in the Missouri River basin.

Table 3-15 Estimated Annual Phosphorus Loadings for ISTS and Unsewered Communities

											Estimated P Load Produced (kg)				Estimated P Load Discharged to Surface Waters (kg)				
Major Basin	ISTS Population by Difference	Total Residential Systems	Percent Partially Treated	Percent Failing	Unsewered Areas Population	Avg. Pop. per Household	Direct-to-Tile Systems	Direct-to-Tile Pop.	Remaining ISTS Pop.	Seasonal Pop.	Unsewered Areas	Direct-to-Tile Systems	Seasonal ISTS	Remaining ISTS	Unsewered Areas	Direct-to-Tile Systems	Seasonal ISTS	Remaining ISTS	Total
Cedar River	17,654	4,500	15.7%	34.6%	299	3.92	514	2,016	15,339	0	264	1,784	0	13,568	114	767	0	2,999	3,880
Des Moines River	6,818	5,420	41.1%	23.8%	1,028	1.28	419	536	5,254	191	909	474	56	4,647	391	204	20	1,316	1,930
Lake Superior	39,419	16,000	5.5%	35.0%	342	4.80	0	0	39,077	16,363	303	0	4,825	34,565	130	0	1,415	6,507	8,051
Lower Mississippi	143,466	31,002	10.6%	26.8%	11,272	4.75	450	2,137	130,057	1,676	9,971	1,891	494	115,041	4,287	813	141	21,707	26,949
Minnesota River	158,257	67,100	29.4%	32.8%	25,872	2.55	7,399	18,847	113,538	10,437	22,885	16,671	3,077	100,430	9,841	7,168	1,056	26,377	44,442
Missouri	16,697	5,233	22.1%	33.4%	509	3.27	227	743	15,445	281	450	658	83	13,662	194	283	27	3,275	3,778
Rainy River	33,533	23,928	7.0%	43.1%	6,216	2.02	0	0	27,317	15,395	5,498	0	4,539	24,163	2,364	0	1,431	5,056	8,851
Red River	112,474	46,447	13.1%	27.0%	8,966	2.92	0	0	103,508	16,655	7,931	0	4,911	91,558	3,410	0	1,434	18,038	22,882
St. Croix River	110,520	45,249	2.3%	11.4%	32,612	2.76	0	0	77,908	10,857	28,847	0	3,201	68,913	12,404	0	741	8,987	22,132
Upper Mississippi	453,857	227,515	7.8%	24.7%	154,696	2.32	436	1,014	298,147	67,809	136,836	897	19,993	263,725	58,839	386	5,497	46,250	110,972
TOTAL	1,092,695	472,394	11.6%	26.4%	241,812	2.69	9,445	25,294	825,589	139,665	213,894	22,373	41,180	730,271	91,974	9,621	11,762	140,510	253,867

3.2.7 Non-Agricultural Rural Runoff

As described in Section 2.2.2.6, the ecoregion-based phosphorus export rates and contributory areas for each land cover type within each basin were utilized, along with the basin runoff factors, to calculate the results of the phosphorus loadings for each basin and the state. The phosphorus loading results are shown in Table 3-16. The highest total phosphorus loadings are estimated for the Rainy River, Upper Mississippi River and Lake Superior basins, which combined, represent approximately 75 percent of the non-agricultural rural total phosphorus loadings for each flow condition. For each land cover type the estimated total phosphorus loadings for the high flow condition are typically one-and-one-half to two-and-one-half times as high as the low flow loadings for each basin, with the average flow condition loadings typically mid-way between the high and low flow condition loadings. Table 3-16 shows that deciduous forest represents approximately 45, 50 and 55 percent of the statewide non-agricultural rural total phosphorus loadings under low, average and high flow conditions, respectively. The evergreen forest and commercial/industrial/transportation land cover types each represent approximately 13 percent of the statewide non-agricultural rural total phosphorus loadings under average flow conditions with the commercial/industrial/transportation percentage being higher (19%) under low flow and lower (10%) under high flow conditions.

Table 3-16 Estimated Annual Phosphorus Loadings for Non-Agricultural Rural Land Cover Types

Basin	Hydrology Scenario	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Urban/ Recreational Grasses	Total Kg P
Cedar River	Dry Year	69.8	8.2	1263.7	2.7	0.0	291.1	0.0	1.9	0.0	0.0	28.3	1,666
	Avg Year	73.9	8.7	1338.2	2.9	0.0	510.7	0.0	3.3	0.0	0.0	30.0	1,968
	Wet Year	75.7	8.9	1369.6	2.9	0.0	914.2	0.0	5.9	0.0	0.0	30.7	2,408
Des Moines River	Dry Year	35.8	1.1	1020.1	0.0	0.0	117.5	2.7	3.0	0.1	0.0	98.3	1,279
	Avg Year	41.5	1.3	1183.0	0.0	0.1	469.9	10.6	12.0	0.4	0.0	114.0	1,833
	Wet Year	46.7	1.5	1332.3	0.0	0.3	1108.9	25.1	28.4	0.8	0.0	128.4	2,673
Lake Superior	Dry Year	178.4	93.3	4546.1	92.9	559.1	23219.3	7883.2	10799.0	264.2	177.0	181.0	47,993
	Avg Year	190.7	99.7	4859.4	99.3	887.4	36856.1	12513.1	17141.2	419.4	281.0	193.5	73,541
	Wet Year	204.1	106.7	5201.1	106.3	1198.0	49755.7	16892.7	23140.7	566.2	379.3	207.1	97,758
Lower Mississippi River	Dry Year	214.9	53.6	4496.0	16.3	1.2	4944.9	63.7	348.5	0.3	35.7	313.9	10,489
	Avg Year	238.6	59.6	4991.9	18.1	1.8	7064.2	91.1	497.8	0.4	51.0	348.6	13,363
	Wet Year	252.5	63.0	5284.0	19.2	2.7	10667.0	137.5	751.7	0.6	77.0	369.0	17,624
Minnesota River	Dry Year	539.2	61.4	5962.3	0.3	2.3	3772.9	93.5	197.0	64.2	0.0	1603.9	12,297
	Avg Year	627.1	71.4	6934.2	0.4	6.7	11096.9	274.9	579.3	188.8	0.0	1865.3	21,645
	Wet Year	695.7	79.2	7693.0	0.4	13.4	22193.8	549.9	1158.6	377.6	0.0	2069.5	34,831
Missouri River	Dry Year	39.6	0.7	1412.6	0.0	0.0	48.7	0.2	0.9	0.0	0.1	51.2	1,554
	Avg Year	46.6	0.9	1662.6	0.0	0.0	270.5	0.9	5.1	0.1	0.6	60.3	2,047
	Wet Year	53.0	1.0	1890.4	0.0	0.1	659.9	2.3	12.5	0.2	1.4	68.5	2,689
Rainy River	Dry Year	226.2	42.2	6770.8	189.7	1394.9	27232.8	15260.7	17633.1	2445.7	25.1	199.9	71,421
	Avg Year	248.5	46.4	7436.2	208.3	2324.8	45388.0	25434.5	29388.4	4076.2	41.8	219.6	114,813
	Wet Year	273.7	51.1	8191.5	229.5	3324.4	64904.8	36371.4	42025.4	5829.0	59.8	241.9	161,503
Red River of the North	Dry Year	310.8	41.4	5839.0	122.5	167.6	7806.5	343.6	357.4	396.2	0.1	849.9	16,235
	Avg Year	362.5	48.2	6810.6	142.8	540.7	25182.4	1108.4	1153.0	1278.0	0.4	991.3	37,618
	Wet Year	410.0	54.6	7702.9	161.5	962.4	44824.6	1973.0	2052.4	2274.8	0.7	1121.1	61,538
St. Croix River	Dry Year	252.4	71.7	2257.9	0.0	83.9	9777.1	515.1	810.9	61.3	34.3	734.8	14,599
	Avg Year	293.4	83.3	2624.8	0.0	144.6	16857.1	888.1	1398.2	105.7	59.1	854.2	23,308
	Wet Year	320.0	90.9	2863.2	0.0	212.6	24779.9	1305.6	2055.3	155.4	86.8	931.7	32,801
Upper Mississippi River	Dry Year	2780.6	573.4	11562.3	30.5	695.5	27379.7	5221.9	5762.3	1309.9	1.3	3386.8	58,704
	Avg Year	3181.9	656.2	13231.0	34.9	1337.4	52653.3	10042.2	11081.4	2519.1	2.4	3875.6	98,615
	Wet Year	3509.1	723.6	14591.4	38.5	2032.9	80033.1	15264.1	16843.8	3829.0	3.7	4274.1	141,143

	Hydrology Scenario	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Urban/ Recreational Grasses	Total Kg P
Statewide Totals	Dry Year	4,648	947	45,131	455	2,904	104,591	29,385	35,914	4,542	274	7,448	236,238
	Avg Year	5,305	1,076	51,072	507	5,244	196,349	50,364	61,260	8,588	436	8,552	388,751
	Wet Year	5,840	1,181	56,120	558	7,747	299,842	72,522	88,075	13,034	609	9,442	554,968

3.2.8 Urban Runoff

As described in Section 2.2.2.7, the phosphorus concentrations, runoff coefficients and contributory areas for each urban land cover type within each basin were utilized, along with the annual rainfall amounts for each flow condition, to calculate the results of the phosphorus loadings for each basin and the state. The phosphorus loading results are shown in Table 3-17. The highest total phosphorus loadings are estimated for the Upper Mississippi River basin, which represents approximately 50 percent of the total phosphorus loadings from incorporated areas for each flow condition. The Minnesota River basin represents approximately 20 percent, while no other basin represents more than 10 percent of the total phosphorus loadings from incorporated areas for each flow condition. For each land cover type the estimated total phosphorus loadings for the high flow condition are typically one-and-one-half times as high as the low flow loadings for each basin, with the average flow condition loadings typically mid-way between the high and low flow condition loadings. Low intensity residential land cover represents between 26 and 30 percent of the statewide total phosphorus loadings from incorporated areas under the various flow conditions. The commercial/industrial/transportation and high intensity residential land cover types represent approximately 20 percent and 15 percent, respectively, of the statewide total phosphorus loadings from incorporated areas under the various flow conditions. Agricultural runoff represents approximately 12, 20 and 25 percent of the statewide total phosphorus loadings from incorporated areas under low, average and high flow conditions, respectively.

Table 3-17 Estimated Annual Phosphorus Loadings for Incorporated Urban Areas

Basin	Hydrology Scenario	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Urban/ Recreational Grasses	Agricultural Lands in Incorporated Areas	Total Kg P
Cedar River	Dry Year	738.7	1,251.5	1,827.8	0.0	0.0	46.2	0.0	0.2	0.0	0.0	262.1	413	4,539
	Avg Year	782.3	1,325.3	1,935.6	0.0	0.0	53.9	0.0	0.3	0.0	0.0	277.5	1,002	5,377
	Wet Year	800.6	1,356.4	1,981.0	0.0	0.0	69.4	0.0	0.3	0.0	0.0	284.0	1,278	5,770
Des Moines River	Dry Year	1,097.6	245.8	992.7	0.0	0.0	18.8	0.3	0.2	0.0	0.0	460.6	351	3,167
	Avg Year	1,272.8	285.0	1,151.1	0.0	0.0	23.9	0.4	0.3	0.0	0.0	534.1	537	3,805
	Wet Year	1,433.5	321.0	1,296.4	0.0	0.0	31.5	0.6	0.4	0.0	0.0	601.6	1,042	4,727
Lake Superior	Dry Year	3,598.6	2,472.8	5,495.7	320.0	516.4	5,794.7	896.9	1,309.8	83.7	64.3	1,355.6	1,060	22,969
	Avg Year	3,846.7	2,643.3	5,874.5	342.1	552.0	6,613.3	1,023.6	1,494.8	95.5	73.4	1,449.0	1,824	25,832
	Wet Year	4,117.2	2,829.2	6,287.6	366.1	590.8	7,966.8	1,233.2	1,800.7	115.0	88.5	1,550.9	3,134	30,080
Lower Mississippi River	Dry Year	9,032.4	4,987.8	7,823.2	0.4	181.1	983.8	21.8	83.5	0.2	50.9	4,967.4	5,291	33,423
	Avg Year	10,028.5	5,537.9	8,685.9	0.4	201.1	1,212.7	26.9	103.0	0.2	62.7	5,515.2	10,535	41,909
	Wet Year	10,615.5	5,862.0	9,194.3	0.5	212.8	1,449.9	32.2	123.1	0.2	74.9	5,838.0	12,809	46,212
Minnesota River	Dry Year	24,477.9	8,625.8	14,846.9	11.6	205.0	1,135.2	38.8	44.9	5.7	0.8	8,057.5	5,723	63,173
	Avg Year	28,467.9	10,031.9	17,267.0	13.5	238.4	1,445.1	49.4	57.2	7.2	1.1	9,371.0	11,275	78,225
	Wet Year	31,583.3	11,129.8	19,156.6	15.0	264.5	1,786.3	61.0	70.7	8.9	1.3	10,396.5	16,541	91,015
Missouri River	Dry Year	913.6	223.8	707.4	1.8	0.0	14.2	0.0	0.2	0.0	1.2	389.7	614	2,866
	Avg Year	1,075.3	263.4	832.6	2.1	0.0	18.3	0.0	0.2	0.0	1.6	458.7	1,000	3,652
	Wet Year	1,222.7	299.5	946.7	2.3	0.0	24.0	0.0	0.3	0.0	2.0	521.5	1,859	4,878
Rainy River	Dry Year	800.7	370.1	948.4	122.1	191.4	913.8	226.2	355.9	23.0	2.3	227.1	218	4,399
	Avg Year	879.4	406.5	1,041.6	134.1	210.2	1,066.6	264.1	415.4	26.8	2.7	249.5	502	5,199
	Wet Year	968.7	447.8	1,147.4	147.7	231.6	1,305.2	323.1	508.3	32.8	3.3	274.8	874	6,265
Red River of the North	Dry Year	3,978.4	2,141.3	4,231.8	0.0	13.2	177.9	8.7	5.4	0.4	0.0	1,561.0	1,229	13,347
	Avg Year	4,640.4	2,497.6	4,936.0	0.0	15.4	223.0	10.9	6.8	0.5	0.0	1,820.7	3,599	17,750
	Wet Year	5,248.4	2,824.8	5,582.7	0.0	17.5	277.1	13.5	8.5	0.7	0.0	2,059.3	5,101	21,133
St. Croix River	Dry Year	2,888.4	718.1	2,076.0	0.0	22.8	735.7	109.4	117.1	0.3	16.4	1,631.9	3,397	11,713
	Avg Year	3,357.8	834.7	2,413.3	0.0	26.6	951.3	141.5	151.4	0.3	21.2	1,897.1	7,309	17,104
	Wet Year	3,662.7	910.5	2,632.5	0.0	29.0	1,168.2	173.7	185.9	0.4	26.1	2,069.3	13,421	24,279
Upper Mississippi River	Dry Year	53,550.4	32,497.7	31,620.6	38.9	1,173.4	4,982.4	628.5	814.1	104.1	47.3	17,099.9	21,243	163,800
	Avg Year	61,278.5	37,187.6	36,183.9	44.5	1,342.7	6,190.1	780.9	1,011.4	129.3	58.8	19,567.7	38,038	201,813
	Wet Year	67,579.4	41,011.4	39,904.5	49.1	1,480.8	7,560.0	953.7	1,235.2	157.9	71.8	21,579.7	68,981	250,565

	Hydrology Scenario	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Urban/ Recreational Grasses	Agricultural Lands in Incorporated Areas	Total Kg P
Statewide Totals	Dry Year	101,077	53,535	70,570	495	2,303	14,803	1,931	2,731	217	183	36,013	39,539	323,397
	Avg Year	115,630	61,013	80,321	537	2,586	17,798	2,298	3,241	260	221	41,140	75,621	400,667
	Wet Year	127,232	66,992	88,130	581	2,827	21,638	2,791	3,933	316	268	45,176	125,040	484,924